DEFENSE TECHNOLOGY AREA PLAN

DEPARTMENT OF DEFENSE

UNITED STATES OF AMERICA

January 1997

DTAP

OFFICE OF THE SECRETARY OF DEFENSE

WASHINGTON, D.C. 20301

This *Defense Technology Area Plan* presents the Department of Defense objectives and investment strategy for those technologies critical to Defense acquisition plans, service warfighter capabilities and joint warfighting needs. The *Defense Technology Area Plan* takes a horizontal perspective across Military Services and Defense Agencies efforts, thereby charting the total Defense investment for a given technology.

This third edition of the *Defense Technology Area Plan* embodies many of the refinements we continue to make in our integrated science and technology strategic planning process. The plan identifies the anticipated return on the Defense investment in science and technology through more than 200 Defense Technology Objectives. These Defense Technology Objectives have been refined considerably in this edition of the plan. We have eliminated those with marginal impact, added new objectives to ensure attainment of our strategic goals, and sharpened the focus on several to better articulate the science and technology program payoff. These refinements serve to increase our emphasis on rapid transition of technology to the operational forces. This year's plan has a separate annex which provides an assessment of the potential technology capabilities of other countries vis-à-vis the United States.

The *Defense Technology Area Plan* is a dynamic document. It is the product of corporate planning and provides guidance to the Military Services and Defense Agencies to ensure that their integrated investment in technology development is responsive to the needs of our primary customer--the warfighter--well into the future.

Anita Jones

Anita K. Jones
Director of Defense Research and Engineering

OFFICE OF THE DIRECTOR OF DEFENSE RESEARCH AND ENGINEERING

WASHINGTON, DC 20301-3040

The Defense Technology Area Plan (DTAP) is issued by the Director of Defense Research and Engineering (DDR&E) to guide the Department's Applied Research (6.2) and Advanced Technology Development (6.3) investment decisions.

This edition of the DTAP has been prepared by the ten Defense Science and Technology (S&T) Reliance panels overseen by us, the Reliance Executive Committee. This plan documents our vision, strategy, goals, Defense Technology Objectives (DTOs) and technology roadmaps being pursued during the FY 98 budget and Future Years Defense Plan. The DTAP also identifies the funding allocated for DTOs and the Fiscal Year when these technologies may be transitioned to development to create new warfighting capabilities.

The DTAP provides a means to communicate our objectives and work to our customers: the development community, warfighters, and Congress. Adherence to this DTAP will ensure that the Department's investment in S&T is responsive to our customers, properly focused, affordable, and well executed.

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Defense Technology Area Plan

January 1997

DEPARTMENT OF DEFENSE
DIRECTOR, DEFENSE RESEARCH AND ENGINEERING

INTRODUCTION AND SUMMARY

Technological superiority has been, and continues to be, a cornerstone of our national military strategy. Technologies such as radar, jet engines, nuclear weapons, night vision, smart weapons, stealth, the Global Positioning System, and vastly more capable information management systems have changed warfare dramatically. Today's technological edge allows us to prevail across the broad spectrum of conflict decisively and with relatively low casualties. Maintaining this technological edge has become even more important as the size of U.S. forces decreases and high-technology weapons are now readily available on the world market. In this new environment, it is imperative that U.S. forces possess technological superiority to achieve and maintain the dominance displayed in Operation Desert Storm. The technological advantage we enjoy today is a legacy of decades of investment in science and technology (S&T). Likewise, our future warfighting capabilities will be substantially determined by today's investment in S&T.

In peace, technological superiority is a key element of deterrence. In crisis, it provides a wide spectrum of options to the National Command Authorities and commanders in chief, while providing confidence to our allies. In war, it enhances combat effectiveness, reduces casualties, and minimizes equipment loss. In view of declining defense budgets and manpower reductions, advancing military technology and ensuring that it undergoes rapid transition to the warfighter are national security obligations of ever greater importance.

To fulfill these obligations, the Director, Defense Research and Engineering (DDR&E), has continually enhanced the strategic planning process for defense S&T. The foundation of this process is the *Defense Science and Technology Strategy* with its supporting *Basic Research Plan* (BRP), *Joint Warfighting Science and Technology Plan* (JWSTP), and *Defense Technology Area Plan* (DTAP) (References 1-4). These documents present the DoD S&T vision, strategy, plan, and objectives for the planners, programmers, and performers of defense S&T.

These documents are a collaborative product of the Office of the Secretary of Defense (OSD), Joint Staff, military services, and defense agencies. The strategy and plans are fully responsive to the National Security S&T Council's *National Security Science and Technology Strategy* (Reference 5) and the Chairman of the Joint Chiefs of Staff's *Vision* and *Joint Vision 2010* (JV 2010) (Reference 6), as shown in Figure 1. The strategy and plans and supporting individual S&T master plans of the military services and defense agencies guide the annual preparation of the defense program and budget. The strategy and plans are made available to the U.S. Government, defense contractors, and our allies with the goal of better focusing our collective efforts on superior joint warfare capabilities and improving interoperability between the United States and our allies.

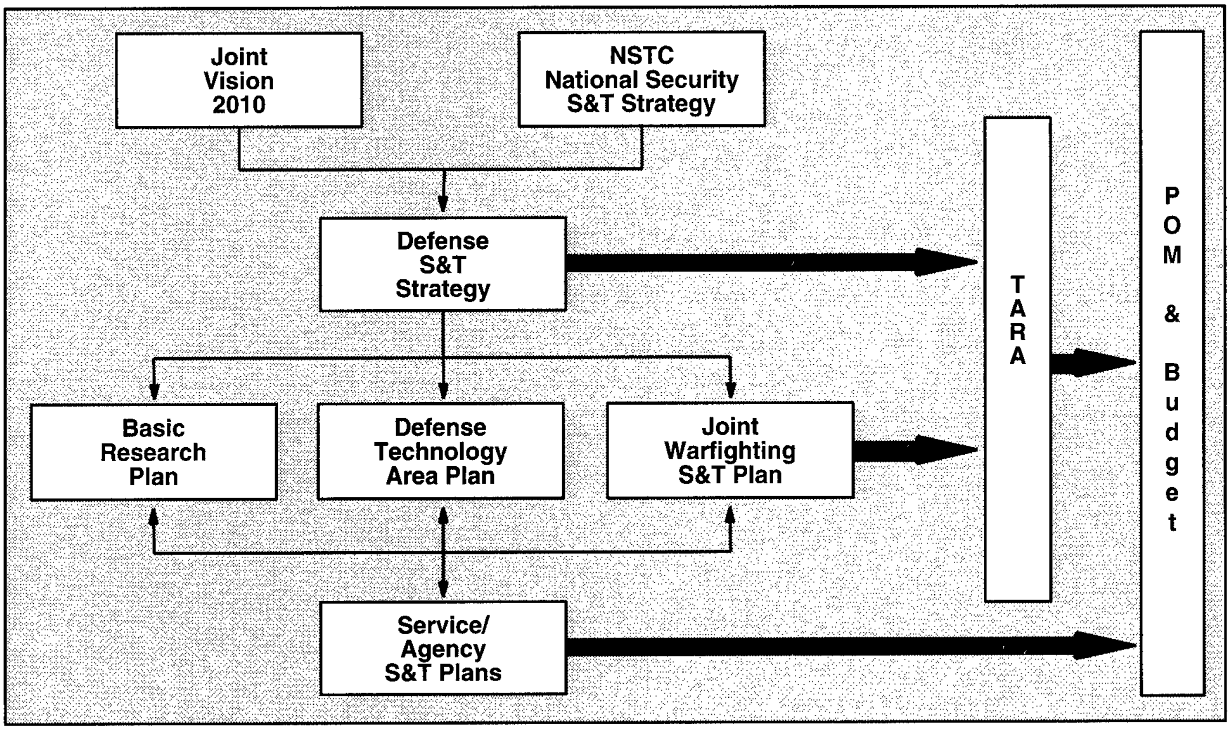

Figure 1. Science and Technology Strategic Planning

Defense Science and Technology Strategy (Reference 1). *The Defense Science and Technology Strategy* is responsive to the Secretary of Defense's vision to "develop and transition superior technology to enable affordable, decisive military capability." The strategy focuses on four generic considerations that have high priority in making strategic decisions about which technologies are pursued:

- *Affordability.* Where appropriate, S&T projects must focus on increasing the effectiveness of a capability and decreasing cost, increasing operational life, and incrementally improving material through planned upgrades.
- *Dual Use.* The S&T program must contribute to building a common industrial base by using commercial practices, processes, and products, and by developing, where possible, technology that can be the base for both military and commercial products and applications.
- *Accelerated Transition.* Advanced Concept Technology Demonstrations (ACTDs) are a key element in the S&T program to focus science and technology on supporting military needs and problems, expediting transitions, and providing a sound basis for acquisition decisions.
- *Strong Technology Base.* The technology base generates DoD's legacy to tomorrow's warfighter. Accordingly, it is imperative to maintain a stable technology base investment to develop options for the truly long term—beyond the threats, situations, and budgets that we can predict.

Basic Research Plan (Reference 2). The BRP presents the DoD objectives and investment strategy for DoD-sponsored Basic Research (6.1) performed by universities, industry, and service laboratories. In addition to presenting the planned investment in each of 12 technical disciplines composing the Basic Research Program, the plan highlights six strategic research objectives holding great promise for the development of enabling breakthrough technologies for revolutionary 21st century military capabilities:

- Biomimetics
- Nanoscience
- Smart structures
- Mobile wireless communications
- Intelligent systems
- Compact power sources

The coupling of the BRP with the DTAP and the JWSTP is carried out in several ways. First, the planning stage of the 12 individual research areas has the active participation of both the service laboratories and the warfighters (through the operating commands, such as the Army's Training and Doctrine Command (TRADOC)). This activity takes place by providing requirements and, oftentimes, serving on planning committees that focus on or include basic research. Second, representatives of the service laboratories and operating commands also take part in the program evaluation process through attendance and participation in service S&T program reviews and the ODDR&E Technology Area Reviews and Assessments (TARAs) reviews.

Joint Warfighting Science and Technology Plan (Reference 3). The JWSTP takes a joint perspective horizontally across the Applied Research (6.2) and Advanced Technology Development (6.3) plans of the services and defense agencies to ensure that the requisite technology and advanced concepts for superior joint and coalition warfighting are supported. It ensures that the near-, mid-, and long-term needs of the joint warfighter are properly balanced and supported in the S&T planning, programming, budgeting, and assessment activities of DoD. The JWSTP is focused around 10 Joint Warfighting Capability Objectives (JWCOs). These objectives support the Joint Warfighting Capability Assessment (JWCA) and the four operational concepts emphasized in *JV 2010*: dominant maneuver, precision engagement, full-dimension protection, and focused logistics. A significant feature of the JWSTP is the identification of mechanisms for the timely transition of technology to the warfighter in the field before it becomes obsolete or falls in the hands of our adversaries.

Defense Technology Area Plan (Reference 4). This DTAP presents the DoD objectives and the Applied Research (6.2) and Advanced Technology Development (6.3) investment strategy for technologies critical to DoD acquisition plans, service warfighter capabilities, and the JWSTP. It also takes a horizontal perspective across the service and defense agency efforts, thereby charting the total DoD investment for a given technology. The DTAP documents the focus, content, and principal objectives of the overall DoD science and technology efforts. This plan provides a sound basis for acquisition decisions and is structured to respond to the DDR&E emphasis on rapid transition of technology to the operational forces. A separaately bound annex to this DTAP provides an assessment of the potential technology capabilities of other countries vis-à-vis the United States.

Taken together, the BRP, JWSTP, and DTAP provide programming guidance for the DoD S&T community.

S&T STRATEGIC PLANNING PROCESS

Oversight. The Director, Defense Research and Engineering (DDR&E), is responsible for the overall direction, quality, and content of the DoD S&T Program. The DDR&E has established an integrated S&T strategic planning process to effectively discharge these responsibilities. This process is accomplished and coordinated through Defense Science and Technology Reliance. Development of the BRP, DTAP, and JWSTP is the responsibility of the Defense S&T Reliance Executive Committee (EXCOM). Membership of the EXCOM is shown below:

EXECUTIVE COMMITTEE
Deputy DDR&E, Chairman
Deputy Assistant Secretary of the Army (Research and Technology)
Chief of Naval Research
Deputy Assistant Secretary of the Air Force (Science, Technology, and Engineering)
Deputy Director, Defense Advanced Research Projects Agency
Assistant Deputy Director for Technology, Ballistic Missile Defense Organization
Deputy Director, Defense Special Weapons Agency

When significant actions are undertaken, an Expanded EXCOM is convened to ensure the widest possible coordination within the DoD research and development community. The membership of the Expanded EXCOM is shown below:

EXPANDED EXECUTIVE COMMITTEE
EXCOM Members
Deputy for Chemical/Biological Matters, Office of the Assistant to the Secretary of Defense (Nuclear, Chemical and Biological Defense Programs)
Deputy Assistant Secretary of Defense for Health Affairs (Clinical Services)
Deputy Under Secretary of Defense for Advanced Technology
Deputy Under Secretary of Defense for Space
Deputy Chief of Staff for Research, Development and Acquisition, Army Materiel Command
Director of Navy Test and Evaluation and Technology Requirements, Office of the Chief of Naval Operations
Deputy for Science and Technology, Air Force Materiel Command
Chairperson, Joint Engineers
Chairperson, Training and Personnel Systems Science and Technology Evaluation Management Committee (TAPSSTEM)

The EXCOM oversees the work of the Defense Committee on Research (DCOR), which is responsible for preparation of the BRP; the 10 technology area panels responsible for preparation of the DTAP; and the 10 JWCO panels responsible for preparation of the JWSTP. These plans build on—but do not duplicate—the service/agency S&T plans. They also consider recent technology forecasts such as OSD's *Revolution in Military Affairs*, the Air Force's *New World*

Vistas, the Army's *Force XXI* and *Army After Next*, the Navy's *Navy After Next,* and the Marine Corps' *Sea Dragon* efforts.

To ensure that the integrated S&T planning is responsive to the strategy, the Defense S&T Reliance network has developed the following goals to guide the effort:

- Enhance the quality of Defense S&T activities and develop world-class products.
- Ensure the existence of critical masses of resources.
- Reduce redundant S&T capabilities and eliminate unwarranted duplication.
- Gain productivity and efficiency through collocation and consolidation of in-house S&T work.
- Preserve the vital mission-essential capabilities of the services throughout the process.

Defense Technology Objectives (Reference 7). The S&T investment is focused and guided through Defense Technology Objectives (DTOs). Each DTO identifies a specific technology advancement that will be developed or demonstrated, the anticipated date of technology availability, the specific benefits resulting from the technology advance, and the funding planned to achieve the new capability. These benefits not only include increased military operational capabilities but also address other important areas, including affordability and dual-use applications, that have received special emphasis in the *Defense Science and Technology Strategy.* JWSTP DTOs are limited to Advanced Technology Demonstrations (ATDs) and Advanced Concept Technology Demonstrations (ACTDs). A key responsibility of the EXCOM is to ensure that DTOs critical to achieving the goals of an ACTD or ATD are being pursued.

The DTOs are presented in a separate volume in two parts—one for this DTAP and one for the JWSTP. The DTAP DTO number consists of a two-letter prefix corresponding to the names of the 10 technology areas addressed in this document, a two-digit numeral that represents the DTO sequence, and a second two-digit numeral that is an undefined field. The letter prefix for the JWSTP DTO number corresponds to the 10 sections (A through J) in Chapter IV of that document, followed by a two-digit sequence number. Thus, DTO numbers easily distinguish JWSTP from DTAP DTOs. The DTO sequence numbers do not connote priorities.

DTAP Development. The 10 technology area panel chairpersons are responsible for preparing their respective DTAP chapters. Technology area panel membership consists of service and appropriate defense agency technical specialists, with a senior service S&T manager serving as chairperson. These individuals have continued the integrated planning activities initiated under the Tri-Service S&T Reliance. The 10 technology area panels, the service chairs, and the DDR&E staff points of contact are shown in Figure 2.

The DTAP identifies the anticipated return on investment through 205 DTOs. More than half of the DTOs are supported by two or more services or defense agencies. Allocation of Defense S&T resources must also consider service-unique requirements, which are not addressed in detail in this DTAP. The execution of the S&T programs to attain the DTOs and service-unique objectives is accomplished through the service and defense agency plans, as shown in Figure 1.

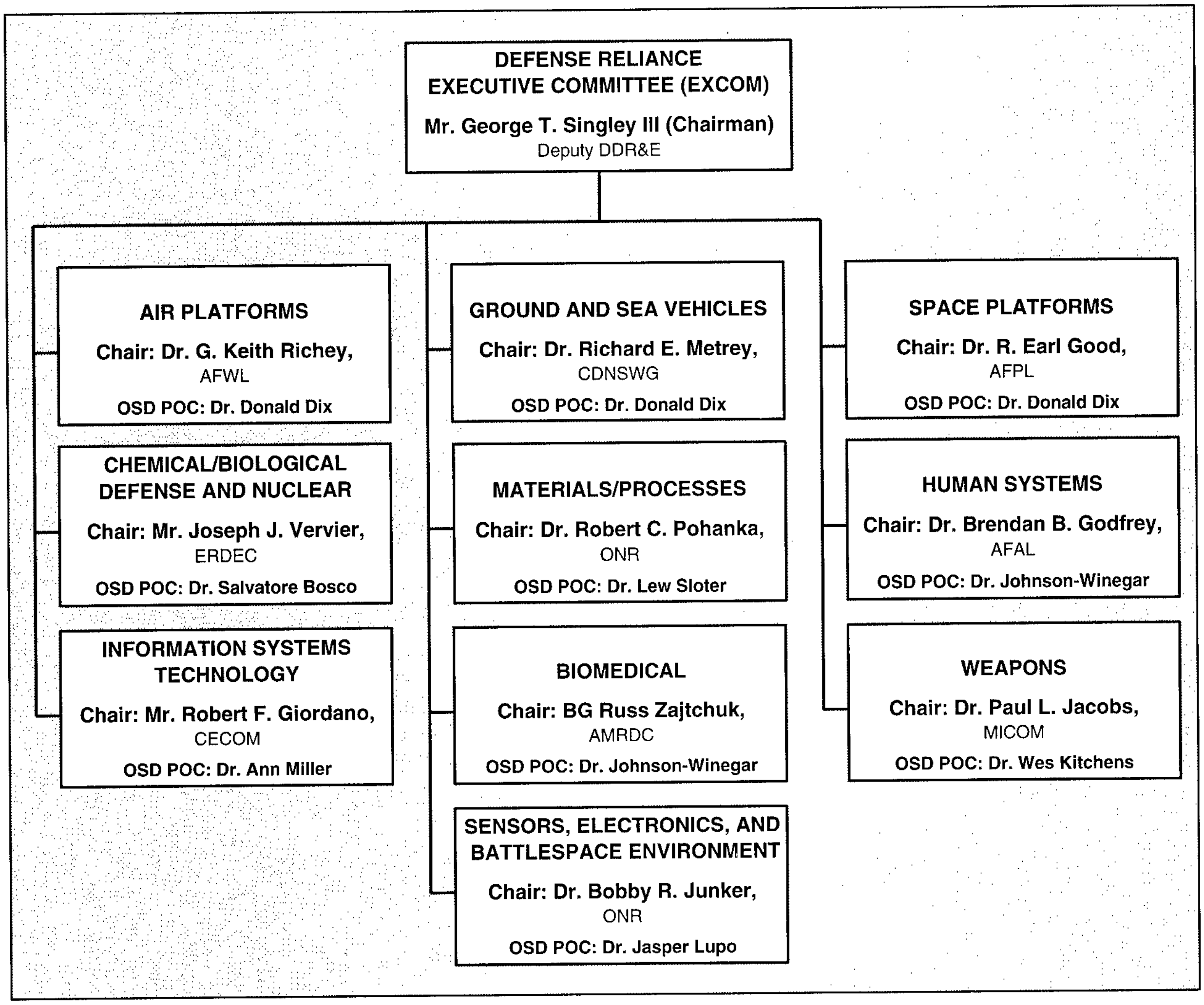

Figure 2. Defense Technology Area Plan Key Personnel

Enabling and Support Technologies. The DTOs provide focus for the development of technologies that address an identified military need. This DTAP also addresses the continued development of the enabling technologies that are critical to sustaining the DTOs, laying the foundation for future DTOs, and precluding technological surprise. These technology development activities involve proof-of-concept experiments, laboratory demonstrations, and evaluations supported by models and simulations. The technology developments also provide for the investigation of innovative technologies that could have significant impact on military applications across a broad spectrum of applications. Investment in enabling technologies supports the S&T strategy goal of maintaining a strong technology base.

Review and Assessment. After publication of the plans documents, Technology Area Reviews and Assessments (TARAs) are held for each of the 10 DTAP technology areas, the basic research program, and the manufacturing technology program. These reviews are conducted by TARA teams. At least two-thirds of the TARA team members are from outside DoD. Most TARA team members are recognized experts from the National Academy of Sciences, the National Academy of Engineering, the Institute of Medicine, the Defense Science Board, the scientific advisory boards of the military departments, industry, and academia. The TARA team is chaired by a senior executive appointed by the DDR&E. The appropriate representatives from the Defense S&T Reliance Technical Panel brief the DoD program as compared to the planning guidance. Special S&T issues identified by the DDR&E and applicable JWSTP ACTDs are also reviewed.

Following the review, the TARA chair briefs the findings and recommendations to the DDR&E-chaired Defense Science and Technology Advisory Group (DSTAG). Included in this briefing are the TARA chair's program recommendations for termination, adjustment, and enhancement to better align the S&T program to comply with the guidance. Based on DSTAG recommendations and decisions, the DDR&E briefs the issues to the Program Review Group (PRG), and program decision memorandums (PDMs) are issued as needed. The TARA process is shown in Figure 3.

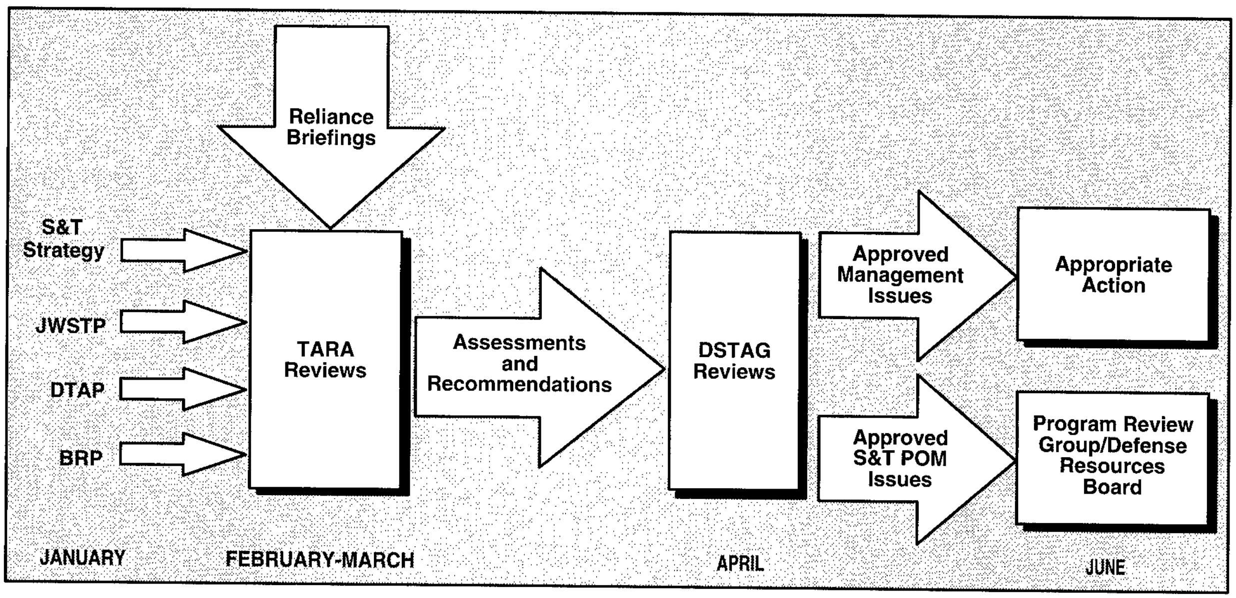

Figure 3. TARA Process in Context

RESOURCES

Table 1 lists the combined Exploratory Development (6.2) and Advanced Technology Development (6.3) S&T funding associated with the DTAP. The portion of DTAP funding related to DTOs is also included. Total 6.2 and 6.3 resource funding for each technology area is presented as the appendix to this DTAP.

The DTAP identifies the advanced concepts and enabling technologies that are essential to enhancing high-priority joint warfighting needs and that will receive funding precedence in the President's Budget and accompanying FYDP.

Table 1. FY 1998 Defense Technology Area Plan
($ in thousands)

Technology Area	Total Funding	DTO Funding
Air Platforms	625,236	235,705
C/B Defense & Nuclear	218,034	113,550
Info Systems Technology	1,210,080	727,117
Ground & Sea Vehicles	308,716	124,900
Materials/Processes	430,523	153,577
Biomedical	295,618	77,900
Sensors, Electronics, & Battlespace Environment	1,390,717	440,506
Space Platforms	163,343	100,522
Human Systems	253,933	102,626
Weapons	914,967	213,858
TOTAL	5,811,166	2,290,261

The following chapters describe the technology development plans for each of the 10 technology areas. The strategic goals and acquisition and warfighting needs identified for the technical area are presented, along with a list of the applicable DTOs. These are followed by discussion of each subarea wherein the specific warfighter needs, goals, and timeframes; major technical challenges; related federal and private efforts; and S&T investment strategy are identified. Each chapter concludes with a glossary of abbreviations and acronyms unique to that discussion. A separately bound annex provides an assessment that rates the general status of foreign capabilities in each of the technology subareas addressed. The United States is included in each table so that an appraisal can be made as to a country's relative capability. The full text of each DTO is given in the *Defense Technology Objectives of the Joint Warfighting Science and Technology Plan and the Defense Technology Area Plan,* contained in a separate volume.

References

1. *Defense Science and Technology Strategy*, Director of Defense Research and Engineering, May 1996, reprinted January 1997
2. *Basic Research Plan*, Director of Defense Research and Engineering, January 1997
3. *Joint Warfighting Science and Technology Plan*, Director of Defense Research and Engineering, January 1997
4. *Defense Technology Area Plan*, Director of Defense Research and Engineering, January 1997
5. *National Security Science and Technology Strategy*, National Science and Technology Council, 1995
6. *Joint Vision 2010*, Joint Chiefs of Staff, 1996
7. *Defense Technology Objectives of the Joint Warfighting Science and Technology Plan* and the *Defense Technology Area Plan*, Director of Defense Research and Engineering, January 1997

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FIGURES

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CHAPTER I
AIR PLATFORMS

1. INTRODUCTION

1.1 Definition/Scope

The Air Platforms technology area includes efforts devoted to piloted and unmanned air vehicles. The five major subareas are shown in Figure I–1. The fixed-wing vehicle subarea includes technology efforts in aerodynamics, flight control, structures, subsystems, and integration (including flight demonstration). It does not include aircraft propulsion, power, human systems, avionics, weapons, materials, or manufacturing technology developments but does consider the overall integration of these disciplines with the airframe. Similarly, the rotary-wing vehicle subarea includes technology efforts in aeromechanics, flight control, structures, and subsystems and demonstrations and excludes the same disciplines that are excluded within the fixed-wing subarea. Integrated high-performance turbine engine technology includes technology efforts in compression systems, combustion systems, turbine systems, exhaust systems, controls and accessories, and mechanical systems as well as demonstrations. The aircraft power subarea includes technology efforts in aircraft power and rotocraft drives. The high-speed propulsion and fuels subarea includes technology efforts in air-induction systems, combustors/ramburners, nozzle/expansion systems, fuels and fuel systems, and structures and materials.

Air Platforms technology interfaces with other technology areas impacting air vehicle system capability, including Information Systems Technology; Materials/Processes; Sensors, Electronics, and Battlespace Environment; Human Systems; and Weapons.

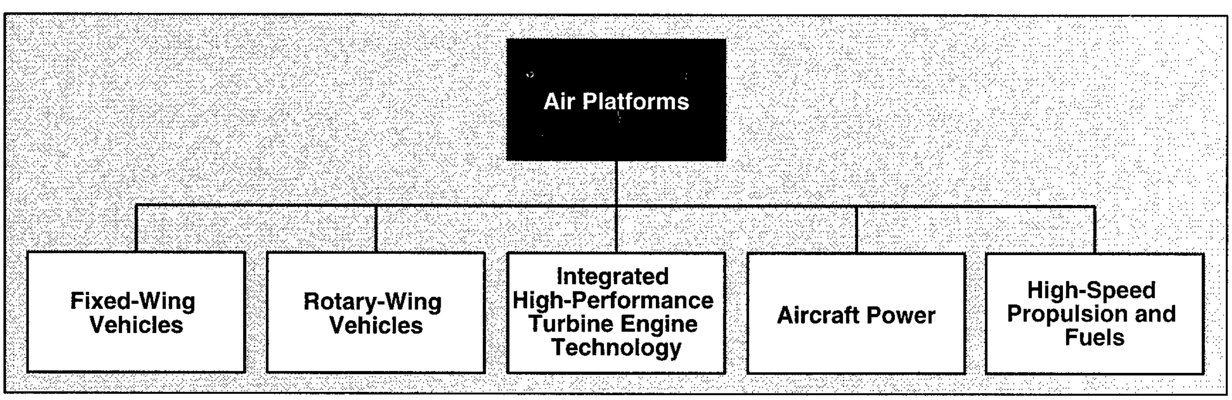


Figure I–1. Planning Structure: Air Platforms Technology Area

A glossary of abbreviations and acronyms used in this chapter begins on page I–31.

1.2 Strategic Goals

Table I–1 illustrates some of the Air Platform technology transition opportunities. The overarching strategic goal for air platform S&T investments is to maintain worldwide military

Table I–1. Air Platform Technology Transition Opportunities

Current Baseline	5 Years	10 Years	15 Years
FIXED-WING VEHICLES SUBAREA			
F–22, F/A–18/E/F C–17, P-3, B–2 MC–130H	F–22, F/A–18E/F Upgrades, JSF C–17, B–2 Upgrades	F–22, F/A–18E/F Improvements, JSF Upgrades C–17, B–2 Improvements	JSF Improvements Medium-Range Bomber SOF, UAVs
ROTARY-WING VEHICLES SUBAREA			
AH–64A, OH–58D	AH–64D, OH–58D	AH–64D, RAH–66	AH–64D (upgrade), RAH–66 (upgrade)
CH–47D, CH–46E, CH–53E	CH–47D, V–22, CH–53E	ICH, V–22, CH–53 (mod)	JTR, V–22, CH–53 (mod)
UH–1N/AH–1W, UH–60A	UH–1N/AH–1W, UH–60A/L	UH–1N/AH–1W, UH–60A/L	CVLA, UH–60 (upgrade)
IHPTET SUBAREA			
YF–19 (Turbofan/ Turbojet) J402/F107 (Expendable Turbine Engines) T700/T406 (Turboshaft/Turboprop)	F–22, F/A–18E/F Upgrades, JSF VSTOL Supersonic Weapon, Longer Loiter UAV, Low-Cost Weapon V–22	F–22, F/A–18E/F Improvements, C–17 Improvements, B–2 Improvements Long Loiter UAV RAH–66	Global Strike A/C, JSF Improvements, SOF, Medium-Range Bomber Ultra Low-Cost Standoff Weapon, Very Long-Range/Long Loiter UAV RAH–66 (upgrade)
AIRCRAFT POWER SUBAREA			
Aircraft Power Components	C–130J, E–8 JSTARS, MEA Components	C–5 Upgrade, C–130 Upgrade, JSF, MEA Integration	Global Strike A/C, JSF Improvements, SOF, Medium-Range Bomber, UAVs
HIGH-SPEED PROPULSION AND FUELS SUBAREA			
Ramjet/Scramjet Propulsion SR–71 JP8, JP10	Adv AMRAAM Cheap Mach 4 Weapon JP8+100 for the Existing Fleet	Combined Cycle Engine Combined Cycle Engine “Hypersonic” Technology Weapon Fuel	Mach 8 Missile Mach 5+ Aircraft Hypersonic Aircraft Fuel

aircraft superiority by providing technologies by 2003 that will enable options for a 65% increase in range; a 35% reduction in takeoff gross weight for the same mission capability; a one-half reduction in acquisition and support costs; and doubling of DoD air vehicle life, while maintaining current survivability levels and enhancing reliability. These payoffs can be achieved through the pursuit of specific technology goals in each of the major air platforms subareas by improving aerodynamics, reducing structural weight fraction, doubling propulsion system capability, increasing efficiency and reducing weight of power systems, reducing production and support costs, and increasing the thermal capability of fuels.

1.3 Acquisition/Warfighting Needs

Aircraft-related acquisition, operation, and support costs constitute about one-third of the DoD budget, and about two-thirds of these costs are associated with the basic air platforms. The relative importance of air platforms in the force structure is not expected to change since there are no foreseeable substitutes for the combination of firepower and mobility provided by aircraft.

Air Platforms subareas are critical to providing a military operational capability for strike, military airlift, early warning, reconnaissance, command and control, ground attack, and sea control. Air Platforms subareas are also critical to many operational tasks including air defense, air superiority, close air support, C^3, disaster assessment and relief, electronic warfare, information warfare, interdiction, medical evacuation, missile defense, reconnaissance and surveillance, sea lane control, search and rescue, special operations, strategic and theater airlift, strategic attack, strategic deterrence, and weather observation.

The DoD *Joint Warfighting Science and Technology Plan* (JWSTP) identifies contributions to the JCS's *Joint Vision 2010*: dominant maneuver, precision engagement, focused logistics, and full-dimensional protection. The foundation for these contributions will come from innovations in several technology areas. Specific contributions from the technology area of Air Platforms include the capability to (1) destroy selected targets over wide areas and long ranges; (2) deliver nonlethal weapons, precise weapons, and surveillance in urban areas; (3) disrupt or degrade enemy defenses across the entire electronic, IR, and visual spectrums; (4) destroy enemy theater ballistic missiles and cruise missiles; (5) provide early detection of biological weapons from long range; and (6) provide enhanced readiness and logistics through improved O&M and life-cycle costs in support of the Joint Readiness and Logistics needs.

In addition, Air Platform technologies have strong dual-use application in the civil sector, thus strengthening U.S. international competitiveness and significantly enhancing our economic security. Commercial applications of these technologies are in aerodynamics; gas turbines; power-by-wire controls; electrically driven subsystems (e.g., electric actuators); extended-life tires; low-cost transparencies; and aging aircraft life extension, low-cost lightweight structures, and multidisciplinary design optimization.

1.4 Support for Combating Terrorism

The spectrum of terrorist actions that can be committed against CONUS and overseas assets spans military installations, national infrastructure, and direct acts against the civilian populace. The outcome of many Air Platforms technical projects will allow for a much enhanced capability to mitigate the effects of many terrorist actions while expanding the political options and military responses.

For example, the Aircraft Hardening Project (in partnership with the FAA) will provide ways to protect civilian airliners against the damage affects of onboard explosive devices or surface-to-air missiles. Live-fire tests conducted for military aircraft have already created a broad database of knowledge on the blast effects of detonating explosives. A new analysis technique to computer-model damage effects on aircraft has already transitioned to the FAA. In addition, work is being done to support state-of-the-art analysis on the effects of damaged fuselage and airfoil sections on airflow. Investigations into new fire prevention technologies such as demonstration of machine vision fire detection and new fire quenching substances and techniques (e.g., electromagnetic fire suppression) hold significant promise for future airliners. Reliable, damage-tolerant systems such as reconfigurable flight control and technologies allowing better subsystem designs for redundancy will be available in the near term.

Both piloted and unpiloted air platforms have always been able to provide near-real-time intelligence data, respond rapidly to terrorist attacks, and bring significant resources to bear in minimum time. Supporting these inherent air platform capabilities are the Improved Precision Airdrop Project. For those missions requiring terminal area landings and takeoffs, ongoing development of high-lift devices, powered-lift technologies, and advanced performance prediction capabilities for advanced short-field transports is occurring. A project to provide transports with pallet off/on loading capability without the use of ground handling equipment is also underway and will speed the on-the-ground time for initial or resupply missions. These technology developments, and others not referenced here, would allow a specialized Special Operations Forces (SOF) air vehicle that provides a clandestine, long-range, all-weather, day/night capability to transport a focused force for preventative or retributional action against a known terrorist organization with little collateral damage—even in urban areas. In fact, the Fixed-Wing Vehicle Technology Development Approach is working short-takeoff, short-landing, and additional technologies necessary for such a vehicle within the SOF family.

2. DEFENSE TECHNOLOGY OBJECTIVES

The DTOs applicable to the Air Platform subareas are as follows:

Fixed-Wing Vehicles

AP.01.00 Advanced Aerodynamic Concepts for Increased Flight Efficiency
AP.02.00 Fixed-Wing Vehicle Structures Technology
AP.03.00 Aircraft Support/Sustainment Reduction
AP.04.00 Flight Control Technology for Affordable Global Reach/Power
AP.05.00 Maturity Demonstration of Advanced Air Platform Technologies
AP.13.00 Affordable/Supportable Fixed-Wing Vehicle Subsystems Technology

Rotary-Wing Vehicles

AP.06.00 Helicopter Active Control Technology
AP.07.00 Demonstration of Advanced Rotor Concepts
AP.14.00 Rotary-Wing Structures Technology
AP.15.00 Rotary-Wing Affordable/Supportable Subsystems Technology
AP.16.00 Signature Reduction Technologies

Integrated High-Performance Turbine Engine Technology

AP.08.00 Fighter/Attack/Strike Propulsion
AP.09.00 Transport/Patrol/Helicopter Propulsion
AP.10.00 Cruise Missile/Expendable Propulsion

Aircraft Power

AP.11.00 Aircraft Power (MEA)
AP.12.00 Rotorcraft Drive

High-Speed Propulsion and Fuels

AP.17.00 Hydrocarbon Scramjet Missile Propulsion
AP.18.00 Improved JP–8 Fuel
AP.19.00 High Heat Sink Fuels (JP–900/Endothermic)

3. TECHNOLOGY DESCRIPTIONS

3.1 Fixed-Wing Vehicles

3.1.1 *Warfighter Needs*

Fixed-wing vehicles are the backbone of global power/global reach and operations from the sea for both our national defense and power projection abroad, supporting four of the five top future warfighting capabilities cited by JCS. Air vehicles are critical to providing air defense; air superiority; close air support; command, control and communications; disaster assessment and relief; electronic warfare; information warfare; interdiction; missile defense; reconnaissance and surveillance; sea lane control; search and rescue; special operations; strategic and theater airlift; strategic attack; strategic deterrence; and weather observation.

The Air Force Modernization and Planning Process and Navy S&T Requirements Guidance differ in detail but share the common overall objective to improve warfighter capability. Upgrades, improvements to current systems (Today's Aircraft Flying Tomorrow—TAFT), and new capabilities for military aircraft systems (Future Aircraft Technology Enhancement—FATE) are the responsibility of the fixed-wing vehicles (FWV) subarea. S&T planning for such upgrades, improvements, and vision for future system possibilities is accomplished within the framework of the FWV Technology Development Approach (TDA). The FWV TDA outlines the DoD approach for executing a program to achieve the goals that will result in the highest payoffs (Table I–2) for the fixed-wing community. Implementing the strategy will result in significant improvements in both operational capability and cost, the two primary contributors to enhanced affordability.

Table I–2. Fixed-Wing Vehicles Payoffs (% improvement)

Payoff	2003	2008	2013
Fighter/Attack Baseline ⇒		**F–22, F–18E/F**	
Reduced Acquisition Costs	10	20	30
Reduced Operations and Support Costs	10	15	30
Increased Lethality	5	10	15
Increased Mission Range	25	30	35
Reduced Susceptibility	15	20	30
Increased Payload	25	30	35
Increased Operational Readiness	10	15	20
Reduced Vulnerability	15	20	25
Reduced Takeoff Gross Weight	10	15	20
Airlift-Patrol/Bomber Baseline ⇒		**C–17, P–3/B–2**	
Reduced Acquisition Costs	10/15	15/20	20/30
Increased Mission Survivability	10/5	20/10	30/15
Reduced Operations and Support Costs	10/10	15/15	20/20
Increased Mission Range	20/10	30/20	40/25
Increased Mission Endurance	15/—	25/—	30/—
Increased Operational Readiness	10/5	15/10	20/15
Increased Payload	20/10	25/15	30/20
Increased Lethality	—/5	—/10	—/15
Special Operations Baseline ⇒		**MC–130H**	
Increased Mission Survivability	30	40	50
Improved Clandestine Operations	40	60	75
Increased Austere Operations Capability	5	10	15
Increased Operational Readiness	10	15	20
Increased Mission Range	15	30	40
Reduced Field Length	20	30	50
Reduced Acquisition Costs	10	15	20
Reduced Operations and Support Costs	10	15	20

Fixed-wing vehicle technologies focus on providing aircraft that meet DoD operational capability and affordability requirements, both now and for the future. All DoD S&T in this subarea is accomplished by the Air Force and Navy (including the Marine Corps). Significant transitions of fixed-wing S&T to meet current and future requirements include:

- Flight and Propulsion Integration technology developed/matured and demonstrated to the degree that it is being proposed as a baseline control system for the Joint Strike Fighter (JSF).
- A deterministic fatigue analysis and failure prediction model named AFGROW has been transitioned to the Air Logistics Centers (ALCs). This capability is used by the ALCs as the standard for predicting crack growth failures.

- Transitioned Direct Manufacture of Low-Cost Composites technology for light-weight, low-cost carbon composite structures for the next generation fighter wing.
- Vapor cycle environmental control system developed under the Integrated Closed Environmental Control System program has been transitioned to F–22 and satisfies cooling requirements for the avionics.
- Aerodynamic solutions have been developed to address the severe unsteady loads in the open weapons bay as well as the acoustic suppression devices that appear as small spoilers in front of the weapons bay on F–117 and B–2 aircraft.
- Transitioned flight control technology in soft switching electric motor control as part of the High-Horsepower Electric Actuation program. This is a pervasive technology and can be used in applications where ac induction motors are used. Soft switching technology reduces thermal losses and increases system efficiency. As an enabling technology for All-Electric Aircraft, O&S costs will be reduced in comparison to baseline central hydraulic actuation systems.

3.1.2 *Overview*

3.1.2.1 Goals and Timeframes. Aggressive goals (Table I–3) have been established to provide affordable combat effectiveness of fixed-wing aircraft while maintaining the nation's pre-eminence in the aircraft industry. The five technology efforts (aerodynamics, flight control, structures, vehicle subsystems, and integration technologies) are clearly focused on overcoming the relevant technology barriers that offer the highest potential for improving overall system capability and cost.

Table I–3. Fixed-Wing Vehicles Technology Development Goals (% improvement over SOA baseline)

	Fighter Attack			Airlift-Patrol/ Bomber			SOF		
Goals	2003	2008	2013	2003	2008	2013	2003	2008	2013
Reduced Production Costs at T1	20	30	40	20/30	30/40	40/50	20	30	40
Reduced O&S Cost	20	30	40	20/20	35/30	45/40	20	30	40
Reduced EMD Cost	20	30	45	20/25	35/35	45/45	20	30	40
Reduced Airframe Weight	20	30	35	20/10	25/15	30/20	20	25	30
Increased Cruise Lift/Drag	10	25	30	10/10	25/15	30/20	10	20	30
Increased Agility-Maneuverability (Manned/Unmanned)	20/*	30/40	35/70	*	*	*	*	*	*
Increased Cargo Airdrop Delivery Accuracy	*	*	*	50/—*	70/—	90/—	*	*	*
Increased Max Trimmed C_L @ Takeoff/Landing	*	*	*	*	*	*	33	133	233

* Not applicable

3.1.2.2 Major Technical Challenges. The major technology challenges include:

- Controlling vortex flow and flow separation in low-observable (LO) configurations.
- Developing and demonstrating an active aeroelastic wing.
- Flight demonstrating innovative tailless aerodynamic control and airframe-mounted LO thrust vectoring technology.
- Retaining performance in lightweight short inlets.
- Uncertain flight control design models.
- Adequate actuator power and response independent of a central hydraulic system.
- Reducing weight of major load-carrying structures while reducing cost and ballistic vulnerability.
- Design concepts to reduce the costs of composite structures.
- Demonstrating injection-molded frameless transparencies.
- Applying titanium matrix composites to demonstrate affordable, lightweight landing gear.
- Repair techniques for aging aircraft.
- Developing methods to reduce the design time of air vehicles.

3.1.2.3 Related Federal and Private Sector Efforts. Non-DoD activities in the fixed-wing subarea include the NASA High-Speed Research (HSR), Advanced Subsonic Technology (AST), and Airframe Systems programs. NASA participates as integrated planning partners in numerous joint and cooperative programs while conducting coordinated research in commuter, subsonic transport, and high-speed/hypersonic vehicles (and their propulsion systems) that have application to military aircraft.

Other non-DoD activities include FAA Aging Aircraft and Commercial Aircraft Hardening programs. In addition, there are cooperative programs with Canada in Nonlinear Aerodynamics and Landing Gear Development; a planned program with the U.K., France, and Germany to develop an airdrop simulation tool; and cooperative programs through The Technical Cooperation Program (TTCP) with Canada, the U.K., and Australia/New Zealand in the areas of aerodynamics, flight dynamics, and aircraft/ship interface.

In the private sector, the major air vehicle and weapon system manufacturers are engaged in a broad spectrum of technology efforts. These include concentrated efforts across industry in virtual prototyping for design, manufacturing, and produceability; tailless fighter aircraft designs using thrust vectoring to reduce weight and extend range; and More Electric Aircraft (MEA) component design and validation. Technologies also being worked include active flow control, supersonic laminar flow control, smart structures incorporating both structural health monitoring and load-bearing sensors, and powered lift/VSTOL. More dramatic configuration design issues include the transfer of fully tailless aircraft technology to military and civilian transport vehicles.

The national FWVP has initiated consortia efforts with the aircraft industry and academia in aero-structures interactions.

3.1.3 *S&T Investment Strategy*

The largest impact on cost and performance of military fixed-wing aircraft is from the technologies associated with aerodynamics, structures, flight control, and subsystems. These technology efforts are the core for the FWVP—a planned, coordinated program among the Air Force, Navy, DARPA, NASA, industry, and academia, operating as an integrated product team (IPT). This program is based on one set of jointly constructed goals that can only be reached through a government-/industry-/academia-coordinated and cost-shared technology approach. The government ensures that the various goals will be met concurrently by integrating individual industry advanced airframe technology plans (AATPs) to meet selected goal sets and by focusing effort on areas not addressed by industry. The national investment supporting the five FWV technology efforts is allocated in proportion to their respective contribution to meeting FWVP goals.

3.1.3.1 Technology Demonstrations.

Extended-Range Demonstration (ERD) TD. This Technology Demonstration addresses DTO AP.05.00, Maturity Demonstration of Advanced Air Platform Technologies. The ERD TD conducts a full envelope (takeoff, low-level penetration, up-and-away maneuvering, supersonic dash, and landing) military flight evaluation of a reduced or eliminated vertical tail/no rudder fighter aircraft using an optimum blend of control effectors and pitch/yaw thrust vectoring in lieu of vertical tail/rudder aerodynamic control. This test will demonstrate the substantial drag reduction/range improvement and cost reduction of a reduced vertical tail/no rudder configuration that retains fighter maneuverability without compromising flight safety.

This program will build directly on the joint USAF/NASA and contractor $30 million investment in the F–15 Active testbed vehicle. Working within an existing NASA Dryden task contract, the USAF initiated an FY95 new start task to develop integrated control logic and to substantially modify the vertical tails (remove rudder and approximately one-half vertical surface) on the F–15 Active vehicle. Based on a signed MOA, NASA Dryden will lead the flight evaluation with participation by AFFTC. The flight evaluation will include a logical progression of more aggressive experiments including fixed rudder, use of the rudder to artificially produce reduced yaw stability, and a rudderless, half-size vertical tail. Testing will assess drag reduction and maneuvering capabilities across the entire F–15 operating envelope and will build confidence in the use of propulsion control as a major design consideration for future tailless fighter aircraft.

Variable In-Flight Simulator and Test Aircraft (VISTA) Simulation System Upgrade TD. This TD addresses DTO AP.05.00, Maturity Demonstration of Advanced Air Platform Technologies. This TD will augment the current F–16 VISTA in-flight simulator with an integrated control system that includes pitch/yaw thrust vectoring to provide a permanent, militarized facility for high-angle-of-attack in-flight simulation, weapons research, and flight research. With enhanced simulation capability of the VISTA/NF–16D, VISTA would be used not only for continued research and development into high-angle-of-attack flight, but also serve as a testbed allowing for significant risk reduction demonstrations of technologies for current and future systems.

This effort will build on the integrated controls with the thrust vectoring technology base provided by the Multi-Axis Thrust Vectoring (MATV) program. Contracts were awarded to Calspan (the VISTA operations contractor), Lockheed Ft. Worth Company, and Pratt & Whitney in early FY95 to design, fabricate, and modify the VISTA/NF–16D with a production-like, full-flight-envelope, axisymmetric-thrust vectoring nozzle. VISTA enhancements will also include the incorporation of a programmable display system (including two helmet-mounted displays) and high-bandwidth actuators for increased simulation fidelity. Once this configuration is validated in ground tests, a rigorous, full-envelope flight test program will begin. This flight test program will demonstrate high-fidelity in-flight simulation over the full flight envelope.

Active Aeroelastic Wing (AAW) TD. This TD addresses DTOs AP.02.00, Fixed-Wing Vehicle Structures Technology, and AP.05.00, Maturity Demonstration of Advanced Air Platform Technologies. The objective of this effort is to flight demonstrate key aspects of the highly innovative AAW concept. The AAW concept, which has been developed through exploratory analytical and wind tunnel tests, has a goal of improving maneuverability while reducing aircraft weight. Studies have shown this technology to have the capability of providing a 7% to 20% reduction in aircraft takeoff gross weight, and therefore reduced production cost.

An AAW may be described as an aeroelastically tailored composite wing designed to require only the stiffness necessary for strength, buckling, and flutter. The wing is designed to respond aeroelastically to multiple leading and trailing edge control surface deflections and to exploit aeroelastically reversed controls, thus providing never-before-achieved wing flight control responses. An active control system is designed to maximize the utility of this control power, thus providing a high-performance wing with complete control authority and power across the flight envelope. To reduce cost, an available F–18 aircraft with a digital flight control system will be used. Design studies will be performed to identify changes to the F–18's wing that increase the wing's flexibility and make the wing suitable for an AAW experimental demonstration. A high-rate actuation system will be installed to upgrade the wing's leading edge control surface. Concurrent flight control development of AAW flight control strategies will also be conducted. Following modification of the F–18 test aircraft, a full envelope flight test will demonstrate the performance benefits that may be achieved through implementation of the AAW concept.

3.1.3.2 Technology Development.

Aerodynamics. Aerodynamics technology will significantly improve aircraft performance by improving lift/drag ratio during cruise and maneuvers, reducing drag while carrying weapons, increasing lift coefficient during landing approach, reducing nozzle weight and cost, reducing inlet weight and volume, and reducing aero design cycle time. Efforts are focused on improving the versatility and efficiency of modeling advanced air vehicles. Technologists will use the computing power that has been developed over the last few years to explore and more fully understand those flight regimes that are characterized by highly dynamic, nonlinear aerodynamic flow (e.g., very high angle-of-attack maneuverability).

Flight Control. Flight control technology provides air vehicle maneuverability, stability, and flightpath control (including multiship control), while ensuring safety of flight, by reducing the weight and drag of lifting and control surfaces, hardware weight, control-related accidents, development time and cost, and maintenance actions. Austere operations are supported by flight control efforts in low-visibility weather autonomous landing guidance systems. Reduced acquisition costs are supported through efforts in low-cost modeling and low-cost control system design techniques. Reduced operations and support costs are addressed by technology developments in electric actuation, optical air data systems, and photonic vehicle management systems.

Structures. Airframe structures technology covers the development of improved lower cost/lower weight structures for all classes of fixed-wing aircraft, from analysis through concept development, experimental demonstration, and incorporation into the aging operational fleets. Improvements will be achieved by increasing structural fatigue life and by reducing structural weight; manufacturing, support, and assembly costs; and development time. The scope covers aging aircraft, smart structures, affordable composite and advanced metallic structures, extreme environment structures, new construction methods, multidisciplinary design optimization, and the exploitation of advanced manufacturing techniques in design.

Subsystems. Vehicle subsystems technology focuses on a balance of developments in aircraft subsystems to decrease aircraft weight, increase mission range, reduce cost of ownership, and enhance survivability and safety. This will be achieved by (1) reducing gear and energy management system weight; support costs; transparency production cost; repair time and component design time, and (2) by increasing tire life and MEA subsystems.

Integration. Integration technology efforts are divided into two broad categories: subsystem-level integration technology and fixed-wing-vehicle-level integration technology. The former examines and exploits the interrelationships among two or more fixed-wing vehicle technologies exclusively: aerodynamics, flight control, structures, and subsystems. These efforts also include the integration of off-the-shelf, *nondevelopmental* (i.e., current state-of-the-art technologies) from non-FWV areas such as propulsion, materials, weapons, and human systems. System-level integration technology broadens the integration task to incorporate *developing* the requisite interface technologies from non-FWV technology areas as they are integrated during system development. It involves development—and ground/flight test and evaluation—of advanced concepts that integrate fixed-wing vehicle aerodynamics, flight control, structures, and aircraft subsystems with other non-FWV technologies for current and future vehicles.

3.1.3.3 Basic Research. Specific basic research programs in robust, multivariable flight control support acquisition cost and increased combat survivability. Work in real-time parameter identification and online control law design directly supports increased combat survivability. Research in computational fluid dynamics and computational electromagnetics supports improvements in combat range and survivability. Research in ballistic impact of composites will reduce combat vulnerability. (See the DoD *Basic Research Plan.*)

3.2 Rotary-Wing Vehicles

3.2.1 *Warfighter Needs*

Operational capability improvements to both military and civil rotorcraft fleets will tremendously impact the overall cost of ownership and the acceptance of rotorcraft by passengers and community. Reducing acquisition and operation costs, diminishing vibration and noise levels, and improving the ability to operate at night and in adverse weather all highlight the vast potential of rotary-wing technology advancements. These improvement goals were developed in concert with both the user and the rotorcraft industry through the development of the government/industry/academia rotary-wing vehicles (RWVs) TDA. This document outlines the DoD approach for executing a program to achieve goals that will result in the highest payoffs (Table I–4) for the rotary-wing aviation community.

Table I–4. Rotary-Wing Vehicles Payoffs (% improvement)

Payoff	Cargo		Utility		Attack/Recon	
	2000	2005	2000	2005	2000	2005
Increase Range (for a fixed payload)	69	131	65	124	91	166
Increase Payload (for a fixed range)	64	113	42	75	69	123
Increase Maximum Cruise Speed	4	8	4	9	4	9
Increase Maneuverability/Agility	30	50	30	50	30	50
Increase Usable Flight Envelope	30	50	30	50	30	50
Reduce Development (DT&E) Costs	11	18	11	20	4	8
Reduce Procurement Costs	17	27	14	23	5	9
Reduce O&S Costs	12	25	10	20	12	23
Increase Mission Reliability	20	45	20	45	20	45
Increase Probability of Survival	20	40	40	60	40	60
Reduce Major Accident Rate	30	50	30	50	30	50

Future operational capabilities (FOCs), as defined by the combat development user community, serve to identify the areas of rotorcraft performance and cost drivers that will most benefit from technological advancements. They also provide rationalization for the pursuit of technologies that provide solutions to real-world problems, avoiding work done "at the margin" that does not provide leap-ahead improvements to the effectiveness and affordability of military (and civilian) rotorcraft. Specific RWV payoffs have been established for three classes of rotorcraft: cargo, utility, and attack/reconnaissance (Table I–4). These operational capability improvements are derived from the subsystem-level technology development goals (Table I–5), which are derived from the technology effort objective defined in the RWV TDA.

Table I–5. Rotary-Wing Vehicles Technology Development Goals (% improvement)

Goals	Cargo		Utility		Attack/Recon	
	2000	2005	2000	2005	2000	2005
Reduce: (scaled empty wt – propulsion wt)/HOGE wt	13	22	13	21	12	20
Increase Cruise Efficiency (ηL/D)	9	19	12	25	12	24
Reduce Development Time to Production	10	17	11	19	11	19
Reduce Vehicle-Related Flyaway $/lb	13	20	9	15	9	15
Reduce Vehicle-Related Maintenance $/fh	25	50	25	50	25	50
Reduce Susceptibility to Threats	20	40	30	50	30	50
Reduce Vulnerability to Threats/Failures	25	45	25	45	25	45

3.2.2 *Overview*

3.2.2.1 Goals and Timeframes. Aggressive goals (Table I–5) have been established to increase the combat effectiveness of DoD rotorcraft and maintain the nation's preeminence in the rotorcraft industry. Four technology efforts (aeromechanics, flight control, structures, and subsystems) focus on overcoming technology barriers that offer the highest potential for improving overall system capability and reducing cost.

3.2.2.2 Major Technical Challenges. The major technology challenges include:

- Accurate prediction and control of stall, drag, and compressibility characteristics that will lead to overall rotorcraft performance improvements.
- Determination of optimal rotorcraft response types, control laws, and control law synthesis methods to achieve better handling qualities and shorten the design and development process.
- Nonintrusive monitoring components and techniques, sensors, algorithms, and methods to improve design and manufacturing processes and to permit real-time monitoring of flight loads and damage.
- Actuators constructed using smart materials for primary control and vibration control of rotorcraft rotor blades.
- Understanding and modeling the effects of terminal area airwakes (e.g., ship superstructures) on the dynamics and flight control of rotorcraft.

3.2.2.3 Related Federal and Private Sector Efforts. Independent R&D (IR&D) efforts are conducted by the nation's four helicopter manufacturers. These efforts have been coordinated with the technology efforts described above, and many topics are being worked jointly through cooperative R&D agreements (CRDAs). NASA has a related rotary-wing technology development program. An Army/NASA joint agreement provides essential personnel and facility resources that supplement, and in many cases simply make possible, the Army laboratory in-house efforts directed at the described goals.

The National Rotorcraft Technology Center (NRTC)—a unique partnership of government, industry, and academia—develops, manages, and executes a research program that is focused on ensuring the continued superiority of rotorcraft systems for DoD, while concurrently strengthening the U.S. rotorcraft industry's ability to compete in the world market. The projects performed by the Rotorcraft Industry Technology Association (RITA) are funded by the Army, NASA, and industry. Since DoD (Army) funding equals approximately 25% of total funding in NRTC projects, this equates to a four-to-one leverage in the technology investment.

3.2.3 *S&T Investment Strategy*

The investment in RWV S&T is an integral part of the overall strategy to improve the military worth of rotorcraft, in concert with S&T investments in avionics, engines, drive systems, the human-system interface, and weapons. RWV S&T focuses on the facets of rotorcraft that can be improved—either incrementally or in generational leaps—through the various disciplines represented within the rotorcraft platform itself: reducing the cost of ownership, expanding upon the already highly versatile capabilities inherent with vertical-lift aircraft, and increasing the public acceptance of rotorcraft through improvements to safety, noise, vibration, and reliability. Coupled with—and anticipating—the coming improvements to mission equipment, engine performance and economy, and the range and lethality of tomorrow's weapons, RWV S&T is carefully coordinated among the Army, Navy/Marines, NASA, and industry so as to provide timely benefits to both new developments and upgrades to current systems over the next 15 to 20 years.

3.2.3.1 Technology Demonstrations.

Helicopter Active Control Technology (HACT) TD. This technology demonstration fulfills DTO AP.06.00. The HACT TD brings together advanced concepts and components to demonstrate the potential improvements from second-generation active control technology. Specifically, HACT will exploit and develop refined concepts for control law design, distributed architecture, software development, and failure management coupled with advanced components for fly-by-light and smart actuators. These have high potential to provide increased safety/reliability with shortened development times. In addition, the pilot will be provided with active cockpit flight controls and advanced displays. The total capability will be used to provide task-tailored handling qualities to demonstrate improved mission effectiveness in critical tasks in all weather and night operations. These technologies would be applied as ingredients in current system upgrades or as a package in a new system such as the Joint Transport Rotorcraft (JTR).

The workload on a vertical-lift pilot and on flight management inhibits pilot situational awareness and response. These limitations directly impact night, adverse weather, and low-altitude operations. Lack of complete control integration (fire/flight/fuel) prevents exploitation of full rotorcraft capabilities, restricts maneuverability/agility, and impacts safety and survivability. Simplified implementation of digital flight control permits customer system-specific tailoring, fleet retrofits, and system upgrades; reduces development and modification costs; and will be available for use in future military systems, as well as in the civil arena.

Rotary-Wing Structures Technology (RWST) TD. The RWST TD (DTO AP.14.00) will take advantage of breakthroughs in advanced materials—including toughened epoxies, smart materials, and metal-matrix composites—and validate their use under the harsh airframe loads of rotorcraft operations. This will be achieved through simulation to correctly identify the optimal manufacturing processes and layouts for a wide range of airframe concepts. The RWST TD will demonstrate robust tooling, processes and inspection techniques and simulation for virtual prototyping of the manufacture of tailored, affordable, and supportable airframe structural concepts. The RWST TD will support reduction in manufacturing and fabrication labor hours through process control and flexible manufacturing, reduce development risk through simulation and prototyping, and yield structurally more efficient airframes. Operation and support costs will be reduced through advanced prognostics/diagnostics.

The RWST TD will exploit emerging technologies to demonstrate advanced airframe concepts that are structurally tailored for efficiency, affordable to produce, and supportable in the field; robust manufacturing tooling and processes to produce high-quality, repeatable structural components; smart materials applications to structural components enabling real-time, in-flight monitoring of structural integrity; and simulation models enabling virtual prototyping of structural component manufacturing fabrication and assembly. RWST technologies will be a key contributor to the JTR TD and will have direct application to the commercial aviation industry. The highly efficient structural concepts and repair technology developed by RWST will also transition seamlessly to the commercial rotorcraft aircraft industry.

3rdGARD Advanced Rotor Demonstration (3rdGARD). The 3rdGARD demonstration focuses on a surge in rotor technology beyond evolutionary aeromechanics concepts. The result of integrating several breakthrough technologies will be an efficient, quiet, and smooth rotor system with very high lift capabilities. The targets of the 3rdGARD demo are:

- By FY04, develop and demonstrate the next generation of rotor system to exploit the full potential of advanced blade configurations and active control systems, improving the current performance ceilings through high-lift airfoils/devices, tailored platforms and tip shapes, elastic/dynamic tailoring methods, active on-blade control methods, and signature reduction techniques. These rotor technologies will be integrated into a base rotor design for wind tunnel and flight test demonstrations to achieve technical objectives of increasing maximum blade loading 25%, increasing rotor aerodynamic efficiency 10%, reducing aircraft loads and vibration loads by 53%, and reducing acoustic radiation by 7 dB. These demonstrations contribute to the system-level payoffs of 136% increase in range or 98% increase in payload, 15% increase in cruise speed, 50% increase in maneuverability/agility, 45% increase in reliability, and 10% reduction in O&S costs for attack rotorcraft.
- In addition to directly supporting achievement of RWV TDA objectives, the 3rdGARD demonstration supports system upgrades for all current and planned rotary-wing systems. The technologies in 3rdGARD directly support the JTR TD and EELS, MBS, DSA, and CSS battle laboratories.
- The potential applications of 3rdGARD are AH–64, UH–60, and RAH–56 upgrades; ICH; JTR development; and other military and civil rotorcraft. Rotorcraft supporting Force XXI objectives will constantly be under the threat of detection, air defense systems attack, and potential air-to-air combat. Improvements to maneuverability, agility, night and adverse-weather capabilities, and low-altitude nap-of-the-Earth (NOE) operations will be paramount.

3.2.3.2 Technology Development.

Aeromechanics. Aeromechanics S&T seeks to improve the performance of rotorcraft by reducing vibration loads, adverse forces, and acoustic radiation while increasing blade loading, aerodynamic efficiency, rotor inherent lag damping, and prediction effectiveness. Efforts are focused on refining analytical prediction methods and testing capabilities, improving the versatility and efficiency of modeling advanced rotorcraft, and achieving breakthroughs through concept applications.

Flight Control. Flight control technology defines the aircraft flying qualities and pilot interface to achieve desired handling qualities in critical mission tasks, synthesizes control laws to facilitate a particular configuration achieving a desired set of flying qualities, improves weapons pointing accuracy, reduces flight test development time, and integrates advanced pilotage systems into the aircraft to exploit agility/maneuverability. Through advanced concepts, the revolution in the power and miniaturization of computers, smaller and more reliable sensors, and production-capable fiber optic components holds tremendous promise for realizing the full potential of the rotorcraft's performance envelope and maintaining mission performance in poor weather and at night.

Structures. Structures S&T focuses on the durability, safety, survivability, and affordability of critical rotary-wing vehicle components. Structures technology efforts provide reductions in manufacturing labor hours/lb while improving structural efficiency, displacement capacity of smart actuators, structural load prediction, and accuracy of cumulative fatigue damage prediction. Improvements in structures technology enhance structural efficiency and performance while reducing both acquisition and operating costs of existing and future rotary-wing vehicles. Without low-cost manufacturing, composites technology cannot reach a level of maturity to compete with metals in providing strength, stiffness, and durability benefits. "Virtual prototyping" will be incorporated to optimize structural designs and to minimize risk in exploring new concepts for future RWV development programs.

Subsystems. Rotary-wing vehicle subsystems encompass a broad range of S&T topics related to the support, sustainment, and survivability of increasingly complex aircraft systems and to the unique problems associated with the application of high-performance weapons on rotorcraft. Efforts include addressing reductions in signatures and improvements in detection of mechanical component failure, as well as hardening to threats through improved crash worthiness and ballistic tolerance.

3.2.3.3 Basic Research. The RWV basic research program is focused on aeromechanics and structures technology. The aeromechanics efforts are directed toward rotor performance and acoustics, computational fluid dynamics, aeroelastic stability, and structural dynamics. Deliverables include an improved understanding of physical phenomena, mathematical models, and complex computer codes that are disseminated to government, academia, and industry. The structures basic research program develops advanced structural analyses, failure criteria, and inspection methods that address fundamental technology deficiencies in both metallic and composite rotorcraft. The overall thrust is to provide an integrated stress-strength-inspection technology for life extension and durability of existing and future rotary-wing vehicles.

Complementing the in-house and contracted RWV basic research effort is the Rotorcraft Center of Excellence (RCOE) program. This program is managed by a joint Army/NASA office of the NRTC through funded cooperative agreements with the Georgia Institute of Technology, Pennsylvania State University, and University of Maryland. The current projects consist of efforts related to efficient low-noise rotors, affordability, low-vibration dynamic systems, advanced drive trains, smart and composite structures, day/night adverse-weather capability, highly reliable and safe operations, and digital-optical integrated flight controls.

3.3 Integrated High-Performance Turbine Engine Technology

3.3.1 *Warfighter Needs*

Today it is well understood, as well as implied in the JCS's *Joint Vision 2010,* that low-casualty battlefield victory is achieved through air dominance. Air dominance is maintained by fielding affordable and durable high-performance air platforms capable of delivering payload when and where needed by the field command. Key to successful air platforms is the propulsion system. Gas-turbine engines have no equal in providing excess power for air platform performance, maneuverability, armament control, and mission flexibility at the lowest overall cost (production, maintenance, deployment, and fuel). The IHPTET program is providing the enabling propulsion research and development to produce the necessary low-risk propulsion technologies to continue the U.S. air dominance position through the next half century. These technologies will enable propulsion upgrades to currently fielded systems and development of future attack, bomber, and cargo aircraft and rotorcraft; subsonic and supersonic missiles; and unoccupied aerial vehicles of many configurations.

The DoD *Joint Warfighting Science and Technology Plan* identifies contributions to JCS's *Joint Vision 2010*. As discussed in this plan, there is still no foreseeable substitute for the firepower and mobility of aircraft and rotorcraft, nor is there a substitute on the horizon for gas-turbine engines as the primary propulsion system. Achievement of the IHPTET goals will provide new weapon systems with the capability to:

- Destroy selected targets over wide areas in support of Precision Force needs.
- Deliver nonlethal weapons, precise weapons, and surveillance in urban areas in support of Military Operations in Urban Terrain needs.
- Disrupt or degrade enemy defenses across the entire electronic, IR, and visual spectrums in support of Electronic Combat needs.
- Destroy enemy theater ballistic missiles and cruise missiles in support of Joint Theater Missile Defense needs.
- Detect biological weapons from long range in support of Chemical/Biological Warfare Defense and Protection needs.
- Provide enhanced readiness and logistics through improved O&M and life-cycle costs in support of the Joint Readiness and Logistics needs.

Examples of system payoffs from IHPTET technologies in support of these needs is shown in Table I–6 and enabled through the engineering application of the technologies developed to meet IHPTET goals (Table I–7). In addition to meeting the above-identified needs, IHPTET enables advanced turbine engines for New World VISTA and Air Force 2025 futuristic systems—in the near term, for Advanced Short-Takeoff/Vertical Landing (ASTOVL) and sustained supersonic cruise; in the far-term, for advanced unmanned aerial vehicles (UAVs), global reach transports, global strike bombers, and rapid reaction fighters. In addition, excess engine power will enable future "electric" directed-energy weapons and new nonhydraulic, nonmechanical aircraft control capability.

Examples of successful IHPTET technologies that have been applied to current propulsion systems include:

- Thrust (power) growth with lower fuel burn for the F100, F110, T800, F404, F414, F119, and F120 engine families (technologies include swept, high-efficiency aero-

Table I–6. Propulsion System Payoffs

Payoff	Phase I (1991)	Phase II (1997)	Phase III (2003)	Phase IV (2009)
Baseline: Global Strike Aircraft/Bomber with "IHPTET Phase I" Propulsion				
Increased Radius @ Constant TOGW	Baseline	+7%	+14%	+20%
Decreased TOGW @ Constant Radius	Baseline	-11%	-25%	-35%
Reduced Aircraft Acquisition Cost	Baseline	-10%	-21%	-28%
Reduced O&M Cost	Baseline	-10%	-23%	-32%
Baseline: Global Reach Transport with GE90/PW4000 Technology Propulsion				
Increased Range @ Constant Payload	Not Assessed	Not Assessed	+23%	+42%
Critical Global Drop Sites Covered	Not Assessed	Not Assessed	+21%	+84%
Increased Payload @ Constant Range	Not Assessed	Not Assessed	+25%	+47%
Baseline: Future Air Force Air Superiority Fighter with F119 Technology Propulsion				
Reduced TOGW @ Constant Radius	-19%	-28%	-33%	Not Assessed
Reduced Fuel Burned	-23%	-32%	-38%	Not Assessed
Baseline: Future ASTOVL Fighter with F119 Technology Propulsion				
Reduced TOGW @ Constant Radius	-20%	-29%	-36%	Not Assessed
Reduced Fuel Burned	-22%	-32%	-42%	Not Assessed
Baseline: Future Navy CAP Fighter with F119 Technology Propulsion				
Reduced TOGW @ Constant Radius	-21%	-30%	-36%	Not Assessed
Reduced Fuel Burned	-27%	-37%	-44%	Not Assessed
Baseline: F–16 with F100-PW-229 Propulsion (Re-Engined Aircraft)				
CAP Mission				
Increased Time on Station @ Constant Radius	Not Assessed	Not Assessed	Not Assessed	+90%
Increased Radius @ Constant Time on Station	Not Assessed	Not Assessed	Not Assessed	+101%
Air-to-Ground Mission				
Increased Dash Distance @ Constant Radius	Not Assessed	Not Assessed	Not Assessed	+125%
Increased Radius @ Constant Dash Distance	Not Assessed	Not Assessed	Not Assessed	+47%

dynamic fan and compressor blading; high-efficiency, low-leakage air seals; lightweight components through innovative design and composite materials; high-velocity, full-flight-envelope noncoking fuel nozzles; high-stability, high-temperature rise, full-fight-envelope re-light combustors; high-temperature, long-life turbines through advanced cooling designs; and innovative low signature nozzles).

- New F100 and F110 fan designs with enhanced field damage and life limits.
- Improved manufacturing for low-cost turbine blades, vanes, and rotors for the F100, F110, T800, F404, and F414 engines.
- Innovative engine control sensors and logic for improved reliability to the F100, F110, T800, and F414 engines.
- Lower cost new engine and maintenance replacement parts through better design and analysis tools for improved wear and life, more efficient manufacturing methods, higher quality material inspections, and processing methods.

Individual service requirements focus on major engine upgrades that are relatively frequent but whose timing is hard to predict. There are two reasons for this. First, engine capability has a large impact on the capability of an existing aircraft. Second, upgrades are dictated by the pace of both threat and technology development. Declining defense budgets are delaying, but not eliminating, the introduction of new vehicles. Thus, we can expect even greater reliance on engine upgrades to maintain superiority against emerging threats. IHPTET is specifically planned in three phases so that advanced technology is available for transition to nearer term system needs. Therefore, any existing system is a candidate for major upgrade including the F–14, F–15, F/A–18, P–3, C–130, UH–60, and AH–64. Systems currently in development, like the F–22, JSF, and RAH–66, will inevitably be upgraded in the future; thus, they will also continue to be recipients of IHPTET technologies.

3.3.2 *Overview*

3.3.2.1 Goals and Timeframes. The IHPTET program, initiated in FY88, is aimed at specific and aggressive goals for all three military engine classes in three time phases (Table I–7). The goals are referenced to the 1987 state of the art and include current and planned DTOs as previously listed. To date, IHPTET has achieved its Phase I goals and progress has been good toward the Phase II goals. Historically, industry funding devoted to the IHPTET goals has slightly exceeded government funding.

3.3.2.2 Major Technical Challenges. The general path to doubling propulsion system capability is well known. Higher temperatures at combustion initiation are required to decrease fuel consumption (via increased compression system pressure ratio) or increase maximum flight speed thereby expanding the flight envelope. Higher maximum temperatures are required to increase the output-per-unit airflow (specific thrust). Less weight-per-unit airflow is required to increase the output-per-unit weight (thrust/weight or power/weight ratio). And all of these advances must be accomplished while maintaining or increasing component efficiencies, durability, and life and by reducing cost. Specific technology development areas include advanced materials that exhibit

Table I–7. IHPTET Development Goals

Fiscal Year	Technology*	Goal
1991	TF/TJ TS/TP EXP	+30% thrust/weight; +100°F combustor inlet temperature +40% power/weight; -20% specific fuel consumption +35% thrust/airflow; -20% specific fuel consumption; -30% cost
1997	TF/TJ TS/TP EXP	+60% thrust/weight; +200°F combustor inlet temperature; -20% acquisition cost; -20% maintenance cost +80% power/weight; -30% specific fuel consumption; -20% acquisition cost; -20% maintenance cost +70% thrust/airflow; -30% specific fuel consumption; -45% cost
2003	TF/TJ TS/TP EXP	+100% thrust/weight; +400°F combustor inlet temperature; -35% acquisition cost; -35% maintenance cost +120% power/weight; -40% specific fuel consumption; -35% acquisition cost; -35% maintenance cost; +100% thrust/airflow; -40% specific fuel consumption; -60% cost

*TF—turbofan; TJ—turbojet; TS—turboshaft; TP—turboprop; EXP—expendable engine (cruise missile)

higher temperature capability and lower density; improved aerothermodynamic design capability for improved component efficiencies and control of heat transfer; innovative structural concepts for part count reduction and improved durability; and compatibility of these developments with lower cost manufacturing processes.

3.3.2.3 Related Federal and Private Sector Efforts. Both NASA and industry participate in the IHPTET program. NASA investment is approximately $20 million in FY96. Industry's discretionary funding focused on IHPTET efforts is estimated to be approximately $100 million in FY96. NASA's High-Speed Civil Transport (HSCT) and Advanced Subsonic Technology (AST) programs are directed specifically at civil engine technology that builds upon IHPTET.

3.3.3 *S&T Investment Strategy*

The program was undertaken in recognition of the large impact of engine performance on the cost and capability of military aircraft. IHPTET is a jointly planned and coordinated program among the Army, Navy, Air Force, DARPA, NASA, and industry. There is one government plan, and the six aircraft turbine engine manufacturers have complementary advanced turbo-propulsion plans (ATPPs) that address IHPTET goals in their respective military market segments. National investments among the various technology demonstrations and technology efforts are allocated in proportion to their respective contribution to meeting IHPTET goals.

3.3.3.1 Technology Demonstrations. Technology demonstrations for IHPTET are divided into the three fundamental classes of gas-turbine engines: man-rated turbofan/turbojet engines for fighter/attack/strike applications, man-rated turboshaft/turboprop engines for transport/patrol/helicopter applications, and expendable engines for cruise missile applications. In all cases, the technology demonstrators have two broad objectives. The first objective is to evaluate, in an actual engine environment, individual component performance resulting from the synergistic effect of each technology acting upon the other. These results help guide further component technology development. The second objective is to credibly demonstrate that the desired component life is achievable—through a combination of modeling and testing—to ensure that the desired durability can be reproduced in other configurations (i.e., only single-point results are demonstrated).

Turbojet/Turbofan Engine Class TD. This technology demonstration fulfills DTO AP.08.00, Fighter/Attack/Strike Propulsion. Individual TF/TJ core components (high-pressure compressor, combustor, and high-pressure turbine) are assembled in building-block fashion in the highly instrumented Advanced Turbine Engine Gas Generator (ATEGG) effort. Ultimately, the remaining components (low-pressure fan, low-pressure turbine, exhaust nozzle, and controls/accessories) are added to the ATEGG core and demonstrated in the Joint Technology Demonstrator Engine (JTDE) effort.

Turboshaft/Turboprop Engine Class TD. This TD fulfills DTO AP.09.00, Transport/Patrol/Helicopter Propulsion. Individual TS/TP components are also assembled in building-block fashion, and the demonstration occurs in a gas-generator configuration within the Joint Turbine Advanced Gas Generator (JTAGG) effort.

Expendable Engine Class TD. This TD fulfills DTO AP.10.00, Cruise Missile/Expendable Propulsion. Individual expendable components are also assembled in building-block fashion, and the demonstrations are in a full-engine configuration within the Joint Expendable Turbine Engine Concepts (JETEC) effort.

3.3.3.2 Technology Development. Technology advances in all of the constituent areas of a gas-turbine engine are required to achieve the IHPTET goals. These constituent areas, identified in the six technology efforts below, are the basis for individual technology development efforts that address specific, time-phased objectives that, when achieved, will collectively result in achievement of IHPTET goals.

Compression Systems. Compression systems consist of fans, compressors, and internal (secondary) flow systems. The major advances required in compression systems are increases in efficiency, increases in specific output of a compression stage (measured by stage loading), reductions in weight, reductions in leakage flows, and operation at higher compressor exit temperatures.

Combustion Systems. Combustion systems are divided into two areas, combustors and augmentors. For combustors, the major advances required are increases in both inlet and outlet temperature capability, reductions in weight, and reduced cost. For augmentors, the major advances required are increases in temperature capability, reductions in weight, and increased efficiency.

Turbine Systems. Turbine systems include turbine vanes, blades, shrouds, disks, cases, support frames, and internal cooling flow hardware. The major advances required for turbine systems are increases in temperature capability, reductions in cooling flow requirements, increases in work done per stage (measured by work produced per unit mass flow), and increases in thermodynamic efficiency.

Exhaust Systems. Exhaust systems include exhaust nozzles, associated structure, and signature reduction features. The major advances required for exhaust systems are decreases in weight for both treated and untreated nozzles, reductions in leakage, and improved functionality in thrust vectoring.

Controls and Accessories. Controls and accessories include the engine fuel management systems, engine/nozzle variable geometry controls, and associated pumps, valves, piping, sensors, actuators, cabling, and digital control computers. The major advances required for controls and accessories are improved control system functionality (thrust vectoring, stall/surge control), and significant reductions in component and control subsystem weight.

Mechanical Systems. The primary components of mechanical systems are bearings, seals, shafts, gearing, and lubrication systems. The major advances required for mechanical systems are increases in the temperature capability of lubricants, increases in the speed capability of bearings and air/oil seals, efficient methods of rotor thrust control, and reductions in weight.

3.3.3.3 Basic Research. IHPTET places a high priority on the quality, content, support, and successful conduct of basic research. The products of the basic research represent significant independent contributions to the national technology base and are normally intended to achieve new knowledge and understanding, develop and maintain technical expertise/capability, and provide new options and approaches for future efforts. Current focus is in the areas of turbine aero research, turbomachinery fluid mechanics, and combustion research to support gas-turbine engine development.

3.4 Aircraft Power

3.4.1 *Warfighter Needs*

By 1998, under an initiative called the More Electric Aircraft (MEA), the ability to eliminate the need for a central hydraulic system through electric power will be technologically demonstrated. This will show a 2.5x increase in aircraft electrical system reliability, a 50% reduction in engine bleed air, and a 100% increase in power system fault tolerance. By 2005, technology will demonstrate a 2x increase in integrated power-unit power densities, environmentally safe 28-Vdc batteries, 10-year high-power density 270-Vdc batteries (>1 kg/kW), no airframe-mounted gearbox, 420x increase in electrical power system reliability, 2x increase in power reliability, and 200% increase in power system fault tolerance for electric flight control and brake actuation systems.

Additional long-term operational payoffs for electrically driven aircraft functions include 60/129 additional aircraft (F–16/F–18, respectively) in a 30-day war due to increased reliability, 15% reduction in maintenance manpower needs, 20% reduction in deployment loads due to reduced ground support equipment, 15% aircraft vulnerability reduction, and reduction to a two-level maintenance of flight actuation subsystems (no hydraulic maintenance). Environmental payoffs include the elimination of aircraft hydrazine usage, a significant reduction in hydraulic fluid and associated cleaning solutions (and, thereby, the need for disposal), and reduction in battery disposal due to an increase in useful life. These reliability, maintainability, and life-cycle cost improvements directly support the JWSTP capability objective of the Joint Readiness and Logistics area and the focused logistics operational concept within *Joint Vision 2010.*

Predecessor technologies have had an excellent historical record of transition success. Recent examples include transition of battery technology to the E–8, electric equipment to the C–130J, and MEA generation I power technologies to JSF. Additional mid-term transition opportunities include the F–16, F–18, F–22, and B–1 systems. These "accelerated transitions" directly support the strategic investment priorities as stated in the *Defense Science and Technology Strategy.*

For military rotorcraft, the mechanical drive system is a significant portion of empty weight, the primary cause of high internal noise levels, and an expensive item to maintain and overhaul. Achievement of the Rotorcraft Drive DTO (AP.12.00) by the year 2000 will allow improvements to be transitioned to the V–22, AH–64, UH–60, CH–47, RAH–66, and future aircraft such as the JTR. Specific payoffs for an AH–64 antiarmor mission include a 15% range increase or a 25% payload increase, a 50% reduction in drive system maintenance labor hours per flight hour, and a significant improvement in system-related readiness issues. The drive system source noise reduction translates directly into increased crew/pilot endurance in the short term and reduced hearing loss in the long term.

3.4.2 *Overview*

3.4.2.1 Goals and Timeframes. The DoD aircraft power program represents a focused development of electrical power technology to significantly reduce costs and improve mission capabilities for DoD aircraft. This is being accomplished by developing new, electrically based, system-level approaches and new technologies that are more reliable, lower in mass, and lower in cost than existing systems. Specific component improvements are in development to achieve the goals listed in Table I–8. In addition, a focused effort for improving the weight, noise, and durability characteristics of the power drive system for rotorcraft is being pursued. These rotorcraft drive system goals are also shown in the table.

Table I–8. Aircraft and Rotorcraft Power Goals

Fiscal Year	Technology	Goal
1998	Aircraft Power	Eliminate central hydraulic system through electric power generation, distribution, and actuation; 10x increase in electrical system reliability; 100% increase in power system fault tolerance
2000	Aircraft Power	0.08 kg/kW, 1-MW synchronous high-temperature superconducting generator at 30 K
	Rotorcraft Drive	Power-to-weight 25% increase, reduce noise by 10 dB, double MTBR
2005	Aircraft Power	>2x increase in integrated power unit power density (300 kW/ft^3 400 Hp/ft^3), environmentally safe 28-Vdc batteries, high-power density 270-Vdc batteries (>1 kg/kW), no airframe-mounted gearbox, 20x increase in power system reliability, 0.05 kg/kW, 1-MW synchronous high-temperature superconducting generator at 50 K
2012	Aircraft Power	300-400 Wh/kg life of aircraft 270-Vdc batteries, 0.03 kg/kW, 1-MW synchronous high-temperature superconducting generator at 80 K.

3.4.2.2 Major Technical Challenges. The MEA concept integrates four technology efforts that each bring their unique technical hurdles:

- *Power generation*—availability of generator high-temperature, high-strength magnetic materials; and improving electronics life and high-temperature tolerance, passively based high heat flux thermal management techniques, turbo-electric machinery integration, and controlling power unit rotor dynamics.
- *Power distribution*—thermal management via passive cooling techniques; reducing fault sensing/switching/reconfiguring times; reducing solid-state device leakage currents and "on" resistance at high temperatures, diode operation temperatures, and speed; and maintaining power density performance with scalability.
- *Energy storage*—lightweight battery materials of construction, charge control under uncontrolled temperatures, development of viable high-energy cathode materials, extreme low-temperature operation, and lithium anode rechargeability
- *Systems integration*—maintaining close current/voltage tolerances, minimizing electromagnetic interference, minimizing the weight/volume of redundancy, optimizing thermal management, system integration to meet form-fit-function and power density for user, and system-level implications of high-power use.

The major challenges for rotorcraft drives involve developing very compact and durable high-reduction ratio gear configurations with excellent efficiency and low-noise characteristics, high-temperature and lightweight lubrication systems, and lightweight, durable, affordable housings.

3.4.2.3 Related Federal and Private Sector Efforts. The electrically based aircraft power program is coordinated with many related efforts across the government and industry. The More Electric Initiative Joint Planning Group, chartered by the Joint Aeronautical Commanders' Group and headed by the Air Force, serves to unify planning and service-specific implementation of the conversion of military systems to electric drive. This team focuses electrical technology for the Air Force's aerospace power and Alternative Fueled Vehicle System Program Office, the Army's electric tank program, the Navy's electric ship and submarine programs, and NASA's Power-by-Wire/Fly-by-Light commercial aircraft program. Another beneficial partnership takes place with the Inter-Agency Advanced Power Group (IAPG), which coordinates all government electrical component activities. Additional close collaboration occurs with the DoD IHPTET program, Air Force Flight Dynamics Directorate's electric actuation programs, and members of the fixed-wing vehicle subarea. There is continuing coordination with DARPA and DOE electric vehicle programs, as well as the U.S. Council for Automotive Research (USCAR) consortium's electric vehicle development activities. MEA-related technology development in FY96 is estimated at $70 million, with industry IR&D programs in related areas accounting for more than $25 million of that total.

The rotorcraft drive programs are conducted jointly between the Army, Navy, and NASA Lewis Research Center. Other organizations and programs supporting the rotorcraft drives goals include the DARPA effort to develop face gears, the Office of Naval Research/Pennsylvania State effort to improve gear durability, and NRTC/Gear Research Institute effort to develop advanced gear and bearing materials.

3.4.3 *S&T Investment Strategy*

In developing aircraft power, emphasis is maintained on specific technology demonstrations in order that the technology effort at the component level can be focused. National investments among the various technology demonstrations and technology development efforts are allocated based on their potential payoff to warfighting needs and their relative contribution to achieving aircraft power goals.

3.4.3.1 Technology Demonstrations. There are three technology demonstrations in aircraft power. Two address the specific goals of aircraft power, and one addresses the goals of rotorcraft drives. Objectives are to evaluate integrated component behavior in realistic environments, validate that the technology is sufficiently developed and understood to be transferred to new aircraft power/rotorcraft drive developments, and improve existing aircraft power/rotorcraft drive capabilities.

Power Management and Distribution for the More Electric Aircraft TD. This TD is one of two that address the needs of DTO AP.11.00, Aircraft Power (MEA). It develops a ground-based demonstrator to integrate and test a 270-Vdc fault-tolerant electrical power distribution system. This system has immediate application to the F–22, F–16, F–18, and all future military and commercial aircraft.

C–141 Electric Starlifter TD. This TD is one of two that address the needs of DTO AP.11.00, Aircraft Power (MEA). It develops electric actuators and required electric power distribution to replace hydraulic-based flight control. A C–141, designated as the Electric Starlifter, is undergoing a 1,000-hour reliability-/maintainability-/supportability-oriented, in-service flight test using electric aileron actuators to provide user confidence and reliability data.

Advanced Rotorcraft Transmission II (ART II) TD. The ART II TD directly addresses the goals of DTO AP.12.00, Rotorcraft Drive. ART II is a subsystem-level demonstration of the performance and durability increases possible through the integration of advanced high-power density and low-noise power transmission gearing, high-temperature and lightweight lubrication systems, and advanced bearings and housings. The demonstrators will be flightweight and representative of major rotorcraft transmission subsystems. They will validate significant improvements in power-to-weight ratios, reduced noise generation, and potentially increased reliability. Fatigue/endurance, noise, and loss-of-lubrication testing will be conducted during FY98–99 to assess goal achievement relative to the DTO. The demonstrators will have application to the V–22, AH–64, UH–60, and CH–47 and to future rotorcraft such as the JTR and Enhanced Apache.

3.4.3.2 Technology Development. Technology advances in both of the constituent areas of aircraft power and rotorcraft drive are required to achieve the aircraft power goals. These constituent areas are represented by numerous individual technical efforts that are aimed at specific technology objectives. The achievement of these objectives collectively result in achievement of aircraft power goals.

Aircraft Power. This activity includes development within four power technology efforts: power generation, power distribution, energy storage, and systems integration. Power generation focuses on increasing reliability and power density for main power and auxiliary/emergency power. Power distribution focuses on increasing the operating temperature for power management and distribution (PMAD) equipment and electrical components, as well as on increasing efficiency, power density, and fault tolerance. Energy storage concentrates on improved battery electrochemistry and packaging to increase energy density, reliability, and battery life, while reducing size, weight, and environmental impact. Systems integration focuses on combining component technologies—through modeling and demonstration—to enhance reliability and fault tolerance.

Rotorcraft Drives. This activity includes developing those component technologies required for very high power density rotorcraft drive systems, including gearing, bearings, housings, lubrication systems, and shafting. Major advances are required to significantly increase drive system power-to-weight ratio, reduce drive system noise, and increase drive system reliability.

3.4.3.3 Basic Research. Aircraft power places a high priority on the quality, content, support, and successful conduct of basic research. The products of the basic research represent significant independent contributions to the national technology base and are normally intended to achieve new knowledge and understanding, develop and maintain technical expertise/capability, and provide new options and approaches for future efforts. Current focus is in the areas of optical measurement techniques, improved plasma-based deposition processes, partial discharge in gases/organic media as a means of simulating high-altitude electrical component behavior and life-limiting phenomina, high-temperature magnetic materials, and high-temperature superconductivity. Research is directed to support the development of advanced, electrically based aircraft and airborne weaponry.

3.5 High-Speed Propulsion and Fuels

3.5.1 *Warfighter Needs*

Realizing the potential payoff for high-speed airbreathing propulsion and high-heat-sink fuels will enable a major step increase in weapon system performance and cost effectiveness. Technology development efforts will enable revolutionary systems that provide long-range, rapid-response capabilities that support the JCS's *Joint Vision 2010* operational concepts titled dominant maneuver, precision engagement, and full-dimensional protection. Achieving the program goals enables the development of revolutionary systems that satisfy a number of JWSTP area needs such as Precision Force, Counter Weapons of Mass Destruction, Joint Theater Missile Defense, and Joint Readiness and Logistics. Within each service, high-speed propulsion technologies are key to the viability of high-payoff concepts that resolve known warfighter deficiencies. Such deficiencies and concepts are documented in operational command documents (e.g., mission needs statements, USAF MAJCOM mission area plans, development plans).

Ramjet missile propulsion systems will revolutionize air combat and surface strike warfare. Ramjets nearly double missile engine total impulse over conventional solid rocket motors. As a result, twofold to fourfold improvements in aircraft air combat exchange ratios are attainable through revolutionary improvements in air-to-air missile (AAM) kinematic capabilities. System concepts highly rated by the warfighters include the Dual-Range AAM, which will face emerging foreign systems propelled by ramjet engines. Relative to rocket propulsion, the ramjet propulsion state of the art offers 2x missile average velocity, +30% launch range, 2x no-escape range, -30% time-to-missile-active-seek range, and -30% time to target. To maintain superiority over the emergency threats, these values will have to be improved (e.g., average velocity of ~5,000 ft/s). Additionally, high-speed strike missile concepts using ramjets provide at least 4x increase in penetration energy against hardened or deeply buried targets, with up to 1,000-nmi standoff ranges. Emerging Air Force and Navy requirements, such as a replacement for the High-Speed Antiradiation Missile (HARM), favor the Mach 4–6 speed available from ramjet propulsion systems. Overall, analyses have shown that ramjet-propelled missile systems can provide a 30x increase in weapon effectiveness over fielded systems.

Advanced/combined-cycle engine (CCE) propulsion systems offer enormous payoffs for future missiles and aircraft. Advanced cycle pulse detonation engines (PDEs) offer an "ultra simple" airbreathing engine capable of self-acceleration over the Mach 0–4 regime. The simplest variants could replace more expensive turbojets and less capable rockets used in a subsonic cruise missile such as AGM–130, Tomahawk, and JASSM. Supersonic PDEs will eliminate the need for integral boosters on supersonic missiles, increasing the packaged total impulse twofold. Mach 5 CCEs will enable tripling unrefueled tactical aircraft ranges (from 300–500 nmi to 1,000–1,500 nmi) without increasing mission flight times. The Air Force's Hypersonic Multi-Role Fighter concept will rely upon a Mach 5 turboramjet. Faster CONUS-based aircraft, such as a Hypersonic Global Range Reconnaissance/Strike Aircraft, will be able to reach any military target in 1 to 2 hours. The Navy is examining Mach 6 cruise missiles employing expendable CCEs to attack targets from long and inherently safe standoff ranges with flight times as short as one-seventh that of subsonic cruise missiles, while retaining end-game target search capabilities needed for theater missile defense missions.

Scramjet propulsion systems can resolve documented warfighter range, timeliness, and survivability deficiencies. Fast-reaction standoff weapons (FRSOWs) using Mach 8 hydrocarbon-fueled scramjet engines will provide a rapid-response weapon capability to counter highly mobile Scud-type weapons from 300 nmi in less than 5 minutes or strike high-value, well-defended targets 1,000 nmi away in 15 minutes. The Air Force favors a scramjet-propelled FRSOW that will be small enough to carry on an F–15E, yet will carry a payload of up to 500 lb. Other high-payoff scramjet and CCE applications include reusable single-stage- and two-stage-to-orbit launch vehicles. Compared to rocket-powered systems, launch windows can be increased by an order of magnitude—10 hours versus 1 hour—as well as improving ascent maneuverability and launch flexibility for military surveillance missions.

High-heat-sink (HHS) fuels such as JP–8+100 will significantly reduce aircraft and engine fuel system maintenance costs incurred due to fuel fouling/coking. JP–8+100 will also provide additional heat sink and thermal stability for future systems. JP–900/endothermic hydrocarbon fuels (H/CF) offer solutions for significant improvements in aircraft thermal management that will enable sustained flight in the Mach 5–8 regime. Ultimately, HHS H/CF enable the use of a single high-temperature-capable jet fuel that eliminates fuel system deposits and related maintenance and is applicable to both air and ground vehicles operating throughout all engine-cycle temperatures and air vehicle speeds.

3.5.2 *Overview*

3.5.2.1 Goals and Timeframes. High-speed propulsion and fuels technology programs will achieve the goals shown in Table I–9. High-speed propulsion goals are referenced to the demonstrated state of the art for three engine classes: ramjet (RJ) for missile applications, scramjet (SCRJ) for missiles and air vehicles, and CCE for manned/unmanned vehicles. Fuel goals are referenced to HHS H/CF for improved fuel thermal stability and air vehicle thermal management cooling capability.

Table I–9. High-Speed Propulsion and Fuels Technology Development Goals

Fiscal Year	Engine Class	Goal
1997	RJ	+100% effective impulse via a variable flow ducted rocket (VFDR)
1998	HHS H/CF	+100°F thermal stability, +50% heat sink (JP–8+100)
1999	RJ	M=3.5–4.0 low-cost missile ATD
2000	CCE	+30% specific thrust, +20% thrust/weight
2001	SCRJ	Freejet demonstration, Isp=850 s, specific thrust = 60 $lb_f/lb_m/s$ @ M=8
2005	HHS H/CF	5x increase in fuel cooling capacity (JP–900) 5–10x increase in fuel cooling capacity (endothermic fuels)

3.5.2.2 Major Technical Challenges. The challenge is to develop critical enabling high-speed technologies required to support the development of high-speed weapon systems and HHS fuels for all services. Required are simple, reliable, high-performance inlets (including airframe-integrated inlets); combustors that deliver optimum performance for ramjets, scramjets, and advanced/CCEs; nozzle/expansion systems that provide thrust over the entire range of vehicle operation; validated high-temperature structural design methods, thermal loads, and materials and fabrication processes for propulsion flowpath components operating for extended periods above Mach 4; and additives for fuels to suppress auto-oxidation and degradation mechanisms while maximizing available energy and providing adequate engine/airframe cooling.

3.5.2.3 Related Federal and Private Sector Efforts. NASA has research efforts in advanced/CCEs and scramjets that are closely coordinated or integrated with DoD. NASA and DoD participate jointly in the development of advanced/CCE and scramjet propulsion systems. To address congressional concerns regarding future fuel availability, DoD is working cooperatively with DOE to develop high-temperature, thermally stable and endothermic fuels from coal.

3.5.3 *S&T Investment Strategy*

In executing this subarea, focus is maintained on specific technology demonstrations in order to determine the technology effort at the component level. National investment among the various technology demonstrations and technology efforts are allocated with their potential payoff to warfighting needs and their relative contribution to achieving high-speed propulsion and fuels goals.

3.5.3.1 Technology Demonstration. The integrated propulsion system technology demonstrators are divided into four families: ramjets, scramjets, combined-cycle engines, and high-temperature fuels. HHS H/CF demonstrations are integrated into applicable engine demonstrators. The knowledge obtained from the demonstrators will provide additional direction for all future exploratory efforts. Additionally, the results will enable the confident transition of technology.

Ramjet TDs. The major challenge is demonstrating propulsion system performance over representative flight envelopes (speed and altitude). RJ components are initially ground demonstrated as individual components and then integrated into full engine ground testing.

Scramjet TD. These demonstrations fulfill DTO AP.17.00, Hydrocarbon Scramjet Missile Propulsion. The major challenge is to demonstrate integrated SCRJ system performance over representative flight envelopes (speed and altitude). Scramjet demonstrator engines will be built upon exploratory development work in the area of storable-fuel, dual-mode ramjet/scramjet technology and will include both sub-scale and full-scale ground test engines using storable H/CF.

Advanced/CCE Demonstrations. Demonstrating low- and high-speed operation is the overall challenge for these demonstrators. More specifically, the major Advanced Cycle Engine technical challenge is to demonstrate the reduction or elimination of the need for an oxidizer to aid in detonating the fuel–air mixture and to demonstrate the operational frequency of pulse-detonation engines. The major CCE challenge is to demonstrate a critical component that eliminates the need for a high-pressure turbine stage in a turbomachinery-based CCE and to then demonstrate transition to and from low- and high-speed operation.

High-Temperature Fuels TDs. These TDs fulfill DTOs AP.18.00, Improved JP–8 Fuel, and AP.19.00, High Heat Sink Fuels. They are conducted using laboratory rigs, engine component simulators, and reduced-scale fuel system/engine simulators. Further testing is conducted in sea-level engine testing culminating with a flight test.

3.5.3.2 Technology Development.

Air-Induction Systems. The air-induction system consists of the engine air inlet and the internal compression region to interface with the engine. Major advances are required to increase overall inlet pressure recovery while reducing system length and weight and attaining acceptable flow quality, distortion, and turbulence at the combustor entrance.

Combustors/Ramburners. This system includes ramjet/CCE ramburner/augmentor and scramjet combustion systems. Major advances are required to significantly increase combustion efficiencies, increase combustor operability range, and develop technologies to improve fuel vaporization, fuel kinetics, combustor piloting and flameholding, and controlled heat release.

Nozzle/Expansion Systems. This area includes single expansion ramp and conventional axisymmetric nozzles. Future exhaust system technology needs include lightweight, high-temperature nozzle materials and structures, advanced nozzle cooling techniques, increased nozzle efficiencies, and high levels of vehicle integration.

Fuels and Fuel Systems. This area includes JP–8+100, JP–900, and endothermic fuels for aircraft and high-speed propulsion systems and the associated fuel delivery systems. Major advances are required to increase fuel thermal stability, improve fuel cooling capability, increase fuel energy density, and reduce system weight and cost.

Structures and Materials. This area includes structural design methods, thermal loads, and material and fabrication processes for flowpath components of high-speed propulsion systems. Major advances are required to validate the structural integrity and environmental tolerance of the principal flow path components of high-speed propulsion systems—such as actively cooled panels, cowl/strut leading edges, fuel injectors, and seals—to operate for extended periods above Mach 4.

3.5.3.3 Basic Research. High-speed propulsion and fuels place a high priority on the quality, content, support, and successful conduct of basic research. The products of the basic research represent significant independent contributions to the national technology base and are normally intended to achieve new knowledge and understanding, develop and maintain technical expertise/capability, and provide new options and approaches for future efforts. Current focus is in the areas of combustion, supercritical fuels, vapor-phase lubricant mechanisms, and ramjet and scramjet propulsion.

GLOSSARY OF ABBREVIATION AND ACRONYMS

3rdGARD	3rdGARD Advanced Rotor Demonstration
AAM	air-to-air missile
AATP	advanced airframe technology plan
AAW	Active Aeroelastic Wing
A/C	aircraft
ac	alternating current
AFFTC	Air Force Flight Test Center (Edwards AFB, CA)
AFGROW	A deterministic fatigue analysis and failure prediction model
ALC	Air Logistics Center
AMRAAM	Advanced Medium-Range Air-to-Air Missile
ART II	Advanced Rotorcraft Transmission
AST	Advanced Subsonic Technology
ASTOVL	Advanced Short-Takeoff/Vertical Landing
ATD	Advanced Technology Demonstration
ATEGG	Advanced Turbine Engine Gas Generator
ATPP	advanced turbo-propulsion plan
C^3	command, control, and communications
C_L	lift coefficient
CAP	combat air patrol
CCE	combined-cycle engine
CONUS	continental United States
CRDA	cooperative research and development agreement
CSS	Combat Service Support Battle Laboratory
CVLA	Cargo Vehicle Light Assault
DARPA	Defense Advanced Research Projects Agency
dB	decibel
DOE	Department of Energy
DSA	Depth and Simultaneous Support Battle Laboratory
DT&E	development, test and evaluation
DTO	Defense Technology Objective
EELS	Early Entry Lethality Survivability Battle Laboratory
EMD	engineering manufacturing development
ERD	Extended-Range Demonstration
EXP	expendable (engine classification)
FAA	Federal Aviation Administration
FATE	Future Aircraft Technology Enhancement
fh	flight hour
FOC	future operational capability
FRSOW	fast-reaction standoff weapon
ft/s	feet per second
FWV	fixed-wing vehicle
FWVP	Fixed-Wing Vehicle Program
FY	fiscal year

HACT	Helicopter Active Control Technology
HARM	High-Speed Antiradiation Missile
H/CF	hydrocarbon fuels
HHS	high-heat-sink
HOGE	hover out-of-ground effect
hp	horsepower
HSCT	High-Speed Civil Transport
HSR	High-Speed Research
IAPG	Inter-Agency Advanced Power Group
ICH	Improved Cargo Helicopter
IHPTET	Integrated High-Performance Turbine Engine Technology
IPT	integrated product team
IR	infrared
IR&D	independent research and development
Isp	specific impulse
JASSM	Joint Air-to-Surface Standoff Missile
JCS	Joint Chiefs of Staff
JETEC	Joint Expendable Turbine Engine Concept
JSF	Joint Strike Fighter
JSTARS	Joint Surveillance Target Attack Radar System
JTAGG	Joint Turbine Advanced Gas Generator
JTDE	Joint Technology Demonstrator Engine
JTR	Joint Transport Rotorcraft
JWSTP	*Joint Warfighting Science and Technology Plan*
K	kelvin
kg	kilogram
kW	kilowatt
LO	low observable
M	Mach number; mega
MAJCOM	U.S. Air Force Major Command
MATV	Multi-Axis Thrust Vectoring
MBS	Mounted Battlespace Battle Laboratory
MEA	More Electric Aircraft
MOA	memorandum of agreement
MTBR	mean time between replacement
MW	megawatt
NASA	National Aeronautics and Space Administration
nmi	nautical mile
NOE	nap of the Earth
NRTC	National Rotorcraft Technology Center
O&M	operations and maintenance
O&S	operations and support
PDE	pulse detonation engine
PMAD	power management and distribution

R&D	research and development
RCOE	Rotorcraft Center of Excellence
RITA	Rotorcraft Industry Technology Association
RJ	ramjet
RWST	Rotary-Wing Structures Technology
RWV	rotary-wing vehicle
s	second
S&T	science and technology
SCRJ	scramjet
SOF	Special Operations Forces
STO	short takeoff
TAFT	Today's Aircraft Flying Tomorrow
TD	Technology Demonstration
TDA	Technology Development Approach
TF/TJ	turbofan/turbojet (engine classification)
TOGW	takeoff gross weight
TS/TP	turboshaft/turboprop (engine classification)
TTCP	The Technical Cooperation Program
UAV	unmanned aerial vehicle
USCAR	U.S. Council for Automotive Research
Vdc	volts dc (direct current)
VFDR	variable flow ducted rocket
VISTA	Variable In-Flight Simulator and Test Aircraft
VSTOL	vertical/short takeoff and landing
Wh/kg	watt-hour per kilogram

CHAPTER II
CHEMICAL/BIOLOGICAL DEFENSE AND NUCLEAR

1. INTRODUCTION

Joint Vision 2010 defines full-spectrum dominance as the key characteristic needed by U.S. forces in the 21st century. Chemical and biological defense and nuclear technology programs are critical for establishing the full dimensional protection that is a precondition for establishing full-spectrum dominance. Developing effective capabilities to deal with weapons of mass destruction (WMD) proliferation threats is also a key element of U.S. strategy, as articulated by the President in *The National Security Strategy of the United States* (February 1996, pp 19–21). The bipolar warfighting scenarios that permeated our cold war strategy in Central Europe have given way to a new force projection strategy, and U.S. forces must be prepared for conflict in a nuclear, biological, and chemical (NBC) warfare environment in a global reach concept. Developing the required capability to project military power to unprepared battlefields has led to a fundamental change in the S&T requirements for the Chemical/Biological Defense and Nuclear area. The ready availability of CB and nuclear and radiological weapons has expanded the WMD threat spectrum from the traditional organized enemy force to include amorphous threats such as terrorism.

1.1 Definition/Scope

The Chemical/Biological Defense and Nuclear technology area is devoted to the development of technology to counter the threat of WMD and to ensure the safety and mission effectiveness of U.S. forces operating within a contaminated environment with minimal impact on logistics. This technology area is divided into nonmedical CB defense and nuclear program areas, with eight subareas as shown in Figure II–1. Medical CB defense technology efforts are included in Chapter VI, Biomedical. Additional information can also be found in the *Joint Warfighting Science and Technology Plan* (JWSTP), Chapter IV, Section I.

A glossary of abbreviations and acronyms used in this chapter begins on page II–28.

1.2 Strategic Goals

The strategic goal of CB defense is the seamless integration of technologies from its four subareas—detection, protection, decontamination, and studies, analyses, and simulations—into a system of systems for horizontal integration across the spectrum of combat and support systems. Detection and warning capabilities must be integrated to provide a cohesive picture of the operational theater through the use of information technologies, such as simulation, to provide operational commanders with the required situational awareness needed for command decisions. When

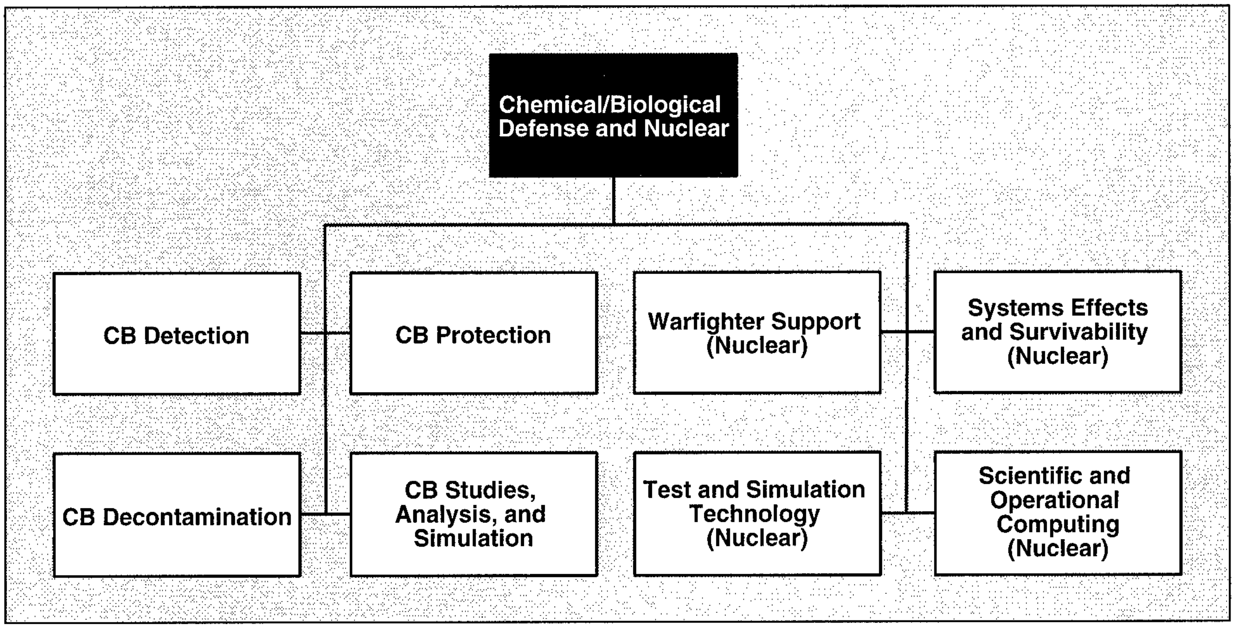


Figure II–1. Planning Structure: Chemical/Biological Defense and Nuclear Technology Area

avoidance is not possible, integrated protection for CB warfare will allow U.S. forces to maintain operational effectiveness in a contaminated environment with minimal impact on logistics. Decontamination may be required for personnel, mission-essential assets, and areas in CB warfare conflicts, particularly for power projection supply and retrograde operations.

The strategic goal of the nuclear program area is to provide technologies needed for an effective, survivable nuclear force that will contribute to the national goal of deterring the threat or use of nuclear weapons. A complementary objective of this program area is to ensure that forces and equipment, especially C^4I systems, are protected against the effects of a nuclear weapon detonation (e.g., transient radiation effects on electronics (TREE), and total neutron dosage). The technologies being developed under this area are designed to prevent such disruptions through the development of radiation-tolerant microelectronics for satellites and of affordable, integrated protection of ground-based C^4I systems, including those that use off-the-shelf equipment.

The entire CB defense and nuclear strategic goal is supplemented by studies, analysis, testing, and simulation in the assessment of NBC threats, joint service doctrine, equipment design/development, soldier/system survivability, and training as well as in providing commanders with decision aids based on the integration and interpretation of real-time data.

1.3 Acquisition/Warfighting Needs

The objective of the CB Defense and Nuclear technology program is to enable our forces to survive, fight, and win in an NBC environment by ensuring a superior defensive posture that protects our forces and equipment and makes chemical, biological, or nuclear warfare a high-risk, low-payoff alternative for opposing forces. To achieve this objective, the warfighter needs to be able to detect, protect, and decontaminate/neutralize CB warfare and radiological threats with minimal logistics burdens.

The basic concept of operations in an NBC-contaminated environment is early detection and warning to provide situational awareness and permit forces to avoid the threat. Chemical detection sensors would be integrated into a variety of platforms ranging from individual battledress to autonomous reconnaissance systems. Early detection and warning of CB threats will enable commanders to activate/deactivate protective/avoidance measures in a timely fashion. This capability can be provided by a real-time sensor network to detect, identify, map, quantify, monitor, and disseminate information on the presence of CB warfare and radiological threats at or below incapacitating/physiological effect levels in the operational theater.

Protection applications for personnel range from clothing/respirator ensembles to filtration systems for vehicles and large-area enclosures, including ships and command posts. Ensembles and respiratory protection that will minimize physiological and psychological burdens are required to maintain peak operational performance capabilities for individual warfighters. New filtration materials and systems are needed to reduce the logistics burden for ground vehicles, ships, aircraft, and large area enclosures.

Systems must also be protected against the effects of a nuclear weapon detonation, particularly sensitive electronic components. The focus is on preventing disruptions to system operations through development of radiation-tolerant microelectronics for satellites and integrated protection of ground-based C^4I systems. The neutralization or destruction of buried or otherwise nuclear-hardened targets with minimal collateral hazard and the fielding of WMD contingency planning systems (including real-time dispersal prediction) is also a focus of warfighter support.

Decontamination capabilities are required to sustain operations in a CB-contaminated environment, to ensure power projection capabilities particularly for ports and airfields of departures, to clean up personnel and wide areas for retrograde and resupply operations, and to reconstitute individual equipment, vehicles, sensitive equipment, and weapon platforms.

Chemical/Biological Defense and Nuclear technology development responds directly to the Defense Guidance, to the Counterproliferation and CB Warfare Defense and Protection technology areas in the JWSTP, and to the Counterproliferation Program Reports to Congress. In confrontations involving WMD proliferants, personnel and systems must be survivable; similarly, effective nuclear forces are required to support deterrence both prior to and during conflicts. The recent Tokyo subway attack is an example of new threat scenarios we are likely to encounter in the future given the ready access to CB and radiological weapons by Third World and terrorist organizations.

The CB Defense and Nuclear technology area plays an important supporting role for other technology areas. Additional JWSTP objectives involve applications of electronic, optical, and computer technologies (e.g., for Information Superiority, Precision Force, Combat Identification, Joint Theater Missile Defense, and Electronic Combat). CB defense and nuclear technology development ensures that the critical systems employed can accomplish their missions if proliferants employ WMD. Some examples of CB defense and nuclear transition opportunities can be seen in Table II–1. This technology base also provides much of our capability to model the propagation of signals and information within weapon-effect-disturbed environments.

Table II–1. CB Defense and Nuclear Technology Transition Opportunities

Current Baseline	5 years	10 years	15 years
CB DETECTION SUBAREA			
Limited number of detectable agents, multiple point sensors Interim biological detection system Chemical detection from 1–5 km Aerosol detection from 30 km Voice alerts Limited availability of digitized data; analog communications	Multiple detectable agents, fewer point sensors CB water and surface contamination monitor Small, lightweight chemical monitor Low dose chemical interior monitor Automated point bio-detection system Early warning bio-aerosol detection from 1–5 km Early warning aerosol cloud detection to 50 km Availability of digitized data Global access of CB data Joint warning and reporting network	Manportable point bio-detection system Chemical detection from 20 km Early warning bio-class aerosol detection Early warning aerosol cloud detection to 100 km Real-time data and time-projection access for operational theater Limited access to virtual reality	Manportable integrated CB detection system Chemical sensor integrated into clothing Early warning chemical and biological aerosol detection Global access to virtual reality of operational theater
CB PROTECTION SUBAREA			
Battle dress overgarment (BDO), chemical protective overgarment (CPO), butyl gloves, vinyl overshoes M40 and MCU-2/P masks; C2 canister Single-pass carbon collective protection filters	Lightweight garments and breathable gloves Improved agent resistance, vision, and compatibility; lower breathing resistance and bulk/weight Improved filter life Regenerative filtration for armored vehicles	CB duty uniform 50% lighter than JSLIST uniform/over-garment Integrated helmet/respirator with visor display, positive pressure breathing, compatibility with weapons sighting systems Noncarbonaceous collective protection filtration	Integrated duty uniform with CB and environmental protection, signature reduction, decontaminable for reuse
CB DECONTAMINATION SUBAREA			
DS2, STB, and improved sorbent technologies	Concepts for aircraft/ship interior decon Concepts for wide area/fixed site decon	Supercritical fluid-based decon for sensitive equipment Demo enzymatic decon DS2 replacement	Strategic modular decon systems and approaches

Table II–1. CB Defense and Nuclear Technology Transition Opportunities (continued)

Current Baseline	5 years	10 years	15 years
CB STUDIES, ANALYSIS, AND SIMULATION SUBAREA			
Transport and diffusion models with terrain features	Microgeography and micrometeorology for CB hazard prediction Collateral effects predictor CB effects into simulators Tradeoff models to assess value added of CB capabilities	Real-time computation of hazards Virtual reality simulators	
WARFIGHTER SUPPORT (NUCLEAR) SUBAREA			
Refocusing of capabilities to respond to proliferation threats underway	Demonstrate and validate initial adaptive planning for counterproliferation	Complete initial dual-revalidation of nuclear stockpile in collaboration with DOE	Continuous adaptation to new requirements as identified by CINCs
SYSTEMS EFFECTS AND SURVIVABILITY (NUCLEAR) SUBAREA			
In process of identifying what must be done to adapt to new, post-cold war protection requirements	By FY98, qualify production-ready, radiation-tolerant 4 M SRAM By FY00, demo radiation tolerant 100 k gate array and 16 M SRAM using 0.35-micron SOI technology		Adaptation of survivability practices to respond to future threats and to take advantage of new technologies
TEST AND SIMULATION TECHNOLOGY (NUCLEAR) SUBAREA			
Consolidation and refocusing on new requirements; incremental improvements to existing capabilities (e.g., flyer plate facility)	IOC for LB/TS with non-ideal airblast simulation capability and implement initial component of new DECADE simulator	Adapt investment strategy to take advantage of technical progress (e.g., new laser sources, National Ignition Facility (NIF))	Take advantage of developments in advanced physics programs (e.g., Laser Microfusion Facility (LMF) and ASCI)
SCIENTIFIC AND OPERATIONAL COMPUTING (NUCLEAR) SUBAREA			
Current-generation supercomputer	Transition to HPC architecture and departmental machines	Interface with ASCI; more emphasis on virtual experiments supported by physics understanding	TBD - timeframe approximates 6+ generations of change in base technologies

1.4 Support for Combating Terrorism

The increase in terrorist incidents and activity, coupled with the ready availability of CB and nuclear radiological weapons, has made NBC terrorism a viable contingency in the expanding WMD threat spectrum. Whereas the focus of this program is on providing immediate capabilities for first-responder activities, including law enforcement, fire/rescue, and emergency care personnel, the full spectrum of CB defense and nuclear radiological technology base will be leveraged to provide near- and mid-term transitions to supplement these capabilities.

Within the CB mission area, enhancements in CB detection capabilities will be provided as technology inserts. Technology for standoff detection and mapping of chemical agent contamination and clouds will be provided (DTO CB.07.10) for protection of high-value, fixed facilities as well as for mobile reconnaissance by first responders. For individual protection, improved filtration materials and selectively permeable membrane clothing materials will minimize the impact of performance for first responders functioning in CB-contaminated environments (DTOs CB.06.12, CB.08.12, and CB.16.12). Improved, nontoxic, noncorrosive, and environmentally safe decontamination materials, such as foam-based catalytic enzymes (DTO CB.09.12), will enable first responders to deal with large or small CB incidents. CB modeling and simulation efforts in the area of hazard prediction will enable authorities directing first-responder activity to better assess potential or actual CB hazards and to aid in the development of realistic contingency plans.

Technology development within the nuclear subareas will also improve DoD and national capabilities for combating terrorism. Within the warfighter support (nuclear) subarea, activities include development and demonstration of physical security technologies suitable for protection of nuclear forces as well as force protection and other counterterrorist applications. Research on the effectiveness of munitions conducted as part of the Hard Target Defeat DTO (CB.13.07) has been adapted to develop an improved understanding of the threats posed by terrorist devices and of the effectiveness of countermeasures against such threats. The Prediction and Mitigation of Collateral Hazards DTO (CB.14.07) is developing improved capabilities for predicting the hazards that might result from terrorist use of WMD. Terrorist threats can be directed at systems as well as personnel. These technical efforts, whose primary purpose is to respond to military requirements, are examples of technologies that can be made available to civilian authorities and organizations responsible for combating terrorism involving CB and nuclear radiological weapons. The systems effects and survivability (nuclear) subarea develops the technologies needed for protection of critical systems as described in the Balanced Electromagnetic Hardening Technology DTO (CB.15.01). This DTO will develop the technologies needed to provide better, more affordable protection against a range of hazards. The test and simulation technology subarea provides unique capabilities for assessing the consequences of terrorist devices and evaluating the performance of protective measures that are described in the Nuclear Hardness and Survivability Testing Technologies DTO (CB.10.07).

2. DEFENSE TECHNOLOGY OBJECTIVES

The DTOs identified and approved for the CB Defense and Nuclear technology area are as follows:

CB Detection

CB.02.10 Joint Warning and Reporting Network
CB.07.10 Laser Standoff Chemical Detection Technology

CB Protection

CB.06.12 Advanced Lightweight Chemical Protection
CB.08.12 Advanced Adsorbents for Protection Applications
CB.16.12 Enhanced Respirator Filtration Technology

CB Decontamination

CB.09.12 Enzymatic Decontamination

CB Studies and Analysis

None

Warfighter Support

CB.10.07* Nuclear Hardness and Survivability Testing Technologies
CB.13.07 Hard Target Defeat
CB.14.07 Prediction and Mitigation of Collateral Hazards

Systems Effects and Survivability

CB.10.07* Nuclear Hardness and Survivability Testing Technologies
CB.12.01 Electronic System Radiation Hardening
CB.15.01 Balanced Electromagnetic Hardening Technology

Test and Simulation

CB.10.07* Nuclear Hardness and Survivability Testing Technologies

Scientific and Operational Computing

None

*This DTO relates to multiple subareas.

3. TECHNOLOGY DESCRIPTIONS

3.1 CB Detection

3.1.1 *Warfighter Needs*

The combat efficiency of forces can be increased by reducing the physiological and psychological effects of operating in a CB-contaminated environment by possessing the ability to constantly monitor for the presence of CB warfare agents. Information provided by a CB warfare agent contamination avoidance network that can detect, identify, map, quantify, and track the threat in the operational theater will provide commanders with the situational awareness necessary for command decisions. A real-time contamination avoidance network composed of various sensors integrated into a variety of platforms ranging from individual battledress, weapon platforms, and standalone units linked to the C^4I system will process and integrate sensor data with geographical, meteorological, and intelligence data to provide an up-to-date and time-projected CB warfare situational threat analysis. The network will provide situational awareness on different levels depending on the need.

In the short term (within the next 2 years), the warfighter will require the capabilities that are described in the operational requirements of the Joint Chemical Agent Detector (JCAD)—formerly the Joint Service Chemical Miniature Agent Detector—and the Joint Biological Point Detection System (JBPDS). The Joint Service Lightweight Standoff Chemical Agent Detector (JSLSCAD) transitioned to engineering, manufacturing, and development in FY96. These will provide capabilities in chemical vapor detection for personal safety, interiors of cargo aircrafts, ground vehicles, ships, and survey monitors; in automated biological agent detection; and in an early warning system for chemical agent vapors, respectively.

In the mid term (3–5 years), the needs are for a Joint Chemical/Biological Agent Water Monitor (JCBAWM) and a Joint Biological Remote Early Warning System (JBREWS). The capabilities described in JBREWS and JCBAWM are to provide an early warning to the presence of biological warfare agents and to detect the presence of contaminants in water.

In the far term (6 years and beyond), the needs will be for capabilities in universal biological agent detection, detection of liquid contaminants on surfaces, and long-range (in excess of 50 km) detection of chemical agents.

3.1.2 *Overview*

3.1.2.1 Goals and Timeframes. The goal of the detection subarea is to provide a real-time capability to detect, identify, map, quantify, track, and disseminate information on the presence of all CB warfare agent threats at levels to protect against incapacitation/physiologically significant effects. Current emphasis is on multiagent sensors for CB point and early warning detection. Within the next 2 years, technology is being transitioned to engineering manufacturing and development phase for JCAD and JBPDS. The technologies will be for a number of sensors that are targeted against either chemical or biological agents. In particular, a pocket-sized chemical vapor point detector (JCAD), an automated biological point detection system (JBPDS), and a passive infrared chemical agent detection system (JSLSCAD) will be available in this timeframe. In the mid term (3–5 years), technology will be available for detecting contaminants in water (JCBAWM) and for providing an early warning to the presence of biological warfare agents (JBREWS). In the far term (6 years and beyond), the technological goals will be for concepts in universal biological warfare agent point and remote detection, detection of liquid contaminants on surfaces, long-range (in excess of 50 km) detection of chemical warfare agents, and an artificial intelligence in a global networked system to provide a complete situational awareness of the operational theater.

3.1.2.2 Major Technical Challenges. The CB detection subarea includes a number of different technologies including analytical and materials characterization techniques such as various forms of spectroscopy and bioassay technologies, materials development, engineering concepts, and information technology (computer and communication hardware and software). The technical challenges are to enhance sensitivity and selectivity; increase number of detectable CB agents; decrease response time; enhance sampling techniques; discriminate from naturally occurring background materials; develop advanced signal processing for detection algorithms; reduce size, weight, and power requirements; integrate data with threat models; integrate sensor systems into C^4I systems; increase computational/communication capabilities; reduce cost; and minimize logistical requirements.

These technical challenges are being met through the development of new immunoassay systems, deoxyribonucleic acid (DNA or genetic) probes, materials for coatings, infrared/ultraviolet (IR/UV) lasers, mass spectrometric technologies for biologicals as well as chemicals, improvements in previously explored technologies such as surface acoustic wave technology, and nonradioactive ionization sources, optics, and pre-concentrators. Nonspecific concepts/strategies are investigating whole cells as a detector, naturally occurring chemical markers in biological materials, enhanced Raman spectroscopy techniques for liquid contaminants on surfaces or contaminants in water, or sampling techniques for collection or introduction into various point detection systems. There are also efforts to understand and characterize biological/chemical/physical properties and physiological effects of CB agents. In addition, technologies are being explored for micromechanical fluidics technologies for sample processing and for imbedding separation and identification technologies in chip-sized devices.

Process and materials engineering, thermal management, component integration, fluidics management, and other new engineering concepts are reducing system size, weight, power, and response time and optimizing detector configurations and logistical requirements. These new engineering concepts, combined with the efforts in the fundamental sciences, are producing advances in technology such as IR/UV detectors that are more uniform, have higher sensitivity and efficiency, and function under conditions close to ambient temperatures instead of –200°C; new lasers that have high outputs, use less power, are smaller in size and weight, and have wider frequency ranges; and selective sampling systems that are more efficient.

The information technologies are responsible for developing new signal processing techniques to analyze sensor data and integrating the information to the threat models along with geographical, meteorological, and intelligence data for dissemination in the C^4I system. The information technologies must be able to handle a tremendous amount of data, both for processing and for manipulation through the network. The CB Defense and Nuclear technology area is responsible for the development and advancement of software algorithms for pattern recognition, signal processing, artificial intelligence, expert systems, virtual three-dimensional simulations, and computer–human interface. The actual computational/communication hardware (design of computer/electronic chips) is outside the scope of this technology area.

The affordability issue is an inherent parameter that is not addressed as a separate issue in the technical challenges. A large number of the efforts described are driven heavily by the affordability issue. Prime examples are nonradioactive ionization sources, detectors that function at ambient temperature instead of –200°C, and component integration.

3.1.2.3 Related Federal and Private Sector Efforts. Chemical and biological detection is a specialized subset of a much larger environmental health and safety area. All CB detection technology, in principle, can be modified to address the larger picture of environmental health and safety. The ability to detect, identify, map, monitor, quantify, and track industrial hazardous and medically infectious materials is considered highly desirable by the commercial sector. The potential benefits of dual-use for the CB detection technology are already being developed through collaborative efforts with environmental and medical groups. In many of these areas, the private sector is working on leap-ahead technologies that can be applied to CB defense problems. Modified versions of a DoD prototype detection system are being used or developed by other government agencies and the private sector for use in non-CB defense capacities.

There is a significant synergy that requires a continuing dialog between defense developers and private industry/academia. CB defense environments carry with them unique requirements in terms of ruggedness, power, and other logistical requirements. Thus, transition of technology from non-CB defense applications requires a significant reengineering effort. Basic research currently being pursued by the national laboratories, other government agencies, academia, and the private sector can be used as a foundation to build the future generations of CB defense detection systems.

One effort currently receiving increased emphasis is the cumulative effects on personnel exposed to subthreshold levels of chemical agents. This partnership between the national laboratories and the government came as a result of lessons learned in Operation Desert Storm. The development of a technology that would measure cumulative low-dose exposure to chemical agents would benefit the individual warfighter, people working in the industrial chemical industry, and first-responder teams.

3.1.3 *S&T Investment Strategy*

3.1.3.1 Technology Demonstrations. All technology demonstrations that are related to contamination avoidance are in the JWSTP.

3.1.3.2 Technology Development. The technology development areas for CB detection are point detection, early warning detection, and information processing and dissemination. Point detection encompasses all sampling (in situ) detectors, both chemical and biological. In addition, the area includes early warning using remotely deployed point detectors (e.g., sampling detectors on an unmanned aerial vehicle (UAV) or positioned at a distance from the troops with communication via wire or radio link). Early warning detection is a technology that electromagnetically observes clouds at a distance including any non-in-situ techniques. Information processing and dissemination technologies will collect and process all detection system information and then disseminate it through the C^4I network. The contamination avoidance subarea has been narrowed and focused from over 55 efforts into 11 areas by the recommendations of the Joint Detection Working Group.

3.1.3.3 Basic Research. Basic research efforts in CB detection are in mass spectroscopy techniques/technologies, optical spectroscopy (includes a wide range of techniques/technologies), olfactory-like chemical sensing, whole-cell-based biosensors, immuno and DNA assay, molecular approaches to optical sensors, and proximal probes. Additional efforts include work in aerosol sciences, micro-machines, and laser development; the physical/chemical/biological characterization of CB warfare agents; and the correlation of these characteristics to nonhazardous materials that can be used as simulants. Basic research relies on work performed by national laboratories, other government agencies, academia, and the private sector in addition to CB defense programs.

3.2 CB Protection

3.2.1 *Warfighter Needs*

The warfighter needs lighter weight, less burdensome, and more efficient clothing and equipment for respiratory and percutaneous protection as well as improved systems and shelters for collective protection. Improvements in respiratory protective equipment will be demonstrated including a 50% reduction in breathing resistance, 50% increase in field of vision, increase in protection to guard against potential future threats, improved system integration and compatibility with weapon sighting systems, and 25% improvement in communications capabilities. Respiratory protection technology is scheduled to transition to the Land Warrior program and program definition/risk reduction phase for the Joint Service General Purpose Mask (JSGPM, formerly RESPO 21).

For percutaneous protection, an overgarment based on selectively permeable membrane technology that is 20% lighter in weight than the standard battledress overgarment will be demonstrated. Further membrane development will lead to an overgarment 20% lighter in weight than the JSLIST overgarment and also 25% more durable and 25% less costly than the first-generation membrane/fabric garment. Ultimately, an agent protective duty uniform that eliminates, or at least minimizes, the need for an overgarment will be developed. Additional efforts involve a stretchable, permeable/adsorptive material with flame-retardant properties for lightweight undergarments, socks, and gloves; thermoplastic elastomers for improved overboots and special-purpose clothing; improved closure systems for ensembles; microencapsulated phase change materials for special-purpose applications; and evolving test methodologies for evaluating new materials. Transition opportunities include Land Warrior, JSLIST P^3I, and advanced development programs. Clothing items resulting from JSLIST P^3I will demonstrate enhancements to JSLIST items. JSLIST P^3I items will be lighter in weight, less prone to causing heat stress, more durable, launderable up to 10 times, decontaminable for reuse, and wearable for a minimum of 45 days.

Protection must also be provided for individuals and for troops inside vehicles, ships, aircraft, and shelters. The collective protection technology area seeks to develop improvements to existing protective equipment that will allow individuals and groups of personnel to operate in contaminated areas as well as to anticipate future threat CB agents that may be able to compromise current protective equipment. Specifically, air purification systems will allow extended, unencumbered operations in enclosures in an agent-contaminated environment and reduce the logistics burden of filter exchange with resultant downtime. Protection against potential filter-defeating chemicals by using regenerative filtration processes will be a major improvement. Regenerative filtration systems are in development for applications such as Comanche helicopters and armored vehicles. Improvements in materials and engineering to measure and extend usable filter lifetimes are also sought for current single-pass filtration systems used throughout the military.

3.2.2 *Overview*

3.2.2.1 Goals and Timeframes. The goals of the protection subarea are to maintain a high level of protection against CB agents and radiological particles while reducing the physiological and logistics burden associated with wearing protective equipment; to integrate CB protection with protection from environmental, ballistic, and other threats; and to provide a protective environment for personnel operating in aircraft, armored vehicles, ships, shelters, and other large area enclosures. In FY97/98, applied research efforts will continue to focus on development of a lower bulk-weight, general-purpose mask to meet joint service requirements. New concepts include flexible filter media, advanced lens materials with semiflexible optical properties, a single-piece cylindrical wrap lens design, and an enhanced aerosol filtration system. JSGPM technology will transition to the program definition/risk reduction phase in FY99.

In FY97, the development and characterization of selectively permeable membranes laminated to lightweight textile fabrics will be completed. The goal is to develop materials for a

CB protective overgarment 20% lighter in weight than the standard battledress overgarment and eliminates, or at least reduces, the use of activated carbon. In FY98, the scale-up of pilot plant production quantities in commercial width will be accomplished. Overgarments will be fabricated, and their efficacy and durability will be demonstrated. In FY99, the evaluation of lightweight, CB-resistant shell fabrics and materials for novel closure systems will be completed and integrated into a lightweight CB duty uniform concept. The goal is to develop a CB protective duty uniform that eliminates, or at least minimizes, the need for an overgarment. The CB duty uniform will be launderable, 30% lighter in weight, and less bulky than the standard duty uniform/overgarment system (JSLIST), with equivalent durability, reduced logistics burden, and lower cost. In FY00, concept lightweight CB duty uniforms will be fabricated and demonstrated for their efficacy and durability. During FY01–03, agent-reactive materials will be developed and incorporated into self-detoxification, lightweight CB clothing systems.

Technology efforts in collective protection have the objective of developing a fundamental understanding and predictive capability for each separation process under investigation. This fundamental understanding will lead to the design of hardware with improved reliability and reduced logistical requirements as compared to current filtration systems. Advanced technology will be used for military platforms currently in development and expected to be fielded within 10 years. Each application (vehicle, aircraft, etc.) requiring collective protection will select an optimum approach (single-pass, pressure swing adsorption (PSA), etc.) early in its development cycle, prior to transition to the program definition/risk reduction phase.

3.2.2.2 Major Technical Challenges. Approaches to reduce breathing resistance and improve comfort of respiratory equipment include bonded carbon flexible filters, improved aerosol filtration media, novel low-resistance respiratory valves, and development of improved sealing and blown air systems. To increase protection and meet future threat levels, approaches include development of improved materials for facepieces, lenses, and seals. Compatibility with current and future optical and weapon sighting systems will be achieved through flexible lens designs and reduced lens eye relief.

Reduction of heat stress associated with CB protective ensembles will be achieved by developing selectively permeable membranes laminated to lightweight shell fabrics, resulting in thin, lightweight materials with low thermal insulation and high levels of water vapor transport for evaporative cooling. Also, the use of microphase change material will be demonstrated for application on extreme temperature protective clothing.

Collective protection poses numerous technical challenges. Inroads are being made on several fronts including advanced catalysts, engineered adsorbent materials, improved reactive impregnates, and regenerative vapor and particulate filtration processes and materials. These efforts are based on relationships between filtration performance and physical/chemical parameters of the various separation media. The lack of service requirements for collective protection hinders the development or investment in research for new materials and technologies.

3.2.2.3 Related Federal and Private Sector Efforts. Individual respiratory protection concepts and technology are being considered by 3M Corporation for application in the next-generation occupational safety equipment. Battelle is currently marketing electronic devices developed for advanced respiratory protection for commercial applications. Cooperative industrial efforts are being discussed with Geomet Technologies for commercial application of respiratory protection concepts in escape and limited-exposure conditions.

W. L. Gore and Associates, Inc., has developed selectively permeable membrane technology that is being thoroughly evaluated for clothing applications. DOE has an effort for the development of apparel for hazardous waste cleanup personnel that is being leveraged. Continuous coordination and collaborative efforts with the National Institute of Occupational Safety and Health (NIOSH) and NASA regarding individual protection technologies are essential.

For collective protection, the Program Manager for Aircrew Integrated Systems (PM ACIS) is evaluating the possibility of retrofitting a regenerative filtration system based on catalytic oxidation or PSA into an existing helicopter. The PM for Comanche is designing a regenerative filtration system based on PSA technology for application in its new helicopter. Private sector efforts incorporating advanced filtration or separation techniques span a wide range of applications from waste stream pollution abatement to gas (air) separation. Regenerative filtration has been used extensively in industry for several decades for gas separation and purification. Application to production of breathable air from contaminated environments and separation of trace contamination from high-flow air streams is only now receiving consideration. Other potential applications include environmental remediation, pulsed-power plasma destruction in the electrical power industry, establishing a protected area within a chemical plant in case of accidental chemical spill, odor reduction in vehicle cabin space, development of non-chloro-fluoro-carbon (CFC) conditioning systems, and PSA-based oxygen concentrators (for high-performance aircraft applications).

3.2.3 *S&T Investment Strategy*

3.2.3.1 Technology Demonstrations. Individual respiratory and percutaneous protection technology will be demonstrated during FY98. Subsequently, selected technologies will transition to the Land Warrior Program. Respiratory protection technologies will also transition to the program definition/risk reduction phase in FY99 for JSGPM. A key transition opportunity for clothing materials, in addition to Land Warrior, is the JSLIST P^3I program. Specific improvements targeted by JSLIST P^3I are launderability up to 10 washings without loss in protective capability, decontamination for reuse, lighter in weight, less prone to causing heat stress, and a minimum wear life of 45 days.

3.2.3.2 Technology Development. Applied research efforts in respiratory protection are focusing on new materials, designs, and manufacturing techniques for lenses, filters, seals, and other mask components. For lightweight CB protective clothing, selectively permeable membranes and membrane/fabric laminates are being developed to meet the goals that include eliminating the dependency on activated carbon. Further work will ensure the durability of garments fabricated from these materials as well as their launderability and potential decontaminability for reuse. Additional efforts are being focused on materials and designs for improved closure systems.

The limited resources for collective protection S&T efforts are being focused on improving existing technologies and systems. Technology development is also continuing in the areas of regenerative filtration (PSA modeling), advanced aerosol filtration materials and approaches, and fundamental efforts to correlate adsorbent composition and filtration performance. Beginning in FY97, new collective protection concepts will be examined, such as using monitors embedded into filter systems to alert users when the useful lifetime of a filter is approaching, thereby maximizing filter life and reducing the overall life-cycle cost and logistics support. Additionally, evaluation of current filter systems against high-production industrial chemicals that are less toxic than nerve agents, but still a potential threat, began in FY96 and will continue in FY97. In a related effort, measurement of filter performance at very low breakthrough levels (i.e., below "no-effects concentrations") will begin in FY97 in an effort to measure data that were previously impossible to obtain under these more critical evaluation conditions. Finally, adsorbent development efforts will continue and expand to examine the possibility of developing non-flammable adsorbents with performance close to that of existing filtration media and systems.

3.2.3.3 Basic Research. Basic research in agent reactive materials is being sponsored by the Army Research Office at Emory University and Oklahoma State University. These materials have the potential to be incorporated into clothing items to provide self-detoxification in future garments. The Office of Naval Research is sponsoring the development of microencapsulated phase change materials for heating and cooling in response to extreme temperature changes. Participants in this work are the Naval Surface Warfare Center, Navy Clothing and Textile Research Facility, Naval Health Research Center, and the University of Minnesota. Cooling systems for special-purpose clothing using these materials have the potential to relieve heat stress. For respiratory and collective protection, fundamental studies of adsorption properties seek to unify several models that describe the adsorption properties of materials based on measured adsorption equilibrium data.

3.3 CB Decontamination

3.3.1 *Warfighter Needs*

There exists a need for enhanced decontamination systems that are noncorrosive, nontoxic, and environmentally safe and suitable for a timely cleanup of CB agents on all materials and surfaces. These materials may be used on personnel, individual equipment, tactical combat vehicles and equipment, sensitive equipment, interior and exterior areas of aircraft and ships, and wide areas such as military bases and shore-based naval installations. This requirement includes decontaminants that both remove and neutralize CB agents, procedures to apply these decontaminants, and techniques that help prevent the spread of CB contamination. These decontamination systems will enable forces to reconstitute personnel and equipment rapidly to increase combat efficiency and lessen the logistic burden.

3.3.2 *Overview*

3.3.2.1 Goals and Timeframes. The goal of the CB decontamination subarea is to develop effective, environmentally safe CB decontamination systems to clean up toxic materials without damaging the contaminated surface or affecting the performance of the equipment being decontaminated. Mid-term efforts focus on sensitive equipment and large, fixed sites such as points of entry/departure (e.g., ports, airbases) and logistics staging areas. Long-term requirements are to replace DS2 and develop concepts for aircraft interior decontamination.

3.3.2.2 Major Technical Challenges. The challenge in this area is finding materials that will meet all the criteria established for a field decontaminant, yet be applicable to the widest range of threat agents. Materials being studied include mild nucleophilic reactants, nucleophilic catalysts, stable oxidants, oxidative catalysts, catalytic enzymes, and organic oxidants. Nucleophilic reagents promote decomposition of G and V agents, while oxidative processes are suitable for H and V agents. The fundamental chemistry of the different chemical classes of agents is a major challenge to overcome. Catalytic enzymes under investigation are intended to detoxify G, V, and H agents. This approach is promising for G and V agents, but is a technical barrier for H agents. The requirement that decontaminants be supplied premixed negatively impacts the shelf life of the chemical reagents useful for decontamination.

Another major challenge is finding suitable liquid decontamination media including surfactant systems or environmentally acceptable organic solvent to serve as the vehicle to carry decontaminants. New decontamination materials need to be stabilized in an appropriate medium. In addition, materials must not interfere with other fielded systems, such as detectors.

Sorbents are an effective way of removing CB contamination from surfaces. However, they do not neutralize the CB contamination removed and thus tend to release absorbed contamination over time. Research into reactive sorbents is an area of potential investigation.

Recent studies have identified interior space decontamination as a critical requirement. This need is especially true in the case of cargo aircraft which may experience interior contamination of critical avionics and other electronic components. The requirement also applies to other interior spaces such as shipboard areas, combat vehicles, and buildings.

Decontamination of points of entry/departure and logistical staging areas is essential to power projection operations. Decontamination of ships and wide-bodied aircraft pose the most critical challenge to deployment operations. The feasibility and potential methods and technology are currently being examined.

3.3.2.3 Related Federal and Private Sector Efforts. Demilitarization research is being done cooperatively with the U.S. Army Chemical Demilitarization and Remediation Agency in two major programs. In conjunction with the Program Manager for Chemical Demilitarization, alternative methods of destroying the U.S. chemical weapons stockpile are being investigated, in consonance with recommendations from the National Research Council. Under the office of the Program Manager for Non-Stockpile Chemical Materiel, methodologies for the destruction of non-stockpile chemical items and related environmental remediation are being developed. The Defense Special Weapons Agency (DSWA) is sponsoring a program to evaluate the effectiveness of a methodology proposed by Russia to destroy their chemical warfare agents stockpile. The DSWA also has a related program in the area of treaty verification where analytical chemistry sampling and analysis methodology are being developed to perform trace-level analysis of chemical agents, agent precursors, and degradation products in assorted environmental matrices. The U.S. Environmental Protection Agency, U.S. Army Environmental Center, and the private sector are performing research on and are developing technologies for site remediation and restoration. The United States is the lead nation for NATO Project Group 31, which is seeking to develop an enzyme-based decontaminant for nerve agents and mustard. The planned decontaminant (based on the U.S. model) is intended for use by all services on equipment, vehicles, facilities, and large areas.

3.3.3 *S&T Investment Strategy*

3.3.3.1 Technology Demonstrations. An FY00–01 demonstration is scheduled for sensitive equipment decontamination. The leading candidate for this demonstration is the use of supercritical carbon dioxide for removal of CB contamination from equipment. Contamination removal, the first step in a two-step decontamination procedure, will be followed by the decontamination of the material collected in the contamination removal process. A second demonstration of technology utilizing fire suppressant and other foams to deliver catalytic enzymes and other materials to effect multiagent decontamination against a broad spectrum of agents is planned for FY06.

3.3.3.2 Technology Development. There is limited funding for decontamination S&T efforts. Available resources are focused on decontaminants, operational materials, and contamination control.

Biochemical investigations in this area are directed toward finding reactive enzymes that will be effective against all CB threat agents. These must be stable in storage and environmentally acceptable. Various approaches are being taken to optimize the use of enzymes. Studies continue into the use of enzymes incorporated into various foam systems. This would allow for the use of fielded firefighters' equipment for surface application.

There exists a requirement to replace DS2 with a significantly less corrosive and more environmentally acceptable material. For this purpose, a study is planned to be initiated in FY98 using commercially available oxidizing detergents. In a recent decontamination workshop, new technologies for future investigation were identified. The most promising approach is the use of supercritical carbon dioxide technology. This approach would require a two-step procedure, using the supercritical carbon dioxide to remove the agent from surfaces, such as sensitive equipment, and following that with destruction of the collected contaminant. Investigations are planned for FY97.

Preventing the spread of contamination or preventing combat equipment from becoming contaminated greatly eases the later decontamination process and permits equipment to be used much more quickly after a CB attack. This technology effort is investigating procedures and materials that will prevent contamination from spreading to the interiors of combat equipment and aircraft or aid in rapid cleanup of contamination to reduce the spread of contamination. Work to date has concentrated on aircraft interiors. In addition, by the end of FY97, a plan will be completed to assess requirements for decontamination of large, fixed sites and a roadmap and funding plan will be detailed.

3.3.3.3 Basic Research. The chemistry at organized interfaces in solutions (micelles, emulsions, microemulsions, vesicles, liposomes) has proved to be extremely useful for enhanced reactivity needed for decontamination technology advances. Recently, novel types of polymeric support termed "starburst" dendrimer polymers have been developed. The ability to attach substances that can serve as catalysts to the surface of dendrimers has been shown. Studies are planned to examine the use of such systems to decontaminate CB agents in environmental matrices.

3.4 CB Studies, Analysis, and Simulation

3.4.1 *Warfighter Needs*

The models generated or enhanced under this subarea will allow CB warfare effects to be assessed either separately or in conjunction with other meteorological and terrain effects in a variety of hazard assessment systems. The primary warfighter need in this area is to develop a simulation capability that integrates all available sensor data (CB detectors along with other relevant information such as meteorological and geographical data) and provides commanders with a decision aid to determine the appropriate protective posture, actions to avoid contamination, and means to predict areas of contamination. CB effects models under development include:

- *Vapor, Liquid, and Solid Tracking Model (VLSTRACK).* Originally developed by the Navy in support of OSD for operational use, this model is being evaluated by all services and will be modified as necessary to become the joint CB model. Its development, verification, and validation are being jointly conducted.
- *CB Defense Integrated Meteorological and Contamination Transport (CBD-IMPACT).* This is a planned upgrade to the Maneuver Control System (MCS) for FY97 to allow operational computing of mesoscale meteorology and subsequent CB hazards on the MCS workstation.
- *Hazard Prediction Systems Integration Program (HPSIP).* HPSIP is being developed for quantifying and visualizing areas affected by and casualties caused by NBC weapons to assess technological and natural hazards associated with operations other than war. The system will be hosted on a UNIX open system workstation with the ability to operate on a laptop computer for field deployments. Weather data digest, population databases, and a Geographic Information System (GIS) will be included.
- *Hazard Prediction Assessment Capability (HPAC).* HPAC is a series of models that address source-term generation, transport and diffusion, and 3D modeling of meteorological conditions with interaction of complex terrain. These models are integrated into a single automated package designed to run on a workstation. The program will assess the impact of an accidental release of hazardous materials during military operations. HPAC is a component of the Counterproliferation ACTD and is being integrated with that ACTD's Munitions Effectiveness Assessment capability.
- *Post-Engagement Ground Effects Model (PEGEM).* This is one of several systems under development by the Ballistic Missile Defense Organization (BMDO) to compute the effects of intercepting a missile with a nuclear, conventional, chemical, or biological warhead. A version of the VLSTRACK model is being modified to meet the requirements of high-altitude transport and diffusion.
- *Advection and Dispersion of Vapor, Evaporating Droplets and Solids (ADVEDS).* Accurately assessing the hazard to naval ships requires the capability to model the flow of air around the complex 3D structure. ADVEDS is a full Navier-Stokes flow solver with the ability to also model evaporation from falling droplets, deposition, and subsequent surface evaporation. The evaporation algorithms from ADVEDS are being used to augment the capabilities of a COTS computational fluid dynamics

model developed by AEA Technology called CFX. These advanced models can also be used for tanks, shelters, buildings, etc.

3.4.2 *Overview*

3.4.2.1 Goals and Timeframes. The overall goal of the CB studies, analysis, and simulation subarea is to develop operational support systems that provide situational awareness and aid command evaluations, integrate sensor data, and permit realistic training and simulation of the CB battlefield environment. A current thrust is to take advantage of the rapidly increasing computational power in personal computers/workstations by incorporating terrain, geolocation information, mesoscale meteorology, and objects such as tanks, ships, or buildings into CB warfare effects models. Steps are also being taken to add a realistic CB warfare capability to models such as JANUS and in wargames. The development of hazard assessment models for use by operational forces is another major focus.

CB warfare models are being continuously improved to provide a more realistic depiction of the hazard. Development and integration into various systems is coordinated with other system improvements to ensure that the maximum synergism is obtained. For example, the fidelity of the CB warfare model must be matched with the fidelity of the meteorological data that are available as an input. The first model to be fielded operationally was PC-based and used single hourly meteorological inputs. The next implementations were operational in FY95 and utilized 3D meteorological grids computed at centralized CONUS sites and transmitted to the command centers in the theaters of operation. By FY98, regional meteorology will be calculated in theater and used by the operational CB warfare models. As more sophisticated methodologies such as Navier-Stokes methods are validated, they may replace current methodologies by the FY97/98 timeframe.

Critical decisions that will be made based on an operational hazard assessment require rigorous verification, validation, and accreditation of models. Likewise, when these models are used for acquisition decisions, such as selection of the best ballistic missile interceptor or the optimal method of early warning of biological threats, it is vitally important that models be based on sound physics and validated with an appropriate set of field trials. In FY95, a semiautomated CB warfare model validation capability was developed. The effort will incorporate over 3,000 data points from both classified and unclassified field trial reports.

3.4.2.2 Major Technical Challenges. The primary technical challenges are data gathering from numerous sensors and sources, data generation for validation of the models, manipulation of large databases for real-time simulations to reduce computer run time, and provision of a simplified output and decision aids for easier interpretation of results. Other technical challenges include evaluation of a 3D Navier-Stokes flow code for more realistic profiles, developing high-resolution models for the distributed interactive simulations (DISs), and establishing threat/toxicity/exposure levels for CB agents with the models under various scenarios.

The lack of a standard CB warfare hazard assessment model for the services has been a problem in the past. This is being overcome by the adoption of the VLSTRACK model by the joint services for nearly all atmospheric CB agent releases. Benefits of VLSTRACK have been established by the BMDO's International Model Comparison Working Group. This standardization means that identical model operation and output can be expected in studies, training, simulation, and operational situations. It has also greatly reduced duplication.

In the area of hazard analysis, study of biological warfare agent detection requirements and medical prophylaxis is receiving added attention. During Operation Desert Storm, the U.S. and its allies had to hastily assemble the capability to analyze the potential biological warfare hazard and how to counter it. A number of data gaps (such as toxicity) are virtually impossible to fill, and others (such as determining the representative size distribution of various releases) are readily achievable. Even now, automated methods to accurately and realistically analyze the effectiveness of existing or planned biological warfare detection/identification systems are not available. Existing models and databases are unsuitable for accurately estimating total airborne concentrations of particles (combination of agent and background aerosol) as a function of size. New algorithms are under development for simulating both point and standoff detectors.

The major reasons for improving the CB warfare methodology in existing combat simulations are to make the simulation more realistic and to facilitate the use of CB warfare effects in wargames or assess the impact of CB warfare on an already well-understood process, such as sortie generation. This requires the use of relatively rigorous CB warfare models. However, most simulations lack the computer power to incorporate complex methodology without unacceptably lengthening their run time. It is possible that two different versions will be needed to satisfy the needs of both the scientific/engineering and the training communities. No data exist for the impact on operations from integrated wings or airlift missions. The measures of effectiveness for these operations are much more complex than, for example, sortie generation models that serve well for air-to-air and air-to-ground missions.

The lack of easy-to-use and credible simulation of CB agent effects has greatly impeded the ability to perform meaningful CB warfare in operational simulations. The ability to incorporate CB warfare effects into both the constructive and the virtual processes of DIS represents a significant technical challenge due to the high-fidelity, engineering-level cloud transport and diffusion model required and pervasive degree to which the CB environment is to be put all through the synthetic battlefield. In order to provide this capability in time to meet urgent materiel development schedules, a broad-based strategy is being followed that includes several simultaneous technology efforts. These involve adaptation of VLSTRACK as a standard transport and diffusion model, point and standoff CB agent detectors, and man-in-the-loop simulators of CB-unique vehicles such as the Joint Service Nuclear, Biological and Chemical Reconnaissance System (JSNBCRS) and the Biological Integrated Detection System (BIDS).

In addition to model development itself, there is a requirement to collect ground-truth data to evaluate model performance. Exercises such as the annual joint field trials at Dugway Proving Ground, as well as a follow-on to other data collections such as the Joint Contact Point over-the-water line source dissemination data collection effort, will provide a valuable basis for critical and now lacking data for evaluation of model performance.

3.4.2.3 Related Federal and Private Sector Efforts. Studies, analysis, and simulation programs support various elements of The Technical Cooperation Program (TTCP), including TP9 (CB Hazard Assessment), the MOU with U.S./U.K./CA including ITF25 (Threat From Industrial Chemicals), and the NATO Ad Hoc Working Group 111 (Modeling and Simulation) and WGE.1 (CB Warfare Hazard Assessment). The Ad Hoc Working Group 111 is studying DISs to resolve command and control, interoperability, and other multinational mission issues (including CB warfare effects).

3.4.3 *S&T Investment Strategy*

Following the 1994 Technology Area Review of CB Defense Science and Technology Base Programs, a CB Modeling Process Action Team (PAT) was established. The NBC Modeling PAT published a final report in September 1996. It recommended that the following structure be implemented to integrate and consolidate all DoD NBC modeling efforts: (1) appoint an existing organization as a central commodity area called the NBC Modeling Capabilities Group under the Joint NBC Defense Board, and (2) designate this group responsible for collecting and prioritizing user requirements and finding materiel acquisition solutions. Recently, PAT members drafted an organizational charter for community review.

3.4.3.1 Technology Development. Providing realistic agent challenge levels for all situations requires continuous improvement in modeling methodologies and algorithms to cover the increasing variety of applications, such as modeling the behavior of CB agents released at high altitudes following the intercept of a CB warhead. Likewise, making hazard models available to and their output suitable for use by the battlefield commander as a decision aid also requires considerable modification to models previously used primarily for research and engineering

3.4.3.2 Basic Research. There is no basic research funding for simulation. However, data from related basic research efforts, such as aerosol sciences, provide critical information for updating models and simulations.

3.5 Warfighter Support (Nuclear)

3.5.1 *Warfighter Needs*

Weapons that are effective and appropriate for proliferation scenarios are needed. Particular emphasis is given to improving capabilities for defeat of hardened targets (especially those associated with WMD) with minimized collateral hazards. This RDT&E applies both to the post-cold-war nuclear mission and to the tasking from the Secretary of Defense to apply nuclear research expertise to improve understanding of advanced conventional munitions and weapon–target interactions.

3.5.2 *Overview*

3.5.2.1 Goals and Timeframes. The goals of the warfighter support (nuclear) subarea are as follows:

- By FY97, complete development of an automated planning system for the airborne portion of the strategic force for U.S.STRATCOM.
- By FY98, transition new physical security applications for nuclear systems to the Army and Air Force; transfer new planning systems for contingency scenarios to NATO; demonstrate and assess options for functional defeat of hardened NBC and C^3I facilities; and complete the WMD theater-level engagement model.

- By FY99, demonstrate an improved capability for forecasting hazards that might result from attack of a facility containing WMD.
- By FY00, complete a 21st century nuclear survivability plan and provide WMD models for the Joint Warfare Simulation (JWARS) and the Joint Simulation System (JSIMS).
- By FY05, complete dual-revalidation of nuclear weapons stockpile.

3.5.2.2 Major Technical Challenges. Long-term stockpile stewardship using only nonnuclear laboratory technologies, plus modeling and simulation, and probabilistic risk assessment is without precedent. Stockpile stewardship involves more than a physics package. DoD must address end-to-end operation of critical delivery and C^3I systems. Planning capabilities must be adapted to proliferant contingencies including, as one example, the attack of a WMD target with conventional weapons in which collateral hazards result from the target. Full-physics effects models must be translated into operational planning/visualization tools. Human response models for single or combined exposure to chemical, biological, or radiological threats must be developed and validated to allow collateral hazards to be reliably assessed.

3.5.2.3 Related Federal and Private Sector Efforts. DOE stockpile revalidation and other Science-Based Stockpile Stewardship activities are critical for accomplishing DoD nuclear missions. Since FY96, DoD dual-revalidation teams have participated in these activities. Research demonstrating safety methodologies and providing better methods for predicting and mitigating collateral hazards has potential for technology transfer to the civil sector.

3.5.3 *S&T Investment Strategy*

3.5.3.1 Technology Development. All of the activities in this subarea involve technology development; there are no basic research or technology demonstrations.

Stockpile Support. Initial dual-revalidation objectives have been defined. Safety research uses probabilistic risk assessment methodologies adapted to multiple-failure point analysis; there is close collaboration with Air Force customers for this work. Physical security R&D for nuclear systems is coordinated by OSD.

Planning Systems for Contingencies Involving Proliferants. Priorities are defined by U.S. CINC and SHAPE users. Target planning capabilities are being adapted to respond to proliferation contingency requirements. Survivability programs focus on the Nuclear Posture Review stockpile. A direct technical support capability has been established to provide support to theater operations, as done during Operation Desert Storm for WMD hazard prediction and target analysis.

Improving Weapons Effectiveness. Particular emphasis is given to evaluating options for defeat or functional disruption of buried and other hardened targets.

Collateral Hazards. Forecasting methodologies are being adapted to address WMD effects dispersion in situations in which local environmental factors dominate. This research contributes to the Joint Warning and Reporting Network DTO (CB.02.10) and to the Prediction and Mitigation of Collateral Hazards DTO (CB.14.07).

3.6 Systems Effects and Survivability (Nuclear)

3.6.1 *Warfighter Needs*

The warfighter needs radiation- and electromagnetic-hardened systems and microelectronic pieceparts in order to survive the threat and perform missions. DoD has unique needs for radiation-hardened microelectronics that can survive radiation fluence levels that COTS microelectronics cannot satisfy. Additionally, the availability of nuclear weapons technology and sophisticated delivery systems has led to the emergence of a new threat from proliferants—the high-altitude detonation of one or two low-yield weapons. Due to proliferation, this threat of employment in a regional conflict is more likely; this threat places unprotected space and ground systems at risk.

This subarea has two technical thrusts: the development of affordable state-of-the-art radiation-hardened microelectronics and the integrated hardening and testing of military systems against high-altitude electromagnetic pulse (HEMP) and high-power microwave (HPM) effects. The objective is to ensure that warfighters have warranted confidence in the survivability of their weapon systems in all radiation environments.

3.6.2 *Overview*

3.6.2.1 Goals and Timeframes. The goals of the systems effects and survivability subareas are as follows:

- By FY97, develop PC-based EMP environment/coupling code and PC-based EM protection tool; complete development of unified EMP/HPM protection and test methodology.
- By FY98, develop wideband (affordable) test method; demonstrate and test radiation-hardened silicon-on-insulator (SOI) analog microelectronics.
- By FY99, demonstrate radiation-hardened submicron (0.35 micron) technology for 16 times reduction in weight and power; demonstrate new EMP/HPM hardening technologies/test techniques.
- By FY00, demonstrate integrated EMP/HPM test methods; demonstrate deep submicron (0.25 micron) technology for radiation-hardened, low-power 1,000 k gate array and 16 M SRAM technology for 100 times reduction in weight and power.
- By FY01, transfer proven EMP/HPM hardware and software technologies and test techniques to the services.

3.6.2.2 Major Technical Challenges. Military systems continually require increased information processing, but state-of-the-art commercial semiconductor processes are designed primarily to maximize profits, usually at the expense of such characteristics as radiation hardness. Thus, succeeding generations of microelectronics have become increasingly susceptible to radiation. DoD must maintain an ongoing effort to radiation harden new generations of microelectronics as they evolve to ensure that warfighters have the survivable state-of-the-art electronics systems needed to survive HEMP, HPM, microwave, and ballistic missile defense-related X-ray threats. Additionally, the ban on underground testing requires the development of new designs, test protocols, and procedures that ensure system survivability, and these must be integrated into DoD planning for strategic systems sustainment and the DOE Science-Based Stockpile Stewardship Plan. Another set of challenges involves measures to provide military and civilian facilities with improved protection against terrorist threats.

3.6.2.3 Related Federal and Private Sector Efforts. Radiation-hardened electronics are critical for the multibillion dollar commercial and civilian space industry. Balanced hardening methodologies have considerable potential for transfer to the private sector. Notable is the proposed use of European Union protection standards that are more stringent than their U.S. commercial equivalents. Computational structural dynamics methodologies for enhancing the survivability of military facilities have direct applicability for providing civilian structures with protection against both natural (e.g., earthquake) and manmade (e.g., terrorist) hazards.

3.6.3 *S&T Investment Strategy*

3.6.3.1 Technology Development. All of the activities in the systems effects and survivability subarea involve technology development; there are no basic research or technology demonstrations.

Radiation Effects. The major objective, which is a DDR&E-directed priority, is development of radiation-hardened electronics enabling technology for missiles and space systems that could be exposed to proliferant nuclear weapons effects. A second objective is to ensure that the communications and sensors of these space assets are not disrupted by the disturbed environment caused by such a high-altitude event. The final objective is to ensure the ground terminals associated with these assets are protected from the HEMP that such an event can produce. Toward these ends, the threats posed by a proliferant's weapons are being better characterized, and methods for protecting and testing that protection are being developed.

Balanced Hardening. The objective in this program is to develop and demonstrate integrated hardening technology and methodologies. These methodologies would reduce costs by allowing a smaller number of validated tests to be conducted to verify protection against multiple hazards. Technology development would involve new lower cost approaches for integrated effects testing and protection validation. This approach is congruent with new DoD acquisition policies mandating much greater use of commercial parts and standards. Priority would be given to protection against HPM and HEMP effects with consideration given to the whole spectrum of electromagnetic (EM) interferences and disturbances. The goal is to achieve the optimum EM protection for systems balancing the competing factors of threat, cost, size/weight, and technical/engineering feasibility.

3.7 Test and Simulation Technology (Nuclear)

3.7.1 *Warfighter Needs*

These technology development efforts respond to Presidential Decision Directive 15 and other national and department direction by providing the capabilities needed to validate military system performance in nuclear and related weapon environments. In the absence of underground tests and without the ability to simulate nuclear weapons effects, there can be little confidence in the ability of military systems to operate in such environments. Sustainment of DoD strategic capabilities requires test and simulation technology to ensure end-to-end confidence in critical delivery and C^3I systems.

3.7.2 *Overview*

3.7.2.1 Goals and Timeframes. The goals of the test and simulation technology subarea are as follows:

- By FY97, develop non-ideal airblast simulation capability at LB/TS; complete safety assessment for strategic aircraft.
- By FY97, conduct tests for the Navy (SSP) at the magnetic flyer plate facility to assess the survivability of reentry bodies on the Trident missile.
- By FY98, transition new nuclear system physical security technologies to the Air Force and Army; begin operating the first quadrant of the DECADE X-ray simulator at AEDC; collaborate with DOE on stockpile dual revalidation through FY05; continue weapon system safety assessments, probabilistic risk assessments, and technical base data studies to support ATSD(NCB), CINCs, and the services through FY05.

3.7.2.2 Major Technical Challenges. Given termination of underground nuclear tests, there are significant shortfalls in simulator fidelity and with respect to the size of objects that can be tested. Due to funding constraints, investment in new, potentially more cost-effective simulation technologies has been curtailed. This effort focuses on consolidation of existing facilities, completion of ongoing development efforts, and incremental improvements to in-place capabilities.

In blast/thermal simulation, a near-term priority is responding to Army requirements by adapting LB/TS to simulate nonideal airblast effects. Once this is done, the limits of existing technology will have been reached. Improvements are needed in blast venting and cryogenic gas systems to significantly reduce the operating cost of the LB/TS. Unmet requirements include improved high-temperature, high-flux thermal sources and the ability to simulate a wider range of blast phenomenologies.

For radiation simulation, there are major shortfalls in capabilities for testing full-size systems or subsystems against all types of X-rays. With the underground testing moratorium, the ability to test the response of materials, optics, and structures to the cold portion (under 40 keV) of the X-ray threat has been severely curtailed. Plasma radiation sources implemented on existing simulators are attempting to fill this gap. At present, available debris-free fluence areas are approximately 5 cal/cm^2. Investigation of innovative and efficient cold X-ray sources with ten times larger debris-free fluences and better fidelity continues. DECADE will provide the capability to test the response of small systems to hot X-rays (>40 keV). DECADE will be constructed in phases. The first phase (DECADE Quad) will provide a 20,000-rad dose over 2,500 cm^2, providing a 400% increase in performance over current hot X-ray simulators. Improvements are needed in cold X-ray plasma radiation source fidelity and stability, debris shields to provide high-fidelity test environments for plasma sources, reliability and repeatability of plasma switches used in radiation simulators, synchronous use of modular pulsed power devices, and diagnostics that can function in the harsh environments produced by X-ray simulators.

Underground testing readiness is being accomplished through the combination of a bare-bones investment in test site infrastructure and development of a reconstitution plan showing what must be done to reconstitute a test capability if this is directed by national authorities at some point in the future.

3.7.2.3 Related Federal and Private Sector Efforts. S&T planning specifically considers the use of DOE simulators to respond to DoD requirements. DOE plans and development efforts that, if successful, might respond to DoD needs are being monitored (e.g., the National Ignition Facility and Science-Based Stockpile Stewardship programs). Significant opportunities for technology transfer to the private sector are associated with some of the technologies in this subarea, including high-energy density capacitors (medical, radar, and commercial power system applications), flash X-ray technology (food processing sterilization), and X-ray modeling and source development (higher resolution, lower exposure, diagnostics).

3.7.3 *S&T Investment Strategy*

3.7.3.1 Technology Development. All of the activities in the test and simulation technology subarea involve technology development; there are no basic research or technology demonstrations.

Blast/Thermal Simulation. LB/TS provides a new, repeatable capability. Programmed enhancements for nonideal airblast simulation respond to Army requirements.

Radiation Simulation. With major inputs from a reliance task force, the DoD nuclear effects simulator suite is being consolidated. This includes transfer and reuse of debris mitigation schemes, cryogenics, and other capabilities to the simulation facilities that are to be retained. New switching technologies for pulsed power sources will be evaluated.

Underground Testing Readiness. In line with national direction, a bare-bones capability for resumption of testing is being sustained at the Nevada Test Site.

3.8 Scientific and Operational Computing (Nuclear)

3.8.1 *Warfighter Needs*

Preservation and application are major themes in computing activities that respond to warfighter requirements for survivable systems and effective nuclear weapons. Preservation is important because DoD's understanding of nuclear weapon effects is based in large part on test data that are unique and, in many instances, perishable. Applications involve the packaging of U.S. nuclear data and physics understanding into advanced computational products that enable fundamentally new capabilities for warfighter interaction and visualization. In addition, aspects of our understanding of nuclear matters require utilization of advanced computational resources, such as investigating the physics involved in weapon-target interactions and extrapolating from test results in circumstances in which new tests are not possible.

3.8.2 *Overview*

3.8.2.1 Goals and Timeframes. The goals of the scientific and operational computing subarea are as follows:

- By FY97, provide users with online access to information and services at DASIAC (DoD Nuclear Information Analysis Center—formerly Defense Atomic Support Information Analysis Center—the DoD repository for nuclear effects information); complete bomb-in-structure modeling; complete collateral effects cloud transport model.
- By FY98, complete distribution of EM–I, the primary engineering handbook for nuclear weapons effects; transition computational support to a combination of the DoD high-performance computing architecture and departmental hardware; complete electro-thermal chemical gun model.
- By FY99, complete incorporation of underground nuclear test data into DARE (Data Archival and Retrieval Enhancement) system.
- By FY00, begin entry of nuclear simulator data into the DARE system.
- By FY01, complete incorporation of reviewed nuclear testing data, and provide users with online access to DARE resources.

3.8.2.2 Major Technical Challenges. The nuclear effects computations program develops tools for accurate prediction of the evolution of turbulent fields embedded in explosions. Past work emphasized nuclear effects topics. Current focuses, which give particular emphasis to counterproliferation-relevant research, include turbulent combustion and afterburning induced by explosions in chamber systems (needed for engineering control over chemical explosions), formation of hazardous combustion clouds (to minimize collateral hazards associated with such events), turbulent combustion in guns (to produce range enhancement via controlled energy release), and turbulent mixing in bomb implosions (a topic to be addressed in stockpile revalidation, e.g., the DOE Accelerated Scientific Computing Initiative). All of these applications are in line with direction from OSD to make use of nuclear technical expertise in designated nonnuclear applications.

It is generally recognized that turbulent mixing is the central unresolved physics problem for virtually all fluid-dynamic phenomena associated with explosions. A six-step approach has been demonstrated as providing reliable prediction of the evolution of turbulent explosion fields: (1) convective mixing simulations of 3D turbulent fields, (2) using adaptive mesh refinement to capture enough of the turbulence spectrum to reach the inertial range, (3) subgrid modeling of molecular processes, (4) averaging 3D solutions to extract fields for engineering analysis, (5) corroborating convective mix approximations by performing 3D Navier-Stokes calculations of turbulent flows for limited spatial domains, and (6) verifying numerical results by comparison with well-controlled laboratory experiments. A variety of state-of-the-art computational methods are used for the compressible and incompressible flow cases.

The nuclear testing database is unique and irreplaceable. Critical information is on perishable media (e.g., films and photography from the 1950s atmospheric test series). Data quality assurance is imperative. This is the last opportunity to involve experimenters who were participants in the atmospheric and underground nuclear test programs in the review of these data. Their insights concerning the merits and limitations of this database must be captured and preserved. For computational aid products, user groups are employed throughout the development process to ensure that products respond to customer requirements.

3.8.2.3 Related Federal and Private Sector Efforts. The DOE organizations responsible for science-based stockpile stewardship plan to use their Accelerated Strategic Computing Initiative as a primary mechanism for sustaining nuclear competence. Appropriate levels of DoD customer involvement (e.g., in dual-revalidation) are required.

3.8.3 *S&T Investment Strategy*

3.8.3.1 Technology Development. All of the activities in the scientific and operational computing subarea involve technology development; there are no basic research or technology demonstrations.

DASIAC/DARE. The DoD Nuclear Information Analysis Center is chartered to preserve DoD nuclear-weapons-related information. DARE is a continuing program that uses optical and magnetic media for long-term data preservation and provides authorized users with online access to data.

Computational Aids. This program develops the authoritative products used throughout the U.S. government and allied nations for nuclear effects data and calculations, including EM–I, the primary technical reference for nuclear weapons effects, and a variety of engineering-oriented computational products.

Nuclear Effects Computations. This program provides computational support for nuclear analyses and operations; an example of the latter was direct technical support to the theater for hazard forecasting during the Gulf War.

GLOSSARY OF ABBREVIATION AND ACRONYMS

3D	three dimensional
ACIS	Aircrew Integrated Systems
ADVEDS	Advection and Dispersion of Vapor, Evaporating Droplets and Solids model
AEDC	Arnold Engineering Development Center
Ah	ampere-hour
ANBCWRS	Automated Nuclear, Biological, and Chemical Warning and Reporting System
ASCI	Accelerated Strategic Computing Initiative
ATSD(NBC)	Assistant to the Secretary of Defense (Nuclear/Biological/Chemical)
BDO	battle dress overgarment
BIDS	Biological Integrated Detection System
BMDO	Ballistic Missile Defense Organization
C^3I	command, control, communications and intelligence
C^4I	command, control, communications, computers and intelligence
cal/cm^2	calories per square centimeter
CB	chemical/biological
CBD-IMPACT	Chemical/Biological Defense Integrated Meteorological and Contamination Transport
CFC	chloro-fluoro-carbon
CINC	commander-in-chief
CONUS	continental United States
COTS	commercial off the shelf
CPO	chemical protective overgarment
DARE	Data Archival and Retrieval Enhancement
DASIAC	DoD Nuclear Information Analysis Center—formerly Defense Atomic Support Information Analysis Center
DBBL	Dismounted Battlespace Battle Laboratory
DDR&E	Director, Defense Research and Engineering
DIS	distributed interactive simulation
DNA	deoxyribonucleic acid
DOE	Department of Energy
DS2	decontamination solution 2
DSWA	Defense Special Weapons Agency
DTAP	*Defense Technology Area Plan*
DTO	Defense Technology Objective
EM	electromagnetic
EM-I	Effects Manual I
EMP	electromagnetic pulse
GIS	Geographic Information System
HEMP	high-altitude electromagnetic pulse
HPAC	Hazard Prediction Assessment Capability
HPC	high-performance computer
HPM	high-power microwave
HPSIP	Hazard Prediction Systems Integration Program

IOC	initial operational capability
IR	infrared
JBPDS	Joint Biological Point Detection System
JBREWS	Joint Biological Remote Early Warning System
JCAD	Joint Chemical Agent Detector
JCBAWM	Joint Chemical/Biological Agent Water Monitor
JSGPM	Joint Service General Purpose Mask
JSIMS	Joint Simulation System
JSLIST	Joint Service Lightweight Integrated Suit Technology
JSLSCAD	Joint Service Lightweight Standoff Chemical Agent Detector
JSNBCRS	Joint Service Nuclear, Biological and Chemical Reconnaissance System
JWARS	Joint Warfare Simulation
JWSTP	*Joint Warfighting Science and Technology Plan*
LB/TS	Large Blast/Thermal Simulator
LMF	Laser Microfusion Facility
MCS	Maneuver Control System
MEA	Munitions Effectiveness Assessment
MOU	memorandum of understanding
NASA	National Aeronautics and Space Administration
NATO	North Atlantic Treaty Organization
NBC	nuclear/biological/chemical
NIF	National Ignition Facility
NIOSH	National Institute of Occupational Safety and Health
OSD	Office of the Secretary of Defense
P^3I	preplanned product improvement
PAT	Process Action Team
PEGEM	Post-Engagement Ground Effects Model
PM	program manager
PSA	pressure swing adsorption (filtration technology)
R&D	research and development
RDT&E	research, development, test and evaluation
RESPO 21	Respiratory Protection System 21
S&T	science and technology
SHAPE	Supreme Headquarters Allied Powers Europe
SOI	silicon-on-insulation
SRAM	static random access memory
SSP	Strategic Systems Program
STRATCOM	Strategic Command
TBD	to be determined
TREE	transient radiation effects on electronics
TTCP	The Technical Cooperation Program

UAV	unmanned aerial vehicle
UV	ultraviolet
VLSTRACK	Vapor, Liquid, and Solid Tracking model
WGE	Working Group of Experts
WMD	weapons of mass destruction

CHAPTER III
INFORMATION SYSTEMS TECHNOLOGY

1. INTRODUCTION

The Information Systems Technology (IST) area is developing the technologies and architectures needed to provide warfighters with the right information, in the right place, at the right time. To accomplish this, there must be flexible architectures that allow:

- Common software for a variety of decisionmaking tool kits.
- Modeling and simulation (M&S) technologies that facilitate early assessment of new technologies and warfighting analyses, enhance our ability to "view" systems and immerse humans in the virtual world, and facilitate more effective utilization of M&S technology for training and mission rehearsal.
- Transparent management and distribution of information among heterogeneous systems.
- Seamless communication systems using commercial and common protocols (allowing transport of information anywhere in the world).
- Computing and software technology that supports the evolution of products inserted into our common systems.

1.1 Definition/Scope

The *Defense Technology Area Plan* (DTAP) for IST covers the five subareas shown in Figure III–1. Because of the high degree of interrelationship among these five areas, the technol-

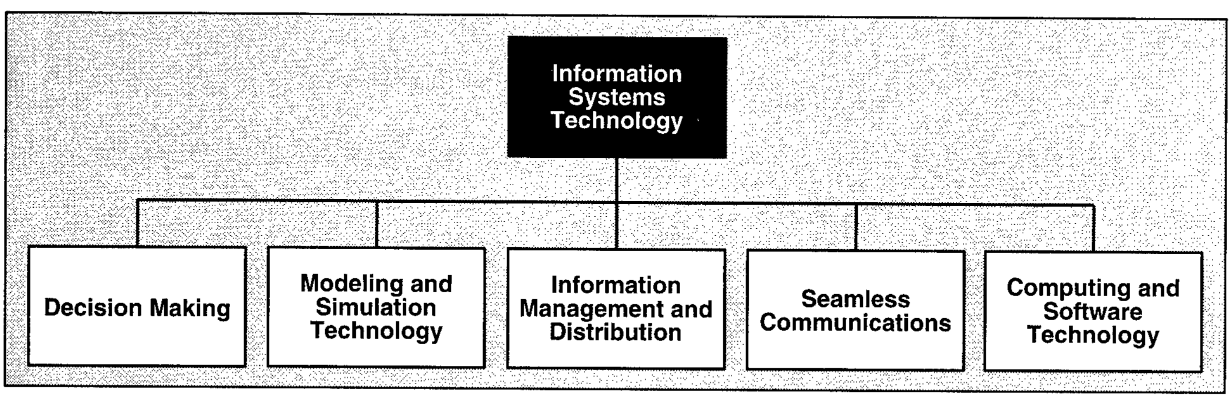


Figure III–1. Planning Structure: Information Systems Technology Area

ogy development efforts for them are being integrated. By integrating them, we achieve greater focus and efficiency from our technologies and provide a common framework for integrating new technologies as they emerge. The overarching concept for integrating service programs in these areas is to implement a "virtual laboratory" connecting service laboratories and users over high-capacity lines that allow interactive and focused experiments to take place. Figure III–2 displays this concept. This approach will maximize the expertise in each service, leverage service technologies, share common products, and achieve interoperability by embracing a common architecture. Figure III–3 shows the focus of these efforts starting on the left with the warfighters' needs, then using the virtual laboratory to integrate programs, and finally including the services' focused efforts in each of the five critical subareas.

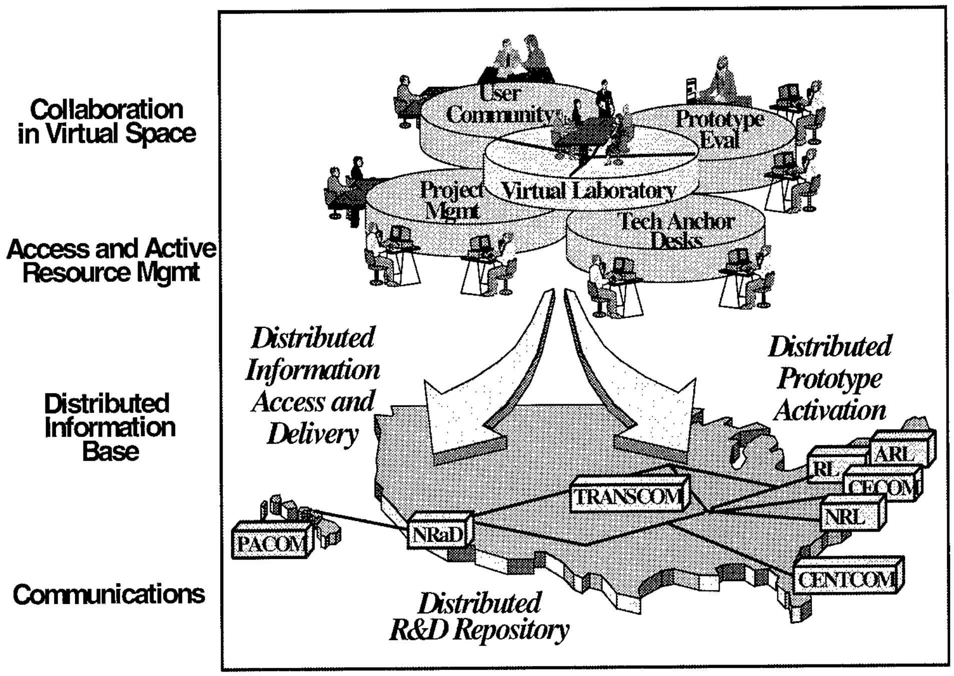


Figure III–2. IST Virtual Laboratory Concept

Figure III–4 illustrates the efforts of these five subareas that, when integrated, become effective command, control, communications, computing, and modeling/simulation building blocks that are pivotal elements of modern warfighting. They will provide the means for collaborative training, planning, mission rehearsal, decisionmaking, information distribution, and successful employment of accurate weapon systems. The efforts in the DTAP are the "glue" that integrates the sensors and provides the critical information to the weapon systems. Achieving this capability requires significant investment, either to leverage the commercial sector or to develop the unique military components.

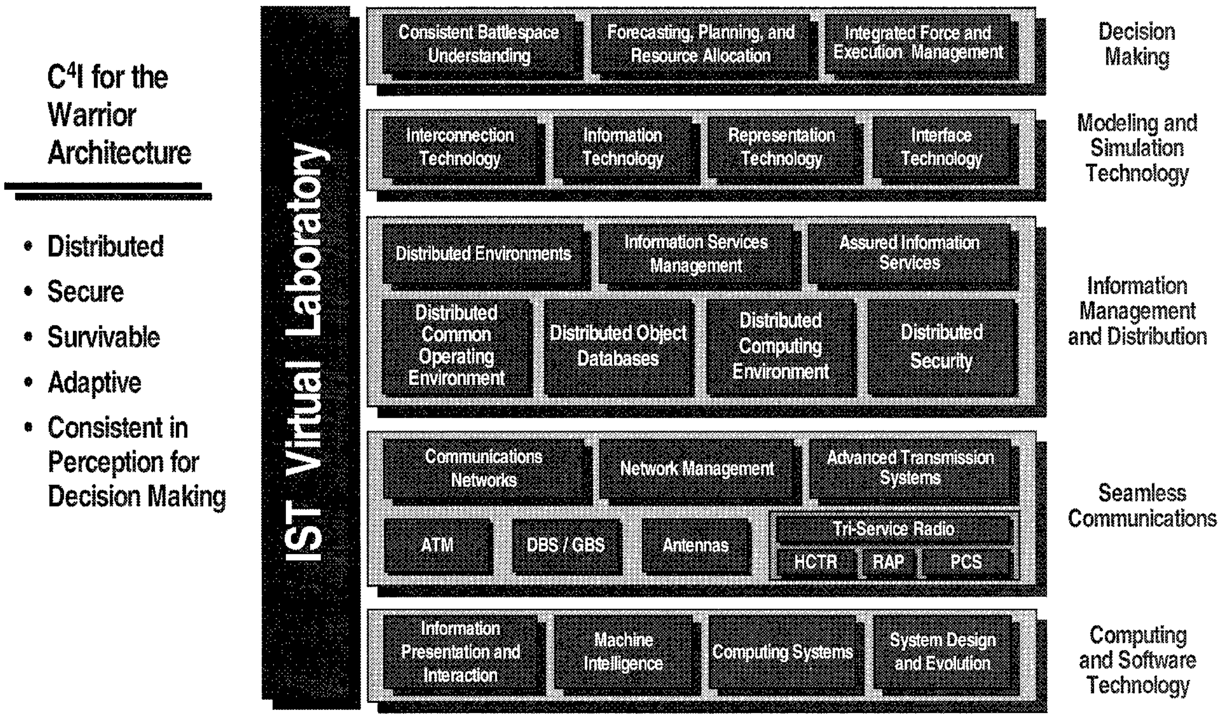


Figure III–3. IST Focus

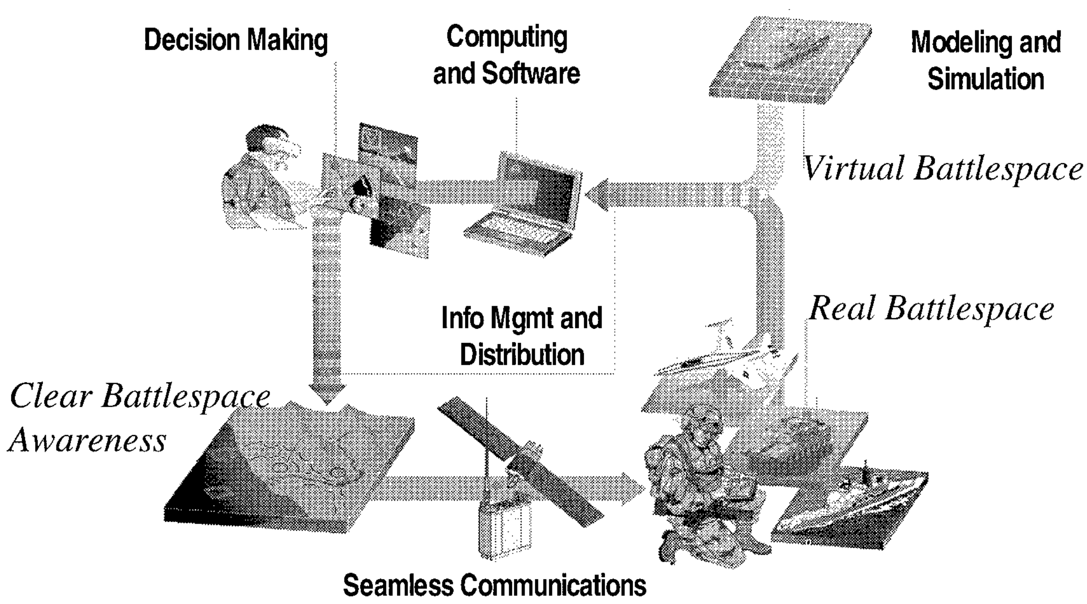


Figure III–4. Integrated, Interrelated Technologies

A brief summary of the five subareas shown in Figure III–1 follows. Decisionmaking is the heart of the command process. It encompasses the development of common, modular elements that connect joint mission planning, rehearsal, execution monitoring, and common pictures of the battlespace. This will provide battlefield picture and situational assessment products that support real-time operations. M&S is a fundamental component of the other four subareas as well as supporting all other DTAP areas and the Joint Warfighting Capability Objectives (JWCOs). M&S technologies will provide both an assessment capability for supporting the development of these other technologies and a capability for facilitating interoperability between simulations and to live command, control, communications, computers, and intelligence (C^4I) systems. Cost-effective development of an M&S application is achieved through the use of a common technical framework for M&S (HLA, CMMS, and data standardization) along with authoritative representations of environments, systems, and human behavior. Information Management and Distribution (IM&D) provides the information infrastructure and products needed by the other four areas (and other DTAP areas) for information security, distributed computing, distributed multimedia databases, and visualization. This movement of information is critical to satisfying the warfighters' needs for the future. Seamless communications spans the globe, interconnecting command echelons, services, and allies worldwide by implementing common transport protocols and dynamic network management. By focusing on wide bandwidth capabilities linked to our currently narrowband tactical systems, including mitigated modems to recover messages during nuclear and natural disturbed environments, we can provide the correct critical information to the warrior anywhere in the world. Computing and software technology will provide an integrated approach for private sector and government efforts. Focus will be on compatible software architectures, improved software tools to reduce development costs, high-performance computing, intelligent agents, and user interfaces.

1.2 Strategic Goals

The top-level goals of the IST research and development programs are to deliver technology solutions that provide:

- Transparent communications between and across command levels/echelons—seamless communications—under any weapon and natural disturbed environments.
- Common architectures as a framework to achieve transparent distribution of information.
- Commonality where common elements are appropriate (e.g., joint decision-making tool kits).
- Readily available, operationally valid models and simulations built to a common technical framework.
- Affordable, advanced, robust, information-processing systems through effectively integrated software, hardware, and connectivity infrastructures.

The goals for IST development have been coordinated with the findings of Advanced Battlespace Information System (ABIS) Task Force. Table III–1 maps the appropriate critical functional capabilities identified in the ABIS study to the DTOs of the IST area. IST programs will develop the technology to provide a real-time, fused, battlespace picture with integrated decisions aids. The technology will provide the processing infrastructure, intelligent/anticipatory data manipulation and distribution, and dynamically adaptive algorithm, broadband communications linkages required for both command and sensor-to-shooter (STS) applications. Warfighters will be able to exchange information unimpeded by differences in connectivity, environmental conditions, processing and interface characteristics. With these capabilities, we will have the ability to establish distributed, virtual staffs that share a common, consistent perception of the battlespace. The warfighter will have the capability to construct distributed task teams among command posts split between areas of operation and rear areas to include continental United States (CONUS) with the resultant linkage of sensors, weapons, and decision makers. Specific examples of the critical benefits provided are included in following sections.

Table III-1. IST DTOs Implement ABIS–Identified Critical Functional Capabilities

ABIS–Identified, "Needed Technologies"	Defense Technology Objectives (abridged)																							
	IS.01 Battlespace Understanding	IS.02 Resource Allocation	IS.03 Execution Management	IS.10 Simulation Interconnection	IS.11 Simulation Info Tech	IS.12 Simulation Representation	IS.13 Simulation Interfaces	IS.15 Distributed Environment	IS.17 Defensive Info Warfare	IS.20 Transaction Comms	IS.21 Assured Communications	IS.22 Network Management	IS.23 Digital Warfighting Comms	IS.24 Information System	IS.28 Intelligent Information	IS.29 Software Technology	IS.30 Embedded Technology	IS.31 Intelligent Control	IS.32 Information Presentation	IS.33 Embedded Computing	IS.34 Battle Management	IS.38 Antenna Technologies	IS.40 Operations Simulation	IS.46 Advanced Logistics
Advanced compression, coding, abstraction for conditioning of information								X		X														
Agents for intelligent inferencing	X	X	X					X								X								
Anticipatory services management tools												X												
Automated data validation & data validity tags	X																							
Automated intelligence preparation of the battlespace (IPB)		X																						
Automated language & syntax translation							X																X	
Automated protocol translation				X	X					X														
Automated mediators & DBMS tools								X								X								
Automated nodal analysis & weaponeering			X																					
Automated target/weapon pairing & update		X																						
Automatic recognition, routing, & analysis of data					X			X							X	X								
Automatic target & infrastructure ID, recognition, behavior, & change detection; battle damage assessment	X															X				X				
Cognitive displays, virtual reality, & 4D real-time presentation	X					X	X									X			X				X	
Cognitive support & decision aids	X	X	X	X	X	X	X														X			X
Distributed, collaborative, virtual workspaces		X	X	X	X	X	X												X				X	X
Distributed, collaborative, continuous, dynamic, automated planning & scheduling		X	X	X	X	X	X								X				X		X			X

Table III-1. IST DTOs Implement ABIS–Identified Critical Functional Capabilities (continued)

ABIS–Identified, "Needed Technologies"	Defense Technology Objectives (abridged)																							
	IS.01 Battlespace Understanding	IS.02 Resource Allocation	IS.03 Execution Management	IS.10 Simulation Interconnection	IS.11 Simulation Info Tech	IS.12 Simulation Representation	IS.13 Simulation Interfaces	IS.15 Distributed Environment	IS.17 Defensive Info Warfare	IS.20 Transaction Comms	IS.21 Assured Communications	IS.22 Network Management	IS.23 Digital Warfighting Comms	IS.24 Information System	IS.28 Intelligent Information	IS.29 Software Technology	IS.30 Embedded Technology	IS.31 Intelligent Control	IS.32 Information Presentation	IS.33 Embedded Computing	IS.34 Battle Management	IS.38 Antenna Technologies	IS.40 Operations Simulation	IS.46 Advanced Logistics
Easily deployable, evolvable, scaleable, plug & play architecture																	X							
Fault-tolerant M&S for mission preview, rehearsal, & training				X	X	X	X																X	
Heterogeneous, multimedia conferencing								X																
High-rate broadcast													X											
Image understanding & pattern recognition						X									X									
Information warfare surveillance & defense tools									X			X												
Intelligent agents for C4ISR tasking		X																						
Intelligent agents for knowledge retrieval, filtering, integration, sanitization, & deconfliction	X	X	X												X									
Intelligent, distributed, object-oriented maps	X				X	X																		
Low-cost techniques for appending robust front ends & "shells" to commercially derived systems								X									X							
M&S for spectrum dominance & information warfare effectiveness evaluation				X	X	X	X																	
Massive data storage & management								X								X								
Multilevel, adaptive, information security									X		X		X											
Multilingual, multimode, interface services							X												X				X	
Joint multisensor & information fusion, sensor cross-cueing, & tracking algorithms	X	X	X																					
Rapid M&S for sensor coverage analysis				X	X	X	X																	
Rapid M&S for situational assessment & COA analysis		X		X	X	X	X																X	
Rapidly deployable tactical fiber extensions																								
Real-time, distributed, object management				X	X																			
Robust, secure, real-time, geolocation & timing																								
Self-adapting tactical, mobile networking										X														
Speech & text understanding							X													X			X	
Tactically extensible, high-rate, asymmetric mobile communications													X	X								X		
Tools for projecting & visualizing grid capabilities in terms of operational needs												X												
Uncertainty management & visualization	X	X													X									
Universal information transaction mechanisms					X					X														
Virtual anchor desk				X			X												X		X		X	X

1.3 Acquisition/Warfighting Needs

The IST technology efforts are critical to the stated joint warfighting needs of Information Superiority, Precision Force, Combat Identification, Joint Theater Missile Defense, Military Operations in Urban Terrain, Joint Logistics and Readiness, Joint Countermine, and Electronic Combat. Table III–2 shows the powerful technology transition opportunities to enhance warfighter capabilities.

Table III–2. Information Systems and Technology Transition Opportunities

Current Baseline	5 Years	10 Years	15 Years
DECISION MAKING SUBAREA			
Time-consuming and manually intensive planning.	Semiautomated situational assessment, planning, and resource allocation.	Automated decision aids with 3D perspective for both information and battlespace.	Fully integrated GCCS applications that are scalable and tailorable to platform, echelon, and warfighter.
Limited interoperability among C^2 systems.	Hyperlink, integrated, sensor and situational 3D information displays.	Hyperlinked information shared among C^2 systems promotes rapid cognition.	All-source hyperlinked information adapted to individual.
Limited battlefield visualization.	Near-real-time 2D/3D visualization.	Fully automated COE applications for assessment, planning, and monitoring.	Joint, common core planner.
Few real-time aids, service-specific systems and tools.	Collaborative, joint framework in place for automation and COE products.		Compatible with COTS, DSS, and EIS products.
MODELING AND SIMULATION TECHNOLOGY SUBAREA			
One-of-a-kind, stove-piped models and simulations cost too much and take too long to build. Some interoperability available through ALSP and IEEE DIS.	Interconnection and information technologies applied to M&S applications currently under development. Simulation generation technologies reduce development costs by a factor of 10 and development time by factor of 5.	Simulation interoperability is expanded throughout the services and across the training, acquisition, and analysis communities.	Simulation interoperability is optimized. Legacy systems (those developed prior to FY96) are either interoperable or no longer in the simulation community.
Use of M&S by live forces to plan and rehearse missions is limited by lack of adequate C^4I simulation interfaces.	C^4I simulation interfaces for limited mission planning and rehearsal.	M&S applications interfaced to live weapons, sensors, test and training ranges, and humans.	Simulation augments operational warrior.

Table III–2. Information Systems and Technology Transition Opportunities (continued)

Current Baseline	5 Years	10 Years	15 Years
MODELING AND SIMULATION TECHNOLOGY SUBAREA (cont'd)			
Environmental databases lack interoperability, reuse, and rapid generation across all domain areas (terrain, ocean, atmosphere, space). Representation of human behavior (especially C^2) is not available.	72-hour generation of cost-effective, high-resolution, small-area-coverage terrain environments. Environmental input to JSIMS and JWARS, supported by standard data. Human behavior C^2 modeling at battalion and company levels.	Fully documented terrain, ocean, and atmosphere databases within 72 hours covering required maneuver areas. Human behavior C^2 modeling at brigade, division, and corps levels.	Able to generate and interface databases of differing resolution in live, virtual, and constructive simulations for all environmental domain areas. Full, authoritative representation of both individual and group behavior for M&S applications.
Individual combatants are not fully immersed in virtual simulations, properly represented in constructive simulations, or adequately instrumented for linking live players to virtual and constructive simulations.	Demonstrate capability to fully immerse individual combatants in virtual environment, represent some human behaviors in constructive simulations, and realistically link live players to virtual and constructive simulations.	Enhance simulation capabilities to reduce the time and cost of assessing individual combatant systems by 25% and reduce cost of training by 30%. Continue to improve representations of human behavior.	Leverage advances in multisensory technologies and instrumentation to further immerse individual combatants in synthetic environments.
INFORMATION MANAGEMENT AND DISTRIBUTION SUBAREA			
Interoperable DCE.	Hybrid real-time/non-real-time DCEs interacting with mobile DCE clusters.	Real-time multimedia object-oriented DBMSs with mobile clusters.	Adaptive intelligent DCEs used for training, simulation, and warfare.
Battlefield data distribution not echelon aware.	End-system aware self-stripping multimedia objects.	Information distribution that is cognizant of echelon, spatial, and temporal issues.	Seamless CINC-to-foxhole information distribution.
Homogeneous, secure system component solutions.	Composable COTS for secure systems solutions.	Secure, high-assurance distributed computing environments.	Automated security policy maintenance with adaptive security structures.
SEAMLESS COMMUNICATIONS SUBAREA			
Mechanisms for fault tolerance.	Intelligent fault recovery.	Automated replication and distribution of assets.	Self-healing systems with predictive fault avoidance.
Circuit, packet, and message switching networks overlayed in a single backbone, 2 Mbps stationary trunk radios, tactical Internet.	ATM utilized for multimedia applications and as a transport for existing, wide-area switched networks, 45-Mbps stationary trunk radios, Ipng, mobile IP, multicast.	ATM/ISDN upgrades to wide-area systems, 45-Mbps OTM radio and 155-Mbps stationary trunk radios, wireless ATM to mobile users.	Tactical B-ISDN, 155-Mbps OTM trunk radios, 600-Mbps stationary.

Table III–2. Information Systems and Technology Transition Opportunities (continued)

Current Baseline	5 Years	10 Years	15 Years
SEAMLESS COMMUNICATIONS SUBAREA (cont'd)			
DBS/GBS demonstrated.	23-Mbps GBS, in-theater injection.	23-Mbps GBS, global theater injection.	Military GBS with high-data-rate reachback.
Single-channel radios with multiwaveform programmability.	Speakeasy/FDR.	Smart radio functions for FDR.	Universal digital radio (the "PC" of communications).
Range extension trials completed, limited advanced warning of communications blackout.	Range extension via relay of opportunity and mobile networks, prediction of blackouts due to adverse environments.	Medium-endurance, communications-relay UAV.	High-endurance, communications-relay UAV.
COMPUTING AND SOFTWARE TECHNOLOGY SUBAREA			
Limited application of reusable software components.	Software-developed component by component with extensive use of COTS/GOTS for SC-21, JSTARS, NSSN, DSP, Cheyenne Mtn., Aegis, and THAAD.	Domain-specific development through specification process only—for JTF C^2, flight simulators, and UAVs.	Warfighter-modifiable systems—for ATR, THAAD, JTF C^2, and UAVs.
Autonomous devices operating independently.	Team tactics demonstrated for autonomous multiagent behavior for hazardous operation in vehicle maintenance, unmanned vehicles, and information fusion.	Plan creation and execution among cooperating intelligent robots for mine clearing, UAVs, information collection, integration, and fusion.	Self-initiated plan creation and execution among cooperating intelligent robots for space system repair, unattended systems, and mine sweeping.
Heavily tethered, limited interaction, single-user VR displays.	Tether-free, multiple-user, single-discipline interaction with 10,000-word vocabulary for mission rehearsal and mission planning applications.	Single-user, immersible VR with 50,000-word vocabulary in multiple-discipline collaboration for JTF, mission simulation, rehearsal, planning, and execution.	Multiple-user, real-time VR for telepresence and UAV mission training.
10 GFLOP/ft^3, militarized.	100 GFLOP/ft^3, militarized for enhanced Aegis and THAAD.	TFLOPS/ft^3, militarized for space-based DEW, ATR, sensor/knowledge fusion, and autonomous UAVs.	100 TFLOPS/ft^3, militarized for real-time situational awareness in the cockpit.

Note: See page III–52 for abbreviation/acronym list.

Access to and exploitation of timely information is a key element of America's future warfighting and crisis management capabilities, as well as its national competitiveness. The projected force-level-multiplier advantage of *information technology* stands far above that of all other technical areas. Such capability, while greatly enhancing the autonomy and survivability of individual units, will quickly provide an advantage in any conflict, supporting early, decisive victory with minimal cost in assets and human life.

The information environment requirements for the industrial, commercial, and financial communities are similar in many ways to the DoD information environment. There are leveragable development activities in the commercial sector addressing many of the same technical issues as DoD. Global industrial and financial institutions must have reliable, global, data access. Their multinational status requires support for heterogeneity. Movement of global markets requires very rapid response to change and guaranteed availability. This creates the need for similar distributed information systems that provide location-transparent access to globally distributed data from both advanced and Third World sites.

Advanced software and computing technologies are essential to supporting both the commercial information environment requirements and the DoD's Joint Staff future joint warfighting capabilities. As much as 90% of the cost of C^4I systems and 80% of the functionality of products such as avionics systems are directly and solely attributable to software. High-performance computing and image understanding coupled with high-performance networking, distributed systems, and mobile computing form the foundations for instantaneous recognition of targets and rapid communication of the information. IST also enables a wide range of defense-critical applications, such as new methods for design enabled by computational models in many science and engineering disciplines. Advanced M&S tools and technologies will provide simulation-based training systems and embedded training that offer more cost-effective means of enhancing individual and unit performance warfighting tools that support C^2 decisionmaking systems and provide a means for conducting mission analyses and rehearsals. For modernization, M&S technology will reduce the time, resources, and risks associated with the acquisition process while enhancing the performance of the acquired systems. Virtual prototypes will be evaluated in realistic synthetic acquisition and operational environments, supporting the many phases of the acquisition process from requirements definition and initial concept exploration to the manufacturing and testing of new systems.

Many of these advances in IST are being driven by commercial developments and products. The results can be brought to bear on DoD problems through cooperative efforts and participation in efforts to set standards and establish policy. Costly DoD-specific development can be avoided with the amortization of costs across government and commercial communities. However, there are aspects of command, control, communications, and computers (C^4) and M&S that must be strongly influenced or directly supported by DoD. In particular, developing the capability to reliably communicate to and among numerous, widely dispersed mobile sites operating in actively hostile environments, identifying friend and foe, achieving information security, and meeting the requirements for military-unique processing and decision support systems will not be achieved without significant DoD support. The IST acquisition strategy is necessarily a pragmatic one—identify the pivotal issues, capitalize on commercial development whenever feasible, leverage development in areas with special military aspects, and sponsor programs in technologies with unique DoD interest that would otherwise not be available to meet DoD needs.

This technology area embodies enormous dual-use potential in numerous areas vital to economic competitiveness and other national concerns. Beside the direct application of this technology to defense sciences and engineering, it has great potential for significant contributions to more effective health care procedures, enhanced education and lifelong learning, more timely and less costly procurement through electronic commerce, more efficiently managed and integrated transportation networks, effective delivery of innovative information services to average citizens, and sound methods of environment monitoring, weather prediction, and pollution control. For example, approximately 80 to 90 percent of DoD's investment in computing and software technology can be credibly regarded as having substantial dual-use potential by even the most conservative of individuals.

A glossary of abbreviations and acronyms used in this chapter begins on page III–52.

1.4 Support for Combating Terrorism

Many of the technologies and developments in the Information Systems Technology area could easily be adapted to provide a capability to combat terrorism. A summary of these capabilities and associated DTOs is provided in Table III–3.

Table III–3. Support for Combating Terrorism

IST Capability	Supporting DTOs
DECISION MAKING	
Visualization tools and techniques. Cognitive displays, virtual reality, and 4D real-time presentation. Distributed, collaborative planning.	IS.01.01 - Consistent Battlespace Understanding IS.02.01 - Forecasting, Planning, and Resource Allocation IS.03.01 - Integrated Force and Execution Management
MODELING AND SIMULATION	
Distributed simulation to predict effects of weapons of mass destruction (e.g., chemical/biological). Training, mission planning, and rehearsal for counterterrorism missions. Prediction of human/group behavior.	IS.10.01 - Simulation Interconnection IS.11.01 - Simulation Information Technologies IS-12.01 - Simulation Representation IS.13.01 - Simulation Interfaces IS.40.01 - Individual Combatant & Small Unit Operations Simulation
INFORMATION MANAGEMENT AND DISTRIBUTION	
Adaptive information systems that can deter, detect, and help identify intrusion attempts that may precede terrorist acts. Mechanisms for distributed environment that could be applied to coordinating disparate law enforcement and military forces. Massive distributed data storage and management.	IS.15.01 - Assured Distributed Environment Support IS.17.01 - Defensive Information Warfare
SEAMLESS COMMUNICATIONS	
Seamless communications across disparate forces and systems. Self-adapting, plug-and-play, and tactically equivalent mobile networking. Adaptive multilevel security.	IS.20.01 - Universal Transaction Communications IS.21.01 - Assured Communications IS.23.01 - Digital Warfighting Communications IS.24.01 - Multimode, Multiband Information Systems
COMPUTING & SOFTWARE TECHNOLOGY	
Multimode, multilingual interfaces. Intelligent agents for retrieval, filtering, and deconfliction. Image understanding and pattern recognition.	IS.28.02 - Intelligent Information Technology IS.31.02 - Intelligent Control IS.32.02 - Information Presentation and Interaction

2. DEFENSE TECHNOLOGY OBJECTIVES

Figure III–5 identifies the DTOs approved for IST by number and shows which subarea in the IST area is responsible for the DTO. A writeup of each DTO is provided in a separate volume. These DTOs were selected not only for their importance to the total DoD technology base effort, but also for their integrative support across this DTAP area. The JWSTP DTOs related to these IST subareas are also shown.

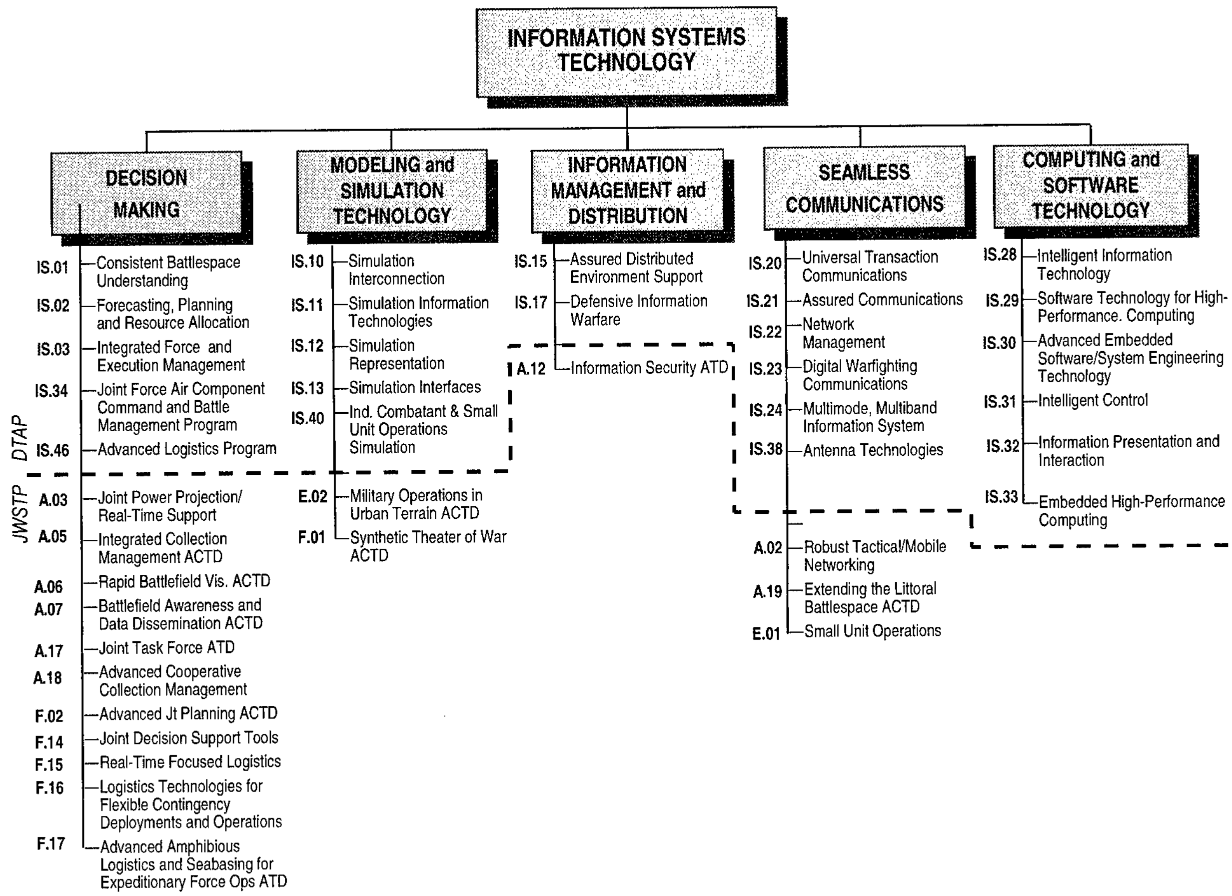


Figure III–5. Taxonomy of Defense Technology Objectives

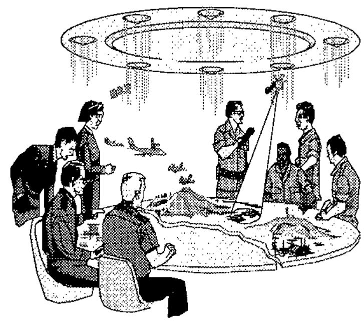
3. TECHNOLOGY DESCRIPTIONS

3.1 Decision Making

3.1.1 *Warfighting Needs*

As warfighters execute critical real-time decisions that shape the outcome of battles, the certainty of information conspires to slow and confuse that process. Warfighters need C^2 decision aids that permit the rapid assessment, planning, and execution of missions to ensure swift attainment of goals through constraint-based, information-intensive systems. These decisionmaking systems must organize, explore, and recommend options across a spectrum of military operations.

This subarea focuses on all elements of the decision-making process from tactical assessment, through course-of-action (COA) analysis, intelligence preparation of the battlefield, plan preparation, deconfliction, to rehearsal and execution. The major subarea emphasis is on acquiring, organizing, and manipulating information needed to dominate and neutralize adversary forces. This includes a real-time awareness of the location, activity, and intent of friendly, adversary, and neutral forces throughout the battlefield area, providing a common and consistent understanding of the current situation. One of this subarea's primary objectives is to achieve information superiority by meeting warfighter needs for a flexible command with a supporting information-presentation system that can be configured rapidly and a structure dynamically adapted to optimize force effectiveness and survivability. This subarea applies leading-edge M&S, computing, and software technologies to significantly improve warfighter performance by eliminating laborious, time-consuming manual procedures and processes that pervade U.S. operational assessment, planning, and execution. Computer-aided processes and procedures replace exclusively human ones. The warfighter is provided with an intuitive view of his battlespace, an enlightened perspective of information (C^2, intelligence, logistics, weather, trends, expected outcomes, and other critical data), and the ability to explore alternatives in faster-than-real time (e.g., exploring 10-hour battles in several minutes).



Technology Focus

- Consistent Battlespace Understanding
- Forecasting, Planning & Resource Allocation
- Integrated Force and Execution Management

Goals

- Acquire and Assimilate Information to Dominate and Neutralize Adversary Forces *Includes:*
  - ➤ Near-Real-Time Awareness of Locations and Activity
  - ➤ Common Awareness of Current Situation
  - ➤ Interactive 2D/3D Presentation of Tactical Situation
- Conduct Course of Action (COA) Analyses, Allocate Resources, Wargame to Explore Battlespace Options

Figure III-6. Decision Making Focus and Goals

3.1.2 *Overview*

3.1.2.1 Goals and Timeframes. The goal of the decision making subarea is to provide automated, real-time decision support to the warfighter. The warfighter will rapidly interpret and understand information provided to him through interactive 2D/3D presentation of the tactical situation (situational assessment cues identifying troop formations, site fortifications, potential problems, or interest areas). The commander will view relevant forecasts for weather, enemy intent, enemy strength over time, friendly strength, and logistics tail, conduct COA analyses, allocate resources, initiate a wargame (real-time simulation) to explore battlespace options, and collaboratively plan and rehearse battles. Such a capability will result in the precise direction of a diverse, synchronized task force armed with overpowering information superiority and decisionmaking capability. Table III–4 shows the goals and timeframes for the decision making subarea. Figure III–7 shows the decision-making technologies development roadmap.

3.1.2.2 Major Technical Challenges. The major challenges are as follows:

- Develop applications that organize and effectively present complex, distributed information using advanced pattern recognition algorithms, knowledge bases, and goal-directed and constraint-based reasoning, and that employ intelligent agents for semiautomated, intelligent information retrieval, fusion, and presentation.
- Fuse planning information with actual information in real time.
- Provide real-time simulation (wargaming), collaborative planning, and rehearsal with sufficient fidelity on tactical systems to influence battle outcomes.
- Provide decision support in the presence of uncertain, incomplete, or absent information.
- Develop applications for dynamic scheduling/coordination of assets for interdependent tasks.
- Provide collaboration tools that permit the spectrum of operations to be performed by remote, dispersed elements of a task force.

3.1.2.3 Related Federal and Private Sector Efforts. A multitude of efforts relate to this subarea, both federal and private. Private investment spans virtual reality (VR), decision aids, decision support systems, executive information systems, advanced database engines, artificial intelligence (AI), and related technologies and is estimated to be $1.9 billion.

3.1.3 *S&T Investment Strategy*

3.1.3.1 Technology Demonstrations. Technology demonstrations are scheduled for FY97 with the XVIII Airborne Corps and U.S. Atlantic Command (ACOM), Operation Joint Endeavor, 3rd Fleet, and the Army's Task Force XXI (TFXXI) experiment. These demonstrations will include collaborative planning, 2D/3D visualization and mission rehearsal, force synchronization, and dynamic force monitoring. Each program cited lists relevant demonstration opportunities.

Joint Force Air Component Commander. The JFACC program will streamline and revolutionize command and control of joint and coalition air forces through the incremental development, integration, evaluation, demonstration, and transition of technologies and systems. These systems enable new operational concepts for planning and execution that will significantly improve the responsiveness, efficiency, effectiveness, and flexibility of joint air operations. The resulting capabilities (1) transform air operations planning of the JFACC from a reactive, sequential system to one that provides continuous, near-real-time predictive planning, as well as rapid response to dynamic situations; (2) provide robust planning enabling rapid evolution of alternatives, with less human involvement during complex planning processes, and allowing rapid feedback on campaign accomplishment; (3) provide a JFACC planning and execution system that can be tailored to theater needs, with significant reachback capabilities where appropriate; and (4) provide a system that can support a range of operational concepts, especially decentralized execution of operations.

Table III–4. Decision Making Goals

Short Term (97-98)	Mid Term (99-01)	Long Term (02+)
Integrated multisensor air/land/sea picture on digital maps (theater and national products) with hyperlinks to multimedia information products.	Scalable, battlefield visualization shared across the joint force for plans, logistics, weather; real-time friend/enemy situational representation.	Fully automated, multidimensional, tailored, "virtual battlefield view" (100% consistent across echelons, measured against time).
Semiautomated, collaborative situational assessment. Semiautomated identification and force analysis tools.	Partly automated situational reasoning, target and threat analyses, decision making under uncertain conditions; automated "situation server" demonstration to support planning, replanning, pattern recognition, tactical picture management, intelligent cueing.	Fully automated situational reasoning supported by multimedia techniques for STS targeting, combat identification, multihypothesis data fusion, and resource allocation under uncertain conditions.
Planning systems of differing architectures interconnected for theater COA, campaign plan, battle plan, force-level air-mission plan preview in <12 hours.	Cognitive decision support for distributed situational assessment, supported by dynamic 3D virtual battlefield displays.	Automated situation projection; fully automated links to planning, rehearsal, and other decisionmaking tools; automated warfighter cueing to prioritized issues.
Automated air operations planning aids. Semiautomated applications for COA analysis, time and event-based forecasting, route planning, and limited resource allocation functions.	Demonstration for distributed, cooperating agents and algorithms for COA generation and crisis response, automated plan generation, plan deconfliction, resource allocation, targeting, and weaponeering.	Joint, common-core mission planner with service-unique modules; compatible with COTS, DSS, and EIS products.
Semiautomated near-real-time dissemination of mission tasking and time-critical information; use DBS/GBS with enroute C^4I updates for replanning and rehearsal.	Fully integrated collaborative planning (planning support from remote anchor desks, split-base operations for logistics and asset visibility); distributed, in situ mission rehearsal.	Fully automated real-time situational assessment, forecasting, plan generation, resource allocation including weapon/target pairing, and mission rehearsal.
Demonstrate air battle plan repair for up to 25% of sorties contained in original plan.	Automated real-time dissemination of mission tasking, mission status and time-critical information. 2D and 3D perspective displays to aid rapid understanding of battlespace (less than 1 hour).	Fully interactive, distributed wargaming.
Limited real-time alerts or "pointers" to identify problem areas or areas of interest.	Replan entire missions across single echelon in less than 1 hour; integrate effects and constraints assessment from total asset visibility status changes.	Integrated all-mission, all-echelon replanning and execution (2,500-sortie integrated ATO regenerated and retasked at 1-hour intervals); fully automated and tailored displays based on echelon, mission, region and other factors; extensive use of intelligent agents.

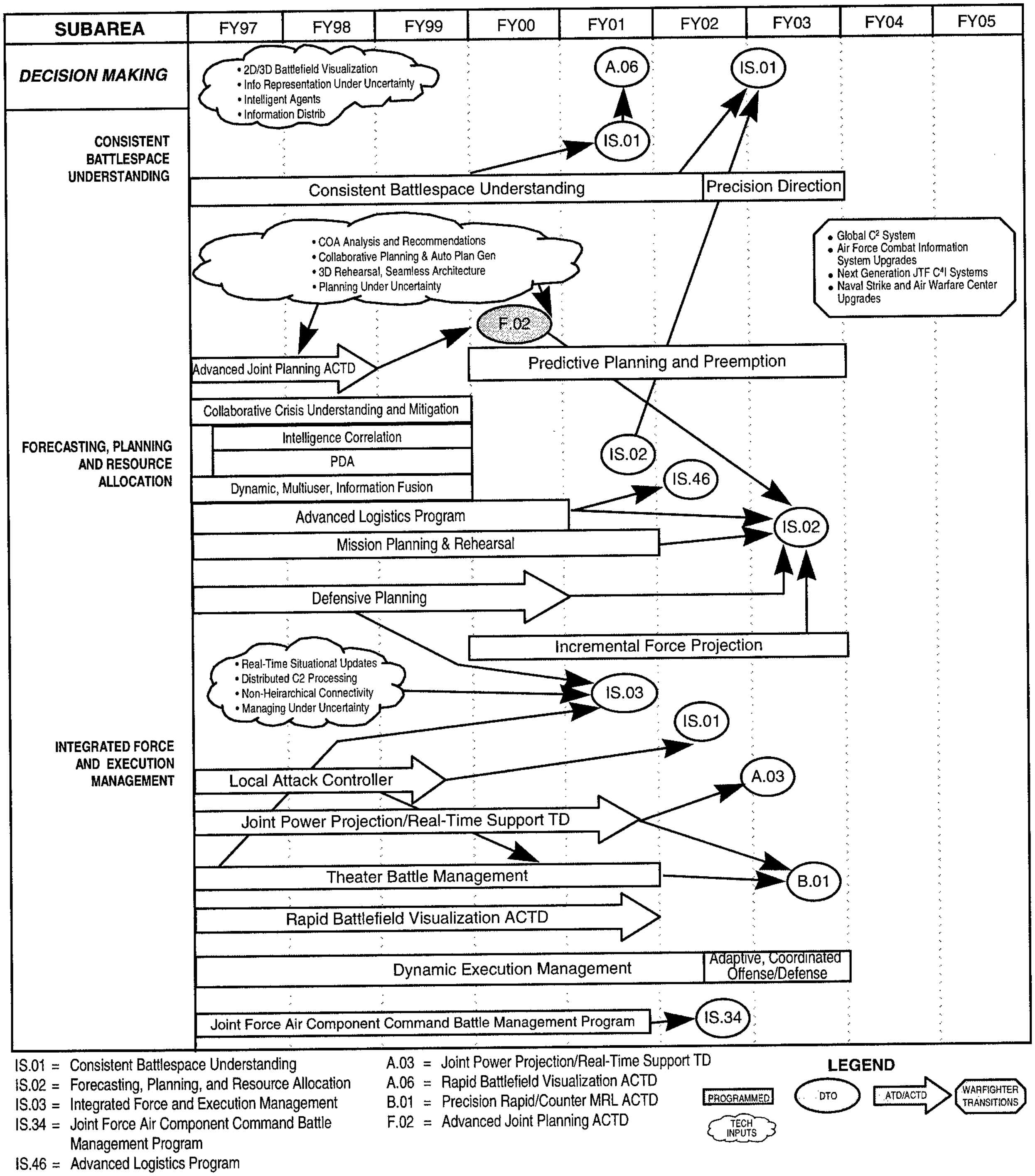


Figure III–7. Decision Making Technologies Roadmap

Advanced Power Projection and Execution. APPEX provides force-level planning within GCCS—Joint Maritime Command Information Strategy (JMCIS) to support coordinated plan development over a distributed network using advanced interactive graphics, shared object-oriented databases, and computer-assisted planning tools. APPEX provides interfaces to the Navy's JMCIS, Tactical Aircraft Mission Planning System (TAMPS), and Contingency Tactical Automated Planning System (CTAPS) for intelligence, imagery, and mission data. APPEX operators rapidly build plans, edit routes, and coordinate missions in space and time. The missions can involve air, ground, and sea platforms. APPEX provides a 3D visualization of the missions in relation to the surrounding terrain, threats, and forces to support the planning, briefing, and execution phases. Coordination of this 3D visualization effort with those of the Rapid Battlefield Visualization ACTD is underway. In FY96, an APPEX prototype was fielded tested on the U.S.S. *Theodore Roosevelt* by Carrier Air Wing Three. APPEX stations in the intelligence center and two ready rooms were integrated via an ATM-based network. Plans in FY97 include expansion of APPEX to support execution monitoring and force management and the installation of APPEX at naval strike and air warfare centers for continued operator evaluation. APPEX will provide feeds to JFACC and other Army/Air Force programs.

Advanced Joint Planning ACTD. AJP will provide ACOM, Joint Staff, and other CINC elements with an increased ability to rapidly plan, package, and deploy forces to multiple regional conflicts. The three primary areas of focus are on force readiness and deployment planning, force employment planning, and force rehearsal and evaluation. Technologies developed by DARPA and others will be tailored for this purpose, integrating and evolving operational concepts in close collaboration with operators and sustainers. This new functionality will provide a supported, leave-behind capability at ACOM. One of the components will be transitioned through the Defense Information Systems Agency (DISA) GCCS Leading Edge Services (LES) into the GCCS core service for application with other users. AJP addresses a different scope and echelon of planning challenges than JFACC and APPEX.

Dynamic Multiuser Information Fusion. DMIF will provide the joint warfighter with a clear and actionable picture of the battlespace. The program will develop advanced information fusion applications for transition to the service fusion systems (Army All-Source Analysis System (ASAS), Air Force Combat Information System (CIS), JMCIS, Marine Intelligence Analysis System (IAS), and Global Command and Control System (GCCS)) in support of joint force operations.

Battlefield Awareness and Data Dissemination ACTD. BADD is demonstrating advanced information integration, intelligent filtering, and high-bandwidth satellite communications to provide a consistent operational picture extending from tactical to theater levels, with different aggregations and views of the information for each echelon. BADD demonstrations emphasize advanced techniques for fusing, displaying, and aggregating relevant, multimedia information. A warfighter's associate (WFA) computer workstation is used to present tailored information to the commander and staff. WFA is based on COTS technology and will employ advanced, higher level applications for data and tactical visualization developed from the Army's technology base program and other DARPA and service programs.

Defensive Planning and Execution ATD. The DPE effort consists of two parts, an ATD and a follow-on development process that will support the integration of DPE capabilities into existing fielded systems. The ATD will reduce risk by developing and demonstrating an automated capability for force level planning and execution management of defensive counterair assets and active and passive defense assets (in conjunction with offensive assets) to be tasked with the destruction or neutralization of enemy aircraft and theater missiles. The follow-on effort will develop and integrate into components of the GCCS (1) effective (optimal) employment of air/ground surveillance, air defense, and attack operations assets; and (2) capabilities that support distributed, dynamic scheduling and target handoff by evaluating tactical-level capabilities, enforcing force-level management, and adhering to encoded doctrine while following joint rules of engagement (ROE) during allocation of weapon platforms across services.

Rapid Battlefield Visualization ACTD. The RBV ACTD will demonstrate the ability to respond swiftly to any global crisis, by rapidly mapping and developing a high-resolution digital map of the area of operations, and then employing that map in an advanced C^4I visualization system. The RBV workstation will display terrain features, C^2 environmental, cultural, logistical, and other relevant information in a 3D VR. The RBV workstation is a functional equivalent of the BADD WFA and, where appropriate, they are the same machine. Application modules for these workstations will be imported from the battlespace command and control (BC^2) ATD. These include situational assessment; forecasting; COA analyses; collaborative battle planning, replanning, and rehearsal; wargaming; and execution monitoring. Current iterations of the RBV workstation are providing a limited set of the aforementioned functions to the XVIII Airborne Corps and ACOM in a series of live exercises. The BC^2 ATD will support the RBV ACTD in demonstrating multiechelon, multiservice, multinational interoperability among the C^4I systems cited above.

Advanced Logistics Program. ALP will develop and demonstrate software tools and protocols needed to gain control of the logistics pipeline and enable the warfighter to project and sustain overwhelming combat power sooner. Specifically, ALP will produce advanced information technology to put the right materiel in the right place, at the right time, while supporting the need to do so with reduced reliance on large DoD inventories. The program will develop a shared technology base of information manipulation and planning tools to support planning, execution, monitoring, and focused replanning throughout the logistics pipeline. This will be demonstrated through a system that tightly couples continuous planning and execution monitoring in an interoperable COA and logistics support environment linking CINC Operations (J3) and Logistics (J4) staff, Defense Logistics Agency (DLA), and U.S. Army Transportation Command (TRANSCOM). The program will focus on four main areas: (1) transportation tools to track assets and make smarter use of lift, (2) rapid supply services for faster and more flexible acquisition of supplies, (3) force sustainment planning and sourcing, (4) logistics COA feasibility planning that is linked to the war plan.

Battlespace Command and Control ATD. The BC^2 ATD will leverage commercial and service systems and development efforts in advanced decision aids to provide an integrated, joint-force/coalition-force capability for commanders and staff. These aids include automated situation assessment, COA analysis, all-terrain route planning, force synchronization, limited interactive wargaming, and force monitoring. Coalition and joint service interoperability will be addressed at the protocol, message, and linguistics (COTS machine language translation) levels.

Joint Task Force ATD. The JTF ATD develops and demonstrates advanced technologies needed for defense operations for the 21st century. The program develops advanced information processing concepts to support a geographically dispersed staff for crisis management. These include an architecture and infrastructure, software tools, applications, and repository that can be integrated to form the foundation of a next-generation JTF C^4I capability for planning, execution, and management of joint force operations including the areas of logistics, transportation, weather, and communications. This technology base will facilitate a scaleable joint planning, replanning, and execution system providing enhanced collaboration, visibility, and common perception of the battlespace.

3.1.3.2 Technology Development. The decision making subarea comprises three major technology activities: consistent battlespace understanding (CBU); forecasting, planning, and resource allocation (FPRA); and integrated force management (IFM). When integrated, they represent the fundamental C^4I processes of "assess, plan, and execute." Technology is being actively pursued to achieve the goals outlined in Table III–3 above.

Consistent Battlespace Understanding. CBU is developing a capability to continuously acquire, fuse, and analyze multisensor, multisource, and multimedia data to form a coherent tactical picture. This tactical picture includes awareness of the overall theater and tactical situations of friendly, enemy, and neutral forces and an understanding of the constraints and environment in which they operate. Improved assimilation and a deepened understanding of the tactical situation will reduce casualties and fratricide, while ensuring a dominant posture for friendly operations.

CBU demonstrates technology that enables the commander to exploit and shape the battlespace by dynamically directing and integrating tactical and supporting intelligence, surveillance, and reconnaissance resources for targeting, weaponeering, mission preview, battle damage assessment (BDA), and combat assessment. This capability provides end-to-end, task-synchronized, multimission support products to the warfighter to facilitate the application of precision weapons, precision forces, and rapid response. Some technical challenges are collection, exploitation and organization of information, quality assessment and correlation of information, intelligent filtering and preparation of information, fusion of the picture, presentation of the picture, and automated, collaborative situational awareness.

Forecasting, Planning, and Resource Allocation. FPRA is developing and will demonstrate a planning system that provides a core of integrated forecasting and planning tools to support the generation of joint plans across echelons, services, and mission areas. The goal is a 75% common planning system across the services, with a capability for service-unique applications that examine available information, forecast possible outcomes, and plan the allocation and scheduling of resources in pursuit of an identified mission objective. In collaborative planning, the impacts of planning at one site will be reflected at other sites to support coordination, deconfliction, and group decisionmaking. An objective is to achieve collaborative planning across distributed force and mission areas, within a 1-hour planning cycle, and deconflict, refine, preview, finalize, and update integrated plans within 3 hours.

FPRA focuses on distributed planning processes that provide look-ahead, multioption optimization of offensive and defensive strategy across time, space, resources, and EM spectrum. Subsets of this process include collaborative crisis assessment, target/shooter pairing and continuous plan generation, collaborative plan refinement, deconfliction, and evaluation. The process will also provide the ability to rapidly tailor systems and updates as stimulated by threat actions. Program examples designed to overcome existing FPRA technical challenges are battlespace commander's decision aids, joint force air component command, optimal route planning, and advanced joint planning. Within these and other decisionmaking programs, mission planning/rehearsal initiatives support forecasting and COA generation using knowledge bases and case-based, goal-based, and constraint-based reasoning. Real-time updates, mission evaluation, and wargaming will be used.

Integrated Force Management. IFM is developing advanced capabilities to dynamically synchronize and manage the execution of tactical operations across joint forces using intelligent, knowledge-based rules of engagement. The goal of this effort is to achieve fully synchronized friendly force activities, including real-time retasking and retargeting (with cued, timely delivery of the latest and best information) between distributed sensors, decisionmakers, and shooters. Fully coordinated operations across the force will result in faster adjustment of mission plans in a dynamic tactical environment and a reduction in casualties and fratricide.

IFM is developing a capability to recognize and predict enemy intent, collaboratively adjust and resynchronize forces, and integrate offensive and defensive systems across services. This supports force-wide coordination of scheduling, placement, dynamic tasking, and retasking of detection and engagement assets. ATDs and technology initiatives in IFM focus on the integrated planning and execution of coordinated operations at the tactical level (e.g., brigade, wing, battle group, and below) and explore detailed platform, weapons, and target models. In addition, sophisticated optimization algorithms are being investigated for achieving synchronized, coordinated tactics. Simulation support focuses on detailed event rehearsal and effectiveness evaluation versus aggregate-level attrition assessment. Some challenges for execution management are dynamic, broad-ranging monitoring and synchronization; development of effective knowledge bases for pattern recognition; and automated doctrine, resource reassignment and execution deconfliction, dynamic sensor-to-shooter targeting, plan repair, execution coordination, and context-based intelligence.

Small Business Innovation Research. Several interrelated SBIR efforts are being coordinated and focused on artificial intelligence/knowledge-based/expert-system-based approaches to automated situational assessment, COA analysis and recommendation, automated doctrine recognition, intelligent sentinels, and related technologies. Each of these developments will feed service programs through the DTAP, the decisionmaking web site, and collaboratory activities.

3.1.3.3 Basic Research. There are several critical ongoing research efforts required to meet the challenges of Information Superiority, Precision Force, and Joint Readiness and Logistics technology areas. Rule-based, knowledge-based, and AI modules are required that can provide the intelligent agent functions for a broad spectrum of applications with imperfect data. Also required are 3D rendering algorithms that permit perspective viewing on a range of computer platforms from low to high end, and interactive force-on-force wargaming models to permit real-time simulation of potential battle actions and to explore related options.

3.2 Modeling and Simulation Technology

3.2.1 *Warfighter Needs*

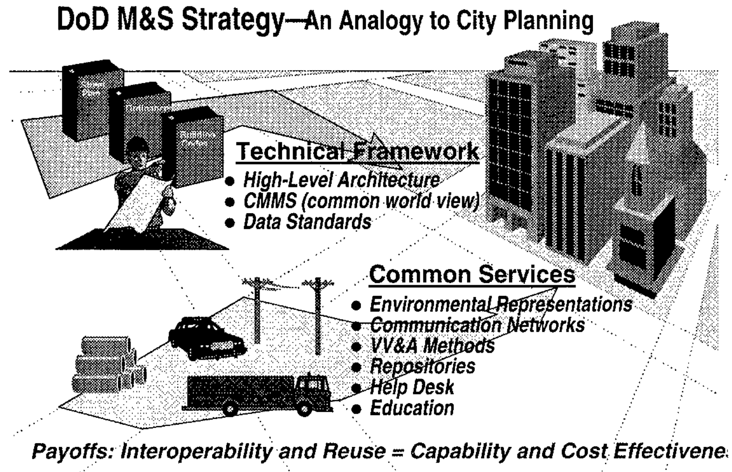


Figure III–8. Modeling and Simulation Strategy

Modeling and simulation technology complements and augments warfighter needs and capabilities across all IST subareas, several other DTAP areas, and all JWSTP areas, especially Information Superiority and Joint Readiness and Logistics. Advanced M&S tools and synthetic environments offer more effective and less resource-intensive means of enhancing individual and unit performance. M&S can substantially contribute to improving the pillars of military capability—readiness, modernization, force structure, and sustainability. M&S will enable cost-effective joint and combined training, mission planning, and mission rehearsals involving active and reserve forces, multiple echelons, and computer-generated simulations of large-scale forces (friendly, neutral, and hostile) on a synthetic battlefield. These distributed, interactive, synthetic environments will bridge large geographic regions and involve entire joint forces from senior commanders to individual warriors. The use of M&S will reduce time, resource requirements, and risks associated with the acquisition process. Representations of proposed systems (virtual prototypes) will be used to support acquisition activities, significantly reducing the time and expense of concept exploration, engineering, manufacturing, and follow-on support activities (e.g., training, maintenance). Decision makers can effectively and quickly simulate and then evaluate the consequences of alternative force structures with known or projected capabilities placed in various mission scenarios. High-fidelity models of logistics, personnel management, medical support, etc., will be integrated with combat models to allow a comprehensive analysis of sustainability.

These technology developments support all Joint Warfighting Capability Objectives in areas of training, mission planning/rehearsal, battlefield visualization, assessment of tactics/doctrine, and acquisition support. For example, M&S supports Information Superiority through support to BADD and RBV ACTDs; Joint Readiness and Logistics through support to Synthetic Theater of War (STOW) and AJP ACTDs; and Joint Countermine through support to the Joint Countermine ACTD Simulation (JCOS) efforts.

Transition opportunities exist with the development of advanced M&S applications, including the Joint Simulation System (JSIMS), Joint Warfighting Simulation (JWARS), National Air and Space Model (NASM), Warrior Simulation 2000 (WARSIM 2000), and others.

3.2.2 *Overview*

3.2.2.1 Goals and Timeframes. M&S core technologies must provide a cost-effective and timely capability to authoritatively represent systems, processes, and operational environments. M&S must provide readily available and operationally valid environments for DoD components to train jointly; develop doctrine and tactics; formulate operational plans; assess warfighting situations; support technology assessments, system upgrades, and system developments; and conduct force structure analyses and assessments. Research is needed to more broadly and authoritatively apply models and simulations across all of DoD. Supporting technologies are being developed in other subareas of the IST area, as well as in other DoD technology areas (e.g., Human Systems; Sensors, Electronics, and Battlespace Environments; and Materials/Processes) and in the commercial sector. Major M&S efforts are in the areas of (1) simulation interconnection, (2) simulation information technologies, (3) simulation representation, and (4) simulation interfaces. The efforts of interest concentrate on the technologies that bring about distributed, seamless, interactive, and adaptable models and simulations. Efficiency is gained through sharing, reuse, and standardization of data and common data structures; models and algorithms; data exchange protocols; M&S services; improved exercise generation and control; interfaces; and network communications. The M&S goals are shown in Table III–5. Figure III–9 shows the M&S technology roadmap.

Table III–5. Modeling and Simulation Technology Goals

Short Term (97–98)	Mid Term (99–01)	Long Term (02+)
	INTERCONNECTION	
First-generation, run-time infrastructure development representing a 20% improvement in performance over proof-of-concept prototypes. The development and testing of initial prototype object model development software will reduce development by 25%. Design and develop industry-based, run-time infrastructure software demonstrating a 25% performance improvement and broad-based portability at a 25% cost reduction.	Prototype initial automated tools to support federation development generating an initial 20% reduction in development time and subsequent 20% with the implementation of advanced automated tools. Run-time infrastructure advances using next-generation software and hardware will demonstrate an additional 20% increase in performance.	Advanced support software will demonstrate automation of the end-to-end process from identifying candidate simulations to configuring, operating, and monitoring federation operations demonstrating a 50% decrease in time and manpower over FY96 levels.
	INFORMATION	
Initial consistent, conceptual models of the mission space prototype will be delivered to JSIMS and WARSIM 2000; second-generation data interchange format for critical subcategories of five M&S data areas (scenario, doctrine and operations, environment, equipment, and force description); accreditation support services methodology. VV&A recommended practice guide will be published.	Conceptual models and problem domain models visualized graphically using advanced, manipulatable 3D models; conceptual information retrieval based solely on graphical or iconic inputs. At least 50% of the major simulation program developers will have contributed to population of the CMMS. Data interchange formats incorporate emerging, complex data structures from highly derived data, and allow object-oriented data to be passed across all M&S data areas; prototypes of simulation system support tools.	CMMS will represent DoD activities, and warfighters will have worldwide access to conceptual models of DoD processes; evolutionary data interchange format products that support all data elements for the M&S community; data security; sophisticated complex data modeling techniques, tools, and structures.

Table III–5. Modeling and Simulation Technology Goals (continued)

Short Term (97–98)	Mid Term (99–01)	Long Term (02+)
	REPRESENTATION	
Initial capability to generate a 2,500-km^2 M&S terrain database within 72 hours to meet identified crisis mission rehearsal requirements; enhanced weapon system effects representations; tools and technical methods to acquire and represent the effects of human performance.	Full capability to generate a 2,500-km^2 M&S integrated consistent terrain, oceans, atmosphere, and space database within 72 hours from multiple sources at multiple resolutions; representation of human C^2 decisionmaking process to company and battalion surrogates.	Tools for dynamic, scaleable (micro to macro) adjustment to representations within and among simulations that run in real time; interface specifications for seamless, consistent, synthetic environments; libraries of entity models; effectively represent the human C^2 decisionmaking process for brigade, division, and corps surrogates.
	INTERFACES	
Leverage COMPASS to develop and demonstrate an HLA-compliant prototype Modular Reconfigurable C^4I Interface (MRCI) initially for a limited number of C^4 systems. Subsequent MRCI development will support larger numbers of C^4 and Intelligence systems including JSIMS, and GCCS.	Build on the success of MRCI development for C^4I systems to develop reconfigurable interfaces for design and manufacturing systems. Reduce operator training time by 75% through improved interfaces to CFORs and by CGF-to-C^4ISR system interfaces. Multiplexed tactical datalink to simulations.	Provide reconfigurable simulation interfaces to humans. Full C^4I to simulation linkages to support mission planning and rehearsal in the battle area.
	INDIVIDUAL COMBATANT AND SMALL-UNIT OPERATIONS SIMULATIONS	
Technical requirements for human-simulation interfaces across DoD. Define a multisensory, real-time networked simulation of the battlefield that immerses the individual combatant in 3D geographical space using virtual reality technologies.	First-generation prototype of dismounted warrior immersion in synthetic environment. Develop a robust individual and small-unit synthetic force capable of representing doctrinally correct Army and USMC behaviors from individual to battalion level across diverse terrains. Develop field instrumentation for the individual soldier that enables entity state, position location, and weapon employment information to be seamlessly transmitted and collected across diverse terrains.	Full immersion of all live players into virtual world. Demonstrate linkages between virtual, constructive, and live instrumented simulations to enable individuals to participate in distributed combined arms exercises and experiments. Modify and expand the simulation systems to reduce the time and cost for advanced concepts and prototyping of new soldier systems by 25%. Reduce the cost of training individual and small units by 30%.

3.2.2.2 Major Technical Challenges. For interconnection, the major technical challenges include (1) establishing architectural design, protocols and standards, and multilevel security (MLS), (2) providing the maximum possible interoperability among simulations at different levels of resolution, and (3) establishing application gateways, time-management services, servers, and translators that will provide common services to all simulations. The ability of emerging commercial network services and products to meet critical M&S needs must be examined.

Developing coherent, complete, and consistent Conceptual Models of the Mission Space (CMMS) is also a difficult task. CMMS is an abstraction of a joint mission-essential task list that serves as a frame of reference for M&S development by capturing the features of entities

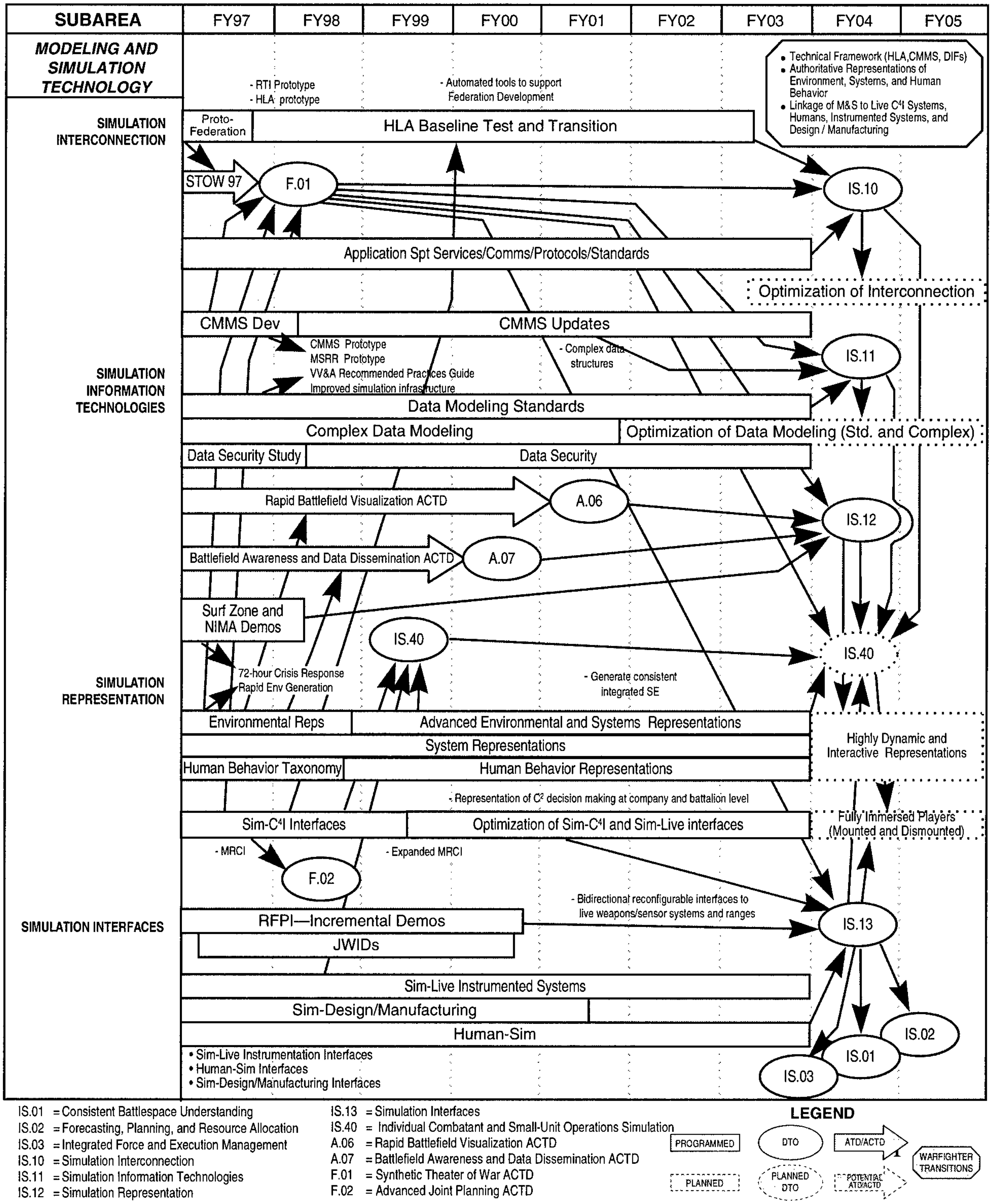


Figure III–9. Modeling and Simulation Roadmap

involved in any mission and their key actions and interactions. DoD M&S spans a wide range of missions (from unconventional to other-than-war missions) and M&S applications (from system acquisition activities to mission planning and rehearsal). The need for valid quantitative assessments of effectiveness and performance will lead to the collection of classified data. The distributed and interactive nature of advanced M&S capability make the standardization and securing of data an extremely complex technical concern.

Representations of terrain, the ocean, the atmosphere, and space must span large and diverse regions and must account for a large number of significant conditions and effects. Major challenges include the rapid generation and near-real-time interaction of these representations. New object-oriented, multispectral representations of synthetic environments are needed to enhance M&S support to battlefield awareness systems. The representation of human behavior must reflect human capabilities, cognitive processes, limitations, and conditions that influence behavior (e.g., morale, stress, fatigue). Providing variable human behavior for friendly, enemy, and nonhostile personnel remains a significant challenge.

Interfaces between live systems and synthetic environments must overcome two problems: (1) the interfaces between live systems and synthetic environments must be responsive and complete, and (2) representations of live systems in synthetic environments and synthetic forces in live systems are needed to provide a consistent and coherent exercise at different levels of resolution. A key challenge for supporting training while on the move (OTM) is providing responsive interfaces to synthetic environments for personnel using real C^4I systems. An OTM distributed M&S capability for training is challenged by the bandwidth capability available from tactical communications systems.

Individual combatant and small-unit operations simulations require:

- Human representation and visualization of individuals and weapon states.
- Human performance modeling.
- Human system interfaces that are unencumbered and elicit realistic perfomance.
- Networked simulations for interoperability with other dissimilar simulations.
- Computer-generated forces that contain realistic individual and unit-level behaviors with C^4I representation.
- Synthetic terrain with relevant resolution/fidelity to allow operations in a tactically correct manner.
- Instrumentation for high-precision engagement simulation to allow for data capture and analysis.

3.2.2.3 Related Federal and Private Sector Efforts. DoD leads the M&S community in facilitating the interoperability of models and simulations among themselves and real-world C^4I systems. DoD also provides the most authoritative representations of the natural environment and systems. Other government agencies (Department of Transportation, Federal Aviation Administration, National Highway Traffic Safety Agency, Department of Justice, Federal Emergency Management Agency, and related state and local governments) use distributed M&S

to accomplish their missions and participate in the development of M&S standards. Both DoD and the commercial sector are heavily involved in efforts to standardize M&S information. DoD has the lead in the development of CMMS, the management of complex data, and the development of simulations for analysis and assessment. The National Center for Atmospheric Research (NCAR) develops representations of weather. The private sector is addressing the modeling and simulation of individual and group behavior in terms of market research efforts and in evaluating combined human and system performance (e.g., automotive sector). DoD, other government agencies, and the commercial sector are all heavily involved in M&S interfaces (e.g., DoD training systems, commercial entertainment interfaces, commercial design and manufacturing interfaces). DoD is leveraging industry's advances in visual displays, graphics quality, and application of M&S in the design and manufacturing process.

3.2.3 *S&T Investment Strategy*

3.2.3.1 Technology Demonstrations. M&S is used as a tool in all of the DoD technology areas to support conceptual analysis, technology development, acquisition, testing, fielding, sustainment, operational effectiveness, training, and planned product improvement. Therefore, it is demonstrated in concert with most current DoD technology developments. Although all services and agencies are developing M&S applications, most of these enabling technology development efforts are funded by DMSO, DARPA, DSWA, and the Army. Demonstrations of M&S are oriented toward showing advances in the application of M&S as a tool. Demonstrations are grouped according to the M&S DTOs.

Simulation Interconnection Demonstrations. A complex of programs was selected as candidate "proto-federations" for the purposes of developing and demonstrating a high-level architecture (HLA) prototype. These programs are grouped in the proto-federation based on a combination of technical issues being addressed, characteristics of the member programs, and common mission interests. The initial groupings are shown in Table III–6. The STOW 97 ACTD will be the first DoD program to be totally committed to demonstrating the DoD M&S HLA as its architecture.

Table III–6. Initial Proto-Federation Groupings

Proto-Federation	Member Programs
Platform Federation	BFTT, JTCTS, BDS-D, STOW, CCTT
Joint Training Federation	Eagle, JSIMS, NASM, NSS, DEEM
Analysis Federation	JWARS
Engineering Federation	JMASS, T&E-EW, SBD, IADS

Simulation Information Technologies Demonstrations. CMMS prototypes were completed in FY96 for use in the M&S development process. The use of CMMS prototypes will be demonstrated in STOW 97 and in the development of JSIMS and WARSIM 2000. Additionally, common data interchange formats (DIFs) and larger DoD data standardization efforts will be available to reduce the time it takes to move the data from the data producer to the data user and to enhance M&S interoperability.

Simulation Representation Demonstrations. Authoritative representations of the environment will be demonstrated in many initiatives over the next few years. A surf zone demonstration will integrate atmosphere, terrain, and ocean databases. The interferometric synthetic aperture radar (IFSAR) will demonstrate the use of high-altitude radar to acquire data to support the Digital Terrain Elevation Data (DTED) program. The National Imagery and Mapping Agency has many pilot projects to demonstrate the fusion of data from various sensors to develop high-resolution databases. The nomination and adoption of authoritative representations of systems will begin soon. Initial plans for developing human behavior representations are being coordinated with some of the nation's top behavioral scientists.

Simulation Interface Demonstrations. In FY97 an HLA-compliant prototype MRCI will be demonstrated for a limited number of C^4 systems (AFATDS, MCS, CTAPS). By FY98, MRCI will be further developed to support larger numbers of C^4I systems to include JSIMS and JMCIS (intelligence components). In FY98 the plan is to demonstrate a 100% increase in USMTF, VMF, and TACFIRE message set size accommodated within the common DIF used in general by HLA federations and in particular by the MRIC. MRCI capability and COMPASS services (collaborative session management, geo-registered overlay management, analysis, composite mission preview, and simulated mission rehearsal capabilities) will be integrated to develop a comprehensive set of modeling and simulation services within the DII COE Version 3.0. In FY99–01 MRCI will be expanded to develop bidirectional, reconfigurable interfaces to other live weapons and sensor systems and test and training ranges. In FY02 development of reconfigurable simulation interfaces will be initiated to support full immersion of humans.

The Rapid Force Projection Initiative (RFPI) ACTD uses force-on-force simulations to progressively demonstrate incremental enhancements in live-synthetic environment interfaces culminating in an integrated live-virtual demonstration in a DIS environment. Joint Warrior Interoperability Demonstration (JWID) demonstrates the use of distributed collaborative planning and M&S services over a wide range of C^4I systems from CINC/Commander, Joint Task Force (CJTF) level to unit level.

Individual Combatant and Small Unit Operations. By FY99 there will be a demonstrated capability to fully immerse the live combatant in the synthetic environment, to include control of semiautomated forces through voice and gesture recognition. By FY00 linkages will be established between virtual, constructive, and live instrumented simulations to enable individuals to participate in distributed combined arms exercises and experiments.

3.2.3.2 Enabling Technology Efforts. In addition to efforts in support of the DTOs, the Army is conducting M&S technology development efforts in areas including human immersion, live-to-virtual linkages, representations of the dynamic environments and human behavior, and interoperability/reuse of simulations. The efforts are being coordinated with appropriate M&S POCs and MSEAs. The DARPA-sponsored Defense System Internet program supports the technology development efforts identified in the Simulation Interconnection DTO.

3.2.3.3 Technology Development. M&S supports and draws on the advances in all of the IST subareas, as well as in other technology areas. Within the IST area, M&S will benefit from advanced developments in seamless communications, information management and distribution, and computing and software. M&S will not only benefit from technology developments in decision making, but M&S will be a key element in advancing the state-of-the-art in that subarea. Closely related R&D activities efforts, in other DoD technology areas, that specifically support M&S-enabling technologies include (1) the modeling of environments in Sensors, Electronics, and Battlespace Environment that supports the development of physics-based authoritative representations of terrestrial, ocean, lower atmosphere, and space/upper atmosphere environments; (2) the Human Systems technology area efforts that will complement and support the development of the human-simulation interfaces; and (3) the simulation-manufacturing interfaces being developed in the Materials/Processes technology area. The M&S development efforts that will be supported within the M&S subarea or coordinated in other technology areas include the following development efforts:

- High-level architecture
- Application support services
- Dynamic multicast grouping technologies
- Data structures, dictionaries, enumerations, and interchange formats
- Simulation system support tools
- Authoritative representations of the environment
- Simulation-C^4I interfaces
- Authoritative representations of human and group behavior
- Authoritative representations of systems
- Network communication services
- Protocols and standards
- Conceptual models of the mission space
- Complex data modeling techniques, tools, and formats/structures
- Simulation analysis and assessment
- Simulation-instrumented live systems interfaces
- Human-simulation interfaces (immersion technologies)
- Simulation-design and manufacturing interfaces
- Scenario generation.

3.2.3.4 Basic Research. The ongoing development of efficient mathematical algorithms is needed to enhance the performance of modeling and simulation. To enhance the ability to create, maintain, and exploit distributed simulation systems, ongoing basic research is needed in auto-code generation, real-time distributed databases, automated knowledge capture, dynamic data probes, plan representation techniques, and intelligent software agents. Behavioral science research supports the development of authoritative representations of individual and group C^2 behavior. This research is not included in current DoD cognitive and neural science research programs.

3.3 Information Management and Distribution

3.3.1 *Warfighter Needs*

The information management and distribution subarea encompasses warfighter needs and capabilities related to information warfare (IW) and information systems. IW and information systems include information, information-based processes, information systems, and computer-based systems either individually or in combination with each other. The JCS C^4I for the warrior initiative describes a global infosphere providing the right information at the right time in the right place. The key to providing this capability is a distributed information management and distribution system that forms the backbone information infrastructure of all future C^4I systems. Many capabilities (not currently available) will be an integral part of this information environment. Providing technologies that allow automated, adaptive, and robust information resource management means that we can free the warfighter from the mundane and tedious tasks required to review and distribute information. Incorporating a context-based rather than a message-based approach, information synchronization and management can be formally automated allowing warriors (especially those at the fighting echelons) to concentrate on mission execution rather than on complex computer operations. Automated collaboration of mission planning and monitoring of plan execution can continue at all levels and in real time.

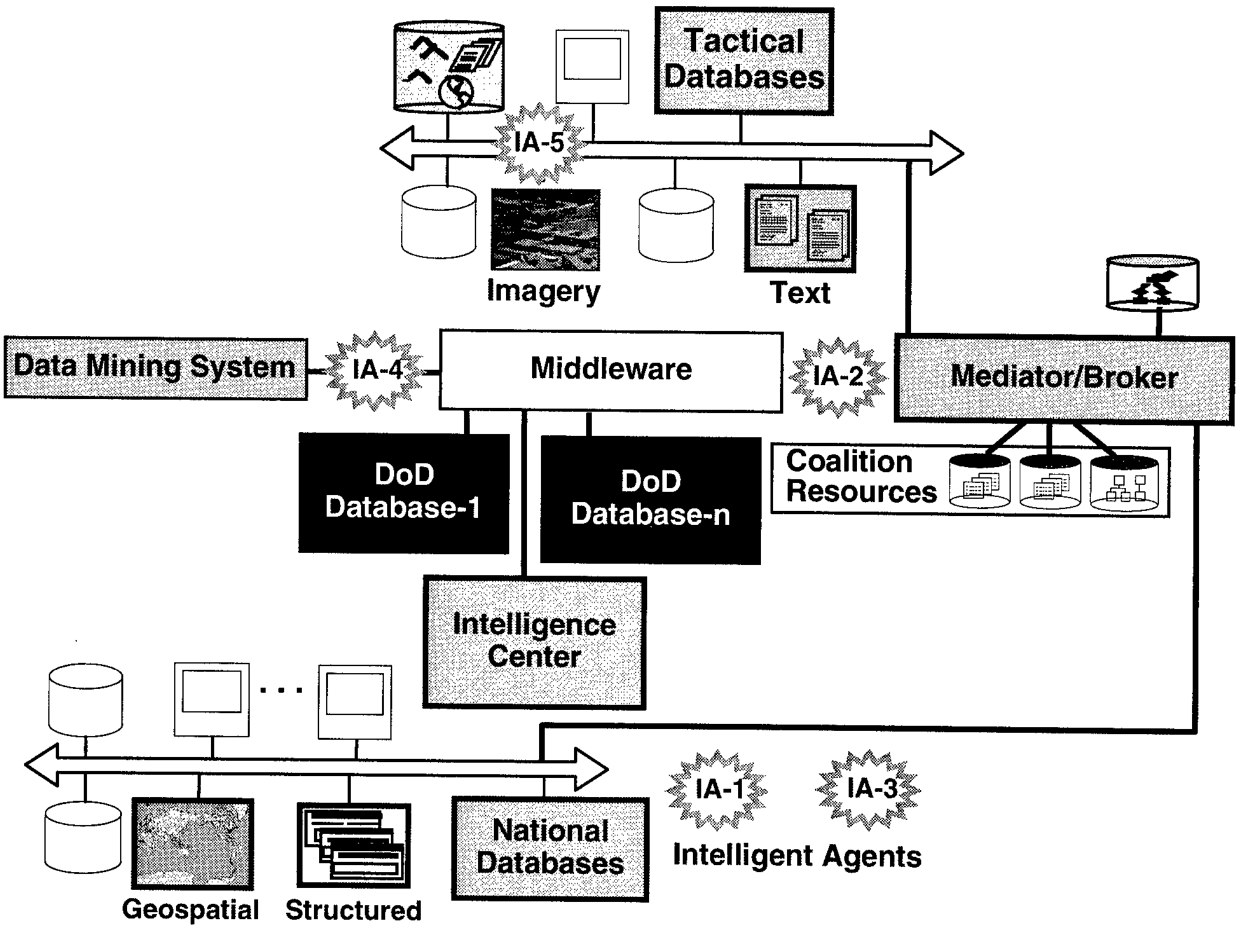


Figure III–10. Information Management and Distribution

3.3.2 *Overview*

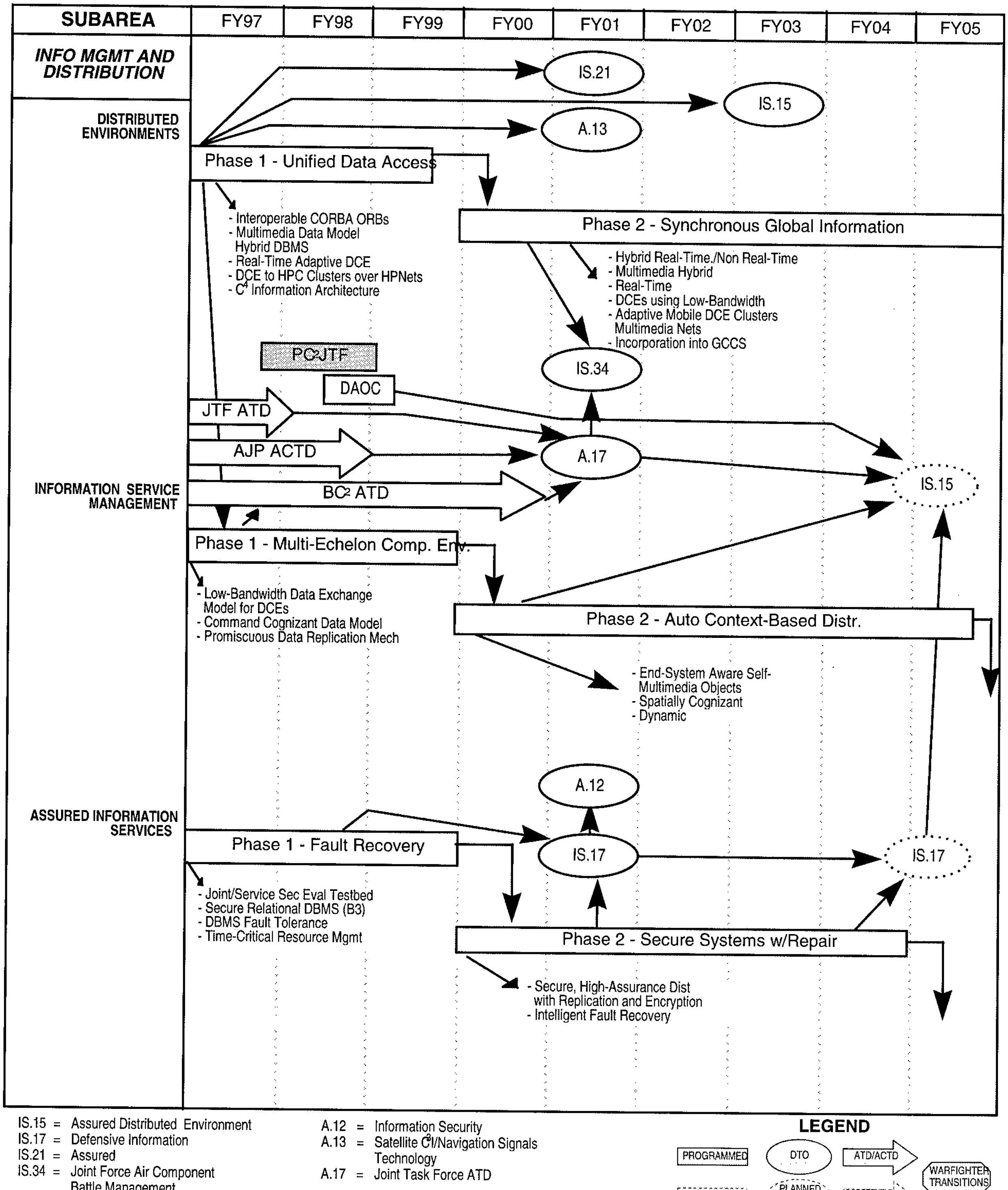
3.3.2.1 Goals and Timeframes. Development of the required warfighter capabilities for information management and distribution necessitate development in the constituent areas of distributed environments, information services management, and assured information services. These technology efforts will provide the warfighter with the ability to:

- Access mission-critical data from any location on the globe in a location transparent manner.
- Collaborate on mission plans at all levels and monitor execution in real time.
- Assess mission plans through rehearsal using synthetic environments.
- Ensure continuation of mission-critical functions and survive loss of resources by dynamically reconfiguring where functions are executed and how information flows.
- Provide reachback from deployed forces to garrison and support units.
- Support interoperability among both joint and coalition forces.
- Support extension of the information backbone to highly mobile, deployed forces through the integration of mobile distributed computing nodes.
- Maintain access control, authentication, integrity, and availability of classified data in a distributed information environment accessible by users with differing clearances and needs to know.

Table III–7 illustrates the anticipated progress. A roadmap that focuses on the linkages and key relationships associated with the corresponding DTOs is provided as Figure III–11.

Table III–7. Information Management and Distribution Goals

Short Term (97–98)	Mid Term (99–01)	Long Term (02+)
Demonstration of distributed computing environments built on an ATM backbone (>100 Mbps)	Internetted giga-operation hybrid computing clusters	Self-aware, reconfigurable, distributed computing environments of several hundred nodes
Demonstration of real-time distributed computing across homogeneous clusters	Integrated, fixed-site, mobile node, distributed, computing environment of >200 nodes	Hybrid, real-time/non-real-time, heterogeneous, global information system
Demonstration of object-based multimedia database management system supporting text, graphics, imagery, video, and audio	Uniform, global service model for open systems architectures	Intelligent agents for information location and integration
Demonstration and simulation of lower echelon initial digital information architecture	Experimentation and demonstration of command-level information management, distribution, and database capabilities	Interoperability of joint forces using common information management and distribution with capability to access, share, and protect critical information
Fault recovery mechanisms for real-time heterogeneous clusters	Fault-recovery mechanisms in hybrid real-time and non-real-time distributed computing environments	System adaptivity based on predictive mechanisms for resource allocation and fault avoidance
Dynamically reconfigurable clusters based on static performance policy	Intelligent-agent-based reconfiguration using user-definable performance policy	Self-learning adaptivity using static and dynamic optimizing policies
Secure guards, firewalls, intrusion detection systems at B3 level of trust	MLS distributed computing clusters at B3 level of trust	MLS object-oriented global information system with integrity and assured service



IS.15 = Assured Distributed Environment
IS.17 = Defensive Information
IS.21 = Assured
IS.34 = Joint Force Air Component Battle Management

A.12 = Information Security
A.13 = Satellite C3I/Navigation Signals Technology
A.17 = Joint Task Force ATD

Figure III–11. Information Management and Distribution Roadmap

3.3.2.2 Major Technical Challenges. The critical technical challenges fall into the areas associated with the infrastructure for the distributed environments, mechanisms to support information services management that reside within the distributed environment, and the ability to deploy assured information services. In the distributed environments infrastructure area, the critical technical challenges are (1) scalability to several thousand nodes and schedulability of time-critical operations that are physically dispersed across large geographic areas, (2) varied user populations and applications, (3) multiple processor types, (4) capabilities and configurations, and (5) integration of both real-time and non-real-time operating environments within the same overall system. An important issue is compatibility with emerging commercial system standards and heterogeneous computing bases while retaining DoD's desired operational capabilities. (DoD's needs are not always within commercial industry perceptions of requirements or priorities.)

To provide the necessary information services management within the distributed environment requires the development of mechanisms for managing all types of data both on individual hosts and across the distributed environment. To attain this capability, the critical technical challenges to be met include (1) developing data models and storage-and-retrieval architectures capable of handling all modalities of data in a seamless way, (2) merging and synchronizing time-dependent and non-time-dependent data, (3) developing intelligent agents capable of autonomously navigating complex database structures and extracting information for a user, (4) developing natural language and other nonparametric interfaces to support "intuitive" access and retrieval of data from the database management systems, (5) developing adaptive information distribution techniques based on context-based, as opposed to message-based, distribution, (6) using the information context for smart distribution over low-bandwidth communications in order to selectively control the quantity of information exchanged, (7) providing the capability to respond to complete information exchange failures, and (8) scaling these information distribution techniques to large systems of communications nodes.

The key to developing assured information services is adaptivity within the distributed environment to allow dynamic response to varying loads of crisis management or system failure, and protection of the information within the system from attack or compromise. The critical technical challenges include (1) security mechanisms for multiclustered, real-time heterogeneous distributed environments, (2) adaptivity mechanisms that support the selective application of fault tolerance and fault avoidance strategies, (3) reconfiguration mechanisms to support graceful degradation, (4) replication mechanisms to ensure the consistency of information, (5) intelligent resource managers to dynamically respond to crisis overloads, and (6) system architectures that permit the secure use of COTS computers, software, and networks.

3.3.2.3 Related Federal and Private Sector Efforts. In many ways, the information environments for the industrial, commercial, and financial communities mirror the military information environment. As a result, there are leveragable development activities in the commercial sector addressing many of the same technical issues as the military. Global corporations and financial institutions have the need for global data access. Their multinational status requires support for heterogeneity. Movement of global markets requires very rapid response to change and guaranteed availability. This creates the need for similar distributed information environments that provide location-transparent access to globally distributed data. Initiatives such as the Object Management Group (OMG) Common Object Request Broker

Architecture (COBRA) and the Open Software Foundation Distributed Computing Environment are providing commercial standards for distributed information environments that will guide the evolution of commercial product lines. In addition, the current strategy is to migrate the GCCS to support COBRA compliance in later releases as outlined in the GCCS Software Requirements Specification for DII COE V4. They will also have a major impact on future military systems, which will be primarily COTS based. The need to protect proprietary information and financial data demands information system security. Here the commercial sector has capitalized on DoD investment in MLS and has developed commercial products for secure operating systems, secure database management systems, intrusion detection systems, and secure system design tools. Although the commercial sector has made progress enhancing the security considerations of mainstream commercial products, a great deal more remains to be done. Several federal and private organizations are pursuing efforts for assured information services. Both the National Security Agency and the National Institute of Standards and Technology continue to be leaders in the development of information systems security mechanisms. NASA and DOE did pioneering work in the areas of fault tolerance and high-assurance systems. A number of universities under DoD, National Science Foundation, and private sponsorship have done extensive work in fault tolerance and system integrity.

3.3.3 *S&T Investment Strategy*

3.3.3.1 Technology Demonstrations.

Distributed Air Operations Center Prototype. This prototype will demonstrate the application of distributed computing and distributed database management tools and systems to operational requirements of the air operations center (AOC) that performs force-level tactical air planning. The prototype will show how the functions of the AOC can be physically dispersed over a local or wide area and still retain the integrated functionality of collocation, as well as uniform accessibility to all required databases. This demonstration contributes to the fulfillment of DTO IS.15.

Survivable Distributed Information Environment. This program will demonstrate the capability of a distributed computing system composed of internetted local clusters of computers to operate successfully under stress by gracefully degrading rather than failing. The goal is to provide a level of continuing mission support in the presence of sporadic and overlapping faults, hostile action, or anomalous behavior episodes. This capability will include dynamic repositioning of both processes and data to the remaining computational elements to provide continued mission execution. This demonstration contributes to the fulfillment of DTO IS.17.

3.3.3.2 Technology Development. In the distributed environments technology effort, development is focused on (1) real-time, heterogeneous-distributed computing environments, (2) distributed computing over high-bandwidth global grids, (3) distributed computing over low-bandwidth RF communications, (4) distributed, object-oriented, multimedia database management, (5) optimal tasking assignment to distributed resources, (6) interoperability among distributed, federated database management systems, and (7) scalability of COTS products to very large scale DoD configurations.

In the information services management area, development needs to focus on (1) adaptive resource management paradigms that allow dynamic reallocation of tasks to computing resources, (2) mechanisms to automatically control information exchange among nodes to limit the quantity of data based on the context of the application and available communications bandwidth, (3) mediators to assist in the acquisition of information from multiple sources within the distributed information environment, and (4) integration of both real-time and non-real-time control mechanisms within a single distributed environment.

In the attainment of assured information services, development is focusing on (1) extension of security mechanisms in the composeability of COTS products to meet DoD needs, (2) development of adaptive security mechanisms that accommodate resource modifications in resource sets without violating security policy, (3) adaptive fault tolerance and avoidance mechanisms, (4) intelligent agents to dynamically respond to intermittent failures by reconfiguring the computing resource set, and (5) integrity mechanisms to ensure the validity and consistency of information in the global environment.

3.3.3.3 Basic Research. Basic research is being directed at the fundamental science problems of this subarea in numerous areas:

- Intelligent agents
- Active database strategies
- Transaction-oriented protocols
- Data abstractions of military concepts
- Real-time operating system schedulers
- Object data models
- Deductive database structures
- Promiscuous data replication mechanisms
- Formal verification tools
- Fault tolerance mechanisms
- Dynamic replication mechanisms.

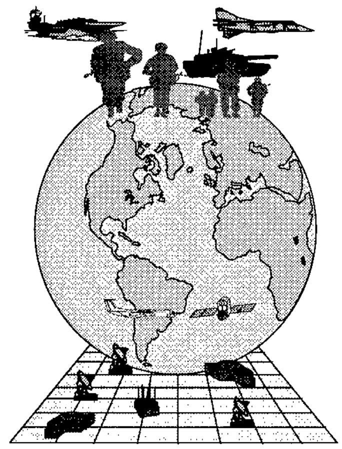
ARL has established a broad 6.1-funded federated laboratory (Fed-Lab) under the Advanced Telecommunications and Information Distribution Research Program (ATIRP). The ATIRP is being executed through a multiyear collaborative consortium among the Army, industry, and academic institutions. Two of the five ATIRP research areas directly impact the IM&D program and DTOs by exploring the areas of information distribution and defensive information warfare. Products from the ATIRP will feed into both of the IM&D DTOs. Contributing consortium members include Lockheed Sanders, Motorola, Bellcore, Massachusetts Institute of Technology, University of Maryland, and the University of Delaware.

3.4 Seamless Communications

3.4.1 *Warfighter Needs*

The seamless communications subarea facilitates several of the warfighters needs and capabilities, including Information Superiority, Joint Readiness and Logistics, Military

Operations in Urban Terrain, and virtually all other JWSTP areas. Communication is the mechanism to achieve secure, reliable, timely, survivable, command and control and superior battlefield know-ledge. This subarea addresses technologies needed by the warfighter to obtain effective access to, and utilization of, global uninterrupted communications services. Seamless communications connotes assured, user-transparent, secure connectivity between globally dispersed sanctuary locations and positions in theater—down to the lowest echelon foot soldier or marine and to each ship and aircraft. This connectivity will be accomplished using a combination of U.S. government, foreign government, commercial infrastructures, and military surface- and space-based RF networks. A range of transmission media, bandwidths, signal specifications or standards, and protocols will be accommodated automatically by the networks. Voice and all types of data (e.g., text, graphics, imagery, video) will be handled within a uniform, information transport infrastructure. These technologies will provide the commander with high-capacity, flexible, tactical communications to serve all categories of users (including mobile) and satisfy the need for high-confidence communications with anyone regardless of system limitations throughout all phases of the battle.



- Easily Deployable, Scaleable Plug and Play Architecture
- Management & Protection of Services
- High-Rate Broadcast
- Services Extend Fully to Mobile Users
- Flexibility to Form Tactical Action Teams to Fit the Situation
- Full Leveraging of Distributed Staffs and Information, Anywhere in Global Infrastructure

Figure III–12. Seamless Communications Technology

3.4.2 *Overview*

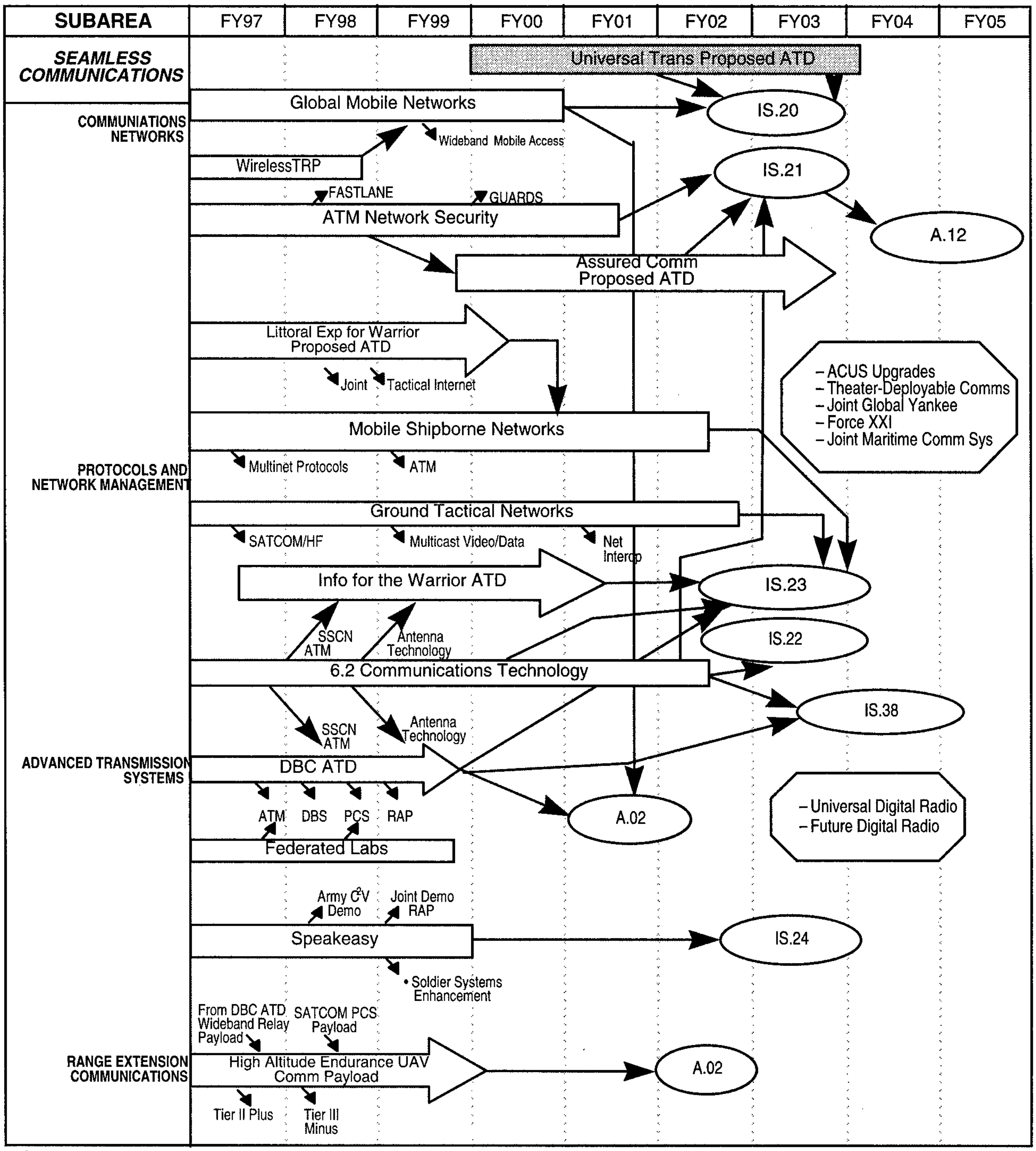
3.4.2.1 Goals and Timeframes. The goal of the seamless communications subarea is an affordable, survivable, self-managing, MLS communications system that provides the warfighter with user-transparent connectivity for voice and C^2I systems data over the entire combat/garrison operational continuum. The warfighter must have the confidence and ability to communicate to whomever and wherever needed throughout the phases of the battle, with no attention to different operational levels of security. The system must fully support wideband and narrowband OTM C^2I data/voice interconnections throughout a land battle zone at least 100 km deep and provide robust and seamless connectivity between ground, air, and naval elements of the coalition combat force dispersed over distances up to 200 km. Achieving this goal will require significant enhancement of tactical communications systems; development of automated, seamless, interfaces between tactical systems and between tactical and global communications systems; development of sophisticated new radio and antenna systems for the airborne and ground OTM portion of the warfighting force; the evolution of theater/global broadcast systems as an integral element of seamless communications; and the development of artificial intelligence tools for network planning, engineering, management, and operations. General, time-phased goals that represent the collective effort for seamless communications are provided in Table III–8. A roadmap that focuses on the linkages and key relationships associated with the corresponding DTOs is provided as Figure III–13.

Table III–8. Seamless Communications Goals

Short Term (97–98)	Mid Term (99–01)	Long Term (02+)
Integrated, low-rate voice, data, and video; independent wideband voice and data services	Low-rate interactive applications over tactical Internet, extensive TCP/UDP/IP, 10% ATM utilization	Collaborative, wideband multimedia applications over tactical communications, megabits to the warfighter, more than 50 percent ATM utilization
Separate circuit-/packet-/message-switched networks, tactical Internet with IP	Integrated message and data networks; mobile multicast IP-fielded, wireless ATM	Tactical narrowband and broadband ISDNs
2-Mbps LOS trunk radios	45-Mbps LOS trunk radios, stationary operation	155-Mbps trunks OTM
2.4-kbps UHF SATCOM, 16-kbps SHF DSCS; no DBS	23-Mbps GBS, high-data-rate spot-beam coverage	GBS constellation, high-data-rate spot-beam and medium-data-rate global coverage
Single-channel radios with limited programmability	Programmable, simultaneous RF interoperability, bridging four bands, many waveforms	Smart radio functions, autoselection of bands, waveforms, jam resistance, LPI/D, EMI/RFI management
Limited network management capability; lack of environmental effects prediction for C^3 disruption or distortions	Semiautonomous network management with commercial interworking	Self-healing networks with seamless, commercial interworking

3.4.2.2 Major Technical Challenges. Major technical challenges in this subarea include:

- Communications equipment interoperability in multivendor, multinetwork, joint/combined force, and commercial environments.
- Framing protocol for tactical asynchronous transfer mode (ATM) links.
- Protocols for high-data-rate subscriber loops subject to sporadic disturbances (i.e., Narrowband Integrated Services Digital Network (N–ISDN) and Broadband ISDN (B–ISDN) loops supporting OTM airborne/surface/subsurface vehicles).
- Forward error correction for tactical ATM.
- Building a fully Internet-compliant, tactical packet network using legacy radios such as Single-Channel Ground and Airborne Radio System (SINCGARS).
- Integration of data and voice over low-bit-rate links.
- Heavy multipath and deep fade effects.
- Security.
- Development of network management and control protocols that can withstand the onset of federated and nonfederated jamming attacks.
- Increases in transmit efficiency and jam resistance.
- Development of conformal arrays for airborne and OTM antenna applications.



IS.20 Universal Transaction Communications
IS.21 Assured Communications
IS.22 Network Management
IS.23 Digital Warfighting Communications
IS.24 Multimode, Multiband Information System
IS.38 Antenna Technologies

A.02 Robust Tactical/Mobile Networking
A.11 Counter Camouflage Concelment and Deception ATD
A.12 Information Security ATD

LEGEND

PROGRAMMED, DTO, ATD/ACTD, WARFIGHTER TRANSITIONS, PLANNED, PLANNED DTO, POTENTIAL ATD/ACTD

Figure III–13. Seamless Communications Roadmap

3.4.2.3 Related Federal and Private Sector Efforts. Extensive research that supports the goals of this subarea is being conducted by the telecommunications industry. The military is leveraging literally billions of dollars of commercial investments in achieving its objectives by active participation in standards bodies, promotion of commercial development, and appropriate DoD-specific research.

3.4.3 *S&T Investment Strategy*

3.4.3.1 Technology Demonstrations.

Digital Battlefield Communications ATD (Army). The DBC ATD will exploit emerging commercial communications technologies to support multimedia communications in the highly mobile dynamic battlefield environment. These applications will require advances in communications bandwidth and extensions in "untethered" technology to provide the global reach expected by the warfighter of the 21st century. These will leverage services introduced to the commercial world and will supplement some and replace other legacy communications systems. The replaced legacy systems are those unable to keep pace with the military's rapidly increasing demand for communications capacity and global reach in support of split-based operations on a worldwide scale.

The Army will evolve an integrated communications infrastructure that uses commercial standards and protocols to achieve seamless global interoperability. This ATD, begun in 1995, introduced a wideband packet radio called the Surrogate Digital Radio. This radio was procured to add additional capacity to the Tactical Internet in TFXXI. Commercial ATM technology will be integrated into Area Common User Systems (ACUS) such as the Army's Mobile Subscriber Equipment (MSE) to provide "bandwidth on demand" to support multimedia information requirements of the 2d Armored Division in preparation for thorough warfighter evaluation in TFXXI. Continued laboratory experimentation by the services will be supported using DISN LES interconnections. The ATD will research DBS technology through a series of coordinated experiments intended to develop a GBS capability for the services. Through cooperation with the other service laboratories and with DARPA's BADD ACTD, Tri-Service experiments with GBS are planned for TFXXI and other joint exercises. Leveraging supporting 6.2 technology base efforts in the services, low-profile SATCOM antenna technology for military UHF, SHF, and commercial (C, Ku, X) SATCOM bands will be evaluated in OTM applications using various tactical platforms. MLS requirements will be met by the Tactical End-to-End Encryption Device (TEED). Commercial surface-based and satellite-based PCS technology will also be demonstrated in TFXXI to support the need for wireless access to the ACUS.

In order to extend ATM multimedia services to forward tactical units, a radio access point (RAP) will be prototyped and tested. The RAP uses a high-capacity trunk radio (HCTR) to provide OTM communications through a wideband airborne relay communications package to the ATM-enabled ACUS. These airborne relay packages will be developed and tested through a coordinated tri-service effort and will be coordinated with the DARO and DARPA for platform availability. The airborne relay package and the HCTR will be tested initially at a bandwidth of 45 Mbps and then at 155 Mbps OTM and 600 Mbps for stationary use. These bandwidths are required to support ATM trunks designed for multimedia tactical battle management systems and their embedded M&S components. In its post-ATD form, each airborne relay is required to support primary and hot backup links to multiple OTM RAPs. Applicable technologies identified through the commercial communications technology program and through the Army battlelabs' ACT II program will be inserted where appropriate into this ATD. The ATD will conclude in FY99 by supporting the Corps XXI advanced warfighter experiments (AWEs).

Information for the Warrior ATD (Air Force). This ATD's objective is to demonstrate multimedia C^2 information reachback from a deployed force to the National Command Authorities and stay-behind resources using a high-performance, multinational civil infrastructure. DoD and the allied ministries of defense have concluded that extremely wide bandwidth communications needed to support the next-generation mission planning and execution functions cannot be attained without reliance on the rapidly emerging global commercial infrastructure that includes undersea and land-based fiber optic cables and SATCOM communications. This specific demonstration will provide in-transit visibility for deployed Air Mobility Command aircraft to the Tanker-Airlift Control Center through this infrastructure. This requires (1) the integration of Air Force legacy RF transmission equipment, (2) the rapid integration of the DoD's communications network management and control functions into the civil infrastructure to produce a virtual private military network, (3) the ability to interact cooperatively with participating allied coalition nations using this infrastructure at ATM rates, and (4) development of a process whereby DoD can rapidly tap into prepositioned entry points in the commercial infrastructure to extend connectivity hundreds of miles into an area of conflict or crisis. The goal of this demonstration is to provide the capability to use, monitor, and manage assets across all these dissimilar networks and maintain interoperability within a deployed JTF. This effort will develop and demonstrate control algorithms to maintain connectivity within a dynamic deployed environment under wartime stress.

Secure Survivable Communications Network Phase II. This phase of the SSCN program will integrate commercial ATM switching technologies into the surface, tactical wideband communication networks to support the multimedia information needs of deployed elements of the Air Combat Command such as the AOC. A fieldable package will be developed to investigate and resolve the technical issues associated with integrating ATM into the typical environment of tactical transmission systems. The driving motivation is to eliminate the duplication in current network deployments and improve the warfighters' capability to easily manage the scarce bandwidth.

Speakeasy. Speakeasy is a joint service R&D program sponsored by the Air Force Rome Laboratory (RL), CECOM, and DARPA. Speakeasy is planned to be the services' next generation tactical radio. More than "just a radio," Speakeasy will be a Modular, Multifunction Information Transfer System (MMITS) with application outside the DoD and military. Speakeasy will offer federal and civil agencies the opportunity to gain wide interoperability, flexibility through reprogrammability, and economical advantage through a system wherein vendors of various products compete at the module level to provide required capability. Speakeasy is an attempt to create the "PC" of the radio world. The MMITS PC/workstation holds potential for many vendors, not just *radio* manufacturers. Memory, signal processing, software, test and instrumentation, routing/networking, media processing, I/O interfaces, vocoders, programmable filters, encoding/decoding, RF engineering, and many other technical disciplines have a part to play in such an information transfer system.

The Speakeasy Phase II (6.3a) R&D program is developing the architecture for a six-channel (four programmable channels, one GPS receive-only channel, one commercial cellular phone channel) multiband, multimode radio. It will result in six ADMs available in late FY99. These Speakeasy ADMs are being designed with a peripheral component interface (PCI) bus backplane and using Personal Computer Memory Card International Association (PCMCIA) format modules. The Speakeasy program employs a model-year build-and-test strategy that will provide prototypes with increasing capability starting with a year-one model in late 1996, followed by a model in late FY97, and another in late FY98. The final model will be available at the completion of the contract in FY99. Using this strategy, the Speakeasy program hopes for feedback from users to ensure that the final units available in late FY99 are nearly production ready. The final units are expected to be approximately 0.4 ft^3 in size, weigh 30 pounds or less, draw no more than 60 watts, and be capable of being ruggedized for use in most military applications.

The Speakeasy radios will be capable of simultaneously operating over four channels, in bands anywhere in the continuous 2-MHz to 2-GHz range, employing waveforms that can be either instantly selected from memory or downloaded from floppy disk as needed, or reprogrammed over the air. The reprogrammable nature of Speakeasy will allow users to load any legacy or future waveform software. The following waveforms are being implemented: HF; HF modem; SINCGARS; HQ I&II; UHF SATCOM (and Demand Assignment Multiple Access (DAMA)); commercial (AMPS) cellular telephone (not part of the four programmable channels); air traffic control and civil aviation waveforms (VHF bands); a ~2-Mbps wireless packet waveform; GPS-receive capability (not part of the four programmable channels); an LPI/D waveform; and the Enhanced Position Location Reporting System (EPLRS) waveforms.

Technology Reinvestment Project. Under the DARPA TRP (dual-use applications), six projects have been initiated in the area of digital wireless communications and networking systems: Advanced Communications Engine; Defense Applications for a Multiple Path Beyond Line-of-Sight Communications Network; Digital Wireless Communications and Networking Systems Program; High-Speed Digital Wireless Battlefield Network; Miniature Filters for Wireless Networks; and a government/industry Digital Wireless Testbed. These projects directly complement efforts on going in the services and are being executed by service laboratories and centers.

Global Mobile Information Systems. DARPA initiated the GloMo program in 1995 to develop and demonstrate technologies that address the continuing advances in high-speed communication, signal processing, and miniaturization. These technologies open new opportunities for advancing the state of the art in mobile, wireless, multimedia information systems. The program supports a number of projects at various organizations ranging from concept development to prototype demonstration. The program results will be integrated into ongoing development programs in the services.

3.4.3.2 Technology Development. The services are jointly developing feeder technology to enable the conduct of 6.3A technology demonstrations and the ATDs discussed above. The design of new waveforms is being pursued to provide LPI capabilities for both surface and airborne applications. A joint program is developing HCTR technology for wide-bandwidth point-to-point and OTM operations. To support a worldwide reachback capability for a deployed joint force, the services are developing small, rapidly deployable SATCOM ground station technology, data compression techniques, techniques for ensuring seamless connectivity by incorporating commercial standards such as ATM, and when necessary, common standards such as DAMA.

To enable rapid information access by OTM surface, subsurface, and airborne vehicles, all services are working jointly in the area of optical phased array antennas for SATCOM and air-to-surface use. Army, Navy, and Air Force 6.2 project lines are integrating and evaluating commercial high-speed network technology and protocols such as synchronous optical network (SONET), IPng, and ATM for performance in tactical applications. The overriding goal is the seamless interconnection of heterogeneous tactical communications systems utilizing, to the maximum extent possible, commercial communications standards and protocols. A driving motivation is to provide the deployed forces with the same communication services that they used as part of their training in garrison. Participation in various commercial and industrial forums ensures current knowledge and immersion of military laboratory personnel in emerging commercial market standards and maximizes the chances to influence the development path of commercial products. Tactical multinet gateways to be fielded by the Army in TFXXI evolved by modification and enhancement of COTS routing products, allowing ATM- and non-ATM-based networks to seamlessly exchange multimedia applications data. Hierarchical video routing will be investigated to automatically route limited resolution battlefield imagery to users with constrained bandwidth while, at the same time, allowing users with adequate bandwidth full-resolution video services.

A long-term focus of the technology base will be to provide dynamic and fault tolerant protocol functionality to enhance battlefield survivability and improve operations OTM. Dynamic network reconfiguration without user intervention will be required at all levels. Broadcast services over ATM, hierarchical video routing, and mobile, multicast IPs will be developed for integration into the Army's DBC ATD, the Navy's Tactical Internetworking Joint ATD for Littoral and Expeditionary Warfare, and the Air Force's Information for the Warrior Program. In later years, protocol enhancements for large networks will be evaluated for application to the next-generation joint military communications architecture. Lastly, all services are actively participating in the DISA/DARPA joint program initiative called the LES that provides wideband connectivity among all participants. All services will shortly be interconnected via the LES infrastructure and will be able to conduct joint experiments and share developments in a way never before possible.

3.4.3.3 Basic Research. The services support a broad spectrum of basic research topics in the seamless communications subarea including:

- Network-based simulation
- LPI/D waveform design
- Quality-of-service-based protocols for mobile environments
- Multitiered network structures
- Dynamically adapting protocols
- Multidimensional routing functions
- Metrics for network assessment and evaluation.

ARL, in coordination with CECOM and as part of the IST subpanel, has initiated a broad 6.1-funded research program to explore technical solutions in the areas of wireless digital battlefield communications, tactical and strategic interoperability, and information distribution for multimedia services. This program, known as the federated laboratories, is being executed through a multiyear collaborative partnership among the Army, academic institutions, and industry. These efforts directly complement, and in many cases feed, the DBC ATD and the Tactical Interworking ATD.

3.5 Computing and Software Technology

3.5.1 *Warfighter Needs*

Computing and software technologies (as is the case with M&S) are crucial to all joint warfighting needs and capabilities. In the information age, warfighting is adversely affected or significantly enhanced by the speed, accuracy, quality, relevance, and comprehensiveness of information provided for applications such as C^4I, precision weapons, logistics support, and readiness support. In such applications, a few well-trained humans, augmented or assisted by high-performance, automated, and intelligent systems, can outperform dozens, hundreds, and sometimes thousands of semiautomated or poorly automated personnel. The computing and software foundations developed by this subarea provide the advantage in any conflict or operation permitting early, decisive victory or rapid noncombat response in operations other than war with minimal cost in assets and human life. Advancements in software and software development productivity support both the capability and the affordability of new and upgraded defense systems. Computing and software technologies such as software engineering, software reengineering, software reuse, and software acquisition strategy will have enormous impact on future weapon systems, weapon system upgrades, product improvements, and system performance advancements. Pervasive throughout all technology areas, and as important, are embedded high-performance computing, embedded software and system engineering, distributed and interacting systems, knowledge-base design, advanced hardware/software system architecture technology, information presentation and interaction, and intelligent information technology.

3.5.2 *Overview*

3.5.2.1 Goals and Timeframes. Four related but distinct technical aspects make up the computing and software technology subarea:

- Information presentation and interaction
- Machine intelligence
- Computing systems
- System design and evolution.

Specific computing and software goals and timeframes are shown in Table III–9. A roadmap that focuses on the linkages and key relationships associated with the corresponding DTOs is provided as Figure III–15.

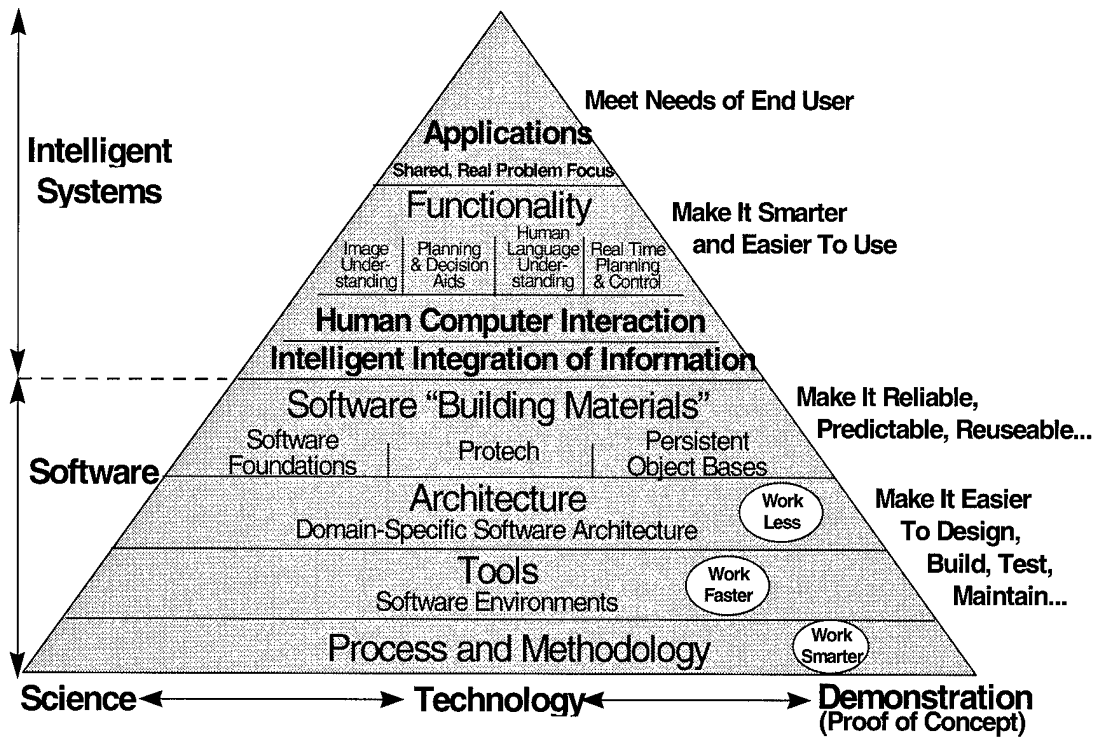


Figure III–14. Computing and Software Technology

3.5.2.2 Major Technical Challenges.

Information Presentation and Interaction. Humans perform best when they are presented with all the relevant information when they need it, as they need it, where they need it, with no extraneous or conflicting information. Such a presentation of information should also be in chunks that a human can handle, and in a highly comprehensible form. This is a tall order with currently available technologies. The overall goal of the proposed DTOs is to allow humans in the loop to exploit all information without reaching "information overload" and respond in a timely manner. The approach is to make maximum effective use of all the human senses and intellect to perform this task in as natural appearing an environment as possible.

One technical challenge is to build and incorporate affordable, high-resolution, large 3D and time-resolved displays into systems to depict an accurate picture of the situation to the visual senses and further enhance those system interfaces with natural language and gesture I/O. A second technical challenge is to provide a truly interactive VR depiction of the situation with human "immersion." The situation depiction will then be further enhanced by removing artificial tethers such as helmet-mounted displays and data gloves, providing real-time updates to the depiction, and allowing the immersion of multiple humans at the same time. Some visualization aids rely on sensing the location and orientation of the participants. Participant location and orientation are used to adjust the presented visual scenes. Yet another problem is that inaccurate or delayed tracking can induce virtual reality sickness (akin to motion sickness). Therefore, a third challenge is improvements in measurement resolution, accuracy, and responsiveness needed to promote improvements in aids to visualization.

Table III–9. Computing and Software Technology Goals

Short Term (97–98)	Mid Term (99–01)	Long Term (02+)
INFORMATION PRESENTATION AND INTERACTION		
Heavily tethered, helmet-mounted 3D displays	Single-user immersible VR with precalculated displays, tether-free 3D displays	Multiple-user immersible VR, real-time displays
Limited (10,000-word), speaker-dependent vocabularies	Medium (50,000-word), speaker-independent vocabularies	Large, speaker-independent vocabularies
Single-user, single-discipline collaboration	Multiple-user, single-discipline collaboration	Multiple-user, multiple-discipline collaboration
MACHINE INTELLIGENCE		
Real-time planning for intelligent devices	Real-time adaptation of intelligent devices to changing situations	Plan creation and execution among cooperating intelligent robots
Autonomous devices operating independently on single tasks	Team tactics demonstrated for autonomous multiagent behavior	Self-initiated plan creation and execution among cooperating intelligent robots
Unintegrated and unfiltered data searches in cyberspace	Filtered information searches by multiple intelligent agents in cyberspace for very large data sources	Filtered and integrated responses to information queries in cyberspace for very large data sources
COMPUTING SYSTEMS		
100 GFLOP/ft^3 for militarized HPC	500 GFLOP/ft^3	TFLOP/ft^3
10–20% efficiency on MPP	50% overall efficiency on MPP	
Max 300 GFLOPs sustained	Scaleable designs to 10 TFLOPs	Scaleable designs to 100 TFLOPs
Baseline performance on ATR	10x baseline on ATR	
SYSTEM DESIGN AND EVOLUTION		
Cost, quality, and performance certification/assurance process for COTS or other reusable components	Minimum testing; hybrid approach to high-assurance states; predictable behavior	Continuous monitor performance/behavior; analysis and monitoring of assurance; cost of recertification proportional to system change
Real-time capability for dynamic languages	Cohesive dynamic language environment for application evolution	Life-cycle application of dynamic language technology
Minimal software design rationale capture across life cycle	Infrastructure for effective software life-cycle information capture and management	Reuse of design; transparent heterogeneous geographically distributed software life-cycle information access
Common architecture description language	Domain-specific development through specification process only	Generation of systems using behavior and architecture specifications; reuse of architecture components
Developed component by component with extensive use of COTS/GOTS	Domain-specific development through specification process only	Warfighter-modifiable systems in place

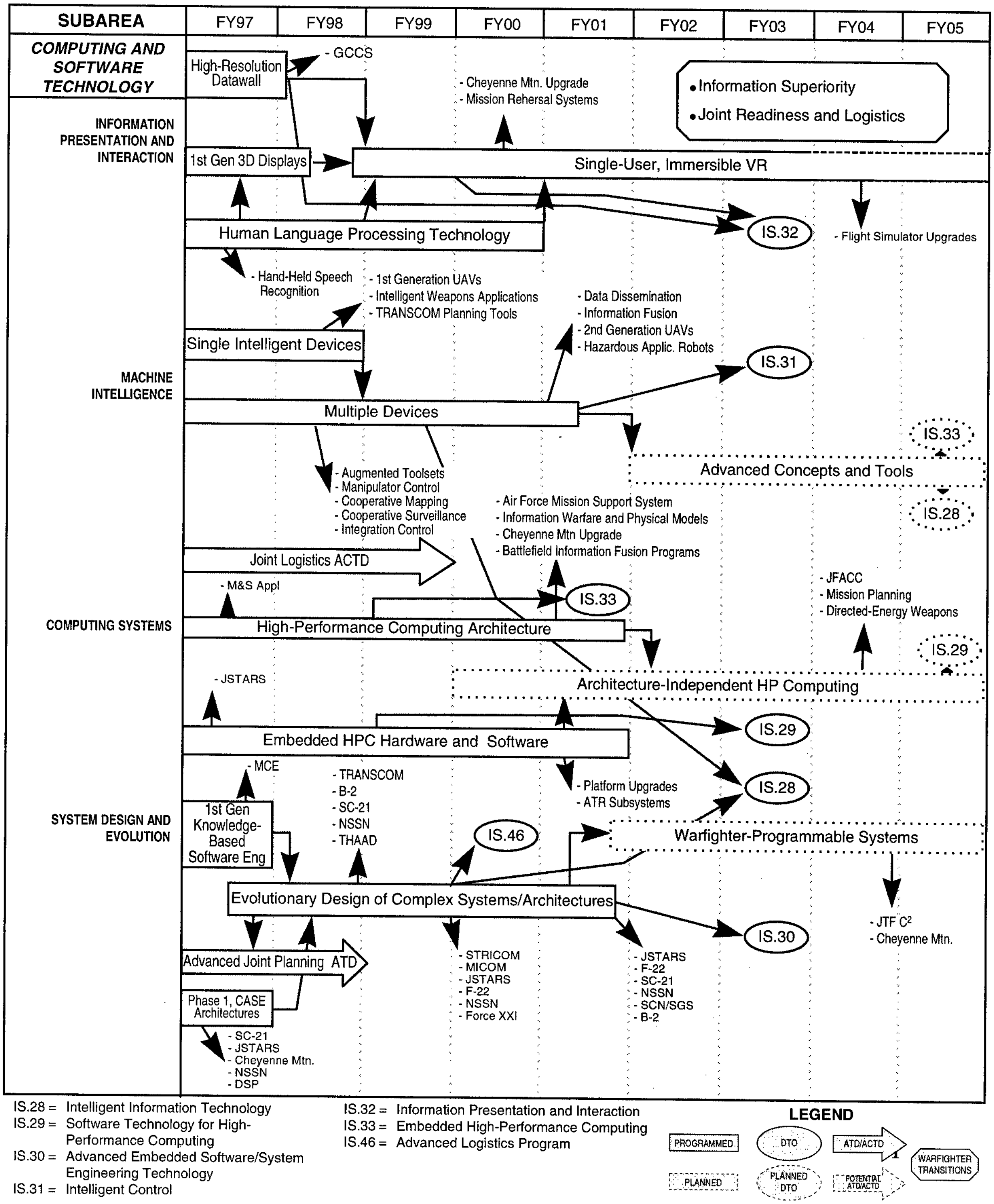


Figure III–15. Computing and Software Technology Roadmap

Machine Intelligence. In a complex warfighting environment, humans can possess and comprehend only a limited proportion of the existing knowledge at any time. So the trend is to embed intelligence into a variety of systems so that they do not place demands on the human operators, but actually assist them. The overall goal is to develop intelligent information system technology to enable a new level of capability to semantically search, group, monitor and update large collections of heterogeneous knowledge bases, provide techniques for automated reasoning to advance the capabilities of single and multiple autonomous robotic systems, and provide intelligent aids to human decisionmaking. Deep challenges remain in integrating reactive and reflective planning; achieving control in unstructured, real-time environments; automating cooperation among multiple intelligent systems; reorganizing very large knowledge bases using simulated devices and environments to debug and optimize complex control software; and exploiting varieties of machine learning methods in conjunction with those simulations. Meeting these challenges contributes to the ability for autonomous and semiautonomous vehicles and weapons platforms to operate undersea, over the sea, on the ground, or in the air, as well as allowing intelligent software agents to conduct efficient information searches in cyberspace and to better aid in decision making.

Computing Systems. For the technologies involved with computing systems, the overall goals are to overcome the inevitable (and already present in some applications) limitations in computational throughput and the cost, power, size, and weight requirements for single or small numbers of networked computers. These requirements and limitations impact weapon systems, simulators, and engineering support systems. The technical challenges are to cut the costs and size of giga- and tera-floating point operation (FLOP) computers so that they fit into a weapons package, to make efficient use of parallel and massively parallel computing assets, and to design systems that will allow easier and low-cost transition to the future commercial advancements in both hardware and software to achieve truly architecture-independent, high-performance computing.

System Design and Evolution. With the explosive growth of new knowledge in almost all disciplines, new system designs are the order of the times in order to avoid technical obsolescence. This situation presents enormous challenges in the area of system design and evolution. The overall goal of this technology area is to reduce the time and cost of building, deploying, and evolving software-intensive systems while increasing the overall quality in terms such as residual errors, reusability, and integrity. A subgoal is to allow the warfighter to program the system needed for the specific battle environment. The technical challenges are to develop or automate techniques (1) for forward system engineering approaches and provide tools that have a systematic, holistic approach to design and information management across the system life cycle; and (2) for the activities associated with the reengineering and reverse engineering of legacy systems for modernization or reuse.

3.5.2.3 Related Federal and Private Sector Efforts. For information presentation and interaction, major related efforts include NASA work on human-computer interfaces for the Space Shuttle, the proposed NASA Space Station, and ground control workstations and private sector applications in the business domain. Private sector participants include Apple Corporation, Microsoft Corporation, Sun Microsystems, IBM, Xerox PARC, and AT&T Corporation. Universities having substantial research efforts in this area, funded through domestic and international customers, include Carnegie Mellon University, Stanford University, the University of Southern California, Georgia Institute of Technology, Massachusetts Institute of Technology, Virginia Polytechnic Institute, and the University of Arizona. The university focus is almost solely on commercial applications of novel interface technologies, virtual reality, and intelligent user interfaces.

Machine intelligence R&D, while getting the majority of its funding from DoD, is augmented with programs from NASA, dealing with expert systems and intelligent controls; DOT, dealing with applications on land (intelligent highways) and air traffic control; and DOE, concentrating on control of industrial processes. The NSF supports a broad program of basic research in robotics and intelligent systems. In addition, there are a significant number of industrial firms that have IR&D projects studying related machine intelligence technology.

Computing systems represents a significant part of the U.S. program in high-performance computing and communications, which involves the Department of Education, NSA, DOE, EPA, NASA, NSF, NIST, and the National Oceanic and Atmospheric Administration (NOAA). Most of the major vendors of high-performance computing systems, including the workstation manufacturers Hewlett-Packard, Sun Microsystems, and Silicon Graphics, are building on the scaleable computing technology developed by the programs that are part of this subarea. Sun Microsystems' Java language is giving a strong boost to intelligent agents on networks. There are major technology efforts underway at industry/government-sponsored consortia, such as the Microelectronics and Computer Technology Consortium, often involving DoD sponsorship matched with significant industrial cost sharing. The TRP has also targeted some of this technology for dual-use development and defense conversion.

System design and evolution is an area of widespread national concern as well as one that offers great opportunities for introducing high-impact and affordable systems. DoD R&D organizations are addressing these challenges by working closely with the industrial sector. DARPA and RL are major sponsors of the Evolutionary Design of Complex software (EDCS) Program. Other affiliated organizations/minor sponsors include DoD Software Engineering Institute, U.S. Army, and NSF. The NSF has government-industry-university cooperative research centers, two examples of which are the Software Engineering Research Center collocated at Purdue University and the University of Florida; and the Center for Information Management Research, collocated at the Georgia Institute of Technology and the University of Arizona. The Software Productivity Consortium (SPC) in Herndon, VA, gets its basic funding from about 15 major companies with a strong interest in increasing their software productivity and from DoD. DoD laboratories and the SPC have agreements to share and expand on their successful software engineering products. By congressional action, the National Applied Software Engineering Center has been established, due in no small part to the efforts of the service laboratories and DARPA.

3.5.3 *S&T Investment Strategy*

3.5.3.1 Technology Demonstrations. Information presentation and interaction is a supporting technology and, as such, has no current formal technology demonstrations. However, a technology demonstration (TD) for developing speech recognition for future DSPs in handheld com-puters was funded by the TRP and demonstrated a family of continuous speech recognition capabilities ranging from small vocabulary for command and control to a large vocabulary for dictation.

Machine intelligence has TDs in autonomous vehicles and image understanding architecture (IUA) vision and covers a technology demonstration that is key to the decision making IST subarea, namely USTRANSCOM planning tools. The USTRANSCOM planning tools demonstration is aimed at developing the next generation of generic AI planning, resource allocation, and scheduling technology. It is responsible for the capture of new AI planning capabilities in robust, application-ready software tools, and the demonstration of the feasibility of their application against employment and deployment crisis action planning tasks within the context of USTRANSCOM exercises.

The autonomous vehicles area focuses on ground vehicles for phase IV of a four-phased program. This phase will integrate a reconnaissance, surveillance, and target acquisition subsystem with a multiple vehicle mission subsystem, resulting in the robust navigation of a team of four vehicles as a screening force in support of manned vehicles. The IUA vision demonstration is a TRP to develop and demonstrate important image understanding (IU) products by using and enhancing existing IU software technology and COTS hardware technology in a common architecture. The result will be an architecture that will allow IU capabilities in deployed systems to improve as rapidly as the technology is delivered.

The computing systems area has a large technology demonstration that provides many enabling technologies for the information management and distribution IST subarea as well as the business and combat missions of DoD. Information infrastructure services focus on the cyberspace areas of electronic transactions, information management, and transaction support services, including common authentication, authorization, and accounting services; resource registration and discovery; real-time multimedia interoperability; and adaptive computing services.

In the system design and evolution technology, the EDCS program will demonstrate the next generation of technologies, processes, and development environments beyond computer-aided software engineering (CASE) and knowledge-based engineering to address the unique requirements of large-scale, complex systems with long life cycles where missions and performance requirements tend to evolve over the life of the system. The objective is to scale-up the incremental development and prototyping paradigms as a means to increase effectiveness of systems and systematically reduce risks over the entire system life cycle. TDs will address (1) the evolution of a system implementation through effective information management and rational capture capabilities, (2) a knowledge-based environment in which all aspects of a system life cycle are formalized, (3) language support for evolutionary development of software components, (4) specification techniques for complex software architectures, (5) software systems with components written in multiple programming languages, and (6) experimental tools to support the refinement of software prototypes into production quality systems.

3.5.3.2 Technology Development. The information presentation and interaction aspect of this subarea requires advancements in many technologies to achieve the goals for optimizing human performance in the information-intensive combat environments of the present and future. Some needed advancements will be funded by the commercial sector, but in many cases, DoD must scale up the "game oriented developments" to real-world military applications. DoD must make continued investments in:

- Real-time adaptable user interfaces
- Crew-aiding systems
- Intuitive multiuser interfaces
- Real-time processing and display of solid objects
- Locomotion control
- Robust real-time speech recognition and understanding
- Text processing, understanding, and multilingual translation
- Interface and interaction development tools to facilitate design and development of interfaces, human-computer dialogs, integration of human and computer control, system composition and integration, and VR fidelity.

Machine intelligence, an area most heavily influenced by DoD investment, will focus on the following areas to achieve its objectives for automated reasoning and autonomous vehicles:

- Extensions and alternatives to rule-based systems, particularly CASE-based reasoning
- Machine learning and machine vision
- Tools for the offline design and online adaptation of fielded systems
- Hybrid (incorporating both human and computer) control strategies including behavior-based architectures and, for semiautonomous control, incorporation of the technologies covered in information presentation and interaction into robotic systems
- Real-time, autonomous planning and scheduling of tasks that can deal with temporal aspects and uncertainty
- Integration of intelligent systems across domains
- Tools to reorganize very large knowledge bases
- The general tools and technology to build and validate intelligent systems.

In the area of computing systems, advancements in both hardware and software technologies are needed to achieve its objectives for overcoming the DoD mission shortfalls resulting from high cost or computationally bound computing systems. These listed advancements recognize the progress being made for commercial applications and are geared to capitalize on that progress as well as the projected progress for commercial applications. Investment is needed in:

- Real-time operating systems for high-performance computing.

- Common building-block architectures for military applications that are portable between underlying components.
- TFLOP scaleable embedded systems.
- Computing networks that keep up with processor performance.
- Caching models, hardware-accelerated communications, and multithreaded systems to overcome latency problems.
- Architectures and commercial leveraging and packaging to overcome the still prohibitive costs per MFLOP for embedded and nonembedded systems.
- Tools, strategies, and architectures for reducing the huge gap between sustained and peak performance.
- Tools to overcome the verification gap for complex computing hardware (e.g., the Pentium bug).
- Scaleable design algorithms to overcome design complexity.
- Computational prototyping and low-cost evaluation to overcome the high cost of physical prototyping of complex hardware.
- Software engineering tools to assist in making most efficient use of parallel and massively parallel computation architectures.

The system design and evolution aspect needs technology advances in a number of areas to meet its goals for rapid development and delivery of low-cost, high-quality, software-intensive systems. There is a broad reliance on tools and techniques for improving the processes associated with the software-intensive system from conception through system retirement. These include:

- Software reengineering and reuse technologies including rationale recapture and understanding, domain analysis, respecification, and architecture transformation.
- Fault-tolerance methods for critical system applications.
- System and software engineering frameworks and components including requirements analysis, real-time analysis, common design records (with tailored views for the various stakeholders in system development), constraint management, truth-maintenance, group collaboration, analysis and mining of design information, multimedia, simulation/modeling, and interoperability.
- High-assurance techniques to support software for distributed, real-time, and heterogeneous computing architectures.
- Integrated automation tools, in some cases embodying knowledge-based technology, to assist system builders in exploring the total system design space and in synthesizing alternative system configurations including hardware, software, and human processes.

- Evaluation and assessment technologies that enable uniform and consistent measurements of critical attributes throughout the system development process and support revalidation of outcomes at each level of system abstraction and step of refinement.
- Production technology for building complex computing systems including automated capabilities to precisely specify software architectures, to analyze architectural influences on systems performance, and to facilitate composition of software systems through software module reuse.

3.5.3.3 Basic Research. In support of the above technology development program, significant investments in basic research should be continued to overcome gaps in both theory and the scale of the existing theories for computing and software technologies, including:

- Human—computer interaction
- Human language technology
- Machine-learning methods (particularly genetic algorithms)
- Planning and AI-based design
- Very large knowledge bases
- Intelligent integration techniques
- Dynamic, very high level languages
- Parallel programming languages and "parallelizing" techniques
- Vision and image understanding
- Virtual reality
- Alternative computing paradigms, such as artificial neural networks, neuro-fuzzy logic, biologically based neural networks, and hybrid digital/optical processing
- Operating system and resource management
- Formal methods for software engineering
- Software prototyping, development, and evolution
- Software architecture evaluation metrics
- Engineering of knowledge-based systems
- Software intensive system predictability for both conventional and AI-based systems
- Software understanding/rationale capturing
- High-assurance techniques.

GLOSSARY OF ABBREVIATION AND ACRONYMS

2D	two dimensional
3D	three dimensional
4D	four dimensional (three dimensional plus time)
ABIS	Advanced Battlespace Information System
ACOM	Atlantic Command
ACT II	Advanced Concept Technology II
ACTD	Advanced Concept Technology Demonstration
ACUS	Area Common User Systems
AFATDS	Advanced Field Artillery Tactical Data System
AI	artificial intelligence
AJP	Advanced Joint Planning
ALP	Advanced Logistics Program
ALSP	Aggregate-Level Simulation Protocol
AMPS	Advanced Mobile Phone Service
AOC	air operations center
APPEX	Advanced Power Projection and Execution
ARL	Army Research Laboratory
ASAS	All-Source Analysis System
ATD	Advanced Technology Demonstration
ATIRP	Advanced Telecommunications and Information Distribution Research Program
ATM	asynchronous transfer mode
ATO	air tasking order
ATR	automatic target recognition
AWE	advanced warfighting experiment
B3	level of security assurance
BADD	Battlefield Awareness and Data Dissemination
BC^2	battlespace command and control
BDA	battle damage assessment
BDS-D	Battlefield Distributed Simulation—Development
BFTT	Battle Force Tactical Trainer
B-ISDN	Broadband Integrated Services Digital Network
BMDO	Ballistic Missile Defense Organization
bps	bits per second
C^2	command and control
C^2I	command, control, and intelligence
C^2V	Command and Control Vehicle
C^3	command, control, and communications
C^3I	command, control, communications, and intelligence
C^4	command, control, communications and computers
C^4I	command, control, communications, computers, and intelligence
C&S	computing and software
CASE	computer-aided software engineering
CBU	consistent battlespace understanding
CCTT	Close Combat Tactical Trainer
CECOM	(U.S. Army) Communications-Electronics Command
CENTCOM	Central Command
CFC	Combined Forces Command

CFOR	command forces
CGF	computer-generated force
CGS	common ground station
CINC	commander-in-chief
CIS	Combat Information System
CJTF	Commander, Joint Task Force
CMMS	Conceptual Model of the Mission Space
COA	course of action
COE	common operating environment
COMPASS	Common Operational Modeling, Planning, and Simulation Strategy
CONUS	continental United States
CORBA	Common Object Request Broker Architecture
COTS	commercial off the shelf
CTAPS	Contingency Tactical Automated Planning System
DAMA	demand assignment multiple access
DAOC	Distributed Air Operations Center
DARO	Defense Airborne Reconnaissance Office
DARPA	Defense Advanced Research Projects Agency
DBC	Digital Battlefield Communications
DBMS	database management system
DBS	Direct Broadcast Satellite
DCE	distributed computing environment
DDBMS	distributed database management system
DEEM	Dynamic Environmental Effects Model
DEW	directed-energy weapon
DIF	data interchange format
DII	Defense Information Infrastructure
DIS	distributed interactive simulation
DISA	Defense Information Systems Agency
DISN	Defense Information Systems Network
DLA	Defense Logistics Agency
DMA	Defense Mapping Agency
DMIF	Dynamic Multiuser Information Fusion
DMSO	Defense Modeling and Simulation Office
DOE	Department of Energy
DOT	Department of Transportation
DPE	Defensive Planning and Execution
DSCS	Defense Satellite Communications System
DSI	Defense Simulation Internet
DSP	digital signal processor
DSS	Decision Support System
DSWA	Defense Special Weapons Agency
DTAP	*Defense Technology Area Plan*
DTED	Digital Terrain Elevation Data
DTO	Defense Technology Objective
DVI	data/voice integration
EDCS	Evolutionary Design of Complex Systems
EHF	extremely high frequency
EIRP	effective isotropic-radiated power
EIS	Engineering Information System
ELF	extremely low frequency

EM	electromagnetic
EMD	engineering and manufacturing development
EMI	electromagnetic interference
EPA	Environmental Protection Agency
EPLRS	Enhanced Position Location Reporting System
EW	electronic warfare
FDR	Future Digital Radio
FEC	forward error correction
FLOP	floating point operation
FO	fiber-optic(s)
FPRA	forecasting, planning, and resource allocation
FY	fiscal year
Gbps	gigabit per second
GBS	Global Broadcast Services
GCCS	Global Command and Control System
GFLOP	giga-floating point operations
GHz	gigahertz
GloMo	Global Mobile Information System
GOTS	government off the shelf
GPS	Global Positioning System
HCI	human–computer interface
HCTR	high-capacity trunk radio
HF	high frequency
HLA	high-level architecture
HPC	high-performance computing
HQ	Have Quick
IADS	Integrated Air Defense Simulation
IAS	Intelligence Analysis System
ID	identification
IEEE	Institute of Electrical and Electronic Engineers
IFM	integrated force management
IFSAR	interferometric synthetic aperture radar
IM&D	Information Management and Distribution
INC	Internet controller
I/O	input/output
IP	Internet protocol
IPB	intelligence preparation of the battlespace
IPng	Internet protocol, next generation
IR&D	independent research and development
ISDN	Integrated Services Digital Network
ISR	intelligence, surveillance, and reconnaissance
IST	Information Systems Technology
IU	image understanding
IUA	image understanding architecture
IW	information warfare
JBC	joint battle center
JCOS	Joint Countermine ACTD Simulation
JCS	Joint Chiefs of Staff
JFACC	Joint Force Air Component Commander

JMASS	Joint Modeling and Simulation System
JMCIS	Joint Maritime Command Information Strategy
JPS	Joint Precision Strike
JPSD	JPS demonstration
JSIMS	Joint Simulation System
JSTARS	Joint Surveillance Target Attack Radar System
JTCTS	Joint Tactical Combat Training System
JTF	Joint Task Force
JWARS	Joint Warfare Simulation
JWCO	Joint Warfighting Capability Objective
JWID	Joint Warrior Interoperability Demonstration
JWSTP	*Joint Warfighting Science and Technology Plan*
kbps	kilobits per second
km	kilometers
LES	(DISA) Leading Edge Services (Network)
LOS	line of sight
LPI/D	low probability of interception/detection
M&S	modeling and simulation
Mbps	megabits per second
MCA	multichannel architecture
MCC	Microelectronics and Computer Technology Consortium
MCOPS	Maritime Campaign Operations Planning System
MCS	Maneuver Control System
MFLOP	mega-floating point operation
MHz	megahertz
MICOM	U.S. Army Missile Command
MLS	multilevel secure
MMITS	Modular, Multifunction Information Transfer System
ModSAF	Modular Semiautomated Force
MOUT	Military Operations in Urban Terrain
MPP	massively parallel processors
MRCI	Modular Reconfigurable C^4I Interface
MRL	multiple rocket launcher
MSE	Mobile Subscriber Equipment
MSEA	Modeling and Simulation Executive Agent
MSRR	Modeling and Simulation Resource Repository
NASA	National Aeronautics and Space Administration
NASM	National Air and Space [Warfare] Model
NCAR	National Center for Atmospheric Research
NCCOSC	Naval Command, Control and Ocean Surveillance Center
NIMA	National Imagery and Mapping Agency
N-ISDN	Narrowband Integrated Services Digital Network
NIST	National Institute of Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
NRaD	NCCOSC Research and Development Division
NRL	Naval Research Laboratory
NSA	National Security Agency
NSF	National Science Foundation

NSS	Naval Simulation System
NSSN	Next-Generation Nuclear Attack Submarine
OCONUS	outside continental United States
OMG	Object Management Group
OODBMS	object-oriented database management system
ORB	Object Request Broker
OTM	on the move
PACOM	Pacific Command
PCI	peripheral component interface
PC^2JTF	Portable Command and Control Joint Task Force
PCMCIA	Personal Computer Memory Card International Association
PCS	Personal Communications System
PDA	planning and decision aids
POC	point of contact
POM	program objective memorandum
R&D	research and development
RAP	radio access point
RBV	Rapid Battlefield Visualization
RDEC	(U.S. Army CECOM) Research Development Engineering Center
RF	radio frequency
RFI	radio frequency interference
RFPI	Rapid Force Projection Initiative
RL	U.S. Air Force Rome Laboratory
ROE	rules of engagement
RSTA	reconnaissance, surveillance, and target acquisition
S&T	science and technology
SATCOM	satellite communications
SBD	simulation-based design
SBIR	small business innovation research
SC–21	21^{st} Century Surface Combatant
SHF	super high frequency
SINCGARS	Single-Channel Ground and Airborne Radio System
SONET	synchronous optical network
SPC	Software Productivity Consortium
SR	surveillance and reconnaissance
SSCN	Secure Survivable Communications Network
STOW	Synthetic Theater of War
STRICOM	(U.S. Army) Simulation, Training, and Instrumentation Command
STS	sensor-to-shooter
T&E	test and evaluation
TACFIRE	tactical fire
TAMPS	Tactical Aircraft Mission Planning System
TCP	Transmission Control Protocol
TD	Technology Demonstration
TEED	Tactical End-to-End Encryption Device
TF	task force
TFLOP	tera-floating point operation
TFXXI	(U.S. Army) Task Force Twenty-One
THAAD	theater high-altitude air defense

TMD	theater missile defense
TMG	Tactical Multinet Gateway
TOC	tactical operations center
TRADOC	(U.S. Army) Training and Doctrine Command
TRANSCOM	(U.S. Army) Transportation Command
TRP	Technology Reinvestment Project
UAV	unmanned aerial vehicle
UDP	User Datagram Protocol
UHF	ultra high frequency
USMTF	U.S. message text format
VHF	very high frequency
VMF	variable message format
VR	virtual reality
VV&A	verification, validation, and accreditation
VV&C	verification, validation, and certification
WARSIM 2000	Warrior Simulation for year 2000
WFA	warfighter's associate
XVIII ABC	18th Airborne Corps

CHAPTER IV
GROUND AND SEA VEHICLES

1. INTRODUCTION

1.1 Definition/Scope

The Ground and Sea Vehicles technology area addresses platform and system technologies that support ground vehicles (land combat and tactical vehicles and amphibious vehicles with a ground combat role) and sea vehicles (surface ship combatants, submarines, and unmanned undersea vehicles (UUVs)). For ground vehicles, this includes intravehicle digitization, propulsion and power, track and suspension, chassis and turret structures, vehicle subsystems, hydrodynamics, integrated survivability, fuels and lubricants, and integration technologies. For surface ship combatants and submarines, this includes structural systems, maneuvering and seakeeping, power and automation, and signature control. For UUVs, this includes electrochemical and thermal technologies for energy/propulsion systems; guidance, effectors, and mission control technologies; and vehicle communications, navigation, and stealth/silencing technologies. The subareas covered by this technology area are identified in Figure IV–1.

A glossary of abbreviations and acronyms used in this chapter begins on page IV–17.

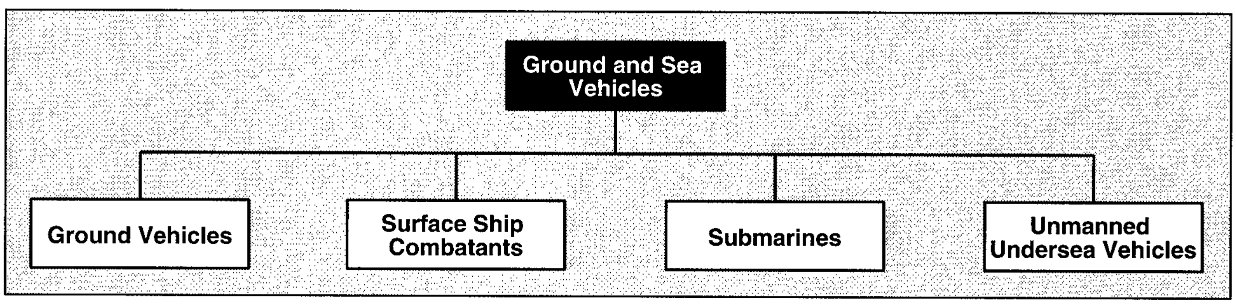


Figure IV–1. Planning Structure: Ground and Sea Vehicles Technology Area

1.2 Strategic Goals

The strategic goals for this technology area are driven by the warfighting needs described in Section 1.3 and the realization that budget constraints will exist for the foreseeable future, thus impacting the acquisition and operation of all future military systems. Therefore, the primary strategic goal is to develop and demonstrate technologies for technological superiority of ground and sea vehicle systems over those of current and future adversaries, while significantly reducing the life-cycle cost. Budget constraints will also restrict the number of deployed systems, putting a premium on the ability of new systems to remain on station longer, whatever the threat. Therefore, an additional strategic goal is to provide options that will enable major improvements in survivability and reliability. With fewer new systems, another goal is to develop and demonstrate technology aimed at system upgrades. Ground vehicle technologies will provide future systems with greater deployability (40- to 50-ton tank); more lethal combat systems through integration of advanced weapons; and more survivable scout, cavalry, and infantry systems through stealth, advanced armors, and hit avoidance techniques. Sea vehicle technologies will provide options for increased stealth and survivability, provide reliability, and reduce life-cycle costs. Achieving these goals in the first decade of the 21st century will significantly contribute to the military effectiveness of future vehicle systems.

1.3 Acquisition/Warfighting Needs

The Ground and Sea Vehicles technology area supports the land and littoral Joint Warfighting Capability Objective (JWCO) and the strategic mobility and sustainment JWCO. The former JWCO domain extends from 300 nmi at sea, through all forcible entry operations (amphibious, airborne, air assault, special operations), sustained land combat, and operations other than war (OOTW). The strategic mobility and sustainment JWCO is concerned with the timely arrival of all forces and equipment, the support of campaign objectives during major regional contingencies (MRCs), and the ability to execute an OOTW. Key planned products and transition opportunities are shown in Table IV–1.

Land combat vehicles, integrated with the combined arms force, are the central component of the land battle and Force XXI. Amphibious assault vehicles are likewise key to littoral operations and a seamless transition from sea to ground maneuver. The Navy's current doctrine, *Forward . . . From the Sea*, emphasizes the littoral region as the primary operational area of surface ship combatants, submarines, and UUVs and continuing the more traditional role of protecting the sea lanes. In support of this doctrine, surface ship combatants, submarines, and UUVs play a critical role in the Navy's joint mission support areas of strike, littoral warfare, strategic deterrence, surveillance, strategic sealift, forward presence, and readiness.

1.4 Support for Combating Terrorism. Not applicable.

2. DEFENSE TECHNOLOGY OBJECTIVES

Ground Vehicles

GV.01.06	Future Scout and Cavalry System
GV.02.06	Future Combat System
GV.03.00	Ground Vehicle Electronic Systems
GV.04.00	Advanced Ground Vehicle Mobility Systems
GV.05.00	Ground Vehicle Chassis and Turret Technologies

Surface Ship Combatants

GV.06.02	Surface Ship Integrated Topside Concepts
GV.07.02	Surface Ship Advanced Electrical Power System
GV.08.01	Surface Ship Automation

Table IV–1. Anticipated Technology Transition Opportunities

Current Baseline	2000	2005	2010
GROUND VEHICLES SUBAREA			
Virtual Prototyping	Abrams, Bradley, Tactical Vehicles	Future Scout & Cavalry System (FSCS)	Future Combat System (FCS), Future Infantry Vehicle (FIV)
Imp Armor, Signature Suppression, Active Protect, Hit Avoidance, Laser Protection & Fire Suppression	Abrams, Bradley, Tactical Vehicles	FSCS, Recon Scout Vehicle, Crusader	FCS, FIV
Band Track, Semiactive Suspension, Advanced Propulsion, Electric Drive	Abrams, Bradley, Tactical Vehicles	FSCS	FCS, FIV
Lightweight Materials, Composite Structures		FCS, SV, Recon Scout Vehicle, Crusader	FCS, Future AAV, FIV
Elec Architecture, Advanced Crewstation Technology	Abrams, Bradley Tactical Vehicles	FCS, SV	FCS, FIV
SURFACE SHIP COMBATANTS SUBAREA			
Integrated Topside Systems	LPD17	SC21	CVX
Combat-Tolerant ADH Systems		SC21	CVX, Far-Term Fast Sealift
Automated HM&E Control Systems		SC21	CVX
Advanced Degaussing System	MCM1, MHC51, LPD17	SC21	CVX
Uninterruptible Electric Power		SC21	CVX
SUBMARINES SUBAREA			
Machinery Truss Support System		NSSN Upgrades	Post-NSSN
Integrated Stern			Post-NSSN
Quiet Electric Drive		NSSN Upgrades	Post-NSSN
EM Signature Control	NSSN, SSN–21		Post-NSSN
Low-Cost Propulsor		NSSN, Trident, SSN–688	Post-NSSN
Advanced Hybrid Propulsor	NSSN	NSSN Upgrades	Post-NSSN
Advanced Vibration Reducer	NSSN		Post-NSSN
UNMANNED UNDERSEA VEHICLES SUBAREA			
Battery	SDV, MK30		Common Battery
Thermal Energy	LMRS		Reconfig. UUV
Torpedo Energy		MK48, LHT, ATT	Smart Torpedo
Precision Navigation	LMRS		Reconfig. UUV
Controllers	LMRS, MK30		Reconfig. UUV
Communications	LMRS ATD		Reconfig. UUV
Silencing	LMRS		Reconfig. UUV

Submarines

GV.09.02	Submarine Advanced Machinery Truss Support System
GV.10.01	Submarine Signature Control
GV.11.02	Submarine Electric Drive Systems

Unmanned Undersea Vehicles

GV.12.01 Mission-Reconfigurable Unmanned Undersea Vehicle

3. TECHNOLOGY DESCRIPTIONS

3.1 Ground Vehicles

3.1.1 *Warfighter Needs*

The ground vehicle technology subarea addresses warfighter operational capability requirements (OCRs) per TRADOC Pamphlet 525–66, 1 December 1995. In the short term (1–2 years), the ground vehicle technology program concentrates on transition of affordable, easily integrateable technologies that address mobility, survivability, and deployability for upgrade of existing, fielded systems. In the mid term (3–5 years), the ground vehicle community will conduct subsystem, integrated vehicle system, and integrated vehicle subsystem ATDs. These ATDs will provide the technology answers needed for the start of the FSCS, FIV, FCS, and other evolving combat, combat support, and combat service support system programs. Virtual prototyping will develop and demonstrate tools so cost, schedule, and risk may be reduced 30% by exploring concept alternatives at program initiation. Technical and affordability goals will be demonstrated through efforts in the FSCS DTO. Far-term (6+ years) plans include furthering technology including doubling cross-country ride performance for the combat vehicle fleet with DARPA/TARDEC active/semiactive suspension technology, electric drive and gun, and tactical operations employing highly agile, robust, semiautonomous ground vehicles. The FCS DTO will integrate the far-term technologies into a vehicle system-level field experiment platform to demonstrate increases in system effectiveness between 20% and 30%, while achieving reduction in system volume and weight by 7% to 15% and 15% to 30%, respectively.

3.1.2 *Overview*

3.1.2.1 Goals and Timeframes. The goals for the ground vehicles subarea in the years 2003 and 2008 are listed in Table IV–2.

Table IV–2. Ground Vehicles S&T Goals (%)

Goal Area	2003	2008
Reduce Development Time and Cost	30	50
Reduce Manufacturing Costs and Improve Producibility	15	30
Reduce O&S Costs	4	8
Reduce Nonpayload Weight Fraction	15	30
Improve Vehicle Ride Quality	50	100
Increase Vehicle Survivability via Reduced Hit Probability	33 (FSCS)	3.7 (FCS)
Increase Vehicle Survivability via Reduced Signature	16 (FSCS)	2.7 (FCS)
Increase Vehicle Survivability via Reduced Penetration	23 (FSCS)	2.7 (FCS)

3.1.2.2 Major Technical Challenges. This broad technical area has numerous challenges in achieving deployability goals while increasing survivability and lethality against future threats. Crewstation technologies that allow crew size reduction at a reduced crew workload must be accomplished; this is similar to accomplishments in aircraft. Driver automation techniques that improve mobility and increase utility of the vehicle driver must be integrated. Vehicle data rates and software lines of code approach those of fighter aircraft, but must be designed and maintained at generation crewstation and intravehicle electronics suite (IVES) architecture. Training will be done in the motorpool with full crewstation compatibility with the DSI. Special-purpose standalone trainer simulators will no longer be needed. Similarly, the ground vehicle integrated survivability DTO is confronting unique technical barriers. Signature reduction technologies similar to aircraft must be robust in a dirty environment with high shock loading. Visual signature reduction concerns unique to the ground vehicle must be addressed. Mobility component weight and volume must be reduced while power increases to support subsystem electrical loads. Critical to meeting all these technical challenges in an affordable and timely manner is the use of virtual prototyping (VP) and integrated product and process development (IPPD). VP and IPPD have been incorporated into ground vehicle ATDs requiring quality, affordability, and producibility to be among the primary development goals, in addition to the traditional technical performance.

3.1.2.3 Related Federal and Private Sector Efforts. Ground vehicle independent research and development (IR&D) programs amounting to $15 million per year are leveraged. All vehicles, except tanks and certain related combat vehicles, use upgraded commercial heavy-duty engines. The military's VP vision encourages leading-edge technologies to be compatible with industry leaders (i.e., Boeing Aircraft, Ford Motor, and Chrysler Corporations) and their current development efforts.

Basic advanced automotive technologies are being transitioned through the TACOM National Automotive Center's (NAC's) initiatives and programs with the Department of Energy and industry. Diesel engine development (four-cycle direct injection, compression ignition, and direct injection) is being worked by USCAR and the "big three" automakers under the national Partnership for New Generation Vehicle (PNGV) program. Diesel improvements are being made for all vehicles that use commercial heavy-duty engines. Smart vehicles are under development to demonstrate application of standard SAE data buses for vehicle infrastructure so that future electronic control and components can be easily added. NAC focuses on acquiring emerging automotive technologies not currently within DoD or the DoD contractor inventory into technology demonstrations for evaluation by the U.S. Army.

The Visual Perception Laboratory supports dual-need automotive research programs in vehicle detectability by leveraging extensive capabilities in both industry and academia. An ongoing CRDA with General Motors uses this laboratory to measure the conspicuity of commercial and military vehicles on the nation's road system to increase visibility and reduce traffic accidents. The same facility operates to augment available field test data for the early test and evaluation of concept vehicle signature detectability. This facility is also a key element in calibrating and validating visual acquisition models to predict human performance in detecting ground vehicle camouflage and signature modification systems.

3.1.3 *S&T Investment Strategy*

3.1.3.1 Technology Demonstrations. ATDs and TDs are planned in all technical areas:

- *Crewman's Associate ATD*—demonstrate advanced crewstation soldier-machine interfaces for ground combat vehicles achieving a reduction in crew members or crew workload with improved situational awareness, operations on the move, and night operations.
- *Hit Avoidance ATD*—demonstrate electronic warfare and active protection in an affordable combination providing a reduction in hit probability from the current 0.8–0.9 to 0.2. The modular architecture will provide the capability for an integrated hit avoidance suite to be reconfigurable to meet evolving threats and to be tailorable to other vehicles, battlefield needs, and locations.
- *Composite Armored Vehicle ATD*—demonstrate a 33% structural weight reduction in a modern, lightweight vehicle design through the full integration of structure, armor, and signature management while validating producibility, repairability, and affordability in parallel with its performance-oriented goals.
- *Ground Propulsion and Mobility TD*—demonstrate advanced mobility technologies in track, suspension, propulsion, and electric drive technologies that will increase ride performance and platform stability of ground vehicle systems.
- *Future Scout and Cavalry System ATD*—demonstrate all relevant chassis, sensor, survivability, communications, and mobility technologies that address scout-specific signature management, battlefield transportability, and platform stability issues in an electronically integrated system. This ATD will use the results of the DARPA hybrid electric vehicle applied to a scout mission. It addresses an Army requirement for a C–130 transportable scout vehicle.
- *Tactical Robotic Ground Vehicle TD*—demonstrate semiautonomous navigation in urban and tactical terrain.
- *Reconnaissance Scout Vehicle*—demonstrate vehicle integration and mission payloads to fulfill USMC and USSOCOM missions that require internal transport via V–22 tilt-rotor aircraft. Propulsion and suspension are key to developing the lightweight, narrow class of vehicles. This program will use DARPA results from the hybrid electric vehicle program.
- *Combat Power Program*—a DARPA-sponsored program to demonstrate energy storage and hybrid electric drive power systems, to include integration of components into an advanced electric architecture. Technology will be applied to Army and Marine Corps scout vehicle demonstrations and will be scaleable to the FCS.
- *Future Combat System TD*—demonstrate, on a full-up vehicle platform, the physical and electronic integration of a selected leap-ahead lethality system (i.e., EM\ETC, liquid propellant, missile, or conventional tank gun improvements), advanced crewstations integrated with open standard electronic architectures and embedded train-

ing, advanced distributed/area defense systems, next-generation tank propulsion systems, and other advanced combat vehicle technologies.

3.1.3.2 Technology Development. Five ground vehicle technology development efforts include system integration, chassis and turrets, integrated survivability, mobility, and intravehicle digitization:

- System integration optimizes future system performance through establishing technology requirements/needs in conjunction with user-integrated concept teams and identifying future concept potential resulting from the new set of technological capabilities. VP, IPPD, and system-level field experiment demonstrators are the primary ground vehicle system integration tools to simultaneously drive and establish technology goals and refine future system concept performance payoffs. Emerging vehicle requirements include the FSCS, FCS, and FIV.
- The chassis and turrets technology investigates new materials applied to both ground vehicle chassis and turret requirements of new and system upgrades. The primary challenges are new lightweight structures and armor, signature treatments, and affordability.
- Integrated survivability provides the ground vehicle an integrated set of survivability capabilities by achieving a balance of detection, hit, penetration, and damage avoidance technologies including laser protection and fire suppression.
- Mobility focuses on tracked wheeled and amphibious ground vehicles. It includes track and suspension, engine (including electric power generation), transmission, propulsion unit (amphibious), fuels and lubricants, and various ancillary components (e.g., cooling and air filtration systems).
- Intravehicle digitization develops and applies an open systems approach that integrates the vehicle digitization technologies with advanced crewstations that will enable current and future ground vehicles to effectively function and train on the real and virtual digital battlefield.

3.1.3.3 Basic Research. Critical research is being pursued in a number of ground vehicle programs. Significant work is being performed at the Center of Excellence for Automotive Research, the research module of TACOM's NAC. Collocated with the U.S. big three automakers in the Detroit area, the Center of Excellence for Automotive Research is an innovative university-industry-government consortium leveraging commercial dual-use technology in an extremely cost-effective manner to support the Army in areas of critical defense-focused automotive research. A primary thrust of the center includes development of complete computer simulations of defense-related vehicles. These simulations allow manufacturers to significantly reduce Army costs and design cycle time, along with the need for multiple Army hardware prototypes. Representative research areas of the center are vehicle terrain dynamics, vehicle hardware/human interface simulation, modeling and simulation of vehicle structures, advanced mobility simulation, and system integration. At the current time, 35 industrial companies, including the domestic automakers, are intimately participating in the research of the center.

The In-House Laboratory Independent Research (ILIR) program emphasizes state-of-the-art, in-house research that is absolutely critical if the Army is to maintain its worldwide technological leadership in the area of military ground vehicles. The program includes numerous leveraged collaborations between Army laboratory and university researchers that results in dramatically improved performance and cost effectiveness of Army systems, while allowing unique and high-technology results to be infused in the shortest possible time. The ILIR tasks of this program cover all generic areas of ground vehicle technology. Representative tasks include, but are not limited to, advanced propulsion technology including ceramic engines without the need for cooling systems, unique vehicle signature analysis using acoustic and infrared wavelets, innovative ground vehicle simulation of active suspensions, and noninvasive thermal modeling of vehicle and engine characteristics.

Applied research is also being independently pursued in the areas of nonlinear vehicle dynamics and advanced propulsion systems. The work provides improved analytical tools to produce better performing components and systems in reduced time and cost. The work provides the scientific foundation for computer and laboratory-based modeling of the dynamics of tracked and wheeled vehicle performance to support modern warfare development, deployment, evaluation, and training. A principal thrust is real-time hardware and soldier-in-the-loop modeling of dynamics capability. The goal is to develop and demonstrate the theory and methodologies necessary to augment or eliminate expensive field and laboratory testing in many aspects of system design, acquisition, evaluation, and product improvement. The work also analytically examines advanced propulsion characteristics that offer significant potential in the areas of improved fuel economy, enhanced power density, reduced cost, and greater reliability.

3.2 Surface Ship Combatants

3.2.1 *Warfighter Needs*

Table IV–3 portrays improvements directly related to warfighter needs addressed by the surface ship combatants subarea. Correlation between the needs and goals defined in Section 3.2.2.1 are also shown. The payoff quantification is based on a balanced combination of the payoff areas for the DDG–51 Flight IIA.

Table IV–3. Surface Ship Combatants S&T Impact on Warfighter Needs

Warfighter Needs	Payoffs (%)		Goal Area									
	2000	2005	1	2	3	4	5	6	7	8	9	10
Decrease Probability of Mission Loss	50	85	✓	✓	✓	✓		✓				
Reduce HM&E Acquisition Cost	15	30					✓					✓
Reduce HM&E O&S Cost	35	55					✓			✓	✓	
Increase Offensive Payload	50	100	✓	✓					✓	✓		
Increase Mobility	20	30						✓		✓		
Increase Sustainability	20	35					✓			✓		
Increase Littoral Operating Envelope	20	25	✓	✓				✓				

3.2.2 *Overview*

3.2.2.1 Goals and Timeframes. The goals listed in Table IV–4 represent potential improvements in hull, mechanical, and electrical (HM&E) subsystems for the indicated timeframes. Indicated improvements are relative to the notional Flight IIA upgrade to DDG–51-class destroyers.

Table IV–4. Surface Ship Combatant S&T Goals (%)

No.	Goal	2000	2005
1	Reduce Signatures	90	97
2	Reduce EM Interference and Emissions	99	–
3	Reduce Vulnerability	40	50
4	Improve Damage Control	25	50
5	Reduce Manning	20	40
6	Improve Seakeeping	20	35
7	Increase Power Density	30	40
8	Reduce Fuel Consumption	20	30
9	Reduce Maintenance Cost	25	40
10	Reduce Manufacturing Cost	10	20

3.2.2.2 Major Technical Challenges. The surface ship combatants S&T community is facing numerous technical challenges critical to the development of affordable ships that will meet future requirements such as operation in littoral regions. Principal challenges include (1) reducing both topside weight and volume while reducing signatures and increasing sensor performance; (2) minimizing weight and volume of HM&E systems while increasing combat tolerance and decreasing life-cycle costs; (3) improving damage fight through and recovery while minimizing manning levels and equipment redundancy; and (4) providing automated intelligent monitoring and control systems for HM&E equipment.

3.2.2.3 Related Federal and Private Sector Efforts. The surface ship combatants subarea leverages both private sector and other government investments. For instance, ship hardening efforts relate to the FAA Commercial Aircraft Hardening program, the Foreign Ship and Submarine Vulnerability Program, and weapon development programs. Another example is that the power and automation area has an effort in power electronic building blocks (PEBBs) that is coordinated with DOE, DARPA, Army, and Air Force.

3.2.3 *S&T Investment Strategy*

3.2.3.1 Technology Demonstrations. Four ATDs are planned in the surface ship combatants subarea:

- *Advanced Enclosed Mast/Sensor System*—demonstrate the capability to fully integrate sensors, electromagnetics, signature reduction, and structures into an affordable mast having improved warfighting capabilities.
- *Multifunction Electronic Radiation System*—demonstrate a low-signature, multifunction communication system fully integrated into a composite structure.

- *Advanced Degaussing*—significantly reduce surface ship underwater electromagnetic signatures in order to decrease vulnerability to underwater mines.
- *Low-Observable, Multifunction Stack*—demonstrate lightweight stack configuration with embedded communication antennas and having low radar cross section (RCS) and infrared (IR) signatures.

3.2.3.2 Technology Development.

Signature Control. This technology area consists of three tasks: topside signature reduction, underwater signature reduction, and electromagnetic compatibility (EMC). The focus of the topside signature reduction effort is on developing methods to predict both RCS and IR signatures for complex ship topsides; developing concepts to fully integrate antennas, structures, and topside equipment into low-observable configurations; and reducing signature hull configurations. Underwater signature reduction addresses the development of acoustic silencing techniques for sea-connected piping systems and underwater hull appendages as well as methods to monitor and control real-time changes in magnetic signatures resulting from secondary magnetic fields. The EMC effort develops methods to predict the EM performance of topside antennas and concepts for embedding antennas into low-observable composite structures.

Power and Automation. This technology area comprises three tasks: mechanical power and auxiliary systems, advanced electrical systems, and damage control. Current and future efforts under the mechanical power and auxiliary systems task are directed at the development of improved power generation sources such as fuel-efficient gas turbine engines and diesel-fuel-fed fuel cells. The focus of the advanced electrical systems effort is power distribution concepts that are highly survivable and provide uninterruptable electrical power, high-energy-density permanent magnet motors, and intelligent ship control systems. The damage control task focuses on the development of affordable and survivable sensors, automated damage control systems, alternatives to ozone-depleting fire suppression agents, and tactical decision aids.

Structural Systems. This technology area comprises three tasks: hull structures, topside structures, and weapon effects. The hull structures effort is focused on the development of new hull structural concepts, failure prediction methods, and probabilistic-based structural design methods. The focus of topside structures is on affordable, lightweight configurations that can be integrated with signature control measures antennas and combat protection schemes. The weapons effects area addresses methods to predict the effects of both above-water and below-water weapons on ship systems and affordable concepts that will protect ship systems from the effects of a variety of weapon threats.

Maneuvering and Seakeeping. This technology area has three tasks: seaway operability and survivability, advanced hull form concepts, and advanced propulsor concepts. The seaway operability and survivability task is focused on design criteria and tactical decision aids to maintain the dynamic stability of ships that have been damaged. The advanced hull form concepts task addresses efforts that are hydrodynamically efficient, have low signature and good seakeeping characteristics, and are able to effectively accommodate advanced propulsor concepts. The advanced propulsor concepts task emphasizes propulsor technologies that are efficient, produce low signatures, and can be configured to be highly survivable compared to current conventional propulsors.

3.2.3.3 Basic Research. The principal basic research efforts that directly support exploratory and advanced development efforts include micromechanics analysis for high-power solid-state devices, artificial intelligence for fault-tolerant electric circuit breakers, and unsteady Reynolds averaged Navier-Stokes for hydrodynamics.

3.3 Submarines

3.3.1 *Warfighter Needs*

The submarines subarea develops technologies to ensure U.S. submarine stealth superiority and to provide maximum performance at minimum cost. The submarines subarea includes technologies traditionally associated with HM&E systems. Efforts in this subarea are focused on submarine stealth, survivability, habitability, reliability, maneuvering, propulsion, affordability, automation, and payload capacity. These efforts provide essential technologies for submarines to support joint warfighting capabilities for decisive combat against regional forces, a range of capabilities for lower end operations, countering weapons of mass destruction, and near-perfect real-time knowledge and communication. Table IV–5 portrays potential improvements in warfighter needs that can be achieved through efforts in this subarea. The baseline is the SSN–688.

Table IV–5. Submarine S&T Impact on Warfighter Needs

	Payoffs (%)	
Warfighter Needs	**2000**	**2005**
Decrease Probability of Mission Loss	10	20
Reduce HM&E Acquisition Cost	5	20
Reduce HM&E O&S Cost	5	15
Increase Payload	10	25
Increase Sustainability	5	15
Expand Submerged Operating Envelope	10	25
Reduce Time to IOC	10	30

Transition opportunities include NSSN, post-NSSN, and Trident and SSN–688 backfits. Transitions require a high degree of performance verification given the severe operating environment, issues of crew safety and nuclear power, and platform cost.

3.3.2 *Overview*

3.3.2.1 Goals and Timeframes. The overall goal is to provide technology options for covert survivable platforms having improved joint warfighting capabilities. All goals are referenced with respect to the SSN–688 class with the exception of signature reduction goals, which are referenced with respect to the SSN–21 class. Due to security issues associated with submarine programs, quantification of goals and payoffs is often classified. Specific technology development goals are listed in Table IV–6. These goals represent the projection of impact that current and planned technology development could have on submarine platforms.

Table IV–6. Submarine S&T Goals (%)

Goal	2000	2005
Reduce Design Cycle Cost and Time	10	20
Reduce Construction Cost and Time	10	20
Reduce Maintenance Cost and Time	10	20
Reduce Vulnerability to Weapons Effects	30	80
Reduce Signatures – Non-Littoral	40	80
Reduce Signatures – Littoral	40	80
Improve Submerged Operating Envelope	10	20
Reduce HM&E Weight and Volume Fraction	–	10
Increase Thrust per Propulsion System Weight and Volume	5	30
Reduce HM&E Manning Demand	–	40
Reduce Damage Recovery Time	–	20

3.3.2.2 Major Technical Challenges. The driving design requirements for submarines are control of acoustic signatures and shock resistance. These requirements influence all submarine systems and submarine costs. To achieve further reductions in acoustic signature and increases in shock resistance while reducing cost, new system-level approaches must be developed. An improved understanding of the physics of acoustics, underwater explosions, structural response, and hydrodynamics must be implemented in simulation-based design in order to evaluate these new approaches. Key challenges are (1) identification and reduction of force transmissions that result in radiated noise, (2) improved understanding of the hydrodynamic forcing mechanisms and the resulting response and acoustic radiation of structural components to these forces, (3) understanding of complex energy dissipating mechanisms for acoustic/shock isolation systems, and (4) capability to predict highly complex hydrodynamic flows to reduce the need for experimental evaluation and enable development of propulsors and maneuvering concepts. Nonacoustic signature technology is increasing in importance due to emphasis on littoral operations.

3.3.2.3 Related Federal and Private Sector Efforts. The related federal and private sector efforts are limited due to the unique operating environment and the security issues associated with nuclear submarines. Research developments are monitored for potential relevance. Those efforts identified as relevant are coordinated through direct interaction and informal communication with the scientific community. Cooperation with foreign governments is limited by national security issues, although the United Kingdom has provided submarines for joint EM signature reduction efforts. Computational and fluid dynamics work is coupled with NASA and the aerospace industry when appropriate, and the power and automation area has an effort in power electronic building blocks (PEBBs) that is coordinated with DOE, DARPA, Army, and Air Force. The unique operating environment and requirements of submarines result in a limited community capable of addressing S&T issues.

3.3.3 *S&T Investment Strategy*

Submarine S&T investment strategy explores and develops technologies that provide design, construction, and operational options. Efforts are focused on ATDs and on technology developments supporting resolution of fleet deficiencies.

3.3.3.1 Technology Demonstrations. One demonstration is planned in the submarine subarea:

- *Advanced Vibration Reducer*—develop a full-scale prototype system that reduces submarine far-field acoustic signature. The prototype system has been demonstrated on a full-scale land-based test facility. At-sea testing will provide proof-of-concept system validation.

3.3.3.2 Technology Development.

Signature Control. The objective is developing technologies that control acoustic and nonacoustic submarine signatures, within an acceptable cost, to ensure the stealth superiority of U.S. submarines against all threats. Acoustic signatures remain the most exploitable signature. Technology efforts are focused on fundamental areas of structural acoustics, hydroacoustics, electromagnetic signatures, and other nonacoustic signatures. Major sources of acoustic signatures are internal noise sources, transient noise from payload launch and other discharges, flow noise over the hull and appendages, propulsor-generated noise, and active sonar interrogation. Submarines are vulnerable to nonacoustic detection when operating in the littorals on or near the surface. Nonacoustic silencing must be compatible with acoustic silencing technology.

Structural Systems. The objectives are developing technologies that build structures providing balanced static and shock performance, providing shock and acoustic attenuating structures to support use of COTS equipment for cost reduction, supporting modular construction for cost reduction, and developing a computational live-fire capability to reduce the need for explosive shock testing.

Power and Automation. The objectives include reducing the weight, volume, energy, and maintenance impact of nonnuclear propulsion, machinery, and electrical systems. These systems support all aspects of operations—propulsion, electric power, combat systems, payload launch, sonar, and life support—while meeting acoustic, shock, and SUBSAFE requirements. A key to achieving these objectives is the development of a reduced complexity, decentralized electrically powered system. This approach supports and is compatible with the application of automation for reduced manning demand and damage recovery time. This effort also supports the development of electric drive propulsion technology.

Maneuvering and Seakeeping. The objective is developing lower cost and improved performance propulsor concepts with improved maneuverability for littoral operations, fail-safe maneuvering systems, and simulation-based design capability to support new concept development and reductions in design cost. In addition to encompassing maneuvering and propulsion powering, this area is closely coupled with acoustic signature control. The dominant noise sources in the propulsor often require a demanding tradeoff between contradictory physical requirements of acoustic and hydrodynamic disciplines. This effort also supports the hydrodynamic design of advanced sail concepts.

3.3.3.3 Basic Research. The basic research needs are improved physics-based understanding of structural acoustics, hydroacoustics, static and dynamic structural response, hydrodynamics, and electric system stability. With this understanding, new concepts can be developed that address the critical phenomena, and analysis tools can be constructed that enable both concept development and design tools for designers. In addition, materials that provide improved acoustic and nonacoustic performance and are compatible with deep submergence requirements are needed.

3.4 Unmanned Undersea Vehicles

3.4.1 *Warfighter Needs*

The high-priority missions of UUVs have been identified in the *UUV Program Plan*, April 1994: mine reconnaissance, surveillance, intelligence collection, and tactical oceanography. All UUV missions and ASW targets require reduced life-cycle cost; practical, long-range/-endurance propulsion systems with 4–7 times the energy density of the zinc or silver oxide battery; a 10x improvement in low-speed (hover <4 knots) control in energetic shallow water environments for sensors and vehicle recovery; a 10x improvement in mission reliability/robustness; a 30x increase in communications data rate for offboard sensor data processing and mission monitoring; and a 10x improvement in affordable, covert precision navigation for marking targets, navigating tributaries, and recovering vehicles. For clandestine operations and sensors, the low-frequency acoustic signature must be reduced by 6 dB in order to meet Sea Wolf stealth requirements, and the EM signature must be reduced 10x in order to meet sensor and target requirements.

PMO–403 is the transition agent for all UUV technologies. The technology under development is available for the potential integration into the LMRS and the MK30 ASW training target. For weapons, reduced life-cycle cost, environmentally benign, high-power/-energy-density propulsion systems with 2–4 times the power density of the MK–48 ADCAP torpedo are required. PMO–402 and PMO–406 are the transition agents for weapon technologies. The technologies under development are available for potential integration into the multipurpose and half-length torpedoes and torpedo defense initiatives.

3.4.2 *Overview*

DARPA established a UUV Technology and Rapid Prototyping Program in the late 1980s. ONR's complementary Science and Technology Program was established in FY95 following the publication/release of the Navy's *UUV Program Plan.*

3.4.2.1 Goals and Timeframes. The goals delineated in Table IV–7 meet the needs of the fleet and realize the warfighting potential of UUVs, ASW training targets, and weapons. The improvements indicated below for UUVs are based on and are relative to rechargeable zinc or silver oxide undersea batteries for energy, the Adjustable Diversity Acoustic Telemetry System (ADATS) for undersea communications, and the tactically sized Large-Diameter UUV (LDUUV). The improvements for torpedo energy systems are relative to the MK–48 ADCAP torpedo.

Table IV-7. Unmanned Undersea Vehicles S&T Goals

Goal	2000	2005
Increase Low-Rate (UUV) Energy Density	4x	8x
Increase High-Rate (Torpedo) Energy Density	2x	4x
Reduce Energy Systems Life-Cycle Cost	50%	75%
Improve Trajectory/Hover Control/Accuracy	2x	10x
Reduce Autopilot Design, Cost, and Time	50%	75%
Improve Mission Reliability/Robustness	4x	10x
Improve Navigational Accuracy	10x	100x
Reduce Navigation System Sost	50%	–
Increase Acoustic Communications Data Rate and Range	10x	20x
Reduce UUV Acoustic Signatures	50%	75%
Reduce UUV Magnetic Signatures	4x	10x

3.4.2.2 Major Technical Challenges. The major technical challenges are (1) energy density and cycle life for batteries; (2) affordable, robust thermal combustors and high-efficiency compact heat engines for environmentally benign thermal propulsion; (3) stable, continuous operation of the aluminum seawater Vortex combustor for super-cavitating high-speed torpedoes; (4) precise trajectory control at low speeds in energetic complex (nonlinear) shallow-water environments and fault tolerance for reliability and advanced mission capability; (5) high data rate, long-range, coherent, shallow-water (multipath) undersea acoustic communications for offboard data processing and mission monitoring; (6) affordable, covert, tactically sized, geophysical field matching/mapping precision navigation; and (7) acoustic and EM signature reduction by advanced sensors, designs, coatings, and passive and active cancellation techniques.

3.4.2.3 Related Federal and Private Sector Efforts. DARPA and DOE are developing new power sources that could have undersea vehicle applications. Promising technologies are undergoing testing at Navy laboratories. The NSF is funding the Naval Postgraduate School (NPS) to investigate intelligent control systems for autonomous underwater robotics applications.

3.4.3 *S&T Investment Strategy*

3.4.3.1 Technology Demonstrations. Laboratory and at-sea testing and demonstration are important to the technology development process in order to benchmark performance and progress and to ensure useful end products. In FY97, the following at-sea technology demonstrations are being conducted: propulsor, adaptive nonlinear autopilot (>4 knots), mission path planner, half-duplex undersea acoustic communications, and in-stride GPS. In FY98, the following technology demonstrations are planned: 100 Ah lithium/cobalt dioxide rechargeable battery, nonlinear autopilot at low speeds (<4 knots), and subsystem fault detection and compensation. In the mid and far terms, technology demonstrations will focus on a nonlinear, adaptive, autopilot controller at low speeds; high-rate and long-distance undersea acoustic communications to submarines and relay buoys; geophysical map navigation; fault detection and compensation; and low-rate wick/Stirling UUV propulsion, high-rate torpedo Hydrox propulsion, aluminum seawater Vortex combustor, alternate fuels, and an electric rechargeable battery for a torpedo propulsion system.

3.4.3.2 Technology Development. Technology advances in all of the constituent areas of undersea vehicles are required in order to meet fleet requirements and to realize the full potential of UUVs and weapons. The technology objectives are as follows:

- Affordable, safe, and environmentally benign low-rate rechargeable lithium batteries, and the long-endurance thermal lithium wick/Stirling propulsion system.
- Affordable, safe, and environmentally benign high-rate and -power thermal Hydrox, aluminum seawater Vortex combustor, and alternate fuel (chemical) systems.
- Precision guidance and control using adaptive "sliding mode" nonlinear autopilot effector control and artificially intelligent mission control in environmentally complex nonlinear environments.
- Affordable coherent signal processing for high-rate and long-distance undersea acoustic communications in the shallow-water multipath environment.
- Covert (passive) geophysical map matching and map creation for precision navigation.
- Acoustic and EM signature reduction by passive and active methods.

3.4.3.3 Basic Research. New chemistries, catalysts, and manufacturing processes are under development for rechargeable batteries and fuel cells. New high-temperature combustors, environmentally benign chemical reactants, and high-efficiency turbines and engines are under development for thermal systems. Artificial intelligence, neural networks, and fuzzy logic technologies are being used to improve guidance and control performance and reliability.

GLOSSARY OF ABBREVIATION AND ACRONYMS

AAV	autonomous air vehicle
ADATS	Adjustable Diversity Acoustic Telemetry System
ADCAP	Advanced Capability Torpedo
ASW	antisubmarine warfare
ATD	Advanced Technology Demonstration
COTS	commercial off the shelf
DARPA	Defense Advanced Research Projects Agency
DIS	Distributed Simulation Internet
DOE	Department of Energy
DSI	Distributed Simulation Internet
EM	electromagnetic
EMC	electromagnetic compatibility
EMI	electromagnetic interference
ETC	electrothermal-chemical
FAA	Federal Aviation Administration
FCS	Future Combat System
FIV	Future Infantry Vehicle
FSCS	Future Scout and Calvary System
GPS	Global Positioning System
HM&E	hull, mechanical, and electrical
HYDROX	Fuel and oxidizer for half-length torpedo consisting of hydrogen and oxygen
ILIR	In-House Laboratory Independent Research
IOC	initial operational capability
IPPD	integrated product and process development
IR	infrared
IR&D	independent research and development
IVES	intravehicle electronics suite
JWCO	Joint Warfighting Capability Objective
LDUUV	Large-Diameter Unmanned Undersea Vehicle
LHT	Lightweight Hybrid Torpedo
LMRS	Long-Term Mine Reconnaissance System
NAC	National Automotive Center
NASA	National Aeronautics and Space Administration
NSSN	Next-Generation Nuclear Attack Submarine
NPS	Naval Postgraduate School
NSF	National Science Foundation
O&S	operations and support
OCR	operational capability requirement

ONR	Office of Naval Research
OOTR	operations other than war
PEBB	power electronic building block
PMO	program management office
PNGV	Partnership for New Generation Vehicle
RCS	radar cross section
S&T	science and technology
SDV	Swimmer delivery vehicle
SLID	Small Low-Cost Interceptor Device
SV	scout vehicle
USSOCOM	U.S. Special Operations Command
TACOM	U.S. Army Tank Automotive Command
TARDEC	U.S. Army Tank Automotive Research Development and Engineering Center
TD	Technology Demonstration
TRADOC	U.S. Army Training and Doctrine Command
USCAR	United States Council for Automotive Research
USSOCOM	U.S. Special Operations Command
UUV	unmanned underwater vehicle
VP	virtual prototyping

CHAPTER V
MATERIALS/PROCESSES

1. INTRODUCTION

1.1 Definition/Scope

The Materials/Processes Technology area addresses all of the DoD needs in hardware, platform, and infrastructure development. This technology area encompasses four broad foundational technologies (Figure V–1). These four subareas pursue developments in Air Platforms; Chemical/Biological Defense and Nuclear; Ground and Sea Vehicles; Sensors, Electronics, and Battlespace Environment; and Weapons. The Materials/Processes area also deals with avoidance of environmental degradation due to manufacturing, modification, and refurbishment of all hardware and platforms and with improving the quality of the environment via remediation and other means. The interrelationships between the four foundational technologies are linked as a continuum from research and development (R&D) to production to concern about undesirable manufacturing byproducts, deployment to the field, environmental quality, and finally, to performance. Also shown in Figure V–1 are the strategic goals that were adopted for the Materials/Processes technology area. These are further discussed in the next section.

The four foundational technologies have the following programmatic content:

- *Materials and Processes for Survivability, Life Extension, and Affordability.* Provides enabling materials technologies to ensure the survival of the individual combatant and equipment, ensure maximum effectiveness of the force via understanding of the operational situation, and maximize the ability of the force to neutralize hostile threats. Develops environmentally benign materials such as new corrosion-resistant alloys, coatings, and lubricants; and processes, such as corrosion control, fatigue analysis, nondestructive evaluation (NDE), and condition-based maintenance, to significantly extend the lives of current and new defense assets and address environmental regulatory goals. Furnishes basic materials on which new and upgraded platforms will rely for increased performance, survivability, and longevity at affordable costs.

- *Manufacturing Technology.* Supports force modernization and readiness by focusing on affordability through manufacturing cost reduction, achievement of large savings in manufacturing design and fabrication lead times, reduction of scrap and rework costs through integrated design and manufacturing approaches, and streamlined production management. In particular, emphasis is placed on speeding the transition of

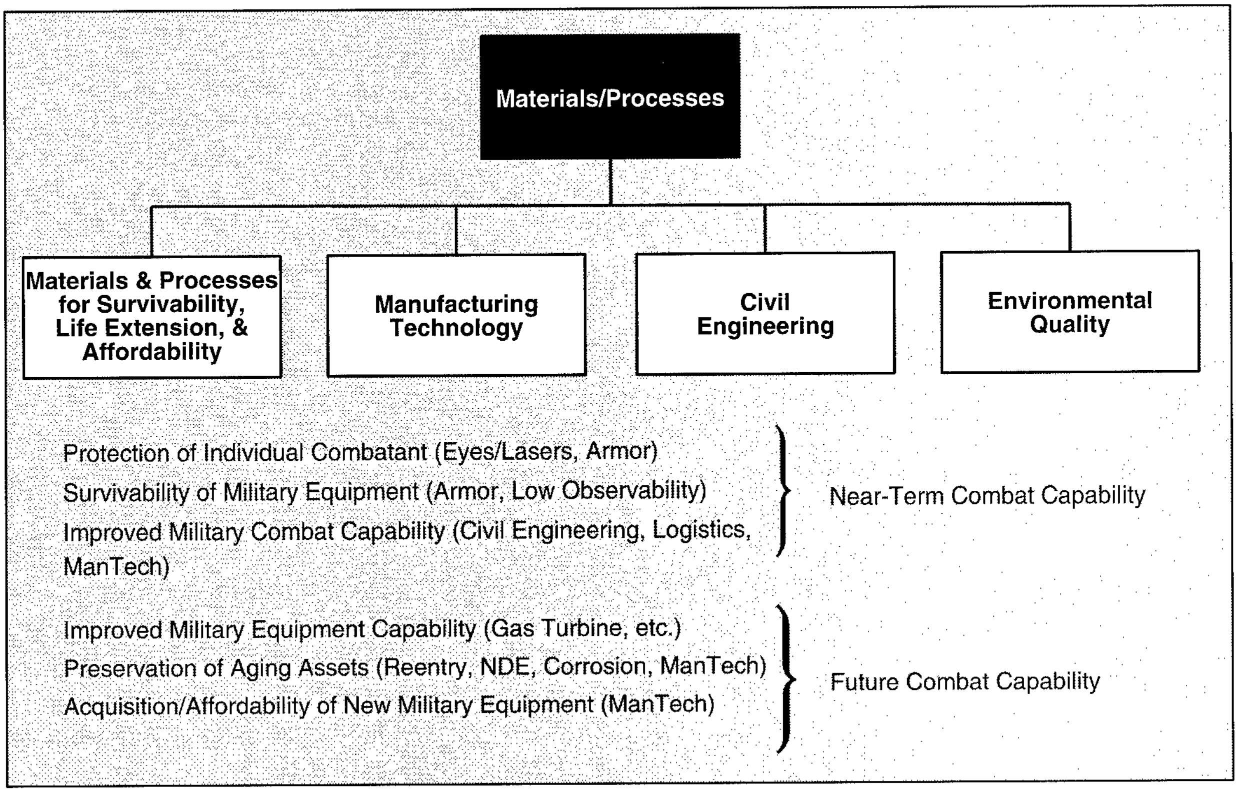


Figure V–1. Planning Structure: Materials/Processes Technology Area

leading edge technologies, such as advanced composite materials, metals, and complex electronic systems out of the laboratory and into fielded weapon systems, utilizing the latest in manufacturing techniques and processes.

- *Civil Engineering.* Supports all aspects of technology necessary for force deployment, protection, and sustainment, including logistics planning, amphibious assault and logistics-over-the-shore, base and in-theater infrastructure (from combat trails to major logistical/operational airfields), and protective structures in the field and at installations and bases (from foxholes to fortifications). Of particular military consequence are support for mobility, countermobility, survivability, amphibious assault, and logistics-over-the-shore.
- *Environmental Quality.* Provides, in partnership with other foundational disciplines, advanced technologies that enable Department of Defense components to comply with environmental regulations, prevent pollution from defense facilities and operations, restore soil and groundwater contaminated by past practices, protect air quality, conserve DoD wetlands and ranges essential for critical readiness training, and reduce costs of cleanup and disposal. These technologies permit our warfighters to train in any theater, at any time, while complying with all local regulations and with minimal environmental impact.

A glossary of abbreviations and acronyms used in this chapter begins on page V–32.

1.2 Strategic Goals

Materials/Processes technologies are fundamental to DoD platform, weapons, infrastructure, and logistical needs. Continued progress in Materials/Processes is essential (1) to realize increased affordability, performance, and sustainability in DoD systems and operations; (2) to enhance deployment, protection, and sustainment; and (3) and to attain acceptable environmental quality in the production and use of these systems. Strategic goals were adopted for the Materials/Processes area and are consistent with the Joint Chiefs of Staff (JCS) Warfighting Capabilities as described in the JCS *Joint Vision 2010*, the *Joint Warfighting Science and Technology Plan* (JWSTP), the Air Force *New World Vistas*, the Army's *Force XXI*, and the Marine Corps' *Sea Dragon* efforts. These goals are listed below in order of utility from current to future, from the warfighter's perspective. Also listed below each of the strategic goals are the projects that contribute directly to each of these goals. Most of these projects are defense technology objectives (DTOs) that are presented in a separate volume.

Protection of Individual Combatant

- *Laser Eye Protection*—develop improved protection from low-energy visible and near-infrared battlefield laser devices operating outside the fixed band capabilities of current eye-protection systems. (DTO MP.01.01)
- *Protective Materials for Combatant and Combat Systems Against Conventional Weapons*—reduce the weight of combat system armor materials (including transparent armor) by 30%. Reduce the weight of currently used personnel armor vests and face shields by 40% and 30%, respectively. (DTO MP.05.01)

Survivability of Military Equipment

- *Airframe Radar Cross Section*—develop materials, processes, and structures with reduced signatures for current and future military aircraft.
- *Firefighting Capabilities for the Protection of Weapon Systems*—develop enhanced firefighting agents, fire detection and suppression systems, firefighter protective equipment, and firefighter training systems. (DTO MP.16.06)
- *Structures and Fortifications for Force Protection Against Conventional Arms*—develop and demonstrate technologies to protect against threats ranging from small arms, to terrorist weapons, to advanced conventional weapons with multispectral sensor capabilities.

Improved Military Equipment

- *Missile Defense*—develop and demonstrate cost-effective processes for ultra-stiff, low-cost, lightweight polymer composite components for missile interceptors. (DTO MP.24.06)
- *Materials and Processes for Integrated High-Performance Turbine Engine Technology*—develop advanced materials and processes to enable the demonstration of gas-turbine engines with higher operating temperature and rotational speeds necessary to

provide twice the thrust-to-weight or half the specific fuel consumption (compared to current systems) while reducing cost on a per-pound-of-thrust or per-shaft-horsepower basis. (DTO MP.02.01)

- *Armament and Ordnance Materials To Reduce Shot-to-Kill Ratios*—provide advanced tungsten-based alloys or composites to replace depleted uranium in kinetic energy penetrators; provide improved IR dome materials as seeker covers for precision-guided munitions.
- *Aircraft and Missile Thermostructural Materials*—develop and demonstrate organic, metal, and ceramic matrix composites for aircraft and missile structures and thermo-structural composite materials to achieve weight and performance improvements up to 50% greater than now attainable.
- *Computing and Signal Processing Materials for Use in High-Temperature Shock and Radiation Enrivonments*—develop wide bandgap semiconductors (primarily silicon carbide (SiC)) that will operate at temperatures up to 500°C, and rad-hard, thin-film magnetic memory materials for permanent information storage. (DTO MP.06.01)

Improved Combat Capability

- *Airfields and Pavements To Support Force Projection*—provide improved reliability of airfields and pavements to support strategic deployment from CONUS and operational employment in the theater of operations. (DTO MP.17.11)
- *Wartime Contingencies and Bare Airbase Operations*—demonstrate airmobile shelters, airmobile utility systems, and rapid runway pavement repair systems that reduce response times, airlift requirements, and cost of "global reach." (DTO MP.14.11)
- *Higher Sea State Logistics Support for Expeditionary Forces*—develop an Advanced Cargo Beaching Lighter for ship-to-shore operations in higher sea states and for offloading supplies to the Elevated Causeway System; for the Asia-Pacific region, this would allow at least 50% more days on which operations could proceed. (DTO MP.12.11)
- *D-Day Fuel Support for Expeditionary Forces*—provide the capability to efficiently transfer up to 100,000 gallons of fuel per day from ship to shore in assault operations over 25-nmi standoff distances, compatible with amphibious (L-class) shipping and LCAC operations. (DTO MP.13.11)
- *Mobility, Countermobility, and General Engineering*—provide technologies for use of expedient materials and methods to reduce worldwide construction and maintenance cost and develop near-real-time ground mobility and transportation infrastructure evaluation software.

Preservation of Aging Assets

- *Affordable Sustainment of Aging Aircraft Systems*—develop and demonstrate affordable repair, maintenance, and remanufacturing technologies and practices to deal with the maintenance and repair demands imposed by military aircraft that are and will continue to be in use far beyond their intended design life. (DTO MP.07.06)

- *Affordable, Short-Lead-Time Parts Production and Repair*—provide information technology for rapid, efficient response to production and repair requirements. Develop and demonstrate the enterprise system integration needed to reduce cycle time by 20–50% for low volume military system repair and spare parts production. (DTO MP.23.06)
- *Nondestructive Evaluation for System Life*—demonstrate enhanced eddy current inspection hardware and software to achieve a 25% reduction in the cost of inspection system maintenance for the Engine Structural Integrity Program and Retirement-for-Cause Program. (DTO MP.03.01)
- *Materials and Processes for Reentry Vehicle Technology*—develop advanced nosetip, heatshield, and antenna window materials and processes to extend the life of the current intercontinental ballistic missile and submarine-launched ballistic missile reentry vehicle systems. (DTO MP.04.01)
- *Materials and Processes for Metal Cleaning, Corrosion Control and Coatings*—develop new, better, and environmentally acceptable corrosion control and paint technologies to reduce the $5.5+ billion annual Navy and Air Force cost associated with the current approaches. (DTO MP.07.01)

Acquisition/Affordability of New Military Equipment

- *Affordable Multimissile Manufacturing ATD*—develop advanced missile design and manufacturing enterprise concepts and systems to reduce the cost of tactical missiles by 25–50%. Demonstrate new production methods and flight qualify new hardware for at least two missile systems to validate unit cost reduction potential. (DTO MP.08.06)
- *Producible Designs for Affordable Force Modernization*—Develop and demonstrate the technologies needed for much shorter, lower cost development and production cycles by creating more producible designs and efficiently exploring many more design alternatives prior to design release. (DTO MP.09.06)
- *Interferometric Fiber Optic Gyro Flexible Manufacturing ATD*—provide flexible design and robotic-based electronic packaging and inspection technology to manufacture tactical grade and navigation grade IFOGs on a single production line in order to make low-volume defense components comparable in cost to high-volume commercial production. (DTO MP.10.06)
- *Capable Electronics Manufacturing Processes*—provide improvements to first-time manufacturing yield at all levels of electronics integration to achieve 50% cycle-time reduction and 30% cost reduction for missile components, radar upgrades, and space power generation. Levels of integration include advanced electronic materials, active components, printed wiring boards, and box-level assemblies. (DTO MP.22A.06)

- *Capable Metals Manufacturing Processes*—develop affordable, robust manufacturing processes and capabilities for metals and special materials critical to fabrication and upgrade of defense systems over their full life cycle. (DTO MP.22B.06)
- *Capable Composites Manufacturing Processes*—provide composite airframe and ground vehicle structures that can compete with metal structures not only on a structural performance basis but on a cost basis in order to facilitate the increased use of composites to attain more effective weapon systems. (DTO MP.22C.06)

Environmental Quality

- *Hazardous and Toxic Waste Treatment/Destruction for DoD Operations*—develop and demonstrate advanced technologies for "end-of-the-pipe" treatment of difficult-to-destroy wastes generated by DoD operations, and reduce the costs of complying with existing environmental regulations. (DTO MP.17.06)
- *Cleanup of Contaminants*—provide less expensive and more effective technologies for the characterization and treatment of soils and groundwater contaminated with hazardous and toxic wastes from past DoD activities for potential application at over 21,000 sites in order to reduce the estimated $30–35 billion cleanup cost. (DTO MP.18.06)
- *Plasma Arc Shipboard Waste Destruction System ATD*—develop and demonstrate an effective method for thermal destruction of shipboard waste to greatly reduce the volume of shipboard waste that must be stored until return to port. (DTO MP.01.06)

Some key specific transition goals are listed in Table V–1.

1.3 Acquisition/Warfighting Needs

All military hardware relies on materials/processes for its performance and, indeed, its very existence. Military operations, including low-intensity conflict and peacekeeping, critically depend on the availability, fieldability, and dependability of military equipment and associated logistical paths. Space permits few examples here, but it is worth noting that the weight of individual systems largely determines the number of sorties that can be made; and attrition rates of equipment in peacetime operations depend most sensitively on wear and corrosion, which determine the maintenance costs. The Secretary of Defense September 1996 report on protection of U.S. forces deployed abroad outlines initiatives required to adequately safeguard overseas forces. The importance of environmental quality (EQ) is recognized in formal Service/DUSD(ES) requirements and places an additional burden on military operations.

1.4 Support for Combating Terrorism

Within the Materials/Processes technology area there are numerous examples of projects that address the terrorism threat.

Table V–1. Materials/Processes Technology Transition Opportunities

Current Baseline	5 Years	10 Years	15 Years
MATERIALS AND PROCESSES FOR SURVIVABILITY, LIFE EXTENSION, AND AFFORDABILITY			
GEOSAT, LOSAT	GEOSAT FO	Adv EHF	HEXSAT
F/A–18E/F, F–22, V–22, B–2, C–17, AH–64A	Aircraft Upgrades, AH–64D	Aircraft Upgrades, JSF, RAH–66	Aircraft Upgrades, ASTOVL
DDG–51, CVN–73, SSN–21	SLEP, CVN–77, LPD–17, NSSN	SC–21, Post-NSSN	CVX, Far-Term Fast Sealift
M1, M2/M3, LAV	M1/2/3 Upgrades, Crusader	Future Scout Vehicle, Crusader Mod	Future Main Battle Tank
MANUFACTURING TECHNOLOGY			
Army: Javelin, ITAS/IBAS, TWS, DVE, EFOGM	Apache Longbow, HTI, Aviation B-Kit, LRAS[3], Stinger Blk II, OICW	RAH–66, LOSAT, FMST, BAT P3I, Future Scout Vehicle	Future Main Battle Tank, Miniature Missile, Smart Munitions
Navy: F/A–18C/D, EA–6B, DDG–51, AIM–9R, Aegis, CVN–73	LPD–17, CVN–77, SLEP, NSSN, V–22	SC–21, Post-NSSN, JSF, UUV	CVX, Far-Term Fast Sealift, JSA
Air Force: F–15, F–16, C–17, C–141, AMRAAM, AWACS	F–22, JDAM, JSOW, JASSM, WCM, AMRAAM II	JSF, Tier-3 UAV, JSTARS Upgrade	JSA, Aircraft Upgrades, Next Gen A/S Missile, AWACS II
CIVIL ENGINEERING			
Conventional Engineering for Strutures/ Logistics Vulnerable Troop Facilities	3x Strength Concrete 5x Effectiveness in Ship-to-Shore Throughput Survivability Measures for Deploying Forces Protection From Terrorist Threats	8x Strength Concrete in MilCon Ground Mobility Simulations Construction Using In-Theater Materials to Repair Transportation Infrastructures Deployable Floating Fleet Facilities	50% Reduction in Construction Labor Marginal Material Pavements Survivable Critical Facilities Sea-Based Logistics for Power Projection
ENVIRONMENTAL QUALITY			
Heavy Metal Electroplating, Volatile Organic Solvents, Cleaning Landfill Disposal of Hazardous Wastes Costly Pump & Treat Remediation Restriction in Training To Avoid Unknown Impacts High Costs of Operating Restrictions for Environmental Security	50% Reduction in Hazardous Waste via Material Substitution 75% Reduction in NOx from JETCs, AGE, & Ships Complete In Situ Destruction of DNAPLs Range Scheduling Management for TES Environmental Compliance of Defense Industrial Support Systems	Replacement of Volatile Organic Paint & Depaint 90% Reduction in VOC Emissions Production Facilities Integrated GPS/ Advanced Sensors for Contaminant GIS Mapping 75% Reduction in Soil Erosion on Bases & Ranges Unencumbered Operations of Ships and Submarines	Complete Restoration of Sites with Ordnance or Heavy Metals Risk-Based Ecosystem Use Models Global Compliance and Nonpolluting DoD Systems

1.4.1 *Materials and Processes for Survivability, Life Extension, and Affordability*

Nondestructive Evaluation for System Life (DTO 03.01). DoD-developed NDE technologies have long played a role in antiterrorism. The most common NDE tool used for this purpose is the airport X-ray security system, and one of the most rapidly expanding NDE areas is inspection of checked baggage. Because of the clandestine nature of the terrorist threat, finding arms, bombs, illicit substances, smuggled goods, and contraband is an ever present task. NDE sensing mechanisms include ultrasonic, magnetic, thermal/infrared, radiation (X-ray and neutron), electromagnetic, microwave, visual, and optical—essentially any means of examining an object without unpacking or handling it. Many of the advanced and more sophisticated NDE sensor technologies under development by DoD and other government agencies have potential for detecting, monitoring, and characterizing terrorism-related materials and systems. For example, the advanced acoustic, magnetic, and laser sensor technologies being developed for flaw detection and manufacturing process control applications could potentially be used to detect and locate submarines and mines in shallow water. Advanced NDE electromagnetic sensor techniques using radar and microwaves could support the detection of buried structures and mines. Some general categories of NDE applications in antiterrorist activities include:

- Bomb and hidden arms detection in public places/conveyances.
- Detection and classification of the chemicals and materials from which terrorist weapons are manufactured.
- Clandestine sensoring of terrorist activities include pre-assault surveys, monitoring traffic in terrorist materials through hidden or embedded sensors, and locating terrorist bomb fabrication and other manufacturing activities.
- Support of antiterrorist forces with portable sensors and surveillance-enhancing equipment like GPS-integrated cameras and portable mass spectrograph sniffers.

A number of NDE approaches have been investigated in recent years for the noninvasive detection and characterization of explosives concealed in baggage or packages. Most of these approaches are based on neutron or X-ray technologies. The neutron technique essentially detects nitrogen, while nuclear and quadrupole resonance (NMR and NQR) techniques provide information on molecular structure. An NQR system recently became commercially available to screen packages, briefcases, and small baggage for the presence of explosives or illegal drugs. This technology can be used to detect and characterize hazardous chemicals and biological agents.

Other DoD-supported NDE technologies either already developed or currently under development with potential application to combating terrorism include passive and active tagging systems; remote sensing and noncontact measurements (such as optical, thermal, and laser/ultrasonics under development for manufacturing process control); enhanced visual methods (under development for flaw detection in aging aircraft); airborne infrared sensing for hidden or concealed objects; data fusion for combining inputs from multiple sensors to generate enhanced output or sensitivity; and signature classification and signal processing.

Ultralight Metal Foams. Ultralight metal foams are of particular interest because of their capability to absorb large quantities of mechanical energy compared with other types of structural materials. Such materials, which also have high strength-to-weight and stiffness-to-weight properties, offer opportunities for inexpensive blast protection for U.S. troops when installed as cores of sandwich panel walls. Applications involve protection from truck bombs (in buildings) and in ship bulkheads, etc. The energy-absorption capability comes from the gradual buckling of the individual metallic ligaments that make up the microstructure of such materials. Metallic foams also have excellent vibration damping thermal insulating capabilities.

Protective Materials for Combatant and Combat Systems Against Conventional Weapons (DTO MP.05.01). Projects are underway directed at protecting the individual soldier (potentially law enforcement officers) against small arms at 60% the weight of current armor systems. Several will develop transparent armor face shields for protection against small arms artillery and bomb fragment, and blast for soldiers, law enforcement officers, and bomb disposal teams; and windows for vehicles and shelters at 70% the weight of current armor systems. Other projects will provide armor materials and armor systems to protect combat, tactical, law enforcement, and bomb disposal vehicles at 70% the weight of current armor systems against medium kinetic energy threats, artillery and bomb fragments, and blast.

1.4.2 *Civil Engineering*

Structural Hardening. A critical component of terrorist threat protection is structural hardening—a high-priority research effort in the civil engineering area of survivability and protective structures. The objective is to provide methods for cost-effective designs and techniques to retrofit conventional building elements (windows, doors, roofs, and walls) for protection against terrorist and saboteur weapons. As part of an international cooperative program involving researchers from the United States, Israel, and Great Britain, a series of experiments were completed in October 1996 that investigated the effects of vehicle bomb blasts on buildings. Also included were the blast effects of structural retrofits for walls, windows, and doors. An "antiterrorism planner" for the field combat engineer is in development; this PC-based tool will provide a vulnerability assessment of building types subjected to a variety of assumed threats (e.g., vehicle bombs, small arms) and provide recommendations for expedient structural hardening. The Army is leveraging R&D in counterterrorism with the Secret Service and with the Departments of State and Treasury (ATF). The Army (WES) and DSWA conducted experiments and high-performance computations to support Secretary Perry's Report to the President on Force Protection. The Air Force and Army provided technical support to headquarters CENTCOM in formulating housing and facility protection designs and in conducting site evaluations in Saudi Arabia for relocation of U.S. forces. Finally, the results from research in survivability and protective structures directly support a Downing report recommendation to "provide technical assistance and information on force protection from the DoD to units in the field."

1.4.3 *Environmental Quality*

Hazardous and Toxic Waste Treatment/Destruction for DoD Operations (DTO MP.17.06). Environmental quality technologies to restore contaminated groundwater, surface water, and solids are applicable to the cleanup of any terrorist eco-damage. Sensor technology under development for environmental application to detect contaminants in air, soil, and water have equal utility as screening tools for terrorist threats. Some of these complementary technologies that are being pursued in chemical/biological defense R&D pertain to detection of a variety of organic and inorganic compounds including energetic materials, POLs and related hydrocarbons, halogenated solvents, and heavy metal containing materials. Predictive models under R&D for groundwater flow to drinking water aquifers and atmospheric dispersion of toxic clouds have valuable uses to assess possible terrorist threats and to evaluate extent of damage after a terrorist-induced environmental event.

2. DEFENSE TECHNOLOGY OBJECTIVES

The focus of the Materials/Processes technology area efforts is the attainment of 25 DTOs:

Materials and Processes for Survivability, Life Extension, and Affordability

MP.01.01	Laser Eye Protection
MP.02.01	Materials and Processes for Integrated High-Performance Turbine Engine Technology
MP.03.01	Nondestructive Evaluation for System Life
MP.04.01	Materials and Processes for Reentry Vehicle Technology
MP.05.01	Protective Materials for Combatant and Combat Systems Against Conventional Weapons
MP.06.01	Computing and Signal Processing Materials for Use in High-Temperature Shock and Radiation Environments
MP.07.01	Materials and Processes for Metal Cleaning, Corrosion Control and Coatings
MP.24.06	Missile Defense

Manufacturing Technology

MP.07.06	Affordable Sustainment of Aging Aircraft Systems
MP.08.06	Affordable Multimissile Manufacturing ATD
MP.09.06	Producible Designs for Affordable Force Modernization
MP.10.06	Interferometric Fiber Optic Gyro Flexible Manufacturing ATD
MP.22A.06	Capable Electronics Manufacturing Processes
MP.22B.06	Capable Metals Manufacturing Processes
MP.22C.06	Capable Composites Manufacturing Processes
MP.23.06	Affordable, Short-Lead-Time Parts Production and Repair

Civil Engineering

MP.12.11	Higher Sea-State Logistics Support for Expeditionary Forces
MP.13.11	D-Day Fuel Support for Expeditionary Forces
MP.14.11	Wartime Contingencies and Bare Airbase Operations
MP.16.06	Firefighting Capabilities for the Protection of Weapon Systems
MP.17.11	Airfields and Pavements To Support Force Projection
MP.18.11	Life-Extension Capabilities for the Navy's Aging Waterfront Infrastructure

Environmental Quality

MP.01.06	Plasma Arc Shipboard Waste Destruction System ATD
MP.17.06	Hazardous and Toxic Waste Treatment/Destruction for DoD Operations
MP.18.06	Cleanup of Contaminants

3. TECHNOLOGY DESCRIPTION

3.1 Materials and Processes for Survivability, Life Extension, and Affordability

3.1.1 *Warfighter Needs*

Advanced materials is an enabling technology for all DoD systems and accordingly, is essential in attaining most of the Joint Warfighting Capability Objectives. Specific examples are cited below.

Survivability. Under the objective for Military Operations in Urban Terrain, by 2001, a 40% weight reduction will be realized in helmets and vests for protection against small arms projectiles and fragments, along with face shield and window protection at 30% weight reduction. Similar weight reduction will also be achievable in vehicles through the substitution of titanium armor for steel. By 2000, the system damage threshold of electro-optical sensors to both short-pulse and long-pulse fixed-wavelength laser threats will be improved by a factor of ten thousand, while sustaining required levels of optical transmission.

Lethality/Surveillance. Relative to the Precision Force area, increased lethality will be possible through tungsten-based antiarmor penetrators. This objective will be further enhanced through advances in IR/radar sensor materials that will yield greater erosion resistance and a 50% increase in detection range and a twofold improvement in target acquisition and tracking. These advances plus the epitaxial growth of defect-free semiconductors will provide a threefold improvement in space surveillance and secure spacecraft laser communications, factors that are critical to the Joint Theater Missile Defense technology area.

Life Extension. Although none of the Joint Warfighting Capability Objectives address life extension specifically, the limited number of new systems being procured, along with the Chairman of the JCS goal of maintaining force structure, demands that technology be developed to ensure the extended life of current military systems with no degradation, while incorporating improvements in warfighting capability. The KC–135 tanker fleet is now anticipated to be kept in service until 2040, and the Navy is extending the lives of aircraft by using stress- and corrosion-resistant steels for landing gear and high-strength applications. These examples are typical of the life extension efforts being contemplated for other aircraft, ships, armored vehicles, trucks, and essentially all systems needed to ensure military superiority. The payoff potential for these effective life extension programs can be as large as $20 billion per year.

Affordability. Reduced costs are significant factors in several of the Joint Warfighting Capability Objectives, both through reductions in acquisition costs and supportability costs. For example, a Joint Readiness and Logistics objective anticipates improvements in deployment/sustainment through engines with ceramic components, unlimited life expectancy batteries, and low-cost unmanned aerial vehicle (UAV) airframes. The latter is also a goal of the Joint Countermine area. Examples of cost reduction through material substitution include reskinning the wing of the RC–135 using lightweight metallic alloys, and organic- and metal-matrix composites (OMCs and MMCs) to extend the life of this reconnaissance asset and extend its range by 30% with an attendant increase in loiter capability. Similarly, low-cost composite process techniques have been demonstrated in a retrofit of the F–117 fighter aircraft trailing edge components resulting in 50% reduced acquisition cost and a threefold extension in component life. The use of high-strength, low-alloy (HSLA) steel in place of high-yield (HY) steels has saved over $135 million during the past 10 years in surface ship construction. Future ship and submarine construction cost savings via HSLA are projected to be at least $30 million per year. Net shape processing technologies (i.e., precision hot iso-static investment castings for V–22) are being used to reduce materials processing/systems assembly costs and life-cycle costs.

3.1.2 *Overview*

3.1.2.1 Goals and Timeframes. Table V–2 lists the goals of the materials and processes for survivability, life extension, and affordability.

Table V–2. Goals for the Survivability, Life Extension, and Affordability Subarea

Time	Area	Goals
2000	Ballistic Protection	30–40% weight reduction for small arms and fragment protection
	Laser Protection	Optimization and fielding of eye protection for the most probable fixed battlefield laser threats
	Transducers	90% reduction in submarine/ship acoustic radiation via active control
	Infrared Domes	200% improvement in rain and dust durability for supersonic IRST sensor
	Electromagnetic Sensors	50% increase in IR sensing range, twofold improvement in target identification
	Life Extension/Reliability	Twofold increase in aircraft paint system lifetime with reduced chromates and volatile organic compounds (VOCs)
		NDE methods for standard crack and corrosion detection, including detection of cracks under installed fasteners
		Enhanced turbine disc inspection hardware and software
		50% reduction in corrosion-initiated flaws resulting in 40% life-cycle component cost savings
	Affordable Processing	90% reduction in small lot (10–100) component costs via intelligent and flexible materials processing
	OMC	10–20% cost reduction via innovative processing and structural unitization.
	Low-Cost Ti	40% weight reduction and immunity to corrosion via substitution of $7/lb structural Ti alloys for steel
	Engine Materials	40% component weight savings via substitution of intermetallics for nickel superalloys
2005	Ballistic Protection	20–30% weight reduction in hardened shelters for personnel
	Laser Protection	Interim protective solutions for low-energy threats (filter wheels, tunable filters, tristimulus filters for eyes)
	Low Observability	Independently controllable emissivity/reflectivity coatings
	Infrared Domes	Affordable processes for growth and polishing of diamond domes
	Electromagnetic Sensors	50% improved detection by superconducting magnetic sensors

Table V–2. Goals for the Survivability, Life Extension, and Affordability Subarea (continued)

Time	Area	Goals
2005 (cont'd)	Life Extension/Reliability	Degradation monitoring sensors for life management with 30% reduction in ship maintenance hours
		60% life increase for helicopter replacement parts via increased corrosion and fatigue resistance
		NDE detection of hidden corrosion in aircraft; 25% O&S cost savings
	Affordable Processing	40% savings via biotech processing industry to provide water-based, low-energy, environmentally compatible manufacturing
		Co-curing technology to reduce weight by 10% in composite aircraft structure
	OMC	25–50% weight reduction in ship superstructures with lowered signature
		Environmentally stable materials for aircraft structures with 25% O&S savings
	Ti	50% reduction in welding and machining costs
	Engine Materials	30–50% reduction in fuel consumption and 50% less nitrogen oxides via ceramic components
2010	Low Observability	Adaptive coatings/systems that respond automatically to background and threats
	Transducer	Full active vibration control of ship systems, virtually eliminating acoustic signature
	Electromagnetic Sensor	Affordable, reproducible SiC for 350–500°C electronics
		Condition-based maintenance for 80% reduction in mechanical flight mishaps
	Life Extension/Reliability	Automated NDE for corrosion and crack detection
	Affordable Processing	40% reduction in rework costs associated with wear via advanced coatings
		50% reduction in the cost of elastomeric components/materials via electroset processing and control of properties
		60% cost reduction in production of welded platforms via computer feedback control with integrated nondestructive inspection (NDI) acceptance system
	OMC	Complete field repairability of composite structures
	Engine Materials	Reliable joining and inspection of ceramics and metals for hybrid components

3.1.2.2 Major Technical Challenges.

Improve Survivability of Personnel and Systems. The principal challenges in making ultralight personnel protection are to reduce the weight and cost of ceramic components while at the same time increasing ballistic performance and optimizing ceramic-composite systems performance. The major challenge involved in protecting eyes and sensors from battlefield lasers is to develop materials and concepts for components that extend the range of protection, maximize optical transmission, and permit tuning of "rejection" wavelengths to defend against a wide range of (long- and short-pulse) laser threats. The major challenges for signature control are cost reduction (which includes acquisition, inspection, and repair costs), weight reduction, and the development of materials systems and related processing technology for "building in" low observability into structures rather than adding it on.

Enhanced Situational Awareness. Major challenges are the development of materials and material concepts for improved sensors (sensitivity and selectivity) and for improved guidance, data acquisition, analyses, and transmission systems (radiation hard). Meeting these challenges will necessitate the development of improved processing techniques to eliminate or control the microscopic defects in bulk and epitaxially grown semiconductors, superconductors, ferroelectrics, and piezoelectric and magnetic materials. Improved processing techniques will increase the production yield while reducing the size and costs of sensor systems.

Increase Lethality and Pinpoint Accuracy. The major challenge involved in extending the durability of IR domes and windows for high-speed flight through rain and dust is the development of efficient, low-cost diamond deposition and polishing techniques and compatible antireflection coatings.

Extended Service Life and Enhanced Reliability. NDE is essential (1) to enable the service life extension of current weapon systems, principally through the development of enhanced methods for crack and hidden corrosion detection quantification, and (2) to allow effective implementation and integration of time-directed and condition-based maintenance of mechanical equipment and structural components on all DoD platforms. Challenges in NDE encompass the development and application of highly accurate, rapid, wide-area inspection and reliable and cost-effective methods, equipment, instrumentation, and sensors needed to enhance processing, reduce costs, and verify the quality of advanced materials systems.

Current DoD corrosion-resistant coatings have limited service lives and do not comply with emerging environmental regulations. Long-life, environmentally compatible coatings must be developed using high-solids-content, waterborne, and powdered polymers. Also of importance is the development of durable environmentally stable organic matrix materials. There is a need for improved elastomers and seals, including lightweight aircraft sealants that reduce fuel leakage, decoupling elastomeric coatings that reduce vibrations in ships and submarines, and acoustically transparent seals for sonar arrays. The performance of fluids and lubricants must be improved through enhancements in durability, service life, and resistance to fire and corrosion. Cost-effective materials processing methods must be developed that ensure reproducibility and material quality.

Affordable Systems and Operations. The challenge in reducing construction costs for ships and submarines using steel alloys is to develop affordable mill processing and improved fabrication and welding technologies. The challenge in the development of and transition to lightweight aluminum alloys (e.g., aluminum-lithium) for aircraft is to achieve uniform mechanical properties in all directions and improve corrosion resistance. For tailored OMCs, the challenge is to develop systems that simultaneously meet the structural, electromagnetic signature, and durability requirements of military systems. Additionally, for OMCs, to achieve major cost reductions, materials and techniques for processing at low temperatures (150°F) and pressures (nonautoclave methods) must be developed. The challenge in developing new and improved lightweight titanium alloys and high-temperature intermetallic materials, both for propulsion systems, is to achieve acceptable mechanical properties coupled with resistance to the environment.

High-Temperature Propulsion and Structural Materials. Challenges include (1) improving the properties of superalloy disks for turbine engines, now limited in terms of their resistance to creep in the rim burst strength in the bore and long-life durability in oxidizing environments; (2) high-temperature advanced intermetallic materials and composites, which currently lack balanced engineering properties; (3) environmental stability of ceramic materials under thermomechanical cyclic loading; and (4) development of affordable processing for advanced materials.

3.1.2.3 Related Federal and Private Sector Efforts. With support from the Departments of Commerce and Energy and agencies such as the Federal Aviation Administration and the National Institutes of Health, various electronic and transducer technologies are being transferred to the automotive, aviation, and medical fields. These include collision-avoidance radar, high-speed optical switching and computing components, superconducting motors, methods for detecting environmental pollutants, and medical imaging devices. The DOC and the abrasives industry are supporting basic research on the physics and growth of diamond. NASA, DOE laboratories, DOC's National Institutes of Standards and Technology, FAA, and supporting industries are involved in related efforts in aging aircraft, service life extension, reliability, and cost reduction, with collaboration occurring at the program level. The Department of Transportation's highway infrastructure renovation and Nuclear Regulatory Commission containment vessel programs depend heavily on advances in defense technologies such as NDE and composite materials. Weight reduction, increased quality, and cost reduction are major objectives in virtually all vehicle and aircraft R&D programs. Two DOE programs, Continuous Fiber Ceramic Composites (CFCCs) and Ceramic-Matrix Composite (CMC) Multimegawatt Turbines, are based on recent defense technologies. Increasing use of advanced materials in civilian applications will reduce the costs of defense-specific uses. Significant work is also being carried out in eliminating hexavalent chromium from coatings, sealants, and maintenance chemicals through the aerospace chromium elimination (ACE) team.

3.1.3 *S&T Investment Strategy*

3.1.3.1 Technology Demonstrations. There are three Technology Demonstration (TD) programs in this subarea.

The *Laser Protection TD Emphasis* is on test and validation of day/night protective devices or schemes that are compatible with cockpit displays and life-support equipment to provide full retinal protection. Also, validation of laser protection schemes in actual electro-optical sensor systems and developmental breadboards for fixed-wavelength threats at short and long pulsewidths, high transmission levels (near term), and agile wavelength threats (long term) are included. Early operational assessments of protective eyewear are in progress. Modules are being developed for specific sensor system retrofits and testing.

The *Advanced Nondestructive Evaluation TD* is dedicated to significantly increasing the accuracy, reliability, and affordability of early detection of safety and service-life-limiting defects and deterioration damage (e.g., minor but widespread fatigue damage and hidden corrosion) particularly in aging weapon systems. Advances include high-speed semiautomated, noncontact scanning of large surface areas, real-time in situ monitoring of structural integrity-sensitive locations based on the use of new probe/sensor concepts and high-speed data processing, and application of accurate NDE characterization and damage growth prediction processes to forecast the remaining safe and economical life of components.

The *Electrochemical Power Sources TD* focuses on extending the life of electrochemical power sources (i.e., rechargeable batteries and fuel cells) for a wide range of portable electronic equipment. Methods will be developed for fully automated production and rapid prototyping of rechargeable batteries that provide three times the energy per weight/volume of existing systems, with deep discharge and elimination of self discharge. Simplified fuel cell technology will enable the use of military (logistics) fuels for portable power with a twofold improvement in efficiency over existing generator systems and reductions in pollution and noise.

3.1.3.2 Technology Development. To achieve the necessary advances in materials and reproducible low-cost processing technologies, focused time-phased programs are directed at modeling functional behavior, improving physical properties, and reducing the cost and weight of systems. Programs include the synthesis, processing, and characterization of materials and subscale demonstration components. Topics include:

- Advanced composite, ceramic, and metallic armor materials to protect the individual combatant and combat systems against conventional weapons.
- Advanced materials and concepts (e.g., absorbing dyes, filters, optical switches and limiters, nonlinear optical elements) for protection of warfighters and equipment from laser threats.
- Sensor and device materials (e.g., semiconductors, superconductors, ferroelectrics, piezoceramics, magnetic, nonlinear optical materials) that will enable significant increases in information gathering, analysis, and dissemination to improve battlefield situation awareness and precision-strike enhancements.
- Signature control materials and repair processes, including specialty coatings and absorbers, to minimize the IR, visual, radar, acoustic, and magnetic signatures of weapon systems.
- Electromagnetic domes/windows with durable coatings to minimize rain/dust damage; and tungsten-based, antiarmor penetrators for enhanced weapon delivery and lethality.
- Advanced NDE technology for characterizing defense materials and structures, wide area inspections, and supporting manufacturing requirements and for providing the capability to detect a wide variety of in-service and aging system problems, including hidden corrosion, cracks under installed fasteners, and flaws in welded joints and critical components (e.g., turbine blades, discs).
- Advanced coatings for ground equipment, ships, submarines, and aircraft that meet environmental regulations, extend system lifetimes, and reduce overall maintenance costs.
- Advanced battery materials having higher energy/density and extended service life.
- Improved hydraulic fluids, engine coolants, turbine engine lubricants, and greases for all DoD vehicles, ships, and aircraft.

- Advanced tools such as diagnostic algorithms, prognostic methods, and robust sensors that can be integrated into a variety of defense systems to enhance reliability.
- Industrial artificial intelligence methods for affordable process control and pattern recognition as well as other critical fabrication and manufacturing processes for weapons and platforms.
- Metallic structural materials for DoD systems, including ferrous-based alloys (steels), nonferrous alloys (low-cost titanium), and MMCs having lighter weight, lower cost, and greater in-service durability.
- OMCs, including both thermoset and thermoplastic matrices for aircraft structures, ship bulkheads and superstructures (low signature), turbine engine ducts/cases, and spacecraft structures.
- High-temperature metals and intermetallic materials, including titanium-based alloys, superalloys, and advanced intermetallics for turbine and rocket engine components.
- Ceramics and carbon-carbon (C/C) composites, including monolithic ceramics and CMCs for turbine engines, rocket engines, diesel engines, spacecraft solid and liquid engines and spacecraft trusses, and thermal management system assemblies.

3.1.3.3 Basic Research. Many areas of basic research are relevant to this subarea. Analytical model development and research on new metals and ceramics and associated processes have increased the predictive capability and multihit tolerance for lightweight armor. Materials modeling and simulation of electronic interactions and nonlinear optical properties may enable development of materials that protect eyes and sensors from laser damage. Also included are biotechnology and biomimetic studies on synthesis of new chemical compounds and materials. Understanding of piezoelectric and magnetic materials will enable the development of highly sensitive sensors for awareness and mine detection.

Basic research also is crucial to understanding of degradative processes (e.g., corrosion, wear, fatigue) that limit the service life of DoD systems. Advances in sensors, diagnostics, and information storage and analysis are needed to make condition-based maintenance and high-cycle fatigue prediction and control a reality. New materials for lubricants and corrosion control and antifouling coatings are expected to emerge from surface chemistry and applied materials research. Basic research in materials, mechanics, and data analysis will enhance the sensitivity of NDE methods and improve ruggedness. Basic research continues to produce novel means of extending the life and increasing the energy density of batteries and fuel cells for DoD electronics and power systems. Micro-alloyed steels are being characterized and scientifically designed for use in weapon systems. High-temperature and structural carbon fibers are being synthesized continuously and combined with new chemical resins. Properties of the resulting composites can be defined more precisely due to advances in surface science and methods for evaluation at the atomic level. Basic research on intermetallic alloys has improved the ductility of these brittle systems, and mechanical design research has made it possible to design even rotating systems with brittle metallic and ceramic materials.

3.2 Manufacturing Technology

3.2.1 *Warfighter Needs*

Force readiness and force modernization are fundamental needs of the warfighter. Defense budget reductions in recent years have created situations where the needs for both readiness and modernization could not be met simultaneously, and one or the other has been sacrificed. In this environment, affordability and rapid cycle times for acquisition of new systems and repair of existing systems are key to ensuring that the United States maintains an appropriate mix of systems and forces that are ready to respond to the defense missions of the future. Warfighters need a responsive industrial base with advanced manufacturing technologies and processes that reduce costs and lead times at every level—in the design process, in development, in production, and in the support of fielded systems. Those same issues (affordability and cycle time reduction) are the predominant aims of the manufacturing technology (ManTech) subarea. World-class commercial companies have demonstrated overall product development and production-cost reductions as well as cycle-time reductions on the order of 50% in comparison with formerly used approaches. Despite the major differences in products and customer requirements, cost and cycle-time savings in that same range are feasible for military products as well.

Affordability. Sharply reduced acquisition and support costs that permit the purchase of more systems or spare parts or the insertion of more new technology into existing systems for the same budget level have obvious implications for both readiness and modernization.

Cycle Time. Typical development cycles for new major weapon systems currently stretch to more than 10 years, while new generations of electronics technology arrive every 3 or 4 years. This mismatch makes fielding obsolescent equipment in our latest weapon systems almost unavoidable. A capability for rapid system acquisition or technology insertion would permit the fielding of today's technology—with rapid upgrades possible as threats or missions changed over time. Rapid repair and production cycles would allow quicker response to the changing needs of the force. Short cycle times almost invariably create significant cost reductions and will also allow other costs (e.g., purchase of spare parts or development of new systems) to be deferred to future budget years. Again, the implications for readiness and modernization are clear.

Timely Implementation of Cost Reductions and Cycle-Time Improvement. Despite the powerful influence of DoD budget reductions, sweeping cost reductions and cycle-time improvements will not occur spontaneously. Traditional defense suppliers, often shielded from the forces of competition based on price and speed to market, do not always have efficient practices and processes compared to the world's leading commercial firms. Also, traditional DoD contracting and incentives approaches do not provide a simple profit motive for improvement. World-class commercial manufacturers have focused on systematic elimination of inefficiency and non-value-added cost in all areas. In addition, there are militarily important technology areas where commercial rather than defense firms are the technology leaders. ManTech is working to create major shifts in the cost and speed with which military products are developed, produced, and repaired by benchmarking the best practices in the industrial world and fostering their widespread implementation. ManTech is working to eliminate barriers that impede military access to affordable commercial products and production of military goods on efficient commercial production lines.

Flexibility. The days of uniform mass production are largely gone in the commercial world. Commercial companies have learned how to be flexible in their approach to manufacturing so as to be able to add custom product features, mix products on production lines, and affordably make ever smaller lots of products to respond to changing needs of their customers. Warfighters require that same affordable manufacturing flexibility. It is very efficient for DoD to make the maximum use of commercial processes and products to meet defense needs. Nevertheless, the development and production methods that are successful in the commercial world often need significant adaptation and demonstration to ensure that they are robust enough to deal effectively with the need for superior defense products.

Rapid Transition of Defense-Essential or Defense-Unique Technologies. There are critical areas where defense-essential products have no commercial counterpart (e.g., munitions, traveling wave tubes, obsolete electronic components) or where the defense application is so far ahead of potential commercial applications that DoD must invest to ensure that key products and processes are available to support readiness and modernization (e.g., thrust vectoring nozzles for short takeoff and landing aircraft, interferometric fiber optic gyros for navigation). Therefore, ManTech is also investing in developing manufacturing processes and capability to support defense-essential product technologies. Heavy emphasis is placed on maturing defense-essential technologies emerging from development to foster rapid, low-risk transition of advanced technology out of the laboratory and into new systems or to extend the useful life of existing military systems. Thus, ManTech has a strong and direct influence on the readiness and modernization of the forces available to the warfighter.

3.2.2 *Overview*

3.2.2.1 Goals and Timeframes. The goals of the manufacturing technology subareas are presented in Table V–3.

3.2.2.2 Major Technical Challenges.

Improve Affordability and Reduce Development Cycle Time for Military Products. Challenges include:

- Demonstrating the effectiveness of the new/improved manufacturing or repair processes on defense-essential products in realistic production conditions to validate cost and capability data and speed their acceptance by industry and product centers.
- Rapidly developing, validating, and deploying tools and methods that can bring 50% reductions in design and development cost and cycle time in a military product environment that demands rapid insertion of leading-edge technologies.
- Rapidly developing, validating, and deploying factory and business processes and practices that can reduce production and repair costs and cycle times on the order of 50% from current levels in an environment where production runs are rapidly becoming shorter, where the supplier base is rapidly shrinking, and where repairable assets are increasingly scarce.

Table V–3. Goals for the Manufacturing Technology Subarea

Time	Area	Goals
2000	Capable Processes for Low-Risk Fielding of Advanced Defense-Essential Technologies	Widespread implementation of 6-sigma methodology Reduce costs to $700/axis for tactical grade IFOG Reduce costs to $1,500/axis for navigation grade IFOG Demo 50% reduction in composite material fabrication costs
	Affordable Military Capability via the World's Best Industrial Capabilities	Missile component demos of 25% cost and time savings Demo 30–50% avionics cost reductions using commercial line Demo 30–50% cost reduction for aircraft parts and subsystems
	Producible Designs for Affordable Force Modernization	Demo 40% reduction in producibility design changes Demo 25% reduction in time to incorporate design changes Demo 95% first-pass yields for critical electronic components
	Affordable, Short-Lead-Time Production & Repair at Low Volume	Demo 30% reduction in supplier management costs, 75% reduction in supplier contracting time, and 50% reduction in supplier lead times Demo integrated scheduling for several military products in simultaneous low-volume production Demo 80% reduction in lead time for work order release
2005	Capable Processes for Low-Risk Fielding of Advanced Defense-Essential Technologies	Demo 6-sigma for engine turbine and composite structure repair processes Demo production-ready process variability control for military-unique chips, modules, boards, and near net shape parts Demo green board design tools and processes Demo continued IFOG cost reduction slope of 10%/axis/yr Demo 75% cost reduction for optics components
	Producible Designs for Affordable Force Modernization	Demo 80% drop in design changes for producibility Demo 30% reduction in production transition cycle time Demo methods to ensure 6-sigma capability at design release Demo accurate manufacturing cost-estimating tools in preliminary design 10x more design alternatives in 1/2 time for seekers and sensors
	Affordable, Short-Lead-Time Production & Repair at Low Volume	Demo 90% reduction in time to reschedule compete supply chain Routine use of direct vendor delivery in production and repair Demo 80% reduction in in-process inventory—mechanical subsystems Demo 40% reduction in in-process inventory—repair facilities
2010	Capable Processes for Low-Risk Fielding of Advanced Defense-Essential Technologies	Green-board design tools and processes fully deployed 6-sigma capability for military-unique digital and analog chips Demo 5x better yield in growth and polishing diamond IR domes
	Affordable Military Capability via the World's Best Industrial Capabilities	Demo 80% cost reduction in turbine engine materials Demo 50% reduction in design and qualification time for mechanical and electronic subsystems
	Affordable, Short-Lead-Time Production & Repair at Low Volume	Demo 80% reduction in in-process inventory in repair facilities Demo 60% reduction in production cycle time for complex electromechanical assemblies

Reduce the Risk and Cycle Time To Field Defense-Essential Advanced Technology. Challenges include:

- Developing, refining, and characterizing manufacturing processes for leading-edge superiority technologies just emerging from the laboratories and that do not have market forces to speed their maturation (e.g., thrust vectoring nozzles for aircraft, interferometric fiber optic gyros for navigation).
- Supporting defense-unique products that have no commercial counterpart (e.g., munitions, traveling wave tubes, specialized explosives and propellants, obsolete electronic components).

Designers of defense-essential products require mature processes that will have sufficient cost and capability data to support a 6-sigma approach to design so that the latest technology can be incorporated with reduced risk to cost, schedule, and system performance. Reliable process capability and cost information must be made available to designers in such a way as to promote confident and affordable incorporation of new technology options in new product designs and systems upgrades. Promoting the incorporation of integrated product/process development (IPPD) into the military supplier network is required to achieve significant cycle-time reductions from design through first-time insertion and also achieve predictable and affordable first-time process yield.

3.2.2.3 Related Federal and Private Sector Efforts. The ManTech subarea is actively leveraging funding and related efforts from other federal and private sector sources to advance the area's affordability and speed goals. The objective is to ensure that ManTech only fully funds those things that are defense-essential and beyond the normal risk of industry. DOC and military service acquisition programs have currently committed in excess of $20 million to be expended between FY95–98 on current ManTech programs. In addition, the DOC, DOE, and NSF sponsor between $10–20 million per year in related work in electromechanical design and manufacturing. The individual service laboratories and the national laboratories also provide crucial feed technologies to this subarea's technology base. National and international standards efforts are important to the goals of ManTech as are the technology deployment efforts managed by NIST. Most of ManTech's efforts build directly on private sector products, practices, processes, and lessons-learned that are the result of many years and many dollars of investment by private industry. One such example is a ManTech effort that builds on an earlier 5-year, $5 million assessment by MIT of the worldwide automotive industry (International Vehicle Program). During FY95–98, aerospace industry companies will contribute over $2 million as part of the Lean Aircraft Consortium and between FY96–98 another $7.5 million as part of the Lean Implementation Initiative. Other types of private sector commitments include corporate-funded travel and data gathering in support of active projects, as well as extensive capital investments that companies make to participate in pilot programs and in implementing program results.

3.2.3 *S&T Investment Strategy*

Investments with industry are designed to build on the experience and developments coming out of highly competitive commercial businesses. Two issues are addressed through these investments:

- Demonstration and transfer of best commercial practices and market forces to the manufacture of defense goods.
- Creation of mature manufacturing processes to support production of defense-unique goods that are not influenced by normal market forces.

3.2.3.1 Technology Demonstrations. ManTech contains two programs formally recognized as Advanced Technology Demonstration programs: DTO MP.08.06, Affordable Multimissile Manufacturing ATD, and DTO MP.10.06, IFOG Flexible Manufacturing ATD. ManTech programs typically have technology demonstrations as a key objective. Examples from current ManTech programs include:

- Military avionics from an automotive electronics production line (50% cost savings).
- Military aircraft structure using commercial practices and processes (50% cost reduction).
- Cost reductions in composite engine duct structures (50%).
- Cost and cycle-time reductions for machining precision aspherical optical lenses (30–50%).
- Integrated electronic board and module test information libraries to generate test source code.
- Integrated scheduling throughout a mechanical product supply chain by adapting commercial tools (90% reduction in reschedule time).

3.2.3.2 Technology Development. ManTech encourages teaming of DoD laboratories and development centers with universities and industry research organizations, defense contractors, and technology vendors to ensure insertion paths for new technologies. The largest ManTech investments in technology development are targeted on maturing advanced military-essential technologies emerging from 6.2 and 6.3 development to accelerate and reduce the risk of their transition into military products. Examples include:

- Improved yield for multiple bandgap solar cell manufacturing (by 50%).
- Qualification of polymeric sabots for 25mm M919.
- Laser processing technology for low-cost powdered titanium structural members.
- Technology for composite armored vehicles.
- Fiber placement for high-performance airframe structures.
- Low-volume silicon wafer process for very large scale integrated (VLSI) digital parts.
- Staring-class Dewar production processes.

3.2.3.3 Basic Research. ManTech relies on continuing advances in a broad spectrum of basic research. Examples include sensors, metrology, and microelectromechanical systems (MEMS) for real-time process feedback and control, innovative material processing concepts, new chemical processes (especially to reduce environmental effects), robotics, knowledge representation, and modeling and simulation in a broad sense, from product and process physics to queuing theory. These research areas are becoming even more important as defense production quantities decline and first-item quality or time-to-field fleet become the keys to affordability.

3.3 Civil Engineering

3.3.1 *Warfighter Needs*

The civil engineering subarea directly supports emerging warfighter requirements by providing technologies for force deployment, employment, protection, sustainment, and base support. These technologies are critical to strategic, operational, and tactical missions in all climatic and geographical areas. Six high-priority requirements are addressed:

- *Mission planning and execution technologies* that are both faster and less manpower-intensive than current systems are being developed for mobility/countermobility (M/CM), survivability, and general engineering (G-Eng) missions. The M/CM/G-Eng analytical software will be integrated into command and control architectures.
- *Ship cargo discharge concepts and operational systems* to enable rapid transfer of cargo to shore from amphibious assault and strategic sealift ships in higher sea states and from longer standoff distances than currently possible. This will increase operational availability for regions such as the Far East from 15 to 25 days per month.
- *Bare airbases* are being designed with mobile, easily deployable facilities to enable increased numbers of sorties from forward locations, very rapid reaction times, and reduced deployment costs.
- *Force protection technologies* (e.g., foxholes, fixed facilities) are being designed and improved to defend against weapon threats ranging from small arms to terrorist weapons to advanced conventional weapons with multispectral sensor capabilities. Relevant innovations include battlefield protective fortifications, simplified vulnerability/survivability assessments, facility retrofits, and designs to counter the effects of conventional weapons and terrorist threats.
- *Firefighting agents and equipment* are being developed to protect weapon systems, critical facilities, munitions and fuel stores, and personnel to reduce system damage and casualties resulting from fires and to accelerate reconstitution of warfighting capabilities.
- *Pavement design, repair, and material criteria* are under development to ensure reliable support for current and future-generation aircraft and vehicles used in military operations. Relevant innovation requirements include advanced material characteristics and construction technologies, advanced analytical models to allow rapid and accurate pavement capacity determinations, and criteria to use local materials, thus minimizing logistical construction burdens and reduce time to availability.

3.3.2 *Overview*

3.3.2.1 Goals and Timeframes. The goals of the civil engineering subarea are shown in Table V–4.

Table V–4. Goals of the Civil Engineering Subarea

Year	Goal
1997	Demonstrate lightweight, low-volume deployable power generator (40% smaller/50% lighter than current systems) Develop new global near-real-time mobility modeling and knowledge-based obstacle planning with reliability quantification Increase biodegradability of firefighting foam by 50%
1998	Minimize shipping container marshaling by increased contents visibility, saving up to $150 million per operation Develop procedures for retrofitting building components against vehicle bomb threats Simplify survivability analysis procedures for assessment and construction of field fortifications Provide camouflage materials and lightweight material revetments for fortifications/aviation asset protection
1999	Demonstrate pavement design and repair systems using local materials and modified pavement binders reduce construction costs by 10% Develop lighter mats for repairing/expanding aircraft operating surfaces; reduce weight by 50% Increase operational availability of ship discharge lighterage by 67%; increase capacity by 300%
2001	Develop very high strength constructable (200 MPa) concrete for hardened structures (3x current) Demonstrate use of lightweight components for modular construction of protective structures Reduce waterfront structure maintenance fivefold Develop hardening techniques for walls and roofs to resist terrorist mortar attacks Develop library of material models for conventional weapons effects code development Develop assessment and installation technologies to reduce elevated causeway installation time from 9 to 7 days Demonstrate superconductive generator for bare base applications Reduce firefighter heat stress by 50%, and improve training by 90% using virtual reality
2002	Develop pavement design and repair systems for new aircraft using smart materials to increase functional life by 10 years Provide materials/methods for worldwide construction with limited resources Provide technologies to rapidly assess/repair/upgrade bridge structures Develop stealth shelter technologies for low-visibility bare base operations
2005	Reduce infrastructure acquisition, maintenance, and repair costs by 20% of 1990 Reduce facilities energy consumption by 30% of 1985 Improve firefighting vehicle response by 75% with active suspension and forward-looking IR
2006	Validate survivability/vulnerability assessment model that includes camouflage concealment detection measures Develop self-erecting air-mobile shelters, reducing time and manpower by 80% and 50%, respectively Demonstrate advanced fuel cell power generation for bare bases; increase efficiency by 30% Provide common representation of M/CM/G-Eng in C/C architecture with improved throughput capabilities

3.3.2.2 Major Technical Challenges. The major technical challenges include development of lightweight, high-strength, high-ductility, or innovative adaptive construction materials and criteria for expedient and long-term force protection (e.g., carbon fiber wraps, mylar films, radar-absorbing and thermally reflective coatings); characterization of nonlinear, viscoelastic, visco-plastic material response under dynamic loading (e.g., projectile penetration, explosive detonation, vehicle movement, breakwater interaction with waves); development of three-dimensional, coupled analytical software that replicates nonlinear material behavior for use in accurate assessment of mobility and structural response; development of innovative construction concepts for mobile military operations; and advancement of understanding of the physics of fire and extinguishing mechanisms.

3.3.2.3 Related Federal and Private Sector Efforts. The 1994 Laboratory Infrastructure Capability Study concluded that DoD has unique civil engineering R&D programs, execution capabilities, and supporting facilities, and that the U.S. construction industry cannot provide the civil engineering technologies required by DoD. The study report stated: "The DoD civil engineering function currently has a very high percentage of in-house R&D expertise. The Panel proposes that the service engineering labs be greatly expanded and used as a springboard for building a broad-based government-industry-academic applied research effort in this technology area." The unique nature of DoD's civil engineering S&T capabilities is reflected by the fact that government agencies use DoD civil engineering laboratories' unparalled expertise and facilities for performance of unique research worth over $100 million each year. DoD laboratories accept only reimbursable work that complements their own capabilities and does not interfere with their DoD S&T responsibilities. The civil engineering program uses and contributes to a Civil Engineering Research Foundation coordinated industry and government 10-year plan for high-performance contruction materials. It also builds on (and partially relies on) fundamental advances by the NSF's university-executed research in several engineering disciplines and technologies (cementious materials, composites, nondestructive testing, structural and geotechnical dynamics).

3.3.3 *S&T Investment Strategy*

3.3.3.1 Technology Demonstrations. Twelve TDs and ATDs are planned in this subarea:

- *Total Distribution ATD* will describe and evaluate transportation infrastructure within a theater of operation. It will integrate knowledge- and physics-based algorithms using a common infrastructure for data structures, the graphic information system, and military algorithms to transfer data into usable countermobility and survivability information.
- *Logistics Over-the Shore TD* will demonstrate the feasibility of an innovative Rapidly Installed Breakwater System (RIBS) capable of reducing local sea state conditions from sea state 3 to sea state 2 or lower.
- *Higher Sea State Logistics Support for Expeditionary Forces ATD* (MP.12.11) will demonstrate the open-sea connection of the modular designed Amphibious Cargo Beaching Lighter (ACBL). The ACBL is being developed for sea state 3 capability in ship-to-shore transfer of cargo in support of assault operations and for retiring the present ship-to-shore barge systems. The ACBL will increase operational days per month in high sea state regions for low- and medium-intensity conflicts from 15 to 25

days, reduce assembly time from 5 to 2 hours, and increase cargo-carrying capacity from one to three Abrams tanks.

- *D-Day Fuel Support for Expeditionary Forces ATD* (MP.13.11) will demonstrate lightweight, high-strength, collapsible fuel containers and handling systems to move fuel from ship-to-shore during the initial stages of amphibious assault. The DMFD in 500-, 1,500-, and 5,000-gallon, continuously woven, seamless fuel bladders will be delivered ashore by high-speed landing craft or helicopter.

- *Life-Extension Capabilities for the Navy's Aging Waterfront Infrastructure* (MP.18.11) will increase the load capacity to meet new mission performance and safety requirements. This will be demonstrated through (1) structural composite reinforcements to accommodate high concentrated crane loads for which the structural design and the old piers were not designed (cost $5 million versus $30 million for demolition and replacement); (2) concrete repair technology with extended durability (from the present 3 years to 15 years); (3) corrosion stabilization steel reinforcements using plasma-sprayed titanium sacrificial electrodes to extend pier life by 20 to 30 years; and (4) improved modeling for assessing pier structural safety with respect to operational loads and recently updated environmental resistance requirements.

- *New Family of Portable Shelters ATD* will demonstrate advanced composite panels for use with the prototype Modular Erectable Rigid Wall Shelter (MERWS). The modified MERWS will be substantially lighter than the existing Bare Base Shelter, and it will be more energy efficient.

- *Lightweight Deployable Power Generator ATD* will demonstrate a prototype advanced lightweight generator (120 kW) with motor/generator sets that are 40% smaller and 50% lighter than current systems. This technology will significantly reduce the airlift and logistics support required for bare base deployments.

- *Simplified Survivability Analysis TD*, which is included within the mobility and survivability battlefield operating system of the Army's Battle Command System, will be demonstrated at Prairie Warrior 97 and Task Force XXI Advanced Warfighting Experiment.

- *Advanced Training System TD* will demonstrate a virtual reality firefighter training system that will improve significantly the effectiveness and safety of firefighter training, thereby greatly reducing casualties and damage to weapon systems from fires.

- *Poor Visibility Emergency Response System ATD* will demonstrate an all-weather, day-and-night, crash-and-fire-rescue capability that will enable effective rescue response in inclement weather, redressing a current DoD deficiency.

- *Pavement Material TD* will demonstrate material characterization, design, and repair systems through laboratory testing and field evaluations to verify design system criteria for the use of "smart" materials, local materials (which may not be the best type or quality), and modified pavement binders.

- *Expedient Surfaces TD* involves field evaluations of innovative surface materials (e.g., geotextile mats) and installation procedures to verify reductions in construction time and the capability to provide service for military aircraft and vehicles.

3.3.3.2 Technology Development. Many of the emerging technologies in this subarea are candidates for future TDs and ATDs. Technologies under development include:

- *Countermobility* technologies will provide knowledge-based obstacle planning, techniques, and equipment used for realistic CM engineering using obstacle planner software, employment options, and resourcing.
- *Mobility* technologies will provide accurate, near-real-time accurate mobility assessments using high-resolution, high-fidelity, all-weather mobility models; worldwide, high-resolution mobility data; and common representation of M/CM.
- *Transportation infrastructure assessment technologies* will provide criteria to assess, maintain, repair, upgrade, and construct theater-of-operation transportation networks that encompass the use of expedient surfacing materials and RIBS for improved logistics throughput. Amphibious logistics technologies will enable rapid transfer from ship-to-shore of cargo in higher sea states with improved offloading on the elevated causeway. Accelerated pile cutting and joining (splicing) techniques, reducing times from 90 to under 5 minutes, will allow for quicker elevated causeway installations. Improved site selection procedures via acoustic subbottom profiling will reduce total piling operations for a typical elevated causeway installation.
- *Fuel transfer logistics* technologies will extend ship-to shore pumping of fuel from standoff distances of 5,000 to 20,000 ft, new packaging concepts will reduce shipping platform needs by 30%, and ship-to-shore batch liquid/fuel delivery systems will enable execution of the Marine Corps' operational maneuver from the sea operations.

Four technology objectives are planned:

- *Composite Materials* will be integrated into panels and deployment approaches for transportable matting for aircraft runways. Performance testing will simulate aircraft traffic on a variety of subgrades.
- *Force Protection Fortifications and Structures Technologies* will provide materials, criteria, and software suites for the design and construction of survivability measures to counter a wide variety of threats, including terrorism and advanced conventional munitions.
- *Combined Firefighting and Hazardous Materials Ensembles* will permit sustained operations in intense heat and highly toxic chemical environments. An ultra high speed detection and suppression system will suppress munitions and high-energy fuel fires at the incipient stage.
- *Pavement Material, Design, and Repair System Criteria* will provide reliable pavements and airfields for advanced current and future-generation aircraft using "smart" and local materials at reduced construction and maintenance costs. Knowledge representation models, decision processes, and optional resource allocation techniques

will ensure that installation-management decisions are integrated with force structure and weapon system decisions. Cold-climate construction techniques and inspection technologies will provide for expedient condition assessment and repair.

3.3.3.3 Basic Research. Relevant basic research focuses on enhancing understanding of stress-strain relationships at the smallest aggregate of particles within the soil matrix, the constitutive behavior of construction materials, and soil-moisture-strength relationships as a function of climatic influences across the world. These efforts will directly contribute to development of a high-resolution, high-fidelity mobility model that accurately predicts worldwide vehicle movements, both on and off road. In addition, research on constitutive behavior and micromodeling of asphalt concrete provides basic understanding of asphalt response to loads. Basic research on the constitutive behavior of concretes is leading to improved predictions of the responses of concrete slabs to projectile impact and penetration and of concrete structural elements to blast loadings.

3.4 Environmental Quality

3.4.1 *Warfighter Needs*

Research and development in the environmental quality (EQ) subarea supports formal service-approved user requirements. EQ research objectives are to improve the performance of pollution control equipment, provide the capabilities to mitigate the impacts of novel new materials being adopted for advanced weapon systems, minimize environmental impacts associated with peacetime training, and when possible, reduce weapon system life-cycle cost. DoD mission readiness requires unencumbered operation of ships, aircraft, and ground vehicles. Support facilities such as maintenance depots, shipyards, weapon stations, munitions plants, and bases require advanced pollution mitigation technologies to maintain weapon systems in mission-ready condition. Local, national, and international environmental regulations restrict military operations by increasing operating costs, reducing maintenance capabilities, and limiting training areas and opportunities. Efforts in environmental quality contribute directly to the Joint Readiness Warfighter Objective and to all weapon systems and testing platforms by reducing both the restrictions on peacetime military operations and the cost of compliance from these environmental protection laws. New technologies are developed for DoD-specific problems if suitable technology is not commercially available or when the best available technologies are either too costly or fail to meet performance criteria under military operating conditions.

Work is divided into four areas: cleanup, compliance, pollution prevention, and conservation. Advanced technologies in cleanup are under development to characterize and treat soils and groundwater contaminated with hazardous and toxic compounds. Contaminants of military interest are explosives, energetics, dense nonaqueous-phase liquids, and heavy metals. The objectives are to reduce cleanup costs, expedite cleanup, and ensure the protection of human health and the environment. Existing control technologies may not meet anticipated air, water, land, and noise regulations for future weapons systems.

Technical efforts in compliance provide advanced "end-of-the-pipe" pollution control, treatment, recycling, and disposal technologies. Hazardous and toxic gaseous, liquid, or solid wastes are undesirable, but currently unavoidable byproducts of DoD systems, operations, and processes.

Complementing compliance technologies is pollution prevention. Maintenance and manufacturing processes are being developed to improve material performance and to avoid the hazardous waste and fugitive emissions generated by DoD installations, facilities, and equipment. These efforts will both reduce the burden placed on existing pollution control equipment and the overall amounts of hazardous compounds released to the environment. Soil, marine, and cultural resources at and around sea, land, and air ranges are susceptible to degradation from military operations.

Work in conservation is intended to mitigate and redress impacts on DoD training ranges from readiness training and weapon development testing.

3.4.2 *Overview*

3.4.2.1 Goals and Timeframes. Technologies under development are listed in Table V–5.

3.4.2.2.2 Major Technical Challenges. Challenges include developing technologies to detect and map subsurface contaminants masked by the density and opaqueness of earth media; quantifying the biological, chemical, and physical heterogeneity at the large number of contaminated

Table V–5. Goals of the Environmental Quality Subarea

Time	Goals
1998	Demonstrate nontoxic, easy-release antifouling coatings; eliminate heavy metal pollution
	Demonstrate no-/low-VOC, low-observable paint coatings; significantly reduce fugitive emissions
	Reduce NOx emissions from jet engine test cells and ground equipment by 90%
	Demonstrate advanced sensors and samplers for real-time monitoring of subsurface contaminants; reduce O&M costs 50%
	Determine effects of smokes and obscurants on plants and animals
2000	Develop advanced atmospheric models for launch ranges; increase space vehicle availability by 50%
	Reduce by 50% the use and disposal of toxic chemicals listed by the EPA
	Reduce volume of shipboard and facility hazardous waste disposal by 50%
	Develop advanced sensors for detection of UXO—35% cost savings
	Develop land-based carrying-capacity model to improve training realism—$15 M/yr savings
	Determine the effects of maneuvers on TES
2002	Develop pollution-free paint and depaint system; demonstrate zero fugitive emissions from facilities
	Demonstrate advanced biological treatment of energetic and complex organic wastes; reduce cost by 50%
	Reduce cost of energetic material remediation from $1.00–5.00 kgal to $0.10–2.00 kgal
	Demonstrate advanced visualization of subsurface contamination—50% reduction in analysis and selection time
	Accurately monitor and predict noise impacts on TES; demonstrate proactive training noise avoidance
2005	Develop hybrid sensor/GPS/GIS field instrumentation to detect and monitor DNAPLs in real time—25% cost reduction
	Demonstrate mobile hazardous material destruction system for battlefield/bare base deployment
	Eliminate all polluted wastewater discharges from ships; exceed MARPOL criteria worldwide.

sites; accurately predicting the interactions of biological (including the interactions and pathways of aerobic and anaerobic microorganisms), chemical, and physical phenomena in the subsurface; optimizing treatment at varying concentrations and states of mixing; and incorporating the different views of acceptable risk held by regulators and stakeholders.

In pollution control and prevention, challenges include the diversity and complexity of waste streams; variability in the concentrations and composition of wastes; energetic instability of propellants, explosives, and pyrotechnics; and destruction or conversion of wastes and contaminants without the production of unwanted or hazardous byproducts. Additionally, development of new materials and processes that are environmentally acceptable and meet or exceed military performance criteria are under development. The use of novel new materials in future weapon systems will pose problems in materials and environmental sciences that have yet to be realized. Lastly, military training ranges must adapt to changes in mission, equipment, and training. DoD land and resource managers must understand vastly complex ecosystems and predict the response of sensitive species to operations-induced stress. Affordable modeling and biophysical technologies must be developed to mitigate, restore, and minimize damage to natural and cultural resources to allow unencumbered use of training and testing ranges.

3.4.2.3 Related Federal and Private Sector Efforts. Environmental quality technical efforts are pursued collaboratively and cooperatively with EPA, DOE, NASA, USDA, academia, and private industry. The highest degree of program integration are in situ and ex situ bioremediation; DoD site characterization and analysis; DoD groundwater modeling; thermal and nonthermal plasma destruction of hazardous effluents; advanced membranes for chemical separation; specialized catalysts and regenerable chemical sorbents for air pollution control; electrochemistry; biotechnology, photolytic oxidation, sonic reaction enhancement, and supercritical water oxidation for the destruction of recalcitrant wastes; carrying-capacity models; natural resource characterization; and integrated decision support models for management of land, cultural resources, ecosystems, and threatened and endangered species.

3.4.3 *S&T Investment Strategy*

3.4.3.1 Technology Demonstrations. Five technology objectives will be demonstrated:

- *Hazardous and Toxic Waste Treatment/Destruction for DoD Operations*—develop and demonstrate advanced technologies for end-of-the-pipe treatment of difficult-to-destroy wastes generated by DoD operations and reduce the costs of complying with existing environmental regulations.
- *Metal Cleaning Processes and Coating Materials*—develop, demonstrate, and transition environmentally compliant surface preparation and metal cleansing processes, paints, and other coating materials for military systems in order to meet pollution prevention.
- *Cleanup of Contaminants*—provide less expensive and more effective technologies for the characterization and treatment of soils and groundwater contaminated with hazardous and toxic wastes from past DoD activities at over 21,000 sites in order to reduce the estimated $30–35 billion cleanup cost.

- *Plasma Arc Shipboard Waste Destruction System*—develop and demonstrate an effective method for thermal destruction of shipboard waste to greatly reduce the volume of shipboard waste that must be stored until return to port.
- *Sustainable Land Use for Training and Testing*—develop the tools to quantify and predict the impacts of military activities on land usage and to understand the associated military and environmental risks to provide increased flexibility in land use and no loss of training lands due to overuse.

3.4.3.2 Technology Development. Technologies under development are listed in Table V–6.

Table V–6. Environmental Quality Technologies

Technology	Purpose
Instrumentation, Sensors & Monitors (Fiber Optics, Laser Fluorescence, Remote, Low Level)	VOCs, DNAPLs, POL, UXO, Water Quality, Treatment Process Control, Noise, Air Emissions, and Cultural & Natural Resources
Hazard Prediction & Assessment Modeling	Treatment Alternatives, Fate & Effects of Contaminants and Ecosystem & Human Health Impacts
Biotechnology (Remediate, Filtrate, & Destroy)	Mil Site Remed, PEP Wastes, HAPs, & VOCs
Advanced Waste Destruction Processes (Supercritical Fluids, UV/Chemical Oxidation, etc.)	Solid, PEP, & Hazardous Wastes
Air Emissions Control (Nonthermal Plasma, Catalysts, Sorbents, Fuel Cells)	Jet Engine, Ground Equipment & Ship Engine NOx & Greenhouse Gases
Waste Concentration/Separation (Membrane, Electrostatic, Ultrasonic, Radio Frequency)	Ship & PEP Wastewaters & Heavy Metal Sludges
Waste Immobilization and Vitrification	Treatment Residues and Lead-Based Paint
Nonpolluting Processes (CO_2, Oxygen Plasma, etc.)	Cleaning for Metal Working and Machining
Nonpolluting Coatings (e.g., Antifouling)	Ships, Aircraft, & Military Equipment
Acoustic Survey Techniques	Locate, Identify, & Track Marine Mammals

3.4.3.3 Basic Research. Basic research improves our understanding of the fundamental phenomena and underlying mechanisms needed to exploit emerging EQ technologies. Extending the life cycle of aging weapons systems in an era of strict environmental regulation is a critical need in DoD. Structural materials research is providing valuable insights into corrosion detection and material life extension. Basic research in materials chemistry, intelligent systems, hydrodynamics, and meteorology will enhance the effectiveness of contaminant sensing, treatment and modeling in the air and subsurface. Advances in biotechnology, materials chemistry, and processes are providing valuable new technologies for hazardous waste treatment. Scientific data from terrestrial sciences and ocean sciences provide models for the behavior of threatened and endangered species and of anthropological and cultural resources providing for ecosystem-level management at land and sea ranges.

GLOSSARY OF ABBREVIATION AND ACRONYMS

ACBL	Amphibious Cargo Beaching Lighter
ACE	aerospace chromium elimination
AGE	aerospace ground equipment
AM^3	Affordable Multimission Manufacturing
AMRAAM	Advanced Medium-Range Air-to-Air Missile
ASTOVL	Advanced Short Takeoff and Vertical Landing
ATD	Advanced Technology Demonstration
ATF	Alcohol, Tobacco and Firearms
AWACS	Airborne Warning and Control System
CBN	chemical/biological/nuclear
C/C	carbon/carbon
CENTCOM	Central Command
CFCC	continuous fiber ceramic composite
CM	countermobility
CMC	ceramic matrix composite
CONUS	continental United States
CVX	Aircraft Carrier Experimental
DARPA	Defense Advanced Research Projects Agency
DNAPL	dense nonaqueous phase liquid
DOC	Department of Commerce
DOE	Department of Energy
DOL	Department of Labor
DSWA	Defense Special Weapons Agency
DTAP	*Defense Technology Area Plan*
DTO	Defense Technology Objective
DUSD(ES)	Deputy Under Secretary of Defense (Environmental Security)
DVE	drivers vision enhancer
EFOGM	Enhanced Fiber Optic Guided Missile
EHF	extremely high frequency
EPA	Environmental Protection Agency
EQ	environmental quality
FAA	Federal Aviation Administration
FMST	Future Missile System Technology
FO	forward observer
FY	fiscal year
G–Eng	general engineering
GEOSAT	Geosynchronous Satellite
GIS	Geographic Information System
GPS	Global Positioning System
HAP	hazardous air pollutant
HEXSAT	Nanosatellite System Concept
HM&E	hull, mechanical and electrical
HSLA	high strength, low alloy
HY	high yield

IBAS	Improved Bradley Acquisition System
IFOG	interferometric fiber optic gyro
IPPD	integrated product/process development
IR	infrared
IRST	infrared search and track
ITAS	Improved Target Acquisition System
JASSM	Joint Air-to-Surface Standoff Missile
JCS	Joint Chiefs of Staff
JDAM	Joint Direct Attack Munition
JETC	jet engine test cell
JSA	Joint Strike Aircraft
JSF	Joint Strike Fighter
JSOW	Joint Standoff Weapon
JSTARS	Joint Surveillance Target Attack Radar System
kW	kilowatt
LAV	light armored vehicle
LCAC	landing craft air cushion
LOSAT	Line-of-Sight Antitank
$LRAS^3$	Long-Range Advanced Scout Surveillance System
ManTech	manufacturing technology
MARPOL	marine pollution
MEMS	microelectromechanical systems
MERWS	Modular Erectable Rigid Wall Shelter
M/CM	mobility/countermobility
MIT	Massachusetts Institute of Technology
MMC	metal-matrix composite
M/P	Materials/Processes
MPa	megapascals
NASA	National Aeronautics and Space Administration
NDCEE	National Defense Center for Environmental Excellence
NDE	nondestructive evaluation
NDI	nondestructive inspection
NIST	National Institute of Standards and Technology
nmi	nautical mile
NMR	nuclear magnetic resonance
NOx	nitrous oxide
NQR	nuclear quadrupole resonance
NSF	National Science Foundation
NSSN	Next-Generation Nuclear Attack Submarine
O&M	operations and maintenance
O&S	operations and support
OICW	Objective Individual Combat Weapon
OMC	organic-matrix composite
PEBB	power electronic building block
PEP	propellants, explosives, and pyrotechnics
POL	petroleum, oil, lubricants

R&D	research and development
RIBS	Rapidly Installed Breakwater System
S&T	science and technology
SiC	silicon carbide
SLED	surface light emitting diode
SLEP	Service Life Extension Program
TD	Technology Demonstration
TES	threatened and endangered species
Ti	titanium
TWS	thermal weapons sight
TWT	traveling wave tube
UAV	unmanned aerial vehicle
USDA	U.S. Department of Agriculture
UV	ultraviolet
UXO	unexploded ordnance
VLSI	very large scale integrated
VOC	volatile organic compound
WCM	wired-cored matrix
WES	Waterways Experiment Station

CHAPTER VI
BIOMEDICAL

1. INTRODUCTION

1.1 Definition/Scope

The Biomedical science and technology area is divided into seven technology subareas (Figure VI–1), with joint coordination and cooperation within and among subareas accomplished through the Armed Services Biomedical Research Evaluation and Management Committee and its subordinate joint technology coordinating groups. The program is focused to yield superior technology in support of the DoD mission to provide health support and services to U.S. armed forces. Unlike other national and international medical S&T investment that is focused on public health problems of the general population, military medical S&T is concerned with preserving combatants' health and optimal mission capabilities despite extraordinary battle and nonbattle threats to their well being. Preservation of individual health and well being sustains warfighting capabilities.

A glossary of abbreviations and acronyms used in this chapter begins on page VI–24.

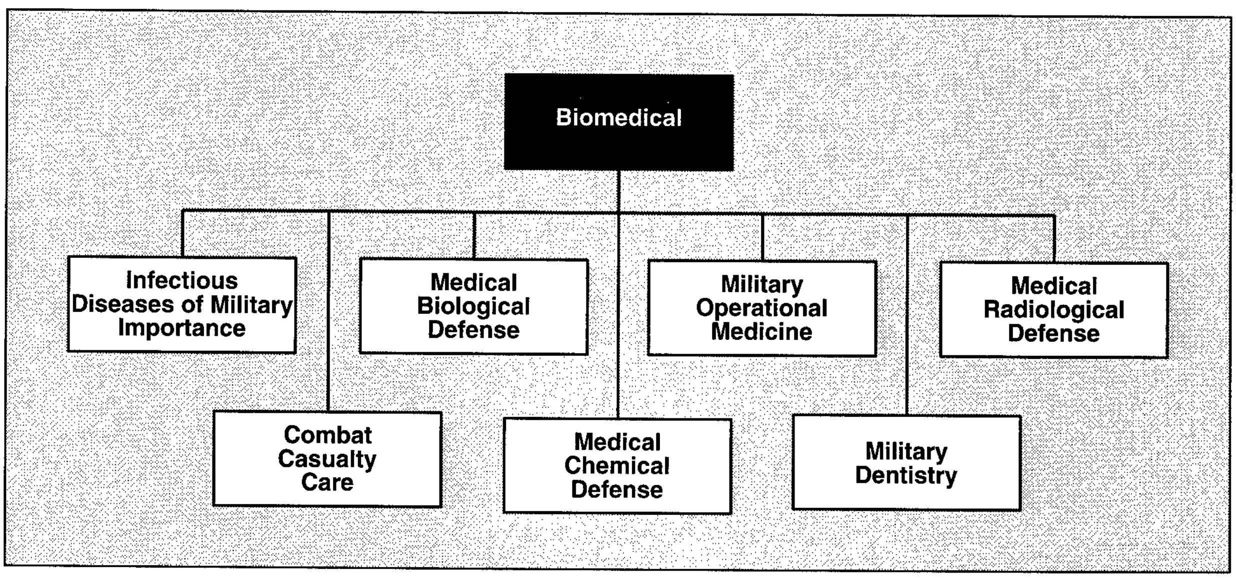


Figure VI–1. Planning Structure: Biomedical Technology Area

1.2 Strategic Goals

The strategic goals of the Biomedical technology area include:

- Providing medical technology to enable a full spectrum of military operations for crisis and conflict resolution.
- Protecting and sustaining warfighters from battle and nonbattle health threats.
- Optimizing military performance; survival and stabilization of combat casualties.
- Providing the world's best casualty evacuation and medical support.
- Providing new-generation medical equipment to support battle and nonbattle operations.

1.3 Acquisition/Warfighting Needs

Modern warfighting strategy emphasizes preparedness for regional rather than global conflict utilizing continental U.S. (CONUS)-based forces. Joint Staff-defined requirements emphasize preventive medicine to reduce casualties resulting from disease and nonbattle injuries, immediate life-saving treatment, resuscitative care and stabilization, and technologies for rapid evacuation of casualties to definitive-care CONUS-based facilities. The deployable health service support structure must recognize and overcome logistics and communications constraints, reducing its in-theater medical footprint and the lift requirements associated with a forward positioning of medical care assets, while simultaneously providing medical communications systems that are fully integrated with operational command systems. Capability to enhance personnel readiness for joint and combined operations is an identified warfighting need.

Table VI–1 shows the technology forecast for the military Biomedical area. Development of novel vaccines will protect deployed forces against a number of debilitating and life-threatening infectious diseases to which they are now vulnerable. Life-support systems with enhanced mobility and physiological monitoring capability will be provided to enable in-flight maintenance of patient stabilization, allowing safe long-range evacuation of critically injured service personnel. Provision of vaccines, protectants, and therapeutics directed against biological and chemical threat agents will deter and constrain proliferation of these weapons while defeating their use. Scientifically based operational doctrine and ration supplements will improve and better sustain individual operational capabilities. Evacuations for dental emergencies will be reduced by application of improved forward diagnostic and dental treatment technologies. New radioprotective strategies will be developed that provide protection against both prompt and late effects of ionizing radiation.

Table VI–1. Biomedical Technology Forecast

Current Baseline	2000	2005	2010
INFECTIOUS DISEASES OF MILITARY IMPORTANCE SUBAREA			
Drugs for prevention and treatment of malaria Vaccines for hantavirus Monoclonal antibodies for forward diagnosis	Campylobacter vaccine Field assays for malaria diagnosis Topical antileishmanial Shigella vaccine	Combined malaria vaccines (falciparum/ vivax) Combined dengue vaccines Second-generation ETEC vaccine	Broad spectrum antivirals Single-dose vaccines Shigella DNA vaccine Combined enteric vaccines
COMBAT CASUALTY CARE SUBAREA			
Antimicrobial dermal dressing Intraosseous vascular access device Small-volume resuscitation solutions 10–12-wk extended liquid red cells Frozen platelets in DMSO	Improve blood storage Reduce far-forward intravenous fluid requirements Medical decision-assist devices Provide individual O_2 generators for evacuation	Free-radical scavenger to reduce secondary effects of trauma DHEA immuno-protectant Intensive care evacuation platform Local hemostatic agents Field blood substitute Universal blood reagents	"Extensive care" evacuation platform Hibernation drug O_2 free-radical scavengers
MEDICAL BIOLOGICAL DEFENSE SUBAREA			
Microencapsulated vaccines for SEB Genetically engineered vaccines for VEE botulinum vaccine Forward-deployed diagnostics	Bioengineered toxin scavengers Ricin protection	Nucleic acid therapy Human monoclonal antibody therapy	Nucleic acid immunizations Combined oral vaccine
MEDICAL CHEMICAL DEFENSE SUBAREA			
Cyanide pretreatment drug Topical skin protectant Improved anticonvulsant	Catalytic pretreatment for agents Reactive topical skin protectant	Monoclonal antibodies for nerve agent protection Vesicant agent countermeasure	Receptor-targeted therapeutics Immunoprophylaxis for CW agents Vesicants countermeasure
MILITARY OPERATIONAL MEDICINE SUBAREA			
Blast standards Spatial disorientation model Vestibular test battery	Performance enhancing nutrients Vigilance/alertness monitor Electromagnetic radiation standards RF radiation dosimeter Advanced laser protection	Physiological status monitors Spatial awareness incorporation into trainers Improved injury prevention guidelines Pharmacodynamic model of neurotoxicity	Sleep/alertness enhancers Treatments for laser retinal injury Memory enhancers Strength enhancers
MILITARY DENTISTRY SUBAREA			
Microencapsulated antibiotics Filmless dental imager Rapid dental diagnostics	Ultra long duration anesthetics Fiber optic dental probe	Nonmetal shrapnel visualization CAD/CAM prosthetics	Surgical robotics Dental disease prophylaxes Epidemiology update
MEDICAL RADIOLOGICAL DEFENSE SUBAREA			
Immunomodulator therapy Anti-emetic compounds	Novel radioprotective drugs Fieldable biodosimetry capability	Modeling for casualties in NBC environments	Combined injury treatment protocols

1.4 Support for Combating Terrorism

Proliferation of biological, chemical, and nuclear weapons of mass destruction (WMD) among diverse states and the rising potential for terrorist access to WMD, especially as the result of state-sponsored terrorism, poses health threats that are directly confronted by component subareas within the Biomedical area. The medical biological defense, medical chemical defense, and medical radiological defense subareas most directly support combating terrorism. These subareas develop and provide superior medical countermeasures to protect, diagnose, and treat personnel exposed to the effects of WMD. These personnel include both military personnel involved in counterterror activities and the civilian populace who are potential victims. Less directly, other Biomedical subareas support combating terrorism through technologies to provide for casualty management under austere and mass casualty situations. Principal Defense Technology Objectives (DTOs) contributing to counterterrorism are:

MD.04.J00	Medical Countermeasures for Botulinum Toxin
MD.13.J00	Medical Countermeasures for Staphylococcal Enterotoxin B
MD.14.J00	Medical Countermeasures for *Yersinia pestis*
MD.15.J00	Medical Countermeasures for Encephalomyelitis Viruses
MD.05.J00	Chemical Agent Prophylaxes
MD.07.J00	Medical Countermeasures for Vesicant Agents

Demonstrated scientific excellence and accomplishments of these DTOs and related technologies within the Biomedical area deter and constrain areas that might otherwise be very attractive terrorist initiatives. The effectiveness of these technologies defeat the use of such weapons by terrorist organizations. Finally, applications of the technologies contribute to effective monitoring of terrorist activities.

2. DEFENSE TECHNOLOGY OBJECTIVES

The DTOs applicable to the Biomedical subareas are as follows:

Infectious Diseases of Military Importance

MD.02.J00	Vaccines for Prevention of Malaria
MD.06.J00	Prevention of Diarrheal Diseases
MD.12.J00	Antiparasitic Drug Program

Combat Casualty Care

MD.03.J00	Far-Forward Assessment and Treatment for Blood Loss; Development of Blood Products and Resuscitation Fluids
MD.09.J00*	Advanced Medical Technology—Advanced Field Medical Support in Forward Combat Areas
MD.11.J00	Far-Forward Assessment, Treatment, and Management of Combat Trauma and Severe Hemorrhage and Sequelae

*Joint program involving both combat casualty care and military operational medicine subareas.

Medical Biological Defense

MD.04.J00	Medical Countermeasures for Botulinum Toxin
MD.13.J00	Medical Countermeasures for Staphylococcal Enterotoxin B
MD.14.J00	Medical Countermeasures for *Yersinia pestis*
MD.15.J00	Medical Countermeasures for Encephalomyelitis Viruses

Medical Chemical Defense

MD.05.J00	Chemical Agent Prophylaxes
MD.07.J00	Medical Countermeasures for Vesicant Agents

Military Operational Medicine

MD.01.J00	Sustained Operations Enhancement Ensemble
MD.08.J00	Laser Bioeffects Countermeasures
MD.09.J00*	Advanced Medical Technology–Advanced Field Medical Support in Forward Combat Areas
MD.10.J00	Toxic Hazards Evaluation Tools

*Joint program involving both combat casualty care and military operational medicine subareas.

3. TECHNOLOGY DESCRIPTIONS

3.1 Infectious Diseases of Military Importance

3.1.1 *Warfighter Needs*

Infectious diseases pose a significant threat to successful completion of military missions, especially when U.S. forces have no natural immunity or protection. For example, diarrheal disease affects 20–30% of soldiers deployed outside continental U.S. (OCONUS), malaria infection rates of up to 600 per 1,000 troops annually were seen in Vietnam, and cutaneous and visceral leishmaniasis infections were the most common chronic infection in Operation Desert Shield/Storm veterans. Dengue fever hospitalization rates in Haiti reached 5.3 per 10,000 personnel per week despite emphasis on personal protective measures. Prevention of disease by immunization is a valuable force multiplier and enables the full spectrum of military alternatives for resolution of regional conflict.

The Joint Staff has requested priority for medical technology supporting prevention and treatment of diseases. Near-term control measures will depend on existing personal protective measures and personal hygiene for the prevention of malaria and diarrheal diseases. Mid-term impact includes adding a licensed antibiotic to the routine treatment of drug-resistant malaria. Far-term introduction of new vaccines will prevent 80% of all cases of malaria, 80% of the most common causes of diarrhea, and 90% of all cases of dengue that would occur in unvaccinated personnel. Much of this work is conducted in the six DoD OCONUS laboratories and supports the Presidential Decision Directive NSTC–7, "Emerging Infectious Diseases," 12 June 1996, which calls for DoD to conduct a global surveillance program for infectious disease.

3.1.2 *Overview*

3.1.2.1 Goals and Timeframes. The goals of the infectious disease subarea are to protect soldiers from incapacitating infectious diseases by the development of vaccines and prophylactic drugs and to return infected personnel to duty by the discovery of effective drug treatment. It is anticipated that the most common worldwide infections affecting U.S. warfighters can be controlled by vaccines by the year 2007. In addition, this program will identify endemic disease threats throughout the world supporting a database of emerging infectious diseases so that informed decisions can be made about military operations in these areas.

Vaccines are the most cost-effective means of preventing illness. Since it commonly requires 20 years or more to develop and field an FDA-approved vaccine, there is an ongoing, simultaneous application of new technologies to control many different militarily important infectious diseases. Infectious disease organisms such as hantavirus, HIV, and those causing malaria are continually evolving and appearing in new locations. Benign diseases today can become militarily important tomorrow. Military infectious disease research must remain at the forefront of technological advances to address these problems before they become warstoppers.

3.1.2.2 Major Technical Challenges. Major technical challenges that concern all aspects of infection and immunity must be effectively countered by innovative technical approaches. In malarial infections, parasites undergo multiple developmental stages throughout the life cycle during which these stages are exposed to the immune system for only brief periods of time. A countermeasure is to design multivalent vaccines that stimulate an immune response to multiple stages. A major technical barrier for the antiparasitic drug program is the problem of increasing parasite drug resistance. The approach to this problem is to search for new classes of compounds by using structure activity chemical searches and by using fingerprinting to determine structure activity relationships to direct the synthesis of new classes of drugs.

A major technical barrier for enteric vaccines is enhancing the immune response at the intestinal mucosal surface to prevent enteric infections. The technical approach includes formulating mucosal adjuvants and studying the best approach to deliver the antigens and the adjuvants to the mucosal immune system. Dengue vaccine development is complicated by the phenomenon of immune enhancement. Antibody to one serotype of dengue may increase the severity of symptoms caused by later infection with another dengue serotype. To counter this barrier, the approach is to formulate a tetravalent vaccine to protect against all four types of dengue simultaneously and consider immunization strategies that involve combined use of more than one type of vaccine (attenuated, killed, recombinant, or DNA vaccines).

3.1.2.3 Related Federal and Private Sector Efforts. Only the military investigates infectious diseases from basic research through concept exploration to product development. DoD has a combination of CONUS and OCONUS laboratories to conduct all stages of product development and evaluation. Military infectious disease research is advanced by over 200 cooperative research and development agreements (CRDAs) and material transfer agreements with industrial and academic partners. The National Institutes of Health (NIH) focuses on basic research and vaccine prototypes, but lacks U.S. government facilities for testing products for endemic disease outside the United States. The Centers for Disease Control and Prevention (CDC) are expert at epidemiology and vaccine delivery, but lack the capability for vaccine preparation and testing in OCONUS locations. Academic centers focus on basic research and pathogenesis. Industry emphasizes products marketable in the United States and limits basic research. The military program is coordinated with other federal programs to prevent unnecessary duplication of efforts. These and private sector efforts are exploited to the greatest extent possible. An initiative for interagency cooperation in global surveillance for emerging diseases using advanced technology will enhance communication links between OCONUS and CONUS laboratories, NIH, and CDC.

3.1.3 *S&T Investment Strategy*

Technology efforts are arrayed according to the type of etiologic agents that cause infection and disease. Distribution of investment within and among these broad agent areas is allocated in accordance with the impact of each agent on military operations, the potential contribution of technology to overcoming the threat posed by the agent, and the feasibility of achieving technology objectives through military investment. As knowledge advances, new technologies for improving diagnosis, treatment, and prevention are broadly shared among efforts on different agents.

3.1.3.1 Technology Demonstrations. The Antiparasitic Drug Program includes the validation of the effectiveness of candidate drugs prior to full-scale development. FDA regulations, as promulgated through the Code of Federal Regulations (21 CFR), restrict demonstrations involving unlicensed drugs to laboratory testing in nonhuman models. Before starting human testing, an investigational new drug application must be filed with the FDA. Drugs currently under investigation include one licensed antibiotic (for which malaria is an unlicensed indication for use) and four other antimalarial drug candidates. A new drug for the treatment of leishmania skin lesions is also under study. Efforts will explain mechanisms of parasite resistance to drugs and find alternative countermeasures to resistance in the far term.

3.1.3.2 Technology Development. Medical countermeasure development efforts are arrayed in the following functional areas:

- *Parasitic diseases*, including vaccines for prevention of malaria, development of antiparasitic drugs, identification of antiparasitic drug resistance patterns, identification and control of insect vectors for parasitic diseases, diagnosis of leishmaniasis, and vaccines for prevention of leishmaniasis.
- *Bacterial diseases*, including vaccines for Shigella, enterotoxigenic E. coli, Campylobacter, meningococci, and organisms responsible for sepsis and septic shock; also, diagnosis of rickettsial infections.
- *Viral diseases*, including vaccines for dengue virus, hepatitis virus, viral hemorrhagic fever, encephalitis, hantavirus, filovirus, and HIV.

Each of these areas is supported by the key technologies of improved vaccine production and delivery, the development of forward-deployable diagnostic tests, and surveillance of emerging diseases of military importance.

3.1.3.3 Basic Research. For every infection, basic research must focus on characterization of the etiologic agent, transmission of the agent, pathogenesis and natural history of disease, the protective host immune response, and finding suitable *in vitro* and *in vivo* models of infection. Military infectious disease basic research funding is focused to exploit advances resulting from other federal and private sector investments for use in DoD applications and also to provide new medical knowledge. These programs are managed to ensure provision of strong scientific capabilities to effectively exploit fundamental advances in biomedical science in a manner that is responsive to the peculiar and unique research needs of the technology area.

3.2 Combat Casualty Care

3.2.1 *Warfighter Needs*

Combat casualty care is constrained by logistics, manpower, and the hostile operational environment. These constraints pose challenges that are rarely encountered in civilian trauma care. Military casualties may wait for hours before definitive medical care can be provided. Initial treatment and subsequent evacuation occurs in austere field, airborne, and shipboard environments characterized by limited supplies (e.g., blood, resuscitation fluids) and limited diagnostic and life-support equipment. Fifty percent of combat deaths are due to uncontrolled blood loss, and provision of perishable blood and blood products far forward presents severe logistics challenges. Head injury and complications from trauma are also major contributors to loss of life and extended morbidity.

Provision of acute and critical care is labor intensive and must frequently be provided by nonphysician medical personnel. Military medical personnel must be provided with the tools and techniques to overcome these austere conditions. This technology must be compatible with the warfighter's operational mission and available resources, overcoming the constraints of communications and logistics that are typical in military operations. Although the military environment imposes extreme requirements on equipment and techniques, much of the technology required by the military has dual-use applications to meet presently unaddressed needs in rural medicine, disaster medicine, and civil disturbance trauma care.

New doctrine emphasizes immediate life-saving treatment, resuscitative care and stabilization, and evacuation of casualties to definitive care at CONUS-based facilities, with few lengthy in-theater hospital stays. The Joint Staff has requested R&D emphasis on immediate life-saving treatment, resuscitative care and stabilization of medical casualties, rapid casualty evacuation with maintenance of medical support, and smaller, lighter medical equipment sets to reduce requirements for strategic and tactical lift for deployment and sustainment. Products and knowledge generated through combat casualty care research will result in smaller, lighter equipment, with enhanced capability to supplement and complement the skills of far-forward medical personnel. This will field state-of-the-art trauma care on the front lines of combat where it is needed most. This research will also improve the supply of critical blood and blood products and reduce large manpower and logistics burdens associated with processing, storing, and maintaining fresh supplies of these perishable items at forward echelons. Efforts will also enhance the operational capability of military medical personnel in combat environments, resulting in conservation of medical manpower, reduced reliance on field hospitals, and reduced acute and long-term military health care costs. These efforts, along with development of new modalities to treat intractable medical problems of particular significance in military casualty populations, will reduce combat deaths and disability and enable far-forward and sustained quality of care through all levels.

Near-term opportunities include the demonstration of modules for field collection and storage of medical data, which ultimately will impact operational capabilities by enhancing medical situational awareness, improving in-theater patient regulating, improving continuity of care through all levels, and enabling more accurate diagnosis in rear areas. Mid-term opportunities for transition to advanced development include enhanced storage modalities of liquid blood and blood products to reduce logistics burdens for sustainment of medical units, and the demonstration of advanced, intensive-care life-support evacuation platforms to enable efficient long-range air evacuation with sustained medical support. Long-term transition opportunities include countermeasures to mitigate brain and spinal cord trauma, improving survival, reducing long-term disability, and maintaining physical performance capability.

3.2.2 *Overview*

3.2.2.1 Goals and Timeframes. A near-term goal is to enhance diagnostic and triage methods and information processing for the rapid determination of various trauma-specific medical indices; this will aid in triage processes and advanced medical management. A second near-term goal is to reduce the present logistics burden. Efforts that minimize the weight and cube of those medical materials required to be far forward and that reduce the number of items projected as necessary are required to better enable U.S. forces to fight and win. A mid- to long-term goal is to improve battlefield treatment capabilities at Echelons 1 and 2 to reduce mortality and morbidity. Also in the mid to long term, medical management of disease and nonbattle injuries will be improved to minimize lost duty time. A long-term goal is to fully exploit advanced sensors and intelligent systems to extend advanced casualty diagnostics and treatment far forward.

3.2.2.2 Major Technical Challenges. Major technical challenges include:

- Identification of effective, nontoxic oxygen-carrying blood substitutes.
- Identification of early prognostic physiological indicators of shock, and the development of corresponding noninvasive or minimally invasive sensing technologies.
- Stabilization of red blood cells without destroying function while eliminating in-theater pre-transfusion processing requirements.
- Maintenance of the usability of blood/blood substitutes using equipment that is available or easily transported to the combat environment.
- Overcoming immune system responses to donor blood cells.
- Lack of knowledge regarding the physiologic and cellular factors underlying the body's response to hemorrhage and subsequent resuscitation.
- Reversing complex detrimental inflammatory and physiological cascades initiated by reduced blood flow and anoxia subsequent to hemorrhage.
- Lack of knowledge of the detailed mechanisms responsible for brain edema and cytotoxicity following head injury.

3.2.2.3 Related Federal and Private Sector Efforts. The NIH is the major sponsor of U.S. biomedical scientific research on trauma, providing estimated annual funding of approximately $120 million. Military researchers exploit NIH's provides basic research in injury mechanisms. However, much of the NIH program is directed at within-hospital management of problems such as septic shock, blunt trauma, and wound healing, while the military focuses on prehospital resuscitation and life support. Industry, by and large, is uninterested in prehospital trauma care research because of the difficulty and high cost of the required clinical research in relation to the relatively small anticipated market for products. The military actively solicits and exploits private sector expertise through extramural contracts with universities and industry, and via cooperative agreements and more than 20 CRDAs between civilian firms and the government in support of combat casualty care research projects.

3.2.3 *S&T Investment Strategy*

Technology efforts are arrayed against functional threat areas that impact on the quality and efficiency of early phases of trauma care: prehospital care (identification, diagnosis, triage, resuscitation, stabilization, and life support, including care during extraction from combat and evacuation), resuscitative and life-saving surgery, and critical care. S&T thrust areas are necessarily diverse to address the variety of technologies required within these areas, encompassing medical knowledge, drugs, biologicals, and medical devices. Investment within and among threat areas is allocated in accordance with each threat's impact on combatants' health and frequency of injury occurrence, or its impact on medical operations (including logistics and manpower considerations); the potential contribution of technology to overcome each threat; and the feasibility of achieving technology objectives through military investment.

3.2.3.1 Technology Demonstrations. The advanced medical technology (field medical support) effort will provide advanced, noninvasive physiological sensors for life-support monitoring and diagnosis; lightweight, portable fluid and ventilatory support equipment; and intelligent medical decision-making systems. These provisions will allow early state-of-the-art life support and care during evacuation that is sustainable with minimal manpower. Individual components of the system will be developed in stages, focusing initially on manually operated platforms and progressing ultimately to a computer-assisted life-support system integrated with telemedicine systems under development in other programs. Efforts will exploit advances in basic knowledge of the pathophysiology of shock and will focus on the integration of noninvasive sensor, microelectronic, and information-processing technologies into novel systems. The physiological sensing technology that will be developed as part of these systems can, in addition to its uses in trauma care, provide real-time awareness of operational capability for functioning personnel; thus, this demonstration is being jointly supported by both the military operational medicine and the combat casualty care subareas.

3.2.3.2 Technology Development. Efforts are arrayed into the following functional areas:

- *Combat casualty assessment,* including far-forward-compatible systems for creation and management of patient records and theater regulation of patient flow.
- *Blood and resuscitative fluids*, including preservation of and substitutes for blood and blood products, minimizing traumatic blood loss, and development of materials and doctrine for fluid resuscitation.

- *Combat trauma*, including discovery and development of drugs, biologicals, and medical procedures to prevent or minimize secondary organ system injury and failure (including brain and spinal cord injury) after major trauma; repair of musculoskeletal injuries; countermeasures to systemic sepsis; care of combat casualties in extreme environments; and development of diagnostic and therapeutic medical devices and associated software and data processing systems for resuscitation, stabilization, life support, and surgical support.

Efforts directed towards physiological sensor technologies and software and data processing systems for casualty diagnosis are partially applicable to physiological monitoring of uninjured personnel. The latter is a focus of the military operational medicine subarea (Section 3.5), with which these efforts are jointly pursued. In contrast to operational medicine efforts, combat casualty care efforts focus on a wider range of physiological end points and on the data integration that is required for accurate diagnosis and patient management.

3.2.3.3 Basic Research. Basic research focuses on physiological, humoral, and cellular responses to hypoxic, ischemic, anoxic, and other types of injury. Such research is needed to identify potential diagnostic and prognostic indicators and sites for medical intervention and to find suitable *in vitro* and *in vivo* models of injury.

3.3 Medical Biological Defense

3.3.1 *Warfighter Needs*

A biological warfare (BW) attack could produce thousands of casualties over an area of thousands of square kilometers. Use of vaccines and pretreatments to prevent casualties can protect the fighting force and maintain unit operational effectiveness against this contingency. In the absence of complete prophylaxis, diagnostic capabilities can enhance treatment, reduce mortality, and improve return to duty. The direct payoff from the biological defense investment is the reduction, even elimination, of casualties that would otherwise follow a BW attack. The indirect payoff is that effective products against BW deter employment and proliferation of BW capabilities by hostile forces, bolstering the confidence of the fighting force. Near-term opportunities for transition to advanced development include a first-generation vaccine to protect against lethal effects of staphylococcal enterotoxin B (SEB). Mid-term transition opportunities include a vaccine to protect against lethality produced by ricin and botulinum toxins and *Yersinia pestis* (plague); and a second-generation SEB toxin vaccine to protect against both lethality and incapacitation. In the long term, vaccines effective against filoviruses (e.g., Ebola virus) will be transitioned.

3.3.2 *Overview*

3.3.2.1 Goals and Timeframes. The goal of the medical biological defense research program is to ensure the sustained effectiveness of U.S. forces in a BW environment. The objectives are to:

- Prevent casualties by use of medical countermeasures (e.g., vaccines, toxoids, pretreatment drugs).

- Diagnose disease with forward deployable kits and confirmation assays.
- Treat casualties, prevent lethality, and maximize return to duty using antitoxins and therapeutic drugs.

Current prophylaxes are inadequate since they do not cover all agents, immunization schedules are too long, no approved diagnostic kits exist, and specific treatment is extremely limited.

3.3.2.2 Major Technical Challenges. Major technical challenges include appropriate model systems for investigational purposes, generation of immune responses to small molecules, and expression vectors for recombinant products. In addition, a major technical challenge for diagnostic devices is the requirement to differentiate between clinical signs of infectious diseases and BW agents. Reliable diagnostics for BW agents must remain a prelude to effective medical countermeasures. (Efforts to develop BW diagnostic capabilities are described in this chapter; efforts to improve BW agent detection are described in Chapter II, Chemical/Biological Defense and Nuclear of this document, and in Chapter IV, Section I, Chemical/Biological Warfare Defense and Protection of the *Joint Warfighting Science and Technology Plan.*)

3.3.2.3 Related Federal and Private Sector Efforts. There is little interest in medical biological defense S&T in the private sector or in federal organizations outside of the military services because identified BW threats are of little general medical interest and because extensive congressionally mandated safety measures that are required in order to work with these agents are burdensome. The research program includes 5 CRDAs, 4 small business innovation research (SBIR) contracts, and 29 contracts with universities in the U.S. and abroad. There are also four funded agreements with other government agencies (Veterans Administration and the Army Research Office) and nonprofit organizations in the United States. A recent NIH review confirmed that the missions of the NIH and Medical Biological Defense Research Program are unique, and that there is no duplication of their efforts.

3.3.3 *S&T Investment Strategy*

Technology efforts are arrayed according to the validated medical threat agents that they address. The amount of effort is distributed to these threats in accordance with their impact on operations, the potential contribution of technology to overcoming each threat, the feasibility of achieving technology objectives through military investment, and the need to maintain a technology base that is capable of responding to emerging threats and avoiding technological surprise. Technology efforts include a long-term approach to prophylaxis development for broad-spectrum antiviral, antibacterial agents as well as for broad-spectrum diagnostic capabilities.

3.3.3.1 Technology Demonstrations. Efforts focus on the development of medical countermeasures against the threats of ricin toxin and SEB. For ricin toxin, microencapsulation delivery systems for vaccine candidates will be evaluated, and a second-generation recombinant vaccine that will offer greater safety over toxoided components and an enhancement in protective immunity will be demonstrated. For SEB, initial *in vivo* preclinical studies to demonstrate efficacy and safety of a second-generation recombinant vaccine candidate will be conducted. In addition, efficacy of a pentavalent vaccine for botulinum toxin will be demonstrated. Future efforts will focus on evaluation of cross-protective capabilities, feasibility of a combined serotype vaccine candidate with a second-generation vaccine, and more extensive studies of safety, efficacy, stability, and production parameters in multiple models.

3.3.3.2 Technology Development. Medical countermeasure (e.g., vaccines, therapeutics, diagnostics) development efforts are arrayed into the following functional areas:

- *Protein toxins*, including SEB, ricin, botulinum toxin, *C. perfringens* toxin, and venoms.
- *Bacterial agents*, including *Y. pestis* (plague), *Brucella* (brucellosis), *B. anthracis* (anthrax), *C. burnetii* (Q-fever), *V. cholerae* (cholera), *F. tularensis* (tularemia), *B. mallei* (glanders), and *R. prowazekii* (typhus).
- *Viral agents*, including encephalomyelitis viruses, variola (smallpox), and filoviridae (e.g., Ebola virus).
- *Neuroactive compounds*, including sodium channel neurotoxins, peptide ionophores, and other physiologically active biological substances.
- *Diagnostics*, including confirmatory diagnostic tests and diagnostic reagents. This effort is leveraged with research in the subarea of infectious diseases of military importance where similar technologies are being employed or evaluated.

3.3.3.3 Basic Research. Basic research focuses on biochemical, immunological, or microbiological characterization of the etiologic agent, pathogenesis of disease, the protective host immune response, and finding suitable *in vitro* and *in vivo* models of infection and injury.

3.4 Medical Chemical Defense

3.4.1 *Warfighter Needs*

Medical chemical defense technologies are essential to protect and sustain U.S. forces during a CW attack and to provide the world's best chemical casualty care. Medical chemical defense provides medical countermeasures directed against CW threats. Efforts are conducted in response to joint service CW requirements, supporting national defense needs as articulated in the JWSTP and Defense S&T Strategy. Countermeasures are needed to prevent or decrease the incidence of vesticant agent injuries, reduce the severity of resulting injuries, minimize incapacitation, and decrease the substantial burden that such injuries place on the medical treatment system. An approved topical protectant is needed that both blocks penetration of the skin by chemical warfare agents and simultaneously detoxifies the agents; this countermeasure will function as a supplement to the Mission-Oriented Protective Posture chemical protective ensemble. An improved nerve agent pretreatment is needed to provide extended protection against nerve agents, without performance-reducing side effects or the need for extensive post-exposure therapy; this will increase operational flexibility. In addition to their personnel protective effects, effective medical countermeasures against CW threats may provide the additional benefit of deterring the use of these weapons.

3.4.2 *Overview*

3.4.2.1 Goals and Timeframes. The mission of the medical chemical defense subarea is to preserve combat effectiveness by timely provision of medical countermeasures in response to joint service CW defense requirements. This mission is accomplished by three goals:

- Maintain technological capability to meet present requirements and counter future threats.
- Provide individual-level prevention and protection to preserve the fighting strength.
- Provide medical management of CW casualties to enhance survival and expedite and maximize return to duty.

3.4.2.2 Major Technical Challenges. Major technical challenges include developing effective pretreatments completely devoid of side effects, developing suitable animal models, extrapolating efficacy test results from animals to man, and generating immune responses to small molecules.

3.4.2.3 Related Federal and Private Sector Efforts. Forty-two CRDAs are active within the medical chemical defense subarea. Three SBIR contracts support activities within the research program, as do the 50 extramural R&D contracts with government agencies, universities, nonprofit organizations, and industry both in the U.S. and in other countries (e.g., the Netherlands, Israel).

3.4.3 *S&T Investment Strategy*

Technology efforts are arrayed according to the medical threat agents that they address. The amount of effort is distributed to these threats in accordance with their impact on operations, the potential contribution of technology to overcoming each threat, and the feasibility of achieving technology objectives through military investment.

3.4.3.1 Technology Demonstrations. Efforts focus on the development of medical countermeasures against threats from nerve and vesicant agents. For nerve agent countermeasures, safety and efficacy sufficient to justify commitment to advanced development activities will be demonstrated in FY96 for an advanced anticonvulsant component for the soldier-buddy-use nerve agent antidote, and in FY00 for an improved nerve agent prophylaxis. A similar demonstration of safety and efficacy for a candidate medical countermeasure for sulfur mustard (HD) is planned for completion by FY99.

3.4.3.2 Technology Development. Medical countermeasure development efforts are arrayed into the following functional areas:

- *Vesicant agent countermeasures*, focusing on therapeutic drugs for HD.
- *Nerve agent countermeasures*, focusing on an advanced anticonvulsant and biological prophylactic approaches.
- *Skin and patient decontamination*, focusing on a reactive topical skin protectant.

- *Chemical casualty management*, focusing on diagnosis, prognosis, treatment, and disposition of chemical casualties. This effort includes initiatives to improve far-forward diagnostic capabilities, and it is coordinated with efforts in CW agent detection where similar technologies are being employed or evaluated.

(Efforts to develop CW diagnostic capabilities are described in this chapter; efforts to improve CW agent detection are described in Chapter II, Chemical/Biological Defense and Nuclear of this document, and in Chapter IV, Section I, Chemical/Biological Warfare Defense and Protection of the JWSTP.)

3.4.3.3 Basic Research. Basic research focuses on chemical and biochemical characterization of agent interactions with biological target molecules, characterization of molecular and cellular mechanisms of pathogenesis, and identification and development of suitable *in vitro* and *in vivo* models of injury.

3.5 Military Operational Medicine

3.5.1 *Warfighter Needs*

Military operational medicine addresses the full range of threats and challenges known to limit human effectiveness. These threats and challenges span such diverse issues as deployment and combat stress as well as gender differences in response to high-g forces during tactical flight operations. Science and technology elements share a common goal of reducing the human costs of national security operations through an effort encompassing operational hazards and materiel threats.

Efforts focusing on operational hazards utilize biomedical science to attain the broadest possible performance envelope for the warfighter. The range of individual operational circumstances includes arctic to desert environments, stationary watch to operations beyond Mach 2, high-altitude to deep-diving and submarine operations, and shipboard operations to intense land combat. Stress is pervasive in battle; it claims one direct casualty for every four wounded and is contributory to one in five physical casualties. Neuroscience-based studies are designed to effectively extend an individual's capacity to withstand battle stress. Fatigue and sleep loss may account for 20% of all injuries on the battlefield and are prominent factors in the degradation of military performance.

Work in progress targets sleep as a manageable resource. A near-term impact of this research will be an operational doctrine for pharmacological interventions to counter fatigue and sleep loss. In the mid term, a joint guidance for planning and conducting sustained operations that optimize human performance will be fielded. Heat and cold restrict human performance. Biomedical technologies are applied to improve understanding of the mechanisms of heat and cold injury and to reduce the operational impact of these and related environmental challenges. In the long term, biological means to modify environmental injury will be developed.

Demands of modern warfare continue to outstrip the information processing capacity of the human nervous system. The goal is to maximize the effectiveness of human operator capabilities and hardware performance. These initiatives combine to enhance military power and effectiveness and to reduce casualties, whatever the mission. They form the core of medical efforts to protect the lives, safety, and capabilities of individual warfighters and system operators.

Hazards from military systems and operations regularly challenge the health and safety of military personnel. The potential for death, injury, or performance degradation is systematically explored for hazards ranging from sustained operations, fatigue, munitions exhaust gases, and blast effects to the mechanical strains and jolts associated with physical training and operational platforms. A reduction of the environmental and the operational threats to personnel will reduce the likelihood of accidents and injuries. For instance, operational mishap losses for FY90 through FY94 totaled $4.4 billion with a loss of 472 lives in the Navy and Marine Corps. Incorporation of the medical R&D products in the naval service will reduce these peacetime casualties. A reduction in mishaps by only 5% will result in a 5-year savings of $217 million and the saving of 23 lives. Greater monetary savings will be realized for the recapture of lost workdays due to injuries occurring while in training or while forward deployed.

Systems and operations threats, either singly or in combination, are detailed and individual exposure criteria are established. Materiel developers are supported with specialized databases and evaluations to ensure that affordable, realistic efforts are directed at minimizing risk to tomorrow's warfighters. For example, the application of safe frequency and power exposure standards, to be developed in the near term, will guide laser and electromagnetic radiation system developers away from harmful frequency/power mixes. This simultaneously identifies safer regions of the spectrum that can be used at higher power for greater range and effectiveness. Biomedical information is critical to development of frequency-agile laser eye lenses that will afford effective protection against deliberate and accidental laser eye injury and will be of special importance to aviators and special operations personnel. This program represents an active partnership between biomedical scientists and materiel developers that seeks affordable options for ensuring both system safety and operational effectiveness.

3.5.2 *Overview*

3.5.2.1 Goals and Timeframes. War remains a test of the individual's will both to endure and to master potentially overwhelming conditions. Thus, the inherent challenge facing the warfighter evolves with the development of operational doctrine, materiel systems, and mission scenarios. The objectives are to:

- Develop and promote biomedical contributions to operational readiness.
- Sustain the health and performance of operational warfighters.
- Provide the bases for scientifically sound doctrine for optimizing recovery following stress.
- Quantify the combined effects of multiple diverse stressors in support of improved operational concepts, tactics, and doctrine.
- Maintain developments in coordination with the operational C^4I logistics requirements and capabilities.

3.5.2.2 Major Technical Challenges. The major challenge for sustained operations enhancement is modeling the threshold, onset, and course of fatigue in order to objectively determine when unacceptable levels of fatigue threaten mission safety or success. For RF radiation bioeffects, the technical challenge is to identify and quantify the absorption, transduction, and bioeffects of exposure to RF radiation under diverse operational conditions and multiple exposure parameters. The major challenge for the development of toxic hazards evaluation tools is identifying and evaluating molecular events/biochemical markers as accurate predictors of human toxicity from operational exposures to hazardous materials. For physical performance optimization and musculoskeletal injury, the challenge is to determine the cycle of damage and the rate of repair of the human body following military physical training. Without this biomedical knowledge, DoD cannot build optimally safe training programs for military-unique occupations. The challenge for advanced medical technology is determining the physiological adaptations for man-machine interface of electro-optical displays and automated command consultation systems and the provision of remote consultation for deployed medical personnel.

3.5.2.3 Related Federal and Private Sector Efforts. Industry and academic partnerships are so woven throughout the program that scientific publications without coauthorship from outside are rare. Civilian resources are fully exploited when appropriate. Military laboratories, however, possess unique equipment and have access to deployed forces and environments that can be fully exploited only by DoD-uniformed scientists who have the operational experience to conduct key aspects of the research. Major government agencies include the Department of Health and Human Services, Veterans Administration, NASA, National Science Foundation, National Toxicology Program, DOE national laboratories, and DOT. Contractors/industry partners include universities, nonprofit organizations, private industry, foreign organizations, small business initiatives, 26 CRDAs, and 7 consortia.

3.5.3 *S&T Investment Strategy*

As with combat casualty care, the investment strategy is to learn from technology demonstrations and use this experience to better define and refine requirements and evaluate new technologies. Included are telemedicine technology demonstrations to develop the National Telemedicine System. In executing the military operational medicine research program, technology efforts are arrayed according to the medical threats that they address. Distribution of investment among these threats is in accordance with their impact on operations, the potential contribution of technology to overcoming each threat, and the feasibility of achieving technology objectives through military investment.

3.5.3.1 Technology Demonstrations. Telemedicine demonstrations continue not only to fill emergent gaps in support but also to identify new requirements and refine existing needs. As part of this effort, the development of the clinical efficacy measurement tools and the cost/benefit tradeoffs of telemedicine in remote, forward-deployed areas is imperative. DoD remains the organization most involved in the National Telemedicine Test Bed. Advanced medical technology (field medical support) is jointly supported by both the military operational medicine and the combat casualty care subareas. In support of the military operational medicine mission, integration of a set of noninvasive physiological sensing technologies will be demonstrated that can enable situational decision making by commanders based on real-time knowledge of the individual and collective physical capability of deployed personnel.

These sensing capabilities also have applications to trauma care; the medical application of these technologies are described within the combat casualty care subarea. Additional efforts will assess and validate the value of tactile (vibratory) stimulators in augmenting currently available cues across a representative range of simulated and operational training environments. Use of such stimuli has potential to reduce spatial disorientation accidents in the military and to improve navigation and awareness of target locations for sonar/radar operators. Efforts are currently focused on selection of appropriate signal transducers with several options available; a flight test of an improved vibrotactile prototype is planned in FY97.

3.5.3.2 Technology Development. Efforts are arrayed into the following functional areas for local and remote support to operational commanders:

- *Operational medicine and human performance,* including medical assessment for selection and classification of personnel, effects of sustained and continuous operations, sleep and performance, operational stress, visual performance, spatial orientation, physical fitness and endurance, musculoskeletal injuries and physical performance, nutrition, safety of flight, diving, surface support, and noise.
- *Biodynamic (biomechanical) stress*, including effects and guidelines to reduce the hazards of maneuvering acceleration, abrupt acceleration and impact, vibration and motion, and repeated impact jolt; auditory and whole-body blast bioeffects; and noise effects related to operations.
- *Physiology in extreme environments,* including heat and cold stress, high-altitude effects (both terrestrial and aerospace), immersion, and hyperbaric stress.
- *Non-ionizing radiation bioeffects*, including laser bioeffects and effects of RF and electromagnetic radiation.
- *Health effects of toxic hazards,* including occupational toxicology and health risk assessment and environmental effects of military toxic hazards.
- *Telemedicine initiatives*, to define and refine requirements and identify the optimum locations for each level of requirements prior to, during, and after hostilities.

3.5.3.3 Basic Research. Basic research focuses on development of *in vitro* and *in vivo* models for risk assessment and the evaluation of physiological responses to operational stressors, development of animal behavioral models of human performance, and identification of humoral and other mediators of responses to operational stressors.

3.6 Military Dentistry

3.6.1 *Warfighter Needs*

Dental disease is an ever-present decrement to military readiness. Historically, dental disease and maxillofacial trauma cause 10–20% of all evacuations among deployed personnel. A substantial effort to prevent these casualties requires dental manpower not available in the military's dental corps. Military dental research focuses on military-specific needs, namely, eliminating troop evacuations due to dental disease and on decreasing the morbidity and mortality due to maxillofacial trauma. It provides the only avenue to develop improved readiness either by preventing dental emergencies or by faster, easier, and more effective far-forward treatment of those that do occur in order to eliminate evacuations.

Near-term opportunities for transition to advanced development include predictive diagnostic tests for oral pathogens, microencapsulated antibiotics to protect wounds against infection, more effective diagnostic capability using portable digital imaging systems, and better geographical capabilities via teledentistry. Mid-term transition opportunities include materiel development and improved storage capabilities that will extend the utility of expensive prepositioned dental supplies and ultra long acting local anesthetics that will further limit or delay evacuation requirements. Long-term transition opportunities include new anesthetics that will selectively control pain without interfering with myelinated neurons responsible for motor and touch functions and novel sustained release pharmaceuticals that will prevent dental emergencies among deployed personnel.

3.6.2 *Overview*

3.6.2.1 Goals and Timeframes. The ultimate goals of the military dentistry subarea are to eliminate patient evacuation due to dental disease and to decrease the morbidity and mortality following maxillofacial trauma. More specifically, in the area of predictive diagnostics, goals are to identify and treat likely casualties in advance of deployment. In the area of far-forward diagnostics and therapy, goals are to develop better means of far-forward diagnosis using a filmless hand-held X-ray device or teledentistry consultations. Other goals include completing a dental database of dental care needs in recruits, improving ways to control pain and prevent wound infection, and developing improved and more storage stable dental materials.

3.6.2.2 Major Technical Challenges. Major technical challenges include an incomplete knowledge of safe, effective antiplaque agents and the ability to sustain long-term protection from disease causing oral bacteria; the absence of optimal reconstructive surgical procedures (including surgical robotics capability) to restore form and function of the jaw following massive maxillofacial trauma; and an incomplete knowledge of ways to stimulate bone formation and control bleeding in large bony defects.

3.6.2.3 Related Federal and Private Sector Efforts. In April 1994, a Joint Services Dental Rebuild Conference special review and analysis was conducted over 2 days in which the entire Army and Navy Dental Research and Development Program was reviewed by a blue ribbon panel including representatives from the National Institute of Dental Research, NIH. The mission-specific orientation of the military dentistry effort was confirmed, and no duplication of effort was found among Army, Navy, and NIH programs.

3.6.3 *S&T Investment Strategy*

Technology efforts are arrayed according to validated deficiencies identified by requirements sponsors. In turn, investment in these efforts are correlated with the technological ability to solve the problem, the impact the solution will have on the deficiency, and the associated costs.

3.6.3.1 Technology Demonstrations. Wound sepsis is a significant cause of morbidity in maxillofacial injuries and is also of importance in orthopedic and soft tissue injuries, affecting 20–35% of all war casualties. Aggravating this threat is the emerging phenomenon of increasing microbial resistance to conventional antibiotic therapies. A single-dose therapy technology that sustains release of antibiotics from polymeric, biodegradable microspheres, when applied directly into wounds, has been shown to have improved efficacy over conventional systemic antibiotic therapy. This technology is now mature and ready for investigational new drug (IND) preparation/clinical trials.

3.6.3.2 Technology Development. Efforts are arrayed into the following functional areas:

- *Maxillofacial trauma care*, including antibiotic development; local anesthetics; bone repair devices, materials, and methodologies; and diagnostic devices.
- *Dental disease and dental emergencies*, including evaluation of dental materials, equipment, drugs, and procedures; periodontal disease diagnosis, prognosis, and prevention; patient and dental records management systems; and dental epidemiology.

3.6.3.3 Basic Research. Basic research focuses on initial formulation of candidate antibiotic and anesthetic delivery systems, development of models for drug discovery and evaluation, identification of causative mechanisms in the pathogenesis of periodontal diseases, and identification of candidate diagnostic markers of oral disease.

3.7 Medical Radiological Defense

3.7.1 *Warfighter Needs*

With the growing risk of nuclear proliferation through clandestine nuclear programs, the threat of the use of a nuclear weapon or other radiation weapons remains real and substantial. Because it is likely that military missions will be conducted in radiation environments, the development of prophylactic and treatment protocols and knowledge of the health risks are essential to permit safe military operations in a radiation environment. Because exposure to radiation well below lethal levels can significantly alter the immunological status of the service member, it is essential that both risk assessments and medical countermeasures consider the combined insult of radiation exposure and other battlefield toxins, especially biological and chemical warfare agents. Operational planning and medical treatment require projection of increased casualty rates resulting from agent interactions. Predictive models for agent interactions will be developed and incorporated into existing models to provide improved projections of casualty rates.

Prevention of incapacitating and lethal ionizing radiation injuries will enable mission continuation and accomplishment in the nuclear or radioactive combat environments. Accurate casualty prediction models, particularly in combined nuclear/biological/chemical (NBC) environments, are required for effective command decision making and force structure planning to ensure mission success. An advanced biological dosimetry methodology is required for reliable determination of individual radiation exposure(s) for triage, treatment decisions, and long-term risk assessment. Anticipated increases in the use of depleted uranium (DU) munitions are expected to produce a significant number of casualties wounded with such weapons. DU research will ensure that service personnel receive optimal treatment to mitigate risks from DU exposure and protect them and their offspring.

Potential payoffs in the short term include the development of therapeutic and protective strategies to permit 95% survival after acute exposure to supralethal ionizing radiation (doses less than 10 Gy). Advanced high-dose dosimetry methodology will be provided for health risk assessment. In the mid term, improved therapeutic and protective strategies will be extended to chronic exposures and late effects (e.g., cancer). Initial models for BW and CW/radiation interactions will provide needed data for counterproliferation targeting and consequences of execution considerations. Recommendations for improved medical treatment protocols for DU fragments will be provided based on assessment of toxicological, reproductive, and carcinogenic risk. In the long term, automated biodosimetry methodology will be available for a wide range of doses and dose rates of radiation exposure. New models will provide predictive data for NBC interactions to predict mortality and incapacitation from combined exposures. Protective and therapeutic strategies will allow access to a variety of radiation environments with minimal health risks. New biotechnology products will be tested as they become available for their application to radioprotection and therapeutics.

3.7.2 *Overview*

3.7.2.1 Goals and Timeframes. The goals of the medical radiological defense subarea are to develop prophylactic and therapeutic approaches to radiation injury alone and combined with other battlefield toxicants and to define human health risks associated with operational radiation exposures. Specific subgoals and timeframes are as follows:

- *Radiation prophylaxis:* To develop drug regimens, given prior to or shortly after exposure, for protecting personnel from the adverse health effects of acute and chronic exposures to ionizing radiation. First-generation prophylactic agents will be identified by FY97, with improvements each subsequent year.
- *Assessment:* (1) To estimate and model human health risks in low-dose/low-dose-rate exposures characteristic of the fallout fields from nuclear weapons and reactor accidents (FY99). (2) To define the most important interactions of radiation with other toxicants (FY98–02). (3) To develop an advanced bioindicator system with the sensitivity to provide definitive dose assessments for acute, protracted, and multiple exposures (FY98). An advanced bioindicator methodology for high doses will be fully developed in FY98 followed by a low-dose system in FY01.
- *Radiation injury treatment*: To develop improved protocols for the treatment of injuries from radiation alone or in combination with other battlefield injuries (FY01).

3.7.2.2 Major Technical Challenges. Toxicity represents a major challenge to the development of protective and therapeutic drugs. To overcome this, new pharmaceutical and bioengineered products will be tested, novel immunomodulators will be examined, and drug combinations will be assessed in order to minimize the adverse reactions.

Since testing can not be done in humans, most data are obtained in animal models, primarily rodents. Selected critical results will be repeated in higher species. In addition, historical human radiation exposures (e.g., radiotherapy patients, accident victims) are surveyed, compiled, and analyzed systematically for comparisons with laboratory animal studies. Ongoing studies of exposed populations in the former Soviet Union (FSU) and the results obtained from those studies will facilitate this process.

The processing time and technical complexity of bioindicator assays present challenges for their implementation. In an effort to automate the bioindicator methods, multiple approaches will be assessed for application and simplification. Fielding of bioindicator capacity will involve use of specialized equipment developed in house linked with COTS technology.

3.7.2.3 Related Federal and Private Sector Efforts. Although many agencies conduct radiobiology research, these efforts do not address military requirements that are the focus of the DoD research program. NASA has a radiation program funded at a level of about $6 million annually, with most research focused on the biological effects of cosmic rays. The National Cancer Institute, through its Chemical and Physical Carcinogenesis Program, provides about $20 million for basic radiation research and for epidemiological studies in the U.S. and FSU. A separate program at the National Cancer Institute (Extramural Radiation Research Program) provides about $45 million for basic and radiotherapy-related research on ionizing radiation. The DOE funds basic radiobiology research at a level of approximately $5 million. The Nuclear Regulatory Commission funds approximately $1 million on modeling and prediction of effects of reactor accidents.

3.7.3 *S&T Investment Strategy*

3.7.3.1 Technology Demonstrations. A multiple bioassay strategy will provide reliable radiation dose assessment for various radiation scenarios to ensure proper medical treatment of radiation casualties. Use of one bioindicator endpoint has been validated for use in cases of high-dose (3–10 Gy)/partial-body exposures. This has direct impact on current medical treatment decisions of bone-marrow transplant versus cytokine and antibiotic therapy. A second assay, the conventional dicentric aberration, has also been improved and is suitable for rapid and automated analysis. These bioindicator service capabilities are now ready for implementation.

3.7.3.2 Technology Development. Efforts are arrayed into the following functional areas:

- *Radiation casualty management*, including use of new, advanced biotechnology products to treat immunohematopoietic injuries and bacterial, mycotic, and viral infections.
- *Risk assessment of NBC interactions*, including quantitation of the extent to which radiation increases susceptibility to BW or CW agents; this effort will greatly improve BW/CW casualty risk models.
- *Radiation bioindicators*, including an automated multiparameter dose assessment capability that can be fielded far forward on the battlefield to improve the rapid triage of ionizing radiation casualties.

- *Medical treatment strategies for DU hazards*, including risk assessments for male and female personnel wounded by DU munitions.

3.7.3.3 Basic Research. There are no basic research efforts in this subarea.

GLOSSARY OF ABBREVIATION AND ACRONYMS

ACTD	Advanced Concept Technology Demonstration
ATD	Advanced Technology Demonstration
BW	biological warfare
CAD	computer-aided design
CAM	computer-aided manufacturing
CDC	Centers for Disease Control and Prevention
CFR	Code of Federal Regulations
CONUS	continental United States
COTS	commercial off the shelf
CPC	chemical protective clothing
CRDA	cooperative research and development agreement
CW	chemical warfare
DDR&E	Director of Defense Research and Engineering
DHEA	dehydroepiandrosterone
DMSO	dimethyl sulfoxide
DNA	deoxyribonucleic acid
DOE	Department of Energy
DOT	Department of Transportation
DTO	Defense Technology Objective
DU	depleted uranium
EEE	Eastern equine encephalitis
FDA	Food and Drug Administration
FSU	former Soviet Union
FY	fiscal year
HD	sulfur mustard
HIV	human immunodeficiency virus
IND	investigational new drug
JWSTP	*Joint Warfighting Science and Technology Plan*
NASA	National Aeronautics and Space Administration
NBC	nuclear/biological/chemical
NIH	National Institutes of Health
OCONUS	outside continental United States
R&D	research and development
RF	radio frequency
S&T	science and technology
SBIR	small business innovation research
SEB	staphylococcal enterotoxin B

VEE	Venezuelan equine encephalitis
WEE	Western equine encephalitis
WMD	weapons of mass destruction

CHAPTER VII

SENSORS, ELECTRONICS, AND BATTLESPACE ENVIRONMENT

1.0 INTRODUCTION

1.1 Definition/Scope

The Sensors, Electronics, and Battlespace Environment (SE&BE) program area addresses technology for the sensors, electronics, and battlespace environment in 14 subareas (Figure VII–1). The sensor technology developed here has broad application to warfighting needs including strategic and tactical surveillance as well as identification and targeting of land, sea, air, and space threats under all conditions. In addition, SE&BE encompasses the research and development, design, fabrication, and testing of electronic materials; digital, analog, microwave, optoelectronic, and vacuum devices and circuits; and electronic modules, assemblies, and subsystems. Finally, SE&BE provides for the study, characterization, prediction, modeling, and simulation of the terrestrial, ocean, lower atmosphere, and space/upper atmosphere environments to understand their impact on personnel, platforms, sensors, and system; enable the development of tactics and doctrine to exploit that understanding; and optimize the design of new systems.

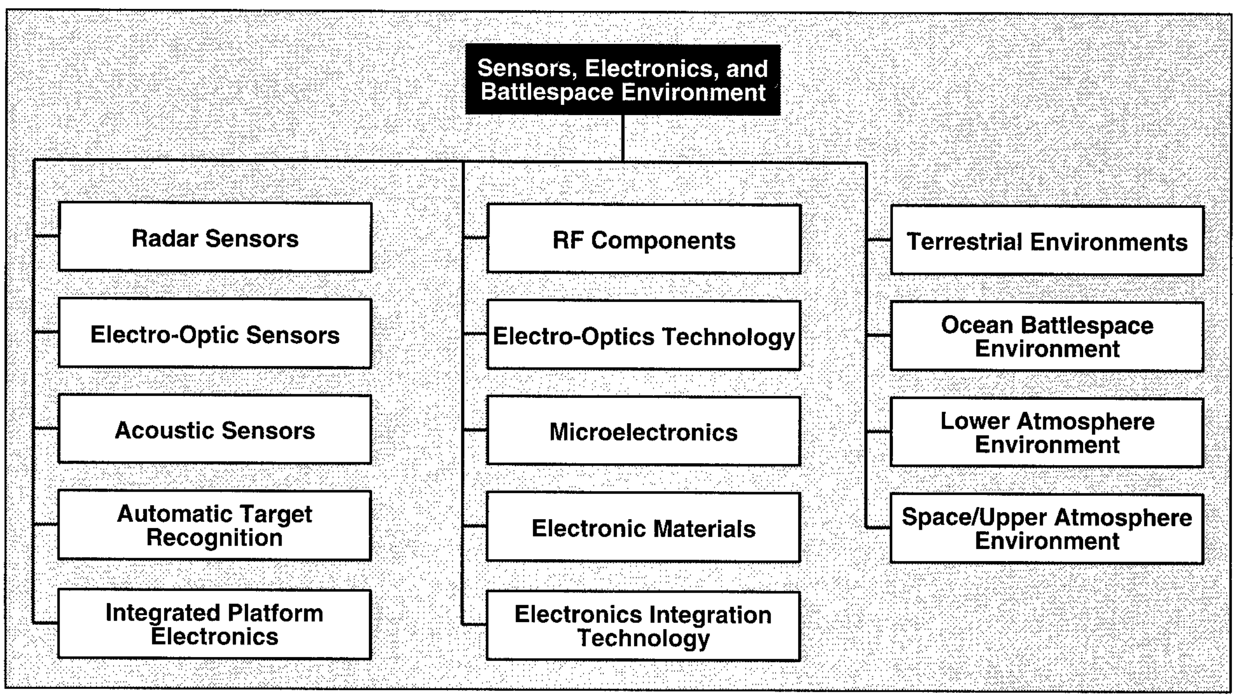


Figure VII–1. Planning Structure: Sensors, Electronics, and Battlespace Environment Technology Area

In the material that follows only *some* of the key objectives of the science and technology (S&T) programs in SE&BE are explicitly described. Funds not reflected in DTOs also addresses many other objectives just as important to DoD in the areas of SE&BE. In addition, most of the demonstrations described in this chapter were enabled by earlier science and technology efforts. For example, compact high-power RF transmitters were enabled by the development of the microwave power module (MPM), which is two and one-half times more powerful, ten times smaller, and one-third as costly as current technology. In turn, the MPM was possible only because of the DoD-supported efforts in gallium arsenide (GaAs) materials development and monolithic microwave integrated circuits (MMIC) technology. Similarly, the science and technology foundations for future technology demonstrations are being laid by the current S&T programs.

A glossary of abbreviations and acronyms used in this chapter begins on page VII–61.

1.2 Strategic Goals

The vision for this area is to provide the military with perfect situation awareness of the expanded battlefield in all environments. This will enable the warfighters to assess the scope and intent of the enemy and develop superior tactics for achieving whatever political/military goal is selected. Investment in this area ensures that the U.S. will continue to maintain the warfighting edge through all-weather, day/night surveillance, precision targeting, and damage assessment; detection and tracking of difficult targets such as cruise missiles, antiship missiles, ballistic missiles, mines, and submarines; and positive target identification. In addition, this must be accomplished at an affordable cost in a diminished production base.

Examples of specific goals include 90% probability of detection of time-critical targets that are camouflaged or concealed by foliage; a threefold increase in infrared (IR) detector focal plane array sensitivity at 50% weight and cost reduction; 50% resolution improvement for thermal imaging systems; improved night/adverse-weather pilotage; orders of magnitude increased bandwidth for control and processing RF communications and surveillance providing seamless sensor-to-shooter capability; high-power switches operating at greater than 100 volts and at current densities exceeding 1,000 amps/cm^3; 16 times improvement in over-the-horizon detection of sea-skimming cruise missiles; 100% improvement in submarine periscope detection through the application of advanced analog-to-digital converter technology; 75% reduction in design time/cost for system integration using "virtual" prototyping; improved forecast capability for small-scale currents and waves in the littoral coastal area; and 95% improvement in global C^{3}I specification by fusing ground and space data. These developments provide technologies crucial to meeting the Joint Warfighting Capability Objectives (JWCOs).

1.3 Acquisition Warfighting Needs

SE&BE technologies provide the foundation for the critical "eyes, ears, and brains" of nearly all decision-making systems, tactical and strategic weapons systems, and intelligence collection and processing. They are the key to force multiplication (the ability of a minimal number of U.S. personnel and platforms to defeat a much larger enemy force), and their continued advancement is critical to the avoidance of technological surprise on the battlefield by enabling comprehensive intelligence gathering and achieving total situational awareness over the extended battlespace. Essential for the development and operation of DoD's information-gathering capabilities is the complete understanding of the environment in which these sensors operate and the impact of that environment on the operation of the sensors. With this knowledge, U.S. forces will be able to optimize their sensors and tactics to use the entire battlespace and its environment.

Consequently, the SE&BE subareas address key requirements identified in the *Joint Warfighting Science and Technology Plan.* As Table VII–1 shows, these technologies are particularly critical to the needs and capabilities associated with Information Superiority, Precision Force, Combat Identification, and Joint Theater Missile Defense.

Table VII-1. Connectivity of JWCOs to Sensors, Electronics, and Battlespace Environment Technology Area

	Joint Warfighter Capability Objectives									
SE&BE	Information Superiority	Precision Force	Combat Identification	Joint Theater Missile Defense	Military Operations in Urban Terrain	Joint Readiness & Logistics	Joint Countermine	Electronic Combat	CB Warfare Defense & Detection	Counter Weapons of Mass Destruction
Radar Sensors	●	●	●	●	○	◬	◬	◬		◬
EO Sensors	●	●	●	●	●	◬	●	○		◬
Acoustic Sensors	●	●	●	●	◬	●	●			◬
Automatic Target Recognition	●	●	●	◬	◬		◬			◬
Integrated Platform Electronics	●	◬	◬	◬	○		○	●		
RF Components	●	◬	●	●	◬	◬	●	●		
EO Technology	●	●	●	●	◬		◬	◬	○	●
Microelectronics	●	●	●	●	●	●	●	●	●	●
Electronic Materials	●	●	●	●	●	●	●	●	●	●
Electronics Integration Technology	●	●		●	●	○	○	●	○	●
Terrestrial Environments	●	◬	○	◬	●	●	◬	○	○	●
Ocean Environment	●	●	●	●	◬	●	●		◬	◬
Lower Atmosphere Environment	●	●	○	●	●	●	○	○	●	◬
Space/Upper Atmosphere Environment	●	●	◬	●	◬	●		●	◬	◬

● Strong Support ◬ Moderate Support ○ Marginal support

In addition, SE&BE technology accomplishments contribute to developments in other defense technology areas. For example, the results of a number of these activities enhance the operability of the CB Defense and Nuclear area's Joint Warning and Reporting Network (JWARN) (CB.02.10), Laser Standoff Chemical Detection Technology (CB.07.10), and Hard Target Defeat (CB.13.07) efforts. SE&BE results also find application in the Consistent Battlespace Understanding (IS.01.01) work performed within the Information Systems Technology area. The Ground and Sea Vehicle area's Future Scout and Cavalry System (GV.01.06) and Mission Reconfigurable UUV (GV.12.01) utilize sensor suites that could be enhanced, directly or indirectly, by the results of SE&BE development efforts. The Protection Technologies (SP.15.06) effort in the Space Platforms area benefits from research being done in SE&BE's space/upper atmosphere subarea. Similarly, efforts in that subarea and in the lower atmosphere subarea contribute to the success of the Weapon's technology area's development activities with regard to the Ground-Based Laser ASAT System (WE.10.08.F) and Airborne Lasers for TMD (WE.04.04).

1.4 Support for Combating Terrorism

The technologies developed by the SE&BE panel make a significant contribution to the physical security component for combating terrorism; however, information, information systems, and communication security also benefit from the work in this technology area. The key to providing physical security is detecting, locating, and neutralizing terrorists employing chemicals (explosives and toxins) or biological agents through the use of advanced sensors, information processing and fusion, lightweight microelectronics, and knowledge of the threat environment.

Radar, EO, and acoustic sensor technologies are the rudimentary elements in the ability to detect and locate the tools employed by terrorists. Radar sensor technologies are developing the ability to detect and locate terrorists in hiding or under tree canopies using low-frequency synthetic aperture radar employing knowledge-based signal processors and signal detection and discrimination algorithms. In addition, low-cost electronically scanned antennas are being developed to provide high-resolution airborne surveillance for U.S. border protection. EO sensors provide the advantage of passive surveillance using the airborne or ground-based Advanced Infrared Search and Track System to see at night and in adverse weather. Also, IR focal plane arrays (FPAs) employing multifunction sensor signal processing have the ability to locate and pinpoint snipers in all terrains. The detection of chemical and biological agents utilizing the appropriate wavelength operating modes of multifunction lasers at extended ranges has significantly increased the perimeter of defense. Acoustic sensor technology contributes to the protection from seaborne and subsurface terrorism by developing towed sonar systems that reliably detect and classify small, very quiet submarines in shallow water.

Electronics and electronic components including electronic materials are strong contributors to combating terrorism. Low-power RF devices are being developed that provide improved sensitivity at reduced noise while minimizing power consumption yielding lightweight man-portable surveillance and detection systems. In addition, the millimeter-wave power modules used by detection and location systems are being improved to provide compact, lightweight transmit/receive modules. Night vision devices employing advanced FPAs play a role in anti-terrorist activities by providing passive surveillance in night and adverse weather. Semiconductor laser diodes and diode arrays being developed for application in photonics are also useful as nighttime IR illuminators and target designators. Large-capacity, fast-access optical memories and advanced displays being developed can provide large online databases for fast screening and visualization of terrorist activity. Microelectromechanical system (MEMS) technology allows devices to be constructed that detect very specific chemicals in trace amounts. Using membranes that are constructed to selectively identify specific chemical compounds, a miniature sensor can be developed to detect the chemicals used in bomb construction or taggants used to identify explosive materials. Since the sensors are miniaturized, a number of separate sensors, each sensitive to different materials, can be integrated with the electronic processor for classification onto a single unit allowing a portable sensor employing inexpensive and selective sensors to detect a range of explosive materials.

Timely knowledge of the threat environment is critical to combating terrorism. As a spinoff of a program to develop miniaturized spacecraft instrumentation, a small credit-card-size sensor was developed to detect very small quantities of hydrazine, a chemical of concern to rocket motor engineers. The sensor, when modified, can also be used to detect certain other specific chemical agents. The sensor uses a conductive polymer whose resistivity changes if it reacts with small quantities of a certain specific chemical. The sensor can be worn by personnel and would sound an alarm if the specific chemical is detected. The sensor could be configured to be sensitive to one or more chemicals that are indicative of specific type of terrorist activity, such as the installation of a bomb. In another effort, an extremely sensitive mass spectrometer that can be flown on an aircraft to detect trace quantities of various chemicals is being developed. This instrument is now being flown through missile plumes to look for the presence of ozone-destroying chemicals. However, the same instrument could also be used to fly through regions where terrorists are suspected of building bombs or other devices that might give off small quantities of certain chemicals.

2.0 DEFENSE TECHNOLOGY OBJECTIVES

Radar Sensors

SE.01.02 Low-Cost Electronically Scanned Antenna
SE.02.01 Foliage Penetration Detection Algorithm Demonstration
SE.03.01 Enhanced Moving Target Detection Development
SE.04.02 High-Frequency Surface Wave Radar Shipboard Demonstration
SE.05.01 Automatic Radar Periscope Detection and Discrimination

Electro-Optic Sensors

SE.06.01 Multifunction Electro-Optical Sensors and Signal Processing
SE.07.02 Advanced Pilotage
SE.08.01 Advanced Infrared Search and Track Systems
SE.09.02 Multifunction Laser

Acoustic Sensors

SE.13.02 Lightweight, Broadband, Variable-Depth Sonar
SE.14.02 Multistatic Active ASW
SE.15.01 Affordable High-Performance Towed Arrays

Automatic Target Recognition

SE.19.03 Affordable ATR via Rapid Design, Evaluation, and Simulation
SE.20.01 ATR for Reconnaissance and Surveillance

Integrated Platform Electronics

SE.23.02 Integrated Platform Avionics Demonstration
SE.24.02 Advanced Common Electronic Modules

RF Components

SE.26.01 Millimeter-Wave Power Modules
SE.27.01 Microwave SiC High-Power Amplifiers
SE.28.01 Low-Power RF Electronics

Electro-Optic Technology

SE.33.01 Advanced Focal Plane Array Technology
SE.35.01 Optical Processing and Memory
SE.36.01 Photonics for Control and Processing of RF Signals

Microelectronics

SE.37.01 High-Density Radiation-Resistant Microelectronics
SE.38.01 Microelectromechanical Systems
SE.57.01 Analog-to-Digital Converter

Electronic Materials

SE.39.01 Wide-Bandgap Electronic Materials Technology

Electronics Integration Technology

SE.29.01 Design Technology for Radio Frequency Front Ends
SE.43.01 Energy Conversion/Power Generation
SE.44.01 Power Control and Distribution

Terrestrial Environments

None

Ocean Battlespace Environment

SE.45.01 Forecast of Littoral Currents and Waves
SE.47.01 Autonomous Ocean Sampling Network: Mapping of Ocean Fields

Lower Atmosphere Environment

SE.52.01 Weather/Atmospheric Impacts on Sensor Systems
SE.53.01 On-Scene Weather Sensing Prediction Capability

Space/Upper Atmosphere Environment

SE.55.01 Space Radiation Mitigation for Satellite Operations
SE.56.01 Satellite Infrared Surveillance Systems Backgrounds

3.0 TECHNOLOGY DESCRIPTIONS

3.1 Radar Sensors

3.1.1 *Warfighter Needs*

Radar sensors programs directly support JWSTP's areas of Information Superiority, Precision Force, Combat Identification, Joint Theater Missile Defense, Counter Weapons of Mass Destruction, Military Operations in Urban Terrain, and Joint Countermine by offering "near-perfect," real-time knowledge of the enemy on a global basis. Important objectives include heightened ability (20-dB improvement) to detect low-RCS targets using surface-based and airborne wide area surveillance (WAS) sensors; breakthrough capabilities to detect and classify foliage-concealed, time-critical targets as well as underground targets; development of affordable hardware (<$200,000/copy) to provide decisive target acquisition and fire control capabilities for armored vehicles, and an increase in radar instantaneous bandwidth (to 1 GHz and beyond) to achieve improved target classification, identification, and tracking.

Service requirements for radar are moving beyond detection to target classification, which is now driving radar performance to high-resolution, precisely registered n–dimensional measurement capability. Because cost reduction is an important aspect of all new DoD systems, significant use of COTS equipment and novel electronically scanned antenna designs are being pursued. The UHF/L–band array technology is targeted for transition to upgrades to the Navy E–2C and to the Air Force E–3 radars. The associated space-time adaptive processing algorithms will have application to all airborne radars where nulling of clutter and jamming is required. The low-frequency ultra wideband (UWB) radar and the concealed target detection (CTD) algorithm programs lead to required capabilities in battlefield surveillance from platforms such as UAVs. The high-frequency (HF) surface wave and UWB technology is planned for transition to improve/upgrade the Navy's surface fleet surveillance and over-the-horizon (OTH) targeting capabilities.

3.1.2 *Overview*

3.1.2.1 Goals and Timeframes. The radar sensor can provide capability for all-weather, long-range detection, location, and recognition capability of significant military targets. However, continued technology development is required to meet the evolving needs of the warfighter. The goals of the radar program are listed in Table VII–2. Meeting these goals depends on advances in ATR (3.4), RF components (3.6), microelectronics (3.8), electronic materials (3.9), and electronics integration (3.10) as well as understanding the battlespace environments (3.11, 3.12, 3.13, 3.14).

3.1.2.2 Major Technical Challenges. The alignment of radar DTOs with the JWSTP is accomplished by defining key challenges. The DTOs are then defined by the specific near-term and long-term goals and milestones associated with each challenge. Three key radar sensor challenges are affordability, enhanced detection and discrimination of low-RCS targets in difficult environments (clutter, noise, and CC&D), and enhanced resolution and quality imaging.

Table VII–2. Radar Sensors Subarea Goals and Timeframes

Fiscal Year	Goal
FY97	Develop/fabricate/test a shipboard HFSWR that can detect low-flying antiship missiles at OTH ranges exceeding 20 nmi.
FY00	20 dB improvement in clutter cancellation. 10x improvement in resolution.
FY03	Detect targets in foliage, ground, and buildings (90% P_d).
FY05	Counter 1,000-fold reduction in RCS. 75% cost reduction of radars.

Affordability. This major technical challenge's objective is to improve the capability of radar sensors while significantly improving affordability, especially in an environment of declining quantities of weapon system platform integration opportunities, thus reducing the sensor production base. Specific examples of this challenge include utilization of COTS and MMIC, and development of digital receivers and low-cost electronically scanned arrays (ESAs). By making radars more affordable, the warfighter will reap the benefits of the acquisition of larger numbers of more capable systems previously unavailable to his budget. This will have a pronounced effect on future radar systems, especially UAVs, helicopters, and tanks. The long-term goal for this challenge is a 75% reduction in the production cost of radars.

Enhanced Detection/Discrimination of Low-RCS Targets in Difficult Environments. This major technical challenge's objective is to improve the detection and track of advanced targets in severe clutter and interference (intentional and nonintentional environments). Specific research areas include foliage and ground penetration using low-frequency OTH detection of low-altitude, cruise missiles using HF surface waves; detection of targets in severe clutter from moving platforms using space-time adaptive processing and offboard sources; improved target tracking using advanced algorithms (e.g., knowledge-based techniques, multiple hypothesis testing); and detection of stationary targets using real and synthetic aperture radar (SAR) techniques. Long-term goals are a 20-dB improvement in clutter cancellation, countering a 1,000-fold reduction in radar cross section, and detection of targets in foliage, under ground, and in buildings with a 90% P_d. This capability will deliver to the warfighter superior knowledge of the battlespace in any environment.

Enhanced Resolution and Quality Imaging. This major technical challenge's objective is to improve the capability to produce fine, high-quality, one- and two-dimensional displays of airborne, ground, and sea targets of interest. A major research area in this challenge is the detection of a periscope in high sea clutter. Other research areas include image-while-scan inverse SAR (ISAR) using superresolution techniques and multipath mitigation using very wide bandwidths to develop enhanced, low-angle tracking for fire control solutions. A long-term goal of this challenge is an order-of-magnitude improvement in resolution using more capable signal processors, algorithms, and advanced waveform generation techniques. This capability will provide the warfighter with enhanced detection and recognition of targets of interest.

3.1.2.3 Related Federal and Private Sector Efforts. Advanced radar sensors are primarily developed for government applications. Data from airborne space-based efforts are relevant to NASA and NOAA research efforts in weather detection, global change, atmospheric remote sensing, astronomy/astrophysics, and orbital debris tracking, along with numerous private sector spacecraft programs. Surface and airborne radar technology is useful to the Department of Transportation, local and federal law enforcement agencies, the medical community, and multiple organizations for humanitarian purposes (e.g., search and rescue, buried mine and tunnel detection).

3.1.3 *S&T Investment Strategy*

Overcoming the technical challenges defined in Section 3.1.2.2 requires an investment strategy that will achieve the required long-term goals. To achieve the affordability goal of a 75% reduction in production costs of radar by FY05, utilization of COTS and MMIC technology must be coupled with the development of digital receivers and low-cost ESA antennas. To achieve the enhanced detection and discrimination of low-cost RCS targets in difficult environments, technology efforts must result in a 20-dB improvement in clutter cancellation, countering a 1,000-fold reduction in RCS, and the detection of targets in foliage, under ground, and in buildings with a probability of detection of 90%. Research efforts will focus on low-frequency radars for foliage and ground penetration. Research efforts will apply advanced algorithms to enhance target tracking. Real and SAR technologies will be applied to overcome the challenges of detecting stationary targets in clutter. To solve the difficult problem of detecting targets in severe clutter from moving platforms, space-time adaptive processing techniques will be applied. Significant improvements in image resolution requires technology investment that incorporates more robust signal processors, algorithms, and advanced waveform generation techniques.

3.1.3.1 Technology Demonstrations. None.

3.1.3.2 Technology Development.

Low-Cost Electronically Scanned Antennas (DTO SE.01.02). Candidate lens and antenna material technologies will be evaluated by the Army, Navy, and Air Force to significantly reduce radar system costs and improve radar system reliability while maintaining overall system performance.

Foliage Penetration Detection Algorithm Demonstration (DTO SE.02.01). Experiments will be conducted using low-frequency SAR sensors to yield statistics to support development of foliage penetration radar system technology and requisite target detection and discrimination algorithms.

Enhanced Moving Target Detection Development (DTO SE.03.01). This technology development will focus on detection of targets in severe clutter from moving platforms using space-time adaptive processing and offboard sources, improved target tracking using advanced algorithms, and detection of stationary targets using real and SAR techniques.

High-Frequency Surface Wave Radar Shipboard Demonstration (DTO SE.04.02). The HFSWR demonstration will provide OTH critical early warning of low-flying missiles (30 seconds for Mach 2+ target) and cue weapon engagement radars.

Automatic Radar Periscope Detection and Discrimination (DTO SE.05.01). This technology development will demonstrate the advanced radar technology necessary for surface ship and airborne radars to automatically detect exposed periscopes in the presence of sea clutter and small targets and debris found in the littoral environment.

3.1.3.2 Basic Research. The basic research in new wide bandgap semiconductors, such as SiC and Group V nitrides, promises the potential for extremely high-power, high-efficiency amplifiers that could significantly reduce size, weight, volume, and power requirements of radars thereby enabling more powerful air-based radar systems. Progress in high-temperature superconductors offers the potential for ultrastable oscillators, channelized filters with extremely sharp cutoffs, and 20-bit, high-speed A/D converters to enable radars with required dynamic range to handle the high environmental clutter of the littorals. Finally, a recent breakthrough in research offers, for the first time, the capability to perform real-time, true nonlinear filtering for target tracking.

3.2 Electro-Optic Sensors

3.2.1 *Warfighter Needs*

Fielding of superior electro-optical (EO) sensors will provide force multiplication in (1) Information Superiority—addressed through high-quality, long-range imaging and nonimaging data from sensors digitally interfaced into the C^4I infrastructure; (2) Precision Force—addressed through (a) high-resolution multisensor systems for target acquisition and fire control, guided munitions, and aided target processing to drive battle tempo, (b) high-resolution, distributed sensors for large fields of view/regard, and (c) inexpensive ground vehicle day/night imagers; (3) Joint Theater Missile Defense—addressed through long-range passive infrared search and track; (4) Combat Identification—addressed through multifunction and multisensor concepts; and (5) Military Operations in Urban Terrain—addressed through land and littoral unattended, robotic, and individual soldier multispectral sensors. Transition opportunities exist for all future military and commercial space systems. Aircraft applications include F–14, F–15, F–16, F–18, F–22, JSF, E2C, C–130, C–141, V–22, AH–64, SH–60, Comanche, Kiowa Warrior, and the AC–130 gunship. Surface applications include, M1 Main Battle Tank and subsequent improvements, M2/M3 Bradley Fighting Vehicle, Future Scout Cavalry System, Landing Assault Vehicle upgrades, AAAV, Future Scout Vehicle, TOW Missile System, and underwater mine reconnaissance sensors.

3.2.2 *Overview*

3.2.2.1 Goals and Timeframes. The broad goals (shown in Table VII–3) are to provide affordable sensors that enable U.S. forces to maintain a decisive warfighting edge in performing tactical target detection, identification, acquisition, engagement, mobility missions, and battle damage observation. These goals also are to provide superior warfighter capabilities in the detection, discrimination, and tracking of theater ballistic missiles. All goals are based on improving current performance, while paying particular attention to life-cycle ownership cost. Meeting these goals depends on advances in EO technology (3.7), microelectronics (3.8), electronics integration technology (3.10), and electronic materials (3.9) as well as understanding the battlespace environments (3.11, 3.13, and 3.14).

Table VII–3. Electro-Optic Sensors Subarea Goals and Timeframes

Fiscal Year	Goal
FY97	Achieve 7x clutter rejection for F–14D IRST. Demonstrate multifunction/multiband laser 2–20-watt multiple wavelength output.
FY98	Assess target ID methods for airborne application–90% probability of ID @ 100 km. Demonstrate ultrawide (40 x 80 degrees) night pilotage system.
FY99	Demonstrate air-air and air-ground target ID at extended ranges (20 nmi).
FY00	Assess high-resolution concept demonstrator with 2,000 x 2,000 elements, 90-deg wide FOV, low-power IR imaging sensor.
FY01	Demonstrate hyperspectral smart sensing.
FY02	Complete testing of multispectral detection and ID for deep hide targets ($Pd > 90\%/Pfa < 0.01/km^2$).

3.2.2.2 Major Technical Challenges. The major technical challenges are to improve the capability of EO sensors and to reduce their size, weight, and power requirements while maintaining affordability. Specific challenges include (1) active (laser-based) sensors—providing robust multifunctionality while maintaining compact size and low-power requirements compatible with existing weapon system platform constraints, and providing compact, efficient laser sources with substantial average powers at multiple wavelengths while accommodating eye-safe operation; (2) individual soldier systems—development of lightweight, affordable system integrated optics; and (3) through the multisensor systems—use of shared or distributed aperture systems in order to control size that will improve drag characteristics and reduce cost, implementation of alternate sensing modes (e.g., polarization) to extract more scene information and reduction of the dependence on spatial resolution, and signal processing to enable multifunction sensing and fusion of multiple sensors.

3.2.2.3 Related Federal and Private Sector Efforts. Advanced EO sensors are primarily developed for government applications. Data from space-based efforts are relevant to, and to be coordinated with, NASA and NOAA research efforts in global change, atmospheric remote sensing, astronomy/astrophysics, and orbital debris tracking, along with numerous private sector spacecraft programs. Surface and airborne tactical technology are coordinated with the Department of Transportation (night driving, ship navigation), FAA (aircraft runway navigation and pilotage), local and federal law enforcement agencies (surveillance, physical security), the medical community (diagnostics, human vision aids), and multiple humanitarian organizations (search and rescue, buried mine detection). Industrial applications of thermal imaging technology involving calibrated measurement of temperatures are also leveraged.

3.2.3 *S&T Investment Strategy*

National investments are made to address warfighting needs and to maintain the U.S. force warfighting margin. Particular emphasis is paid to affordability, which is critical in an environment of lower weapon system quantities. Investment in multifunction sensors is also pursued where more than one battlefield capability can be provided through a single system, precluding the need for multiple systems. Key thrusts are in five areas.

Passive EO Sensors. Passive (nonemitting) long-range sensing with high sensitivity and resolution of tactical and strategic targets are being pursued. These are configured to operate either individually or as part of multisensor/multispectral systems. This thrust area supports JWSTP DTOs D.02, D.03, E.02, G.02, G.04, G.11, H.02, H.07, J.03, and J.04.

Active EO Sensors. Technologies are being developed to enable system capabilities for solid-state, eye-safe lasers for long-range precision track and target identification. Multifunction lasers to address multiple platform and operating functions (including ranging, designation, and micro-Doppler, visible, and IR countermeasures) are emphasized. This thrust area supports JWSTP DTOs C.01, C.02, C.04, E.02, and I.02.

Multifunction Sensor Suites. Development of multifunction sensor suites capitalizes on the synergism of individual sensors operating together (to include shared aperture) to allow greater range performance and reduction of target false alarms. This includes agile sensors, multimode FPAs, and multispectral sensors. In addition, this operating mode compensates for the shortcoming of individual sensors due to weather and battlefield obscurants. This thrust area supports JWSTP DTOs B.05, B.06, B.09, C.03, D.02, D.03, G.02, G.04, G.11, H.02, and H.07.

Signal Processing. Signal processing maximizes the performance potential of modern EO sensors through efficient high-speed processing of signals. This allows for alternative modes of operations, affording real-time panoramic battlespace awareness. This thrust area supports JWSTP DTOs D.02, D.03, and G.04.

Modeling and Simulation. Performance and simulation modeling of sensors, targets, and scenes will allow technology assessment, training, and doctrine development through virtual prototyping as a part of the hardware development process. This thrust area supports JWSTP DTOs A.06, A.07, B.02, C.03, E.02, F.01, and F.04.

There are three areas of technology focus.

EO Sensor Fusion and Targeting. This is directed at enhancing targeting capability in an expanded battlespace with improved precision for direct fire, indirect fire, precision-guided weapons, bomb damage assessment, and enhanced location and identification of a wider variety of targets. It capitalizes on the fusion of EO and allied sensors, incorporating advanced FPAs, automatic target recognition, multifunction lasers, radars, and C^4I to sharply increase the target acquisition and target ID range, target location accuracy, multiple target tracking capability, and target servicing rates.

Target Signature Measurement, Modeling, and Management. This is directed at acquiring and predicting the EO signatures of adversarial and friendly ground and air targets in support of tactical analyses, developing and evaluating aided target recognizer algorithms, simulations employing virtual prototypes for warfighting tactical assessment, and training in a manner that reduces the overall need for field and flight data acquisition and testing. This will also demonstrate technologies that enable development of signature management and detection systems that deny acquisition of friendly force assets by threat sensors.

Integrated Sensor Modeling and Simulation. Efforts include advancing the state of the art in synergistic modeling and prototyping capabilities to permit end-to-end predictive modeling and hardware tradeoff for performance evaluation of new technologies in a virtual environment.

Techniques will include high-resolution synthetic image generation and presentation on tactically relevant displays, distributed operational simulations interfaced with virtual prototyping and stereo lithographic facilities, interactive multimedia for readily accessible training, and digital signal interface format for evaluation of human observer performance with and without aided target recognition processors and algorithms.

3.2.3.1 Technology Demonstrations. EO sensors technology demonstrations will illustrate improved platform pilotage and threat protection.

Advanced Pilotage (DTO SE.07.02). This effort will demonstrate improved night and adverse-weather pilotage. Included will be all-aspect viewing via fixed-mounted sensors providing full-sphere coverage, large staring arrays, and multispectral image fusion. Image intensification and second-generation thermal imaging will be demonstrated to yield a 50% improvement in resolution. A 25% increase in FOV will be demonstrated along with a dual-spectrum system that uses a helmet-mounted display. Low-light-level charged coupled device (CCD) and advanced thermal imaging technology approaches (e.g., DTO SE.33.01, Advanced Focal Plane Array Technologies) will be fused and tested for operations in various light levels. Additional emphasis will be placed on color scene presentation with a helmet-mounted color display.

Advanced Infrared Search and Track Systems (DTO SE.08.01). This effort will develop IRST approaches for TMD, cruise missiles, and aircraft detection. Advanced thermal sensors and digital signal processing technology will be employed, with multiple service capitalization on common components and subsystems. Ground vehicle focus is on on-the-move air defense operations. Fixed-wing focus is on antiair warfare and TMD at ranges beyond 500 km.

3.2.3.2 Technical Developments. Key technical developments will result in capabilities for improved precision targeting, passive TMD, laser functions, and signal processing.

Multifunction Laser (DTO SE.09.02). This effort will develop laser sources and systems for multifunction applications. The approach is to utilize a single laser source embedded in a system to accomplish multiple functions (e.g., rangefinding, designation, identification), thus enhancing affordability and platform size capability. Multiwavelength output of 0.26–12 microns will be demonstrated allowing eye-safe operating modes for more robust training and for minimizing personnel injury. Horizontal technology integration approaches will be investigated across multiple system platforms.

Multifunction EO Sensors and Signal Processing (DTO SE.06.01). This effort will advance development in signal processing and multidimensional target detection, discrimination, and tracking for shipboard, ground vehicle, and airborne applications. This effort will develop IRST approaches for TMD, cruise missile and aircraft detection for ships, air defense from on-the-move ground platforms and fixed-wing antiair, and TMD. TMD ranges are beyond 500 km and cruise missile detection at 13 nmi. Advanced thermal sensors and digital signal processing technology will be employed, with multiple service capitalization on common components and subsystems.

3.2.3.3 Basic Research. Basic research capitalized on in this area includes physics, target acquisition (advanced IR focal plane research and image science); physics, radiation (blue-green lasers); electronics, solid-state and optical electronics (uncooled IR detectors, wide-gap semiconductors, nonlinear optical materials); and electronics, information electronics (IR target recognition and image analysis, sensor fusion, and digital signal processing).

3.3 Acoustic Sensors

3.3.1 *Warfighter Needs*

Joint warfighting capabilities in the areas of Information Superiority, Combat Identification, Joint Readiness and Logistics, and Joint Countermine are particularly dependent on acoustic, magnetic, and seismic sensor technology. These sensors provide reliable undersea and terrestrial surveillance against threat targets. Such surveillance is required to achieve and maintain battlespace dominance to enable timely execution of joint/combined operations in support of national security objectives. Undersea acoustic sensor efforts are unique and critical to the Navy.

This subarea develops surveillance and environmental science using acoustics and magnetics to detect, classify, track, and localize quiet threat targets in all operating environments, across all missions, and with all platforms. Acoustic sensors are the primary sensors of choice to detect threat submarines operating below periscope depth. However, the increasingly quieter nuclear threat and the diesel-on-battery threat limit traditional passive narrowband processing, yielding shorter detection ranges. This demands higher array gain (by using more sensors) and adaptive signal processing to counter these quieting trends. Emphasis on active sonars is also increasing to counter this threat. The operational shift to the littorals presents a more difficult environment. The littoral region exhibits increased clutter from biologics, commercial shipping, and background ambient noise. This results in higher false alarm rates and greater weapons expenditures. To counter the environmental effects, fusion of data from acoustic and magnetic sensors with other nonacoustic sensors is finding increased emphasis. Effective multisensor data fusion offers more robust detection and classification performance and a greater range of adaptability. Larger array apertures require emphasis on affordability if such systems are ever to be fielded.

Navy applications include undersea surveillance in both open ocean and in highly variable, cluttered, shallow water areas. The sensors may be hull-mounted, towed, and deployed on a variety of platforms, including surface ships, submarines, fixed-wing aircraft, and helicopters. Army applications encompass shore area and battlefield surveillance used to detect and classify ground and air targets. The systems used are mounted on both stationary and mobile platforms. They are also used to detect mines at short ranges.

3.3.2 *Overview*

3.3.2.1 Goals and Timeframes. The worldwide proliferation of modern, quiet, diesel-electric submarines requires increased emphasis on the use of active sonar and full-spectrum passive processing. Improved classification for existing active sonar systems is the short-term (<5 years) goal. Within 10 years, high-gain passive systems and active sonar systems that can adapt to the highly variable littoral environment and accurately classify targets in high-clutter environments with reduced false alarm rates are required. Modern Army battlefield acoustic systems have demonstrated the capability to detect, classify, and identify ground targets at ranges in excess of 1 km and helicopters beyond 5 km with meter-sized sensor arrays, while netted arrays of sensors have been used to track and locate battalion-sized armor movements over tens of square kilometers in non-line-of-sight conditions.

Far-term improvements will extend these capabilities to tactical ranges. Significant goals are shown in Table VII–4. Advances for meeting these goals depend on progress in EO technology (3.7), understanding the ocean battlespace environments (3.12), and acoustic and magnetic materials.

Table VII–4. Acoustic Sensors Subarea Goals and Timeframes

Fiscal Year	Goal
FY98	Demonstrate optical array technology providing 5x decrease in acquisition costs with higher bandwidths and dynamic ranges. Transition signal processing algorithms to the surface ship SQQ–89 sonar system, improving active classification by decreasing false alarms by an order of magnitude. Test 100x wider frequency band magnetic sensors.
FY99	Transition signal processing algorithms to the helicopter dipping sonar system, improving active classification in shallow water. Demonstrate multistatic ASW operation using a battery-powered deployed active source with submarine towed array receivers and multistatic signal processing techniques. Demonstrate ability to track large vehicle formations with real-time tracking and identification.
FY00	Demonstrate 5x increase in active source bandwidth. Test environmentally adaptable volumetric passive arrays that can provide near real-time aperture flexibility.
FY01	Test the LBVDS.
FY05	Demonstrate optical array technology providing a further 2x reduction (overall 10x relative to FY95) in towed array acquisition costs and programmable apertures. Demonstrate data-linked, autonomous-distributed, deployed sensor systems. Demonstrate 10x area coverage using integrated all-sensor fusing.

System development to achieve the above goals requires a balanced investment in both signal processing and sensor designs. Improved sensor systems providing increased array gain, aperture, sensitivity, source level, and bandwidth will not be fully optimized without corresponding improvements in signal processing techniques. Accordingly, many projects in this subarea emphasize both sensor and signal processing technology development.

3.3.2.2 Major Technical Challenges. In general, the major technical challenges are to provide:

- Highly effective USW shallow-water ASW that can adapt to the environment, include high-resolution environmental modeling and measurement, and incorporate "through the sensor" environmental characterization.
- Low-cost options for USW systems (affordability).
- Improved tactical decision aids through the use of near-real-time simulation coupled with more capable sensing and modeling of the tactical environment.

Specific technical challenges include (1) active sonar detection techniques for targets in clutter caused by nontarget geologic features, biologic and manmade objects on the bottom, and reverberation from surface, bottom, and volume interactions (e.g., CST–5 sea trial data show "routine" deep-water performance hampered by 2 to 12 false tracks per hour; and in shallow water, performance impeded by more than 300 false tracks per hour); (2) passive sonar—algorithms capable of detecting targets in the midst of interference from local and distant shipping; and (3) passive and active sensors—compact, high-power, lower and broader frequency active acoustic sources and larger aperture receiving arrays in affordable applications on a diverse range of platforms.

3.3.2.3 Related Federal and Private Sector Efforts. COTS plays a significant and growing role in this subarea. Telecommunication technology, fiber optics with associated laser, coupler, and splitter technology, polyvinylidene fluoride (PVDF) materials, and computationally intensive hardware are applicable examples.

3.3.3 *S&T Investment Strategy*

The investment strategy for acoustic sensors is focused in two technology areas.

Sensor Signal Processing Technology. Efforts are aimed at developing active waveform designs, improving signal processing and displays to reduce clutter and false alarm rates encountered in cluttered environments, investigating bistatic and multistatic detection schemes, providing algorithms and data fusion techniques that increase P_d with reduced false alarms, and demonstrating long-range ground and air target detection and identification at low cost. Resolving closely spaced targets or target-like objects is addressed by improving array bearing accuracy and beamforming. Other techniques include passive processing, which exploits the complete spectrum of target-emitted signals, platform noise suppression, and ambient (e.g., wind) noise discrimination.

Sensor signal processing technology is divided into three major thrusts:

- Active algorithms and techniques, which include active acoustic techniques for detecting and classifying echoes reflecting off small, quiet submarines in the difficult littoral environment. Major challenges include operations in reverberation-limited environments, high clutter and false target rates, and low/no-Doppler targets that provide few target motion clues.
- Passive algorithms and techniques, which include algorithm development for detection, classification, and localization of a variety of sea, land, and air targets using that target's emitted signals. This subarea includes both passive acoustic and magnetic techniques for ASW and air acoustics, magnetic, and seismic techniques for battlefield target detection.
- Data fusion and interoperability, which include raw sensor data fusion and coherent intersensor processing; techniques for cooperative engagement of multiple platforms for target detection, classification, and localization; and tactical data fusion for improved undersea and battlefield awareness.

Active/Passive Sensor Technology. Active efforts will develop innovative, high-power transducers using new high-energy density transduction materials (e.g., the electrostrictive lead magnesium niobate (PbMN), the magnetostrictive Terfenol–D). Array element interactions will be modeled to aid in providing affordable, compact sources with minimal ship impact that can be towed at the optimum depth determined by the environmental conditions and the target's depth. Deployed or offboard sensors and distributed systems are needed to provide alerts and cueing to tactical platforms. Efforts include the development of affordable, lightweight, extended bandwidth optical sensors, velocity sensors, micromachined sensors, and rugged, soldier-mounted acoustic sensors for long-range and early warning threat detection. Sensor noise models and noise mechanism insights are required to optimize aperture designs.

Active/passive sensor technology is divided into three major thrusts: acoustic/seismic transduction includes technologies for development of individual sensors or sources for both active and passive acoustics and passive seismic applications. Magnetic/nonacoustic sensors include technologies for development of individual sensors for magnetic and other nonacoustic applications, such as wake detection sensors. System development, integration, and test include efforts that incorporate the individual sensor developments from the previous two thrusts and develops platform-specific sensor systems for the detection/classification/localization of targets. This subarea includes testing in the operational environment for data collection, system testing, and concept demonstration, with the goal of gaining support for transition of such technologies to higher funding category programs.

3.3.3.1 Technology Demonstrations.

Lightweight, Broadband, Variable-Depth Sonar (DTO SE.13.02). The LBVDS will combine advances in high-energy density transduction materials and in broad frequency bandwidth waveform generation and signal processing in a 1- to 6-kHz sonar system that provides a shallow-water-environment USW capability to naval surface ship platforms. Real-time clutter rejection, reverberation suppression, target highlighting, and classification will be evaluated through sea tests of the broadband waveforms. A compact, towable source projector and receive array with manageable ship design and operational impact will be developed and used as the testbed. The LBVDS payoff will be an estimated 20-dB improvement in detection and classification, more rapid localization, and a false alarm goal of less than one per hour against quiet, slow submarines and mines in shallow water. The technology is targeted for transition to SC–21.

Multistatic Active ASW (DTO SE.14.02). This DTO develops and demonstrates a multistatic ASW capability, which incorporates an advanced acoustic source for use of surface ships, submarines, aircraft, and deployed distributed sensors. The majority of the DTO addresses the long-endurance, low-frequency active source (LELFAS) that starts in FY98 and will develop and demonstrate a leave-behind active source with a 30-day life that is commandable using underwater acoustic communications technology. The LELFAS will be packaged in a half-length MK 48 torpedo-sized unit, capable of deployment from a submarine, surface ship, or maritime patrol aircraft. The LELFAS source frequencies will be designed to be compatible with existing sensors in order to provide a multistatic ASW capability.

Affordable High-Performance Towed Arrays (DTO SE.15.01). This DTO develops, delivers, and operationally tests an improved towed array for tactical submarines and surface ships. The affordable array technology ATD is an integral portion of this DTO and is scheduled to start in FY98. This ATD will demonstrate a new approach for constructing all-optical towed arrays with potential for greater than 90% reduction in per-channel cost and inherent versatility for use over a very wide acoustic bandwidth.

Rapid Force Projection Initiative ACTD (JWSTP Precision Force DTO B.02). This ACTD is supported by hunter and standoff killer systems. Acoustics efforts that support the ACTD include the Hunter Sensor Suite (HSS) ATD (JWSTP Precision Force DTO B.09), the Integrated Acoustics System (IAS), the Intelligent Minefield (IMF) ATD, and the Remote Sentry (RS) ATD. The acoustic sensors and processing developed in these ATDs are used to provide early warning and target position to cue imaging sensors to detect targets.

3.3.3.2 Technology Development. System development to achieve the goals outlined in Section 3.3.3.1 requires a balanced investment in both signal processing and sensor designs. Improved sensor systems providing increased array gain, aperture, sensitivity, source level, and bandwidth will not be fully optimized without corresponding improvements in signal processing techniques. Accordingly, many projects in this subarea emphasize both sensor and signal processing technology development as stated in Section 3.3.3.

3.3.3.3 Basic Research. This subarea is interdisciplinary, drawing on efforts in materials, mathematical, computer, information, cognitive, neural, surveillance, and battlespace environmental sciences. Environmental effects play a major role in sensor performance, and insight into the complexities offers a means to develop adaptable systems.

3.4 Automatic Target Recognition

3.4.1 *Warfighter Needs*

Automatic target recognition (ATR) addresses the following JWOC: (1) Information Superiority—ATR gives real-time identification of an adversary from high-bandwidth sensors (providing sufficient knowledge to neutralize the enemy) and yields enormous data compression for transmission on battlefield datalinks; (2) Precision Force—ATR's real-time identification of forces over a wide area compresses the C^4I timeline for responsive sensor-to-shooter operations and enables timely reacquisition of target for strike platform; (3) Combat Identification—ATR gives beyond-visual-range ID to launch missiles at long range, enabling lethal enemy engagement, reduced fratricide, and ownship survival; (4) Joint Theater Missile Defense—ATR enables finding ground-based missile launchers in a timely manner consistent with elusive adversary operations, discriminating between RVs and decoys during reentry, and discriminating between cruise missiles and slow-moving, low-flying confusers; (5) Military Operations in Urban Terrain—ATR enables finding targets in cluttered urban environment to precisely identify targets allowing precision weapon employment resulting in minimal collateral damage; (6) Joint Readiness and Logistics—ATR synthetic scene generation and modeling provides capabilities for enhanced simulation and training; (7) Joint Countermine—ATR technology enables rapid detection of mines; and (8) Counter Weapons of Mass Destruction—ATR aids in timely bomb damage assessment. ATR is needed for both ISR and weapon-delivery systems. Transitions planned for JSTARS, P–3, S–3, U–2R, Tier 2, Tier 2+, Tier 3–, F–14, F–15, F–16, F–18, F–22, Apache, Comanche, AWACS, Abrams, Bradley, MSX, THAAD, Destroyer, CG–47, DDG–51, DDG–993, and DD–963.

3.4.2 *Overview*

The ATR subarea is related to battlespace environments and sensors of this DTAP. Knowledge of battlespace environments can facilitate ATR evaluation and utility studies. Sensors and ATR are tightly intertwined as sensors provide the data for ATR development, and ATR is a key objective of sensor design. The ATR subarea also leverages computing technologies reported in the Information Systems Technology area (Chapter III) and the ATR work reported in the Weapons area (Chapter X).

3.4.2.1 Goals and Timeframes. The ATR program goals are grouped into two categories: those organized by target class (land, sea, air) driven by the need to improve ATR performance, and those that are general ATR goals driven by the need to reduce both acquisition and life-cycle costs. The goals and timelines for ATR are shown in Table VII–5.

Table VII–5. Automatic Target Recognition Subarea Goals and Timeframes

Fiscal Year	Goals
FY97	Ground targets—open targets/standard configuration. Airborne targets—10 target types. Surface targets—100 large combatant ship classes. Reentry vehicles—discriminate debris. Target insertion—2 months for classification, 6 months for ID.*
FY02	Ground targets standard configuration—up to 30% target obscuration; 150x search area. Airborne targets—35 target classes. Surface targets—small craft; 20 classes. Reentry vehicles—discriminate crude decoys. Target insertion—24 weeks for target classification, 6 weeks for target ID.* Affordability—2x–4x reduction in development time, 2x reduction in software costs, 10x reduction in hardware costs.
FY07	Ground targets—multiple target configurations including articulation, light CC&D; 1,000x search area. Airborne targets—100 target classes. Surface targets—small craft; 100 classes. Reentry vehicles—discriminate sophisticated decoys. Target insertion—48 hours for target ID.* Affordability—6x–10x reduction in development time, 6x reduction in software costs.

*Varies significantly depending on whether target is captured or denied, target complexity, sensor, and recognition approach.

3.4.2.2 Major Technical Challenges. The major technical challenge for ATR is contending with the combinatorial explosion of target signature variations caused by permutations of target configuration (e.g., stores, articulation, manufacturing, wear/tear), target/sensor acquisition parameters (e.g., aspect, depression, squint angles), target phenomenology (e.g., cavity responses, glints, IR thermal behavior), and target/clutter interaction (e.g., foliage masking, camouflage). ATR systems must maintain low false alarm rates in the face of varying and complex backgrounds, and they must operate in real time. Another extremely important challenge for ATR is the evaluation and prediction of ATR field performance given the practical limitation that data sets cannot represent the extreme variability of the real world. The ability to rapidly insert new targets and to train algorithms on the fly in the field to support flexible and sustained employment of

ATR are important challenges. A key technical challenge is the development of affordable ATR solutions that employ an open architecture. This will provide capability growth via expandable hardware and software insertion.

3.4.2.3 Related Federal and Private Sector Efforts. Image processing technologies are used in medical imaging, law enforcement, automated manufacturing, transportation sensing, remote sensing, environmental sensing, robotics, and multimedia. Commercial computer technologies are leveraged as well.

3.4.3 *S&T Investment Strategy*

Technology is divided into four areas. Note that high-performance computing is a key enabler for each technical area. Also note that the Moving and Stationary Target Acquisition and Recognition (MSTAR) technology development is advancing the state of the art in all four areas.

Algorithm developments address the key technical challenge—combinatorial complexity of ATR. Approaches include the development of both data-driven and model-based approaches using single and multiple radar and EO sensors. Developments include multidisciplinary technologies utilizing advances in signal processing, decision and estimation theory, artificial intelligence, operations research, and computer science. Key programs include MSTAR, image understanding program, imaging ATR, and multisensor fusion.

Affordability developments leverage open architecture initiatives and design tools. Algorithm tools focus on a common environment to reduce ATR development and evaluation cost and improve algorithm performance via shared and distributed algorithm design, reuse of software, and decoupling of software development from real-time high-performance computer (HPC) architectures. The key program activity is integrating the development of Khoros and the image understanding environment as the ATR standard. The hardware component of affordability is addressed by leveraging commercially developed multichip modules to design and demonstrate a family of affordable, miniaturized, high-density, high-performance image and digital signal processors. These efforts use HPC processors and RASSP-developed design tools to meet cost and performance objectives.

Database development, including signature modeling and scene synthesis efforts, is the backbone of ATR progress. Databases support the development and evaluation of ATR algorithms for single/multisensor EO and radar systems. Signature modeling is critical to rapid target insertion capability and provides a cost-effective complement to measured data to evaluating multispectral ATR. Synthetic data also provide a practical means of exploring complex multisensor ATR design spaces. Scene synthesis efforts uniquely provide high-fidelity models for distributed, interactive simulations to assess the warfighting payoff of new technologies such as ATR, including performance of postulated advanced sensor systems against future conventional and low-observable (LO) threats. Key developments include Electronic Terrain Board, Xpatch, and Creation.

Scientific evaluation promotes accelerated and orderly ATR development by providing statistically significant performance feedback that pinpoints algorithm deficiencies to developers and provides valid field performance data to the respective service users for use in transition decisions. Scientific evaluation includes the development of performance estimation/bounding theories to guide ATR development. Strong ATR predictive theories will provide developers the tools to focus efforts at the knee of the curve in the highly complex ATR design space. Standard metrics and evaluation procedures are jointly developed as part of the efforts of the ATR Working Group. Collaboratively developed evaluation methodologies and shared data sets enable direct comparison of algorithms/processors among developers across the services and development agencies.

3.4.3.1 Technology Demonstrations.

Semiautomated Imagery Processing ACTD (JWSTP Information Superiority DTO A.09). This technology demonstration develops template-based ATR coupled with terrain and force structure analysis, object-level change detection, image/map registration, human computer interface, and interactive target recognition. Model-supported exploitation technology developed by the RADIUS program will be integrated and applied to site monitoring. ATR-aided data compression technology developed by the Clipping Service program will be used to reduce datalink requirements. The final demonstration delivers software modules integrated into imagery exploitation migration systems. Key imagery platforms include Tier 3– and U–2R.

Reentry Vehicle Discrimination Technology Demonstrations. These efforts develop discrimination algorithms to separate RVs from debris and sophisticated decoys using radar and EO sensors. Collection and analysis of missile flight data are used to validate signature models and develop/evaluate discrimination algorithms.

Advanced ID ATD (JWSTP Combat Identification DTO C.03). The objective of this DTO is to develop radar signal processing algorithms that provide reliable identification of noncooperative maneuvering aircraft at all target/sensor aspect angles from long standoff ranges. The technology approach is to develop algorithms to continually adapt radar's ID processing to target dynamics and mission demands on the radar system by fusing multiple radar/RF modes—ESM, RSM, and HRR and by performing advanced ISAR imaging techniques via an adaptive range/Doppler imaging process. Potential technology insertion platforms include F/A–18, F–14, F–15, F–16, F–22, and AWACS.

3.4.3.2 Technology Development.

Affordable ATR via Rapid Design, Evaluation, and Simulation (DTO SE.19.03). The objective of this DTO is to reduce the cost and development time for ATR systems including single and multisensor ATRs for land and air targets. Technology advancements will be made in the areas of high-fidelity, real-time synthetic signature and scene simulation; image and performance evaluation metrics, standards, facilities, and tools; large, high-quality, ground-truthed, multisensor databases; algorithm development tools and environments; integrated design environments, and high-performance computing. Standardized methodologies and databases will be integrated with industry and academia via the ATR Working Group.

ATR for Reconnaissance and Surveillance (DTO SE.20.01). This DTO will develop the capability to automatically recognize targets using high-range-resolution radar and ISAR for moving targets and high-resolution SAR for stationary targets. Advances in high-resolution imaging for both stationary and moving targets and advances in hybrid ATR algorithms using elements of both template and model-based approaches will be developed. This advanced imagery exploitation capability will be demonstrated using imagery from a number of reconnaissance/surveillance platforms to meet service-specific exploitation needs. Demonstrations are planned for JSTARS, U–2R, Predator, S–3, and P–3.

3.4.3.3 Basic Research. ATR is a key focus for the 6.1 community. Basic research investment in ATR subarea technologies is estimated at $11 million. Important research themes include multi-resolution processing, fusion, advanced and nonlinear signal processing, computational electromagnetics, algebraic invariance, artificial intelligence and knowledge-based systems, advanced imaging techniques and inverse processing, and distributed/parallel computing. Recent key initiatives include the reduced signature target recognition effort focused on advanced algorithm and computational electromagnetic research; the Federated Lab effort focused on research partnerships between university, industry, and service labs; the signal processing and AI program; the single-sensor ATR program; and the Center for Imaging Science and the sensor processing program.

3.5 Integrated Platform Electronics

3.5.1 *Warfighter Needs*

Government and weapon system contractors concur, using the F–22 and RAH–66 as baselines, that by FY00 procurement, support, and development costs will each be reduced by 10%; mission-capable rate will improve by 20%; first-pass kill will improve by 30% for fixed-wing attack aircraft; nap-of-the-earth engagements will improve by 10% for rotary-wing attack aircraft; and aircraft attrition rates will decrease by 5%. By FY05 each of these improvements nominally will be twice that projected by FY00. These advancements have transition potential for a wide variety of military aerospace systems (i.e., F–15/F–16/F–18/F–117/AH–64 upgrades and retrofits; RAH-66/V–22/F–22 growth; F–18/F–22 derivatives; and the new JSF development). The technology developed under this subarea can be applied to commercial and civilian aircraft, ships, automobiles, and spacecraft. Development of the latest commercial aircraft—the Boeing 777—is incorporating greater levels of integration. Military use of commercial technology, tools, and standards will enhance transition opportunities. Joint warfighting S&T being supported by this subarea primarily include Precision Force, Combat Identification, Joint Theater Missile Defense, Electronic Combat, and Information Superiority.

3.5.2 *Overview*

IPE develops the technology needed to integrate the advancements made in the individual sensor areas. The payoffs described above will be achieved through IPE technology developments and demonstrations that in turn will be integrated into higher level simulations and demonstrations using laboratory testbeds. The efforts in this area draw on the output of the technology developed in radar sensors (3.1), EO sensors (3.2), RF components (3.6), microelectronics (3.8), and electronics integration technology (3.10). In addition, IPE is closely linked to the Air Platforms and Human Systems DTAPs.

3.5.2.1 Goals and Timeframes. Table VII–6 shows the goals and timeframes for the IPE area.

Table VII–6. Integrated Platform Electronics Subarea Goals and Timeframes

Fiscal Year	Goal
FY00	Reduce integration development, procurement, and support costs by 30%. Reduce size, weight, and cooling requirements by 25%. Increase reliability by 30%. Reduce both electronic emissions and apertures by 50% and double real-time, all-source information fusion capabilities.
FY05	Reduce integration development, procurement, and support costs by 50%. Reduce size, weight, and cooling requirements by 50% for fixed-wing and 40% for rotary-wing aircraft. Increase reliability by 50%. Reduce both electronic emissions and apertures by 75% and increase real-time, all-source information fusion capabilities by 5x.

3.5.2.2 Major Technical Challenges. Significant new approaches are needed for the avionics system hardware and software. Cost reductions include the R&D phase as well as the O&M support costs. Obsolete parts and software rehosting are critical logistics problems that require multiple innovative approaches. Engineering/manufacturing development (EMD) time must be shortened and operational lifetime extended to be compatible with this era of fast technology turnover. Designs must be transparent to rapid, frequent technology upgrades using commercial components. Wide-bandwidth, high-dynamic-range-sensor components that can be time-shared to support multiple functions are needed. Low-cost COTS hardware and software components with plug-and-play capabilities and that can be packaged to survive military environments must be supported architecturally using open system architectures based on commercial endeavors. Development of reliable, super high density connectors and fiber optic components to implement high-bandwidth networks must be developed, matured, and inserted into systems. Incremental upgrades to legacy software and mechanisms to allow existing software to coexist with new software without extensive revalidation is critical to cost reduction and the use of COTS components. Major advancements are required in multilevel secure data manipulation, system-level sensor management, and fusion, which are keystones to the future of situation awareness and improved crew productivity with reduced crew size—perhaps the mantra for UAVs.

3.5.2.3 Related Federal and Private Sector Efforts. Commercial aircraft avionics is best represented by the Boeing 777 and Airbus. However, these platforms do not possess nor require the avionic offensive and defensive functions that are the core capabilities of the military attack platforms. However, there are numerous technology advancements in the commercial sector roughly characterized by COTS that indeed impact the lower level function required to implement the military-unique offensive and defensive functions. These will be fully exploited primarily to address affordability.

3.5.3 *S&T Investment Strategy*

In order for the warfighter to realize the capabilities provided by sensors, decision aids, and weapons, they must be integrated in a manner such that the warfighter can understand situation awareness, mission plan, and contingencies; and such that the systems can be affordably, physically, and functionally integrated onto the platform. IPE develops the technologies and tools to accomplish this, including electronic system architecture (fault tolerance, standards and interfaces, interconnects, modeling and simulation); resource and information technology (shared resource management); integrated EO and RF multifunctional/multifrequency apertures; and electronic signal and data processing (packaging, power management, cooling, modularity/commonality). The payoffs cited in Section 3.5.1 will be achieved through IPE technology developments and demonstrations, which, in turn, will be integrated into higher level simulations and demonstrations using laboratory testbeds.

3.5.3.1 Technology Demonstrations.

Integrated Platform Avionics Demonstration (DTO SE.23.02). This DTO is a structured tier of continuing demonstrations of the sub-subarea advancements and their integration into higher level avionic functions. It will show low-cost solutions for future tri-service retrofit and forward-fit applications in integrated avionics by utilizing tri-service development products in a series of testbed demonstrations.

Advanced Common Electronic Modules (DTO SE.24.02). This DTO will develop advanced common electronic modules for common sensor interfaces and digital processing computing nodes. It is a specific aspect of the lower level sub-subarea demonstration of the Integrated Sensor System (ISS). This DTO, however, is focused on application to the SH–60 helicopter platform, whereas ISS is focused on attack aircraft in general.

3.5.3.2 Technology Development. The Smart Skins Array ATD is developing and demonstrating the technical feasibility, operational utility, and support benefits of structurally embedded antenna arrays. Architecture objectives are to reduce interconnect network costs by 50% and increase performance by 8x (FY00) and 50x (FY05); increase design productivity by 2x (FY00) and 5x (FY05); improve plug and play of new technology into existing systems by 70% (FY00) and 85% (FY05); improve resource allocation within the backplane, real-time reconfiguration about faults (FY00) and dynamic resource allocation within a distributed system (FY05); increase mean time before critical failure by 3x (FY00) and 6x (FY05).

Information management objectives are to improve target/threat detection 20% (FY00) and 40% (FY05); improve target/threat location 15% (FY00) and 30% (FY05); improve target/threat identification probability 20% (FY00) and 35% (FY05); and reduce own-aircraft detectability 100:1 (FY00) and 200:1 (FY05).

Integrated EO objectives are to reduce the cost of multispectral shared apertures 50% (FY00) and 75% (FY05); and develop affordable, 350-m/s large area optical windows (FY00).

Integrated RF objectives are to reduce number of apertures 10% (FY00) and 20% (FY05); reduce life-cycle cost of aperture suite 20% (FY00) and 30% (FY05); reduce aggregate aperture RCS 10 dB (FY00) and 15 dB (FY05); and reduce total weight of apertures 25% (FY00) and 35% (FY05).

Signal and data processing objectives are to increase sustained throughput 4x (FY00) and 16x (FY05); increase memory density 6x (FY00) and 32x (FY05); decrease cost 33% (FY00) and 66% (FY05); and demonstrate reusable mission software 50% (FY00) and 60% (FY05).

3.5.3.3 Basic Research. A revolutionary approach to fusion algorithms is required of the mathematics research area. As of now, these most demanding algorithms are being attacked as evolutionary extensions of what exists today. Basic research in the area of high-speed devices that will allow movement of the A/D interface toward the sensor can revolutionize the implementation architecture of avionic functions.

3.6 RF Components

3.6.1 *Warfighter Needs*

The successful pursuit of national objectives requires the continued superiority of our military-essential RF electronics. The widening variety of military missions challenges these systems to be increasingly flexible, timely, and precise on their application. The RF components' sub-thrust is meeting this modernization challenge by developing affordable electronics technology for information dominance and improved dexterity in national strategy and response actions.

Radar remains DoD's primary all-weather sensor to provide capabilities such as surveillance, situation awareness, self and area defense, targeting, terminal guidance, and battle damage assessment. In addition, a major complement to the hardkill capability of weapons is the softkill afforded by EW systems that can potentially handle a much larger attack force than hardkill weapons. Finally, the glue that holds all these capabilities together to form an effective warfighting force is the communications networks. These three areas rely heavily on and are enabled by RF technology, which represents the key to force multiplication (the ability of a minimal number of U.S. platforms and personnel to defeat a much larger enemy force) and the avoidance of technological surprise on the battlefield. The following Joint Warfighting Capability Objectives are supported: Information Superiority, Precision Force, Combat Identification, Electronic Combat, Joint Theater Missile Defense, Military Operations in Urban Terrain, Joint Countermine, and Joint Readiness and Logistics.

The availability of affordable, manufacturable RF electronic components that satisfy the performance, weight, size, interoperability, cooling, and maintainability requirements of military systems is vital for sustaining the competitive edge of U.S. forces over their adversaries. These warfighting capabilities require reductions in size, weight, volume, power consumption, and costs. Advanced high-performance and affordable RF solid-state, vacuum electronic, frequency control, and antenna technologies are currently being transitioned into a broad range of military systems, including the F–15/ALQ–135, LANTIRN, AMRAAM, MILSTAR, GEN–X, GBR, GPS Longbow, Patriot, SADARM, Scamp, Staff, and F–22 radar and EW arrays.

3.6.2 *Overview*

3.6.2.1 Goals and Timeframes. The RF components thrust involves the technology required to generate, control, radiate, receive, and process VHF, UHF, microwave, and millimeter-wave signals. The technologies under development are applicable to solid-state and vacuum electronic devices, low-noise signal and frequency control components, microwave power modules (MPMs), monolithic microwave integrated circuits (MMICs), transmit/receive (T/R) modules, advanced packaging and interconnect technology, and antennas. The five technology thrusts that compose the RF component subarea are solid-state electronics, vacuum electronics, signal and frequency control, antenna support, and multichip assemblies. The results of these efforts enable many of the goals in radar sensors (3.1); Weapons—ordnance (Chapter X); Electronic Combat—

threat warning, self-protection, and mission support (JWSTP Section 4.H); Information Systems Technology—seamless communications (Chapter III); and Space Platforms—space vehicles (Chapter VIII). The timeframes of the goals of the RF components area is presented in Table VII–7.

Table VII–7. RF Components Subarea Goals and Timeframes

Fiscal Year	Goal
FY97	Develop affordable, very compact, millimeter-wave transmitters generating 30–50 watts in the 18–40-GHz range for EW, radar, and communications systems. Develop 75-watt 3-GHz static induction transistor (SIT) power amplifiers for air defense transmitters and 10-watt X-band SiC MESFET. Develop low-power GaAs RF ICs for advanced receivers using heterojunction ICs for low-noise amplification over wide bandwidths.
FY98	Demonstrate wide bandgap semiconductor SiC devices for high-power/high-temperature RF sensor transmitters: 300 watts at 3 GHz. Produce InP millimeter-wave (35–140 GHz) circuits and subsystems for use in smart weapons, all-weather multispectral vision systems, and IFF systems with costs low enough to allow affordable field insertion. Evaluate MMPM technology for EW application with the implementation of a 1 x 8 active steerable array and ALE–50-based MMPM towed decoy. Demonstrate low-noise, ultrastable frequency source with 5x improvement in acceleration sensitivity for improved slow target detection.
FY00	Demonstrate miniature digital receivers for multifunction radar, communications, and EW RF sensors. Achieve efficient full digital beamforming capability on transmit and receive. Achieve two orders of magnitude reduction in frequency control oscillator acceleration sensitivity.
FY02	Develop advanced RF, optical, and digital components for fully integrated, multifunction radar, EW, and communications compact sensors. Demonstrate GaN high-power, efficiency microwave amplifiers at $\geq$10 GHz.

3.6.2.2 Major Technical Challenges. A particularly challenging technical obstacle confronting military systems is in producing affordable solid-state and vacuum power amplifiers for broadband microwave and millimeter wave applications that simultaneously achieve high output power, high efficiency, small volume, and acceptable linearity. Specifically, amplifiers meeting these objectives have instantaneous bandwidths extending over frequency ranges from 1 to 18 GHz, 18 to 40 GHz, 40 to 75 GHz, 75 to 110 GHz, and 110 to 140 GHz at costs ranging from one-fifth to one-tenth that which can be achieved using present design approaches and manufacturing capabilities. Another technical challenge is the achievement of two orders of magnitude improvement in frequency clock stability where size is critical and where stress due to shock and vibration are factors. A third major technical challenge is to develop RF solid-state components that reliably operate at junction temperatures greater than 300°C. Such components are needed for compact sensors that operate in extreme military environments. Another technical challenge is to develop highly integrated, low-power consumption RF electronics for advanced RF and digital applications. This includes devices, ICs, and high-density multichip assemblies. Specific needs are for a family of miniature digital receivers for use in radar and EW sensors. A final challenge is to develop reconfigurable, adaptive beamforming for affordable compact and shallow-depth phased array antennas used in C^4I and radar applications.

3.6.2.3 Related Federal and Private Sector Efforts. Related efforts include metrology work with DOC/NIST and joint programs with NASA in solid-state and vacuum electronics.

3.6.3 *S&T Investment Strategy*

Four major thrusts are being undertaken in order to address the deficiencies noted in Section 3.6.2.2.

Solid-State RF Electronics. A generic technical obstacle associated with the front end of military systems is producing affordable and compact solid-state RF electronics with adequate sensitivity, bandwidth, and dynamic range for use in the frequency range extending from 0.1 to 140 GHz. One specific challenge is achieving high output power, high efficiency, and small volume with acceptable dynamic range, linearity, and low-power consumption. Similarly, there is need for increasingly capable and affordable small signal/low-noise components and integrated circuits for amplification and signal processing at the higher frequencies and over broader bandwidths; compact multifunction downconverters and related receiver components, at costs ranging from one-fifth to one-tenth that which can be achieved using present design approaches and manufacturing capabilities; and advanced devices that operate in severe environments (e.g., high temperatures). The following projects are being undertaken in order to address these deficiencies:

- Leverage development of novel semiconductor materials, device structures, and circuit designs to realize enabling RF electronics including 10–100-watt, low-cost, solid-state RF power sources and wide bandgap devices operating at temperatures above 250°C.
- Development of advanced design tools and high dynamic range, power, and multifunction processes to realize significant across-the-board cost reductions in design, fabrication, assembly, and testing.
- Continued effort at the interchip level to develop improved, more compact packaging and interconnect technology, and at the intrachip level to increase the level of RF IC integration.

Vacuum Electronics. This thrust involves the development of vacuum electronic devices and related components and materials technologies to meet DoD system insertion needs. The impact of this thrust is new capabilities, improved performance, survivability, and greater affordability of military electronic systems. These objectives will be achieved by exploiting scientific advances and technological opportunities and by channeling industrial activities into areas of importance to the national defense. The major challenge is finding ways to achieve higher power output, efficiency, and linearity over broad bandwidths extending from 1 to 18 GHz, 18 to 40 GHz, 40 to 75 GHz, 75 to 110 GHz, and 110 to 140 GHz at a cost that is 2x to 10x lower than can be achieved using present design approaches and manufacturing capabilities. The effort includes (1) integrating a solid-state driver with a vacuum power booster to produce compact power sources, (2) computational techniques extending from electromagnetic simulations to final product design and manufacturing, (3) high-performance millimeter-wave devices exploiting fast- and slow-wave technologies, and (4) vacuum microelectronics and supporting technologies (e.g. improved magnetics, dielectrics, electron emitters, and materials technology).

Signal and Frequency Control. The objectives of this thrust are to develop ultrastable, low-noise frequency sources, digital synthesizers, and clocks for radar, communications, navigation, and IFF systems. Such development will provide higher time and frequency accuracy with lower power consumption, ultra high stability in small volume and in severe environments, and lower noise close to the carrier, especially in vibrating environments. Examples of these improvements include:

- Two orders of magnitude reduction in vibration sensitivity of oscillators, stable oscillators, and microresonator filters in a size comparable to MMIC chips.
- High-accuracy clocks that are 10x smaller and 10x lower power consumption with 10x higher accuracy.
- New piezoelectric materials. Microcomputer-compensated, low-power clocks.
- Novel miniaturized resonators for highly integrated microwave circuit applications.
- Microresonators for ultra high stability.
- Miniaturized atomic frequency standards using optical pumping techniques.
- Microresonator arrays for uncooled IR and biological and chemical sensors.

Antennas and Multichip Assemblies. This thrust involves the development of supporting and enabling technology for low-cost shared aperture, multiple function antennas, advanced transmit/receive functionality, digital beamforming capabilities, and conformal and reconfigurable agile arrays. Of particular importance is the determination of viable approaches for reconfiguring apertures to perform multiple functions and provide failure correction. This effort includes the development of analytical tools to provide adaptive and deterministic control of array antennas conformal to military platforms and to enable predictive simulation of new concepts and techniques. Advanced monolithic integrated components and multichip assembly technology will be employed to increase phased array reliability and reduce cost. This effort leverages related electronic integration technology to achieve multiple interconnected components within advanced, thin, lightweight packages for reliable low-cost operation at SHF and EHF. Development of agile beamforming and conformal array technology represents a major advance in DoD system capabilities.

3.6.3.1 Technology Demonstrations. None.

3.6.3.2 Technology Development.

Millimeter-Wave Power Modules (DTO SE.26.01). The primary objective is the development of 18–40-GHz power modules technology and facilitating the transition and insertion of power modules into a wide range of radar, electronic warfare, and military communications systems. This DTO supports JWSTP Information Superiority DTOs A.10, High-Altitude Endurance Unmanned Aerial Vehicle ACTD; A.13, Satellite C^3I/Navigation Signals Propagation Technology; and A.02, Robust Tactical/Mobile Networking.

Microwave SiC High-Power Amplifiers (DTO SE.27.01). The primary objective is to develop compact, lightweight, highly efficient L- through X-band microwave, solid-state transmitter building blocks from wide bandgap materials (e.g., advanced SiC-based field effect transistors

(FETs) and static induction transistors (SITs)) that meet output power, power density, efficiency, linearity, operating voltage, and temperature to provide size, reliability, and life-cycle cost advantages over competing Si- and GaAs-based, solid-state amplifiers and tube-based RF transmitter systems. This DTO supports JWSTP Information Superiority DTO A.02, Robust Tactical/Mobile/Networking, and Joint Theater Missile Defense DTO D.04, Advanced X-Band Radar Demonstration.

Low-Power Radio Frequency Electronics (DTO SE.28.01). Affordable, low-power consumption RF electronics are being developed for military manportable communications and for airborne/space platforms that are volume and weight starved. This effort addresses development of devices and technology for power-efficient RF electronics including high-efficiency amplifiers and sources, ultrastable frequency control oscillators and clocks, miniaturized low-loss filters and microresonators, and enhanced thermal management technologies. This DTO supports JWSTP Information Superiority DTOs A.02, Robust Tactical/Mobile Networking, and A.13, Satellite C^3I/Navigation Signals Propagation Technology; Precision Force DTOs B.03, Precision Signals Intelligence Targeting Systems ACTD, and B.05, Target Acquisition ATD; Combat Identification DTO C.01, Battlefield Combat Identification ATD; Joint Theater Missile Defense DTO D.04, Advanced X–Band Radar Demonstration; and Military Operations in Urban Terrain DTO E.01, Small Unit Operations TD.

3.6.3.3 Basic Research. Basic research in the RF component technology area is directed toward the synthesis of advanced semiconductor, superconductor, ceramic, piezoelectric, ferroelectric, ferromagnetic, and ferrite materials; the development of affordable processing sequences for them; and the realization of accurate predictive modeling and simulation algorithms and techniques. The successful completion of research tasks in these areas will enable development of high-performance, reliable, low-cost structures for RF devices and components used in DoD systems. Basic research efforts provide technology options for device and component designers and fabricators that may lead to the realization of improved or entirely new classes of devices and components. Specific device/component-related goals that motivate these efforts are achievement of improved device performance (e.g., higher frequency, higher temperature operation, higher efficiency, lower noise, reduced complexity, and ability to support small feature sizes), lower cost, higher yield, improved predictability of properties, and greater reliability.

3.7 Electro-Optic Technology

3.7.1 *Warfighter Needs*

The detection, precise location, specific identification, and tracking of targets and an accurate battlefield damage assessment are key elements of the JWCOs of Information Superiority, Precision Force, Combat Identification, Joint Theater Missile Defense, Military Operations in Urban Terrain, Electronic Combat, and Counter Weapons of Mass Destruction. EO offers advanced technology solutions to the problems of high-resolution target location and identification, nighttime surveillance, and high-capacity data storage and processing. In addition, electro-optics is the basic technology of displays, which are crucial to all man-in-the-loop systems. The continued development of high-performance, man-in-the-loop, and autonomous systems using advanced EO technology will substantially advance global surveillance and communications; all-weather, day/night, camouflage-resistant precision strike missions against fixed and mobile targets; advanced antisubmarine warfare capabilities; and space and sea control systems.

3.7.2 *Overview*

3.7.2.1 Goals and Timeframes. High-performance sensors, displays, and data storage and processing will be required to meet future warfighter needs. Photonics will provide high-capacity, rapid-access data storage; distortionless wideband analog fiber optic communications for sensor, emitter, and antenna remoting; ultra high speed data processing for real-time analysis of SIGINT and ELINT data; and new approaches to steering and control of microwave beams. Display technology will address the problems of developing high-definition, helmet-mounted displays for the individual soldier and the aircraft pilot. A short-term goal is to demonstrate the capability of the active matrix electroluminescent display (AMEL) to operate with analog inputs for low power and compatibility with existing signal sources. Cost reductions in IRFPAs will be sought through uncooled sensor technology and by improvements in the functionality of cooled IRFPA technology. New applications will be addressed through development of multispectral sensors. Laser technology will attempt to lower the cost per watt of semiconductor lasers, develop long-lived blue laser diodes, and demonstrate eye-safe tunable monomode optical fiber lasers. Specific goals are listed in Table VII–8. Long-term (FY01–FY05) goals include integration of IRFPA and ATR functions, 3D stereoscopic displays, and monolithic optoelectronic integration leading to 2D optical "smart" pixel arrays for high-speed parallel processors.

Table VII–8. Electro-Optic Subarea Goals and Timeframes

Fiscal Year	Goals
FY97	Demonstrate thin-film ferroelectric FPA with NEDT of 0.05 K. Demonstrate integrated high-resolution, 60-deg FOV, low-power helmet-mounted sensor. Develop thermally compensated, high-resolution strain sensor for HASS.
FY98	Demonstrate 3D WORM optical memory system. Demostrate 2–18-GHz optical interconnect for airborne RF signal distribution. Design composite hull fiber optic sensor system for Fast Patrol Boat (FPB). Demonstrate long-lived (>100 hours) room-temperature blue laser.
FY99	Demonstrate parallel optical interconnects to 2.5 Gbytes/s. Demonstrate 1–100-GHz optical RF frequency synthesizer for EW, ELINT, and ECM. Demonstrate 0.01° NEDT uncooled FPA with 30-micron pixels. Build FPB fiber optic sensor system and conduct sea trials. Demonstrate eye-safe (1.5–1.6 mm) 3-W monomode fiber laser.
FY00	Demonstrate 1–100-GHz channelizer for ELINT/SIGINT. Demonstrate capability of 3D read–write–erase optical memory. Demonstrate full-color, high-resolution (>1,000 lines) "smart" display.

3.7.2.2 Major Technical Challenges. Key challenges in the laser diode array area include extending the range of available wavelengths in the MWIR and LWIR bands and reducing size, weight, power consumption, and cost. A cost target of $1 per peak watt is sought. In focal plane arrays, the key short-term challenges are in improving sensitivity and reducing cost through functionally improved and new uncooled sensor technology. Longer term, multispectral cooled

FPAs will address the problem of detecting dim and camouflaged targets automatically in ground clutter.

The enormous potential of photonics technology for high-speed data transmission and processing is being exploited for peculiarly military applications. The key technical challenges are in extending the capability of optical recording and data storage to provide increased capacity and faster retrieval to allow processing of SIGINT and ELINT data in real time, using the vast bandwidth of optical waveguides for microwave transition on optical fiber, which allows sensor remoting in SATCOM and ECM applications and developing high-speed, 2D parallel processors for a range of applications including antijammer beam-null steering. Fiber optic sensors are needed for hydrophones and strain-sensing in composites and pose challenges in components, sensor array fabrication, multiplexing, and signal processing. The key challenge in displays for military applications is the development of the helmet-mounted display where low-power consumption, low weight, and high resolution are the principal requirements. Long-term needs are focused on a full-color, high-resolution display with integrated drive electronics.

3.7.2.3 Related Federal and Private Sector Efforts. There are significant commercial activities in flat-panel displays, optical recording, and fiber optics for telecommunications and local broadband services. There is also work at various federal laboratories where development of fiber optic subsystems for specialized tasks such as nuclear test instrumentation have typically been addressed. The DoD-funded efforts use COTS technology wherever possible, supplemented by research and development of the technology and components needed for military applications. A typical example of this approach in the photonics area is the use of COTS optical fiber technology combined with government-sponsored development of the advanced laser sources and detectors needed for military requirements for high-speed analog communications.

3.7.3 *S&T Investment Strategy*

The EO technology subarea is organized in four major thrusts.

Compact Solid-State Lasers. The goals are to meet future laser requirements for infrared countermeasures against IR-guided missiles; design multifunction lasers for ranging, designation, IFF, and laser radar functions; and develop electrically driven, high-energy lasers for sensor and platform destruction that require lasers well beyond the extrapolated state of the art of flashlamp-pumped or diode-pumped solid-state lasers. Each application area has implicit wavelength requirements that generally reduce performance of current lasers by factors of three or more. Also, laser packaging for field use has been a long, expensive process. This thrust is aimed at developing the essential elements of laser technologies that offer the potential of order-of-magnitude or greater performance improvements with intrinsic advantages in wavelength control and packaging. Specific needs for this technology are referenced in the JWCOs of Electronic Combat (for IRCM, e.g., affordable, compact laser, minimum 2-W/20-kHz, mid IR) and Military Operations in Urban Terrain (for laser ranging). This thrust also addresses MOUT needs for laser illuminators and target designators not explicitly referenced.

Two technologies recommend themselves as having the potential of substantial improvements in performance. For the lower power missions, direct laser diode operation at the wavelengths of interest in the visible through the MWIR bands now appears possible. For higher power applications, the use of arrays of fiber lasers appearsto be an attractive candidate. This thrust is aimed either at validating the promise of these technologies or of finding even more attractive systems. The emphasis is on demonstrating device performance characteristics of an acceptable nature in power and lifetime, demonstrating the power scaling of the technology, and deriving system concepts for stressing missions.

Focal Plane Arrays. The FPA thrust focuses on the development of military-unique electro-optical devices and components for optical sensing and the integration thereof into sensor systems. The goals of this thrust are to provide faster, more accurate detection and targeting capabilities combined with the benefits of low weight and low power. Specific objectives include:

- Large, staring, cooled IR arrays for multispectral detection.
- Uncooled arrays with improved sensitivity and resolution and, combined with low-light-level imaging, increased reliability through the employment of staring technology.
- Sophisticated and advanced growth techniques for monolithic integration of smart silicon processors and UV through VLWIR detector arrays.
- Arrays with active and passive sensing capability for LO target detection and identification.
- More affordability and reproducibility of FPAs.

These objectives are obtained by integrating multispectral/hyperspectral FPAs with smart readout ICs, innovative micro-optics, and adaptive micro-/nano-electronics into tactical dewars. The more distant goals involve UV through MMW smart temporal and multispectral sensing with processing that emulates human vision. The results of this thrust will provide the warfighter with increased situational awareness, enhanced defense suppression, increased detection and identification of LO targets, and improved precision weapon delivery for increased lethality and survivability. Needs for IRFPA technology are extensively documented in the JWSTP under the following JWCOs: Information Superiority (multispectral smart surface sensors); Combat Identification (IRFPA, advanced IR sensors); Joint Theater Missile Defense (large format high-uniformity LWIR FPAs, high-sensitivity multispectral IR sensor); and Joint Countermine (multispectral/hyperspectral imaging). There are obvious needs for IRFPA imagers under MOUT that are not referenced explicitly in JWCO goals.

Displays. This thrust addresses an extremely wide range of system requirements. At one extreme, there is the miniature, low-power, low-weight, flat-panel devices for cockpit and individual soldier applications. This part of the thrust builds on the effort by DARPA to develop miniature digital displays. State-of-the-art optics (diffractive, aspherics, hybrids, etc.), sensors (CCD, intensified CCD), and flat-panel displays (AMEL, FED, FLCD, etc.) will be investigated and selected for future helmet-mounted, high-resolution display/sensor systems. Concurrent development of sensor readouts and display driver electronic architectures will be used to optimize power and bandwidth. In the longer term, all solid-state sensor and display systems with digital input/output imagery and symbology will be developed to integrate the individual soldiers and aviators into the digital battlefield. At the other extreme of this thrust are large, high-definition color displays for use by battlefield commanders for multimode C^3 information and battle briefing. More advanced technical investigations address 3D image presentation for applications where depth perception is a critical requirement for understanding the information presented. Explicit references to display technology needs in the JWSTP are scarce; however, there are requirements for compact, low-weight and -power, high-resolution displays for such applications as the Helmet-Mounted Sensory Ensemble (DTO HS.12.02), and it is mentioned as a key technology in the JWSTP chapters on Information Superiority and MOUT. Large, high-definition displays are also an implied requirement for such applications as the Rapid Battlefield Visualization ACTD (DTO A.06).

Photonics. Photonics technology uses light for the transmission and processing of information and offers the potential advantages over conventional electronics of vastly enhanced data throughput and information capacity. From the military viewpoint, photonics provides both enhancements in existing systems, some of which are already close to being available in the inventory, and entirely new applications in areas such as high-speed processing, communications, surveillance antenna and receiver systems, automatic target recognition, electronic warfare, signals intelligence systems, and high-speed communications networks that are well beyond the capability of conventional electronics. These enhancements are necessary in order to achieve future requirements for enhanced system performance within the size, weight, power consumption, and volume constraints imposed by military platforms.

The thrust is organized into five divisions: optical memory and storage, optical processing and interconnects, photonics for antennas and radio systems, fiber optics sensors, and high-speed communications networks. This effort includes the development of devices and subsystems to demonstrate and quantify military system impact. This work is funded by the services, DARPA, and BMDO. There are numerous explicit references to photonics technology needs in the JWSTP and other needs that are implicitly addressed by emerging photonics technology, for example in ATR and tracking. The relevant JWCOs are Information Superiority (mass storage of information, tailored search and retrieval of information, automatic target recognition, rapidly deployable tactical fiber extensions, etc.); Precision Force (EFOG sensor system, multisensor ATR); Combat Identification (secure datalinks); Joint Theater Missile Defense (lasercom, high-speed optical datalinks, target discrimination algorithms); Military Operations in Urban Terrain (high-bandwidth datalinks, ATR, lightweight optoelectronics); Joint Readiness and Logistics (secure, high-rate, high-bandwidth communications); Joint Countermine (ATR); Electronic Combat (wideband datalinking); and Chemical/Biological Warfare Defense and Protection (remotely employable technologies, embedded monitors).

3.7.3.1 Technology Demonstrations. A number of ATDs have been approved in the photonics thrust. The Air Force has two ATDs in optical memory: High-Capacity Jukebox (AF/ACC, FY98) and 3D Memory (AF/AIA/AETC, FY01). In the area of fiber optics, two Air Force ATDs have been approved: Analog RF and Millimeter-Wave Optical Signal Distribution (AF/AIA, FY01) and Optical Control of Phased Arrays for Multimode Communications (AF/C^4A, FY01). In the optical signal processing area, one Air Force ATD is the Integrated C^3I Optical Processor (AF/ACC, FY01). The Navy has four ongoing fiber optic ATDs: Advanced Autonomous Decoy (N/PEO(TAD), FY95–97); Advanced ECM Transmitter for Ship Self-Defense (N/PEO(TAD), FY96–98); Precision Strike Navigator (N/ONR, FY96–98); and Multifucntion Electromagnetic Radiating System (N/NSPAWAR, PMW176 & SEA03K2, FY97–99). In the FPA thrust, the Army has a single ATD: Multifunction Staring Sensor Suite.

3.7.3.2 Technology Development.

Advanced Focal Plane Array Technology (SE.33.01). This DTO includes both cooled and uncooled arrays. The cooled technology focuses on dual-band and multispectral sensing for detecting dim and camouflaged targets in background clutter. The uncooled technology development aims for improved sensitivity and resolution while maintaining low cost, weight, and power consumption. The integration of IR and low-light-level FPA imaging in a single package will improve nighttime rifle sight effectiveness and allow the development of low-cost missile seekers.

Optical Processing and Memory (SE.35.01). This DTO addresses the problems associated with development of a 3D write once–read many (WORM) times optical memory for high-capacity data storage needs, advanced 3D read–write–erase memory, high-speed parallel guided-wave and free-space optical interconnects, and a one trillion operations per second optoelectronic processor demonstration. High-speed signal processing and information storage for C^4I is driven by such operational realities as increasing jammer densities and the new requirements for low-observable surveillance and manipulation of large intelligence databases in real time. The processing requirements for many of these functions cannot be met conventionally. Hybrid or all-optical techniques offer a realistic solution to this processing dilemma.

Photonics for Control and Processing of RF Signals (EW, radar, and communications) (SE.36.01). This DTO exploits the huge bandwidth of monomode optical fiber to replace bulky, lossy, narrowband, and dispersive RF cable and waveguide. Optical fiber delay lines provide unprecedented bandwidth, which suggests their use as true time-delay elements in a microwave-phased array. Further, high-quality optical sources allow the novel implementation of RF systems on optical carriers with their attendant reduction in size (e.g., RF filters, channelizers, up/down converters). These applications are being developed. Multigigahertz analog fiber optic interconnects are being developed for high-fidelity remoting of antennas over kilometer distances. Full-scale optically controlled phased arrays for SATCOM and ECM applications are planned for FY00. A major aspect of these efforts is the development of components such as millimeterwave modulators, detectors, and semiconductor laser optical sources.

3.7.3.3 Basic Research. Research is an important component of the EO effort where much of the technology is emerging. Key basic research is being done in electronic and optical materials. The extensive work on GaN for blue lasers is a good example. Many photonics applications are component limited; consequently, there are significant research efforts for development of devices and components including guided-wave modulators; semiconductor lasers, switches, and spatial light modulators; and smart pixel arrays. In addition, research is being directed toward new nonlinear optical materials and techniques. The long-term goal of research in this area is monolithic integration of optics and electronics.

3.8 Microelectronics

3.8.1 *Warfighter Needs*

The warfighter has become critically dependent on the ability of systems to process, store, and transmit information to achieve force multiplication through remote and distributed awareness and control. Key military equipment (e.g., sensor packages, satellites, manportable communications equipment) must meet stringent military requirements as described in *Joint Vision 2010* (e.g., radiation and high-temperature environments, extended operating lifetimes, lower weight, high performance) to achieve force multiplication throughout the range of potential warfighter environments. A crucial factor affecting DoD's ability to provide superior capabilities to the warfighter is the cost of electronic systems, which depends directly on the producibility, quality, and cost of microelectronics devices, circuits, and fabrication technologies. The challenge facing DoD is to formulate an investment strategy that leverages the more than $150 billion commercial microelectronics market while still maintaining technology leads in low-volume areas that are key to military applications.

Over the short term (1–2 years), electronic systems enabled by microelectronics should double the capability for processing information in the battlespace, while reducing cost, power consumption, and weight by a factor of two. In the mid term (3–5 years), it is expected that microelectronics will enable a doubling of sensing resolution, range, or speed; reduce power consumption by a factor of 10; and reduce weight by a factor of 10. In the long term (6–10 years), microelectronics innovations should provide an order-of-magnitude improvement in the range of sensing capabilities, while decreasing cost, power consumption, and weight by more than a factor of 100.

The technologies for signal conversion and processing, low-power, radiation-resistant microelectronics, and microelectromechanical systems (MEMS) all have the potential to significantly increase the capabilities of weapon platforms and information systems and simultaneously decrease their size, weight, cost, and assembly complexity. The dramatic rate of microelectronics technology innovation has also created the need to ensure that the warfighter has access to current state-of-the-art microelectronics to sustain superiority. Toward that end, the rapid transition of new technology to the industrial base and insertion of new (possibly commercial) technologies into military systems will continue to play an increasingly important role in meeting future warfighter needs.

3.8.2 *Overview*

The microelectronics technology is geared toward meeting very unique military requirements through the exploitation of pivotal technologies based on a range of electronic materials (e.g., silicon and its compounds SiGe and SiC; GaAs and other III–V compounds) and novel processes for new device structures (e.g., MEMS and radiation-resistant components) and circuit applications (e.g., A/D converters and inertial measurement systems). Military use of these technologies, associated with deep submission, 250-nmi feature sizes, will enable order-of-magnitude advances in sensors, low-power systems, and complex, radiation-resistant integrated electronic functions (for signal conversion, processing, amplification, and microelectromechanical sensing) These are to be implemented with advanced design architecture. This will allow handling of 10–1,000 times more data at several hundred times higher throughput through parallelism, functional density, and device speed, and covering a broad spectral range from dc to several tens of gigahertz.

3.8.2.1 Goals and Timeframes. The United States must maintain its military superiority in an era of rapidly changing microelectronics technology. This superiority is based on (1) force multiplication through advanced microelectronics (technology and component applications) with a minimum number of platforms and personnel, and (2) actively avoiding technological surprises in future combat scenarios. In this context, the microelectronics subarea develops device, circuit, and fabrication technologies to realize digital, analog, and mixed-signal integrated circuits that are needed for introduction in a timely and planned fashion into weapon systems ensuring superiority over our adversaries. Specific goals are shown in Table VII–9.

Table VII–9. Microelectronics Subarea Goals and Timeframes

Fiscal Year	Goal
FY97	Develop techniques to integrate 100,000 transistors and 1,000 sensing/actuating elements in MEMS devices. Develop an integrated inertial guidance system on a chip. Develop a 12-bit, 100-Msps GaAs HBT A/D converter. Develop a 16-bit, 125-Msps A/D converter in CMOS/SOS. Demonstrate a radiation-hard, single-chip, 16-bit processor on SOI.
FY 98	Develop fabrication technology to produce submicron, radiation-resistant microelectronics withstanding total doses of 1 Mrad(Si), dose rate upsets of 10^8 rad(Si)/s, and resistant to single-event upset. Develop an ultra low power (<1 mW), 16- to18-bit, 2–100-Ksps ADC for unattended, remotely deployable sonar (shallow-water ASW). Develop a 10-bit, 1-Gsps GaAs HBT A/D converter. Develop a radiation-hard, 32-bit data processor and a 4 M bit radiation hard static memory technology. Demonstrate an InP Δ-Σ modulator for a double-down conversion receiver. Fabricate a BiFET transceiver chip set for DRFM/DIFM.
FY99	Develop a 4- to 5-bit, 20-Gsps A/D converter in CMOS/SOS (associated with subnanosecond RF memories for EW). Develop a high-density, radiation-hard, mixed-signal sensor processor. Demonstrate a BiFET transceiver chip set in DRFM/DIFM brassboard.
FY00	Develop a 6- to 10-bit, multi-GHz (2–6 Gsps) A/D converter in CMOS/SOS for OTH radar surveillance. Transfer BiFET IC technology to pilot production.
FY01	Develop highly integrated nanometer-feature-size, MEMS-based microsystems that integrate sensors, processing circuits, and I/O (actuators, displays), produced by affordable, flexible fabrication techniques. Develop deep-submicron, radiation-resistant microelectronics fabrication technology for microelectronics components. Develop a detailed model of aircraft flight under control of multiple (>10,000) distributed and embedded MEMS sensors, actuators, and processing elements.
FY03	Develop a 16- to 20-bit, 20-Msps–1-Gsps A/D converter for communication, C^4I, EO, navigation, antisubmarine warfare, and missiles.

3.8.2.2 Major Technical Challenges. The warfighter's needs and projected threats are translated into technology goals aimed at removing the bottlenecks and barriers to the affordable collection and processing of information. As the commercial microelectronics market has experienced explosive growth, industry has focused increasingly on large commercial markets and less on critical military characteristics (e.g., radiation hardness, multigigahertz operation, MEMS capability). It is now even more important that DoD surmount the following technical challenges: (1) provide radiation-harden new generations of ICs at an affordable cost that provide the warfighter with survivable state-of-the-art electronic systems, (2) model and simulate mixed analog and digital circuits with greater bandwiths at multigigahertz clock rates, and (3) reduce MEMS fabrication complexity to lower the cost of fabricating MEMS products.

3.8.2.3 Related Federal and Private Sector Efforts. External programs (including support contracts) account for approximately 85% of the current government S&T investment in this subarea. Specific efforts include:

- Consortia (Sematech and SRC) created to implement an industrial investment plan specifically in the microelectronics area. Unfortunately, much of their focus has been on the technology needed for high-volume, state-of-the-art products (e.g., memories and processors) rather than on the specialized products that the military requires.
- Efforts at Sandia National Labs to establish a capability in radiation-hardened microelectronics.
- MEMS activities at various organizations, including Sandia National Laboratories, Lawrence Livermore National Laboratories, and U.C.–Berkeley.

3.8.3 *S&T Investment Strategy*

The microelectronics technology subarea applies a range of electronic materials technologies (e.g., Si and its compounds, GaAs, other III–V compounds) to develop advanced devices and circuits that support a number of key DoD applications. These advanced devices and circuits are either not available from industry or require performance superior to those available from industry. The components and subsystems that depend on advanced technologies are critical to communications (e.g., satellites); radar (e.g., digital warning receivers and automatic target recognition devices); ECM and jammers; avionics systems; command and control; intelligence, surveillance, and reconnaissance; digitized battlefield; ASW, ASSW, and mine detection; and smart munitions. These components and subsystems include:

- D/A and A/D converters supporting faster, cheaper, and more accurate processing for sensing and communications.
- Direct digital synthesizer (DDS) devices for low probability of intercept (LPI) communications and C^4I.
- High-temperature and high-power SiC devices and circuits for sensing and performance.
- Radiation-hardened silicon bulk and SOI microelectronics that withstand natural and nuclear radiation.
- MEMS devices enabling very tightly controlled automatic manufacturing and orders-of-magnitude improvement in the performance and density of mechanical systems.

Microelectronics technology supports all of the Joint Warfighting Capability Objectives. In particular, microelectronics provides critical support to six of the JWCOs: Information Superiority, Precision Force, Joint Theater Missile Defense, Joint Countermine, Electronic Combat, and Chemical/Biological Warfare Defense and Protection. The microelectronics subarea comprises thrusts in four areas: advanced manufacturing, high-performance signal processing components, radiation-resistant electronics, and MEMS.

3.8.3.1 Technology Demonstrations. None

3.8.3.2 Technology Development.

Analog-to-Digital Converter (DTO SE.57.01). Novel Si and III–V devices are being developed from materials such as SiGe, SiC, TFSOS, GaAs, and GaN. These novel devices will be used to achieve low-power SOI circuits and high-performance circuits and applications (e.g., high temperatures, high-speed data and signal processing, wide bandwidths, high-speed/low-power A/D and D/A converters). In the long term, substantial operations enhancements will eliminate low-frequency conversions, allowing the placement of the A/D converters at the sensor (or antenna) for the immediate processing of the analog signal into a digitized format. System enhancements will be realized in (1) radar for detection in high-clutter environments; (2) deployable sensor systems and SIGINT for unattended, remotely controlled applications; and (3) surveillance (HFDF) EW and ESM for real-time computation of DOA and TOA to changing emitters, channels, and environments requiring high-performance components. Specific efforts include:

- CMOS/SOS technology development (funded by the Navy).
- High-speed GaAs and InP heterojunction bipolar transistor (HBT) development (funded by DARPA).
- Flexible, high-performance A/D converter development analyzing the tradeoff between speed and resolution (funded jointly by DARPA, Navy, and Air Force).

This DTO strongly supports three JWCOs: Joint Theater Missile Defense (DTO D.02, Integrated Sensor/Data Fusion Demonstration, and D.03, Discriminating Interceptor Technology Program); Joint Countermine (G.12, Lightweight Airborne Multispectral Countermine Detection System); and Electronic Combat (H.09, Sensor Fusion/Integrated Situation Awareness TD).

High-Density Radiation-Resistant Microelectronics (DTO SE.37.01). Fabrication capabilities are being developed to produce state-of-the-art radiation-resistant microelectronics. Investment is focused on leveraging commercial advances in the fabrication of microelectronics to produce key military components with performance and density close to commercial devices, yet able to withstand the severe radiation environment of space and strategic applications. Specific efforts include:

- Radiation-hard bulk CMOS and SOI process and memory development (funded by DSWA).
- Radiation-hard processor and memory development (funded by the Air Force).
- Radiation-hard nonvolatile memory and analog circuit development (funded by BMDO).

This DTO strongly supports two JWCOs: Information Superiority (DTO A.13, Satellite C^3I/Navigation Signals Propagation Technology); and Joint Theater Missile Defense (D.05, Advanced Space Surveillance).

Microelectromechanical Systems (DTO SE.38.01). Reliable, repeatable, MEMS-specific fabrication techniques are being developed. These techniques will be fed into developing MEMS devices and circuits that integrate sensing, actuation, computation, communication, and control components. Specifically, DARPA (in conjunction with the Army and Air Force) is funding the establishment of a MEMS fabrication infrastructure, physical science work to understand individual MEMS devices, and MEMS applications (e.g., an inertial measurement system). This DTO strongly supports four JWCOs: Information Superiority (DTO A.10, High-Altitude Endurance Unmanned Aerial Vehicle ACTD, and A.14, Tactical Unmanned Aerial Vehicle ACTD); Weapons (WE.12.02, Antijam GPS Flight Test); Precision Force (B.03, Precision SIGINT Targeting Systems ACTD); and Chemical and Biological Defense and Protection (I.03, Airbase/Port Biological Detection ACTD).

3.8.3.3 Basic Research. The DoD basic research (6.1) investment in microelectronics is concerned with developing novel processes, devices, and circuits using innovative materials and physical mechanisms. Over the past 20 years, several large programs have been planned and executed jointly. Most notably, a joint venture on the physics of compound semiconductor interfaces was a highly successful defense-wide approach to setting national goals for surface and interface electronics. This effort continues to broadly impact on infrared detectors essential for operations under realistic battlefield conditions; wide-bandgap semiconductors critical for RF applications and high-power shipboard switching devices; and optical computing devices that provide major weight and size reductions in aircraft signal processors. Another highly successful joint venture was the Ultra Small Electronics Research (USER) program, the precursor for the National Technology Roadmap for Semiconductors developed by the U.S. Semiconductor Industry Association.

3.9 Electronic Materials

3.9.1 *Warfighter Needs*

Warfighters are increasingly exploiting electronic systems to achieve force multiplication. The performance and price of components in these systems depend directly on the reproducibility, quality, and cost of electronic materials synthesis and processing. Electronic materials science also is the enabling technology for electronic and EO devices, whose payoffs include higher maintainability, lighter weight, smaller volume per function, higher data rate processing, and higher frequency/bandwidth operation—characteristics essential for establishing military dominance in areas such as avionics, radar, C^4I, guidance, target identification, surveillance, and navigation. For example, development of III–V semiconductor substrate and films/nanostructures will make more compact radars and higher frequency and data rate communication systems possible in the mid term (3–5 years). In the mid and long terms, materials for IRFPAs will make possible modules capable of broader band detection, multiple color response, and room temperature operation; wide-bandgap semiconductors will make electronics available that operates at 300–500°C (e.g., near engine components), as well as compact ultraviolet laser systems for full-color display applications and high-density optical data storage. Because electronic materials technologies are inherently dual use, DoD programs will benefit civilian electrotechnology, whose enhanced capabilities will benefit military technologies in time.

3.9.2 *Overview*

3.9.2.1 Goals and Timeframes. The electronic materials subarea develops materials, fabrication processes, and device structures that are not supported commercially; are necessary for developing RF, microelectronics, and EO devices and components; and combine affordability with high performance for use in DoD systems. Major goals are listed in Table VII–10.

Table VII–10. Electronic Materials Subarea Goals and Timeframes

Fiscal Year	Goal
FY98	Demonstrate 3-inch diameter substrate wafers of 4H and 6H SiC with uniform doping and defect density < 10^3/cm^2 across the entire wafer; high-resistivity SiC substrates. Develop controlled p-doping of GaN epitaxial films. Develop reproducible epitaxial growth of doped and semi-insulating, low-defect density (<10^5/cm^2) GaN. Demonstrate reliable shallow p-type doping technology for epitaxial growth of GaN.
FY99	Develop a commercially viable SiC epitaxy process that yields materials properties (defect density, control of dopants) that exceed substrate quality. Develop a means to synthesize GaN substrates of 1 inch or greater diameter. Develop effective doping of high aluminum alloy ratio AlGaN material.
FY01	Demonstrate substrates for high-quality films of Group III nitride (III–N) and II–VI semiconductors.

3.9.2.2 Major Technical Challenges. Most electronic materials efforts are linked by the need to reduce the concentration of deleterious defects; to control material composition (including intentional, judicious introduction of impurities), structure, and morphology in order to tailor properties; and to develop fabrication and characterization methods that result in high-quality materials at affordable prices. Additional challenges depend on specific materials and the maturity of the technology. The near-term challenge for high-temperature semiconductors and HTS materials, both of which are at early stages of development, is to produce material having properties suitable for demonstration devices and small-scale components. Substrates that match the lattice constants and thermal expansion coefficients of III–N films are especially needed. For the more nearly mature GaAs- and InP-based materials, challenges include fabrication of larger diameter substrates having lower defect densities, higher uniformity, and lower cost; further control and exploitation of the relationships among growth environments and resulting properties—particularly controlling heterostructure interfaces such as InGaAs/InP; and minimizing the strain induced by lattice mismatches between constituents of the heterojunctions. Key technical challenges for IR detector materials are the achievement of greater uniformity, more precise process control, and, for heterostructure detectors, control of interfaces and strain.

3.9.2.3 Related Federal and Private Sector Efforts. AT&T, Hewlett-Packard, Texas Instruments, Raytheon, Lincoln Labs, Hughes, and several universities have important III–V epitaxy programs. NIST works with AF–RL/ERX and AF–WL/ELD to characterize wafers manufactured by contractors in the Title III GaAs substrate program. M/A–COM, Litton Airtron, and AXT market GaAs substrates; Crystacomm and AXT produce InP substrates. (No company, however, conducts significant internally funded R&D.) Hewlett-Packard, APA Optics, ATMI, and some universities conduct important III–N work. Cree, Westinghouse, and North Carolina State University fabricate SiC. NASA, NIST, LANL, Sandia, ANL, Lincoln Labs, AT&T, IBM, Westinghouse, Conductus, Superconductor Technologies, Dupont, and several universities have important HTS programs.

3.9.3 *S&T Investment Strategy*

The electronic materials subarea is directed toward the development of new materials and the improvement of existing materials intended for device applications. Device/component performance and reduced cost are the benchmarks of success. This subarea encompasses substrate development, epitaxial growth, dopant incorporation and control, control of interface abruptness and quality, bandgap engineering, and development of materials/device interfaces and structures. Materials development supports device development thrusts by providing quick turnaround of materials growth and characterization, the ability to tailor growth and processing techniques to optimize parameters, and development of processing materials and techniques. Classes of interest include semiconductor, superconductor, ferro/ferrimagnetic, ferroelectric, and nonlinear optical (NLO) materials.

3.9.3.1 Technology Demonstrations. The electronic materials subarea is primarily an enabling technology. Upon optimization of materials and processes, the growth or processing technology is transitioned to device development projects and to industry for scale-up or commercialization. Thus, electronic materials technologies are "demonstrated" by successful transitions into the device/component community.

3.9.3.2 Technology Development. By targeting high-leverage technologies, notably materials technologies that have diverse electronic and electro-optic applications, this subarea anticipates the needs of the DoD electron device and component communities. Key areas of investment are summarized below.

Wide-Bandgap Electronic Materials Technology (DTO SE.39.01). The focus is on growth of large-area SiC substrates for high-power RF and high-temperature electronics; on use of (Al,Ga,In)N materials for these electronic applications; on producing and detecting green, blue, and ultraviolet light; and on creating field-emitting arrays. The III–N efforts include growth of lattice and thermally matched substrates (e.g., ZnO and Li aluminate, as well as high-risk, high-payoff efforts to grow GaN as a substrate) and also of films and heterostructures by OMCVD and MBE techniques. This DTO directly supports Joint Theater Missile Defense DTO D.04, Advanced X–Band Radar Demonstration.

Intermediate bandgap III–V semiconductors efforts include development of advanced InP substrates; III–V films, heterostructures, and nanostructures grown on GaAs and InP substrates by OMCVD and MBE; and SiGe heterostructures for RF HBTs. GaAs-based materials development is being pursued because GaAs still dominates microwave electronics and because certain GaAs-based ternary alloys have been identified as candidates for high-speed applications. InP-based materials (plus antimonides) are being developed for very high frequency/high data rate applications (300-GHz transistors are possible) and for possible displacement of GaAs in high-power and low-noise microwave applications. InP-based materials are, moreover, the mainstay of optoelectronics for telecommunications. Thus, they are being developed for optically implemented control functions (e.g., of radar antenna remoting and true time delay control of phased array antennas), as well as for communications applications and OEICs.

IR detector materials are being developed for applications that include IRFPAs for surveillance and night/all-weather operations. Films and structures based on InAs/GaSb superlattices (capable of detecting wavelengths >12 μm) and SiGe (for Schottky barrier devices) are being developed in pursuit of these goals. Work in the high-temperature superconductivity area emphasizes development of $YBa_2Cu_3O_7$ films and structures whose near-zero electrical resistance can be exploited to create extraordinarily narrowband filters and compact high-frequency, high-bandwidth antennas. Also under development are materials for mid-IR optical amplifiers and oscillators (e.g., for frequency-agile lasers), optical computing/storage, target identification, free-space optical interconnects, and optical data storage.

Patterning efforts include lithographic resists by self-assembled monolayers for creating device features <0.25 μm and proximal probe methods for nanoscale device patterning. Processing and equipment efforts, synergistically linked to semiconductor film/nanostructure deposition work described above, emphasize development and technology transfer of promising process technologies. Examples include the Desorption Mass Spectrometry feedback and the Linear Motion Oven for improving molecular beam epitaxy (MBE) yield; use of Sb surfactant, In predeposition, and flashoff in GaAs/InGaAs MBE growth; development and applications of a conical sputter source; and development and characterization of an OMCVD close-spaced reactor.

3.9.3.3 Basic Research: Basic research opens up fruitful new areas of exploratory development. Consistent with electronic materials' character as an enabling technology, many 6.2 efforts are strongly coupled to basic research tasks. Basic research is employed to create the knowledge base undergirding the exploratory development efforts; exploratory development efforts help direct basic research along high-impact paths, and may also generate specific technologies that enhance research work. Specific basic research material efforts that will enable key technology development are atomic control of structures, investigation of new concepts for growth and patterning of nanoscale device structures, and materials tailored for multiple spectrum sensors. Continued investigation of fundamental properties of wide-bandgap materials feeds directly into materials and device technology.

3.10 Electronics Integration Technology

3.10.1 *Warfighter Needs*

Many of the Joint Warfighting S&T areas require significant advancements in affordable high-performance electronics technology, a major challenge given the relatively small volume of specialized military parts needed compared to commercial production volumes. Specifically, miniaturized, power-efficient, reliable, high-performance circuitry is needed for Information Superiority, Precision Force, Joint Theater Ballistic Missile Defense, and Electronic Combat. Today, the cost, performance, size, weight, power consumption, testability, reliability, and maintainability parameters of military systems must all be dealt with on an integrated basis.

3.10.2 *Overview*

The electronics integration technology (EIT) thrust is critical to all electronic equipment as it affects the performance, reliability, affordability, power generation, conditioning, and distribution for virtually every type of system, both military and commercial. The thrust includes:

- Integrated design environment technology.
- Test, reliability, and quality assurance tools, methods, and standards aimed at enabling comprehensive synthesis, design, and diagnostics from the individual transistor to the assembled multiboard system.
- Packaging and interconnect technologies for mixed-signal assemblies containing analog, digital, microwave, millimeter wave, and optoelectronic devices in conjunction with microelectromechanical devices that will preserve device performance throughout an electronic system while increasing reliability and reducing size, weight, volume, and cost.
- Energy conversion and power generation including advanced batteries, fuel cells, engine-driven generators, capacitors, and other direct-energy conversion technologies for manportable C^4I, soldier systems, communications equipment, sensors, combat service support applications, lightweight tactical operations centers (TOCs), tactical power systems, and emergency power
- Power control and distribution including power electronic building blocks (PEBBs), which will revolutionize the way electric power is produced, distributed, and used for land/air/underwater vehicle propulsion, tactical power systems, electric weapons and vehicles, emergency power, silent power generation, smart munitions, manportable C^4I, and soldier systems.

3.10.2.1 Goals and Timeframes. DoD efforts in this area particularly address the long-term thrusts for maintaining the "technology edge"; for reducing the size, weight, and power; and for improving the testability, affordability, and quality of electronics. Major goals are listed in Table VII–11. The impact of the thrusts in this area is pervasive through many of the technologies described in the DTAPs.

3.10.2.2 Major Technical Challenges. Two to three orders of magnitude faster and more affordable "virtual prototyping" of electronic subsystems must be achieved, based on VHSIC hardware description language (VHDL) reusable and interoperable model libraries, and development of analog, mixed-signal, and VHDL analog mixed signal (VHDL–AMS) language capabilities extending to the high-frequency domain. Environmental assessments and sensors, failure analysis/mode identification, reliability and maintainability assessment tools and techniques, built-in self test (BIST) techniques, automated test generation and fault simulation, and diagnostic evaluators are also key challenges.

The next generation of multichip module (MCM) technologies must be developed for high-speed, mixed-signal circuits and increased levels of integration including microelectromechanical devices and buried components in an effort to achieve additional sensor/data/signal

Table VII–11. Electronics Integration Technology Subarea Goals and Timeframes

Fiscal Year	Goal
FY98	Develop signal processing "virtual" prototyping capability and demonstrate 75% design time/cost reduction. (Typically 12 months to 3 months; \$500K to \$125K) Demonstrate a 75% reduction in fault simulation and test generation in design time/cost for digital electronics. (Typically 4 months to 1 month; \$100K to \$25K) Achieve 1-month MCM design cycle with 80–90% recurring cost reduction. (Typically 6 months to 1 month; \$150K to \$30K) Increase primary battery energy by 40% using Li/Mn02. Demonstrate a 10x increase in power density and a factor 3–5 in reliability and switching speed for PEBBs (typically on-card 5–10 W/in^3 to 50–100 W/in^3).
FY01	Develop GHz rate MCMs for affordable mixed analog/digital subsystems. Develop capability to efficiently perform fault simulation and test development of analog and mixed signal electronics. Demonstrate high-energy battery for soldier system: 1/2 size battery for SOF. Demonstrate digitally controlled vehicular power at 10% of the cost of current practice.
FY03	Demonstrate 1–10-kW field power source: thin, conformal battery for soldier system. Demonstrate full-system CAE and integrate into scaleable manufacturing.

processor miniaturization for the individual warfighter, satellites, autonomous vehicles, and ATR processors. Rechargeable lithium-ion cell chemistries with energy densities greater than 100 Wh/kg may be alternatives for C^{4}I training, tank starting, and silent watch. Efficient electrode catalysts in fuel cells are key to 400-Wh/kg manportable fuel cells for soldier system micro-climate cooling. Development of advanced fuel cell components for use in liquid fueled systems and thermal/water management integration techniques are barriers to small fuel cell systems. Diesel fuel processing techniques are critical to the success of the liquid fueled mobile electric power cell programs. PEBB power quality (<3% total harmonic distortion), power density (50 kW/ft^3), and quiet operation must be achieved based on:

- Concurrent engineering.
- Interim products such as high-power MOS-controlled thyristors (MCTs) for megawatts rectification.
- High-efficiency (85–90%), high-density (>200 W/in^3) power converters for control, sensor, and device electronics from the prime power to the multiple low-voltage-regulated load outputs, immune to the harsh EMI (PEBB environment).
- Use of existing manufacturing infrastructure within the U.S. industrial capability in order to ensure commercial viability of the PEBB products.
- Affordability, failure analysis/prediction tools and techniques, built-in test techniques, and diagnostic evaluators.

The next generation SC–21 (Surface Combatant of the 21st century) requires technology insertion of PEBBs to ensure affordability of future "force multiplier" weapon systems.

3.10.2.3 Related Federal and Private Sector Efforts. Related design efforts include tool and computing environment standardization activities under the purview of the CAD Framework Initiative, a consortium of many of the key players in the Electronic Design Automation (EDA) and the Semiconductor Industry Association (SIA) communities. Related electronic module/ subsystem and packaging efforts include MCM development at Sandia National Laboratory and consortium efforts at the Microelectronics and Computer Technology Corporation, the Microelectronics Center of North Carolina, and Semiconductor Research Corporation. The IEEE Computer Society has established a study group under the Design Automation Technical Committee to begin standardization of fault model and simulation techniques and methodologies. The Waveform and Vector Exchange Standard (WAVES) has been established under the Design Automation Standards Committee.

3.10.3 *S&T Investment Strategy*

The EIT subarea is directed at the exploitation of modern electronics to provide a competitive battlefield edge by investing in the development of an integrated design environment closely coupled to high-reliability technologies, advanced packaging and interconnect technologies for mixed signal assemblies, improved power generation and sources, and distributed power architectures. The technology efforts, developments, and demonstrations are designed using a strategy that capitalizes on U.S. industrial capabilities, with the overall objective of meeting present and future military system and subsystem cost and performance objectives. As a result of the long life cycle of military systems and reduced DoD budgets, this technology addresses both new and fielded systems. In the area of design, the strategy is to demonstrate, via an integrated design environment, virtual prototyping and design reuse, reduction in acquisition cost, design cycle time, and life-cycle cost for mixed signal electronic systems. The objectives will be to reduce system development, reengineering, operation and support cost, and life-cycle cost of electronic systems by 4x. The impact on DoD systems will be affordable, maintainable, and upgradable electronic systems.

By using the Rapid Prototyping of Application-Specific Signal Processor (RASSP) program concepts of model-year upgrades, the objective will be to put into place the capability to field state-of-the-art electronic systems rather than fielding 10-year-old obsolete technology. In the areas of dependability, performance, and affordability, the strategy is aimed at achieving an order-of-magnitude increase in mean time between maintenance action, a tenfold reduction in unnecessary maintenance actions, and a 4x decrease in support cost. Design tools and built-in test methodologies are being produced that incorporate reliability technology at the earliest stages of system development. Efficient diagnostic methodologies to enable fault detection and isolation at the component, board, and system levels will be developed. These tools will be utilized by DoD and the commercial industrial base in the design, development, production, and maintenance of cost-effective, dependable systems that meet customer needs.

The growing need for increased functionality in mobile military systems requires the integration of mixed-mode digital, analog, microwave, millimeterwave, electro-optical, and microelectromechanical components. The strategy is to work closely with industry to develop low-volume access to high-volume commercial fabrication lines and to employ higher integration at both the chip and the packaging levels in an effort to preserve on-chip speeds within a factor of 2 throughout the subsystem. Advanced packaging approaches include using MCMs, three-dimensional interconnect techniques, and chip-level protective coatings to eliminate expensive hermetic enclosures. These concepts will be applied to mixed mode assemblies to permit the affordable, reliable assembly of various analog and digital device technologies on a common substrate along with optoelectronic and microelectromechanical components. Even though commercial products are becoming more sophisticated, many military sensor and signal processing assemblies are required to operate over a wider temperature range and meet more stringent size, weight, and power requirements than are achievable by using COTS components and packaging approaches.

Significant military capabilities such as smart weapons, secure wireless communications, covert tags, individual soldier computers, navigation aides, and tactical information assistants will be enabled using affordable multichip module capabilities. The strategy of the efforts in the area of energy conversion/power generation are aimed at lightening the soldier's burden by providing smaller, lightweight, environmentally compatible power sources with high-power and energy densities. This will include demonstration of superior, low-cost primary and rechargeable batteries and other silent portable power sources, as well as other logistically acceptable sources of mobile tactical power such as generators, fuel cells, solar power converters, and other advanced energy conversion devices.

Lastly, the strategy of the distributed power and control efforts is to develop standard power components or building blocks and an architecture that will provide high-quality, responsive, low-voltage power conversion at the point of load. This is the objective of the PEBB program which is striving to revolutionize the way electric power is produced, distributed, and used through the demonstration of a 9x improvement over the next 9 years (versus 7x over the last 40 years) in the product of power density, switching speed, reliability, and cost. The impact of this effort will be to provide a system solution that replaces complex power electronic circuits with a single architecture and brings added value to the services in the form of reduced size, weight, and performance, such as reduction of total harmonic distortion and quiet operation for shipboard systems. For the SC–21, the power density of PEBB is projected to achieve 50 kW/ft^3 at \$0.05/watt, up from the present 36 kW/ft^3 at \$3.00/watt.

3.10.3.1 Technology Demonstrations. None.

3.10.3.2 Technology Development. The technology efforts within the EIT subarea are viewed as critical to the affordability and performance of all new and currently fielded electronic equipment. These efforts are concerned with breakthroughs in CAE methods and tools, dependability and performance technology, advanced mixed signal MCM technology, energy conversion and power generation technology, and power control and distribution advancements including PEBBs for a more highly distributed power architecture. DARPA's work in the packaging and interconnect area, which was included as part of the EIT subarea last year, is now being reported under DTO SE.24.02, Advanced Common Electronic Modules.

Design Technology for Radio Frequency Front Ends (DTO SE.29.01). Tools and processes are being developed for the rapid and efficient design of MMIC, multichip assemblies (MCAs), and mixed signal electronic subsystems. The overall goals are to drive down the cost of RF component and multichip module assembly development, enhance system portability, upgrade reliability, and reduce life-cycle costs. These goals will be accomplished with improved virtual prototyping, reduced design cycle time, improved tool integration, and behavioral modeling.

Energy Conversion/Power Generation (DTO SE.43.01). This DTO will demonstrate small, lightweight, low-cost, environmentally compatible power sources with high-power and energy densities by providing in FY98 at least a 50–100% increase in energy density for electrochemical, electromechanical, and other direct energy conversion devices. This advancement in energy density will enable corresponding reductions in portable power source size and weight (30–50%) and support increased power demands for manportable electronics, sensors, lightweight TOCs, etc., contributing to the military's ability to project mobile forces, execute longer missions, and provide "power on the move." Approaches include improved battery materials and chemistries and more efficient electrode catalysts for fuel cells. All efforts will improve the deployability, tactical mobility, and effectiveness of a CONUS-based fighting force.

Power Control and Distribution (DTO SE.44.01). This DTO addresses advanced military platforms that are becoming "all electric" or "more electric" systems. To meet the challenging objectives in the generation, conversion, and distribution of electric power requires minimizing the cost, weight, and volume/size of power electronics, while maximizing performance (the product of current density, standoff/blocking voltage, and turnoff time or switching frequency). The approach will improve power device efficiency, circuit topologies, and thermal techniques and will develop a family of common power components. These advanced systems anticipate improvements of 10x in power density and a factor of 3–5 in the reliability and switching speed for PEBBs over the present generation conversion and distribution systems technology. The power control and distribution (PCD) envelope must encompass commonality, performance (i.e., power density), affordability, maintainability, and dual-use applicability for efficient use of resources. This DTO will develop the technologies to revolutionize, through the use of PEBBs, the way electric power is produced, stored, distributed, and used. By using the U.S. industrial infrastructure for volume manufacturing, the projected cost reduction for both military and private sector applications will be achieved.

3.10.3.3 Basic Research. Computer-aided, engineering-oriented research at the Computer Engineering Research Consortium of Ohio and within other universities ranges from individual "niche" tool development to unified environments for end-to-end electronic system development. Much research is currently being conducted in digital signal processor (DSP) design systems, algorithms, architectures, and software systems. CAE tools for low-power electronic systems are also in research and development at the University of California, Berkley. Research is also being conducted to provide very high energy density portable power sources. Technologies being researched include zinc-air batteries and advanced hydrogen-based fuel cell architectures that use polymer-exchange membrane systems and new hydrogen storage mechanisms at locations such as International Fuel Cell Corporation.

3.11 Terrestrial Environments

3.11.1 *Warfighter Needs*

The warfighter requires high-resolution geospatial information, terrain visualization technologies, and knowledge of climatic effects that collectively provide a relevant common picture of the battlespace to dominate maneuver, execute precision strike, protect the force, and win the information war. Battlespace domination will be achieved through all-weather, air-land-sea continuous operations based on superior knowledge of the terrain, weather impacts (on both friendly and enemy capabilities), and enhanced all-weather, day/night sensor performance. By providing terrain visualization capabilities, including physics-based environmental effects, commanders will be able to train as they intend to fight, execute mission planning and rehearsal within realistic constraints, and ultimately conduct superior military operations.

3.11.2 *Overview*

The terrestrial environments subarea emphasizes characterization and modeling of the physical phenomena, processes, interactions, and effects associated with terrain and its surface/ subsurface features at scales of interest to ground combat forces.

3.11.2.1 Goals and Timeframes. The terrestrial environments goals and timeframes are shown in Table VII–12.

Table VII–12. Terrestrial Environment Subarea Goals and Timeframes

Fiscal Year	Goal
FY98	Demonstrate an integrated, dynamic IR/MMW terrestrial background scene generation capability for synthetic environments. Develop image perspective transformation technology for use with imagery to rapidly evaluate sub-10-meter resolution terrain data and position reality. Demonstrate virtual reality-based battlefield environments that place the soldier in an environment with replicated actual terrain and climate, creating a highly detailed realistic setting for training and mission planning/rehearsal.
FY03	Demonstrate spatially distributed, physics-based, 3D ground state and weather effects in future distributed simulations. Develop multiscale/multiproduct geospatial data generation software capable of generating large integrated terrain databases at multiple levels of detail.
FY08	Demonstrate knowledge-based systems for predicting the performance of multimode sensing systems (IR and MMW) over winter-impacted terrain. Demonstrate automated feature extraction and attribution capability.

3.11.2.2 Major Technical Challenges. A number of major technical challenges remain:

- Modeling the interaction among air, snow, frozen ground, and unfrozen soil layers to predict acoustic energy propagation.
- Developing a knowledge-based system for predicting the performance of multimode sensing systems (IR and MMW) over winter-impacted terrain.
- Using knowledge-based systems, inferencing techniques, and geostatistical interpolation to identify and attribute terrain features, both natural and manmade, within the enemy's decision cycle.
- Developing a total force positioning and navigational capability for the Army that is all weather, day/night, resistant to jamming, and operable in areas where GPS may not work such as buildings, canyons, and a triple canopy jungle.

- Achieving joint interoperability through the promulgation of standard, reusable, verified, and validated mapping, charting, and geodesy software.
- Generating dynamic, physics-based terrain and environments in near real time for distributed modeling and simulation, mission planning, and rehearsal.
- Exploiting and disseminating multiple scene/multiple sensor imagery and derived terrain/target information using high-speed digital networks.

3.11.2.3 Related Federal and Private Sector Efforts. Other investment in terrestrial environments research is relatively low because of the focus on warfighting needs.

3.11.3 *S&T Investment Strategy*

Providing improved knowledge of the terrestrial environments encompasses varied requirements. The winter environment presents a severe challenge to not only the performance of materiel, but also its operability. Snow and frozen ground dramatically alter the propagation of acoustic and seismic energy. The infrared and millimeter wavelength signatures of terrain features change markedly with freezing and thawing. Icing may dramatically change aircraft performance and impact communications capability. The ability to quantify and model these processes and their effects is essential to system design, test and evaluation, mission planning, and wargaming. Developmental efforts in the topographic sciences concentrate (1) on remote sensing, spectral characterization and analysis, rapid geospatial data generation, point positioning, land navigation, surveying, environmental analysis; and (2) on the effects on tactical operations; interoperability of mapping, charting, and geodesy software; exploitation and dissemination of geospatial data; battlefield visualization; and distributed interactive modeling and simulation.

The terrestrial environments subarea includes cold regions and topography. Research emphasizes techniques for the rapid generation of high-resolution geospatial information; improved capabilities for receiving, interpreting, and disseminating topographic imagery/data; and characterization and modeling of physical phenomena, processes, interactions, and effects associated with terrain and its surface/subsurface energy response at scales and frequencies of interest to ground combat forces. Accurate physics-based models provide realistic portrayals of the environment for combat simulations while also enhancing the all-weather performance of targeting and surveillance sensors. These technologies, along with improved positioning/navigation capabilities and digital communications, collectively enhance the warfighters' capability to dominate the battlespace through rapid exploitation of geospatial data and battlefield visualization. The terrestrial environments area will more fully exploit the data from radars (3.1), electro-optic sensors (3.2), and the planning/rehearsal of military missions. Research in the terrestrial environments subarea supports the Rapid Battlefield Visualization (RBV) ACTD and the MOUT ACTD and contributes to the development of the Synthetic Theater of War (STOW).

3.11.3.1 Technology Demonstrations.

Rapid Battlefield Visualization ACTD (JWSTP Information Superiority DTO A.06). The RBV ACTD will demonstrate capabilities to collect source data and generate high-resolution digital terrain databases within the timelines required by the commander for crisis support and force projection operations. The RBV ACTD will also demonstrate capabilities for the commander to manipulate and display terrain databases, integrated with current situation data, to determine how to achieve his objectives and visualize his desired end state.

3.11.3.2 Technology Development. None.

3.11.3.3 Basic Research. The requirement for terrestrial environments research stems from the impact that the terrain and the environment have on virtually all aspects of military ground activity. The modern power projection military force must be able to perform at full capability throughout the world, in operational theaters that may range from equatorial to polar latitudes, and in terrain that may vary from coastal beach and lowlands to deserts and mountains. In the 21st century, detailed information will be required regarding terrain conditions along with a sophisticated capability for terrain information collection, processing, analysis, visualization, and dissemination. There is an important need for an improved ability to understand terrain and utilize terrain information for military operations in order to lessen the impacts of terrain and environmental conditions, particularly in areas of climatic extremes. Research in this area comprises both field studies and laboratory research related to the acquisition, analysis, interpretation, and modeling of information about terrain and terrain behavior under different climatic conditions. Research on terrain characteristics, dynamics, and effects is aimed at enhancing the current capability to interpret and utilize remotely sensed elevation and feature information at a variety of scales.

3.12 Ocean Battlespace Environment

3.12.1 *Warfighter Needs*

The warfighter needs an affordable, reliable operational capability in all environments and the ability to foresee environmental changes that may affect his capabilities. The variable ocean environment greatly affects warfighter operations, such as movement of equipment and supplies over the beach, cruise missile targeting, or aircraft carrier operations; it also affects the performance of the sensors and systems used by the warfighter. Knowledge of this environment and its impact on the various sensors available to the warfighter are critical to the choice of sensor(s), ability to gain knowledge of the tactical battlespace, and effective delivery of weapons. Knowledge of the ocean battlespace environment is important to the Joint Warfighter S&T areas of Information Superiority, Precision Force, Combat Identification, Joint Countermine, Joint Theater Missile Defense, and Joint Readiness and Logistics. These needs translate to the requirements for understanding processes and phenomenology; measurements and mapping; nowcasts and forecasts of ocean variability; and translation of environmental effects to their impacts on sensors, platforms, structures, and operations. The products in this subarea are designed to increase the warfighter's knowledge of his battlespace environment to unclutter his tactical picture, give him tools to decide on tactics, and give him an advantage over his opponent through exploitation of environmental variability.

3.12.2 *Overview*

3.12.2.1 Goals and Timeframes. Anticipated conflicts encompassing the ocean battlespace environment involve increasing emphasis on mine, special, and amphibious warfare in addition to continuing concerns with antisubmarine warfare. Thus, increasing emphasis is on the coastal, shallow, and semienclosed sea areas where the ability to predict and simulate the spatial and temporal variability of the environment is a formidable challenge. The fundamental goal is sufficient understanding of the environment's effects on weapons, tactics, and operations, coupled with affordable technologies to observe, describe, and predict those effects. A complementary underlying goal is to encourage and aid the design and use of naval systems that are able to exploit environmental variability to military advantage. Anticipated goals are reflected in Table VII–13. Advances in understanding the ocean environment are critical for the design of new acoustic, optical, and electromagnetic sensors; signal analysis; and command and control.

Table VII–13. Ocean Battlespace Environment Subarea Goals and Timeframes

Fiscal Year	Goal
FY01	First range-dependent, on-scene, adaptive-weapon, frequency-acoustic propagation model. 3D turbulence model for localized sediment scour in real time. 1/8 degree North Pacific Oceanographic Prediction System.
FY06	Remote in situ autonomous coastal sensing system. Autonomous sea floor mapping system. Full spectrum noise model for ASW and MCM frequency bands.

3.12.2.2 Major Technical Challenges. Past efforts have been predicated on the construction of databases supplemented by limited onsite information and have been aided by large-scale predictive models driven by large-scale observational programs. As the warfighter's needs move from the open sea to the littoral and the battlespace expands in complexity and rapidity of change, the science and technology of the ocean battlespace environments continues to develop models for forecasts and is moving toward the use of models as tools to interpolate and extrapolate and as a means to extract maximal information from available and disparate observations. The challenges are:

- Very high resolution current, wave, surf, and tidal forecasting models coupled to atmospheric models for support of operations in shallow water.
- Measurements and models of physical and biological processes that impact acoustic, optical, and electromagnetic propagation at surveillance and weapons frequencies.
- Models of fluid-sediment interaction relevant to mine burial.
- Specialized sensing systems for ocean processes in shallow water.
- Remote sea floor mapping capabilities.
- Models of the ocean environmental effects on acoustics, optics, and electromagnetics such that environmentally adaptive signal processing can be developed (in cooperation with acoustic and other programs) to enhance clutter rejection and improve target detection.
- Joint service efforts with warfare system developers to quantify the impact of environmental characteristics on warfare systems and operations.

3.12.2.3 Related Federal and Private Sector Efforts. With the exception of coastal engineering, industry investments are small. Federal S&T is this area has been supported for many years by NOAA, NSF, USGS, MMS, NASA, and DOE; none of these non-DoD programs are aimed at warfighter requirements, especially if those requirements involve non-U.S. waters.

3.12.3 *S&T Investment Strategy*

Not all successful battlespace environment products result in formal, large-scale acquisition programs. Many result in a small number of software applications resident on just one or only a few DoD computers. Thus, the S&T transition and investment strategies have evolved to respond to the specific needs of a few specific customers, and issues such as affordability are not always critical since the major costs are, for example, in the first (and sometimes *only*) copy of some ocean forecasting software. Affordability mainly applies in the acquisition of ocean data through measurement and monitoring and the consequent construction of databases.

The ocean battlespace environment covers the domain from the bottom of the ocean to and including its surface and from deep water to the beach, including the waves breaking on the beach and the consequent modifications of the beach. The range of scales covered extends from fully global, transoceanic scales (10,000 km) down to the scale at which small eddies erode the bottom and bury mines (<1 m) and extends further to the scales of turbulence and of particulate and biological matter that scatter high-frequency sound and limit optical transmission in the water.

Seven distinct program elements (two in 6.1, the rest in 6.2 and higher) support the efforts, supplemented by partial funding from, and cooperative efforts with, many other PEs. The programs in this area include the scientific disciplines of oceanography, ocean geophysics and geology, hydrodynamic and sediment processes, and environmental aspects of ocean acoustics, which are linked to the Basic Research Program. The ocean battlespace environment area is divided into four technology thrusts for addressing warfighter requirements: models/forecasts, sensors and data, small-scale ocean processes and applications, and cooperative (performance and funding) efforts with other programs.

Ocean Models/Forecasts. This thrust covers global to littoral scales (about 1 km), with primary emphasis on support of undersea warfare, secondary emphasis on amphibious and strike warfare, and joint logistics over the shore (JLOTS). Developments in this thrust will primarily support the following areas of the JWSTP: Information Superiority, Joint Readiness and Logistics, Joint Countermine, Precision Force, Joint Theater Missile Defense, and Combat Identification. The primary technology topics are:

- Global models for regional boundary conditions.
- Regional models for littoral boundary conditions.
- Littoral models supporting ASW and other coastal operations.
- Relocatable, nested models.
- Wave models for shallow and coastal waters.
- Onboard models using real-time data.

Sensors and Data. This thrust covers all scales and warfare areas, but concentrates on regional and smaller scales at which traditional instrumentation is less effective. It focuses on deployable, affordable measurements and monitoring for real-time input to on-scene models and environmental characterizations. Also included are concerns with the movement of data between locations, the design and construction of databases, and data fusion. These topics are usually pursued jointly with other programs. Developments in this thrust will primarily support efforts in the following areas of the JWSTP: Information Superiority, Joint Countermine, and Combat Identification. The primary technology areas are:

- Use of organic fleet sensors.
- Adaptive/conditional sampling.
- Autonomous networks.
- Expendable and remote observational techniques.

Small-Scale Oceanography. This thrust covers littoral scales down to 1 meter and smaller, with primary emphasis on support of mine warfare, secondary emphasis on amphibious warfare (AMW) and antisubmarine warfare (AIW). Developments in this thrust will primarily be relevant to the Joint Countermine and Precision Forces areas of the JWSTP. The primary technology topics are:

- Measurement, monitoring, and analysis of all significant natural phenomena related to acoustic, optical, and electromagnetic detection/classification of mines.
- Integration of real-time, small-scale data with historical data sets.
- Understanding of effects of the small-scale environment on systems and operations.
- Prediction of changes in the small-scale environment.

Cooperative Programs. This thrust covers all ocean scales but concentrates on the ASW and MIW areas; consequently, developments under this thrust will primarily serve the following areas of the JWSTP: Information Superiority, Joint Countermine, and Combat Identification. Due to the necessity for the various DTAP areas and subareas to work together, not just coordinate, the ocean battlespace environment has designated a major thrust specifically to work with other DTAP subareas; this is equivalent to interprogram element cooperation in the performance of activities. The general objectives are to identify, for all warfare areas, the most critical environmental factors they must deal with and to provide that critical information when, and in the form, needed with the overriding long-term objective to more rapidly transition their products and methodologies to partnering program elements.

3.12.3.1 Technology Demonstrations. There are no specific ocean battlespace environment technology demonstrations at the present time. However, S&T developed under this subarea will be used in the Joint Mine Countermeasures ACTD involving Navy, Marine Corps, and Army, and in the Submarine Acoustic Communications ATD involving only the Navy. In general, S&T developed in this subarea establishes basic environmental understanding on which many system developments will rely.

3.12.3.2 Technology Development.

Forecast of Littoral Currents and Waves (DTO SE.45.01). This program aims to improve forecast capability for the small-scale currents and waves in the littoral coastal areas. The accurate characterization and forecast of the surf, coastal ocean currents, and waves are important to contingency planning, operational planning, and execution of a number of joint warfighter operations in the littoral environment. This program will establish capabilities important to the Information Superiority and Joint Readiness and Logistics areas of the JWSTP.

Autonomous Ocean Sampling Network: Mapping of Ocean Fields (DTO SE.47.01). Using an autonomous UUV, real-time ocean and bathymetric data that are necessary for MIW, AMW, and ASW operations will be acquired. Of great significance is the ability of UUVs to conduct ocean sampling in a covert manner, especially in those littoral operations where military interest must remain concealed but where environmental data are necessary prior to the operation. Capabilities established here will be of special relevance to the Joint Countermine and Information Superiority areas of the JWSTP.

3.12.3.3 Basic Research. Numerous basic research programs in both the Navy and the Army are in direct support of these technology efforts. Notably, the Army's efforts in surface wave prediction have critical application to the Navy and Marine Corps. The Navy programs in the areas of physical oceanography, remote sensing, coastal dynamics, geology and geophysics, oceanic biology, underwater acoustics, and the associated observations, databases, and models are key to enabling the development of the modeling and measuring techniques discussed above. Examples of research programs today that may provide the critical underlayment for tomorrow's applications include topics in nonlinear systems and chaos theory, aerosols, nested models for tactical scale predictions, multisensor data assimilation, and nonrandom distributions of biological sources of optical scattering.

3.13 Lower Atmosphere Environment

3.13.1 *Warfighter Needs*

The nature of conflict has evolved to highly localized, intense but short-lived battles involving the use of high-tech weaponry. This, in turn, has shifted the focus of lower atmosphere environment support to the warfighter. This shift emphasizes the need for battlespace awareness products in greater detail, spatially and temporally, than were ever required in the strategically driven cold war. The increasing use of weapons, intelligence, and surveillance systems operating at EO and microwave frequencies places greater dependence on information on the radiative and physical characteristics of the lower atmosphere.

As a result, the warfighter needs knowledge of the lower atmosphere environment, its dynamics, and its impact on sensor and weapon systems. Therefore, lower atmosphere environment emphasis is on specifying and forecasting atmospheric conditions such as temperature, pressure, rainfall, humidity, wind direction and velocity, cloud cover, acoustic and electromagnetic transmission, and visibility—all of which directly affect the warfighter's ability to see and operate ships, aircraft, ground vehicles, and most weapons and surveillance systems. This drives the need for weather sensing, analysis, prediction, and tailored application approaches that represent more completely the physical processes unfolding in the Earth's sensible atmosphere. Achieving this requirement demands a capability to continuously observe or monitor the battlespace in 3D using remote and in situ sensors operating on space, ground, and air (manned and unmanned) platforms. The changing role of U.S. forces toward a reactive force available for deployment to small-scale conflicts anywhere on the globe requires that this monitoring capability be available around the world on extremely short notice.

As was demonstrated in Operation Desert Storm, weather was the major cause of aborted strike missions, causing 40% of ordnance to be unused over targets and greatly compromising battle damage assessment. Increased knowledge and quality/timeframe of forecasts are needed to ensure that operations occur successfully, with reduced casualties and decreased costs, in system development and asset utilization. A unique DoD need is provision of operational support in data-sparse and data-denied areas. Emphasis must be placed on the development of tailored weather decision aids and on the simulation of weather elements in support of system acquisition, training, and wargaming.

3.13.2 *Overview*

3.13.2.1 Goals and Timeframes. Lower atmosphere environment emphasis is to provide tactical-scale atmospheric specifications and forecasts on a global basis; develop the real-time tools to assess the environment and its effects on system performance and operations; and develop the techniques of atmospheric measurement, analysis, and prediction with seamless, global, continuous coverage. The application of these technologies in the natural environment will result in measurement, monitoring, and prediction systems that will be truly full spectrum, providing the real-time capability to support air, land and sea operations across the battlespace. Better understanding of the lower atmosphere and its dynamics is critical to radar (3.1), EO sensors (3.2), ATR (3.4), electro-optics technology (3.7), and command and control for mission planning. The goals of this area are shown in Table VII–14.

3.13.2.2 Major Technical Challenges. The challenges are to develop revolutionary new on-scene and remote sensors; data acquisition, data integration, and quality control systems; battle-scale analysis and prediction capability; and artificial intelligence (AI) technology for atmospheric product management.

Table VII–14. Lower Atmosphere Environment Subarea Goals and Timeframes

Fiscal Year	Goal
FY98	Demonstrate software prototype of night vision goggles with performance capable of 75% prediction accuracy. Deliver automated weather analysis system for shipboard and battlefield applications, reducing forecast time by a factor of 5.
FY01	Integrate infrared target signature models into decision aids, reducing by 50% the need for flight test hours. Enhance regional and global prediction systems to provide, for the first time, explicit forecasts of visibility and clouds.
FY04	Extend global ocean-atmosphere-coupled prediction model's forecast range to 4–6 days. Fully exploit theater battlespace weather data through the use of 4D data assimilation techniques.

3.13.2.3 Related Federal and Private Sector Efforts. NSF, NOAA, NASA, and FAA participate in lower atmosphere environment S&T. Their efforts are coordinated with those of DoD through the Office of the Federal Coordinator for Meteorology. There is a clear distinction between the work described here that focuses on battlespace application and the R&D in the broader civilian meteorological community. There is only a very small industrial base in this area.

3.13.3 *S&T Investment Strategy*

The long-term goal of this subarea is to evolve a theater-level battlespace weather awareness system that can be activated on short notice anywhere worldwide anytime warfighter requirements dictate.

In executing the lower atmosphere environment subarea, focus is maintained on joint service weather requirements and capabilities. The challenges are to provide current battlespace weather information (natural and manmade) on a global basis, predict battlespace weather information out to 2 weeks, and provide tailored tactical decision aids for all weather-sensitive systems. Meeting these challenges will require the development of revolutionary new on-scene and remote sensors; data acquisition, data integration, and quality control systems; battlescale analysis and prediction capability; and AI technology for atmospheric product management. Specifically, DTO SE.52.01 is providing technology support (weather impact decision aids) to JWSTP Information Superiority DTO A.07, Battlefield Awareness and Data Dissemination.

Technology advances in all constituent areas of atmospheric science and target signatures are required to achieve the lower atmosphere environment goals. Key thrusts include new ways to observe and predict atmospheric parameters on theater space and time scales, data fusion techniques, improved knowledge of boundary layer physics and explicit cloud processes leading to improved numerical weather prediction models, and tailored application methods in support of specific weapon systems. The focus in this program is on atmospheric measurements, prediction, simulation, and development of system-specific, tailored weather decision aids.

3.13.3.1 Technology Demonstrations. None.

3.13.3.2 Technology Development.

Weather/Atmospheric Impacts on Sensor Systems (DTO SE. 52.01). The objectives of this program are to develop and validate the models that translate the measured or forecasted state of the atmosphere into terms that define the impact of the atmosphere on specific combat systems and operations. A common requirement for all these systems is a knowledge of the propagation characteristics at the required wavelengths (from the visible to microwave regions).

On-Scene Weather Sensing and Prediction Capability (DTO SE.53.01). The objectives of this program are to develop local, regional, and global prediction systems that sense, describe, and forecast battlespace environment parameters in support of mission planning; ship, aircraft, and ground vehicle movement; logistics; and strategic and tactical operations that degrade gracefully as communications and weather observational systems degrade.

3.13.3.3 Basic Research. Advances in basic research critical to the technology developments in this subarea are detailed in Section 4.10 of the *Basic Research Plan.* It is directed toward understanding the basic physical processes relevant to extended forecasting models for:

- Directly diagnosing critical meteorological parameters for battle regions (cloud ceilings, bases, and tops; precipitation intensities; visibility; icing; and turbulence).
- Developing improved algorithms to exploit new satellite multispectral sounders and imagers for cloud, water vapor, and temperature retrieval providing greater vertical resolution than currently available.
- Developing microphysical models to characterize cloud, aerosol, and low-level moisture properties that impact DoD systems and operations.
- Understanding the turbulent nature of the atmosphere over water, littoral regions, and complex land surfaces.
- Understanding of how energy is exchanged between the surface of the Earth and the lowest layers of the atmosphere, with particular emphasis on the evolution of cloud systems and the marine atmospheric boundary layer.

3.14 Space/Upper Atmosphere Environment

3.14.1 *Warfighter Needs*

Information superiority relative to the space/upper atmosphere environment is required in order to maintain control of the "high ground" during all levels of engagement. Inadequate knowledge of the space environment, in which and through which DoD must operate, jeopardizes the safety and effectiveness of warfighting units. At the same time, the possibility that the enemy is using electronic warfare places a high demand on DoD systems to distinguish hostile actions from naturally occurring events and to respond accordingly. The increased specification, mitigation, and exploitation techniques associated with the space/upper atmosphere environment subarea goals will be major contributors to Information Superiority, Joint Theater Missile Defense, and Electronic Combat technology areas.

The key objectives are to provide the warfighter with superior knowledge, tactics, and capabilities. Recognized communications deficiencies in recent warfighter engagements (i.e., Panama, Bosnia, and the Persian Gulf) have identified the need for improved C^3I battlespace specifications. Requirements for C^3I specifications are now an integral part of the CONOPS for GPS and AFSATCOM. Improved filter specifications and clutter-suppression algorithms are needed to optimize the performance of military satellite surveillance systems, specifically the Space-Based Infrared System (SBIRS). Overall, the increased military dependence on space operations makes it imperative that DoD space systems function reliably irrespective of natural space environment disturbances. In this regard, the Air Force has predicted that the approaching solar maximum may lead to significant adverse operational impacts unless precautionary measures are undertaken. The objectives of the space/upper atmosphere environment subarea, once satisfied, will provide the warfighter with superior capabilities to assess and exploit the space and upper atmosphere environments.

3.14.2 *Overview*

Because DoD is committed to using space assets in the future for such important mission areas as communication and surveillance, it is necessary to accumulate a detailed knowledge of the space environment and how it impacts the performance of typical DoD systems that must operate there in continuous, reliable service. Many measurements have been made of the space environment; however, few measurements are available to DoD on a real-time continuous basis. The impulsive, dynamic, often disruptive nature of the space environment must be measured in a standardized, disciplined manner that parallels weather measurements made in our lower atmosphere by meteorological services throughout the world. The long-term goal of this subarea is to operationally deploy a series of validated space environmental models that will provide DoD with accurate, reliable predictions by FY07.

3.14.2.1 Goals and Timeframes. The technologies developed within this subarea are directed toward specifying and exploiting those space and upper atmosphere environmental conditions that limit the effectiveness of military systems. The goals and timelines (Table VII–15) have been specified within existing fiscal constraints to demonstrate that warfighter information superiority in this subarea results in dominant warfighting capabilities. Understanding the steady-state conditions and the dynamics of the space and upper atmosphere environment are critical for the design and operation of DoD space systems, military communication networks, and IR target signatures/surveillance imaging.

Table VII–15. Space/Upper Atmosphere Environment Subarea Goals and Timeframes

Fiscal Year	Goal
FY98	75% improvement in localized communications connectivity specification for the Mid East region. 25% improvement in IR sensor accuracy for atmospheric, cloud, and terrain backgrounds. 100% decrease (elimination) of spacecraft charging hazards using charge control techniques.
FY01	80% improvement in prediction accuracy of C^3 outages using space-based sensor system. 50% improvement in target-image reconstruction using clutter suppression techniques. 25% decrease in technology insertion time for new space power systems.
FY03	95% improvement in global C^3I specification by fusing ground and space data. 80% improvement in radar target geolocation and target-image reconstruction. 95% increase in satellite anomaly prediction and space environmental mitigation.

3.14.2.2 Major Technical Challenges. The theoretical foundations of the space and upper atmosphere environment have steadily progressed since the mid 1970s due to the availability of scientific data from DoD, civil, and foreign sources. For example, we know that space disturbances that adversely affect military operations in and through space are caused by environmental effects such as ionospheric density fluctuations, atmospheric composition variations, and space charged-particle radiation. However, the availability of in-space monitors of the near-Earth space environment is limited, and we are required to use "space weather data" that happen to be available rather than measurements of the specific space effect that we know to be the causative force. As a result, realistic predictions of the space environment are essentially nonexistent, and warfighter support is limited to using predictions based on statistics or climatology.

Current efforts must be geared to obtaining the necessary space environmental measurements on a continuous and timely basis, improved forecast capability through the development of first-principle models of space and upper atmosphere environment, and better knowledge of spacecraft-environmental interactions. Specific technology development areas include advanced space environmental modeling and monitoring, atmospheric transmission and IR background phenomenology, and dynamic models of vehicle interactions with space plasmas.

3.14.2.3 Related Federal and Private Sector Efforts. NASA, NOAA, and NSF are involved with DoD in a strategy to achieve, within the next 10 years, a system to provide timely, accurate, and reliable space environment observations, specifications, and forecasts. Included in this strategy is support to the space/upper atmosphere environment for specifying, predicting, and mitigating the adverse space environmental effects on military space systems. The National Space Weather Program operates under the auspices of the Office of the Federal Coordinator for Meteorological Services and Supporting Research. Agency roles and missions specify that DoD is responsible for developing and transitioning first-principles models of the near-Earth space environment for operational utility.

3.14.3 *S&T Investment Strategy*

Three major thrusts are focused on assessing space environmental impacts on DoD operations: ionospheric effects, optical effects, and space effects. The first thrust has within it a technology demonstration having the near-term goal of validating the approach and providing a residual operational capability, as described in the JWSTP Information Superiority DTO A.13, Satellite C^3I/Navigation Signals Propagation Technology.

The second and third thrusts are more appropriately considered as technology developments and have within them several near-term goals that are captured within Satellite IR Surveillance Systems Backgrounds (DTO SE.56.01) and Space Radiation Mitigation for Satellite Operations (DTO SE.55.01) technologies. Overall investment in these areas include demonstrations of space and atmospheric environmental models and of space environmental sensors. These investments will provide DoD with unparalleled capabilities to specify and predict space environmental impacts on warfighting systems. Specifically, DTO SE.56.01 is providing technology support (IR background characterization) to JWSTP Joint Theater Missile Defense DTO D.05, Advanced Space Surveillance; and DTO SE.55.01 provides identification and warning of natural space anomalies support to several JWSTP DTOs that rely upon an uninterupted flow of information from operational spacecraft, such as Information Superiority DTOs A.13 and A.16. Furthermore, these investments benefit DoD in areas such as improved radar target geolocation and target detection and tracking for Enhanced Moving Target Detection Development (SE.03.01), interpreting signals and images important to ATR for Reconnaissance and Surveillance (SE.20.01), and Multifunction EO Sensor Signal Processing (SE.06.01).

3.14.3.1 Technology Demonstrations. None.

3.14.3.2 Technology Development. Technology advances in the following constituent areas are required to fully achieve the goals of the space/upper atmosphere environment program.

Satellite IR Surveillance Systems Backgrounds (DTO SE.56.01). Technology developments within this DTO are for developing scene-depiction modeling and simulation tools that correctly specify spatial structure in atmospheric, cloud, and terrain radiance backgrounds. Currently, these technology developments are focused to support space-based surveillance and threat warning systems such as SBIRS.

Space Radiation Mitigation for Satellite Operations (DTO SE.55.01). Technology developments under this DTO are to establish the causal relationship between the space radiation environment and (1) satellite anomalies, (2) space-systems degradation, and (3) systems failure; develop techniques and instrumentation that mitigate the adverse effects of space radiation; and enable warning capabilities for potentially deleterious satellite operations. Currently, these technologies are focused to support all space-based military systems.

3.14.3.3 Basic Research. As noted in Section 3.14.2.2, the major challenges for the space/upper atmosphere environment subarea are the lack of an adequate number of spaceborne instruments measuring and reporting in real time the various necessary space environmental effects that are known to cause problems to DoD operations and a unified theoretical foundation for developing predictive models of the near-Earth space environment. The fundamental knowledge for understanding how the energy flows from the Sun, through the magnetosphere, into the ionosphere and upper atmosphere is incomplete and must be obtained before truly accurate and timely predictions of the space effects on DoD assets can be possible. It is this energy flow within the space and upper atmosphere environment that manifests itself in increased ionospheric disturbances on military communications and navigation, large variations in atmospheric densities that affect IR optical transmissivity, and enhanced space-charged particle fluxes that affect satellite operations. The basic research programs must provide this fundamental understanding.

GLOSSARY OF ABBREVIATION AND ACRONYMS

2D	two dimensional
3D	three dimensional
4D	four dimensional (three dimensional plus time)
AAAV	Advanced Amphibious Assault Vehicle
ACTD	Advanced Concept Technology Demonstration
A/D	analog to digital
AEW	airborne early warning
AFSATCOM	Air Force Satellite Communications Command
AI	artificial intelligence
AIN	Army Interoperability Network
AMEL	active matrix electroluminescent display
AMRAAM	Advanced Medium-Range Air-to-Air Missile
AMS	analog mixed signal
AMW	amphibious warfare
ANL	Armstrong National Laboratory
ARL	Army Research Laboratory
ASAT	antisatellite
ASW	antisubmarine warfare
ATD	Advanced Technology Demonstration
ATR	automatic target recognition
AWACS	Airborne Warning and Control System
BiFET	bipolar field effect trransistor
BIST	built-in self test
BMDO	Ballistic Missile Defense Organization
C^3I	command, control, communications and intelligence
C^4I	command, control, communications, computers and intelligence
CAD	computer-aided design
CAE	computer-aided engineering
CB	chemical/biological
CC&D	countercamouflage, concealment, and deception
CCD	charged coupled device
cm^3	cubic centimeters
CMOS	complementary metal oxide semiconductor
CONOPS	Concept of Operations
CONUS	continental United States
COTS	commercial off the shelf
CTD	concealed target detection
D/A	digital to analog
DARPA	Defense Advanced Research Projects Agency
dB	decibel
DDR&E	Director Defense Research and Engineering
DDS	direct digital synthesizer
DIFM	digital intermediate frequency modulator
DOA	direction of arrival
DOC	Department of Commerce
DOE	Department of Energy

DRFM	digital radio frequency modulator
DSP	digital signal processor
DSWA	Defense Special Weapons Agency
DTAP	*Defense Technology Area Plan*
DTO	Defense Technology Objective
ECM	electronic countermeasure
EDA	Electronic Design Automation
EFOG	enhanced fiber optic guided
EHF	extremely high frequency
EIT	electronic integration technology
ELINT	electronic intelligence
EMD	engineering/manufacturing development
EMI	electromagnetic interference
EO	electro-optic(al)
ESA	electronically scanned array
ESM	electronic support measure
EW	electronic warfare
FAA	Federal Aviation Administration
FED	field emission device
FET	field effect transistor
FLCD	ferro-electric liquid crystal display
FOV	field of view
FPA	focal plane array
FPB	Fast Patrol Boat
FY	fiscal year
Ga	gallium
GaAs	gallium arsenide
GaN	gallium nitride
GaSb	gallium antimony
GBR	ground-based radar
GHz	gigahertz
GPS	Global Positioning System
HASS	High-Accuracy Strain Sensing
HBT	heterojunction bipolar transistor
HF	high frequency
HFDF	
HFSWR	High-Frequency Surface Wave Radar
HPC	high-performance computer
HRR	high-resolution radar
HSS	Hunter Sensor Suite
HTS	high-temperature superconductor
IAS	Integrated Acoustics System
IC	integrated circuit
ID	identification
IEEE	Institute of Electrical and Electronic Engineers
IFF	identification friend or foe
IMF	intelligent minefield
IMINT	imagery intelligence

InP	indium phosphorus
I/O	input/output
IPE	integrated platform electronics
IR	infrared
IRCM	infrared countermeasure
IRFPA	infrared focal plane array
IRST	infrared search and track
ISAR	inverse synthetic aperture radar
ISR	intelligence, surveillance, and reconnaissance
ISS	Integrated Sensor System
JCS	Joint Chiefs of Staff
JLOTS	joint logistics over the shore
JSF	Joint Strike Fighter
JSTARS	Joint Surveillance Target Attack Radar System
JWARN	Joint Warning and Reporting Network
JWCO	Joint Warfighting Capabilities Objective
JWSTP	*Joint Warfighting Science and Technology Plan*
K	kelvin
km	kilometers
ksps	thousand samples per second
LANL	Los Alamos National Laboratory
LANTIRN	Low-Altitude Navigation Targeting Infrared for Night
LBVDS	Lightweight, Broadband Variable Depth Sonar
LCD	liquid crystal display
LELFAS	long-endurance, low-frequency active source
LO	low observable
LPI	low probability of intercept
LWIR	long wavelength infrared
M&S	modeling and simulation
MBE	molecular beam epitaxy
MCA	multichip assembly
MCM	mine countermeasure; multichip module
MCT	MOS-controlled thyristor
MEMS	microelectromechanical systems
MESFET	metal semiconductor field-effect transistor
MHz	megahertz
MILSTAR	military strategic, tactical, and relay (satellite)
MIW	mine warfare
MMIC	monolithic microwave integrated circuits
MMPM	millimeterwave power module
MMS	Marine Mineral Survey
MMW	millimeter wave
MOS	metal oxide silicon
MOUT	Military Operations in Urban Terrain
MPM	microwave power module
m/s	meters per second
Msps	Mega samples per second
MSTAR	Moving and Stationary Target Acquisition and Recognition
MWIR	mid-wavelength infrared

NASA	National Aeronautics and Space Administration
NAVAIR	Naval Air Command
NAVOCEANO	Naval Oceanographic Office
NAVSEA	Naval Sea Systems Command
NEDT	noise-equivalent delta temperature
NEXRAD	Next Generation Radar
NIST	National Institute of Standards and Technology
NLO	nonlinear optics
nmi	nautical mile
NOAA	National Oceanic and Atmospheric Administration
NSF	National Science Foundation
NSW	Naval Special Warfare
OCONUS	outside continental United States
OEIC	opto-electric integrated circuit
OMCVD	organo-metallic chemical vapor deposition
OMICs	opto-microwave integrated circuit
ONR	Office of Naval Research
OTH	over-the-horizon
OUSD	Office of the Under Secretary of Defense
P_d	probability of detection
PbMN	lead magnesium niobate
PCD	power control and distribution
PE	program element
PEBB	power electronic building block
Pfa	probability of false alarm
PVDF	polyvinylidene fluoride
R&D	research and development
RASSP	Rapid Prototyping of Application-Specific Signal Processors
RBV	Rapid Battlefield Visualization
RCS	radar cross section
RF	radio frequency
RS	Remote Sentry
RSM	radar signal modulation
RV	reentry vehicle
S&T	science and technology
SADARM	seek-and-destroy armor
SAR	synthetic aperture radar
SATCOM	satellite communications
Sb	antimony
SBIRS	Space-Based Infrared System
SC–21	Surface Combatant of the 21st century
SE&BE	Sensors, Electronics, and Battlespace Environment
SERDP	Strategic Environmental Research and Development Program
SHF	super high frequency
SIA	Semiconductor Industry Association
Si	silicon
SiC	silicon carbide
SiGe	silicon-germanium
SIGINT	signals intelligence

SIT	static induction transistor
SOF	Special Operations Forces
SOI	silicon-on-insulator
SOS	silicon on silicon
STOW	Synthetic Theater of War
TFSOS	thin-film, silicon-on sapphire
THAAD	Theater High-Altitude Air Defense
TMD	theater missile defense
TOA	time of arrival
TOC	tactical operations center
TOW	Tube-Launched Optically Guided Weapon
T/R	transmit/receive
UAV	unmanned aerial vehicle
UHF	ultra high frequency
USER	Ultra Small Electronics Research
USGS	United States Geological Survey
USSPACECOM	U.S. Space Command
USW	undersea warfare
UUV	unmanned undersea vehicle
UV	ultraviolet
UWB	ultra wideband
VHDL	VHSIC hardware description language
VHF	very high frequency
VHR	very high resolution
VHSIC	very high speed integrated circuit
VLWIR	very long wavelength infrared
W	watt
WAS	wide area surveillance
WAVES	Waveform and Vector Exchange Standard
Wh/kg	watthour per kilogram
WORM	write once–read many

CHAPTER VIII
SPACE PLATFORMS

1. INTRODUCTION

1.1 Definition/Scope

Our coordinated exploratory and advanced development efforts in the Space Platforms area advances multiple technology areas used to support the core functions needed in space and launch vehicles and propulsion. The major subareas of Space Platforms are launch vehicles, space vehicles, and propulsion, with the taxonomy depicted in Figure VIII–1. Technology programs for the launch vehicles subarea include aero/thermal; guidance, navigation, and control (GN&C); recovery; robotics/docking; survivability; electrical power; and range operations. Included in this subarea are ballistic missile and strategic sustainment technology. The space vehicles subarea refers to the spacecraft bus (as opposed to the entire spacecraft, which includes both the bus and the mission payload) and has technology programs for thermal management, structures, survivability, GN&C, power, and satellite control. Sensors, electronics, and information systems technologies unique to space and launch vehicles are presented in other chapters but are referenced for completeness. The propulsion subarea technology efforts (Integrated High-Payoff Rocket Propulsion Technology (IHPRPT) are for boost and orbit transfer, spacecraft, and tactical propulsion.

A glossary of abbreviations and acronyms used in this chapter begins on page VIII–24.

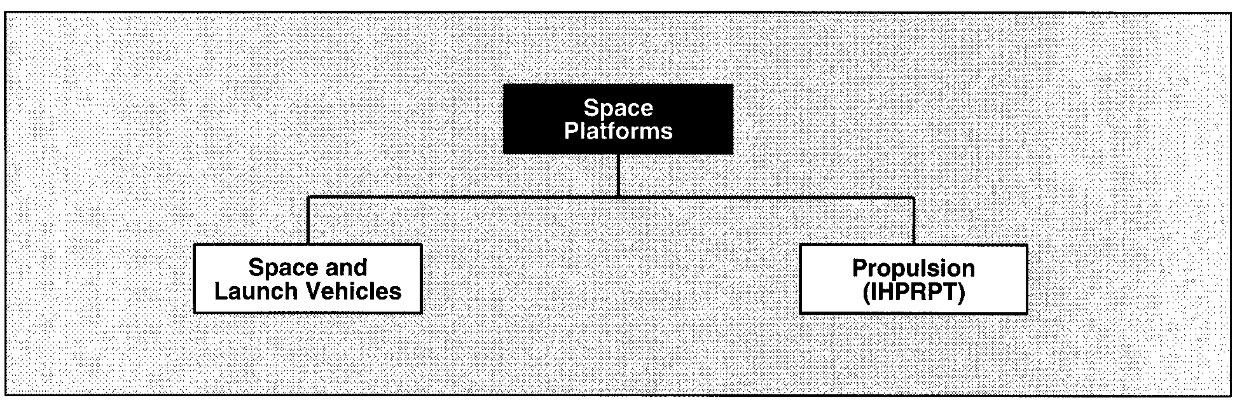


Figure VIII–1. Planning Structure: Space Platforms Technology Area

1.2 Strategic Goals

The overarching strategic goal for Space Platforms is to make space access and operations affordable. From space, a whole range of critical information collection and distribution functions become possible with both robust global reach and little forward-based infrastructure. Information provided U.S. military personnel by space-based systems includes weather, forces location/movement, environmental monitoring, transportation routes, advanced warning on weapons deployment, and weapons targeting. Future space systems could allow application of space-based force against ballistic missiles and other threats. Maintaining U.S. dominance of space is threatened by the high cost of space systems and drives subarea goals.

The primary goal for the launch vehicles subarea is to reduce the cost per pound for delivering payloads to their required orbits. A reduction in turnaround time between launches is also a goal. The goals for the space vehicles subarea are to construct spacecraft that are lighter, are smaller, require less power, and have a longer functional lifetime with lower life-cycle costs while maintaining and improving overall system performance and operation. Achievement of these goals is grounded in the basic technologies of structures, power, electronics, etc., and will only be accomplished as these technologies are strongly supported and demonstrated for space vehicle application. Space propulsion subarea goals are focused on development of rocket propulsion engines and motors with improved performance for transition into existing or new systems. Boost and orbit transfer propulsion systems will demonstrate improvements in specific impulse, mass fraction, thrust to weight, reliability, reusability, and cost. Spacecraft propulsion systems will demonstrate improvements in specific impulse, thruster efficiency, and mass fraction. Tactical propulsion systems will demonstrate increased delivered energy and improved mass fraction. Reaching the Space Platform goals will enable key technology transition/transfer opportunities as shown by subarea in Table VIII–1.

1.3 Acquisition/Warfighting Needs

DoD is required by the National Space Policy to maintain the capability to execute the space mission areas of space support, force enhancement, space control, and force application. Within these four mission areas, the United States Space Command (USSPACECOM) conducts the missions of space launch and space system control; terrestrial surveillance, intelligence, warning, communications, navigation, mapping/geodesy/charting, environmental monitoring, and command and control; space surveillance, space system protection, and space system negation; and ballistic missile defense, aerospace defense, and power projection. Force applications and space control are emerging USSPACECOM missions. The military space plane (MSP) provides a capability in these missions and in spacelift. Technology development needs for the MSP parallel the reusable launch vehicle (RLV) until FY05. RLV and early MSP technology needs are included in the Space Platforms DTAP.

USSPACECOM assets support five of the ten JCS Joint Warfighting Capability Objectives (JWCOs): Information Superiority, Precision Force, Electronic Combat, Counterproliferation, and Joint Theater Missile Defense. Information Superiority is supported by the USSPACECOM missions of surveillance; intelligence; communications; mapping, geodesy, and charting; environmental monitoring; and command and control. Precision Force is supported by the surveillance, intelligence, command and control, communications, and navigation missions.

Table VIII–1. Space Platforms Technology Transition Opportunities

FY 2000	FY 2005	FY 2010
SPACE LAUNCH VEHICLES SUBAREA		
RLV Reusable LH2 Tank Payload Shroud Cryo Propellant Tank	RLV SSTO LV Structure	
ELV and Strategic Sustainment IMU Components Multiuse Battery	ELV and Strategic Sustainment Long-Life Inertial Guidance Units Post-Boost Control System Material Update	ELV and Strategic Sustainment Missile Aging and Surveillance Predictions for Individual Motors
Upper Stage/OTV Chemical/Solar Thermal Propulsion	Upper Stage/OTV Autonomous Navigation	Upper Stage/OTV Propulsion Life-Cycle Surveillance High-Efficiency Control System
SPACE VEHICLES SUBAREA		
Space Structures and Control Fiberoptic Sensors Passive Lateral Axial Isolation Cryogenics Reverse Brayton Cooler Satellite Control On-Board Health Status Space Power Systems NiH_2 Batteries Double-Junction Solar Cells Thermal Management Loop Heat Pipes Threat Warning & Attack Reporting & Protection Laser Microbolometer Fixed Wavelength Coatings	Space Structures and Control Passive Lateral/Active Axial Cryogenics Microcooler Satellite Control Machine Learning Systems Space Power Systems Li Ion Batteries Triple-Junction Solar Cells Thermal Management Carbon-Carbon Radiator Threat Warning & Attack Reporting & Protection RF Sensor Active Nonlinear Optics	Space Structures and Control Hybrid Axial Isolation Cryogenics Laser Cooler Space Power Systems Flywheel Storage Solar Dynamic Systems Thermal Management Capillary Pumped Loops Threat Warning & Attack Reporting & Protection Integrated Laser & RF Sensors Wavelength Agile Optics
SPACE PROPULSION SUBAREA		
RS-27 Upgrade EELV Tech Insertion Titan SRMU Solar Electric Propulsion	Environmentally Clean Motors Russian Engine Tech Reusable Cryo Engine Shuttle Replacement	Rapid Response ELV Improved Russian Engine Tech Trans. Atmospheric Vehicle

Electronic Combat is supported by surveillance, intelligence, communications, and command and control. Counterproliferation is supported by the surveillance and intelligence missions, and Joint Theater Missile Defense is supported by the surveillance, intelligence, communications, and command and control missions. All of these space missions are in turn supported by the launch and space system control missions and by the space-unique aspects of system integration and acquisition.

The military services through Air Force Space Command (AFSPC), Naval Space Command (NAVSPACECOM), and Army Space and Strategic Defense Command (ASSDC) provide USSPACECOM with the systems and personnel to carry out space missions. Each military service envisions a force that is highly dependent on space systems to conduct land, sea, and air operations in the 21st century. The Air Force New World Vistas of air and space power for the 21st century stresses the essential context of space in achieving global reach—global power capabilities. Navy and Marine Corps describe a globally mobile force that will be highly dependent on space systems to provide C^3I, precision navigation, mapping, targeting, and bomb damage assessment. Such a naval force will need dominance in space as well. DoD will require new technologies if the services are to field the advanced space systems that the United States will require to continue to dominate the high ground of space.

The Space Platforms technology area will provide the services with the new and improved launch and space vehicles technologies to support, expand, or enable the five JWCOs above and all USSPACECOM missions. The development of lighter, stronger space vehicles will allow a stepdown in launch vehicles or increased launch mass margin on current launch vehicles. For high-power geosynchronous Earth orbit (GEO) communications payloads, new technologies in space vehicles could be available to allow a launch vehicle stepdown from the current heavy launch vehicle (HLV) to an Atlas IIAS. Similarly, future technology developments should increase on-orbit life and reduce life-cycle costs. The development of new materials, avionics, production methods for launch vehicles, and reduced system costs should reduce the cost to low Earth orbit (LEO) from the current levels to at least $1,000/lb and reduce the time between launches from months to days. The development of affordable, expendable boost and strategic propulsion systems will enhance the strategic agility of U.S. space forces. The operational improvements for boost and orbit transfer propulsion systems by the years 2000, 2005, and 2010 include 7%, 13%, and 18% increases in payload capability or launch cost reductions of 12%, 20%, and 27%, respectively. Individual improvements presented in this chapter are measured against 1995 technology as opposed to planned improvements or future developments.

1.4 Support for Combating Terrorism

As the United States is very dependent on space, it is vital to protect our space assets from rogue attack. Tracking, observing, and pinpointing terrorists will have to depend on the use of global assets. Space platforms provide the vehicle in space from which intelligence, communications, weapons, and surveillance payloads may operate to combat terrorism. Space Structures and Control (DTO SP.03.06) technologies provide the structural components and control systems used in Large Precise Structures (SP.05.06) for surveillance and intelligence payloads, with the Satellite Control (SP.09.01) systems providing autonomous ground and space operations, portable ground operations, data dissemination, and advanced operator environments for satellite control. Extended on-orbit life of space missions is possible with Space Power System Technologies (SP.08.06), Thermal Management Technology (SP.02.07), and Orbit Transfer Propulsion AT (SP.11.06). Threat Warning and Attack Reporting (SP.16.06) sensors monitor for, detect, identify, locate, characterize, and report a threat against critical U.S./Allied satellites. Cryogenic Technologies (SP.01.06), Boost Propulsion (SP.10.06), and Protection Technologies (SP.15.06) round out the complement of technologies necessary to the space platform system.

2. DEFENSE TECHNOLOGY OBJECTIVES

Space Vehicles and Launch Vehicles

SP.01.06	Cryogenic Technologies
SP.02.07	Thermal Management Technology
SP.03.06	Space Structures and Control
SP.05.06	Large Precise Structures
SP.08.06	Space Power System Technologies
SP.09.01	Satellite Control
SP.15.06	Protection Technologies
SP.16.06	Threat Warning and Attack Reporting
SP.19.06	Technology for the Sustainment of Strategic Systems

Space Propulsion

SP.10.06	Boost Propulsion (ET)
SP.11.06	Orbit Transfer Propulsion AT
SP.13.06	Tactical Rocket Propulsion AT

The following DTOs are not reported in this Space Platforms chapter, but are reported in the *Joint Warfighting Science and Technology Plan* (JWSTP) and other chapters of this document. However, they describe technology programs that are indispensable to the success, sustainment, and survival of space platforms.

A.06	Rapid Battlefield Visualization ACTD
A.07	Battlefield Awareness and Data Dissemination ACTD
A.09	Semiautomated Imagery Processing ACTD
A.13	Satellite C^3I/Navigation Signals Propagation Technology
B.03	Precision SIGINT Targeting System
D.02	Integrated Sensor/Data Fusion Demonstration
D.03	Discriminating Interceptor Technology Program
D.05	Advanced Space Surveillance
CB.12.01	Electronic System Radiation Hardening
CB.15.01	Balanced Electromagnetic Hardening Technology
SE.28.01	Low-Power RF Electronics
SE.37.01	High-Density Radiation-Resistant Microelectronics
SE.38.01	Microelectromechanical Systems
SE.55.01	Space Radiation Mitigation for Satellite Operations
SE.56.01	Satellite Infrared Surveillance Systems Backgrounds
WE.41.04	Multimission Space-Based Laser
IS.23.01	Digital Warfighting Communications
IS.24.01	Multimode, Multiband Information System

3. TECHNOLOGY DESCRIPTIONS

Space vehicles and launch vehicles are a single subarea within the Space Platforms technology area. In many cases, technologies for space vehicles and launch vehicles are unique and for that reason they are discussed separately (Sections 3.1 and 3.2); the propulsion subarea is described in Section 3.3.

3.1 Launch Vehicles

3.1.1 *Warfighter Needs*

The warfighter must have the ability to deploy, sustain, augment, and recover on-orbit space forces and assets in support of the ground mission. The launch vehicles (an element of the space vehicles and launch vehicles subarea) must provide this service in a reliable, responsive, and affordable manner.

The AFSPC 96 Spacelift mission area plan (MAP) details the launch vehicle task as: "generate the launch mission, execute the launch mission, perform post-launch operations, employ the launch ranges, spacecraft initialization, operate space assets, and reposition space assets." The Spacelift MAP further describes technology required to support future concepts, which in turn will eliminate the current deficiencies of existing systems.

Launch vehicle technologies target reducing the cost of launch; making launch schedules more responsive to user requests; improving the flexibility and operability of the range to support multiple users while significantly reducing operating costs; improving the ability to reposition on-orbit assets; improving the ability to recover, repair, and deploy on-orbit assets; and providing the additional capability of "global mobility via space."

3.1.2 *Overview*

The set of DoD S&T efforts included in the launch vehicles subarea encompass structures, aero/thermodynamics, GN&C, recovery, robotics/docking, survivability, electrical power, and range operations.

3.1.2.1 Goals and Timeframes. The subarea goals, system payoffs, and timeframes for the launch vehicles technologies are listed in Table VIII–2. The goals and payoffs are shown for the ELV, upper stage/orbital transfer vehicle (US/OTV), and RLV. The technologies and associated objectives required to achieve the space vehicles goals and payoffs are detailed in Table VIII–3.

Table VIII–2. Launch Vehicles Subarea Goals and Payoffs

	FY 2000			FY 2005		
Space Vehicles	**ELV**	**US/OTV**	**RLV**	**ELV**	**US/OTV**	**RLV**
Subarea Goals						
Mass Fraction	0.058	0.089	0.093	0.044	0.067	0.07
System Cost	$39M	$40M	$329M	$22M	$29M	$224M
Flts Between Referb	–	N/A	5	–	5	10
System Payoffs						
$/lb Mass Delivered	$3,500	$4,000	$5500	$2,000	$2,500	$3,750
No. Transfers/Vehicle	–	1	–	–	25	–
Turnaround Time	–	N/A	50 days	–	5 days	25 days
No. Flts/Vehicle	–	–	150	–	–	200

Table VIII–3. Launch Vehicles Subarea Technology Objectives

Year	Technology	Objectives
2000	Structures	Reduced structural mass: OTV 35%, ELV 40%, RLV 40% Reduced structural cost: OTV 40%, ELV 40%, RLV 40% Reduced dynamic launch loads ELV, RLV: Lateral 5x, Axial 5x Reduced on-orbit disturbances: OTV 10x
	Aero/Thermal	RLV: increase high-temp materials reusability 400 cycles
	GN&C	ELV/strategic sustainment: gyroscopes with 0.01-deg/hr drift, 8-yr MTBF
	Recovery	RLV: recoverable mass of 90%
	Robotics/Docking	OTV: replenishable & replaceable of 0%
	Survivability	OTV: decrease radiation safety factors by 5x OTV: improve debris knowledge by 5x
	Power	Increase primary battery cycling rate ELV, RLV: 10 cycles Increase battery cycling OTV: 35000 cycles
	Range Operation	RLV: range turnaround time of 36 hr Strategic sustainment: NDE on solid rocket fuel
	Vehicle Control	OTV: reduce control costs by 30%
2005	Structures	Reduced structural mass: OTV 50%, ELV 55%, RLV 55% Reduced structural cost: OTV 55%, ELV 55%, RLV 55% Reduced on-orbit disturbances: OTV 10x
	Aero/Thermal	RLV: increase high-temp materials reusability 500 cycles
	GN&C	ELV/strategic sustainment: gyroscopes with 0.01-deg/hr drift, 15-yr MTBF
	Recovery	RLV: recoverable mass of 95%
	Robotics/Docking	OTV: replenishable & replaceable of 85%
	Survivability	OTV: decrease radiation safety factors by 4x OTV: improve debris knowledge by 10x
	Power	OTV: BOL conversion efficiency of 35% OTV: specific energy density of 150 Wh/kg OTV: PMAD efficiency of 93%
	Range Operation	RLV: range turnaround time of 24 hr Strategic sustainment: NDE on solid rocket fuel
	Vehicle Control	OTV: reduce control costs by 40%

3.1.2.2 Major Technical Challenges. Major technical challenges for expendable launch vehicles (ELVs) include development of lightweight, low-cost, composite structures and propellant tanks; development of low-cost, fault-tolerant avionics; and development of lightweight, low-cost, and high-power density batteries. Reusable launch vehicles will require major breakthroughs in structures, thermal protection systems for reentry vehicles, instrumentation systems for vehicle health management and component failure diagnosis, propellant handling components and systems, and modular component designs to facilitate rapid refurbishment or repair.

3.1.2.3 Related Federal and Private Sector Efforts. Currently identified technology efforts include those by the USAF evolved ELVs (EELVs), NASA X-33/RLV, McDonnell Douglas Delta III, Lockheed Martin Atlas IIAR, Orbital Science Corporation Pegasus, and several other private sector startup programs to include teaming with foreign manufacturers (primarily, former USSR republics).

3.1.3 *S&T Investment Strategy*

Launch vehicle investment is directed toward reducing the cost of launch vehicles while improving performance, reliability, autonomy, availability, and reusability.

3.1.3.1 Technology Demonstrations. At present, no technology demonstrations are uniquely associated with the launch vehicle subarea.

3.1.3.2 Technology Development.

Structures. This work is focused on the development of structures and structural control technology for DoD launch and ballistic missile vehicles. Work on tankage for launch vehicles is now being included in this technology effort. Work on nozzles and cases for rocket systems is not included here but is included in the space propulsion discussion (Section 3.2). Structures for hypersonic vehicles are not included in Space Platforms, but are covered under Air Platforms. In the same vein, work on ground-based ballistic missile interceptors is not covered here, but is covered under Weapons. This technology effort overlaps with space vehicle structures and space propulsion. The Advanced Composite Interstage Program is developing a new and innovative launch vehicle interstage concept using the composite isogrid design and fabrication technology. The Lightweight, Low-Cost Composite Payload Shroud Program is developing a payload shroud using the same structural concept but on a much more complex shape subject to significantly different loads. The use of composite isogrid structures will reduce fairing and interstage manufacturing cost and weight, resulting in reduced cost of launching space payloads and the ability to launch heavier/larger payloads into a higher orbits. The increasing DoD need to reduce launch cost has led to a significant investment increase in launch vehicle structural component and structural control technology. Programs are exploring active control, passive damping techniques, precision deployable orbital structures, and advanced mechanisms to reduce the structural load that space vehicles must survive during launch.

Aero/Thermal. This effort is focused on aerodynamic loads and thermal heating to which a launch vehicle is subjected as it ascends through the Earth's atmosphere. Reusable launch vehicles are also subject to such stresses on descent. This technology effort overlaps with space vehicle thermal management but usually deals with stresses of higher magnitude and shorter duration than do space vehicles.

Guidance, Navigation, and Control. This work addresses advanced science and technologies for launch from Earth. GN&C encompasses both launch vehicle and ballistic missile guidance. This technology effort overlaps space vehicle GN&C but has to deal with much higher acceleration rates.

Recovery. Developing the capability to recover assets from space and return them to Earth or refurbish/repair on-orbit is the thrust of this work. NASA's Space Shuttle is the only current system with any recovery capability.

Robotics/Docking. This focuses on developing technologies that enable autonomous docking procedures, remote materials, and propellant transfer.

Survivability. This addresses developing hardened components that are required to survive space launch and US/OTV space environments.

Electrical Power. To address the storage and distribution of electrical power onboard launch vehicles, emphasis is on battery technology to support short-duration, high-demand electrical loads and OTV power conversion efficiency and energy density of storage technologies.

Range Operations. This work focuses on safety, handling, and control technologies for segments of the launch vehicle system that do not fly but are directly tied to flight such as trajectory monitoring, command destruction, and range turnaround operations.

3.1.3.3 Basic Research. Basic research supporting the launch vehicle systems is leveraged from the space vehicle technology programs and from related federal, university, and private sector efforts.

3.2 Space Vehicles

3.2.1 *Warfighter Needs*

Space vehicle technology goals translate into payoffs to the warfighter in terms of increased warfighter capabilities. Payoffs to satellite systems include lower cost, longer life, and increased reliability for existing and new satellite families. This technology area also provides solutions to numerous AFSPC deficiencies, such as inadequate near-Earth coverage, high O&M costs, inadequate satellite element set accuracy, inadequate terminal mobility, insufficient communications capacity, inaccuracy of data, vulnerability of ground facilities, and slow deployment of space assets. Advanced space sensor, precision orbital structure, and cryogenic technologies will help provide all-weather, day/night operation and detection of airborne targets down to cruise missile size. GPS technology advances allow for improved targeting of Earth-based objects and precision strikes. Sensor, precision orbital structure, and cryogenic technologies are applicable to SBIRS, SMTS, NPOESS, space-based JSTARS, AWACS alternatives, and NASA EOS. Space power transition targets include NPOESS, GPS IIF, SBIRS, MILSTAR, space-based JSTARS, AWACS alternatives, FLEETSATCOM, and SMTS. Communications transition targets are MILSATCOM (e.g., FLEETSATCOM and MILSTAR) as well as any mission requiring high-data-rate transmission.

The USAF has taken steps to transition to a common core telemetry, tracking, and control (TT&C) in the next few years that will support multiple satellite families. Satellite control technology is directed at evolving the core to support existing and future warfighter needs and migrating autonomy for satellite control from the ground segment to the space segment. GN&C technology also supports satellite autonomy, relieving large O&M costs and performing the guidance portion for global delivery of precision conventional warheads. Survivability technology advances include advanced hardening techniques, development of radiation and other environmental effects models, a satisfactory method to allow COTS devices to operate properly in space, and miniaturization of a threat warning and attack reporting package. These will permit any space system to be produced at lower costs and to function longer and more reliably. In addition to the listed systems, advanced electronics technologies enable future space systems that are envisioned to support the warfighter into the 21st century.

3.2.2 *Overview*

The set of DoD S&T technology efforts included in the space vehicles subarea encompasses thermal management, structures, survivability, GN&C, power, and satellite control.

3.2.2.1 Goals and Timeframes. The subarea goals, system payoffs, and timeframes for the space vehicles technologies are listed in Table VIII–4. The goals and payoffs are shown for both the LEO Surveillance and GEO High-Power Communications applications. The technologies and associated objectives required to achieve the space vehicles goals and payoffs are detailed in Table VIII–5.

Table VIII–4. Space Vehicles Subarea Goals and Payoffs

	FY 2000		FY 2005	
Space Vehicle	**LEO (Surv)**	**GEO (Comm)**	**LEO (Surv)**	**GEO (Comm)**
Subarea Goals				
Bus Power Load	1,050 W	5,560 W	840 W	5,050 W
Bus Mass	160 kg	1,960 kg	115 kg	1,410 kg
Control Costs	$142M	$142M	$131M	$131M
System Payoffs				
Launch Mass	485 kg	6,700 kg	430 kg	5,360 kg
On-Orbit Life	5 years	7 years	7.5 years	7 years
Life-Cycle Cost	$835M	$1,490M	$1,010M	$1,370M
Geolocation	244 meters	260 meters	114 meters	194 meters
Launch Family Class	LLV1	Titan IV	LLV1	Titan IV

3.2.2.2 Major Technical Challenges. The technical challenges in developing advanced technologies and subsystems for space vehicles focus on reducing weight, size, and cost; isolating vibration; and increasing power efficiency, reliability, and overall spacecraft lifetime.

Thermal Management. The technical challenges in this area include mitigation of material stresses, parasitic losses, and contamination sources at low temperatures; improvement in motor and cold interface heat transfer efficiencies; lack of materials with adequate heat capacities at cryogenic temperatures; development of improved adaptive and passive vibrational control; lack of understanding of thermodynamic and fluid flow processes in cryocooler components; difficulty in combining thermal engineering and electronics engineering to introduce high-thermal conductance material into electronics components; development of rapid and reliable startup and long-term operation capability of two-phase capillary devices in zero-g and adverse-g environments; developing advanced materials to dissipate heat fluxes from microelectronics devices and capillary wicks with less than 1 micron pore size; and flexible or rotatable joints for deployable radiators.

Structures. Structures challenges include structural isolation without constraints on rattle space (clearance); understanding dynamics arising from interactions with the space environment, structural materials, individual components, control systems, the launch vehicle, and the spacecraft; cost-effective manufacturing techniques; development of rapid, nonpyrotechnic release mechanisms and high-fidelity, ground-based experimental simulations; increased reliability/durability of multifunctional structure connections; and deployable, large lightweight structures.

Table VIII–5. Space Vehicles Subarea Technology Objectives

Year	Technology	Technology Objectives
2000	Thermal Mgmt	Reduce cryocooler specific mass by 47% to 8 kg/W Reduce cryocooler specific power by 29% to 50 $W_{input}/W_{cooling}$ Increase cryocooler lifetime by 150% to 5 yr Decrease cryocooler vibrations by 10x to 0.1 Nrms Increase heat transport by 80% to 4.5 kW-m Decrease subsystem mass by 5% to 0.038 kg/W_{EOL} Decrease required heater power by 20% to 0.088 W_{HEAT}/W_{TOTAL} Increase heat flux by 24% to 3.8 W/cm^2 Decrease electronic component temperature by 5°C to 120°C
	Structures	Reduce satellite structural mass by 35% and cost by 10% Decrease dynamic launch impulse loads by 5x Decrease on-orbit vibrations experienced by payloads by 10x
	Survivability	Reduce discrepancies between model predictions, ground and space flight test values for radiation effects Develop design guidance for hardening sensors against directed energy Reduce weight of threat warning/attack reporting by 4x Reduce power for threat warning/attack reporting by 3x Reduce RF effects susceptibility to 15 dB Increase laser-stressed sensor performance by a factor of 1 Reduce COTS radiation safety factor by 5x
	GN&C	GPS (sat) receivers with 10-m absolute positioning, improved timing; 7-W power, 0.7-kg weight, direct Y-code acquisition Gyroscopes with 0.01-deg/hr drift, power 10 W, weight 0.45 kg, 8-yr MTBF Autonomous navigation capable of 25–50 meters radial
	Power	Develop solar arrays that are 28% efficient and produce 100 Wh/kg Develop 100 Wh/kg rechargeable battery Increase battery cycling capability by 14% to 35,000 cycles Increase PMAD conversion efficiency by 6% to 90% Increase bus voltage by 364% to 130 Vdc
	Electronics and Communications (enabling technologies)	Increase processor throughput by 10x Demonstrate space-qualified components with submicron feature size
	Satellite Control	Reduce ground instructor manpower by 50% Reduce control costs by 30% Increase space vehicle autonomous operations to 5 days between ground contact Reduce health status data analysis time by 25% (from 24-hr baseline)

Table VIII–5. Space Vehicles Subarea Technology Objectives (continued)

Year	Technology	Technology Objectives
2005	Thermal Mgmt	Reduce cryocooler specific mass by 67% to 5 kg/W Reduce cryocooler specific power by 43% to 40 $W_{input}/W_{cooling}$ Increase cryocooler lifetime by 275% to 7.5 yr Decrease cryocooler vibrations by 100x to 0.01 Nrms Increase heat transport by 260% to 9.0 kW-m Decrease subsystem mass by 15% to 0.034 kg/W_{EOL} Decrease required heater power by 35% to 0.072 W_{HEAT}/W_{TOTAL} Increase heat flux by 79% to 5.2 W/cm^2 Decrease electronic component temperature by 5° C to 115° C
	Structures	Reduce satellite structural mass by 50% and cost by 25% Decrease dynamic launch loads to a satellite by 5x Decrease on-orbit disturbances experienced by payloads by 50x Provide precision deployable RF (0.5 to 10 GHz) structure capable of rms antenna element position knowledge on the order of lambda 50 (or subarray pattern matching to 40 dB from peak) over antenna structure sizes with longest dimension from 100 to 500 wavelengths
	Survivability	Improve ground-based debris catalog to include debris down to 1 cm Perform debris measurements in space Reduce weight of the threat warning/attack reporting by 10x Reduce power of the threat warning/attack reporting by 5x Reduce RF effects susceptibility to 10 dB Increase laser-stressed sensor performance by 2x
	GN&C	GPS receivers with 5–10-m absolute positioning, <200-cm^3 volume, 7-W power, <0.5-kg weight, antijam, antispoof Gyroscopes with <0.01-deg/hr drift, volume <200 cm^3, <8-W power, <0.4-kg weight, 15-yr life Autonomous navigation accuracy better than 25 m radial
	Power	Develop solar arrays that are 35% efficient and produce 120 Wh/kg Develop 150 Wh/kg rechargeable battery Develop energy storage elements with cycle limits capable of 15- to 30-yr life at orbital altitudes on the order of 1,000 to 4,000 km Increase PMAD conversion efficiency 93% Increase bus voltage by 436% to 150 Vdc
	Electronics and Communications (enabling technologies)	Increase processing throughput by 2x Decrease power consumption by 90% Reduce cost with space-qualified versions of COTS parts
	Satellite Control	Reduce ground instructor manpower by 75% Reduce control costs by 40% Increase space vehicle autonomous operations to 20 days between ground contact Reduce health status data analysis time by 50% (from 24-hr baseline)

Survivability. The challenges are to develop radiation-tolerant space devices and systems, develop techniques to allow space applications of COTS devices, improve reliable high-precision survivability simulations, develop miniaturized laser and radar threat detectors and optical systems jamming protection, and characterize space debris hazards.

GN&C. The challenges are to mitigate or reduce radiation exposure and plasma effects; eliminate ring laser gyroscope (RLG) mechanical dithering; improve RLG mirror durability; improve light sources, coil selection, and windings for interferometric fiber optic gyroscopes (IFOGs); improve micromachining processes; provide on-board precise time and reliable frequency signals and laser tracking; obtain accurate ephemeris data; and develop hardware/ software interface for autonomous navigation.

Power. The challenges include increased compatibility and applicability of advanced materials in the space environment; more efficient photovoltaics; viability of manufacturing; feasibility of solar concentrators; feasibility of solar thermal conversion; highly reactive chemicals; runaway electrochemical reactions; life limiters in energy storage (e.g., electrode wear); lack of high-voltage, high-power, and high-efficiency space-qualified components fabricated from advanced semiconductors; and lack of space-qualified and optimized circuit design for off-the-shelf components.

Space Electronics and Communications. Technical efforts that are enabling technologies and critical to the success of the space platforms technology area include increasing space radiation hardness of recently available small feature size, high-performance electronics technologies, knowledge of space radiation attenuation properties of advanced structural and packaging materials, advanced packaging to dissipate heat in a vacuum without out-gassing, advanced insulated device technologies, and integrated microelectromechanical systems (MEMS). Communications challenges are development of high-capacity optical communications system area networks; development of an efficient modem; and improvement of the ability to manufacture ultra lightweight, higher frequency antennas, GaAs PHEMT MMIC (gallium arsenide pseudomorphic high-electron mobility transistor monolithic microwave integrated circuits), low-power high-speed custom integrated circuits, silicon carbide devices, and MMICs for high-power radiation research.

Satellite Control. The challenges are to overcome vendor-specific dependencies in COTS software; exploit distributed artificial intelligence capabilities; develop integration of an intelligent trainer with a multisatellite ground system; use model-based reasoning and machine learning for anomaly resolution; reduce development and sustainment costs when DoD does not drive the market; and develop reliable, verifiable artificial intelligence-based systems for payloads that are autonomously self-controlled and self-navigating, and provide information on demand to the warfighter.

3.2.2.3 Related Federal and Private Sector Efforts. Outside DoD, the primary government organizations funding space vehicles technology development are NASA, National Systems, and DOE. Historically, the NASA investment matches that of DoD in many of the technologies, while the DOE investment is considerably smaller. National Systems makes a significant investment in space vehicles technology. Formal coordination with NASA is under the DoD/NASA Aeronautics and Astronautics Coordinating Board. Joint program planning and management of technology development (e.g., NASA/DoD IPT) is coordinated among these organizations and the user community to ensure maximum return on government investment of R&D funding. The related NASA programs of greatest relevance are the New Millennium Program and the Small Satellite Technology Initiative. Various pervasive technologies, such as space power, thermal management, and structures, are closely coordinated with the responsible NASA technology centers. Industry is estimated to be investing $220 million of their IR&D funds in related space technology. This work is typically focused on developing a competitive capability for near- and far-term corporate goals. Additionally, there are focused commercial ventures for space-based systems, such as communication and surveillance systems, that complement these efforts. The recent appearance of a strong, well-capitalized commercial presence in space allows DoD to leverage advances in these systems. Commercial space manufacturers' private capital, short development cycle, and frequent new starts permit a new arena for rapid maturation of space platform technology. DoD has formed a cooperative research and development agreement (CRDA) with the commercial sector to provide opportunities for space demonstration of the technology and to share in the cost of development in some areas, such as energy storage. Industry has plans for both highly autonomous spacecraft and architectures for large, distributed networks of satellites. Similar advances are occurring in the international arena as well.

3.2.3 *S&T Investment Strategy*

3.2.3.1 Technology Demonstrations. The space vehicles technology demonstration program provides an architecture to assist technologies in the validation and assessment of their performance. The technology demonstration architecture spans from small, component-level assessments to integrated demonstrations that address the use of technology in solving warfighter deficiencies. The overall architecture allows for the validation and assessment of technologies in a simulated ground environment or space environment depending on the needs of the experimenter(s) and the environment required to provide a true assessment and validation of the technologies capabilities in meeting its performance criteria.

USAF Integrated Space Technology Demonstration Program. The USAF ISTD program will demonstrate medium-risk, high-payoff system concepts and payload(s) through the design, integration, and validation of emerging technologies in real-world environments. The objectives of the ISTD program are to show how emerging technologies can be used to resolve high-priority mission deficiencies, validate technology for use in operational systems, examine new methods to demonstrate technologies, and acquire military capability by leveraging commercial space systems.

As the first ISTD mission, Warfighter–1 (WF–1) objectives are to evaluate/validate hyperspectral technologies in the orbital environment, demonstrate utility of hyperspectral imagery to the government user community, demonstrate leveraging of commercial space systems to meet DoD needs, and launch nominally within 36 months of contract award.

The scope of the WF–1 includes design, fabrication, integration, test, launch, spacecraft operations, and algorithm development as well as supporting/performing on-orbit payload operations, mission planning, anomaly resolution, and data reduction and processing. WF-1 will demonstrate emerging sensor technologies and the ability to perform target detection and terrain classification using these technologies. A large portion of the data collected will focus on target and background signatures to serve as a scientific database for algorithm development and exploitation studies within the WF–1 and other programs.

The system requirements for the WF–1 sensor have a minimum of 60 spectral bands in the spectral region between 0.4–2.5 μm. The exact placement and width of the bands is to be determined by system trade studies. The sensor will have a 5-km minimum swath width and a single hypercube image at least 100 km^2. The sensor will provide hyperspectral data necessary to detect targets (listed in Table VIII–6) against various backgrounds. The WF–1 system will be used to develop a database of terrain classification data for the terrain elements including variations due to seasonal changes, sun/look angles, and atmospheric conditions. Space flight is a cost-effective way to acquire the background data over the wide range of conditions and locations.

Table VIII–6. Warfighter–1 Demonstration Conditions

Test Cases	Test Conditions
Tactical Targets Set	Mobile armor (15-m^2 size)
	Transportable launchers (30-m^2 size)
	Ships and surfaced submarines (350-m^2 size)
	Camouflaged targets (25-m^2 size)
Backgrounds	Desert, temperate zone, snow, forest, grasslands, agricultural, littoral zone
Terrain Elements	Desert, littoral zone, snow, wetlands, disturbed soil and vegetation, snow and ice, temperate zone forest, grassland and agricultural, vegetation and coverage, urban, tropical zone, forest

The first ISTD flight will demonstrate targeted FY00 DTO goals for Cryogenic Technologies (SP.01.06.F), Space Structures and Control (SP.03.06.NF), High-Density Radiation-Resistant Microelectronics (SE.37.01.FH), Integrated Sensor/Data Fusion Demonstration (D.02), and Digital Warfighting Communications (IS.23.01.AFN). These programs directly support the AFSPC, including the Space Warfare Center, and military users of tactical space imagery.

USAF MightySat. The USAF MightySat program is a quick turnaround series of small, satellite-based experiments that test a limited set of high-payoff emerging and exploratory technologies. These elements can be either in situ experimental bus components (batteries, solar cells, etc.) or standalone experiments (imagers, sensors, etc.). The MightySat platform functions as an experimental test bed exploring such objectives as demonstrating concept feasibility, developing a critical knowledge base to exploit new capabilities, identifying system risks under space environmental conditions, and providing flight heritage for critical components scheduled for deployment on future DoD space systems. Table VIII–7 details the key technology demonstrations within the MightySat program.

Navy Earth-Map Observer Program. The NEMO program is to demonstrate the utility of hyperspectral imagery collection and exploitation in support of naval missions. NEMO will utilize innovative hyperspectral imaging, on-board parallel processing, and advanced algorithms for spectral and spatial feature identification. The program will develop an inexpensive, long-term, Earth-imaging spacecraft to characterize the optical environment in the littoral zone as it affects the performance of Navy optical systems for bathymetry; the evaluation of sea-bottom types; and

Table VIII–7. USAF MightySat Technology Demonstrations

Flight Experiment	DTO/JWSTP: Technology Demonstrations	Launch
MightySat-I	SP.03.06.NF: Validate manufacturing process for composite structures, I-beam assembly, low-shock release devices	FY97
	SP.08.06.FCH: Validate solar cell efficiency and space environment degradation	
	SE.37.01.FH: High-density radiation-resistant microelectronics	
MightySat-II.1	SP.03.06.NF: High-performance composite structures, structures thermal and radiation shielding	FY99
	D.02: Fourier transform hyperspectral imager	
	SE.37.01.FH: High-density radiation-resistant microelectronics	
	SP.11.06.F: Thrusters	
MightySat-II.2	SP.16.06.F: Threat warning and attack reporting	FY00
	SP.03.06.NF: Structures and control	
MightySat-II.3	SP.03.06.NF: Structures and control	FY01
MightySat-II.4	SP.03.06.NF: Structures and control	FY03
	SE.37.01.FH: High-density radiation-resistant microelectronics	

the detection of mines, submarines, and submerged hazards. NEMO will also demonstrate the intelligence gathering and preparation of battlespace capabilities of hyperspectral sensing for supporting the warfighter. The innovative algorithm to be used on this system is the Optical Real-Time Adaptive Spectral Identification System (ORASIS), which was developed by the Navy. The ORASIS algorithm allows, for the first time, real-time processing of imaging spectrometer data on a spacecraft. The NEMO satellite will be developed in cooperation with industry. Once the prototype has been developed and proven, the technology will be transitioned to industry.

USAF Integrated Ground Demonstration Program. This program is intended to demonstrate high-risk/high-payoff system- and payload-level concepts via the ground integration of emerging technologies. This is accomplished by characterizing technology interfaces and interactions in a simulated environment. This technology integration capability provides the ability for evaluating advanced payload, system, and mission concepts while the hardware and software is still recoverable for future development as well as allowing for the simulation of hardware or software still in the concept phase to be placed in an integrated systems environment. Ground demonstrations, while an important part of the integrated demonstrations effort, are currently not funded.

STP Small Experiments and Demonstrations. The DoD Space Test Program (STP), managed by the Space and Missile Test and Evaluation Directorate, supports technology developers in the Army, Navy, Air Force, BMDO, and DOE by providing these experimenters with the spacecraft bus, integration of the experiment payloads, launch services, and 1 year's on-orbit operations. STP funding is used to support experiments that do not have the funding to provide their own means of access to space. In addition, program management directive (PMD) guidance for STP calls for one small launch vehicle flight (Pegasus-class with satellite of less than 1,000 pounds) every 2 years and one medium launch vehicle flight (Delta-class with satellite of 6,000 to 10,000 pounds) every 4 years. Experiments are selected through the Space Experiments Review Board (SERB) which meets annually to consolidate and prioritize space experiments proposed from all of the services and agencies; experiments are ranked primarily by military relevance.

Although STP-sponsored experiments do not individually have significant funding or visibility, collectively they are the backbone of space vehicle science and technology program. An example of these small experiments is the Navy's Microelectronics and Photonics Test Bed (MPTB). The objectives of the MPTB project are (1) select (by SPOs) devices and subsystems for test, (2) perform ground-based radiation tests, (3) predict space results, (4) construct MPTB space hardware, (5) launch in FY 97, (6) analyze space data, and (7) develop new radiation effects models. The MPTB experiment will space qualify devices and subsystems and demonstrate that COTS devices can operate in selected orbits. Another program, the Missile Technology Demonstration Flight, will demonstrate range safety and instrumentation to augment the use of range radar for safety and range metrics. Other examples that are currently manifested (and the flights they are on) are Electromagnetic Propagation Experiment (STEP 4); Compact Environment Anomaly Sensor (TSX–5); Beryllium–7-Induced Radiation Experiment (Cosmos); and Polar Orbiting Geomagnetic Survey II (DMSP S–15).

3.2.3.2 Technology Development. The space vehicles subarea consists of six technology efforts. Technology advances in all of these efforts are required to achieve the overall goals of this subarea.

Thermal Management. The thermal management effort encompasses the development of cryogenic and conventional spacecraft bus thermal management technologies required for temperatures ranging from 10 to 900 K. Technology development includes replacement of large, heavy, short-lived cryogenic reservoirs with small, lightweight, highly efficient, and long-lived mechanical cryocoolers. Innovative components and system configurations are developed, characterized, and tested for reliability and endurance. These include advanced thermal integration components, very high heat flux heart transfer devices, capillary wicking devices, ambient temperature thermal energy storage, passive and active thermal control devices for cooling of advanced microelectronics devices, and deployable radiators and coatings.

Structures. The structures effort is being conducted to discover new ways of making lightweight, low-cost, and precise structures for space and launch vehicles and to develop new methods to prevent vibration and structural dynamics from degrading the performance of future DoD systems. Other efforts address technology for space vehicles and include concepts for lighter weight, lower cost, higher performance solar array, radiator, antenna, and electronic enclosure structures; multifunctional structures; and smart mechanisms for solar arrays and other deployable structures. Work on inflatable structures for antennas or optics is included in this technology effort. Work on nozzles and thrusters for spacecraft is included in the space propulsion subarea (Section 3.3).

Survivability. The survivability effort includes advanced hardening techniques, models of device response to space radiation, and methods to allow COTS devices to operate properly in the lower dose space radiation orbits.

GN&C. The GN&C effort encompasses autonomous navigation with GPS receiver technology, star trackers, and navigation instruments. A primary objective is to increase navigation and attitude determination accuracy while reducing instrumentation size, power, and mass and increasing operational reliability. Increased accuracy and reliability objectives for GPS technology are space-qualified atomic clock, increased precision, stability, reproducibility with size, power, and mass reduction.

Space Power. The space power effort covers the development of all required components for satellite power subsystems including power generation, energy storage, and power management and distribution. Technology development includes generating nonphotovoltaic energy, investigating alternate photovoltaic material and cell designs, and increasing the solar concentration ratio of arrays. For energy storage, programs include demonstrating life, performance, and safety of NaS cells while working to develop advanced lithium-based batteries. Investigations into flywheels and other nonelectrochemical storage devices have also been started. High-voltage solid-state relays, hybrid control patches, and integrated power chips are key power management technology approaches for the next 5 years.

Satellite Control. Satellite control technology development will investigate user-friendly graphical data viewing, stored data for the life of the satellite, and extensive online data analysis tools; automate data in pass plan manuals, capture expert knowledge in computer-based knowledge bases, and utilize model-based reasoning and machine learning to resolve anomalies; and support reactive, dynamic training integrated into the actual operational system with no human trainer in the loop. Trade studies will be performed to determine which functions have higher payoff for automating on-board from an O&M and survivability perspective. Some ongoing work in autonomous orbit control will be flight tested. Other high-payoff areas will be developed further and readied for experimental flight testing.

3.2.3.3 Basic Research. In addition to the following areas, the space vehicles technology subarea relies on the results of basic research from Information Systems Technology, Materials/ Processes, and Sensors, Electronics, and Battlespace Environment.

Thermal Management. Basic research in this technology effort is focused on cryogenic technology. The objectives of the cryogenic regenerator effort are to measure cryocooler regenerator performance under operating conditions and to develop a numerical model for predicting regenerator performance. Numerical models do not currently exist for transient operation. The technology approach is to develop an experiment that incorporates a pulse tube cryocooler. Operating data will be gathered in the 30–100-Hz range. These data will be compared with existing models for both transient and steady-state operation. Finally, an analytic model will be developed and verified for the transient case.

Structures. Two ongoing basic research efforts are of particular interest in this area. One is developing a fundamental understanding of how the different aspects of the space environment (atomic oxygen, UV, vacuum, protons, electrons, and hypervelocity debris) interact to affect space structures and structural materials. The other effort is exploring development of new mathematical control algorithms and approaches to structural control and vibration damping.

GN&C. Ongoing basic research relating to this technology subarea is in high-temperature superconducting materials and atom traps. Low-temperature, low-noise resonating cavities and the means to trap and interrogate atoms' quantum frequencies may lead to new technologies for generating precise navigation signals in space. GPS receiver applications needing accurate time from very low power accurate oscillators will benefit from these basic efforts.

3.3 Space Propulsion

3.3.1 *Warfighter Needs*

The goals of the Integrated High-Payoff Rocket Propulsion Technology (IHPRPT) program, under DoD/NASA sponsorship, translate into payoffs to the warfighter in terms of increased capabilities. Payoffs to launch vehicle systems include performance, cost, and reliability improvements to existing launch systems, expendable launch systems, and new reusable vehicles. The operational increases for boost and orbit transfer propulsion systems by the year 2000, 2005, and 2010 include 7%, 12%, and 18% increases, respectively, in payload capability for new expendable boosters (over the 25,000-lb baseline to LEO). An alternative to increasing the payload on a lift vehicle would be to launch payloads on smaller, more capable vehicles to reduce the need for costly heavy-lift vehicles. The resulting launch cost reductions would equate to savings of 12%, 20%, and 27% in cost-per-pound to orbit. These savings are in addition to the savings seen from design and process changes. For a new reusable launch system, the payload improvements by 2000, 2005, and 2010 approach 69%, 121%, and 170% over the life of the vehicle with cost reductions of 57%, 78%, and 90%, respectively.

Spacecraft goals will result in increased warfighter payoffs through reliable critical information gathering and global communication capabilities at reduced costs. Space vehicles in geosynchronous orbit will be able to extend their on-orbit life up to 45%, increase repositioning capabilities by a factor of 2 to 5, or increase useful mission payload mass by 10% to 30%. This last capability can mean an ability to increase the number or types of transponders, potentially manifest the same payload on less expensive launch vehicles, or increase the survivability of the satellite by allowing for increased shielding material. Communication and reconnaissance payloads will be able to reposition more often and more rapidly to support the warfighter needs in local theaters of operation without significantly sacrificing satellite life. More reliable deployment and on-orbit operation throughout the life of the satellite will provide greater assurance in asset availability. Higher performance compact propulsion systems will also enable the deployment of smaller payloads into higher energy orbits. For medium-lift vehicle class geosynchronous space vehicles launched at a conservative rate of six per year, meeting the IHPRPT goals would result in cost savings of $60 million, $130 million, and $240 million by 2000, 2005, and 2010, respectively.

Tactical missile propulsion systems will have increased range, increased maneuverability for flexible targeting opportunities, or increased kill effectiveness with decreased size providing greater weapons carriage capability under the IHPRPT program. For size-constrained systems, an alternative to decreasing the weapon size could include increasing the warhead payload or increasing the range by increasing the amount of loaded propellant. For tactical missile systems, a 10%, 25%, and 100% increase in payload capabilities can be achieved for the three IHPRPT phases (2000, 2005, and 2010). For divert propulsion systems, the number of theater missile defense systems needed to cover a given area can be reduced by 26%, 45%, and 60% through the three phases.

3.3.2 *Overview*

3.3.2.1 Goals and Timeframes. The IHPRPT initiative was started in FY94, with primary program impacts beginning in FY95. The program is based on achieving the goals (with respect to 1993 state-of-the-art baselines) shown in Table VIII–8 for boost and orbit transfer (B/OT), spacecraft (S/C), and tactical (T).

Table VIII–8. Space Propulsion Subarea Goals*

Year	Technology	Goal
2000	B/OT**	-25% Failure Rate, +15% Mass Fraction (Solid), +5-sec Isp,*** -15% Hardware Costs, -15% Support Costs, +30% Thrust/Wt (Liq)
	S/C	+10% Isp (Chem/Solar Thermal), +15% Mass Fraction, +15% Thruster Efficiency (Solar Electric)
	T	+3% Delivered Energy, +10% Mass Fraction (w/TVC), +2% Mass Fraction (w/o TVC), Maintain Cost/Safety/Survivability
2005	B/OT**	-50% Failure Rate, +25% Mass Fraction (Solid), +21-sec Isp,*** -25% Hardware Costs, -25% Support Costs, +60% Thrust/Wt (Liq)
	S/C	+15% Isp (Chem/Solar Thermal), +25% Mass Fraction, +30% Thruster Efficiency (Solar Electric)
	T	+7% Delivered Energy, +20% Mass Fraction (w/TVC), +5% Mass Fraction (w/o TVC), Maintain Cost/Safety/Survivability

* All percentage goals are percent change from the baseline.

** An additional goal for reusable propulsion systems of 20 missions between removal is also included in B/OT propulsion.

*** B/OT Isp goal represents a combination of specific propulsion improvements at the following respective levels:

Cryogenic Engine: 1% (2000), 2% (2005)
Hydrocarbon Engine: 13% (2000),15% (2005)
Solid Motor (Castor 120 Propellant): 2% (2000), 4% (2005)
Hybrid Motor: 8% (2000), 11% (2005).

3.3.2.2 Major Technical Challenges. The doubling of rocket propulsion system capability will be achieved through a combination of technology initiatives. To meet the propulsion system goals, investigations to increase the energy of propellants, increase the efficiency of combustion processes, increase the combustion chamber operating pressures, decrease the inert weight of propulsion systems, and improve the efficiency of thrust magnitude/vector control systems will be concurrently developed and consolidated. Specifically, propellant developments involve increasing performance (energy, density) and reducing costs (manufacture, storage, handling, testing) while improving the environmental acceptability.

For all rocket propulsion systems, the IHPRPT initiative will provide cost reductions in a system while improving payload capability. Achieving this goal will require significant performance improvements. Future propellant requirements include improved reliability and environmental acceptability, increased safety, greater performance, longer service life, and lower life-cycle costs. Propellant management devices, combustion and energy conversion devices, and control systems require innovative subcomponent and component design methods, manufacturing techniques, and materials for the respective component and application area developments. The major advances required in liquid propellant combustion devices include an increase in theoretical-specific impulse (Isp) by increasing chamber pressure, increases in Isp efficiency as measured by Isp actual/Isp theoretical, reductions in weight, reductions in cost, and increases in reliability (measured by decrease in part count).

The solid propulsion area consists of nozzles and the igniter. In solid propulsion, the major advances required are in increasing Isp efficiency, decreasing component weight and volume, decreasing component cost, and increasing reliability. The electric propulsion area of satellite propulsion includes the power processing components and the thrust chamber assembly, including the electrode. Major advances are needed in improving the power processing efficiency, the energy conversion efficiency, and combustion chamber life.

The wide range of missions for tactical systems require multifaceted technology applications to address the higher performance needs with improved survivability and environmental compliance—at no compromise to cost or safety. Increasing propellant energy for the under 10,000 lb-s total impulse motors, 10,000–75,000 lb-s total impulse motors, over 75,000 lb-s total impulse motors, gun-launched motors, and assist boost motors requires development and application of new propellant ingredients (for smoky, reduced smoke, and minimum smoke propellants). These ingredients (fuels, oxidizers, and binder systems) will have to be of higher heats of formation or higher density. Near-term approaches include GAP, ADN, CL20, and perhaps metallic hydrides.

Propellants will have to be formulated to eliminate current burn-rate and combustion stability problems at pressures above 3,000 psi and with greater strength than currently available to allow higher volumetric loading. One approach to this may be the incorporation of ingredients such as GAP-Azide. In addition, tactical systems will no longer be limited to solid-propulsion concepts. Liquid and especially gel propellants will be investigated for possible use. Propellant development for divert propulsion (with emphasis on minimum smoke propellants) involves adding ingredients to cool the flame temperature. Additional work is needed to reduce the oxidation index of the propellant. Reducing or eliminating the amount of oxygen produced in the exhaust is the only way to achieve this. Tailoring propellant chemical properties to reduce the oxidation characteristics of the propellant gases is necessary to meet the cost and safety goals in divert propulsion. These cooling ingredients already exist and further development is not required.

In all tactical applications, meeting environmental regulations as well as safety/survivability requirements will continue to be a major technical challenge. High-pressure operation will be investigated through propellant ballistic modification for intercept applications.

3.3.2.3 Related Federal and Private Sector Efforts. All DoD agencies, NASA, and industry participate in IHPRPT. Industry rocket propulsion IR&D investment for FY96 is approximately $50 million. NASA FY96 investment for IHPRPT-related programs for the RLV is approximately $20 million.

3.3.3 *S&T Investment Strategy*

The key to the IHPRPT process is the simultaneous achievement of the goals. Technology demonstrations conducted during each of the three phases will quantify the degree of success in reaching the goals. The technology demonstrators do not have to be a complete propulsion system demonstration. They may be individual components or a combination of components. The requirement is to prove justifiable, analytical connectivity that the compilation of the demonstrated technologies would work together as an acceptable propulsion unit. As a metric, the empirical or analytical data will be compared to baselines identified at the initiation of IHPRPT. Following demonstration, the technologies may transition economically to new propulsion systems or to improvements to current propulsion systems.

3.3.3.1 Technology Demonstrations. Technology demonstrations for IHPRPT are divided into three fundamental propulsion classes. Each class is a separate family of demonstrations.

Boost and Orbit Transfer Propulsion. These demonstrations, when successful, fulfill DTO (SP.10.06.F). The demonstrators for this mission application area are divided into (1) propulsion systems that lift payloads from ground level to orbit elevation (boost propulsion), and (2) propulsion systems (orbit transfer) that move payloads from one orbit (such as LEO) to another orbit elevation (GEO). Specific boost demonstrations will occur at the end of each IHPRPT phase. In 2000 the component improvements will feed into an integrated demonstration. In 2005 further component improvements will integrate into a high-performance (4,000-psi chamber pressure) booster class demonstration. Orbit transfer component improvements will feed into a FY00 high-performance (1,200-psi chamber pressure) upper stage/orbit transfer demonstration and a FY05 high-performance (1,500-psi chamber pressure) upper stage/orbit transfer demonstration.

Spacecraft Propulsion. The technology demonstrators for this mission application include two areas: chemical propulsion (e.g., solar electric) and nonchemical propulsion (e.g., solar thermal). In all cases, these system demonstrations will be conducted at simulated altitude conditions permitting direct measurement of performance at space conditions. Solar electric demonstrations (pulsed plasma thruster and hall thruster) by 2000 and 2005 will integrate all developments for satellite stationkeeping and repositioning. By 2010 advanced solar thermal propulsion systems and advanced solar electric propulsion systems (ion thrusters) for orbit transfer missions will be demonstrated.

Tactical Propulsion. These demonstrations, when successful, fulfill several DTOs. The extensive, integrated, full-scale propulsion system evaluations begin with sea-level evaluations of the delivered performance in a rocket engine/motor. Next, evaluations are performed to demonstrate performance at environmental conditions simulating captive flight and launch conditions for tactical missiles. Divert and gun-launched propulsion system evaluations include hover, quick-response maneuvering conditions, and high-acceleration environments.

3.3.3.2 Technology Development. Once the goals and payoffs have been established and confirmed as worthwhile, the technology advancements needed to achieve the goals are determined. The propulsion technologies in BO/T and S/C are divided into the same four component technology areas. These four areas, which represent the rocket propulsion system technology improvement areas, are propellants, propellant management devices, combustion and energy conversion devices, and control systems. The efforts in the propellant area include solid, liquid, hybrid, gels, and liner development. Propellant management efforts include work in tanks, feed systems, bladders, turbomachinery, thermal protection systems, cases, pressurization systems, and insulations. Combustion and energy conversion efforts include work in injectors, igniters, combustion chambers, nozzles, gas generators, preburners, and all components of electric and solar propulsion systems (except the propellant). Control system work includes actuator, health monitoring, thrust management, ordnance, valve, and thrust vector control system development.

The projects are technology specific as opposed to being system specific, allowing for global propulsion system improvements applicable to all rocket propulsion systems. Goals within each application area address where the R&D specialists will overcome operational deficiencies and meet requirements and needs defined by the propulsion system users. Subsequently, goals are subdivided into the component technology improvements needed to meet the goals. These component improvements are identified and represent component area objectives toward which the technologists will work in laboratory R&D projects.

This goal–objective relationship connects the R&D laboratories to the user community in a way that streamlines the work done by both communities and enables the needs of both groups to be satisfied. The result of the IHPRPT process is the fulfillment of a set of goals that integrates the technologists with the user community and provides maximum payoffs for future space systems.

3.3.3.3 Basic Research. The Phillips Laboratory Propulsion Directorate has several basic research projects supporting development in boost and orbit transfer and in spacecraft propulsion. In B/OT, one combustion development project (supercritical combustion), two propellant development projects (chemically bound excited states and nonequilibrium flow characteristics), and three materials development projects for rocket components (synthesis, carbon materials research, and material mechanics research) exist. In spacecraft propulsion, the plasma diagnostics project supports electric propulsion development.

GLOSSARY OF ABBREVIATION AND ACRONYMS

ACTD	Advanced Concept Technology Demonstration
AFSPC	Air Force Space Command
ASSDC	Army Space and Strategic Defense Command
AWACS	Airborne Warning and Control System
BMDO	Ballistic Missile Defense Organization
BOL	beginning of life
B/OT	boost and orbit transfer
C^3I	command, control, and communications
COTS	commercial off the shelf
CRDA	cooperative research and development agreement
dB	decibel
DOE	Department of Energy
DTO	Defense Technology Objective
EELV	evolved expendable launch vehicle
ELV	expendable launch vehicle
EOS	end of service; Earth Observation System
GaAs	gallium arsenide
GEO	geosynchronous Earth orbit
GN&C	guidance, navigation, and control
GPS	Global Positioning System
HLV	heavy launch vehicle
IFOG	interferometric fiber optic guided
IHPRPT	Integrated High-Payoff Rocket Propulsion Technology
IMU	integrated measurement unit
IPT	integrated product team
IR&D	independent research and development
Isp	theoretical-specific impulse
ISTD	Integrated Space Technology Demonstration
JSTARS	Joint Surveillance Target Attack Radar System
JWCO	Joint Warfighting Capability Objective
JWSTP	*Joint Warfighting Science and Technology Plan*
K	kelvin
kg	kilogram
LEO	low Earth orbit
LV	launch vehicle
MAP	mission area plan
MEMS	microelectromechanical systems
MILSATCOM	military satellite communications architecture
MILSTAR	military strategic, tactical, and relay (satellite)

MMIC	monolithic microwave integrated circuits
MPTB	Microelectronics and Photonics Test Bed
MSP	military space plane
MTBF	mean time between failure
NaS	sodium sulfur
NASA	National Aeronautics and Space Administration
NAVSPACECOM	Naval Space Command
NDE	nondestructive evaluation
NEMO	Navy Earth-Map Observer
NPOESS	National Polar-Orbiting Environmental Satellite System
Nrms	Newton root mean square
O&M	operations and maintenance
ORASIS	Orbital Read-Time Adaptive Spectral Identification System
OTV	orbit transfer vehicle
PHEMT	pseudomorphic high-electron mobility transistor
PMAD	power management and distribution
PMD	program management directive
R&D	research and development
RF	radio frequency
RLG	ring laser gyroscope
RLV	reusable launch vehicle
S&T	science and technology
SBIRS	Space-Based Infrared System
S/C	spacecraft
SERB	Space Experiments Review Board
SMC	Space and Missile Systems Command
SMTS	Space and Missile Tracking System
SPO	system program office
SRMU	solid-rocket motor upgrade
SSTO	single-stage-to-orbit
STP	Space Test Program
TT&C	telemetry, tracking, and control
TVC	thrust vector control
USSPACECOM	U.S. Space Command
US/OTV	upper stage/orbital transfer vehicle
UV	ultraviolet
W	watt
WF–1	Warfighter–1
Wh	watthour

CHAPTER IX
HUMAN SYSTEMS

1. INTRODUCTION

1.1 Definition/Scope

The Human Systems program provides technologies and methods to ensure that the military's most critical resource—its people—are properly selected, trained, and equipped to perform effectively and as safely as possible. Cost reduction through more efficient use of personnel and equipment is a key secondary goal. Four subareas comprise the Human Systems technology area (Figure IX–1). These four subareas are a consolidation of the nine 1996-97 Human Systems technology subareas. The consolidation enhances cross-service coordination and presents a clearer picture of this multifaceted technology area.

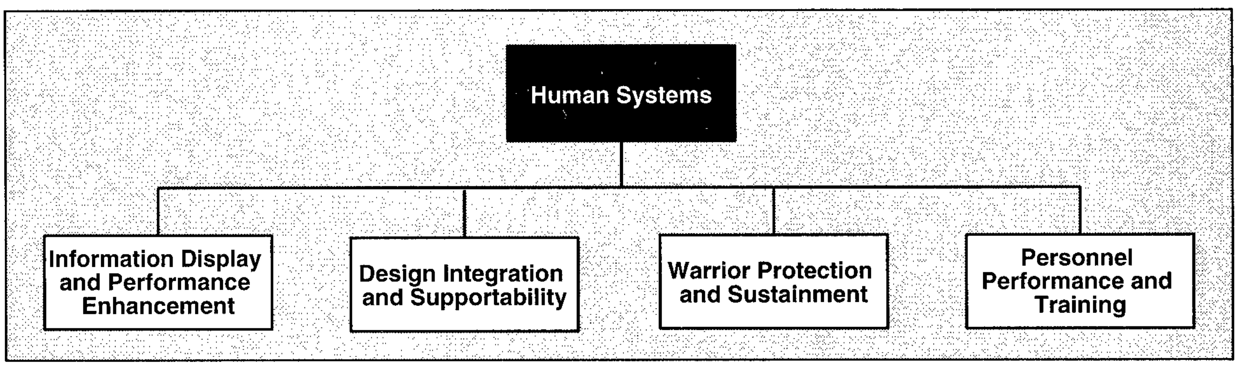


Figure IX-1. Planning Structure: Human Systems Technology Area

Information display and performance enhancement technologies support future joint warfighting needs in data visualization, aural and visual interface, immersive interface, intelligent aiding and decision support, supervisory control and teleoperation, and physical aiding.

Design integration and supportability technologies support the fielding of affordable, effective equipment needed for future military operations by advancing the state of the art in human system design tools, performance requirements estimation, performance metrics, crewstation integration, operational logistics, and acquisition logistics.

Warrior protection and sustainment technologies support mission capabilities through personal protection, escape/crash safety, survival and rescue, warrior systems, warfighter systems modeling, advanced airdrop, food and nutrition, and airbeam technologies for shelters.

Personnel performance and training technologies strengthen unit readiness and reduce costs through advances in force management and modeling, selection and classification, human resource development, simulation-based training, training strategies, and training efficiency.

The key to force lethality, survivability, and unit efficiency is the effective use of human resources. People are the most critical component of weapon systems. They are also the most costly component. Personnel and related costs exceed $70 billion annually, with an additional $20–30 billion spent on training. This represents about 40% of the $241 billion FY97 defense budget. The Human Systems S&T program directly contributes to *all* Joint Staff future warfighting capabilities by optimizing the use of the DoD's most critical resource—its people. The impacts of these technologies include (1) substantial increases in unit readiness through more robust training techniques while reducing costs, (2) improved mission performance through more effective information displays and decision support system, (3) casualty reduction from enhanced protection and escape systems, and (4) enhanced mobility by better logistics and troop sustainment technologies. Combat systems will be designed to capitalize on human strengths and mitigate weaknesses while simultaneously improving sustainment and support of warfighting systems. Advances in warrior protection systems address concerns about casualties in conflict. By providing the personal protection and life support necessary to meet current and future threats, these technology efforts make the individual warrior more effective and achieve force multiplication. With fewer soldiers executing the mission, we decrease the tax burden and put fewer warfighters in harm's way while still achieving mission objectives. Advances in Human Systems technologies are essential for the services to meet their global commitments in combat and peackeeping roles.

A glossary of abbreviations and acronyms used in this chapter begins on page IX–27.

1.2 Strategic Goals

The Human Systems technology area takes a unique, multidisciplinary approach to the human role in combat operations. Our collective capability to draw on the physical, biological, biomedical, and behavioral sciences plus human factors engineering is needed more than ever. Instead of facing a single massive threat, the joint warfighter is challenged by the potential of simultaneous, multiple, low-intensity conflicts. Instead of having a robust DoD budget, we must conduct both operations and acquisition with tightly constrained resources. This change in the operational backdrop has compelled a corresponding change from the services, where the focus has shifted from a force with new and larger weapon systems with increasing speed, range, and firepower to a smaller force with fewer weapon systems but with more functionality, fewer "hands on" training hours, fewer people, less acquisition, and aging systems that must be maintained. This change in focus places a growing demand on the human who is "in the loop" of every weapon system.

The strategic goal for investment in Human Systems technology is to maintain a high degree of combat readiness and mission performance with affordable systems and a smaller force deployed across the globe under diverse conditions. To achieve this goal, the services must place increasing emphasis on "force-multiplying" weapon systems and on the training and retention of qualified people and their personal protection, sustainment, and survival during operations. For the full range of weapon systems, Human Systems technology is integral to major gains in operability, effectiveness, availability, and affordability. Over a weapon system's life cycle, the cost of the people to operate and maintain the system typically is significantly higher than cost of the system's hardware. Through vigorous application of Human Systems technologies to current and future weapon systems, we can achieve gains such as 50% reductions in average crew size; 25% reductions in physical, perceptual, and cognitive workload; 15% or more reduction in the weight of personal equipment; 30% overall weight reduction in ballistic protection while decreasing casualties; doubling of critical decision-making accuracy and reliability; quadrupling of overall crew member situation awareness; 80% reduction in fatalities and injuries from aircrew escape; and 50% reduction in total life-cycle costs.

1.3 Acquisition/Warfighter Needs

Human Systems technologies provide the foundation for all weapon systems operation and maintenance. All weapon systems, including unattended vehicles, depend on Human Systems technologies—there are no unmanned systems.

The information display and performance enhancement (ID&PE) subarea supports the following Joint Warfighting Capability Objectives (JWCOs), as detailed in the following paragraphs: (1) Information Superiority, (2) Precision Force, (3) Combat Identification, (4) Joint Theater Missile Defense, (5) Military Operations in Urban Terrain, and (6) Counter Weapons of Mass Destruction. Military payoffs from improved information management include a 50% reduction in display costs; a fivefold increase in the probability of detection and pinpoint targeting with integrated visual and 3D auditory displays; and a 50% reduction in attrition during night or adverse-weather operations, resulting from enhanced situation awareness. Additional benefits include a 240% increase in viewing area for night vision goggles, a 50% increase in targets destroyed, a doubling of first-pass kills through the use of helmet displays that use rapid, high-offboresight targeting, and a 15% reduction in missed targets due to enemy deception and denial practices. Additional payoffs from technologies to aid human performance in diverse, stressful situations include eliminating procedural errors for operators of tactical workstations; reducing crisis planning by 50%; permitting standoff target sorting and selection; and improving situation assessment by a factor of three in operating mobile armor, tactical aircraft, carrier battle groups and command centers.

Planned military transitions include helmet-mounted display integration for the F–14, F–15, F/A–18, RAH–66, command and control vehicle (C^2V), and Force XXI Land Warrior (FXXILW). Technologies to assist and expand human performance are targeted for operators of new systems such as the M1A3, composite armor vehicle, advanced field artillery system, M2/3A2, advanced infantry fighting vehicle, battle command vehicle, RAH–66, F–22, Joint Strike Fighter (JSF) variants, unmanned scout vehicle, other teleoperated combat support vehicles, Smart Ship, and Surface Combatant 21; as well as for upgrades to existing systems such as AH–64, F/A–18E/F, and Aegis shipboard combat system. A program for helmet-mounted displays will provide an integrated headgear system (for mounted and dismounted crews) to increase situational awareness and magnify the system's ability to fulfill demanding operational needs. Helmet-Mounted Sensory Ensembles (HMSE) and 3D audio technology are making significant contributions to reducing the "cost per kill" of target engagement. HMSE, coupling wide-field-of-regard targeting with high-offboresight weapons, will yield greater success ratios in one-on-many engagements, while 3D audio has shown a twofold improvement in ground target acquisition. These improvements permit attacks on multiple targets in a single pass as well as reduced engagement time in the threat area. Tri-service applicability for these technologies ultimately translates into a lower unit cost throughout the DoD. Additionally, the cost per kill goes down as weapon effectiveness is boosted by improved human-system interfaces. Beyond the military gains, ID&PE programs produce enabling technologies critical to the National Information Infrastructure Initiative to satisfy the information needs of the civil sector.

Operations and support costs account for most of total weapon system life-cycle costs. For some aircraft, support costs exceed 80% of total life cycle costs. Design integration and supportability (DI&S) technologies offer enormous payoffs for rapid and comprehensive design of crewstations and support systems in two domains: curtailing life-cycle (acquisition and support) costs and maximizing operability and combat effectiveness. Both are vital to meeting the strategic goal of maintaining a high degree of combat readiness and mission performance commensurate with a lean force structure and declining defense resources. The critical importance of military S&T investment in human-centered design technology was highlighted in the Air Force blue ribbon panel strategic review, New World Vistas.

DI&S programs are advancing the state-of-the-art in human-centered design so that more effective systems can be fielded more quickly and at lower cost, thereby contributing to the JWCOs, especially those for Information Superiority, Precision Force, Joint Theater Missile Defense, and Joint Readiness and Logistics. Example payoffs include quantifying the system performance baseline and crew limitations at acquisition Milestone I, reducing by 50% the time needed to develop and evaluate the crew system, reducing by 75% design-induced operator errors, mitigating design-induced operator fatigue, and reducing by a factor of 10 the need for redesign at the test and evaluation stage. Supportability-oriented payoffs include improved troubleshooting tools to allow field maintenance technicians to reduce diagnostic errors by 15% during repair. Successful demonstration of the Integrated Maintenance Information System (IMIS) on F–16 aircraft resulted in adoption of the technology for the F–22 and JSTARS. Such improved methods for identifying and eliminating design-related supportability problems during system development can increase weapon system availability by 10% during operational use. Weapon system transition targets include land vehicles such as the Advanced Field Artillery System, new air vehicles from the JSF program, and upgrades to the entire range of land combat vehicles and aircraft.

Warrior protection and sustainment (WP&S) technologies are high-payoff investments that support many JCS mission capability areas. Essentially, the objective is to expand the operational environment in which all individual combatants can perform, thus increasing both mission effectiveness and individual safety in combat and noncombat operations. Advances in ballistic protective materials technology will increase protection and performance of armor systems for the individual warfighter while minimizing the weight, bulk, and cost penalties. Advanced aircrew escape technologies will be exploited for near-term applications to F/A–18E/F, F–22, JPATS, and the JSF program. Foreign technology from the Russian K–36 ejection seat will also be exploited. The Army's S&T demonstration program, FXXILW, will enhance warfighter survivability by integrating the following technologies into the existing clothing/protective system while maintaining the current capabilities of the system: combat identification, integration into the digitized battlefield, improvements in target acquisition, and the provision of "hooks" or connections to future infantry systems. All systems will be designed to reduce the overall logistics burden and unit cost. Performance enhancing ration components will increase the warfighter's mental acuity, physical performance, endurance, and ability to deal with battlefield stress. Breakthroughs in diesel fuel combustion, thermal fluid heat transfer, and heat-driven refrigeration will allow for more cook-prepared meals in forward areas, thus enhancing field quality of life at reduced O&S costs. Finally, initiatives in precision airdrop technology will provide capabilities critical to both rapid worldwide insertion of CONUS-based initial forces and just-in-time resupply of rapidly moving forces. Work in warfighter systems modeling is aimed at developing a simulated environment to support analytical capabilities and promoting rigorous individual combatant tradeoff analyses to quantify alternative system concepts, equipment, and operational policy.

Payoffs from the personnel performance and training (PP&T) subarea include increased personnel and unit readiness, minimized personnel dislocations costly to personnel readiness, reduced training costs and time, reduced attrition from training (including flying training), and improved mission effectiveness through higher performance levels of military members. The operational commander will see improved mission performance through more efficient allocation of personnel to duties that match individual strengths, and reduced manpower requirements through better alignment of job structures to accomplish the mission. Intelligent, computer-aided training technologies will significantly reduce training development time and costs, improve the ability to deploy training tools, and improve trainee performance by at least 30%. Research on how to train tactical decision-making potentially will increase decision-making accuracy by 40% and timeliness by 30%. In other areas, air combat units will be able to deploy with complete ground-based training systems, to realistically rehearse missions anywhere in a timely manner, and to fulfill all training requirements—in addition to those that their flying hours program will allow.

1.4 Support for Combating Terrorism

Human Systems technologies are critical components in a systemic S&T effort to provide protection from terrorist activities. These technologies are needed to protect people from the adverse effects of explosive devices, protect crew members and passengers from injury or death associated with vehicle strikes, enhance human performance in hazardous night operations, enhance readiness and performance through use of advanced training technologies, and facilitate the sharing of information between law enforcement agencies to enhance decision support processes.

Programs To Counter Explosive Devices. Ballistic protective materials systems provide enhanced blast and ballistic protection to the individual warfighter (DTO HS.05.05). These systems have direct application to protective products such as explosive ordnance disposal suits (the Army's suit was used during the Summer Olympics bombing incident in 1996), countermine suits, and antisniper ballistic protective vests. These technologies will greatly enhance law enforcement operations. Human Systems scientists and engineers are studying the blast effects of explosive devices to support DoD needs to optimize material systems for both fragmentation and blast effects. The Supervisor-Controlled Teleoperation and Physical Aiding program can be used to remove, disarm, or disrupt bombs and other explosive devices. Additionally, such systems can be used to deploy sensors that could be coupled to the Helmet-Mounted Sensory Ensemble (DTO HS.12.02) and night vision goggle programs (DTO HS.17.05).

Programs To Counter Vehicle Strikes. Human factors engineering analyses (DTO HS.08.06) influenced the design of the Army's Armored Security Vehicle and probably will influence future designs.

Programs To Counter Night Operations. Night Vision Goggle Technology (DTO HS.17.05) can provide counterterrorism agencies with distinct advantages in observation and interdiction.

Programs To Simulate Terrorist Operations. Authoring Tools for Adaptive Training Systems (DTO HS.04.06) can be used to develop simulation-based training in the full spectrum of terrorist activities. Realistic training can be developed for potential terrorist targets (e.g., security police, ambassadors to foreign countries, military personnel, family members assigned in foreign countries) in how to respond to different strikes. Virtual environments can provide particularly effective training in counterterrorism operations such as (1) identification of terrorists and terrorist activities, (2) response to terrorist strikes, (3) hostage response to terrorists, (4) negotiation with terrorists, and (5) explosive device removal and disarming. Human Systems technologies could also contribute to preparation for hostile information warfare (IW) operations. Advanced training technologies, including the capability to participate in multiship distributed simulation and the Distributed Interactive Simulation (DIS) network, provide effective training environments for the information warfighter. Finally, terrorist strike scenarios can be introduced into other integrated training and simulation platforms to increase awareness and effective law enforcement response to terrorist and criminal behavior.

Programs To Enhance Law Enforcement Information Sharing. Intelligent decision support and distributed collaborative technologies can link law enforcement agencies so they can share information. In addition, these technologies will enhance the planning and coordination of counterterrorism strikes using "smart" decision support systems to quickly process large quantities of information (DTO HS.21.06).

2.0 DEFENSE TECHNOLOGY OBJECTIVES

Information Display and Performance Enhancement

HS.06.01	Cognitive Engineering for Battlespace Dominance
HS.12.02	Helmet-Mounted Sensory Ensemble
HS.17.05	Night Vision Goggle Technology
HS.19.05	Rotorcraft Pilot's Associate
HS.21.06	Weapon System Decision Support

Design Integration and Supportability

HS.07.06	Crew Station Integration Demonstrations
HS.08.06	Crew System Engineering Design Tools
HS.13.06	Human-Centered Automation Testbed
HS.14.04	Human Performance Metrics for Theater Missile Defense

Warrior Protection and Sustainment

HS.01.00	Advanced Aircrew Escape
HS.02.06	Advanced Hybrid Oxygen System

HS.05.05	Ballistic Protection for Individual Survivability
HS.10.05	Force XXI Land Warrior
HS.18.02	Precision Offset, High-Glide Aerial Delivery of Munitions, Equipment, and Personnel
HS.20.06	Warfighter System Modeling

Personnel Performance and Training

HS.03.06	Aircrew Distributed Mission Training Technology
HS.04.06	Authoring Tools for Adaptive Training Systems
HS.09.06	Development of Advanced Embedded Training Concepts for Shipboard Systems
HS.11.06	Force XXI Training Strategies
HS.15.06	Integrated Personnel Management Technologies
HS.16.06	Interactive Multisensor Analysis Training Technology

3.0 TECHNOLOGY DESCRIPTIONS

3.1 Information Display and Performance Enhancement

3.1.1 *Warfighter Needs*

Today's battlespace environment presents a plethora of tactical information. Demands are increasing, at every level of command, to enable warfighters to select the right information at the right time to extend their performance envelopes. The complexity and lethality of the combat environment demands that special attention be given to extending the warfighter's situation awareness and enhancing the ability to plan and execute operations while an enemy is still assessing the situation.

ID&PE efforts identify candidate technologies for enhancing situation awareness and help the military planner understand how technologies can be integrated to respond to operational demands. ID&PE technologies provide cost-effective displays that present timely and pertinent information to optimize decisionmaking. Advanced displays will carry information that contributes to the Joint Staff's goal of maintaining near-perfect, real-time knowledge of the enemy and communicating that information to all forces in near real time. Near-real-time knowledge of the enemy enables real-time maneuver dominance strategies. Specific goals, listed in Table IX–1, are to eliminate procedural error for operators of tactical workstations; cut crisis planning time by half; enable standoff operations (air, mounted, dismounted) outside of threat weapon ranges; improve, by a factor of three, the speed and accuracy of situation assessment and planning at each echelon of military operations (command level down through the individual combatant) in operating mobile armor, tactical aircraft, carrier battle groups, and command centers; and improve weapon system operational capabilities through computer-supported combat decision aids. Auxiliary aiding research will achieve significant reduction in warfighter risk through automated assistance tools and improve the coordination and planning of logistics support through advanced database visualization and management tools. Inherent in each goal is the need to exploit the technology while maximizing affordability and minimizing the supportability costs.

Table IX–1. Information Display and Performance Enhancement Technology Transition Opportunities

Current Baseline	1–3 Years	3–5 Years	5+ Years
High-resolution, wide-field-of-view, night-vision devices Advanced database visualization tools for logistics anchor desk Missile trajectory and target prediction algorithms for Talon Lance	Ejection-safe helmet displays linked to missiles for multiple high-offboresight kills in fighters/helicopters Real-time cognitive decision aiding for advanced rotorcraft and composite vehicles Night-driving and low-bandwidth sensors for unmanned ground vehicles Models for tactical situation assessment and decision making for real-time operations	Decision support system aiding collaborative planning and mission monitoring for joint commanders 3D audio displays will expand crew situational awareness, speech intelligibility, survivability, and effectiveness Support system prototypes for collaborative decision making and distributed information processing	Advanced data fusion and processing will provide near-real-time information for battlefield awareness and rapid replanning Large color graphic displays will support 3D views of tactical information, while 3D audio, speech recognition, and color helmet displays will support threat warning and targeting for aircraft, ground forces, and ships Architectures to significantly augment cognitive, perceptual, and physical task performance applicable to all services, defense agencies, and private-sector spinoffs Immersive virtual reality devices will support combat crew stations including remotely piloted vehicles

Helmet display and performance-aiding technology transitions are underway via demonstrations in F–14, F–15, F/A–18, and RAH–66 aircraft. 3D and other display technologies are on the horizon. These technologies will transition to new-build, forward-fit, and retrofit programs, including F–22, RAH–66, F/A–18E/F, JSF, M1A1, M2A1, M3A1 AH–1G, AH–1S, AH–64, OH–58, OH–6A, AWACS, UH–1N, UH–60A, C–141, P–3, land vehicle night-driving systems, Aegis combat system, CVN–76, advanced Tomahawk weapon control, ship self-defense system, next-generation attack submarine, CINCPAC Political Military Anchor Desk, joint maritime command information system, land attack targeting project, and advanced sensor technology programs. Technology transition opportunities to improve system operability, combat performance, and supportability are targeted to new systems such as M1A3, composite armor vehicle, M2/3A2, future scout and cavalry vehicle, future infantry fighting vehicle, future reconnaissance vehicle, advanced field artillery system, command and control vehicle, and battle command vehicle, FXXILW, RAH–66, JSF, F–22, Smart Ship, Advanced Combat Direction System, and Surface Combatant 21; and to upgrades to existing systems, such as AH–64, F–15E, F/A–18E/F, F–14 Quickstrike, and Aegis combat system.

3.1.2 *Overview*

3.1.2.1 Goals and Timeframes. The ID&PE subarea goals are (1) to enhance the warfighter's situation awareness through exploitation and integration of emerging sensor, display, and processor technologies for organizing, managing, and displaying vast amounts of information; and (2) to greatly enhance mental performance while adapting emerging display and performance technologies to the unique tactical requirements projected for tomorrow's battlefield. These complementary goals will significantly enhance military performance by optimizing the utility of the information and the ability of the operator. The enhancements and timeframes for meeting these goals are shown in IX–1.

3.1.2.2 Major Technical Challenges. The ID&PE subarea faces numerous challenges. These challenges include presenting information (visual, aural, haptic) to the warfighter using intuitive displays. The combat environment compounds the need to present this critical information via easily interpreted displays that do not add to the mental or physical workload of the warfighter. New ways to represent and visualize information extracted from a complex data domain are essential; too many information sources threaten to overwhelm the human capacity to monitor, broadcast, and query data sources. For effective human performance on the digitized battlefield, systems data access must be robust, controllable, and able to convey the right information at the right time and in the right context. Multimodal control and input methods including touch, speech, eye tracking, and natural language are key examples of potential solutions. Additionally, ID&PE research must provide an effective bridge between the operational and developmental communities through the refinement of diagnostic performance metrics that focus on the warfighter-information systems interface.

Another challenge is to extend warfighter capabilities (physical, cognitive, psychological). Meeting this challenge involves merging existing models of biodynamics and ergonomics with the emerging models of human cognition, decisionmaking, and human stress levels. These parameters must subsequently be transitioned to and integrated with weapon systems models, C^3I models, and realistic human-in-the-loop mission scenarios through the DI&S subarea efforts. Additional challenges include accelerating technology maturation for very high speed, real-time mission planning and decision support systems; developing decision support tools to monitor and counter the adverse effects of high operational stress and high operator performance levels; and developing computerized, collaborative, intelligent support systems to enhance physical performance and decision making on the battlefield and in the battle group. Since target acquisition is a key to successful military operations, performance aids must be developed that, when combined with active and passive sensors, can provide information on the effects that texture, shape, and color have on weapons' signatures. These aids will improve detection and identification of objects in underwater and aerospace environments. Rotorcraft, in particular, often must operate in high-threat scenarios for which the integration of advanced mission equipment functions and data presents a major challenge. Technologies to aid performance will reduce helicopter vulnerability and thus increase survivability and first-time mission success by improving real-time internal situation awareness through data fusion, innovative information presentation, and cognitive decision aids.

3.1.2.3 Related Federal and Private Sector Efforts. Related efforts are underway at NASA, FAA, Wright State University, the University of California (at Berkeley and Santa Barbara), Stanford University, Ohio State University, Carnegie Mellon University, and the Ohio Consortium for Virtual Environment Research. Furthermore, cooperative R&D agreements with industry have been negotiated, including the Army Research Laboratory's Federated Laboratory Program. The Department of Veterans Affairs is working on neural network recognition of hand gestures and the neurological substrate of auditory localization. International efforts also include a Nunn Program sponsorship involving the U.S. Air Force and the French government for S&T research in helmet-mounted displays, 3D audio displays, and haptic displays. Additionally, there is a Nunn Program endeavor with the United Kingdom to advance helmet-mounted tracking technology and to develop and evaluate virtual control alternatives and adaptive interfaces. Other cooperative activities include work under the auspices of The Technical Cooperation Program (TTCP) and the Advisory Group for Aerospace Research and Development (AGARD).

3.1.3 *S&T Investment Strategy*

3.1.3.1 Technology Demonstrations. ID&PE demonstrations are confirming the operational potential of helmet displays for multiuse day/night operations and the ability to use models of cognition and artificial intelligence technologies in tactical decision support systems.

The Air Force and Navy are completing the congressionally initiated ATD of helmet-mounted tracker/display (HMT/D) equipment in fighters, using new Navy missile seekers to expand the field of regard. This includes aircraft-specific HMT/D integration on the F–15, F–14, and F/A–18. The Helmet-Mounted Sight–Plus (HMS+) adds functionality through color miniature components.

The Visually Coupled Acquisition and Targeting System (VCATS) ATD is demonstrating technology for the Joint Helmet-Mounted Cueing System by rapid line-of-sight cueing of the missile seeker to the target and by standardizing integration of HMT/Ds into cockpits and simulators.

The Panoramic Night Vision Goggle (PNVG) ATD expands the potential for night operations. The PNVG will demonstrate wide-field-of-view, ejection-safe night vision systems that accommodate the full pilot population, are compatible with life-support equipment, and meet pilot performance criteria.

Flight demonstrations of an advanced image analyst workstation are scheduled on the Joint Surveillance Target Attack Radar System (JSTARS) E–8C aircraft. These demonstrations are designed to show how operator-aiding subsystems and interfaces support the JWCOs of Information Superiority, Precision Force, and Combat Identification.

The Rotorcraft Pilot's Associate (RPA) ATD is the services' premier demonstration program to assist decision making in combat. The RPA's objective is to apply artificial intelligence and advanced computing and decision support technologies to the integration and management of next-generation mission equipment and digital battlefield information to enhance the lethality, survivability, and mission effectiveness of combat helicopters. When fully developed, the RPA will assist reconnaissance/attack helicopter crew members in performing mission functions that will improve overall mission effectiveness and survivability.

3.1.3.2 Technology Development. To capitalize on the human's cognitive capability and flexibility, easily grasped information must be presented to the operator of any system, especially during combat. Technologies emerging in ID&PE address the presentation (visual, aural, and force feedback) of intelligent aiding and decision support information. Advances in display, information management, and decision support technology offer significant potential for enhancing the interface between the warfighter and future weapon systems. Such technology, however, must be appropriately focused and matched to the unique requirements of the human operating in a complex, information-rich, and highly time-stressed battlefield environment. Without careful consideration of the human factors (cognitive, physiological, organizational) issues involved in this technology integration, the services' technology development efforts will not realize the full potential of advanced weaponry and sensors or attain the high levels of performance required to meet and suppress advanced threats.

A data visualization effort confronts the data overload problem for cross-service applications spanning command centers, vehicle crew members, and individual combatants. It exploits computer graphics, voice control and sound cues, better display symbology, and stereo 3D displays. Aural and visual interface research develops information management criteria for advanced component technology to maximize the information throughput and minimize the likelihood of operator overload in either the visual or the auditory processing channel. It focuses on uses of aural and visual cues to present spatial information (1) for integrated flight, weapon, and sensor operations across the range of aircraft, ships, command centers, helicopters, tanks; and (2) for the individual warfighter.

Intelligent-aiding and decision support technologies are producing computational techniques and quantitative models of physical processes and data processing and information display for use by military planners and strategic/tactical decisionmakers. Distributed collaboration technology is the key to effective joint mission planning, situation assessment, and mission monitoring by command staffs and extended teams that are physically separated.

Supervisory control and teleoperation technologies can be applied to integrate sensors, platform control techniques, and dexterous manipulation devices with remotely controlled robotic systems.

Immersive interface efforts exploit component technologies from other ID&PE efforts to develop an advanced, multiuser environment consisting of integrated surround-screen, helmet display, 3D auditory input, and tactile force feedback.

3.1.3.3 Basic Research. As outlined in Sections 3.5 and 4.12 of the Basic Research Plan (BRP), scientists conducting basic research in ID&PE are refining understanding of how humans function in a complex, information-rich, and highly stressful battlefield environment. They are discovering visual display and performance-aiding principles to increase the warfighter's effectiveness through weapon system design. Additional research is revealing new design principles for individual displays and full user interfaces, including virtual environment and multimodal displays and workstations. Reverse engineering from the BRP will feed basic discoveries in vision, touch/manipulation, and locomotion into the modeling of fundamental human perception, cognition, and motor-control associated with complex display and decisionmaking tasks, to understand how they can enhance warfighter performance. Neural networks and other simulation techniques are producing advances in modeling individual and team decisionmaking. An additional research effort is exploring all issues associated with integrating a human with electronic agents and interfaces, while still another is investigating novel user-control channels and theoretical paradigms for human control systems.

3.2 Design Integration and Supportability

3.2.1 *Warfighter Needs*

The application of effective design integration and supportability technology from this subarea will be key toward meeting all 10 JWCOs because of the central need that warfighters have for weapon systems and equipment that are affordable, supportable, human-friendly, and designed from the warrior-as-user perspective. Affordability in the face of declining military budgets is a key challenge facing national defense leaders. Human performance requirements and support costs contribute heavily to the development and maintenance expenses of modern combat systems. Cost can be controlled by optimizing individual system performance through the integration of human capabilities and limitations into the design of the system and by trimming the logistics tail. Since support exceeds 80% of total life-cycle costs for many systems, particularly aircraft, and since many systems remain in the inventory longer than planned, configuration control can be a 40-year challenge or even longer. Identifying ways to eliminate supportability problems during the acquisition of a weapon system will increase weapon system availability to the warfighter by 10%. Improved troubleshooting tools will reduce diagnostic and repair errors by 15%, resulting in faster maintenance and improved combat readiness for land and air systems. Accurately estimating supportability requirements will reduce personnel-related costs by 25% over the weapon system life cycle. Transition opportunities in this subarea are shown in Table IX–2.

Table IX–2. Design Integration and Supportability Technology Transition Opportunities

Current Baseline	1–3 Years	3–5 Years	5+ Years
Test agencies from each service will be able to plan and evaluate man-machine systems using common support tools Electronic database offering quantified and diagnostic data will be distributed to designers and a crew-centered cockpit design process	Valid metrics established for assessing human decision making, operator workload, and situation awareness Develop a test planning, analysis, and evaluation software tool for evaluating automation concepts in distributed interactive simulation from a human interface perspective Develop a model for evaluating operator situation awareness and related displays and environments, particularly related to theater missile defense	Human performance metrics will correlate to weapon system effectiveness Supportability methods and tools will generate a 40% improvement in field maintenance and depot performance in combat and peacetime operations Aircraft battle damage assessment and repair aid that significantly reduce turnaround time Tools will improve onboard diagnostic decision making for just-in-time maintenance on ships Validated suite of tools will enable accurate estimation of human performance requirements for weapon systems, along with mechanisms for reducing such requirements early in design	Analytic and simulation tools to design for operability will be proven, including an operator integration test bed that enables designers to accommodate warfighter needs Fully functional electronic crew associate will support platform operations

Crew-centered design processes are tailorable for both new acquisitions and system upgrades. Applications exist for the services' various air-, land-, and sea-based systems. Transition opportunities include land vehicles such as M1A2 Plus, air vehicles including JSF—as well as upgrades to the entire range of fixed-wing and rotary-wing aircraft—and the Navy's surface and subsurface platforms. Human Systems design and test tools are targeted for JPATS, JSF, and TMD, and the upgrades to F–15, F/A–18E/F, F–22, B–1, B–2, Comanche (AH–66), and Apache Longbow (AH–64D). Users concerned with assessing soldier–system performance, effectiveness, usability, and acceptability include the DCSPER, ARIEM, DWHRP, NRDEC, ARDEC, and SOF. Transition targets for supportability systems include the Oklahoma City Air Logistics Center, the Air Combat Command, the Air Force Materiel Command, and the Army's Automated Information System program managers. Weapon system transition targets include Arleigh Burke-class ships, land vehicles such as the Advanced Field Artillery System, new air vehicles such as the JSF, and upgrades to existing air, land, and sea systems.

3.2.2 *Overview*

3.2.2.1 Goals and Timeframes. Design integration and supportability goals include (1) developing a national technology base in human performance modeling and assessment, (2) designing tools for physical accommodation, (3) devising methods for human error assessment, (4) developing tools for estimating and evaluating human performance requirements, (5) demonstrating how to achieve effective crew system integration during design, and (6) developing tools to both streamline and enhance the weapon system support infrastructure. The ultimate aim is to improve weapon system effectiveness, availability, and affordability. All of the design integration tools are set in the context of weapon system engineering. The timeframes for meeting these goals are shown in Table IX–2.

3.2.2.2 Major Technical Challenges. The complexity of warfighter missions and weapon systems has increased as a result of improved sensors, advanced communications and data processing capabilities, increased threats, and more powerful propulsion systems and munitions. A massive amount of human performance data collected over the years could aid in designing systems to deal with this complexity, but it either is not available to the design integration community or is difficult to locate and interpret. Consequently, integration is performed late in the design process, and evaluations rely on costly physical prototypes. Industry crewstation designers lack the analysis and design tools comparable to those available in other disciplines. Models and measures to design for effective human performance are needed, but must link to the CAD/CAE tools used in vehicle engineering. Largely due to human variability, quantitatively linking the human interface to system effectiveness is considerably more difficult than establishing such criteria for physical systems.

To improve supportability, maintenance depot technicians require the means to directly intercommunicate with all electronic maintenance systems, to obtain all necessary information on the depot line, and to view large drawings and schematics at the immediate work site. Shipboard maintainers need tools to help interpret information from equipment diagnostic sensors in order to fully realize the potential of just-in-time maintenance. As DoD moves away from paper-intensive design and logistics, new challenges arise. Among these are how data are stored and managed, how data are integrated across multiple distributed platforms, how data are shared among diverse disciplines, how legacy data are incorporated, how the human is integrated into the new environment, how organizations and their processes exploit automation, and what metrics are used to measure success. In today's budget-constrained operational environment, systems must be designed to be operated and maintained by affordable levels of manpower with affordable training, a definite challenge when estimating human resources in early system formulation.

3.2.2.3 Related Federal and Private Sector Efforts. Numerous undertakings in the federal and private sectors are technically applicable to DI&S efforts: FAA investments in design integration for air traffic control; NASA investments in design integration for Space Shuttle improvements, civil transports, general aviation, and future space operations; and IR&D programs in the aerospace sector of the domestic economy. DoD has unique supportability requirements, including improved maintenance capabilities for combat environments, rapid deployments, and varied contingency missions. Commercial industry (e.g., Boeing and Northwest Airlines) and the FAA are leveraging the DoD system supportability technologies to improve maintenance and support of commercial airliners. In addition, the Nuclear Regulatory Commission is adapting DoD electronic technical manual technologies.

3.2.3 *S&T Investment Strategy*

3.2.3.1 Technology Demonstrations. The basic DI&S strategy is to place S&T resources in those areas that can (1) showcase the technology where the operational payoff is greatest, (2) reduce the risk of technology insertion in specific applications that evidence technology maturity, and (3) produce technology transition products for customers. This subarea includes demonstrations that are incorporated in the DTOs along with demonstrations that are not DTOs. The DTO-related demonstrations generally concentrate on how to help design and integrate the human-system interface with weapon systems (and with operated equipment) during acquisition. These DTOs strive to place the human-system engineering design practice on a sound scientific basis, show how the technology can be exported to crewstation design and redesign work, demonstrate that simulation technology can produce data to help set the human-system requirements at the "front end" of acquisition, and produce human performance metrics that link to system effectiveness metrics to evaluate the human-system interface during development. Several ACTDs and ATDs proposed by Joint Theater Missile Defense, Precision Force, and Joint Readiness and Logistics offer the potential to exploit the impact of these technological efforts. Additional subarea demonstrations concentrate on how to drastically cut the cost of the support "tail" of maintenance- and logistics-related functions, providing technology transition products usable for both developmental and fielded systems.

3.2.3.2 Technology Development. The DI&S technology base has two areas: design integration and supportability. Within the design integration area, the design tools program provides design technology building blocks for crewstation designs across service applications. It develops the underlying engineering processes, design aids, guidelines, software systems, databases, man-machine system models, and standards that allow man-machine models to be integrated with conventional design principles. The crewstation integration program explores mission-unique integration concepts for specific platforms, missions, tactics, and operating procedures. The human performance requirements estimation program concentrates on developing methods for folding such requirements for new systems into the materiel design process. Within the supportability area, the operational logistics program focuses on field-oriented supportability, especially maintenance performance and logistics planning tools. Also critical to supportability is a condition-based maintenance program that would develop tools to help maintainers decide when and what to maintain on shipboard equipment in order to efficiently provide just-in-time maintenance. Collectively, the supportability work targets affordability gains for next-generation combat systems, interrelates maintenance requirements analysis and design tradeoffs, applies information systems providing integrated electronic technical data to the maintenance/repair depots, and introduces supportability requirements estimation methods into the acquisition process while incorporating personnel-related considerations.

3.2.3.3 Basic Research. Basic research in human performance, particularly in cognitive processes and their degradation from physical and mental stress, will provide important input to human performance models, human requirements estimation methods, and crewstation design tools. Basic research in computer software development will allow for fundamental improvements in crewstation design tools and ease of developing human performance models and accessing associated databases.

3.3 Warrior Protection and Sustainment

3.3.1 *Warfighter Needs*

Success on the battlefield relies heavily on continuous availability of warfighters and on optimizing their performance. Keys to accomplishing this are to mitigate personnel risk and to enhance the capabilities of individual warfighters in an operating environment. Warrior protection and sustainment technologies enable warfighters to perform their missions and survive in normal and emergency operational environments. This research serves Joint Staff warfighting needs in a multitude of areas. Capabilities provided by FXXILW will be technology upgrades and linkages to the digitized command and control network with near-real-time battlefield intelligence. The thrust of this effort is to seamlessly integrate, at the individual combatant level, the following capabilities with the protective clothing/load-bearing system: individual combat identification, wireless interfaces, system voice control, rapid target acquisition, communications/radio enhancements, self-contained navigation and display, unexposed firing/viewing, and signature suppression/control.

The incorporation of individual combatant identification will reduce incidents of fratricide. Other enhanced capabilities for the individual warrior—including improved ballistic protection, enhanced load bearing, countermeasures to sensors, and laser eye protection—will permit the services to engage regional forces promptly in decisive combat while protecting the force. Many of the WP&S technologies will result in reduced casualties, increased mission duration, and faster turnaround time, which ultimately reduces manpower costs and saves lives. Many of the technologies also have widespread applications for both the military and civilian sectors, making them a wise RDT&E investment with high-resource-leveraging potential. Multifunctional and passive thermal management materials are simpler, lower cost, and easier to support than multiple components and mechanical systems. Although systems may be more costly on an individual basis, the systems will be more lethal and the individual more survivable; ultimately, it will be more cost effective with a smaller standing army. Conflicts are occurring more and more frequently in urban terrain/environments. Programs such as the Military Operations in Urban Terrain (MOUT) ACTD will lead to revolutionary breakthroughs by providing the warfighter—as a weapon systems platform—a more effective, efficient, and precise/accurate means of fighting. This means that soldiers in MOUT largely support surgical operations, imparting little collateral damage.

To protect crew members during emergencies, the advanced aircrew escape and related advanced ejection seat technologies can reduce by 50% the out-of-envelope fatalities and injuries caused by high-speed ejections. New g-protection technologies can enable pilots to match the aircraft's structural envelope, providing a significant tactical advantage in air combat. High-altitude exposure imposes risks that must be quantified, and protective/avoidance procedures and systems will be developed. Self-generating breathing gas technology is needed to meet the large-flow demands of transport aircrews and to eliminate the need to purchase and handle liquid oxygen (LOX). This technology will cut logistics costs and eliminate injury risks.

Advanced airdrop technology will permit rapid worldwide insertion of CONUS-based forces, allow for precise battlefield resupply, provide for low-cost insertion of remote sensors and munitions, leverage nonstandard parachute designs/manufacturing techniques for cost savings and performance enhancements, and incorporate nonparachute decelerators for reduced impact velocity. Additionally, warrior sustainment will benefit from performance-enhancing rations to increase the warfighter's mental acuity, physical performance, endurance, and ability to deal with battlefield stress. Nonthermal preservation and active packaging technologies will result in the capability to provide a variety of rations with improved sensory and nutritional quality, thus improving warfighters' nutritional intake. Application of breakthroughs in diesel fuel combustion, heat-driven refrigeration, and thermal fluid heat transfer will enable fielding of rapidly deployable kitchens, more cook-prepared meals, and consequent enhancements to quality of life in the field and reductions in O&S costs. Inflatable airbeam structures enable rapidly deployable shelters in forward areas, enhancing the ability to treat casualties and to maintain and repair battle-critical weapons platforms.

These technology developments are high-payoff investments that support the following JWCOs: Military Operations in Urban Terrain, Combat Identification, Chemical/Biological Warfare Defense and Protection, Joint Readiness and Logistics, Precision Force, and Joint Countermine. Transition opportunities include technology insertions into the Land Warrior advanced development program; integrated multifunctional fabrics to the Joint Service Lightweight Integrated Suit Technology Preplanned Product Improvement (JSLIST P^3I), aircrew, and soft-shelter programs; microclimate-conditioning (MCC) equipment; ballistic protective materials; and anthropometric/human factors consideration for helmet development programs (e.g., infantry helmets, combat vehicle crewmen helmets, motorcycle helmets). Soldier and marine enhancement programs (SEP/MEP) have also provided a mechanism to insert transition-ready technologies directly from S&T efforts to nondevelopmental items and get them into the hands of the combatant quickly. Other transitions include F/A–18E/F, F–22, JPATS, and JSF; advanced hybrid oxygen technology for transport aircraft and field hospitals; aircrew environmental cooling; altitude protective procedures and systems; sustained acceleration protective procedures and systems; and seating components such as advanced restraints, energy absorbers, inertia reels, and seat cushions.

In sustainment, specific transitions include high-glide-ratio, flexible-wing technology to full-scale gliding wings that result in greater payloads, offset distances, and accuracy; improved efficiencies in cost of delivery; enhanced survivability of delivery aircraft; and rapid deployment of equipment on the drop zone. Also included is targeted nutrient delivery, novel food preservation, integral heating, and equipment/energy technologies to augment standard combat and special-purpose-ration and field feeding systems (MREs, T-rations, assault rations, cold and hot weather rations), and airbeam technology for forward area maintenance shelters.

Dual-use applications include high-performance fibers for ballistic/blast protection for law enforcement agencies. Flame- and thermal-resistant fibers have strong dual-use in firefighting applications, race car driving, and aircraft piloting. MCC applications will benefit industrial workers, law enforcement personnel, firefighters, and medical patients. Other dual uses include applications for disaster and humanitarian relief through advances in airbeam technology and novel heating technology; shelf-stable bread technology and thermoelectric heater technology for recreational activities and performance-enhancing components for sports.

Specific opportunities for technology transition in this subarea are shown in Table IX–3.

3.3.2 *Overview*

3.3.2.1 Goals and Timeframes. The WP&S subarea's goal is to enable warfighters to fully exploit weapon system capabilities despite battlefield and environmental hazards and enemy threats. The enhancements proposed to meet this goal, and their timeframes, are shown in Table IX–3.

3.3.2.2 Major Technical Challenges. The basic challenges of the WP&S subarea are to protect and sustain warfighters and enable them to operate effectively, while withstanding environmental hazards (heat, cold, wind, blast, vibration, acceleration, motion, and altitude), and combat threats (ballistic munitions, sensors, battlefield lasers). A fundamental challenge is to develop and integrate advanced multifunctional protective materials while simultaneously reducing the weight

Table IX–3. Warrior Protection and Sustainment Technology Transition Opportunities

Current Baseline	1–3 Years	3–5 Years	5+ Years
Demonstrate safe escape from combat aircraft at speeds above 700 KEAS			
Determine the effects of decompression sickness and positive pressure breathing at high altitude	Enable fighter crews to endure combat maneuvers for 30% longer without significant increases in fatigue or reduction in performance	Reduce weight, volume, and cost of crew oxygen-generation systems by 20%; increase oxygen recovery rate by 50%; and conduct a proof-of-concept demonstration of a large-flow oxygen system for large aircraft	Test modular, integrated, life-support technologies to improve cockpit mobility while reducing injuries and fatalities in air operations
Test an advanced aircrew personal environment cooling system		Transition advanced thermal management materials with microencapsulated phase change material	Transition lightweight, low-power, portable MCC technologies

Table IX–3. Warrior Protection and Sustainment Technology Transition Opportunities (continued)

Current Baseline	1–3 Years	3–5 Years	5+ Years
Demonstrate a parachute with novel design that achieves a reduction in weight, bulk, and manufacturing costs (compared to fielded parachutes) and provides equivalent flight performance	Demonstrate a parachute retraction system using clustered parachutes that provides a less than 10-ft/sec soft-landing capability	Demonstrate a less than 10-g soft-landing airbag system for cargo airdrop	Demonstrate a soft-landing airbag system for airdrop, cutting rigging/derigging times and providing roll-on/roll-off capabilities that greatly improves early-entry forces' military readiness and survivability on the drop zone
Standard dismounted infantry equipment	A robust squad exercise of dismounted infantry using FXXILW equipment to perform typical operations	Integrate technology upgrades to the Land Warrior system	Demonstrate follow-on technology advancements to FXXILW
Separate vests offering fragmentation protection (PASGT) and small arms protection (Ranger body armor)	Advanced material system for protection against combined fragmentation and small arms threats	Integrate and transition improved small arms/ fragmentation protection technologies to advanced development	Transition improved materials technology for enhanced countermine protection systems to advanced development
Exercise an integrated, DIS-compliant model that assesses the combined effects of select battlefield threats and physiological stressors	Expanded suite of modeling, simulation, and analytic tools to quantify warfighter lethality and survivability provided by the individual combatant concepts and equipment		
Specialized protection is provided by separate standalone ensembles		Demonstrate combat uniform systems that reduce the soldier's thermal signature by 50% from background levels	Transition combined protection using nonaramid fibers, resulting in a fabric system with a 50% decrease in cost of flame protection that increases overall soldier survivability
Demonstrate Modular Appliance Technologies, Centralized Heating (MATCH)	Integrate MATCH technologies into a mobile feeding system	Demonstrate rapidly deployable, highly efficient, cost-effective field feeding system technology	Demonstrate a small integrated diesel reformer that will enable field kitchens to use commercial gas-fired appliances
Develop performance-enhancing ration components and shelf-stable, intermediate moisture meat/bread enrobed sandwiches	Demonstrate modulated nutrient release during periods of high-energy demand and operational flexibility of mobility enhancing ration components	Identify and explore nonthermal preservation techniques	Validate nonthermal preservation techniques and optimize the incorporation of complex carbohydrates for modulated energy release
Demonstrate quick erect large-area night maintenance shelter based on high-pressure airbeam technology	Optimize airbeam technology for transition to the aviation maintenance shelter		

and bulk associated with increased multithreat protection. The countersurveillance challenge is to provide passive protection against advanced sensors. Integrated protective clothing and individual equipment (CIE) challenges include development of cost-effective uniform materials that provide protection against multiple threats without imposing a heat stress penalty, thermal stress management through passive material solutions, and development of material test procedures that correlate with field performance. The laser eye-protection challenge includes the development of frequency-agile nonlinear materials that exhibit low switching thresholds/high third-order nonlinearities and can be integrated into both day and night combat operations. The warfighter systems' modeling challenge is to develop or acquire and implement high-fidelity, valid models of human responses that quantify the contribution of individual warfighter system components to warfighter effectiveness and survivability. The FXXILW challenge is to functionally integrate a variety of warfighting components (e.g., developments in microelectronics and signal processing, sensors, flat-panel displays, advanced materials) onto the human platform and the protective clothing/load-bearing system to enhance the warrior's mobility, cognition, survivability, etc.

Specific challenges for aircrew protection include:

- Understanding the response and injury mechanisms from windblast.
- Developing means for safe aircrew escape at high speed and adverse aircraft attitudes.
- Developing analytical models for human response to ejection forces.
- Accommodating females and small males during emergency escape.
- Identifying limits on mass and center-of-gravity for head-mounted equipment.
- Developing instrumented mannequins for impact/sled tests.
- Understanding the windblast and burn hazards at high mach temperatures.
- Delaying fatigue and loss of consciousness under sustained g forces.
- Developing design criteria for aircraft seats, restraints, and helmets under vibration, acceleration, and impact forces.
- Supporting operations at cabin altitudes above 20,000 feet.
- Eliminating aircraft modifications for respiratory protection.
- Increasing oxygen recovery levels with onboard nitrogen generation.
- Providing self-generated flight and medical-grade oxygen.

A challenge in field ration development is that the natural complexity of food systems affects their chemical, physical, and nutritional characteristics. Processing can lead to undesirable changes that are further compounded by lengthy, uncontrolled storage. To mitigate individual and crew performance degradation due to lack of nutrition, performance-enhancing nutrients should be incorporated; to ensure product safety, packaging innovations must provide increased protection in hostile environments. Clean, reliable diesel combustion, efficient heat transfer, safe methods for storing perishable subsistence, and modularization and integration of components are needed to support transportable kitchens for all environmental extremes. Airdrop challenges include modeling transient parachute-opening processes, developing a reliable deployment process for semirigid wing, developing nonparachute decelerators for soft landing of components, and developing sensor systems for airdrop applications.

3.3.2.3 Related Federal and Private Sector Efforts. NASA has WP&S-related programs in the area of space vehicle recovery systems and rations for space feeding. Independent industry R&D adds to the technology base, as do small business innovation research (SBIR) contracts. Additionally, the services participate in NATO's AGARD and warfighter standardization and modernization efforts. For example, the foreign comparative test program includes examination of the Russian K–36 ejection seat. Other active NATO working groups address ballistic protection efforts (behind-armor effects and trauma effects from nonlethal weapons). There is also strong interest for collaboration in the ballistic protection area from the United Kingdom, France, Denmark, the Netherlands, Canada, and Sweden. The United States is playing a lead role in several major NATO and ABCA/TTCP programs related to soldier systems and soldier modernization resulting in a NATO Staff Target for Soldier Modernization, the NATO Advisory Industrial Group (NIAG) Prefeasibility Study on Soldier Modernization, and cooperative soldier system demonstrations and human performance models. DoD and DOJ have a memorandum of understanding (MOU) that includes ballistic protective technologies. DOE is currently conducting ballistic protective materials research to complement DoD efforts. Improved technologies for lightweight ballistic protection for individuals and vehicles continue to be a technology thrust for cooperative efforts with industry.

NASA and FEMA are working with DoD on advanced firefighter clothing. The Navy is active in the NFPA firefighting standards-setting. There is strong participation in TTCP for textile materials, human factors, modeling and simulation, and soldier modernization. Data exchange agreements (DEAs) exist with France, Germany, Korea, Sweden, Australia, and the Netherlands.

By participating in the Center for Advanced Food Technology consortium with Rutgers University, the government leverages more than $3 million in basic research with a $40,000 investment. DEA's for military feeding and personal protection and survival-related technologies exist with Germany, Israel, France, Korea, Norway, Sweden, and Canada. There is an MOU with USDA to ensure mutually supportive and nonduplicative programs. The Research and Development Associates for Military Food and Packaging Systems, Inc., an industrial–academic organization, holds semiannual forums to coordinate and address military needs.

The Army continues to participate as a member of the National Parachute Technology Council (NPTC), which is a forum where multiservice/agency programs are coordinated and leveraged. As a result of the NPTC and through other partnering programs, the Army is working with industry to explore the performance of gas-injected airbags for possible uses in industry and airdrop applications. The Army and NASA are collaborating to leverage the GPADS technology and apply it as the recovery system for the NASA X–35 recovery vehicle. The Army is also working with Draper Labs and NASA to develop a guidance, navigation, and control (GN&C) package that can be used to guide parafoil systems. The application of GN&C technology to parafoil systems results in a unique and significant challenge in terms of control theory and the development of the system's control algorithms. The combination of a parafoil system with a payload results in as many as 12 degrees of freedom—the ultimate reason for the control challenge. This is as opposed to 6 degrees of freedom in a typical air platform. Pressurized flexible composite technology has further dual-use applications including inflatable ejection seat stabilizers, deployable high-glide wings, and mobile floating platforms.

3.3.3 *S&T Investment Strategy*

3.3.3.1 Technology Demonstrations. The Crew Protection for Advanced Escape Systems demonstration is validating the technologies required for a safe escape envelope matching the entire flight regime of combat aircraft with the future flying population. This includes safe escape at high speeds and in low-altitude/adverse-aircraft attitudes. The work includes proof-of-concept equipment, high-speed sled testing, and flight testing. The FXXILW program will demonstrate the integration of risk mitigating technology upgrades (e.g., individual combat identification, wireless interfaces, system voice control, rapid target acquisition, communications/radio enhancements, self-contained navigation and display, unexposed firing/viewing, signature suppression/control) to the Land Warrior system. Through an early user evaluation, user feedback on proposed technology insertions will be collected. The ballistic protection program will demonstrate an advanced material system for protection against combined fragmentation and small arms threats.

In the airdrop program, demonstrations include a novel parachute design that achieves a 20% reduction in weight, bulk, and cost; a less-than-10-g airbag system that provides an all-weather, rapid roll-on/roll-off airdrop capability; and a 5,000- to 10,000-pound semirigid wing, high-glide airdrop system. The DoD food program will demonstrate thermal processes to ensure product quality, microbiological safety, and prevention of oxidation/product degradation through in-package additives; the capability to modulate nutrient release during periods of high-energy demand; and a rapidly deployable, combat-efficient field feeding system prototype based on advances in diesel combustion in a catalytic vaporizing burner, thermal fluid heat transfer, and refrigeration. Finally, the shelters program will demonstrate an optimized airbeam technology suitable for a large maintenance shelter—for helicopters and tanks, for example.

3.3.3.2 Technology Development. Warrior protection technologies counteract the physical forces and threats present in normal and emergency operations. Included are individual and crew-station equipment and structures, environmental control systems, human physiology and biomedical effects, and human susceptibility to mechanical forces. The S&T work addresses breathing systems and comprehensive protection (altitude, sustained acceleration, whole-body vibration, lasers, microwaves, thermal threats, bioacoustics, escape-and-survival subsystems, protection against flechettes, small arms, fragmentation, and blast threats from mines and bursting munitions); textile materials for camouflage; fibers, fabrics, clothing, and individual equipment systems for protection in all climates and environments; integrated application of anthropometry, biomechanics, and biophysics; and technology/system integration for individual warrior protection.

Crew evacuation technology offers life-sustaining equipment for patient care during air transportation. Escape/crash safety technology addresses escape from tactical aircraft using ejection seats and methods to optimize occupant survivability during a crash and emergency egress. Other sustainment-related technologies include nutritional bioavailability, food/texture/structure optimization, quantifying acceptability, nutrition/performance relationships, packaging, preservation, stabilization, and validation of process effectiveness; combustion, heat transfer, thermoelectric power generation, automatic control, and refrigeration technologies; coatings and concepts for airbeam structures and textile-based shelters; designs and concepts for parachutes/gliding wings and cargo/personnel airdrop systems; and theoretical/computational prediction and experimental determination of decelerator behavior and performance.

3.3.3.3 Basic Research. WP&S related research includes an understanding of polymer functionality through synthesis, characterization, and processing. Biotechnological approaches to new ballistic materials involve mimicking the processes found in nature to produce new ceramics. Basic research in support of frequency-agile-laser eye protection involves understanding the thermal and refractive nonlinear response of materials in insulation and in tandem and using biotechnological methods (enzyme-driven polymer synthesis) to develop new nonlinear optical materials. Additionally, the nonlinear optics of the eye and the bioeffects of operationally relevant laser frequencies and power are being investigated. Other basic research investigates brain biochemistry under high-g conditions.

Airdrop research efforts focus on computational techniques for predicting the opening phase parachute performance with any given design. Preservation and stabilization research for improved rations includes determination of factors controlling migration of water molecules among macromolecules in complex foods that affect the physical characteristics of foods after processing and storage. Improved thermal processing of rations by ohmic heating will be guided by basic modeling and in temperature mapping of multicomponent foods.

3.4 Personnel Performance and Training

3.4.1 *Warfighter Needs*

Personnel performance and training technologies have an overarching and direct force-multiplying effect on personnel and unit readiness in all critical elements of the joint warfighting objectives. Personnel performance technologies will improve the services' capabilities to select and classify the highest quality applicants (more than 160,000 per year). Personnel quality translates into reduced attrition, reduced time in skill training, and more capability on the battlefield. New generations of aptitude tests coupled with more sophisticated assignment systems will save 15% in the time required to achieve warfighting skill proficiency. Personnel performance technologies are critical in defining future requirements and ensuring maximum mission capability as the services assume new roles and missions. Table IX–4 lists technology transition opportunities in this subarea.

Contemporary training readiness challenges include preparing for a diverse set of contingency operations while maintaining the capability to conduct major engagements. Added to this complexity of training management are pressures to reduce the training budgets for flying hours, steaming days, and operating tempo. Training technologies are being developed to reduce the cost and increase the effectiveness of current training and to re-engineer future training processes. New aircrew training methods will soon be in use that will improve mission performance and reduce aircraft safety incidents by at least 25%. Through use of advanced, simulator-based mission rehearsal systems, combat units will be able to conduct training that is currently too hazardous or unaffordable. Low-cost, high-fidelity cockpit simulators that are deployable and can be

Table IX–4. Personnel Performance and Training Technology Transition Opportunities

Current Baseline	1–3 Years	3–5 Years	5+ Years
A training seat allocation system will reduce student awaiting instruction time by 15% Methods for training tactical decision making will improve performance by 40% Prototype DIS-based, structured training programs will increase readiness of National Guard units by 50%	A 10% improvement in forecasting multiyear accessions, promotions, and retention (to prevent costly overruns in personnel appropriations while meeting skill requirements) A multirole aircrew simulation testbed will be demonstrated, integrating four advanced simulation cockpits with next-generation visuals in 360-deg displays, with an advanced control station and threat systems that will increase pilots' capability to conduct air superiority missions by 30%, close air support missions by 25%, and interdiction missions by 35% Prototype virtual environment trainer for submarine piloting will be developed and demonstrated	A 10% increase in reliability for measuring leadership capabilities An ability to prescribe a set of recruitment, promotion, and retention policies needed over a succession of years to achieve future force levels More effective strategies for manning units, ships, and squadrons to minimize the turnover of critical personnel during key readiness periods New tests and assignment algorithms will result in a 20% decrease in training time Training and performance assessment tools developed for units participating in Division XXI will be evaluated Training techniques and strategies will be demonstrated and evaluated in advanced warfighting experiments	A comprehensive system designed to match individuals to jobs and career paths, across services, that best fit their interests, temperaments, and capabilities A personnel planning system will integrate manpower requirements determination and allocation with end-strength and skill inventory management and with personnel distribution and assignment Better recruiting and selection techniques will reduce moving costs by $60 million per year Authoring tools will be able to reduce training development time and costs by 90% Combined arms training strategies for the digitized battlefield will increase training efficiency by 50% Seamless simulation environments will allow actual combat systems, manned simulators, constructive wargames, and other simulations to exercise on virtual battlefields

networked will be available in many aviation squadrons within 3 to 5 years for "on-demand" training. Night vision device training systems will increase warfighters' night operational capability by 40%. Virtual environment technology will provide crucial training for submarine piloting to augment on-the-job training. Future training developers will produce valid, high-quality instruction modules in one-tenth the time nominally required today. Warfighters will conduct highly realistic joint/coalition training in integrated virtual, live, and constructive synthetic environments, increasing combat capability by 30% and saving at least 60% in current training budgets.

Because of the breadth of its impact, the PP&T program has substantial personnel and budget leverage. The program impacts the DoD's 1.6 million active duty personnel and its 1.6 million reservists, the $70 billion manpower appropriation, and the $14 billion training budget.

Only very modest savings in these accounts from PP&T research achievements are necessary to offset the research investment.

3.4.2 *Overview*

3.4.2.1 Goals and Timeframes. The PP&T goals will be achieved through advances in force management and modeling (FM&M), improved selection and classification (S&C) methods, and new human resource development (HRD) technologies. The enhancements to these goals, and their timeframes, are shown in Table IX–4.

3.4.2.2 Major Technical Challenges. For PP&T, technical improvements are needed in statistical forecasting, mathematical optimization, information science, and artificial intelligence. Other technical challenges include needed advances in job analysis that identifies mental requirements, self-report and self-inventory measures that resist falsification, more objective measures of mission performance, and battle command performance effectiveness baseline measures.

Technical approaches in training are needed to determine the effects of simulation on training readiness that cannot be assessed independently of the program of training. Visual systems are needed that can provide cost-effective, realistic imagery to warriors and visual cues in virtual battlefields used for training. Realistic training, practice, and timely feedback need to be provided to widely dispersed small units. Military instruction needs to be managed and modified more efficiently to respond to demands for just-in-time training.

3.4.2.3 Related Federal and Private Sector Efforts. The PP&T program cooperates fully with investments by the FAA, Departments of Labor and Commerce, and the Office of Personnel Management. Joint research efforts are continuing with the U.S. Military Academy, the U.S. Army War College, and the Industrial College of the Armed Forces. Cooperative research and development agreements are in place with Howard University, the University of the District of Columbia, and the University of Maryland.

Decision-making research is being conducted at NASA Ames for training and at FAA for aeronautical decision-making and air traffic control training research. Joint research is underway with Lockheed-Martin and medical equipment providers to improve medical training using virtual environment (VE) technologies. DSWA is developing instructional methods and technologies to sustain nuclear weapon expertise. The DSWA system will incorporate classroom, distance learning, and computer-based instruction, which will feature real-time accident response exercises and simulation scenarios.

Many military PP&T technologies have dual uses and will transition across the services, other government agencies, industry, and the educational community. Advances in testing technologies benefit industrial firms that hire at the unskilled entry level. Advanced techniques will also be available for executive development and optimal career planning and management; motivating and supporting a workforce of increasing diversity; and dealing with organizational restructuring. The training and simulation principles obtained from crew-coordination and stress research can be applied in civilian air traffic control and hospital emergency room contexts. Intelligent tutors in physics and medicine are projected for transition to the private sector in the near term. Foreign language tutors will meet the need for rapid skill train-up and sustainment and embody a clear application to civilian education and business training needs. Low-cost, high-fidelity, cockpit training simulations have the potential to significantly lower the cost of commercial flight training.

3.4.3 *S&T Investment Strategy*

3.4.3.1 Technology Demonstrations. An integrated personnel management demonstration program will provide tools for making accurate personnel planning, policy, and budgetary decisions that are responsive to financial and personnel changes over time. Developing battle command expertise will demonstrate training tools and techniques in realistic field and laboratory exercises. The Intelligent Job Advertising and Selection System will demonstrate decreased moving costs, while increasing skill matches (fleet readiness) and the number of assignments meeting personnel preferences. The manpower, personnel, and training (MPT) in the Acquisition Decision Support System, developed in close coordination with the DI&S subarea, will ensure that MPT issues are properly and cost effectively integrated into new and upgraded weapon systems.

Aircrew-distributed mission training technology will develop and demonstrate an aviation training strategy that makes the most effective use of simulators, training devices, and live exercises for initial flight skills through unit combat tasks. By FY01 Force XXI training strategies will develop and demonstrate new training and evaluation technologies that prepare operators and commanders to take the maximum advantage of evolving digitized C^3 systems. The training research will incorporate the use of virtual, constructive, and live simulations to demonstrate and evaluate selected prototype training techniques. An advanced embedded training capability will be developed and demonstrated to improve CIC team decisionmaking performance, reduce training time, and reduce the number of required instructors. Interactive multisensor analysis training (IMAT) will develop new training techniques for very complex warfare tasks (training for future threats of littoral warfare, where on-the-job training is dangerous and not feasible). Simulation in training for advanced readiness will develop and demonstrate training technologies to raise the training readiness levels by 50% in National Guard units by FY97. The Training Impact Decision System will develop and demonstrate a decision support system to conduct "what if" analyses of proposed changes in personnel, budget, and training resources. The Deployable Night Vision Device (NVD) Training System will be developed to train warfighters in NVD use. These technologies can address the effectiveness of several joint warfighter efforts (i.e., Precision Strike, Joint Readiness and Logistics, and Countermine).

3.4.3.2 Technology Development. Technology advances are needed in the following areas to achieve PP&T goals. An improved model of human abilities must be developed to efficiently and optimally assign personnel to jobs. Measures of human abilities must be expanded to incorporate personality characteristics such as motivation, temperament, and values. Validation of newly developed test batteries must continue in order to determine the predictability and utility of these new instruments. New job-structuring methods must be developed to provide improved personnel assignment and manpower modeling. New methods for optimizing and simulating crewing alternatives must be developed along with improved assignment technologies. Rapid changes in the scope and nature of military operations require new leadership assessment devices and leader development technologies.

Simulation-based training technologies need to be developed that realistically train warfighters in combat/support tasks that would be otherwise too costly, very difficult, or unsafe to train using actual equipment. The instructional capabilities of DIS systems need to be maximized and assessed to effectively deliver distributed training to individuals and units. Performance measures and feedback techniques need to be developed to ensure that synthetic training environments will be used effectively for estimating and maintaining training readiness. Cost-effective training strategies must be provided to maintain combat readiness via seamless combinations of virtual, constructive, and live simulation components. The efficiency of developing and delivering individual training must be improved to reduce the cost of military classroom instruction by 25%. Prototype intelligent tutoring systems in technically challenging military occupations need to be developed for skill acquisition and sustainment.

3.4.3.3 Basic Research. Efforts are underway to develop a better understanding of the motivational, situational, and personality characteristics of leaders and how their skills are developed within various organizational structures. A goal of the program is to develop a conceptual model of leader-team performance. Also, a conceptual model is under development to relate the millions of possible assignment alternatives to readiness. If mathematical formulation is feasible, faster and more efficient algorithms will facilitate solving these problems.

Efforts are underway to better understand the interactions among task characteristics, individual differences, feedback, and training practices that affect the development of cognitive or mental models and contribute to information processing, learning, and retention. Also, basic research efforts will investigate new algorithms for improving speech recognition systems to support weapon system trainers, the role of spatial abilities in the training effectiveness of distributed interactive simulations, and the training impacts of individualized automated instruction.

GLOSSARY OF ABBREVIATION AND ACRONYMS

3D	three dimensional
ABCA	America–Britain–Canada–Australia
ACTD	Advanced Concept Technology Demonstration
AGARD	Advisory Group for Aerospace Research and Development
ARDEC	Armament Research, Development and Engineering Center
ARIEM	Army Research Institute of Environmental Medicine
ATD	Advanced Technology Demonstration
AWACS	Airborne Warning and Control System
BRP	*Basic Research Plan*
C^2V	command and control vehicle
C^3I	command, control, communications, and intelligence
CAD/CAE	computer-aided design/computer-aided engineering
CIC	combat information center
CIE	clothing and individual equipment
CINCPAC	Commander-in-Chief Pacific Command
CONUS	continental United States
DCSPER	Deputy Chief of Staff for Personnel
DEA	data exchange agreement
DI&S	design integration and supportability
DIS	Distributed Interactive Simulation
DOE	Department of Energy
DOJ	Department of Justice
DSWA	Defense Special Weapons Agency
DTAP	*Defense Technology Area Plan*
DTO	Defense Technology Objective
DWHRP	Defense Women's Health Research Program
FAA	Federal Aviation Administration
FEMA	Federal Emergency Management Agency
FM&M	force management and modeling
FXXILW	Force XXI Land Warrior
FY	fiscal year
GN&C	guidance, navigation, and control
GPADS	Guided Parafoil Air Delivery System
HMS+	Helmet-Mounted Sight–Plus
HMSE	Helmet-Mounted Sensory Ensembles
HMT/D	helmet-mounted tracker/display
HRD	human resource development
ID&PE	information display and performance enhancement
IMAT	interactive multisensor analysis training
IMIS	Integrated Maintenance Information System

IR	infrared
IW	information warfare
JAST	Joint Attack Strike Technology
JPATS	Joint Primary Aircrew Training System
JSF	Joint Strike Fighter
JSLIST	Joint Service Lightweight Integrated Suit Technology
JSTARS	Joint Surveillance Target Attack Radar System
JWCO	Joint Warfighting Capability Objective
JWSTP	*Joint Warfighting Science and Technology Plan*
KEAS	knots equivalent airspeed
LOX	liquid oxygen
MATCH	Modular Appliance Technologies, Centralized Heating
MCC	microclimate conditioning
MEP	marine enhancement program
MOU	memorandum of understanding
MOUT	Military Operations in Urban Terrain
MPT	manpower, personnel, and training
MRE	meal ready to eat
NASA	National Aeronautics and Space Administration
NATO	North Atlantic Treaty Organization
NFPA	National Firefighter's Protection Agency
NHTSA	National Highway Traffic Safety Administration
NIAG	NATO Industrial Advisory Group
NPTC	National Parachute Technology Council
NRDEC	Natick Research, Development, and Engineering Center
NVD	night vision device
NVG	night vision goggle
O&S	operations and support
P^3I	preplanned product improvement
PASGT	Personal Armor System for Ground Troops
PNVG	Panoramic Night Vision Goggle
PP&T	personnel performance and training
R&D	research and development
RDT&E	research, development, test, and evaluation
RPA	Rotorcraft Pilot's Associate
S&C	selection and classification
S&T	science and technology
SBIR	small business innovation research
SEP	soldier enhancement program
SOF	Special Operations Forces
SPO	system program office
TMD	theater missile defense
TTCP	The Technical Cooperation Program

USDA	U.S. Department of Agriculture
VCATS	Visually Coupled Acquisition and Targeting System
VE	virtual environment
WP&S	warrior protection and sustainment

CHAPTER X
WEAPONS

1. INTRODUCTION

1.1 Definition/Scope

The Weapons technology area includes efforts devoted to armament and electronic warfare technologies for all new and upgraded nonnuclear weapons. The Weapons area consists of 12 subareas grouped in three broad categories, illustrated in Figure X–1. The efforts in these subareas are directed toward providing demonstrated technology that better enables the warfighter to incapacitate or destroy enemy personnel, materiel, and infrastructure and to provide defense against or countermeasures to his ability to wage war.

Conventional weapons (CW) focus on munitions, their components and launching systems, guns, tactical propulsion, bombs, rockets, guided missiles, projectiles, special warfare weapons, mortars, mines, countermine systems, torpedoes, explosive ordnance disposal, and

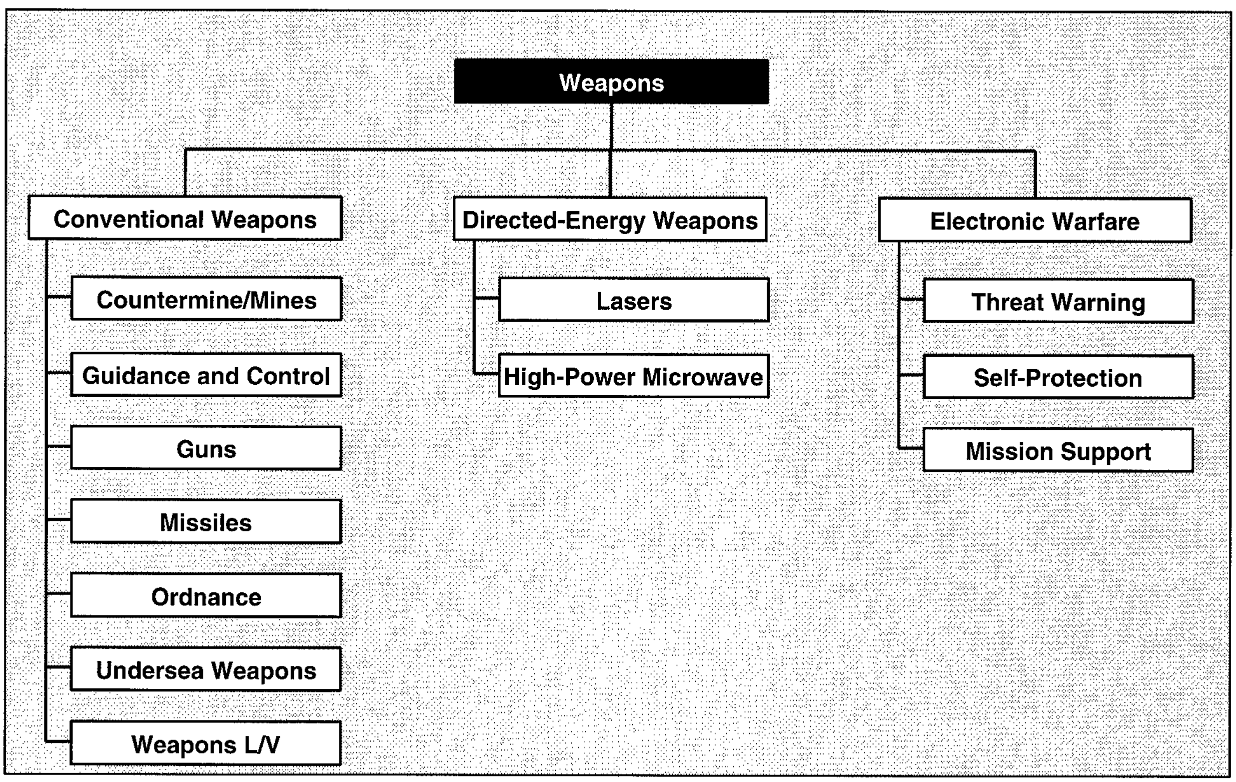


Figure IX–1. Planning Structure: Weapons Technology Area

underwater weapons and their associated combat control. CW subareas include countermine/mines, guidance and control, guns, missiles, ordnance, undersea weapons, and weapon lethality/vulnerability.

Directed-energy weapon (DEW) technologies are those that relate to the production and projection of a beam of intense electromagnetic energy or atomic/subatomic particles that are used as a weapon. Directed-energy weapons and devices generate energy that travels at or near the speed of light from a beam source directly to the target. Directed energy includes the laser DEW and high-power microwave DEW subareas. The only particle beam effort is supported by previous year funding and is not discussed further.

Electronic warfare (EW) is responsible for developing technology that provides U.S. military forces with the capability to survive in their execution of all operations/missions by maximizing their unchallenged, operational use of the electromagnetic spectrum—while denying the same from the enemy by using electromagnetic means to detect and attack enemy sensor, weapon, and command infrastructure systems. The underlying technologies within EW are divided into three principal subareas: threat warning, self-protection, and mission support.

The combined expenditure for weapons in FY97 is $839 million, of which $510 million is allocated to CW technologies, $122 million to the development of EW technologies, and $207 million to DEW development. The figures are considerably less than those in the FY96 DTAP because some DTAP DTOs from FY96 are now reported in the *Joint Warfighting Science and Technology Plan* (JWSTP). The FY98 request of $721 million would allocate $490 million to CW, $114 million to EW, and $117 million to DEW.

A glossary of abbreviations and acronyms used in this chapter begins on page X–63.

1.2 Strategic Goals

The overarching strategic goal for weapons technology investment is to develop and transition superior weapons technology that will provide the services with affordable and decisive military capabilities to execute future missions. The specific goals in CW technologies mainly focus on systems to destroy enemy personnel, materiel, and infrastructure, but with a growing emphasis on incapacitation through nonlethal technologies. The specific goal of the EW and DEW technology efforts is to control and exploit the electromagnetic spectrum for maximum effectiveness of U.S. military operations.

1.3 Acquisition/Warfighting Needs

Weapons technology provides the decisive military capabilities for the future. It responds to the services' operational needs for cost-effective system upgrades and next generation systems in support of the top Joint Warfighting Capability Objectives (JWCOs) in the JWSTP. The Weapons technology activities directly support JWCOs of Precision Force, Joint Theater Missile Defense, Military Operations in Urban Terrain, Joint Countermine, Electronic Combat, Information Superiority, and Counterproliferation, and contribute support to Combat Identification. In addition, the Weapons technology program directly responds to congressional mandates (e.g., the live fire test provisions of the National Defense Authorization Act (1987), Chapter 139, Section 2366 of Title 10, United States Code). Specific objectives of weapons technology programs address:

- The need for affordable all-weather, day/night precision strike against projected mobile and fixed targets.
- Gun/missile systems to support the development of advanced, lighter weight air/land combat vehicles and tanks, ship and vehicle self-defense systems, and lightweight high-performance gun systems for artillery applications and naval surface fire support missions.
- The capability to detect, identify, and jam RF weapon system sensors and advanced imaging/pseudo-imaging infrared (IR) missile seekers.
- Projecting lethal force precisely against an enemy with minimal friendly casualties and collateral damage.
- Development of adaptive technologies for advanced radar warning/electronic support receivers, processors, and modulation techniques that can respond/reconfigure to a changing RF environment.
- Effective mine detection and neutralization capability to permit movement of forces ashore during amphibious assaults and during movement on land.
- All-weather defense against low-observable cruise missiles, aircraft, and ballistic missiles.
- Disruption or destruction of missiles and projectiles in various phases of flight.
- Disruption or destruction of adversary communications and information systems.
- Control of space.
- Suppression of enemy air defenses.
- Undersea superiority through highly lethal underwater attack and defense capabilities against ASW/ASUW platforms at long range, in shallow water with weapons, counterweapons, and countermeasures with increased speed, reduced weight, and lower acoustic signature.
- Real-time integration of "on-platform" sensor information with off-platform theater/battlespace information to yield situation assessment, threat geolocation, and decision aides to combat identification, targeting, and damage assessment objectives.
- The denial, degradation, and deception of enemy command, control, and navigation functions.
- The use of nonlethal technologies for a variety of missions.

Weapons technologies have transition potential to a wide variety of weapons system and platforms; Table X–1 illustrates some of these opportunities.

Table X–1. Weapons Technology Transition Opportunities

Subarea	Current Baseline	5 Years	10 Years	15 Years
CONVENTIONAL WEAPONS SUBAREAS				
Countermine/ Mines	AN/PSS–12	IVMMD, ASTAMIDS	HSTAMIDS, STAMIDS	Mine Hunter Killer, AMDS, LAMIDS
	MICLIC	JAMC, SASMB	ESMB, ORSMC	
	None	WAM	IMF/Area Denial	
	Radiant Clear	NAVOCEANO WSC	ONI (SABRE), CINC JIC	
	SQQ–32/ASQ–14; RMOP Magic Lantern (DC)	SQQ–32/AQS–20 improvement; ALMDS (improved rapid recon); RMS V4; LMRS; rapid airborne surf zone minefield recon	RMS P1, RMS P2	Multispectral airborne sea mine recon system; multiplatform clandestine recon
	SLQ–48 (1-on-1 Sea Mine Neutralization System); ML58 line charge	RAMICS; DET/SABRE; high-speed magnetic & acoustic influence sweep source components; extended standoff surf zone breaching	Extended standoff DET/SABRE; Magic Carpet/Thunder Road; obstacle breaching; in-stride, distributed neutralization of VSW/surf zone mines	Focused shock wave breaching system; combined mine & obstacle clearance of the surf zone & beach zone
	Quickstrike sea mine conversion kits for MK80-series GP bombs; MK65 Quickstrike sea mine; SLMM; Captor antisubmarine sea mine	Sea Mine IFF; remote control; SLMM improvement; littoral sea mine	Armed surveillance network	
Guidance and	SFW	JDAM		
Control	AIM–9	AIM–9X—IIR seeker		Dual-range missile
	AMRAAM	LADAR	LOCAAS & FOG IMU	JASSM
	TOW	FMTI—IIR seeker & FOG IMU	FOTT	
	Hydra 70	LCPK—strapdown laser seeker, scatterrider guidance	Guided 2.75" rocket	
	MLRS Free Rocket	GMLRS—GPS/IMU	Guided extended-range MLRS	
	Stinger	Small-diameter, antiair seeker	Stinger Blk II	

Table X–1. Weapons Technology Transition Opportunities (continued)

Subarea	Current Baseline	5 Years	10 Years	15 Years
Guns	M16 rifle; M16/M203 systems	OICW	OCSW	OPW/OSW
	BFVS & LAV armament	AC–130 gunship upgrades	BFVS; LAV & Apache armaments upgrades	AAAV upgrades; JSF armament
	Apache armament; AC–130 gun ship; F–16 armament	FSCS armament	FIV armament	
	Paladin 30-km range and rate-of-fire 120mm mortar range	120mm mortar range and effectiveness improvement	Crusader 40-km range and extended rate-of-fire	Extended 50-km range
	Abrams gun/ammo	Abrams ammo upgrades	XM291 with ETC	FCS armament
	M16A2 rifle; M203 grenade launcher; 12-gauge shotguns	OOTW static HPM/DE devices; blunt-impact munitions; EMT pulse vehicle stopper	OOTW mobile DE devices	OOTW DE devices for purposes other than delay/denial
Missiles	EFOGM	MAT	MAT–D	Future precision strike weapon
	Hydra 70	LCPK	Guided 2.75" rocket	
	TOW/Longbow/ Atlas	FMTI	FOTT	
	LOSAT	CKEM	LOSAT P^3I	
	Tomahawk		Fast Hawk (low-cost missile)	Future precision strike weapon
	Maverick	JASSM		
	SLAM; Harpoon	Slamer	Survivable airframe	
	HARM		Adv SEAD	
	AMRAAM/AIM-9	AMRAAM/AIM–9X	ASMT	
Propulsion	MLRS/ATACMS	DRE	Air-breathing prop	
	AMRAAM/AIM-9	AMRAAM/AIM–9X	Air-breathing prop	
	BAT		Powered LOCASS	
	TOW	FMTI Prop	FOTT smart prop	
Launchers/ Airframe	MLRS M270; vertical launch system	HIMARS; concentric canister launcher	M270 lightweight launcher	Arsenal ship

Table X–1. Weapons Technology Transition Opportunities (continued)

Subarea	Current Baseline	5 Years	10 Years	15 Years
Ordnance	BLU–109/BLU–113	ICBM with kinetic penetrator	ICBM with explosive-loaded penetrator	Multiple penetrators in an ICBM
Missiles	Patriot, AMRAAM	Patriot upgrade PROTEC; adaptable warhead	Programmable integrated ordnance suite, AMRAAM P^3I antimateriel submunition warhead	Dual-range missile guidance integrated fuzing
Hard-Target Penetration	BLU–109, BLU–113; GBU–24, –27; AGM–130	Hard-target smart fuze	Adv unitary penetrator miniature munition, conv penetrator for ICBMs, JAST 1000	Multievent fuze Boosted penetrator
Bombs	MK–83, –84	Enhanced MK–83	Enhanced 1,000-lb GP bomb	Multipurpose bomb
	Joint programmable fuze	Explosive, JDAM	JASSM	Antijam proximity fuze
Undersea Weapons	Bulk and shaped-charge warhead: MK50 MK48	Enhanced bubble energy MK50 MK48	Hybrid MEMS S&A; all undersea weapons	Explosive-driven magnetic flux shaped charge
	Torpedo planar acoustic array	Broadband sonar MK50 ADCAP	Conformal hull array: LHT UUV	Biodynamic, broad-band signal process: LHT ADCAP MK50
	Noise CMs: ADC MK2	Automatic torpedo, attack tracker	Antitorpedo	ATT threat salvo capability; smart, adaptive CMs; LHT/ATT
Weapons Lethality/ Vulnerability	Largely empirical; experimental data intensive (costly)	Semi-empirical standardized methodologies and data	Largely physics-based low requirement for experiments	Fully automated real-time connectivity with DIS
DIRECTED-ENERGY WEAPONS SUBAREAS				
Laser	Chemical laser and beam control	Beam control ATD; ABL demo; SBL ground demo; IRCM laser demo	Operational GBL ASAT; operational ABL/SBL demo	Operational SBL constellation
	Semiconductor laser		Conformal laser array demo	FotoFighter aircraft
	Free electron laser	1-kW demo		
High-Power Microwave	Wideband HPM	IRCM HPM demo; C^2W/IW ATD	Operational IRCM	Operational C^2W/IW system
	Narrowband HPM	Explosively powered device demo	Active denial system; SEAD demo	Operational SEAD system

Table X–1. Weapons Technology Transition Opportunities (continued)

Subarea	Current Baseline	5 Years	10 Years	15 Years
ELECTRONIC WARFARE SUBAREAS				
Threat Warning RF	All Operational ALR–XX	ALR–XX improvements		JSF
	SLQ–32		AIEWS	
	SEI test units	P3; CID	ALR–XX improvements	Weapon embedded SEI; JSF
Situation Assessment	JMCIS; CEC	IEWCS; SIRFC; SOF platforms	Tactical platforms (F–15/ –16/–18/–22); strategic platforms (B–1B, JSTARS, AWACS); Apache/ Commanche	JSF; CEC upgrades
EO/IR	AVR–2; AAR–44; AAR–47; AAR–54	Common MWS; F–22 LBRM Warning System	2-color staring array; LBRM Warning System	JSF-IR Distributed Aperture Warning System
Self-Protection RF	All Operational ALQ–YY	On-board ECM upgrade ATD	IDECM; SIRFC; B–1B DSUP; ALQ–YY improvements	JSF; SIRFC improvements
	SLQ–32	Advanced ECM Transmitter ATD	AIEWS	Integr AIEWS/DEW Laser Weapon
	POET; Gen-X & Chaff	ALE–50, ALE–47		
	Nulka; SRBOC	Eager ATD		TMET decoy
EO/IR	ATIRCM	SOF DIRCM; SIIRCM	Large Tactical Aircraft; Laser IRCM	SIIRCM; Improved LGW CM
				Large Tactical Aircraft; Laser EO/IRCM
	ASTE Tier I; MJU–27A/B	ASTE Tier II; BOL IR; MJU-27 upgrade	I^2R CM; Flares/ Multispectral CM; Cooperative IRCM	
Mission Support C^2W	Classified platforms (AF only)	IEWCS	Orion	
	TSQ–138; TLQ–17A; TLQ–33	ALQ–99 improvement; ICAP III		
RF	EF–111A/EA–6B	ALQ–99 improvement; ICAP III	Tactical Jamming Pod	Tactical Jamming UAV

1.4 Support for Combating Terrorism

Weapons research and development activities are producing many new technological capabilities that can ultimately be used to help counter the growing terrorism threat to the United States and our allies. Technologies that can contribute to combating terrorism include advanced sensors and signal processing techniques including biological sensors, data fusion, autonomous robotic systems, multispectral imaging, directed-energy devices, simulation and modeling techniques, high-speed signal and image processing, automatic target recognition, tunable munitions that can produce variable-level target effects, low-cost precision munitions and miniature munitions that minimize collateral damage, aimable or adaptable warheads, guidance-integrated fuzing, enhanced penetration weapons, hard target fuzes, molecule development and explosive formulation for higher energy density and less sensitive explosives, techniques for reliably predicting target damage, and potential collateral effects and performance/utility of munitions and ordnance resulting in survivability/lethality improvements to material and personnel.

Directed-energy weapons (DEW) technology contributes to the counterterrorism effort through the aircraft self-protect DTOs (WE.19.08 and WE.42.08 for high-power microwave (HPM) and laser weapons technology, respectively) and the IRCM laser technology DTO (WE.43.08), all of which offer potential means to defeat shoulder-launched IR-guided missiles that may threaten U.S. and Allied large aircraft, both commercial and military. In addition, HPM technology developed for C^2W/IW applications (DTO WE.22.09) can be used to defeat terrorist electronic systems, including communications hardware. There are also projects within the laser and HPM supporting technology efforts that are applicable to detection and neutralization of a variety of potential terrorist threats. Hardening technology developed under the HPM supporting technology efforts will help protect U.S. electronic systems from attack by terrorist C^2W/IW systems.

The area of electronic warfare, by its very nature, is aimed at the real-time protection of the warfighter and associated combatant platforms from known/anticipated adversarial threats, in a given theater of world conflict (reference the definition of "Electronic Combat" in Chapter 4, Section H of the JWSTP). By contrast, the terrorist threat can be depicted in general terms as one using an unpredictable method of destruction, at an unpredictable location, and at an unpredictable time. As such conventional EW methods and technologies are applicable only if allowed sufficient intelligence, surveillance, and terrorist "trend" information. Aspects of offensive command and control warfare (C^2W) in the EW subarea of mission support can contribute to developing a counterterrorism (CT) capability by adapting the C^2W developments in the electronic support (ES) and electronic attack (EA) of modern communications networks that terrorist organizations may use. CT benefits could be realized in terms of these C^2W contributions to intelligence, surveillance, and reconnaissance (ISR) of the terrorist threat and in the disruption of his command and control structure/cycle.

Finally, ongoing landmine countermeasures research efforts offer a variety of solutions to the terrorist use of the mine threat. The Vehicle Mounted Mine Detector and Handheld Standoff Mine Detector systems employ infrared and ground-penetrating radar technologies for detecting metallic and nonmetallic antitank mines. Sensor fusion and automatic target recognition are being used to enhance detection speeds and to reduce false alarm rates. The mine hunter/killer, initiated in FY96, is a technology-based effort that will provide forward-looking detection and neutralization of landmines along routes. The Lightweight, Multispectral Airborne Mine Detector program that starts in FY98 will combine multiple sensors, detection algorithms, and processors to display, in real time, the locations of mines. This airborne system will be ideal for the detection of mines along routes long favored by terrorists as a means of interrupting commerce. The DoD Humanitarian Demining program also has an application to combat terrorism through its Mine Awareness Database that provides a description of more than 700 mines in a CD-ROM format to rapidly classify the threat. An effort is also underway to exploit "sniffing" technologies to detect explosive compounds in mines and other explosive devices. Lastly, there is a modeling and simulation effort in distributed interactive simulation (DIS) that may assist in training personnel and developing doctrinal approaches for utilizing promising technologies to combat terrorism.

A number of Weapons DTOs contribute to a counterterrorism thrust:

- WE.12.02—Antijam GPS Flight Test
- WE.17.02—Hammerhead
- WE.19.08—HPM Aircraft Self-Protect Missile Countermeasures
- WE.22.09—High-Power Microwave C^2W/IW Technology
- WE.23.08—Modern Network Command and Control Warfare Technology
- WE.34.02—Objective Crew-Served Weapon Technology Demonstration
- WE.43.08—Advanced Multiband Infrared Countermeasures Laser Source Solution Technology
- WE.48.08—Missile Warning Sensor Technology
- B.15—Antimateriel Warhead Flight Test
- B.18—Low-Cost Precision Kill
- B.19—Cruise Missile Real-Time Retargeting
- B.21—Miniaturized Munition Technology Guided Flight Tests
- E.04—Non-Lethal Weapons Technical Demonstration
- All 10 Joint Countermine DTOs

These DTOs will mature and demonstrate new technologies that can be used to provide for the early warning and defeat of terrorist attacks on aircraft, ships, and fixed/moving targets and provide effective lethal mechanisms for attacking enclaves being used to harbor terrorists, neutralizing terrorists, or disrupting terrorist operations.

2. DEFENSE TECHNOLOGY OBJECTIVES

CONVENTIONAL WEAPONS

Countermine/Mines

WE.02.07	Land Mines
WE.45.07	Sea Mines
B.14	Intelligent Minefield ATD
G.01	Land Mine Neutralization
G.02	Land Mine Detection
G.04	Joint Countermine ACTD
G.05	Rapid Battlefield Mine Reconnaissance
G.06	Rapid Sea Mine Neutralization
G.07	Autonomous Shallow-Water Influence Sweeping
G.08	In-Stride Amphibious Breaching
G.09	Advanced Mine Reconnaissance/Minehunting Sensors

G.11	Advanced Mine Detection Sensors
G.12	Lightweight Airborne Multispectral Countermine Detection System

Guidance and Control

WE.12.02	Antijam GPS Flight Test
WE.13.02	Counteractive Protection System
WE.17.02	Hammerhead
WE.21.02	Fiber Optic Gyro-Based Navigation Systems
WE.27.02	Concurrently Engineered Ball-Joint Gimbal Imagery Seeker
WE.35.02	Air Superiority Missile Technology
WE.38.02	Highly Responsive Missile Control
WE.51.02	Small Diameter Antiair Infrared Seeker
B.02	Rapid Force Projection Initiative ACTD
B.19	Cruise Missile Real-Time Retargeting ATD
B.21	Miniaturized Munition Technology Guided Flight Tests

Guns

WE.18.02	Direct Fire Lethality
WE.33.02	ETC and EM Armaments for Direct Fire
WE.34.02	Objective Crew-Served Weapon TD
E.04	Non-Lethal Weapons Technical Demonstration

Missiles

WE.07.02	Future Missile Technology Integration Program
WE.25.02	Multimode Airframe Technology Demonstration
WE.39.02	Tactical Missile Propulsion
WE.50.02	Compact Kinetic Energy Missile
B.16	Concentric Canister Launcher ATD
B.17	Low-Cost Missile ATD
B.18	Low-Cost Precision Kill

Ordnance

B.15	Antimateriel Warhead Flight Test

Undersea Weapons

WE.29.02	Antitorpedo Torpedo ATD
WE.32.02	Broadband Torpedo Sonar Demonstration

DIRECTED-ENERGY WEAPONS

Lasers

WE.04.04	Airborne Lasers for Theater Missile Defense
WE.10.08	Ground-Based Laser Antisatellite System
WE.41.04	Multimission Space-Based Laser
WE.42.08	Laser Aircraft Self-Protect Missile Countermeasures

WE.43.08	Advanced Multiband Infrared Countermeasures Laser Source Solution Technology
MD.08.J00	Laser Bioeffects Countermeasures
SP.05.06	Large Precise Structures

High-Power Microwave

WE.19.08	HPM Aircraft Self-Protect Missile Countermeasures
WE.22.09	High-Power Microwave C^2W/IW Technology
CB.15.01	Balanced Electromagnetic Hardening Technology

ELECTRONIC WARFARE

Threat Warning

WE.48.08	Missile Warning Sensor Technology
H.07	Enhanced Situation Awareness Insertion ATD
H.09	Sensor Fusion/Integrated Situation Assessment TD

Self-Protection

WE.40.08	Infrared Decoy Technology
WE.46.08	Coherent RF Countermeasures Technology
WE.47.08	Imaging Infrared Seeker Countermeasures Technology
H.02	Multispectral Countermeasures ATD
H.05	Large Aircraft Infrared Countermeasures ATD
H.06	Advanced Electronic Countermeasures Transmitter ATD
H.08	Onboard Electronic Countermeasures Upgrade ATD

Mission Support

WE.23.08	Modern Network Command and Control Warfare Technology
H.04	Miniature Air-Launched Decoy ACTD

3. TECHNOLOGY DESCRIPTIONS

3.1 Countermine/Mines

3.1.1 *Warfighting Needs*

DoD requires mine and countermine systems to directly support U.S. Armed Forces' full-spectrum dominance. This requires technology solutions that support the capability for assured, rapid surveillance, reconnaissance, detection, and neutralization of mines to enable forced entry by expeditionary forces. The capability includes control of the sea and the ability to conduct amphibious and ground force operational maneuvers against hostile defensive forces employing sea, littoral, and land mines. Evolving technologies for offensive mining address the requirements to detect and track a broad spectrum of threats, inter- and intra-minefield communications, and sensor fusion to enhance mining effectiveness. A significant countermine capability ensures that the requisite tempo, survivability, and control of maneuvering forces is achieved. Application of new technology will provide high-confidence countermine surveillance, reconnaissance, and detection; breaching and neutralization; and battlespace management of joint countermine operations.

3.1.2 *Overview*

The focus of technology efforts to achieve warfighting needs includes sensors, signal processing techniques, data fusion, and autonomous robotics systems.

3.1.2.1 Goals and Timeframes. The goals of the countermine/mines subarea are listed in Table X–2.

3.1.2.2 Major Technical Challenges.

Mining. Major technical challenges for offensive land and sea mines include the development of signal processing, sensor fusion, and explosives techniques to support the detection and tracking of quiet, stealthy targets in high clutter environments as well as the C^3 netting of mines/minefields in real time and without endangering U.S./allied forces.

Countermine. Significant technological challenges exist in countermine surveillance, reconnaissance, and detection. Mines come in a wide variety of designs. This variety, as well as the differences in mine operating environments (sea, surf, beach, land), precludes a single design solution to the detection problem. The challenge is to detect and identify mines and minefields in high background clutter with an acceptable false alarm rate. Differentiation of land, beach zone, and bottom sea mines from clutter in various soil, foliage, and terrain types is difficult. In both maritime and land environments, buried nonmetallic mines are virtually undetectable. Optical, magnetic, and acoustic sensors have limited effectiveness in the high ambient noise of the surf zone. Advanced signal processing, multisensor fusion, and automatic target recognition are some of the technology areas that are addressing detection challenges.

Countermine breaching and neutralization are currently slow, tedious, and often dangerous. The reliable neutralization of mines presents several unique challenges. Improved targeting systems and thorough ballistics/hydro ballistics analysis and testing are needed to make directed fire an effective neutralization tool against subsurface naval mines. A technology breakthrough is required to solve the problem of sweeping pressure influence mines. The problems of surf and beach zone breaching are compounded by the fact that mines and obstacles are often deployed together, and the countermine effectiveness of explosive line charges and arrays is significantly degraded when obstacles increase the standoff between the neutralization charge and the mine. Near-term solutions emphasize brute force approaches for the rapid breaching/neutralization of mines and obstacles. For in-stride breaching operations, improved fire control systems must be developed to permit the firing of breaching charges from inbound amphibious land craft through the breaking surf. Improved breaching charges must be developed to provide a high kill probability against mines buried by surf, wind, and tidal action on the beach and on land. New standoff mines present a technological challenge to land warfare. Systems must be developed for in-stride clearance of these mines from the perimeter of the intended route. Development of standoff neutralization technologies using kinetic energy, focused shockwaves, or other directed-energy applications offer approaches to solving neutralization challenges.

Table X–2. Countermine/Mines Subarea Goals and Timeframes

Applications/Mission	Short Term (1–2 Years)	Mid Term (3–5 Years)	Long Term (6+ Years)
Countermine surveillance, reconnaissance, and detection	Baseline and exploitation of current mapping, survey and intel capabilities/products.	Intermittent surveillance of mining activities.	Continuous, fused all-source I&W of enemy mining activity including mine stockpiles and capabilities.
	7x improvement in VSW clandestine recon (incl buried mines). 6 nmi^2/hr search rate for DW/SW mines.	Rapid recon (80 nmi^2/hr) of surf zone through craft land zone.	Autonomous multiplatform clandestine reconnaissance/kill capability (land & sea).
	Continued development of multiple technologies including data fusion and ATR to enhance detection capability.	Demonstrate forward-looking radar; evaluate potential enhancements for standoff distance and enhance weather capability.	Demonstrate hyperspectral/ multispectral technologies.
	Explore passive IR with active laser, downlooking ground-penetrating radar, and SAR technologies for improved capability to detect/kill mines.	Evaluate hyperspectral and multispectral technologies to enhance airborne and ground detection performance.	Demonstrate acoustic and seismic performance enhancements to ground-based detection systems.
		Investigate acoustic and seismic technologies for ground-based detection.	
		Investigate passive IR/microwave technologies to identify scatter mines.	
Countermine breaching and neutralization	Demonstrate off-route smart mine clearance of neutralized top- and side-attack mines.	Demonstrate an explosive/ kinetic neutralization system in a ground vehicle.	Demonstrate laser DE for mine neutralization. (Will be evaluated for inclusion in an electron beam neutrali-zation system in FY08.)
	Integrate ground-based detection with standoff neutralization technology.	Demonstrate RF technology to detect electronically fuzed mines from standoff distances.	
		Develop a chemical non-explosive means to neutralize mines.	
		Demonstrate enhanced explosives capability.	
	Demonstration in-stride mine clearance of assault lanes (surf zone through beach zone) using explosive line charges and nets fired from sea.	Demonstrate in-stride clearance of near-surface sea mines (to 20-ft depth), using helo-fired high-velocity munitions.	Demonstrate in-stride clearance of mines and obstacles from the surf zone through the craft landing zone using enhanced explosive arrays.

Table X–2. Countermine/Mines Subarea Goals and Timeframes (continued)

Applications/Mission	Short Term (1–2 Years)	Mid Term (3–5 Years)	Long Term (6+ Years)
Countermine breaching and neutralization (cont'd)	Demonstrate rapid sweeping of shallow and VSW influence mines using advanced lightweight sweep systems. Investigate novel techniques for the rapid neutralization of mines and obstacles in breach lanes from the surf zone through the craft landing zone.		Demonstrate directed shock-wave technology applications for neutralizing sea mines.
Countermine battlespace management	Demonstrate end-to-end simulation of all mine warfare operations including the integration of models/simulations into tactical decision aids. Demonstrate enhanced protection of soft-skinned vehicles from blast and fragment effects of AT and AP mines. Improve individual protection materials. Develop means to digitally characterize mined areas. Demonstrate the reduction of large ship magnetic signatures using open-loop degaussing.	Demonstrate distributed interactive simulation capability for tactics development, training, and acquisition tradeoff analyses. Demonstrate blast deflection/energy absorption enhancements for personnel and vehicles. Demonstrate secondary magnetic field reduction on MCM ships.	Continue vehicle design analysis to enhance mine blast protection for soft-skinned vehicles.
Humanitarian demining	Build on congressional Special Interest Program to demonstrate COTS equipment for mine detection and clearance.	Develop training initiatives that address multiple languages, detection of mines from aerial and ground platforms, low-cost neutralization, protective systems for personnel and clearance verification technologies.	Long-term thrusts will be derived from the Countermine Program, the UXO Clearance Program, the EOD/LIC Program, and Special Operations Technology developments.
Explosive ordnance disposal	Demonstrate high-frequency acoustic array for high-resolution images in turbid water. Demonstrate high-velocity linear shaped charge for the disablement of the explosive firing train of a weapon of mass destruction (WMD).	Investigate broadband transmissions to neutralize electronics of electronic safe and armed fuzes. Demonstrate autonomous subsumption robotics for small UXO clearance.	Develop vehicle-mounted laser neutralization system to increase standoff to 250 meters.
Mining	Demonstrate detection/classification and localization of quiet submarines and surface ships at medium water depths (150 to 600 ft).	Demonstrate a remote command/control capability.	Demonstrate feasibility of an intelligent, intercommunication sea minefield network.

Countermine battlespace management offers unique technical challenges. The countermine commander, to be effective, requires fuzed mine warfare intelligence in a timely manner. Currently, for both land and amphibious operations, the electronic dissemination of information regarding suspected minefields, actual mine locations, and cleared routes or areas is often inaccurate and unreliable. Mine warfare environmental sampling, databases, and modeling efforts must contribute to decisions in S&T development of sensors and systems as well as to commander's real-time tactical decision aids (TDAs) in the field. Reduction in the vulnerability of land vehicles, watercraft, and personnel to threat mines is a critical technical challenge involving magnetic signature reduction, blast deflection/absorption, and other mitigation technologies.

Humanitarian Demining. There are a number of promising technologies that can enhance demining capabilities. For *individual mine detection,* the major technical challenge is discriminating land mines from metal debris. Future efforts to improve detection will focus on providing a discrimination capability that includes the fusion of multisensor information and the incorporation of advanced signal processing techniques. In the area of *mine clearance*, cost-effective and efficient clearance techniques will be needed to clear land mines in all types of terrain. For *neutralization*, the challenge is to develop safe, reliable, and effective methods to eliminate the threat of individual mines without moving them—new technologies will be needed to economically and safely neutralize the latest mine threats. For *mine awareness and demining training systems*, the challenge is integration of the latest computer and training technologies, database links, and automated multilingual capabilities into a system that can be shared in an international environment.

Explosive ordnance disposal (EOD) technical challenges include developing low-cost robotic devices and extended standoff ordnance detection to ensure personnel and equipment safety and extending the capability of magnetic and inductance sensors to detect buried unexploded ordnance.

3.1.2.3 Related Federal and Private Sector Efforts. The Army Environmental Center recently completed a range cleanup at the Jefferson Proving Ground. DOE and EPA requirements for test range and dump site remediation have led to the joint DoD/DOE Multisensor Underwater Debris Detection System (MUDDS) project. Sandia National Laboratory is exploring new breaching concepts using foam bridges as well as chemical sensing devices for explosives detection and location. DARPA has been conducting an autonomous mine-hunting and -mapping UUV demonstration and is developing a synthetic aperture sonar for long-range underwater object detection. DARPA has also invested in low-cost robotics technology for use in very shallow water, surf zone, and beach zone mine and obstacle clearance.

3.1.3 *S&T Investment Strategy*

3.1.3.1 Technology Demonstrations. The technology demonstrations in the countermines/mines (conventional weapons) subarea are in land mines (WE.02.07), sea mines (WE.45.07), humanitarian demining, and joint countermine technologies.

Land Mines. The land mine warfare area is being re-evaluated by the Integrated Concept Team of Unmanned Terrain Domination (UTD). The UTD concept is defined as the ability to achieve total situational awareness in an area of operations, to evaluate data received inside that area, to develop courses of action that are consistent with the commander's intent, and then to employ systems and tactics to accomplish the objective. The technologies required to meet the objective are initially being accomplished by the Intelligence Minefield (IMF) Concept. The follow-on technologies will evolve from the IMF and encompass the Area Denial Concept. The overall objectives will be to provide sensors, communication links, and shooter platforms capable of meeting the UTD objectives at extended ranges and against a variety of mounted and dismounted threat targets. Technology will also be used to develop alternatives to antipersonnel land mines (APL) as directed by the Defense Science Board Task Force in response to the Presidential directives on APL. An Advanced Technology Demonstration of an Area Denial Concept is planned.

Joint Countermine. The overall objective is to demonstrate countermine surveillance, reconnaissance, and detection technologies and in-stride neutralization clearance technologies to improve a joint task force's ability to conduct seamless countermine operations from the sea, through the surf/beach zone, to the land objective. Joint countermine includes the following demonstrations that are described in the JWSTP DTOs:

- Mine Hunter Killer (MH/K) ATD—G.01
- Vehicle-Mounted Mine Detector (VMMD) ATD—G.02
- Joint Countermine ACTD–G.04
- Littoral Remote Sensing Demonstration—G.04
- Coastal Battlefield Reconnaissance and Analysis (COBRA) ATD—G.05
- Rapid Airborne Mine Clearance System (RAMICS) ATD—G.06
- Advanced Lightweight Sweep System (ALISS) Technology Demonstration—G.07
- Explosive Neutralization Technology Demonstration—G.08
- Advanced Mine Reconnaissance/Minehunting Technology Demonstration—G.09
- Advanced Mine Detection Sensor (AMDS) Technology Demonstration—G.11
- Lightweight Airborne Multispectral Countermine Detection System (LAMIDS) ATD (proposed)—G.12

Humanitarian Demining. Technology demonstrations are planned in four areas:

- Mine clearance—improved mechanical clearance devices for use in nearly all terrains.
- Individual mine detection—improved hand-held metallic and low metal AP mine detector; improved vehicle-mounted AP mine detector for use on all types of roads.
- Neutralization—new marking system using improved positioning and marking technologies; improved explosive foams; laser applications.
- Mine awareness and demining training—fully automated, multilingual training system.

3.1.3.2 Technology Development. Technology developments support the countermine/mines subareas and address near-, mid-, and long-term military requirements. Major task areas are:

- *Mining*— real-time processing, advanced sensors, remote control, and intermine/intrafield communications multisensing fusion, remote control, real-time communication datalinks, real-time visual target area surveillance (particularly in regards to

APL alternatives), deterrent platforms to include multiple warhead technology, robotic platforms, and delivery systems to cover the required depth of battlefield.

- *Countermine*
  - Surveillance, reconnaissance, and detection—exploitation of NTM sensors, real-time processing, autonomous vehicles/networking/low-cost robotics, advanced sensors (acoustic, magnetic, electro-optic, ground penetration radar, chemical), advanced signal processing, multispectral/hyperspectral imaging, automatic target recognition/computer-aided detection, multisensor fusion, and efficient power generation
  - Breaching and neutralization—robotics, kinetic energy, directed energy (ground-penetrating radar, direct shock waves), energetics, chemical neutralization, and hypervelocity projectiles
  - Battlespace management—distributed interactive simulation and magnetic signature suppression
  - EOD—detection sensors, energetics, robotics, diver equipment design, and vulnerability mitigation.
- *Humanitarian demining*—the demining program uses expertise from government, industry, academia, foreign countries, the United Nations, and nongovernmental organizations to produce practical solutions to locate minefields (or confirm their absence); detect individual mines; clear and destroy a large number of mines rapidly and safely; enhance the safety of deminers; and provide tools to facilitate mine awareness and deminer training. Current and planned projects are:
  - Minefield detection and marking
    - Mast-mounted QA sensors to locate minefields and mine-free terrain
    - Utility of ASTAMIDS in demining role
    - Bio-sensors and vapor collectors to confirm presence/absence of explosives
  - Individual mine detection
    - IR/GPR/pulsed induction mine detector
    - Mini mine detector
    - Hand-held trip wire detector
    - Ground-based QA system
    - Vehicle-mounted mine detector
    - Sensor imaging
    - Canines
  - Mine clearance
    - Remote-controlled ordnance disposal system
    - Mine-clearing plow
    - Confined area blade
    - Towed heavy roller

    - Light tine roller
    - Berm processing assembly
    - Enhanced mine rake
    - Improved mini flail platforms
    - Heavy grapnels

- Neutralization

    - Explosive foam dispensed from vehicles or personnel backpacks
    - Chemical neutralization
    - Mine marking and neutralization system
    - Shaped charges
    - Explosive demining device

- Individual tools

    - Extended length weed eater
    - Extended length probe with acoustic verification system
    - Vehicle protection kit
    - Demining kit (cart and backpack)
    - Mine locating marker
    - Blast and fragment container

- Mine awareness and demining training: expanded development of multimedia, multilingual, mobile training system.

3.1.3.3 Basic Research. Basic research contributing to the countermines/mines subarea includes (inter alia) ocean optics, coastal sciences, coastal meteorology, coastal mixing, ocean acoustics, coastal benthic boundary layer, high-frequency scattering, autonomous ocean sampling, sediment transport/dynamics, high-temperature superconducting ceramics, signal analysis, image representation, perceptual science, energetics, solid mechanics, virtual environments, laser and electro-optics, remote sensing, computational neural science, electromagnetic sensors, magnetic sensors, acoustic sensors, chemical sensors and stimulants, sensor fusion and signal processing, multispectral/hyperspectral, kinetic and directed energy, and infrared.

3.2 Guidance and Control

3.2.1 *Warfighting Needs*

Future warfighting will require more affordable precision-guided weapons that are smaller, lighter, and significantly more effective than current systems. This requires guidance and control (G&C) that supports a three-to-one reduction in the number of PGMs required to defeat high-priority targets including time-critical mobile targets (e.g., TELs). As an example, the guided MLRS will reduce the number of rockets needed to defeat targets by at least a factor of 8 over existing systems, depending on target type and range, and result in a cost per kill reduced by a factor of 5. A decrease in false target acquisition and track over currently fielded systems will reduce both weapons launched per target and the number of sorties required to destroy a given target thereby reducing aircraft losses. G&C also supports high guidance accuracy (precise guidance) that will significantly reduce collateral damage by allowing use of smaller warheads. Future seekers will provide all-weather, completely autonomous operation, with increased standoff ranges against a broad target set in a very hostile, low-observable environment and with reduced incidents of fratricide. Potential transitions include MLRS, FOTT, JDAM, AMRAAM, AIM–9X, LHT/ATT, guided 2.75" rocket, and Stinger.

3.2.2 *Overview*

The focus of technology efforts to satisfy warfighting needs includes image/signal processing; modeling, test, and simulation; guidance components; and radiation guidance.

3.2.2.1 Goals and Timeframes. The investment strategy being followed is to improve the effectiveness of weapon G&C systems so that fewer weapons are needed per target. This reduces the overall cost of expending such weapons in combat and supports a parsimonious acquisition philosophy. We focus on affordability by emphasizing simulation to reduce R&D costs and to improve training and readiness; by linking G&C component development with manufacturing S&T; by utilizing commercial products when feasible; by increasing emphasis on hardware and software co-design; and by identifying critical shelf-life issues early in the acquisition cycle. The goals are listed in Table X–3.

3.2.2.2 Major Technical Challenges. Guidance and control challenges include design and manufacture of low-cost, high-performance G&C components; multimode/multispectral seekers; high-speed signal and image processing; reliable aimpoint selection; jam-resistant datalinks; and miniaturization and hardening of inertial measurement units (IMUs). Additional challenges include:

- Multispectral missile seekers to improve effectiveness in the presence of countermeasures.
- Precision guidance of small-diameter weapons.
- Enhanced air defense target acquisition including masked targets to increase survivability.
- Autonomous target acquisition to reduce collateral damage and fratricide.

3.2.2.3 Related Federal and Private Sector Efforts. Advances in computer technology have greatly aided G&C. Automotive interests in inertial sensors help tremendously in cost reduction. There are many SBIR tasks that support G&C efforts. Much of the service- and industry-developed G&C control technology is distributed through the Guidance and Control Information and Analysis Center (GACIAC). Significant industry IR&D is performed in this area.

3.2.3 *S&T Investment Strategy*

The investment strategy is to improve effectiveness of G&C systems so that fewer weapons are needed per target. Improved munition effectiveness will reduce required sortie rates and therefore launch platform (strike aircraft) attrition. Individual component cost is reduced as the various technologies evolve.

Table X–3. Guidance and Control Subarea Goals and Timeframes

Application/Mission	Short Term (1–2 Years)	Mid Term (3–5 Years)	Long Term (6+ Years)
Fire support	Demo advanced imaging autotracker algorithms that meet the require-ments of FMTI. Demo long-range, fiber-optic-guided (FOG) missile capable of ranges greater than 40 km. Complete guided flight test of semirigid wing platform.	Demo low-cost, ruggedized, miniature inertial compon-ents for use in missile guidance, position location, navigation, and fire control. Develop next generation of laser diode HWIL scene projectors. Conduct RFPI ACTD culminating with large-scale field exercises. Demo long-range fiber optic dispenser with improved pack stability over military environment.	
Air defense	Demo sensor suite for air defense missile target acquisition. Complete LADAR scatter field test. Demo low-cost, ruggedized pigtailing approach for lithium-niobate-integrated optic wave guides. Demo multirole survivability radar in midcourse missile flight test.	Complete DIAL remote spectroscopy of targets. Demo capability to perform NCTR of air targets with special algorithms using air defense radar. Demo advanced datalink technology capability including data compression, spread spectrum, and CM techniques for secure missile C^2. Develop integrated circuitry for use in HWIL simulation of RF guided missiles. Demo FMTI technology in flight test. Upgrade to Stinger through integration with IIR seeker.	FMTI Phase II ATD complete with 8–10 missile flights and soldier testing in realistic scenarios.
Close combat	Demo north alignment to within 5–10 mrad in under 3 min at a production cost of <$5,000. Complete simulations and obtain accuracy assessment for alternative strap-down guidance concepts. Demo a G&C technique for precision air delivery systems. Demo a minimum-volume electronic controller for electro-mechanical actuators.	Develop the hardware and software for an imaging seeker that can auto acquire and select the impact point on a target. Demo advanced terminal homing auto-tracker in minimum-sized, low-power package. Demo an unmanned autonomous ground vehicle navigation and target detection capability.	Low-cost precision kill guided 2.75" rocket flight and user test.

Table X–3. Guidance and Control Subarea Goals and Timeframes (continued)

Application/Mission	Short Term (1–2 Years)	Mid Term (3–5 Years)	Long Term (6+ Years)
Develop inexpensive electronically scanned array hardware for missile seekers	Demo tracking ability with small number (10–15) of transmit/receive units made with conventional hardware and mounted on conical surface of radome for 13-in missile.		
Develop signal processor to rapidly identify selected target in air defense site and select aimpoint		Develop a signal processor with neural net algorithms to guide to a selected target from any attack aspect in JSOW size weapon.	
Develop gimbal-less 94-GHz seeker tracker concept for SEAD applications		Develop 94-GHz gimbal-less seeker that tracks at least 30 deg off boresite.	Frequency-adaptive antenna system with no moving parts.
Develop high frame-to-frame image compression for application to bomb damage indication via imager data linked to damage assessor	Demo 300:1 image compression dynamically at 30-Hz or higher frame rate.	Demo 1000:1 image compression at 100-Hz frame rate.	
Defeat fixed high-value targets	Develop antijam GPS guidance system. Low-cost ($3–5k) increment for substantial antijam performance. Demo small, low-cost FOG IMU for tactical applica-tions. Cost goal is $6k for 25 in³ IMU with <1 deg/hr drift rate.	Demo AJ GPS/INS guidance on JDAM-type flight vehicle in heavy jamming environ-ment. Maintain current GPS/INS accuracies. Develop and demo very low cost (<$2k) micro-machined IMUs with tactical (1–10 deg/hr) drift rate.	Develop and demo intelli-gent GPS/INS guidance system. Increase perform-ance against multiple (more than 3) high-power jammers. Develop multiple sensor using MEMS tech to provide tactical grade performance for <$1 k/IMU.
Demo all-weather seeker	Demo basic SAR seeker design that will integrate with a GBU-15.	Free-flt test 3 GBU–15s configured with SAR seekers to demo integrated munition performance.	Demo advanced short-response mission planning, real-time targeting, and reduced seeker cost.
Develop and demon-strate precision LADAR seekers	Develop LADAR seeker designs utilizing currently available technology.	Build and captive flt test advanced tech LADAR seeker designs for Small Smart Bomb and for Warrior.	Utilizing further LADAR tech developments, build and evaluate advanced tech LADAR seeker for the Dual-Range Missile.
Demo all-weather accurate guidance small warhead (SSB)	Demo SSB w/INS GPS	Demo SSB with terminal seeker	

3.2.3.1 Technology Demonstrations. The following technology demonstrations include those supporting the DTOs:

- Future Missile Technology Integration (WE.07.02)
- Air Superiority Missile Technology (ASMT) (WE.35.02)
- Antijam GPS Flight Test (WE.12.02).
- Fiber Optic Gyro-Based Navigation Systems (WE.21.02).
- Hammerhead (WE.17.02).
- Concurrently Engineered Ball-Joint Gimbal Imagery Seeker (WE.27.02).
- Counteractive Protection System (WE.13.02).
- Highly Responsive Missile Control (WE.38.02)
- Small Diameter Antiair Infrared Seeker (WE.51.02)
- Miniaturized Munition Technology Guided Flight Tests (B.21)
- Cruise Missile Real-Time Retargeting ATD (B.19)

The following additional demonstrations are planned:

- EFOGM ATD, to demonstrate a fiber optic guided missile system capable of multipurpose precision kill to 15-km range, high survivability through standby and defilade launch, and day/night/adverse-weather operation. Deliveries of systems will begin in 1998 in support of the RFPI ACTD.
- Guided MLRS ATD, to demonstrate significant (20x) accuracy improvement of the MLRS extended-range free rocket by addition of a low-cost G&C system. Flight tests will be conducted in 1997–98 in support of the RFPI ACTD.
- Precision-Guided Mortar Munition ATD, to demonstrate a precision-guided (2 mils) mortar concept using advanced G&C technology and integrated man-portable fire control to ranges in excess of 15 km in 1997 as part of RFPI ACTD.
- Rapid Force Projection Initiative ACTD, to demonstrate automated target transfer from forward sensors to air-transportable standoff killers with the capability to engage armor and other high-value targets beyond traditional direct fire ranges. A major system field exercise using Army light forces will occur in FY98.
- Strike Weapons Adaptable Video and Data, a next-generation, podless video and datalink system for weapons control. The improved weapon control performance, real-time BDA, and real-time targeting capability accruing from this technology development will reduce cost per kill through greater first-pass success, lower strike aircraft vulnerability, and fewer assets.

3.2.3.2 Technology Development. Technology development efforts, supporting demonstrations described above, address longer term military applications. Major task areas are:

- *Image and signal processing,* which includes collecting and analyzing large amounts of data, correlation techniques, and algorithms for acquiring and classifying and identifying targets.

- *Software and simulation,* which includes imbedded software development and simulation of guided systems and synthetic scene generation, scene projectors, digital simulation, and hardware-in-the-loop simulations.
- *Radiation Guidance,* which includes acoustic, RF, MMW, LADAR, passive IR seekers, multimode seekers, and datalinks.
- *Guidance, navigation, and control components,* which includes inertial sensors and GPS components, radomes, actuators, and unique structural elements.

3.2.3.3 Basic Research. Basic research supports all four G&C technology subareas. In signal/image processing, research is conducted to support algorithm development (e.g., wavelets, image algebra, model-based vision, superresolution, optical correlation filters), processing platforms (silicon architectures, optical correlators, analog and digital platforms), and processing systems approaches through *biomimetics*. Research is underway to understand the sensor fusion problem for multimode, multispectral seekers. In software and simulation, research is conducted to support advanced guidance laws, state vector estimators, autopilots, and INS/AJGPS systems; to continue development of synthetic target/background scene generation capability; to validate existing codes with measured data for all sensors of interest; and to evaluate signal/image processing algorithms. Scene projection technology is continuing development to enable realistic hardware-in-the-loop simulations for guided munitions equipped with passive IIR, dual-mode (current emphasis on passive IIR and MMW), and LADAR seekers. Closed-loop guidance and control coupled with advanced image/signal processing will enable development of autonomous munitions as *intelligent systems*. Radiation guidance research supports understanding target/background signature phenomenology, weather effects, and countermeasure effects on various seeker types (e.g., polarization signatures, passive MMW phenomenology, the various subsystems required to support eye-safe LADAR, conformal electronically steered (RF) arrays). In the guidance component area, hardware and software approaches to the antijam GPS problems are being investigated, and research supporting higher performance, more affordable IFOG, and micromechanical inertial systems (*nanosystems*) is being conducted.

3.3 Guns

3.3.1 *Warfighting Needs*

DoD requires capabilities of improved range, penetration, and combat effectiveness of guns at lower total acquisition cost over existing systems. The Objective Individual Combat Weapon (OICW) will replace current M16 rifles, M203 grenade launchers, night vision devices, and laser rangefinders with a single integrated system with enhanced operational capability and increased effectiveness. The OICW will deliver 3–4 times the hit probability of existing systems beyond 500 m and an all-new defilade target attack capability out to 300 m. The Objective Crew-Served Weapon (OCSW) will provide a lightweight, two-man portable, single replacement weapon systems for a current 40mm MK 19 grenade machine gun and the caliber .50 heavy machine gun. Fielding of the XM982 extended-range artillery projectile will immediately enhance the range of existing 155mm artillery and extend the range of the developmental XM297 Crusader solid-propellant cannon up to 50 km. An ETC version of the 120mm XM291 tank gun will provide 17-MJ muzzle energy and increase armor penetration over the currently fielded 120mm

M256 system. Nonconventional weapons technologies will provide the field commander with a capability to tailor target effects from less-than-lethal to lethal for small caliber weapons against lightly armored materiel and personnel. Energetic materials that are 10% more powerful, yet less sensitive, will enhance explosively formed penetrator kill capability. Selective-mode warheads will be demonstrated that can defeat both a heavy armored target (10–20% increase in performance compared to Javelin) and a lightly armored target (fourfold increase in lethality as compared to a standard shaped charge). Potential transitions include STAFF and upgrades for AAAV, BFVS, CIWS, Abrams, Paladin, Crusader, and Patriot.

3.3.2 *Overview*

3.3.2.1 Goals and Timeframes. The goals are to develop technologies for small, medium, and large caliber guns, gun propellants, power supplies/conditioning, and fire control, with enhanced performance and compact, lightweight configurations at affordable costs. The major goals are shown in Table X–4.

3.3.2.2 Major Technical Challenges. Challenges in the guns subarea include packaging constraints for ETC technologies that provide compact, high-efficient plasma ignitors; new high-energy-density/propellant formulation, consistent repeat rate, and desirable life cycles of pulse-forming network; advanced medium-caliber composite barrel with high-efficiency rail design, compact, and affordable pulse and prime power system and ammunition handling technologies for high rate of fire; accurate laser ranging, efficient fragmentation, and systems and weight minimization for OICW; and efficient fragmentation, electronics miniaturization (for fire control and fuze), systems integration, and overall system weight for OCSW. Challenges for ERA/XM982 include the multifunctional electronic fuzing module, base burner, forward rocket motor, and cargo expulsion. Challenges for EM guns include high-strength, thick-section composites, high-current density, fast-actuating and -recovering solid-state switches, high-efficiency launchers, thermal management, and reduced mass armatures. Challenges for nonlethal technology are wave propagation and antenna design for acoustics, and component size and wave propagation/generation for DE devices.

There are several industry R&D coalition concerns:

- Detailed, validated, interior ballistics models support the 50% muzzle energy increase claimed. The 10% armor penetration increase is predicted by similarly validated terminal ballistics models. Note that the 50% muzzle energy increase (to 17 MJ) equals the muzzle energy of the 120mm penetrator that has simulated armor in field tests.
- Study has reconfirmed the value of electric gun development, and additional technology demonstrations can be accomplished at relatively low cost.
- The uniform ignition of disk propellant is a critical mechanism of the solid-propellant electrothermal-chemical (ETC) program. An equally important mechanism is temperature compensation (achievable by ETC only). ETC will force cold propellant charges to perform as hot charges, thereby achieving peak pressures near the limits of the gun. A concept under investigation would give "always hot" performance at a fraction of the electric input of current, plasma-injector methods. This

Table X–4. Guns Subarea Goals and Timeframes

Application/Mission	Short Term (1–2 Years)	Mid Term (3–5 Years)	Long Term (6+ Years)
Objective individual and crew-served weapons	Demo OICW system prototype, 12 lb, Ph = 0.5 @500 m, 0.3 @ 1,000 m; probability of incapacitation 0.2 against defilade target at 300 m.	Demo OCSW prototype weighing less than 38 lb that can defeat defilade targets and 51mm RHA.	Demo OICW and OCSW in Battle Lab experiments.
Tank lethality enhancements	Demo 120mm KE cartridge defeat of 2005 ERA projected threat with 50% increase in lethality over the M829A2.	Demo 30% increase in system accuracy under stationary conditions over M829A2/M1A2. Demo 300% increase in hit probability at 3 km over M1A2 under dynamic conditions.	
Nonlethal weapons for operations in a full-spectrum conflict (e.g., crowd control)	Demo nonpenetrating AP blunt impact munitions launched from platforms (M16A2, 40mm M203GL, 12-gauge shotguns, etc.) for both point target and crowds at 10–50-m range. Demo DE device over delay/denial.	Demo an EM pulse vehicle stopper. Complete acoustic device health and safety assessment.	Demo advanced nonlethal concepts. Demo mobile DE device.
Direct-fire lethality, range, system performance enhancement alternatives for future combat vehicles	Demo medium-caliber EM gun technologies for amphibious land vehicles with 0.3-MJ muzzle energy, 3-salvo, 5 rd/salvo, 300 rd/min and penetration effectiveness at 1,000 m.	Demo prototype medium-caliber EM gun system concepts for potential future insertion opportunities. Demo medium caliber bursting munition.	
Improve indirect fire capabilities for artillery and mortars	Demo extended-range artillery projectile (ERA/ XM982) capable of immediately enhancing the range of existing 155mm weapons and extending the range of the developmental 155mm howitzer system to 50 km.	Demo 155mm lightweight automatic howitzer with 25% more rapid emplacement and 50% higher rate of fire. Demo precision-guided mortar munition with first round point/armor target effectiveness at 15 km.	
System performance enhancement for Abrams PIPs and the FCS	Demo 14-MJ muzzle energy in 120mm M256. Demo 1.5 J/g specific energy in pulsed-power system.	Demo 17-MJ kinetic energy at muzzle in 120mm XM291. Demo hypervelocity launchers with 100-rd life.	Transition ETC or EM technology for PIPs or FCS applications.
System performance enhancement for naval surface combatants	Demo medium-caliber resin/carbon fiber composite barrels with 50% increased MTBF for future naval gun system.	Demo ETC technologies capable of 22-MJ muzzle energies with a 5-in gun system.	Transition ETC technologies for PIP or naval surface combatants.

would further reduce the volume and mass of the pulse power supply. Another component of ETC is the reduction in ignition delay and predictability of the delay. Both have been demonstrated in scaled experiments with single initiators. The experiments must be demonstrated at full scale and with multiple injectors, if they are needed in the final design.

- The cannon caliber EM gun demonstration referred to is indeed a demonstration. The prototype system has already been built. The critical components (pulse power supply, launcher, and integrated launch package) have been independently demonstrated at near their design performance points. The complete end-to-end system remains to be demonstrated.

3.3.2.3 Related Federal and Private Sector Efforts. Commercial advances in metallurgy, energetic materials, power supply and conditioning, aerodynamics, advances in composite materials (needed for rotating machine pulse power supplies), computational mechanics, and related technologies support gun technology efforts. These efforts are closely integrated with all DoD in-house efforts.

3.3.3 *S&T Investment Strategy*

3.3.3.1 Technology Demonstrations. Gun technology demonstrations include the following in support of DTOs:

- Direct Fire Lethality (WE.18.02)
- ETC and EM Armaments for Direct Fire (WE.33.02)
- Objective Crew-Served Weapon TD (WE.34.02)
- Lightweight Automated 155mm Howitzer. Demonstrate technologies as part of the killers in the RFPI ACTD
- Non-Lethal Weapons Technical Demonstration (E.04)

Additional technology demonstrations include:

- Cannon Caliber EM Gun, to demonstrate a prototype medium-caliber EM launcher system to defeat light armor or hard targets at 1,000-m ranges using existing prototype subsystem hardware.
- Army/DNA Joint Program, to demonstrate 140mm lethality from a 120mm ETC system (XM291 cannon and pulsed power) in a configuration compatible with the M1A2.
- Navy/DNA Joint Program for Future Naval Surface Combatants, to demonstrate ETC technologies capable of 22-MJ energies with a 5-inch gun system.

3.3.3.2 Technology Development. Technology development efforts support demonstrations described above; they lay the foundation for demonstration and address longer term military applications. Major task areas are:

- Small caliber systems to develop technologies for future individual and crew-served small arms weapon/munitions systems yielding enhanced effectiveness and sustainability.
- Medium caliber systems to provide "modified NDI" technology options, with concept analysis and component/subsystem experiments in the areas of reduced dispersion guns, enhanced bursting and KE ammunition, turret stabilization, and associated fire control for near-/mid-term platform programs.
- Large caliber systems to develop guided mortar munitions, extended-range and extended-accuracy artillery projectiles, ETC and EM tank guns, low-cost munitions, and increased smart submunitions.
- Future generic gun technologies to provide variable-level target effects and weapons-related technologies that are caliber independent.

3.3.3.3 Basic Research. Research in mathematics, chemistry, physics, computer science, materials science, electronics, and mechanics all support critical technology requirements for future armament systems. Focused research in the penetration physics of hypervelocity projectiles and research in high-energy density power supplies support future electric gun requirements. These basic research studies provide an essential foundation for the gun system technology required to defeat future threats and ensure that our forces can maintain a technological edge.

3.4 Missiles

The missile subarea includes technology efforts in flight mechanics, propulsion, missile airframe, launchers and launch mechanisms, and missile component integration technical demonstrations.

3.4.1 *Warfighting Needs*

The warfighter requires increased aircraft loadouts to improve mission/sortie effectiveness. A threefold increase in the number of individually targeted weapons by FY05 meets the requirements for multiple kills per pass and increases the weapon effectiveness against area targets. A twofold increase in weapon standoff distances by FY05 meets the requirement for increased aircraft survivability. Finally, a reduction in time-to-target to less than 5 minutes meets the FY10 requirement to defeat time-critical targets.

The warfighter also requires lighter, smaller, more affordable weapons with increased performance. Airframes must be lighter and have reduced radar cross section. Propulsion units must provide increased agility, delivered energy, and mass fraction while reducing sensitivity to unplanned hazard stimuli. Technology advances in divert propulsion systems will be available to demonstrate a reduction in the number of theater missile defense systems to cover a given area by 26% (FY00) and 60% (FY10). Potential transitions include Army and Navy tactical missions, Air Combat Command, and several space missions within Air Force Space Command.

3.4.2 *Overview*

The focus of technology efforts to satisfy warfighter needs includes ramjets; ducted, solid, liquid, and hybrid rockets; and launchers and airframes.

3.4.2.1 Goals and Timeframes. The goals of the missiles subarea are listed in Table X–5.

Table X–5. Missiles Subarea Goals and Timeframes

Application/Mission	Short Term (1–2 Years)	Mid Term (3–5 Years)	Long Term (6+ Years)
Agile propulsion for short- and medium-range antiair missions	Low-cost TVC nozzle feasibility demo. Minimum signature CL–20 propellant (Isp 248s) motor performance demo. Demo of gelled liquid propellant flight weight engine.	Low-cost integrated aero/ TVC composite case motor demo. Demo of high Pc (4,000 psi) combustion of CL–20 propellant.	Clean ADN propellant (Isp 252s) motor performance demo.
Standoff propulsion for medium- and long-range antiair/surface missions	Performance demo of low-cost missile inlet and combustor components. Ground test of valveless/ throttable-ducted rocket. Ground test of flight weight GAP-fueled ducted rocket. Ground test of variable-flow ducted rocket. Ground test of low-drag ramjet having bent-body combustor.	Motor performance demo of metallized CL–20 propellant (Isp 272s). Demo of high-stiffness, low-weight composite case. Flight demo of low-cost missile RJ system (M>3).	Demo of low-cost/erosion, carbon-carbon material for nozzle throats. Demo of efficient, low-erosion fiber or cloth-reinforced insulation material. Freejet demo of hydrocarbon-fueled scramjet (Isp 850s; thrust 60 lbf/lbm/s at M8).
Gun-launched propulsion for surface fire support	Demo propellant ballistics (P_c 5,000–8,000 psi; n< 0.6). Optimized high-performance lightweight case.	Motor performance demo of prototype motor (high Pc, composite case) Isp >270.5 for gun launch.	Gun-launched flight test of prototype motor (high Pc, composite case, wrapped around fins) to demo performance (range > 3.5 nmi). IM tests of prototype motor.
Launchers/dispensers	Demonstrate non-pyrotechnics launcher for JSF. Reduce rack weight by 10% and increase maintainability. Demonstrate lightweight, C–130 transportable artillery rocket system.	Design low-cost dispenser for LOCAAS and SSB. Increase weapon loadout threefold. Design as integral shipping container and dispenser.	
Increase weapon standoff	Design and wind tunnel test (full scale) wing extension kit for SSB. Increase SSB range to 40 nmi.	Flight test demo wing extension kit for SSB	Design and ground test fast reaction standoff weapon for time-critical targets.
Missile integration demonstrations	MAT - 40-km flt test. Fast Hawk (Low-Cost Missile).	FMTI ATD - flt test 8–10 missiles. ASMT - unguided flt demo. LCPK - guide flt demo. Survivable airframe.	ASMT - guided flt demo. Hypersonic missile (M >6.0)

3.4.2.2 Major Technical Challenges. Missile challenges include the following:

- Efficient packaging of all missile components in a TOW-size missile that has the ability to lock onto ground vehicles in clutter at ranges up to 5 km and lock-on after launch up to 10 km. Missile will use gel motor technology to vary thrust allowing flyout to longer ranges.
- Dynamically stable flight without aerodynamic control surfaces of a bending airframe ramjet missile, a self-starting annular inlet with 68% pressure recovery at Mach 3, 60,000-ft altitude, and stable bent body combustion during maneuver and all flight regimes.
- Development and integration of miniaturized guidance and control actuation technology with an advanced composite, high-performance propulsion system in a small diameter hypervelocity missile using advanced KE penetrator designs.
- A low-cost, small producible, strap-down mechanism and guidance components for precision guidance of a highly rolling small rocket (2.75 in) capable of a CEP of 1 foot.
- Payout of fiber optic cable to 40 km in missile-size canister, low-cost turbojet technology for both boost and sustained flight, and an airframe that can be reconfigured for flyout (slow) and engagement (fast) modes.
- Integration of a launch system into ships that can accommodate the firing of a wide range of missiles including ESSM, Tomahawk, Standard Missile Block 4, and ATACMS.
- Controllability of an airframe that is shaped for very low drag and low RCS.
- Incorporation of attachments into composite missile airframes without compromising the operational capability of the missile.
- Low-cost, lightweight composite external surfaces that can satisfy high-temperature (1,000°F) and high-stiffness requirements of a tactical missile.

Solid propellant propulsion challenges lie in increasing propellant energy and density without increasing sensitivity, improving inert propulsion materials strength-to-weight/volume ratios, and reducing erosion and weight of insulation and nozzle materials.

The challenges for air-breathing propulsion lie in high-combustion efficiencies, reduced erosion and weight of combustor insulation, elimination or reduction to acceptable levels of ramjet combustor oscillations, and increasing the performance and reducing the size of ramjet components

3.4.2.3 Related Federal and Private Sector Efforts. NASA, DoD service labs, industry, and academia conduct research into advanced materials, aerodynamics, computational fluid dynamics, and shock and vibration that are monitored by the various subject matter experts through participation in conferences, symposia, and joint committees such as the joint Army, Navy, NASA, and Air Force Propulsion Committee. DoD and industry have efforts in propulsion technology, flight mechanics, and vehicle structures. Also, NASA has efforts in propulsion technology for space and orbit transfer, some of which are translatable to tactical propulsion as is tactical technology to their area of interest. Industry propulsion IR&D investment in FY95 was approximately $55 million. Further, these propulsion efforts are focused through the Integrated High-Payoff Rocket Propulsion Technology (IHPRPT) and Integrated High-Performance Turbine Engine Technology (IHPTET) efforts that are highly coordinated and integrated efforts with all services, NASA, and industry.

3.4.3 *S&T Investment Strategy*

3.4.3.1 Technology Demonstrations. Missile technology demonstrations include those that support the following DTOs:

- Future Missile Technology Integration Program (WE.07.02)
- Multimode Airframe Technology Demonstration (WE.25.02)
- Air Superiority Missile Technology (WE.35.02)
- Tactical Missile Propulsion (WE.39.02)
- Compact Kinetic Energy Missile (WE.50.02)
- Concentric Canister Launcher ATD (B.16)
- Low-Cost Missile ATD (B.17)
- Low-Cost Precision Kill (B.18)
- High-Mobility Artillery Rocket System (B.13)

Additionally, the following demonstrations are planned:

- Ducted Rocket Engine TD, a joint program under the auspices of the U.S. DoD/Japan Defense Agency Systems and Technology Forum to demonstrate the technologies for a ducted rocket propulsion system for air-defense applications. The feasibility of a ducted rocket engine to increase the kinematic envelope of medium surface-to-air missiles while meeting minimum smoke and insensitive munitions guidelines will be demonstrated.

- Survivable Airframe TD, to demonstrate the flight worthiness of a wingless, subsonic, survivable multimission standoff weapon airframe. This effort combines three emerging technologies: low-drag lifting body shape, thrust vector control, and novel louvered inlet concepts. The airframe is both low cost and has inherently low RCS. Lifting body shape is optimized for minimum drag and volumetric efficiency.

3.4.3.2 Technology Development. Technology development efforts support demonstrations described above by providing the foundation for the demonstrations and by addressing longer term military applications needs/requirements. Major task areas are:

- Solid-propellant formulation with emphasis on increased specific and density impulse, high-strength mechanical properties, acceptable burning rate properties at high pressure, and environment compatibility while maintaining low sensitivity.

- Gelled liquid propellant engine development.

- High-strength-to-weight per volume composite case development having acceptable attachments.

- Fiber-reinforced, low-erosion, heat-conductivity, density insulation material development that has low lot-to-lot variability.
- Development of low-cost processes for fabricating low-erosion, carbon-carbon nozzles and nozzle inserts.
- Low-cost, compact TVC nozzle system development.
- Variable thrust ducted rocket development.
- Development of high-performance inlets/combustors/fuel management for integration into hypersonic and supersonic ramjet systems.
- Low-drag, high-control force aerodynamic control surfaces.
- Methodologies and techniques to model external and internal aerodynamics, fluid dynamics/propulsion interactions, fluid dynamics/optical interaction, fluid dynamics/guidance interaction, aerothermochemical aspects of target detection and identification, and aerothermochemical aspects of electromagnetic signature of targets and backgrounds.
- Advanced missile airframes to support highly maneuverable missiles.
- Methodologies and techniques for target and background signature modeling and signal generation for real-time scene generation and projection with application for hardware-in-the-loop simulation.

3.4.3.3 Basic Research. Of special interest are quantum chemistry, synthesis of energetic materials, combustion mechanisms, flow structures in combustors, advanced high-specific-strength materials, computational fluid dynamics methods, better visualization of analytical results, new fiber/resin systems, and reduced production cost of advanced composite components

3.5 Ordnance

3.5.1 *Warfighting Needs*

DoD requires improvement over existing systems:

- Aimable warheads in new/upgraded air-to-surface missiles that increase kill probability to 1.0 and reduce requirements for missiles by 20–30%.
- Adaptable warheads that are more lethal and resistant to modern countermeasures and reduce munitions inventory requirements by 30–40%.
- Penetrating weapons that have 300% greater penetration capability and destroy 50% more hard targets.
- Guidance integrated fuzing (GIF) that increases warhead lethality by 20–30% over existing systems.
- G&C/fuzing that costs 20% less than current systems, enabling more single-shot kills, fewer sorties, or quicker capture of air superiority, surface, and undersea target neutralization.

- Combined effects EFP warheads lethal against both light and heavy armored targets thereby reducing munition requirements by 30–40%.
- Antiarmor warheads that maintain the overmatch against threat armor systems.
- Significant increases in penetration depths translate into at least 50% more hard targets that can be destroyed or disabled with single shots.
- Smaller, more lethal weapons that enhance the JSF and the F–22.
- Hard-target, smart-fuze accuracy to defeat buried hard targets.
- Smart fuzes that guide the global penetrator warheads loaded with explosives and that withstand 400% higher acceleration than existing systems.

Transition opportunities include AIM–9X, Standard Missile, Tomahawk, Evolved Sea Sparrow, dual-range air-to-air missile, AMRAAM, Patriot, STAFF P^3I, SADARM PI, Javelin, TOW follow-on, M829, F–22, JSF, JASSM, SSTD, LHT, Sidewinder, Patriot, and antisurface systems such as ARMs, JDAMs, and JSOWs.

3.5.2 *Overview*

Ordnance is the lethal or nonlethal mechanism of the munition that enables warfighters to incapacitate, neutralize, or destroy enemy personnel, materiel, and infrastructure to a degree that will inhibit the enemy's ability to engage in warfare.

3.5.2.1 Goals and Timeframes. The major goals for the ordnance subarea are to improve weapon lethality, multimission flexibility, and survivability and to reduce cost. The goals are listed in Table X–6.

Table X–6. Ordnance Subarea Goals and Timeframes

Application/Mission	Short Term (1–2 Years)	Mid Term (3–5 Years)	Long Term (6+ Years)
Antiarmor—defeat advanced armor and armor protection systems		Demo long EFP for smart weapon system. Demo advanced countermeasure warhead in missile flight Demo standoff fuze against reactive/active armor. Demo combined effects EFP warhead against light and heavy targets	Demo 300% increase in probability of kill in dynamic armor engagement scenarios.
Bombs	Conduct JDAM target ECM requirements analysis and susceptibility testing.	Demo JDAM ECM-resistant proximity fuze based on MMIC architecture.	Implement waveform-agile, ECM-hardened sensor for PGM and GP bomb antijam capability.
Gun munitions	Demo advanced GPS-based artillery registration.	Demo standoff fuze against reactive/active armor (AA). Demo miniaturized electronic fuzing for OICW bursting munition (guns).	Demo detection of CM targets in clutter for sensor-fuzed weapons (AA). Eliminate UXO

Table X–6. Ordnance Subarea Goals and Timeframes (continued)

Application/Mission	Short Term (1–2 Years)	Mid Term (3–5 Years)	Long Term (6+ Years)
Hard target—defeat WMD in storage, production, and the field	Evaluate chemical & thermal defeat mechanism and quantify performance.	Demo interim capability in prototype (BLU–109M) 2,000-lb warhead.	Expand lethal mechanism to harder and more diverse target spectrum.
Hard target—defeat hardened C^3 and countermeasured buried targets	Double penetration capability of BLU–109.	Boost penetration velocity using external propulsion, increase penetration depth 300%.	Introduce advanced high-energy density explosives into hard target supersonic penetrators.
Hard-target penetration technology	Development of shock and temperature insensitive components. Nonvolatile memory for hard-target test events records.	Advance hard-target L/V analysis, including synergistic effects of blast and fragmentation warheads and maturation of statistical techniques to qualify uncertainties. The results should reduce the need for testing and produce cost and time savings of 30:1 (test analysis). Penetrate reinforced concrete targets greater than 20 ft.	Hard-target penetrating radar actively determines stratification of penetration media to determine in void burst point. Use advanced kill mechanisms to defeat electronic components and chem/bio agents. Use multisensor, noninertial void sensors for hard-target penetration fuzing.
Missiles—defeat spectrum of air and surface threats using target-adaptable warheads, reactive fragments, advanced explosives, and hypervelocity missiles for time-critical targets	Conduct flight test of multimode warhead and submunition. Quality advanced explosive for aimable warhead.	Demo reactive fragments lethality.	Demo next generation of adaptable warheads capable of expanding target spectrum and range of missions.
Missiles	Architecture for modular missile and environment simulation based on JMASS. Imaging IR analysis and design. Clutter discrimination algorithm.	Proximity and GIF modules for simulation library. Imaging IR fuze/safe & arm and focus warhead integration. Distributed initiation systems. Low-energy S&A devices.	Imaging IR fuze for dual-role missile application. Demonstrate GIF aimable warhead capabilities. Increase operational range for IR fuzes. Increase CM capabilities for active IR fuzes. Low-cost electronic S&A devices.

3.5.2.2 Major Technical Challenges. Ordnance challenges include insensitive explosives with enhanced performance; quantification of very high velocity penetrator performance; development of material property models for adaptable warhead designs; all-weather, clutter ECM and chaff performance; high-resolution target imaging; safe and affordable multimode warhead initiation; and high-fidelity simulations for modeling system performance. For improved weapon lethality, challenges include cockpit-selectable robust algorithms for determining target parameters and computing warhead events in real time, high-fidelity sensors, and affordable high-shock survival components.

3.5.2.3 Related Federal and Private Sector Efforts. DOE explosives technology efforts are integrated with DoD efforts. Most benefits in this area are derived indirectly from advances in related areas of electronic research.

3.5.3 *S&T Investment Strategy*

3.5.3.1 Technology Demonstrations. Demonstrations include:

- *Ordnance Program.* The ordnance program was funded to demonstrate concepts that defeat weapons of mass destruction. The demonstration includes a flight testing of prototype systems. The project is expected to take 3 years and cost about $15 million. The prototype (a modified BLU–109 warhead) will incorporate advancements in warhead/lethal mechanisms, fuzing, damage assessment, and guidance and control.
- *Conformable Antenna Array.* The conformable antenna array technology demonstration for use as a fuze sensor in adjunct guidance antiradiation homing mode.
- *Optical Safe/Arm/Fire.* An optical safe/arm/fire device demonstration to show that RF radiation will not trigger explosive elements.
- *Antimateriel Warhead Flight Test.* (Described in JWSTP DTO B.15.)

3.5.3.2 Technology Development. Technology development efforts support demonstrations described above, lay the foundation for success, and address longer term military applications. Major task areas are described in the following paragraphs.

The *missiles* area includes air-to-air, air-to-surface, surface-to-air, and surface-to-surface missile warheads, fuzes, and explosives developed specifically for these ordnance packages. This includes 6.2 and 6.3 technologies for the warheads and fuzes, but only 6.3 for the explosives. Key technologies include advanced initiation and materials for aimable warheads and active and passive IR imaging for target detection and burst-point selection. For air-intercept encounters, key fuze technologies provide improved capability (increased lethality) for conventional edge-detection, side-looking target detection devices (TDDs) and development of guidance integrated fuze (GIF) concepts. Technology for conventional side-looking TDD improvements is being developed to provide weather capability, clutter discrimination, reduced jitter, precision separation timing, improved contact sensitivity, and increased warhead energy on target. All provide increased reliability and lethality. GIF technology is leading to a shift from edge detection and time delay algorithms to predictive algorithms, target aimpoint signal processing using high-range active systems, and passive imaging-type detectors to provide an increased capability for conventional and directional warheads. Ordnance technology for antisurface applications is moving from height of burst (HOB) to direct target detection to place more energy on target and reduce collateral damage while increasing lethality and reducing overall cost through the number sorties necessary to kill a target. The key for the antisurface and air application is the development of technology that truly provides an ordnance package.

The *advanced explosives* task area covers the generic 6.1 and 6.2 explosive technologies. It includes molecule development and formulation work. At the 6.3 level, it covers explosive processing and life-cycle work. Formulations for a specific ordnance package are included in that topic if accomplished at the 6.3 level. This topic covers generic technology areas needed to improve performance characteristics of explosives that have benefits and spinoffs for use in a broad range of applications. Key technologies include explosive formulations that provide significantly increased blast and fragmentation over existing formulations.

The *hard target* task covers penetration of cut-and-cover facilities, concrete or earth-covered facilities above ground, runways, and buried facilities. Technologies include fuzing, warheads, and 6.3 explosive work that supports this area. Key technologies are high-strength, high-toughness steels and heavy metal alloys for penetrator cases, high-energy-density explosives for restricted-volume penetrator warheads, explosives that can survive the high shock loading associated with hard target penetration, and precise fuzing against a wide spectrum of hardened targets with extensive and multiple layers. The hard-target smart fuze and advanced unitary penetrator components of the Counterproliferation ACTD contribute to this objective and are discussed in the JWSTP.

The *bombs* category includes general-purpose bomb technologies in warheads, fuzing, and 6.3 explosives. Key technologies are high-energy-density insensitive explosives, improved fragmentation control, and advanced initiation.

Ordnance components fit into the *gun munitions* area. Technologies include warheads, fuzing, and explosive payloads. The miniaturized 6.2 fuzing work will provide the basis for eventual integration of the full fuzing function with GPS/IMU into low-cost competent munitions.

The *land mines* task covers technologies in fuzing, explosives, and warheads developed specifically for the blocking, fixing, turning, and disrupting of armored and light vehicles and dismounted forces. This includes 6.2 and 6.3 technologies for the warheads and fuzing, but only 6.3 for the explosives.

The *antiarmor* category covers ordnance technologies in fuzing, explosives, and warheads for defeating heavily armored tanks and personnel carriers. This includes 6.2 fuzing sensors work to provide a standoff capability for projectiles and missiles to counter explosive reactive armor and active protection systems.

3.5.3.3 Basic Research. Research in mechanics is focused on gun propulsion; warheads and materials for antimateriel, antiarmor, and hard targets; mechanics of armor/antiarmor materials; explosives; and weapon system structures. These research areas are all critical for improving the performance of U.S. weapon systems. Basic research studies provide an essential foundation for the weapons technology required to defeat future threats and ensure that our forces can maintain a technological edge. Research is performed by a blend of university and in-house components uniquely suited to supplying the technologies needed for advanced weapons systems. Research related to mathematics and computer science, physics, chemistry, materials science, electronics, and mechanics all support our weapons technology requirements.

3.6 Undersea Weapons

3.6.1 *Warfighter Needs*

With the shift in focus from global confrontation to regional conflicts in shallow water and littoral zones, a deficiency became obvious regarding the capability of undersea weapons to successfully attack threat submarines under such harsh environmental conditions. Moreover, the problem is compounded by low-signature diesel/electric submarines operating in the shallow waters armed with modern, lethal weapons. Technological superiority and affordability of next-generation undersea weapons is needed to ensure the ability to cope with an evolving threat in harsh environments. The return on investment includes the capability to provide deep-water-equivalent performance against the quiet, small diesel/electric targets in shallow water, which will be available in the mid term (i.e., 3 to 5 years). By employing broadband sensors and signal processing, the capability to defeat sophisticated countermeasures will be available in the far term. A new capability to disable incoming torpedoes will be available to the fleet in about 5 years. In addition, significant efforts are directed toward reducing cost of ownership through commonality of subsystem hardware and software and, where possible, entire systems over the next 3–10 years.

The end of the cold war drastically changed the outlook for production of all-up-round torpedoes and significantly reduced the planned inventory. DoD's assessment of industrial issues for torpedoes indicates all-up-round production is not needed now, but there are requirements for advancing weapon technologies, upgrading and maintaining the current inventory, and supporting torpedo operations. Planned block upgrade programs will continue to improve performance of the MK48 ADCAP and MK50 torpedoes through FY05. Technology transitions are currently planned for the Lightweight Hybrid Torpedo (LHT) with an IOC of 2002 and the hard-kill torpedo defense programs for both surface ships and submarines, which will reach IOC in 2002–05. Explosives and warhead technologies will transition explosives with increased performance for both bulk and directed-energy warheads. In addition, a MEMS-based (microelectromechanical systems) safe and arm device is being developed as a potential common unit for backfit into all torpedoes and possibly all undersea weapons.

3.6.2 *Overview*

The objective of the undersea weapons S&T program is to develop and demonstrate technologies that contribute to the neutralization of threat submarine targets, countering (both soft and hard kill) enemy torpedoes, and assessing tactical battle scene and weapon employment tactics. The effort is organized in four areas: torpedo guidance and control, torpedo countermeasure and counterweapon devices, undersea warheads and explosives, and combat control. Torpedo propulsion and UUV technologies are covered in the Ground and Sea Vehicles area (Chapter IV).

3.6.2.1 Goals and Timeframes. The underlying tenet of undersea weaponry is innovative technology leading to affordable, effective weapons. The program encompasses the technology process from basic research, through applied research and advanced development, and transitions the promising candidate technologies to weapon systems upgrades. It is focused, productive, and responsive to the needs and requirements of the warfighters. Some of the major technology development milestones (when the capabilities are available for transition) are shown in Table X–7.

3.6.2.2 Major Technical Challenges. The primary challenge is to provide undersea weapon performance in the adverse, harsh, shallow-water environment that is equivalent to deep-water capability. Quiet, slow, or bottomed targets operating in cluttered shallow water areas present a detection and classification challenge to both the platform and the weapon because of the reverberant, noisy acoustic conditions. Moreover, the clutter creates a plethora of false targets that must be recognized by identifying features of various false targets. As a result, simultaneous tracks must be

Table X–7. Applications and Missions for the Undersea Weapons Subarea

Short Term (1–2 Years)	Mid Term (3–5 Years)	Long Term (6+ Years)
Intelligent controller to provide robust tactics and counter-countermeasure capability (1997) High-resolution sensors (1998) Initial hard-kill torpedo defense capability (1998)	Increase the P_k performance of U.S. torpedoes by 50% in the littoral regions (1999) Hard-kill torpedo defense capability for submarines and surface ships (2000) Broadband sonar (2000) Hybrid MEMS fuze/safe and arm (2001)	Cooperative engagement using post-launch bidynamic intersensor (weapon and platform) processing to perform either post-launch re-targeting or improve accuracy (2002) 40% reduction in development and ownership costs for both current and future undersea weapons (2005) Technologically superior and multimission-capable undersea weapons using ≥50% common subsystems (2010) Antitorpedo salvo capability (2005) Smart adaptive countermeasures (2006)

maintained on several contacts. The reverberant, noisy, congested environment coupled with the quiet, slow target results in close-in engagements that demand fast reaction. Achieving this performance is a challenge that requires organizing and coordinating several undersea weapon technology areas including shipboard fire control, weapon sensors and signal processing, trackers, precision homing, and warhead lethality.

The challenge of platform survivability is met by a multilayer defense strategy that includes both smart, adaptive countermeasures and hard-kill counterweapons able to defend against attacking weapons of various capabilities, including salvos. Improved post-launch retargeting and countermeasure identification will be possible by development of bidynamic, intersensor processing whereby the weapon and platform sensors are simultaneously and cooperatively processed to better define the engagement environment. The weapon's challenge is fast, accurate target DCL (detection, classification, and localization), intelligent mission control, and precision homing to achieve selective warhead placement on the target to ensure target destruction. Increased lethality warheads enhance the probability of kill by development of explosive formulations that produce higher bubble energy and shock performance. Alternatively, standoff distances can be increased while still achieving effective mission kill. A major challenge is development of a common, small, reliable safe and arm device for various weapons while retaining the multiple environmental interlocks required to satisfy current safety standards.

3.6.2.3 Related Federal and Private Sector Efforts. Because of the broad, varied technology areas involved in developing undersea weapons, many federal and private sector performers are involved. In FY95 (a representative year), the undersea weaponry budget was $34.0 million, of which $6.5 million went to industry, $13.0 million to Navy warfare centers, and $14.5 million to university laboratories. Although most of the technology is Navy-unique, some funding is leveraged by participation with organizations interested in similar pursuits. For example, this program is participating with DARPA, universities, and industry to develop MEMS technology that has the potential to allow a common, low-cost weapon S&A. Other examples of technology areas where the program joins with federal and private efforts are sensor materials and arrays, simulation-based design, explosive formulations, signal processing, intelligent control, and COTS processors.

3.6.3 *S&T Investment Strategy*

S&T investments for undersea weaponry are selected in conjunction with OPNAV sponsors and PEO(USW) with emphasis shared between performance enhancement and reduction of cost of ownership. The program provides an integrated effort comprising basic research that supports an applied research program which, in turn, leads to current and planned ATDs and the advanced development undersea weaponry core line, which begins in FY97.

3.6.3.1 Technology Demonstrations. The undersea weaponry program has two ATDs in FY97: Shallow-Water Guidance and Control (FY97 is the final year) and Antitorpedo Torpedo (DTO WE.29.02) (FY97 is the first year). A Broadband Torpedo Sonar Demonstration (WE.32.02) is planned to begin to FY99 that will provide major improvements in shallow-water detection, classification, and countermeasure resistance. It is supported by 6.2 enabling technologies from FY97 through FY01. In addition, the 6.3 core line described in the following text supports the broadband demonstrations beginning in FY98 and continuing through FY02. The Shallow-Water G&C ATD relates to specific software upgrades for shallow-water performance enhancements that can be implemented in an efficient manner. The Antitorpedo Torpedo ATD addresses both surface ship torpedo defense (SSTD) and submarine torpedo defense (SMTD). Technologies developed and demonstrated will be transitioned to the Lightweight Hybrid Torpedo Program. Additionally, the Broadband Torpedo Sonar Demonstration supports DTO WE.32.02. The need for torpedo component prototyping and transition of technology improvements is addressed by the 6.3 core line for undersea weaponry. The 6.3 core line is the bridge between applied research and the industrial base.

Shallow-Water G&C Technology Demonstration. The goal is to demonstrate a torpedo guidance system capability to detect, classify, and home against a low-speed or bottomed diesel/electric submarine in shallow-water environments with performance equal to or better than current deep-water capability. The effort involves embedding new detection, classification, and environmental adaptation processing algorithms within the structure of a fuzzy-logic-based torpedo intelligent controller. New sensors will be employed to provide high-resolution image processing against small shallow-water threat targets. Achievement of the goals would provide a 30–50% (site dependent) improvement in probability of hit for current weapons in shallow water environments. This capability significantly increases the capability of the Navy's air, surface, and submarine ASW forces to realize a single weapon kill against a diesel/electric submarine threat. Transition targets are the MK50 and the MK48 ADCAP torpedoes. These weapons contain software-based guidance systems and have block upgrade programs in place to insert these improvements.

Antitorpedo Torpedo Demonstration. The goal is to demonstrate ATT homing and fuzing technologies that can be incorporated into existing and planned torpedo and submarine defensive warfare systems (SDWS). This will be accomplished by embedding the homing and fusing technologies developed in the applied research program into a prototype G&C system and demonstrating performance against torpedo targets in clean, CM, salvo, ship wake, and shallow-water environments. Technologies to be demonstrated include high-range-resolution waveforms, high-pulse-rate signal and image processing, adaptive CCM processing, integrated homing and fuzing, acoustic intercept receiver, data fusion, and torpedo-defense-specific tactics. These technologies and capabilities will be based on common hardware and software technology compatible with existing and future torpedo systems (i.e., 21-, 12.75-, and 6.25-inch diameter weapons). In this way, a significant and cost-effective warfighting improvement can be quickly provided for existing inventories and future weapons. Because of the open architecture design, COTS common processor, and homing and fusing software modules approach, the capability can be directly transitioned to current and planned torpedo and SDWS programs.

Broadband Torpedo Sonar Demonstration. The goal is to demonstrate bandwidths five times that of existing torpedo sonars. Broadband sensors and signal processing technologies will be developed in the 6.2 program, and demonstrated in-water in an ATD, planned for a FY99 start. The ATD will integrate broadband sensors and signal processing techniques developed in the 6.2 program into a test vehicle and demonstrate improved performance in shallow-water environments against artificial targets, real targets, and countermeasures. The demonstrations will show detection ranges increased by a factor of two and false-alarm probabilities reduced by a factor of two, relative to existing narrowband systems. These demonstrations will be concluded in FY01. The sensors and signal processing demonstrated will be capable of being inserted with minimal impacts into existing operational torpedo inventories and into any new torpedo developments, and would provide significant, cost-effective enhancements to warfighting capabilities.

Core Line Technology Demonstrations. Many Third World and some developed countries contribute to the proliferation of inexpensive, quiet, diesel/electric submarines equipped with advanced countermeasures and lethal underwater weapons. These armaments pose a significant threat, particularly in the shallow-water regions where their quiet, slow-speed, or bottomed tactics foster close-in, quick-reaction encounters. New, innovative technologies must be inserted into weapons to counter this threat and ensure survivability of U.S. submarines and surface ships. The 6.3 advanced development core program addresses the issue of maintaining superiority through affordable innovation. Moreover, through its programs, the core effort retains sufficient industrial base to quickly and efficiently reconstitute torpedo production. Selected efforts for component prototyping provide either significant cost reductions or performance enhancements. The transition candidates are applicable to heavyweight, lightweight, and torpedoes for SDWS. Three efforts will begin in FY97. First is identification of a fuel and closed-cycle cooling system to replace the current open-cycle Otto fuel engines used in a large number of U.S. torpedoes. Otto fuel is a toxic substance, pollutes exercise areas, and requires an engine teardown after each exercise use. Second is a simulation-based design capability to analyze system cost and performance interaction. Moreover, the customer will be able to interact with the simulation in near real time. The third takes 6.2 technology for broadband sensors and processing toward a demonstration of a highly capable broadband guidance and control system for lightweight and heavyweight torpedoes. This broadband demonstration is the basis for the Broadband Torpedo Sonar Demonstration DTO (WE.32.02).

3.6.3.2 Technology Development. Undersea weapons embrace those technologies that contribute to the neutralization of submarine targets, countering and hard killing of enemy torpedoes, and assessment of tactical battlespace/weapon employment tactics. The work is separated into four efforts:

Guidance and Control. This effort includes a broad regime of technologies acting together or singly to detect, classify, engage, and neutralize submarines and surface ships. Particular emphasis is directed toward the quiet diesel/electric submarine operating in the harsh, shallow-water environment and often at slow speeds or bottomed. Among the technologies are detection, classification, feature extraction, simulation and test, acoustic arrays, fuzzy logic, intelligent controllers, inference machines, COTS-based processors, simulation-based design, and CCM techniques. Reduction in false targets by application of intelligent control promises improved resistance to countermeasures. Three principal tasks compose this technology effort: shallow-water G&C technology, advanced G&C technology, and simulation and test. This technical area is the key enabling technology for both the Antitorpedo Torpedo DTO (WE.29.02) and the Broadband Torpedo Sonar DTO (WF.32.02).

Torpedo Countermeasure and Counterweapon Devices. The objective is development of affordable technologies that provide submarines and surface ships with a robust layered defense capability possessing a high degree of protection against torpedo attack to ensure platform survivability. These technologies include hard-kill (i.e., a counterweapon and supercavitating guns and projectiles), soft-kill (both sonar and torpedo acoustic countermeasures), and shipboard DCL capabilities to quickly identify and track threat weapons. Some of the challenges include defense against a salvo of attacking weapons; provision of advanced countermeasures that support an effective layered defense strategy; fuzing in or near the wake with a fuze that conforms to the restricted space available in a small counterweapon; the quick-reaction required by the close-in encounters in cluttered, congested littoral zone engagements; and detection of and precision homing on an attacking torpedo with closing speeds near 120 knots. These technologies are important enabling technologies for the Antitorpedo Torpedo DTO.

Undersea Warheads and Explosives. This effort is structured to address the top priorities identified in the PEO(USW) document "Science and Technology Needs for Undersea Weaponry" dated September 29, 1994. The effort will provide explosives formulations meeting both operational performance requirements and the Navy's insensitive munitions requirements. None of the explosives in current undersea weapons meets the insensitivity munitions requirements. Consequently, these explosives are operating under waivers. New explosives technology to be developed under this task will transition to the Insensitive Munitions Advanced Development (IMAD) program for qualification and subsequent insertion into the fleet. The warheads development effort will provide design tools and concepts, which will permit computer-aided design and performance evaluation of warhead modifications. Six tasks that are essential non-DTO enabling technologies are the foundation of the warheads and explosives effort:

- Investigation and evaluation of novel explosive mixes that promise improved performance.
- Development of technologies needed to design and implement underwater explosives specifically formulated to maximize performance for a specified requirement.
- Development of theoretical and experimental methodology capable of describing the behavior and detonation characteristics of explosive formulations.
- Development of a small, reliable, MEMS-based fuzing safe and arm device.
- Development of fully coupled fluid/structure interaction models to simulate effects of underwater explosions near solid structures.
- Development of advanced concepts for a common torpedo warhead.

Combat Control. Technologies produced by this effort are applied to enhancing the undersea warfare effectiveness of submarines and surface ships by exploiting available information, reducing system response times, working toward better use of warfighting assets, and ensuring increased own-ship survivability. In addition, affordability is addressed through software upgrades to existing tactical systems, reduction of manning and training requirements, and pursuing commonality across submarine and surface ship equipment and software. There are three tasks. The first is undersea warfare tactical engagement information management, which seeks to develop and demonstrate the technologies and capabilities that produce an accurate, unambiguous, and timely platform-level tactical picture. The second task is vehicle pre- and post-launch management, which directs efforts toward assessing and classifying the threat and then rapidly placing weapons to best counter the enemy. The final task's objective is to develop a situational awareness for responding effectively and to survive close-in, quick-reaction torpedo encounters.

3.6.3.3 Basic Research. Much of the basic research (6.1) relating to undersea weapons is under the direction and responsibility of the same scientists involved with undersea weaponry applied research (6.2). They have responsibility for 6.1 and 6.2 resources, participate in formulating and managing ATDs, and are involved with the 6.3 core line. This link provides a key influx of high-quality science into undersea weaponry that carries through to the fleet. In addition, other ONR basic research program managers are encouraged through technology area workshops to focus basic research tasks on topics with application to undersea weaponry technology. In this way, innovative science programs are influenced to contribute ultimately to the undersea weapon technology base. Some relevant research areas are:

- Active control
- Data fusion procedures
- Fuzzy logic
- Tracking techniques
- Neural nets
- Intelligent control
- High-heat flux density
- Intermetallic-based warheads
- Wake characterization
- Modeling of energetic reactions
- Classification and sorting methods
- Electromagnetic force-based explosives
- Situational awareness

3.7 Weapon Lethality/Vulnerability

3.7.1 *Warfighting Needs*

DoD requires the ability to accurately assess the lethality of U.S. weapons and the vulnerability of U.S. systems. Without this capability, it is impossible to assess the U.S. posture in future conflicts, the advantages to be gained by pending U.S. weapon/platform developments, or the threats posed by foreign developments. Weapon lethality/vulnerability (WL/V) investments yield a 5:1 payoff early in the design phase of the development cycle, providing the cost-effective means for optimizing conventional weapon technologies. The timely use of WL/V analyses also supports the warfighter through reduced U.S. casualties and enhanced battlefield performance. Formerly, lethality assessments were largely based on experimentation on actual equipment, a prohibitively costly procedure. Through WL/V, analytical tools are being developed that reduce experimentation with a documented investment payback of 30:1. Common software architectures have led to standardized methodologies across the four services, leading to traceable, high-confidence predictions of friendly weapon lethality and significantly increased survivability of friendly personnel and systems. Transition of these tools yield validated payoffs in developmental and inventory systems, support for COEAs, and more economic fulfillment of live-fire testing requirements, as prescribed in Chapter 139, Section 2366 of Title 10, U.S. Code.

3.7.2 *Overview*

The focus for the WL/V technology is twofold: (1) to provide the capability to improve and evaluate the lethality and survivability of advanced weapon system concepts and technologies, systems in acquisition, and fielded weapon systems, and (2) to reduce reliance on costly tests/experiments while improving overall analysis capabilities. Significant progress has been made in the past 5 years through:

- Development and maintenance of a tri-service WL/V master plan, with resulting coordination of service WL/V programs.
- Tri-service use of common computer codes and data.
- Close ties between the tri-service WL/V community and the weapon and platform developers to achieve improved performance at significant life-cycle cost savings.

3.7.2.1 Goals and Timeframes. The major goals for WL/V are to support the tri-service weapons community through the provision of analytical tools and databases. The number of U.S. systems required to undergo live-fire testing and evaluation in accordance with U.S. code has remained constant despite defense spending reductions. Programs are phased so as to concentrate on the production of methodologies, capabilities, and environments of general utility in the near term (1–2 years) in order to support high payoffs in the mid term (3+ years). The goals are development of tools in the areas listed in Table X–8.

3.7.2.2 Major Technical Challenges. The technical challenges in the WL/V subarea are developing statistically reliable predictions of target damage resulting from all sources and combinations of ballistic mechanisms (penetrator, fragments, blast, shock, fire, etc.). Challenges also include performance/utility prediction that relates target damage states to diminished system performance, and L/V software environments that support expeditious and extensive WL/V analyses.

3.7.2.3 Related Federal and Private Sector Efforts. Many of the WL/V products and codes are distributed to other government organizations and industry through the Survivability Vulnerability Information Analysis Center (SURVIAC). It is estimated that industry uses L/V products in support of government analyses at a funding level of approximately $40 million per year. This figure is expected to increase with the continued "right sizing" of the federal defense workforce.

With the reduction of defense spending for procurement of major weapon platforms, the need for analyses using constructive models or man-in-the-loop distributed interactive simulations will require more information to be made available to evaluate technology upgrades and to justify new procurement programs. The basis for these decisions is, in part, WL/V modeling.

In the WL/V arena, many civilian agencies both use and contribute to DoD results, including law enforcement agencies, shock-trauma units in hospitals, the American Association of Automobile Medicine, universities, and many other private sector industries.

Table X–8. Weapon Lethality/Vulnerability Subarea Goals and Timeframes

Application/Mission	Short Term (1–2 Years)	Mid Term (3–5 Years)	Long Term (6+ Years)
Primary penetrator phenomenology	Hit-to-kill (TBM); special armor penetrator; concrete penetration.	Exoatmospheric intercept; hypervelocity methodology	Validation of deep, hardened target methodology
Fragment/debris phenomenology	Characterize current materials; component dysfunction analyses	Reactive materials; hypervelocity impact	Physics-based debris generation
Blast and shock phenomenology	Structural defeat; shock propagation.	Advanced materials response; complex environment generation	Accurate prediction for hardened buried targets
Fire and fumes phenomenology	Personnel effects; fire initiation models	Fire propagation; toxic fume dispersion	Accurate solution for deep, hardened targets
Damaged target response models	6-DOF models for aircraft; improved technology for assessment of degraded performance	Extension of method to foreign system	Accurate models of battle damage assessment
L/V supporting technologies	Advanced target geometry technology; cone and solid-core geometry analysis; target uncertainty model	Statistical technology; standard software environment for L/V analyses	Real-time connectivity with DIS

3.7.3 *S&T Investment Strategy*

3.7.3.1 Technology Demonstrations. An analytical extension to the penetration model to predict scaling will be demonstrated and validated in the WL/V subarea.

3.7.3.2 Technology Development. Technology development efforts support demonstrations described above, lay the foundation for demonstrations, and address longer-term military applications. Major task areas are:

- *Primary penetrator phenomenology*, to develop algorithms that predict defeat of armor and protective cover.
- *Fragment/debris phenomenology,* to develop rapidly accurate algorithms that predict fragment penetration.
- *Ballistic blast and shock phenomenology,* to predict complex blast wave environments, target structural response, and component failure in combination with other L/V tools.
- *Fire and fumes phenomenology,* to account for catastrophic effects of fires and hazardous fumes.
- *Advanced simulations,* to model important synergistic effects of multiple environments.
- *Damaged target response,* to provide a sound link relating combat damage to quantifiable target residual capability and post-attack damage assessment.

- *Supporting technologies,* to exploit computer science, graphic techniques, and advanced statistical techniques for enhancing the fidelity of and confidence in L/V analyses.

3.7.3.3 Basic Research. Scientific computing research feeds the performance modeling of weapon systems and components, as well as the U.S. weapons design process. Broad-based research programs in ballistic sciences provide essential algorithms and data required to support L/V analyses of advanced warfighting concepts and technologies.

3.8 DEW Lasers

3.8.1 *Warfighter Needs*

DoD requires improved or new capabilities in strategic and tactical missile defense, cruise missile defense, satellite negation, high-resolution imagery, air defense, ship defense, ground combat and close support, and aircraft self-protection. All of these requirements can be addressed by laser weapon systems. Laser and optical system technology offers the potential for a paradigm shift in weapon systems for the 21st century:

- Long-range, speed-of-light delivery to target
- Graduated engagements, from disrupt to destroy
- Surgical—minimum collateral damage, low fratricide
- Multiple, low-cost shots—large number of kills per platform
- All-aspect engagements—unconstrained by kinematics or gravity
- Synergism with high-resolution optical sensing—imaging, surveillance, standoff detection.

These advantages will provide dramatic improvements in current weapon capabilities and enable new missions that are not currently possible. Within the next 5 years, this includes transition of semiconductor laser technology to nonlethal weapons (illumination, designation, dazzling) and medical laser applications. After the turn of the century, potential new weapon capabilities include the airborne laser (ABL) for boost-phase negation of theater and cruise missiles at long range; ground-based laser (GBL) for negation of LEO satellites; space-based laser (SBL) for theater/national missile defense, ASAT, surveillance, target designation, and active and passive target discrimination; moderate-power laser systems for robust infrared countermeasures; passive and active laser/optical systems for remote sensing/standoff detection; laser weapons for antiship missile defense; and laser weapons for platform/base self-protection and offensive capabilities in tactical engagements.

3.8.2 *Overview*

3.8.2.1 Goals and Timeframes. Technology development and demonstration efforts are oriented to establish a mature and comprehensive technology base to support laser weapon systems development decisions. In many cases, this requires an integrated demonstration of laser and optical technology components and subsystems. Major goals and associated timeframes are listed in Table X–9.

Table X–9. DEW Laser Subarea Goals and Timeframes

Application/Mission	Short Term (1–2 years)	Mid Term (3–5 years)	Long Term (6+ years)
ABL for boost-phase negation of theater missiles at long range (up to 600 km)	COIL device, atmospheric measurements, adaptive optics, and beam control technology to support ABL demonstrator development.	Demo adaptive optics and beam control technology to ensure ABL design meets operational performance requirements; identify and begin development/test of promising advanced technology concepts.	Advanced COIL, adaptive optics, and beam control technology to provide 20–30% increase in ABL operational range.
GBL for negation of LEO satellites	COIL device technology at baseline levels; feasibility demos of adaptive optics for atmospheric compensation and active satellite tracking.	Integrated beam control demo/full-scale demo of weapons-class performance for all atmospheric compensation and beam control functions.	Advanced COIL, adaptive optics, and beam control technology to support design optimization and performance growth for GBL ASAT system development.
SBL for TMD, NMD, ASAT, surveillance, target designation, and active and passive target discrimination	Demo integrated beam director, beam control, and laser resonator. Ground demo acquisition, tracking technology.	Demo uncooled laser resonator optics. Fly acquisition, tracking experiment. Demo high-efficiency laser nozzles. Demo CW high-power phase conjugation.	SBL readiness demonstrator.
Laser system for IR countermeasures, based on damage/destroy mechanisms		Establish vulnerability of target set; demo laser device feasibility and scaling for selected wavelength.	Ground demo of integrated laser system performance against IR-guided missile hardware in realistic scenarios.
Laser weapons for anti-ship missile defense	Evaluate target lethality & utility of various laser concepts for ASMD. Demo 1-kW FEL.		
Semiconductor/solid-state laser sources and integrated beam control	Transition semiconductor laser technology to non-lethal and medical applications.	Demo architecture for scaleable, coherent semiconductor laser diode arrays; demo concept for electronic beam steering.	Demo coherent array scaling to moderate and high power; establish feasibility of conformal arrays and integrated laser source/beam control.

3.8.2.2 Major Technical Challenges. The major technical challenges being addressed in the area of laser devices are increasing laser device efficiency, reducing system size and weight to meet platform constraints, and scaling to high power while maintaining good beam quality. For some applications, the laser device must also operate at a specific wavelength or in a particular wavelength band. Another major challenge is to develop and integrate the high-energy laser system technologies to make them realistically operational. These complex weapon systems must demonstrate very high reliability with little if any day-to-day maintenance. They must also be capable of being operated by crews (not scientists) or even of operating completely unattended. This is particularly true of any space-based system.

Major technical challenges being addressed in beam control efforts include development and demonstration of adaptive optics hardware to compensate for distortions in the beam train and in propagation to the target, application of laser beacon concepts to sense distortions caused by atmospheric turbulence, rejection of high-bandwidth jitter induced by platform and atmospheric turbulence, compensation for tilt anisoplanatism, active tracking and illuminator/target effects, aimpoint designation and maintenance, and overall beam control system integration and performance evaluation.

In the area of laser effects, the major technical challenge addressed is determining the materials, configuration, functional characteristics, and vulnerability of potential targets. To assess the payoff of specific applications and to support system development decisions, a significant challenge is the development of modeling and simulation tools to determine weapon system performance and military effectiveness. Finally, an important challenge for the operational application of laser systems is to establish accurate safety thresholds for the protection of personnel.

3.8.2.3 Related Federal and Private Sector Efforts. DoD organizations have primary responsibility for development and application of high-power laser technology. However, there is some complementary activity within DOE and industry. Lawrence Livermore and Sandia National Laboratories have laser source development and some beam control programs, with emphasis on laser fusion (Livermore) and power beaming (Sandia) applications. The Thomas Jefferson National Accelerator Facility in Newport News, VA, is developing an industry consortium of potential users and a materials test facility to use the Navy-funded 1-kW IR free electron laser (FEL).

As a direct spinoff of DoD research, the civilian astronomy community has embraced adaptive optics and laser beacon sensing technology to improve resolution of ground-based telescopes by compensating for distortions introduced by atmospheric turbulence.

There are also related DoD efforts that support the DEW S&T effort. In FY97 the Army and DARPA will complete their joint Diode-Array Pumped Kilowatt Laser (DAPKL) program. This laser is a candidate for target illumination to support DEW lasers.

The joint U.S./Israeli Tactical High-Energy Laser (THEL) ACTD, although not an S&T demonstration, will provide useful information to the S&T technology efforts. The THEL offers a cost-effective, speed-of-light, continuous-kill capability against multiple, low-signature, maneuvering tactical threats.

High-energy laser effectiveness tests have demonstrated significant capability against the evolving air threat, using realistic targets and timelines. The High-Energy Laser System Test Facility (HELSTF) is funded through Army T&E (6.5). It has been used by all services to conduct high-power S&T experiments and demonstrations in support of their individual programs. HELSTF operates and maintains DoD's only integrated, open-range HEL test bed.

3.8.3 *S&T Investment Strategy*

3.8.3.1 Technology Demonstrations. Laser DEW technology development encompasses several demonstrations, intended to establish a level of technology maturity that supports transition to systems development programs. Major demonstrations support five DTOs:

- ABL technology demonstration (WE.04.04)
- GBL integrated beam control demonstration (WE.10.08)
- SBL Alpha/LAMP integration demonstration (WE.41.04)
- High-altitude balloon experiment (WE.41.04)
- Performance demonstrations of uncooled laser resonator, deformable mirror, high-efficiency laser nozzles, and continuous-wave phase conjugation (WE.41.04)
- Damage/destroy laser IRCM demonstration (WE.42.08)
- FotoFighter phased array laser diode demonstration (WE.42.08)
- Advanced multiband IRCM laser source solution (MISS) demonstration (WE.43.08).

3.8.3.2 Technology Development. Technology development efforts complement the technology demonstration efforts described above to fully support laser weapon system development decisions and to lay the foundations for future demonstration efforts to address longer term military applications and capabilities. Major task areas include:

- Chemical oxygen-iodine laser (COIL) device technology, with emphasis on improved efficiency and lightweight designs to reduce system weight and improve operational suitability.
- FEL device technology, a laser concept that allows selection of precise wavelengths in the near to mid infrared for optimum propagation, with emphasis on scaling to high average power while maintaining compactness and high wall-plug efficiency
- Advanced laser technology, considering new lasing concepts and target interaction phenomenology with the potential to further improve laser power per unit weight and overall military effectiveness.
- Nonlinear optics technology, with the potential to produce frequency-agile laser sources and, by phase conjugation, to automatically correct for phase distortions in an optical train or propagation path for both laser propagation and imaging applications.
- Passive and active high-resolution imaging technology, including concepts for image reconstruction, real-time processing, and aperture synthesis, both to support laser weapon functions (target verification, aimpoint designation and maintenance, damage assessment) and to provide situational awareness in terrestrial and Earth-orbit (out to geosynchronous altitudes) arenas.

- The application of laser source, beam control, and optical sensing technologies to remote sensing/standoff detection applications, addressing needs for target identification, kill assessment, and adjunct missions such as counterproliferation and the intelligence preparation of the battlefield.
- High-power optical components, to provide optical coatings, mirrors, windows, and other specialized optical components that can operate and endure in a high-power laser beam train without inducing significant distortion or loss.
- Target vulnerability assessment efforts, to include target model development, analytical vulnerability assessments, experimental testing and assessment validation, and military effectiveness analysis.
- Technology and experiments, to understand and characterize the atmospheric propagation environment, including turbulence effects over extended propagation paths and organized structures in turbulent flow fields such as boundary layers.
- System effectiveness assessments for antiship missile defense, including target vulnerability, laser propagation with emphasis on thermal blooming, and military utility.
- Experiments and modeling, to establish accurate safety thresholds for personnel protection.

3.8.3.3 Basic Research. Basic research efforts for high-power lasers emphasize the fundamental understanding of the limitations of laser technology and its application and the investigation of promising new approaches and concepts. Efforts are conducted in advanced laser concepts, nonlinear optics, optical image sensing and reconstruction, optical tomography of turbulent flow fields, and advanced concepts for adaptive optics and laser beacon sensing.

3.9 High-Power Microwave

3.9.1 *Warfighter Needs*

DoD requires improved capabilities in countering artillery fire, ship defense against cruise missiles, aircraft self-protection, suppression of enemy integrated air defense systems, space control, security, counterproliferation, and disruption or destruction of command and control assets. All of these requirements can be addressed by HPM weapon systems that upset or damage the electronics within the target. HPM weapons offer military commanders the option of:

- Speed-of-light, all-weather attack of enemy electronic systems.
- Area coverage of multiple targets with minimal prior information on threat characteristics.
- Surgical strike (damage, disrupt, degrade) at selected levels of combat.
- Minimum collateral damage in politically sensitive environments.
- Simplified pointing and tracking.
- Deep magazines and low operating costs.

Coordinated Army, Navy, Air Force, and DSWA HPM transition plans are focused on demonstrations of mission-oriented concepts: aircraft self-protection, antiship missile defense, and countermunitions (EW electronic attack—degrade/neutralize enemy defenses); and lethal suppression of enemy air defense (SEAD) and C^2W/IW (precision force, MOUT, and IW). Potential warfighter payoffs include generic protection against a wide variety of missile/munition threats (IR, EO, RF, laser-guided), improved effectiveness and lower attrition rates of friendly systems, and negation (permanent damage, long-term disruption, and temporary degradation) of enemy command, control, and general information systems. Finally, electronic protection techniques developed under the HPM program are being transitioned to users in order to harden U.S. systems against hostile HPM weapons or inadvertent EMI/EMC. Joint development and test projects demonstrate the maximization of investments to meet individual service/agency mission requirements.

3.9.2 *Overview*

3.9.2.1 Goals and Timeframes. Technology development and demonstration efforts are oriented to establish a mature and comprehensive technology base to support microwave weapon systems development decisions. In many cases, this requires an integrated demonstration of microwave source, pulsed power, and antenna subsystems. Major goals and associated timeframes are shown in Table X–10.

Table X–10. High-Power Microwave Subarea Goals and Timeframes

Application/Mission	Short Term (1–2 Years)	Mid Term (3–5 Years)	Long Term (6+ Years)
HPM system for point defense	Demo compact, high-power UWB source. Demo high-average-power narrowband source.	Live fire demo.	Ship self-defense demo, countermunition demo.
HPM system for C^2W/IW	Effects assessments.	Field demo.	Airborne demo.
HPM system for SEAD	Demo compact, high-power narrowband source.	Explosively driven single-pulse device demo.	Multiple-pulse device demo.
HPM system for space control	Effects assessments.	Modeling and simulation for concept development.	Field demo.

3.9.2.2 Major Technical Challenges. The major technical challenges for HPM weapons include developing and demonstrating:

- Compact, high-peak-power or high-average-power HPM sources.
- Compact, high-gain, ultra wideband (UWB) antennas.
- Compact, efficient, high-power, pulse power drivers.
- Compact, efficient prime power sources.
- Predictive models for HPM effects and lethality.

- Low-impact hardening of systems against hostile and self-induced EMI.
- Affordable system integration meeting military platform requirements.

3.9.2.3 Related Federal and Private Sector Efforts. DoD organizations have primary responsibility for the development and applications of HPM technology. However, both DOE and private sector efforts complement military HPM programs. Lawrence Livermore, Los Alamos, and Sandia National Laboratories have HPM source development and effects programs that directly support service efforts. The private sector has evolved both independent and cooperative RF effects programs. CRDAs have been initiated to develop and transition improved techniques for measuring electromagnetic interference. The electronics industry as a whole is working closely with the services to ensure compliance with new international standards for EM protection.

3.9.3 *S&T Investment Strategy*

In executing the DoD HPM program, focus is maintained on specific technology demonstrations in order that the technology effort at the component level can also be focused. DoD investments among the various technology demonstration and technology development efforts are allocated in accordance with their potential payoff to warfighting needs and their relative contribution to achieving the HPM goals.

3.9.3.1 Technology Demonstrations. HPM weapons encompass a number of technology demonstrations in the field. Major demonstrations support two DTOs:

- Aircraft self-protection demonstration (WE.19.08)
- Command and control warfare/information warfare demonstration (WE.22.09)
- Suppression of enemy air defenses demonstration (WE.22.09)

3.9.3.2 Technology Development. Coordinated Army, Navy, Air Force, and DSWA HPM technology developments are subdivided into a number of major constituent areas:

- *Compact, high-power UWB sources*: Includes fourfold increase in UWB output power. Technical barriers include voltage standoff of solid-state switches and fabrication of these switches. Weight should be ~500 lb and volume ~1.5 ft^3 (exclusive of antenna and pulse power).
- *Compact, high-power, narrowband HPM sources:* Includes sixfold increase in narrowband pulse length and narrowband tunability up to an octave. Technical barriers include cathode breakdown and production of plasma within the device as well as efficient extraction of microwave energy. Weight should be ~500 lb and volume ~1.5 ft^3 (exclusive of antenna and pulse power).
- *Compact, high-power, high-gain UWB antennas:* Focuses on lightweight antennas able to radiate high peak and average power with very low losses. Requires reduction to 18-inch antenna diameter with approximately 15–20 dB of antenna gain.
- *Compact, efficient, high-power pulse power drivers:* Develops compact (~500 lb in less than 10 ft^3), high peak power (>50 GW) packages.

- *Explosively driven pulsed power sources*: Focuses on explosively driven magnetic flux compressors for current and power amplification. Technical barriers include reducing power losses between the exploding armature and helical stator, coupling and timing requirements of multiple-staged generators, and weight and size reduction of fast opening and closing switches.
- *HPM effects and lethality*: Includes RF testing of a wide range of air, sea, land, and space military assets; RF effects database development; reliable prediction of RF effects to permit extrapolation to other systems; development of innovative countermeasure techniques; and incorporation of HPM into accepted military weapon engagement models.
- *HPM bioeffects*: Assesses biological effects necessary to establish safety thresholds for personnel protection.
- *Systems integration meeting military platform requirements*: Encompasses integrating pulse power drivers, HPM sources, and output antennas into military platforms such as fixed- and rotary-wing aircraft, naval combatants, land vehicles, aircraft pods, UAVs, and munitions.
- *Low-impact hardening of systems against hostile and self-induced EMI:* Includes transitioning EM hardening to users in response to existing EMI/EMC problems and projected threats; identifying susceptibilities in U.S. air, land, sea, and space militarily critical systems; and developing hardening countermeasures that minimally impact system performance, cost, or maintainability.
- *Evaluation of additional applications*: Based on effects assessments and technology development efforts, identifies additional militarily useful applications. Applications under consideration include ASMD, counterproliferation, countermunition, and space control. These evaluations will lead, where appropriate, to additional technology demonstrations.

3.9.3.3 Basic Research. Basic research efforts for high-power microwaves emphasize the fundamental understanding of the limitations of microwave technology and its application and the investigation of promising new approaches and concepts. Efforts are conducted in RF sources, antennas, and pulsed-power systems and in RF effects phenomenology.

3.10 Threat Warning

3.10.1 *Warfighting Needs*

The warfighter needs to know, unambiguously and in real time, the total threat situation ("picture") that endangers successful completion of the operational mission—whether the warfighter is at the battlespace command level, the battlegroup level, in the single-seat cockpit, or on the front line. For optimal response in a threat environment—whether the response is one of threat avoidance, ECM, lethal counter attack, evasive maneuver, or in combination—the warfighter needs to positively know the threats that are present, their parameters, locations, and intentions in time to invoke that response.

The S&T in the threat warning subarea will provide the next generation of advanced receivers, processors, antennas/apertures, and software algorithms to directly address future warfighter requirements. One of the key future requirements will be to integrate and correlate (i.e., sensor fusion) a wide variety of multispectral sensors (i.e., RF, IR, EO, UV, acoustic) to obtain a much improved all-weather, all-geometry threat situation awareness. On a component level, circuit miniaturization and digital trends will yield affordable receivers, which have improved operational performance and are lighter, smaller, more reliable, and more prime power efficient. Planned improvements in receiver/processor performance, COTS and open-adaptive, real-time, symmetric-multiprocessing (RTSMP) architectures will provide faster threat detection and recognition and an increased ability to decipher multiple, simultaneous, coherent, complex-modulation signals. Digital receivers incorporating these processor advantages will allow rapid reconfiguration of the receiver at the unit level through software updates in lieu of expensive and time-consuming hardware changes. Advanced location algorithm developments, coupled with antenna/apertures more accurate in angular threat determination, and advances in sensor technology and information fusion techniques will provide unambiguous resolution of the threat environment ("situation awareness"), thereby allowing the warfighter to optimize his/her response. Threat warning technology has multiple opportunities to make tri-service transitions into combat systems with RF or EO/IR receivers.

3.10.2 *Overview*

3.10.2.1 Goals and Timeframes. The primary focus of this subarea is to provide the warfighter the ability to detect, geo-locate, identify, track, and classify potential threat <u>and friendly</u> systems at long range with high accuracy. This new technology includes receivers, antennas/apertures, processors, sensor-fused algorithms, and signal analysis algorithms, which will provide adequate time to respond with appropriate countermeasures. Major goals and associated timeframes are listed in Table X–11.

3.10.2.2 Major Technical Challenges. Development of a high-accuracy subdegree direction finding (DF) capability requires interferometric techniques, close tolerance amplitude/pulse tracking RF receiver components, and low signal threshold detection. Development of functional elements, using monolithic microwave integrated circuits (MMIC) packaged into 1/30 of the current volume, is the major technical challenge for an all MMIC EW receivers. The complex task of assembling a digital RF receiver involves the development and integration of high-speed, high-resolution digitizers and high-throughput digital processing for spectral analysis and dynamic range extension. Achieving real-time threat identification and location includes pulse-level specific emitter identification (SEI) extraction, processing, and automation. In order to develop a highly stable RF receiver for detection and tracking of hostile emissions requires expanded processing bandwidth and dynamic range for environment characterization. In the area of EO/IR, the major technical issues are to increase the detection range of existing sensors by 100%; improve their angle-of-arrival determination to better than 1 degree; enhance probability of detection to over 95%; and reduce false alarms to less than one per hour. The EO technology challenges include increasing sensor sensitivity and dynamic range, providing angle-of-arrival information for CM cueing, and increasing the detection bandwidth to encompass the aforementioned laser threats. Threat identification, off-axis detection, and ATR with jam-resistant software require component/processing improvements.

Table X-11. Threat Warning Subarea Goals and Timeframes

Application/Mission	Short Term (1–2 years)	Mid Term (3–5 years)	Long Term (6+ years)
Improved threat emitter location and combat identification.	Develop and demo integrated hardware with multiple software algorithms to perform real-time threat ID and location.	Develop and demo integration of precise location/ identification with offensive targeting cues to yield rapid subdegree threat geolocation.	
	Develop and flight demo single RF aperture with 2-deg DF, 2π coverage, real-time threat ID, and geolocation.		
	Single EO aperture, hemispherical 2-deg DF flight demo.	Develop EO sensor and fiber optic technology to detect, identify, and localize laser-based threats.	Develop and demo fully integrated multispectral 2-deg DF ES system.
	Demo 1-deg passive missile warning with UV sensors.	Develop and demo 2x UV detection range with uncooled IR FPA.	Demo IR distributed aperture warning system.
Increased receiver processor throughput and fusion of offboard data.		Develop techniques for fusion with RF sensors to improve capability to detect and classify threats.	Develop and demo full real-time information in the cockpit (RTIC), automatic response reasoning, and real-time "out" of the cockpit (RTOC) capabilities.
Common digital receiver architecture and significant size reduction.	Develop and demo an EW receiver fabricated entirely from MMIC for aircraft, ships, and other platforms.	Develop and demo a wide-band, digital receiver for EW applications to be used onboard aircraft and ships.	Develop and demo DSP & fiber optic integration with RTSMP directly behind intercept apertures.
Worldwide merchant ship tracking.	SEI equipment on board at least one platform in all major theaters.	Develop and demo combat identification using SEI technology.	Develop weapons-embedded SEI.

3.10.2.3 Related Federal and Private Sector Efforts. Digital receiver and processor technologies have both private and federal applications. However, the EW sector demands are higher, with requirements for wider bandwidth, faster tuning, more instantaneous dynamic range, and high probability of signal detection. In the processor area, the two application requirements overlap, and COTS technologies are frequently adapted for DoD use. EW-related investments here focus on military needs not met by the commercial sector vis-à-vis computer architectures and digital signal processing (DSP).

3.10.3 *S&T Investment Strategy*

In executing the threat warning subarea, focus is maintained on specific technology demonstrations that synergistically integrate advanced antennas/apertures, processors, receivers, and software algorithm technologies. National investments among the various technology development and demonstration efforts are allocated in accordance with their potential payoff to warfighting needs, affordability, and relative contribution to achieve threat warning goals.

3.10.3.1 Technology Demonstrations. Threat warning encompasses multiple technology demonstration efforts as captured by the MWS technology DTO (WE.48.08) and two JWSTP DTOs (H.07 and H.09). The latter set concentrates on the areas of precise identification, geo-location of threat emitters in real time, and fusion of onboard sensor information with offboard theater asset information to provide unambiguous situation awareness and integrated multispectral electronic support warning with optimal multispectral response. Key to the Joint Warfighter Critical Objectives of Information Superiority and Combat Identification will be the efforts demonstrating RTIC and, in the reverse path, real-time information RTOC. By tying multispectral EW sensors into the digital battlefield/battlespace, all air and surface platforms and joint command operation centers will have situational awareness for subsequent targeting, battle damage assessment, and mission planning—while avoiding fratricide.

3.10.3.2 Technology Development. The service efforts in the threat warning subarea are divided into three classes and support the technology demonstrations identified above:

- *RF technology:* Develop advanced receiver, low-signal detection, and rapid parametric conversion capabilities using MMIC, fiber optic/opto-electronic, and digital technologies leading to highly stable receivers, integrated antennas/apertures, digitizers, processors, and software. For affordability, COTS processors and open/scaleable architectures are emphasized.
- *IR/Ultraviolet (UV) technology:* Develop IR/RF warning sensor fusion; multicolor IR band energy detection schemes; distributed high-angular-resolution/gimbal-less shared apertures; active, laser-based detection techniques; missile signature model validation; and algorithms to detect low-level signatures in a low-noise/high-clutter background over long ranges.
- *EO technology:* Develop low-cost laser warning technologies including high-temperature, broadband, high-dynamic-range sensors; angle-of-arrival resolution; spectral and coherent discrimination; repetition rate and pulsewidth determination; threat identification; low false alarm rate; and crew and CM system cueing for high-performance aircraft versus laser designator, rangefinder, and beamrider threats. In order to achieve the overall goal of a comprehensive, real-time affordable threat warning capability, a wide variety of the above multispectral sensors (e.g., RF, IR, EO, UV, acoustic) will be integrated and correlated.

3.10.3.3 Basic Research. Basic research initiatives that contribute to the threat warning subarea include physics supporting detector technologies, sensor research, and sensor improvements; advanced semiconductor and opto-electronic materials; high-temperature superconductor materials; chemistry for improved detector and sensor technology and submicron processes (for faster, efficient, affordable DSP devices and for uncooled EO/IR focal plane arrays); advanced machine reasoning (e.g., artificial intelligence); and advanced electromagnetics/antenna principles for broadband, low-signature, coherent curved/planar/distributed apertures.

3.11 Self-Protection

3.11.1 *Warfighter Needs*

The warfighter has a mission to accomplish, yet is faced with a threat environment dominated by more complex and robust weapon systems worldwide. Survivability of the warfighter and integrity of his/her platform—whether ship, aircraft, or ground vehicle—is paramount. The self-protection subarea will produce advanced, automated active jammer technologies and associated/integrated EA/ECM techniques across the RF, EO, and IR spectrums. Critically linked to the employment of the appropriate counter is the previous subarea of threat warning because it provides accurate warning and SA in time to execute the optimum self-protection response. Development of automated, effective, and reliable self-protection systems will free crews to concentrate on executing their assigned mission, putting the weapon on target, etc. Self-protection technology has opportunities to make a transition at all levels of weapon system development. Specifically, these systems include advanced multispectral expendables, decoys, and IR and RF jamming systems; and incremental upgrades to existing systems with compact, reliable, space and weight saving technologies. Technology insertion will play a pivotal role toward enhancing existing systems so that they will remain effective into the 21st century.

3.11.2 *Overview*

3.11.2.1 Goals and Timeframes. The self-protection technology subarea addresses (1) the ability to counter microwave and MMW RF threat radars via the development of advanced coherent jamming and deception technologies, and development of decoys for self-protection and angular deception of sensors; (2) laser technology to detect/perform scan analysis and jam EO and IR threat systems, and improving flares in the IR, UV, and RF bands that will be capable of defeating multimode or monomode threats; and (3) advanced component insertion/architectures that result in reduced size, cost, and weight of active CM systems. Major goals and associated timeframes are listed in Table X–12.

3.11.2.2 Major Technical Challenges. In the basic threat engagement, to the first order, the decision to employ self-protection is linked to the threat warning function—the challenge being the optimal, precise selection and timing of the CM (e.g., premature electromagnetic radiation from the platform only serves to highlight its presence/location to the threat; poorly timed flare ejections will be rejected by the ECCM features of the IR missile). This issue/challenge becomes even more critical for low-observable (LO) platforms and for Special Operations Forces (SOF) missions. The LO challenge is in the development of self-protection hardware, materials, electronic techniques, and the digital modeling thereof that will be compatible with this class of platform. In the decoy arena, RF challenges include developing increasingly more sophisticated electronics to fit within existing dispensers at an affordable cost; enhancements to chaff technology to extend the frequency coverage; and protecting slow-moving, large cross section ships from the ASCM. In the IR, the challenges include decoy techniques for the forecasted class of imaging seekers, development of composite flare materials that emulate the signatures of the warfighter's platform, maintaining the position of the flare/decoy in missile seeker's field-of-view (FOV), and achieving covert effectiveness where dictated by the mission. In the RF jamming area, multiple challenges include jammer design

Table X–12. Self-Protection Subarea Goals and Timeframes

Application/Mission	Short Term (1–2 years)	Mid Term (3–5 years)	Long Term (6+ years)
Microwave through MMW jamming capability for shipborne, airborne, and ground platforms.	Develop and demo MMW power module. Develop fiber-optic-coupled/controlled towed decoy. Develop and demo integrated MPM phased array architectures.	Demo MMW fiber optic link and phase shifter. Develop MMW towed decoy. Develop low-cost DRFM technology. Develop multiple tap delay line technology. Develop and demo broadband, polarization-agile transmit/receive architecture with 3–5-deg beam control.	Develop and demo integrated multispectral self-protection system. Demo multi-tactical platform/ALQ-compatible integration in a wideband configuration.
Defeat advanced IR imaging seekers using expendable CM and jamming.	Investigate and lab demo baseline CM techniques.	Exploit foreign FPAs. Conduct live-fire, cable-car test of fiber-optic-coupled, multiline lasers and expendables.	Develop and demo compact, integrated, laser-based, closed-loop IRCM capability.
Laser-based IRCM capability.	Integrate and test DARPA Phase 1 laser (2 W, all bands) under MSCM & TACAIR DIRCM ATDs. Deliver DARPA Phase II multiband laser (20 W, 10–20 kHz).	Demonstrate large aircraft IRCM capability.	Expand laser bands to long-wave IR and visible camera (40% increase in jamming band). Develop packageable/compact multiline IR source laser.
Defeat advanced non-imaging IR missile seekers employing sophisticated CCMs using expendables.	Experimental evaluation of the advanced expendable concepts including spectrally balanced two-color flare.	Field testing of expendable concepts for aircraft and ship protection.	Transition demonstrated technology to the warfighter.
Defeat advanced ASM seekers using onboard advanced transmitters and offboard decoys.	Initial demo of Eager preferential decoy.	Demonstration of advanced ECM transmitter technology.	Incorporate advanced transmitter and decoys into AIEWS design.

with high transmitter-receiver isolation; coherent, high-fidelity jamming waveforms; reactive/retro directive capability; coordinated, time-synchronized, multiple platform response; and a modular design scaleable to all platforms. In the IR/electro-optical regime, major challenges involve the radiation of multiple laser wavelengths necessary to jam a variety of threat missiles simultaneously; demonstrating small, low-cost laser pointing and tracking devices to deliver adequate multiband laser energy in the high maneuver dynamics of combat aircraft; designing and demonstrating EO/CM fieldable prototype for ship self-defense; tracking incoming threats via reflected laser energy or missile plume emissions; and steering IR/EO laser beams without the need for a complex, costly, stabilized gimbal platform.

3.11.2.3 Related Federal and Private Sector Efforts. DoD has the primary/sole responsibility for self-protection S&T within the federal government—with very few applications to the private sector. This subarea is supported by the IR&D investments of numerous defense industry contractors.

3.11.3 *S&T Investment Strategy*

In executing the self-protection subarea, focus is maintained on specific technology demonstrations that synergistically integrate advanced antenna/aperture, transmitter/source, and coherent/digital exciter techniques with their companion threat warning functions in order that mutually parallel technology development progress can be achieved. National investments between the technology and demonstration efforts are allocated in accordance with their potential payoff to warfighting needs and affordability, and their relative contribution to achieving self-protection goals.

3.11.3.1 Technology Demonstrations. In the near term, as recommended by the 1995 and 1996 Technology Area Review and Assessments (TARA) of EW, the number one EW S&T priority is IRCM. In the aggregate, this posture is reflected by the concerted efforts in no less than six formal EW DTAP DTOs. In FY96–97, these six are synergistically supported/supplanted by the vital, new Missile Warning Sensor Technology DTO (WE.48.08) and those DTOs in the previously discussed DEW area (WE.19.08, .42.08, and .43.08). In FY96, the DARPA Tri-Service Laser Program provided the services two multiband IR laser sources. DARPA tri-service contracts are pursuing competing technologies toward achieving the 20-W/20-kHz goal (DTO WE.09.08 in FY96). Also ending in FY97, the TACAIR DIRCM ATD will take the first step of demonstrating the feasibility of laser-based IRCM for future tactical applications via a flyable testbed. Its results, along with JWSTP DTO H.05, will form the basis for a planned, cooperative, major AF/N demonstration of an affordable, fixed-wing/transonic IRCM capability.

In the RF subarea, there are two funded ATDs: "Eager" (ending in FY97) and the Advanced ECM Transmitter. The Eager ATD system will provide an integrated offboard, towed, hovering decoy EA system, while the Advanced ECM Transmitter ATD (H.06) will demonstrate a true time-delay phased-array EA transmitter. Both ATD systems are scheduled to transition into the Advanced Integrated Electronic Warfare System (AIEWS). Additionally, two new RFCM demonstration-level efforts have been incorporated into this year's plans (WE.46.08 and H.08). In particular, WE.46.08 has the strong transition potential for impacting the ALQ upgrades to the aging airborne platform inventory, the future AIEWS, and planned demonstrations for next-generation standoff/standin jamming architecture/systems (see following Section 3.12).

3.11.3.2 Technology Development. The service and agency efforts in the self-protection subarea are divided into three classes:

- *RF technology*: Reduce the risk of enabling RF technologies required to develop and demonstrate reactive, polarization-agile, coherent electronic countermeasures against advanced radars using noncooperative target recognition algorithms (e.g., pulse Doppler, pulse compression, synthetic aperture radars, inverse synthetic aperture radars, low probability of intercept, ultra wideband). This enabling technology consists of MPM transmitters, digital RF memories, multiple tapped delay lines, phased-array dual-polarized antennas, and methods for antenna isolation. Additional system and subsystem technologies are being developed for MMW EA, LO, antiradiation missile (ARM), CM, RF decoys, and expendable vehicle technology to provide platform-like decoys (kinematic fly-along for aircraft and slow moving for ships and ground platforms).

- *IR technology:* Develop IR decoy technologies, including IR materials, decoy configuration and deployment concepts, and decoy ejection sequencing algorithms to address the capability of IR seekers to discriminate aircraft and ships from decoys. Develop IRCM to provide capabilities to detect, analyze, jam, and exploit imaging and advanced IR seekers.
- *EO technology:* Develop laser devices with improved frequency agility, efficiency, reliability, and strength, while also reducing size, cost, and weight of active CM systems.

3.11.3.3 Basic Research. The research in the self-protection subarea is similar to the threat warning subarea (Section 3.10.3.3). Additional research includes physics and chemistry for basic IR source materials used in IR decoys; band-gap-engineered materials to lead to cascade lasers for highly efficient, room-temperature, mid-IR laser sources for jamming; neural net processing supporting development of efficient and effective algorithms for missile detection; fiber optics development for beam transport required for distributed aperture warning receivers; and nanostructure research in optical filters supporting development of spectral filters for missile warning sensors.

3.12 Mission Support

3.12.1 *Warfighter Needs*

As proven by Operation Desert Storm, an effective standoff EA campaign against both enemy radar sensors and communications infrastructure damages the enemy's ability to determine the location and intent of our joint forces and its ability to control offensive or defensive forces. The S&T in mission support will significantly enhance warfighter operations by proactively separating the enemy command element from its forces by disrupting information handling systems, C^3 nodes/links, navigation systems, long-range integrated air defense systems, and other electronic aids that provide battlefield/situation assessment to enemy forces. This degradation of the enemy's C^3/ Integrated Air Defense System (IADS) structure must be effectively accomplished without hindering those same elements of our own. Opportunities for transitioning the C^2W and counter-IADS mission support technology efforts exist in current EA systems. Future systems designed for exploitation, countersurveillance communications, and radar tracking will afford a fertile environment for testing and application of this technology. Also included in this subarea is the pursuit of advanced distributed simulation technologies, which will reduce the time and cost required to develop the entire scope of EW system capabilities discussed in Sections 3.10–3.12, resulting in a faster transition to the warfighter's operational "arsenal" at an affordable acquisition cost. Simulation and modeling will also result in more EW advanced systems with increased capability, as proposed modifications and performance enhancements can be tested by the S&T and user communities for effectiveness prior to development and production.

3.12.2 *Overview*

3.12.2.1 Goals and Timeframes. Modern battlefield commanders require information as never before, not merely information on enemy numbers, location, movement, readiness, weapon capabilities, control structures, or awareness of friendly actions, but also on similar information on his/her own forces and those of allies. To provide this information to friendly forces and denying the same to the threat commander, EW systems technology thrusts in the mission support technology subarea address three elements: RF mission support, electronic protection (EP), and EW employment. EW technologies provided will increase the capabilities of EW systems to:

- Intercept and selectively deceive or totally disrupt enemy C^2, surveillance and weapon systems while maintaining uninterrupted friendly communication links.
- Employ automated data fusion processes to ensure timely intelligence and rapid, tactical decision making to operate inside of the enemy's decision cycle.
- Invoke modeling and simulation to investigate new and untried system architectures.
- Increase the readiness of our forces through training on simulators using actual EW systems.
- Exploit available threat systems to increase survivability through better knowledge of doctrine and tactics, better knowledge of weapon system capability, and increased CM effectiveness to "paint a different picture" of the battlespace to the threat commander.

Major goals and associated timeframes are shown in Table X–13.

3.12.2.2 Major Technical Challenges. The principal challenge of the C^2W role is the global spread of extremely affordable, portable, modern telecommunications technology. Extremely complex modulation formats, multiplexing schemes, and spread-spectrum coding pose severe hurdles to the ES system in its real-time abilities to identify, detect, and intercept. Given that challenge, the EA portion of the system must accomplish "surgical" attacks on enemy C^2 and navigation aids with minimal collateral/fratricidal damage due to the commonality of frequencies/systems used by both forces and nonaligned third parties. In the HF communications region, resurging interest in this "comms" method imposes severe hardware challenges on ECM and ESM subsystems (by virtue of the multi-meter wavelengths involved) and affordable integration thereof on a broad class of existing, operational warfighter platforms (small, mobile ground vehicles; airborne; and shipborne)—e.g., efficient broadband amplifiers and antennas, over-the-horizon detection schemes. The third C^2W challenge is the capability to correlate and combine all force sensors (active and passive) data to provide a complete tactical picture. For RF mission support, the challenges are threefold: creating an architecture for an affordable, next-generation support/SOJ capability; demonstrating low-cost, effective electronic enhancements to the SEAD mission; and providing capabilities to direct/protect the flow and handling of friendly information systems.

3.12.2.3 Related Federal and Private Sector Efforts. Although EW is primarily used by DoD organizations, there are commercial activities pursuing directly related technologies. DoD EW technology efforts are complemented by industry initiatives, particularly in the area of advanced communications. EA techniques against modern threat C^3 systems are also being applied in an EP fashion to efforts protecting our own military and commercial communications and computer networks through the development of common tool sets for information protection. DoD, law enforcement, customs, and other federal organizations have been partners with the commercial sector

Table X–13. Mission Support Subarea Goals and Timeframes

Application/Mission	Short Term (1–2 Years)	Mid Term (3–5 Years)	Long Term (6+ years)
Exploitation and jamming of mobile and digital C^3 systems	Demo 10x increase in number of HF signals that can be simultaneously countered, through optimized techniques and increased wideband power generation.	Demo techniques of countering current digital communications to introduce significant delay in the threat commanders' decision cycle from his/her information databases.	Demo techniques for countering future reconfigurable, multimedia, computer-intensive mobile networks.
Robust, all-aspect antiship missile CM (ASCM) simulation capability	Add a cloud cover model to the IR predictive code for the cruise missiles EW simulation.	Provide an RF/IR digital model representative of the multispectral environment.	
Extension of target collection range, attack and mobility of IEW Common Sensor (IEWCS)	Demo 40% collection range exercise through UAV test.	Demo a 90% increase in precision location capability for targets outside range of IEWCS and selective jamming attacks in UAV flight test; integrate and demo with airborne IEWCS platforms.	Demo target collection and location at over 75% extended ranges on planned mobile digital communications using UAV tethered to IEWCS.
Develop capability to surgically counter C^2W systems with minimal fratricide	Test communication/ navigation CM capabilities against ground and airborne platforms.	Demo airborne CM against future navigation systems.	Demo precision attack techniques as CM against global high-capacity communication/navigation systems.
Airborne multiple sensor fusion	Complete the multi-INT sensor correlation with moving target indicator.	Demo advanced airborne planning algorithms and effectiveness tools for multisensor tasking and reporting using dB-to-dB interfaces.	Integrate SIGINT/MTI sensor cross-cueing and situation displays into IEWCS and All-Source Analysis System (ASAS).
Next-generation RF support jammer	Develop and demo integrated MPM phased-array architectures.	Develop and demo broadband, polarization-agile transmit/receive architecture with 3–5-deg beam control.	Demo tactical platform (include UAVs and pods) integration into a wideband configuration.
C^2W visualization/ simulation technology	Live intel data coupled with visualization/simulation technology. Perform predictive analysis on efforts of EA to C^2 networks.	Couple visualization/ simulation technology with test assets.	Advanced display technology to on-the-fly display 3D view of EOB.
Force-on-force simulation technology	Increase fidelity of sensor model emulations.	Develop tri-service interoperability.	Embed into operational systems.
Counter ECM false targets and false images in SARs	Dev and demo neural network processor to counter ECM signals.	Conduct flight test in aircraft, JSTARS.	Integrate processor to counter false SAR signals into tactical fighter such as the F–22, F/A18–E/F, and JSF.

and academia in the development of technology for countering criminal and terrorist activities. Industry is involved in data fusion applications running the gamut from strategic intelligence production and tactical situation awareness development to automated production, preventive maintenance, and autonomous robot applications. Spinoffs from DoD work in data fusion include factory automation, advanced safety systems, multisensor diagnostic systems, and earth resource management. Also, DoD visualization/simulation technology is able to leverage off of dramatic advances from the computer graphics industry.

3.12.3 *S&T Investment Strategy*

In executing the mission support subarea, focus is maintained on specific technology demonstrations, which synergistically integrate advanced antenna/aperture, processor, receiver, and transmitter technologies, yet also foster technology developments in these same areas that are focused on the component/functional level. National investments among various technology demonstration and technology developments efforts are allocated in accordance with their potential payoff to warfighting needs, affordability, and relative contribution to achieving mission support goals.

3.12.3.1 Technology Demonstrations. In accordance with the TARA recommendations in April 1996, the second most important area in EW S&T is C^2W. Hence, the demonstrations in mission support depict this posture and provide incremental achievement to reach WE.23.08. Objectives include significant tactical battlefield fusion visualization and decision aids, CM to advanced forms of navigation aids, EA against modern information networks/communications, and development of advanced C^2W receiver and transmitter architectures/components. The other major EW demonstration is embodied on the joint warfighter side by DTO H.04 and is geared to assist lethal SEAD. Other mission support demonstrations will be conducted in accordance with this subarea's investment strategy.

3.12.3.2 Technology Development. The service efforts in the mission support subarea are divided into three classes.

EW mission support technology will develop the technology to attack the enemy C^2, IADS, and information distribution networks. Detection, degradation, deception, and destruction are all part of the total requirement. A development goal is to provide the capability to surgically counter both communication and navigation systems by disrupting C^3 nodes and links without negatively impacting friendly use during war, and most particularly, operations other than war to avoid disruption of communication facilities of other nations and international humanitarian organizations. An additional goal is to develop the enabling technologies required to field the next-generation integrated RF support jammer concept to electronically counter search, surveillance, targeting, and other advanced radars. This enabling technology includes multibeam, dual-polarized, real-time, phased-array antennas/apertures; microwave power module transmitters; reactive coherent techniques generator using DRFMs and programmable tapped delay lines; integrated threat warning; multiplatform coordination; improved antenna isolation; and improved surgical jamming to prevent fratricide.

EP (ECCM) technology will provide protection against threat EA enhancements. This portion of the EW S&T program develops necessary technology to perform vulnerability assessments to ensure that U.S. weapons, C^3, and C^3I systems have adequate and cost-effective hardening. This technology is at a basic S&T level, which is quickly transferred/transitioned to system developers for rapid insertion of protection techniques/upgrades to operational systems. Radar mission effectiveness will be demonstrated for advanced fire control radars, such as in the F–22, F/A–18E/F, and JSF, based on electronic protection (EP) technologies. Radar mission effectiveness will also be demonstrated for ground-based fire control radars.

EW simulation will support detailed engineering analyses of both specific EW equipment and technologies and computer-intensive higher order simulations. This is necessary to analyze all levels from one-on-one to force-on-force scenarios. Simulation visualization technologies are also needed to allow immediate, man-in-the-loop evaluation and interaction with EW scenarios. Developed technologies will provide joint service interoperability between constructive, virtual, and live assets, which will result in a more realistic environment to perform operational analysis and training.

3.12.3.3 Basic Research. Basic research efforts are underway that support this mission support subarea. Signal processing research in modulation characterization, fast adaptive super-resolution beamforming, noise reduction, adaptive direction-finding algorithms, and antenna size reduction using high-temperature superconducting (HTS) components directly apply to ES and EA against modern communication, RF emitter, and information systems. Basic research efforts in data fusion emphasize the theoretical underpinnings of information combination and investigate promising new approaches and concepts in providing timely tactical battlefield intelligence fusion and situation assessment needed for effective EA. Investigations are being conducted in the development and evaluation of new paradigms for machine-based reasoning, advanced database management system design, optimal constraint-based resource management, and new-evidence combination methodologies.

GLOSSARY OF ABBREVIATION AND ACRONYMS

μm	micrometers
3D	three dimensional
AA	antiarmor
AAAV	Advanced Amphibious Assault Vehicle
AAM	air-to-air missile
ABL	airborne laser
ACTD	Advanced Concept Technology Demonstration
ADC	Acoustic Device Countermeasure
ADCAP	advanced capability
ADN	explosive ingredient
AHMCM	Antihelicopter Mine Countermeasure
AIEWS	Advanced Integrated EW System
AJ	antijam
ALMDS	Airborne Laser Mine Detection System
AMDS	Advanced Mine Detector System
AMRAAM	Advanced Medium-Range Air-to-Air Missile
AP	antipersonnel
APL	antipersonnel land mine
ARM	antiradiation missile
ASAS	All-Source Analysis System
ASAT	antisatellite
ASCM	antiship cruise missile
ASM	air-to-surface missile
ASMD	antiship missile defense
ASMT	air superiority missile technology
ASTAMIDS	Airborne Standoff Minefield Reconnaissance and Detection System
ASTE	Advanced Strategic and Tactical Infrared Expendable
ASUW	antisurface ship warfare
ASW	antisubmarine warfare
AT	antitank
ATACMS	Army Tactical Missile System
ATD	Advanced Technology Demonstration
ATGW	Antitank Guided Weapon
ATIRCM	Advanced Threat Infrared Countermeasures
ATR	automatic target recognition
ATT	Antitorpedo Torpedo
AWACS	Airborne Warning and Control System
BAT	Brilliant Antitank
BDA	battle damage assessment
BFVS	Bradley Fighting Vehicle System
BMD	ballistic missile defense
BRP	*Basic Research Plan*
C^2	command and control
C^2W	command and control warfare
C^3	command, control, and communications
C^3I	command, control, communications and intelligence

CCM	counter-countermeasure
CEC	cooperative engagement capability
CEP	circular error probable
CID	combat identification
CINC	commander-in-chief
CIWS	Close-In Weapon System
CKEM	Compact Kinetic Energy Missile
CM	countermeasure
CM/M	countermine/mine
CMWS	Common Missile Warning System
COEA	cost and operational effectiveness analysis
COIL	chemical oxygen-iodine laser (lases at 1.3 µm)
COTS	commercial off the shelf
CRDA	cooperative research and development agreement
CT	counterterrorism
CW	continuous wave; conventional weapons
DAPKL	Diode-Array Pumped Kilowatt Laser
DARPA	Defense Advanced Research Projects Agency
DCL	detection, classification, and localization
DE	directed energy
DET	distributed explosive technology
DEW	directed-energy weapons
DF	direction finding
DIA	Defense Intelligence Agency
DIAL	differential absorption LIDAR
DIRCM	directed infrared countermeasure
DIS	distributed interactive simulation
DNA	Defense Nuclear Agency
DOE	Department of Energy
DOF	degrees of freedom
DRE	ducted rocket engine
DRFM	digital radio frequency modulator
DSP	digital signal processing
DSUP	defense system upgrade
DSWA	Defense Special Weapons Agency
DTO	Defense Technology Objective
DW	deep water (> 200 ft)
EA	electronic attack
ECCM	electronic counter-countermeasure
ECM	electronic countermeasure
EFOGM	Enhanced Fiber Optic Guided Missile
EFP	explosively formed projectile
EM	electromagnetic
EMC	electromagnetic compatibility
EMI	electromagnetic interference
EO	electro-optic
EOB	Electronic Order of Battle
EOCM	electro-optic countermeasure
EOD	explosive ordnance disposal
EP	electronic protection
EPA	Environmental Protection Agency

ERA	explosive reactive armor
ERGM	Extended-Range Guided Missile
ES	electronic support
ESM	electronic support measure
ESMB	Explosive Standoff Minefield Breacher
ESSM	Evolved Sea Sparrow Missile System
ETC	electrothermal-chemical
EW	electronic warfare
FCS	Future Combat System
FEL	free electron laser
FIV	Future Infantry Vehicle
FMBT	Future Main Battle Tank
FMTI	Future Missile Technology Integration
FOG	fiber optic guided
FOTT	follow-on to TOW
FOV	field-of-view
FPA	focal plane array
FY	fiscal year
G&C	guidance and control
GAP	glycidyl azide polymer
GBL	ground-based laser
GHz	gigahertz
GIF	guidance integrated fuzing
GMLRS	Guided Multiple Launch Rocket System
GP	guided projectile
GPR	ground-penetrating radar
GPS	Global Positioning System
GSTAMIDS	Ground Standoff Mine Detection System
GW	gross weight
HARM	High-Speed Antiradiation Missile
HEL	high-energy laser
HELSTF	High-Energy Laser System Test Facility
HF	high frequency (lases at 2.8 μm)
HIMARS	High Mobility Artillery Rocket System
HOB	height of burst
HPM	high-power microwave
HSTAMIDS	Handheld Standoff Mine Detection System
HTS	high-temperature superconducting
HWIL	hardware-in-the-loop
I&W	intelligence and warning
I^2R	imaging infrared
IADS	Integrated Air Defense System
ICAP	improved capability upgrade
ICBM	intercontinental ballistic missile
ID	identification
IDECM	integrated depressive ECM
IEW	intelligence electronic warfare
IEWCS	Intelligence Electronic Warfare Common Sensor
IFF	identification friend or foe

IFOG	Interferometric Fiber Optic Gyroscope
IHPRPT	Integrated High-Payoff Rocket Propulsion Technology
IHPTET	Integrated High-Performance Turbine Engine Technology
IIR	imaging infrared
IM	insensitive munition
IMAD	Insensitive Munitions Advanced Development
IMF	intelligent minefield
IMU	inertial measurement unit
INS	Inertial Navigation System
INT	intgrated
IOC	initial operating capability
IR	infrared
IR&D	independent research and development
IRCM	infrared countermeasure
Isp	specific impulse
ISR	intelligence, surveillance, and reconnaissance
IVMMD	Interim Vehicle-Mounted Mine Detector
IW	information warfare
JAMC	Joint Amphibious Mine Countermeasure
JASSM	Joint Air-to-Surface Standoff Missile
JDAM	Joint Direct Attack Munition
JIC	Joint Intelligence Center
JMASS	Joint Modeling and Simulation System
JMCIS	Joint Military Command Information System
JSF	Joint Strike Fighter
JSOW	Joint Standoff Weapon
JSTARS	Joint Surveillance Target Attack Radar System
JWCO	Joint Warfighting Capability Objective
JWSTP	*Joint Warfighting Science and Technology Plan*
KE	kinetic energy
km	kilometer
kW	kilowatt
LADAR	laser radar
LAMIDS	Lightweight Multispectral Countermine Detection System
LAMP	Large Aperture Mirror Program
LAV	light armored vehicle
lbf	foot-pound-force
LCPK	Low-Cost Precision Kill
LEO	low Earth orbit
LGW	laser-guided weapon
LHT	Lightweight Hybrid Torpedo
LIC	low-intensity conflict
LIDAR	light detection and ranging
LMRS	Long-Term Mine Reconnaissance System
LO	low observable
LOCAAS	low-cost antiarmor submunition
LOSAT	line-of-sight antitank
L/V	lethality/vulnerability

MAT	multimode airframe technology
MCM	mine countermeasure
MEMS	microelectromechanical systems
MICLIC	mine clearing line charge
MISS	multiband IRCM laser source solution
MJ	megajoule
MLRS	Multiple Launch Rocket System
MMIC	monolithic microwave integrated circuits
MMW	millimeter wave
MOA	memorandum of agreement
MOU	memorandum of understanding
MOUT	Military Operations in Urban Terrain
MPM	microwave power module
MSCM	multispectral countermeasure
MTBF	mean time between failure
MTI	moving target indicator
MTV	Mobile Test Vehicle
MUDDS	Multisensor Underwater Debris Detection System
MWS	Missile Warning System
NASA	National Aeronautics and Space Administration
NAVOCEANO	Naval Oceanographic Office
NCTR	noncooperative target recognition
NDI	nondestructive inspection
NMD	national missile defense
nmi	nautical mile
NTM	national technical means
OCSW	Objective Crew-Served Weapon
OICW	Objective Individual Combat Weapon
ONI	Office of Naval Intelligence
ONR	Office of Naval Research
OOTW	operations other than war
OPW	objective personnel weapon
ORSMC	Off-Route Smart Mine Clearance
OSW	objective sniper weapon
P^3I	preplanned product improvement
P_d	probability of detection
P_h	probability of hit
P_k	probability of kill
PEO(USW)	Program Executive Office (Undersea Warfare)
PGM	precision-guided munition
PI	product improvement
PIP	product improvement program
POET	Phase One Evaluation Team
PROTEC	Programmable Ordnance Technology
psi	pounds per square inch
QA	quality assurance
R&D	research and development
RAMICS	Rapid Airborne Mine Clearance System
RCS	radar cross section

RECO	remote control
RF	radio frequency
RFPI	Rapid Force Projection Initiative
RHA	rolled homogenous armor
RJ	ramjet
RMOP	Remote Minehunting Operational Prototype
RMS	Remote Minehunt System
RTIC	real-time information in the cockpit
RTOC	real-time information out of the cockpit
RTSMP	real-time symmetric multiprocessing
RV	reentry vehicle
S&A	safe and arm
S&T	science and technology
SABRE	Shallow-Water Assault Breaching System
SADARM	seek-and-destroy armor
SAM	surface-to-air missile
SAR	synthetic aperture radar
SASMB	Side Attack Standoff Minefield Breacher
SBIR	small business innovation research
SBL	space-based laser
SDWS	Submarine Defensive Warfare System
SEAD	suppression of enemy air defense
SEI	specific emitter identification
SFW	sensor-fused weapon
SIGINT	signals intelligence
SIIRCM	suite of integrated infrared countermeasures
SIRFC	suite of integrated radio frequency countermeasures
SLAM	Standoff Land Attack Missile
SLMM	Submarine-Launched Mobile Mine
SMTD	submarine torpedo defense
SOF	Special Operations Forces
SOJ	standoff jamming
SRBOC	Super Rapid Blooming Off-Board Chaff
SSB	Small Smart Bomb
SSTD	surface ship torpedo defense
STAFF	Smart Target Activated Fire and Forget
SURVIAC	Survivability Vulnerability Information Analysis Center
SW	shallow water (200 to 40 ft)
T&E	test and evaluation
TACAIR	tactical aircraft
TARA	Technology Area Review and Assessment
TBM	tactical ballistic missile
TD	Technology Demonstration
TDA	tactical decision aid
TDD	target detection device
TDP	technical data package
TEL	transportable erectable launcher
THEL	Tactical High-Energy Laser
TMD	theater missile defense
TMET	transonic missile engagement target
TOW	Tube-Launched Optically Guided Weapon
TVC	thrust vector control

UAV	unmanned aerial vehicle
UTD	Unmanned Terrain Domination
UUV	unmanned underwater vehicle
UV	ultraviolet
UWB	ultra wideband
UXO	unexploded ordnance
VSW	very shallow water (40 to 10 ft)
W	watt
WAM	wide area munition
WL/V	weapon lethality/vulnerability
WMD	weapons of mass destruction
WSC	Warfighting Support Center

APPENDIX

RESOURCE FUNDING

FY 1998 DEFENSE TECHNOLOGY AREA PLAN
($ in thousands)

Technology Area	Total Funding	DTO Funding
Air Platforms	625,236	235,705
C/B Defense & Nuclear	218,034	113,550
Info Systems Technology	1,210,080	727,117
Ground & Sea Vehicles	308,716	124,900
Materials/Processes	430,523	153,577
Biomedical	295,618	77,900
Sensors, Electronics, & Battlespace Environment	1,390,717	440,506
Space Platforms	163,343	100,522
Human Systems	253,933	102,626
Weapons	914,967	213,858
TOTAL	5,811,166	2,290,261

DEFENSE TECHNOLOGY AREA FUNDING
($ in thousands)

Technology Area	FY97	FY98	FY99	FY00	FY01	FY02	FY03
Air Platforms	487,328	625,236	622,804	637,996	685,231	712,005	743,504
C/B Defense & Nuclear	219,368	218,034	216,489	219,825	222,614	236,896	242,538
Info Systems Technology	1,133,756	1,210,080	1,300,500	1,373,995	1,426,951	1,518,655	1,543,153
Ground & Sea Vehicles	335,269	308,716	349,235	375,992	429,576	430,496	465,644
Materials/ Processes	585,561	430,523	426,605	423,697	418,068	485,194	510,706
Biomedical	340,983	295,618	324,020	317,215	314,688	312,554	314,769
Sensors, Electronics, & BE	1,340,953	1,390,717	1,487,011	1,565,426	1,533,331	1,489,350	1,527,867
Space Platforms	238,324	163,343	180,992	200,685	214,154	221,250	217,103
Human Systems	271,300	253,933	248,128	244,138	232,062	236,468	241,293
Weapons	1,015,150	914,967	942,836	1,012,222	1,004,250	1,030,973	1,058,870
Total	5,967,991	5,811,166	6,098,619	6,371,191	6,480,925	6,673,841	6,865,446

DEFENSE TECHNOLOGY SUBAREA FUNDING
($ in thousands)

Subarea	FY 97	FY 98	FY 99	FY 00	FY 01	FY 02	FY 03
AIR PLATFORMS							
Fixed-Wing Vehicles	283,795	420,938	401,861	398,295	433,405	449,018	464,941
Rotary-Wing Vehicles	31,991	23,593	32,929	49,322	61,940	68,630	79,379
IHPTET	123,461	132,239	136,686	140,900	145,086	148,036	151,717
Aircraft Power	20,977	24,692	28,920	27,605	22,007	22,715	23,392
High-Speed Propulsion & Fuels	27,104	23,774	22,408	21,874	22,793	23,606	24,075
Technology Area Total	**487,328**	**625,236**	**622,804**	**637,996**	**685,231**	**712,005**	**743,504**
DTAP DTO Total	**213,816**	**235,705**	**262,043**	**271,761**	**261,927**	**265,408**	**285,511**
% DTAP DTOs of Total	**44%**	**38%**	**42%**	**43%**	**38%**	**37%**	**38%**
CHEMICAL/BIOLOGICAL DEFENSE & NUCLEAR							
CB Detection	56,501	40,919	37,529	34,008	33,112	38,913	40,786
CB Protection	13,626	10,103	8,673	9,788	10,225	11,677	11,200
CB Decontamination	10,604	4,458	4,251	4,220	6,555	6,873	7,609
CB Studies, Analysis, & Simulation	5,923	4,673	4,987	6,496	6,382	8,008	8,116
Systems Effects & Survivability (Nuclear)	29,838	36,463	37,659	40,929	42,918	46,712	47,661
Test & Simulation Technology (Nuclear)	36,603	45,205	44,306	43,465	41,197	41,575	41,955
Scientific & Operational Computing (Nuclear)	14,563	17,530	18,008	17,604	17,390	17,390	17,390
Warfighter Support (Nuclear)	51,710	58,683	61,076	63,315	64,835	65,748	67,821
Technology Area Total	**219,368**	**218,034**	**216,489**	**219,825**	**222,614**	**236,896**	**242,538**
DTAP DTO Total	**92,287**	**113,550**	**115,251**	**119,269**	**112,056**	**115,990**	**115,799**
% DTAP DTOs of Total	**42%**	**52%**	**53%**	**54%**	**50%**	**49%**	**48%**
INFORMATION SYSTEMS TECHNOLOGY							
Decision Making	164,414	207,641	215,937	196,094	201,522	167,243	168,273
Modeling & Simulation Technology	194,605	168,789	182,260	219,311	235,701	254,644	280,735
Information Management & Distribution	351,861	381,251	419,739	466,986	584,512	673,814	657,230
Seamless Communications	120,948	114,802	125,684	119,515	76,943	84,512	84,616
Computers & Software Technology	301,928	337,597	356,880	372,090	328,273	338,442	352,299
Technology Area Total	**1,133,756**	**1,210,080**	**1,300,500**	**1,373,995**	**1,426,951**	**1,518,655**	**1,543,153**
DTAP DTO Total	**665,555**	**727,117**	**768,079**	**722,605**	**661,206**	**364,382**	**361,202**
% DTAP DTOs of Total	**59%**	**60%**	**59%**	**53%**	**46%**	**24%**	**23%**

DEFENSE TECHNOLOGY SUBAREA FUNDING
($ in thousands) (continued)

Subarea	FY 97	FY 98	FY 99	FY 00	FY 01	FY 02	FY 03
GROUND & SEA VEHICLES							
Ground Vehicles	125,227	107,949	143,803	144,523	170,313	191,076	212,791
Surface Ship Combatants	143,847	128,535	125,927	150,542	179,158	157,938	169,632
Submarines	52,595	60,077	66,671	67,727	66,549	67,926	69,295
Unmanned Undersea Vehicles	13,600	12,155	12,834	13,200	13,556	13,556	13,926
Technology Area Total	**335,269**	**308,716**	**349,235**	**375,992**	**429,576**	**430,496**	**465,644**
DTAP DTO Total	**148,300**	**124,900**	**148,300**	**149,500**	**137,800**	**114,200**	**118,700**
% DTAP DTOs of Total	**44%**	**40%**	**42%**	**40%**	**32%**	**27%**	**25%**
MATERIALS/PROCESSES							
M&P for Survivability, Life Extension, & Affordability	224,166	198,204	200,330	202,950	222,852	286,475	307,192
Manufacturing Technology	157,108	97,661	84,592	74,080	47,714	41,037	43,114
Civil Engineering	54,380	26,888	31,288	34,736	36,276	37,544	35,942
Environmental Quality	149,907	107,770	110,395	111,931	111,226	120,138	124,458
Technology Area Total	**585,561**	**430,523**	**426,605**	**423,697**	**418,068**	**485,194**	**510,706**
DTAP DTO Total	**203,654**	**153,577**	**141,918**	**131,589**	**98,781**	**80,614**	**13,689**
% DTAP DTOs of Total	**35%**	**36%**	**33%**	**31%**	**24%**	**17%**	**3%**
BIOMEDICAL							
Infectious Diseases of Military Importance	58,246	65,298	63,895	54,683	55,762	56,414	57,522
Combat Casualty Care	97,345	123,608	146,478	147,726	141,466	135,584	133,401
Medical Biological Defense	21,057	25,334	26,783	26,664	27,148	27,728	28,378
Medical Chemical Defense	46,558	23,089	24,508	24,330	24,805	25,337	25,929
Military Operational Medicine	106,205	46,200	49,931	51,265	52,800	54,509	56,256
Military Dentistry	311	324	424	309	277	288	290
Medical Radiological Defense	11,261	11,765	12,001	12,238	12,430	12,694	12,993
Technology Area Total	**340,983**	**295,618**	**324,020**	**317,215**	**314,688**	**312,554**	**314,769**
DTAP DTO Total	**83,500**	**77,900**	**70,479**	**63,664**	**54,571**	**47,200**	**34,300**
% DTAP DTOs of Total	**24%**	**26%**	**22%**	**20%**	**17%**	**15%**	**11%**

DEFENSE TECHNOLOGY SUBAREA FUNDING
($ in thousands) (continued)

Subarea	FY 97	FY 98	FY 99	FY 00	FY 01	FY 02	FY 03
SENSORS, ELECTRONICS, AND BATTLESPACE ENVIRONMENT							
Radar Sensors	99,315	112,273	123,058	114,100	105,035	94,122	96,040
Electro-Optic Sensors	127,821	120,268	103,151	129,597	122,161	109,969	115,391
Acoustic Sensors	84,653	116,693	142,517	156,500	120,150	122,727	125,628
Automatic Target Recognition	128,330	169,601	192,668	181,256	182,144	187,142	199,022
Integrated Platform Electronics	78,639	87,884	87,854	108,578	116,973	119,100	116,145
Radio Frequency Components	106,755	88,073	81,882	70,482	74,544	79,589	81,334
Electro-Optic Technology	206,943	155,519	164,683	139,965	144,589	104,489	106,056
Microelectronics	187,051	206,523	232,098	273,427	273,661	277,019	275,690
Electronic Materials	75,866	64,672	78,825	80,705	84,091	78,950	84,476
Electronics Integration Technology	90,387	88,144	114,960	156,695	163,336	167,766	174,087
Terrestrial Environments	9,613	10,426	11,007	11,023	11,111	11,296	12,906
Ocean Battle Space Environment	50,117	34,864	46,303	49,009	40,492	41,084	42,089
Lower Atmosphere Environment	54,491	38,583	42,610	41,260	42,830	43,742	45,018
Space/Upper Atmosphere Environment	40,972	97,192	65,394	52,827	52,215	52,356	53,984
Technology Area Total	**1,340,953**	**1,390,717**	**1,487,011**	**1,565,426**	**1,533,331**	**1,489,350**	**1,527,867**
DTAP DTO Total	**445,216**	**440,506**	**422,907**	**273,145**	**36,463**	**4,300**	**0**
% DTAP DTOs of Total	**33%**	**32%**	**28%**	**17%**	**2%**	**0%**	**0%**
SPACE PLATFORMS							
Space & Launch Vehicles	178,035	117,590	122,449	139,871	151,823	157,827	153,733
Propulsion (IHPRPT)	60,289	45,753	58,543	60,814	62,331	63,423	63,370
Technology Area Total	**238,324**	**163,343**	**180,992**	**200,685**	**214,154**	**221,250**	**217,103**
DTAP DTO Total	**113,534**	**100,522**	**109,720**	**100,794**	**98,852**	**84,429**	**85,109**
% DTAP DTOs of Total	**48%**	**62%**	**61%**	**50%**	**46%**	**38%**	**39%**

DEFENSE TECHNOLOGY SUBAREA FUNDING
($ in thousands) (continued)

Subarea	FY 97	FY 98	FY 99	FY 00	FY 01	FY 02	FY 03
HUMAN SYSTEMS							
Personnel Performance & Training	84,996	83,753	88,592	88,789	92,430	93,218	95,293
Info Display & Performance Enhancement	40,779	38,076	37,683	36,681	34,281	35,253	36,467
Warrior Protection & Sustainment	75,571	69,825	66,541	66,306	50,859	53,033	52,713
Design Integration & Supportability	69,954	62,279	55,312	52,362	54,492	54,964	56,820
Technology Area Total	**271,300**	**253,933**	**248,128**	**244,138**	**232,062**	**236,468**	**241,293**
DTAP DTO Total	**116,636**	**102,626**	**77,064**	**68,981**	**67,311**	**12,650**	**13,210**
% DTAP DTOs of Total	**43%**	**40%**	**31%**	**28%**	**29%**	**5%**	**5%**
WEAPONS							
Conventional Weapons							
Countermine/Mines	146,041	125,182	133,888	145,867	133,208	135,839	139,008
Guidance & Control	317,053	324,792	297,772	263,484	244,872	256,232	264,423
Guns	89,556	79,445	95,819	98,874	113,887	119,128	120,232
Missiles	18,165	11,012	13,056	9,303	9,137	11,758	10,384
Ordnance	64,689	58,276	56,807	91,601	99,689	103,000	107,963
Undersea Weapons	32,314	32,063	39,002	41,122	36,671	37,637	38,376
Weapons L/V	28,784	36,015	38,639	38,779	31,260	29,052	29.914
Directed-Energy Weapons							
Lasers	141,311	62,752	62,413	61,455	59,741	61,033	62,739
High-Power Microwave	38,927	33,445	35,089	37,383	38,521	39,463	40,519
Electronic Warfare							
Threat Warning	23,958	23,808	24,085	24,654	25,270	24,654	25,129
Self-Protection	62,656	57,392	61,594	66,992	70,536	67,483	69,655
Mission Support	51,696	70,785	84,672	132,708	141,459	145,694	150,528
Technology Area Total	**1,015,150**	**914,967**	**942,836**	**1,012,222**	**1,004,250**	**1,030,973**	**1,058,870**
DTAP DTO Total	**264,596**	**213,858**	**214,407**	**167,902**	**147,075**	**121,440**	**109,744**
% DTAP DTOs of Total	**26%**	**23%**	**23%**	**17%**	**15%**	**12%**	**10%**