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Select Astronaut Observations and Highlights of Space Shuttle Program Payloads and Experiments

Supplement to *Wings in Orbit: Scientific and Engineering Legacies of the Space Shuttle* (NASA/SP-2010-3409)

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Table of Contents

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1.0 INTRODUCTION

This Technical Memorandum (TM) serves as an addendum to the NASA/SP-2010-3409 book titled *Wings In Orbit: Scientific and Engineering Legacies of the Space Shuttle*, which was edited by Wayne Hale, Helen Lane, Gail Chapline, and Kamlesh Lulla, and was published by the Government Printing Office. This document has been compiled to provide *selected highlights* of the science and engineering payloads, experiments, engineering and scientific tests, and other technical activities that were carried out during the Space Shuttle era. *It is very important to note that this TM highlights selected payloads and experiments to offer glimpses into the intensive scientific and engineering initiatives throughout the Space Shuttle Program.* We spent countless hours reviewing NASA publications, non-NASA literature, research reports, press kits, and other documents during the preparation of the *Wings In Orbit* book. This TM is a by-product of these efforts.

While this document is quite detailed and highly informative, it is neither comprehensive nor encyclopedic. Our intention is to give readers an overview of the shuttle science and engineering payloads. In addition, we have included selected personal observations provided by a handful of astronauts who responded to our call for submitting personal experiences by the shuttle flight crew. We gratefully acknowledge their contributions to this publication. These essays provide insights into the shuttle operations as experienced by those who flew this magnificent machine.

The shuttle has been a crown jewel in NASA's human spaceflight program for over 3 decades. This spectacular flying machine served as a symbol of our nation's prowess in science and technology as well as a demonstration of our nation's "can-do" attitude. The Space Shuttle Program was a major leap forward in our quest for space exploration.

So, what made Space Shuttle unique? The shuttle launched as a rocket, served as an orbital workstation and space habitat, and landed like a glider. The American engineering that conceived of, designed, and manufactured the shuttle was innovative for its time, providing capabilities beyond our expectations in all disciplines related to the process of launching, working in space, and returning to Earth. We learned with every succeeding flight how to operate more efficiently and effectively in space. This knowledge will translate to all future space vehicles and the ability of their crews to live and work in space.

The Space Shuttle served as a workhorse for space operations and scientific research. Satellite launching, repair, and retrieval provided the satellite industry with important capabilities. The Department of Defense, national security organizations, and commercial companies used the shuttle to support their unique missions. Without the shuttle and its servicing mission crews, the magnificent Hubble Space Telescope astronomical science discoveries would not have been possible. Laboratories carried in the payload bay of the shuttles provided opportunities to use microgravity's attributes for understanding human health, physical and material sciences, and biology. Shuttle research advanced our understanding of planet Earth, our own star—the sun—as well as our atmosphere and oceans. From orbit aboard the shuttle, astronaut crews collected hundreds of thousands of Earth observation images and used innovative radar sensors to map 90% of its land surface.

The Space Shuttle laid the foundation for international collaboration, which expanded considerably during this era. Canada provided the robotic arm that helped with satellite repair and served as a mobile crew platform for performing extravehicular activities during construction of the International Space Station and upgrades and repairs to Hubble. The European Space Agency provided a working laboratory to be housed in the payload bay during the period of flying the series of space laboratory missions. Both contributions were technical and engineering marvels. Japan, along with member nations of the European Space Agency and Canada, had many successful science and engineering payloads. This collaboration provided the basis for necessary interactions and cooperation.

The International Space Station—the completion of which was only possible with the shuttle—further demonstrates the role of international cooperation as nations including Russia, Japan, Canada, and the member nations of the European Space Agency join the United States to ensure that our quest for ever-increasing knowledge of our universe continues to move forward.

This "Remarkable Flying Machine" has been an unqualified success and will remain forever a testament to the ingenuity, inventiveness, and dedication of the NASA/industry team.

Finally, we offer this document to illustrate the range and scope of science and engineering research that is a vital legacy of the Space Shuttle Program.

How to use this addendum:

The data on the Space Shuttle flights highlighted here are in chronological order by date(s) of the mission. The summaries are high-level descriptions of the experiments/engineering tests, etc. Please refer to the appropriate section of Wings In Orbit *for more information.*

2.0 SELECT ASTRONAUT OBSERVATIONS

2.1 William Anders

Legacy of the Space Shuttle Program Scientific and Engineering Accomplishments
Some Financial Perspective

Without trying to belittle the many scientific and engineering accomplishments of the Space Shuttle Program, it needs to be recognized that the shuttle has been an excessively expensive endeavor that has caused financial hemorrhaging in NASA since the program's inception in the early 1970s. Though the vast majority of this book will justifiably focus on the shuttle's many achievements, a more balanced perspective is especially important now as NASA retires the shuttle and embarks on another major thrust into space and might mistakenly use the shuttle's development program as a model for future conventional ("throw away") boosters and new spacecraft.

In the early 1970s, just prior to President Nixon's second election, NASA lobbied the White House and Congress for a reusable Space Transportation System (STS)—more commonly called the Space Shuttle—that was advertised by NASA to reduce the cost to orbit by a factor of 10. At the time, the Office of Management and Budget and others were suggesting a smaller manned, recoverable "test vehicle" to get a better handle on technical, operational, and cost issues before committing to the larger "full up" approach advocated by NASA.

As the recently (1969) appointed executive secretary of the National Aeronautics and Space Council chaired by the vice president and whose members were various Cabinet officers, it was my job to objectively present various space policy options to the White House for decision. In the midst of the shuttle deliberations, I received a phone call from Bob Halderman, one of Nixon's top aids (and later caught up in the Watergate scandal). He wanted to know which of the two competing concepts, large or small, would employ the largest number of aerospace workers in California (a key state in the upcoming election). I told him that obviously the larger the program, the higher the employment in California. And, that was it. Large it was to be. To compound the challenge to NASA, when the NASA administrator, Dr. James Fletcher, went to the Western White House to brief the president, Fletcher forgot to ask for a planned $500 million contingency and therefore the program was plagued with underfunding and resultant schedule slippages and possible engineering and operational compromises from the start.

The shuttle has been spectacular, but a balanced story of the program should also reflect that, with regard to the past and future boosters, it has been a bit of a cuckoo in the nest. Rather than reduce the cost to orbit by a factor of 10 as originally advertised, it actually INCREASED the cost by a factor of 10. A 100-fold error for which NASA as a whole has paid dearly. Its domination of the NASA budget for over 3 decades has resulted in the delay or cancellation of many other manned and unmanned programs that likely would also have left a great legacy in "scientific and engineering achievements" as well—though there would have been less jobs in both California and NASA.

Today, NASA is faced with the almost unbelievable course of having to buy conventional booster and re-entry rides from its Cold War and space race competitor, Russia, while scrambling to redevelop our own stable of conventional boosters and manned spacecraft that have essentially been ignored since the 1970s.

While reaching for the stars, we must be careful not to overreach and thereby fall short.

2.2 Robert Cabana

From Small Beginnings, Great Things Come

Of all the missions that have been accomplished by the Space Shuttle, the assembly of the International Space Station (ISS) certainly has to rank as one of the most challenging and successful. Without the Space Shuttle, the ISS would not be what it is today. It is truly a phenomenal accomplishment, especially considering the engineering challenge of assembling hardware from all parts of the world, on orbit, for the first time and having it work. Additionally, the success is truly amazing when one factors in the complexity of the cultural differences between the European Space Agency and all its partners—Canada, Japan, Russia, and the United States. It wasn't easy getting to where we are now, but it certainly has been rewarding.

When I look back on where we were in 1994, when I was chief of the Astronaut Office, and where we are today, just short of final ISS assembly 15 years later, it's hard to believe what we've achieved. It's a tribute to the team and the international partnerships. Early on, many doubted that we could do it. Some claimed that the technical challenges were too high, the cost was too much, and the partnerships were too difficult. In 1994 few astronauts wanted to be involved with the ISS, when the shuttle was flying eight times a year. It was a challenge to find astronauts who were willing to be pulled from the busy, day-to-day work of the shuttle to be part of a program that was still mostly on the drawing board. It was even more of a challenge when it came time to assign the first long-duration flight crews for the ISS, when it meant long stays away from home training in Russia and learning technical systems at a detailed level in a foreign language. In spite of the ground work that was laid with the Russians during the Shuttle-Mir program, the first ISS crews had to overcome many obstacles, and it wasn't easy. These crews paved the way for all crews that followed, providing many lessons learned and improving the training flow and our relationship with our partner.

When the Russian Functional Cargo Block (FGB), known as Zarya—which means sunrise in Russian—launched on November 20, 1998, it paved the way for the launch of Space Shuttle Endeavour, carrying the United States ISS Node 1, called Unity, in the payload bay. The first assembly mission had slipped almost a year, but in December 1998, we were ready to go. Our first launch attempt on December 3 was scrubbed, after counting down to 18 seconds, due to technical issues with the Auxiliary Power Units.

The next day the weather cleared, and I have a beautiful picture of Endeavour on the pad with a rainbow over it that was on the front page of Florida Today. Now, I have to share why that was so special to me. My daughter Sarah and I are real The Wizard of Oz aficionados. Right before we, the crew, went into quarantine, the remastered copy of The Wizard of Oz was released, and Sarah and I went to see it. Our first day on orbit, our wake-up music was Judy Garland singing "Somewhere Over the Rainbow," and it really got to me. I always tell folks that somewhere over the rainbow, dreams do come true, because we launched with a textbook count for the second launch attempt the evening of December 4 and had an absolute dream flight.

Endeavour performed flawlessly. The Space Shuttle is such an amazing machine. No other vehicle has matched its capabilities or versatility, and it will be many years before we have another vehicle like it, if ever.

The handling qualities of the Orbiter during rendezvous and proximity operations are superb and amazingly precise. During training in the simulator, I was able to stabilize the FGB about 3 feet from the end of the arm, ready for capture. The shuttle could actually be flown in to grab Zarya instead of using the arm. On orbit is not the same as the simulator, and things are a little different. Throughout the rendezvous, Jim Newman was providing me information on range and range rates and what inputs he thought were right for the situation. I filtered his input with all the other data available, and we flew a precise rendezvous profile, eventually bringing the FGB, a 45,000-pound mass, into the payload bay 3 feet from the arm. At this point, I was relying solely on the end effector camera on the arm and a centerline camera in the payload bay to keep Zarya centered. We were waiting to fly over a Russian ground site for confirmation that the FGB was in free drift before we grappled it, to avoid a force fight and damage to either vehicle. While we were waiting, we reached a dead band for the attitude hold on the Digital Autopilot (DAP) and the big jets (800-pound thrusters vice 50-pound verniers) fired to keep us centered. The attitude correction coupled into a translation, and suddenly, this 45,000-pound mass starts moving toward the arm and into the payload bay. I immediately began making Translational Hand Controller inputs to move away from it, to no avail. We were in the B DAP for fine control, and I didn't have enough control power. Quickly switching to the A DAP, I was able to get the FGB moving away from Endeavour, avoiding impact with the arm or the shuttle. During the whole event, which went by very quickly, there was dead silence in the cockpit. Jim Newman, who was normally providing lots of verbal help in this arena as he had taught it as an instructor prior to his selection as an astronaut, was totally quiet. When I asked him about it afterwards, his reply was, "I know when to keep my mouth shut." Once stabilized and over a Russian ground site, we got the "go" for grapple, and Nancy Currie did a superb job on the arm, grappling Zarya and berthing it to the Orbiter docking station. With that task complete, we were ready to lift Unity out of the payload bay and attach it to Zarya. Again, it was the shuttle's unique capabilities that made all of this possible.

On December 10, Sergei Krikalev and I entered the Space Station for the first time. What a unique and rewarding experience it was to enter this new outpost side by side. It was a very special 2 days that we spent working inside this fledgling space station.

That evening, Jim Newman was up on the flight deck sending e-mails home and just looking out the window when he decided to take one more look inside this amazing Space Station before turning in. Our rule was you could be up past sleep time if you were quiet and didn't disturb those crew members who needed a full 8 hours. We had a darkened ship on the middeck for crew sleep, and Jim was very quiet as he made his way down past Jerry Ross and Rick Sturckow, who were plastered to the wall in their sleeping bags. Where the internal airlock used to be, we had four large bags that were the size of refrigerators. Two were mounted on the floor, and two were on the ceiling. As you faced the airlock hatch, Nancy Currie was sleeping between the two on the right side, and I was between the two on the left. Jim knew that he would be in trouble if he disturbed me, so he was very careful as he moved by to go up through the airlock to the pressurized mating adapter and into Unity. He was sheepishly chagrined to find Sergei Krikalev and me wide awake and working in the ISS, trying to get as much done as we could. We were still pulling out launch restraint bolts from the panels that provided structural integrity for launch loads but were no longer needed on orbit.

We worked and talked late into the night about what this small cornerstone would become and what it meant for international cooperation and the future of exploration beyond our home planet. It was an evening that I will never forget. I made the first entry into the log of the ISS, and the whole crew signed it the next day.

A little over 3 hours from crew wake-up, I finally had to call an end to our time together, so we could get some rest for the very busy day we had ahead of us, even though I wished it would never end.

Since that flight, the Space Station has grown to reach its full potential as a world-class microgravity research facility and an engineering proving ground for operations in space. As it passes overhead, it is by far the brightest star in the early evening and morning skies and is a huge symbol of the preeminent and unparalleled capabilities of the Space Shuttle.

In closing these reflections on ISS, we talk much of the Space Shuttle hardware and the engineering accomplishment that it is. But more than the hardware, the Space Shuttle and the Space Shuttle Program are a result of the people behind it. It is a uniquely talented, qualified, dedicated contractor/civil service team that has made the Space Shuttle what it is and is responsible for what it has accomplished. It is a team that comes to work every day with smiles on their faces, and a team that takes on all challenges and continually succeeds in the face of adversity. It's what makes NASA such a great place to work and what has made the Space Shuttle the phenomenal success that it has been.

2.3 Leroy Chiao

My Perspectives of the Space Shuttle Program

General Comment

To me, the Space Shuttle is an amazing flying machine. It launches vertically as a rocket, turns into an extremely capable orbital platform for many purposes, and then becomes an airplane after re-entry into the atmosphere, for landing on a conventional runway. Moreover, it is a reusable vehicle, which was a first in the US space program.

It is said that imitation is the most sincere form of flattery. One look at the Soviet Buran shuttle tells the observer that many features were copied from the US design. It is a testament to US engineering and will, that the US shuttles have been flying for 27 years, while the Soviet Buran made but a single, unmanned test flight before being retired and mothballed. Indeed, private conversations with Russian specialists confirm that the Buran program very nearly bankrupted the Soviet space program and stretched their technical abilities to the limit. Other nations also tried to build manned reusable shuttles, but all were canceled before even one flight test (French Hermes, Japanese Hope shuttle projects).

The Space Shuttle Program presented me the opportunity to become a NASA astronaut and to fly in space. I grew up during the early days of the US program and followed the early missions. I was 8 years old when Apollo 11 landed on the moon. Even as a young boy, I realized that the world had changed and I wanted to be a part of it! I never forgot that dream and years later, I planned to apply to NASA to become a shuttle astronaut when I watched the first launch of Columbia in April 1981.

In addition to being a superb research and operations platform, the Space Shuttle also serves as a bridge to other nations. Never before had foreign nationals flown aboard US spacecraft. On shuttle, the US has flown representatives from nations all around the world. Space is an ideal neutral ground for cooperation and the development of better understanding and relationships between nations.

STS-65: Space Shuttle Columbia (Spacelab)

My first flight! Twenty-five years after the Apollo 11 mission inspired my dream of becoming an astronaut, I flew my first space mission aboard the first Space Shuttle. By coincidence, we launched on the namesake of the Apollo 11 Command Module, off of the same launch pad as Apollo 11 and during the 25th anniversary of the Apollo 11 mission (including launch, moon landing and return to Earth).

Ours was a Spacelab mission, the Second International Microgravity Laboratory. We flew with Japanese astronaut Chiaki Mukai and trained with French astronaut Jean-Jacques Favier. We traveled to Japan, Canada, and Europe to train with the scientists and specialists from those countries who had experiments on board. The genuine friendships that formed and our the interesting discussions of world events from different perspectives was illuminating. I believe that this was a wonderful model of how to improve international relations.

Spacelab was a superb research platform. It was an efficient use of the shuttle payload bay to maximize scientific research return. Working around the clock in two shifts during our 2-week mission, we accomplished over 82 scientific investigations, which was actually more than was completed during my $6^1/_2$-month mission aboard the International Space Station (ISS) on Expedition X!

The Space Shuttle/Spacelab combination to me represents the best research platform for short-duration microgravity research.

STS-72: Space Shuttle Endeavour (Extravehicular Activity [EVA]Testing of ISS Tools and Construction Techniques)

On this mission, I flew with Japanese astronaut Koichi Wakata, who used the robotic manipulator to retrieve the Japanese Space Flyer Unit, and Brian Duffy who served as the commander. I performed my first two EVAs on this mission. We used the shuttle payload bay as a microgravity testing ground in the actual space environment, to test tools and construction techniques that would be used to build the ISS.

Two main concepts were proven during these tests. One was the use of a Body Restraint Tether, which, by eliminating the requirement for the overhead and logistics of using Articulating Portable Foot Restraints for many tasks, made it possible to complete the demanding timelines of ISS assembly flights to come. The other major test was the demonstration of deploying a hinged cable tray and the mating of associated connectors. These trays are used today in several places on the ISS to interconnect modules with electrical and fluid lines.

Without Space Shuttle as an EVA test bed, we would not have been nearly as successful as we have been so far in assembling the ISS. Our test was the third in the series of EVA Development Flight Tests.

STS-92: Space Shuttle Discovery (ISS Assembly Flight 3A. Z1 Truss and PMA-3)

I was part of the crew on this flight of Discovery, along with Brian Duffy and Koichi Wakata, whom I flew with on STS-72. On this mission, I served as the EVA lead. We put into practice many of the EVA lessons learned on STS-72.

The Space Shuttle again proved its flexibility and capability for ISS construction missions. We used the vehicle to carry Z1 and PMA-3 to ISS. Koichi used the robotic arm to install these elements and we used the shuttle EVA system to complete the installation of these elements and bring them to life.

Upon our landing, I realized that my shuttle days were behind me. I was about to begin training in the Expedition Corps. I finally flew as the commander and NASA science officer of Expedition X 4 years later, aboard Soyuz TMA-5.

But on that afternoon, as we walked around and under Discovery, I savored the moment and felt a mixture of awe, satisfaction, and a little sadness. Shuttle to me represents a triumph and remains, to this day, a technological marvel. We have learned so much from the program, not only in the advancement of science and international relations, but also from what works and what doesn’t on a reusable vehicle. The lessons learned from shuttle will make future US spacecraft more reliable, safer, and more cost effective.

I love the Space Shuttle. I am proud and honored to be a part of its history and legacy.

2.4 Eileen Collins

The Chandra X-Ray Observatory: One of the Shuttle's Many Success Stories

On July 23, 1999, I had the incredible privilege of commanding the Space Shuttle Columbia, which took the Chandra X-Ray Observatory into space. At that time, Chandra had a 5-year mission, which it has now far surpassed. That mission was to obtain unprecedented images of x-ray objects such as black holes, supernovas, neutron stars, and other exotic x-ray sources that are billions of light years away. Chandra is one of NASA's four great observatories, the others being the Hubble Space Telescope, the Compton Gamma Ray Observatory, and the Spitzer Space Infrared Telescope. Conceived in 1976, Chandra is named after Subrahmanyan Chandrasekhar, a well-loved Indian-American physicist.

Some fun facts I like to tell people: Chandra can focus so well, it could read a newspaper at half a mile. If the surface of the Earth was as smooth as Chandra's mirrors, the highest mountain would be no greater than 6 feet tall. As for our shuttle flight, we had the heaviest and largest payload ever launched on a shuttle. STS-93 was also the last shuttle to launch an Inertial Upper Stage booster assisted payload.

STS-93 was a dream mission for me. Not only did I have an opportunity to command a Space Shuttle mission, but I could marry it with a longtime hobby of mine: astronomy. When I was a child in upstate New York, I would look to the stars at night, and feel inspired and excited. I wanted to travel to each one of those points of light. I wanted to know what was there, what were they made of. Were there people there?

After I joined the Air Force, I moved to Oklahoma to attend pilot training. The wide-open, dark, clear skies encouraged me to buy my first telescope. I began buying books and magazines on astronomy, and spent most of my spare time reading! During that assignment, in 1981, I watched the first Space Shuttle, Columbia, rocket into space with John Young and Bob Crippen. Many new shuttle astronauts came to my base, Vance Air Force Base, for a standard parachute training class. This combination of exposure to the night skies and the emerging Space Shuttle Program greatly inspired me to plan my career around my eventual application to the astronaut program!

After over a year of training for STS-93, and several unexpected launch delays, to ensure "we got it right," my crew headed to the launch pad on July 20, 1999, which interestingly coincided with the 30th anniversary of Apollo 11. With many VIPs in attendance, and a beautiful clear summer night, the launch was manually halted at T-8 seconds, by a very sharp attentive engineer, who saw the "hydrogen spike" in the aft compartment. He knew this could mean a serious leak, so he made the right call, all in the interest of saving the shuttle, pad, crew, and cargo. Fortunately, it was later determined to be a sensor failure, and we were subsequently cleared to launch again in 2 days. Then, after a single weather scrub (the weather officer had given us a "100%" chance of "GO" that night!), we rescheduled for the 23rd and lit up the Florida sky shortly after midnight. Well, this was no ordinary launch! Five seconds after liftoff, we saw a "Fuel Cell PH" message in the cockpit, received a call from Houston, and learned we had an AC Phase 1 short, which took out two main engine controllers! Fortunately, due to the shuttle redundancy, we did not lose any of our engines. And unbeknownst to us, there was a second problem: at start-up, a pin had popped loose from a main engine injector plate; hit several cooling tubes, causing us to leak hydrogen all the way to orbit. A "LOX low-level cutoff" resulted in a "15 foot per second under-speed" from our target. (Note: the mixture ratio caused us to run out of liquid oxygen before the liquid hydrogen.)

Fortunately, the robustness of the main engines prevented the hydrogen leak from further deteriorating. The Space Shuttle Program never again “pinned” a main engine ejector plate. As for the electrical short, after our mission it was determined that a screw had been rubbing against a wire bundle during many mid-body maintenance sessions. Since this area was not often inspected, the wear and tear went unnoticed until the failure. The shuttle fleet was then grounded for several months to conduct thorough wiring inspections, resulting in many lessons learned for aging spacecraft. (Note: not all shuttle wiring was capable of being inspected, as a small portion is inaccessible, a problem that should be corrected for future reusable spacecraft.)

By coincidence, the electrical short was the same malfunction we practiced in our last ascent simulation. It was something we were prepared for. But the hydrogen leak was a type failure mode of which we were unaware.

Despite the launch issues surrounding our mission, I believe it was the right decision to launch Chandra on the shuttle. Although this decision had been made many years before the Challenger accident of 1986, the Chandra mission reaped the benefits of a shuttle launch and human presence. True, a shuttle launch is more expensive than an expendable rocket, but it is like buying insurance for your more expensive missions, to ensure they are not lost for technical problems. For example, in 1993, when the Gamma Ray Observatory high gain antenna would not deploy, astronaut Jerry Ross shook it loose on the during an extravehicular activity, and saved a mission that may have otherwise been lost. In this sense, our crew was present and available to “fix” many potential problems. We trained for numerous mechanical, electrical, or communication problems on the Inertial Upper Stage booster or the telescope itself. As an added benefit, the astronaut crew can take the message of astronomy to the public while also inspiring human spaceflight.

Today, the Chandra X-Ray Observatory is increasing our understanding of the origin, evolution, and destiny of the universe. It is truly a marvelously incredible product of human ingenuity. The data will be around for generations of worldwide scientists to digest, as we discover our place in the universe. I see Chandra as an expression of our curiosity as humans. As we search to discover what makes up this wondrous universe we live in, creations like Chandra will be far and away worth the investment we put into them. Chandra is one of the successful, productive, and mighty success stories of the Space Shuttle Program!

2.5 Gregory Harbaugh

In my opinion, one of the major achievements of the Space Shuttle era was the dramatic enhancement in productivity, adaptability, and efficiency of extravehicular activity (EVA), not to mention the numerous EVA-derived accomplishments. At the beginning of the shuttle era, the extravehicular mobility unit had minimal capability for tools, and overall utility of EVA was limited. However, over the course of the Space Shuttle Program, EVA became a planned event on many missions and ultimately became the fallback option to address a multitude of on-orbit mission objectives not to mention vehicle anomalies. In my opinion, speaking as the EVA program manager for 4 years (1997 – 2001), this was the result of incredible reliability of the extravehicular mobility unit thanks to its manufacturers (Hamilton Sundstrand and ILC Dover), continuous interest and innovation led by the EVA crew member representatives, and amazing talent and can-do spirit of the engineering/training teams. In my 23 years with NASA, I found no team of NASA and contractor personnel more technically astute, more dedicated, more innovative, nor more ultimately successful, than the EVA team.

Some of the specific achievements that I believe warrant special recognition and elaboration:

a) first-ever EVA incapacitated crew member rescue demonstration (STS 54)

b) first-ever EVA satellite rescue (Intelsat); (satellite rescues occurred multiple times)

c) first-ever EVA satellite servicing as a planned system upgrade (Hubble Space Telescope – multiple missions)

d) first-ever EVA-based space systems/station assembly as a planned integral part of the assembly process (International Space Station [ISS])

e) first-ever EVA untethered operations

f) first-ever EVA manned maneuvering unit operations

g) first-ever EVA emergency self-rescue capability (SAFER)

h) world's largest neutral buoyancy training facility

i) unprecedented mission success ratio versus EVA mission goals and objectives

j) first-ever EVA for entry vehicle inspection and repair

h) first-ever five-EVA mission

i) first-ever 10.2 psi cabin pressure to reduce prebreathe protocol time

(One way to evaluate the impact of EVA would be to look, mission by mission, at how many missions would have fallen short of their objectives had the EVA[s] not been successful.)

I'm sure there are more accomplishments worthy of note – you get the point. EVA became an indispensible part of the Space Shuttle Program. EVA could and did fix whatever problems arose, and became an assumed tool in the holster of the mission planners and managers. In fact, when I was EVA program manager we had shirts made with the acronym ‘WOBTSYA” – meaning ‘we’ve only begun to save your Alpha’ (the ISS name at the time). We knew when called upon we could handle just about anything that arose.

With regard to specific mission achievements, I am quite proud to have been part of so many. Some of my personal highlights:

a) STS-39 – one of the most complex missions ever flown. Actually, two missions combined into one, with 24-hour round-the-clock operations. It is my understanding that this mission led to breakthroughs in America’s understanding of the characteristics of missile signatures in space and thus has enhanced America’s ability to identify and protect ourselves from such threats in the future. If that is truly the case, I would respectfully suggest that this is one of the greatest, and most under-recognized, achievements of the shuttle era.

b) STS-61, STS-82, etc – on-orbit servicing of the Hubble Space Telescope. Clearly this series of missions is well recognized as spectacularly successful in not only correcting the initial optics problem with Hubble but also dramatically enhancing the telescope’s capabilities well beyond the designers’ initial fondest hopes. With repeated servicing, the telescope’s mission life has been extended significantly. I will leave it for the experts to judge, but I suspect Hubble has to be considered one of the greatest astronomical observatories in human history.

c) STS-71 – the first docking of a Space Shuttle with the Russian Mir space station. This was the first time in about 20 years that an American and a Russian space vehicle rendezvoused and docked in space. The fact that the timing constraints (5-minute docking window) and docking conditions (<.01 fps closure rate at contact, +/- 2 or 3 degrees in attitude and 2 or 3 inches in misalignment) were so tight, and that the shuttle was highly successful in meeting those constraints (and doing so repeatedly on subsequent missions to both Mir and the ISS) is a testament to the crew, the engineers and trainers, the mission planners, and the many individuals who negotiated the agreements with our Russian partners that made it possible. A spirit of cooperation and mutual respect ran deeply through this mission from both Russia and America. If ever there was a mission that represents the potential for future international cooperation and exploration of Mars or other planetary bodies, this was it.

d) STS-54 – the aforementioned incapacitated crew member rescue demo. This was a wake-up call on how little we knew about rescuing our EVA partner, and it led to much further work on how to successfully retrieve a crew member who could not return to the airlock under his/her own power as well as the development of the SAFER jet pack.

2.6 Tom Jones

Space Radar Lab Operations Aboard Space Shuttle Endeavour

In early 1992, I learned that Linda Godwin and I would be flying on a "Mission to Planet Earth," applying sophisticated planetary remote sensing techniques to our own world. Simply put, Space Radar Laboratory – 1 (SRL-1) was a powerful radar camera that would create highly detailed digital images by recording the echoes of radar energy beamed at Earth from the shuttle. The mission was designed to prove the worth of space-based radar in detecting and monitoring natural and human-caused changes on Earth's surface. The prototype radar system was a joint effort by NASA's Jet Propulsion Laboratory and the German and Italian space agencies. SRL-1 would be a 9-day mission, with the radar operating around the clock to capture as much Earth imagery as possible. Rather than scan the planet indiscriminately, the radar science team would focus most of its efforts on "supersites" around the globe where a number of problems in Earth science could be addressed in daily radar passes over the region.

Much more sophisticated than Magellan or previous radar satellites, SRL was the proof-of-concept for a permanent radar observatory. The shuttle offered an attractive science platform for this shakedown test, providing power, pointing the payload bay antennas at the science targets, and transmitting and recording radar science data. The orbiter would also return the radar to Earth for repair, adjustment, and reflight. The crew would not only operate the shuttle, but save further expense by simplifying the data recording system and providing on-orbit repairs or adjustments. Avoiding the construction of a satellite to perform these functions would save hundreds of millions of dollars. SRL could then be refurbished and reflown to take another in-depth look at our changing planet

From the results of the previous two shuttle radar flights, SIR-A and SIR-B (flown on STS-2 and STS-41G), Linda and I learned that the crew could provide crucial information from orbit to help interpret the new radar images. Environmental conditions such as rain, thunderstorms, dust, and standing water could alter the radar echo and confuse the image analysis. The SRL teams at their supersites planned to record local conditions, including wind velocity, relative humidity, temperature, soil moisture, and the presence of rain or severe storms. This "ground truth" would be used to calibrate and correct the orbital data, extending the usefulness of radar imaging to much larger areas.

Though ground truth was available at the supersites, hundreds of other radar targets around the globe would have few, if any, investigators present to validate the orbital measurements. This was where the astronauts came in. From orbit, we planned to radio our visual observations of each target to the payload operations control center, just across the hall from Mission Control in Johnson Space Center's (JSC's) Building 30. Using an array of 14 cameras, the crew would record video and shoot thousands of still photos for later comparison to the radar imagery. Our science photography and visual observations would serve as the "ground truth" for the far-flung science targets.

Because SRL's radars operated around the clock, regardless of weather and lighting conditions below, our STS-59 crew would have to split into two shifts of three crew members each. These Red and Blue teams would each pull a 12-hour shift, with another 4 hours allotted for shift handover, housekeeping chores, meals, exercise, and whatever unplanned work might pop up.

The usual routine was 16 hours awake, followed by 8 hours of sleep. Our shift (Jay Apt, Rich Clifford, and me) would normally begin after an hour or so of “post-sleep,” time to clean up, grab breakfast, and take a short handover briefing from Sid Gutierrez, Linda, and Kevin Chilton. Each of our 9 work days would be full of radar and photography work, focusing on the more than 400 science targets the SRL team had selected for radar examination. After 12 hours, we’d turn operations over to the Red shift again, taking another 3 hours for dinner and routine housekeeping before heading off to sleep.

Orbital mechanics determined the pace of our efforts. At an altitude of 120 nautical miles, our ship completed one orbit in just under 90 minutes; sunrises and sunsets alternated every 45 minutes. Just as we’d trained in the simulator, we focused on our three main responsibilities: orbiter pointing, data recording, and photography. Our cockpit bustled with SRL science photography during daylight; night passes were somewhat calmer.

Pointing Endeavour to align the radar with our earthbound targets proved to be the most demanding challenge for the crew: we would make a record 495 maneuvers during the mission. Each had to occur precisely on schedule to cover the targets and obtain the highest quality radar images; each required us to tell Endeavour’s computers exactly when and how to fire the 44 thrusters that controlled our attitude in space. Checking the flight plan, we would consult the printed attitude timeline, which was faxed up to us each day, key the planned maneuver into the computer, double-check the start time, and execute. The general purpose computers would then fire the thrusters at the appropriate time to get us in position for the data take. For large changes in attitude, the big primary thrusters thudded and spat flame, pivoting the ship with 870 pounds of force each. We could see smaller corrections through the rear windows as the tiny vernier jets, with just 24 pounds of thrust, flickered against the star-filled sky.

Accuracy was all-important: Mission Control Center literally watched our keystrokes from the ground, and usually gave a verbal confirmation that we’d loaded the maneuver correctly. Rich, Jay, and I took turns handling the entries and managing the autopilot, generally about once every 45 minutes. My fingers never touched the shuttle’s hand controllers; all SRL maneuvering was done via keystroke. The computers then initiated each thruster firing, slewed the ship around, and stopped us at the proper attitude.

Another high-priority but low-tech job was recording the precious imaging data. The digital echoes from the three separate wavelengths (designated L-, C-, and X-band in radar terminology) transmitted by SIR-C and X-SAR produced 225 million bits of data (Megabits) per second, far exceeding the orbiter’s maximum transmission rate to the ground of 50 Megabits per second. To capture this flood of radar imagery, we carried approximately 166 tape cassettes, each slightly larger than a VCR cartridge, and capable of storing 50 billion bytes (gigabytes) of data. The Radar Lab would fill a tape about every 30 minutes. Each planned tape change was noted on our science timeline, which the payload operations control center faxed up to us daily. We set timers on board to make sure we didn’t miss one. Swapping tapes in the Payload High-Rate Recorders was about as difficult as inserting a tape and changing the channel on a VCR, but a missed tape would result in data irretrievably lost. We couldn’t afford a mistake.

Our most rewarding job was science photography. During daylight passes, Rich, Jay, and I reviewed upcoming radar targets, referenced the kind of imagery required by the science team, and armed ourselves with up to four 70mm Hasselblads and two large-format Linhof cameras. As a target such as California’s Death Valley came over the horizon, we had about 30 seconds to acquire it visually, take a light meter reading, and position ourselves for a clear view through the windows. Snapping madly away from the two overhead and one of the pilots' side windows, we'd document the weather, surface and vegetation state on film, then type the general conditions and specific film magazines used into our laptop log. We'd also slew the payload bay's color TV camera to match the radar's downward view of the Earth, recording the observing conditions below on videotape. We looked like a crowd of tourists mobbing the bus windows at a Grand Canyon overlook, but we had more than 10,000 frames of film to expose, and were determined to bring back an optical record to compare with the radar images.

The flat, rectangular SRL antenna looked "up" from the cargo bay, so to point the antenna panels at the ground, Endeavour flew upside down with respect to the Earth. We usually flew with a constant 26º roll bias from the vertical, aiming the radars out to the left or right of our ground track to image a swath of Earth anywhere from 9 to 56 miles wide, and hundreds of miles long. There was no spinning radar dish out in the payload bay: instead the SIR-C radar beams were steered electronically by the phased-array antenna panels, 18 each for L-band and C-band, respectively. The German-Italian X-SAR antenna, a narrow 12- by 0.4-meter strip along the upper edge of the SIR-C array, was tilted mechanically by ground command to match SIR-C's radar beam; the X-SAR antenna was the only moving part of SRL we could see.

The view from the overhead and aft windows was stunning, as if staring up through the roof of a greenhouse at a planet filling half the sky. A glance "up" from work on switches and computers always drew a sharp intake of breath at the scenery rolling by just 138 miles below. I often needed sunglasses to cut the glare from expanses of snow or clouds. But I couldn't screen out the sheer emotional impact of finally seeing our planet's subtle beauty and glorious complexity. I could never grow bored with this view.

The radar work was a pleasure, particularly our Earth observations and the radio interactions with our Jet Propulsion Laboratory colleagues, our link to the science team around the globe. The SRL people were ecstatic over the radars' performance, detecting features as small as 66 feet across. We filled tape after tape with superb imagery, and Mission Control Center faxed a few samples of the pictures back to us, along with portions of the Measurement of Air Pollution from Satellites (MAPS) global carbon monoxide map, which corresponded well with the smoke and fires we were observing from orbit. The shuttle radar passes, pollution numbers, and ground truth measurements were stitching together a truly impressive Earth sciences mission, exceeding the best hopes of SRL's designers and investigators. Aside from our minor galley problem, Endeavour was performing well; Mission Control Center had seen just a minor glitch or two on the orbiter.

Our work went on around the clock in a demanding yet comforting routine. On the 10th day of STS-59, we deactivated Space Radar Lab. The science team was ecstatic: in 939 data takes totaling 65 hours of radar operation, SRL had scanned 5.4% of Earth's surface, filling 166 tape cassettes with 47 terabits of radar imagery. Printed out on paper, those radar images would fill 20,000 volumes of an encyclopedia documenting the changes, both natural and man-made, affecting our planet's surface. The MAPS experiment had logged 211 hours of observations on Earth's carbon monoxide abundance, fulfilling 100% of its mission objectives. Through 9days of radar operation, we'd had only two minor failures: one of SIR-C's 18 C-band antenna panels, and the cockpit's Number 3 payload recorder. SRL-1 had proven an unqualified success.

Even before STS-59 launched, I'd been assigned to fly with the SRL-2 crew on STS-68, scheduled for late summer 1994. This second Radar Lab flight was largely a continuation of SRL-1's work, with some ambitious new wrinkles added. Jet Propulsion Laboratory had always planned to fly the new instrument at least two and preferably three times, testing the radars' ability to monitor seasonal variations in rain forests, croplands, wetlands, ocean currents, sea ice, soil moisture, glaciers, and snow cover. Similarly, MAPS wanted to track seasonal changes in carbon monoxide production, watching for shifts across the globe in industrial pollution and large-scale biomass burning. Jet Propulsion Laboratory would have preferred 6 months between missions to capture a full seasonal swing, but competing demands on the shuttle schedule moved SRL-2 up to late summer. A pad abort at T-1.5 seconds on August 18, caused by an overheating main engine turbopump, forced us to slip 6 weeks. Finally, on September 30, 1994, Endeavour roared aloft with SRL-2 and my crewmates on STS-68. Less than 10 hours after reaching orbit, the SLR team in Houston had the radars humming, and our crew swung into its first full day of remote sensing operations.

At the time of the first shift handover we were treated to dramatic evidence of how quickly Earth's surface can remake itself. As our eighth orbit carried Endeavour across the Sea of Okhotsk and east Asia's Kamchatka peninsula, we began to see something strange out the aft-facing windows. Jeff Wisoff called down to Steve Smith, Dan Bursch, and me on the middeck: "Get up here now and take a look at this!" A dark smudge of smoke cut the distant horizon along the Pacific coast. A thunderstorm, perhaps, with its anvil streaming out far to the east? Or maybe dust, lofted by high winds. But the terrain surrounding the smoke was clear; this didn't look like a weather phenomenon. We knew this was an active volcanic region, and soon we identified the source of the dark cloud. It was Kliuchevskoi, Asia's tallest volcano, in full eruption.

Kliuchevskoi, at 15,908 feet, is the most prominent of the string of active volcanoes forming the backbone of the Kamchatka peninsula, at the boundary between the Eurasian and Pacific tectonic plates. As the Pacific oceanic crust is carried under the overriding Eurasian plate to the west, molten rock rises to the surface and creates one of the most active volcanic fields in the world.

Kliuchevskoi is halfway down the east coast of Kamchatka; on SRL-1, we'd photographed the region and observed a light dusting of ash on the twin peaks of the mountain, quiet beneath its blanket of April snow. Now the volcano had roused itself.

By sheer serendipity, we'd launched on the very day that Kliuchevskoi roared back into life. We could see little of its summit, entirely shrouded in dark clouds of ash boiling 50,000 feet into the stratosphere. The ash plume shot straight up from the mountain almost to the stratosphere, where it was caught by the jet stream and swept out over the Pacific. Satellites tracked the plume 350 miles to the southeast, where it later forced traffic controllers to divert airliners around the dust and ash.

We soon had every camera on board zeroed in on the eruption as Endeavour gave us a dramatic, down-the-throat view of this most impressive lesson in geology. The northernmost peak was generating spectacular ash explosions, while Kliuchevskoi's southern summit contributed only a dirty plume of steam. The neighboring Bezymianny volcano threw its own wisp of steam into the massive plume. Dirty fallout from the eruption coated the downwind slopes of all three mountains.

While our photos of Kliuchevskoi in "full afterburner" were dramatic, many of the details of what was happening near the summit, such as the extent of lava flows, location of the eruptive vents, and changes in the mountain's snow and ice cap, were obscured by the spectacular ash and steam plume. But the radars easily penetrated the ash cloud; the science team reprogrammed their observations to scan the eruption three times a day for the first week of the mission. They tracked the eruption's progress from start to finish, despite a snow-laden weather system that hid the mountain completely from our cameras. SRL's real-time monitoring capability may be a forerunner of future systems that can warn of eruptions at dozens of dangerous volcanoes threatening populous regions of the globe, from Naples to Seattle.

Kliuchevskoi was just the start of SRL-2's ten-day look at our dynamic planet. We were repeating most of the observations made on STS-59, looking carefully for natural and man-made change at our 572 science targets, including the nineteen supersites devoted to major Earth science investigations. Over Hawaii and the Galapagos we mapped lava flows to determine the history of past eruptions and track Kilauea's present outbursts. At Raco, Michigan on the Upper Peninsula, the radar identified both the mix of trees and the carbon content of the northern forests. Across the Sahara, SIR-C's L-band radar penetrated the desert sands and revealed the ancient watercourses that still feed modern oases; above Libya's Wadi Kufra, the images created a subsurface map for geo-archaeologists to locate artifacts and better interpret the history of early people and climatic cycles.

Just as on STS-59, we worked under the gun of the relentless mission clock, maneuvering the orbiter, changing data tapes (we carried 199 of the 50-Gigabyte cassettes), and carpeting the ground with our science photography. While our launch time and orbital lighting combined to treat Jeff and the pilots to North American and European passes, the Blue Shift covered Asia and Africa during the mission's first few days.

Our final challenge of the mission was to test a concept using radar to obtain three-dimensional maps of Earth's surface. In the early 1990s, much of Earth's topography was imprecisely known, especially in remote regions of Asia, Africa, and South America. Using a technique called radar interferometry, which is roughly analogous to stereo photography, Jet Propulsion Laboratory could combine radar images taken from nearly identical orbits to construct three-dimensional topographic maps. With a vertical error of less than 50 feet, these maps are precise enough to steer a cruise missile, or monitor the ominous swelling of a dangerous volcano.

The catch was that our repeat orbits could be separated in space by no more than 300 feet or so. Mission Control Center and our crew combined to perform the most precise orbital maneuvers ever seen in the Space Shuttle Program, putting Endeavour in an orbit for the first 6 days that nearly matched our SRL-1 flight path of last April. At times the two orbits differed by only 33 feet, well within the tolerances for creating successful interferometric images. For days 7 to 10, we lowered our orbit to a height of only 124 miles, an altitude that put Endeavour on a path matching its orbit of the previous day. This exacting navigation, where Mike Baker and Terry Wilcutt, manually firing the orbiter's thrusters, adjusted our orbital velocity to an accuracy of 1 part in 2 million, produced long swaths of closely overlapping images. The interferometry passes produced digital elevation maps that not only reveal the topography, but also actual shifts in Earth's surface of just a few centimeters. Detection of such small-scale changes can help predict hazards in volcanic or earthquake-prone areas.

The statistics from the flight were truly astounding, even to us on the crew. In our 11 days, 5 hours, 46 minutes, and 8 seconds in space, we'd recorded 910 data takes with the SIR-C and X-SAR radars (about 80 hours of radar imaging). If we could transfer all that data to today's compact discs, the information would fill a stack of CDs more than 65 feet high.

Perhaps the most promising result was the successful demonstration of interferometry to create topographic maps of Earth's surface. During SRL-2, we obtained over a million square kilometers of repeat-pass interferometry data. Our images of advancing lava flows and the changing shape of Kilauea volcano, along with those of rapidly advancing glaciers in Chile's Patagonian ice fields, showed the great potential for satellite interferometry in mapping global change. The Jet Propulsion Laboratory radar team immediately began planning for a third radar mission, this time with the goal of mapping most of Earth's topography in one 11-day flight. Our efforts on STS-68 led directly to the success of the Shuttle Radar Topography Mission in 2000; maps from that ambitious project were put to immediate use by U.S. troops in southwest Asia during the war on terror.

During our radar and interferometric observations, we'd maneuvered Endeavour roughly 470 times, including 44 nose-to-tail swaps, every one on time. Back in Houston, we spent days at the light tables in Building 8 poring with our Earth observations team over the 13,000 still-camera images of our planet from the flight.

Jet Propulsion Laboratory's image processing lab released a stream of imagery, augmented by our photography, which drew a complex portrait of our changing world. The two missions had proven that a space-based radar in permanent orbit could significantly improve our ability to monitor Earth's complex and dynamic surface. I was particularly interested in the archaeological results from SRL: the "radar rivers", still watering Saharan oases; ancient settlements along western China's Silk Road; buried traces of that country's original Great Wall; caravan tracks pointing back to Arabia's lost city of Ubar; and the intricate, 1,000-year-old waterworks surrounding the Cambodian temples of Angkor Wat.

Among the best examples of the shuttle's capabilities as a science platform, the SRL missions demonstrated again the utility of having astronauts participate closely in operating a cutting-edge payload. The SRL-1 crew worked backed up the science teams in Houston as they brought their advanced SAR to life, then provided extensive photographic imagery to verify the radar's performance. The near-flawless shuttle maneuvering found Endeavour in attitude for every one of hundreds of radar data takes. When the Payload High Rate Recorder #2 malfunctioned on SRL-2 during the midst of our critical interferometry passes, Steve Smith and Jeff Wisoff prepared a replacement unit stored in the middeck, disconnected the broken Payload High-Rate Recorder on the aft flight deck, and installed the oven-sized replacement, all within the span of a few hours. Thanks to their quick work, science losses proved minimal. Just as impressive, our SRL-2 pilot team flew precise manual orbit changes that enabled a hugely successful interferometry demonstration. Both flights were characterized by close science coordination between ground- and space-based science teams, a model for future shuttle and ISS operations that maximized the research return under very demanding timing, power, and pointing constraints. Adding to the rewards of these two low-altitude, high-inclination flights was the opportunity for the crews to study and savor the most satisfying Earth views ever given grateful astronauts.

2.7 Richard Searfoss

Perspectives on Neurolab

I had the privilege of commanding STS-90 Neurolab, an extremely specialized fundamental research mission focusing on the effects of weightlessness on the brain and nervous system. Now I'm no life scientist—my technical background is in physics, engineering, and flight test. But it was nevertheless incredibly rewarding to join a dedicated team that included not just NASA, but the National Institutes of Health and some of the top researchers and academic institutions in the world, to strive with disciplined scientific rigor to really understand some of the profound changes to living organisms—changes that take place in the unique microgravity environment. Other than the responsibility for safe operations, I viewed my primary role as the Neurolab commander as science enabler, calling upon my operational experience to build the team and lead the crew and those who supported us while staying "customer-focused." The customers were, of course, the scientists who counted on the flight crew to acquire the data for their very ambitious experiments. My personal mission-oriented approach was that for the risks I gladly took to fly this mission, I wanted to do much more than the "rocket jockey" flight operations skills, as important as they are. I, and the entire crew, viewed the science as the real "mission that mattered."

It's amazing that even though at the time STS-90 flew on Columbia, we had been flying humans to space for nearly 40 years, so much of our understanding of the effects on humans was either anecdotal or a complete mystery. Neurolab, in its particular area of focus, was extremely productive in unveiling many of those mysteries. In fact, the compilation of peer-reviewed scientific papers from this mission was so extensive as to produce a 300-page book, the only such product to my knowledge from the Space Shuttle Program. As an operations and engineering-type guy, I can get through the abstracts and the basic gist of these life science papers, but I get lost in the details, so I'll leave it to the scientists to testify of the import, fundamental scientific value, and potential for Earth-based applications that came from Neurolab. It's enough for me to realize that, as astronauts, my crew and I played an important role in advancing real and significant science in a unique way.

With STS-90 as the last of 25 Spacelab missions, NASA reached a pinnacle of overall capability to meld complex, leading-edge science investigations with the inherent challenges of operating in space. Building on all previous Spacelab flights, but particularly the focused life science work of STS-40, STS-58, and STS-78, Neurolab finished up the Spacelab program spectacularly, with scientific results second-to-none of any human space mission flown. What a joy to be part of that effort! It was unquestionably the honor of my professional life to be a member of the Neurolab team in my role as commander.

2.8 Dafydd Williams

Having experienced the thrill of the weightless environment of human spaceflight, my body is forever different. Humans adapt remarkably well to the many physiologic challenges associated with leaving the Earth's gravitational environment. For me, these started at the time of main engine cut-off. After 7 minutes of the $8^{1}/_{2}$-minute ride to space, in which the shuttle's three main engines and two solid rocket boosters provide approximately 7.5 million pounds of thrust, I could feel the G forces pushing me like an elephant sitting on my chest as they climbed to three times that on Earth. Instantaneously, the crushing pressure resolved as I was thrown forward against my harness when the main engines shut down. This created a sense of tumbling head over heels, identical to performing forward somersaults as a child. With both hands, I pulled myself down in the shuttle seat to recreate the gravitational sense of sitting in a chair and surprisingly the tumbling stopped. I had experienced my first illusion of spaceflight! The first day of my first mission was associated with many interesting insights into the many physiological changes taking place in my body. My face felt puffy. I had a mild headache the first day in space. Over the first few days of the mission, I experienced mild low back pain as my vertebral column elongated an inch and a half. Floating freely inside the shuttle with fingertip forces gently propelling us on a somewhat graceful path reminded me of swimming underwater—with the notable absence of any resistance as we moved in the cabin. Perhaps my diving background helped my brain prepare for what it would be like floating freely in space. Over the course of the mission, each of the crew adapted to the freedom of living and working in all parts of our three-dimensional world. The ceiling became the floor. Having a conversation during a meal with someone who was upside down in front of you became routine. This newfound freedom was short lived when, during re-entry into the Earth's atmosphere, I felt the forces of gravity gradually building. Standing on the middeck after landing, I felt gravitationally challenged and I initially confused the three-degree nose-down tilt of the shuttle after landing as forward motion—a classic illustration of the tilt/translation hypothesis in which I misperceived the forward tilt of the Orbiter for forward motion. As I walked with a broad-based ataxic gait onto the crew transfer vehicle, I felt gravitationally challenged, as though my arms weighed twice what they normally do. Moving my head created an instant sense of vertigo that took hours to resolve. The vestibular readaptation to being a gravitational creature took a day or so, Amazingly, on my second spaceflight 10 years later, when I arrived in space it seemed like I had never left and as I floated gracefully looking back at the Earth, it reminded me that I will always remain a spacefarer at heart.

Exploration—The Quest for Knowledge

Like so many children growing up in the 1960s, my dreams were captivated by human space exploration and I followed the historic achievements of NASA with great interest. In those days, there were only a few things that could stop me from exploring the nearby woods and creek close to our house. The space program was one of them. As John Glenn boarded the Friendship 7 spacecraft at 11:03 Universal Time Code on February 20, 1962, I was glued to the television set. Following liftoff at 14:47 and a 5-minute ride on an Atlas rocket later described as "bumpy," he achieved orbit and spoke words I will never forget—"zero-G and I feel fine." The woods were never the same after that—the heavens and the allure of space beckoned.

In a decade that changed the world, the words of Walter Cronkite chronicled the remarkable achievements of space exploration. As Neil Armstrong spoke with mission control "Houston, Tranquility Base here—

the Eagle has landed," the magnitude of the moment was captured perfectly by Cronkite with his loss of words to describe such an important event. Everyone was speechless. This was an achievement for humanity, the most remarkable feat in the history of human exploration, immortalized forever as Neil Armstrong stepped onto the lunar surface and reported "That's one small step for a man, one giant leap for mankind." The calming voice of the most trusted man in America brought the world back from the moment at the close of the day when Cronkite signed off with his trademark “And that’s the way it is—July 20th, 1969.”

In 10 years, NASA had achieved the impossible. The dedication and commitment of the space program to scientific research and technology development brought a challenge to those of us in school—what would we be able to achieve? What would the legacy of our generation be? The allure of exploration drew me into a career in science and medicine, relentlessly trying to understand physiology in an era where human adaptation to undersea and space exploration challenged the limits of knowledge.

That scientific quest ultimately took me down the path of my childhood dreams, enabling me to live, work, and explore the two remaining frontiers as an astronaut and aquanaut. The second selection of Canadian astronauts took place in 1992, and I was fortunate to be able to join the Canadian astronaut program. However, never in my wildest imagination did I think that 29 years after hearing Walter Cronkite’s Apollo 11 commentary, I would be at a luncheon in Houston to celebrate NASA’s 40th anniversary as Director of the Space and Life Sciences Directorate at Johnson Space Center, listening to him speak with Senator John Glenn on the Space Shuttle Discovery.

After my first spaceflight in April 1998, I was asked by George Abbey, director of Johnson Space Center, to join the scientific team at the center to lead the transition from shuttle-based research to the new era of scientific utilization of the International Space Station. The chance to work with some of the most talented scientists, clinicians, and engineers in the world was an opportunity that redefined for me the meaning and importance of scientific research.

The directorate was created after the Gemini Program as the Medical Research and Operations Directorate with Dr. Charles A. Berry as the first director and Dr. Lawrence F. Dietlein leading the human research program. The early research efforts were critical to enabling the success of the Apollo Program and many were relieved when Dr. Berry reported in 1967,"Although much remains to be learned, it appears that if man is properly supported, his limitations will not be a barrier to the exploration of the universe."

As the Apollo Program ended in 1972, the Medical Research and Operations Directorate was renamed the Life Sciences Directorate as preparations were made for research on board the Skylab space station. The biomedical results of the three missions were subsequently published by NASA and were used to plan future shuttle life science research ultimately creating a knowledge base in bioastronautics required for long-duration spaceflight.

In 1977, the Life Sciences Directorate was combined with the Science and Applications Directorate to become the Space and Life Sciences Directorate. This change significantly increased the functional responsibilities of the directorate by adding lunar and planetary science, Earth observations, and space science to the existing research and operational activities in life sciences, space medicine, experiment development, and payload management.

The first flight of the shuttle in April 1981 created exciting new opportunities for short-duration microgravity research using middeck lockers as well as the Spacelab and Spacehab research modules in the payload bay of the Orbiter. In preparation for future missions to the International Space Station, NASA developed the Extended Duration Orbiter program that extended the capability to keep the shuttle in space to 16 days. Fourteen missions used the Extended Duration Orbiter pallet with astronauts from 40 shuttle flights participating in 36 Extended Duration Orbiter medical project life science investigations expanding the knowledge and experience with long-duration spaceflights.

The quest to understand how to send humans farther and keep them in space longer continued with the NASA-Mir missions in preparation for the long-duration flights aboard the International Space Station. Up to this point, the Russian space program had extensive experience with long-duration spaceflight on board a series of space stations. NASA extended its experience with the seven Mir long-duration astronaut missions. The lessons learned were of great value in developing a roadmap for future life science research.

As the millennium drew to a close, the research efforts of the Space and Life Sciences Directorate and the recently formed National Space Biomedical Research Institute were focused through development of a critical path roadmap for bioastronautics research that would provide the knowledge and expertise to further the goals of human space exploration. The International Space Station is ideally suited as an exploration-enabling research platform to support the quest to send humans back to the moon and on to Mars.

As NASA approaches the transition between the shuttle and the new Orion crew exploration vehicle, a new generation of explorers will learn first-hand that “the cause of exploration and discovery is not an option we choose; it is a desire written in the human heart.” When that next generation of explorers leaves footprints on the path back to the moon and creates a new path for humans to go to Mars, the hard work and dedication of the space and life science team will have played a critical role in that success. Every member of the team has earned his or her place on that path of exploration; the quest for knowledge.

3.0 PAYLOADS AND EXPERIMENTS

3.1 US Department of Defense

STS-4

Classified.

STS-7

Get Away Special:

> Space Ultraviolet Radiation Environment. Tested motorized door assembly on Get Away Special canister. Investigated ultraviolet radiation environment in space in Get Away Special canister.

STS-8

Radiation Monitoring Equipment. Sponsored by Department of Defense. Measured ionizing radiation exposure to crew within Orbiter cabin.

STS-9

Auroral Photography Experiment-A. Integrated in Spacelab. Air Force-sponsored payload designed to study aurora, or Northern and Southern lights, and phenomena of shuttle glow—an illumination around the shuttle caused as spacecraft encountered atomic oxygen in orbit.

STS-41B

Radiation Monitoring Equipment. See STS-8.

Cosmic Ray Upset Experiment. Designed to resolve questions concerning upsets, or changes in logic state of a memory cell, caused by highly active energetic particles passing through a sensitive volume in memory cell.

STS-41C

Radiation Monitoring Equipment. See STS-8.

Long Duration Exposure Facility Experiments. Deployed experiments ranging from materials to medicine to astrophysics. All experiments required free-flying exposure in space, but no extensive electrical power, data handling, or attitude control systems.

STS-41D

Deployed Leasat 2 defense communications satellite.

Radiation Monitoring Equipment. See STS-8.

Cloud Logic to Optimize Use of Defense Systems. US Air Force experiment quantified variation in apparent cloud cover as a function of the angle at which clouds of various types are viewed.

STS-41G

Auroral Photography Experiment-A. See STS-9.

Radiation Monitoring Equipment. See STS-8.

Get Away Special:

> Trapped Ions in Space-1. Investigated an unexpectedly large flux of heavy ions (electrically charged ions of oxygen and heavier atomic elements) first observed in an experiment on board Skylab in 1973 and 1974.

STS-51A

Deployed Leasat 1 defense communications satellite.

Radiation Monitoring Equipment. See STS-8.

STS-51C

Classified. First dedicated Department of Defense (DoD) flight. Deployed DoD satellite.

Cloud Logic to Optimize Use of Defense Systems. See STS-41D.

Orbiter Experiments Autonomous Supporting Instrumentation System. Collected and recorded environmental measurements during various in-flight phases of Orbiter.

Visual Function Tester. US Air Force-sponsored test measured sensitivity of the eye to image contrast at threshold. Part of a series of vision performance experiments on shuttle to assess effect of microgravity on visual function.

Interim Operational Contamination Monitor. Provided continuous measurement of collected particulate and molecular mass at pre-programmed collection surface temperatures.

STS-51D

Deployed Leasat 3 defense communications satellite.

STS-51G

High Precision Tracking Experiment. Tested ability of a ground laser beam director to accurately track an object in low-Earth orbit.

Space Ultraviolet Radiation Environment. See STS-7.

STS-51I

Deployed Leasat 4 defense communications satellite. Retrieved, repaired, and redeployed Leasat 3.

STS-51J

Classified. Dedicated to Department of Defense. Deployed two Defense Satellite Communications Systems.

Orbiter Experiments Autonomous Supporting Instrumentation System. See STS-51C.

Air Force Maui Optical Site tests. Allowed ground-based electro-optical sensors located on Mt. Haleakala, Maui, Hawaii, to collect imagery and signature data of Orbiter during cooperative over flights.

Cloud Logic to Optimize Use of Defense Systems. See STS-41D.

Radiation Monitoring Equipment. See STS-8.

Visual Function Tester. See STS-51C.

Visual Function Tester-Model II. US Air Force-sponsored test measured sensitivity of the eye to image contrast at threshold. Part of a series of vision performance experiments on the shuttle to assess effect of microgravity on visual function.

STS-61A

Get Away Special:

> Deployed Global Low Orbiting Message Relay Satellite. Demonstrated ability to read out, store, and forward data from remote ground-based sensors.

STS-61C

Particle Analysis Cameras. Studied particle distribution within shuttle bay environment.

Get Away Special:

> Flexible Beam Experiment. Sponsored by US Air Force Academy and NASA. Studied structural oscillations in space.

STS-26

Orbiter Experiments Autonomous Supporting Instrumentation System. See STS-51C.

STS-27

Classified. Dedicated to Department of Defense. Deployed a side-looking radar, all-weather surveillance satellite.

Air Force Maui Optical Site tests. See STS-51J.

Auroral Photography Experiment-A. See STS-9.

Radiation Monitoring Equipment. See STS-8.

Visual Function Tester-Model II. See STS-51J.

Cloud Logic to Optimize Use of Defense Systems. See STS-41D.

Orbiter Experiments Autonomous Supporting Instrumentation System. See STS-51C.

Cosmic Ray Upset Experiment. See STS-41B.

STS-29

Air Force Maui Optical Site tests. See STS-51J.

Orbiter Experiments Autonomous Supporting Instrumentation System. See STS-51C.

STS-30

Air Force Maui Optical Site tests. See STS-51J.

STS-28

Classified. Dedicated to Department of Defense. Deployed two defense communications satellites.

Air Force Maui Optical Site tests. See STS-51J.

Radiation Monitoring Equipment. See STS-8.

Cloud Logic to Optimize Use of Defense Systems. See STS-41D.

Visual Function Tester-Model II. See STS-51J.

Cosmic Ray Upset Experiment. See STS-41B.

Interim Operational Contamination Monitor. See STS-51C.

Shuttle Activation Monitor. Measured gamma-ray data within Orbiter as a function of time and location.

Multi-Purpose Experiment Canister. Modified Get Away Special canister carried a classified experiment sponsored by US Air Force Space Systems Division.

Ascent Particle Monitor. Measured contaminants in cargo bay during launch and ascent.

Military Man in Space. Series of tri-service experiments designed to assess humans’ visual and communication capabilities from space. Areas of investigation included dynamic shuttle tasking, near real-time information relay, and quantification of astronaut's visual resolution limits.

Latitude-Longitude Locator. Experimented with determining precise latitude and longitude of objects observed from space.

STS-34

Sensor Technology Experiment. Measured natural radiation background.

STS-33

Classified. Dedicated to Department of Defense.

Air Force Maui Optical Site tests. See STS-51J.

Radiation Monitoring Equipment. See STS-8.

Cloud Logic to Optimize Use of Defense Systems. See STS-41D.

Visual Function Tester. See STS-51C.

Cosmic Ray Upset Experiment. See STS-41B.

Auroral Photography Experiment-B. US Air Force-sponsored payload designed to study aurora, or Northern and Southern lights, and phenomena of shuttle glow—an illumination around shuttle caused as spacecraft encountered atomic oxygen in orbit.

STS-32

Deployed Leasat 5 defense communications satellite.

Retrieved Long Duration Exposure Facility Experiments.

Interim Operational Contamination Monitor. See STS-51C.

Latitude-Longitude Locator. See STS-28.

STS-36

Classified. Dedicated to Department of Defense. Deployed KH 11-10 electro-optical reconnaissance satellite.

Radiation Monitoring Equipment. See STS-8.

Visual Function Tester. See STS-51C.

Visual Function Tester-Model II. See STS-51J.

STS-31

Air Force Maui Optical Site tests. See STS-51J.

Radiation Monitoring Equipment. See STS-8.

Ascent Particle Monitor. See STS-28.

STS-41

Air Force Maui Optical Site tests. See STS-51J.

Radiation Monitoring Equipment. See STS-8.

Sensor Technology Experiment. See STS-34.

STS-38

Classified. Dedicated to Department of Defense. Deployed electronics intelligence satellite.

Air Force Maui Optical Site tests. See STS-51J.

Radiation Monitoring Equipment. See STS-8.

Visual Function Tester. See STS-51C.

Auroral Photography Experiment-B. See STS-33.

Spaceborne Direct View Optical System. Tested optical system that allowed astronauts to view targets on Earth.

STS-35

Ultraviolet Plume Instrument. Sensor package that collected images of ultraviolet emission from rocket plumes in space and measured ultraviolet backgrounds seen from a space platform.

STS-37

Air Force Maui Optical Site tests. See STS-51J.

Ascent Particle Monitor. See STS-28.

Radiation Monitoring Equipment. See STS-8.

STS-39

Cryogenic Infrared Radiance Instrumentation For Shuttle on the Air Force Payload 675 space vehicle. Sponsored by the Strategic Defense Initiative Organization. Operated in infrared portion of electromagnetic spectrum and obtained simultaneous spectral and spatial measurements of airglow and auroral emissions.

Infrared Background Signature Survey. Strategic Defense Initiative Organization-sponsored program for obtaining scientific data for use in development of ballistic missile defense sensor systems.

US Air Force Space Systems Division sponsored a set of complex payloads.

US Air Force Cloud Logic to Optimize Use of Defense Systems program. See STS-41D.

Radiation Monitoring Equipment. See STS-8.

Ultraviolet Plume Instrument. See STS-35.

Multi-Purpose Experiment Canister. See STS-28.

STS-43

Air Force Maui Optical Site tests. See STS-51J.

Auroral Photography Experiment-B. See STS-33.

STS-48

Cosmic Radiation Effects and Activation Monitor experiment. Department of Defense-sponsored experiment. Designed to collect data on cosmic ray energy loss spectra, neutron fluxes, and induced radioactivity.

Shuttle Activation Monitor. See STS-28.

Ascent Particle Monitor. See STS-28.

Radiation Monitoring Equipment. See STS-8.

STS-44

Deployed the Defense Support Program satellite designed to detect nuclear detonations, missile launches, and space launches from geosynchronous orbit.

Interim Operational Contamination Monitor. See STS-51C.

Shuttle Activation Monitor. See STS-28.

Ascent Particle Monitor. See STS-28.

Cosmic Radiation Effects and Activation Monitor experiment. See STS-48.

Air Force Maui Optical Site tests. See STS-51J.

Radiation Monitoring Equipment. See STS-8.

Visual Function Tester. See STS-51C.

Terra Scout. Earth observation experiment that used skills of a trained analyst to perform observations. Explored man/machine interface between skilled technicians and advanced sensors.

Military Man in Space. Series of tri-service experiments designed to assess humans' visual and communication capabilities from space. Areas of investigation included dynamic shuttle tasking, near real-time information relay, and quantification of astronaut's visual resolution limits.

STS-42

Radiation Monitoring Equipment. See STS-8.

Get Away Special:

> Space Thermoacoustic Refrigerator. A refrigeration cycle used sound to pump heat with only one moving part. Used standing sound waves and inert gas to produce refrigeration.

Visual Photometric Experiment. Measured visible light reflected by intergalactic dust. Data from these measurements were used to validate and update existing data collected in earlier experiments and helped provide background measurements of visible light for use in space surveillance.

STS-45

Radiation Monitoring Equipment. See STS-8.

Cloud Logic to Optimize Use of Defense Systems. See STS-41D.

Visual Function Tester-Model II. See STS-51J.

Space Tissue Loss. Sponsored by Walter Reed Army Institute of Research and NASA's Life Sciences Division. Module was developed to help scientists and Army medical practitioners understand more about effects of spaceflight on fragile life systems, including immune system, muscle, and bone.

STS-53

Last dedicated Department of Defense mission. Classified. Deployed Satellite Data System.

Shuttle Glow. US Air Force experiment used Arizona Imaging Spectrograph to investigate shuttle/environment interactions such as atomic oxygen surface glow on Orbiter's tail and other surfaces and wake phenomena.

Cryogenic Heat Pipe experiment. Joint Department of Defense/NASA experiment to test advanced technology that would make it easier to reject excess heat from infrared sensors, instruments, and space vehicles.

Orbital Debris Radar Calibration System experiment. Primary objective was to provide a source for fine-tuning of Haystack Radar, located in Tyngsboro, Massachusetts, and operated by Lincoln Laboratory at the Massachusetts Institute of Technology for the US Air Force. NASA used information from radar as part of inputs gathered to measure amount of debris in Earth orbit.

Battlefield Laser Acquisition Sensor Test. Army space project jointly sponsored by Army Space Command, Army Space Technology Research Office, and Night Vision Electro Optics Directorate. Designed to demonstrate technology associated with using a space-borne laser receiver to detect laser energy from ground-based test locations.

Hand-held, Earth-oriented, Real-time, Cooperative, User-friendly, Location-targeting and Environmental System. Enabled a shuttle astronaut to point a camera at an Earth feature, record image, and determine latitude and longitude.

Cosmic Radiation Effects and Activation Monitor experiment. See STS-48

US Air Force Cloud Logic to Optimize Use of Defense Systems program. See STS-41D.

Radiation Monitoring Equipment. See STS-8.

Space Tissue Loss. See STS-45.

Visual Function Tester-Model II. See STS-51J.

Microencapsulation in Space. US Army-sponsored project. Objective was to increase knowledge of microencapsulated drug technology.

STS-56

Air Force Maui Optical Site tests. See STS-51J.

Cosmic Radiation Effects and Activation Monitor experiment. See STS-48.

Radiation Monitoring Equipment. See STS-8.

Hand-held, Earth-oriented, Real-time, Cooperative, User-friendly, Location-targeting and Environmental System. See STS-53.

Space Tissue Loss. See STS-45.

STS-51

High Resolution Shuttle Glow Spectroscopy-A. Obtained high-resolution spectra in visible and near-visible wavelength range (4,000 angstroms to 8,000 angstroms) of shuttle surface glow as observed on Orbiter surfaces that face velocity vector while in low Earth-orbit.

Radiation Monitoring Equipment. See STS-8.

Auroral Photography Experiment-B. See STS-33.

STS-60

Auroral Photography Experiment-B. See STS-33.

STS-62

Brilliant Eyes Thermal Storage Unit. Studied cryogenic heat dissipation as part of experiment that investigated use of very cold liquids—cryogens—for the purpose of heat dissipation.

Auroral Photography Experiment-B. See STS-33.

STS-59

Space Tissue Loss. See STS-45.

Visual Function Tester. See STS-51C.

STS-65

Military Applications of Ship Tracks. Sponsored by Office of Naval Research. Part of research program developed to examine effects of ships on marine environment using high-resolution imagery of ship tracks.

STS-64

Military Applications of Ship Tracks. See STS-65.

Radiation Monitoring Equipment. See STS-8.

STS-68

Military Applications of Ship Tracks. See STS-65.

Cosmic Radiation Effects and Activation Monitor experiment. See STS-48.

STS-66

Space Tissue Loss. See STS-45.

Middle Atmospheric High Resolution Spectrograph Investigation. Integrated on Cryogenic Infrared Spectrometers and Telescopes for the Atmosphere on the Shuttle Palette Satellite. Measured dayglow in 1,900 to 3,200 angstrom region and measured concentrations of hydroxide and nitric oxide in the mesosphere and themosphere—30- to 150-km (19- to 93-mile) altitude—to an accuracy of 2 km (1.2 miles).

STS-63

Cosmic Radiation Effects and Activation Monitor experiment. See STS-48. Integrated in Spacehab.

Radiation Monitoring Equipment. See STS-8. Integrated in Spacehab.

Space Tissue Loss. See STS-45. Integrated in Spacehab.

Shuttle Glo Experiment. Sponsored by US Air Force/Phillips Laboratory. Studied Earth's thermosphere, ionosphere, and mesosphere energetics and dynamics using broadband spectroscopy. Also studied spacecraft interactions with the atmosphere by observing shuttle and Mir glow, shuttle engine firings, water dumps, and fuel cell purges.

Far Ultraviolet Imaging Spectrograph. Integrated on Spartan 204. Studied astronomical and artificially induced sources of diffuse far-ultraviolet radiation.

Window Experiment. Integrated in Spacehab. Studied chemistry and dynamics of low-Earth orbit by collecting data about such phenomena as shuttle thruster plumes, water dumps, and atmospheric nightglow.

STS-70

Military Applications of Ship Tracks. See STS-65.

Hand-held, Earth-oriented, Real-time, Cooperative, User-friendly, Location-targeting and Environmental System. See STS-53.

Radiation Monitoring Equipment. See STS-8.

Space Tissue Loss. See STS-45.

Visual Function Tester. See STS-51C.

Microencapsulation in Space. See STS-53.

Window Experiment. See STS-63.

STS-69

Charging Hazards and Wake Studies. US Air Force Phillips Laboratory experiment to expand understanding of interactions of space environment with space systems and hazards these interactions create for satellite systems.

Auroral Photography Experiment-B. See STS-33.

Space Tissue Loss. See STS-45.

STS-74

Shuttle Glo Experiment. See STS-63.

STS-76

Get Away Special:

> Trapped Ions in Space. Sponsored by Naval Research Laboratory. Measured a recently discovered belt of energetic cosmic ray nuclei trapped in Earth's magnetic field to quantify radiation hazards in space and lead to better theoretical understanding of how these cosmic ray nuclei have become trapped in Earth's magnetic field.

STS-77

Metal Thermal Experiment. Sponsored by US Air Force Phillips Laboratory to evaluate performance of liquid metal heat pipes in microgravity conditions.

Brilliant Eyes Ten Kelvin Sorption Cryocooler Experiment. Funded by US Air Force Space and Missiles System Center and the Department of Defense’s Ballistic Missile Defense Organization. This microgravity experiment carried an instrument that can quickly cool infrared and other sensors to near absolute zero.

Space Tissue Loss. See STS-45.

STS-78

Microgravity Effects on Standardized Cognitive Performance Measures using the Performance Assessment Workstation. Sponsored by US Air Force Armstrong Laboratory. Identified effects of fatigue vs. microgravity on specific information processing skills.

Midcourse Space Experiment. Obtained ultraviolet, infrared, and visible data from sensors on Midcourse Space Experiment satellite of Orbiter thruster firings under controlled conditions and to determine instrumentation capabilities of experiment by observing Orbiter hard body.

Space Tissue Loss. See STS-45.

STS-79

Midcourse Space Experiment. See STS-78.

STS-80

Cell Culture Module. Formerly Space Tissue Loss. Validated models for muscle, bone, and endothelial cell biochemical and functional loss induced by microgravity stress. Purpose was to evaluate cytoskeleton, metabolism, membrane integrity, and protease activity in target cells, and to test tissue loss pharmaceuticals for efficacy.

Midcourse Space Experiment. See STS-78.

STS-81

Cosmic Radiation Effects and Activation Monitor experiment. See STS-48.

STS-83

Cryogenic Flexible Diode. Conducted tests of heat pipes in space to gain advances in passive thermal control technology.

STS-84

Cosmic Radiation Effects and Activation Monitor experiment. See STS-48.

Radiation Monitoring Equipment. See STS-8.

STS-94

Cryogenic Flexible Diode. See STS-83.

STS-85

COOLLAR Flight Experiment. Demonstrated operation of a J-T cycle cryocooler designed for space applications. Demonstrated collection and distribution of oil used to lubricate long-life J-T compressor, and the collection, storage, and application of liquid nitrogen to provide uniform and precise temperature control of components with varying heat loads.

Middle Atmospheric High Resolution Spectrograph Investigation. See STS-66.

Midcourse Space Experiment. See STS-78.

STS-86

Cosmic Radiation Effects and Activation Monitor experiment. See STS-48.

Shuttle Ionospheric Modification With Pulsed Localized Exhaust. Studied complex interactions of exhaust vapors with background atmosphere. Information will someday help the United States detect, identify, and track the flight of unfriendly space vehicles.

Cell Culture Module. See STS-80.

STS-87

Midcourse Space Experiment. See STS-78.

STS-89

Cosmic Radiation Effects and Activation Monitor experiment. See STS-48.

Shuttle Ionospheric Modification With Pulsed Localized Exhaust. See STS-86.

STS-91

Cosmic Radiation Effects and Activation Monitor experiment. See STS-48.

Shuttle Ionospheric Modification With Pulsed Localized Exhaust. See STS-86.

STS-95

Petite Amateur Naval Satellite. A small telecommunications satellite used to enhance education of military officers at Naval Postgraduate School.

Cryogenic Thermal Storage Unit. Demonstrated functionality of four important spacecraft thermal control devices in microgravity: 60K Thermal Storage Unit; Cryogenic Capillary Pumped Loop; Cryogenic Thermal Switch; and Phase Change Upper End Plate.

Cell Culture Module. Integrated in Spacehab. See STS-80.

STS-88

Shuttle Ionospheric Modification With Pulsed Localized Exhaust. See STS-86.

Deployed MightySat-01. Experimental US Air Force Research Laboratory satellite.

STS-93

Space Tissue Loss. See STS-45.

Cell Culture Module. See STS-80.

Micro-Electromechanical Systems. Examined performance of a suite of devices under launch, microgravity, and re-entry conditions. Devices included accelerometers, gyros, and environmental and chemical sensors.

Lightweight Flexible Solar Array Hinge. Consisted of several hinges fabricated from shape-memory alloys, which allow controlled,shockless deployment of solar arrays and other spacecraft appendages. Demonstrated deployment capability of a number of hinge configurations on STS-93.

Shuttle Ionospheric Modification With Pulsed Localized Exhaust. See STS-86.

Midcourse Space Experiment. See STS-78.

STS-108

Shuttle Ionospheric Modification With Pulsed Localized Exhaust. See STS-86.

STS-110

Shuttle Ionospheric Modification With Pulsed Localized Exhaust. See STS-86.

Ram Burn Observations. Observed shuttle Orbital Maneuvering System engine burns for purpose of improving plume models.

STS-111

Ram Burn Observations. See STS-110.

STS-112

Ram Burn Observations. See STS-110.

Spatial Heterodyne Imager for Mesospheric Radicals. Measured ultraviolet light spectrum emitted by hydroxyl molecules in the 30- to 100-km (19- to 52-mile) altitude range of the atmosphere and added to body of global hydroxyl observations.

STS-113

MicroElectricoMechanical System-based PICOSAT Inspector. Tested two miniature satellites in space for enhanced satellite command.

STS-107

Miniature Satellite Threat Reporting System. US Air Force-sponsored payload demonstrated new communications technology developed by US Air Force Research Laboratory in Albuquerque, New Mexico. All on-orbit operations were performed and sufficient data were downlinked to prove the concept.

STS-115

Ram Burn Observations. See STS-110.

STS-116

Atmospheric Neutral Density Experiment. Measured density and composition of low-Earth orbit atmosphere while being tracked from the ground. Data will be used to better predict movement of objects in orbit.

Radar Fence Transponder. Student experiment from US Naval Academy used picosatellites to test Space Surveillance Radar Fence and experimental communications transponders.

MicroElectricoMechanical System-based PICOSAT Inspector. See STS-113.

STS-117

Ram Burn Observations. See STS-110.

STS-118

Cell Culture Module – Immune Response of Human Monocytes in Microgravity. Department of Defense Space Test Program. Research used cell culture in microgravity as model of reduced immune function. Examined response of human immune cells in microgravity to new chitosan-based antibacterials.

Cell Culture Module – Effect of Microgravity on Wound Repair: In Vitro Model of New Blood Vessel Development. Department of Defense Space Test Program. Research used cell culture in microgravity as model of wound healing. Examined how microgravity alters new blood vessel development—a key component of wound and tissue repair.

Ram Burn Observations. See STS-110.

STS-120

Air Force Maui Optical Site tests. See STS-51J.

STS-122

Air Force Maui Optical Site tests. See STS-51J.

STS-123

Rigidizable Inflatable Get Away Special Experiment. Operated in shuttle cargo bay and was designed to test and collect data on inflated and rigid structures in space. Operated in Department of Defense canister for all payload ejections.

STS-126

Pico-Satellite Solar Cell Experiment. Tested space environment effects on new solar cell technologies.

STS-119

Shuttle Ionospheric Modification With Pulsed Localized Exhaust. See STS-86.

STS-127

Atmospheric Neutral Density Experiment – 2. Two microsatellites launched from shuttle payload bay measured density and composition of the low-Earth orbit atmosphere while being tracked from the ground. Data will be used to better predict movement and decay of objects in orbit.

Shuttle Exhaust Ion Turbulence Experiments. Used space-based sensors to detect ionospheric turbulence inferred from radar observations of previous Space Shuttle Orbital Maneuvering System burn experiment using ground-based radar. The first firing to be approved by NASA and the Department of Defense had incredible video of firing as it occurred during darkness taken on orbit.

STS-128

Shuttle Ionospheric Modification With Pulsed Localized Exhaust. See STS-86.

STS-129

Shuttle Exhaust Ion Turbulence Experiments. See STS-127 for description. Measurements were taken during Flight Day 11.

Shuttle Ionospheric Modification With Pulsed Localized Exhaust. See STS-86.

STS-132

Shuttle Ionospheric Modification With Pulsed Localized Exhaust. See STS-86.

STS-133

Ram Burn Observations. See STS-110 for description. Provided unique and spectacular data for analysis.

Shuttle Ionospheric Modification with Pulsed Localized Exhaust. See STS-86.

STS-134

Air Force Maui Optical Site tests. See STS-51J for description. MAUI observation was completed on Flight Day 15 with four primary Reaction Control System burns lasting 144 seconds over Air Force Maui Optical and Supercomputing Site.

Ram Burn Observations. See STS-110 for description. Data were acquired on Flight Day 16 using three dedicated Primary Reaction Control System burns.

STS-135

Pico-Satellite Solar Cell Experiment. See STS-126 for description. Allowed for gathering of spaceflight performance data before launch of new satellites with new solar cell technology as primary power source. Satellite was deployed from the shuttle, marking the 180th and final satellite deployment by the Space Shuttle Program. The satellite was declared healthy and operating after its deployment.

Space Tissue Loss − The Effects Microgravity on Stem Cell-Based Tissue Regeneration: Keratinocyte Differentiation in Wound Healing. Investigated effects of microgravity on tissue regeneration and wound healing in space. Conducted in hopes of helping research methods of treating Earth-bound injuries where cellular degeneration and decreased immune response occur in traumatic wounds and unused limbs.

3.2 International/Construction of International Space Station

STS-41C

Deployed the Long Duration Exposure Facility, which gave critical evidence of performance and degradation of materials in low-Earth orbit, and data about micrometeoroid and orbital debris the International Space Station would face. Data were used to improve engineering requirements for station.

Long Duration Exposure Facility Experiments. All experiments required free-flying exposure in space, but no extensive electrical power, data handling, or attitude control systems

STS-41D

Ran tests with a deployable solar power wing to validate International Space Station construction techniques.

STS-41G

Astronauts demonstrated safe capability for in-space resupply of dangerous rocket propellants in payload bay apparatus.

STS-61B

Astronauts practiced extravehicular activity techniques for space-station-sized structures.

STS-32

Retrieved the Long Duration Exposure Facility. See STS-41C for description.

STS-37

Explored mobility aids and extravehicular activity handling limits.

STS-88

Rendezvoused with Russian Zarya control module and attached Unity connecting module, providing foundation for future International Space Station components.

Performed three extravehicular activities for a total time of 21:22 (hours:minutes).

> Mated electrical connectors for Node 1 activation. Installed handrails, foot restraints, and communications hardware. Installed extravehicular activity hardware and removed pressurized mating adaptor 2 cables.

STS-96

Transferred logistical supplies from Orbiter to International Space Station.

Performed one extravehicular activity for a total time of 7:55 (hours:minutes).

> Installed two cargo booms, tool carriers, foot restraints, handrails, and inspected antennas on US Unity module.

STS-101

Equipped International Space Station with new or replacement gear and transferred more than a ton of supplies into International Space Station for use by its future residents.

Performed one extravehicular activity for a total time of 6:44 (hours:minutes).

> Installed cargo boom, secured crane, replaced environment control system antenna, installed handrails and television camera cable.

STS-106

Prepared International Space Station for first crew and connected power, data, and communications cables between recently launched Russian Zvezda module and Russian Zarya control module. Focused on unloading cargo from Orbiter and a Progress supply craft already docked to opposite end of station.

Performed one extravehicular activity for a total time of 6:14 (hours:minutes).

Routed cables between Russian Zarya and Zvezda modules.

STS-92

Performed four extravehicular activities for a total time of 27:19 (hours:minutes).

Installed Z1 truss and third pressurized mating adapter.

Routed cables between US Unity module and Z1 truss, transferred and deployed S-band antennas.

Routed cables between pressurized mating adaptor 3 and US Unity module, opened hatches on Z1 truss.

Installed electrical power converters on Z1 truss and routed cables.

Installed Z1 truss hardware and conducted Simplified Aid for Extravehicular Activity Rescue flight test.

STS-97

Performed three extravehicular activities for a total time of 19:20 (hours:minutes).

Installed P6 solar arrays on Z1 truss, set up for radiator and solar array deployment.

Installed P6 solar array electrical cables, installed S-band antenna, configured station for arrival of Destiny.

Installed floating potential probe to measure plasma electrical potential, Z1 radiator sensor, antennas, television camera cable, and completed solar array deployment.

Delivered and connected first set of US-provided solar arrays to International Space Station, prepared docking port for arrival of US laboratory Destiny, installed floating potential probes to measure electrical potential surrounding station, installed a camera cable outside Unity module, and transferred supplies, equipment, and refuse between Orbiter and station.

STS-98

Delivered, attached, and activated Destiny module to International Space Station.

Performed three extravehicular activities for a total time of 19:49 (hours:minutes).

Transferred pressurized mating adaptor 2 from US Unity module to Z1 truss, retrieved and mated Destiny to US Unity module, connected Destiny to station systems.

Moved pressurized mating adaptor 2 from Z1 truss to Destiny, installed exterior shutters to Destiny window, set up base for Canadian-built Canadarm-2 installation.

Installed S-band antenna to Z1 truss, installed cables to between Destiny and pressurized mating adaptor 2, practiced carrying a disabled astronaut.

STS-102

Delivered Expedition 2 crew members James Voss and Susan Helms as well as Russian crew member Yury Usachev; returned Expedition 1 crew members William Shepherd and Russians Yuri Gidzenko and Sergei Krikalev to Earth. Transferred supplies, equipment, and science racks from Multi-Purpose Logistics Module.

Performed two extravehicular activities for a total time of 15:26 (hours:minutes).

Configured US operating segment for Multi-Purpose Logistics Module docking.

Installed cargo carrier, backup cooling pump to Destiny, finished mating cables installed during previous spacewalk.

STS-100

Delivered and attached Canadian-built Canadarm-2 outside station's Destiny module. Transferred supplies and scientific equipment racks to station via Multi-Purpose Logistics Module.

Performed two extravehicular activities for a total time of 14:50 (hours:minutes).

> Installed Canadian-built Canadarm-2 on Destiny, installed ultra-high frequency antenna in vicinity of pressurized mating adaptor 2.
>
> Removed ultra-high frequency antenna from Unity and configured Unity starboard port, mated Canadarm-2 cables.

STS-104

Delivered and attached Quest airlock to Unity node of International Space Station.

Performed four extravehicular activities for a total time of 16:30 (hours:minutes).

> Mated Quest airlock to Unity.
>
> Installed three high-pressure gas tanks on Quest airlock, installed foot restraints and handrails.
>
> Installed handrails and four high-pressure oxygen tanks in Quest airlock, installed thermal panels to external tanks.

STS-105

Brought Expedition 3 crew member Frank Culbertson and Russian crew members Mikhail Turin and Vladimir Dezhurov to International Space Station and returned Expedition 2 crew members James Voss and Susan Helms as well as Russian crew member Yury Usachev to Earth. Payload included early ammonia servicer for installation on exterior of station, and Multi-Purpose Logistics Module.

Performed two extravehicular activities for a total time of 11:45 (hours:minutes).

> Installed cooling system ammonia container on P6 truss, installed two material specimen containers on Quest airlock.
>
> Installed handrail and routed two power cables on Destiny.

STS-108

Delivered Expedition 4 Russian crew member Yuri Onufrienko along with crew members Carl Walz and Daniel Bursch to International Space Station and returned Expedition 3 crew member Frank Culbertson and Russian crew members Mikhail Turin and Vladimir Dezhurov to Earth. Payload contained Multi-Purpose Logistics Module with supplies for station.

Performed one extravehicular activity for a total time of 4:12 (hours:minutes).

> Installed thermal covers on solar array drives; installed mounting platforms.

STS-110

Performed four extravehicular activities for a total time of 28:22 (hours: minutes).

> Installed starboard zero truss and mobile transporter to Destiny module.
>
> Installed and secured S0 truss to Destiny, mated power cables.
>
> Continued S0 installation, removed launch restraints and thermal installation.
>
> Installed first section of transporter for Canadian-built Canadarm-2.
>
> Installed handrail bridge between Quest airlock and S0 truss, installed handrails and floodlights.

STS-111

Delivered Expedition 5 crew member Peggy Whitson along with Russian crew members Valery Korzun and Sergei Treshchev to International Space Station and returned Expedition 4 Russian crew member Yuri Onufrienko along with crew members Carl Walz and Daniel Bursch to Earth. Payload contained Multi-Purpose Logistics Module with supplies for station as well as mobile remote service base system.

Performed three extravehicular activities for a total time of 19:31 (hours:minutes).

> Installed power and data grapple fixture on P6 truss, moved protective panels from Orbiter payload bay and temporarily stowed on pump module assembly-1.
>
> Installed mobile base for Canadian-built Canadarm-2.
>
> Serviced Canadian-built Canadarm-2.

STS-112

Payload included S1 integrated truss segment and crew and equipment translation aid cart A, attached to International Space Station.

Performed three extravehicular activities for a total time of 19:41(hours:minutes).

> Installed S1 truss segment, installed second S-band antenna and external television camera, removed crew and equipment translation aid-A cart and radiator beam launch restraints.
>
> Installed second television camera, completed removal of cart and radiator launch restraints, mated ammonia tank hydraulic line connectors on S1 truss.
>
> Recovered mobile transporter interface umbilical assembly, perform S0 and S1 ammonia loop line operations.

STS-113

Delivered Expedition 6 crew members Kenneth Bowersox and Donald Pettit and Russian crew member Nikolai Budrian to International Space Station and returned Expedition 5 crew members Peggy Whitson and Russian Valery Korzun and Sergei Treschev to Earth. Delivered and attached P1 truss to station.

Performed three extravehicular activities for a total time of 19:55 (hours:minutes).

> Mated cables between P1 and S0 truss segments, installed spool positioning devices and wireless video system external transceiver assembly relay, removed keel pins, moved crew and equipment translation aid-A cart from P1 to S1.
>
> Installed spool positioning devices and S0/P1 ammonia line jumpers, mated ammonia tank hydraulic lines on P1 truss segment, reconfigured primary bus cable harnesses.

STS-114

Payload contained Multi-Purpose Logistics Module with supplies for International Space Station.

STS-121

Payload contained Multi-Purpose Logistics Module with supplies for International Space Station. Delivered Expedition 13/14 crew member Thomas Reiter of Germany to station.

Performed three extravehicular activities for a total time of 21:29 (hours:minutes).

> Installed blade blocker on S0 truss, tested combination of robotic arm and Orbiter Boom Sensor System as platform.
>
> Restored station’s mobile transporter car to full operation.
>
> Tested repairs on Thermal Protection System reinforced carbon-carbon panels, removed fixed grapple bar and installed on ammonia tank in station’s S1 truss.

STS-115

Delivered and attached truss section P3/P4, a pair of solar arrays, and batteries, along with supplies for International Space Station.

Performed three extravehicular activities for a total time of 19:19 (hours:minutes).

Connected power cables on P3/P4 truss, configured solar alpha rotary joint, removed circuit interrupt devices.

Released locks on solar alpha rotary joint.

Powered up cooling radiator, replaced S-band radio antenna, installed insulation for communications antenna.

STS-116

Delivered and attached P5 segment and new solar arrays. Delivered payload of supplies and equipment for International Space Station and Expedition 14/15 crew member Sunita Williams. Returned to Earth Expedition 13/14 crew member Thomas Reiter of Germany.

Performed four extravehicular activities for a total time of 25:46 (hours:minutes).

Aligned and installed P5 on end of P3/P4 truss, partially retracted station's P6 port side array.

Reconfigured power on channels 2 and 3 of outpost's electrical system.

Finished power work outside station, rearranged power on electrical channels 1 and 4.

Fully retracted P6 solar array.

STS-117

Delivered and attached S3/S4 truss and set of solar arrays to International Space Station. Delivered Expedition 15/16 crew member Clayton Anderson to station and returned to Earth Expedition 14/15 crew member Sunita Williams.

Performed four extravehicular activities for a total time of 27:58 (hours:minutes).

Installed and activated S3/S4 truss segment.

Removed launch locks on solar alpha rotary joint, helped retract an old solar array.

Repaired thermal blanket on Orbiter's port Orbital Maneuvering System pod, installed vent on station's Destiny laboratory, helped fold up older solar array.

Removed last solar alpha rotary joint launch restraints, prepared joint for rotation.

STS-118

Delivered and installed starboard S5 truss on International Space Station as well as External Stowage Platform 3 and replacement control moment gyroscope.

Performed four extravehicular activities for a total time of 23:13 (hours:minutes).

Installed S5 truss segment, retracted forward heat-rejecting radiator from P6 truss.

Installed control moment gyroscope onto Z1 segment of station's truss.

Relocated S-band antenna sub-assembly from P6 to P1, installed new transponder on P1 and retrieved P6 transponder, moved two crew and equipment translation aid cards.

Installed external wireless instrumentation system antenna, attached a stand for Shuttle Robotic Arm extension boom, and retrieved two materials experiment containers.

STS-120

Delivered and installed Harmony Node 2 module and relocated P6 truss on International Space Station. Returned to Earth Expedition 15/16 crew member Clayton Anderson.

Performed four extravehicular activities for a total time of 27:18 (hours:minutes).

Installed Harmony module in its temporary location, readied P6 truss for relocation, and retrieved failed radio communications antenna.

Disconnected cables from P6 truss to enable it to be removed from Z1 truss, outfitted Harmony module, mated power and data grapple fixture, and reconfigured connectors on S1 truss.

Installed P6 truss segment with its set of solar arrays to its permanent home, installed spare main bus switching unit on stowage platform.

Repaired solar array.

STS-122

Delivered and installed European Space Agency's Columbus laboratory. Delivered Expedition 16 crew member Leopold Eyharts of France to International Space Station and returned to Earth Expedition 16 crew member Daniel Tani.

Performed three extravehicular activities for a total time of 22:08 (hours:minutes).

Installed grapple fixture on Columbus in payload bay and prepared electrical and data connections on module, moved Columbus into position.

Replaced large nitrogen tank used for pressurizing station's ammonia cooling system and made minor repairs to Destiny laboratory debris shield.

Transferred and installed two external experiment facilities to the European Technology Exposure Facility.

STS-123

Delivered and attached pressurized section of Japanese Experiment Logistics Module and Special Purpose Dexterous Manipulator to International Space Station. Delivered Expedition 16/17 crew member Garrett Reisman to station and returned to Earth Expedition 16 crew member Leopold Eyharts of France.

Performed five extravehicular activities for a total time of 33:28 (hours:minutes).

Prepared experiment logistics module-pressurized section for unberthing from payload bay.

Assembled Canadian Special Purpose Dexterous Manipulator known as Dextre.

Outfitted Dextre, prepared Spacelab logistics pallet for landing, moved the materials International Space Station Experiment 6 experiment to Columbus module.

Replaced a failed remote power controller module on station's truss.

Conducted a heat shield repair demonstration.

Transferred Orbiter Boom Sensor System to temporary stowage location on S1 truss, installed experiment logistics module-pressurized section trunnion covers.

STS-124

Delivered and attached pressurized module of Japanese experiment module Kibo to International Space Station. Delivered Expedition 17/18 crew member Gregory Chamitoff to station and returned to Earth Expedition 16/17 crew member Garrett Reisman.

Performed three extravehicular activities for a total time of 20:32 (hours:minutes).

Released straps on Shuttle Robotic Arm elbow joint camera, transferred Orbiter Boom Sensor System back to shuttle, and prepared Japanese experiment module—pressurized module Kibo—for installation.

Installed covers and external equipment to Kibo, prepared for relocation of experiment logistics module-pressurized section, prepared a nitrogen tank assembly for removal, and removed a television camera with failed power supply.

Removed and replaced starboard nitrogen tank assembly, finished outfitting Kibo laboratory, and reinstalled a television camera with a repaired power supply.

STS-126

Payload contained Multi-Purpose Logistics Module with supplies for International Space Station. Delivered Expedition 18 crew member Sandra Magnus to station and returned to Earth Expedition 17/18 crew member Gregory Chamitoff.

Performed four extravehicular activities for a total time of 26:41 (hours minutes).

> Began cleaning and lubrication of starboard solar alpha rotary joints, and replacement of 11 trundle bearing assemblies.
>
> Lubricated the Space Station Robotic Arm’s latching end effector "A" snare bearings, continued cleaning and lubrication of starboard solar alpha rotary joints.
>
> Completed cleaning, lubrication, and replacement of all but one trundle bearing assembly on starboard solar alpha rotary joints.
>
> Completed replacement of trundle bearing assemblies on starboard solar alpha rotary joints, lubricated port solar alpha rotary joints, installed a video camera, performed Kibo robotic arm grounding tab maintenance, installed spacewalk handrails on Kibo, and installed Global Positioning Satellite antennae on Kibo.

STS-119

Delivered and installed integrated truss segment and set of solar arrays and batteries to International Space Station. Delivered Expedition 18 crew member Koichi Wakata of Japan to station and returned to Earth Expedition 18 crew member Sandra Magnus.

Performed three extravehicular activities for a total time of 19:04 (hours:minutes)

> Installed S6 truss to S5 truss, connected S5/S6 umbilicals, released launch restraints, removed keel pins, stored and removed thermal covers, and deployed S6 photovoltaic radiator.
>
> Partially installed an unpressurized cargo carrier attachment system on P3 truss, and installed a Global Positioning Satellite antenna to Kibo laboratory.
>
> Relocated crew equipment cart, lubricated station arm grapple snares, and attempted deployment of cargo carrier.

STS-127

Delivered exposed facility of Japan's Kibo laboratory to International Space Station. Delivered Expedition 20 crew member Tim Kopra and returned Expedition 20 crew member Koichi Wakata from Japan.

Performed five extravehicular activities for a total time of 32:30 (hours:minutes).

STS-128

Delivered Expedition 20/21 crew member Nicole Stott and returned Expedition 20 crew member Tim Kopra.

With Multi-Purpose Logistics Module, carried experiment and storage racks to International Space Station.

Performed three extravehicular activities for a total time of 20:14 (hours:minutes).

STS-129

Delivered components including two spare gyroscopes, two nitrogen tank assemblies, two pump modules, an ammonia tank assembly, and a spare latching end effector for Space Station Robotic Arm to station. Returned Expedition 20/21 crew member Nicole Stott.

Performed three extravehicular activities for a total time of 18:27 (hours:minutes) .

STS-130

Delivered final connecting node, Node 3, and Cupola—a robotic control station with six windows around its sides and another in the center that provided a 360-degree view around International Space Station.

Performed three extravehicular activities for a total time of 18:14 (hours: minutes).

STS-131

Carried Multi-Purpose Logistics Module filled with science racks that were transferred to laboratories of International Space Station. Performed three extravehicular activities for a total time of 20:17(hours:minutes).

STS-132

Carried integrated cargo carrier to deliver maintenance and assembly hardware, including spare parts for space station systems. The second in a series of new pressurized components for Russia, a mini research module, was permanently attached to bottom port of Russian Zarya module.

Performed three extravehicular activities for a total time of 21:20(hours:minutes).

STS-133

Delivered express logistics carrier 4, Multi-Purpose Logistics Module, and critical spare components to International Space Station.

Delivered express logistics carrier 4, the Permanent Multi-Purpose Logistics Module Leonardo, and critical spare components to International Space Station.

Robonaut 2. Dexterous humanoid robot designed to both work alongside astronauts and handle tasks too risky for humans using its dexterous manipulation capabilities. Delivered to International Space Station on STS-133.

Two extravehicular activities were performed on this flight for a total time of 12:48 (hours:minutes).

STS-134

Delivered Alpha Magnetic Spectrometer, the express logistics carrier 3, consumables, scientific experiments and hardware, and spare parts such as a spare arm for Special Purpose Dexterous Manipulator (Dextre).

Four extravehicular activities were performed on this flight for a total time of 28:43 (hours:minutes). Extravehicular activities performed on this flight were final shuttle-performed extravehicular activities.

STS-135

Carried the Multi-Purpose Logistics Module Raffaello to International Space station with supplies and spare parts, and then returned Raffaello with trash and unneeded equipment. Also returned failed External Thermal Cooling System Pump module on Lightweight Multi-Purpose Carrier. Shuttle middeck contained additional supplies and experiments that were transferred to space station.

Delivered Robotic Refueling Mission to space station to demonstrate and test the tools, technologies, and techniques needed to robotically refuel and repair satellites in space.

No extravehicular activities were performed during this mission.

3.3 Education

STS-4

The Effects of Diet, Exercise, and Zero Gravity on Lipoprotein Profiles. Goal was to determine whether any alterations occur in lipoprotein profiles during spaceflight.

The Effects of Space Travel on Levels of Trivalent Chromium in the Body. Goal was to determine whether any alterations occur in chromium metabolism during spaceflight.

Get Away Specials—Activated first Get Away Special after an electrical problem was corrected:

Drosophilae Melanogaster (Fruit Fly) Growth Experiment. Student experiment designed to provide a means of raising and separating succeeding generation of fruit flies in microgravity for study. Equipment was tested for future flight on Long Duration Exposure Facility.

Artemia (Brine Shrimp) Growth Experiment. Studied genetic effects of microgravity on cysts hatched in space. Shrimp were observed by a 35mm motor-driven Nikon camera with a 55mm micro-Nikkor lens.

Surface Tension Experiment. Studied shape of a liquid meniscus in microgravity using an aluminum block containing holes filled with solder that is heated, thus allowing solder to flow and form a meniscus shape.

Composite Curing Experiment. Completed cure of B-staged (partially cured) epoxy resin-graphite composite sample in microgravity for comparison with 1*g* samples. Analyzed sample postflight to determine quality of wetting between resin and graphite fibers and to test tensile strength of sample.

Thermal Conductivity Experiment. Mixed oil and water in orbit and heated mixture to measure thermal conductivity of mixture from data obtained from temperatures of heater wire mixture and air around cylinder.

Microgravity Soldering Experiment. Studied separation of flux from solder while soldering in microgravity. The solder was analyzed postflight for trapped pockets of flux and was compared with solder processed on Earth.

Root Growth of Lemna Minor L. (Duckweed) in Microgravity. Used a 35mm Nikon camera to photograph growth patterns of Duckweed. Electron microscopy compared control and flight specimens.

Homogeneous Alloy Experiment. Aluminum chamber containing a powdered bismuth-tin mixture was heated, allowing alloying to take place. Alloy was returned for testing on ground.

Algal Microgravity Bioassay Experiment. Monitored growth rate of unicellular green algae Chlorella vulgaris in microgravity. A fixative was injected at the end of experiment to preserve cells for postflight analysis.

STS-5

Growth of Porifera in Zero Gravity. Designed to study effect of zero gravity on sponge, Porifera, in relation to its regeneration of structure, shape, and spicule (needle-like structure that supports soft tissue) formation following separation of the sponge.

Convection in Zero Gravity. Designed to study surface tension convection in zero gravity. Studied effects of boundary layer conditions and geometries on onset and character of convection.

Formation of Crystals in Weightlessness. Purpose was to compare crystal growth in microgravity to that in 1*g* to determine if weightlessness eliminates causes of malformations in crystals.

STS-6

US Air Force Academy Cadet Experiments:

Metal Beam Joiner. Worked to demonstrate that soldering of beams can be accomplished in space.

Metal Alloy. Worked to determine if tin and lead would combine more uniformly in microgravity.

Foam Metal. Worked to foam metal in microgravity forming a metallic sponge.

Metal Purification. Tested effectiveness of zone-refining methods of purification in a microgravity environment.

Electroplating. Worked to determine how evenly a copper rod can be plated in a zero-gravity environment.

Microbiology. Tested effects of weightlessness and space radiation on microorganism development.

STS-7

Get Away Specials:

> West German High School Student Experiments. Five experiments designed by West German high school students included a crystal growth, a nickel catalyst, biostack, plant contamination by heavy metals, and a microprocessor-controlled sequencers experiment.
>
> Purdue University Experiments. Students conducted three experiments in space science, biological science, and fluid dynamics.
>
> California Institute of Technology Student Experiments. Undergraduate students designed experiments to examine oil and water separation in microgravity, and to grow radishes from seeds in space. Developed a computer to run and monitor the payload.
>
> Observation of a live ant colony. Ants were housed in a special farm and placed in Get Away Special canister, along with television and movie cameras, to see whether weightlessness affects colony's social structure.

STS-8

Biofeedback Mediated Behavioral Training in Physiologic Self Regulator: Application in Near Zero Gravity Environment. Determined whether biofeedback training learned in 1*g* (on Earth) can be successfully implemented in microgravity (in orbit).

STS-9

Shuttle Amateur Radio Experiment. Provided public participation in space program, supported educational initiatives, and demonstrated effectiveness of making contact between shuttle and amateur "ham" radio stations on the ground.

STS-41B

Effects of Weightlessness on Arthritis. Shuttle Student Involvement Program experiment studied effects of microgravity on arthritis using rats.

Get Away Specials:

> Utah State University-University of Aberdeen Experiments. Utah State University studied capillary waves in liquids and thermocapillarity. University of Aberdeen studied dimensional stability, light scattering, and flew spores in space.
>
> American Institute of Aeronautics-Utah Section experiments. Brighton High School students in Salt Lake City, Utah, flew radish seeds to be sprouted in microgravity. University of Utah attempted to crystallize proteins in a controlled temperature environment in microgravity. Utah State University students conducted experiments including a redesigned re-flight of a soldering experiment and tested a heat pipe to be used in a future space experiment.

STS-41C

A colony of honey bees in space. Compared quantitatively the size, shape, and volume and wall structure of honeycomb structures. Attempted to determine characteristics of hive construction of Apis mellifera honey bees in microgravity.

STS-41D

Float Zone Experiment. Designed to compare a crystal grown by "float zone" technique in a low-gravity environment with one grown in an identical manner on Earth.

STS-41G

Get Away Specials:

> Trapped Ions in Space Experiment. Investigated unexpectedly large flux of heavy ions (electrically charged ions of oxygen and heavier atomic elements) first observed in an experiment on board Skylab in 1973 and 1974.

Physics and Material Processing Experiments. Studied basic physical processes or, in some cases, their effects on a variety of processes. They include the following:

Capillary Waves Under Zero-Gravity. Excited waves in a water surface and photographed results.

Solder Flux Separation. Studied separation of flux and solder in microgravity.

Heat Pipe Experiment. Tested a fluid flow system, which was later used in an electrophoresis experiment.

Thermocapillary Convection. Studied flow patterns set up by a temperature difference.

STS-51D

Statoliths in Corn Root Caps. Looked at effect of weightlessness on formation of statoliths (gravity-sensing organs) in plants, and was tested by exposing plants with capped and uncapped roots to spaceflight.

The Effect of Weightlessness on the Aging of Brain Cells. Experiment (using houseflies) showed accelerated aging in their brain cells based on an increased accumulation of age pigment in, and deterioration of, neurons.

STS-51B

Northern Utah Satellite. Air traffic control radar system calibrator that measured antenna patterns for ground-based radars operated in United States and member countries of the International Civil Aviation Organization.

STS-51G

Get Away Specials:

Texas Student Experiments. El Paso, Texas, and Isleta, Texas, high school students designed experiments that included growth of lettuce seeds, barley seed germination, growth of brine shrimp, germination of turnip seeds, regeneration of flat worm planeria, wicking of fuels, effectiveness of antibiotics on bacteria, growth of soil mold, crystallization in microgravity, symbiotic growth of unicellular algae chlorella and milk product kefir, operation of liquid lasers, and effectiveness of Dynamic Random Access Memory computer chips without ozone protection.

STS-51F

Shuttle Amateur Radio Experiment. See STS-9.

Plant Carry-On Container. Allowed select group of students considering space sciences as a career option to study plant gravitropism with a focus on development of a diet and delivery system that could provide purified diets in a non-contaminating process.

STS-61B

Get Away Special:

Towards a Better Mirror. An effort to stimulate Canadian student interest in the space program. Selected high school students from a national competition flew an experiment to fabricate mirrors in space that would provide higher performance than Earth-made mirrors.

STS-61C

Argon Injection as an Alternative to Honeycombing. Examined ability to produce a lightweight honeycomb structure superior to Earth-produced structures.

Formation of Paper in Microgravity. Studied formation of cellulose fibers in a fiber mat under weightless conditions.

Measurement of Auxin Levels and Starch Grains in Plant Roots. Studied geotropism of corn root growth in microgravity as well as determined whether starch trains in the root cap are actually involved with auxin production and transport.

Get Away Specials:

Project Explorer Payload. Contained student experiments studying solidifications of lead-antimony and aluminum-cooper alloys, a study of the morphological and anatomical study of primary root system of radish seeds, a study of growth of metallic-appearing needle crystals in an aqueous solution of potassium tetracyanoplatinate, and a radio transmission experiment sponsored by Marshall Amateur Radio Club.

STS-26

Utilizing a Semi-Permeable Membrane to Direct Crystal Growth. Attempted to control crystal growth through use of a semi-permeable membrane.

Effects of Weightlessness on Grain Formation and Strength in Metals. Heated a titanium alloy metal filament to near melting point to observe effect that weightlessness had on crystal reorganization within the metal.

STS-29

Chicken Embryo Development in Space. Goal was to determine effects of spaceflight on development of fertilized chicken embryos.

The Effects of Weightlessness on the Healing Bone. Conducted to establish whether environmental effects of spaceflight inhibit bone healing.

STS-34

Zero Gravity Growth of Ice Crystals From Supercooled Water With Relation To Temperature. Observed geometric ice crystal shapes formed at supercooled temperatures, below 0°C (32°F), without the influence of gravity.

STS-31

Investigation of Arc and Ion Behavior in Microgravity. Student experiment studied effects of weightlessness on electrical arcs.

STS-35

Shuttle Amateur Radio Experiment. See STS-9.

Space Classroom, Assignment: The Stars. The Astro-1 science crew taught a live astronomy lesson on orbit with focus on electromagnetic spectrum and its relationship to high-energy astronomy mission.

STS-37

Shuttle Amateur Radio Experiment. See STS-9.

STS-40

Get Away Specials:

Orbital Ball Bearing Experiment. Tested effects of melting cylindrical metal pellets in microgravity.

Chemical Precipitate Formation. Investigated rate of formation and terminal size of precipitate particles when growth is not impaired by settling due to gravity.

Five Microgravity Experiments. One attempted to grow large zeolite crystals. Another studied behavior of fluids in microgravity. A third, the Environmental Data Acquisition System, recorded information about sound, light, temperature, and pressure within Get Away Special can. The fourth measured acceleration of the shuttle along three axes with a high degree of precision. A fifth experiment studied the fogging of film in space.

The Effect Of Cosmic Radiation On Floppy Disks & Plant Seeds Exposure To Microgravity. Investigated static computer memory (floppy disks) to determine if cosmically charged particles will produce changes in data integrity or structure. Looked for changes in physiology or growth of 38 different types of plant seeds.

STS-42

Get Away Special:

Brine Shrimp/Air Bubbles in Microgravity. The artemia (brine shrimp) experiment attempted to hatch and grow shrimp in microgravity. The air/water chamber of the fluid physics experiment measured amounts of air injected into a chamber filled with distilled water resulting in air bubbles of different sizes.

A Study of Motion of Debris in Microgravity and Investigation of Mixing of Low Melting Point Materials in Microgravity. Successfully used a movie camera to photograph the motion of debris in microgravity, and remelted two low melt-point materials that were premixed on Earth and then left the materials to cool and resolidify. These experiments, designed by students, were first payloads from China to be carried aboard a shuttle.

Convection in Zero Gravity. Studied effects of boundary layer conditions and geometries on the onset and character of convection.

Zero-G Capillary Rise of Liquid Through Granular Media. Studied a measured capillary flow of liquids through densely packed course granular media in microgravity. Astronauts videotaped the timed progression of liquid through different diameter-sized glass beads.

STS-45

Shuttle Amateur Radio Experiment. See STS-9.

STS-50

Shuttle Amateur Radio Experiment. See STS-9.

STS-47

Shuttle Amateur Radio Experiment. See STS-9.

Get Away Special:

Boy Scouts of America's Exploring Division. Contained seven experiments from different Boy Scout Explorer posts including studies on capillary pumping, cosmic rays, crystal growth and emulsions, fiber optics, floppy disks, fluid droplets, and command, power, and mechanical systems.

Kansas University Space Program Experiments. Volunteer undergraduate engineering and science major conducted experiments on crystallizing enzymes, researched cell formations, and flew seeds on orbit to test effects that the space environment might have had on seed germination rates.

Ashford School of Kent England Experiments. First British school experiment payload to fly in space studied cobalt nitrate crystals in a sodium silicate solution, and studied crystal growth in chemical gel solution.

University of Washington Engineering Student Experiments. Performed a test with an experimental cooling system using centrifuge and water, and flew a micro heat pipe.

STS-52

Commercial Materials Dispersion Apparatus Instrumentation Technology Associates Experiment. Instrumentation Technology Associates donated a portion of hardware flown for student experiments in their Student Space Education Program to increase awareness and interest in science and space technology.

STS-54

Application Specific Preprogrammed Experiment Culture System Physics of Toys. Carried a collection of children's toys for an educational post-flight videotape on the Physics of Toys.

STS-56

Solar Ultraviolet Experiment. Studied extreme ultraviolet solar radiation as it affects Earth's ionosphere.

Atmospheric Detectives, ATLAS 2 Teacher's Guide. Developed for use with middle school students to complement and teach science objectives of the ATLAS 2 mission.

Shuttle Amateur Radio Experiment-II. See STS-9. Shuttle Amateur Radio Experiment.

Mustard Seed Germination. Seeds and newly developing reproductive tissue of *Brassica rapa* were flown. Materials returned were used to propagate successive generations of the plant to assess long-term effects on heredity patterns.

Fish Egg Hatching. Studied how microgravity affects hatching process of annual killifish of Zanzibar, Africa.

Heart Cells In Culture. Using heart cells, this experiment attempted to determine effect(s) of microgravity on morphology and rate of heart "beats" of heart muscle cells.

Mushroom Spore Generation. Using a selected strain of *Agaricus bisporus* (the cultivated mushroom), this experiment attempted to determine effect(s) of microgravity on development of mushroom spores.

Mustard-Spinach Seed Germination. Attempted to determine effects of microgravity on mustard-spinach seed germination process.

Commercial Materials Dispersion Apparatus Instrumentation Technology Associates Experiment. See STS-52.

STS-55

Shuttle Amateur Radio Experiment. See STS-9.

STS-57

Shuttle Amateur Radio Experiment. See STS-9.

Get Away Special CAN DO experiment.

350 small passive student experiments.

GEOCAM. Photographed Earth to examine changes in the past 20 years.

STS-58

Shuttle Amateur Radio Experiment. See STS-9.

STS-60

Shuttle Amateur Radio Experiment. See STS-9.

Wake Shield Facility:

Fast Plants. Studied effects of space radiation on plants' generation.

A second student experiment determined orbital variation of Earth's magnetic field from electron diffraction data obtained in Wake Shield Facility thin film growth experiments.

Get Away Special:

Orbiter Stability Experiment. Measured vibration spectrum of Orbiter structure that was present during normal Orbiter and crew operations.

STS-59

Shuttle Amateur Radio Experiment. See STS-9.

STS-65

Shuttle Amateur Radio Experiment. See STS-9.

STS-64

Shuttle Amateur Radio Experiment . See STS-9.

Get Away Specials:

Distillation Experiment. Separated a mixture of two common organic liquids—trichlorotrifluoroethane and chloroform—in microgravity by distillation.

Float Zone Instability Experiment. Investigated convective instabilities in float zone geometries.

Pachamama. Studied effects of microgravity on photosynthetic ability of the plant lichen.

Bubble Interferometer Experiment. Observed bubbles in a microgravity environment.

Acoustics in Microgravity. Recorded visually how sound affects dust particles in near-zero gravity.

Reproduction of Parameciums. Studied effects of microgravity on reproduction of insects.

Studied contact between oil and water droplets for investigating effect of microgravity on surface interaction of different kinds of liquids.

Conducted a general survey of surface interaction of solids and liquids under microgravity conditions.

STS-68

Get Away Specials:

University of North Carolina A&T State University Experiments. Students involved in the university's Student Space Shuttle Program conducted experiments that studied effects of microgravity on survival, mating, and development of the milkweed bug, and conducted a chemistry experiment that used microgravity in an attempt to improve growth quality and size of a crystal of Rochelle salt.

University of Alabama in Huntsville and University of Alabama in Birmingham Experiments. Students conducted experiments on The Microgravity and Cosmic Radiation Effects on Diatoms, The Concrete Curing In Microgravity, Root Growth In Space, and Microgravity Corrosion.

STS-67

Shuttle Amateur Radio Experiment. See STS-9.

Commercial Materials Dispersion Apparatus Instrumentation Technology Associates Experiment. See STS-52.

STS-71

Shuttle Amateur Radio Experiment. See STS-9.

STS-70

Shuttle Amateur Radio Experiment. See STS-9.

STS-69

MagField Experiment. Determined variation of Earth's magnetic field from magnetometer and electron diffraction data obtained during the Wake Shield mission.

Commercial Materials Dispersion Apparatus Instrumentation Technology Associates Experiment. See STS-52.

Get Away Specials:

Millcreek Township School District Experiment. Investigated performance of electroheologic fluid-filled beams as structural dampers in space.

STS-73

Students Participate in Mission Investigations. Students interacted with astronauts to discuss and compare on-board microgravity experiments with similar ground-based experiments.

STS-74

Shuttle Amateur Radio Experiment. See STS-9.

STS-75

Educational Activities. Recorded aspects of Tethered Satellite System and United State Microgravity Payload-3 for educational videos for use as teaching aids.

STS-76

KidSat. Enabled students to configure their own payload of digital video and a camera for flight on shuttle, command the camera from their classrooms, and download their images of Earth in near real-time.

Shuttle Amateur Radio Experiment. See STS-9.

STS-77

The Biological Research In a Canister. Intended to aid in discovery of the mechanism(s) behind one endocrine system in insects, which may aid in research on endocrine systems in general, including human systems.

Get Away Specials:

Caltech's Gamma-ray Astrophysics Mission. Studied an enigmatic source of cosmic radiation known as gamma-ray bursts.

Space Popcorn. Contained popcorn kernels in zip-lock bags as an experiment by an elementary school. After being flown, students popped the popcorn and compared it with a similar sample maintained in 1*g*.

Robert Gordon University and Elrick Primary School Experiments. Robert Gordon University of Aberdeen, Scotland, investigated a proposal that low-level gravitational fields can be measured by observing their effect on the convection current present in a heated liquid. Children from Elrick Primary School near Aberdeen, Scotland, studied effects of spaceflight on growth patterns of selected samples of seeds, oats, wheat, barley, and nape-oil.

STS-78

Shuttle Amateur Radio Experiment. See STS-9.

STS-79

Shuttle Amateur Radio Experiment. See STS-9.

STS-80

Student Experiment on ASTRO-SPAS. Electrolysis experiment designed to study various metal salt solutions with two electrodes in microgravity.

DARA Project. Gave students data gathered on the mission for the study of general astronomy, the life and death of stars, stellar spectral analysis, as well as how to work with data on computers via the Internet.

Space Experiment Module. Stimulated and encouraged direct student participation in creation, development, and flight of zero-gravity and microgravity experiments on shuttle.

Commercial Materials Dispersion Apparatus Instrumentation Technology Associates Experiment. See STS-52.

STS-81

KidSat. See STS-76.

STS-94

Shuttle Amateur Radio Experiment. See STS-9.

STS-85

Space Experiment Module. See STS-80.

Distribution and Automation Technology Advancement - Colorado Hitchhiker and Student Experiment of Solar Radiation. Demonstrated distributed, interactive, and intelligent control approaches that enable space payloads to be operated by scientists from their home institutions.

Produced educational products that captured the interest of students and motivated them toward careers in science, engineering, and mathematics.

Get Away Special:

> Investigated root growth during a shuttle mission.

STS-86

Canadian Protein Crystallization Experiment. Biotechnology flight experiment that intended help advance treatment and possible cures for some debilitating diseases as well as bacterial and viral infections.

KidSat. See STS-76.

Seeds in Space-II. Passively exposed a group of tomato seeds, in hand-sewn Dacron® bags, to the vacuum of space.

STS-87

Collaborative Ukrainian Experiment. Evaluated effects of microgravity on the pollination and fertilization of *Brassica rapa* (Wisconsin Fast Plants) seedlings.

Educational Activities. Produced educational products that captured the interest of students and motivated them toward careers in science, engineering, and mathematics.

STS-89

Get Away Special:

> Vortex Ring Transit Experiment. Investigated propagation of a vortex ring through a liquid-gas interface in microgravity.

EarthKAM. Engaged students in selecting sites around the world to be photographed during shuttle flights, allowed them to participate in solving real-world problems that arose, and encouraged them to use tools of modern science, (computers and Internet) to study the images and Earth Science processes illustrated.

STS-90

Get Away Special:

> Collisions into Dust Experiment. Students at the University of Colorado at Boulder performed experiments that analyzed gentle collisions of dust particles in an attempt to shed new light on sources of dust in planetary rings.

STS-91

Get Away Special:

> Chemical Unit Process. Studied effects of extracting phosphate ions, used widely as a fertilizer, from phosphate ore mined on Fort Hall Reservation, Idaho.
>
> Nucleic Boiling. Studied effects of microgravity on bubble formation and temperature gradients as water is heated to a boil during flight.
>
> Crystal Growth Experiment. Studied formation and growth of chemical crystals in microgravity.
>
> Popcorn and Radish Seeds in Space. Studied effects of microgravity on popcorn kernels and radish seeds.
>
> Genotoxicology Experiment. Determined degree to which DNA is damaged by exposure to cosmic radiation in a space environment.

Space Experiment Module. See STS-80.

STS-95

Space Experiment Module. See STS-80.

Educational Activities. A 30-minute voice session to capture the interest of students and motivate them toward careers in science, engineering, and mathematics.

Commercial Instrumentation Technology Associates Biomedical Experiment. Instrumentation Technology Associates donated a portion of hardware flown for student experiments in their Student Space Education Program to increase awareness and interest in science and space technology.

Get Away Special:

Studied effects of space on life cycle of the American cockroach.

STS-96

Student-Tracked Atmospheric Research Satellite for Heuristic International Networking Equipment. Deployed a small student built satellite covered in mirrors that students watched sweep across the sky in the morning and evening twilight hours.

STS-93

Space Technology and Research for Students. Investigated predator/prey relationship between ladybugs and aphids and the chrysalis and wing development of Painted Lady butterflies in space.

Shuttle Amateur Radio Experiment-II. See STS-9. Shuttle Amateur Radio Experiment.

STS-99

EarthKAM. See STS-89.

Filmed NASA astronaut activities in high-definition television for educational purposes.

STS-101

Mission to America's Remarkable Schools. Stimulated and encouraged direct student participation in creation, development, and flight of zero-gravity and microgravity experiments on shuttle.Space Experiment Module. See STS-80.

STS-106

Get Away Special:

Aria-1. Involved students in hands-on space science and encouraged them toward science, engineering, and technology careers.

Space Experiment Module. See STS-80.

STS-97

Educational Activities. Provided live television of the mission to classrooms in hopes of attracting students to careers in science, engineering, and mathematics.

STS-98

Educational Activities. Educational videos made during flight for students.

STS-102

Space Experiment Module. See STS-80.

Get Away Special:

Aria-2. Involved students in hands-on space science and encouraged them toward science, engineering, and technology careers.

STS-105

Get Away Special:

Cell Growth in Microgravity. Observed root cell growth in microgravity by germinating Vicia Faba bean seeds in space.

Space Experiment Module. See STS-80.

STS-108

Student-Tracked Atmospheric Research Satellite for Heuristic International Networking Equipment. See STS-96.

Get Away Specials:

Exposure of Seeds to Space. Examined cell mutation and modifications in several types of seeds exposed to space environment.

Nucleic Boiling. Boiled water inside a chamber and videotaped the action of bubbles.

Chemical Unit Process. Conducted a water purification experiment.

Crystal Growth. Grew crystals from chemicals commonly found in the human body.

Popcorn and Seeds. Exposed popcorn to space for evaluation by students on Earth.

PSU Germinator I. Designed to answer questions related to sustained plant life in space and provide an affordable space-rated test chamber for microgravity and life science researchers.

Magnetometer. Recorded three-dimensional model of magnetic moment of the shuttle and measured distortions of the uniform background signal from currents that produce a part of Earth’s magnetic field.

Orbital Debris Experiment. Measured acoustical signature from hits on the shuttle by micro-meteors or space junk to test a concept for a future space station monitoring sensor.

Space Experiment Module. See STS-80.

STS-109

Provided live television downlink of mission to classrooms in hopes of attracting students to careers in science, engineering, and mathematics.

STS-107

Space Technology and Research Students Experiments. Education experiments included with Spacehab’s commercial payload:

Ants in Space. Students from Fowler High School in Syracuse, New York, studied tunneling behavior of Harvester Ant in microgravity. Most objectives were met through downlinked videos and photos.

Chemical Garden. Students from Ort-Matzkin School in Haifa, Israel, worked to observe growth of cobalt and calcium chloride salt filaments in a sodium silicate solution in microgravity. Student’s hypotheses were validated through downlinked video and photos.

Astrospiders- Spiders in Space. Students from Glen Waverely Secondary College, Melbourne, Australia, studied Garden Orb Weaver’s web building and other characteristics in microgravity with the hypothesis that the spider would build a different web in microgravity. A different web design was observed from downlinked video, but due to the accident, physical properties of the silk web could not be analyzed.

Spice Bees in Space. Students from Liechtenstein Gymnasium School, Liechtenstein, analyzed behavior of carpenter bees and their tunnel-boring characteristics in microgravity. The bee’s borrowing characteristics in space were observed through downlinked video, but due to the accident, the wood block could not be analyzed.

Silkworm Life Cycle During Spaceflight. Students from Jingshan School, Beijing, China, observed and characterized effects of microgravity on development of silkworm eggs, larvae, pupae, and adults. Dowlinked video and photos showed the metamorphosis process, which completed most objectives.

STS-116

Radar Fence Transponder. Used picosatellites to test Space Surveillance Radar Fence and experimental communications transponders.

STS-118

Educator Astronaut Program. Teacher-turned-astronaut Barbara Morgan facilitated education opportunities and activities that used the unique environment of spaceflight to attract students to careers in science, technology, engineering, and mathematics.

Education Payload Officer-Kit C. Maintained plants during mission and captured still images of plant growth.

Education Payload Officer-Educator. Carried plant seeds into space and captured still images of seeds in microgravity. Used video and still photography to capture data of experiment activities in space.

In-flight Education Downlinks. From space, astronauts performed live question-and-answer sessions with students.

Commercial Generic Bioprocessing Apparatus Science Insert – 02. Provided imagery of plant germination and growth and crystal growth in space to students on Earth.

STS-119

Educator Astronauts Joseph Acaba and Richard Arnold.

STS-127

Dual RF Astrodynamic GPS Orbital Navigator Satellite.

Demonstrated autonomous rendezvous and docking in low-Earth orbit and gather flight data with GPS receiver strictly designed for space applications.

STS-131

Educator Astronaut Dorothy Metcalf-Lindenberger.

Education Payload Operations-Robotics. Two on-orbit demonstrations explained robotic arm operations and scientific investigations.

In-Flight Education Downlinks. Crew participated in live in-flight education downlinks to answer questions from students.

STS-134

Student Spaceflight Experiments Program. Science, technology, engineering and mathematics education initiative began in June 2010 allowed students from pre-college age to college students and science institutions to fly experiments on the shuttle and, in the future, the International Space Station. The following experiments flew on STS-134 as part of this program:

Development of Prokaryotic Cell Walls in Microgravity. This Shelton High School of Shelton, Connecticut experiment worked to observe development and integrity of prokaryotic cell wall of bacteria.

Apples in Space. This Crystal Lake Middle School, Broward County, Florida, experiment allowed two apple seeds to germinate, with one being on Earth and the other on the shuttle, compare growth results once the seeds were planted on Earth.

The Effect of Microgravity on the Ability of Ethanol to Kill E. Coli. Designed by Orange County, Florida's, Maitland Middle School worked to determine whether ethanol would be able to kill Escherichia coli (E. coli) in microgravity.

Efficiency of Microencapsulation in Microgravity as Compared to Gravity. Sponsored by the Lincoln Hall Middle School of Lincolnwood, Illinois. Examined efficiency of microencapsulation of space and compared it to efficiency of microencapsulation in gravity environment of Earth.

The Effect of Microgravity on the Viability of Lactobacillus GG. The Academy @Shawnee, Jefferson County, Kentucky, experiment. Studied effect of microgravity on viability of Lactobacillus GG, a probiotic used as a preservative to keep dairy products fresh.

What is the Effect of Microgravity on the Growth Rate of Murine Myoblasts? Conducted by Copper Mill Elementary School, Zachary, Louisiana. Worked to see how microgravity affected growth rate of murine myoblasts isolated from adult mice.

Swimming Patterns and Development of Zebra Fish after Exposure to Microgravity. Designed by Esperanza Middle School, Saint Mary's County, Maryland. Tested development of fish in microgravity by exposing zebra fish embryos to microgravity to prove their hypothesis that microgravity causes development problems in fish.

Honey as a Preservative on Long Duration Space Flights. Created by the Harry A. Burke High School, Omaha, Nebraska. Studied whether honey can prevent raw foods spoiling while in space.

Effects of Microgravity on Lysozyme's Antibacterial Properties. Designed by the Omaha North High Magnet School, Omaha, Nebraska. Worked to determine how microgravity affects lysozme's antibacterial properties.

Does the Radiation exposure effect seed germination without the protection of the ozone layer? The Tse Bit ai Middle School of the Central Consolidated School District in New Mexico tested to see whether seeds exposed to higher radiation would decrease or increase sprouting and speed up or slow down seedling growth of seeds.

The development of Minnow Fish Eggs in Space. Milton Terrace South Elementary School, Ballston Spa Central School District, New York experiment worked to see how a lack of gravity affects the development of Minnow fish eggs.

Brine Shrimp Development. Designed by Mendenhall Middle School of Guilford, North Carolina. Observed whether there were any changes in brine shrimp in microgravity when compared to normal development on Earth.

Urokinase Protein Crystal Growth. Jackson Middle School, Portland, Oregon, experiment. Designed to grow urokinase protein crystals for researchers to learn more about treatments for cancers.

The Effect of Microgravity on Biofilm Formation by E. coli on Polystyrene Particles. El Paso Community College Transmountain Campus and Transmountain Early College High School, El Paso, Texas, investigation worked to determine whether biofilm formation is influenced by microgravity conditions.

Microgravity's Effects on Morphogens in Common Species. Hillcrest High School of the Canyons School District, Utah, investigation worked to determine effect of microgravity on diffusion of activin in Xenopus laevis.

How does spaceflight alters mutation rate, growth rate, rate of plasmid uptake, and ability to withstand subsequent stressors in a bacterial strain? The Ballard High School in Seattle, Washington studied how being in space would affect bacteria behavior in both space and then back on Earth.

STS-135

Student Spaceflight Experiments Program. See STS-134 for program description. The following experiments flew on STS-135 for this program:

Microgravity Yeast Experiment. Parkridge Elementary School in Peoria, Arizona, tested effect of zero gravity on yeast's microscopic structure to find a solution to keep astronauts healthy in space by getting the grains they need.

Microgravity's Effect on Tomato Growth. Annie Fisher of the science, technology, engineering and math (STEM) Magnet School in Hartford, Connecticut, worked to establish effects of microgravity on development of a tomato plant to research ways for providing food to astronauts on long-duration space flights.

Will Microgravity Effect the Development of Goldfish? Skinner West Classical, Fine Arts, & Technology School of Chicago, Illinois, investigated whether microgravity changed the development of a fertilized goldfish egg by comparing space-flown eggs to eggs that stayed on Earth.

All Mixed Up (Based on Gause's 1932 Experiment): The Effect of Microgravity on the Interaction of Paramecium bursaria and Paramecium caudatum in a Mixed Culture, using Yeast and Bacteria as a Food Source. Avicenna Academy Science Community Collaboration Crown Point, Indiana, tested effect of microgravity on interaction of two types of paramecia: P. bursaria and P. caudatum based on an experiment Georgyi Gause studied on Earth.

How Does Microgravity Affect the Maximum Cell Size of Tardigrades? Ridge View High School in Galva-Holstein, Iowa, studied how microgravity would affect cell size of tarigrades, commonly referred to as "water bears," in hopes of detecting any significant growth differences between microgravity specimens and Earth-bound specimens.

Physiological effects of microgravity on germination and growth of Arabidopsis thaliana. The Henry E. Lackey High School of Charles County, Maryland, investigated effect of microgravity on growth of plant structures during seed germination.

The Growth Rate of Lactobacillus acidophilus in Microgravity. Montachusett Regional Vocational Technical High School in Fitchburg, Massachusetts, worked to determine whether growth rate of Lactobacillus acidophilus, a bacteria responsible for dental caries (tooth decay), is more accelerated in space or on Earth.

Effects of Microgravity on Goodstreak Wheat. The Potter-Dix Schools in Potter and Dix, Nebraska, studied whether microgravity improved Goodstreak's germination, root development, and shoot growth.

The Effects of Microgravity on Oil Production in Salt-stressed Chlamydomonas reinhardtii. LPS Science Focus Program in Lincoln, Nebraska. Studied whether stress response of C. reinhardtii grown in microgravity deferred from Earth-bound C. reinhardtii.

Effects of Microgravity on Osteoblast Specialization and Bone Growth. The Bridgewater Raritan High School in Bridgewater-Raritan, New Jersey, explored possible solutions to bone loss problem in space by attempting to make a more efficient osteoblast.

Deposition and Formation of Zinc Phosphate Crystals in Microgravity. The Yeshiva Ketana of Long Island, Inwood, New York, investigated reaction of sodium phosphate with zinc chloride to produce sodium chloride and a precipitate of zinc phosphate to grow hopeite crystals to compare to Earth-grown crystals.

3.4 Earth Science

STS-2

Office of Space and Terrestrial Applications. Conducted experiments to view and image Earth to gather data on plant growth and variety of other subjects. All experiments and their command-telemetry interfaces operated properly.

Nighttime/Daytime Optical Survey of Lightning Experiment. Recorded motion pictures and photo cell readings of lightning and thunderstorms as seen from orbit. Data and knowledge that resulted from the lightning survey contributed to better understanding of evolution of lightning in severe storms.

Ocean Color Experiment. Designed to demonstrate ability to locate plankton or chlorophyll concentrations and identify circulation features by mapping color patterns in the ocean. Operated successfully and overall image quality and spectral information were excellent.

Shuttle Imaging Radar-A. Obtained map-like images of Earth's surface for geologic exploration using radar imagery to record differences in surface roughness and terrain attitude. Used to delineate such geological features as faults, anticlines, folds and domes, drainage patterns, and stratification. Penetrated extremely dry Selima Sand Sheet, dunes, and drift sand of Eastern Sahara, revealing previously unknown buried valleys, geologic structures, and possible Stone Age occupation sites.

Shuttle Multispectral Infrared Radiometer Experiment. Determined the spectral bands to be included in a future high-resolution imaging system for mapping rocks associated with mineral deposits from space. Sampled 80,000 km (50 miles) of Earth's surface and detected specific clay and carbonate minerals in Mexico in previously unmapped mineral deposit.

Feature Identification and Location Experiment. Tested a technique for autonomously classifying Earth's features into four categories: water, vegetation, bare land, and clouds/snow/ice.

Measurement of Air Pollution from Satellites Experiment. Provided information as to what happens to industrial wastes after they enter atmosphere by measuring distribution of carbon monoxide in troposphere on a global scale. Measured distribution of carbon monoxide in middle troposphere, upper troposphere, and lower stratosphere, setting a baseline for future research.

STS-3

Solar Ultraviolet Spectral Irradiance Monitor. Used a complement of spectrometers to measure intensity of solar ultraviolet continuum at different wavelengths. Instruments were checked out on this flight.

STS-4

Nighttime/Daytime Optical Survey of Lightning Experiment. See STS-2.

Investigation of Space Transportation System Atmospheric Luminosity. Worked to obtain photographs and measure luminosity or glow of unknown origin that enveloped certain parts of Orbiter during re-entry and descent. Several photographs of luminosity were taken with exposures up to 400 seconds.

STS-5

Investigation of Space Transportation System Atmospheric Luminosities. Worked to determine spectral content of Orbiter-induced atmospheric luminosities that have relevance to scientific and engineering aspects of payload operation using cameras. Camera film data indicated presence of optical “glow.”

STS-6

Nighttime/Daytime Optical Survey of Lightning Experiment. See STS-2.

STS-8

Investigation of Space Transportation System Atmospheric Luminosities. See STS-5. At 222-km (120-nmi) altitude, experiment was accomplished and glow phenomena were recorded.

STS-9

An Imaging Spectrometric Observatory. Objectives were to obtain first daytime measurements of airglow spectrum from extreme to infrared, monitor shuttle-induced contamination, and worked to serve as a precursor to future flights. Around 80% of objectives were completed during flight.

Active Cavity Radiometer Solar Irradiance Monitor. Measured solar irradiance to determine degree and direction of possible variations in sun's total output of energy as part of a long-term program to study physical behavior of the sun and its effect on Earth's climate.

Space Experiments with Particle Accelerators. Carried out active and interactive experiments on and in Earth's ionosphere to study auroral production in upper atmosphere, ionospheric parameters such as anomalous resistivity, plasma coupling and other processes, and effects of particle interactions on atmospheric dynamics. Used electron beam accelerator, magneto plasma dynamic arc jet, and associated diagnostic equipment. Accomplished approximately 80% of objectives.

European Space Agency Experiments:

> Grille Spectrometer. Worked to determine vertical distribution profiles of trace constituents in stratosphere, mesosphere, and thermosphere to study chemical and dynamical atmospheric processes. In spite of unfavorable flight conditions, the experiment led to the first measurement of water, carbon dioxide, and methane in mesosphere.
>
> Waves in the OH (hydroxl) Emissive Layer. Studied large-scale structure of atmospheric OH emission structure and investigated possible relationships between OH emission structure and meteorological phenomena. All objectives were completed.
>
> Investigation on Atmospheric H and D through the Measurement of Lyman-Alpha. Studied various sources of Lyman-alpha emissions in atmosphere, in interplanetary medium, and possibly galactic medium. Major accomplishment was quantification of amount of deuterium in thermosphere.
>
> Metric Camera Experiment. Tested mapping capability of high-resolution photography. Completed approximately 80% of planned objectives.
>
> Solar Spectrum. Measured absolute solar irradiances in wavelength range from 180 to 3,000 nanometers and measured variables of solar irradiances in given wavelength. Data gained were related to aeronomy and climatology of Earth and its atmosphere and to solar physics.
>
> Measurement of the Solar Constant. Worked to measure absolute value of solar constant to +/- 0.1% and to measure long-term variations in solar constant using absolute self-calibrating radiometer called SOLCON.

STS-41D

Vehicle Glow Experiment. Used nine strips of material attached to Remote Manipulator System to test intensity of glow caused by these materials at different altitudes.

STS-41G

Shuttle Imaging Radar-B. Provided data for studies of geography, geology, hydrology, oceanography, vegetation, and ice applications. Provided significant data on ocean wave and internal wave patterns, oil spills, and ice zones. Geological images revealed that the sensor can evaluate penetration effect in dry soil from buried receivers. Validated existence of subsurface dry channels in Egyptian desert.

Large Format Camera. Evaluated utility of orbital photography for cartographic mapping and land use studies at scales of 1:50,000. Obtained 2,289 photographic frames, including high-priority imagery of Mt. Everest in Nepal and oblique photography of Hurricane Josephine off the eastern coast of the United States. Experiment was considered a success.

Measurement of Air Pollution from Satellites Experiment. See STS-2.

Feature Identification and Location Experiment. Developed means to automatically classify surface materials into one of four categories: water, vegetation, bare ground, or clouds and snow. Successfully compared ratios of reflected solar radiation in two wavelength bands to make real-time classification decisions about the four primary features mentioned above.

Earth Radiation Budget Experiment. Designed to measure energy exchange between Earth-atmosphere system and space. Measurements of global, zonal, and regional radiation budgets on monthly time scales helped in climate prediction and in development of statistical relationships between regional weather and radiation budget anomalies.

Deployed Earth Radiation Budget Satellite. Gathered required radiation budget data, aerosol data, and ozone data to assess climate change and ozone depletion that led to further understanding of ozone depletion. Carried several experiments relating to Earth sciences.

Stratospheric Aerosol and Gas Experiment II. A seven-channel sunphotometer on Earth Radiation Budget Satellite that measured stratospheric aerosols, ozone, water vapor, and nitrogen dioxide during spacecraft sunrise and sunset. Yielded high-quality ozone measurements and gave scientists the ability to monitor the ozone profile for trends and changes throughout the stratosphere.

Measurement of Optical Emissions (glow) on and from the Shuttle Orbiter. Purpose was to gain a better understanding of shuttle glow during deorbit burn. Experiment provided characteristics and causes of glow to make sure Canadian Wide Angle Michaelson Doppler Imaging Interferometer experiment would not be affected. Secondary objective was to gather data on the southern aurora (aurora australis), air glow at nighttime, and bioluminescence of oceans.

Sunphotometer Earth Atmosphere Measurements. Measured local atmospheric constituents and spectrally monitored acidic haze. Absolute accuracy needed to be established from space to obviate effects of Earth's atmosphere on instrument's calibration and to investigate distribution of water vapor and other atmospheric gases, which affect the chemistry of the ozone layer, and to determine density and distribution of Mexico's E1 Chichon volcanic cloud before it had completely disappeared. E1 Chichon volcano erupted March 26, 1982.

STS-51B

Auroral Imaging Experiment. Obtained data through systematic photos, videotapes, and films of aurora through Orbiter windows to gain better insight into energetic particle processes in Earth’s atmosphere. Accomplished 18 observations, and marked the first time since Skylab auroral observations had been made on a crewed US spaceflight, and first time a crewed American space vehicle had passed directly through an aurora.

Atmospheric Trace Molecule Spectroscopy. Identified distribution, by altitude, of 30 to 40 different gases between 10 and 140 km (6 and 85 miles) above Earth's surface. Made 150 independent atmospheric spectra.

STS-51F

Solar Ultraviolet Spectral Irradiance Monitor. See STS-3 for description. Made spectral scan of sun with excellent accuracy.

STS-26

Mesoscale Lightning Experiment. Designed to obtain nighttime images of lightning to better understand effects of lightning discharges on each other, on nearby storm systems, and on storm microbursts and wind patterns, and to determine interrelationships over an extremely large geographical area.

Earth Limb Radiance Experiment. Provided photographs of Earth's horizon that allowed scientists to measure radiance of twilight sky as a function of sun's position below horizon.

STS-30

Mesoscale Lightning Experiment. See STS-26.

STS-34

Shuttle Solar Backscatter Ultraviolet. Designed to calibrate similar ozone-measuring space-based instruments on National Oceanic and Atmospheric Administration's Television and Infrared Observation Satellites. Measured solar irradiance and radiation backscattered from Earth's atmosphere in 12 discrete ultraviolet wavelength channels. Measurements were used to determine vertical distribution of ozone in the atmosphere.

Mesoscale Lightning Experiment. See STS-26.

STS-32

Mesoscale Lightning Experiment. See STS-26.

STS-41

Shuttle Solar Backscatter Ultraviolet. See STS-34.

STS-38

Photographed Mount Kilimanjaro to study climate change. Data collected set a baseline for further research on glacier recession and climate change.

STS-43

Shuttle Solar Backscatter Ultraviolet. See STS-34.

STS-48

Upper Atmosphere Research Satellite. Conducted research in atmosphere above tropopause by measuring global budget of constituent trace gases and their chemical, dynamic, and radiative behavior. Data collected helped define role of upper atmosphere in climate and climate variability.

STS-45

Atmospheric Trace Molecule Spectroscopy. See STS-51B for description.

Millimeter Wave Atmospheric Sounder. Measured water vapor, ozone, and chlorine monoxide (a key compound that contributes to ozone loss) as well as temperature and pressure in middle atmosphere. Yielded information about altitude profiles of temperature and pressure as well as profiles for water vapor, ozone, and chlorine monoxide in stratosphere and mesosphere.

Imaging Spectrometric Observatory. Obtained daytime and nighttime low-light level spectroscopic measurements of atomic and molecular species in middle and upper atmosphere from extreme ultraviolet to infrared and measured spectral features to determine composition of the atmosphere, down to trace amounts of chemicals measured in parts-per-trillion. Spatial imaging technique appears to be a viable means of obtaining temperatures in middle and lower thermosphere, provided that good information is also obtained at higher altitudes, as contribution of overlying, hotter nitric oxide is non-negligible.

Atmospheric Lyman-Alpha Emissions. Measured abundance of two forms of hydrogen—common hydrogen and deuterium or heavy hydrogen—and determined ratio of atmospheric hydrogen to deuterium in the atmosphere. Deuterium's relative abundance compared to hydrogen at altitudes that this experiment studied is an indication of atmospheric turbulence in lower thermosphere.

Shuttle Solar Backscatter Ultraviolet. See STS-34.

Grille Spectrometer. See STS-9.

Solar Ultraviolet Spectral Irradiance Monitor. See STS-3.

Measurement of the Solar Constant. See STS-9.

Solar Spectrum. See STS-9.

Atmospheric Emission Photometric Imaging. Worked to investigate ionospheric transport by observing magnesium ions, studied optical properties of artificially produced electron beams, measured electron cross section for selected atmospheric species, and studied natural airglow and natural auroras.

Active Cavity Radiometer Solar Irradiance Monitor. See STS-9.

STS-46

Deployed the European Retrievable Carrier, which included Earth Sciences payloads.

STS-52

Laser Geodynamics Satellite II. Provided a permanent reference point in a stable orbit for precision Earth dynamics measurements such as crustal motions, regional strains, fault motions, and polar motion. Provided a reference point for measurement of Earth rotation variations, solid Earth tides, and other kinematic and dynamic parameters associated with earthquake assessment and alleviation.

Sun Photo Spectrometer Earth Atmosphere Measurement. Made multi-spectral measurements of ozone and nitrogen compounds that play an important role in controlling ozone balance especially in presence of chlorine. Measured atmospheric transmission, or degree to which light is absorbed in Earth's atmosphere, in visible and near-infrared parts of solar spectrum.

STS-53

Hand-held, Earth-oriented, Real-time, Cooperative, User-friendly, Location-targeting and Environmental System. Enabled a shuttle astronaut to point a camera at an Earth feature, record the image, and determine latitude and longitude of the feature. Provided an Earth observation system for military, environmental, oceanographic, and meteorological applications.

Shuttle Glo Experiment. Studied spacecraft glow; measured effects of solar extreme ultraviolet radiation on Earth’s atmosphere; studied ionosphere, thermosphere, and mesosphere; and recorded temperature and temperature gradients and pressures of major constituents of the atmosphere to validate global models.

STS-56

Shuttle Solar Backscatter Ultraviolet. See STS-34.

Atmospheric Trace Molecule Spectroscopy. See STS-51B.

Millimeter Wave Atmospheric Sounder. See STS-45.

Hand-held, Earth-oriented, Real-time, Cooperative, User-friendly, Location-targeting and Environmental System. See STS-53.

Solar Ultraviolet Spectral Irradiance Monitor. See STS-3.

Measurement of the Solar Constant. See STS-9.

Solar Spectrum. See STS-9.

Active Cavity Radiometer Solar Irradiance Monitor. See STS-9.

Solar Ultraviolet Experiment. Studied extreme ultraviolet solar radiation as it affected Earth’s ionosphere. Total of 22 orbits of solar radiation data were collected, which represented more than 16 times the minimum requirements.

STS-55

Modular Optoelectronic Multispectral Stereo Scanner. Provided imaging data for photogrammetric mapping and thematic mapping applications in cartography, land-use, ecology, and geology. Investigations of environment, agriculture, forestry, and urban development as well as digital mapping and landscape modeling with high degree of automation were improved by using specific capabilities of sensor.

Galactic Ultrawide-Angle Schmidt System Camera. An ultraviolet camera used to take wide-angle pictures of Milky Way galaxy, younger stars, and gas clouds and pictures of Earth’s atmosphere. Over 100 pictures were taken of the galaxy and Earth’s atmosphere.

STS-57

Retrieved the European Retrievable Carrier.

STS-62

Shuttle Solar Backscatter Ultraviolet. See STS-34.

Experimental Investigation of Spacecraft Glow Experiment. Investigated aura of light created around leading or front-facing surfaces of spacecraft orbiting Earth called spacecraft glow. Seven orbits of prime operations were performed with 100% of objectives completed.

Spacecraft Kinetic Infrared Test Experiment. Collected spectral readings in infrared region, and obtained infrared glow data. Observations were obtained during quiescent and non-quiescent orbital environments roll maneuvers in and out of velocity vector, day and night, and significantly different/varying altitudes.

STS-59

Shuttle Imaging Radar-C. Investigated characteristics of Earth's surface such as vegetation extent and biomass condition, soil moisture and snow properties, recent climate change and tectonic activity, and ocean wave spectra.

X-band Synthetic Aperture Radar. Provided all-weather monitoring of Earth's land and ocean surface to provide data for studies of vegetation extent and biomass condition, soil moisture and snow properties, recent climate change and tectonic activity, and ocean wave spectra. Data were used by the international science community to better understand the global environment and how it is changing.

Measurement of Air Pollution from Satellites Experiment. See STS-2.

STS-64

Lidar In-Space Technology Experiment. Made measurements of stratospheric and tropospheric aerosols, planetary boundary layer, cloud top heights, and atmospheric temperature and density in the 10- to 40-km (6- to 25-mile) altitude range. These data provided the first highly detailed global view of vertical structure of cloud and aerosol from Earth's surface through the middle stratosphere.

Get Away Special:

> Ozone Measurements of Earth’s Upper Atmosphere in Ultraviolet. Took ozone measurements of Earth’s upper atmosphere in ultraviolet 200 to 400 nanometer spectral range using a Charge Couple Device-based spectrometer.

STS-68

Shuttle Imaging Radar-C. See STS-59.

X-band Synthetic Aperture Radar. See STS-59.

Measurement of Air Pollution from Satellites Experiment. See STS-2.

STS-66

Millimeter Wave Atmospheric Sounder. See STS-45.

Atmospheric Trace Molecule Spectroscopy. Determined detailed compositional structure of Earth's atmosphere from 20 to 120 km (12 to 57 miles) at 2- to 3-km (1- to 2-mile) vertical resolution and its global, seasonal, and long-term variability, and studied partitioning of solar energy at levels in the atmosphere characterized by dissociation of many constituents and by breakdown of thermodynamic equilibrium.

Shuttle Solar Backscatter Ultraviolet. See STS-34.

Cryogenic Infrared Spectrometers and Telescopes for the Atmosphere. Measured temperatures and trace gases mixing ratios in Earth’s atmosphere with unprecedented spatial resolution from a 300-km (186-mile), 57-degree inclination orbit.

Middle Atmospheric High Resolution Spectrograph Investigation. Measured dayglow in the 1,900-3,200 angstrom region and measured concentrations of hydroxide and nitric oxide in mesosphere and thermosphere (30- to 150-km [19- to 93-mile] altitude) to an accuracy of 2 km (~1 mile). Data collected show a detailed history of morning formation of a strongly peaked layer of hydroxyl at an altitude of 68 km (42 miles).

Solar Ultraviolet Spectral Irradiance Monitor. See STS-3 for description. Collected highest precision solar ultraviolet radiation measurements in its 15-year lifetime to that point.

Measurement of the Solar Constant. See STS-9.

Solar Spectrum. See STS-9.

Active Cavity Radiometer Solar Irradiance Monitor. See STS-9.

STS-63

Shuttle Glo Experiment. Studied spacecraft glow, measured effects of solar extreme ultraviolet radiation on Earth's atmosphere; studied ionosphere, thermosphere and mesosphere; and recorded temperature and temperature gradients and pressures of major constituents of the atmosphere to validate global models.

STS-70

Hand-held, Earth-oriented, Real-time, Cooperative, User-friendly, Location-targeting and Environmental System. See STS-53.

STS-69

Shuttle Glo Experiment. See STS-63.

STS-74

Shuttle Glo Experiment. See STS-63.

Visual Earth Observations. Monitored observable Earth surface changes and image ephemeral events (hurricanes, plankton blooms, and volcanic eruptions) to incorporate into a database of human observations. Eighty-three hours of Earth observations were made and 3 million laser pulses were fired.

STS-72

Shuttle Solar Backscatter Ultraviolet. See STS-34. Data from first flight in combination with information from an earlier satellite have been used to estimate ozone trends in upper stratosphere. After 1,600 hours of on-orbit operating time during previous shuttle missions, this was the final flight of this experiment.

Shuttle Laser Altimeter-01. Acquired samples of land topography and vegetation data and provided an in-space engineering test bed for future spaceflight laser sensors.

STS-76

Visual Earth Observations. See STS-74.

STS-79

Visual Earth Observations. See STS-74.

STS-81

Visual Earth Observations. See STS-74.

STS-84

Visual Earth Observations. See STS-74.

STS-85

Shuttle Laser Altimeter-02. Served as pathfinder for both technology and science by demonstrating the potential for acquiring a global array of land-cover vertical structure and high-resolution topographic transects using laser-radar. Direct measurements of height of clouds as well as high-resolution profiles of land and surface vegetation canopies over land targets were acquired.

Infrared Spectral Imaging Radiometer. Tested new technology, infrared imaging with an uncooled detector array, and techniques for cloud observations from space. Successfully acquire 24 hours of low-resolution and 11 hours of high-resolution data.

Cryogenic Infrared Spectrometers and Telescopes for the Atmosphere. Three telescopes made atmospheric observations along parallel tracks of trace constituents and temperature distributions with hope for increased latitudinal coverage of the atmosphere beyond that of data gathered during STS-66. Measured atmospheric spectra for 183 hours and obtained 44,000 altitude profiles for emissions of up to 17 trace gasses.

Middle Atmospheric High Resolution Spectrograph Investigation. Focused on obtaining new vertical profile data on distribution of hydroxyl in the mesosphere and upper stratosphere under different conditions from STS-66. Over 206 hours of operation provided 73 orbits of hydroxyl data and 52 orbits of nitrous oxide data.

Measurement of the Solar Constant. See STS-9.

Shuttle Glo Experiment. See STS-63.

STS-86

Visual Earth Observations. See STS-74.

STS-87

Shuttle Ozone Limb Sounding Experiment/Limb Ozone Retrieval Experiment. Worked to demonstrate that vertical profiles of ozone could be measured with high resolution from solar ultraviolet scattering from Earth's atmospheric limb. Instruments operated well during flight.

STS-89

Visual Earth Observations. See STS-74.

STS-90

Get Away Special:

> Ozone Measurements of Earth's Upper Atmosphere in Ultraviolet. Took ozone measurements of Earth's upper atmosphere in ultraviolet 200 to 400 nanometer spectral range using a charge couple device-based spectrometer.

STS-91

Visual Earth Observations. See STS-74.

STS-95

Photographed Flooding in Honduras. Collected photographs of flooding in Honduras from Hurricane Mitch. Provided an understanding of the scale of the hurricane's impact.

Measurement of the Solar Constant. See STS-9.

STS-88

Photographed Urban Growth in Cairo. Collected photographs of the city of Cairo to study growth of population in Cairo metropolitan area. Population densities within the city are some of the highest in the world, and the urban area has doubled to more than 400 square km (249 square miles).

STS-99

Shuttle Radar Topography Mission. Acquired a high-resolution topographic map of Earth's land mass (between 60°N and 56°S) and tested new technologies for deployment of large rigid structures and measurement of their distortions to extremely high precision. Almost 80% of land surface was covered, providing a near-global topographic database superior to any developed previously.

STS-112

Spatial Heterodyne Imager for Mesospheric Radicals. Tested newly developed technology and a new interferometric technique called Spatial Heterodyne Spectroscopy to measure ultraviolet light spectrum emitted by hydroxyl molecules in the 30- to 100-km (19- to 62-mile) altitude range of the atmosphere and to add data acquired by previous experiments. All mission objectives were accomplished.

STS-107

Measurement of the Solar Constant. See STS-9.

Shuttle Ozone Limb Sounding Experiment /Limb Ozone Retrieval Experiment. See STS-87 for description. Data were lost but enough were returned to consider the experiment around 80% successful.

Mediterranean Israeli Dust Experiment. Studied temporal and spatial distribution and physical properties of atmospheric desert aerosols over North Africa, the Mediterranean Sea, and the adjacent Atlantic Ocean. Recorded less dust than expected due to climatic conditions, and met all objectives in observing sprites and performing calibrations.

STS-122

Installed the Solar External Payload Facility of Columbus on the International Space Station, which contained the Solar Spectrum (see STS-9) experiment and other payloads.

STS-130

Installed the Cupola Observation Module used as a robotics workstation, and for Earth observations.

3.5 Space Science

STS-3

Microabrasion Foil Experiment. Measured numbers, chemistry, and density of micrometeorites encountered by spacecraft in near-Earth orbit.

Plasma Diagnostics Package. Comprehensive assembly of electromagnetic and particle sensors used to study interaction of Orbiter with its surrounding environment by taking measurements of electric and magnetic fields within 13.7 m (45 ft) of Orbiter, ion and electron densities, energies and spatial distribution, electromagnetic waves over a broad frequency range, and worked to determine characteristics of electron beam emitted by Fast Pulse Electron Generator.

Solar Flare X-Ray Polarimeter. Worked to measure x-rays emitted during solar flare activities on the sun.

STS-9

Far Ultraviolet Astronomy Using the Faust Telescope. Searched for ultraviolet stars and other astronomical ultraviolet sources in the 110- to 200-nm band using Far Ultraviolet Space Telescope and an electronic interface module. Accomplished around 95% of objectives.

European Space Agency Experiments:

> Isotopic Stack Measurement of Heavy Cosmic Ray Isotopes. Used a stack of plastic sheets to measure heavy cosmic-ray nuclei, and worked to determine source, acceleration, propagation, and age of cosmic rays. Very Wide Field Galactic Camera. Worked to make a general ultraviolet survey of a large part of celestial sphere using a camera with wide field of view in two modes. Spectroscopy in X-Ray Astronomy. Studied detailed features in cosmic x-ray sources and their associated temporal variations over a wide energy range.

STS-41C

Solar Maximum Repair Mission. Retrieved, repaired, and released damaged Solar Maximum observatory. This first on-orbit repair of a crippled spacecraft worked to replace attitude control system module and main electronics box on Polarimeter/Polarimeter, and placed a cover over the gas vent of X-Ray Polychrometer. Repairs were successful.

STS-41G

Canadian Space Agency Experiments:

> Measurement of Optical Emissions (glow) on and from the Orbiter. Purpose was to gain a better understanding of shuttle glow during deorbit burn. Provided characteristics and causes of glow to make sure Canadian Wide Angle Michaelson Doppler Imaging Interferometer experiment would not be affected. Secondary objective was to gather data on southern aurora (aurora australis), air glow at night time, and bioluminescence of oceans.
>
> Sunphotometer Earth Atmosphere Measurements. Measured local atmospheric constituents and spectrally monitored acidic haze. Sunphotometer's absolute accuracy needed to be established from space to obviate effects of Earth's atmosphere on instrument's calibration and to investigate distribution of water vapor and other atmospheric gases, which affect chemistry of ozone layer; and to determine density and distribution of E1 Chichon volcanic cloud before it had completely disappeared. Mexico's E1 Chichon volcano erupted March 26, 1982.

Get Away Special:

> Trapped Ions in Space. Investigated unexpectedly large flux of heavy ions first observed in experiment on board Skylab in 1973 and 1974.

STS-51D

Astronomy Photography Verification Test. Tested low light photographic equipment in preparation for visit by Halley's Comet.

STS-51B

Studies of the Ionization and Galactic Cosmic Ray Heavy Nuclei. Used newly designed detector mounted on experiment support structure to determine composition and intensity of energetic ions from the sun and other galactic sources. After an in-flight maintenance procedure to correct an issue around two-thirds of experiment's operational timeline was completed.

STS-51G

Shuttle Pointed Autonomous Research Tool for Astronomy. First flight of this free-flying experiment designed to perform medium-resolution mapping of x-ray emission from extended sources and regions. Release and capture of experiment were completed during mission.

Get Away Special:

> Space Ultraviolet Radiation Experiment. Worked to measure natural radiation field in upper atmosphere at extreme ultraviolet wavelength between 50 and 100 nm. Measurements provided a means of remotely sensing ionosphere and upper atmosphere.

STS-51F

Solar Magnetic and Velocity Field Measurement System/Solar Optical Universal Polarimeter. Used an instrument complement of telescope and video cameras to observe sun's magnetic field activity in different wavelengths and polarizations in visible light. After an unexplained shutdown early in the mission, the instrument performed almost perfectly. Scientists were confident that data gathered would be the best and longest run of solar granulation data collected up to that point.

Coronal Helium Abundance Spacelab Experiment. Used a telescope and spectrometer to detect hydrogen and helium emission lines to assess solar hydrogen and helium abundance. Downlink television from instrument revealed never-before-witnessed birth of a spicule, and resolution of the telescope was good.

Solar Ultraviolet High Resolution Telescope and Spectrograph. Used a telescope and spectrograph system to observe solar radiation from sun's outer layers and recorded data on film and video.

Plasma Diagnostics Package. See STS-3 for description. Device performed flawlessly on pallet, on Remote Manipulator System, and as a free-flyer, and was one of the high points of Spacelab 2 (STS-51F) mission.

Plasma Depletion Experiments for Ionospheric and Radio Astronomical Studies. Effects of shuttle thruster firings on ionosphere were measured from five radio observatories on the ground. Four of eight burns were completed, and preliminary data indicated that Orbital Maneuvering System burns produced "holes"—or troughs—of depleted plasma that persisted in ionosphere for more than 1 hour.

Elemental Composition and Energy Spectra of Cosmic Ray Nuclei Between 50 GeV/Nucleon and Several TeV/Nucleon. Two-ton egg-shaped Cosmic Ray Nuclei Detector was located on a special support structure at end of pallet train so it was exposed to space throughout the mission. Particles that entered the detector were counted and identified automatically with data being transmitted to the ground. Detector operated well throughout the mission, recorded 24 million particle events, and around 30,000 of those were of the extremely high-energy variety.

Hard X-Ray Imaging of Clusters of Galaxies and Other Extended X-Ray Sources/X-Ray Telescope. Used two telescopes observing at different resolutions to detect distant and intense regions of x-ray emission to create x-ray images of remote clusters of galaxies and other interesting x-ray sources. Telescopes operated well throughout mission with good image quality, detector sensitivity, and stability.

A Small Helium-Cooled Infrared Telescope. Measured infrared radiation from variety of sources. Telescope operated well throughout mission but did not achieve its primary objective of an all-sky survey in all planned wavelengths due to a strong background source that saturated many detectors. In spite of high background radiation problem, a reasonably good sky map was obtained.

STS-30

Magellan Mission. Successfully deployed Magellan probe, which went on to Venus to map 98% of that planet's surface.

STS-34

Galileo Mission. Successfully deployed Galileo probe, which went to Jupiter and its moons to study the planet's atmosphere, satellites, and surrounding magnetosphere.

STS-31

Hubble Space Telescope. Launched Hubble Space Telescope to begin its scientific mission. Shuttle carried Wide Field Planetary Camera, Goddard High Resolution Spectrograph, Faint Object Camera, Faint Object Spectrograph, and High Speed Photometer.

STS-41

Ulysses Mission. Launched Ulysses spacecraft to begin its mission to study the sun. Spacecraft became first probe to explore polar regions of the sun, and made some scientific observations of Jupiter en route to its orbit around the sun.

STS-35

Astro-1 Observatory:

Hopkins Ultraviolet Telescope. This first major telescope capable of studying far ultraviolet and extreme ultraviolet radiation from a wide variety of objects worked to provide new information on the evolution of galaxies and quasars, physical properties of extremely hot stars, and characteristics of accretion disks around white dwarfs, neutron stars, and black holes. More than 40 hours of observations on 77 different targets were obtained with a spectra of key examples of almost every major class of astronomical object including distant galaxies, quasars, stars, star clusters, and clouds of gas and dust in our galaxy.

Wisconsin Ultraviolet Photo-Polarimeter. This 51-cm (20-in.) telescope with a 5.5-arc-minute field of view was designed to measure polarization and intensity of ultraviolet radiation from celestial objects such as hot stars, galactic nuclei, and quasars. This telescope was the first and most comprehensive effort to exploit unique powers of polarimetry at wavelengths not visible on Earth, and in its two shuttle flights obtained ultraviolet spectropolarimetry for 121 objects and spectra-only for 65 objects.

Ultraviolet Imaging Telescope. Designed to perform deep, wide-field imaging of objects such as hot stars and galaxies in broad ultraviolet wavelength bands. Observed 66 astronomical targets during flight.

Broad Band X-Ray Telescope. The Broad Band X-Ray Telescope was the first focusing x-ray telescope operating over a broad energy range (.3-12 keV) with moderate energy resolution (90 eV at 1 keV and 150 eV at 6 keV). Results included resolution of iron K line in binaries Cen X-3 and Cyg X-2, detection of evidence of line broadening in NGC 4151, and the study of cooling flow in clusters.

STS-37

Compton Gamma Ray Observatory. Shuttle deployed Compton Gamma Ray Observatory—the second of the Great Observatories and the heaviest astrophysical payload that had been flown to date. Designed to study the universe in invisible, high-energy form of light called gamma rays that cannot penetrate Earth's atmosphere.

STS-48

Cosmic Radiation Effects and Activation Monitor Experiment. Department of Defense-sponsored experiment designed to collect data on cosmic ray energy loss spectra, neutron fluxes, and induced radioactivity. All operations occurred according to nominal plan.

STS-44

Cosmic Radiation Effects and Activation Monitor Experiment. See STS-48.

STS-45

Far Ultraviolet Space telescope. Studied astronomical radiation sources at ultraviolet wavelengths inaccessible to observers on Earth.

STS-46

European Retrievable Carrier. Carried space science investigations such as Wide Angle Telescope—designed to detect celestial gamma and x-ray sources with photon energies in the range 5 to 200 keV and determine the position of the source—as well as experiments of other scientific disciplines.

STS-53

Cosmic Radiation Effects and Activation Monitor Experiment. See STS-48

STS-54

Diffuse X-Ray Spectrometer. Studied hottest components of interstellar medium, gases at temperatures at approximately 1,000,000°K (1,799,540°F) by detecting the x-rays emitted there to work to provide important clues to origin, evolution, and physical state of this constituent of the Milky Way galaxy. Good data were obtained, and first-ever spectra of the diffuse soft x-ray background in energy band from .15 to .284 keV were obtained.

STS-56

Shuttle Point Autonomous Research Tool For Astronomy- 201. Free-flying payload studied velocity and acceleration of solar wind and observed aspects of sun's corona to help scientists understand physics of the sun's corona and the solar wind. Deployed and retrieved during flight. Excellent data were obtained.

Cosmic Radiation Effects and Activation Monitor Experiment. See STS-48.

STS-55

Galactic Ultrawide-Angle Schmidt System Camera. An ultraviolet camera used to take wide-angle pictures of Milky Way galaxy, younger stars and gas clouds, and pictures of Earth's atmosphere. Over 100 pictures were taken of galaxy and Earth's atmosphere.

STS-57

European Retrievable Carrier. See STS-46 for description. Successfully retrieved during flight.

Get Away Special:

> High Frequency Variations of the Sun. Measured and analyzed high-frequency variations of sun by analyzing light that the sun releases to Earth to better determine physics of the sun and other stars.

STS-51

Orbiting and Retrievable Far and Extreme Ultraviolet Spectrometer – Shuttle Pallet Satellite (ORFEUS-SPAS). Joint US-German endeavor used German-built ASTRO-SPAS satellite and carried one-diameter ORFEUS-Telescope with Far Ultraviolet and Extreme Spectrographs, Interstellar Medium Absorption Profile Spectrograph, and other non-astronomy payloads. Mission was designed to investigate very hot and very cold matter in the universe. Payload was deployed, retrieved, and performed over 100% of planned free-drift science operations. Scientists estimated it would take almost 2 years to evaluate data that were collected.

STS-61

Hubble Space Telescope Servicing Mission 1. On first servicing mission to Hubble, new instruments and hardware were installed to correct problems with telescope's mirror and to extend the life of the telescope. Completed the following servicing tasks:

1. Replaced solar arrays.
2. Replaced Rate Sensing Unit 2.
3. Replaced Wide Field Planetary Camera I with Wide Field Camera II.
4. Installed four new instrument fuse plugs.
5. Installed new Magnetic Sensing System 1.
6. Replaced Rate Sensing Unit 3 along with Electronic Control Unit 3.

7. Replaced failed Solar Array Drive Electronics 1 assembly with a new Solar Array Drive Electronics package.
8. Installed power supply redundancy kit for Goddard High Resolution Spectrometer.
9. Installed 386 coprocessor on Hubble's DF-224 primary computer.
10. Installed new Magnetic Sensing System 2.
11. Installed four new 6-ampere gyro fuse plugs in place of 3-ampere plugs being used at the time.
12. Replaced Electronic Control Unit 1.

STS-65

Japanese Space Agency:

Real-time Radiation Dosimetry and Biological Experiments for Heavy Charged Particles in Spacecraft. Investigation of radiation levels for space weather forecast to investigate how space environment between sun and Earth influences radiation levels in low-Earth orbit. Because there were no significant solar events, almost all detected particles were either galactic cosmic rays or from the South Atlantic Anomaly of radiation belt.

STS-64

Shuttle Point Autonomous Research Tool For Astronomy- 201. See STS-56 for description. Payload was deployed, operated autonomously for approximately 47 hours, and retrieved during mission.

STS-68

Cosmic Radiation Effects and Activation Monitor Experiment. See STS-48.

STS-63

Shuttle Point Autonomous Research Tool For Astronomy- 204. Operated as both a free-flyer and while attached to Remote Manipulator System. Carried Far Ultraviolet Imaging Spectrograph designed to study astronomical that included nebulae, celestial diffuse background radiation and nearby external galaxies, and artificially induced sources such as shuttle surface glow. Data were obtained of shuttle surface glow, and almost 48 hours of free-flight observations were accomplished.

Cosmic Radiation Effects and Activation Monitor Experiment. See STS-48. Integrated in Spacehab.

STS-67

Astro-2 Observatory:

Hopkins Ultraviolet Telescope. See STS-35 for description. Improvements were made to equipment, five times more data were obtained during Astro-2 when compared to Astro-1, and 385 science pointings at 260 unique astronomical targets during mission.

Wisconsin Ultraviolet Photo-Polarimeter. See STS-35.

Ultraviolet Imaging Telescope. See STS-35 for description. All planned targets were observed during flight.

Get Away Special:

Endeavour, Australian Space Telescope. This 100-mm (4-in.) binocular reflecting telescope was the most significant space payload built by the Australian space industry in more than 2 decades, and worked to take images in ultraviolet spectrum of targets that included star-forming regions, nearby galaxies, and violet galactic events. Observations were conducted on-orbit for later data analysis.

STS-69

Shuttle Point Autonomous Research Tool For Astronomy-201-03. See STS-56 for description. Primary objective was to understand physical circumstances of the corona of the sun during time of passage of Ulysses spacecraft over the north pole of the sun. A major portion of the science mission was completed before the spacecraft entered into minimum reserve shutdown configuration.

International Extreme Ultraviolet Hitchhiker. Designed to measure and monitor long-term variations in magnitude of absolute extreme ultraviolet flux coming from the sun, and studied extreme ultraviolet emissions from plasma torus system around Jupiter originating from its moon Io. The following two complementary experiments comprised the International Extreme Ultraviolet Hitchhiker:

Solar Extreme Ultraviolet Hitchhiker. Set of instruments designed to provide research scientists with a tool to accurately measure solar flux in the extreme ultraviolet region of solar spectrum. Absolute solar extreme ultraviolet flux required to interpret extreme ultraviolet emissions from Jovian system as well as other solar system atmospheres measured by the Ultraviolet Spectrograph Telescope for Astronomical Research was obtained, observations of the sun were completed, and near simultaneous observations with those obtained by a sounding rocket launched during the mission were obtained.

Ultraviolet Spectrograph Telescope for Astronomical Research. This pair of telescopes with imaging spectrographs measured extreme ultraviolet and far ultraviolet emissions in Jovian system with Solar Extreme Ultraviolet Hitchhiker providing solar flux data needed for proper context. Although some instruments' equipment failed during flight, data were obtained using other methods.

STS-76

Trapped Ions in Space. Measured recently discovered belt of energetic cosmic ray nuclei trapped in Earth's magnetic field to quantify radiation hazards in space and to lead to a better theoretical understanding of how cosmic ray nuclei have become trapped in Earth's magnetic field. Experiment was operated and collected data during flight for analysis.

STS-79

Real-time Radiation Monitoring Device. Successfully measured elemental composition and energy spectra of cosmic radiation in real time.

STS-80

Orbiting and Retrievable Far and Extreme Ultraviolet Spectrometer – Shuttle Pallet Satellite. See STS-51 for description. A total of 422 observations of almost 150 different astronomical objects were obtained.

STS-82

Hubble Space Telescope Servicing Mission 2. Worked to improve Hubble's productivity, extend Hubble's wavelength range into the near infrared for imaging and spectroscopy, greatly increase efficiency of spectrographic science, and replace failed or degraded spacecraft components. The following instruments and components were replaced/installed:

1. Near-Infrared Camera and Multi-Object Spectrometer replaced Faint Object Spectrograph.
2. Space Telescope Imaging Spectrograph replaced Goddard High Resolution Spectrograph.
3. Solid State Recorder replaced one of the reel-to-reel recorders.
4. Fine Guidance Sensor replaced an existing Fine Guidance Sensor that was showing signs of wear.
5. One of Hubble's four Reaction Wheel Assemblies was replaced with refurbished spare.
6. Data Interface Unit 2 was replaced with a spare unit that was modified and upgraded to correct failures that occurred in original unit.
7. The second Solar Array Drive Electronics unit was replaced with the refurbished unit that was returned from orbit from first servicing mission.
8. One of the Engineering Science Tape Recorders was replaced due to its failure.

STS-84

Cosmic Radiation Effects and Activation Monitor Experiment. See STS-48.

Japan Aerospace Exploration Agency:

Measurement of Radiation in Space. Determined response of various types of integrating dosimeters to radiation in space. Application in space of dosimeters tested with accelerator beams.

STS-85

International Extreme Ultraviolet Hitchhiker 2. See STS-69 for description. The following experiments comprised the International Extreme Ultraviolet Hitchhiker 2:

> Solar Extreme Ultraviolet Hitchhiker. See STS-69 for description. Excellent full-disk absolute solar flux data during entire mission. All primary objectives were met or exceeded. Observations consisted of 13 sub-solar data sets, in addition to three at sunset, one at sunrise, and one data set running from sunrise to sunset.
>
> Ultraviolet Spectrograph Telescope foe Astronomical Research. See STS-69 for description. Successfully tracked 34 targets of which 19 provided confirmed spectra, 14 required further analysis, and one was not detected.
>
> Distribution and Automation Technology Advancement Hitchhiker/Colorado and Student Experiment of Solar Radiation. Student experiment worked to improve space payload operations, measure full-disk solar ultraviolet and soft x-ray irradiance, and image the sun in its Lyman-Alpha wavelength. Most mission objectives were completed even though quality science was not obtained due to an instrumentation failure reducing resolution considerably.

Southwest Ultraviolet Imaging System. Payload consisted of a baffled ultraviolet (UV) 18-cm (7-in.) imaging telescope with A 1/MgF2 (UV-reflective) optics, a manual filter change-out assembly, imaging filters, and a Space Shuttle Program-provided video interface unit. During flight, more than 300,000 useful frames in UV range during the nine orbits of viewing opportunity were obtained of the Hale-Bopp comet from shuttle middeck.

STS-86

Cosmic Radiation Effects and Activation Monitor Experiment. See STS-48.

STS-87

Shuttle Point Autonomous Research Tool For Astronomy- 201-04. See STS-56 for description. Due to some problems, solar science data were not obtained after deployment, but the spacecraft was successfully retrieved.

STS-91

Alpha Magnetic Spectrometer. The first time a high-energy particle magnetic spectrometer was placed in orbit with the scientific goal of increasing our understanding of composition and origin of universe by detecting and cataloguing, with a high degree of precision, high-energy charged particles, including antimatter, outside of Earth's atmosphere. Over 200 million events were recorded during flight.

Cosmic Radiation Effects and Activation Monitor experiment. See STS-48.

STS-95

Shuttle Point Autonomous Research Tool For Astronomy- 201-05. See STS-56 for description. All mission objectives were completed with more than 500 solar coronal images being downlinked from White Light Coronagraph instrument, and an additional 600 White Light Coronagraph images and 300 Ultraviolet Coronal Spectrometer images that were stored were obtained during flight.

International Extreme Ultraviolet Hitchhiker 3. See STS-69 for description. The following experiments comprised the International Extreme Ultraviolet Hitchhiker 3:

> Solar Extreme Ultraviolet Hitchhiker. See STS-69 for description. Excellent full-disk absolute solar flux data were obtained, and 18 solar data sets observations were made, including seven at sunset, eight at sunrise, and two data sets running from sunrise through sunset.
>
> Ultraviolet Spectrograph Telescope for Astronomical Research. See STS-69 for description. A total of 54 series of spectral images were obtained, including 17 of Jupiter system and 37 of celestial targets.

Spectrograph/Telescope for Astronomical Research. Studied astronomical targets in ultraviolet. During flight, the azimuth drive of the scan platform became stuck at an azimuth of approximately 87 degrees, and the star tracker and finder cameras failed. Although there were problems, over 80 targets were observed, with 19 observations containing data of immediate interest.

STS-93

Chandra X-ray Observatory. Shuttle deployed the world's most power x-ray telescope at the time, and third Great Observatory called Chandra X-ray Observatory. The telescope was used to observe x-rays from sources such as superflares, supernovae, black holes, quasars, galaxy clusters, and dark matter.

Southwest Ultraviolet Imaging System. See STS-85 for description. Mission focused on obtaining ultraviolet imagery of an array of planetary and astrophysical targets. Data were taken of Venus, the Vulcanoid search fields, the moon, the Jupiter system, the comet Lee, and two calibration targets.

STS-103

Hubble Space Telescope Servicing Mission 3A. Third Hubble Space Telescope Servicing mission. Installed/replaced the following equipment:

1. Replaced all three rate sensor units containing six gyroscopes.
2. Installed six voltage/temperature improvement kits, which helped manage overheating of batteries if overcharged by lowering batteries' charge termination voltage.
3. Installed a new computer that dramatically increased operational capabilities, reduced burden of flight software maintenance, and significantly lowered operational costs.
4. Replaced Fine Guidance Sensor 2 with refurbished unit retrieved during second servicing mission.
5. Replaced failed S-band single access transmitter.
6. Replaced engineering/science tape recorder with a solid-state recorder.
7. Installed new outer blanket layers on bays 9 and 10.

STS-109

Hubble Space Telescope Servicing Mission 3B. Fourth Hubble Space Telescope Servicing mission to upgrade the telescope. Installed/replaced the following equipment:

1. Replaced both solar arrays as well as diode box controllers.
2. Replaced power control unit, which represented one of the most difficult tasks ever performed up to that time during an extravehicular activity.
3. Replaced European Space Agency Faint Object Camera with Advanced Camera for Surveys.
4. Installed Near Infrared Camera and Multi-Object Spectrometer Cryogenic Cooler System.
5. Replaced one of the four reaction wheel assemblies.
6. Replaced one new outer blanket layer.

STS-125

Hubble Space Telescope Servicing Mission 4. Fifth and final Hubble Space Telescope servicing mission. Used to upgrade and replace parts one last time. Installed/replaced the following equipment:

1. Installed Wide Field Camera 3 in place of Wide Field Planetary Camera 2.
2. Removed and replaced three rate-sensor units.
3. Changed out Science Instrument Command and Data Handling System.
4. Cosmic Origins Spectrograph replaced Corrective Optics Space Telescope Axial Replacement
5. Installed battery module replacements.
6. Repaired Advanced Camera for Surveys.
7. Repaired Space Telescope Imaging Spectrograph.
8. Removed and replaced Fine Guidance 2.
9. Installed six new gyroscopes.
10. Installed new outer blanket layers.
11. Installed a soft capture mechanism.

STS-134

Alpha Magnetic Spectrometer (AMS)-02. Delivered state-of-the art particle physics detector, designed to search for antimatter and the origin and structure of dark matter, to International Space Station. This first magnetic spectrometer in space will collect information from cosmic sources emanating from stars and galaxies millions of light-years beyond the Milky Way.

Shape Memory Foam (Shape Memory Foam). Evaluated effect microgravity had on characteristics of memory epoxy foam obtained by solid-state foaming on ground consisting of various geometric complexities shaped on ground. Experiment was conducted on Flight Day 7, and was analyzed in hopes of manufacturing a new concept actuator.

3.6 Microgravity

STS-3

Monodisperse Latex Reactor. Experiment series overall description: Polymerization experiments produced highly uniform spherical polystyrene particles, in sizes from 3-30μm, due to the lack of sedimentation in a weightless environment. Particles were made available for sale through the National Institute for Standards and Technology as a Standard Reference Material for particle size classification devices.

Electrophoresis Equipment Verification Test. Evaluated feasibility of separating cells according to their surface electrical charge. This flight tested the equipment and was the first time it had been flown since Apollo-Soyuz Test Project (1975).

STS-4

Monodisperse Latex Reactor. See STS-3 for description.

Continuous Flow Electrophoresis System. Experiment series overall description: Experiments discovered a new fluid behavior-an electrohydrodynamic instability, which had never been observed on Earth because of the effects of gravity. Instability limits ability of electrophoresis technology to purify biological materials. Understanding the physics that underlie the instability helped the design of improved electrophoresis buffer solutions for high-resolution purification of biological materials.

Get Away Specials:

> Microgravity Soldering Experiment. Student experiment studied separation of flux from solder while soldering in microgravity. The solder was analyzed postflight for trapped pockets of flux and was compared with solder processed on Earth.
>
> Composite Curing Experiment. Student experiment completed cure of a B-staged (partially cured) epoxy resin-graphite composite sample in microgravity for comparison with 1*g* samples and analyzed the sample postflight to determine quality of wetting between resin and graphite fibers and to test tensile strength of the sample.
>
> Surface Tension Experiment. Student experiment studied the shape of a liquid meniscus in microgravity using an aluminum block containing holes filled with solder, which is heated and thereby allows the solder to flow and form a meniscus shape.
>
> Thermal Conductivity Experiment. Student experiment mixed oil and water in orbit and heated the mixture to measure thermal conductivity of the mixture from data obtained from temperatures of the heater wire mixture and air around the cylinder.
>
> Homogeneous Alloy Experiment. Student experiment. An aluminum chamber containing a powdered bismuth-tin mixture was heated, thereby allowing alloying to take place. The alloy was returned for testing on the ground.

STS-5

Student Involvement Program Experiments:

> Convection in Zero Gravity. Student experiment designed to study surface tension convection in zero gravity. Studied effects of boundary layer conditions and geometries on the onset and character of the convection.
>
> Formation of Crystals in Weightlessness. Purpose of this student experiment was to compare crystal growth in zero gravity to that in 1*g* to determine whether weightlessness eliminates causes of malformations in crystals.

Get Away Special:

> MAUS Materials Science experiment. Used a combination of gallium and mercury to investigate the dissolution process above the consolute temperature as well as the time-dependent stability of resulting dispersion composed of mercury droplets in gallium. For the first time, x-ray recordings were used to provide real-time data of different states of experiment sequence.

STS-6

Monodisperse Latex Reactor.See STS-3 for description. Performed nominally for three of the four reactors.

Continuous Flow Electrophoresis System. See STS-4 for description. All samples were processed according to flight plan.

Get Away Specials:

> Japanese Artificial Snow Crystal Experiment. Attempted to produce the first artificial snow in space and observe crystals using home video equipment.

US Air Force Academy student experiments:

> Metal Alloy. Worked to determine whether tin and lead would combine more uniformly in microgravity.
>
> Foam Metal. Worked to foam metal in zero gravity, forming a metallic sponge.
>
> Metal Beam Joiner. Worked to demonstrate that soldering of beams can be accomplished in space.
>
> Electroplating. Worked to determine how evenly a copper rod can be plated in a zero-gravity environment.
>
> Metal Purification. Worked to test effectiveness of zone-refining methods of purification in a zero-gravity environment.

STS-7

Monodisperse Latex Reactor. See STS-3 for description. A growth wall was found in all four reactors.

Continuous Flow Electrophoresis System. See STS-4 for description. All six samples were processed and separated well.

Cell Attachment in Microgravity. To study cells cultured in space for electrophoretic separation, it must be determined whether cells grow in space. Cells can only be cultured if they are attached to growth surfaces such as microcarrier beads. Experiment determined that cells attach to growth surfaces even in microgravity with the greatest activity coming in the first 24 hours of microgravity.

Materials Experiment Assembly Experiments:

> Vapor Growth of Alloy-type Semiconductor Crystals. Grew crystals of alloy semiconductors (electronic materials) and provided data for a better understanding of fluid dynamics of vapor transport systems in space. Applications resulting from this type of research included improved semiconductor technology for electronics industry.
>
> Liquid Phase Miscibility Gap Materials. Produced space-formed alloys difficult to obtain on Earth for analysis of their physical, chemical, and electrical properties.
>
> Containerless Processing of Glass Melts. Worked to gain further knowledge of high-temperature, containerless processing of various compositions of glass-forming substances. Three of the eight samples were aluminum oxide; the other five were glass-forming compositions.

German MAUS Experiments:

> Solidification Front. Used a general-purpose rocket furnace to help determine particle movement during melting and solidification of metal alloys. Knowledge gained was of value to the fabrication of composite materials.
>
> Stability of Metallic Dispersions. Designed to develop a technique for taking x-ray photographs of melting and solidification of metals.

Get Away Specials:

> West German High School Student Experiments. Two of the five experiments were of the microgravity discipline that included Crystal Growth experiment and Nickel Catalyst experiment.
>
> Student Experiment. Conducted an experiment that examined oil and water separation in microgravity.
>
> Student Experiment. Studied motion of a drop of mercury immersed in clear liquid.

STS-8

Continuous Flow Electrophoresis System. See STS-4 for description. All six Continuous Flow Electrophoresis System samples were separated in-flight.

Engineering Test of Carry-on Incubator and Cell Attachment in Microgravity. It was determined on STS-7 that cells can be cultured in space at room temperature. Experiment was to determine how cells would grow in an incubator in microgravity. Results indicated that cell growth in space increased because cells could attach to all parts of the microcarrier beads growth surface as opposed to the Earth-based control group, which could only attach to the top of the beads.

Get Away Special:

Japanese Artificial Snow Crystal Experiment. See STS-6.

STS-9

Spacelab 1 experiments-some of the experiments flown on maiden voyage of Spacelab 1:

Vacuum Brazing. Evaluated effects of low gravity on vacuum brazing cycle. Found that the microstructure was independent on the gravitational level, certain gap geometries necessarily lead to filling defects under low-gravity conditions, and convection occurs within braze depot during filling.

Bubble Reinforced Materials. Studied behavior of dispersed phases during a melting and solidification treatment. Experiment was successfully completed.

Solidification and Oswald Ripening of Near Monotectic Zinc-Lead (Zn-Pb) Alloys. Determined whether Zn-Pb alloys could be maintained in dispersed state within miscibility gap and examined coarsening behavior of lead particles. Found that a homogeneous dispersion of fine droplets can be maintained under microgravity and solidified into a homogenous dispersion structure at cooling rates available in the Isothermal Heating Facility, particle coarsening that occurred during a hold in the two-liquid region was compatible with known data for the Pb-Zn system, and disturbance of the Oswald process by Marangoni and residual convection was unimportant.

Melting and Solidification of Metallic Composites. Investigated mechanisms that cause destabilization of metallic suspensions and the effect of interfacial phenomena on preparation and properties of metallic composites, and used what was found for the production of metal matrix composites. Materials were analyzed using radiography, metallography, Vickers macro-hardness tests, tensile tests, fracture surface examination, and abrasive wear tests.

Unidirectional Solidification Of Cast Iron. Investigated transport of sulphur during the directional solidification eutectic cast iron and growth of graphite under microgravity. The sample was analyzed postflight.

Solidification of Aluminum-Zinc (Al-Zn) Emulsions. Studied directional solidification of an Al-Zn vapor emulsion and investigated a new method to obtain an in-situ composite containing regularly dispersed bubbles. Found that the microstructure of the alloy was caused by significant macrosegregation. This may indicate the presence of convective currents within the melt.

Unidirectional Solidification of Eutectics Alloys. Examined different types of eutectic structures produced on ground and under microgravity conditions and compared their characteristics. Worked to verify validity of eutectic growth theories. When results were compared to other microgravity experiments, it was concluded that only fiber-like systems are affected by gravity.

Lead Telluride (PbTe) Crystal Growth. Investigated influence of gravity on lead-telluride crystal production. Three PbTe monocrystals were grown by the Bridgeman method. Results revealed that it is possible to grow large crystals in space of better quality than crystals grown on Earth.

Unidirectional Solidification Of Eutectics (InSb-NiSb). Studied microgravity directional solidification of an indium-nickel-antimony eutectic. Three directionally solidified samples of equal lengths were produced, and after counting the number of eutectic needles per unit area, it was determined that flight samples contained approximately 30% more needle than Earth-processed samples, which meant a finer eutectic structure.

Thermodiffusion in Tin Alloys. Worked to determine thermodiffusion coefficients of tin alloys in a reduced-gravity environment. Twelve sample portions were analyzed postflight.

Growth of Cadmium Telluride (CdTe) by Traveling Heater Method. Worked to produce a CdTe crystal free of gravity-induced defects and micro-inhomogeneities. Flight sample was analyzed postflight.

Growth of Semi-Conductor Crystals of the Traveling Heater Method. Attempted to determine whether doped gallium-antimony crystals grown in microgravity using Traveling Heater method exhibited a reduction in dopant inhomogeneities. Found that dopant inhomogeneities were generally much smaller in space-grown crystals than in Earth-grown crystals.

Crystallization of Silicon Drop. Studied solidification of a silicon drop under low-gravity conditions with the purpose of studying the influence of surface-driven flow in liquid silicon. A crystal was formed and analyzed postflight.

Oscillation Of Semi-Free Liquid Spheres In Space. Studied effects of axial vibrations on semi-free liquid volumes in microgravity reproducing a growing crystal and its feeding liquid phase. Results confirmed previous observations during STS-5 and were in agreement with theoretical models.

Kinetics of Spreading of Liquids in Microgravity. Investigated dynamic behavior of a tethered liquid drop after contact with a plane solid surface. Analysis of recorded film indicated that initially the silicone oil spread rapidly and then the motion decayed to a slower spreading.

Free Convection in Low Gravity. Attempted to verify theoretical calculations that indicated that stable floating zones of 10 cm (3.9 in.) could be established, Marangoni flow created in the zone would be of boundary layer type, and investigated Marangoni flows under a number of parameters. During first test run, Marangoni flow was, for the first time, obtained in space. During last run, the highest floating zone at the time of (L=8 cm [3 in.]) was obtained.

Capillary Forces. Studied capillary behavior of a silicone oil liquid zone held axisymetrically between two end plates, investigated low-gravity formation and properties of thin films forming between contacting solid and liquid and examined stability of the zone. After overspreading during first test run, six different liquid zones were examined, and nine different liquid zones were examined during second run.

Coupled Motion of Liquid-Solid Systems in Near Zero Gravity. Studied behavior of a liquid enclosed in a container during spin-up and spin-down of container, response of contained liquid to forced oscillations, and worked to determine limitations of a computational model to predict fluid behavior. Limited interpretation of data was made due to filmed record being defective.

Floating Zone Stability on Zero Gravity. Worked to form a long cylindrical bridge between two coaxial disks and investigated surface deformation and liquid flow caused by mechanical stimuli. A liquid bridge of silicone oil was established; however, during filling of the zone, the oil overflowed the edge. The anomaly was investigated on orbit, and obtained some meaningful results.

Crystal Growth of Proteins. Investigated crystal growth at a constant temperature, in an increasing thermal gradient, the effect of different protein concentrations on growth, and the influence of wide and narrow diffusion fronts on crystal growth. Space-processed beta-galactosidase crystals were 27 times larger and space-processed lysozyme crystals were 1,000 times larger than their Earth-processed counterparts, and the crystals were well shaped and of good quality.

Self-Diffusion in Liquid Metals. Investigated temperature dependence of self-diffusion and isotope effects in molten tin. Results showed excellent accuracy, lower diffusion coefficients than in ground experiments, temperature dependence of diffusion coefficient not in accordance to Arrhenius law, and pronounced collective motion of atoms at low temperatures and single motion at higher ones.

Adhesion of Metals. Used microgravity environment to study adhesion in collisions with energy transfer of the same order of magnitude of interface energies. Most objectives were reached.

Organic Crystal Growth. Attempted to obtain low-dimensional, electrically conducting organic crystals with a regular structure to study their electronic properties. Due to launch delays, the low-dimensional crystal growth experiment did not yield results, but two calcium-carbonate and two calcium-tartrate crystals were grown.

Crystal Growth by Co-Precipitation in Liquid Phase. Sought to alleviate gravity-driven convection effects to achieve diffusion-dominated crystal growth. Quality and size of crystals obtained demonstrated that space experiments offer an opportunity to obtain monocrystals.

Mercury Iodide Growth. Studied physical vapor transport growth of mercury iodide crystals and attempted to provide a deeper understanding of the coupling between nucleation and convection growth processes from vapor phase. Crystals were grown in space using different methods.

STS-41B

IsoElectric Focusing Experiment. Evaluated effect of electro-osmosis on an array of eight columns of electrolyte solutions as direct current power was applied and pH levels between anodes and cathodes increased. Product separation did occur, but not to extent expected.

Monodisperse Latex Reactor. See STS-3 for description. Monodisperse latex spheres were grown in three of the four reactors.

Acoustic Containerless Experiment System. A material processing furnace experiment that was enclosed in two airtight canisters in Orbiter middeck. A damaged glass sample was returned from on-orbit operations.

European Space Agency Experiment:

> Gas Bubbles in Glass Melts. Observed shrinking of a defined single gas bubble to deliver data for the calculation of the diffusion coefficient. All parts of experiment showed normal behavior until end of run.

Get Away Specials:

> Student experiments. Experiments studied capillary waves in liquids and thermocapillarity.
>
> American Institute of Aeronautics-Utah Section experiments. Attempted to crystallize proteins in a controlled temperature environment in microgravity, and students conducted experiments including a redesigned reflight of a soldering experiment and tested a heat pipe to be used in a future space experiment.

STS-41C

Deployed the Long Duration Experiment Facility, which contained material science and other scientific and application experiments.

Long Duration Exposure Facility Experiments. All experiments required free-flying exposure in space, but no extensive electrical power, data handling, or attitude control systems.

STS-41D

Continuous Flow Electrophoresis System. See STS-4 for description. Eighty-Five percent of samples were processed.

Shuttle Student Involvement Project Experiment:

> Float Zone Experiment. Designed to compare a crystal grown by the "float zone" technique in a low-gravity environment with one grown in an identical manner on Earth.

STS-41G

Advanced Composite Materials Experiment. Experiment involved testing samples of composite materials attached to Canadarm and measuring any deterioration while exposed to conditions of space. Determined performance of materials exposed to true space environment. Over 90% of objectives were met.

Get Away Specials:

> Physics of Solids and Liquids in Zero Gravity. Conducted experiments to discover what happens with a metal or plastic solid collided with water in microgravity and worked to produce new metal alloys and glass composites in space. New materials experiment was successful, but water-object collision experiment was not.
>
> Zero G Fuel System Test. McDonnell Douglas Astronautics Company studied how liquid fuel in partially full tanks could be delivered free of gas bubbles to engines that control and direct spacecraft in orbit.
>
> Physics and Material Processing Experiments. Designed to study basic physical processes or, in some cases, their effects on a variety of processes.
>
> They include the following:
>
> > Capillary Waves Under Zero-Gravity. Excited waves in a water surface and photographed results.
> >
> > Solder Flux Separation. Studied separation of flux and solder in zero gravity.
> >
> > Heat Pipe Experiment. Tested a fluid flow system that was later used in an electrophoresis experiment.
> >
> > Thermocapillary Convection. Studied flow patterns set up by a temperature difference.

STS-51A

Diffusive Mixing of Organic Solutions. Performed experiments designed to grow organic crystals purer and larger than those that can be grown on Earth.

STS-51D

Continuous Flow Electrophoresis System. See STS-4 for description. All samples were processed and no contamination of product was observed in flight.

Protein Crystal Growth. Worked to grow high-quality crystals of complex proteins in microgravity for x-ray or neutron diffraction analysis to obtain information for applications such as improved drug design. STS-51D was the first exploratory flight using protein crystal growth hardware.

Phase Partitioning Experiment. Separated biomedical materials such as cells and proteins in microgravity in attempt to gain higher resolution than could be obtained on Earth. This was the first exploratory flight of Phase Partitioning Experiment equipment.

Get Away Specials:

> Physics of Solids and Liquids in Zero Gravity. See STS-41G for description. Both experiments were successful on this re-flight of the payload.

STS-51B

Solution of Crystals in Zero-Gravity/Fluid Experiment. Worked to develop a technique for solution crystal growth in microgravity, characterize growth environment provided by an orbiting spacecraft and its influence on growth, and determine microgravity's effect on growth of triglycine sulfate crystals. Two triglycine sulfate crystals were grown and, for the first time, scientists were able to see in detail the crystal growth process using Schlieren video imaging and a laser holographic system that rendered three-dimensional images.

Mercuric Iodide (HgI_2) Growth/Vapor Crystal Growth System. Aimed to grow better quality HgI_2 crystals in microgravity by taking advantage of diffusion-controlled growth conditions and by avoiding the problem of strain dislocations produced by crystal's weight. A single crystal was grown that was found to be of higher quality and more homogeneous than any HgI_2 crystals grown on the ground up to that time.

Mercury Iodide Crystal Growth. Studied crystal seed and growth processes with vapor crystal growth technique in two and three zone furnaces. Crystals were grown during flight and were analyzed postflight.

Dynamics of Rotating and Oscillating Free Drops. Performed experiments that tested ability to manipulate drops acoustically in microgravity. This first exploratory flight of the experiment yielded first concrete experimental evidence on manipulation of liquid drops using acoustic radiation pressure forces in microgravity, and was the first time a principal investigator operated and repaired his or her own experiment as a Spacelab crew member.

Geophysical Fluid Flow Cell Experiment. Studied fluid motions in microgravity as a means of understanding convection on the sun, in planetary atmospheres, in Earth's oceans, and in basic fluid physics. These experiments were the first laboratory experiments of convection in spherical rotating shells with radical gravity field, and around 46,000 images were recorded from postflight analysis.

STS-51G

Automated Directional Solidification Furnace. Designed to demonstrate the possibility of producing lighter, stronger, and better-performing magnetic composite materials in a microgravity environment. The four material samples were analyzed postflight on this first flight of Automated Directional Solidification Furnace hardware.

Get Away Specials:

> Liquid Sloshing Behavior in Microgravity. Studied behavior of liquid in a tank under microgravity conditions to validate and refine characteristics of tank-fluid systems and to provide data that would be useful in design of devices that manage propellants in surface tension tanks.
>
> Slipcasting Under Microgravity Conditions. Worked to demonstrate with model materials that slipcasting is possible in microgravity.
>
> Fundamental Studies in Manganese-Bismuth. Worked to produce manganese-bismuth specimens with better magnetic properties than was possible under Earth gravity.

STS-51F

Properties of Superfluid Helium in Zero-Gravity. Performed an engineering assessment of cryostat system and a fluid dynamics investigation into existence of low-frequency capillary waves in thin films of helium. Existence of the waves was clearly established and several hundred recordings were made across a range of temperatures.

Protein Crystal Growth. See STS-51D for description.

STS-51I

Physical Vapor Transport of Organic Solids. Conducted research into ordered organic thin films with an emphasis on controlling the film's physical structure properties so as to affect the film's optical, electrical, and chemical behavior. All nine reactor cells were processed in-flight.

STS-61A

European Space Agency-dedicated flight:

Aluminum/Copper Solid-Liquid Interface Diffusion. Studied influence of convection on solidification of metallic alloys. Diffusion boundary layer measured in aluminum-copper alloys were twice as thick in flight samples compared with ground reference samples, dendrite arm coarsening in aluminum-silicon alloys was found to be slower in microgravity samples solidified with a thermal gradient of approximately 16 K/mm and at a rate of about 5 mm/min. However, at rates of about 8 mm/min (thermal gradient=16 K/mm), the dendrite arm coarsening in the 1*g* and low-gravity processed samples was nearly identical. Therefore, it was concluded that convection only influenced the dendrite arm spacing below a certain solidification front velocity.

Atomic Diffusion and Transport in Liquid Metals. Studied self-diffusion and interdiffusion coefficients in liquid indium-tin alloys. Accuracy of low-gravity diffusion coefficients was about a factor of 10 to 100 better than liquid diffusion results on Earth and is comparable to very good experimental results for diffusion in solids. As expected, the low-gravity diffusion coefficients are lower than the available ground-based data, indicating the absence of convectional contributions, including Marangoni convection, to mass transport. Microgravity measurements are considered to be due to the pure atomic diffusion of the material.

Bubble Motions Induced by Temperature Gradient. Studied thermocapillary convection motion of bubbles in a liquid. Postflight examination of reconstructed holograms revealed changes in silicon oil/air bubble behaviors in three systems, The bubble motion in the oil followed theoretical predictions, but bubble velocity in the oil was 40% less than predicted. Thus, it appeared that differences between different oils are not accounted for by the parameters in the theory. Results suggest that the description of the liquid/gas interface using only surface tension and its temperature dependence is insufficient. Besides the volume shear viscosity, an additional dissipative mechanism at the liquid/gas interface must be taken into account. Present results suggest dilatational surface viscosity as an additional parameter.

Bubble Transport by Chemical Waves. Studied particle transport by chemical waves in low-gravity and more specifically the motion of gaseous inclusions in a reacting liquid. When recording of holograms started, a malfunction occurred, which was not resolved. After film development, holograms exhibited different density values and blurred images. It was possible to identify 20 bubbles of 0.2- to 3.0-mm diameter (50 to 100 smaller bubbles were expected). Of these 20 bubbles, seven could be used for velocity determination. From this limited data, the following interpretation was reported: bubble movement was only for a short period of time as the wave passed; wave direction remained unchanged; and wave velocity was 2.5 mm/minute, which was greater than the bubble velocity but of the same order of magnitude.

Capillarity Adhesion Forces in Liquid Films. Near catenoid zones and rotational and vibrational stimulation of zones along with properties of wetting layers were studied and compared to theoretical data. Excellent agreement between experimental and theoretical data derived from numerical solution of the Laplace capillary equation was found.

Cellular Morphologies In Lead Thallium Alloys. Aim was to investigate effects of convection on cellular solidification. It was concluded only microgravity conditions allow obtaining regular and isotropic three-dimensional cells, necessary for theory validation

Crystallization of a Silicon Sphere. Experiment was designed to study solidification of a silicon drop under low-gravity conditions. Postflight examination of longitudinally sliced, polished, and etched sample revealed a dense pattern of striations. Microscopic growth rate at various parts of the sample (indicated by separation distance of striations) fluctuated greatly. Result indicated the presence of time-dependent flow in the melt.

Dendritic Solidification Of Aluminum(Al)-Copper(Cu) Alloys. Checked that segregation phenomena are reduced in absence of convection, determined second order segregation phenomena, checked existing theories on dendritic solidification, and studied effects of convection on dendritic solidification. Three Al-Cu samples of different compositions were solidified under the same thermal conditions-on the ground and in microgravity to determine dendritic solidification properties. Microgravity-formed dendritic morphology was significantly different from ground samples.

Density Distribution And Phase Separation In Fluids At The Critical Point. Main aim was to study density distribution of fluid samples and phase separation of fluids near critical point. Results indicated that longer equilibration time and also mechanical stirring may be required to achieve homogeneity of fluid samples near the critical point.

Directional Solidification of Indium (In)-Antimonide (Sb) Nickel (Ni)-Antimonide (Sb) Eutectic. Determination of Gravity Induced Convection on Fiber Spacing. Studied directional solidification of an InSb-NiSb eutectic. To thoroughly examine effects of gravity on eutectic spacing, several directional solidification experiments were performed on Earth. These experiments included processing InSb-NiSb eutectics at normal (l*g*) gravity levels, and at higher centrifuge-induced gravity levels. Results from these ground-based studies were compared to those of Spacelab D1 mission (STS-61A) as well as other low-gravity experiments.

Floating Zone Crystallization of Silicon. Experiment was designed to study floating zone crystal growth of a coated silicon sample under low-gravity conditions. Results confirmed findings from previous experiments that time-dependent Marangoni flows were responsible for striations in Si crystals.

Floating Zone Hydrodynamics. Studied formation and stability of a liquid bridge under low-gravity conditions and provided data to better understand hydrodynamics in spaceflight. Growth of Cadmium (Cd) Telluride (Te) by the traveling heater method from Tellurium Solution. Objective was to produce a CdTe crystal free of defects and microinhomogeneties caused by gravity-driven fluid flows. Comparison of space-grown sample with a similarly processed Earth-grown sample demonstrated better performance of low-gravity processed material despite off-nominal operation of the flight facility.

Growth of Lead-Tin-Telluride (PbSnTe) by the Traveling Heater Method. Experiment determined influence of growth method and gravity-driven convection in traveling heater method solution zone on crystal properties. Microgravity enhanced charge carrier mobility in microgravity sample and improved compositional homogeneity.

Growth of Single Crystals of Binary III-V Semiconductors by the traveling heater method (sulphur doped indium-phosphide). Studied growth of semiconductor crystals using traveling heater method. Sample analysis indicated that in the middle of the crystal a bubble was generated, which led to a polycrystalline growth regime in the center, surrounded by single crystalline regions with a few small in-inclusions. Metallic solution growth in space, therefore, offers the possibility of comparing kinetic-related growth properties with effects that are influenced by the growth solution.

Growth of Single Crystals of Binary III-V Semiconductors. Traveling Heater Method (tellurium doped gallium antimonide). Studied growth of semiconductor crystals using traveling heater method. Reportedly, space-grown tellurium doped gallium antimonide crystal was found to be nearly striation free with only residual dopant inhomogeneities, while ground-processed crystals showed pronounced structures of rotational and non-rotational periodic striations over the whole cross-section of the crystal. It was concluded that metallic solution growth in space offers the possibility of comparing kinetic-related growth properties with effects that are influenced by the growth solution.

Growth Rate Measurement of Doped Indium-Antimonide Crystal by a Calorimetic Method under Microgravity. Studied directional solidification properties. Postflight analysis of data and samples revealed that calorimetric measurements can be used for in-situ monitoring of some crystallization parameters.

Heat Capacity near the Critical Point. Measured specific heat of pure sulfur hexafluoride in vicinity of its critical point. Low-gravity specific heat measurements, when compared with theoretical calculations and ground-based measurements, showed that specific heat at the critical temperature were surprisingly below the theoretical one.

Homogeneity of glasses. Investigated nucleation and crystallization of glass in microgravity to obtain an undisturbed structure of the glass. Compared with samples obtained on Earth. Samples of glass in space are much more homogenous, because heterogeneous nuclei from contact zone are not transported to the bulk of the melt. Platinum addition led to a much more fine-grained microstructure compared with samples under normal gravity.

Liquid Motions In Partially Filled Containers. Objectives were to verify results of a computer model that predicted the contained liquid behavior in response to certain excitations and obtain information that would lead to further developments of numerical models of fluid dynamics. Analysis indicated some slip of the contact line during oscillation of the liquid surface.

Marangoni Convection in an Open Boat. Investigated thermal Marangoni convection under a temperature gradient that was aligned parallel to the free surface. Postflight analysis of the film indicated that the sample melted as programmed.

Marangoni Convection in Relation to Mass Transfer from the Liquid to the Gas Phase: MACO A and MACO B. When mass is transferred from a motionless liquid to a gas, convective motions can develop at the interface. Results showed no flow development at a flat interface and showed development of roll cells at the curved interface.

Marangoni Flows. Investigated surface tension-driven convection in one- and two-liquids floating zones. This experimental run provided quantitative results on thermal Marangoni convection. Qualitatively, this experiment's thermal results are congruent with others.

Measurement of the Thermally Induced Ludwig-Soret Effects. Objective was to observe thermal diffusion of a molten salt mixture in such conditions that residual gravity field is small compared to thermal field, and permitting in-situ measurement of the Soret effect. Results proved that, in space, the measured thermo-potential corresponded to a complete cell filling.

Melting and Solidification of Metallic Composites. Worked to gain a better understanding and control of metallurgical production of composite materials. Demonstrated practicability of the recasting (e.g., during welding) of oxide dispersion-strengthened alloys in a microgravity environment.

Mixing And Demixing Of Transparent Liquids. Examined physical mechanisms operating during the mixing and demixing of binary transparent liquids exhibiting a miscibility gap. Marangoni convection caused by non-uniform heating and cooling was lower than expected.

Particles at Melting and Solidification Fronts. Examined low-gravity behavior of particles displaced during melting and solidification. Postflight examination of sample revealed no characteristics of global convection within the melt. There was no clustering or skeleton formation of molybdenum particles. Round bubbles, whose surface is uniformly occupied with molybdenum particles, and others filled with copper were also present within the sample.

Planar Front Solidification of Aluminium(Al)-Magnesium(Mg) Alloys.Studied microgravity, thermo-solutal convection near the solid-liquid boundary of a directionally solidified Al-Mg alloy. Samples of Al-Mg were partially melted and directionally solidified. Microprobe determination of the longitudinal concentration profile and comparison of these data with the 1*g* processed samples indicated that purely diffusive controlled growth conditions occurred in low-gravity processed samples.

Separation of Fluid Phases and Thermocapillary Bubble and Drop Motion in a Temperature Gradient. Studied thermocapillary convective motion of particles in liquids. Thermocapillary convective motion of particles in liquids indicated the Marangoni numbers achieved exceeded limitations for terrestrial observations.

Separation of Immiscible Melts. Studied separation and solidification of immiscible alloys. Results showed size of minority phase droplets, axial temperature gradient inside specimens, and influence of the radial gradient on the transport of the minority phase droplets toward the hotter center were the same as previously found.

Skin Casting on Grey Cast Iron. Investigated microgravity directional solidification of cast iron. Postflight analysis of time-temperature profile revealed temperature fluctuations over distinct periods of time. Whatever the reason, temperature fluctuations are more or less fatal to growing eutectics unidirectionally.

Skin Technology. Eutectic Solidification. Investigated feasibility of casting materials under low-gravity conditions using skin technology. Study illustrated that processing within a wetted skin was possible and that this technique is important in regard to suppression of surface-driven convection under low-gravity conditions and a simple way to compensate for volume change during melting and solidification without use of an external device.

Solutal and Thermal Convection in Germanium-Iodine2 Vapor Phase. Investigated and characterized parameters that govern vapor phase transport during vapor crystal and worked to employ these parameters in theoretical analyses. Using vapor crystal growth technique to grow high-quality crystals of electronic materials at low temperatures, this study showed the quality of these layers were much higher than those made on Earth.

Surface Tension Induced Convection around a Surface Tension Minimum. Investigated Marangoni convection in an aqueous solution of n-heptanol at the temperature corresponding to the surface tension minimum. Found that the effect of nonlinear variation on surface tension on convection flow of a liquid demonstrated that convective flows travel in the same direction-cold side to hot side.

The Behavior of Aluminum Oxide Particles at the Solidification Front of Copper. Studied low-gravity solidification of metallic composites. Suspension distribution illustrated that the particles had been pushed during solidification and corresponded with theoretical predictions.

Thermodiffusion in Liquid Metallic Alloys. Studied isotopic separation of tin (Sn) by thermomigration, the Sn + Silver (Ag) system for which results were available from ground-based experiments, and the Sn + Bismuth (Bi) system studied elsewhere in the Mephisto project. Values of Sn - Ag thermomigration parameters in liquid tin were measured for Sn112, Ag and Bi. It was not possible to obtain these values on the same systems in ground experiments owing to disturbing convection effects.

Vapor Zone Crystallization of Cadmium (Cd) Telluride (Te). Worked to grow a CdTe crystal to explore diffusion-dominated growth. Grew a CdTe crystal from the vapor phase by sublimination/condensation. Due to the seed crystal flow being of poorer quality than Earth samples, comparison to Earth samples was difficult.

STS-61B

Continuous Flow Electrophoresis System. See STS-4 for description. Approximately 1 L (0.3 gal.) of hormone material was processed during flight.

Diffusive Mixing of Organic Solutions. See STS-51A for description. All six experiment cells were processed during flight.

Protein Crystal Growth. See STS-51D for description.

STS-61C

Three-Axis Acoustic Levitator. Studied degree of sphericity attainable and small bubble migration similar to that having to do with the refining of glass.

Initial Blood Storage Equipment. Aimed to better understand the factors that limit storage of human blood by isolating factors such as sedimentation that occur under standard blood bank conditions.

Protein Crystal Growth. See STS-51D for description. Experiment on STS-61C was performed by Senator (then Congressman) Bill Nelson. Experiments were performed with "proof-of-concept" instruments intended to test designs. The Challenger accident took place the following month. When shuttle flights resumed in 1988 with STS-26, a new Protein Crystal Growth instrument-the Vapor Diffusion Apparatus-carried proteins from different companies and institutions. Three proteins produced crystals with significantly improved properties compared to Earth-grown crystals.

Shuttle Student Involvement Program Experiments:

> Argon Injection as an Alternative to Honeycombing. Examined ability to produce a lightweight honeycomb structure superior to Earth-produced structures in metals.
>
> Formation of Paper in Microgravity. Studied formation of cellulose fibers in a fiber mat under weightless conditions.

Get Away Special:

> Studied solidification of alloys for lead-antimony and aluminum-copper combinations, and crystal growth of metallic-appearing needle crystals in an aqueous solution of potassium tetracyanoplatimate.

STS-26

Physical Vapor Transport of Organic Solids. See STS-51I.

Protein Crystal Growth. See STS-51D for description. The new equipment flown-Vapor Diffusion Apparatus-allowed for temperature control and automation of some processes not possible in earlier flights.

Automated Directional Solidification Furnace. See STS-51G for description. Studied manganese and bismuth composites and all runs were completed during flight.

Isoelectric Focusing. An electrophoresis experiment that separated proteins in an electric field according to their surface electrical charge.

Phase Partitioning Experiment. See STS-51D for description.

Aggregation of Red Blood Cells. Designed to provide information on formation rate, structure, and organization of red cell clumps, as well as on thickness of whole blood cell aggregates at high and low flow rates.

Space Shuttle Student Involvement Program Experiments:

> Utilizing a Semi-Permeable Membrane to Direct Crystal Growth. Experiment attempted to control crystal growth through use of a semi-permeable membrane.
>
> Effects of Weightlessness on Grain Formation and Strength in Metals. Experiment heated a titanium alloy metal filament to near the melting point to observe effect that weightlessness had on crystal reorganization within the metal.

STS-29

Protein Crystal Growth. See STS-51D for description.

STS-30

Floating Zone Crystal Growth and Purification. Used Fluids Experiment Apparatus to process melts of different materials including indium and selenium sample this flight. Three of the four samples were processed on orbit.

STS-34

Polymer Morphology. This organic processing experiment explored effects of microgravity on polymeric materials as they were processed in space. Around 78% to 93% of objectives were completed.

Student Experiment:

> Zero Gravity Growth of Ice Crystals from Supercooled Water with Relation to Temperature. Observed geometric ice crystal shapes formed at supercooled temperatures without influence of gravity. Ice crystals were grown on second attempt.

STS-32

Retrieved the Long Duration Exposure Facility.

Floating Zone Crystal Growth and Purification. See STS-30.

Microgravity Disturbances Experiment. Investigated effects of both Orbiter- and crew-induced disturbances in microgravity environment on resulting microstructure of float-zone-grown indium crystals.

Fluids Experiment Apparatus-3 Microgravity Disturbances Experiment. Investigated effects of both Orbiter and crew-induced disturbances in microgravity environment on resulting microstructure of float-zone-grown indium crystals. Completed with 85% of objectives having been met.

Protein Crystal Growth. See STS-51D for description. During the mission, 120 different Protein Crystal Growth experiments were conducted using as many as 24 different proteins.

STS-31

Protein Crystal Growth. See STS-51D for description. Sixty different Protein Crystal Growth experiments using 12 different proteins were flown.

Investigations Into Polymer Membrane Processing. Studied processing of polymer membranes in microgravity with objective to gain a fundamental understanding of the role of convection-driven currents in transport processes that occur during evaporation of polymer membranes and to investigate how those transport processes influence membrane morphology.

STS-41

Investigations Into Polymer Membrane Processing. See STS-31 for description.

Solid Surface Combustion Experiment. Studied basic behavior of fire by examining the spreading of flame over solid fuels without the influence of gravity.

STS-37

Bioserve Instrumentation Technology Associates Materials Dispersion Apparatus. Used Materials Dispersion Apparatus to conduct a variety of liquid-to-liquid processes using two or three fluid experiments, grow crystals, cast thin-film membranes, and conduct biomedical and fluid science experiments. On this first flight of the payload, 17 principal investigators worked to conduct 61 different experiments.

Protein Crystal Growth. See STS-51D for description. Used new hardware called the Protein Crystal Growth Facility. Payload demonstrated techniques for producing crystals for sufficient size to permit molecular analysis by diffraction techniques.

STS-40

Get Away Specials:

> Experiment In Crystal Growth. Grew crystals of gallium arsenide, which are a versatile electronic material used in high-speed electronics and opto-electronics.
>
> Orbital Ball Bearing Experiment. Tested effects of melting cylindrical metal pellets in microgravity.
>
> In-Space Commercial Processing. Conducted five experiments to study possible commercial in-space processing opportunities.
>
> Foamed Ultralight Metals. Intended to demonstrate feasibility of producing, in orbit, foams of ultralight metals for possible application as shock-absorbing panel backing to improve shielding of both crewed and uncrewed vehicles and satellites against hypervelocity impacts, either from micrometeoroids or orbiting debris.
>
> Chemical Precipitate Formation. Investigated rate of formation and terminal size of precipitate particles when growth is not impaired by settling due to gravity.
>
> Five Microgravity Experiments. One attempted to grow large zeolite crystals. Another studied behavior of fluids in microgravity. A third-Environmental Data Acquisition System-recorded information about sound, light, temperature, and pressure within the Get Away Special can. The fourth measured the acceleration of the shuttle along three axes with a high degree of precision. A fifth experiment studied the fogging of film in space.
>
> Semiconductor Crystal Growth Experiment. Investigated potential advantages of crystal growth under microgravity.
>
> Six Active Soldering Experiments. Studied soldering in microgravity.

STS-43

Protein Crystal Growth. See STS-51D for description. Used Protein Crystallization Facility and bovine insulin on this flight.

Investigations Into Polymer Membrane Processing. See STS-31.

Bioserve Instrumentation Technology Associates Materials Dispersion Apparatus. See STS-37 for description. Four Materials Dispersion Apparatus units were flown, and 17 principal investigators explored 36 different experiments in different fields.

Space Acceleration Measurement System. An instrumentation system designed to measure and record accelerations on board the Orbiter and Spacelab. For the first time, successfully obtained measurements on shuttle middeck.

Solid Surface Combustion Experiment. See STS-41 for description.

STS-48

Protein Crystal Growth. See STS-51D for description. Flew variety of proteins and had some problems with syringe tips, but six samples were nominal with full droplets on syringe tips.

Investigations Into Polymer Membrane Processing. See STS-31.

Middeck 0-gravity Dynamics Experiment. Studied mechanical and fluid behavior of components for future spacecraft.

STS-44

Validation of Space Bioreactor Concept for Microgravity Operation (Rotating Bioreactor System). Developed to grow cell cultures in a horizontal cylindrical container that slowly rotated, emulating gravity, and keeping the cells continuously suspended while bathing them in nutrients and oxygen. Performance of all systems were consistent with successful operation for use with living cells and meant the bioreactor design was ready for use in microgravity.

Bioreactor/Flow and Particle Trajectory in Microgravity. Performed on two missions. Experiment was a hardware test of bioreactor systems to evaluate possible cell growth in microgravity. Results indicated that there were no problems with performance of the equipment during runs and that flight experiment data will help advance bioreactor design.

STS-42

Protein Crystal Growth. Made up of 120 individual experiments designed to grow larger and higher-quality crystals of various substances than those grown in a 1*g* environment using vapor diffusion method of crystal growth. The many different crystals obtained were of varied quality and size and were sent to laboratories on the ground for x-ray crystallography and further analysis.

Single Crystal Growth of Beta-Galactosidase and Beta-Galactosidase/Inhibiter Complex. Used Cryostat. This system provided a temperature-controlled environment for protein crystal growth in freezer mode to crystallize the proteins beta-galactosidase and beta-galactosidase/inhibiter complex.

Crystal Growth of the Electogenic Membrane Protein Bacteriorhodopsin. Used Cryostat in the stabilizer mode, the temperature is maintained at +20º C (68º F), while varying salt and buffer content in the samples to determine best concentration for higher quality, larger crystals of the protein bacteriorhodopsin.

Crystallization of Proteins and Viruses in Microgravity by Liquid-Liquid Diffusion. Used Cryostat with duplicate samples of the proteins canavalin, catalase, and the satellite tobacco mosaic virus in freezer and stabilizer mode to determine what benefits microgravity would have on crystallization and for a comparison of crystals obtained from Cryostat using liquid diffusion and Protein Crystal Growth vapor diffusion methods.

Study of Solution Crystal Growth in Low-Gravity. Used Fluids Experiment System to grow triglycine sulfate crystals, obtain holographic and video data of the crystals, and obtain fluid flow data for possible higher quality crystals for possible use with infrared detector technology. Many holograms were made, and crystals and data were returned to a laboratory on the ground.

An Optical Study of Grain Formation: Casting and Solidification Technology. Solidified a salt and water solution that modeled the freezing of alloys using Fluids Experiment System and optical equipment for the study of the development of advanced metal alloys. Data obtained hoped to help eliminate and study imperfections that form during alloy solidification that can cause alloy weakness.

Vapor Crystal Growth Studies of Single Mercury Iodide Crystals. Worked to grow a large, high-quality mercury iodide crystal, which can be used as a sensitive x-ray or gamma-ray detector, using the Vapor Crystal Growth System and a preflight grown seed crystal for analysis and comparison on the ground. A large mercury iodide crystal was grown, which preliminary reports indicated was the largest space-grown crystal at that time.

Mercury Iodide Nucleations and Crystal Growth in Vapor Phase. Grew six mercury iodide crystals in a controlled environment and studied benefits of crystal growth in microgravity. Crystals grown were returned to a laboratory to determine best conditions for crystal growth, and for further analysis.

Organic Crystal Growth Facility. Used Organic Crystal Growth Facility-a facility used to grow highly conductive materials such as superconductors-to grow a single, large, high-quality crystal composed of charge transfer complexes tetrathiafalvelene and {nickel $(dmit)_2$ $\}_2$ for study due to the difficulty growing such single crystals on Earth.

Study of Density Distribution in a Near-Critical Simple Fluid. Examined and analyzed density distribution in sulfur hexafluoride above and below its critical point using visual observation, interferometry, and light-scattering techniques. Experiment used European Space Agency's Critical Point Facility on its first shuttle flight.

Heat and Mass Transport in a Pure Fluid in the Vicinity of a Critical Point. Studied heat and mass transport in the gas sulfa hexafluoride using the Critical Point Facility, interferometry, and direct observation. Results were compared with ground-based test results to determine whether heat and mass transport is more efficient in microgravity.

Phase Separation of an Off-Critical Binary Mixture. Using the Critical Point Facility, examined how a fluid at critical point separates from a single phase to form two phases, and how changes in temperature affected phase formation. Found important information about phase separation that could only be demonstrated in microgravity.

Critical Fluid Thermal Equilibrium Experiment. Measured temperature and density changes of sulfur hexafluoride at a resolution not possible on Earth using cells integrated into the Critical Point Facility. Worked to understand the time it takes for a sample to reach temperature and density equilibrium as the critical point is approached.

Space Acceleration Measurement System. See STS-43 for description. During the International Microgravity Laboratory-1 (STS-42), this system was used to support microgravity experiments, primarily Fluids Experiment System and Vapor Crystal Growth System experiments.

Gelation of Sols: Applied Microgravity Research. Investigated influence of microgravity on processing of gelled sols (dispersions of solid particles in a liquid often referred to as colloids). After the flight, results were returned for further research in an attempt to enhance structural uniformity of ceramic composite materials through space processing.

Phase Partitioning Experiment. Worked to increase purity of the separated cells from the phase partitioning process. Data useful for separation and purification of cells involved in transplants and treatment of disease was studied.

Investigations into Polymer Membrane Processing. Investigations into Polymer Membrane Processing investigated physical and chemical processes that occur during formation of polymer membranes to increase knowledge base for improved commercial membrane processing techniques.

Get-Away Specials:

Marangoni Convection in a Floating Zone. This investigated the influence of rotation on steady and oscillatory Marangoni convection induced through surface tension gradients. Experiment was operated successfully.

Glass Bubbles In Glass Melt. Glass fining-the removal of all visible gaseous inhomogeneities from a glass melt-by heating a glass sample with an artificial helium bubble in its center to remove the bubble.

The Effect of Gravity on the Solidification Process of Alloys. This worked to improve the understanding of the effect of gravity on solidification process of alloys by using three experimental furnaces and an energy buffer. Experiment operated nominally.

Separation of Gas Bubbles from Liquid. Modes of bubble movement in liquid under microgravity conditions were examined in this experiment. Might have had a malfunction due to low battery voltage.

The Effect of Gravity on the Solidification Process of Alloys. Investigated effect of gravity on solidification process of alloys.

STS-45

Investigations Into Polymer Membrane Processing. See STS-31.

Get Away Special:

Experiment In Crystal Growth. See STS-40 for description. Additional features such as the enhanced ability to analyze convection effects on crystal growth in microgravity were added to this re-flight of the experiment.

STS-49

Commercial Protein Crystal Growth Experiment. Worked to grow protein crystals for applications such as the pharmaceutical industry for new protein-based drugs. Flew a newly designed commercial refrigerator incubator module, which allowed for a pre-programmed temperature profile along with Protein Crystal Growth Facility.

STS-50

Orbital Processing Of High-Quality Cadmium Telluride (CdTe) Compound Semiconductors. Investigated quantitatively the influence of gravitationally dependent phenomena on growth and quality of alloyed compound semiconductors. Both ground and flight samples showed infrared transmission close to theoretical, infrared microscopy confirmed that the principal precipitates were Te and their size and density suggested that flight- and ground-based samples cooled similarly and had a similar composition, macrosegregation was found to be low even in 1*g* crystals, and flight samples were higher in structural perfection than ground samples.

The Study of Dopant Segregation Behavior During the Growth of Selenium-Doped Gallium Arsenide (GaAs) in Microgravity. Investigated techniques for obtaining complete axial and radial uniformity during crystal growth of selenium-doped GaAs. Measurement of selenium dopant distribution indicated that the first sample initially achieved diffusion growth but was driven to a complete mixing regime, second sample was always in a complete mixing regime, and voids in center line of the crystal were found to correlate with the position in the crystal when translation rates doubled.

Crystal Growth of Selected II-VI Semiconducting Alloys by Directional Solidification. Worked to determine how structural, electrical, and optical properties of selected II-VI semiconducting crystals are affected by growth in a low-gravity environment. Even though the experiment was terminated inadvertently after about 30% planned completion, it was successfully demonstrated that mercury cadmium telluride alloy ingots partially grown and quenched on the ground can be back-melted and regrown in space under nearly steady-state growth conditions.

Vapor Transport Crystal Growth of Mercury Cadmium Telluride (HgCdTe) in Microgravity. Investigated relationship between convective flow, mass flux, and crystal morphology, and identified effects of microgravity on crystal properties of HgCdTe. Results demonstrated considerable improvements of flight samples in terms of surface morphology, chemical microhomogeneity, and degree of crystallographic perfection and uniformity over ground samples.

Surface Tension Driven Convection Experiment. Studied basic fluid mechanics and heat transfer of thermocapillary flows in microgravity.

Core-Centering of Compound Drops in Capillary Oscillations: Observations on USML-1 Experiments in Space (STS-50). Conducted experiments on liquid shells and liquid-core compound drops using acoustic levitation in microgravity. Observed first compound drop, and observed that their inner and outer interfaces became concentric when excited into capillary oscillations.

Bifurcation of Rotating Liquid Drops: Results from US Microgravity Laboratory-1 (STS-42) Experiments in Space. Conducted experiments on rotational bifurcation of liquid drops where drops were levitated and spun using acoustic fields in microgravity. Successfully resolved discrepancies existing between previous experimental results and theoretical predictions, spherical drop results agreed well with predictions, and flattened drop results established a family of curves with the spherical drop as the limiting case.

Surface Characterization Through Shape Oscillations of Drops in Microgravity and 1g. Investigated surface properties of liquid in the presence of surfactants and investigated coalescence of droplets with surfactants using a variety of techniques that disturb the interface between drops. Although there were some instrumentation problems, the data obtained validated the overall approach for studying drop dynamics and measuring materials properties.

Protein Crystal Growth. See STS-51D for description. A total of 33 proteins were selected for crystallization. Results varied for each protein on the flight. New Glovebox Vapor Diffusion hardware flown was successful.

Zeolite Crystal Growth. Evaluated synthesis of large zeolite crystals in microgravity. Found that larger, more defect-free zeolite crystals could be grown in high yield on orbit.

Zeolite Glovebox Experiment. Examined and evaluated mixing procedures and nozzle designs that work to enhance the middeck Zeolite Crystal Growth Experiment. Illustrated that real-time observation of the mixing process was necessary to ensure gel uniformity without excessive shear, and bubble formation was minimized through real-time observation, analysis, and resulting crew-initiated corrective actions.

Solid Surface Combustion Experiment. Studied the way flames spread over solid fuels in an environment where gravity-driven buoyant and externally imposed air flows were absent. Obtained data during flight to add to results gained from previous experiments.

Space Acceleration Measurement System. See STS-43 for description. Accelerations were successfully measured in support of experiments flown.

Orbital Acceleration Research Experiment. Measured acceleration and vibrations to which scientific experiments were exposed in different locations on Orbiter. Absolute acceleration levels were derived at Orbital Acceleration Research Experiment location, Orbiter center-of-gravity, and Spacelab Crystal Growth Facility.

Passive Accelerometer System. Measured low-level accelerations caused by atmospheric drag and shuttle's gravity-gradient attitude. Passive Accelerometer System was used successfully during flight.

Interface Configuration Experiment. Investigated the shape that fluid surfaces assume for specific containers in microgravity. Found that after the containers were filled in orbit, an initial equilibrium interface from the symmetric continuum reoriented to a stable interface that was not rotationally symmetric, in accordance with mathematical theory.

Solid Surface Wetting Experiment. Worked to determine best tip shape for injectors that deploy drops in the drop physics module and to identify optimal surface treatment for the tips. Tips to be tested were successfully used during flight, and the design for improved tips to be used on other US Microgravity Laboratory flights were based on results obtained.

Fiber Pulling in Microgravity. Investigated advantages of pulling optical fiber from liquids in space. Found that the time required for a long column of silicone oil to break up was in reasonable agreement with a prediction of a theory developed in 1892 by Lord Rayleigh for most likely the first time due to the inability to perform such an experiment on Earth. Honey and corn syrup broke almost immediately during any attempt to draw them into fibers.

Nucleation of Crystals from Solutions in a Low-g Environment. Demonstrated and evaluated a new technique for initiating and controlling nucleation of crystals in a solution. The value of the new method was successfully demonstrated by providing significantly better control over the nucleation and growth process compared to conventional techniques.

Oscillatory Dynamics of Single Bubbles and Agglomeration in an Ultrasonic Sound Field in Microgravity. Explored how large and small bubbles behave in space in response to an ultrasound stimulus. Confirmed that the strong acoustic levitation field used on Earth can bias resonance frequencies, found a method partially from experimental results that simplifies the interpretation of measurements in 1*g*, and illustrated the various aspects of bubble dynamics without the complication of gravitationally induced buoyancy.

Stability of a Double Float Zone. Determined whether a solid cylinder could be supported by two liquid columns and remain stable in space. Successfully demonstrated a simple passive vibration isolation platform using a rubber band suspension, proved the Double Float Zone to be stable for modest lengths of liquid, and observed an unexpected asymmetry in the position of the float piece.

Marangoni Convection in Closed Containers. Determined whether surface tension-driven convection can occur in closed containers in microgravity and under what conditions. No evidence of partial wetting between the liquid and walls in the experiment was found, and a bubble that formed in the non-wetting system did have Marangoni convection around the bubble that acted as a pump circulating fluid throughout the volume.

Smoldering Combustion in Microgravity. Observed smoldering characteristics of polyurethane in microgravity. Found that temperature and char patterns were similar to ground samples, found the smolder process on orbit to be in a "weak" regime due to heat losses from the reaction zone that were significant in comparison to heat generated by the reaction, and found more significant production of light combustion gasses in the microgravity sample.

Wire Insulation Flammability Experiment. Examined ignition and combustion of electrical wire insulation in microgravity. Provided a significant introductory database for electrical wire insulation and burning in a low-speed convecting environment, accomplished the first controlled demonstration of flame spreading in forced convection ever conducted in space, and observed several unexpected and unique microgravity combustion phenomena.

Candle Flames in Microgravity. Examined whether candle flames can be sustained in space, and studied interaction and physical properties of diffusion flames. Flame color, size, and shape behaved in a quasi-steady manner, the finite size of the glovebox combined with the restricted passages of the candlebox inhibited observation of true steady-state burning. Concluded that a candle can burn indefinitely in air in a large-enough quiescent microgravity environment. The candle flame in air became and remained hemispherical and blue after an initial transient, and the flame tip was suggested as the location of maximum reactivity from results, unlike a candle in normal gravity.

Oscillatory Thermocapillary Flow Experiment. Worked to determine conditions for the onset of oscillations in thermocapillary flows in silicone oils. Found that although steady thermocapillary flow and indications of oscillations were observed in some tests, in general the vapor bubbles generated by the epoxy fillet disturbed the flow before it became oscillatory; therefore, the critical temperature differences were not determined and the flow remained steady even at the Marangoni number. This showed that the Marangoni number was not an appropriate parameter to describe the onset of oscillations.

Particle Dispersion Experiment. Investigated how fine particles aggregate in air, and evaluated a technique for dispersing particles uniformly as a starting point for aggregation experiments. During the experiment, a gas-pulse method of dispersing granular materials inside eight modular experiment chambers was successfully tested. The technique further demonstrated the ability of an air pulse to redisperse particles once they were free-floating in the chamber. Showed that aggregation experiments could be conducted in small chambers, aggregating natural materials form amorphous and filament structures, and aggregation can lead to the formation of "giant" particle clusters with commensurately large electrical fields around them.

Investigations into Polymer Membrane Processing. See STS-31.

Directed Polymerization Apparatus: Directed Orientation Of Polymerizing Collagen Fibers. Used the glove box and a directed polymerization apparatus to demonstrate that orientation of collagen fibers, which have potential uses as synthetic implant materials, can be directed in microgravity in absence of fluid mixing effects.

STS-46

Deployed the European Retrievable carrier, which contained microgravity payloads such as Protein Crystal Growth Facility as well as payloads of other discipline types.

Limited Duration Environment Candidate Materials Exposure. Worked to provide engineering and scientific information to those involved in materials selection and development for space systems and structures by exposing such materials to representative space environments to obtain data for analysis. The payload operated nominally for its 40-hour material sample exposure.

STS-47

Protein Crystal Growth. See STS-51D for description.

Space Acceleration Measurement System. See STS-43 for description.

Solid Surface Combustion Experiment. See STS-41 for description. A good burn was achieved, but with an uneven flame.

Get Away Specials:

> Student Experiment. Students conducted experiments in different Get Away Special canisters on crystallizing enzymes. Studied cobalt nitrate crystals in a sodium silicate solution and crystal growth in chemical gel solution.
>
> Thermal Conductivity of Liquids in Microgravity. This first Get Away Special from France performed thermal conductivity measurements of distilled water and two silicone oils.
>
> Planar Solid/Liquid Interface. Studied breakdown of a planar solid/liquid interface when growth rate increases from stable to unstable conditions.
>
> QUESTS Canadian payload. Contained 15 furnaces for studies of diffusion in metals when in the liquid state and for temperature-gradient studies.
>
> Nucleate Pool Boiling. Investigated heat transfer and vapor bubble dynamics associated with nucleation, bubble growth/collapse, and subsequent motion.

Japanese Payloads for Japanese sponsored Spacelab J:

> Growth Experiment of Narrow Band-gap Semiconductor Lead-Tin-Telluride (PbSnTe) Single Crystal in Space. Attempted to produce a crystal with a constant Pb/Sn ratio along growth axis and a low dislocation density by avoiding thermal convection in microgravity. The difference between flight and ground crystals was clarified, and valuable information on improvement of crystal quality was obtained.

Growth of Lead-Tin-Telluride (PbSnTe) Single Crystal by Traveling Zone Method. Investigated possibility of growing a PbSnTe single crystal using the floating zone method. Results indicated that a single crystal grown in space has high quality when compared to Earth-grown crystals, and a single crystal with large specific gravity can be grown under microgravity.

Casing of Superconducting Composite Materials. Investigated influence of gravity on formation of composite structure of monotectic solidification reaction. Preparing Aluminum-Lead-Bismuth (Al-Pb-Bi) alloys with uniform structure using microgravity environment and fabricating superconducting wire by deforming the flight-processed Al-Pb-Bi alloys was successful, but a problem of gas holes needed to be further studied.

Formation Mechanism of Deoxidation Product in Iron Ingot Deoxidation with Two or Three Elements. Studied deoxidation of steel in microgravity. Experiment was operated successfully and two samples seemed to be well mixed.

Preparation of Particle Dispersion Alloys. Conducted melting and solidification experiments in space using three Nickel-TitaniumCarbon (Ni-TiC)-type dispersion alloys prepared by powder metallurgical techniques. Flight samples showed uniform dispersion of TiC particles while ground samples illustrated macro- and microscopic segregations together with advanced grain growth of TiC particles, and flight samples had higher hardness values of which the deviation was smaller. Results indicated melting and solidification in microgravity is favorable for uniform dispersion.

Diffusion in Liquid State and Solidification of Binary System. Objective was to determine precise inter-diffusion coefficients in the liquid state of gold-silver binary alloys systems and to observe its solidification structure. Experimental difficulties that were particular in microgravity were revealed.

Behavior of Glass at High Temperatures. Performed a melting experiment of a glass specimen floating under the microgravity environment. Obtained continuous observation of expansion and deformation of glass in microgravity during changes in glass volume without disturbance. A change in shape from cubic to round and a change in volume during the softening stage were clearly observed during the melting of the glass sample in microgravity. At high temperatures, large bubble formation and devitrification appeared.

Growth of Spherical Silicon Crystals and Surface Oxidation. Worked to manufacture spherical silicon crystals under microgravity, and to investigate the impurity incorporation mechanism. Also worked to oxidize the surface on Earth for studying the interface between the substrate and the oxide layer. Data were used for silicon manufacture.

Study on solidification of immiscible alloy. Objective was to clarify the solidification mechanism of an alloy with a hypermonotectic composition to help develop techniques for production of homogeneous alloys in space. Data from this study provided insights into hypermonotectic composition.

Fabrication of an Ultra-low Density, High-stiffness Carbon Fiber and Aluminum Composite. Worked to fabricate low-density, high stiffness carbon fiber/aluminum alloy composite to develop a new method of in-orbit fabrication of structural components in space by melting the aluminum alloy coating on an aggregate of short carbon fibers. Under microgravity, a three-dimensional random arrangement of short fibers becomes possible without sedimentation of the alloy, thus permitting an improvement in performance of composite material, and high stiffness. Experiment showed limitations of microgravity manufacture.

Study on Liquid Phase Sintering. Objective was to study behavior of solid particles in a liquid matrix during liquid phase sintering. Microstructural anomalies were found in specimens sintered in microgravity.

Fabrication of Si-As-Te semiconductor in microgravity environment. Objective was to fabricate homogeneous multi-component amorphous semiconductors in microgravity, and to make a series of comparative characterizations of amorphous structures as well as their electronic properties for materials prepared in space and on Earth. Results showed that further study of material processing in space would contribute greatly to the understanding of the physics of disordered materials as well as to the development of new materials for semiconductor electronics.

Gas Evaporation in Low Gravity. Objectives were to investigate the evaporation process in a gas atmosphere, and to obtain fine particles of homogeneous size by evaporating silver (Ag)in low gravity. In low gravity, the vapor of material evaporated in a gas atmosphere may possibly be concentrated with high density near the vapor source by a blanket effect of atmospheric gas in which the diffusion coefficient of vapor is very small, especially in high pressure of heavy atomic gas.

Drop Dynamics in an Acoustic Resonant Chamber and Interference with the Acoustic Field. Studied theoretical behaviors of molten material drops in a tri-axial acoustic resonant chamber. An acoustic chamber can be used for contact-less manipulation of liquid drops and melts. Due to problems, planned operations were not performed, but the size of the liquid drop was large enough to allow a plot of the data that could not be obtained by the ground-based experiment.

Bubble Behavior in a Thermal Gradient and Stationary Acoustic Wave. Monitored behavior of bubbles under microgravity in presence of temperature gradients and stationary acoustic waves, and obtained basic data on interference between rate of movement and distance between bubbles. Behavior of multiple bubbles in liquid in the container subjected to a thermal gradient showed changes from Earth.

Preparation of Optical Materials For Use in the Non-visible Region. Attempted to melt raw materials in contact-free suspension under microgravity to produce glass ingots of high purity and high transmissivity as required for optical materials used in applications in the non-visible (infrared) spectrum. High-purity oxide-based infrared-transparent glass was produced.

Marangoni Effect-induced Convection in Materials Processing Under Microgravity. Investigated characteristics of Marangoni convection in a liquid column simulating the Bridgman crystal growth process. Marangoni convection did not occur in spite of the temperature gradient on the free surface and suppression of buoyancy convection under microgravity.

Solidification of Eutectic System Alloys in Space. Determined whether primary crystals in solid structures exist as equiaxial crystals, and whether equiaxial crystal particles are formed under microgravity. As crystals in the aluminum-copper alloy melted and solidified under microgravity they did not move due to convection, and crystal growth was solely from the walls of the crucible.

Growth of Samarskite Crystals under Microgravity Conditions. Investigated advantage of microgravity condition growth of samarskite single crystals for identification of the phase relationships. No samarskite crystal growth was observed.

Crystal-Growth Experiment of Organic Metals in Low Gravity. Purpose was to grow large, high-quality single crystals of a typical organic metal using an ideal diffusion method for evaluation of physical properties. No growth or crystals were obtained.

Crystal Growth of Compound Semiconductors (InGaAs) in a Low-gravity Environment. Worked to grow a crystal of indium-gallium-arsenic having a homogeneous composition by the Bridgeman method. Produced the crystal of a ternary compound semiconductor. Effects on segregation due to suppression of convection in microgravity were confirmed, and reduction of residual gravity was found to be important in improving homogeneousness of the crystal.

STS-52

Lambda-Point Experiment. Measured heat capacity and thermal conductivity of helium close to lambda point with smearing effect of gravity removed. Over 90 high-resolution passes through the lambda point were completed with over 5,000 Lambda-Point Experiment commands sent and executed by the experiment, and the experiment collected a significant amount of data just above the transition temperature.

Materials for the Study of Interesting Phenomena of Solidification on Earth and in Orbit. Joint American-French experiment studied behavior of metals and semiconductors as they solidified to help determine effect gravity had during solidification at the point were solid meets liquid. Performed very well during mission with test runs running at speeds ranging from 15 mm/hr to 75 mm/hr, interesting behavior during microgravity disturbances. When the furnace changed, pulling rates were observed, and curves showing undercooling as a function solidification rate were refined.

Space Acceleration Measurement System. See STS-43 for description. Accelerations were successfully measured in support of experiments flown.

Materials Exposure in Low Earth Orbit. Canadian experiment worked to determine performance of new materials exposed to true space environment. Results contributed to development of effective ground-based space simulation facilities capable of testing/screening spacecraft materials.

Phase Partitioning in Liquids. Canadian experiment studied applications for separation and purification of cells involved in transplants and treatment of disease. All experimental operations were completed successfully and additional data were received.

Queens University Experiment in Liquid-Metal Diffusion. Canadian experiment worked to gain a better understanding of industrial diffusion processes. Able to process 30 out of 35 samples during flight.

Heat Pipe Performance Experiment. Successfully conducted tests to develop technology that will make it easier for a space vehicle to reject heat generated by its equipment and crew.

Commercial Materials Dispersion Apparatus Instrumentation Technology Associates Experiments. Used materials dispersion apparatus to provide industry and commercial development of space users with low-cost experimentation opportunities in areas such as protein crystal growth, thin-film membrane formation, zeolite crystal growth, bioprocessing, and live test cells. Experiments had 80% to 85% of objectives met of the 31 experiments flown.

Crystal Vapor Transport Experiment. Provided an opportunity for scientists to learn more about growing larger and more uniform industrial crystals for use in producing faster and more capable semiconductors. All four samples were successfully processed.

Commercial Protein Crystal Growth. Worked to provide data for better understanding and improving of techniques for protein crystal growth in space. Experiment met all objectives while on orbit.

STS-53

Fluid Acquisition and Resupply Equipment. Investigated dynamics of fluid transfer in microgravity.

STS-54

Lymphocyte Locomotion in Microgravity (stationary incubator system). Studied lymphocyte locomotion in space. Locomotion was significantly impaired in microgravity. Impaired locomotion indicated a potential for suppressed immunity in the later stages of long-duration missions (about 1 year).

Solid Surface Combustion Experiment. See STS-41 for description. Used Plexiglas® instead of ashless filter paper for the test, and two burns were completed satisfactorily.

Commercial Generic Bioprocessing Apparatus. Conducted 28 separate commercial investigations, loosely classified in three application areas: biomedical testing and drug development; controlled ecological life support system; and agricultural development and manufacture of biological-based materials.

Bioreactor/Flow and Particle Trajectory in Microgravity. See STS-44.

Human Lymphocyte Locomotion in Microgravity. Understanding movement of white blood cells is a vital step for cancer researchers to determine how to help lymphocytes penetrate the tissue to kill tumors. Experiment examined how movement of white blood cells is affected by microgravity since, on Earth, lymphocytes movement is impaired the closer they get to the tumor.

STS-56

Lymphocyte Locomotion in Microgravity (stationary incubator system).See STS-54.

Commercial Materials Dispersion Apparatus Instrumentation Technology Associates Experiments. See STS-52.

STS-55

Flight dedicated to European Space Agency research:

Cellular and Dendritic Solidification of Aluminium-Lithium Alloys. The measured thermal gradients and front velocities were roughly constant in a study of the influence of convection in the liquid phase on deep cell-dendrite transition and established the precise correlation between interfacial microstructure and processing parameters.

Convective effects on growth of Gallium-Indium-Antimony (GaInSb) Crystals. Analyzed the use of rough crucibles in space for the growth of semiconductor crystals. Samples showed an outer surface morphology in agreement with the theory of semiconductor dewetting in space.

Crystallization of Nucleic Acid-Protein Complexes. Studied the structure of ribosomal 5S ribosomal RNAs, their protein complexes, and the structure of the elongation factor elongation factor thermo unstable (EF-TU)complex.

Crystallization of Ribosomal Particles. Aimed to obtain ribosomal crystals of a low mosaic spread that diffracted well to higher resolution limits than that of Earth-grown crystals. Regardless of the design of the crystallization chambers, almost every droplet yielded crystals even without seeding.

Diffusion of Nickel In Liquid Copper (Cu) -Aluminum (Al) and Copper (Cu) - Gold (Au) Alloys. Aimed to determine diffusion coefficient of nickel with respect to the concentration of solute atoms of Al and Au.

Directional Solidification of a thermo-solutal instable Cu-Mn Alloy. Measured convective stability of thermo-solutal instability binary alloy Copper-Manganese (Cu-Mn) during directional solidification with planar growth morphology. The microprobe measurement of Mn concentration along the sample axis demonstrated that in the case of samples solidified under reduced gravity, no microsegregation took place.

Directional Solidification of the LithiumFluorine- LithiumBariumFluorine3 (LiF-LiBaF3) Eutectic. Studied buoyancy convection and gravity microtexture of the lamellar dielectric eutectic system LiF-LiBaF3. The expected systematic differences in lamellar spacings between zero-gravity and ground reference samples of the lamellar dielectric eutectic system LiF-LiBaF3 were not found, but flight samples were found to have slightly better texture quality and better composition homogeneity than ground samples.

Eutectic Crystallization. Worked to enable development of high-strength aluminum alloys, and studied morphology of solidification front and the final microstructure by mass transport in the liquid by diffusion and convection. A reduction of interdendritic eutectic spacing lambda under microgravity convection conditions was observed for all tested solidification parameters.

Floating Zone Crystal Growth of Germanium. Effects of capillary flow on segregation of gallium and germanium crystals by floating zone technique under vacuum were investigated on two crystals. The first part of the longitudinal concentration profile was close to what would be expected from diffusion controlled growth and then radial segregation started to develop, which led to a non-axisym-metrical solute distribution with minimum concentration at the surface.

Floating-Zone Growth of GalliumArsenic (GaAs) under Microgravity. Microgravity conditions provided the possibility to grow much larger GaAs crystals by the floating zone method than under 1*g*. A GaAs:Te single crystal of 20-mm diameter and length was grown by the floating-zone method during spaceflight.

Higher Modes and their Instabilities of Oscillating Marangoni Convection in a Large Cylindrical Liquid Column. Investigated higher oscillating modes of the Maragoni convection and their transitions into non-periodic states in a large column as a function of the aspect ratio of the column and of the Marangoni numbers.

Hysteresis of the Specific Isochoric Heat During Heating and Cooling Through the Critical Point. Objective was to better understand the hysteresis of specific heats (C_v) between heating and cooling observed during experiment on board Spacelab D-1 mission. Measurements confirmed the theoretical prediction that isochoric heat C_v diverges at the critical point. Universal values determined from microgravity measurements were in remarkably good agreement with theoretical predictions. Experimental results confirmed the enhanced temperature propagation when approaching the critical point. Data in both the one-phase and the two-phase regions were in good quantitative agreement with numerical calculations based on the "piston effect" theoretical model.

IDILE: Measurements of Diffusion Coefficients in Aqueous Solution (HL-IDILE). Measured diffusion coefficients through interferometric holography observations of refractive index changes due to evolution of concentration profiles as a function of time. Objectives were completed.

Influences on the Stability of Metal/Ceramic Dispersions with nm-Particles During Directional Solidification. Worked to determine agglomeration rate and hence the probability of adhesion between colliding nm-oxide particles without superimposed gravitational sedimentation and convection effects. Examined interaction between oxide particles and dendritic or cellular solidification fronts with respect to distribution of particles within the matrix. Found that the stability of dispersion does not depend on the wetting between the metal and the ceramic and that London/vander-Waals forces were sufficient to keep oxide particles together even if they were surrounded by the melt.

Interfacial Tension and Heterogeneous Nucleation in Immiscible Liquid Metal Systems. Studied effect of different ceramic materials, used as crucibles, on solidification of Copper-Lead (Cu-Pb) alloys. Study demonstrated that boron nitride seems well suited container material for Cu-Pb alloys.

Interferometric determination of the Differential Interdiffusion Coefficients of Binary Molten Salts on D-2 (STS-55). Aimed to determine influence of thermal convection on diffusion measurements. Although unexpected bubbles provided complications, coefficients were about 30% lower than ground studies.

Liquid Columns Resonances (LICOR). Aimed to reach a consistent understanding of axial oscillation of long cylindrical liquid columns supported by coaxial disks. Experiment confirmed the theoretical models and brought new insight into determination of resonance frequencies by using pressure sensors and applying frequency ramps.

Marangoni-Benard Instability. Objectives were to validate critical Marangoni number calculations and study effects of nonlinear temperature distributions on the onset of convection. For the steady state conditions, the objective was to measure the critical temperature gradient. Good concordance was obtained for first and second runs, and a technical problem occurred during third run.

Nucleation and Phase Selection During Solidification of Undercooled Alloys. Goal was to determine degree of undercooling for different alloy compositions by measuring recalescence temperature and comparing with nucleation theory. The microstructure of space samples exhibited a fine-grained eutectic structure with some primary silver dendrites. These dendrites were interrupted at several locations, giving indication of remelting during recalescence.

Onset of Oscillatory Marangoni Flow. Investigated transition of thermocapillary convection in liquid bridges from axisymmetric to three-dimensional oscillatory regime to understand its physical mechanism. Experiment provided quantitative data on Marangoni convection and the first observation of the structure of the oscillatory disturbance.

Phase Separation in Liquid Mixtures with Miscibility Gap on D-2. Studied liquid/liquid phase separation in a binary liquid mixture with a miscibility gap. When thermostat was turned off, temperature gradients were generated, which caused thermocapillary droplet migration. This led to enhanced coagulation of droplets and an increase of droplet diameter.

Remelting of Nearly Eutectic Fe-C-X Alloys in a Ceramic Mold Skin. Investigated formation of carbon monoxide in contact with carbon rich melt under reduce pressure, the condition of the transition zone between the rod segments and the element distribution achieved with reduced thermal convection in comparison to the ground remelted samples. The melt metallurgical manufacture of components consisting of zones with different compositions seems possible under microgravity.

Separation Behavior of Monotectic Alloys. Transport mechanisms of droplets in Aluminum (Al)-melts were investigated by directional melting of sandwich-like samples of Aluminum (Al)-Silicon (Si) - Bismuth (Bi) alloys in which Bi-droplets were dispersed.

Single Crystal Growth of GalliumArsenic (GaAs) by the Floating Zone Method on D-2. Studied influence of a horizontal magnetic field on Marangoni convection as well as the feasibility of a temperature-controlled As-source for stoichiometry control. Growth of five single crystalline floating zone-GaAs crystals occurred and, by means of numerical calculations during the preparation phase of the mission, the Marangoni convection was in an unsteady state with and without magnetic field, as the magnetic field strength was too low for damping out its time dependence.

Solution Growth of GalliumArsenic (GaAs) Crystals under Microgravity. Worked to clarify effects of the convection-free growth on GaAs crystal, such as growth morphology, compositional homogeneity, and crystalline perfection. Surface morphology of flight crystal samples was ripple-like without macrosteps while the ground samples had larger surface roughness. There was no apparent difference in growth thickness among the six substrate in-flight samples while ground samples had growth thickness on upper substrates twice as thick as that of lower substrate.

Soret Effect Measurement in a Molten Salt Mixture in Space. Studied thermodiffusion, also called Ludwig-Soret effect, which permits a transport of matter in a mixture that is submitted to a thermal gradient. Diffusion was much slower than predicted from ground research. Thermodiffusion tends to enrich the cold side of the cell with silver and consequently enrich the hot side of the cell with potassium.

Stability of Long Liquid Columns. Aim of experiment was to measure outer shape deformation of long liquid bridges near their stability limit under microgravity. Mechanical behaviors of liquid bridges in microgravity were found in good agreement with theory.

Stationary Interdiffusion in a Non-Isothermal Molten Salt Mixture. Worked to show that a stationary state could be attained during a 24-hour-duration experiment, and intended to evidence a variation of the interdiffusion coefficient with the mixture composition.

Traveling Heater Method - Growth of GalliumArsenic (GaAs) from Gallium Solutions - Experiment MD-ELI-TRABE. Worked to grow crystals for later analysis for items such as dopant inhomogeneties on the macro and micro scale. Traveling heater method growth of Te-doped GaAs was successfully performed. Absence of time-dependent convection in the µg (mainly diffusion) crystal allowed for the analysis of weak dopant inhomogeneities, which are overlaid by strong convectional type I striations in the lg (diffusion + solutal convection) crystal. All pulse markers, even the weak one-second pulses, were clearly detected in the µg -crystal and gave precise information about the start of growth, the local growth rates, and the curvature of the growth face-both as a function of growth time.

STS-57

Retrieved the European Retrievable carrier.

Equipment for Controlled Liquid Phase Sintering Experiments. Investigated liquid phase sintering of metallic systems focusing on composites of hard metals in a tough metal matrix.

Gas Permeable Polymeric Materials. Worked to determine whether certain types of polymers made in microgravity while the shuttle was in orbit are different from the same polymers made at the same time on the ground.

Investigations into Polymer Membrane Processing. See STS-31.

Liquid Encapsulated Melt Zone. Part of a series of tests that attempted to determine feasibility of commercial, space-based production of materials for applications in the computer, optics, and sensor/detector industries.

Support of Crystal Growth Experiment. Supported Zeolite Crystal Growth experiment by providing information required to establish Zeolite Crystal Growth autoclave mixing protocol so that resulting crystal growth was optimized.

Zeolite Crystal Growth. See STS-50 for description.

Protein Crystal Growth. See STS-51D for description.

Three-Dimensional Microgravity Accelerometer. Helped chart effects of deviations of microgravity on experiments being conducted in space.

Space Acceleration Measurement System. See STS-43 for description.

Application-specific Preprogrammed Experiment Culture (controller culture system). Test was part of the bioreactor project, which was aimed at developing a series of hardware concepts for facilitating development of human cells and tissue cultures in microgravity where cells can grow in all directions for extended periods of time. Test of concept cell culture system revealed that design assumptions were not consistent with autonomous operation in space. Conflicting subsystems must be isolated by barriers, and findings guided subsequent cell culture systems design.

Fluid Acquisition and Resupply Experiment. See STS-53 for description. All objectives were met on orbit.

Commercial Protein Crystal Growth. See STS-49.

Commercial Generic Bioprocessing Apparatus. Processed biological fluids by mixing components in microgravity.

Consortium for Materials Development in Space Complex Autonomous Payload-IV. Investigated growth of nonlinear organic crystals by a novel method of physical vapor transport in weightlessness of space.

BioServe Pilot Laboratory. Determined response of cells to various hormones and stimulating agents in microgravity.

Organic Separation. Explored use of phase separation techniques in microgravity conditions to separate cells, cell fragments, and heavy molecules.

Physiological Systems Experiment. Investigated role of two growth factors involved in accelerating or enhancing tissue repair.

Fluid Acquisition and Resupply Experiment. See STS-53.

Get Away Specials:

> Multiple Experiments. Multi-disciplinary package experiments on solidification/crystallization of saccharin and cryogen transfer, electrode occlusion, bubble formation, microgravity bonding, crystal growth, fluids in microgravity, and silver crystal growth.
>
> Crystal Growth of Gallium-Arsenide. Studied growth of gallium-arsenide crystals in microgravity.
>
> Semi-Conductors/Superconductor Experiment. Conducted four different kinds of experiments: three were materials experiments on semi-conductors and a superconductor; the other was on boiling an organic solvent under weightlessness.

Crystal Growth. Studied crystal growth of indium gallium arsenic from vapor phase under weightlessness, crystal growth of three selenic-niobium from vapor phase, and crystal growth of an optoelectric crystal by the diffusion method and formation of superferromagnetic alloy.

Pool Boiling Experiment. Objective was to improve understanding of the boiling process by observing heating and vapor bubble dynamics associated with bubble growth/collapse and subsequent bubble motion.

European Space Agency Experiments:

Crystal Growth of Ribonuclease A. Worked to grow protein crystals large enough to allow characterization of molecular structure by using well known methods of x-ray diffraction or neutron diffraction. A few small crystals of ribonuclease A were obtained in one of the hanging-drop reactors.

Crystal Growth of the Electrogenic Membrane Protein Bacteriorhodopsin. Grew bacteriorhodopsin crystals using liquid-liquid-diffusion technique in microgravity to lessen detrimental effects on hydrophilic interactions, which are weak and easily disturbed and result in considerable crystal disorder on Earth. Crystal growth in microgravity resulted in a significant improvement in compact morphology of needles.

Diagnostic Experiments for Protein Crystallogenesis on Spacehab-01. Planned to evaluate effects of microgravity on the rate of nucleation and the size of the crystals, and to obtain some measurements to characterize quality of some crystals to set a benchmark for future crystallographic investigations. Crystals were grown and used for analysis.

Investigation of Lysozyme Protein Crystal Perfection from Microgravity Crystallization - 1. Worked to grow high-quality-in terms of perfection-lysozyme crystals and examine them via rocking width measurements. Crystals were grown and the mosaicity of microgravity crystals were three times smaller than corresponding Earth controls.

Rhodopsin Crystallisation in Microgravity. Crystallized visual pigment rhodopsin with the purpose of high-resolution structure analysis. There was a slight improvement in crystal dimensions.

Ribosome Crystallization. Aimed to use microgravity to obtain ribosomal crystals of a low mosaic spread, diffracting well to higher-resolution limits than that of current Earth-grown crystals. Although still too small for x-ray crystallography, some crystals grown in space were of a rather isotropic shape, which showed the potential of microgravity.

STS-51

Limited Duration Space Environment Candidate Materials Exposure. Introduced development composite materials such as polymeric, coated polymeric, and light metallic composites to flux atomic oxygen atoms in low-Earth orbit. Operations were completed as planned.

Commercial Protein Crystal Growth. See STS-52 for description. The Block II configuration of Commercial Protein Crystal Growth was flown, and over 100% of operational requirements were met.

Investigations into Polymer Membrane Processing. See STS-31 for description. The crew flash evaporated mixed solvents in absence of convection to control porosity of a polymer membrane successfully.

STS-60

Wake Shield Facility. A 3.7-m (12-ft) diameter, stainless steel disk designed to generate an "ultra-vacuum" environment in space within which to grow thin semiconductor films for next generation electronics was flown. First time, internationally, where the vacuum of space was used to process thin film had some difficulties, but crystals were grown during flight.

Equipment for Controlled Liquid Phase Sintering Experiments. See STS-57 for description. After a brief false start due to a software discrepancy, all processing objectives were met.

Space Experiment Facility. Provided furnaces for growth of crystals and for processing of other materials. Hardware worked well and "B" side semiconductor crystal appeared to have grown exceptionally well and produced a well-formed crystal.

Commercial Protein Crystal Growth. See STS-52 for description. This flight was the first time protein nucleation had been detected in space.

Three-Dimensional Microgravity Accelerometer. See STS-57.

Space Acceleration Measurement System. See STS-43 for description.

Get Away Specials:

The Orbiter Ball Bearing Experiment. Tested effects of melting cylindrical metal pellets in microgravity with the hope of producing a new kind of ball bearing. Goal was to create world's first seamless, hollow ball bearing.

Pool Boiling Experiment. See STS-57 for description. Previous flights of this experiment were successful and results from those experiments were used to improve the science return on this flight.

STS-62

Advanced Automated Directional Solidification Furnace. Studied directional solidification of semiconductor materials in microgravity. Performed over 240 hours of directional solidification of the mercury-cadmium telluride sample, and temperature distribution in the furnace during growth was as expected.

Materials for the Study of Interesting Phenomena of Solidification on Earth and in Orbit. See STS-52 for description. Found that the morphological stability of various crystallographic orientations was significantly affected by anisotropy of interface kinetics and surface energies, and differential Seebeck signals allowed monitoring of interfacial phenomena.

Isothermal Dendritic Growth Experiment. Used the material succinonitrile to study dendritic solidification of molten materials in microgravity. Experiment was extremely successful, observed significant differences between dendritic growth rates on Earth and in orbit, and observed the tip splitting of dendrites at extremely small temperature differences below the freezing point that was believed to have never been observed on Earth.

Critical Fluid Light Scattering Experiment-Zeno. Studied behavior of xenon at its "critical point." Provided a precise, excellent data set to contribute to measurements on liquid-vapor critical points, demonstrated the possibility of making high-precision materials measurements in microgravity, and demonstrated the use of a flexible ground-commanded experiment.

Space Acceleration Measurement System. See STS-43 for description. Accelerations were successfully measured in support of experiments flown.

Thermal Energy Storage. Successfully studied microgravity behavior of two different thermal energy storage salts that undergo melting and freezing.

Cryogenic Two Phase. Studied performance of microgravity nitrogen space heat pipe and cryogenically cooled, vibration-free, phase-change-material thermal storage unit thermal energy control technologies. All objectives were completed when testing Brilliant Eyes Thermal Storage Unit, and it was found that Brilliant Eyes Thermal Storage Unit phase-change material became the coldest by 40°C (104°F) in spaceflight history at the time. The space heat pipe was the first nitrogen heat pipe to fly in space. Even though the pipe did not start, valuable data concerning formation of liquid slugs and liquid nitrogen behavior in microgravity were obtained.

Limited Duration Space Environment Candidate Material Exposure. Exposed three identical sets of materials containing 264 samples each to evaluate materials being considered for use in space structures. The sets successfully gathered data.

Protein Crystal Growth. See STS-51D for description. A new Thermal Enclosure System was used in place of two middeck lockers, the first flight of commercially purchased Protein Crystal Growth plates was made, and all objectives were completed.

Commercial Protein Crystal Growth. See STS-52.

Growing Cells Without Nutrient Replenishment (Stationary Incubator System). Colon cancer cells and cartilage cells were grown in chambers to determine how long it took to deplete medium of nutrients while in microgravity. Rapidly metabolizing cells (colon) depleted medium and commenced to decline. Slower metabolizing cells (cartilage) thrived for longer periods. Design of automated "feeding" systems must account for cell metabolic rate.

STS-59

Get Away Specials:

> Freezing and Crystallization Process of Water in Spaceflight. Examined freezing and crystallization process of water in spaceflight by studying growth patterns of ice crystals in microgravity. Growth patterns were captured by a video recorder.
>
> Thermal Conductivity Measurements. This re-flight of first Get Away Special from France-due to issues with the experiment during STS-47-explored thermal conductivity measurements on three silicone oils having different viscosities.

STS-65

Liquid Phase Sintering in a Microgravity Environment. Examined how gravity changes the heavy alloys tungsten, nickel, and iron during sintering process for combining dissimilar metals using the large isothermal furnace developed by the Japan Aerospace Exploration Agency. Microstructural features that had never been seen in tungsten-heavy alloys were created, and it was found that microgravity greatly affected the samples' microstructural development.

Mixing of a Melt of a Multicomponent Compound Semiconductor. Worked to develop a new technique for uniformly mixing melted compound semiconductors using Maragoni convection and the large isothermal furnace in an attempt to create higher quality alloys and compound semiconductors. Samples were processed in microgravity and it was found that indium-antimony space-grown samples were almost spherical.

Effect of Weightlessness on Microstructure and Strength of Ordered Titanium (Ti)-Aluminum (Al) Intermetallic Alloys. Melted and then resolidified a titanium-aluminum alloy where titanium diboride had been added using the large isothermal furnace in an attempt to increase the high-temperature strength of the material, therefore improving the microstructure. Microgravity did enhance uniformity of the microstructure of the alloy.

Effects of Nucleation by Containerless Processing in Low Gravity. Worked to better understand details of how metals solidify and investigated ways the solidification process could be controlled using Electromagnetic Containerless Processing Facility. Data were collected even though only one undercooling cycle on zirconium was obtained.

Structure and Solidification of Deeply Undercooled Melts of Quasicrystal-Forming Alloys. Studied unique structural icosahedral-shaped atom arrangement of some metallic alloys called quasicrystals using Electromagnetic Containerless Processing Facility. Experiments were performed on melts of different compounds and the first observation of a large porous morphology of Aluminum(Al_{65})Copper(Cu_{25})Cobalt(Co_{10}) alloy occurred during tests.

Thermodynamics and Glass Formation of Undercooled Metallic Melts and Thermodynamic Properties of Metallic Glasses and Undercooled Alloys. Used Electromagnetic Containerless Processing Facility and different alloys. Studied a new mathematical method called the AC method for heat capacity calculation of alloys in an attempt to better understand undercooling and metallic glass formation fundamentals. The AC method worked well for both experiments. An especially large amount of data were obtained during experimenting with NiNb alloy, which solidified in a metastable phase that's existence had never been proven before.

Viscosity and Surface Tension of Undercooled Metallic Melts and Measurement of the Viscosity and Surface Tension of Undercooled Metallic Melts and Supporting Magnetohydrodynamic Calculations. Both experiments worked to gain a better understanding of microscopic interactions within molten metals during undercooling, specifically examining viscosity and surface tension characteristics using the Electromagnetic Containerless Processing Facility. Experiments on most samples were completed, and it was found that ground and data from International Microgravity Laboratory-2 differed by 5% and showed excellent agreement when ground-based data were corrected for the effect of external forces.

Experiments Separating Animal Cell Culturing Solution in High Concentration in Microgravity. Grew animal cells in cultures and then separated their cellular secretions using the free-flow electrophoresis unit to work toward validating electrophoresis method in space and provide knowledge for future space-based biotechnology production. It was found that the cells cultured produced twice as much protein as those cultured on Earth, and electrophoresis was much more stable in space than on Earth.

Applications of Continuous Flow Electrophoresis to Rat Anterior Pituitary Particles (Part 1). Used cell culture kits, free-flow electrophoresis unit, and continuous-flow electrophoresis to separate organelles contained in a rat pituitary cell lysate during microgravity operations. Found that continuous-flow electrophoresis processing in microgravity was advantageous, a microgravity-feeding interactive effect occurred and affected hormone output and cell surface charge, and microgravity processed samples had increased throughputs, greater bandspreads, and better discrimination of some growth variants.

Feeding Frequency Affects Cultured Rat Pituitary Cells in Low-Gravity (Part 2). Used the free-flow electrophoresis unit to perform first studies of possible effects of cell feeding on hormone release from each of the six types of major hormone-containing cell types. Found differences in quantity and quality of growth hormone and prolactin released from primary rat pituitary cells, and changes were similar to those found in pituitary cells of space-flown rats after 7 to 14 days in microgravity.

Separation of Chromosome DNA of a Nematode, C. elegans, by Electrophoresis. Investigated utility of the proprietary free-flow electrophoresis unit for efficient separation of nematode chromosomes in microgravity conditions free of convection. Two types of chromosomes were efficiently separated from a chromosome DNA mixture, and a new computer program was used to monitor the experiment in space from the ground.

Purification of Biological Molecules by Continuous-Flow Electrophoresis in a Microgravity Environment. Used a unique method for protein solutions separation and the applied research on separation methods using electrophoresis equipment to determine optimal conditions for separating biological species from a mixture, evaluate quality of separation, verify model of the process, demonstrate relevance of microgravity to process performance, and study possibility of applying results to purifying useful substances. Stable flows were obtained, which showed instabilities found on Earth were of gravitational origin, and microgravity and concentrated samples allowed the throughput to be increased by a factor of five while rendering an equally pure and biologically active product.

The Crystallization of Apocrustacyanin C_1. Used vapor diffusion method and European Space Agency's Advanced Protein Crystallization Facility to crystallize Apocrustacyanin C_1. Space crystals were of larger and higher quality than most grown on the ground and provided the first evidence for depletion zones around crystals, as was expected in microgravity.

Crystallization of Collagenase and Photoreaction Center under Microgravity. Grew crystals in microgravity, attempted to quantify influence of microgravity on nucleation rate, and improve diffraction and mosaicity. Results showed that collagenase space-grown crystals recorded stronger intensities and signal-to-noise ratio than ground controls, Photoreaction Center space-grown crystals diffracted much less than ground crystals due to protein aging, and Advanced Protein Crystallization Facility was found to be a good facility that only needed minor improvements.

Crystallization of Rhodopsin in Microgravity. Attempted to grow rhodopsin crystals large enough for x-ray diffraction in different conditions using Advanced Protein Crystallization Facility. It was found that microgravity seemed to enhance crystallization. Even though crystals grown were not large enough for diffraction, some had larger structures than those observed on the ground. Longer growing periods were needed for obtaining crystals suitable for x-ray diffraction.

Crystallization of RNA Molecules. Worked to grow RNA molecule crystals in microgravity for analysis using Advanced Protein Crystallization Facility and vapor diffusion dialysis. The size of space crystals were three times larger in volume than those grown on the ground, but resolution was not better. Number of space-grown crystals were lower than ground-based tests.

Studies of Lysozme Protein Crystal Perfection from Microgravity Crystallization. Studied effects microgravity had in terms of perfection on crystallization of the well-studied protein chicken egg white lysozyme using dialysis method and Advanced Protein Crystallization Facility. Crystals were analyzed after the flight and found that rocking width data showed microgravity-grown crystals displayed intensity levels three to four times that of Earth-grown crystals, and large perfect regions were visible within microgravity-grown crystals while Earth controls had a crumbly network.

Crystallization of Octarellins and Copper Oxalate. Worked to grow crystals of a de nova protein called octarellin and other substances using hanging drop and dialysis methods as well as Advanced Protein Crystallization Facility. Experiment was first crystals for a de nova protein the size of octarellin, and obtained small crystals that allowed researchers to approach conditions required for crystallizing artificial proteins.

Microgravity Effects on Macromolecule and Virus Crystallization. Performed macromolecule and virus crystal growth in microgravity to analyze crystals and explore which classes of macromolecule crystals benefit from microgravity the most, and what aspects of the process are important for obtaining optimal results. Changes in diffraction properties and alterations in average or maximum size of crystals were observed, and crystals grown in space had morphological modifications.

Crystal Growth of Ribonuclease S. Attempted to grow larger, higher-quality crystals of Ribonuclease S in microgravity for further analysis and comparison with Earth-grown crystals. Crystals grown in microgravity had increased perfection as measured by reduced mosaicity, concordance, and by the agreement between diffraction data sets. Space-grown crystals had more uniform morphologies than Earth-grown crystals.

Crystallization of Ribosomal Particles in Space. Tried to improve ribosome crystal morphology and size using microgravity, Advanced Protein Crystallization Facility, and vapor diffusion method. Crystals grown without seeding indicated the potential of microgravity for ribosome crystal growth, and crystals grown had more isotropic shapes, which had never been observed on Earth.

Crystallization of Bacteriorhodpsin. Crystallized Bacteriorhodpsin proteins using Advanced Protein Crystallization Facility, two different growth techniques, and varying ingredients. Crystals grown using liquid-liquid diffusion had sharp edges, smooth faces, and increased sizes up to 200 µm in length. Adding benzamidine hydrochloride to crystals grown with liquid-liquid diffusion resulted in improved compact alignment of crystalline filaments, increased crystal size, and higher resolution x-ray diffraction data.

Bubble Migration, Coalescence, and Interaction with the Solidification Front. Using the bubble drop particle unit, experiment studied movement of bubbles at the liquid-solid interface as test materials first melted and then solidified. Also studied how drops of liquids behaved when exposed to a temperature gradient and interact with the solidification front. Experiment was affected by an equipment failure, but some results were obtained. It was found that surfactant strongly affected the migration of bubbles in a liquid matrix formed by melted paraffin, which prevented development of the surface tension gradient.

Thermocapillary Migration and Interactions of Bubbles and Drops. Studied movement and shape of gas bubbles and liquid drops in silicone oil when a temperature gradient was established within a container in bubble drop particle unit. Tests confirmed predictions of models for migration velocities of bubbles and drops, and made unique observations of interactions between a small and large fluid drop.

Bubble Behavior Under Low Gravity. Investigated how different sized bubbles of inert gas moved within a liquid. Achieved a milestone in thermocapillary research, which was the first demonstration of thermocapillary migration from hot to cold liquids.

Thermocapillary Convection in a Multilayer System. Studied surface- tension forces within three layers of fluids using a container located in the bubble drop particle unit in an attempt to learn how to control fluid flows in the middle layer. Experiment obtained the first data on pure thermocapillary instability in a multilayered system; built an efficient, mechanically stable three-layer system that could be made applicable for improved microgravity crystal growth using an encapsulated floating zone; and confirmed theoretical and numerical predictions.

Nucleation, Bubble Growth, Interfacial Phenomena, Evaporation, and Condensation Kinetics. Studied boiling processes and bubble dynamics using bubble drop particle unit to provide a better understanding of evaporation and condensation in a supersaturated and subcooled liquid with an initial uniform temperature. Obtained first measurements of growth and collapse of bubbles in a homogeneous supersaturated and subcooled liquid in microgravity over long periods, and determined evaporation and condensation coefficients.

Dynamics of Liquids in Edges and Corners. Studied behavior of liquid surfaces, capillary surfaces, making precise measurements of angles where liquids and solid surfaces meet in containers of irregular cross section. Data revealed dependence of the fluid-solid contact angle on temperature and posed questions regarding the role of hysteresis in critical-wetting phenomena. Bubble drop particle unit and test container operated perfectly during flight for this experiment.

Critical Phenomena in Sulfur HexaFluoride (SF_6) Observed Under Reduced Gravity. Explored thermalization and phase transition kinetics in SF_6 near its critical point, and studied a unique phenomenon called the piston effect using European Space Agency's Critical Point Facility. First observed that thermalization by piston effect is dramatically disturbed by buoyancy-driven convection, first observed two different regimes of phase separation in the same sample, and measured state variables and key parameters.

Adiabatic Fast Equilibration and Thermal Equilibration Bis Experiments. Using Critical Point Facility, Adiabatic Fast Equilibration studied effects of electric fields and heat pulses on a SF_6 fluid sample above and below the critical temperature. Thermal Equilibration Bis measured the time constant for thermal diffusion above the critical temperature. Measured adiabatic response of fluid to a heat pulse and late stages of density equilibrium and obtained first measurements of isothermal increase of density of a near-critical sample as a function of applied electric field.

Density Equilibrium Time Scale. Worked to improve understanding of mechanisms by which heat flow and density stabilization occurred in a fluid substance near its critical point using the Critical Point Facility. Found that the piston effect alone does not lead to short equilibrium times-the times necessary for the sample to become homogenous scale with correlation length-and balloelectricity and surface tension convection have major influence on bubble and droplet distributions in phase separating fluids.

Heat Transport and Density Fluctuation in a Critical Fluid. Measured propagation of heat within a fluid near its critical point. Found that isentropic heating offered a powerful tool for assessing equations of state in vicinity of the critical point, and evaluation of density fluctuations obtained by light-scattering measurements were promising.

Influence of g-jitter on Convection and Diffusion. Clarified effects of gravity vibrations and residual gravity on diffusion in a liquid using Vibration Isolation Box Experiment. Observed enhanced diffusion caused by g-jitter, and recorded data indicating that convection caused g-jitter.

Thermally Driven Flow Experiments. Observed a state of vapor/liquid separation and liquid holding, measured an axial displacement of liquid movement, and verified feasibility of a thermal accumulator. Three basic elements necessary for a thermal pressure controller (gas-liquid partition, liquid retention in the core, and the movement of liquid between vessels) were confirmed. Distance of liquid movement was almost as predicted.

Space Acceleration Measurement System. See STS-43 for description. Recorded data were processed and presented to primary investigators to aid in their assessments of microgravity environment during their experiment operations.

Orbital Acceleration Research Experiment. Measured acceleration and vibrations to which scientific experiments were exposed in different locations on Orbiter. Recorded data were processed and presented to primary investigators to aid in their assessments of microgravity environment during their experiment operations.

Quasi-Steady Acceleration Measurement. Measured steady, low-frequency, residual quasi-steady accelerations between 0 and 0.02 hertz. Obtained data on accelerations in g-jitter range, and demonstrated role of microgravity measurement for controlling payload and facility operations.

Convective Stability of Solidification Fronts (Moni). Used NIZEMI to test a mathematical model for making predictive calculations of the onset of convection. First observation of growth transition from near diffusive to convective mass transport in a melt as a function of increasing g-level, and was the first use of NIZEMI for directional solidification.

Commercial Crystal Growth. Sponsored by Office of Advanced Concepts and Technology. Contained 60 different samples focusing on six proteins working to grow high-quality protein crystals. Crystals were grown in five of the six protein samples-two proteins yielding good results, which yielded three crystals of x-ray diffraction-grade.

Commercial Protein Crystal Growth. See STS-49.

STS-64

Robot Operated Materials Processing System. This first US robotics system to be used in space aimed to improve properties of materials by processing them in space by using a robot to transport each of a large variety of semiconductors from storage racks to halogen lamp furnaces where their crystal structures were re-formed in heating and cooling cycles. Demonstrated that the use of robotics in space is viable and can reduce the costs of developing and manufacturing semiconductors.

Solid Surface Combustion Experiment. See STS-41 for description. Burned plexiglas in a mixture of 50% oxygen and 50% nitrogen at twice the normal atmospheric pressure. Two burns were successfully completed.

Get Away Specials:

Distillation Experiment. Student experiment separated a mixture of two common organic liquids-trichorotrifluoroethane and chloroform-in microgravity by distillation.

Float Zone Instability Experiment. Student experiment investigated convective instabilities in float zone geometries. Primary goal to verify plateau instability limit.

Bubble Interferometer Experiment. Student experiment observed the formation of bubbles in microgravity, looked for evidence of drainage in the bubble after it had formed, looked for interference bands due to bubble wall thickness gradients, and observed surface tension-induced motions on bubble surface.

Chinese Student Experiments. Microgravity portion of payload studied contact between oil and water droplets for investigating effect of microgravity on surface interaction of different liquids, and conducted a general survey of surface interaction of solids and liquids in microgravity.

Formation of Silicon-Lead (Si-Pb) Alloy. Investigated formation of a superconducting alloy not mixable on the ground.

Boiling Experiment. Observed bubble formation when an organic solvent boiled under microgravity and the absence of convection.

Crystal Growth of 3-Selenic-Niobium from the Vapor Phase. Investigated process of crystal growth from vapor phase of a one-dimensional electric conducting material.

Crystal Growth of the Optoelectronic Crystal by the Diffusion Method. Investigated diffusion process of optoelectronic crystal growth from the saturated solution.

Electrophoresis Experiment. Separated samples by free-flow electrophoresis microgravity for use particularly in the area of drug manufacturing for biological/biotechnological products.

Feasibility of Depositing Different Materials in a Vacuum Environment in Microgravity. Exposed evaporation sources and target substrates to the vacuum of space for analysis using a Get Away Special canister with a motorized door assembly.

QUESTS-2 Get Away Special Payloads:

Droplet Growth in Liquid-Liquid Systems. Aimed to develop a better understanding of droplet growth in liquid-liquid systems by adding particles of a third material to constrain motion due to surface tension forces, while microgravity eliminated gravity-driven settling.

Metal-matrix Composites for Application Demanding High Performance. Attempted to grow more uniform metal-matrix composites in microgravity than those grown on Earth.

Distribution of Reinforcing Material Produced in Microgravity and in One Gravity. Samples of aluminum reinforced with various materials were melted then solidified on Earth and on orbit to compare distribution of reinforcing material to gain an understanding of the process and the relative importance of various phenomena influencing the properties.

STS-68

Commercial Protein Crystal Growth. See STS-52.

Get Away Specials:

Microgravity Effects on Growth Quality and Size of Crystal Rochelle Salt. Objective of this student experiment was to use the microgravity environment to improve growth quality and size of a crystal of Rochelle salt.

The Concrete Curing In Microgravity. Student experiment designed to give scientists and engineers valuable data about the feasibility of mixing and curing concrete in a microgravity environment.

The Microgravity Corrosion Experiment. Student experiment designed to examine effects of microgravity on mutation and growth of pitting in metals.

The Study of the Breakdown of Planar Solid/Liquid Interface during Crystal Growth. Studied breakdown of a planar solid/liquid interface during crystal growth by processing a sample of germanium treated with gallium.

STS-66

Protein Crystal Growth. See STS-51D for description. Flew Crystal Observation System in a Thermal Enclosure System and the vapor diffusion apparatus housed in a Single-locker Thermal Enclosure System for continued research on protein crystal growth. This flight produced highest yields and largest crystals of any protein crystal growth experiment flown on shuttle up to that time, according to the principal investigator.

Space Acceleration Measurement System. See STS-43 for description. Successfully supported protein crystal growth experiments during flight.

Heat Pipe Performance and Working Fluid Behavior in Microgravity. Investigated thermal performance and fluid dynamics of heat pipes operating with asymmetric and multiple heating zones under microgravity conditions in this second heat pipe performance experiment (See STS-52). Good data were provided on 10 different axially grooved aluminum/Freon heat pipes in 38 individual tests that showed that under-filled pipes had significantly better performance than was seen in ground tests.

STS-63

Commercial Protein Crystal Growth. See STS-52. Used Vapor Diffusion Apparatus and Protein Crystallization Facility on this flight.

Equipment for Controlled Liquid Phase Sintering Experiments. See STS-57 for description.

Gas Permeable Polymeric Materials. See STS-57 for description.

Handheld Diffusion Test Cell. Evaluated experiment chambers designed for new observable protein crystal growth apparatus and evaluated growth of protein crystals by diffusion of one liquid into another. All on-orbit operations were completed.

Protein Crystallization Apparatus for Microgravity. Tested a new design for growing large quantities of protein crystals in orbit. The new design used the vapor diffusion method and could hold more than six times as many samples as normally accommodated in same amount of space. Operations were successfully completed on orbit.

Space Acceleration Measurement System. See STS-43 for description. Supported protein crystal growth experiments, and was deactivated on Flight Day 6 due to the optical disk drives not recording. Prior to that time, the experiment operated properly.

Three-Dimensional Microgravity Accelerometer. See STS-57 for description. Due to problems with the unit's hard drives, the unit was shut down on orbit but was powered for ascent and descent where it functioned as expected.

Solid Surface Combustion Experiment. See STS-41 for description. Used Plexiglas and an environment of 50% oxygen and 50% nitrogen at one atmosphere pressure on this flight. All operations were completed on orbit.

Fluids Generic Processing Apparatus-1. Studied containment, manipulation, and transfer of pressurized, supersaturated, two-phase fluids in microgravity.

STS-67

Commercial Materials Dispersion Apparatus Instrumentation Technology Associates Experiments. See STS-52 for description. More than 30 individual experiments containing some 400 samples flew on this flight. There were problems with heaters on the 20°C (68°F) side of the commercial refrigeration module.

Protein Crystal Growth. See STS-51D for description. The vapor diffusion apparatus contained in a Thermal Enclosure System and the protein crystallization apparatus for microgravity contained in the Single-locker Thermal Enclosure System flew on this flight. This was second test of newly designed protein crystallization apparatus for microgravity. This was the longest active-crystal-growth flight of the protein crystal growth program up to that point.

STS-70

Colon cancer cells in the NASA Space Bioreactor (Rotating Bioreactor System). Tested bioreactor system's performance in microgravity using colon cancer cells. Found that microgravity cell culture facilitates reassembly of cells into tissue-like structures and tissue growth in microgravity expressed characteristics and products of the tumor usually seen in pathological specimens. Furthermore, the space cultures produced factors not seen in standard culture. Space cultures produced carcinoembryonic antigen-a factor important in the metastasis of colon cancer to the liver. This was an exciting model to study the early phase of metastasis and potentially develop interventional therapy.

Commercial Protein Crystal Growth. See STS-52 for description. Flew the Protein Crystallization Facility contained in a thermal control enclosure. Experiment was successfully completed with no anomalies.

STS-69

Wake Shield Facility. See STS-60 for description. The Wake Shield Facility was released and retrieved on orbit and successfully completed thin-film growth.

Commercial Materials Dispersion Apparatus Instrumentation Technology Associates Experiments. See STS-52.

Electrolysis Performance Improvement Concept Study. Examined effects of microgravity on electrolyte distribution in Static Feed Electrolyzer electrolyte retention matrix.

Get Away Special:

> Microgravity Smoldering Combustion Experiment. Studied effects of smoldering combustion in long-term microgravity using polyurethane foam. Payload was operated as planned during flight.

STS-73

Surface Tension Driven Convection Experiment. See STS-50 for description. Gathered extensive data on instability of fluid flows caused by variations in surface temperatures and observed oscillations that had not been seen on Earth except in small containers. Scientists were enabled to clearly pinpoint when fluid flow transitioned from stable to oscillatory using downlinked video, and they found that when the temperature was increased past the point where oscillations began, flows became erratic.

Drop Dynamics Experiment. Gathered high-quality data on dynamics of liquid drops in low gravity for comparison with theoretical predictions and ground-based studies using small drops.

Science and Technology of Surface Controlled Oscillations. Used drop physics module to examine the influence of surfactants on behavior of drops. Experiment measured oscillation of a spherical drop in its quadrupole mode, oscillation of a drop about a deformed shape, the slow static squeezing of the drop from spherical to nearly flat, and superoscillations of drops when radiation forces maintaining the drop in flattened state were suddenly reduced. After further investigation, scientists were able to understand the physics of oscillations and were able to extract material properties such as dynamic surface tension and surface viscosities.

Geophysical Fluid Flow Cell Experiment. Studied how fluids move in microgravity in an attempt to better understand the large-scale fluid dynamics of planetary and stellar atmospheres. Found good agreement between simulations of onset of instability and the experiment, observed more complicated and transitory convection at rotation than found in models, found a lack of experimental evidence for vacillatory states and states with high-speed zonal jets as predicted in some theories and models, and approximately verified a simple scaling law for existence of columnar convection turbulence in highly stressed shells.

Orbital Processing of High Quality Cadmium Zinc Telluride (CdZnTe) Compound Semiconductors. See STS-50 for description. Flight samples were found to be much higher in structural perfection than samples grown in gravity under identical growth conditions. In regions where solidification had occurred without wall contact, free surfaces evidenced virtually no twinning.

The Study of Dopant Segregation Behavior During the Crystal Growth of Gallium Arsenide (GaAs) in Microgravity. See STS-50 for description. Successfully processed two crystals contained no voids, unlike crystals grown during US Microgravity Laboratory-1, which contained voids.

Crystal Growth of Selected II-IV Semiconducting Alloys by Directional Solidification. See STS-50 for description. One crystal of mercury zinc telluride approximately 1.9 cm (0.75 in.) in size was grown for postflight analysis.

Vapor Transport Crystal Growth of Mercury Cadmium Telluride (HgCdTe) in Microgravity. See STS-50 for description. Focused on initial phase of vapor crystal growth. A single crystal that consisted of a layer of HgCdTe on a cadmium telluride base was grown.

Zeolite Crystal Growth. See STS-50 for description. Crystals grown on orbit were larger than Earth-grown counterparts, and were improved over US Microgravity Laboratory-1 flight-grown crystals.

Zeolite Glovebox Experiment. See STS-50 for description. In addition to the mixing results, four glovebox autoclaves that contained no nucleation control agent and reaction mixtures developed to produce Zeolite A at low temperature were mounted on outside of Zeolite Crystal Growth Furnace. Visual observation of the progress of crystallization occurring in microgravity was achieved for the first time.

Interface Configuration Experiment. See STS-50 for description. Results supported validity of the concept of macroscopic contact angle and thereby its use in predicting fluid behavior under reduced gravity. Results indicated role of hysteresis in impeding orientation to equilibrium.

Oscillatory Thermocapillary Flow Experiment. See STS-50 for description. Found that the onset of oscillations was delayed when container was made more shallow.

Fiber Supported Droplet Combustion. Tested a technique for studying combustion-specifically droplet combustion-in microgravity. Confirmed theories about how fuels burn in microgravity, resulted in larger droplet extension diameters than any initial droplet size capable of being studied on Earth. Burning time was 10 times longer than any other experiment runs, and the data obtained confirmed scientific predictions about burn rate and amount of fuel remaining after the fire went out.

Protein Crystal Growth- Glovebox. Worked to confirm advantages of crew interaction in the process of growing protein crystals in microgravity. Experiment attempted to crystallize seven different proteins, which varied in results; however, most samples did not grow good quality crystals, possibly due to protein damage because of launch delays.

Colloidal Disorder-Order Transitions. Examined the question: How does the density of a substance finely and uniformly dispersed within another substance of a different phase-a colloid-affect its transition from a liquid to an ordered solid phase? Observed a stable disc-shaped crystal with dendrites projecting outward from its edges-a phenomenon that had not been seen on Earth. Photographic and downlinked data revealed growing crystals throughout a sample that was thought to be too densely packed to grow crystals.

Particle Dispersion Experiment. See STS-50 for description. Confirmed theory concerning behavior of dust and particle clouds in that aggregation occurs in all dust clouds drawn together by static electrical charges. All materials tested showed a similar propensity to aggregate due to electrostatic attraction.

Single-Locker Protein Crystal Growth - Two Methods. Processed more than 800 protein samples and tested new protein crystallization apparatus for microgravity and diffusion-controlled crystallization apparatus for microgravity facilities. Crystallization results varied with each protein type, with some not crystallizing well and others providing high-quality, large crystals.

Crystal Growth by Liquid-Liquid Diffusion. Used four handheld diffusion test cell units containing four test cells, each of which grew crystals by diffusing one liquid into another.

Commercial Protein Crystal Growth. See STS-52 for description. Although the yield of diffraction-quality protein crystals was small, invaluable information and experience were gained that gave insight for future hardware improvements.

The Crystallization of Apocrustacyanin C_1. See STS-65 for description. Three Apocrustacyanin C_1 crystals were grown in microgravity and two were grown as ground controls. The best crystal grown was a microgravity-grown crystal.

Crystal Structure Analysis of the Bacteriophage Lambda Lysozyme. Worked to produce crystals suitable for high-resolution x-ray structure determination and analysis of the small protein of 158 amino acids called bacteriophage lambda lysozyme. Only thin needle-shaped crystals, too small for analysis, were grown in microgravity.

Crystallization of Ribonucleic Acid (RNA) Molecules Under Microgravity Conditions. Analyzed influence of gravity on crystallization of RNA molecules. Results showed that crystallizations in space provided more and larger crystals than those in corresponding ground controls.

Crystallization of Monoclinic and Triclinic Lysozyme. Triclinic and monoclinic crystals of lysozyme were grown in microgravity using the Advanced Protein Crystallization Facility. Lysozyme proved to be a good candidate for understanding the influence of microgravity on protein crystal growth.

Crystallization of Thermophilic Aspartyl-tRNA Synthtase (ttAspRS) and Thaumatin. Studied crystallization of ttAspRS, and the plant-sweetening protein called thaumatin. No crystals of diffractable size of ttAspRS were grown on flight, but thaumatin crystals grown were large and of high quality, thus allowing scientists to reach the conclusion that microgravity provides an environment for growth of higher crystallographic quality crystals as judged by their intensity of diffraction and mosacity.

Crystallization in Space of Designed and Natural (a/ß)-Barrel Structures. Pursued crystallization of both natural and de novo designed a/ß-barrel structures. Needle-shaped microcrystals of octarelin II, many small and regular crystals of Thermotoga maritima triosephosphate Isomerase (TIM), and irregular, needle-shaped crystals of poor quality of hTIM and monomeric hTIM mutant were obtained from flight crystal growth.

Crystallization in a Microgravity Environment of CcdB, a Protein Involved in the Control of Cell Death. Worked to improve crystal quality, solve a systematic twinning problem of CcdB, and crystallize a specific double mutant. Crystals of Wild-type CcdB were obtained and found to still have twinning present. Obtained some mutant CcdB crystals in space.

Crystallization of Glutathione S-Transferase in Microgravity. Grew Glutathione S-Transferase crystals in space for comparative analysis with ground samples to determine value of growing crystals in microgravity. Crystals that were grown during flight were of poorer quality than others grown on Earth.

Protein Crystal Growth: Light-Driven Charge Translocation Through Bacteriorhodopsin. Crystal growth of Bacteriorhodopsin was done stabilize weak hydrophilic interactions. Three different habits of Bacteriorhodopsin crystal growth were observed-needle, cubic, and balk-shaped crystals-and experiments performed on orbit and on the ground led to a new experiment protocol.

Crystallization of Ribosomal Particles in Space. Attempted to use on-orbit microgravity environment to extend morphology, size, and improve internal order and mechanical properties of ribosomal particle crystals. Found that ribosomal particle crystals can be grown in space, and almost all crystals were of a round shape, which was a property that had never been observed on Earth. Also, the potential of microgravity-grown crystals was demonstrated because some crystals had morphologies of better proportions than on Earth and had a more isotropic shape.

Crystallization of Sulfolobus Solfataricus Alcohol Dehydrogenase. Crystallized alcohol dehydrogenase enzyme that occurs in large amounts in the livers of mammals, where it plays an important role in several physiological functions including breakdown of alcohol.

Crystallization of the Epidermal Growth Factor Receptor. Worked to grow epidermal growth factor receptor crystals to help solve epidermal growth factor to pave the way for drug design and novel concepts of therapeutic treatment of tumors. Data from three crystals were obtained. Results confirmed data from previous flights that stated that Earth-grown crystals yield comparable results but require larger sizes and more time to grow. Epidermal growth factor receptor seemed to benefit from microgravity growth.

Crystallization of Photosystem I Protein Complex. Attempted to crystallize the photosynthesis protein Photosystem I-one of the proteins responsible for the main conversion of visible light into chemical energy. Crystals that were of diffraction quality were grown. Data were obtained.

Crystallization of Rhodopsin in Microgravity. See STS-65 for description. Crystals were grown in spite of some hardware failures, but were too small for effective analysis.

Space Acceleration Measurement System. See STS-43 for description. Accelerations were successfully measured in support of experiments flown.

Orbital Acceleration Research Experiment. See STS-65 for description. Provided real-time quasi-steady acceleration measurements.

Three Dimensional Microgravity Accelerometer. Measured absolute level of microgravity acceleration and microvibrations during flight. New technologies were validated, and real-time microgravity data were obtained.

Suppression of Transient Accelerations By Levitation Evaluation. Tested a first-of-its-kind device developed in 5 months that was designed to isolate a small, sensitive science experiment from high-frequency accelerations. Suppression of Transient Accelerations By Levitation Evaluation was successful in lessening effects of microgravity disturbances.

Dendritic Growth of Hard-Sphere Crystals. Observed crystalline phases grown in microgravity to determine whether either the convection or the viscous stresses of settling affect the process. Dendritic crystals were grown on orbit for observation.

STS-72

Protein Crystal Growth. See STS-51D for description. Flew an enhanced version of the protein crystal growth vapor diffusion apparatus that introduced a triple-barreled syringe to improve mixing of experiment solutions. Four apparatus trays were housed in a single middeck locker, and each tray had 20 experiment chambers.

Commercial Protein Crystal Growth. See STS-52 for description. On this flight, batch temperature-induction crystallization methodology was used to produce crystals of a new form of recombinant human insulin whose parent molecule is used for treatment of type I diabetes. Experiment performed well and no anomalies were reported.

Get Away Special:

> Protein Crystal Growth. Examined effect of microgravity on protein-crystal nucleation using 16 different crystallization units. Crystal form and size were recorded on photographic film for postflight examination and evaluation.

STS-75

Advanced Automated Directional Solidification Furnace. See STS-62 for description. All three crystal growths were completed of the lead-tin-telluride samples.

Critical Fluid Light Scattering Experiment-Zeno. See STS-62 for description. Found best detailed confirmation, at the time, of adiabatic effects occurring in critical fluids in response to wall temperature changes.

Isothermal Dendritic Growth Experiment. See STS-62 for description. Collected information on more than 120 separate dendritic growth experiments.

Materials for the Study of Interesting Phenomena of Solidification on Earth and in Orbit. See STS-52 for description. Correlated, for the first time, effects of microgravity disturbances on homogeneity of the samples.

Space Acceleration Measurement System. See STS-43 for description. Operated well during flight.

Orbital Acceleration Research Experiment. See STS-65 for description.

Forced-Flow Flamespreading Test. Studied flame spreading over solid fuels in low-speed air flows. Ten flat samples and five cylindrical samples were successfully burned, and data obtained were compared to results of theoretical predictions.

Radiative Ignition and Transition to Spread Investigation. Studied behavior of both flaming and smoldering ignition events, transition from ignition to flame/smoldering spread, and the flame/smoldering growth pattern in air. Twenty-one flaming experiments and four smoldering experiments were conducted.

Comparative Soot Diagnostics. Worked to better understand soot processes in flames produced in microgravity. Successfully produced controlled quantities of smoke particulate from a variety of sources, and measured response of shuttle and International Space Station detectors to the smoke sources.

Commercial Protein Crystal Growth. See STS-52 for description. Tested 128 samples and included the first joint US-Latin America experiment in protein crystal growth.

STS-77

Gas Permeable Polymeric Materials. See STS-57 for description. This third flight of the payload worked to develop enhanced polymers for use in contact lenses.

Commercial Protein Crystal Growth. See STS-52.

Plant Generic Bioprocessing Apparatus. Investigated change in production of secondary metabolites in microgravity.

Fluids Generic Bioprocessing Apparatus-2. Attempted to determine whether carbonated beverages could be produced from separately stored carbon dioxide, water, and flavored syrups, and whether resulting fluids could be made available for consumption without bubble nucleation and resulting foam formation.

Handheld Diffusion Test Cell. Used four handheld diffusion test cell units containing eight test cells each to grow protein crystals by diffusing one liquid into another. Payload was analyzed postflight.

Commercial Float Zone Furnace. Had goal of producing large, ultra-pure compound semiconductor and mixed oxide crystals for electronic devices and infrared detectors. Experiment performed above expectations having processed 14 materials while only 12 were planned to be processed. Three materials were processed for the first time in microgravity.

Space Experiment Facility. See STS-60 for description. Flew a crystal growth experiment and a metals experiment using the transparent furnace for the crystal growth experiment and the opaque furnace for the metals experiment. Both experiments were successful. Crystals grown in the transparent furnace were the first success for that test run after previous flights.

Liquid Metal Thermal Experiment. Evaluated performance of liquid metal heat pipes in microgravity. Successfully demonstrated heat pipe performance over a range of temperatures and powers, duplicated 1*g* ground tests, and evaluated start-up and cool-down phenomena. Three liquid potassium heat pipes were the hottest to operate in space up to that point.

Get Away Specials:

> Subcooled and Saturated Pool Boiling in a Microgravity Environment Experiment: Heat Transfer Phenomena. This German MAUS experiment aimed to gain knowledge on the definition of dominant heat transport phenomenon depending on gravity level, obtain measurement of complete Nukiyama curves, investigate bubble dynamics in microgravity, and determine applicability of nucleate pool boiling for heat exchange facilities in space laboratories.
>
> Reaction Kinetics in Glass Melts. Studied mass transport by diffusion to better understand a process involved in formation of a glass melt to produce a more high-quality glass in the future. Investigation of mass transport by pure diffusion is not possible on Earth.
>
> Diffusion Coefficient Measurement Facility. Measured speed at which mercuric iodide (solid) is evaporated and then transported as a vapor in microgravity. Experiment worked to gain knowledge to improve crystal growth in microgravity.
>
> Nanocrystal Get Away Special. Processed 38 samples of an advanced new class of materials called nanopourous crystalline semiconductors for a better understanding of requirements for high-quality crystals on Earth.
>
> Atlantic Canada Thin Organic Semiconductors. Payload was designed to produce thin organic films using physical vapor transport method, which consisted of vaporizing sample material within an ampoule and condensing a thin film onto a plate.
>
> Microgravity Smoldering Combustion Experiment. See STS-69 for description. Experiment focused on one-dimensional smoldering of polyurethane foam with objective to provide a better understanding of controlling mechanisms of smoldering.
>
> Pool Boiling Experiment. See STS-57 for description. Experiment broadened its range of parameters in this re-flight.

STS-78

Bubble and Drop Interaction with Solidification Fronts. Worked to better understand behavior of bubble and drops with solidification front in an attempt to improve alloy and glass production by learning how to prevent or minimize the impact these interactions have on solidified products. Results showed that bubble and droplets of a diameter of 5 to 10 mm (0.2 to 0.4 in.) were engulfed by the front, no Marangoni thermocapillary bubble migration was observed, and some bubble absorption did confirm some theoretical expectations.

Boiling on Small Plate Heaters under Microgravity and a Comparison with Earth Gravity. Studied boiling heat transfer on five heaters of different size and shape. Found that boiling in microgravity is an efficient method of heat transfer. The boiling process is self-stabilizing. It was the first time the thermocapillary jet mode was observed for moderate subcooling state and the flow pattern was studied. Boiling process seemed to be almost independent of system acceleration.

The Electrohydrodynamics of Liquid Bridges. Investigated stability of columns of a dielectric material-a liquid in this test-that barely conducted electricity when it was placed in another liquid or air when subjected to an electric field. Experiment was successful, and highlighted strong points in the theory as well as areas that needed improvement.

Nonlinear Surface Tension Driven Bubble Migration. Continued investigations into motion of bubbles immersed in a liquid in a container with hot and cold walls on opposite sides. Experiment confirmed results from International

Microgravity Laboratory-2 mission (STS-65), and detected the stopping of bubbles around 8°C to 10°C (46°F to 50°F) by putting cold wall temperature at 5°C (41°F).

Oscillatory Thermocapillary Instability. Investigated behavior of liquids bounded by free interfaces in an attempt to learn more about the liquid's flow due to Marangoni convection. Results proved the curtain concept of fluid was efficient. For the first time, oscillatory thermocapillary convection was observed at the onset of Marangoni-Benard instability, and demonstrated the existence of an oscillatory mechanism that is a specific feature of multilayer systems.

Thermocapillary Migration and Interaction of Bubbles and Drops. See STS-65 for description. Results were consistent with previous findings. There was a general agreement with theoretical predictions, and it was found, in bubbles and drops, that they would move away from the axis of the cell when trailing a small leading bubble or drop.

Thermocapillary Convection in Multilayer Systems. Successfully observed and measured features of thermocapillary convection on multilayer systems heated parallel to interfaces. The curtain concept of the fluid cell was proven to be efficient. Quantitative velocity fields on thermocapillary convection in multilayer systems were obtained.

Comparative Study of Cells and Dendrites During Directional Solidification of a Binary Aluminum Alloy at 1*g* and under Microgravity. Examined cellular and dendritic arrays under conditions in which convection is minimized and diffusive phenomena are dominant. Showed that coupling between natural convection and morphological microstructures can be strong even when solidification is performed in both thermal and solutal stabilizing configuration.

Coupled Growth in Hypermonotectics. Worked to obtain a better understanding of solidification processes in immiscible alloy systems. Three immiscible aluminum indium samples were directionally solidified. Two of those samples contained voids that were sufficient in size to modify solidification parameters locally during processing.

Effects of Convection on Interface Curvature during Growth of Concentrated Ternary Compounds. Studied fluid flows during solidification of ternary compound gallium-indium-antimony to better understand phenomena that occur and have an impact on the quality of the solid. Chemical segregations in flight sample showed an unexpected homogenization of liquid all along the solidification. Crystal-crucible interactions were quantified for the first time.

Equiaxed Solidification of Aluminum Alloy. Examined columnar to equaixed transition in a refined aluminum alloy under conditions where convection was minimized, diffusive phenomena were dominant, and where nuclei density was controlled through refiner content. For the first time, a continuous transition from a purely equiaxed to an anisotropic solidification microstructure as a function of solidification rate and local temperature gradient was shown. The aspect of the anisotropic microstructure was not as anticipated in models.

Interactive Response of Advancing Phase Boundaries to Particles. Worked to better understand interaction between free-floating particles and the growing edge of a solidification material to help verify theoretical models used in development of materials and industrial processes. Results showed a large variety of particle behavior.

Particle Engulfment and Pushing by Solidifying Interfaces. Worked to improve understanding of the physics of liquid metals containing ceramic particles as they solidify and investigated aspects of processing metal mixtures in microgravity to improve processing on Earth. A flight methodology was developed and successfully tested, and some pushing was observed in different samples.

Crystallization of Epidermal Growth Factor Receptor - Epidermal Growth Factor. Crystallized epidermal growth factor receptor, which is an important predictor for a series of human diseases, using five reactors in Advance Protein Crystallization Facility. Ten crystals from two reactors were analyzed but were of poor quality. Found that epidermal growth factor receptor crystal growth favored microgravity over ground growth.

Crystallization of Apocrustacyanin C_1. See STS-65 for description. Apocrustacyanin C_1 was crystallized and analyzed using various methods after flight.

Crystallization of Engineered 5S rRNA Molecules. Crystallized for analysis 5S rRNA, which interacts with proteins and is essential for biological activity in the part of the cell that produces proteins. All seven reactors used produced crystals, and crystals grown on orbit were larger than those grown on the ground.

Crystallization of Thermus Thermophilus AspRS. Worked to crystallize two tRNA proteins in dialysis cells in Advance Protein Crystallization Facility on orbit to determine the influence microgravity has on crystallization.

Crystals grown in space were consistently and significantly larger, and were of a higher quality than ground-grown crystals.

Monitoring of Lysozyme Protein Crystal Growth in Microgravity via a Mach-Zehnder Interferometer and Comparison with Earth Control Data. Worked to grow crystals in microgravity for analysis of growth medium and quality of resulting crystals. Detected a surprising fringe reversal during flight, and more microgravity-grown crystals became available for analysis as of a result of the experiment.

Crystallization of the Nucleosome Core Partial in Space. Crystallized the nucleosome core particle- the larger part of the nucleosome, which is part of the complex that forms core material in cells that have a definite center-on orbit. Crystals grown on orbit were not as large or of as high a quality as those grown on the ground in optimal conditions, and they did not show significant differences with corresponding ground controls.

Crystallization of Photosystem I. See STS-73 for description. Even though no crystals were grown on orbit, the experiment led to new insights in the first events during Photosystem I crystallization. When compared with ground samples, experiment showed the significant influence microgravity has on nucleation rate.

Mechanism of Membrane Protein Crystal Growth: Bateriorhodopsin - Mixed Micelle Packing at the Consolution Boundary, Stabilized in Microgravity. Worked to crystallize bacteriorhodopsin in microgravity. Conditions allowed for growth of tightly packed crystals of different habits, showed a 20-fold enlarged volume of cubic-shaped bacteriorhodopsin when compared with ground controls, and revealed a new observation of the nucleation of small cubic-shaped bacteriorhodopsin crystals on the endpart of the surface of needles of multicrystalline needle clusters.

Crystallization in a Microgravity Environment on Ccdb, a protein Involved in the Control of Cell Death. Attempted to grow higher-quality crystals of Ccdb, and attempted to crystallize Ccdb mutants for multiple isomorphous replacement (MIR) work. A novel crystal was grown that was suitable for structure determination using the MIR method, and with the new crystal form the structure of Ccdb was solved.

Crystallization of Sulfolobus Solfataricus. Had goal to grow high-quality ß-Nicotinamide Adenine Dinucleotide Reduced Form- complexed Sulfolobus solfataricus Alcohol Dehydrogenase due to its biotechnological potential. Crystals grown in space were larger than those grown in ground controls but were comparable to the best Earth-grown counterparts, achieved significantly higher-resolution diffraction data, displayed increased stability when exposed to x-rays, and were found to have undesirable phenomena called twinning.

Growth of Lysozyme Crystals at Low Nucleation Density. Used a new approach to lysozyme crystallization to evaluate usefulness of ground-based experiments in predicating growth behavior under microgravity conditions, tested accuracy of computer simulations of one-dimensional cells developed in terrestrial laboratories, and worked to get information on how Advance Protein Crystallization Facility performed as a device for purely diffusive counter-diffusion experiments. Crystals grown were analyzed on the ground after flight.

Analysis of Thaumatin Crystals Grown on Earth and in Microgravity. Grew and analyzed Thaumatin crystals grown on orbit. The space-grown crystals were consistently and significantly larger, and were more defect-free than ground samples. A clear correlation between ultimate crystal size and protein concentration was found. This was first experiment to produce crystals grown by multiple methods and analyze crystals by both approaches.

Space Acceleration Measurement System. See STS-43 for description. Accelerations were successfully measured.

Orbital Acceleration Research Experiment. See STS-65 for description. Provided real-time quasi-steady acceleration measurements.

Microgravity Measurement Assembly. Measured both high- and low-frequency spacecraft disturbances using sensor heads place at selected locations on Spacelab.

STS-79

Engineering Cartilage in Space (Rotating Bioreactor System). Shuttle delivered this operating experiment to Mir laboratory in space. Intent was to use microgravity conditions to engineer cartilage that may be suitable for transplantation. Results were the longest continuous cell culture (137 days) in the history of the space program to that point. The cartilage was pliable but expressed many characteristics of mature cartilage. Subsequent ground-based research showed that immature cartilage remodels far better than mature following transplantation into experimental animals. Experiment identified components of cartilage that are not synthesized in space, suggesting that cartilage repair in space may be impaired

Extreme Temperature Translation Furnace. Tested facility designed to allow space-based processing up to 1,600°C (2,912°F) and was designed to investigate how flaws form in cast and sintered metals. Only one of the four samples were processed and the facility could only reach 979°C (1,794°F).

Commercial Protein Crystal Growth. See STS-52 for description. Flew newly developed commercial vapor diffusion apparatus and 128 individual samples involving 12 different proteins on this flight.

Mechanics of Granular Materials. Aimed to develop a quantitative scientific understanding of the behavior of cohesionless granular materials in dry and saturated states at low confining pressures and effective stresses. Data gained would hopefully help scientists understand behavior of Earth's surface during earthquakes and landslides.

STS-80

Wake Shield Facility. See STS-60 for description. Facility was released and retrieved, successfully produced seven of seven possible thin-film structures, and grew an additional eighth oxide thin-film before facility was powered down. Facility had been improved before flight, which resulted in enhanced performance.

Commercial Materials Dispersion Apparatus Instrumentation Technology Associates Experiments. See STS-52 for description. A total of more than 900 experiments were included in payload with the key activity being an attempt to grow large protein crystals of urokinase for research linked to breast cancer inhibitors.

Cell Culture Module. Formerly Space Tissue Loss. Validated models for muscle, bone, and endothelial cell biochemical and functional loss induced by microgravity stress. Purpose was to evaluate cytoskeleton, metabolism, membrane integrity, and protease activity in target cells, and to test tissue loss pharmaceuticals for efficacy.

STS-83

See STS-94 for the re-flight of the Microgravity Science Laboratory (MSL-1). Re-flight of MSL-1 occurred due to shortening of the STS-83 mission because of problems with Orbiter's Fuel Cell 2.

Protein Crystal Growth. See STS-51D.

Diffusion in Liquid Lead-Tin-Telluride. Attempted to establish accurate measurement for diffusion coefficient of liquid lead-tin-telluride in relative to temperature.

STS-84

Protein Crystal Growth. See STS-51D for description. Used second-generation vapor diffusion apparatus and Commercial Refrigerator/Incubator Module. Experiment was supported by the Protein Crystal Growth-Single Locker Thermal Control System personnel. Experiment provided ultrapure samples of several protein systems for use in providing scientific data for development of new therapeutic treatments.

Morphological Transition and Model Substances. Investigated solidification-one of the most fundamental processes in the industrial production of materials-with an area of key interest being surface shape and structure of growing solid material. Facility operated 30% slower than expected due to cooling phase taking longer than expected. Experiment completed 11 of the 15 planned steps.

Liquid Motion Experiment. Studied energy dissipation effects for liquids in rotating tanks to obtain data to improve design of spacecraft. Data were obtained and analyzed.

Commercial Vapor Diffusion Apparatus. Worked to grow high-quality crystals-of importance in design of drugs-of various proteins using vapor diffusion method.

Japanese Experiments:

> Crystallization Experiment on Adrenodoxin reductase /3-isopropylmalate dehydrogenase. Experimental crystallization of isopropylmalate dehydrogenase was performed in an attempt to effect improved crystallization with maximum resolution and mosaic character. Additional crystallization of adrenodoxin reductase was also performed. Several crystals checked in the diffraction experiment showed greater maximum resolution than Earth grown control.
>
> Utilization of Microgravity to Improve the Resolution Limit and Quality of Crystals of Biologically-Important Proteins. Determined whether microgravity improved resolution limit of crystals of biologically important proteins and protein complexes whose structures are indispensable in the field of life science. All crystals

obtained in space were larger and more well-shaped and seemed to be positively affected by microgravity when they were compared with ground crystals.

Crystallization of Luciferase from Japanese Firefly, Luciola cruciata (Genji-botaru). Worked to crystallize in microgravity high-quality crystals of firefly luciferase to gain insights into details of catalytic mechanism by x-ray analysis. Several thick-plated crystals were clearly superior to their Earth-grown counterparts grown on the flight.

Protein Crystal Growth in Microgravity. Aimed to clarify effect of microgravity on mechanisms of protein crystal growth, but experiment found there were no significant differences in molecular packing between space- and Earth-grown crystals although lattice constants of space-grown crystals were a little shorter than Earth-grown ones.

Multiwavelength Anomalous Diffraction Analysis of Protein Crystals Grown in Microgravity. Examined possibility of growing in microgravity crystals more suitable for analysis by multi-wavelength anomalous diffraction. Best diffraction-quality crystal was microgravity-grown as determined from resolution dependence of *R* factor (*Rmerge*).

Crystal Structure Analysis of Prostaglandin D Synthase. Attempted to crystallize Prostaglandin D Synthase in space, and compare quality of the crystals with those grown on Earth to verify theoretical advantages to crystallization of proteins in microgravity. The mosaicity of space-grown crystals was higher than Earth-grown ones.

Molecular Science for the Electron-Transfer Reaction Mechnisms of Plastocyanin. Attempted to produce good quality crystals of appropriate size for x-ray structural analysis and several spectroscopic studies to clarify relationship between molecular structure and electron transfer reaction mechanisms. Obtained crystals were extremely small, colorless, transparent, and of unsatisfactory quality for structural studies.

Dissolution Rate of a Single Crystal of Hen Egg-White Lysozyme in Microgravity. Worked to identify which processes are most effective for protein crystallization in microgravity by measuring dissolution rate of a single crystal of hen egg-white lysozyme in both microgravity and on Earth. There was no significant difference between protein crystal dissolution rate on Earth and in microgravity using protein crystallization by vapor diffusion apparatus.

Evaluation of Microgravity Environment on Ribonuclease S Crystal Growth. Attempted to understand relations between protein crystal resolution and its improvement in space, and tried to grow three ribonuclease S crystal forms by micro-seeding technique and analyze an effect of solution viscosity on crystal quality. Obtained crystals were of uniform growth on each axis and of uniform size. No significant differences in lattice constants were observed between crystals grown on the ground and in space.

Crystallization Under Microgravity, and X-ray Structure Analysis, of Protease and Protease Inhibitors. Aimed to produce high-quality space-grown crystals for high-resolution analysis on Earth. Crystals of protease A were generally larger than those obtained on Earth.

STS-94

Laminar Soot Processes. Collected data on flame shape, type, and amount of soot produced under various conditions, and temperature of soot components of laminar jet diffusion flames, which could lead to ways to contain unwanted fires, limit fatalities from carbon monoxide emissions, and improve theoretical models of combustion. Obtained data on properties of soot and its production process, found that non-buoyant flames were twice as large as ground-based flames, found the flames emitted soot sooner than expected, and discovered a new mechanism of flame extinction caused by radiation from soot.

Structure of Flame Balls at Low Lewis-number. Studied behavior of a newly discovered spherical, stable, stationary premixed gas flame phenomena called "flame balls." Experiment was first premixed gas combustion ever performed in space, measured weakest flames ever burned at that time, observed longest-lived gas flames ever burned in space at that time, found conclusive evidence of limitation of existing models of lean hydrogen-oxygen combustion chemistry, found first conclusive demonstration of effect of reabsorption of emitted radiation on the burning characteristics of a flame, and had first conclusive demonstration of the impact of accelerations caused by Orbiter vernier thruster firings and water dumps.

Droplet Combustion Experiment. Collected information on burning rates of flames, flame structures and conditions when extinguishing a flame with the hope of gaining information that could lead to cleaner, more efficient ways of burning fossil fuels and generating heat and power on Earth. Experiment gained a great deal of information on combustion of heptane droplets, especially in helium-oxygen mixtures.

Fiber-Supported Droplet Combustion. Studied how fuels burn and tested new techniques of droplet deployment and ignition using thin fibers for positioning. This was first microgravity experiment to be performed in which droplet arrays were burned. Scientific return was estimated to be 240% with 125 runs being completed out of the originally planned 52 runs.

Protein Crystallization Apparatus for Microgravity. Protein crystallization apparatus for microgravity was used for optimization and production of protein crystals in microgravity for applications in structural biology, and was used to further crystal growth research with an emphasis on the role of microgravity in improving the size and quality of crystals. One of the highest-resolution protein structures as a result of microgravity was produced, and the first example of microgravity enablement for a neutron diffraction study was provided by the largest crystal to be produced at that time.

Second-Generation Vapor Diffusion Apparatus. Used vapor diffusion technique to process 11 different proteins in 80 crystallization chambers. Experiments successfully produced diffraction-sized crystals in eight of the 10 compounds, of which five produced crystals that yielded the best x-ray diffraction data ever collected for those compounds.

Hand Held Diffusion Test Cells. Used a device designed to use the liquid-liquid diffusion method called Hand Held Diffusion Test Cells to crystallize macromolecules in microgravity, and crystallize conventional organic molecules. Eight of the 11 protein compounds produced crystals, and improvements were found in design and performance of Hand Held Diffusion Test Cells, overall instrument design, and procedures employed.

Physics of Hard Spheres Experiment. Examined changes that occur during transition of substances from liquids to solids and solids to liquids, and helped test the Expedite the Processing of Experiments to International Space Station rack hardware. Results show that crystals nucleate and grow faster in space than in the 1*g* environment, particle movement is considerably different in space than on Earth, and hard spheres vibrate about their equilibrium positions but are constrained within the crystal lattice.

Measurement of the Diffusion Coefficient Using the Shear Cell Method. Conducted diffusion experiments using the shear cell method-an improvement of the long capillary method-and verified utility and shear cell mechanism employed. The shear cell method was confirmed as a sufficiently practical method of measuring diffusion coefficient with high precision.

Diffusion of Liquid Metals and Alloys Under Microgravity. Worked to establish an accurate measurement for fundamental variables important in industry and basic science, which regulate diffusion of liquid tin relative to temperature. Diffusion and temperature coefficients under microgravity were different than ground-based, and some aspects of diffusion mechanisms were determined by investigating temperature dependence of the diffusion coefficient.

Diffusion in a Compound Semiconductor Lead-tin-telluride Melt. Worked to establish an accurate measurement for diffusion coefficient of liquid lead-tin-telluride in relative to temperature, which is extremely important in the process of manufacturing single-crystal semiconductor materials of high quality. Diffusion coefficient for lead-tin-telluride was determined accurately in the wide temperature range.

Liquid Phase Sintering II. Tested theories of liquid phase sintering and studied the coalescence of materials during liquid phase sintering, and changes that occur in the material's pores, which allow the mixing of fluids during liquid phase sintering. Experiment isolated and mathematically described the universal grain size distribution for liquid phase sintering, created a model for slumping and distortion during liquid phase sintering, predicted and observed grain agglomeration in dilute solid content systems, and revisited Young's equation and found Gibb's original treatment was incorrect due to a gravity term dropped from the derivation.

Diffusion Process in Molten Semiconductors. Worked to determine diffusion coefficient relative to temperature, impurities, and diameter of sample. Experiment hoped to establish accurate measurements for the fundamental variable that regulate diffusion of tracers of gallium, silicon, and antimony in melted germanium.

Accurate Measurements of Impurity Diffusion Coefficients in Ionic Melts Under Microgravity. Worked to clarify characteristics of materials produced through electrostatic interaction between positive and negative ions. Experiment was the first successful case of precise measurement of diffusion coefficient of an impurity in an ionic melt using the nonsteady electrochemical method.

Space Acceleration Measurement System. See STS-43 for description. Accelerations were successfully measured.

Quasi-Steady Acceleration Measurement. See STS-65 for description. Located in rack 3 of Spacelab, the Quasi-Steady Acceleration Measurement system measured accelerations during flight.

Orbital Acceleration Research Experiment. See STS-65 for description. Experiment had a real-time data interface with Spacelab high-rate multiplexor, which was used to downlink Orbital Acceleration Research Experiment data to the scientific community.

Microgravity Measurement Assembly. See STS-78 for description. Significant disturbances were detected during AstroPGBA installation and a problem with the middeck locker extension tool.

Thermophysical Properties of Undercooled Metallic Melts. Measured surface tension, viscosity, and electrical conductivity of liquid and undercooled alloys, specifically palladium-copper-silicon and cobalt- palladium. Demonstrated feasibility of oscillating drop technique for measuring surface tension and viscosity of high-temperature melts, resolved a longstanding controversy regarding viscosity of palladium-copper-silicon and, for the first time, measured electrical conductivity of undercooled liquid metals.

Thermophysical Properties of Advanced Materials in the Undercooled Liquid State. Measured heating properties of undercooled metallic substances to help researchers understand how metallic glass forms in zirconium-based alloys. Specimens showed excellent stability in the undercooled melt, which made possible for first-time measurements of the specific heat in an extended temperature range from the stable into the undercooled liquid regime.

Measurements of the Surface Tension of Liquid and Undercooled Metallic Melts by Oscillating Drop Technique. Studied surface tension of liquid metal drops, which were levitated and positioned in an electromagnetic field. Found that the method to analyze temperature-time profiles from pyrometric measurement on electromagnetically levitated droplets is successful.

Study of the Morphological Stability of Growing Dendrites by Comparative Dendrite Velocity Measurements on Pure Ni and a Dilute Ni-C Alloy in the Earth and Space Laboratory. Investigated dendritic solidification velocity resulting from small levels of melt undercooling. Measurements, for the first time, delivered quantitative data of crystal growth velocity as a function of undercooling as measured in space on metallic systems under the conditions of significant reduction of natural and forced convection. Unexpectedly, the results compared well with results of terrestrial experiments.

Undercooled Melts of Alloys with Polytetrahedral Short-Range Order. Investigated recently discovered subject of quasicrystals using three quasicrystal-forming alloys of aluminum-copper-iron and aluminum-copper-cobalt. Due to contamination problems with the flight samples, no significant undercoolings were achieved on orbit, but corresponding ground-based studies did obtain results.

Thermal Expansion of Glass Forming Metallic Alloys in the Undercooled State. Investigated thermal expansion of multicomponent amorphous alloys in the wide temperature range between the melting and the glass transition point. Thermal expansion was measured during flight, samples were imaged with high-resolution measuring cameras, pictures were processed on the ground, and a newly developed method for Electromagnetic Containerless Processing Facility worked successfully.

Experiments on Nucleation in Different Flow Regimes. Worked to better understand specific details on how metals solidify, such as pinpointing what phenomenon kicks off solidification, and investigated ways in which the solidification process could be controlled. Found no significant change in nucleation behavior in the range of flow conditions tested.

Alloy Undercooling Experiments. Measured solidification velocity in steel alloys using a combination of video and sophisticated temperature measurement techniques, and studied speed at which the crystallization process occurred. Observed double recalescence events in hypoeutectic ternary steel alloys at much lower undercoolings than previously reported, identified and characterized mechanism for nucleation of the stable phase after initiation of metastable growth, and developed a model that demonstrated the existence of a difference between the high convective environment of ground-based electromagnetic levitation and that obtainable in microgravity.

Measurement of Surface Tension and Viscosity of Undercooled Liquid Metals. Worked to demonstrate a containerless technique to measure viscosity and surface tension of reactive and undercooled liquid metals including zirconium, gold, and metallic glass-forming alloys. Demonstrated, for the first time, the containerless measurement of viscosity on a liquid metal, and obtained precise, containerless measurement of surface tension and its temperature dependence over a wide temperature range.

AC Calorimetry and Thermophysical Properties of Bulk Glass-Forming Metallic Liquids. Measured thermophysical, including specific heat capacity, thermal conductivity, nucleation rates, surface tension, viscosity, and thermal expansion of two bulk metallic glass-forming alloys. The specific heat capacity was measured by AC modulation calorimetry in the stable and undercooled melt. Temperature dependence of the specific heat as well as external relaxation time and specific volume appeared to exhibit an anomaly tentatively identified as phase separation in the liquid.

Coarsening in Solid-Liquid Mixtures. Examined the process of coarsening in metals and worked to use results developed during the mission to compare with current theoretical models. All planned nine test runs were completed during flight.

Bubble Drop Nonlinear Dynamics. Tested newly developed techniques for levitation of drops and trapping of gas and vapor bubbles in microgravity for adaption in that environment. The first data for nonlinear free-decay frequency for a totally free drop were obtained, the first accurate data for a drop deformation as a function of acoustic pressure were obtained, and an effective method for bubble positioning and manipulation in microgravity was discovered.

A study of Fundamental Operation of a Capillary-driven Heat Transfer Device in Microgravity. Investigated fundamental fluid physics phenomena thought to be responsible for failure of capillary-pumped loop devices in low gravity. Provided significant insight into the fundamental operation of a capillary pumped loop heat transfer device in low gravity, and revealed that the criteria used at the time to design such systems, which ignored the presence of liquid in the so-called adiabatic vapor transport region and ignored the dynamics within the evaporator pores, was inadequate for low-gravity systems.

Internal Flows in a Free Drop. Investigated capability of non-contact and remote manipulation techniques at the time for controlling position and motion of liquids in low gravity. Experiment demonstrated quiescent positioning and control of the rotation of a liquid can be achieved using acoustic levitation microgravity and that the phenomena provided data on dependence of acoustic torque pressure and internal flows in a liquid drop.

Diffusion in Liquid Lead-Tin-Telluride. See STS-83.

Cryogenic Flexible Diode. Tested heat pipe technology on orbit to gain advances in passive thermal control technology with hope that advances made in space could transfer to commercial applications on Earth. First American-made loop heat pipe and highest capacity cryogenic heat pipe ever developed were demonstrated during flight.

STS-85

Critical Viscosity of Xenon. Measured viscosity of xenon under a set of conditions that could not be achieved on Earth to obtain a more uniform sample density, and explored the vapor/liquid critical point. More than 10,000 measurements of viscosity were made as the ample temperature was controlled with desired precision at selected temperatures near the critical temperature of xenon, and hardware operated nearly flawlessly during flight.

Stand Alone Acceleration Measurement Device and the Wide Band Stand Alone Acceleration Measurement Device. The Stand Alone Acceleration Measurement Device was designed to measure low-frequency acceleration during launch and landing, and the Wide Band Stand Alone Acceleration Measurement Device measured acceleration at a higher frequency range.

Bioreactor Demonstration System. Tested a system designed to perform cell biology experiments under controlled condition on small samples of materials. Configuration B was flown, which worked to verify operation of the specimen temperature controller. Phase I mammalian cell growth activities and phase II fluid dynamics observation activities were completed.

Protein Crystal Growth/Single-Locker Thermal Enclosure System. Protein Crystal Growth. See STS-51D for description. Used protein crystallization apparatus for microgravity and Single-Locker Thermal Enclosure system to process a total of 630 specimens on this flight. All science objectives were completed.

Solid Surface Combustion Experiment. See STS-41 for description. Contained one polymethyl methacrylate fuel sample on this flight. The hexan material burn was successfully completed.

Evaluation of Space Environment and Effects on Materials. Exposed several small samples to environment of low-Earth orbit and collected cosmic dust. Success rate was 122%.

A Study of the Effects of g-jitter on Bubble Displacements Using the Microgravity Isolation Mount. Used microgravity isolation mount to study effects of vibration on bubble dynamics.

Colon Cancer Cells in the NASA Space Bioreactor (Rotating Bioreactor System). See STS-70 for description.

Protein Crystallization Apparatus for Microgravity/Single-locker Thermal Enclosure System. Worked to grow protein crystals using vapor diffusion for later evaluation on Earth. Total of 630 specimens flown on flight.

STS-86

Commercial Protein Crystal Growth. See STS-52 for description. Used commercial refrigerator/incubator module and commercial vapor diffusion apparatus on this flight. Experiment operated as planned.

Cell Culture Module. See STS-80.

STS-87

Advanced Automated Directional Solidification Furnace. See STS-62 for description. A single lead-tin-telluride ampoule and a single mercury-cadmium-telluride ampoule were successfully processed during flight.

Confined Helium Experiment. Worked to better understand effects of miniaturization on material properties that could lead to smaller and more efficient electronic devices with reduced costs. A total of 40 high-resolution sweeps through the transition region were collected, and good measurements were made when mapping detailed heat capacity curve near the finite size peak, the shift of the peak from bulk transition temperature, and surface-specific heat behavior above and below transition.

Isothermal Dendritic Growth Experiment. See STS-62 for description. Completed on-orbit phase of data collection for this experiment series.

Materials for the Study of Interesting Phenomena of Solidification on Earth and in Orbit. See STS-52 for description. The hardware operated well, and 35 Seebeck solidification and melting cycles were completed, yet only 13 of those cycles had been planned.

Enclosed Laminar Flames. Examined effect of different air flow velocities on stability of laminar, nonturbulent flames. Around 50 test points (flames) were conducted, and temperature and stability limit information gained were compared with numerical predictions in an effort to validate the understanding, at the time, of that type of flame.

Wetting Characteristics of Immiscibles. Investigated a possible cause-droplet wetting along the container walls-of the unexpected separation of immiscible alloy components into layers in microgravity. All 12 samples of succinonitrile/glycerin were processed, and many findings followed preflight predictions. Some results indicated that wetting characteristics may be a more dominant factor in microgravity processing than the experiment team anticipated.

Particle Engulfment and Pushing by a Solid/Liquid Interface. Studied behavior and movement of particles as a sample was solidified from one end to the other in a convection-free microgravity environment. Experiment ran eight samples successfully, and preliminary results showed that the critical velocity agreed with experiment team's theoretical model. An experimental method was developed during flight and was implemented through direct interaction with the crew operating the experiment.

Space Acceleration Measurement System. See STS-43 for description. Performed flawlessly during flight.

Orbital Acceleration Research Experiment. See STS-65 for description. Performed well during flight.

Turbulent Gas-Jet Diffusion Flames. Worked to gain an improved understanding of the characteristics of transitional and turbulent gas-jet diffusion flames with the hope that data gained could improve efficiency of turbulent furnaces and engines on Earth.

Loop Heat Pipe Experiment. Investigated unique thermal energy management system that could be used on commercial satellites. Test was successful; commercial satellite designers could feel comfortable using technology.

Get Away Specials:

> Cement Mixing Experiment. Allowed cement samples to mix with water in microgravity to compare the samples with others produced on Earth to analyze microgravity's effects on the combination. Also studied potential of using cement or similar materials in space.
>
> Configuration Stability of Fluid Experiment. Investigated effects of microgravity on configuration of a two-phase fluid system.
>
> Asphalt Evaluation Experiment. Explored effects of exposure to the exosphere on asphalt.

STS-89

Mechanics of Granular Materials. See STS-79 for description.Six samples were successfully processed during flight.

Get Away Specials:

> Vortex Ring Transit Experiment. Student experiment worked to answer basic questions about fluid atomization with scientific objective being to observe liquid drop formation process in the case of surface-tension-dominated interface dynamics. Investigated propagation of a vortex ring through a liquid-gas interface in microgravity.
>
> Structure of Marangoni Convection in Floating Zones. Used microgravity environment to eliminate buoyancy convection to allow the study of Marangoni convection without disturbances.
>
> Glass Fining. Worked to gain further insight into process of glass fining-removal of all visible gaseous bubbles from a glass melt to improve glass quality.
>
> Super Cooling. Studied super cooling-the temperature difference between the melting point and solidification temperature-in microgravity. Results on Earth were compared with flight results in an attempt to investigate maximum degree of super cooling that could be obtained near pure diffusion conditions.
>
> Processing of High Critical Test. Attempted to process superconductors that could perform at higher temperatures. Research could allow computers to be made much faster, and faster trains that hover off the tracks could be developed.
>
> The Growth of Gallium Antimony. Looked at influence of microgravity on crystal growth and attempted to grow more homogeneous crystals in space than on Earth.
>
> Liquid Phase Epitaxy. Worked to grow a crystal rod in space and compared it to a crystal rod grown on Earth.
>
> Wettability Test. Showed how big a bubble forms, whether the liquid beaded up, where it stays together, and other characteristics of different materials such as nickel and iron. Testing was done at several different temperatures and a camera was set up to take pictures of the test.

STS-90

Bioreactor Demonstration System Experiments:

> Human Kidney Cells (stationary incubator system). Analyzed genes that are turned on and off in space. Numerous genes were affected in microgravity. Results strongly suggest that terrestrial life is not preprogrammed for changes in gravity experienced in space. Also emphasized the influence of physical forces on normal everyday life processes.
>
> Microgravity Induced Differentiation of HL-60 Promyelocytic Leukemia Cells. Studied differentiation (maturation) of bone-marrow-like cells, which have the ability to become myriad immune cells found in the human physiology.

Get Away Specials:

> Collisions into Dust Experiment. Student experiment analyzed gentle collisions of dust particles in space, which could shed a new light on sources of dust in planetary rings. On this flight, six self-contained experiments were flown, and the payload operated nominally on orbit.
>
> Pulse Tube Cooling Technology. Demonstrated pulse tube cooling technology in microgravity and worked to gain operational experience with smallest cryocooler built at the time.

STS-91

Commercial Protein Crystal Growth. See STS-52 for description. A primary objective was to grow parasitic enzyme crystals in space for the Chagaspace Project. Payload operated nominally.

Solid Surface Combustion Experiment. See STS-41 for description. Experiment was successfully performed, and two different cylindrical polymethyl mathacralate samples were burned.

Growth and Morphology, Boiling, and Critical Fluctuations In Phase Separating Supercritical Fluids. Performed three experiments that tested current theories and measured properties not possible in Earth's gravity for phase transitions, vapor to liquid, and vice versa, near a unique thermodynamic state.

Get Away Specials:

Atlantic Canada Thin Organic Semiconductors. Processed organic materials into thin films in microgravity to better understand the role gravity plays in affecting the forming of thin films.

Microgravity Industry Related Research for Oil Recovery. Investigated using microgravity environment to develop new technologies that could have an impact on the Canadian oil industry, environmental cleanup, and the world's future oil reserves. Three separate experiments —Diffusion Coefficients of Crude Oil, Foam Stability, and Capillary Flow—were flown.

Chemical Unit Process. Student experiment aimed to learn how microgravity affects extracting phosphate ions from phosphate ore that was mined on student's reservation.

Nucleic Boiling. Student experiment studied effects of microgravity on bubble formation and temperature gradients as water was heated to a boil during flight.

Crystal Growth Experiment. Student experiment studied formation and growth of chemical crystals in a microgravity environment.

STS-95

Advanced Gradient Heating Facility. Facility was a Bridgeman furnace designed for directional solidification and crystal growth. Nine processing runs were planned. Some problems occurred during flight that caused the loss of one of the samples.

Advanced Organic Separations Experiment. Provided capability to separate and purify biological materials in microgravity. Facility supported three different experiments. Hemoglobin Separation Experiment evaluated advanced separation technology for a recombinant or genetically engineered hemoglobin product. Microencapsulation Experiment's primary microcapsule to be produced on this flight was encapsulating two complementary drugs-an antitumor drug and an immune stimulant-to create a potent time-released drug for colon cancer treatment. Phase Partitioning Experiment worked to give researchers better insight into methods for isolating specific cell populations. Aerogel. Worked to produce aerogel and study effects of gravity on aerogel production so that pore size could be controlled and a clear aerogel could be produced.

Commercial Instrumentation Technology Associates Biomedical Experiment. Performed research that focused on growing crystals of the protein urokinase and the development of microcapsules. Some temperature variation occurred with the 6°C (43°F) commercial refrigerator/incubator module during flight.

Commercial Protein Crystal Growth. See STS-52 for description. Used Vapor Diffusion Apparatus, Protein Crystallization Facility, and a commercial refrigerator/incubator module for each facility on this flight.

Facility for Adsorption and Surface Tension. Investigated surface phenomena at liquid-liquid and liquid-gas interfaces in microgravity to eliminate effects of buoyancy- and gravity-driven convection. Experiment was activated as planned but shut down unexpectedly during flight several times. Around 60% to 70% of experiment was completed.

Microencapsulation Electrostatic Processing System. Studied formation of anti-tumor capsules containing two kinds of drugs, evaluated performance of the system, and worked to advance production of multilayer microcapsules on Earth.

Internal Flows in a Free Drop. Used microgravity science glovebox to measure internal fluid flows induced by the acoustic field and areas of different temperature on the surface of the drops, and measure surface tension of the drops. All activities were completed, and the expected results were not observed during second run of experiment.

Colloidal Disorder-Order Transition. Used colloids and microgravity science glovebox to learn more about how the organizations of atoms change as they form into orderly solid structures. Observed dendrites for a sample with a volume fraction between 0.494 and 0.545, and revealed that crystallization can occur in samples that have a volume larger than the formerly reported glass transition of 0.58.

Structural Studies of Colloidal Suspensions. Used microgravity science glovebox to study fundamental properties of colloids to help scientists better understand their nature and make them more useful for technology. Revealed that gels formed from the colloid polymer solution are stable over long periods of time in microgravity.

Organic Crystal Growth. Investigated an anisotropic property of organic ferromagnets.

Protein Crystallization Apparatus for Microgravity. See STS-94.

Second-Generation Vapor Diffusion Apparatus/Single-Locker Thermal Enclosure System. Worked to grow crystals of eight different proteins and ribonucleic acids in 80 crystallization chambers. Although power was not provided for thermal control due to lack of crew time available to perform the procedure, nine out of 10 cells in the equipment contained crystals of sufficient quality to be used in next step of experiment.

Space Acceleration Measurement System. See STS-43 for description. Free-flyer unit flown on this flight supported Hubble Space Telescope orbital system test.

Commercial Generic Bioprocessing Apparatus. See STS-57.

Advanced Separation Payload. Contained Advanced Separation Bio-Processing facility to support three commercial investigations, Hemoglobin Separation experiment, Microencapsulation experiment, and Phase Partitioning experiment.

Phase Partitioning Research. Worked to give researchers better insight into methods for isolating specific cell populations.

Commercial BioDyn Payload. Commercial bioreactor for space-based investigations. Experiment's conductors are as follows:

Recombinant Proteins Research. Studied preliminary process for growing proprietary recombinant protein that can decrease rejection of transplanted tissue.

Microencapsulation Research. Researched ways to improve microencapsulating material for cells that produce insulin in the human body.

Tissue Engineered Heart Patches and Bone Implants Research. Focused on space-grown bone implants and "heart patches" (cardiomyocytes tissue) to replace damaged heart muscle.

Anti-Cancer Products From Plant Cells in Culture Research. Investigated production of anticancer drugs from plant cells.

European Space Agency Experiments:

Self Standing Drawer /Morphological Transition and Model Substances. See STS-84 (Morphological Transition and Model Substances).

Crystallization of a Collagen-Model Polypeptide. Aimed to deepen the structural analysis of triple collagen helix and gain further insights on microgravity's influence on the crystallization process. Crystals were grown in all reactors, microgravity-grown crystals exhibited a significant improvement in terms of dimensions and resolution limit, and the best improvement up to that time was achieved for a bio-macromolecule crystal growth in microgravity.

Crystallization of Grb2, a Signal Transduction Protein. Worked to obtain better crystals to solve the structure at higher resolution. Eight experiments were conducted. Found the liquid/liquid phase separation droplets from flight samples were much larger than Earth samples.

Crystallization of Photosystem I. Objective was to grow improved-quality crystals of Photosystem I for analysis using improved crystallization conditions including seeding techniques. Results clearly showed the influence of nucleation on crystallization.

Crystallization of Subtilisin & Substrate-Analogue Complexes for atomic Resolution X-ray data collection. Aimed to grow highly ordered macromolecular crystals suitable for atomic resolution data collection in combination with synchrotron radiation. Most experiment crystals obtained in microgravity were perfectly shaped according to bipyramidal crystal morphology, and were larger in volume in comparison to the ground-control-grown crystals.

Crystallization of De Novo Designed Alpha/Beta-Barrel Structures. Attempted to crystallize de novo design of proteins on a/b barrel scaffold named Octarellins. Only small crystals were obtained.

Crystallization of Domain A and E from Thermus flavus 5S rRNA. Worked to grow RNA crystals in microgravity to reduce effects of influences such as convection and sedimentation, which RNA crystals are sensitive against. Most data sets from the space-grown crystals were of higher quality and were used for structural analysis and refinement.

Crystal Structure Analysis of the Outer Surface Glycoprotein of the Hyperthermophile Methanothermus fervidus. Aimed to produce well-ordered crystals suitable for high-resolution x-ray structure determination and analysis. Some small crystals of the S-layer glycoprotein of Methanothermus fervidus were obtained.

Detached Crystal Growth of CadmiumTelluride (CdTe) and Related Compounds. Objectives were to apply dewetting to growth of CdTe to get single crystals with low structural defects, and to look at the stoichiometry of the grown crystal. Despite a power breakdown of the furnace, it was found that structural properties of the sample were improved compared to ground crystals at the time.

Dynamics of Surface Tension Response to Aperiodic and Harmonic Surface Area Disturbances. Worked to confirm assertion that dilational modulus is a well-defined thermodynamic parameter of an interfacial system, governing the whole interfacial dilational process.

Extraordinary Features of Antibodies from Camelids. Explored possibilities of microgravity conditions for production of high-quality crystals. Crystals grown were of diffraction quality.

Intermetallic Particles Adjusting to Cooperative Eutectic Growth in Ternary Alloys. Investigated a new type of divorced eutectic growth, which had been observed during the preparation of a preceding solidification experiment in space. Comparison with ground samples showed that, under equal conditions, particles grown in space reach nearly double in size, and the initial pushing phase as well as the distance between particle layers also is at least twice as large as under Earth conditions.

Study of Adsorption Kinetics by the Expanded Drop Technique. Studied adsorption kinetics of a polyoxyethylenated non-ionic sufacant at the water/hexane interface.

Study of the Exchange of Matter and Dilational Rheology of Liquid Interfaces by the Oscillating Bubble Technique. Studied dynamics of adsorption of a soluble surfactant at water/air interface by characterizing dynamic I.T. response to high-frequency harmonic disturbances of bubble surface area.

Thaumatin Crystals Grown in Gel Matrix. Addressed the question whether immobilizing crystals in a gel may be a remedy for the problem of turbulence in crystallization reactors. Crystal motion was observed in during flight, and the model protein thaumatin crystallized in the agarose gel. By employing an agarose gel in a microgravity environment, new insights in mechanisms of protein crystallogenesis were achieved, crystals of superior and more uniform crystallographic quality were obtained in the medium in microgravity as compared to controls prepared under otherwise identical conditions on Earth, and crystals grown in agarose gel either in microgravity or on Earth were significantly better than reference crystals prepared in parallel in solution, with a diffraction signal in average 20% more intense.

STS-88

Get Away Special:

Vortex Ring Transit Experiment. See STS-89.

STS-93

Gelation of Sols: Applied Microgravity Research. See STS-42 for description. On this flight, 50 to 100 samples were expected to be generated.

Commercial Generic Bioprocessing Apparatus. See STS-57. A Tissue, Ladybug, and National Institutes of Health-B Experiment were flown as part of payload.

Cell Culture Module. See STS-80.

STS-101

Self Standing Drawer/Morphological Transition and Model Substances. See STS-84 (Morphological Transition and Model Substances) for description. A total of eight samples and 27 of the 28 runs were completed successfully.

Commercial Protein Crystal Growth. See STS-52 for description. Successfully studied protein crystal growth of human alpha interferon 2b—a protein pharmaceutical used against several afflictions—on this flight.

Protein Crystal Growth Biotechnology Ambient Generic Payload. Designed to provide opportunities to grow high-quality protein crystals in microgravity, and required minimal crew support.

STS-106

Human Kidney Cells (stationary incubator system). See STS-90 for description.

STS-105

Ovarian tumor cells (stationary incubator system). Investigated whether a space cell culture gave a gene expression profile more like the actual tumor in the patient or like that observed in standard cell culture on Earth. Tissue assemblies were remarkably similar to native tumor. New model for ovarian cancer and new insights to potential targets for chemotherapy were obtained.

Colon cancer (stationary incubator system). Found changes in programmed cell death and products associated with spread of the tumor, and created novel signals for progression of disease and potential targets for therapy.

Neuroendocrine cells (stationary incubator system). Synthesis of products important in pain suppression and in maturation of cell lineage. These observations were to be possibly used in designing strategies for nerve growth and regeneration.

Kidney Cells (stationary incubator system). Found that renal cells in space produce hormones and by-products that are of potential commercial value. Precursors of vitamin D were secreted in abundance and were biologically compatible with potential commercial use.

Get Away Special:

Microgravity Smoldering Combustion Experiment. See STS-69 for description.

STS-108

Antibody Production by Human Lymphoid Tissue (Stationary Incubator System). Antibody synthesis was significantly inhibited in space cells programmed to make antibodies before flight made antibodies in space. Cells stimulated to make antibodies while in space failed to do so. There were implications for declining immunity in long-duration missions.

Hitchhiker Payload:

Collisions into Dust Experiment. See STS-90 for description. Second flight of this experiment was a follow-on to first experiment.

Argentine Experiments Package as Get Away Specials:

Transport Fluids in Non-Circular Tubing. Looked at flow of fluids in microgravity through various geometric-shaped tubes to determine most efficient way to transport fluids in space.

Surface Vibration of Water Drops. Scientists measured surface vibration generated by surface tension in water drops in microgravity.

Migration of Drops and Bubbles in Microgravity. Studied convection of water drops and bubbles in microgravity to determine feasibility for future development of a detector of drop and bubble movement based on thermal changes.

Crystal Formation and Growth in a Microgravity Environment. Worked to determine differences in crystal growth between Earth and space.

Maximum Accelerations Register. This experiment recorded maximum acceleration of Orbiter during flight to aid in development of an acceleration recorder that did not require electrical energy.

Geophysical Fluids Movement. Goal was to use microgravity to simulate atmospheric and sea movement in spherical bodies to better understand Earth's atmosphere and oceans.

Microgravity Smoldering Combustion Experiment. See STS-69 for description. Payload operated nominally on orbit.

Nucleic Boiling. Student experiment boiled water inside a chamber and videotaped action of bubbles.

Crystal Growth. Student experiment aimed to grow crystals from chemicals commonly found in the human body.

Weak Convection Influencing Radial Segregation. The influence of weak convection, caused by surface tension forces on radial dopant segregation, was studied in seven mirror furnaces using floating zone technique and antimony.

STS-107

Prostate Cancer (NASA Rotating Bioreactor). Grew prostate cancer cells in microgravity using the Bioreactor Demonstration System. Prostate cancer cells were grown along with cells from bone marrow as a means to understand how metastasis to bone marrow grow so aggressively. Experiment had largest tissue structures grown in space. The prostate cancer produced PSA and other factors associated with the disease. No further results were obtained due to the loss of STS-107 on return.

Mechanics of Granular Materials. See STS-79 for description. A significant amount of data from flight experiments were downlinked and stored on the ground, and several planned experiments were enhanced to provide greater return and a 10th experiment was added. After taking a preliminary look at the data, scientists indicated that several important results were captured.

Structure of Flame Balls at Low Lewis-number. See STS-94 for description. All 15 planned initial burns and reburns, and seven extra reburns were completed on orbit. Data return were due to successful downlinking or all sensor data and gas chromatograph files, and many image files. New discoveries and new spaceflight records at the time for lean burning combustion were documented by the principal investigator.

Laminar Soot Processes. See STS-94 for description. Important results were obtained from 14 out of 15 successful planned runs. Sensor and image data were downlinked from 7 of 14 tests, and partial data from another 7 tests. The principal investigator indicated that the quality of flames equaled the best quality flames from STS-94, which allowed the principal investigator to extend mathematical models to more practical, turbulent flames found on Earth.

Water Mist Fire Suppression Experiment. Studied how a water mist system puts out flames with the aim of developing a commercially viable water-based fire-fighting system. Around 90% of data were downlinked to Mission Control and important scientific results were obtained on mist behavior characterization, suppression, and extinguishment of lean, stoichiometric, and rich flames, and exploratory suppression tests of near lean limit flames.

Critical Viscosity of Xenon. See STS-85 for description. Around 10% of the in-orbit data were lost, but recorded data exceeded minimum goals, which allowed experiment to be judged a complete success.

Zeolite Crystal Growth. Studied development of improved zeolite materials for storing hydrogen fuel and applied research to detergents, optical cables, gas and vapor detection for environmental monitoring and control, and chemical production techniques. Some crystals were recovered after the accident for analysis.

Commercial Instrumentation Technology Associates Inc. Biomedical Experiments Payload. Conducted more than 20 separate experiments including cancer research, commercial experiments, and student experiments. Many samples from the payload were recovered for analysis after the accident.

Space Acceleration Measurement System. See STS-43 for description. Space Acceleration Measurement System-Free Flyer unit was flown on this flight. Around 60% to 90% of mandatory sensor data were saved, but most (98%) non-critical data were lost.

Orbital Acceleration Research Experiment. See STS-65 for description. Equipment collected and downlinked approximately 90% of mandatory data to support Structure of Flame Balls at Low Lewis-number and Water Mist Fire Suppression Experiments. Data loss affected the accuracy of Orbital Acceleration Research Experiment data below 10 microgravity.

European Space Agency Experiments:

> Adsorption Dynamics and Transfer at Liquid/Liquid Interfaces. This experiment with two others performed in Facility for Adsorption and Surface Tension addressed single and multiple interfaces, as affected by various surfactants. All telemetry and video data were downlinked, but some data were corrupted by ground computer problems, some of which were partially recovered.
>
> Dilational Properties of Interfaces. See Adsorption Dynamics and Transfer at Liquid/Liquid Interfaces experiment for description and results.
>
> Interfacial Rheology and the Effects of Vibrations on Interfacial Properties. See Adsorption Dynamics and Transfer at Liquid/Liquid Interfaces experiment for description and results.

STS-110

Protein Crystal Growth- Single-locker Thermal Enclosure System. Provided incubator/refrigerator module that housed different devices for growing biological crystals in microgravity.

STS-111

Biotechnology Water Treatment System. Tested water purification system to allow use of shuttle fuel cell water on future flights of biotechnology cell-culture experiments instead of pure ionized water that must be launched with the experiment. Twelve samples were successfully retrieved from Orbiter galley for this experiment.

3.7 Space Biology

STS-3

Cytological and Ultrastructural Studies on Root Tissues. Root cap cells are identified as gravity-sensing tissues in roots. Study was to determine to what extent gravity influences organization of gravity-sensing tissues. Results showed that in a microgravity environment, root caps of plants do grow abnormally and do not perform their normal function, due to lack of gravity.

Karyological Observations in Developing Root Seedlings. Studied effects of microgravity on growth of oat and mung bean seedlings. Determined that the oat grew irregularly, including a large amount of roots growing upward, and did not mature properly, but mung bean's root structure was in good condition despite the fact that the roots were slightly more contracted and had a lower spread compared to ground control plants.

The Influence of Weightlessness on Lignification in Developing Plant Seedlings. Plants produce a large amount of structural polymers, cellulose, and lignin to grow upright against gravity. Experiment was designed to determine whether production of lignin and growth of plants is gravity dependent or based on genetics. Results indicated that gravity does play a part in orientation of plants since microgravity-raised plants had many roots (25% to 40%) growing upward and there was lignin reduction in spaceflight-reared plants.

STS-8

Animal Enclosure Module Inflight Test. Flown for the first time on this mission. Goal was to determine whether the module could safely transport rats in future missions. Determined that the module needed minor changes, but overall the rats returned to Earth healthy and safely and crew members were not affected by rats being on board.

STS-51B

1,25-Dihydroxyvitamin D3 Receptors in Space Flown vs. Ground Control Rat Kidneys. Bones undergo reduction in bone mineralization in microgravity. Experiment examined the 1,25-Dihydroxyvitamin D3 receptors, which are responsible for retaining calcium in kidneys, to see if receptors are altered in microgravity. Results indicated that receptors are not affected by microgravity and that bone demineralization is not a result of receptor alteration.

Atriopeptin in Atria and Plasma of Rats Orbited Aboard NASA Spacelab-3 for Seven Days. Experiment was to determine whether the release of atriopeptins, which cause changes in blood vessels and kidney function, are a result of the bodily fluid shift that astronauts experience in microgravity. Determined that flight rats did not have a statistically different amount of atriopeptins, but it was also necessary to take in-flight samples in addition to postflight samples in future experiments.

Biochemical and Morphological Evaluation of the Effects of Space Flight on Rat Salivary Glands. Observation and analysis of salivary glands in both rats and humans gives insight into body's reaction to stress and other environmental factors. Experiment studied biochemical and morphological changes in rat salivary glands caused by spaceflight. Determined some biochemical changes in rats' saliva and salivary glands and that testing human saliva and salivary glands may be useful in studying stress-related body responses to spaceflight.

Bone Maturation in Rats Flown on the Spacelab-3 Mission. Goal was to determine if spaceflight alters maturation of weight-bearing bones in the rat body. Results indicated that microgravity does impair bone growth and a relative increase in skeletal maturations, which could be due to spaceflight-associated decrease in bone turnover.

Census of Osteoblast Precursor Cells in Periodontal Ligament of Spacelab-3 Rats. Bone tissue is affected by spaceflight. Experiment was to determine factors that affect bone tissue and to study the recovery of tissue cells postflight. Determined that younger rats cells recovered better than older rats and that the effect of spaceflight on bone tissue was most likely a response to multiple factors such as unloading, fluid shifts, and an altered circadian rhythm.

Changes in Functional Metabolism in the Rat Central Nervous System Following Spaceflight. Since many physiological systems are affected by spaceflight, it is important to know how metabolic activity of the brain is affected. Experiment studied rats' brains that had been exposed to microgravity. Results indicated that neural metabolism of rats was affected by spaceflight, but it was not possible to determine whether the motor system was also affected.

Early Adaptation in Altered Gravitational Environments in the Squirrel Monkey. Effect of altered gravitational environments on eating habits of squirrel monkeys was studied in this experiment, with one group of monkeys subjected to microgravity and the other group subjected to 1.5*g* using Earth-based centrifugation. Study showed that both groups of monkeys showed some symptoms similar to those that astronauts experience in space, which indicated that changes in both hypo- and hypergravity can induce symptoms similar to those associated with Space Adaptation Syndrome.

Effect of Flight in Mission SL-3 on Cytokine Production by Rats. The immune system has been shown to be affected by spaceflight. Study used rats to determine whether production of interferons-proteins that fight disease-is affected by spaceflight. Results indicated that production of interferons was affected by spaceflight.

Effect of Flight in Mission SL-3 on Interferon-Gamma Production by Rats. Aimed to investigate effect of spaceflight on production of interferons. Determined that spaceflight reduced the amount of interferons produced, in addition to reducing the size of the spleen, which is where T-lymphocytes reside. It was not possible to determine whether this was due to spaceflight, or due to stress caused by spaceflight.

Effect of Seven Days of Spaceflight on Hindlimb Muscle Protein, RNA and DNA in Adult Rats. Slow twitch muscles are most affected by spaceflight and microgravity. Experiment studied leg muscles of rats to determine whether the factors related to muscle atrophy on Earth (protein content, DNA, RNA) are also related to muscle atrophy in space. Results indicated a decreased protein content, an increase in DNA concentration, and a decrease in RNA concentration in the rats' leg muscles, which corresponds with muscle atrophy on Earth.

Effects of Weightlessness on Neurotransmitter Receptors in Selected Brain Areas. Many physiological changes are associated with spaceflight. Study aimed to determine whether those effects also resulted in a change in neuro receptors in the brain of rats flown on this mission. Determined that release and uptake mechanisms were affectedby spaceflight, including increase in the receptor responsible for spatial mapping of an environment, suggesting the brain must make major changes to spatial mapping in microgravity.

Electron Microscope Analyses of Calcium, Sulfate, Magnesium, and Phosphorous Distribution in Incisors of Spacelab-3 Rats. Effect of spaceflight on mineralization of bones is an important issue in astronauts. Study used rats' incisors, which preserve a 30-day record of growth, to study how mineralization of bone is affected by microgravity. Results indicated that mineralization of bones is affected by spaceflight, resulting in an increase in calcium concentration and a decrease in magnesium concentration.

Hematologic Parameters of Astrorats Flown on Spacelab-3. The hematologic system, or blood system, was affected by spaceflight in the past. Experiment used rats flown aboard this mission to study parameters that are affected. Determined that there was an increase in hematocrits, red blood cell counts, hemoglobins, and a decrease in percentage of lymphocytes present in the blood system as a result of the rats' exposure to microgravity.

Hepatic Enzyme Adaptation in Rats after Spaceflight. Hepatic enzymes are responsible for regulation of the breakdown of pharmaceutical agents, nutrients, and hormones in the liver. Experiment studied whether the concentration of hepatic enzymes are altered by exposure to microgravity. Results showed that some enzymes experienced a change as a result of spaceflight and that the effects of these changes should be studied in the future.

Hepatic Enzymes of Sphingolipid and Glycerolipid Biosynthesis in Rats from Spacelab-3 Rats. Examined how activities of some of the enzymes responsible for lipid metabolism in the liver of a rat are affected by spaceflight. Results indicated that cellular adjustments occur in the liver as a result of exposure to microgravity.

Homeostasis and Biological Rhythms in the Rat During Spaceflight. Studied regulation of body temperature and heart rate in rats to better understand how the body reacts to being exposed to a microgravity environment. Determined that both heart rate and body temperature regulation are affected by spaceflight and that the circadian rhythm (biological clock) is also altered in microgravity.

Microgravity Associate Changes in Pituitary Growth Hormone Cells Prepared from Rats Flown on Spacelab-3. Focused on effect of microgravity on the release of growth hormones in rats flown aboard this mission. Growth hormones were observed to decrease in rats exposed to microgravity, suggesting that spaceflight does affect growth hormones and may contribute to the atrophy that is a result of spaceflight.

Osteocalcin as an Indicator of Bone Metabolism During Spaceflight. Osteocalcin is a protein produced by bone formation cells in the body and has been observed to be a good indicator for bone formation and turnover. Study examined how the production of osteocalcin was affected by spaceflight. Results showed that it appears to be a sensitive indicator of effects of spaceflight on bone metabolism.

Otoconical Morphology in Space-Flown Rats. Spaceflight affects the gravity-sensing organs of both humans and rats. Experiment aimed to determine whether gravity-sensing organs of rats undergo alterations or degeneration due to spaceflight. Results indicated that the organs do not undergo any kind of degeneration, but that alterations had begun to occur as a result of spaceflight.

Plasma Renin Concentration of Rats Orbited for 7 Days Aboard NASA Spacelab-3. Renin is secreted by the body to help control blood pressure. Study examined effect of spaceflight on renin concentration in rats. Results showed that there was no difference between spaceflight rats and the ground control rats, but this could be due to the 12-hour delay between re-entry and sampling of rats.

Rat Maintenance in the Research Animal Holding Facility During the Flight of Spacelab-3. Examined ability of Research Animal Holding Facility to adequately carry and house animals that were flown aboard this mission. Determined that the Research Animal Holding Facility carried and returned animals in a healthy state and that it was adequate for future missions.

Reduction of the Spermatogonial Population in Rat Testes Flown on Spacelab-3. Studied effect of spaceflight on amount of sperm present in the rat testicle. Rats exposed to spaceflight underwent an approximately 7% decrease in testes weight and amount of sperm, most likely due to stress though space radiation could have possibly played a part.

Results of Examination of the Respiratory System in Spacelab-3 Flight Rats. Examination of respiratory systems of all the groups of rats (control groups and flight groups) showed that the rats all developed virus-like lesions.
Spacelab-3: Histomorphometric Analysis of the Rat Skeleton. Examined physiological effects of spaceflight on the skeleton of the rat. Determined that the major factor in skeletal alteration as a result of spaceflight is inhibition of bone growth.

The Influence of Space Flight on the Rat Soleus. Spaceflight is known to cause weight-bearing muscles to atrophy but the exact reason is not clearly known. Study demonstrated using space-flown rats that one of the reasons weight-bearing muscles atrophy is that slow twitch fibers are replaced with fast twitch fibers as well as the muscles decreasing in size and weight.

Microgravity Changes in Heart Structure and Cyclic-AMP Metabolism. Examined change in heart muscle energy metabolism in rats as a result of exposure to microgravity. Results indicated that heart muscle energy metabolism is indeed affected by microgravity and this may help explain why animals and humans undergo cardiac deconditioning as a result of spaceflight.

Morphologic and Histochemical Studies of Bone Cells from SL-3 Rats. Spaceflight is known to cause bone loss. Experiment examined cellular activity of the bone-forming cells in space-flown rats. Determined that activity of the cells stayed mostly the same but that the size of the cells decreased, which would contribute to the smaller amount of bone formation observed in spaceflight.

Response of Amino Acids in Hindlimb Muscles to Recovery from Hypogravity and Unloading by Tail-Cast Suspension. Examined recovery period of space-flown rats as well as determining whether an on-Earth suspension model could be used to mimic effects of microgravity. Results indicated that amino acids in space-flown rats recovered quickly and that the suspension model may be a viable model for the effects of spaceflight.

Microbial Monitoring. The Research Animal Holding Facility was flown for the first time on this mission and it was necessary to perform an extensive microbial monitoring protocol to determine whether the Research Animal Holding Facility caused an increase in microorganisms and increased the threat of cross contamination between crew and animals. Determined that there was not a large increase in microorganisms and that no cross contamination occurred.

STS-51F

Gravity-Induced Lignification in Higher Plants. Lignin is considered one of the most important structural polymers that enable plants to grow vertically against gravity. Experiment studied effect of microgravity on production of lignin in plants. Space-flown plants showed a decrease in lignin of up to 24% compared to ground-raised controls, thus demonstrating that gravity is a major inducing factor in the production of lignin in plants.

STS-61A

European Space Agency-dedicated flight research:

Antibacterial activity of antibiotics in space conditions. Results showed that bacteria cultivated in space exhibit an increased resistance to the antibiotic Colistin. Three tentative explanations can be advanced: observations reflect an increased proliferation of bacteria in spaceflight; the transport of antibiotics into cells might be altered by spaceflight conditions; a combined effect of both phenomena mentioned above might be the cause of the observed apparent increased resistance.

Differentiation and Embryogenesis in Aniseed Cell Cultures in Microgravity.On Earth, cell cultures of aniseed differentiate into well polarized embryoids within 7 days. Aim of experiment was to study development of plant organ polarity and gravity-perceiving tissues in microgravity. Preliminary electron microscope examination of roots revealed the presence of well-developed statocytes whose amyloplasts were easily distinguished in size, form, and starch contents from those found in adjacent root tissues. Further growth of plantlets formed in space after landing yielded normal anise plants.

Effects of microgravity on genetic recombination in E. coli. Aim was to determine whether microgravity influences mechanisms responsible for the exchange of genetic information between organisms - phage to bacteria. Microgravity exerted a positive effect on conjugation. It seems that in microgravity, mating pairs or aggregates are less likely to be disrupted than in the presence of gravity and thus give rise to higher recombination frequencies.

Embryogenesis and organogenesis of Carausius morosus under spaceflight conditions. Results of experiment showed that it is possible to separate radiation effects from microgravity effects and also from combined effects of these two factors in space. Early stages of development of Carausius morosus eggs turned out to be highly sensitive to single hits of cosmic ray particles as well as to temporary exposure to microgravity during their development. In some cases, the combined action of radiation and microgravity even amplified the effects exerted by single parameters of space.

Embryogenesis of Drosophila melanogaster. Exposure to microgravity caused changes in oviposition and early embryonic development. It also caused some abnormalities, delay in development, potentially shorter life spans, and decreased the number of larvae hatched.

Contraction behavior and protoplasmic streaming in the slime mould. Aim was to test whether cells that are not specialized for the perception of gravity are nevertheless affected by weightlessness. The highly regulated contraction-relaxation cycles demonstrated a clear-cut reaction to weightlessness, which can be regarded as an active regulation of the organism in an attempt to adapt its gravity-compensating mechanisms to the new, stimulus-free conditions. A second decrease in contraction periods, which occurred after 45 to 90 minutes of weightlessness, could be interpreted as an adaptation to the zero-gravity condition after a prolonged exposure to it. Main result of Biorack experiment is a strong indication that there is a general gravisensitivity in a cell that is not specialized for gravity perception.

Graviperception of lentil seedling roots grown in space. No difference in lentil roots or sensitivity of gravisensing cells, and no ultrastructural differences in statocytes of roots.

Gravireception of cress roots (Lepidium sativum L.). The study strengthened the assumption that under microgravity conditions, changes in physiological parameters of cress roots may be mainly expressed as structural changes of components of the gravity-perceiving system.

Growth and differentiation of Bacillus subtilis under microgravity conditions. The behavior of Bacillus subtilis in microgravity was different than comparable ground controls. Differences were the cells started growth several hours earlier, increased in optical density, and the distribution of spores formed.

Structure and function of the gravireceptor. During development of the larvae gravisensor, cells may compensate to microgravity. Or, the construction failsdue to the effort of detecting acceleration necessary for a proper development. In the near absence of gravitational stimuli, the primary receptor would enlarge, becoming observable.

The circadian clock of Chlamydomonas reinhardii in space. Under microgravity conditions, both types of Chlamydomonas reinhardii showed well-expressed circadian rhythms. The periods in space did not differ significantly from rhythms of ground control experiments.

The Paramecium experiment. The growth rate of Paramecium was significantly higher in microgravity compared to the in-flight 1*g* control as well as control on ground.

Effect of microgravity on hybridoma mammalian cell behavior and structure. Four different types of results were expected: potential changes in ultrastructure of cells fixed in flight; potential changes in capacity of RNA biosynthesis by uridine incorporation; ability of non-fixed flight cells to resume normal growth; and alteration of amino acid contents in growth medium. No clear effect of microgravity on cell proliferation was observed, as the number of cells found in zero-gravity cultures was slightly lower than in the corresponding 1*g* controls in flight and on ground, but higher than in a parallel control culture in a laboratory incubator in identical plastic bags. The proliferation rate of cells grown in this control experiment was smaller compared to normal laboratory conditions.

STS-29

Chromosomes and Plant Cell Division in Space. Tested whether the normal rate of root tip growth is maintained in a microgravity environment and whether fidelity of chromosomal partitioning is also maintained in spaceflight. Results showed that root growth was 40% to 50% greater in space, but in all directions not just downward, and that chromosomal aberrations were present in 3% to 30% of dividing cells in space-flown plants.

STS-34

Effects of Microgravity on Growth Hormone Concentration and Distribution in Plants. The plant growth hormone, indole-3-acetic acid, is a possible indicator of effects of microgravity on growth of the plant. Experiment hypothesized that microgravity affected concentration and distribution of this plant hormone. Results indicated that there were no chemical changes in the plant, but rather the problem with growing plants in space is providing a substitute stimulus for gravity to correct the orientation of plant roots in space.

STS-32

Characterization of Neurospora crassa Circadian Rhythms in Space. Studied circadian rhythm of Neurospora crassa with the objective of determining whether the circadian rhythm of plants is an internally driven process and not driven by external cues such as light. Results indicated that the circadian rhythm of plants is indeed an internally driven process that is modified slightly by environmental cues including, to a minor extent, gravity.

STS-41

Physiological Systems Experiment. Objective was to test hypothesis that a growth-hormone deficiency occurs during spaceflight and that this deficiency contributes to the bone loss and decreased tissue function observed following microgravity exposure. Determined that genetically engineered growth hormone treatment of space-flown rats did not affect their muscle atrophy or bone degeneration, thus indicating that a different hormone or process is responding to skeletal unloading in microgravity and that there is a tissue-specific immune response to microgravity exposure.

Investigations with shoots of small plants, *Hemerocallis* and *Haplopappus gracilis* demonstrated that, in space, roots grew in random directions and that root production was 67% to 95% greater.

STS-40

Effects of Spaceflight on Rat Erythroid Parameters. Experiment was carried out over missions STS-40 and STS-58. Astronauts have been known to lose red blood cell mass as a result of exposure to a microgravity environment. Used rats to study the parameters of red blood cells. Determined that spaceflight affected rats' bone marrow progenitor cells, but not any of their red blood cell parameters.

In-flight and Post-flight Changes in Skeletal Muscles of Space Life Sciences (SLS)-1 and SLS-2 Spaceflown Rats. Experiment was carried out over missions STS-40 and STS-58 (SLS-2). Determined that weight-bearing muscles show atrophy as a result of being exposed to a microgravity environment. This atrophy corrects itself postflight, and edema and lesions are also two other postflight phenomena as a result of spaceflight.

Studies with jellyfish ephyrae showed hormonal changes while in space and abnormal swimming behavior both during spaceflight and after returning to Earth.

Flower And Vegetable Seeds Exposure To Space. Sent 19 varieties of flower and vegetable seeds into space to determine how unknown variables of microgravity affect seed growth.

STS-48

Physiological and Anatomical Rodent Experiment 1. Goals were to examine if the use of tail suspension methods as models for microgravity unweighting effects on developing rats is valid and to determine whether microgravity causes an increase in glucose intake in the presence or absence of insulin. Results showed that the tail suspension method is a viable model for microgravity and that, in the presence of insulin, the uptake of glucose was much higher in suspended and space-flown rats as compared to control group rats.

STS-42

Chondrogenesis in Micromass Culture of Mouse Limb-bud Mesenchyme Exposed to Microgravity. Studied effect of a microgravity environment on cartilage development in mouse cells. Results indicated that cells did undergo a shape change from flattened to rounded that is associated with cartilage development, but did not fully develop in other respects.

Genetic and Molecular Dosimetry of HZE Radiation. Cosmic ray radiation is a major feature encountered during spaceflight. Experiment examined biological effects of radiation environment using a soil nematode. Determined that there were no obvious physiological differences caused by cosmic rays, but noted some chromosomal mutations in space-flown nematodes that were significantly greater than from ground control groups.

Gravitropic Threshold. Plants on Earth orient with respect to the gravitational vector as driven by gravity. Experiment examined effect of different magnitudes of artificial gravity (centrifugation) on the plant. Results showed that, as a general trend, autotropic responses increased as the g-stimulus increased.

Microgravitational Effects on Chromosome Behavior. Studied effect of microgravity on behavior of chromosomes using two different types of yeast, which are microbial analogs of human cell division. There were no major differences in cell yield caused by microgravity, but there was a higher occurrence of some phenotypes in space compared to the ground control group.

Response to Light Stimulus Phototropic Transients. Studied plant seedling curvature induced by exposure to light in microgravity environment. Determined that curvature response was not significantly different in-flight compared to ground-based specimen, but that autotropic reversal and oscillation in curvature occurred in space.

Friend Leukemia Virus Transformed Cells in Microgravity. Studied Friend leukemia cells to study adaptation of living cells in microgravity and attempted to learn about how the gene responsible for hemoglobin synthesis is regulated. Found that the hemoglobin produced was the same in zero-gravity and ground 1*g* samples, and that the behavior of single cells does not change in microgravity.

Proliferation and Performance of Hybridoma Cells in Microgravity. Studied how cell performance (biosynthesis and secretion) is altered by altered gravity conditions in an attempt to see if cells produce material more rapidly in space, which would allow for practical manufacture of some pharmaceutical products in space. Found that changes in metabolic parameters indicated microgravity did have an impact on certain cellular processes, and that bioprocessing these cells in space did not appear to be profitable with respect to commercial production of monoclonal antibodies at that time.

Dynamic Cell Culture System. Tested biological performance of Dynamic Cell Culture System in operation in space, and studied effect of microgravity on hamster kidney cells. Found that the system can be used for biological experiments on long-term Spacelab missions, and microgravity had no effect on growth and metabolism of hamster kidney cells.

Effects of Microgravity and Mechanical Stimulation on the in-vitro Mineralization and Resorption of Fetal Mouse Bones. Studied response to microgravity of embryonic mouse leg bones in an attempt to better understand effects of microgravity on bone growth maintenance and repair before long spaceflights are planned. Demonstrated that under in vitro conditions, bone cells in fetal mouse long bones respond to microgravity with a decreased mineralization and an increased resorption when compared to on-board 1*g* centrifuge paired controls.

Why Microgravity Might Interfere With Amphibian Egg Fertilization and The Role of Gravity in Determination of the Dorsal/Ventral Axis in Developing Amphibian Embryos. Worked to clarify role of gravity in earliest stages of embryonic development that determine the future front and back sides of the body by studying the fertilization of eggs and embryo development of frogs in space. Found that gravity is not required for establishment of the dorso-ventral axis in the Xenopus embryo, and the time taken for gastrulation in space is similar to that on Earth under identical experimental conditions.

Effects of Space Environment on the Development of Drosophilia Melanogaster. Attempted to study the development of eggs of the fly Drosophilia (fruit fly) when exposed to microgravity. Due to a sterilization method using ethylene oxide, all flies died during the mission, and only 2 days of data were obtained.

Dosimetric Mapping Inside Biorack. Measured and documented radiation environment inside Biorack to give scientists radiation environment information to assist with experiment evaluation, and compared experimental data with theoretical predictions. Radiation environment data were obtained, and it was found that the radiation load on astronauts during International Microgravity Laboratory (IML) -1 was somewhat higher than the mean annual public exposure but was well below limits defined for spaceflight activities.

Embryogenesis and Organogenesis of Carausius. Studied influence of cosmic radiation and low gravity on stick insect eggs (Carausius morosus) at the early stages of their development. Detected morphological and developmental changes during embryo development in Carausius flight samples-changes that had not been found during previous tests.

Gravity-Related Behavior of the Acellular Slime Mold Physarum Polycephalum. Studied slime mold to gain a better understanding of microgravity effects on behavior and circadian cycle of organisms. Confirmed results from previous experiments, proved existence of complex mutual influences of the acceleration and light stimulus reaction chains, revealed that light- and acceleration-stimulus reaction chains share their last units, and implied the existence of a gravireceptor.

Growth and Sporulation in Bacillus Subtillis Under Microgravity. Studied and measured growth and sporulation of Bacillus subtilis under microgravity conditions. Found that, contrary to predictions, Bacillus subtilis are affected by gravity and that in the case of growth rate, the change occurs at a time when other profound alterations in the cell's physiology take place including an increase in the rate of cell separation.

Studies on the Penetration of Antibiotics in Bacterial Cells in Space Conditions. Studied effects of antibiotics in bacteria cells cultivated in vitro in space conditions in an attempt to learn more about the fact that bacteria might be more resistant to antibiotics in space due to the thicker structure of their cells walls. Observations made during flight indicated that antibiotics are less efficient in space, which confirmed previous results.

Transmission of the Gravity Stimulus in Statocyte of the Lentil Root. Worked to determine minimum amount of simulated 1*g* exposure required for plants to regain gravity sensitivity and reorient their roots after exposure to microgravity. Found that the bending of roots grown in microgravity and then placed in simulated gravity was greater than ground simulations, ground regulation of curvature was dependent on gravity, and initial rate of curvature was dependent on amount of gravity stimulus.

Growth, Differentiation, and Development of Arabidopsis thaliana under Microgravity Conditions. Aimed to quantify structural and behavioral changes that take place in the germinating seed of the small plant Arabidopsis thaliana when exposed to microgravity, and deliver space-flown developing seedlings for later ground testing. Experiment was successful in providing seedlings for further ground study, and was able to record information about the behavior of Arabidopsis thaliana during exposure to microgravity.

Effect of Microgravity Environment on Cell Wall Regeneration, Cell Divisions, Growth and Differentiation of Plants From Protoplasts. Aimed to provide basic knowledge of the development of plant cells under microgravity, which is essential if plants are to be grown in space for food and other products. Found that in plant protoplasts, cell wall formation and cell division takes place under microgravity, but processes are delayed when compared to 1*g* samples and that few, small cell aggregates formed under microgravity.

Biostack. Used four Biostack packages to gather data on space radiation's effects on biological materials for further study and to aid in improved designs for spacecraft radiation protection. Data were successfully obtained during flight.

Japanese Space Agency: High-energy Cosmic Radiation Monitoring and Analysis of Biological Specimens. Radiation detector functioned normally, and detection performance was as specified. Comparison of biological specimens with an earthbound control experiment revealed the following:

- no difference in survivability and mutation rates of hay bacillus spores
- no difference in incubation rates for harvested prawn spawn
- no difference in germination rates of corn seeds; however, the mutation rate for leaves following germination was slightly higher in sample recovered from space.

STS-50

ASTROCULTURE™. Evaluated critical subsystems essential for space-based plant growth applications. Results from flight indicated device worked as well in microgravity as it had on Earth.

STS-46

Microgravity-Induced Effects on Pituitary Growth Hormone Cell Function: A Mechanism for Muscle Atrophy in Manned Space Flight. Spaceflight has been shown to affect structure and function of pituitary growth hormone cells. Experiment studied effect of microgravity on pituitary growth hormone cells of space-flown rats. Results showed that there were changes in chemical and cellular composition of cell cultures that affected growth hormone cells and their response to microgravity.

STS-47

Effect of Weightlessness on Development of Amphibian Eggs. Amphibian eggs on Earth will rotate upon fertilization to align with the gravitational field and this rotation may possibly play a role in the normal development of the amphibian. Experiment determined that microgravity did not critically affect development of embryos. When free-swimming tadpoles were returned to Earth, it was found that they had failed to inflate their lungs as a result of exposure to microgravity. Such a failure will result in an inability of the tadpoles to complete metamorphosis.

Gravity and the Stability of the Differentiated State of Plant Embryos. Objectives were to determine whether spaceflight affected development and chromosomal behavior of daylily cells. Results indicated that there were significant alterations in chromosomes of the cells in addition to there being a lower number of cell divisions.

Bread Yeast in Microgravity. Compared behavior of bread yeast in absence of gravity to behavior of bread yeast in normal atmospheric conditions.

Study of the Effects of Microgravity on Cell Growth of human Antibody Producing Cells and their Secretions. Compared cell growth, nutrient consumption, and antibody secretion by a human B cell hybridoma between cells cultured in space and the ground. No significant differences in either antibody secretion or cell proliferation were observed between cultures after flight and the ground cultures, and the increasing effect on antibody production during flight disappeared on the ground.

STS-52

Effect of Weightlessness on Bone Histology, Physiology, and Mechanics. Degeneration of both bones and muscles is experienced by astronauts and animals as a result of spaceflight. Experiment used a medicinal compound (Merck & Co.'s MK-217) on rats to try to prevent bone loss. Results showed that the compound did reduce microgravity-induced bone lose, but bone formation was still significantly reduced in space-flown animals.

STS-54

Developmental and Physiological Processes Influencing Seed Set in Microgravity. Experiment was to determine effects of microgravity on Arabidopsis thaliana seed development and to understand effects of weightlessness on plant reproduction. Found that reproductive development was aborted at an early stage in space-flown plants and that space-flown plants had significantly lower carbohydrate content compared to ground raised plants.

Effect of Spaceflight on Oxidative and Antioxidant Enzyme Activity in Rat Diaphragm and Intercostal Muscles. Purpose was to examine effects of microgravity on oxidative and anti-oxidative enzyme levels in respiratory muscles in space-flown rats. Results indicated that there were no changes in most respiratory muscles, except for the diaphragm.

Effects of Spaceflight on Morphology of the Rat Adenohypophysis. Studied the morphological response of adenohypophyseal cell types, which are part of the endocrine system, to spaceflight. Results indicated that the changes that occurred as a result of spaceflight appeared to be compensatory changes in the endocrine system, rather than pathological damage to the anterior pituitary.

Effects of Spaceflight Stress on Pro-opiomelanocortin, Proenkephalin A and Tachykinin Neurpeptidergic Systems in the Rat Posterior Pituitary. Stress causes secretion of three stress peptides beta endorphins, methionine enkephalins, and substance P, which have different effects on the body. Experiment examined effect of spaceflight on the levels of these peptides in response to stresses of spaceflight. Lower levels of methionine enkephalins and substance P were found in space-flown rats but beta endorphins did not decrease.

Effects of Zero Gravity on Biochemical and Metabolic Properties of Skeletal Muscle Fiber-Types. Focused on effect of spaceflight on proteins responsible for muscle contraction in skeletal muscle fibers. Results showed a reduction in slow twitch proteins and an increase in fast twitch fibers.

Influence of Spaceflight on the Production of Interleukin-3 and Interleukin-6 by Rat Spleen and Thymus Cells. The immune system is known to be affected by spaceflight. Experiment examined activity of two cytokines-interleukin-3 and interleukin-6. Results showed increased production of both cytokines, demonstrating that spaceflight can enhance production of cytokines in immune system.

Spaceflight Changes in Skeletal mRNA. Bone degeneration has been observed to be a problem in space-flown rats and astronauts. Experiment determined that turning on and off gene expression is a regulating factor in bone development. Data obtained in this experiment indicated that skeletal unloading that is a result of spaceflight resets the pattern of gene expression in bone-forming cells, resulting in decreased maturation of the bones.

STS-56

Acute Adaptation of Bone to Spaceflight. Hypothesis of this experiment was that the unloading of bones due to microgravity during spaceflight results in defective bone growth and that gravity is necessary for normal bone development. Results indicated that a depression in cell differentiation of bone-forming cells was caused by microgravity.

Cell Kinetic and Histomorphometric Analysis of Microgravitational Osteopenia. Spaceflight is known to affect bone structure. Experiment aimed to determine whether spaceflight blocks formation of bone-forming cells, where in the body this blocking occurs, and how long it takes for the condition to recover upon return to Earth. Confirmed that spaceflight does affect formation of bone-forming cells, but that this condition returned to normal after 24 hours postflight.

STS-55

European Space Agency dedicated research. Biological response to extraterrestrial solar ultraviolet radiation and space vacuum. Study demonstrated protective role of ozone layer for spores, but effect of solar ultraviolet radiation and/or space vacuum varied by species.

Development of vestibular-ocular reflex. In fish and tadpoles, there was no effect of microgravity on clear-eye response to regular right-left movements of their body. This showed that development of the dynamic vestibular-ocular reflex was not affected by microgravity.

Electrofusion and regeneration of sunflower protoplasts under microgravity considering the ultrastructure. In a study of the production of somatic hybrids of plants, there was no significant difference between ground and spaceflight in general structures of organelles, mitochondria, plastids, and nuclei. The calli generated from flight protoplasts were generally smaller than ground controls and entered a dormant stage after 4 weeks of culture.

Electrofusion of plant cell protoplasts: Synthesis and morphological/biochemical characterization of heterospecific hybrids. The combination of growth and metabolite parameters points toward a down-regulation of energy metabolism in cells grown under microgravity while retaining 1*g* rates of cell division and growth.

Electrofusion of protoplasts from Digitalis Lanata EHRH, and Digitalis Purpurea L. suspension cultures under microgravity conditions and enzymatic characterization of the fusion products. Between spaceflight and ground studies, the cultures of Digitalis Lanata changed their metabolic abilities but their growth rates and morphology were identical. There were no hybrid cell lines and no intraspecific fusion products among the regenerated Digitalis clones.

Fluctuation test of bacteria cultures. The rate of genomic mutation and rate of loss of a plasmid were practically the same in microgravity and under the 1*g* reference centrifuge thus radiation hormesis was highly improbable.

Fruiting body development. The microgravity-grown fruiting bodies exhibited random orientation compared to cultures grown under 1*g* where fruiting bodies were pointing exactly in the opposite direction of the acceleration force. In microgravity, the tendency was to grow away from the substrate. Two totally different growth reactions—gravity-independent avoidance reaction and gravity-dependent orientation—occurred. Microgravity did not impair cap morphogenesis and growth intensity, although flat and somewhat twisted stripes occurred.

Graviperception and neuronal plasiticity: structure and functional related neuronal plasticity of the central nervous system of aquatic vertebrates during early ontogenetic development under microgravity. Effects of long-term exposure to altered gravity on swimming performances of fish and toad larvae after return to 1*g* can be followed from their swimming traces. Taken together, these observations clearly demonstrate the strong influence of altered gravity on the behavior of the animals.

Graviperception and neuronal plasticity: comparative investigations of weightlessness effects on structural development and function of the gravity perceiving organ of two water living vertebrates (Xenopus laevis, Oreochromis mossambicus). The curved body shape reflected the preferred loop swimming mode of the tadpoles. Hypo- and hypergravity did not affect development of gravity-perceiving systems and no significant changes occurred in the mass of the otoliths in utricle, in contrast with other reports.

Gravisensitivity of cress roots. Microgravity-grown roots exhibited large bending angles and the root curvature became very visible within 10 minutes. Twenty-four hours after lateral acceleration, roots had changed from bending to straight growth, thus suggesting the existence of an important automorphogenetic component in plant growth processes.

Influence of conditions in space on expression and stability of genetic information in bacteria. No differences between microgravity samples and the 1*g*-grown controls in the yield of cells and biomass, plasmid activity, ultraviolet sensitivity, time lag for readaptation to exponential growth.

Significance of gravity and calcium ions on the production of secondary metabolites in cell suspensions of Aesculus hippocastanum L. Microgravity did not affect secondary metabolite production in this pharamaceutical relevant cell culture.

STS-57

Effects of Weightlessness on Tissue Regeneration in Rodents. Longer-duration space travel will increase likelihood of minor injuries. Study examined effect of microgravity on repair of those injuries. Tissue regeneration process was shown to be stunted and altered in microgravity.

STS-51

Chromosomes and Plant Cell Division in Space. Studied effect of microgravity on photosynthetic functions of super-dwarf wheat. Determined that photosynthetic functions were altered by microgravity.

Developmental and Physiological Processes Influencing Seed Production in Microgravity. The lack of convective air movement in a microgravity environment could limit a plant in gas exchange and other functions. Experiment determined that a pollen transfer problem was observed in plants that were in a microgravity environment.

Plant Metabolism and Cell Wall Formation in Space (Microgravity) and on Earth. Purpose was to compare space-flown super-dwarf wheat with earthbound wheat in both physical and biochemical properties. Root growth seemed to be the only major factor that differed between the two groups.

STS-58

This flight enabled scientists to study, for the first time, animals that were sacrificed and tissues obtained prior to enduring re-entry and landing stresses.

Effects of Spaceflight on Rat Erythroid Parameters. See STS-40 (repeat experiment).

In-flight and Post-flight Changes in Skeletal Muscles of SLS-1 and SLS-2 Spaceflown Rats. See STS-40 (repeat experiment).

Microgravity Induced Transformations of Myosin Isoforms and Contractile Properties of Skeletal Muscle. Examined effects of a microgravity environment on an anti-gravity muscle in a rat and the associated protein expression. Determined that microgravity heavily affected contractile properties of the anti-gravity muscle, in addition to less of the slow twitch proteins being expressed and more of the fast twitch proteins being expressed.

Myonuclear Number and Myosin Heavy Chain Expression in Rat Soleus Single Muscle Fibers after Spaceflight. The atrophy of weight-bearing muscles in microgravity is a major problem for astronauts and animals traveling in space. Experiment was to determine whether expression of certain types of proteins had any effect on muscle atrophy. Determined that changes in the number of myonuclei may be a contributing factor to size reduction of weight-bearing muscles in space.

Japanese investigators, Spaceflight Effects on ß-adrenoreceptor and Metabolic Properties in Rat Plantaris muscle. Muscles are known to atrophy is space, but it is the load-bearing (slow twitch) anti-gravity muscles that are usually studied. Experiment examined the fast twitch muscle, Plantaris in rats, and determined that it undergoes a reduction in metabolic activity even though composition of muscle fiber did not change, possibly due to lessening of tension placed on the muscle in microgravity.

Japanese investigators, Vertebral Growth Disturbance in Rapidly Growing Rats During 14 Days of Spaceflight. Examined effects of a microgravity environment on a maturing rat's vertebrae. Determined that being reared in a microgravity environment results in a delay of vertebral maturation, which is an important finding with regard to humans being raised in space.

French investigators, Effects of Spaceflight and Recovery on Rat Humeri and Vertebrae: Histological and Cell Culture Studies. It is well known that microgravity has resulted in skeletal changes in both rats and humans, but changes and subsequent recovery of bones had not been documented until this experiment. Determined that the humeri, thoracic, and caudal vertebrae of rats exhibit different patterns of response to microgravity and subsequent recovery on Earth, suggesting that the difference is due to the different load bearing of each bone.

Russian Investigators, Lymphatic Tissue Changes in Rats Flown on Spacelab Life Sciences-2. The lymphatic system is important in many respects, but most importantly it is used to respond to trigger an immune response in a human's or animal's body. It was observed that lymphatic tissue of a rat did undergo changes in microgravity, but that any changes quickly returned to their original state after returning to Earth's gravity.

Russian Investigators, Effect of Spacelab Life Sciences-2 Spaceflight on Immunologic Parameters of Rats. A microgravity environment has an effect on many different systems in the human and animal body. Determined that the immune system of a rat did change when exposed to the microgravity environment, also suggesting that these changes could increase over time.

Japanese investigators, Cellular Content of p53 Protein in Rat Skin After Exposure to the Space Environment. The protein wt p53 is known to respond to several different stressors, such as heat, ultraviolet radiation, and ionizing radiation. Experiment determined that the group of rats that had experienced spaceflight showed a marked accumulation of the protein compared to ground-based rats, indicating that rat skin cells are exposed to multiple stressors.

STS-60

Ability of Polyethylene Glycol Interleukin-2 to Counteract the Effect of Spaceflight on the Rat Immune System. Studied effect of polyethylene glycol interleukin-2 to prevent or mitigate the negative effects microgravity has on the rat immune system. There was no significant pattern observed in space-flown rats to draw any conclusions about the effect of polyethylene glycol interleukin-2 on the rat immune system.

STS-62

An experiment was conducted by a biotechnology company using rats. Results of the experiment are proprietary.

Physiological Systems Experiment 4. Studied complex interrelationship between immune and skeletal systems during exposure to microgravity.

STS-59

The Effects of Hypogravity on Osteoblast Differentiation. Studied effect of spaceflight on development of bone-forming cells and bone mineralization in rats. Spaceflight was shown to affect development of bone-forming cells and also to inhibit energy metabolism and protein synthesis of bone-forming cells.

Influence of Spaceflight on Bone Cell Cultures. Bones are known to undergo changes as a result of spaceflight. Experiment examined changes undergone by the bone cells. There was a reduction in total ribonucleic acid in the cells, demonstrating that microgravity exerts demonstrable effects on bone cells.

STS-65

Effects of Microgravity on Aurelia Ephyra Behavior and Development. Studied effect of microgravity on development and behavior of jellyfish flown aboard mission. The jellyfish were shown to have altered gravity receptors, abnormal arm numbers, and altered swimming behavior.

Early Development of a Gravity-Receptor Organ in Microgravity. Newt larvae were flown aboard this mission to determine effects of microgravity on development of gravity-sensing organs in the newt. Determined that the gravity-sensing organs were found to be enlarged in space-flown newts and that development of these systems was accelerated.

Gravity and the Stability of the Differentiated State of Plant Embryos. Effect of microgravity on development and chromosome behavior of daylily cells was studied. Space-flown cells were shown to have chromosomal aberration and have reduced rates of cell division.

Biostack. Part of an effort to determine impact of high atomic number energy particles on life in space using three sealed aluminum Biostack containers located in Spacelab, which contained detectors and different biological specimens. Operations of passive detectors were nominal, and after the mission scientists analyzed the data.

Gravisensitivity and Gravi(Geo)taxis of the Slime Mold Physarum polysephalum (Slime Mold). Using the Slow Rotating Centrifuge Microscope, the experiment worked to add to the understanding of how a single cell organism called slime mold senses gravity and attempted to locate specific site at which that perception occurred. Found that the lowest acceleration capable of inducing a response was 0.1*g*, the gravity response was based on direct effects of gravity, and the low acceleration-sensitivity threshold favors rather large dense cell organelles as gravireceptor candidates in Physarum.

Gravitaxis in the Flagellate Euglena gracilis is Controlled by an Active Gravireceptor (Euglena). Tested hypothesis of an active gravireceptor of unicellular flagellate Euglena gracilis under conditions of prolonged microgravity. Random orientation of flagellates at accelerations at and below 0.08*g* confirmed prior results, threshold for orientation was less than or equal to 0.16*g*, and they observed no adaptation during the extended duration of the mission.

Influence of Accelerations on the Spatial Orientations of the Spatial Orientation of Loxodes and Paramecium (Loxodes). Worked to determine the threshold for graviperception of Paramecium and of Loxodes using different accelerations on NIZEMI. Found that the threshold for gravitaxis of Paramecium was between 0.16*g* and 0.3*g*, Loxodes showed no graviresponses to increased accelerations in space but did demonstrate gravitaxis on return to Earth, and prolonged cultivation in space did not change the size and content of barium sulfate of the statocyst organelles of Loxodes.

Chara rhizoids: Studies during a Long Period of Microgravity. Used NIZEMI facility to determine threshold values and minimal amount of gravitational force necessary for rhizoids of the simple plant Chara to react to gravity and change their direction of growth. Demonstrated tip-growing single cells develop normally in microgravity, growing rhizoids maintained their structural polarity and grew straight, and distribution of statoliths was similar to that found in sounding rocket experiments.

Graviresponse of Cress Roots under Varying Gravitational Forces below Earth Acceleration (1*g*) (Cress). Exposed chemically prepared samples of roots from cress plants to varying levels of gravity using NIZEMI to determine lowest level where roots become sensitive to changes in gravity. Found that roots cultivated under microgravity had a higher sensitivity than those grown on the 1*g* centrifuge. Results and those from previous mission suggested nonvalidity of the reciprocity rule, and transformation of gravistimulus occurred near the statoliths.

Cell Microenviromental and Membrane Signal Transduction in Microgravity. Tested possible changes that take place in bacteria during spaceflight by observing cell responses to various stimuli. Observed possible reduced growth lag period of a non-motile culture of E. coli, and found efficient induction of one two-component system regulating the osmoregulation in E. coli in microgravity.

Effect of Stirring and Mixing in a Bioreactor Experiment in Microgravity (Bioreactor). Tested effect of stirring and mixing on growth characteristics of baker's yeast in microgravity, and tested operation of the miniaturized bioreactor. Bioreactor performed well during the flight, found a higher percentage of randomly distributed bud scars in flight cells than in ground cells, and found no remarkable differences in the cell cycle, ultrastructure, cell proliferation and volume, ethanol production, and glucose consumption.

Biological Investigation of Animal Multi-Cell Aggregates Reconstituted under Microgravity Conditions (Aggregates). Evaluated whether organized tissues could be reassembled from single primary cells from dissociated neonatal mouse tissues. Results indicated the initial adhesion among cells was not disturbed in microgravity, and that formation of interconnecting cables did not occur in flight samples.

Replication of Cell Growth and Differentiation by Microgravity: Retinoic Acid-Induced Cell Differentiation (Mouse). Studied effect of microgravity on mouse cell differentiation, which was induced by exposure to retinoic acid. The retinoic acid-induced reporter gene expression was impaired in microgravity, and it was found that there was a need for more experiments to demonstrate effect of microgravity on DNA synthesis.

The Sea Urchin Larva, A Suitable Model for Biomineralization Studies in Space (Urchin). Studied sea urchin embryos and larvae to determine whether the mineralization process that creates the typical sea urchin larva skeleton is normal in space. Found that basic biomineralization occurred in microgravity and no pronounced demineralization was observed. Also found developmental processes such as proliferation and specific differentiation of skeletogenic cells occurred, and the process of their positioning appeared to be more sensitive to environmental factors, possibly including microgravity.

The Effect of Microgravity and Varying Periods of 1*g* Exposure on Growth, Mineralization, and Resorption in Isolated Fetal Mouse Long Bones (Bones). Worked to verify results from IML-1 and other experiments, and tested if varying periods of 1*g* exposure would counteract effects of microgravity on bone mineralization and resorption. Results were verified, which stated microgravity did not affect overall growth but did decrease mineralization, and a decrease in mineralization was not found in long bones placed for 6 hours daily on the 1*g* centrifuge.

Investigation of the Mechanisms Involved in the effects of Space Microgravity on Drosophila Development, Behavior, and Aging (Drosophila). Worked to confirm earlier findings that young male Drosophila fruit flies exposed to microgravity showed acceleration in aging, and studied fruit fly reproduction and development in space. Confirmed accelerated aging of male fruit flies in microgravity, linked increased aging to increased activity and mitochondrial processes, and verified normal development of fruit flies in space.

The Role of Gravity in the Establishment of the Dorso-Ventral Axis in the Amphibian Embryo (Eggs). Examined early stages of frog egg cell division to determine the role gravity plays in directing cell division and differentiation as cells formed a new organism. Found rate of cell divisions unchanged in actual and simulated microgravity, and found that microgravity perturbs blastocoel formation.

Regulation of Cell Differentiation by Gravity in the lentil Root (Lentil). Tested a theory about how gravity-sensing cells at the tip of plant roots regulate root growth. Found that gravity did not affect elongation of roots growing in the vertical position, and the cell cycle in the meristem is regulated by gravity.

Root Orientation, Growth Regulation, Adaptation, and Agravitropic Behavior of Genetically Transformed Roots (Transform). Tested whether growth of plants that grow in any direction, agravitropic roots, apparently unaffected by gravity on Earth was similar to normal roots grown in microgravity. Found similar distribution of amyloplasts in wild-type roots and transgenic root cap cells both in orbit and on the ground. Total growth was higher for roots grown on the ground, and space-grown transgenic root tips were kept alive under sterile conditions.

Plant Growth and Random Walk (Random). Observed root behavior in a weightless environment to increase knowledge of root growth dynamics. Found that average bending direction of plants stayed constant equal to zero despite spontaneous movements performed in weightlessness, the average squared deviation of root movements increased linearly with time during the first period of growth, and growth of roots in weightlessness were smaller than on the ground.

Dosimetric Mapping in Biorack (Biorack). Provided a baseline of radiation data for all Biorack scientists to use when analyzing their respective experiment results. Total doses differed up to a factor of 1.5 and heavy ion fluxes by more than a factor of 6 in different locations, and the mission-equivalent dose for astronauts was calculated from the measurements to be 3.8 mSv.

The Influence of Microgravity on Repair of Radiation-Induced DNA Damage in Bacteria and Human Fibroblasts (Repair & Kinetics). Tested hypothesis that gravity affects ability of biological systems to repair and recover from radiation damage. Results indicated that repair processes function normally in microgravity, the synergistic effects of microgravity and radiation are not a result of a disturbance of intracellular repair, and both prokaryotes and human cells had normal repair pathways in microgravity.

Japanese Space Agency:

Fertilization and Embryonic Development of Japanese Newts in Space. Egg laying was induced in orbit to examine effects of gravity on early development of newt. Development of newt embryos proceeded without fatal disorder at absence of gravity.

Mechanism of Vestibular Adaptation of Fish Under Microgravity. Investigation of the swimming behavior, and adaptation to microgravity and subsequent readaptation on return to Earth using the negative phototropic response as an index, of goldfish from which the vestibule had been removed. The change in swimming behavior and posture due to loss of inputs to the vestibular apparatus under microgravity environment was observed.

Mating Behavior of The Fish Medaka and Development of Their Eggs in Space. To obtain fundamental data for the investigation of fish. The fish mated and laid eggs normally in space. Fish culture technology may be used for the future long-term human space life.

Microgravity Effects on the Growth and Function of Rat Normal Osteoblasts. To reproduce differentiation of bone, which occurs naturally within the body, in a culture medium under microgravity using osteoblasts from marrow from rat femurs, and to clarify effects of microgravity on the expressions of differentiation of bone function such as cell growth, cytokine secretion, and synthesis of bone matrix in terms of indicators such as expressions of cell genes, and cellular secretion of substances related to bone metabolism. Microgravity affects osteoblast differentiation function at the genetic transcription level.

Early Development of a Gravity-Receptor Organ in Microgravity. To clarify role of microgravity on initial development of the gravity receptor in inner ear. Endolymphatic ducts and endolymphatic sacs were elongated rearwards. In the adult newt, all of the otoconia found in the saccule were made of aragonite. These systems developed earlier and were bigger in animals developed in space. Formation of otoconia in the endolymphatic sacs was accelerated in the space sample, and continued increasing on return to Earth.

Gravity and the Stability of the Differentiated State of Plant Somatic Embryos. To determine whether cell division and chromosome behavior in growth process are affected by the space environment. Inhibition of cell division, nuclear anomalies such as micronuclei and polynuclei, and chromosome damage in plant cells were observed.

Dosimetry Measurement and Biological Effects of Heavy Ion Beams in Space Shuttle (Radiation. Effect of Microgravity on DNA repair capability of Deinococcus radiodurans. Accurate investigation of the influence of microgravity on repair of radiation-induced damage using extremely radioresistant bacterium Deinococcus radiodurans. Survival of cells incubated in space increased significantly compared with the control sample on Earth, suggesting that the recovery of this bacterium from radiation damage was enhanced in microgravity.

Dosimetry Measurement and Biological Effects of Heavy Ion Beams in Space Shuttle Radiation. Effects on E. coli Cells and Plasmid DNA. To investigate effects of high-energy cosmic radiation on living organisms using plasmid DNA and a mutant strain of E. coli with defective DNA repair functions, and to obtain an understanding of enzymes related to the form of DNA damage due to cosmic radiation and its repair. No dramatic differences were noted in survivability and rate of induced mutation between space and Earth.

Differentiation of Dictyostelium discoideum in Space. No reproduction of the Dictyostelium discoideum was observed either in orbit or in the control experiment on Earth. Measurement of amoebae reproduction, formation of fruiting bodies, and mutation rate showed no difference between wild strain sample flown in space and control sample on Earth. The radiation-sensitive strain flown in space did not germinate.

STS-64

Somatic Embryogenesis of Orchardgrass in Microgravity. Studied effect of microgravity on development and reproductivity of orchardgrass. Space-flown plants showed reduced cell-division and chromosomal aberrations.

STS-68

Starch Metabolism in Space-Grown Soybean Seedlings. Starch concentration in plant tissue flown in space was tested using space-flown soybean seedlings. Starch concentration was shown to be reduced in space-flown plants, most likely as a result of the decrease in activity of one of the rate-limiting enzymes involved in starch synthesis.

Microgravity Effects on Early Reproductive Development in Plants. Focused on effect of microgravity on the fertility of plants grown in space. Space-grown plants had reproductive development comparable to that of the ground controls, representing the first report of successful plant reproduction in space.

STS-66

Embryonic chicken muscle cell development. There was no effect of microgravity on cellular metabolism or muscle degradation in chick embryonic muscle cells grown in flight, but there was a decrease in protein synthesis and mean myofiber size when compared to ground controls. Chicken embryonic cartilage cells maintained their integrity during flight and produced matrix.

Rodent development in microgravity. Deliveries of litters by rat dams in space were normal although dams did have a significant increase in number of lordosis labor contractions. Flight pups did not exhibit any difficulty in orienting themselves with respect to gravity or retardation in somatic growth. There was no general effect of spaceflight on immune response.

STS-63

Plant growth in microgravity. Microgravity produced genetic alterations in *Triticum aestivum* (super-dwarf wheat) that affected many aspects of the plant's physiology and development: synthesis of ethylene gas; lignification in leaf and root tissues; thickness of cell walls; and enzyme activity. Soybeans flown in space and frozen had a lower starch concentration, lower activity of the starch synthetic enzyme, and higher activity of the sucrose synthetic enzyme than ground controls. Postflight, it was observed that non-frozen seedlings produced twice the amount of ethylene than ground controls.

Immunology experiments with rodents. Results from the rat experiment showed highly variable physiological responses to spaceflight. PEG-IL-2 treatment was not found to be generally therapeutic in relieving the effects of spaceflight on the immune system.

Bone regulation in rodents and chickens during spaceflight. Chicken embryonic osteoblasts showed a reduced gene expression for collagen and osteocalcin and rat L8 myoblast cells showed a significantly decreased ability to fuse and differentiate during spaceflight.

ASTROCULTURE™. See STS-50.

STS-71

Development of Quail embryos in space. Quail embyros in space showed developmental abnormalities, and mortality rate during incubation period was high. No abnormalities in gross morphology were detected.

Long-term plant growth in space. Super-dwarf wheat plants exhibited poor growth and remained vegetative during 90 days in microgravity. Sterile heads of control plants were subsequently determined to be due to ethylene in the Russian space station Mir cabin atmosphere.

Japanese Space Agency Mir experiments:

> Biological Effects of Cosmic Radiation on E. coli, Plasmid DNA, and Human Cells – The Effects on Living Organisms of Long-term Habitation of Space. The surviving number of E. coli cells in space sample was significantly less than that in control sample remaining on Earth due to damaged DNA.
>
> Survival Rates and Genetic Effects on Yeast (Saccharomyces cerevisiae) during Long Term Space Flight aboard the Russian space station Mir. In general, no significant differences were found in the measured mutation frequency between ground and spaceflight.

STS-70

Development of rodents and hornworms in flight:

Deliveries of litters by rat dams in space were normal although dams had a significant increase in the number of lordosis labor contractions. Flight pups did not exhibit any difficulty in orienting themselves with respect to gravity. Minimal differences in bone formation were found between flight and control animals and the phase of circadian rhythms was earlier in flight rats than in control animals. Neither the flight pupae nor the ground controls of tobacco hornworm developed significantly while contained in sealed canisters during the experiment. Depleted oxygen and increased carbon dioxide levels were a possible explanation for the lack of development.

Embryonic cells of daylily did not grow in space as well as ground controls and showed various manifestations of stress. Cells with chromosome breaks, bridges, and double nuclei were found in space samples but not in ground controls.

STS-69

Effects of spaceflight on osteoblasts:

Rat osteoblast cells were lost early after inoculation into cartridges in flight; recovery and growth were slow.

There were no significant differences between flight human fetal osteoblast cells and ground controls.

Moss in space: Adaption of Physarum polycephalum (acellular slime mold) to microgravity led to permanently reduced cAMP levels indicating its role in gravity sensing.

STS-72

Effects of spaceflight on neonatal rats:

Only six out of the 20 rat neonates aged 5 days post natal at launch survived the flight while those aged 8 days post natal or older did better with 19 out of 20 survival. All flight rats weighed less than the corresponding ground controls.

The chicken experiment was not initiated due to a hardware malfunction.

ASTROCULTURE^{TM}. See STS-50.

STS-76

Nematodes in space. Nematodes in space showed little effect of gravity on induced mutation frequency in relation to dosereponses.

Osteobast morphology in space. In mice, microgravity affected osteoblast morphology, gene expression, and prostaglandin content. Space-flown Jurkat cells did not proliferate.

STS-77

Growth Factor and Immune System effects caused by spaceflight. During spaceflight, insulin-like growth factor had a beneficial effect on immune system and bone in rats.

Chicken cartilage cells grown in space. Chicken cartilage cells grew well in space but mineralization was affected, especially in younger cells. Tissue-cultured chicken myofibers' response to microgravity was analogous to muscle wasting that occurs in humans and animals in space.

STS-78

Development of the Fish Medaka in Microgravity. Experiment was to determine whether microgravity environment of space had any effect on the development-from embryo-of the fish medaka. Results showed that fish that developed in space did not demonstrate any major morphological differences from fish that developed on Earth. Also determined that space-developed fish retained their ability to reproduce.

Role of Corticosteroids in Bone Loss During Space Flight. It is well known that bone loss occurs during spaceflight. Experiment was to determine whether the stress-induced hormone corticosteroid, which has been associated with decreased bone formation, contributes to that bone loss. Results indicated that rats in the experiment did show an excess of corticosteroid hormone, but flight rats had normal bone mass on return to Earth, suggesting that the hormone does not contribute to bone loss.

Lignin Formation and Effects of Microgravity: a New Approach. This experiment focused on the effect of a microgravity environment on the formation of a reinforcement tissue called compression wood in woody plants, which is formed to correct stress placed on plants caused by bending. Determined that the control group raised on Earth was essentially identical to the space-raised woody plants, showing that microgravity has no effect on plants' ability to make corrections to bending stress by forming compression wood.

STS-79

Japanese Space Agency. Measurement of the Effect of the Space Environment on E. coli Mutant Cells. The contribution of specific genes to repair of DNA damage due to cosmic radiation was apparent; however, there were considerable variations, and it was clear that there was no major damage as with the IML-2 result.

Effect of Microgravity on DNA Repair Capability of Deinococcus radiodurans. No difference was observed for survival of radiosensitive mutant cells whether incubated in space or on the ground. Compared with control samples, induction of newly found DNA repair-related protein PprA was enhanced in microgravity.

STS-80

Spaceflight effects on rodent physiology. Space-exposed rats showed decreased vessel responsiveness in visceral vascular beds; vascular contraction in flight rats was attenuated and relaxation to acetylcholine was diminished.

Human hFOB cells showed vigorous growth during flight and responded to spaceflight primarily in cytokine gene expression rather than in cell function and proliferation.

STS-81

Microbial growth at microgravity. Bacterial growth was enhanced in microgravity compared to spaceflight centrifuge 1*g* and Earth-based controls. Regulation of fibronectin during spaceflight. Analysis of transcriptional and translational control of fibronectin in mice showed that fibronectin regulation does not directly change cell shape, bone matrix formation, or bone growth in microgravity.

Effects of spaceflight on seedlings of mouse-ear cress were smaller and had greater root hair density and abnormal hypocotyl hook structure than ground controls (stationary and rotating clinostat).

Effects of spaceflight on T-cells. Human T-cells, when stimulated with bead-mAb in microgravity, showed a random orientation of microtubule organizing center relative to the cell-bead contact site, which inhibited activation of T-cells.

Spaceflight effects on sperm motility. Microgravity significantly stimulated sperm motility in sea urchins and altered signal transduction pathways via temporal pattern of FP130 phosphorylation.

STS-84

Japanese Space Agency-Mir experiment. An Experiment to Determine the Biological Effects of Cosmic Radiation - Research Involving Induced Mutations in Bacillus subtilis Spores. Focused on genetic effects in an investigation of induced mutations in Bacillus subtilis spores as part of research on biological effects of space environment conducted on the Russian space station Mir. An approximately twofold induction in mutation frequency by the flight was observed with both wild and ultraviolet-sensitive strains.

Japanese Space Agency-Mir experiments:

> The effects of cosmic radiation on diapause silkworm eggs. Differences in hatching and pupation were observed between eggs on Mir and eggs on Earth, but no differences were observed in emergence. Mutation frequency on Mir was 12.4 x 10-3, which is quite high compared with a spontaneous mutation frequency on Earth of n x 10-5.
>
> Effects of Radiation on the Development of Silkworm Embryos. From these results, it appears that unsuccessful blastokinesis and abnormal appearance could be related to exposure to radiation in space and microgravity.

Differentiation and Morphogenesis of Cellular Slime Mold in Space Germination on Earth of spores recovered from live strains was slightly delayed; however, there was no difference in frequency of mutations between space and control samples. No spores were recovered from fruiting bodies of radiation-sensitive strains.

STS-85

Biological Research in Canisters-10. Studied gravitational effects on growth, development, and metabolic processes in Arabidopsis thaliana and tobacco seeds. Investigations identified and cloned genes whose expression is altered when plants are grown in microgravity.

STS-87

Collaborative Ukrainian Experiment. Collection of 10 space biology experiments that included experiments on the Brassica rapa plant, soybeans, and moss was designed to compare changes in ultrastructure, biochemical composition, and function induced by microgravity on the photosynthetic apparatus of Brassica rapa seedlings at different stages of vegetative development, and compare pollination and fertilization processes in microgravity with ground controls. Many students performed the experiment on the ground while the experiments were being conducted on orbit. All operations of the experiments went extremely well and all planned operations were successfully completed.

STS-89

Snails reared in microgravity were about 30% larger than ground controls and showed a significant increase in total statoconial volume.

Flight swordtail fish showed an intense distribution of Immunoreactive-Galanin in the cell bodies of the NOR and a sparse distribution of FMRF-amide fibers in the brains when compared to laboratory controls.

Japanese Space Agency. An Expression Analyses of Genes and Proteins in Yeast Cells Exposed to Cosmic Radiation. Experiment showed that yeast should grow in space in a similar manner to that on Earth, and that the rate of this growth exceeds that on Earth in the case of static cultivation.

STS-90

The Effects of Spaceflight on the Ultrastructure of the Cerebellum. Studies performed in rats that were taken on flight gave a structural basis for neuronal and synaptic flexibility and modifiability in architecture and function due to the effects of microgravity. This adaptation to microgravity resembles neuronal alterations in some neurological disorders, such as a stroke, and the findings may give new insight into rehabilitation and treatment of these disorders.

Italian investigator. Gene Expression in the Rat Brain During Spaceflight. Measuring the expression of certain genes-Fos and Fra in this case-allows the researcher to determine what structures in the brain are being modified. Results identified brain regions that are most affected by adaptation to weightlessness and the subsequent readaptation to Earth's gravity.

Ribbon Synaptic Plasticity in Gravity Sensors of Rats Flown in Neurolab. Experiment indicated that synaptic adaptation to weightlessness occurs rapidly, but synaptic changes are not identical for the two different types of hair cells and maculae. This is a significant finding in regard to long-duration human space travel and also recovery for Earth-based balance disorders.

Japanese investigator. Neural Re-Adaptation to Earth's Gravity Following Return from Space. Spaceflight and weightlessness resulted in a threefold response magnitude of inner-ear gravity sensors to side-to-side movement compared to the earthbound control group; however, 30 hours postflight side-to-side response had returned to normal, parallel with improvement in balance of astronauts postflight.

Ensemble Neural Coding of Place in Zero-G. The brain creates a mental map of a familiar environment using selective neuron fire and external landmarks to mark a subject's place in the environment. Rats during flight had abnormal neuron fire in relation to external landmarks initially, but recovered later in the flight, thus providing a corollary for the disorientation experienced by astronauts initially in spaceflight.

Spanish investigator. Motor System Development Depends on Experience: A Microgravity Study of Rats. Rats raised in microgravity and rats raised on Earth showed significant difference in motor behavior and neuro-anatomical structure. This shows that a motor system-animal or human-adapts for optimal function within the rearing environment, sometimes with changes being permanent.

Neuromuscular Development is Altered by Spaceflight. Determined that weight-bearing activity, absent in a microgravity environment, is necessary for correct development of slow twitch, weight-bearing, and anti-gravity muscles. The development of fast twitch muscles and the elimination of multiple nerve connections to muscle fibers both proceeded the same as the earthbound control group, illustrating that simple movement is enough to develop these.

Gravity Plays an Important Role in Muscle Development and the Differentiation of Contractile Protein Phenotype. The different types of the muscle contraction gene MHC (slow and fast twitch types) are expressed early in development. Discovered that normal weight-bearing activity is essential for expression of slow twitch MHC gene, found in anti-gravity muscles, and is necessary for establishing body and muscle growth in young animals.

Early Developments of Gravity-Sensing Organ in Microgravity. Otholiths are dense stones that rest on sensitive hairs of gravity- and motion-sensing cells, allowing subject to determine direction of gravitational pull. Fish and snails reared in space grew otholiths much larger than ground-reared fish and snails to compensate for the reduced weight of the stones in space, illustrating a critical period of development that can alter growth of gravity-sensing organs.

German investigator. The Development of an Insect Gravity Sensory System in Space CRISP (Crickets in Space). Crickets were born and reared in a microgravity environment on flight to study development of the gravity sensory system. It was shown that development of the gravity sensory system is governed not only by genetic programs, but also by gravitational experience.

French investigator. Development of the Vestibular System in Microgravity. Development of the gravity-sensing organ in rats that are raised in a microgravity environment is not affected; however, nerve connections of these organs to the brain were greatly affected, suggesting that gravity may be important for normal development of the balance system.

Japanese investigator. Development of the Aortic Baroflex in Microgravity. The aortic baroflex receptors are responsible for sensing pressure in blood vessels and sending this information to the brain. Development of the receptors is affected by being reared in a microgravity environment, causing a permanent reduction in the nerve fibers, but the function of the blood pressure control system can readapt to Earth's gravity despite the structural difference.

Neural Development Under Conditions of Spaceflight. Data from this experiment demonstrated that over the studied development window, any impact microgravity has on neural development is short term. Differences cause by microgravity development returned to normal soon after return to Earth.

The Effect of Weightlessness on the Developing Nervous System. Developing brains of young mice were labeled during spaceflight with two markers of DNA synthesis and preserved in fixative for analysis postflight. Work to determine exactly how brain development is modified by microgravity continues, but the experiment demonstrated complex brain studies can be performed in space.

The Effects of Spaceflight on the Rat Circadian Timing System. The circadian timing system is what mammals use as their biological clock on when to sleep and when to be active. Experiment demonstrates that microgravity affects properties of the circadian timing system, specifically the period temporal organization, and synchronization to an external light-dark cycle.

STS-91

Japanese Space Agency:

Analysis of Gene and Protein Expression in Cells Exposed to Cosmic Radiation. See STS-89.

Effects of Microgravity on Recovery of Damaged DNA. Enzymatic activity of DNA ligase that rejoins double strand breaks of DNA molecules artificially synthesized with a restriction enzyme was studied during flight. Results suggested that microgravity hardly affects ligation step of DNA repair processes.

Research Into the Effects of the Space Environment on Induced Synthesis of DNA Recovery Protein. Experiment was designed to elucidate this phenomenon by analysis of the process of recovery from DNA damage at molecular level, and to clarify effects of space environment on DNA repair function of organisms.

The phenomenon of accelerated recovery from radiation damage in the radiation-resistant bacteria Deinococcus radiodurans in space was once again confirmed.

STS-95

Results from flight chicken cells were indeterminable.

Results for oyster toadfish are a combination from STS-95 and STS-90 (Neurolab). Overall, there was an up-regulation of the sensitivity of utricular afferents in flight subjects.

Japanese Space Agency:

Growth Regulation Mechanisms in Higher Plants Under Microgravity Conditions - Changes in Cell Wall Metabolism. Higher plants are subjected to a force of 1*g* on Earth and have evolved a cell wall structure of appropriate strength. As this strength is not required in the microgravity environment of space, it was predicted that metabolism of components of the cell wall structure would change, resulting in softer and more extensible cell walls, thus leading to growth promotion. Results showed growth promotion and changes in cell wall structure.

Gravimorphogenesis in Cucurbitaceae Plants: Development of Peg Cells and the Mechanism of Graviperception in Cucumber Seedlings. When cucumber seedlings are germinated horizontally on Earth, seedlings develop a single peg at the boundary between root and hypocotyls; however, under microgravity, a pair of opposing pegs developed at this location.

Plant Growth and Development, and Auxin Polar Transport Under Microgravity Conditions in Space. To understand growth and development of higher plants under microgravity conditions, clarification of the relationship between gravity and auxin polar transport demonstrated that automorphogenesis and significant growth inhibition occurred in seedlings grown under microgravity conditions in space.

Electrotropism and Gravitropism of Roots of Higher Plants (wild and mutant strains). In this experiment, an electric field was applied to roots while under microgravity, and effects of the electric field and microgravity on growth were observed. In space, this dependent relationship between elongation and the electric field is inactive and thus no longer suppressing growth in the distal elongation zone, while at the same time increasing sensitivity to electric fields to an abnormal degree.

Biological Research in Canister-13 Experiment based on a model system, *Dactylis glomerata* L., for studying the initiation and development of plant embryos. Earlier studies conducted in space indicated that microgravity inhibits earliest cell divisions that lead to embryo formation, which could result in seeds that are formed improperly or seeds that are unable to produce another generation of plants. Results did not show the significant and consistent reduction in embryogenesis obtained in the earlier experiment.

Biological Research in Canister-PEG/C. Objective was to analyze cellular and molecular development of cucumber seedling in microgravity and understand mechanisms by which gravity affects germination. Specific goal was to assess the effect that growth in microgravity has on expansion gene expression and to relate such changes to morphological alterations found for gravity-sensitive peg development. Results indicated there were no detectable differences in expansion gene expression levels for pegs of seedlings grown in space.

ASTROCULTURE™. See STS-50.

STS-93

Biological Research in Canister-11. To grow plants in space, it is essential to understand the effect of microgravity on growth and development, especially at the molecular and cell biological level. The goal was to investigate gravity-regulated gene expression by using Earth- and space-grown seedlings. Data from microarray analysis indicated that expression of certain genes is regulated in microgravity.

STS-101

Gene Transfer Experiment using ASTROCULTURE™ Glove Box. Evaluated method for production of commercially important transgenic plant materials in microgravity using Agrobacterium tumefaciens.

STS-106

Commercial Generic Bioprocessing Apparatus. Explored the ways biological processes are affected by microgravity. One experiment flown examined how spaceflight affected developing system of fruit fly (*Drosophila melanogastor*). Experiment performed nominally during flight with the crew performing daily status checks.

National Institutes of Health B1. Effects of spaceflight on nervous system development and neuromuscular synapse formation were tested in a model genetic organism, *Drosophila melanogaster*. It was observed there were borderline-to-no effects on synaptic connectivity and modest effects on bouton anatomy. There was a significant change in the size of the arbors, their branch number, and number of boutons. These changes are similar to effects seen with a variety of characterized genetic activity mutations. Effects involve postembryonic development, and not those seen with early outgrowth and target recognition. It was also observed that the effects scaled with gravitational exposure, with hypergravity effects running opposite to those that developed on shuttle. Hypergravity effects also showed defects in muscle development including aberrant musculature.

STS-108

Spaceflight effects on bone strength. Mice exposed to microgravity exhibited a decline in femur elastic strength and bone formation when compared to controls. Osteoprotegerin mitigated decline in mechanical strength by preventing an increase in resorption and maintaining mineralization. Spaceflight also induced changes in immune functions, hematopoiesis, and mRNA expression of genes associated with muscle growth and fiber type in mice.

Effects of spaceflight on Quail embryos. Quail embryos in space demonstrated that bone and cartilage are differentially affected; no effects of flight were seen in cartilage or osteocalcin while osteoblast activity declined even in the group maintained on the centrifuge at 1*g*.

Avian Development Facility. Performed tests to validate facility's subsystems and reduce risk in developing next generation of avian development hardware space. Supported experiments that used Japanese quail eggs to study how lack of gravity affects development of avian embryos.

STS-107

Biological Research In Canisters-14. Studied how gravity influences internal structure of moss cells and seeks to understand influences of spaceflight environment on cell growth by determining: age or developmental stage at which moss grows in a non-random pattern when exposed to microgravity conditions; minimum illumination level required to impose a phototropic response on growth pattern of moss in absence of gravity; and, to understand how microgravity affects distribution of cell substructures. After Columbia accident (STS-107), moss colonies were recovered in every experiment container and were sent for analysis.

Biological Research In Canisters. Flew C. elegans nematodes to verify a new synthetic nutrient solution for an International Space Station "model" specimen planned to be used extensively for International Space Station gene expression studies. C. elegans, which were descendents of flown specimens, were retrieved from recovered hardware and all three temperature recorders were recovered and successfully downloaded. Biotube/Magnetic Field Apparatus. Designed to provide insight into the organization and operation of gravity-sensing system of plants and other small organisms. No postflight microscopic data were obtained, but macroscopic data derived from downlinked images provided some information about root growth in a magnetic field in absence of gravity.

ASTROCULTURE™. See STS-50 for description. Sufficient data and video of hardware operation and plant health status allowed for engineering return from this flight.

STS-125

National Laboratory Pathfinder-Vaccine-1C. A commercial payload in support of National Laboratory Pathfinder initiative, which contained pathogenic organisms to be examined to develop potential vaccines for prevention of infections on Earth.

STS-121

Commercial Biomedical Test Module – 2. Used a validated mouse model to examine effectiveness of an experimental therapeutic as a possible countermeasure for muscle atrophy. Combined with exercise, this experimental therapeutic developed by Amgen could one day form the basis for a treatment that will help maintain a high level of physical fitness in future flight crews.

STS-115

Effect of Spaceflight on Microbial Gene Expression and Virulence. Worked to determine effect of spaceflight on virulence potential of pathogenic microorganisms, Salmonella typhimurium, Pseudomonas aeruginosa, and Candida albicans immediately following their return from spaceflight. A wealth of knowledge was obtained from the experiment on orbit. Purpose of experiment was to examine global effects of spaceflight on microbial gene expression and virulence attributes. Experiment was the first study to examine effect of spaceflight on virulence of a pathogen. Results showed that Salmonella grown in spaceflight displayed increased virulence, biofilm-like formation, and global alterations in global gene expression, as compared to synchronous ground controls.

Yeast-Gap. Studied how individual genes respond to microgravity conditions in an attempt to better understand how mammalian cells respond when they are grown in microgravity as well as improve culturing techniques of mammalian cells on Earth.

STS-118

Streptococcus pneumoniae Expression of Gene in Space examined behavior and growth of bacteria in microgravity and investigated effects of the space environment on gene expression, protein production, and virulence of the bacteria *Streptococcus pneumoniae*. Data collected provided insight on what types of bacterial infections may occur during long-duration space missions and the risks to crew members.

STS-121

Phototropism. Objectives were to understand cellular mechanism of phototropism in plants and determine effects of gravity on light perception in plant roots. Results were indeterminate due to software and operation issues.

Fungal Immunity. Investigated immune system function after exposure to spaceflight environment. Fruit flies reared in space for a complete generation showed altered immunity, exhibiting an increased ability to clear a bacterial challenge. Several immunity-related genes were differentially expressed compared to control flies reared on the ground. Paradoxically, at the larval stage, the immune response was depressed, and hemocyte count and effectiveness of phagocytosis of bacterial challenge were both reduced.

STS-123

Bacterial Physiology and Virulence on Earth and in Microgravity to investigate the virulence of *Pseudomonas aeruginosa* in spaceflight compared to that on Earth. RNA gene microarray analyses showed that, overall, 348 genes were either up- or down-regulated. Of the three variables (strain, medium, and spaceflight), the medium had the most effect on gene expression, followed by strain and spaceflight.

Drug Resistance and Virulence. Objective was to investigate alteration in antifungal drug response of *Saccharomyces cerevisiae* after growth in spaceflight compared to growth on Earth.

STS-126

Differentiation of Bone Marrow Macrophages in Space. Investigated how long-term exposure to microgravity affects production of cells critical to the human immune system. Goal was to determine how mouse macrophage differentiation was suppressed during spaceflight. Based on cell surface markers, macrophage differentiation is affected by spaceflight. There was an increase in transcript levels for 74 genes and a decrease in transcript levels for 217 genes. STS-126 confirmed that spaceflight increases cell growth compared to ground controls.

STS-129

Streptococcuspneumoniae Gene Expression and Virulence (reflight). Studies on STS-118 and STS-123 have shown that virulence properties of *S. pneumoniae* increase under spaceflight and simulated microgravity conditions. The STS-129 study furthered the understanding of virulence enhancement and aided in developing countermeasures to protect space travelers from infectious diseases during long-term flight.

STS-130

Phototropism. *Arabidopsis thaliana* seeds were sent into space to better understand how and why plants grow differently in microgravity than on Earth. Scientists used data to better understand how light and gravity affect plant growth. Future astronauts may be able to grow plants as part of life support systems on long-duration space missions to the moon or Mars.

STS-131

Mouse Immunology-1. Spaceflight-induced immunosuppression is a significant obstacle to long-term human space travel. Of foremost concern is whether astronauts/cosmonauts may be able to generate effective protective immune responses against infections while in spaceflight. An innovative mouse experimental model was developed to study how the immune system responds to challenges to the immune system while in the microgravity environment.

Space Tissue Loss. The Stem Cell Regeneration experiment was designed to determine how cells develop into specialized tissue types, or "differentiate" in space. Mouse embryonic stem cells were used because they can differentiate into any type of adult tissue found in the body. Scientists are using them to investigate the ways cells grow and regenerate to better understand the cellular, biochemical, and genetic processes of healing wounds and tissue development in space.

Space Tissue Loss. Goal of Immune Space Tissue Loss experiment was to characterize human cell immune and stress responses to microgravity and the challenge of an infectious agent, *Salmonella typhimurium*, thus providing unique insight into conditions faced by astronauts during spaceflight, as well as how cells in our bodies behave or transition to disease caused by infection, immune disorders, or cancer.

Biological Research in Canister -16. Studied effects of microgravity on the structure and organization of the actin cytoskeleton in plants. This investigation builds on previous ground-based and spaceflight research using the model plant *Arabidopsis*. The study improved knowledge of the basic mechanistic processes, which is vital to develop ways to use plants in extraterrestrial bioregenerative life support systems.

STS-132

Gravitational Effects on Biofilm Formation During Spaceflight. The Micro-2 experiment looks at how gravity alters biofilm formation with the goal of developing new strategies to reduce their impact on operation of spacecrafts and health of their crews.

STS-133

Mouse Immunology-2. Worked to expand knowledge base of effects of the space environment on mammalian immunology. This knowledge base will lay a foundation for applications that will help future long-duration space-flight. Experiment was successfully completed during mission.

Growth and Survival of Colored Fungi in Space (CFS-A). Worked to determine effect of microgravity and cosmic radiation on growth of colored fungi species. Experiment was completed during mission.

STS-134

BIOKon In Space (BIOKIS). Group of seven experiments sponsored by the Italian Space Agency studied cellular biology, radiation and radioprotection, aging germination, and plant growth with the aim to evaluate various biological species to determine genetic distinctions. Experiment was activated on Flight Day 2, was manipulated on Flight Day 3 and 4, and was stowed for return on Flight Day 16.

Eyespots and Macular Pigments Extracted from Algal Organisms Immobilized in Organic Matrix with the Purpose to Protect Astronaut's Retina (Night Vision). Studied response of microalgae strains, which contain eye spots similar to human retina, to space radiation to obtain results applicable to future nutrition programs for astronauts. Experiment operated passively using a battery.

STS-135

Biological Research in Canisters Symbiotic Nodulation in a Reduced Gravity Environment. Investigated microgravity effects associated with microbe-host interactions and cell-cell communication using a plant-bacteria model system. Experiment directly addressed impact of space environment on microbial virulence in a constructed ecosystem.

Assessment of sclerostin antibody as a novel bone-forming agent for prevention of spaceflight-induced skeletal fragility in mice. Used Commercial Biomedical Testing Module-3 to investigate a novel anabolic therapy for prevention of spaceflight-induced skeletal fragility in mice due to observed bone loss in both humans and animals during reduced gravity of spaceflight.

Vascular Atrophy Commercial Biomedical Testing Module-3: STS-135 Space flight's affects on vascular atrophy in the hind limbs of mice. Examined effects of spaceflight on skeletal bones of mice and efficacy of a novel agent that might mitigate loss of bone associated with spaceflight.

Gravitational Effects on Biofilm Formation During Space Flight. Studied how gravity altered biofilm, the aggregation of microorganisms, and formation with the goal to develop new strategies to reduce crew health impact and to minimize harmful effect of biofilm on materials in space and on Earth.

Recombinant Attenuated Salmonella Vaccine. Evaluated ability of spaceflight platform to accelerate recombinant attenuated Salmonella vaccine development against pneumococcal pneumonia to facilitate design and development of next-generation vaccines with improved efficacy and protective immune responses while minimizing unwanted side effects.

3.8 Astronaut Health and Performance

STS-1

Microbial Screening. Performed on 10 missions. Determined that post-flight microbial levels were 20% to 80% higher than preflight levels and that the amount of microorganisms increased with flight duration, indicating that better air filtration methods were needed to protect astronauts from becoming sick as a result of microorganisms.

Validation of Predictive Tests and Countermeasures for Space Motion Sickness. Performed on 15 missions. Focused on determining whether ground-based tests or parameters can be used to predict susceptibility of astronauts to space motion sickness. Results indicated that a single test or parameteris inadequate for predicting space motion sickness and that a large number of cases will be needed to construct a composite index to predict space motion sickness.

Cabin Atmosphere Verification. Sampled cabin atmosphere to characterize contaminant buildup and outgassing behavior of Orbiter components. All levels of contaminants remained well below established safe limits during flight.

Cabin Acoustical Noise. Worked to quantitatively measure extent to which on-orbit cabin acoustical noise met or exceeded levels specified by Johnson Space Center Design and Procedural Standard 145 and aimed to ensure that noise levels were operationally acceptable. Measurements showed excessive noise at a variety of locations, with middeck having generally higher noise than flight deck. From a physiological point of view, noise levels measured were not hazardous to crew members' hearing.

Radiation Dosimeters. Measured, at various points in Orbiter and on crew, radiation dosages received during flight, and maintained medical records of data. Dosimeters were delivered, placed, deployed, re-stowed, and retrieved according to plan. After flight, dosimeters were exposed to radiation and data were lost.

STS-2

Microbial Screening. See STS-1.

Validation of Predictive Tests and Countermeasures for Space Motion Sickness. See STS-1.

Cabin Atmosphere Verification. Determined whether any trace contaminant gas buildup occurred in Orbiter crew cabin during a mission. Toluene was the only compound that approached maximum allowable concentration, and it was found that contaminants falling into systematic poisons category surpassed what was considered an acceptable value.

Cabin Acoustical Noise. See STS-1 for description. Noise levels measured were not hazardous to crew's hearing from a physiological point of view, but some temporary hearing shifts could be experienced.

Radiation Dosimeters. See STS-1 for description. Radiation level doses were low, and in good agreement between measurement methodologies.

STS-3

Microbial Screening. See STS-1.

Validation of Predictive Tests and Countermeasures for Space Motion Sickness. See STS-1.

Cabin Atmosphere Verification. Sampled cabin atmosphere to characterize contaminant gas buildup and outgassing behavior of Orbiter. No toxic hazards of any kind were detected.

Food Packaging. Worked to obtain a subjective evaluation of a new food packaging concept as designed for shuttle operations. Only three packages were used, and it was felt that overall negative reaction to packages was due to lack of training of crew in their use.

Radiation Dosimeters. See STS-1 for description. Radiation dosages received by the crew was in agreement with calculated values, but calculated values at various locations within crew compartment were expected to vary by as much as a factor of two, and that was not indicated by measurements.

STS-4

Cardiovascular Deconditioning Countermeasure Assessment. Performed on eight missions. Fluid shifts as a result of exposure to microgravity can cause orthostatic intolerance, fainting, or light-headedness due to standing, upon return to Earth. Astronauts drank a combination of rehydration fluid and intake salt as a countermeasure to orthostatic intolerance. Results showed that astronauts who consumed fluid and salt had a greater orthostatic tolerance than those who did not, resulting in all subsequent shuttle crew members using rehydration fluid and salt as a countermeasure.

Microbial Screening. See STS-1

Validation of Predictive Tests and Countermeasures for Space Motion Sickness. See STS-1.

Cabin Acoustical Noise. See STS-1 for description. Although data were sparse, it was found that noise levels were not hazardous to crew's hearing although some temporary threshold shifts could have been experienced.

Cabin Atmosphere Verification. Obtained a single sampling of cabin atmosphere for evaluation of contaminant buildup. No toxicological concerns were found.

Space Transportation System Food Packaging Evaluation. See STS-3 (Food Packaging) for description. All objectives were met, and the crew was satisfied with overall performance of new package except for the larger volume of trash that was generated.

The Effects of Space Flight on Levels of Trivalent Chromium in the Body. Aimed to determine whether any alterations occurred in chromium metabolism of crew. No significant changes in body's level of trivalent chromium were found; however, due to abbreviated flight of STS-4, not enough time was provided for a conclusive study.

The Effects of Diet, Exercise and Zero Gravity on Lipoprotein Profiles. Worked to clarify effects of some important variables that might have promoted arterial disease in spaceflight. Found that a 7-day period of weightlessness did not adversely impact serum lipid factors, which are known to raise risks of atherosclerosis. It appeared that microgravity reduced impact of those risk factors.

Radiation Dosimeters. See STS-1 for description. Found that the crew was not exposed to dangerous amount of radiation during flight.

STS-5

Extra Ocular Motion Studies, Pre-, In, and Post Flight. Purpose was to determine whether any abnormalities of horizontal and vertical extraocular motion existed and whether techniques and hardware for measuring this were adequate for spaceflight. Results indicated that there was no evidence of abnormal extraocular motion during spaceflight, with or without space motion sickness, and that hardware used for the experiment was unsuitable for spaceflight.

Near Vision Acuity and Contrast Sensitivity. Performed on nine missions. Two different methods, near vision acuity and contrast sensitivity, were used to assess effect that microgravity has on astronauts' visual ability. Results indicated no significant effect on astronauts' near vision acuity and only a small effect on contrast sensitivity, showing that any visual impairment caused by microgravity would not expected to cause major visual performance degradation.

Assessment of Circadian Shifting in Astronauts by Bright Light. Performed on 32 missions. Studied whether use of bright light on ground could shift circadian rhythms (sleep schedules) by 9 to 12 hours. Results indicated that this was a viable method for helping astronauts shift their sleep schedules prior to flight.

Cardiovascular Deconditioning Countermeasure Assessment. See STS-4.

Head and Eye Motion During Ascent and Entry. Monitored and recorded horizontal and vertical extraocular eye motion before, during, and after launch and re-entry and determine the best method of measurement. Results indicated that there were no large anomalies caused by launch or re-entry and that the method used on STS-8, a two axis rated gyro, was best method for measuring head and eye motion.

Head and Gaze Stability During Locomotion. Performed on 35 missions. Studied changes to locomotor control caused by microgravity and it was determined that coordination between vertical trunk movements and pitched head movements was the major problem and may account for "bouncing" gaze experienced postflight. Observed that veteran astronauts re-adapted to Earth's gravity fastest, suggesting preflight training could be used to help reduce this effect.

Microbial Screening. See STS-1.

Validation of Predictive Tests and Countermeasures for Space Motion Sickness. See STS-1.

Cabin Atmosphere Verification. Obtained cabin atmospheric sample to allow postflight evaluation of cabin atmosphere for trace gas buildup. Higher than expected levels of methane and carbon monoxide were detected, but not in quantities sufficient to raise questions about health of crew. Columbia was proven to maintain a relatively clear and safe cabin atmosphere.

Kinesthetic Ability. Obtained data to determine whether weightlessness results in a shift of body's limb position servo properties. Appeared to be a marked difference in unloaded and loaded accuracies in-flight but relatively little difference between 1*g* and weightlessness. The small amount of data precluded statistically significant analysis.

Photographic Documentation of Body Fluid Shifts. Attempted to measure magnitude of shift of body fluids, especially to the head, and to relate this to individuals affected by Space Adaptation Syndrome and to demonstrate an improved method of measuring limb volume changes. While stockings appeared to have been properly used and changes were present, magnitudes of changes were not consistent with previous work.

STS-6

Extra Ocular Motion Studies, Pre-, In, and Post Flight. Attempted to determine whether there were any abnormalities of horizontal and vertical extraocular motion and whether techniques and hardware for measuring this were adequate for spaceflight. No abnormalities were detected and based on results from STS-5, a precision pantograph mounting was used instead of a flexible head potentiometry and vertical extraocular motion studies were eliminated.

Eye Head Motion During Ascent, Entry, and On Orbit (Gyroscopic Head Motion Measurements). Goal was to demonstrate use of different hardware for use in measuring head motion, which is used to measure eye motion. A model-airplane single axis gyroscope was attached to astronaut's helmet and used to measure head motion. Experiment was successful, but a mounted potentiometer produced better results.

Near Vision Acuity and Contrast Sensitivity. See STS-5.

Assessment of Circadian Shifting in Astronauts by Bright Light. See STS-5.

Cardiovascular Deconditioning Countermeasure Assessment. See STS-4.

Head and Eye Motion During Ascent and Entry. See STS-5. Used a single axis gyroscope to measure head motion.

Head and Gaze Stability During Locomotion. See STS-5.

Microbial Screening. See STS-1.

Validation of Predictive Tests and Countermeasures for Space Motion Sickness. See STS-1.

Medical Restraints and Resuscitator Evaluation. Evaluated medical equipment that might have been needed during an on-orbit emergency. The medical equipment operated well, and it was recommended that medical restraints and resuscitator be standard equipment in medical kit on future flights.

Noise Level Survey. Measured extent to which on-orbit Space Shuttle Challenger cabin acoustic noise met or exceeded specified levels, and worked to verify that noise levels on Challenger were operationally acceptable. Noise levels measured on STS-6 exceeded by 5 to 15 dB at most measurement locations, but was not deemed hazardous to crews' hearing.

Photographic Documentation of Body Fluid Shifts. See STS-5 for description. Qualitative changes could be easily seen.

Inflight Audiometry. Tested and documented crew's ability to hear since there was an apparent loss of hearing due to fluid changes in inner ear. In spite of high noise levels, a decrease in audiometry was found beyond that accountable for by noise alone. Consistent improvement was found by the fourth day.

Cabin Atmosphere Verification. See STS-5 for description. No contamination was found.

STS-7

Extra Ocular Motion Studies, Pre-, In, and Post Flight (Saccadic Tracking). Examined the effect of flight, re-entry, and landing on the performance and strategies of saccadic tracking (i.e., tracking is the rapid motion of the eyes from one target to another to track the different targets). Results indicated significant increases in saccade velocity in flight, but no difference in accuracy.

Extra Ocular Motion Studies, Pre-, In, and Post Flight. Documented abnormalities in horizontal extraocular motion before, during, and after flight and during and after space motion sickness. An Optokinetic drum, driven at different angular rates, was added to the procedures, but results still showed no abnormalities in extraocular motion of subjects.

On Orbit Head and Eye Tracking Task-Optokinetic Study. Studied whether the reflex was affected by microgravity. Determined that microgravity had no effect on the reflex loop. Optokinetic reflex loop is responsible for continuous tracking of a moving series in targets, such as a passing scene during movement, as well as pursuit tracking.

Opthalmoscopy. Performed on two missions. Intercranial pressure could be a cause of the space motion sickness and fluid shift that astronauts experience in spaceflight could cause the pressure. Veins found in the retina are the first place where an increase in intercranial pressure manifests itself. Results showed no abnormalities in the veins, demonstrating that intercranial pressure is not a cause of motion sickness.

Near Vision Acuity and Contrast Sensitivity. See STS-5.

Cardiovascular Deconditioning Countermeasure Assessment. See STS-4.

Microbial Screening. See STS-1.

Validation of Predictive Tests and Countermeasures for Space Motion Sickness. See STS-1.

Kinesthetic Ability. See STS-5 for description. Equipment functioned properly, and good data were obtained.

Leg Volume Stocking- Plethysmography. Attempted to measure magnitude of shift of body fluids, especially to the head, and to relate this to individuals affected by Space Adaptation Syndrome. Good preflight, in-flight, and postflight data were obtained from two crew members.

Cabin Atmosphere Verification. See STS-5.

STS-8

Extra Ocular Motion Studies, Pre-, In, and Post Flight (Saccadic Tracking). See STS-7.

Extra Ocular Motion Studies, Pre-, In, and Post Flight. Experiment to determine whether an astronaut develops abnormalities in extraocular motion during spaceflight. Used voluntary head oscillation and whole body horizontal angular oscillation to measure extraocular motion. Results showed no abnormalities in extraocular motion.

Eye Head Motion during Ascent, Entry, and On Orbit (Gyroscopic Head Motion Measurements). A turntable for rotation of an astronaut's entire body in the horizontal plane as well as a two-axis gyroscope was used to study eye and head motion, which is a different method than used on previous flights STS-5 and STS-6. Results showed the new method was adequate for making measurements while reducing weight and cost compared to other methods.

Opthalmoscopy. See STS-7.

Near Vision Acuity and Contrast Sensitivity. See STS-5.

Cardiovascular Deconditioning Countermeasure Assessment. See STS-4.

Head and Eye Motion During Ascent and Entry. See STS-5.

Microbial Screening. See STS-1.

Preflight and Postflight Parallel Swing Tests. Performed on three missions. The otolith tilt-translation reinterpretation hypothesis was that effects of microgravity on balance system would result in a decrease in the astronaut's ability to sense tilt and translation. Experiment supported assertion of hypothesis and helped provide a basis for proposing a Preflight Adaptation Trainer to prevent disorientation of astronauts experienced during spaceflight and return to Earth.

Validation of Predictive Tests and Countermeasures for Space Motion Sickness. See STS-1.

Acceleration Detection Sensitivity. Worked to determine whether gain of otolith organs was changed by weightlessness and in what direction. All data recorded were questionable due to crew members' great sensitivity to angular motion. A better subject/spring interface was needed to get accurate, reliable data.

Kinesthetic Ability. See STS-5 for description. Test was started, but was eventually eliminated due to time constraints.

Photographic Documentation of Body Fluid Shifts. See STS-5 for description. Satisfactory photography were made of all crew members postflight and in-flight.

In-flight Audiometry. See STS-6 for description. On-orbit examination of by tympanometric testing crew members showed them to be a little tense with little or no pars flaccid movement during insufflation. This, with absence of a good noise level measurement, made threshold measurement questionable.

Body Mass Measurement. Two crew members were to perform linear acceleration tests to determine body mass in orbital flight. No problems occurred with test, except it took too long to stabilize beam balance.

Treadmill Photography. Worked to obtain photographic verification of proper raw exercise treadmill operation. Preflight, 16mm was taken in lateral plane, 12 fixed point were required on treadmill to analyze film, and initial set of points was incompatible with analysis procedure.

Tissue Pressure-Tonometer. Noted lateral counterpressure to help approximate fluid shifts from legs to help study Space Adaptation Syndrome. Readings were nominally obtained preflight, in-flight, and postflight.

Ambulatory Monitoring with and without Skeletal Loading and Other Maneuvers. Aimed to prove/disprove, and provide a basis for evaluation of, the hypothesis that Space Adaptation Syndrome produces large parasympathetic and hormonal discharges. First objective records of physiological events during space motion sickness were recorded, along with recordings of normal space, 1*g* motion sickness, and normal 1*g* situations.

Inflight Countermeasures for Space Adaptation Syndrome with Objective Countermeasures. Worked to find physical methods to reduce conflicting sensory inputs and to find medication to reduce symptoms. After a crew member suffered from Space Adaptation Syndrome, a standard dose of agents was given to crew members. It completely reversed gastrointestinal symptoms and the cervical loading devise and collar developed by Dr Oman at MIT were tried for fit and function.

Hand-Eye Coordination. A hand tracking task of moving point on recording paper was made preflight, in-flight, and postflight to note any changes in sensitivity. Records were examined and no obvious changes in hand-eye coordination were found.

Anatomical Observations. Measured and compared crew member's internal organ locations in 1*g* and on orbit. Palpatation of tissues, especially of the head and neck, and observation of nasal and aural canals, provided new insight into fluid shifts and its effects.

Study of Inflight Fluid Change. Assessed redistribution of fluid volumes influenced by loss of hydrostatic forces. Leg volume shifts were noted, but expected diuresis did not occur except for a moderate nocturnal diuresis.

Evoked Potentials Demonstration. Worked to obtain and document changes in neurological system transducer signals in a space environment. Detailed examination of both early and mid latencies found no evidence of abnormalities in ear or brain areas involved.

Intraocular Pressure. Determined whether intraocular pressures increase with anatomical changes experienced in orbital flight. No statistical difference between preflight and an in-flight intraocular pressure on individual involved, and equipment seemed to give reasonable results but was difficult to use.

Soft Contact Lens Application Test. Tested ability of a crew member to apply a marked contact lens to his or her eye and determine whether the lens would stay in place. Major difficulties were that the lens would not adhere using prescribed procedures. Conclusion was that there should be a better way to accomplish this task.

Cabin Atmosphere Verification. See STS-5.

STS-9

Effects of Prolonged Weightlessness on the Humoral Immune Response of Humans. Humoral immune response system produces white blood cells to combat diseases and is known as a specific defense mechanism. The effect of microgravity on production of white blood cells was studied and it was determined that microgravity does not affect ability of the human body to respond to disease by producing white blood cells.

The Influence of Space flight on Erythrokinetics in Man. Exposure to microgravity leads to a reduction of the number of red blood cells present in the body. Experiment was designed to determine factors involved in this reduction of red blood cells. Results indicate that reduction in red blood cell mass is due to premature destruction of red blood cells and failure of the body to produce more to make up for destroyed blood cells.

Vestibular Experiments. Focused on finding out if the vestibular system, responsible for balance and sensing changes in speed and direction of body movement, is affected by microgravity in a way that causes one to sense head translation instead of tilt, falling reflexes are affected, and visual and tactile clues become more important in spatial orientation determination. Results showed that tilt it still sensed in microgravity, there was only a minor difference in falling reflexes, which recovered quickly on return to Earth, and that reliance on visual and tactile clues varies from subject to subject but does become more important in spaceflight.

Vestibulo-Spinal Reflex Mechanisms. Astronauts' vestibular systems are known to be affected by microgravity. Experiment was designed to assess if changes in the vestibular system would reduce the need for postural reflexes in major muscles and how these reflexes relate to motion sickness. Results indicated that postural reflexes did decline in-flight, but that they returned to normal soon after return to Earth. Those with higher preflight postural reflexes were more susceptible to space motion sickness.

Cardiovascular Deconditioning Countermeasure Assessment. See STS-4.

Microbial Screening. See STS-1.

Validation of Predictive Tests and Countermeasures for Space Motion Sickness. See STS-1.

Cabin Atmosphere Verification. See STS-5.

Canadian Space Agency:

Hop and Drop. Gained a better understanding of Space Adaptation Syndrome.

European Space Agency Experiments:

Ballistocardiography in Weightlessness. Recorded ballistocardiography tracings along the three body axes by means of accelerometric sensors secured to subject's back in microgravity. Recordings were made preflight, in-flight, and postflight.

Effects of Rectilinear Acceleration, Optokinetic and Caloric Stimulation on Human Vestibular Reactions and Sensations. Explored changes in vestibular function and visuo-vestibular interactions on exposure to microgravity on four crew members of Spacelab 1 mission. Found that caloric stimulation elicited nystagmic responses in-flight of non-significantly different magnitude in the quick phase direction from those observed before and after flight, mean threshold for detection of horizontal linear oscillations at 0.3 Hz postflight was similar to the one observed preflight, and ocular counterrolling was significantly smaller in the three subjects.

Effects of Weightlessness on Lymphocyte Proliferation. Worked to establish, by exposing cultures of human lymphocytes to a mitogen during spaceflight, whether functional changes occurred in cells responsible for immune response, and aimed to answer whether cells are sensitive to gravity changes. Results supported the hypothesis, based on experiments in hypogravity and at hypergravity, that microgravity depresses, whereas high gravity enhances cell proliferation rates (at least in the case of human lymphocytes).

Eye Movements During Sleep. Explored influence of spaceflight on Rapid Eye Movements. Taking into account the subject had been 12-hour shifted since 2 weeks before launch, the most striking effect of spaceflight on sleep was the dramatic increase in number of eye movements occurring during first epoch returning to normal after night one.

Mass Discrimination During Weightlessness. Compared discrimination thresholds for same test on the ground and in weightless spaceflight on five astronauts. Mass discrimination in-flight was nearly twice as poor as weight discrimination preflight.

Measurement of Central Venous Pressure and Hormones in Blood Serum During Weightlessness. Worked to determine whether cephalad blood and fluid shift that occurs during spaceflight leads to an increase of venous pressure in upper body. Fluid shift occurring in-flight from lower to upper parts of body and its reversal immediately after recovery seemed to be highly dynamic processes, which took place within 3 to 6 hours.

Microorganisms and Biomolecules in the Space Environment. Aimed to determine response of a resistant microbial system to free space and selected components of this hard environment. Exposure to vacuum for 10 days reduced viability counts to about 50% of those of samples kept at one atm.

STS-41B

Near Vision Acuity and Contrast Sensitivity. See STS-5.

Preflight and Postflight Parallel Swingtests. See STS-8.

Validation of Predictive Tests and Countermeasures for Space Motion Sickness. See STS-1.

Cardiovascular Deconditioning Countermeasure Assessment. See STS-4.

Microbial Screening. See STS-1.

Cabin Atmosphere Verification. See STS-5.

STS-41C

Near Vision Acuity and Contrast Sensitivity. See STS-5.

Cardiovascular Deconditioning Countermeasure Assessment. See STS-4.

Microbial Screening. See STS-1.

Validation of Predictive Tests and Countermeasures for Space Motion Sickness. See STS-1.

Cabin Atmosphere Verification. See STS-5.

STS-41D

Crew Visual Performance. Performed on three missions. Aimed to determine what effects microgravity might have on vision. Determined that in subjects studied there were no statistically significant effects on vision over short-term flights.

Near Vision Acuity and Contrast Sensitivity. See STS-5.

Cardiovascular Deconditioning Countermeasure Assessment. See STS-4.

Validation of Predictive Tests and Countermeasures for Space Motion Sickness. See STS-1.

Blood Pressure Monitoring During Entry. Gathered data on cardiovascular status of astronauts during, and immediately following entry. The data returned were excellent.

Cabin Atmosphere Verification. See STS-5.

STS-41G

Crew Visual Performance. See STS-41D.

Near Vision Acuity and Contrast Sensitivity. See STS-5.

Salivary Cortisol Levels During the Acute Phases of Space Flight. Goal of experiment was to determine whether taking saliva samples in-flight was a feasible way of measuring cortisol levels. Results indicated that this was a suitable method for studying adrenal function and cortisol levels before, during, and after spaceflight.

Validation of Predictive Test and Countermeasures for Space Motion Sickness. See STS-1.

Canadian Space Agency Space Adaptation Syndrome Supplemental Experiments. Gained a better understanding of Space Adaptation Syndromes as sensory functions may gradually deteriorate in space. Astronauts have made large errors when attempting to point at targets when blindfolded.The experiment was designed to measure thereflex and amount of image slip, or changes in Vestibulo-ocular Reflex Gain. Studied occurrence and mechanisms of these illusions—the sensation that the floor that was moving up and down rather than themselves. Space Motion Sickness experiment studied onset of symptoms and evaluated effectiveness of various forms of treatment. Also investigated changes in taste and smell during spaceflight and had possible application to astronaut diets.

Documentation of the Action of Metaclopramide. Assessed bowel activity in crew members with and without Space Motion Sickness symptoms and evaluated affect of metaclopramide in relieving gastrointestinal symptoms. Although no sequence was fully completed, the experiment added to knowledge base.

STS-51A

Assessment of Circadian Shifting in Astronauts by Bright Light (Parts A and B). See STS-5.

Head and Gaze Stability During Locomotion. See STS-5.

Validation of Predictive Tests and Countermeasures for Space Motion Sickness. See STS-1.

STS-51C

Crew Visual Performance. See STS-41D.

Near Vision Acuity and Contrast Sensitivity. See STS-5.

Assessment of Circadian Shifting in Astronauts by Bright Light (Parts A and B). See STS-5.

Head and Gaze Stability During Locomotion. See STS-5.

Noninvasive Estimation of Central Venous Pressure During Space Flight. Performed on six missions. Documented change in central venous pressure during spaceflight. Results showed that central venous pressure decreased during the duration (6 days) of the mission.

Blood Pressure Monitoring During Entry. See STS-41D.

Documentation of the Action of Metaclopramide. See STS-41G.

Head and Gaze Stability During Locomotion. See STS-5.

Validation of Predictive Tests and Countermeasures for Space Motion Sickness. See STS-1.

STS-51D

American Flight Echocardiograph. Acquired in-flight data on effects during course of space adaptation for the purpose of developing optimal countermeasures to crew cardiovascular changes and to ensure long-term safety to people living in weightlessness. Experiment performed well, data were obtained on four crew members each day except for day four, and data were obtained during 10.2-psi cabin operations.

Extra Ocular Motion Studies, Pre-, In, and Post Flight (STS-51D) Examined whether extra ocular motion was affected by space motion sickness as subject involved in experiment was strongly affected by space motion sickness during the first 48 hours of flight. Results indicated no abnormalities in extraocular motion as a result of space motion sickness.

Assessment of Circadian Shifting in Astronauts by Bright Light. See STS-5.

Clinical Characterization of Space Motion Sickness. Performed on six missions. Performed an in-depth study to attempt to define parameters that could be used to predict space motion sickness in astronauts. Determined that there is no good preflight indicator to predict motion sickness and that space motion sickness susceptibility varies from astronaut to astronaut.

Head and Gaze Stability During Locomotion. See STS-5.

Preflight and Postflight Parallel Swing Tests. See STS-8.

Validation of Predictive Tests and Countermeasures for Space Motion Sickness. See STS-1.

Cabin Atmosphere Verification. See STS-5.

Near Vision Acuity and Contrast Sensitivity. See STS-5. Only one set of data was obtained in-flight due to reduced flight duration; only one crew member showed a statistically significant change in contrast sensitivity, and cumulative data suggested that future crews could expect possible increases or decreases in contrast sensitivity.

Blood Pressure Monitoring During Entry. See STS-41D for description. Blood pressures obtained continued to demonstrate no evidence of hypotension during re-entry or egress.

Leg Plethysmography. Measured, quantitated, and established time course of leg volume changes related to fluid shifts during spaceflight, re-entry, and landing. Data were obtained for the first time showing courses of changes in leg on exposure to microgravity. The change seemed to be exponential with a time constant on the order of 6 to 8 hours, which theoretically allowed for “refilling” of legs prior to re-entry.

Medical Tests and Measurements for STS-51D Payload Specialist. Worked to determine whether existing saliva collection method and kit could be successfully used during flight, tested if saliva could be used for pharmacokinetic studies during flight, and identified and estimated changes of drug kinetics during flight. All hardware worked as planned, and some useful data were obtained. Tests were done to determine total water content of the body during multiday exposure to microgravity. For numerous reasons, results were questionable and unreliable.

STS-51B

Autogenic Feedback Training. Experiment was to determine whether Autogenic-Feedback Training an effective countermeasure for space motion sickness and if it was possible to predict susceptibility to space motion sickness based on preflight data. Results indicated that Autogenic-Feedback Training was effective for some, but not all, astronauts and that it was not possible to predict space motion sickness with preflight data.

Assessment of Circadian Shifting in Astronauts by Bright Light. See STS-5.

Combined Blood Investigations. Performed on two missions. Fluid redistribution hypothesis states that losses of body fluid and electrolytes are a result of the headward shift of fluid caused by microgravity. Goal of experiment was to support this hypothesis. Results demonstrated that the hypothesis does not fully explain the loss of electrolytes and fluid, and that further research is required.

Head and Gaze Stability During Locomotion. See STS-5.

Noninvasive Estimation of Central Venous Pressure During Space Flight. See STS-51C.

Leg Plethysmography. See STS-51D.

Documentation of the Action of Metaclopramide. See STS-41G.

Blood Pressure Monitoring During Entry. See STS-41D.

Urine Monitoring System. Checked out a new facility to collect and measure urine samples. Some difficulties were encountered, but the primary objective was met.

Cabin Air Monitoring. Used a solid sorbent sampler to continuously sample Orbiter atmosphere throughout flight. Sampler was flown on flights of a new vehicle, first flights of a vehicle after extensive non-metallic refurbishment in Orbiter cabin, and on all Spacelab crewed module flights.

STS-51G

Clinical Characterization of Space Motion Sickness. See STS-51D.

STS-51F

Assessment of Circadian Shifting in Astronauts by Bright Light. See STS-5.

Combined Blood Investigations. See STS-51B.

Head and Gaze Stability During Locomotion. See STS-5.

Blood Pressure Monitoring During Entry. See STS-41D.

Vitamin D Metabolites and Bone Demineralization. Studied link between bone mineral loss during spaceflight and activity of vitamin D in the human body. Blood samples were collected from the crew.

STS-51I

Clinical Characterization of Space Motion Sickness. See STS-51D.

In-Flight Pharmacokinetics of Acetaminophen in Saliva. Performed on seven missions. Evidence had suggested that effectiveness of some pharmaceutical drugs may change in spaceflight. Experiment examined absorption of common pain medication acetaminophen by astronauts in space. It was confirmed that drug dynamics are changed as a result of spaceflight but this study was not enough to determined exactly how pharmacokinetics are affected since each individual astronaut had different responses to the drug.

STS-51J

Clinical Characterization of Space Motion Sickness. See STS-51D.

Leg Plethysmography. See STS-51D.

Leg Plethysmography. Performed on three missions. It has been previously observed that there is a large amount of bodily fluid shift during exposure to microgravity. Experiment measured leg volume changes that are a result of the fluid shift. Results showed that leg volumes of astronauts changed 10% to 12% due to exposure to microgravity.

STS-61A

Cabin Air Monitoring. See STS-51B.

European Space Agency Dedicated Flight:

> Arm Positioning. Major requirement for execution of a pointing task is that the brain gets quickly aware of the true shape of the body that implies it: knows or predicts the relative positions of target and body; and knows and controls where the pointing limb goes. Control subjects mostly over-indicated and only one under-indicated as low as the astronaut. The latter was resistant to space motion sickness and was an extreme under-indicator. Test could be helpful, in the future, in selecting people less susceptible to space motion sickness.
>
> Causation of Inversion Illusions and Space Sickness. Occurrence of space sickness and of accompanying inversion illusions (i.e., reporting oneself and the room upside down, despite being upright relative to a familiar room) are still poorly understood. The 2-Z axis components were studied and showed that saccular Z-bias might play the main role in cue-free inversion illusions generation processes.
>
> Early Adaptation to Body Fluid and Cardiac Performance. Goal was to quantify fluid shift in microgravity and determine its time course as well as to observe the effect of fluid redistribution on the heart. Preflight tests: Body Impedance and Torso Impedance varied by about 5% during the day. In-flight tests: torso impedance results were not significantly different from preflight ones, leading to the conclusion that most changes already occur during the short period of waiting position on launch pad.
>
> Effects of Microgravity on Lymphocyte Activation (ex-vivo). Studied impact of the stress of spaceflight on immune system of astronauts by measuring mitogenic activation of their lymphocytes prior to, during, and after flight. Activation of lymphocytes from crew members in whole blood cultures was depressed in three of the four crew members.
>
> Effects of Microgravity on Lymphocyte Activation (in-vitro). Tested hypothesis that microgravity depresses lymphocyte activation, and worked to verify result from Spacelab 1. Confirmed results that the in-vitro activation of human lymphocytes of mitogen con A is reduced by 90% in microgravity.
>
> European Experiments on the Vestibular System. Goal of integrated study was to yield improved methods of prevention, prediction, and treatment of space motion sickness. New results were obtained with respect to visual-vestibular interactions, functional significance of neck receptors, and effect of linear oscillation on caloric nystagmus in space. Astronauts observed that proprioceptive and somaesthetic cues influenced their perception of spatial relationships both during and early after the mission.
>
> Mass Discrimination and Adaptation to Weightlessness. See STS-9 for description. The ability to discriminate between the mass of objects in zero gravity is poorer than in 1*g*. In-flight tests showed a greater percentage of errors for long than for short shakes for all subjects, but in any case, both shake attitudes yielded worse results than preflight. This means that fast movements may assist mass perception.
>
> Spatial Description: Aspects of Cognitive Adaptation. Worked to determine relevance of gravity on spatial coordinate assignment, mental representation of space, and the naming of spatial relations. Adaptation to new perceptual situations is largely determined by cognitive ability to use highly abstract mental representations that guarantee adequate mappings of various input information.
>
> The Effect of Microgravity on Plasma-Osteocalcin. Obtained samples preflight, in-flight, and postflight from astronauts for analysis. In-flight samples showed a marked reduction of osteocalcin concentration. Immediately after landing, the bone-Gla protein content of the circulating osteocalcin turned out to be reduced by more than 50%, which may indicate a partial vitamin K deficiency at bone level during microgravity.

Tonometry. Investigated intraocular pressure levels by space-qualified, gravity-independent applanation tonometer. Provided promising results for use of a gravity-independent applanation tonometer to determine intraocular pressure levels.

Venous Pressure in Space. Worked to measure central venous pressure as early as possible in-flight to elucidate entity and time course of such phenomenon. Central venous pressure was lower in-flight than preflight, possibly because the waiting period on the launch pad may already have led to an adaptation or to a more complex and less probable interplay of water loss and antidiuretic hormone compensatory changes.

STS-61B

Assessment of Circadian Shifting in Astronauts by Bright Light. See STS-5.

Clinical Characterization of Space Motion Sickness. See STS-51D.

Head and Gaze Stability During Locomotion. See STS-5.

In-Flight Pharmacokinetics of Acetaminophen in Saliva. See STS-51I.

Inflight Salivary Pharmacokinetics of Scopolamine and Dextroamphetamine. Performed on eight missions. Examined pharmacokinetics of the drug scopolamine in spaceflight by using saliva of astronauts. Few results were obtained due to small sample size and low drug levels in samples, but demonstrated that the time course of the drug was affected by microgravity.

Leg Plethysmography. See STS-51D.

Leg Plethysmography. See STS-51J.

STS-61C

Assessment of Circadian Shifting in Astronauts by Bright Light. See STS-5.

Changes in Total Body Water During Spaceflight. Performed on two missions. Measured change in total body water occurring in astronauts as a result of spaceflight. Determined that total body water decreased 3.4% after 1 to 3 days of exposure to microgravity.

Clinical Characterization of Space Motion Sickness. See STS-51D.

Head and Gaze Stability During Locomotion. See STS-5.

In-flight Assessment of Renal Stone Risk Factor. Evaluated potential for increased risked of renal stone formation as a consequence of spaceflight, and compared that stone-forming potential to that observed in normal subjects during bedrest. Data were collected from one subject.

In-flight Holter Monitoring. Performed on five missions. About 40% of individuals who participate in extravehicular activities are observed to experience cardiac rhythm abnormalities. Experiment studied whether these abnormalities occur during normal spaceflight activities and during exercise while in space. Determined that abnormalities do not occur during normal activities or exercise during spaceflight and that abnormalities observed are a result of the unique nature of extravehicular activities.

In-flight Pharmacokinetics of Acetaminophen in Saliva. See STS-51I

Inflight Salivary Pharmacokinetics of Scopolamine and Dextroamphetamine. See STS-61B.

Leg Plethysmography. See STS-51D.

Leg Plethysmography. See STS-51J.

Otolith Tilt-Transition Reinterpretation. Tested hypothesis that adaptation to spaceflight is a function of sensory rearrangement and that signals from otolith organs during orbital flight are reinterpreted as linear displacements by using a method of measuring ocular torsion first used about 140 years ago. Based on data obtained, eyes showed a compensatory torsional movement to head tilt, and findings supported a concept of sensory substitution, in this case the substitution of neck receptors for missing otolith information.

STS-26

Cabin Air Monitoring. See STS-51B.

Changes in Total Body Water During Spaceflight. See STS-61C.

In-flight Pharmacokinetics of Acetaminophen in Saliva. See STS-51I.

Inflight Salivary Pharmacokinetics of Scopolamine and Dextroamphetamine. See STS-61B.

Otolith Tilt-Transition Reinterpretation. See STS-61C.

Pre- and Postflight Cardiac Assessment. Collected normative data about the effects of spaceflight on volume, mass, and function of heart, and about orthostatic response of cardiovascular system. Heart rate was greater on landing day than before the flight, End Diastolic Volume Index and Stroke Volume Index in supine position were less, and spaceflight caused no significant changes in supine End Systolic Volume Index, ejection fraction, thickness of left ventricular wall or mass or contractility of heart muscle. Results indicated that temporary changes in cardiovascular function may be expected even after short spaceflights of only 4 to 5 days.

STS-27

Cabin Air Monitoring. See STS-51B.

In-flight Pharmacokinetics of Acetaminophen in Saliva. See STS-51I.

Influence of Weightlessness on Baroreflex Function. Performed on seven missions. The ability of the human body to regulate blood pressure and heart rate is referred to as baroreflex function. When baroreflex does not perform properly, it often leads to orthostatic intolerance (fainting or light-headedness due to standing). Experiment examined whether baroreflex function is affected by spaceflight. Determined that short-term spaceflight leads to significant impairment of baroreflex mechanisms.

Salivary Cortisol Levels During the Acute Phases of Space Flight. Performed on three missions. Cortisol is one of the hormones released by the human body in response to stress. Experiment aimed to determine whether collecting saliva samples for cortisol analysis was feasible. Results indicated that this was indeed a feasible approach for measuring stress related body responses, but no determinations of the effect of spaceflight on cortisol levels could be made.

Pre- and Postflight Cardiac Assessment. See STS-26.

STS-29

In-flight Pharmacokinetics of Acetaminophen in Saliva. See STS-51I.

Inflight Salivary Pharmacokinetics of Scopolamine and Dextroamphetamine. See STS-61B.

Influence of Weightlessness on Baroreflex Function. See STS-27.

Noninvasive Estimation of Central Venous Pressure During Space Flight. See STS-51B.

The Relationship of Space Adaptation Syndrome to Middle Cerebral Artery Blood Velocity Measured in Flight by Doppler. Performed on three missions. Astronauts experience a headward bodily fluid shift as a result of being exposed to microgravity. Experiment examined the effect of this shift on blood flow in the brain. Results indicated that blood flow to the brain is indeed affected by microgravity and is a part of Space Adaptation Syndrome.

Pre- and Postflight Cardiac Assessment. See STS-26.

Preflight Adaptation Training. Assisted in developing a standardized Motion Perception Vocabulary and Reporting System that provided for quantitative descriptions of perceptual responses that occur during each phase of spaceflight. Data gained from crew members supported Otolith Tilt-Translation Reinterpretation model of neurosensory adaptation to microgravity, indicated that Preflight Adaptation Training Tilt-Translation Device can reproduce some sensory stimulus characteristics present on orbit, and supported the idea that Preflight Adaptation Training Tilt-Translation Device may be effective in helping to pre-adapt crew members.

STS-30

In-flight Holter Monitoring. See STS-61C.

Inflight Salivary Pharmacokinetics of Scopolamine and Dextroamphetamine. See STS-61B.

Influence of Weightlessness on Baroreflex Function. See STS-27.

Pre- and Postflight Cardiac Assessment. See STS-26.

STS-28

In-flight Pharmacokinetics of Acetaminophen in Saliva. See STS-51I.

Inflight Salivary Pharmacokinetics of Scopolamine and Dextroamphetamine. See STS-61B.

Influence of Weightlessness on Baroreflex Function. See STS-27.

Pre- and Postflight Cardiac Assessment. See STS-26.

Preflight Adaptation Training. See STS-29.

Otolith Tilt-Transition Reinterpretation. See STS-61C.

Postural Equilibrium Control During Landing/Egress. Worked to characterize recovery process for postural equilibrium control in crew members returning from shuttle mission, and worked to validate the dynamic posturography system as a dependent measure for future evaluation of vestibular and/or sensorimotor countermeasures. Results demonstrated unequivocally that balance control is disrupted in all astronauts immediately after return from space, and investigators concluded that otolith mediated spatial reference provided by terrestrial gravitational force vector is not used by astronauts' balance control systems immediately after spaceflight.

STS-34

Inflight Salivary Pharmacokinetics of Scopolamine and Dextroamphetamine. See STS-61B.

Muscle Biopsy. Performed on three missions. Muscle atrophy has been observed in astronauts as a result of spaceflight. Experiment aimed to define morphologic and biochemical changes muscles undergo as a result of spaceflight. Results showed that muscle size decreased from 15 % to 22% after spaceflight and biochemical activity was affected by microgravity, suggesting that rapid adaptive changes occur in size, vascularity, and metabolic properties of skeletal muscle.

The Evaluation of Concentric and Eccentric Skeletal Muscle Contractions Following Space Flight. Performed on five missions. Loss of muscle strength and endurance as a result of spaceflight poses serious hazards to astronauts. Assessed changes in muscle strength and endurance and effect of in-flight exercise on these changes. Results showed that muscle strength and endurance is lost by astronauts because of spaceflight and that loss increases over time, but that exercise may help prevent losses in muscle strength and endurance.

The Relationship of Space Adaptation Syndrome to Middle Cerebral Artery Blood Velocity Measured in Flight by Doppler. See STS-29.

Pre- and Postflight Cardiac Assessment. See STS-26.

Retinal Photography. Analyzed retinal photographs obtained in-flight and determined whether microgravity induced cephalad fluid shifts elevate intracranial pressure, worked to verify and certify in-flight instruments that provided high-resolution retinal images for diagnostics and investigative purposes, and worked to correlate retinal venous dilatation, optic disc elevation, and development of Space Adaptation Syndrome or Central Nervous System disturbances. All planned data were collected.

Sample Collection of Gas Bubbles in Potable Water. Collected samples of shuttle's potable water and returned them for analysis. Gas bubble content was small in samples taken. Results indicated that the gas bubble problem would not be an issue with the new beverage pouch at the time.

STS-33

In-flight Holter Monitoring. See STS-61C.

Influence of Weightlessness on Baroreflex Function. See STS-27.

Muscle Biopsy. See STS-34.

Noninvasive Estimation of Central Venous Pressure During Space Flight. See STS-51B.

Retinal Photography. Space Adaptation Syndrome is a medical problem that affects approximately 50% of astronauts and cosmonauts. Examined the role of increased intercranial or mild cerebral edema as a contributing factor in Space Adaptation Syndrome. Results showed both the retinal arteries and veins dilate during first few days of spaceflight.

Salivary Cortisol Levels During the Acute Phases of Space Flight. See STS-27.

Pre- and Postflight Cardiac Assessment. See STS-26.

Preflight Adaptation Training. See STS-29.

STS-32

American Flight Echocardiograph. See STS-51D for description. Over 100% of objectives were met since all five crew members participated in experiments, whereas it was only planned for two to participate.

Cabin Air Monitoring. See STS-51B.

In Vivo Testing Confirms a Blunting of the Human Cell-Mediated Immune Mechanism During Space Flight. Performed on three missions. Previous studies on effects of spaceflight on the human immune system had all been performed in vitro (postflight). Experiment was performed direct in-flight to better characterize immune system response to spaceflight. Data obtained demonstrated that the immune system undergoes a degradation that maximizes after approximately 5 days into flight and then stabilizes at new lower level.

Changes in Baroreceptor Reflex Function After Space Flight. Performed on five missions. Regulation of blood pressure and heart rate is managed by carotid baroreceptors. Examined effect of spaceflight on baroreflex response. Spaceflight disturbed the function of the baroreceptor reflex. Autonomic regulation of blood pressure and heart rate was irregular upon return from space.

Characterization of Respirable Airborne Particulate Matter in Shuttle Atmosphere. Performed on two missions. Airborne debris was observed on previous shuttle missions and a large amount of particulate matter was found in the air samplers, but particulate matter had never been characterized before. The debris was mostly of organic origin, which will aid in the effectiveness of modifications to cabin air filtration systems.

In-Flight Lower body Negative Pressure: Countermeasure to Reduce Post-Space Flight Orthostatic Intolerance. Performed on seven missions. Studied use of lower body negative pressure and fluid loading as a countermeasure against orthostatic intolerance experienced by many astronauts upon return from spaceflight. Results showed that the combination of lower body negative pressure and fluid loading may be an effective countermeasure against postflight orthostatic intolerance, but that this treatment was impractical for use with the shuttle because one treatment of one astronaut takes approximately 5 hours.

Inflight Aerobic Exercise. Performed on eight missions. Spaceflight has been observed to cause a degeneration of aerobic exercise capacity. Experiment studied use of in-flight aerobic exercise as a countermeasure to postflight aerobic deconditioning. Results showed that in-flight aerobic exercise helps counteract postflight aerobic deconditioning, but did not indicate optimal exercise device or protocol.

Inflight Salivary Pharmacokinetics of Scopolamine and Dextroamphetamine. See STS-61B.

Influence of Weightlessness on Baroreflex Function. See STS-27.

Intraocular Pressure. Performed on seven missions. Intraocular pressure has been observed to be an objective and quantitative measure of head-ward fluid shift that astronauts experience in microgravity. This experiment hypothesized that intraocular pressures will rise immediately upon microgravity entry and drop below preflight levels upon return to Earth. Results indicated that intraocular pressures rose in first 2 days of spaceflight, but that pressures were elevated above preflight levels upon return to Earth.

Muscle Biopsy. See STS-34.

The Evaluation of Concentric and Eccentric Skeletal Muscle Contractions Following Space Flight. See STS-34.

Pre- and Postflight Cardiac Assessment. See STS-26.

Sample Collection of Gas Bubbles in Potable Water. See STS-34 for description. Due to gas bubbles found in water on previous flights, this test was needed to determine what the gas was and how much was present for a fix.

STS-36

In vivo Testing Confirms a Blunting of the Human Cell-Mediated Immune Mechanism During Space Flight. See STS-32.

Hypersomotic Fluid Countermeasure. Performed on five missions. Objective was to study effectiveness of ingestion of three different salt and water combinations during flight as countermeasures to postflight orthostatic intolerance. Ingested volumes of test solutions and of other fluids were too variable for any conclusions to be made.

In-flight Holter Monitoring. See STS-61C.

Postural Equilibrium Control During Landing/Egress. See STS-28.

Pre- and Postflight Cardiac Assessment. See STS-26.

Preflight Adaptation Training. See STS-29.

STS-31

In vivo Testing Confirms a Blunting of the Human Cell-Mediated Immune Mechanism During Space Flight. See STS-32.

Hypersomotic Fluid Countermeasure. See STS-36.

Influence of Weightlessness on Baroreflex Function. See STS-27.

Intraocular Pressure. See STS-32.

Noninvasive Estimation of Central Venous Pressure During Space Flight. See STS-29.

Pre- and Postflight Cardiac Assessment. See STS-26.

The Evaluation of Concentric and Eccentric Skeletal Muscle Contractions Following Space Flight. See STS-34.

Inflight Radiation Dose Distribution. Worked to establish, evaluate, and verify analytical and measurement methods for assessing and managing health risks from exposure to space radiation. Overall physical dose is in fairly good agreement with measurements using thermoluminescent detectors in least-shielded location.

STS-41

Blood Pressure Variability During Space Flight. Performed on six missions. Spaceflight is known to cause changes in cardiovascular function and serious disturbances of cardiac rhythm. This experiment aimed to collect data on cardiovascular changes during spaceflight and document any occurrences of cardiac dysrhythmias. Heart rate and diastolic blood pressure decreased during spaceflight and spaceflight did not increase cardiac dysrhythmias, indicating that microgravity is not stressful to the cardiovascular system.

Changes in Baroreceptor Reflex Function After Space Flight. See STS-32.

Intraocular Pressure. See STS-32.

Retinal Photography. See STS-33.

Visual-Vestibular Integration. Performed on 15 missions. Objectives were to study motion sickness and what contributes to it, evaluate changes in motion perception pre- and postflight, and investigate change in spatial orientation during microgravity adaptation. Determined that motion perception and spatial orientation is strongly affected by spaceflight and that preflight education and simulation helped to reduce incidence of space motion sickness.

Orthostatic Function During Entry, Landing, and Egress. Objective was to collect normative data about heart rate and blood pressure during re-entry and landing and about orthostatic response before and immediately after spaceflight. Systolic and diastolic blood pressure increased during spaceflight and were highest when gravity reached its peak during re-entry and at touchdown, and systolic blood pressure decreased significantly when astronauts first stood up from their seats after landing. Results indicated that re-entry, landing, and leaving the seat after shuttle flights were stressful to the cardiovascular system.

Postural Equilibrium Control During Landing/Egress. See STS-28.

STS-38

In vivo Testing Confirms a Blunting of the Human Cell-Mediated Immune Mechanism During Space Flight. See STS-32.

The Evaluation of Concentric and Eccentric Skeletal Muscle Contractions Following Space Flight. See STS-34.

STS-35

Blood Pressure Variability During Space Flight. See STS-41

Changes in Baroreceptor Reflex Function After Space Flight. See STS-32.

Heavy Isotope Enrichment of Shuttle Galley Water. Shuttle galley water is enriched by deuterium and heavy oxygen and this isotope enrichment could interfere with total body water determination. Experiment examined whether these isotopes interfered with total body water measurements. Determined that isotopes were not a source of error in measurement of total body water.

Inflight Aerobic Exercise. See STS-32.

The Evaluation of Concentric and Eccentric Skeletal Muscle Contractions Following Space Flight. See STS-34.

Pre- and Postflight Cardiac Assessment. See STS-26.

Preflight Adaptation Training. See STS-29.

Orthostatic Function During Entry, Landing, and Egress. See STS-41.

Postural Equilibrium Control During Landing/Egress. See STS-28.

Muscle Size and Lipids. Purpose was to noninvasively quantify changes in size, water, and lipid composition in antigravity (leg) muscles after spaceflight. Cross-sectional area and volume of total leg compartment, soleus, and gastrocnemius were measured and volumes of all three compartments were significantly smaller after both the 7- and 9-day shuttle flights relative to preflight. Decreases represented true skeletal muscle atrophy, and no recovery was apparent 7 days after landing.

STS-37

Cabin Air Monitoring. See STS-51B.

Hydrazine Monitoring. Sampled air to detect presence of hydrazine or monomethylhydrazine to ensure safety of crew after completion of an extravehicular activity. Measurements were taken on orbit.

Hypersomotic Fluid Countermeasure. See STS-31.

Cardiovascular Responses to Lower Body Negative Pressure Following Space Flight. Performed on eight missions. Lower body negative pressure can be used to study orthostatic function of astronauts before and after spaceflight. Experiment used it to test whether orthostatic intolerance is a result of decreased body hydration and impaired cardiac or vascular compensatory response. Results indicated no depressed vascular response, which may be due to the difference between stand tests and lower body negative pressure postflight tests.

Changes in Endocrine Regulation of Orthostatic Tolerance Following Space Flight. Performed on 11 missions. Orthostatic intolerance is a common problem for astronauts upon return from spaceflight. Study examined whether release of regulatory hormones is affected by spaceflight and is a contributing factor to orthostatic intolerance. Determined that the sympathetic nervous system activity and peripheral resistance apparently became uncoupled as a result of spaceflight.

The Evaluation of Concentric and Eccentric Skeletal Muscle Contractions Following Space Flight. See STS-34.

Orthostatic Function During Entry, Landing, and Egress. See STS-41.

Inflight Radiation Dose Distribution. See STS-31.

STS-39

Blood Pressure Variability During Space Flight. See STS-41.

Cardiovascular Responses to Lower Body Negative Pressure Following Space Flight. See STS-37.

Changes in Baroreceptor Reflex Function After Space Flight. See STS-32.

Changes in Endocrine Regulations of Orthostatic Tolerance Following Space Flight. See STS-37.

Effects of Space Flight on Aerobic and Anaerobic Metabolism During Exercise. Performed on 13 missions. Objectives were to investigate use of in-flight aerobic exercise as a countermeasure to postflight aerobic deconditioning and to determine how decreases in aerobic capacity are related to changes in body composition. Determined that in-flight aerobic exercise was an effective countermeasure to postflight deconditioning and that deconditioning was related to a decrease in total body protein, which was most likely the result of a loss of muscle mass.

Inflight Aerobic Exercise. See STS-32.

Pre- and Postflight Cardiac Assessment. See STS-26.

Visual-Vestibular Integration. See STS-41.

Postural Equilibrium Control During Landing/Egress. See STS-28.

STS-40

Cabin Air Monitoring. See STS-51B.

Orthostatic Intolerance After Spaceflight. Performed on missions STS-40 and STS-58. Astronauts returning from spaceflight are known to exhibit symptoms of orthostatic intolerance, which involves elevated heart rate and change in blood pressure as a result of standing, sometimes resulting in fainting. Experiment demonstrated that nine of 14 astronauts tested could not complete a 10-minute stand test upon return from spaceflight, and that the difference between finishers of the test and non finishers was based solely on standing regulation of blood pressure—not heart rate.

Central Venous Pressure in Space. Experiment was carried out over missions STS-40 and STS-58. There is a major central fluid shift in an astronaut's body when they enter a microgravity environment and the best way to understand the dynamics of this shift is to monitor cardiac filling pressure as the astronaut transitions from a 1*g* environment to a microgravity environment. Central venous pressure was used to measure cardiac filling pressure. Determined that central venous pressure decreased, which contradicted the traditional view that it increased when the astronaut entered microgravity, meaning that the relationship between central venous pressure and left ventricular filling pressure is altered in microgravity.

Cardiovascular Response to Submaximal Exercise in Sustained Microgravity. Performed on missions STS-40 and STS-58. Cardiac output, heart rate, blood pressure, and oxygen consumption were measured repeatedly both at rest and at two levels of exercise in six astronauts while in a microgravity environment. Results showed that a microgravity environment causes a cardiovascular system response unlike any accepted Earth simulations.

Forced Expirations and Maximum Expiratory Flow-Volume Curves During Sustained Microgravity on SLS-1. Microgravity is known to influence the mechanical behavior of the human lung and chest wall, and one of the ways to determine how microgravity affects the respiratory system is through the measurement of forced expirations. However, the changes measured could be a result of many different factors, such as an inability of astronauts to stabilize themselves, a reduction in respiratory muscle strength, a change in blood volume, or the shift in bodily fluids experienced in microgravity.

Diet and Nitrogen Metabolism During Spaceflight on the Shuttle. Performed on missions STS-40 and STS-58. Astronauts entering the microgravity environment of space are known to lose body protein and, as a result, they lose weight. Determined that energy intake and nitrogen retention—two factors in weight stabilization—initially dropped sharply but stabilized later in flight, and that a metabolic stress response is an important factor in this adjustment process.

Control of Red Blood Cell Mass in Spaceflight. Performed on missions STS-40 and STS-58. Astronauts have been shown to lose red blood cell mass and plasma volume as a result of spaceflight. Experiment showed that loss of red blood cell mass is due to destruction of newly formed red blood cells in orbit, and that plasma volume recovered rapidly on return to Earth as vascular space is refilled.

Regulation of Body Fluid Compartments During Short-term Spaceflight. Performed on missions STS-40 and STS-58. Goal was to determine the factors involved in regulation of body fluids in the human body when exposed to a microgravity environment. Determined that an increase in urinary excretion and a transport of protein out of plasma maybe have been two of the most important factors of the decrease in body fluids seen in space.

Orthostatic Function During Entry, Landing, and Egress. An ongoing experiment performed on many missions. Astronauts returning to Earth often experience orthostatic intolerance upon standing up for the first time, with symptoms including increased heart rate, nausea, vomiting, light-headedness, and fainting. Experiment measures blood pressures and heart rates of astronauts using instruments placed in their pressure suits. Results indicated that re-entry, landing, and egress places stress on the cardiovascular system. About 20% of astronauts were at or near their limits of cardiovascular performance and may not have been able to perform an unassisted emergency exit.

Assessment of Human Factors. Performed on nine missions. Experiment was a five-part study focused on effects of equipment stowage and deployment techniques, noise levels in Spacelab, excessive vibration, amount of time to perform tasks in space, and the effect crew member navigation through the tunnel into Spacelab had on crew member performance. Determined that detrimental factors included some equipment stowage and equipment techniques that slowed down astronauts, noise levels that affected sleep, concentration, communication, and relaxation, and interruptions while performing tasks. All other factors did not affect performance.

Characterization of Respirable Airborne Particulate Matter in Shuttle Atmosphere. See STS-32.

Inflight Aerobic Exercise. See STS-32.

Inflight Radiation Dose Distribution. Exposure to radiation is an important factor in space travel. Experiment measured exposure of human tissue to radiation through use of a tissue equivalent “phantom” human head. Determined that neutrons do not pose a significant hazard in space, the current model for describing cosmic radiation needs to improve, and time resolve dosimetry can be performed on shuttle.

Muscle Size and Lipids. Exposure to microgravity causes muscle atrophy for many astronauts. Experiment used a magnetic resonance imaging (MRI) facility to measure specific muscle size -pre and post flight Results showed that MRI could measure the deceased in muscle volume due to space flight.

Postural Equilibrium Control During Landing/Egress. Experiment was meant to define and characterize postflight alteration in postural control and stability.

Air Monitoring and Atmosphere Characterization. Evaluated innovative air monitoring instrumentation and worked to characterize shuttle atmosphere. Found that bacterial levels increased moderately as mission proceeded, whereas fungal levels tended to decrease.

STS-43

Blood Pressure Variability During Space Flight. See STS-41.

Cardiovascular Responses to Lower Body Negative Pressure Following Space Flight. See STS-37.

Changes in Baroreceptor Reflex Function After Space Flight. See STS-32.

Changes in Endocrine Regulation of Orthostatic Tolerance Following Space Flight. See STS-37.

Head and Gaze Stability During Locomotion. See STS-5.

In-Flight Lower Body Negative Pressure: Countermeasure to Reduce Post-Space Flight Orthostatic Intolerance. See STS-32.

Inflight Aerobic Exercise. See STS-32.

Postural Equilibrium Control During Landing/Egress. See STS-28.

Visual-Vestibular Integration as a Function of Adaptation. Investigated visual-vestibular and perceptual adaptive responses as a function of longer missions and worked to determine operational impact on performance of re-entry, landing, and egress procedures.

Orthostatic Function During Entry, Landing, and Egress. See STS-41.

STS-48

Hypersomotic Fluid Countermeasure. See STS-36.

Assessment of Circadian Shifting in Astronauts by Bright Light. See STS-5.

Blood Pressure Variability During Space Flight. See STS-41.

Changes in Endocrine Regulation of Orthostatic Tolerance Following Space Flight. See STS-37.

Effects of Space Flight on Aerobic and Anaerobic Metabolism During Exercise. See STS-39.

Head and Gaze Stability During Locomotion. See STS-5.

Visual-Vestibular Integration. See STS-41.

Inflight Radiation Dose Distribution. See STS-31.

Orthostatic Function During Entry, Landing, and Egress. See STS-41.

Air Monitoring and Atmosphere Characterization. See STS-40.

STS-44

Combustion Products Analyzer. Continuously sampled air throughout mission to detect presence of targeted compounds indicative of a thermodegradation event.

Cardiovascular Responses to Lower Body Negative Pressure Following Space Flight. See STS-37.

Changes in Endocrine Regulation of Orthostatic Tolerance Following Space Flight. See STS-37.

Effects of Space Flight on Aerobic and Anaerobic Metabolism During Exercise. See STS-39.

Head and Gaze Stability During Locomotion. See STS-5.

In-flight Holter Monitoring. See STS-61C.

In-Flight to Lower Body Negative Pressure: Countermeasure to Reduce Post-Space Flight Orthostatic Intolerance. See STS-32.

Intraocular Pressure. See STS-32.

Visual-Vestibular Integration. See STS-41.

Orthostatic Function During Entry, Landing, and Egress. See STS-41.

Air Monitoring and Atmosphere Characterization. See STS-40.

Postural Equilibrium Control During Landing/Egress. See STS-28.

STS-42

Mental Workload and Performance Experiment. Focused on motor and cognitive skills associated with interactions between astronauts and on-board computer control systems with the aim of optimizing interactions. Results showed that fine motor control performance was affected in space and that a track ball cuts down movement time more compared to use of a joystick.

Microgravity Vestibular Investigations. Different stimuli on the human sense of orientation were used to test effect of spaceflight on human orientation system. Determined that the human orientation system responds to some stimuli differently in space and most astronauts experienced some motion sickness symptoms.

Cabin Air Monitoring. See STS-51B.

Changes in Endocrine Regulation of Orthostatic Tolerance Following Space Flight. See STS-37.

In-Flight Lower Body Negative Pressure: Countermeasure to Reduce Post-Space Flight Orthostatic Intolerance. See STS-32.

The Relationship of Space Adaptation Syndrome to Middle Cerebral Artery Blood Velocity Measured in Flight by Doppler. See STS-29.

Pre- and Postflight Cardiac Assessment. See STS-26.

Inflight Radiation Dose Distribution. See STS-31.

Air Monitoring and Atmosphere Characterization. See STS-40.

Orthostatic Function During Entry, Landing, and Egress. See STS-41.

Postural Equilibrium Control During Landing/Egress. See STS-28.

Canadian Space Agency Experiments:

- Space Adaptation Syndrome Experiments. Gained a better understanding of Space Adaptation Syndrome.
- Evaluation of Nystagmus In and Out of Weightlessness. Improvement of treatments for inner ear disorders.
- Back Pain in Astronauts. Development of pre-/in-flight techniques to alleviate back pain.

Energy Expenditure in Space Flight. Gained better understanding of energy requirements of astronauts working in space and showed that they had the same energy requirements in flight as on the ground

Measurement of Venous Compliance and Evaluation of Experimental Anti-Gravity Suit. Gained a better understanding of blood pressure/flow from pre- to postflight.

STS-45

Cabin Air Monitoring. See STS-51B.

Cardiovascular Responses to Lower Body Negative Pressure Following Space Flight. See STS-37.

Changes in Endocrine Regulation of Orthostatic Tolerance Following Space Flight. See STS-37.

Effects of Space Flight on Aerobic and Anaerobic Metabolism During Exercise. See STS-39.

Energy and Metabolic Requirements for Extended Duration Space Flight (Energy Utilization). Performed on six missions. If energy balance is not maintained, if energy expenditure exceeds energy intake, it will cause an astronaut to lose lean body mass. Experiment measured total energy expenditure to compare results with predicted energy intake. Determined that astronauts were not eating and drinking enough, thus lowering their energy intake so that their energy balance was off, resulting in a loss of lean body mass that was consistent with predicted effects.

Head and Gaze Stability During Locomotion. See STS-5.

In-flight Use of Florinef to Improve Orthostatic Intolerance Postflight. Performed on 13 missions. Fluid shift experienced by astronauts is also experienced by humans in head-down tilt bed rest. On Earth, the drug Florinef is used to counteract fluid shift. Experiment examined the use of Florinef as a countermeasure to postflight orthostatic intolerance. Results indicated that Florinef caused unacceptable side effects in 5-day regimens, had no effect during 1-day regimens, and did not improve postflight orthostatic intolerance.

Visual-Vestibular Integration. See STS-41.

Collection of Shuttle Humidity Condensate for Analytical Evaluation. Worked to collect representative samples of space-generated humidity condensate to support development of water reclamation and monitoring hardware for International Space Station, and aimed to characterize inorganic and organic constituents of sample to expand database generated by ground-based studies. Condensate samples were collected for analysis on the ground.

Air Monitoring and Atmosphere Characterization. See STS-40.

Orthostatic Function During Entry, Landing, and Egress. See STS-41.

Space Tissue Loss. Sponsored by Walter Reed Army Institute of Research and NASA's Life Sciences Division. Module was developed to help scientists and Army medical practitioners understand more about effects of spaceflight on fragile life systems, including immune system, muscle, and bone.

STS-49

Cabin Air Monitoring. See STS-51B.

Hydrazine Monitoring. See STS-37.

Acoustical Noise Dosimeter Data. Worked to obtain baseline data of time-averaged acoustical noise levels for middeck during daytime and nighttime operations, including data on effects of middeck payloads, intermittent equipment noises, voice/communication on daily averages, and on other systems and laboratories when flown. Data were obtained during flight for evaluation.

Assessment of Circadian Shifting in Astronauts by Bright Light. See STS-5.

Changes in Endocrine Regulation of Orthostatic Tolerance Following Space Flight. See STS-37.

Evaluation of Cardiac Rhythm Disturbances During ExtraVehicular Activity. Performed on three missions. Evaluated whether there is an increased amount of cardiac dysrhythmias during extravehicular activity. Determined that there was no higher occurrence of cardiac rhythm disturbance during extravehicular activity and that there were not any deleterious cardiac events associated with extravehicular activity.

Evaluations of Functional Skeletal Muscle Performance Following Space Flight. Performed on five missions. This study evaluated the changes in arm strength after spaceflight and examined whether extravehicular activity during flight affects those changes. Determined that astronauts did lose arm strength and that taking part in extravehicular activity did not change effects of microgravity on arm strength.

Head and Gaze Stability During Locomotion. See STS-5.

In-flight Use of Florinef to Improve Orthostatic Intolerance Postflight. See STS-45.

Visual-Vestibular Integration. See STS-41.

Inflight Radiation Dose Distribution. See STS-31.

Orthostatic Function During Entry, Landing, and Egress. See STS-41.

Postural Equilibrium Control During Landing/Egress. See STS-28.

STS-50

Acoustical Noise Dosimeter Data. See STS-49.

Acoustical Noise Sound Level Data. Worked to obtain baseline data of octave acoustical noise levels for middeck and flight deck, and data on other types of equipment flown.

Cabin Air Monitoring. See STS-51B.

Assessment of Circadian Shifting in Astronauts by Bright Light (Parts A and B). See STS-5.

Assessment of Human Factors. See STS-40.

Blood Pressure Variability During Space Flight. See STS-41.

Cardiovascular Responses to Lower Body Negative Pressure Following Space Flight. See STS-37.

Changes in Endocrine Regulation of Orthostatic Tolerance Following Space Flight. See STS-37.

Effects of Intense Exercise During Space Flight on Aerobic Capacity and Orthostatic Function. Performed on five missions. Objectives were to measure aerobic capacity pre- and postflight to determine how decreases in aerobic capacity were related to changes in body composition, and to see if use of aerobic exercise in-flight reduced severity of postflight aerobic deconditioning. Determined that astronauts displayed a lower aerobic capacity postflight, partly due to decreases in total body protein most likely linked with loss of muscle mass, but in-flight exercise lessened effect of spaceflight-caused aerobic deconditioning.

Evaluation of Functional Skeletal Muscle Performance Following Space Flight. See STS-49.

Head and Gaze Stability During Locomotion. See STS-5.

In-Flight Lower Body Negative Pressure: Countermeasure to Reduce Post-Space Flight Orthostatic Intolerance. See STS-32.

In-flight Use of Florinef to Improve Orthostatic Intolerance Postflight. See STS-45.

Intraocular Pressure. See STS-32.

Physiological Evaluation of Astronaut Seat Egress Ability at Wheels Stop. Goal was to investigate nature and magnitude of deficits in postural equilibrium control, effect of head position on postural stability, and effect of vision on postural stability upon return to Earth.

Retinal Photography. See STS-33.

Orthostatic Function During Entry, Landing, and Egress. See STS-35.

Postural Equilibrium Control During Landing/Egress. See STS-28.

Air Monitoring and Atmosphere Characterization. See STS-40.

STS-46

Acoustical Noise Dosimeter Data. See STS-49.

Assessment of Circadian Shifting in Astronauts by Bright Light. See STS-5.

Changes in Endocrine Regulation of Orthostatic Tolerance Following Space Flight. See STS-37.

Effects of Intense Exercise During Space Flight on Aerobic Capacity and Orthostatic Function. See STS-50.

Head and Gaze Stability During Locomotion. See STS-5.

Visual-Vestibular Integration. See STS-41.

Orthostatic Function During Entry, Landing, and Egress. See STS-35.

STS-47

Fluid Therapy System. Designed to allow astronauts to administer fluids via IV in the space station. Flown on this mission to test whether it performed adequately in space. The system was able to produce three types of solutions required—all sterilized in space. The pump and other hardware performed as they were expected to perform.

Autogenic Feedback Training Exercise As a Preventive Method for Space Adaptation Syndrome. Autogenic Feedback Training is a combination of biofeedback and Autogenic Therapy that involves training physiological and behavioral responses to microgravity. Experiment examined whether Autogenic Feedback Training was a way to prevent space motion sickness. Determined that Autogenic Feedback Training is an effective way to control space motion sickness in most astronauts.

Magnetic Resonance Imaging. Study used Magnetic Resonance Imaging to determine loss and recovery of leg and back muscles and to examine any changes to disks in the spine that were a result of spaceflight. Results showed that significant muscle loss from both the legs and lower back was observed and that disks in the spine expanded as a result of spaceflight but returned to normal within 24 hours after landing.

Cabin Air Monitoring. See STS-51B.

Assessment of Circadian Shifting in Astronauts by Bright Light. See STS-5.

Assessment of Human Factors. See STS-40.

Cardiovascular Responses to Lower Body Negative Pressure Following Space Flight. See STS-37.

Changes in Endocrine Regulation of Orthostatic Tolerance Following Space Flight. See STS-37.

Energy and Metabolic Requirements for Extended Duration Space Flight (Energy Utilization). See STS-45.

Head and Gaze Stability During Locomotion. See STS-5.

In-Flight Lower Body Negative Pressure: Countermeasure to Reduce Post-Space Flight Orthostatic Intolerance. See STS-32.

Joint US/Russian Investigations: Metabolic Investigations. Performed on two missions. Objectives were to study the fluid shift undergone by astronauts in space and to determine how this affects energy use and dietary uptake of fluid and electrolytes, which may have an effect on the body's ability to adapt to microgravity. Results showed deceased extracellular water, but total body water did not change. Pre- and Post-flight Measurement of Cardiorespiratory Responses to Submaximal Exercise. Performed on 13 missions. Documented degree of aerobic deconditioning after spaceflight and investigated use of aerobic exercise during flight to mitigate the deconditioning effect of spaceflight. Results showed that aerobic capacity was greatly lowered upon return to Earth and those astronauts who exercised in space experienced lesser deconditioning upon return compared to astronauts who did not exercise in space.

Air Monitoring and Atmosphere Characterization. See STS-40.

Inflight Radiation Dose Distribution. See STS-31.

Orthostatic Function During Entry, Landing, and Egress. See STS-35.

Collection of Shuttle Humidity Condensate for Analytical Evaluation. See STS-45.

Evaluation of Samples Obtained from the Urine Monitoring System. Worked to determine whether in-flight sample dilution and volume measurement by the Urine Monitoring System was comparable to the method used in ground-based testing. Samples were collected during flight, but were later found to be contaminated with wastewater from the Waste Collection System.

Japanese Experiments:

> Endocrine and Metabolic Changes of Payload Specialists During Spacelab J. Studied endocrine and metabolic changes of a payload specialist by taking blood and urine samples at different times during Spacelab J. Most parameters in blood and urine were within normal range and excretions of sodium, potassium, calcium, and phosphorous also exhibited typical diurnal variations. A strong correlation between the excretion of antidiuretic hormone or aldosterone with that of cortisol was observed during the in-flight period, and circadian rhythms of the excretory pattern of sodium and potassium were lost during the pre- and in-flight period and were restored promptly upon return to Earth.

> Health Monitoring of Japanese Payload Specialist Autonomic Nervous and Cardiovascular Responses under Reduced Gravity. Monitored health of Japanese payload specialist during flight, investigated autonomic nervous system's response to space motion sickness, evaluated adaptation process of cardiovascular system to zero

gravity, and created database for use in health care of Japanese astronauts by obtaining control data. It was found that the physiological monitoring system must be more portable and must record the time code with continuous data on tape, and an infrared telemetry system was useful for data transmission in Spacelab because it does not limit subject's mobility area.

Comparative Measurement of Visual Stability in Earth and Cosmic Space. Focused on modifications by vestibular inputs to visual perception produced by eye movements in microgravity. Found that there are no differences in eye motility with and without gravity, the antigravity muscle in the neck did not show muscle discharge during the task, there is no cooperative behavior in the neck and eye, adaptation processes for the low gravity were not observed, subjective introspection from the Japanese payload specialist showed some disturbance for visual stability, and there were differences between perception and behavior in postflight behavior.

Manual Control in Space Research on Perceptual Motor Function under Microgravity Condition. Worked to obtain basic data for designing human-machine systems in space, and as well as to investigate human perceptual motor functions. The most important newly found phenomenon was that the subject felt pain when tracking eye movement during orbital experiments. Also, the subject felt difficulty in supporting his body against the reaction force of his hand movement.

STS-52

Acoustical Noise Dosimeter Data. See STS-49.

Assessment of Circadian Shifting In Astronauts by Bright Light. See STS-5.

Cardiovascular Responses to Lower Body Negative Pressure Following Space Flight. See STS-37.

Effects of Intense Exercise During Space Flight on Aerobic Capacity and Orthostatic Function. See STS-50.

Evaluation of Functional Skeletal Muscle Performance Following Space Flight. See STS-49.

Head and Gaze Stability During Locomotion. See STS-5.

Immunological Assessment of Crew Members. Performed on six missions. The risk of spaceflight infections is important to know for long-duration missions, such as for the International Space Station. This experiment assessed that risk and determined that the immune system sees a statistically significant decrease in total T cells and undergoes other alterations in spaceflight.

In-flight Lower Body Negative Pressure Test of Countermeasures and End-of-Mission Countermeasure Trial. Study used a combination of an ingestion of an isotonic saline solution and lower body negative pressure performed 1 day prior to landing as a countermeasure to postflight orthostatic intolerance experienced by many astronauts. Determined that the combination was an effective countermeasure against postflight orthostatic intolerance but it was impractical for use on shuttle because it takes 5 hours to treat one astronaut.

In-Flight Lower Body Negative Pressure: Countermeasure to Reduce Post-Space Flight Orthostatic Intolerance. See STS-32.

In-flight Use of Florinef to Improve Orthostatic Intolerance Postflight. See STS-45.

Intraocular Pressure. See STS-32.

Retinal Photography. See STS-33.

Orthostatic Function During Entry, Landing, and Egress. See STS-35.

Postural Equilibrium Control During Landing/Egress. See STS-28.

Visual-Vestibular Integration as a Function of Adaptation. See STS-43.

Canadian Space Agency Experiments:

Assessment if Back Pain in Astronauts. Better understanding of back pain on Earth.

Body Water Changes in Microgravity. Development on nutritional protocols for long-duration spaceflight and countermeasures used during re-entry.

Illusions During Movement and Vestibular-Ocular Reflex Check. Better understanding of triggers of visual illusions in shuttle. Gained a better understanding of lack of change in vestibulo-ocular reflex in microgravity.

STS-53

Acoustical Noise Dosimeter Data. See STS-49.

Hypersomotic Fluid Countermeasure. See STS-36.

Assessment of Circadian Shifting in Astronauts by Bright Light. See STS-5.

Effects of Space Flight on Aerobic and Anaerobic Metabolism During Exercise. See STS-39.

Head and Gaze Stability During Locomotion. See STS-5.

Intraocular Pressure. See STS-32.

Retinal Photography. See STS-33.

Visual-Vestibular Integration. See STS-41.

Orthostatic Function During Entry, Landing, and Egress. See STS-35.Postural Equilibrium Control During Landing/Egress. See STS-28.

Inflight Radiation Dose Distribution. See STS-31.

STS-54

Assessment of Circadian Shifting in Astronauts by Bright Light. See STS-5.

Head and Gaze Stability During Locomotion. See STS-5.

Immunological Assessment of Crewmembers. See STS-52.

Inflight Aerobic Exercise. See STS-32.

Orthostatic Function During Entry, Landing, and Egress. See STS-35.

Postural Equilibrium Control During Landing/Egress. See STS-28.

Visual-Vestibular Integration as a Function of Adaptation. See STS-43.

STS-56

Assessment of Circadian Shifting in Astronauts by Bright Light. See STS-5.

Cardiovascular and Cerebrovascular Responses to Standing Before and After Space Flight. Performed on 14 missions. Astronauts often feel faint and light-headed upon return to Earth. Experiment examined differences in physiological responses to spaceflight of astronauts who may or may not have become light-headed on landing day. Results showed that the reflexes that maintain blood pressure adapt to microgravity and this results in about one-fourth of astronauts having inadequate cardiovascular responses to standing.

Evaluation of Functional Skeletal Muscle Performance Following Space Flight. See STS-49.

Head and Gaze Stability During Locomotion. See STS-5.

Human Lymphocyte Locomotion in Microgravity. See STS-54.

In-flight Use of Florinef to Improve Orthostatic Intolerance Postflight. See STS-45.

Inflight Aerobic Exercise. See STS-32.

Measurement of Formaldehyde Using Passive Dosimetry. Performed on three missions. Formaldehyde would not be detected by air samplers in the shuttle unless concentration was very high. Experiment measured levels of formaldehyde in atmosphere inside shuttle. Found that the maximum allowable concentration of formaldehyde was being exceeded so potential flight equipment was better tested for its release of formaldehyde prior to being approved for spaceflight on shuttle.

Pre- and Postflight Measurement of Cardiorespiratory Responses to Submaximal Exercise. See STS-47.

Orthostatic Function During Entry, Landing, and Egress. See STS-35.

Postural Equilibrium Control During Landing/Egress. See STS-28.

Inflight Radiation Dose Distribution. See STS-31.

Evaluation of Functional Skeletal Muscle Performance Following Space Flight. See STS-49.

Space Tissue Loss. See STS-45.

STS-55

Acoustical Noise Dosimeter Data. See STS-49.

Acoustical Noise Sound Level Data. See STS-50.

Cabin Air Monitoring. See STS-51B.

Assessment of Circadian Shifting in Astronauts by Bright Light. See STS-5.

Effects of Intense Exercise During Space Flight on Aerobic Capacity and Orthostatic Function. See STS-50.

Evaluation of Functional Skeletal Muscle Performance Following Space Flight. See STS-49.

Head and Gaze Stability During Locomotion. See STS-5.

Immunological Assessment of Crewmembers. See STS-52.

In-flight Use of Florinef to Improve Orthostatic Intolerance Postflight. See STS-45.

Joint U.S./Russian Investigations: Metabolic Investigations. See STS-47.

Orthostatic Function During Entry, Landing, and Egress. See STS-35.

Physical Examination in Space. Worked to identify and quantify normal physical changes that occur in microgravity, develop baseline parameters from which pathologic responses can be identified, and develop standardized techniques for conducting a physical examination in space. Performed twice on the flight, and video was downlinked twice.

Measurement of Blood Volumes Before and After Space Flight. Measured changes in blood volume after spaceflight to support hypothesis that blood volume is reduced post spaceflight.

Evaluation of Samples Obtained from the Urine Monitoring System. See STS-47 for description. Higher percent recoveries were noted in preflight samples versus in-flight and postflight samples, and mass readings were adjusted according to in-flight calibration data and appeared to be more linear as compared to STS-47 data.

European Space Agency dedicated research:

Antigen-specific Activation of Regulatory T-Lymphocytes to Lymphokine Production. Investigated whether Ovalbumin-specific interactions of accessor cell-responder T-helper cells would be facilitated in flight conditions. Level of lymphokine transcripts increased as anticipated in weightlessness-exposed samples, but lymphokine secretion was impaired.

Cardiovascular regulation at 0*g*. Studied cardiovascular responses to rapid expansion of intravascular volume, disuse atrophy, or cardiac and skeletal muscle and its physiological consequences, along with mechanisms responsible for postflight orthostatic intolerance. Hemodynamic response showed no effect of spacefight despite decrease in left ventricular mass, end-diastolic volume, and stroke volume with increase in heart rate.

Central Venous Pressure. This study of changes in central venous pressure in upright, standing, and supine positions showed similar levels in space as on the ground. Changes in rate of whole-body nitrogen turnover, protein synthesis, and protein breakdown. Found significant increase in rate of protein oxidation in flight and 4 days after return, a significant decrease in rate of protein synthesis, and a breakdown or retention in flight and 4 days and 60 days postflight.

Chromosome Aberration. Measured influence of cosmic radiation on chromosomal aberrations in peripheral blood lymphocytes of astronauts. Exposure to cosmic radiation during the D-2 mission had no effect on number of dicentric chromosomes and of sister chromatid exchanges in the blood samples of six astronauts.

Changes in the Rate of Whole Body Nitrogen Turnover, Protein Synthesis and Protein Breakdown. Aimed to measure individual components of whole-body protein metabolism to find out whether changes in those parameters could explain loss of lean body mass. Results indicated a significant increase in rate of protein oxidation in flight and 4 days after return, and a significant decrease in rate of protein synthesis, breakdown or retention in flight, and 4 days after return.

Determination of Segmental Fluid Content and Perfusion. Tested hypothesis that postflight orthostatic intolerance is due to changes in pooling of blood in lower parts of body that occur upon standing after a sudden return to 1*g*. Lower body fluid pooling seemed to be only a minor contributor to postflight orthostatic intolerance.

Effects of Microgravity on Glucose Tolerance. Explored pancreatic function during flight rather than after re-entry through evaluation of glucose, insulin, and C-peptide in response to an oral glucose tolerance test. In-flight tests showed a statistically nonsignificant trend to increased glucose, insulin, and C-peptide, but postflight tests showed that glucose, insulin, and C-peptide came back to preflight levels.

Effects of Microgravity on the Dynamics of Gas Exchange, Ventilation and Heart Rate in Submaximal Dynamic Exercise. The pseudo-random binary sequence technique involving workloads ranging from 20 to 80 watts on a cycloergometer was used in combination with measurement of maximal oxygen uptake, respiratory determination of the anaerobic threshold, and calculation of power-lactate-relationship to validate method for further studies on aerobic performance of muscles. Oxygen transport to exercising muscles was transitorily deteriorated while aerobic capacity of muscles was not affected in 10 days of spaceflight.

Effects of Spaceflight on Pituitary-Gonad-Adrenal Function in the Human. Assessed whether a variety of possible changes to bodily functions really occurs in space. Using a salivary method, indirect evidence indicated that dopamine turnover rate within the brain was increased and a reversible condition of hypoandrogenism occurred.

Left Ventricular Configuration and Function at Rest and Under Stimulation. Analyzed properties of the heart during different phases of flight, including cardiac adaptation to changes of body fluids distribution induced by microgravity. Showed new adaptive state of heart dimensions and property was attained in the course of the mission.

Leg Fluid Distribution at Rest and Under Lower Body Negative Pressure. Tested hypothesis that postflight orthostatic intolerance is due to changes in pooling of blood in lower parts of body that occur upon standing after a sudden return to 1*g*. Lower body fluid pooling was a minor contributor to postflight orthostatic intolerance, which may rather be attributed to changes in central integration mechanisms brought about by microgravity.

Performance of the Personal Dosimetry of the Astronaut's Ionizing Radiation Exposure. Measured radiation exposure of astronauts with dosimeters permanently attached to different positions of their bodies. Measured doses were higher than at rack locations. Waist readings were lower than other positions on the body due to higher body shielding.

Peripheral and Central Hemodynamics. Tested a hypothesis concerning factors affecting decrease in orthostatic intolerance after exposure to microgravity during at least the first 2 days after re-entry from 6 to 13 days in space. Forearm subcutaneous vascular resistance increased promptly and tended to be high during the 1 to 2 days postflight and this maybe a defense mechanism to alleviate decreased orthostatic tolerance.

Pulmonary Perfusion and Ventilation at Rest and Exercise. Investigated whether pulmonary perfusion becomes more homogeneously distributed in absence of gravity. Data from one subject suggested that microgravity does not altogether abolish perfusion inequalities within the lung, suggesting factors unrelated to gravity play an important role in determining distribution of pulmonary perfusion.

Regulation of Volume Homeostasis in Weightlessness: Possible Involvement of Atrial Natriuretic Factor and Cyclic GMP. Investigated whether, under strictly controlled fluid and salt intake conditions, the newly found kidney-derived natriuretic factor urodilatin might cause a fast and sustained natriuresis after a central volume expanding challenge test. A general conclusion was that the human body in the supine position requires about 2 days to regulate the amount of sodium and water provided by an acute saline infusion.

The Influence of Microgravity on Endocrine and Renal Elements of Volume Homeostasis in Man. Investigated how endocrine and renal mechanisms of fluid volume control in humans adapt to microgravity by challenging the system with an intravenous isotonic saline infusion. The microgravity-adapted renal responses to infusion reflected similar ground studies in seated and supine subjects. Norepinephrine, active rennin, and aldosterone were elevated in-flight and not related to renal sodium excretion and urinary flow rate.

The Role of Volume Regulating Hormones and Plasma Proteins in Man for the Adaptation to Micro-G and for the Readaptation to Terrestrial Conditions. Analyzed time course of both hormones regulating red blood cell mass/plasma volume and plasma proteins involved in plasma volume regulation. Thyroid-stimulating hormone increased in-flight as compared to the decrease in erythropoietin levels demonstrating no measureable relationship between the two hormones.

Tissue Thickness and Tissue Compliance, A Long Body Axis Under Micro-g Conditions. Worked to measure fluid shifts within superficial tissues of upper and lower parts of the body. Tissue thickness decreased by about 16 % in the tibia and increase by 7% in the forehead and, as calculated, about 410 ml of fluid leave the lower limbs, but only about 40 ml accumulate in superficial tissues of the head. Process is reversed within the first hour after landing. Swelling of the head superficial tissues tends to decrease within the first 3 to 5 days in space, but it does not disappear totally.

Tonometry – Intraocular Pressure (IOP). Aimed to assess intraocular pressure changes occurring in early phases of microgravity. Immediately after entering microgravity, intraocular pressure increased by about 100%. It declined thereafter to reach preflight values after 4 to 5 days in orbit. First measurements 20 minutes after landing showed a decrease of about 30% compared to preflight data. Basal diurnal IOP rhythm was not affected by microgravity.

Ventilation Distribution in Microgravity Worked to analyze chest wall mechanics for the first time in space and to continue pilot studies upon the role of gravity in lung ventilation distribution performed during SLS-1. Most ventilation inhomogeneity in the lungs depends on non-gravity-related factors and gravity-dependent inhomogeneities of ventilation increase toward periphery of lung.

STS-57

Acoustical Noise Dosimeter Data. See STS-49 for description. One hour of data were collected during last hour of extravehicular mobility unit battery charger operation.

Acoustical Noise Sound Level Data. See STS-50 for description. Made measurements during extravehicular mobility unit battery charger operation.

Cabin Air Monitoring. See STS-51B.

Neutral Body Posture. Investigated changes in posture of human body over the course of the mission. Several different crew postures were exhibited during data acquisition on Flight Day 6, and no single crew member exhibited typical neutral body posture called out in Man-Systems Integration Standards.

Assessment of Circadian Shifting in Astronauts by Bright Light (Parts A and B). See STS-5.

Assessment of Human Factors. See STS-40.

Effects of Intense Exercise During Space Flight on Aerobic Capacity and Orthostatic Function. See STS-50.

Head and Gaze Stability During Locomotion. See STS-5.

Pre- and Post-flight Measurement of Cardiorespiratory Responses to Submaximal Exercise. See STS-47.

Visual-Vestibular Integration. See STS-41.

Orthostatic Function During Entry, Landing, and Egress. See STS-35.

STS-51

Assessment of Circadian Shifting in Astronauts by Bright Light (Parts A and B). See STS-5.

Cardiovascular and Cerebrovascular Responses to Standing Before and After Space Flight. See STS-56.

Gastrointestinal Function During Extended Duration Space Flight. Examined effect of microgravity on function of gastrointestinal muscles responsible for mixing food and propelling it through gastrointestinal tract. Results indicated that the response of the gastrointestinal system was not affected but that intestinal transit time seemed to increase during spaceflight.

Head and Gaze Stability During Locomotion. See STS-5.

Immunological Assessment of Crewmembers. See STS-52.

Inflight Aerobic Exercise. See STS-32.

Inflight Radiation Dose Distribution. See STS-31.

Measurement of Blood Volumes Before and After Space Flight. See STS-55.

Orthostatic Function During Entry, Landing, and Egress. See STS-35.

Postural Equilibrium Control During Landing/Egress. See STS-28.

Visual-Vestibular Integration. See STS-41.

Evaluation of Functional Skeletal Muscle Performance Following Space Flight. See STS-49.

STS-58

Orthostatic Intolerance After Spaceflight. See STS-40.

Central Venous Pressure in Space. See STS-40.

Cardiovascular Response to Submaximal Exercise in Sustained Microgravity. See STS-40.

Diet and Nitrogen Metabolism During Spaceflight on the Shuttle. See STS-40.

Control of Red Blood Cell Mass in Spaceflight. See STS-40.

Regulation of Body Fluid Compartments During Short-term Spaceflight. See STS-40.

Tactile Influences on Astronaut Visual Spatial Orientation: Human Neurovestibular Studies on Space Life Sciences-2 (SLS-2) flight (STS-58). Results showed that when humans can no longer rely on their gravity-sensing organs for spatial orientation, they rely more heavily on other factors such as visual or tactile clues (such as feet indicating down) to determine orientation. However, it was shown that even though all astronauts were disoriented, methods used to determine spatial orientation in microgravity varied from astronaut to astronaut, with some relying on visual clues, some on tactile clues, and some simply on the orientation of his or her body.

Effect of Spaceflight on Ability to Sense and Control Roll Tilt: Human Neurovestibular Studies on SLS-2. Balance and gravity-sensing organs are known to adapt to a microgravity environment. Experiment showed that on return to Earth, astronauts exhibited a lowered ability to control the roll tilt of a platform, and it was also ruled out that this decrease in balance ability was due to changes in neuromuscular function or fatigue.

Perceptual Responses to Linear Acceleration After Spaceflight: Human Neurovestibular Studies on SLS-2. Experiment determined that astronauts returning from spaceflight show a heightened ability to sense linear acceleration. These changes are indicative of a reinterpretation of inertial cues that is beneficial in a microgravity environment, but are not beneficial in Earth's gravity.

Horizontal Angular vestibulo-ocular reflex Changes in Orbital and Parabolic Flight: Human Neurovestibular Studies on SLS-2. Experiment determined that the human brain adapts its "velocity storage" centers to a microgravity environment, but that this adaptation requires some time. Velocity storage centers are responsible for reducing retinal slip—the blurring sensation—and their adaptation to microgravity is one of the factors responsible for disappearance of space sickness after a few days in space.

Dried Blood Method for In-flight Storage. Experiment tested a new method for storing dried blood samples for in-flight use, with the objective of eliminating the need for a freezer or refrigerator to store blood samples during spaceflight. Determined that quality of blood samples collected was superior to former in-flight methods and, in general, 80% of studied samples were preserved for several months without the need to freeze the samples.

Acoustical Noise Dosimeter Data. See STS-49.

Acoustical Noise Sound Level Data. See STS-50 for description. Used Spacelab sound level meter to collect data on flight.

Cabin Air Monitoring. See STS-51B.

Assessment of Circadian Shifting in Astronauts by Bright Light. See STS-51D.

Assessment of Human Factors. See STS-40.

Cardiovascular and Cerebrovascular Responses to Standing Before and After Space Flight. See STS-56.

Energy and Metabolic Requirements for Extended Duration Space Flight. See STS-45.

Head and Gaze Stability During Locomotion. See STS-51A.

Immunological Assessment of Crewmembers. See STS-52.

In-flight Lower Body Negative Pressure Test of Countermeasures and End-of-Mission Countermeasure Trial. See STS-52.

Pre- and Post-flight Measurement of Cardiorespiratory Responses to Submaximal Exercise. See STS-47.

Orthostatic Function During Entry, Landing, and Egress. See STS-35.

Postural Equilibrium Control During Landing/Egress. See STS-28.

Visual-Vestibular Integration as a Function of Adaptation. See STS-43.

Air Monitoring and Atmosphere Characterization. See STS-40.

Energy and Metabolic Requirements for Extended Duration Space Flight (Energy Utilization). See STS-45.

Physiological Evaluation of Astronaut Seat Egress Ability at Wheels Stop. See STS-50.

STS-61

Assessment of Circadian Shifting in Astronauts by Bright Light. See STS-5.

Back Pain Pattern in Microgravity. Back pain is a common symptom for astronauts during spaceflight. Study collected information about the pattern of back pain. Measurements of astronauts showed a significant increase in height within first 24 hours of spaceflight, a reduction in height during an extravehicular activity, and a re-growth to pre-extravehicular activity measurements within 24 hours post-extravehicular activity for nearly all subjects, resulting in back pain.

Cardiovascular and Cerebrovascular Responses to Standing Before and After Space Flight. See STS-56.

ExtraVehicular Activity Dosimetry Evaluation. Radiation exposure received by astronauts must be measured as accurately as possible so a Crew Passive Dosimeter is used to measure radiation. It was shown that during an extravehicular activity, an astronaut does not experience increased radiation exposure unless the astronaut passes through the South Atlantic Anomaly.

Head and Gaze Stability During Locomotion. See STS-5.

Immunological Assessment of Crewmembers. See STS-52.

Pre- and Post-flight Measurement of Cardiorespiratory Responses to Submaximal Exercise. See STS-47.

Visual-Vestibular Integration as a Function of Adaptation. See STS-43.

Inflight Radiation Dose Distribution. See STS-31.

STS-60

Cabin Air Monitoring. See STS-51B.

Assessment of Autonomic and Gastric Function During Spaceflight, Entry, and Landing. Performed on two missions to assess changes in stomach nerve response to food consumption. Stomach nerve activity varied while astronaut was experiencing space motion sickness symptoms. Nerve response to food consumption was shown to decrease initially in space but returned to normal after Flight Day 3, and nerve activity was altered strongly by space motion sickness.

Assessment of Circadian Shifting in Astronauts by Bright Light. See STS-5.

Head and Gaze Stability During Locomotion. See STS-5.

Immunological Assessment of Crewmembers. See STS-52.

Joint U.S./Russian Investigations: Sensory-Motor Investigations. Worked to enhance understanding of adaptation to spaceflight and readaptation after flight on various aspects of human spatial orientation, neurosensory, sensory-motor, physiological, and perceptual functions, and on autonomic gastric functions associated Space Motion System. Most science objectives for voluntary head movements and optokinetic nystagmus were met during flight, but some deletions of tests were needed due to time constraints.

Joint U.S./Russian Investigations: Metabolic. Aimed to determine effect of microgravity on total body water, extracellular fluid volume, peripheral venous pressure, body fluid distribution, sodium/potassium balance, fluid/electrolyte regulatory hormones, and energy expenditure. Results similar to previous space flight studies with few changes in the homestatis of fluid/electrolyte hormones or energy expenditure.

STS-62

In-flight Evaluation of a Portable Clinical Blood Analyzer. Performed on six missions to test a portable device for in-flight analysis of blood samples. Performance of analyzer was similar to its performance on Earth, thus proving useful for immediate analyses of many different parameters in space and also possibly in remote areas on Earth.

Assessment of Circadian Shifting in Astronauts by Bright Light. See STS-5.

Cardiovascular and Cerebrovascular Responses to Standing Before and After Space Flight. See STS-56.

Effects of Space Flight on Aerobic and Anaerobic Metabolism During Exercise. See STS-39.

Energy and Metabolic Requirement for Extended Duration Space Flight (Energy Utilization). See STS-45.

Head and Gaze Stability During Locomotion. See STS-5.

In-flight Assessment of Renal Stone Risk. Performed on four missions to make a preliminary assessment of spaceflight-induced changes in risk factors for kidney stones and influence of astronaut's diet on these risk factors. Spaceflight increased risk factors involved with formation of kidney stones and it was recommended that astronauts drink 2.5 L (2.6 quarts) of water daily to decrease these risk factors.

In-flight Lower Body Negative Pressure Test of Countermeasures and End-of-Mission Countermeasure Trial. See STS-52.

Immunological Assessment of Crewmembers. See STS-52.

Orthostatic Function During Entry, Landing, and Egress. See STS-35.

Postural Equilibrium Control During Landing/Egress. See STS-28.

Visual-Vestibular Integration as a Function of Adaptation. See STS-43.

Air Monitoring and Atmosphere Characterization. See STS-40.

Human Lymphocyte Locomotion in Microgravity. See STS-54.

STS-59

Acoustical Noise Dosimeter Data. See STS-49.

Acoustical Noise Sound Level Data. See STS-50.

Assessment of Circadian Shifting in Astronauts by Bright Light. See STS-5.

Cardiovascular and Cerebrovascular Responses to Standing Before and After Space Flight. See STS-56.

Effects of Space Flight on Aerobic and Anaerobic Metabolism During Exercise. See STS-39.

Head and Gaze Stability During Locomotion. See STS-5.

Measurement of Formaldehyde Using Passive Dosimetry. See STS-56.

Pre- and Postflight Measurement of Cardiorespiratory Responses to Submaximal Exercise. See STS-47.

Visual-Vestibular Integration. See STS-41.

Back Pain Pattern in Microgravity. See STS-61.

Imunological Assessment of Crewmembers. See STS-52.

Orthostatic Function During Entry, Landing, and Egress. See STS-35.

Air Monitoring and Atmosphere Characterization. See STS-40.

STS-65

Acoustical Noise Dosimeter Data. See STS-49.

Acoustical Noise Sound Level Data. See STS-50.

Cabin Air Monitoring. See STS-51B.

Assessment of Circadian Shifting in Astronauts by Bright Light. See STS-5.

Cardiovascular and Cerebrovascular Responses to Standing Before and After Space Flight. See STS-56.

Characterization of Microbial Transfer Among Crewmembers During Space Flight. Performed on eight missions to assess spread of microorganisms among shuttle crew members and their environment. Microbes were shown to spread to other crew members and also were found in crew compartment.

Effects of Space Flight on Aerobic and Anaerobic Metabolism During Exercise. See STS-39.

Head and Gaze Stability During Locomotion. See STS-5.

In-flight Assessment of Renal Stone Risk. See STS-62.

In-flight Lower Body Negative Pressure Test of Countermeasures of End-of-Mission Countermeasure Trial. See STS-52.

Visual-Vestibular Integration. See STS-41.

Air Monitoring and Atmosphere Characterization. See STS-40.

Inflight Radiation Dose Distribution. See STS-31.

Orthostatic Function During Entry, Landing, and Egress. See STS-35.

Postural Equilibrium Control During Landing/Egress. See STS-28

Microgravity Effects on Standardized Cognitive Performance Measures. Aimed to help determine astronauts' mental ability to perform operational tasks in space.

Canadian Space Agency Experiment:

> Spinal Changes in Microgravity. Worked to determine whether lengthening of spinal column can be associated with changes in function of spinal cord or spinal nerve roots that branch off spinal cord, and worked to determine for the first time if lengthening of spinal column causes changes in cardiovascular and bladder functions. Stereophotographs of spine and ultrasound imaging of vertebral spacing were successfully recorded.

Japanese Space Agency Experiment:

> Dosimetry Measurement and Biological Effects of Heavy Ion Beams in Space Shuttle. The real-time radiation monitoring device had high linear energy distribution in good agreement with that obtained previously.

STS-64

Assessment of Circadian Shifting in Astronauts by Bright Light. See STS-5.

Cardiovascular and Cerebrovascular Responses to Standing Before and After Space Flight. See STS-56.

Energy and Metabolic Requirements for Extended Duration Space Flight (Energy Utilization). See STS-45.

Evaluation of Cardiac Rhythm Disturbances During Extravehicular Activity. See STS-49.

Head and Gaze Stability During Locomotion. See STS-5.

In-flight Assessment of Renal Stone Risk. See STS-62.

In-flight Use of Florinef to Improve Orthostatic Intolerance Postflight. See STS-45.

Pre- and Postflight Measurement of Cardiorespiratory Responses to Submaximal Exercise. See STS-47.

Visual-Vestibular Integration. See STS-41.

Orthostatic Function During Entry, Landing, and Egress. See STS-35.

Postural Equilibrium Control During Landing/Egress. See STS-28.

Immunological Assessment of Crewmembers. See STS-52.

Back Pain Pattern in Microgravity. See STS-61.

Characterization of Microbial Transfer Among Crewmembers During Space Flight. See STS-65.

ExtraVehicular Activity Dosimetry Evaluation. See STS-61.

STS-68

Assessment of Circadian Shifting in Astronauts by Bright Light. See STS-5.

Cardiovascular and Cerebrovascular Responses to Standing Before and After Space Flight. See STS-56.

Characterization of Microbial Transfer Among Crewmembers During Space Flight. See STS-65.

Head and Gaze Stability During Locomotion. See STS-5.

In-flight Use of Florinef to Improve Orthostatic Intolerance Postflight. See STS-45.

Pre- and Postflight Measurement of Cardiorespiratory Responses to Submaximal Exercise. See STS-47.

Visual-Vestibular Integration. See STS-41.

Immunological Assessment of Crewmembers. See STS-52.

Orthostatic Function During Entry, Landing, and Egress. See STS-35.

Postural Equilibrium Control During Landing/Egress. See STS-28.

Collection of Shuttle Humidity Condensate for Analytical Evaluation. See STS-45.

STS-66

Cabin Air Monitoring. See STS-51B.

Assessment of Circadian Shifting in Astronauts by Bright Light. See STS-5.

Cardiovascular and Cerebrovascular Responses to Standing Before and After Space Flight. See STS-56.

Effects of Space Flight on Aerobic and Anaerobic Metabolism During Exercise. See STS-39.

Energy and Metabolic Requirements for Extended Duration Space Flight (Energy Utilization). See STS-45.

Head and Gaze Stability During Locomotion. See STS-5.

In-flight Use of Florinef to Improve Orthostatic Intolerance Postflight. See STS-45.

Pre- and Postflight Measurement of Cardiorespiratory Responses to Submaximal Exercise. See STS-47.

Visual-Vestibular Integration as a Function of Adaptation. See STS-43.

Orthostatic Function During Entry, Landing, and Egress. See STS-35.

Postflight Recovery of Postural Equilibrium Control. See STS-28 (Postural Equilibrium Control During Landing/Egress).

Immunological Assessment of Crewmembers. See STS-52.

Monitoring Latent Virus Reactivation and Shedding in Astronauts. Performed on 26 missions to determine effect of spaceflight on reactivation of latent viruses in astronauts. Spaceflight was shown to cause abnormal reactivation of some latent viruses demonstrating that space has an effect on the human immune system.

Space Tissue Loss. See STS-45.

STS-63

Cabin Air Monitoring. See STS-51B.

In-flight Evaluation of a Portable Clinical Blood Analyzer. See STS-62.

Assessment of Autonomic and Gastric Function During Spaceflight, Entry, and Landing. See STS-60.

Assessment of Circadian Shifting in Astronauts by Bright Light. See STS-5.

Effects of Space Flight on Aerobic and Anaerobic Metabolism During Exercise. See STS-39.

Head and Gaze Stability During Locomotion. See STS-5.

Back Pain Pattern in Microgravity. See STS-61.

Immunological Assessment of Crewmembers. See STS-52.

Characterization of Microbial Transfer Among Crewmembers During Space Flight. See STS-65.

ExtraVehicular Activity Dosimetry Evaluation. See STS-61.

Physical Examination in Space. See STS-55 for description.

Joint U.S./Russian Investigations: Sensory-Motor Investigations. See STS-60.

Assessment of Autonomic and Gastric Function During Spaceflight, Entry and Landing. Attempted to observe and analyze changes in stomach nerve response to food consumption over first few days of flight, and evaluated stomach nerve activity when space motion sickness symptoms occurred. Crew members responded normally to ingestion of a meal preflight, and an abnormal decrease in dominant power occurred on Flight Day 1 for all subjects, but response returned to normal on Flight Day 3. Individual differences were observed, but all three crew members experienced moderate to severe loss of appetite on Flight Day 1, and two of them showed mild loss of appetite on Flight Day 3.

STS-67

Assessment of Circadian Shifting in Astronauts by Bright Light (Parts A and B). See STS-5.

Cardiovascular and Cerebrovascular Responses to Standing Before and After Space Flight. See STS-56.

Effects of Space Flight on Aerobic and Anaerobic Metabolism During Exercise. See STS-39.

Head and Gaze Stability During Locomotion. See STS-5.

In-flight Use of Florinef to Improve Orthostatic Intolerance Postflight. See STS-45.

Measurement of Formaldehyde Using Passive Dosimetry. See STS-56.

Pre- and Postflight Measurement of Cardiorespiratory Responses to Submaximal Exercise. See STS-47.

Visual-Vestibular Integration. See STS-41.

Immunological Assessment of Crewmembers. See STS-52.

Orthostatic Function During Entry, Landing, and Egress. See STS-35.

Postural Equilibrium Control During Landing/Egress. See STS-28.

STS-71

Physiological Responses During Descent on the Space Shuttle. Orthostatic dysfunction, problems with cardiovascular system while standing, are well known as an effect of spaceflight on return to Earth. Experiment attempted to determine whether longer-duration (> 3 months) spaceflight resulted in higher risk of orthostatic impairments compared to short-duration (< 16 days) spaceflight. Results indicated that there might not be a greater risk of orthostatic dysfunction as a result of spaceflight, but nothing conclusive can be said because of problems with subjects and the small sample size.

Studies of Orthostatic Intolerance with use of Lower Body Negative Pressure. The cardiovascular system undergoes many changes as a result of microgravity environment of space and both the Russian cosmonauts and the American astronauts use lower body negative pressure devices as a countermeasure to changes in cardiovascular system. Experiment was to determine the time-course and mechanisms of orthostatic intolerance. Determined that heart rate increased in response to lower body negative pressure, but other factors could not be fully studied because of loss of data and difficulty with the crew.

Trace Chemical Contamination: Water Quality. Focus was on water quality of recycled water from condensate on Russian space station Mir, the potable water supplied by Progress spacecraft, and condensate from shuttle with the goal of supporting development of water collection hardware for the International Space Station. It was found that recycled water from Mir met joint US/Russian water quality standards.

Anticipatory Postural Activity. Astronauts experience a loss of balance, including increased swaying while standing, difficulty in rounding corners, and increased body movement during locomotion as a result of living in a microgravity environment. Experiment determined that the ability to generate neuromuscular activation patterns characteristic of preflight movement was compromised postflight and that application of in-flight foot pressure enhanced neuromuscular activation and may be a viable in-flight countermeasure to loss of balance experienced upon return to Earth.

Studies of Mechanisms Underlying Orthostatic Intolerance using Ambulatory Monitoring, Baroreflex Testing, and the Valsalva Maneuver. Objective was to determine whether long-duration spaceflight (> 3 months) had a greater effect on cardiovascular system as compared to short-duration spaceflight (< 16 days). Results indicated that most of the changes to the cardiovascular system were the same between the two flight lengths, which indicates that most changes occur in first few days in space, but long-duration spaceflight did produce heart rhythm disturbance ventricular tachycardia, leaving open the possibility that long-duration spaceflight increases likelihood of heart rhythm disturbances.

Aerobic Capacity Using Graded Bicycle Ergometry. Most astronauts see a significant decrease in aerobic performance on return from spaceflight. Study aimed to find out if a more rigorous exercise program, while in-flight, was a good countermeasure to loss of aerobic performance. Results indicated that subjects completing a greater amount of exercise were closer than those that did not exercise to preflight levels of performance postflight, and that regulation of submaximal exercise is probably linked to stroke volume.

Alterations in Postural Equilibrium Control Associated with Long Duration Space Flight. Experiment was to determine whether effects of microgravity on human balancing ability and gravitational sensory system were more pronounced in subjects returning from long-duration spaceflight (>3 months) compared to short-duration spaceflight (<16 days). It was determined that subjects returning from long-duration spaceflight showed much greater balance control deficits and greater neuromotor disturbances, and recovery from these conditions occurs much more slowly than short-duration spaceflight subjects.

Assessment of Humoral Immune Function During Long-Duration Space Flight. Humoral immune response is the part of immunity that refers to the secreted antibodies the human body uses to fight off invading viruses or bacteria.

Experiment was to determine whether spaceflight affected the function of humoral immune response. Results indicated that there was little to no effect on production of antibodies or their response to an introduced vaccine in subjects.

Microbiological Investigations of the Mir Space Station and Flight Crew. Microbes are a threat to humans in space because of their ability to cause disease, allergies, contaminate air and water supplies, release toxins, and degrade critical materials, making it important to determine if long-duration spaceflight results in an increase in microbial presence on board human spacecraft. Experiment measured and characterized microbes present on Russian space station Mir and compared them to that of shuttle, with results showing that although there was slight increase in microbes aboard Mir, the difference was not statistically significant and it fell under limits set for the International Space Station.

Morphological, Histochemical and Ultrastructural Characteristics of Skeletal Muscle. Experiment was to determine whether long-duration spaceflight resulted in a greater amount of muscle atrophy compared to short-duration spaceflight, which has had many studies documenting the muscle atrophy associated with it. Results indicated that muscle atrophy in long-duration spaceflight (115 days) was about double that of short-duration spaceflight (>14 days), with a muscle volume reduction of 20% even with long-duration subjects exercising while in flight.

Phenotypic and Functional Analysis of Peripheral Mononuclear Cells During Long Duration Space Flight. Scientists have observed changes in the numbers of immune cell subpopulations and alteration in immune cell function as a result of spaceflight previously. Experiment was to determine the kinds of changes in function and amount of immune cells that occur during and after spaceflight. Results indicated that subpopulations of white cells were not significantly altered during flight, nor was there a major change in the function of the cells, but there was a decrease in cells on return to Earth suggesting that any changes formerly observed are an acute response to re-entry and readaptation to gravity.

Viral Reactivation. There are viruses that commonly infect humans and establish a lifelong latent infection in the host. As a result, these viruses are subject to intermittent reactivation from their latent state. Since latent virus reactivation is important to crew health, this experiment investigated reactivation of common viruses and determined that it seems the viruses were reactivated and shed more often in-flight as compared to pre- and postflight.

Effects of Space Flight on Aerobic and Anaerobic Metabolism During Exercise. See STS-39.

In-Flight Evaluation of a Portable Clinical Blood Analyzer. See STS-62.

Pre and Post-flight Measurement of Cardiorespiratory Responses to Submaximal Exercise. See STS-47.

Radiation Measurements in Shuttle Crew Compartment. Measured linear energy transfer spectrum of the complex space radiation in shuttle crew compartment, worked to provide accurate measurement of biologically effective does equivalent, and evaluated risk of single event upsets.

Joint U.S./Russian Investigations: Sensory-Motor Investigations. See STS-60.

Japanese Space Agency Mir experiments:

> Radiobiological Effects of HZE Particles. Effects of single HZE particles using radiobiological methods showed it was more sensitive than non-biological methods.

STS-70

Assessment of Human Factors. See STS-40.

Cardiovascular and Cerebrovascular Responses to Standing Before and After Space Flight. See STS-56.

In-flight Use of Florinef to Improve Orthostatic Intolerance Postflight. See STS-45.

Pre- and Postflight Measurement of Cardiorespiratory Responses to Submaximal Exercise. See STS-47.

Visual-Vestibular Integration. See STS-41.

Characterization of Microbial Transfer Among Crewmembers During Space Flight. See STS-65.

Orthostatic Function During Entry, Landing, and Egress. See STS-35.

STS-69

Characterization of Microbial Transfer Among Crewmembers During Space Flight. See STS-65.

Effects of Space Flight on Aerobic and Anaerobic Metabolism During Exercise. See STS-39.

Evaluation of Cardiac Rhythm Disturbances During Extravehicular Activity. See STS-49.

In-flight Assessment of Renal Stone Risk. See STS-62.

Pre- and Postflight Measurement of Cardiorespiratory Responses to Submaximal Exercise. See STS-47.

Back Pain Pattern in Microgravity. See STS-61.

In-Flight Evaluation of a Portable Clinical Blood Analyzer. See STS-62.

Postural Equilibrium Control During Landing/Egress. See STS-28.

Visual-Vestibular Integration as a Function of Adaptation. See STS-43.

ExtraVehicular Activity Dosimetry Evaluation. See STS-61.

Immunological Assessment of Crewmembers. See STS-52.

Influence of Microgravity and ExtraVehicular Activities on Pulmonary Oxygen Exchange. Worked to determine minimum inspired fraction of oxygen necessary to prevent hypoxemia under selected flight conditions.

STS-73

Cabin Air Monitoring. See STS-51B.

Assessment of Human Factors. See STS-40.

Cardiovascular and Cerebrovascular Responses to Standing Before and After Space Flight. See STS-56.

Characterization of Microbial Transfer Among Crewmembers During Space Flight. See STS-65.

In-flight Use of Florinef to Improve Orthostatic Intolerance Postflight. See STS-45.

Visual-Vestibular Integration. See STS-41.

Air Monitoring and Atmosphere Characterization. See STS-40.

Immunological Assessment of Crewmembers. See STS-52.

Orthostatic Function During Entry, Landing, and Egress. See STS-35.

Postural Equilibrium Control During Landing/Egress. See STS-28.

STS-74

In-flight Use of Florinef to Improve Orthostatic Intolerance Postflight. See STS-45.

Immunological Assessment of Crewmembers. See STS-52.

Visual-Vestibular Integration as a Function of Adaptation. See STS-43.

STS-72

In-flight Evaluation of a Portable Clinical Blood Analyzer. See STS-62.

Characterization of Microbial Transfer Among Crewmembers During Space Flight. See STS-65.

Monitoring Latent Virus Reactivation and Shedding in Astronauts. See STS-66.

Effects of Spaceflight on Bone and Muscle. Investigated mechanism behind effects of spaceflight on musculoskeletal system to counter these effects.

Back Pain Pattern in Microgravity. See STS-61.

Immunological Assessment of Crewmembers. See STS-52.

ExtraVehicular Activity Dosimetry Evaluation. See STS-61.

Influence of Microgravity and ExtraVehicular Activities on Pulmonary Oxygen Exchange. See STS-69.

Visual-Vestibular Integration as a Function of Adaptation. See STS-43.

STS-75

In-flight Evaluation of a Portable Clinical Blood Analyzer. See STS-62.

Characterization of Microbial Transfer Among Crewmembers During Space Flight. See STS-65.

Monitoring Latent Virus Reactivation and Shedding in Astronauts. See STS-72.

Immunological Assessment of Crewmembers. See STS-52.

Characterization of Microbial Transfer Among Crewmembers During Space Flight. See STS-65.

Interaction of the Space Shuttle Launch and Entry Suit and Sustained Weightlessness on Egress Locomotion. Studied impact of the launch and re-entry suit and sustained weightlessness on astronauts' egress locomotion and physiological response, determined by oxygen consumption.

STS-76

Interaction of the Space Shuttle Launch and Entry Suit and Sustained Weightlessness on Egress Locomotion. See STS-75.

Back Pain Pattern in Microgravity. See STS-61.

Immunological Assessment of Crewmembers. See STS-52.

ExtraVehicular Activity Dosimetry Evaluation. See STS-61.

STS-77

Characterization of Microbial Transfer Among Crewmembers During Space Flight. See STS-65.

Monitoring Latent Virus Reactivation and Shedding in Astronauts. See STS-72.

Immunological Assessment of Crewmembers. See STS-52.

Interaction of the Space Shuttle Launch and Entry Suit and Sustained

Weightlessness on Egress Locomotion. See STS-75.

STS-78

Canal and Otolith Interaction Studies. Worked to understand how the human vestibular system adapts on orbit. Direct Measurement of the Initial Bone Response to Space Flight in Humans. Investigated response of human calcium/bone homeostatic system to microgravity and gathered data that would allow prediction of consequences for health of astronauts. Human Sleep, Circadian Rhythms and Performance in Space. Performed first simultaneous study of sleep, 24-hour circadian rhythms, and task performance in microgravity. Magnetic Resonance Imaging After Exposure to Microgravity. See STS-47 (Magnetic Resonance Imaging) for description. Results were differed some from STS-47 results.

Measurement of Energy Expenditure During Spaceflight with the Doubly Labeled Water Method. Performed measurement of relationship between energy needs and calorie intake in space. Reinforced pervious observations that energy intake is below energy needs. Microgravity Effects on Standardized Cognitive Performance Measures. See STS-65 for description. All desired data were collected during the mission.

Relationship of Long-Term Electromyographic Activity and Hormonal Function to Muscle Atrophy and Performance. Worked to find out whether unstressed muscles and the nervous system compensate for changes due to lack of adaptation and atrophy and restore movement ability both on Earth and in microgravity. obtained during flight.

The Effects of Weightlessness on Human Single Muscle Fiber Function. Studied effects of microgravity on skeletal muscle function and worked to establish cellular causes of reduced functional capacity of skeletal muscle. Cabin Air Monitoring. See STS-51B.

Characterization of Microbial Transfer Among Crewmembers During Space Flight. See STS-65.

Monitoring Latent Virus Reactivation and Shedding in Astronauts. See STS-72.

Immunological Assessment of Crewmembers. See STS-52.

Interaction of the Space Shuttle Launch and Entry Suit and Sustained Weightlessness on Egress Locomotion. See STS-75.

Canadian Space Agency Experiment:

Torso Rotation Experiment. Tested effect of weightlessness on rotation of torso during in-flight activities.

European Space Agency Experiments:

An Approach to Counteract Impairment of Musculoskeletal Function in Space. Worked to shed further light on potential mechanisms that govern a decrease in muscle function in response to spaceflight. It was found that maximal voluntary contraction decreased by 8% and maximal electromyogram was reduced by 21% after bed rest, Electromyogram at increased by 20% after bed rest. Following 12-day ambulation, both maximal voluntary contraction and electromyogram were normalized.

The Effects of Microgravity on Skeletal Muscle Contractile Properties. Aimed to evaluate changes induced by spaceflight in muscle function of the human triceps surae, by-passing neural control, through direct muscle electrical stimulation. Results did not show significant impairment in contractive parameter during flight, but rather during recovery.

Effects of Microgravity on the Biomechanical and Bioenergetic Characteristics of Human Skeletal Muscle. Since studies had shown that maximum velocity at which a muscle can contract is inversely related to applied load or resistance, investigators worked to find out whether, and to what extent, that inverse relationship changed in microgravity.

Space Tissue Loss. See STS-45.

STS-79

Immunological Assessment of Crewmembers. See STS-52.

Japanese Space Agency:

Real-time Measurement of Radiation in Space. Purpose was to test a real-time monitor of space radiation.

STS-80

Immunological Assessment of Crewmembers. See STS-52.

STS-81

Immunological Assessment of Crewmembers. See STS-52.

Japanese Space Agency Mir experiments:

Survey of Specific Micro-organisms on Mir—Separation and Identification of Specific Micro-organisms. In some areas, 1.2 million bacteria were detected per ml of water and revealed high frequencies of bacteria resistant to ultraviolet radiation. Also, in situ hybridization clearly revealed the presence of large numbers of yeast bacteria, eubacteria, and many other bacterial strains.

Microflora Investigation Experiment of Microorganisms Inhabiting the Mir Space Station. Experiment was performed to identify strains of microorganisms inhabiting the Russian space station Mir as preparation for its long-term habitation in the International Space Station (ISS), and to detect specific microorganisms exposed to long-term cosmic radiation. From a water sample, 2 million bacteria were detected per ml of 10 strains of ultraviolet-resistant bacteria, including a radiation-resistant strain (Sphingomonas paucimobilis) not previously found.

Mir Environmental Survey—Measurement of Micro-organisms on Mir. The number of bacteria suspended in air in Russian space station Mir was much less than expected due to satisfactory operation of air-cleaning units. New strains of genetically independent bacteria were detected in samples. No strong causative pathogens for respiratory infections were detected. Pathogens higher than level 2 were not isolated from this experiment.

STS-82

Monitoring Latent Virus Reactivation and Shedding in Astronauts. See STS-72.

Immunological Assessment of Crewmembers. See STS-52.

Interaction of the Space Shuttle Launch and Entry Suit and Sustained Weightlessness on Egress Locomotion. See STS-75.

Radiation Measurements in Shuttle Crew Compartment. See STS-71.

STS-83

Cabin Air Monitoring. See STS-51B.

Acoustical Noise Dosimeter Data. See STS-49.

Acoustical Noise Sound Level Data. See STS-50.

Radiation Measurements in Shuttle Crew Compartment. See STS-71.

Interaction of the Space Shuttle Launch and Entry Suit and Sustained Weightlessness on Egress Locomotion. See STS-75.

Immunological Assessment of Crewmembers. See STS-52.

Monitoring Latent Virus Reactivation and Shedding in Astronauts. See STS-72.

STS-84

Acoustical Noise Dosimeter Data. See STS-49.

Interaction of the Space Shuttle Launch and Entry Suit and Sustained Weightlessness on Egress Locomotion. See STS-75.

Immunological Assessment of Crewmembers. See STS-52.

Japanese Space Agency Experiments:

> Synthetic Analysis of Space Radiation Data. Investigation demonstrated that a real-time monitor of the space environment could be completed between the sun and Earth. Also determined if this influences radiation levels in low-Earth orbit, typical of quiet-time radiation levels in the International Space Station's orbit during solar minimum.

Real-time Cosmic Radiation Dosimetry. See STS-79.

STS-94

Cabin Air Monitoring. See STS-51B.

Radiation Measurements in Shuttle Crew Compartment. See STS-71 for description. Showed an east-west asymmetry of dose rates due to trapped protons in low-Earth orbit, as well as a significant neutron contribution to crew radiation doses.

Interaction of the Space Shuttle Launch and Entry Suit and Sustained Weightlessness on Egress Locomotion. See STS-75.

Immunological Assessment of Crewmembers. See STS-52.

Monitoring Latent Virus Reactivation and Shedding in Astronauts. See STS-72.

STS-85

Interaction of the Space Shuttle Launch and Entry Suit and Sustained Weightlessness on Egress Locomotion. See STS-75.

Assessment of Circadian Shifting in Astronauts by Bright Light. See STS-5.

Monitoring Latent Virus Reactivation and Shedding in Astronauts. See STS-72.

STS-86

Adaptation to Linear Acceleration after Spaceflight. Constant linear acceleration was delivered by centrifugation to determine any shift of the orientation axis of vestibular system during spaceflight. Effects of Microgravity on Cell Mediated Immunity and Reactivation of Latent Viral Infections. Examined spaceflight-induced alterations in human immune functions and latent virus shedding.

STS-87

Effects of Spaceflight on Bone and Muscle. See STS-72.

Interaction of the Space Shuttle Launch and Entry Suit and Sustained Weightlessness on Egress Locomotion. See STS-75.

Individual Susceptibility to Post-Spaceflight Orthostatic Intolerance. Studied pre-/postflight differences in astronauts who suffer post-spaceflight orthostatic hypotension and those who did not suffer from post-spaceflight orthostatic hypotension.

STS-89

Individual Susceptibility to Post-Spaceflight Orthostatic Intolerance. See STS-87.

Effects of Microgravity on Cell Mediated Immunity and Reactivation of Latent Viral Infections. See STS-86.

Japanese Space Agency Experiments:

> Real-time Cosmic Radiation Dosimetry See STS-79
>
> Real-time Neutron Spectrum Measurement in Orbit. To develop equipment for real-time measurements of neutron spectrum for use in a radiation exposure management system necessary for human activity in space, and to take measurements to verify predictions of neutron spectrum in orbit. Results were similar to NASA's previous measurements.
>
> Cosmic Radiation Dosimetry with Evaluation of Radiation Quality Using Solid-State Integrating Dosimeters. A method was tested for evaluating both dose and quality of cosmic radiation in a spacecraft by a combination of several dosimeters having different radiation-quality dependence. Knowledge obtained allows the use of solid-state integrating dosimeters having different radiation-quality dependence for measurements of spatial distribution of both dose and quality in a spacecraft.
>
> Synthetic Analysis of Space Radiation Environment Data. See STS-84
>
> Analysis of DNA Damage Due to Cosmic Radiation. Relationship between duration of spaceflight and amount of DNA showed changes in spaceflight samples.

STS-90

Perception of the Spatial Vertical During Centrifugation and Static Tilt. Astronauts were found to perceive tilt in space but inaccurately reported tilt angle magnitude until 2 weeks into on-flight testing. Results indicated that tilt perception is maintained in space and the translation hypothesis was incorrect.

Ocular Counter-Rolling During Centrifugation and Static Tilt. Evidence has suggested that ocular counter rolling is reduced postflight in 75% of astronauts tested. Experiment suggested possibility that in-flight exposure to artificial gravity in the form of 1*g* and 0.5*g* centripetal acceleration could counteract the reduction of ocular counter rolling usually experienced postflight.

The Brain as a Predictor: On Catching Fly Balls in Zero-G. A ball was projected downward at one of three different speeds and the anticipatory motor responses of the astronaut trying to catch the ball were measured. Experiment demonstrated that the central nervous system uses an internal model of gravitational acceleration in addition to sensory information to predict when the ball and hand will contact whether the astronaut is on Earth or in a microgravity environment.

The Role of Visual Cues in Microgravity Spatial Orientation. Results showed that astronauts became more dependent on visual motion cues and more responsive to stationary motion cues with respect to spatial orientation. The direction of what is up and down is labile in microgravity, which can interfere with the ability to interpret shading and recognize complex objects in different orientations.

Visual-Motor Coordination During Spaceflight. Subjects were found to slow down when performing a pointing or grasping task in microgravity, but not when performing a tracking and reaction time task. It is hypothesized that the task-specific pattern of change is due to three factors, where manual dexterity depends on required speed, accuracy, and amount of processing power allocated by the brain to the task.

Neural Control of the Cardiovascular System in Space. Experiment demonstrated that adaptation of the cardiovascular system to microgravity does not result in a defect in regulation of blood vessel constriction upon return to Earth. Cerebral auto-regulation of blood flow is also well maintained both in-flight and postflight.

Influence of Microgravity on Arterial Baroflex Responses Triggered by Valsalva's Maneuver. In a microgravity environment, the heart rate factor of blood pressure regulation is impaired. Experiment attempted to show that constriction and expansion of blood vessels in blood pressure regulation is also impaired, but results showed that only the heart rate portion of blood pressure regulation is affected by microgravity.

The Human Sympathetic Nervous System Response to Spaceflight. Experiment demonstrated that activity and response of the sympathetic nervous system to stress on the cardiovascular system was mildly elevated during and after flight. Changes returned to normal levels after a few days of readaptation to Earth's gravity.

Blood Pooling and Plasma Filtration in the Thigh in Microgravity. The thigh volume is decreased in a microgravity environment as a result of a smaller amount of body fluids. This causes receptors in the musculature in lower part of body to sense a dehydrated state in microgravity.

Sleep, Circadian Rhythms, and Performance During Space Shuttle Missions. Experiment showed that shuttle missions were associated with circadian rhythm disturbances, sleep loss, decrements in brain performance, and alteration in rapid eye movement sleep. Exposure to strange light-dark cycles and shorter than 24-hour rest activity were the probable causes.

Sleep and Respiration in Microgravity. Apneas and hypopneas are respiratory problems that affect sleep on Earth. In microgravity, these problems almost disappear and thus it can be determined that poor quality of sleep in microgravity is not the result of respiratory factors.

Cabin Air Monitoring. See STS-51B.

Assessment of Human Factors. See STS-40.

Interaction of the Space Shuttle Launch and Entry Suit and Sustained Weightlessness on Egress Locomotion. See STS-75.

Effects of Microgravity on Cell Mediated Immunity and Reactivation of Latent Viral Infections. See STS-86.

STS-91

Japanese Space Agency Experiments:

> Measurement of Mutation Rates Under Micro-gravity. See STS-89.
>
> Synthetic Analysis of Space Radiation Environment Data. See STS-84.
>
> Research Into the Effects of the Space Environment on Induced Synthesis of DNA Recovery Protein. Experiment was designed to elucidate this phenomenon by analysis of the process of recovery from DNA damage at molecular level, and to clarify effects of space environment on DNA repair function of organisms. The phenomenon of accelerated recovery from radiation damage in the radiation-resistant bacteria *Deinococcus radiodurans* in space was once again confirmed.

Real-time Cosmic Radiation Dosimetry. See STS-79

Dosimetry Using a Human Body Phantom. A human body phantom was used to determine radiation dose within the body as compared to the traditional skin dose. Since the calculated effective dose equivalent differed only minimally from dose equivalent at skin, it is considered that the conventional method is still appropriate for controlling radiation exposure.

STS-95

Clinical Trail of Melatonin as a Hypnotic. Worked to determine whether use of melatonin improved quality of sleep for astronauts during spaceflight, thereby improving their ability to perform the mentally challenging and physically rigorous tasks required of them. Data were obtained on this first study to assess effects of spaceflight on the sleep patterns of an older astronaut.

Protein Turnover During Space Flight. Investigated effects of spaceflight on whole-body protein metabolism by simultaneously assessing protein turnover and hormonal concentrations with the hope that results would provide crucial information for establishment of a viable ground-based model for protein metabolism. Protein turnover increased in space flight. Effects of Spaceflight on Bone and Muscle. See STS-72.

Effects of Microgravity on Cell Mediated Immunity and Reactivation of Latent Viral Infections. See STS-86.

Space Flight and Immune Function. Experiment was designed to determine functional status of important elements of immune response, and to help with assessment of infectious disease risks of long-term spaceflight. Results showed an increase in neutrophils at landing, and a decrease in lymphocytes. The number of monocytes was unaffected, but cells showed reduced functionality. Most astronauts had decreased lytic activity immediately after flight.

Orthostatic Function During Entry, Landing, and Egress. See STS-35.

Postural Equilibrium Control During Landing/Egress. See STS-28.

Cardiovascular and Cerebrovascular Responses to Standing Before and After Space Flight. See STS-56.

Bone and Mineral Loss and Recovery. Measured spaceflight-induced losses in bone mineral density and lean body mass of long-duration crew members, and worked to determine rate and extent of recovery after returning to Earth. Experiment was performed in conjunction with muscle strength testing to study relationship between muscular fitness and changes in bone density.

Magnetic Resonance Imaging After Exposure to Microgravity. Measured muscular and skeletal changes as a result of exposure to microgravity through use of an magnetic resonance imaging machine. Examined muscle, intervertebral disc, and bone marrow changes in several crew members of varying ages and compared results to data from previous studies. In-Flight Holter Monitoring. Investigated whether heart rate exhibited less variability in microgravity than on Earth, if electrocardiograph changes occurred during flight, and if changes in electrocardiograph related to age occurred during flight. The hardware experienced an anomaly during flight, but this was corrected by restarting the device and replacing the batteries.

Canadian Space Agency Experiment:

> The Perceptual Motor Deficit in Space. Made recommendations for operational and training improvements for coping with the period of adaptation to microgravity.

STS-88

Interaction of the Space Shuttle Launch and Entry Suit and Sustained Weightlessness on Egress Locomotion. See STS-75.

Individual Susceptibility to Post-Spaceflight Orthostatic Intolerance. See STS-87.

Effects of Microgravity on Cell Mediated Immunity and Reactivation of Latent Viral Infections. See STS-86.

Assessment of Human Factors. See STS-40.

STS-96

Space Flight and Immune Function. See STS-95.

STS-93

Interaction of the Space Shuttle Launch and Entry Suit and Sustained Weightlessness on Egress Locomotion. See STS-75.

Monitoring Latent Virus Reactivation and Shedding in Astronauts. See STS-72.

Individual Susceptibility to Post-Spaceflight Orthostatic Intolerance. See STS-87.

Space Flight and Immune Function. See STS-95.

Integrated Measurement of the Cardiovascular Effects of Spaceflight. Assessed stroke volume changes in cardiovascular system and flow redistribution through the body during launch acceleration. Quantified peripheral vasomotor response during launch and entry into microgravity and evaluated arterial tone after several days in microgravity. Also studied peripheral response of fluid shifts toward the legs during re-entry and Orbiter stand test.

STS-103

Individual Susceptibility to Post-Spaceflight Orthostatic Intolerance. See STS-87.

Space Flight and Immune Function. See STS-95.

STS-99

Effects of Spaceflight on Bone and Muscle. See STS-72.

Monitoring Latent Virus Reactivation and Shedding in Astronauts. See STS-72.

Individual Susceptibility to Post-Spaceflight Orthostatic Intolerance. See STS-87.

Space Flight and Immune Function. See STS-95.

STS-101

Cabin Air Monitoring. See STS-51B.

Monitoring Latent Virus Reactivation and Shedding in Astronauts. See STS-72.

Space Flight and Immune Function. See STS-95.

STS-106

Monitoring Latent Virus Reactivation and Shedding in Astronauts. See STS-72.

Individual Susceptibility to Post-Spaceflight Orthostatic Intolerance. See STS-87.

Space Flight and Immune Function. See STS-95.

Eye-Movements and Motion Perception Induced by Off-Vertical Axis Rotation at Small Angles of Tilt after Spaceflight. Assessed changes in otolith information processing following adaptation to microgravity by comparing otolith-induced eye movements and self-motion perception before and early postflight, and worked to determine time course recovery of otolith-tilt responses back to baseline levels by repeating postflight data collection at regular intervals.

STS-92

Effects of Spaceflight on Bone and Muscle. See STS-72.

Individual Susceptibility to Post-Spaceflight Orthostatic Intolerance. See STS-87.

Space Flight and Immune Function. See STS-95.

Monitoring Latent Virus Reactivation and Shedding in Astronauts. See STS-72.

STS-97

Monitoring Latent Virus Reactivation and Shedding in Astronauts. See STS-72.

Space Flight and Immune Function. See STS-95.

STS-98

Individual Susceptibility to Post-Spaceflight Orthostatic Intolerance. See STS-87.

Space Flight and Immune Function. See STS-95.

STS-102

Monitoring Latent Virus Reactivation and Shedding in Astronauts. See STS-72.

Individual Susceptibility to Post-Spaceflight Orthostatic Intolerance. See STS-87.

Space Flight and Immune Function. See STS-95.

STS-100

Monitoring Latent Virus Reactivation and Shedding in Astronauts. See STS-72.

Individual Susceptibility to Post-Spaceflight Orthostatic Intolerance. See STS-87.

Space Flight and Immune Function. See STS-95.

Eye-Movements and Motion Perception Induced by Off-Vertical Axis Rotation at Small Angles of Tilt after Spaceflight. See STS-106.

STS-104

Monitoring Latent Virus Reactivation and Shedding in Astronauts. See STS-72.

Individual Susceptibility to Post-Spaceflight Orthostatic Intolerance. See STS-87.

Space Flight and Immune Function. See STS-95.

Sleep-Wake Actigraphy and Light Exposure During Spaceflight. Inappropriately timed or insufficiently intense light exposure during spaceflight leads to circadian disruption in astronauts. State-of-the-art ambulatory technology was used to monitor sleep-wake activity patterns and light exposure in crew members aboard shuttle, and evaluated effects of spaceflight on crew members' subjective evaluation of the amount and quality of their sleep. Data showed less sleep during space flight.

Spatial Reorientation Following Spaceflight. Examined adaptive changes in spatial reference frame controlling spatial orientation and sensorimotor control, as well as feasibility of using discordant sensory stimuli to instigate state changes in central vestibular processing. Results showed that postular stability significantly decreased with absent visual and altered proprioceptive feedback. Decreased postural performance during head tilts suggests that changes in central vestibular processing contributes to disruption of balance.

STS-105

Space Flight and Immune Function. See STS-95.

Spatial Reorientation Following Spaceflight. See STS-104.

STS-108

Bioavailability and Performance Effects of Promethazine During Space Flight. The primary anti-motion sickness medication used for treating space motion sickness during shuttle missions produced certain side effects that depressed astronauts' central nervous system. Experiment was a systematic evaluation of promethazine bioavailability including side effects and efficiency to determine optimal dosage and type of administration in flight.

Space Flight and Immune Function. See STS-95.

Spaceflight-Induced Reactivation of a Latent Epstein-Barr Virus. Longer duration of shuttle missions increases potential development of latent viruses (not affected by a quarantine period) such as Epstein-Barr Virus. Mechanisms of spaceflight-induced alterations in human immune function and latent virus reactivations as well as the magnitude of immunosuppression as a result of spaceflight were examined. Viral reactivation (as measure, but not clinically observed) occurred during space flight.

Test of Midodrine as a Countermeasure Against Postflight Orthostatic Hypotension. Evaluated efficacy of midodrine—a medicine typically used to treat low blood pressure—in combating hypotension (inability to maintain adequate arterial pressure) in astronauts after spaceflight. Midodrine did not appear to be a good countermeasure.
Pharmacokinetics and Contributing Physiologic Changes During Spaceflight. Changes in gastrointestinal function and physiology due to spaceflight affect the pharmacokinetics of oral medications. Worked to determine changes in gastrointestinal function in microgravity and examined dynamics of orally administered acetaminophen.

STS-109

Bioavailability and Performance Effects of Promethazine During Spaceflight. See STS-108.

Monitoring Latent Virus Reactivation and Shedding in Astronauts. See STS-72.

Space Flight and Immune Function. See STS-95.

Spaceflight-Induced Reactivation of Latent Epstein-Barr Virus. See STS-108.

Test of Midodrine as a Countermeasure Against Postflight Orthostatic Hypotension. See STS-108.

Sleep-Wake Actigraphy and Light Exposure During Spaceflight. See STS-104.

Spatial Reorientation Following Spaceflight. See STS-104.

STS-110

Monitoring Latent Virus Reactivation and Shedding in Astronauts. See STS-72.

Space Flight and Immune Function. See STS-95.

Spaceflight-Induced Reactivation of Latent Epstein-Barr Virus. See STS-108.

Test of Midodrine as a Countermeasure Against Postflight Orthostatic Hypotension. See STS-108.

STS-111

Space Flight and Immune Function. See STS-95.

Eye-Movements and Motion Perception Induced by Off-Vertical Axis

Rotation at Small Angles of Tilt after Spaceflight. See STS-106.

Spaceflight-Induced Reactivation of Latent Epstein-Barr Virus. See STS-108.

Test of Midodrine as a Countermeasure Against Postflight Orthostatic Hypotension. See STS-108.

Sleep-Wake Actigraphy and Light Exposure During Spaceflight. See STS-104.

Spatial Reorientation Following Spaceflight. See STS-104.

Integrated Measurement of Cardiovascular Effects of Spaceflight. See STS-93.

STS-112

Bioavailability and Performance Effects of Promethazine During Spaceflight. See STS-108.

Monitoring Latent Virus Reactivation and Shedding in Astronauts. See STS-72.

Space Flight and Immune Function. See STS-95.

Eye-Movements and Motion Perception Induced by Off-Vertical Axis Rotation at Small Angles of Tilt after Spaceflight. See STS-106.

Effects of Short Duration Spaceflight on Type 1/Type 2 Cytokine Balance and its Endocrine Regulation. Studied effect of spaceflight on Type 1/Type 2-cytokine balance and role of the neuro-endocrine system in that balance. Investigated how stress alters distribution or secretion of Type 1 and/or Type 2 T-cells. Stress plays a role in cytokine balance and endocrine regulation in space flight. Test of Midodrine as a Countermeasure Against Postflight Orthostatic Hypotension. See STS-108.

Sleep-Wake Actigraphy and Light Exposure During Spaceflight. See STS-104.

Spatial Reorientation Following Spaceflight. See STS-104.

STS-113

Bioavailability and Performance Effects of Promethazine During Spaceflight. See STS-108.

Monitoring Latent Virus Reactivation and Shedding in Astronauts. See STS-72.

Space Flight and Immune Function. See STS-95.

Eye-Movements and Motion Perception Induced by Off-Vertical Axis Rotation at Small Angles of Tilt after Spaceflight. See STS-106.

Spaceflight-Induced Reactivation of Latent Epstein-Barr Virus. See STS-108.

Test of Midodrine as a Countermeasure Against Postflight Orthostatic Hypotension. See STS-108.

Pharmacokinetics and Contributing Physiologic Changes During Spaceflight. See STS-108.

Sleep-Wake Actigraphy and Light Exposure During Spaceflight. See STS-104.

STS-114

Chromosomal Aberrations in Blood Lymphocytes of Astronauts. Studied chromosomal aberrations in peripheral lymphocytes of crew members exposed to space radiation to better assess genetic risks of humans in space and optimize radiation shielding.

Monitoring Latent Virus Reactivation and Shedding in Astronauts. See STS-72.

Sleep-Wake Actigraphy and Light Exposure During Spaceflight. See STS-104.

Spaceflight-Induced Reactivation of Latent Epstein-Barr Virus. See STS-108.

Eye-Movements and Motion Perception Induced by Off-Vertical Axis Rotation at Small Angles of Tilt after Spaceflight. See STS-106.

Space Flight and Immune Function. See STS-95.

Bioavailability and Performance Effects of Promethazine During Spaceflight. See STS-108.

Test of Midodrine as a Countermeasure Against Postflight Orthostatic Hypotension. See STS-108.

STS-121

Monitoring Latent Virus Reactivation and Shedding in Astronauts. See STS-72.

Chromosomal Aberrations in Blood Lymphocytes of Astronauts. See STS-114.

Spatial Reorientation Following Spaceflight. See STS-104.

Sleep-Wake Actigraphy and Light Exposure During Spaceflight. See STS-104.

Eye-Movements and Motion Perception Induced by Off-Vertical Axis Rotation at Small Angles of Tilt after Spaceflight. See STS-106.

Space Flight and Immune Function. See STS-95.

Spaceflight-Induced Reactivation of Latent Epstein-Barr Virus. See STS-108.

Bioavailability and Performance Effects of Promethazine During Spaceflight. See STS-108.

STS-115

Chromosomal Aberrations in Blood Lymphocytes of Astronauts. See STS-114.

Spatial Reorientation Following Spaceflight. See STS-104.

Gastrointestinal Function During Extended Duration in Space. Worked to determine changes in the gastrointestinal function and physiology and examined pharmacokinetics of orally administered pharmaceutical probe acetaminophen. Experiment was completed on this flight.

Spaceflight-Induced Reactivation of Latent Epstein-Barr Virus. See STS-108.

Space Flight and Immune Function. See STS-95.

Bioavailability and Performance Effects of Promethazine During Spaceflight. See STS-108.

Sleep-Wake Actigraphy and Light Exposure During Spaceflight. See STS-104.

Monitoring Latent Virus Reactivation and Shedding in Astronauts. See STS-72.

STS-116

Test of Midodrine as a Countermeasure Against Postflight Orthostatic Hypotension. Study was designed to evaluate a new pharmacologic countermeasure for protection from postflight orthostatic hypotension. Combination of studies did not support using midodrine as a countermeasure.

Monitoring Latent Virus Reactivation and Shedding in Astronauts. See STS-72.

Sleep-Wake Actigraphy and Light Exposure During Spaceflight. See STS-104.

Space Flight and Immune Function. See STS-95.

Spaceflight-Induced Reactivation of Latent Epstein-Barr Virus. See STS-108.

Spatial Reorientation Following Spaceflight. See STS-104.

STS-117

Test of Midodrine as a Countermeasure Against Postflight Orthostatic Hypotension. See STS-116.

Space Flight and Immune Function. See STS-95.

STS-118

Test of Midodrine as a Countermeasure Against Postflight Orthostatic Hypotension. See STS-116.

Bioavailability and Performance Effects of Promethazine During Spaceflight. See STS-108.

Monitoring Latent Virus Reactivation and Shedding in Astronauts. See STS-72.

Sleep-Wake Actigraphy and Light Exposure During Spaceflight. See STS-104.

Space Flight and Immune Function. See STS-95.

Spaceflight-Induced Reactivation of Latent Epstein-Barr Virus. See STS-108.

STS-120

Test of Midodrine as a Countermeasure Against Postflight Orthostatic Hypotension. See STS-116.

Validation of Procedures for Monitoring Crewmember Immune Function. Worked to develop and validate an immune monitoring strategy consistent with operational flight requirements and constraints.

Bioavailability and Performance Effects of Promethazine During Spaceflight. See STS-108.

Sleep-Wake Actigraphy and Light Exposure During Spaceflight. See STS-104.

STS-122

Test of Midodrine as a Countermeasure Against Postflight Orthostatic Hypotension. See STS-116.

Validation of Procedures for Monitoring Crewmember Immune Function. See STS-120.

Bioavailability and Performance Effects of Promethazine During Spaceflight. See STS-108.

Sleep-Wake Actigraphy and Light Exposure During Spaceflight. See STS-104.

STS-123

Test of Midodrine as a Countermeasure Against Postflight Orthostatic Hypotension. See STS-116.

Validation of Procedures for Monitoring Crewmember Immune Function. See STS-120.

Sleep-Wake Actigraphy and Light Exposure During Spaceflight. See STS-104.

Spaceflight-Induced Reactivation of Latent Epstein-Barr Virus. See STS-108.

STS-124

Test of Midodrine as a Countermeasure Against Postflight Orthostatic Hypotension. See STS-116.

Validation of Procedures for Monitoring Crewmember Immune Function. See STS-120.

Sleep-Wake Actigraphy and Light Exposure During Spaceflight. See STS-104.

Spaceflight-Induced Reactivation of Latent Epstein-Barr Virus. See STS-108.

STS-126

Sleep-Wake Actigraphy and Light Exposure During Spaceflight. See STS-104.

Spaceflight-Induced Reactivation of Latent Epstein-Barr Virus. See STS-108.

Validation of Procedures for Monitoring Crewmember Immune Function. See STS-120.

STS-119

Thrust Oscillation Seat. Gathered vibration data on crew members' seats during launch to aid the space medicine division in development of unimpeded crew performance specifications. Research helped to provide design criteria for Orion Capsule and crew safety.

Assessment of Human Factors: Effects of Vibration on Visual Performance During Launch. Worked to determine visual performance limits during operation vibration and g-loads, specifically through determination of minimal useable font size using planned Orion display formats.

Validation of Procedures for Monitoring Crewmember Immune Function. See STS-120.

Sleep-Wake Actigraphy and Light Exposure During Spaceflight. See STS-104.

STS-125

Thrust Oscillation Seat. See STS-119.

Spaceflight-Induced Reactivation of Latent Epstein-Barr Virus. See STS-108.

Sleep-Wake Actigraphy and Light Exposure During Spaceflight. See STS-104.

STS-127

Validation of Procedures for Monitoring Crewmember Immune Function. See STS-120.

Sleep-Wake Actigraphy and Light Exposure During Spaceflight. See STS-104.

STS-128

Thrust Oscillation Seat. See STS-119.

Assessment of Human Factors: Effects of Vibration on Visual Performance During Launch. See STS-119.

Grab Sample Container Redesign for Shuttle. Verified shuttle cabin air quality using a new container that was smaller and lighter than the grab sample container being used. New system worked to verify air quality.

Physiological Factors. Aimed to identify key underlying physiological factors that contribute to changes in performance of a set of functional tasks that were representative of critical mission tasks for lunar and Mars operations. Ambiguous Tilt and Translation Motion Cues After Space Flight. Examined how the brain adapts to conflicting sensory conditions that might have resulted in motion disturbance after spaceflight.

Spinal Elongation and its Effects on Seated Height in a Microgravity Environment. Worked to provide quantitative data of the amount of change that occurs in seated height due to spinal elongation in microgravity.

Validation of Procedures for Monitoring Crewmember Immune Function. See STS-120.

Sleep-Wake Actigraphy and Light Exposure During Spaceflight. See STS-104.

STS-129

Grab Sample Container Redesign for Shuttle. See STS-128 for description. Measurements were performed on Flight Day 12.

Sleep-Wake Actigraphy and Light Exposure During Spaceflight. See STS-104.

Ambiguous Tilt and Translation Motion Cues After Space Flight. See STS-128.

Physiological Factors. See STS-128.

Spinal Elongation and its Effects on Seated Height in a Microgravity Environment. See STS-128.

Validation of Procedures for Monitoring Crewmember Immune Function. See STS-120.

STS-130

Ambiguous Tilt and Translation Motion Cues After Space Flight. See STS-128.

Spinal Elongation and its Effects on Seated Height in a Microgravity Environment. See STS-128.

Sleep-Wake Actigraphy and Light Exposure During Spaceflight. See STS-104.

STS-131

Physiological Factors. See STS-128.

Sleep-Wake Actigraphy and Light Exposure During Spaceflight. See STS-104.

STS-132

Sleep-Wake Actigraphy and Light Exposure During Spaceflight. See STS-104.

Spinal Elongation and its Effects on Seated Height in a Microgravity Environment. See STS-128.

Hypersole. Canadian experiment studied changes in skin sensitivity before and after spaceflight in hopes to contribute data to existing studies of aging process and reductions in information relayed by skin sensors that lead to loss of balance control and greater incidence of falls.

STS-133

Sleep-Wake Actigraphy and Light Exposure During Spaceflight. See STS-104.

Physiological Factors. See STS-128.

Hypersole. See STS-132.

STS-134

Sleep-Wake Actigraphy and Light Exposure During Spaceflight. See STS-104.

Hypersole. See STS-132.

The Spinal Elongation and its Effects on Seated Height in a Microgravity Environment

(Spinal Elongation). Provided quantitative data of the change that occurs in seated height due to spinal elongation in microgravity to enhance future spacecraft designs. Equipment was set up in Space Shuttle commander's seat. Measurements were taken of Commander Mark Kelly and Pilot Gregory Johnson, and the data imagery were successfully acquired and downlinked.

Vision. Johnson Space Center Space and Life Science organization-sponsored activity monitored intraocular pressure during short-duration missions. The crew conducted this experiment by using vision acuity charts and Tonometer Kit on Flight Days 2-3, and Flight Day 16.

STS-135

Sleep-Wake Actigraphy and Light Exposure During Spaceflight. See STS-104.

Hypersole. See STS-132.

3.9 Commercial

STS-3

Monodisperse Latex Reactor Experiment. Materials processing experiment designed to develop large, identical-sized (monodisperse) latex particles and help determine whether much larger (up to 40 microns) monodisperse beads can be produced practically and economically in space.

STS-4

Continuous Flow Electrophoresis System. Conducted a process separating biological materials in solution according to their surface electrical charge by passing them through an electrical field.

Monodisperse Latex Reactor Experiment. See STS-3.

STS-5

Deployed two commercial communications satellites—Anik C-3 and SitS-C.

STS-6

Continuous Flow Electrophoresis System. See STS-4.

Monodisperse Latex Reactor Experiment. See STS-3.

Get Away Specials:

> Japanese Artificial Snow Crystal Experiment. Attempted to produce first artificial snow in space and observe crystals using home video equipment.
>
> Seed Experiment. Carried 11.3 kg (24.9 pounds) of common fruit and vegetable seeds into orbit to determine how seeds must be packaged to withstand spaceflight.

STS-7

Shuttle Pallet Satellite. Flew, for the first time, a reusable platform built by German aerospace firm Messerschmitt-Bolkow-Blohm that shuttle deployed in space and retrieved after approximately 9-1/2 hours of free flight and brought back to Earth. Demonstrated how spaceflights could be used for private enterprise purposes.

Continuous Flow Electrophoresis System. See STS-4.

Vapor Growth of Alloy-type Semiconductor Crystals. Grew crystals of alloy semiconductors (electronic materials) to provide data for better understanding of fluid dynamics of vapor transport systems in space.

Liquid Phase Miscibility Gap Materials. Produced space-formed alloys difficult to obtain on Earth for analysis of their physical, chemical, and electrical properties.

Containerless Processing of Glass Forming Melts. Studied high-temperature, containerless processing of various compositions of glass-forming substances. Designed to eliminate impurities and flaws in space-made glass samples and to produce glass from substances that do not form glass on Earth.

Monodisperse Latex Reactor Experiment. See STS-3.

Deployed two communications satellites—Anik C-2, and Palapa Bl. Carried first Shuttle Pallet Satellite.

Get Away Specials:

> Soldering and Desoldering in Space. Investigated soldering and desoldering processes in space environment, looking to the day of space stations when repair techniques will be necessary to maintain highly sophisticated electronic equipment and payloads.
>
> Stability of Metallic Dispersions. Designed to develop a technique for taking x-ray photographs of melting and solidification of metals.
>
> Solidification Front. Designed to help determine particle movement during melting and solidification of metal alloys.

STS-8

Animal Enclosure Module. Demonstrated that enclosure module was capable of supporting six healthy rats on orbit without compromising health and comfort of astronaut crew or rats.

Continuous Flow Electrophoresis System. See STS-4.

Deployed multipurpose satellite INSAT-1B.

Get Away Special:

Japanese Artificial Snow Crystal Experiment. See STS-6.

STS-41B

Shuttle Pallet Satellite. See STS-7 for description. Flew for a second time, but remained in attached mode.

Monodisperse Latex Reactor Experiment. See STS-3.

Cinema 360. Carried cameras aboard shuttle to provide a test for motion picture photography designed for planetarium viewing. The cameras provided excellent film during flight.

Deployed two commercial communication satellites—Westar VI and Palapa B2.

Get Away Special:

Arc Lamp Research. GTE Laboratories conducted research on high-powered gas-discharge lamps used in industrial buildings, stadiums, and other sports facilities to develop a more energy-efficient commercial lamp. Pictures of experiment were taken, and data were obtained on power, temperature, and light output.

STS-41C

IMAX™. Documented crew operations in payload bay and Orbiter's middeck and flight deck along with spectacular views of Earth.

Cinema 360. See STS-41B.

STS-41D

IMAX™. See STS-41C.

Continuous Flow Electrophoresis System. See STS-4.

Deployed two commercial communications satellites—Satellite Business System SBS-D and TELSTAR.

STS-41G

IMAX™. See STS-41C.

Get Away Specials:

Physics of Solids and Liquids in Zero Gravity. The Asahi National Broadcasting Company, Limited, of Tokyo, Japan, conducted experiments to discover what happens when a metal or plastic solid collided with water in microgravity and worked to produce new metal alloys and glass composites in space. New materials experiment was successful. Water-object collision experiment was unsuccessful.

Zero G Fuel System Test. McDonnell Douglas Astronautics Company studied how liquid fuel in partially full tanks could be delivered free of gas bubbles to engines that control and direct spacecraft in orbit.

STS-51A

Diffusive Mixing of Organic Solutions. 3M Company performed experiments designed to grow organic crystals purer and larger than those that can be grown on Earth.

Deployed TELESAT-H, Canadian communications satellite.

Retrieved two malfunctioning satellites—Palapa B2 and Westar VI.

STS-51D

Protein Crystal Growth. Investigated advantages of using protein crystals grown in space to determine complex, three-dimensional structure of specific protein molecules.

Continuous Flow Electrophoresis System. See STS-4.

Deployed a commercial communications satellite—TELESAT-l.

Get Away Specials:

> Physics of Solids and Liquids in Zero Gravity. See STS-41G for description. Both experiments were successful on re-flight of payload.

STS-51G

Automated Directional Solidification Furnace. Designed to demonstrate the possibility of producing lighter, stronger, better-performing magnetic composite materials in microgravity.

Deployed three commercial communications satellites—MORELOS-A, ARABSAT-A, and TELSTAR-3D.

Get Away Specials:

> Liquid Sloshing Behavior in Microgravity. Studied behavior of liquid in a tank under microgravity conditions to validate and refine characteristics of tank-fluid systems and to provide data that would be useful in design of devices that manage propellants in surface tension tanks.
>
> Slipcasting Under Microgravity Conditions. Worked to demonstrate with model materials that slipcasting is possible in microgravity.
>
> Fundamental Studies in Manganese-Bismuth. Worked to produce manganese-bismuth specimens with better magnetic properties than was possible under Earth gravity.

STS-51I

Physical Vapor Transport of Organic Solids. Conducted research into ordered organic thin films with emphasis on controlling film's physical structure properties so as to affect film's optical, electrical, and chemical behavior.

Deployed two commercial communications satellites—ASC-1 and AUSSAT-1.

Deployed Leasat 4 defense communications satellite. Retrieved, repaired, and redeployed Leasat 3.

STS-61B

Diffusive Mixing of Organic Solutions. See STS-51A.

Continuous Flow Electrophoresis System. See STS-4. Tested concept of mass production of hormone material during flight.

IMAX™. See STS-41C.

Deployed three commercial communications satellites—MORE LOS-B, AUSSAT-2, and SATCOM KU-2.

STS-61C

Deployed SATCOM KU-1 commercial communications satellite.

Get Away Special:

> Project JULIE (Joint Utilization of Laser Integrated Experiments). First payload flown by a private hospital. Became first to be displayed at the National Air and Space Museum. St. Mary's Hospital in Milwaukee, Wisconsin, conducted medical and laser experiments on orbit.

STS-26

Physical Vapor Transport of Organic Solids. See STS-51I.

Protein Crystal Growth. See STS-51D.

Automated Directional Solidification Furnace. See STS-51G.

Aggregation of Red Blood Cells. Designed to provide information on formation rate, structure, and organization of red cell clumps, as well as on thickness of whole blood cell aggregates at high and low flow rates.

Earth Limb Radiance Experiment. Provided photographs of Earth's horizon that allowed scientists to measure radiance of twilight sky as a function of sun's position below horizon.

STS-29

Protein Crystal Growth. See STS-51D.

IMAX™. Gathered material on use of observations of Earth from space for an IMAX™ film.

STS-30

Floating Zone Crystal Growth and Purification. Used Fluids Experiment Apparatus to process melts of different materials that formed crystals. Indium samples were processed and data were obtained during flight.

STS-34

IMAX™. See STS-29.

Polymer Morphology Experiment. This 3M-developed organic material processing experiment explored effects of microgravity on polymeric materials in space as they were processed. Completed between 78% and 93% of objectives.

STS-32

Protein Crystal Growth. See STS-51D.

Fluids Experiment Apparatus-3 Microgravity Disturbances Experiment. Investigated effects of both Orbiter and crew-induced disturbances in microgravity environment on resulting microstructure of float-zone-grown indium crystals. Completed with 85% of objectives having been met.

IMAX™. See STS-29.

STS-31

Protein Crystal Growth. See STS-51D.

Investigations into Polymer Membrane Processing. Studied microgravity polymer membrane processing.

IMAX™. See STS-29.

STS-41

Intelsat Solar Array Coupon Experiment. Measured effects of atomic oxygen in low-Earth orbit on Intelsat satellite's solar arrays to judge if stranded satellite's arrays will be seriously damaged by those effects.

Physiological Systems Experiment. Investigated whether biological changes caused by near weightlessness mimic Earth-based medical conditions closely enough to facilitate pharmacological evaluation of potential new therapies.

Investigations into Polymer Membrane Processing. See STS-31.

STS-37

BioServe Instrumentation Technology Associates Materials Dispersion Apparatus. Obtained data on scientific methods and potential commercial applications of biomedical and fluid science processing and activities in microgravity.

Protein Crystal Growth. See STS-51D.

STS-40

Get Away Specials:

> Experiment In Crystal Growth. Grew crystals of gallium arsenide—a versatile electronic material used in high-speed electronics and optoelectronics.
>
> Orbital Ball Bearing Experiment. Tested effects of melting cylindrical metal pellets in microgravity.

Foamed Ultralight Metals. Intended to demonstrate feasibility of producing, in orbit, foams of ultralight metals for possible application as shock-absorbing panel-backing to improve shielding of both manned and unmanned vehicles and satellites against hypervelocity impacts either from micrometeoroids or orbiting debris.

Flower And Vegetable Seeds Exposure To Space. Sent 19 varieties of flower and vegetable seeds into space to determine how unknown variables of microgravity affect seed growth.

Semiconductor Crystal Growth Experiment. Investigated potential advantages of crystal growth in microgravity.

Six Active Soldering Experiments. Studied soldering in microgravity.

In-Space Commercial Processing. Conducted five experiments to study possible commercial in-space processing opportunities.

STS-43

Protein Crystal Growth. See STS-51D.

Investigations into Polymer Membrane Processing. See STS-31.

BioServe Instrumentation Technology Associates Materials Dispersion Apparatus. See STS-37.

STS-48

Protein Crystal Growth. See STS-51D.

Investigations into Polymer Membrane Processing. See STS-31.

Middeck 0-gravity Dynamics Experiment. Studied mechanical and fluid behavior of components for future spacecraft.

Electronic Still Photography Test. Tested applications for digital photography on shuttle.

STS-42

Vapor Crystal Growth Studies of Single Mercury Iodide Crystals. Studied growth of crystals in microgravity.

Gelation of Sols: Applied Microgravity Research. Investigated influence of microgravity on processing of gelled sols—or dispersions of solid particles in a liquid often referred to as colloids.

Investigations into Polymer Membrane Processing. See STS-31.

Protein Crystal Growth. See STS-51D.

IMAX™. Filmed activities in Spacelab module and crew compartment with particular emphasis on space physiology experiments that have a bearing on future long-duration human presence in space.

Get Away Specials:

The Effect of Gravity on the Solidification Process of Alloys. Investigated effect of gravity on solidification process of alloys.

Separation of Gas Bubbles From Liquid. Examined modes of bubble movement in liquid under microgravity conditions.

STS-45

Investigations into Polymer Membrane Processing. See STS-31.

STS-49

Commercial Protein Crystal Growth. Grew protein crystals in space to determine complex, three-dimensional structure of specific protein molecules for pharmaceutical protein industry.

Retrieved, repaired, and redeployed Intelsat VI (F-3) commercial communications satellite.

STS-50

Protein Crystal Growth. See STS-51D.

Investigations into Polymer Membrane Processing. See STS-31.

ASTROCULTURE™. Evaluated critical subsystems essential for space-based plant growth applications. Results from flight indicated device worked as well in microgravity as it had on Earth.

Generic Bioprocessing Apparatus. Supported mixing of fluids and solids in up to 500 individual sample containment devices called fluids processing apparatuses in microgravity. Maiden flight, which contained 132 samples containers and 23 different experiments, was successful.

Crystal Growth Furnace Experiments. Processed four different experiments containing seven electronic crystal samples to study effect of microgravity on growth of a variety of materials having electronic and electro-optical properties.

Zeolite Crystal Growth. Processed multiple crystal samples of zeolite crystals, used as catalysts and absorbents/filters in industrial chemical processes, to provide researchers with data on most-efficient procedures and equipment for producing high-quality zeolite crystals in space. Grew crystals in 38 individual autoclaves.

Directed Polymerization Apparatus: Directed Orientation Of Polymerizing Collagen Fibers. Used the glove box and a directed polymerization apparatus to demonstrate that orientation of collagen fibers, which have potential uses as synthetic implant materials, can be directed in microgravity in absence of fluid mixing effects.

STS-46

Consortium for Materials Development in Space Complex Autonomous Payload. NASA Office of Commercial Programs-sponsored payload studied changes that materials undergo in low-Earth orbit.

Limited Duration Space Environment Candidate Materials Exposure. NASA Office of Commercial Programs-sponsored payload evaluated candidate space structures materials in low-Earth orbit to provide engineering and scientific information to those involved in material selection and development for space systems and structures.

IMAX™. Obtained footage for a film dealing with use of space to gain new knowledge of universe and future of humankind in space.

STS-47

Get Away Specials:

- Planar Solid/Liquid Interface. Studied breakdown of a planar solid/liquid interface when growth rate increases from stable to unstable conditions.
- Bread Yeast in Microgravity. Compared behavior of bread yeast in absence of gravity to behavior of bread yeast in normal atmospheric conditions.

STS-52

Tank Pressure Control Experiment/Thermal Phenomena. Provided some of the data required to develop technology for pressure control of cryogenic tankage.

Physiological Systems Experiment-02. Evaluated a compound that was being developed to treat osteoporosis by testing ability of compound to slow or stop bone loss induced by microgravity.

Heat Pipe Performance Experiment. Conducted tests intended to develop technology that will make it easier for a space vehicle to reject excess heat generated by its equipment and crew.

Commercial Materials Dispersion Apparatus Instrumentation Technology Associates Experiments. Conducted 31 different types of experiments including thin-film membrane formation, zeolite crystal growth, bioprocessing, and live test cells.

Crystal Vapor Transport Experiment. Conducted research aimed at growing larger and more uniform industrial crystals for use in producing faster and more capable semiconductors.

Commercial Protein Crystal Growth. See STS-49.

STS-53

Fluid Acquisition and Resupply Experiment. Investigated dynamics of fluid transfer in microgravity.

STS-54

Commercial Generic Bioprocessing Apparatus. Conducted 28 separate commercial investigations, loosely classified in three application areas: biomedical testing and drug development; controlled ecological life support system; and agricultural development and manufacture of biological-based materials.

STS-56

Commercial Materials Dispersion Apparatus Instrumentation Technology Associates Experiments. Conducted more than 30 studies to obtain data on how microgravity can aid research in drug development and delivery, biotechnology, basic cell biology, protein and inorganic crystal growth, bone and invertebrate development, immune deficiencies, manufacturing processes, and fluid sciences.

STS-57

Equipment for Controlled Liquid Phase Sintering Experiments. Investigated liquid phase sintering of metallic systems.

Gas Permeable Polymeric Materials. Determined whether certain types of polymers made in low gravity while shuttle was in orbit are different from same polymers made at the same time on the ground.

Liquid Encapsulated Melt Zone. Part of a series of tests that attempted to determine feasibility of commercial, space-based production of materials for applications in computer, optics, and sensor/detector industries.

Support of Crystal Growth Experiment. Supported zeolite crystal growth experiment by providing information required to establish zeolite crystal growth autoclave mixing protocol so that resulting crystal growth was optimized.

Zeolite Crystal Growth. Studied development of zeolite crystals in microgravity.

Investigations into Polymer Membrane Processing. See STS-31.

ASTROCULTURE™. See STS-50.

Commercial Protein Crystal Growth. See STS-49.

Environmental Control and Life Support System Flight Experiment. Tested components of water recycling system for International Space Station.

Commercial Generic Bioprocessing Apparatus. Processed biological fluids by mixing components in microgravity.

Consortium for Materials Development in Space Complex Autonomous Payload-IV. Investigated growth of nonlinear organic crystals by a novel method of physical vapor transport in weightlessness of space.

BioServe Pilot Laboratory. Determined response of cells to various hormones and stimulating agents in microgravity.

Organic Separation. Explored use of phase separation techniques in microgravity conditions to separate cells, cell fragments, and heavy molecules.

Physiological Systems Experiment. Investigated role of two growth factors involved in accelerating or enhancing tissue repair.

Fluid Acquisition and Resupply Experiment. See STS-53.

Get Away Specials:

Crystal Growth of Gallium-Arsenide. Studied growth of gallium-arsenide crystals in microgravity.

Semi-Conductors/Superconductor Experiment. Conducted four different kinds of experiments—three materials experiments on semi-conductors and a superconductor; the other on boiling an organic solvent under weightlessness.

Crystal Growth. Studied crystal growth of indium gallium arsenic from vapor phase under weightlessness, crystal growth of three selenic-niobium from vapor phase, crystal growth of an optoelectric crystal by diffusion method, and formation of superferromagnetic alloy.

STS-51

Limited Duration Space Environment Candidate Materials Exposure. See STS-46.

Investigations into Polymer Membrane Processing. See STS-31.

Commercial Protein Crystal Growth. See STS-49.

IMAX™. Obtained footage on general Orbiter scene and remote pictures of Orbiter and stars.

STS-61

IMAX™. Obtained footage of Hubble Space Telescope servicing mission and Orbiter.

STS-60

Equipment for Controlled Liquid Phase Sintering Experiments. See STS-57.

Space Experiment Facility. Provided vapor transport crystal growth furnace.

ASTROCULTURE™. See STS-50.

BioServe Pilot Laboratory. See STS-57.

Commercial Generic Bioprocessing Apparatus. See STS-57.

Commercial Protein Crystal Growth. See STS-49.

IMMUNE. Used drug therapy in attempt to alleviate immunosuppression in rats induced by microgravity.

STS-62

Limited Duration Space Environment Candidate Materials Exposure. See STS-46.

Commercial Protein Crystal Growth. See STS-49.

Middeck 0-gravity Dynamics Experiment. See STS-48.

Commercial Generic Bioprocessing Apparatus. See STS-57.

Physiological Systems Experiment 4. Studied complex interrelationship between immune and skeletal systems during exposure to microgravity.

STS-59

Consortium for Materials Development in Space Complex Autonomous Payload-IV. See STS-57.

STS-65

Commercial Protein Crystal Growth. See STS-49.

STS-64

Get Away Specials:

Boiling in Microgravity. Investigated formation of superconducting material and boiling phenomenon under microgravity and absence of convection.

Crystallization in Microgravity. Investigated crystallization or formation of materials under microgravity and absence of convection.

Electrophoresis in Microgravity. Studied electrophoresis in microgravity for applications in drug manufacturing for biological/biotechnological products.

STS-68

Commercial Protein Crystal Growth. See STS-49.

Get Away Special:

> The Study of Breakdown of Planar Solid/Liquid Interface During Crystal Growth. A sample of germanium treated with gallium was processed using a gradient furnace.

STS-63

BioServe Pilot Laboratory. See STS-57.

ASTROCULTURE™. See STS-50.

Commercial Generic Bioprocessing Apparatus. See STS-57.

Commercial Protein Crystal Growth. See STS-49.

Equipment for Controlled Liquid Phase Sintering Experiments. See STS-57.

Gas Permeable Polymeric Materials. See STS-57.

Immune System Experiment – 2. See STS-60.

Fluids Generic Processing Apparatus-1. Studied containment, manipulation, and transfer of pressurized, supersaturated, two-phase fluids in microgravity.

Charlotte. Experimental robotic device demonstrated automated servicing of experimental payloads and allowed remote video observation aboard pressurized space research laboratory.

Three Dimensional Microgravity Accelerometer. Measured disturbances caused by operating various experiments in Spacehab and residual microgravity resulting from Orbiter rotational motions and by residual resistance at upper atmosphere fringes.

IMAX™. Documented shuttle activities on film to be incorporated in a large-format feature film about NASA's cooperation with Russia.

STS-67

Commercial Materials Dispersion Apparatus Instrumentation Technology Associates Experiments. Collection of experiments explored ways in which microgravity can benefit drug development and delivery for treatment of cancer, infectious diseases, and metabolic deficiencies. Included protein and inorganic crystal growth, secretion of medically important products from plant cells, calcium metabolism, invertebrate development, and immune cell functions.

Protein Crystal Growth. See STS-51D.

Middeck Active Control Experiment. Studied active control of flexible structures in space.

STS-71

IMAX™. See STS-63.

STS-70

Commercial Protein Crystal Growth. See STS-49.

STS-69

Commercial Generic Bioprocessing Apparatus. See STS-57.

Commercial Materials Dispersion Apparatus Instrumentation Technology Associates Experiments. See STS-67.

Electrolysis Performance Improvement Concept Study. Examined effects of microgravity on electrolyte distribution in Static Feed Electrolyzer electrolyte retention matrix.

STS-73

Orbital Processing of High Quality Cadmium Zinc Telluride Compound Semiconductors. Examined effects of gravity on growth and quality of alloyed compound semiconductors.

Zeolite Crystal Growth. See STS-57.

Commercial Protein Crystal Growth. See STS-49.

Commercial Generic Bioprocessing Apparatus. See STS-57.

ASTROCULTURE™. See STS-50.

Three Dimensional Microgravity Accelerometer. See STS-63.

STS-74

IMAX™. See STS-63.

STS-72

Commercial Protein Crystal Growth. See STS-49.

Get Away Special:

> Protein Crystal Growth. Examined effects of microgravity environment on protein-crystal nucleation. Data were provided from 16 different crystallization units on crystal formation during flight.

STS-75

Commercial Protein Crystal Growth. See STS-49.

STS-77

Commercial Generic Bioprocessing Apparatus. See STS-57.

Commercial Protein Crystal Growth. See STS-49.

Gas Permeable Polymer Membrane. See STS-57.

IMMUNE-3. See STS-60.

Advanced Separation Process for Organic Materials. Studied separation technologies for medical products and specifically focused on gravitational effects on manufacture of recombinant hemoglobin products.

Plant Generic Bioprocessing Apparatus. Investigated change in production of secondary metabolites in microgravity.

Fluids Generic Bioprocessing Apparatus-2. Attempted to determine whether carbonated beverages could be produced from separately stored carbon dioxide, water, and flavored syrups, and whether resulting fluids could be made available for consumption without bubble nucleation and resulting foam formation.

Commercial Float Zone Furnace. Attempted to produce large, ultrapure compound semiconductor and mixed oxide crystals for electronic devices and infrared detectors.

Hand-Held Diffusion Test Cell. Contained eight test cells for protein crystal growth per unit, and used liquid-liquid diffusion for crystal growth. Four units were flown.

Space Experiment Facility. Housed a crystal growth experiment that used facility's opaque furnace, and used opaque furnace and liquid phase sintering to bond powdered metals. Both experiments were completed.

STS-79

Extreme Temperature Translation Furnace. Investigated how flaws form in cast and sintered metals.

Active Rack Isolation System. Tested ability to isolate certain classes of science experiments from major mechanical disturbances that might be found on International Space Station.

IMAX™. See STS-63.

STS-80

Commercial Materials Dispersion Apparatus Instrumentation Technology Associates Experiments. See STS-67. Payload included over 900 experiments.

STS-83

Protein Crystal Growth. See STS-51D.

Diffusion in Liquid Lead-Tin-Telluride. Attempted to establish accurate measurement for diffusion coefficient of liquid lead-tin-telluride in relative to temperature.

STS-84

Commercial Vapor Diffusion Apparatus. Worked to grow high-quality crystals—of importance in design of drugs—of various proteins using vapor diffusion method.

STS-94

Protein Crystal Growth. See STS-51D.

Diffusion in Liquid Lead-Tin-Telluride. See STS-83.

Cryogenic Flexible Diode. Tested heat pipe technology on orbit to gain advances in passive thermal control technology with hope that advances made in space could transfer to commercial applications on Earth. First American-made loop heat pipe and highest capacity cryogenic heat pipe ever developed were demonstrated during flight.

STS-85

Protein Crystallization Apparatus for Microgravity/Single-locker Thermal Enclosure System. Worked to grow protein crystals using vapor diffusion for later evaluation on Earth. Total of 630 specimens flown on flight.

STS-86

Commercial Protein Crystal Growth. See STS-49.

STS-87

Loop Heat Pipe Experiment. Investigated unique thermal energy management system that could be used on commercial satellites. Test was successful; commercial satellite designers could feel comfortable using technology.

STS-90

Get Away Special:

> Pulse Tube Cooling Technology. Demonstrated pulse tube cooling technology in microgravity and worked to gain operational experience with smallest cryocooler built at the time.

STS-91

Commercial Protein Crystal Growth. See STS-49.

Get Away Special:

> Microgravity Industry Related Research for Oil Recovery. Investigated using microgravity to develop new technologies that could impact Canadian oil industry, environmental clean-up, and world’s future oil reserves.

STS-95

ASTROCULTURE™. See STS-50.

Commercial Generic Bioprocessing Apparatus. See STS-57.

Commercial Protein Crystal Growth. See STS-49.

Commercial Instrumentation Technology Associates Biomedical Experiment. Researched growing crystals of protein urokinase and development of microcapsules.

Advanced Separation Payload. Contained Advanced Separation Bio-Processing facility to support three commercial investigations, Hemoglobin Separation experiment, Microencapsulation experiment, and Phase Partitioning experiment.

Phase Partitioning Research. Worked to give researchers better insight into methods for isolating specific cell populations.

Protein Crystallization Apparatus for Microgravity. Used vapor-diffusion to grow protein crystals, a process in which liquid in a protein solution was allowed to evaporate, thereby increasing protein concentration and triggering crystallization.

Commercial BioDyn Payload. Commercial bioreactor for space-based investigations. Experiment's conductors are as follows:

Recombinant Proteins Research. Studied preliminary process for growing proprietary recombinant protein that can decrease rejection of transplanted tissue.

Microencapsulation Research. Researched ways to improve microencapsulating material for cells that produce insulin in the human body.

Tissue Engineered Heart Patches and Bone Implants Research. Focused on space-grown bone implants and "heart patches" (cardiomyocytes tissue) to replace damaged heart muscle.

Anti-Cancer Products From Plant Cells in Culture Research. Investigated production of anticancer drugs from plant cells.

STS-88

IMAX™. Filmed scenes of Node 1 grapple and installation, Functional Cargo Block-to-Node 1 mating, Functional Cargo Block operations, extravehicular activity operations, and Earth observations.

STS-93

Commercial Generic Bioprocessing Apparatus. See STS-57. A Tissue, Ladybug, and National Institutes of Health-B Experiment were flown as part of payload.

Gelation of Sols: Applied Microgravity Research. See STS-42.

STS-101

Commercial Protein Crystal Growth. See STS-49.

Protein Crystal Growth Biotechnology Ambient Generic. Provided opportunities to grow high-quality protein crystals in microgravity. Eight containers were used to fly 504 individual experiments.

Gene Transfer Experiment using ASTROCULTURE™ Glove Box. Evaluated method for production of commercially important transgenic plant materials in microgravity using Agrobacterium tumefaciens.

STS-106

Commercial Generic Bioprocessing Apparatus. See STS-57 for description. Studied synaptogenesis in microgravity and kidney cell gene expression during flight.

STS-92

IMAX™. Used a 3-D IMAX™ camera to document scenes of shuttle approach to International Space Station, station assembly tasks, extravehicular activity crew activities, and undocking.

STS-97

IMAX™. Filmed scenes in 3-D of International Space Station approach, unberthing of P6 integrated truss structure, and rotation of truss on Shuttle Robotic Arm.

STS-100

IMAX™. Worked to capture scenes of Orbiter approach, Orbiter undocking, International Space Station assembly tasks, and extravehicular activities.

STS-104

IMAX™. See STS-100.

STS-108

Avian Development Facility. Performed tests to validate facility's subsystems and reduce risk in developing next generation of avian development hardware space. Supported experiments that used Japanese quail eggs to study how lack of gravity affects development of avian embryos.

Commercial Biomedical Testing Module Experiment. Tested treatment for osteoporosis in microgravity.

Get Away Special:

> Weak Convection Influencing Radial Segregation. Studied influence of weak convection, caused by surface tension forces on radial dopant segregation, under microgravity conditions in seven mirror furnaces.

STS-110

Protein Crystal Growth— Single-locker Thermal Enclosure System. Provided incubator/refrigerator module that housed different devices for growing biological crystals in microgravity.

STS-107

ASTROCULTURE™. See STS-50 for description. Sufficient data and video of hardware operation and plant health status allowed for engineering return from this flight.

Commercial Instrumentation Technology Associates Inc. Biomedical Experiments Payload. Conducted more than 20 separate experiments including cancer research, commercial experiments, and student experiments. Many samples from payload were recovered for analysis after the accident.

Zeolite Crystal Growth. Studied development of improved zeolite materials for storing hydrogen fuel and applied research to detergents, optical cables gas, and vapor detection for environmental monitoring and control, and chemical production techniques. Some crystals were recovered after the accident.

Water Mist Fire Suppression Experiment. Studied how a water mist system puts out flames with the aim of developing a commercially viable water-based fire-fighting system. Around 90% of data were downlinked to Mission Control. Important scientific results were obtained on mist behavior characterization, suppression, and extinguishment of lean, stoichiometric, and rich flames, and exploratory suppression tests of near lean limit flames.

STS-125

IMAX™. Obtained footage of final Hubble Space Telescope servicing mission for the 3-D IMAX™ movie *Hubble 3D.*

National Laboratory Pathfinder-Vaccine-1C. A commercial payload in support of National Laboratory Pathfinder initiative, which contained pathogenic organisms to be examined to develop potential vaccines for prevention of infections on Earth.

STS-127

DragonEye Flash Light Intensification Detection and Ranging. Tested Advanced Scientific Concepts "DragonEye" flash Light Intensification Detection and Ranging relative navigation sensor system while in proximity to International Space Station. Reduced uncertainty regarding sensor's performance in space, and provided reference data of station as imaged by sensor.

STS-133

Dragon Eye Flash LIDAR. See STS-127 for description. Second flight of the navigation sensor to be used on SpaceX's Dragon vehicle for International Space Station approach called "DragonEye" incorporated several design and software improvements from previous experiment. Data received were valid, and were sent to sponsors for analysis.

STS-135

Assessment of sclerostin antibody as a novel bone-forming agent for prevention of spaceflight-induced skeletal fragility in mice. Used Commercial Biomedical Testing Module-3 to investigate a novel anabolic therapy for prevention of spaceflight-induced skeletal fragility in mice due to observed bone loss in both humans and animals during reduced gravity of spaceflight.

Vascular Atrophy Commercial Biomedical Testing Module-3: STS-135 Spaceflight's affects on vascular atrophy in hind limbs of mice. Examined effects of spaceflight on skeletal bones of mice and the efficacy of a novel agent that might mitigate loss of bone associated with spaceflight.

3.10 Engineering

STS-1

Window Conditioning and Viewing. Verified performance of window cavity conditioning system during flight phases. Desiccant system functioned satisfactorily.

Main Propulsion System Inerting. Determined and verified time required to vacuum inert Main Propulsion System propellant lines on orbit. Performed vacuum inerting of system hydrogen and oxygen feed lines. Majority of residuals were evacuated within first 10 seconds of 23-minute inerting.

Orbital Maneuvering System Performance and Control. Monitored Orbital Maneuvering System engine performance during two crossfeeds-manual and automatic Orbital Maneuvering System thrust vector control. Burns performed were nominal.

Payload Bay Door Performance. Tested ability to open and close Orbiter's payload bay doors. Succeeded in benign thermal environment of Z-local vertical attitude.

Radiator Inherent Thermal Capacity. Evaluated capacity of radiator and its coolant mass to act as a backup for Flash Evaporator System or ammonia boiler subsystem and absorb heat during re-entry. Radiator can provide some heat sink capability, but should be reactivated at high altitude and in automatic mode.

Ultra High Frequency Performance. Successfully demonstrated ultra-high-frequency voice capability during ascent with transmissions through Solid Rocket Booster plume, on orbit, and as Orbiter exited blackout. During ascent, voice check was weak and noisy but intelligible. Due to location of ground stations, it was not possible to determine when Orbiter left blackout or if blackout occurred.

S-Band Communication and Tracking. Successfully verified combined operations of Orbiter S-band communication, instrumentation, and data processing subsystems, exercised different modes of FM subsystem, and demonstrated turnaround ranging channel operations. Configurations and subsystems performed as expected.

Inertial Measurement Unit Performance and Alignment Verification. Calibrated, aligned, and verified aft Crew Optical Alignment System station. All alignments were performed, and had accuracies slightly better than expected.

Closed Circuit Television System Performance. Demonstrated capability of closed-circuit television to meet design and mission requirements in various environments, and to verify various functions, controls, and overall operation. Completed all objectives. closed-circuit television subsystem was operated with excellent results and no anomalies.

Aerodynamic Coefficient Identification Package. Successfully collected aerodynamic data during hypersonic, supersonic, and transonic flight for verification of ground data.

STS-2

Pre-entry Thermal Conditioning. Defined specific requirements to assure bond line temperatures allowed a safe re-entry from standpoint of Thermal Protection System maximum temperatures and wing glove stress. Critical bottom fuselage re-entry interface temperatures ranged from -16°C (3°F) to 1°C (34°F), the maximum nominal requirements being 15°C (60°F) or greater, and a positive factor of safety margin was found for wing glove stress.

Thermal Control System Performance. Tested adequacy of the Vernier Reaction Control System's starboard forward engine heaters to maintain temperatures above 55°C (130°F) leak detection limit. Vernier Reaction Control System forward engine cooled down too rapidly due to poor thermal insulation design.

Orbiter Entry Aerodynamic Response. Obtained data on handling characteristics of Orbiter as it went from Reaction Control System, to combined Reaction Control System and aerodynamic surface control, to full aerodynamic surface control. Due to equipment failure, results were degraded but indicated that performance was more nominal than STS-1 overall.

Entry Wing and Tail Excitation. Accomplished limited program test input actuations of the elevon and rudder during re-entry for program test input software verification. Responses were detected on the wing and elevon, which verified performance of program.

Window Cavity Conditioning System. See STS-1 (Window Conditioning and Viewing).

Flutter Boundary Evaluation. Performed automatic structural program test input actuations of elevon and rudder during ascent to gather data for flutter margin assessment. Test objectives were fully met and confirmation of performance of program when responses to program test inputs were detected on fin and rudder during ascent.

Orbital Maneuvering System Performance. Successfully demonstrated feed mode switchover during an Orbital Maneuvering System burn, and capability of Orbital Maneuvering System to restart safely following minimum permissible off time.

Hydraulic Circulation Pump Evaluation. Obtained independent thermal response data, thermal interaction data at components, and verified thermostat mode performance. Data from abbreviated test indicated that no problems existed, but a more extensive test was needed.

Hydraulic Fluid Conditioning. Obtained thermal responses of aero surface actuators and hydraulic fluid lines and verified adequacy of the method of thermal conditioning being used to guarantee minimum full performance temperature following re-entry interface. All hydraulic lines met required temperatures except system one standby lines to the elevon.

Reaction Control System Thruster Leak Detection. Exposed the Reaction Control System thruster dribble volume to on-orbit conditions of high volume, thermal soakback, and zero gravity, and determined maximum leak detector temperature drop versus duty cycle All duty cycles showed approximately the same total temperature drop of 4°C (40°F) for the 10 pulses and appeared to be stabilized.

Payload Bay Door Performance. Operated payload bay doors and radiators mechanism to provide an opportunity to detect anomalies prior to any catastrophic occurrences. Payload bay doors met all objectives with no anomalies, and closing and opening times were consistent with STS-1.

Remote Manipulator System Unloaded Performance. Tested Remote Manipulator System in all control modes, evaluated handling characteristics, and performed control dynamics tests. Other than a few noted anomalies, Remote Manipulator System behaved as expected and was controlled easily with smooth responses.

Radiator Inherent Thermal Capacity. Successfully tested and determined that the radiator could be used as a heat sink during re-entry. Test indicated that 33,000 BTUs were absorbed by radiator system during the 16 minutes it was the only source of heat rejection.

Radiator Performance Test. Obtained radiator performance data when forward radiator panels were stowed. No thermal constraints were violated by stowing port radiator because starboard radiator provided a majority of heat rejection during periods of interest.

Inertial Measurement Unit Performance and Alignment Verification. Used the inertial measurement unit number 1 as a reference to verify Crew Optical Alignment System boresight stability from one mission to the next. The +X Crew Optical Alignment System boresight was found to be repeatable to about 0.1 degree between missions, which was well within the tolerance established for backup inertial measurement unit alignment for safe re-entry.

Guidance, Navigation, and Control, Flight Control System and Reaction Control System Maneuvering Performance. Demonstrated capability to maintain attitude holds and determine Reaction Control System propellant usage for one orbit using only nose, and tail jets. Lower than expected propellant usage occurred during tail jet only operation.

Autoland Demonstration. Demonstrated engagement and use of autoland system down to a relatively low altitude. The system preformed well. At preflare, conditions were nominal for both cross range and altitude, and the speed was only 15 knots low, an improvement from 70 knots low at engagement.

Orbiter Rollout Control. Obtained data to evaluate Orbiter lateral control and braking sensitivity during rollout. Differential braking was used to maintain a course within 11 m (36 ft) of runway centerline.

Tile Gap Heating. Successfully measured temperatures of Thermal Protection System tiles and tile gaps during re-entry.

Catalytic Surface Effects. Collected data on surface catalytic efficiency on convective heating rates and found baseline coating was relatively non-catalytic.

Dynamic, Acoustic and Thermal Environment. Obtained in-flight measurements inside payload bay for estimates to assist design and testing of payloads.

Induced Environment Contamination Monitor. Measured contamination environment in and around payload bay, and worked to define contamination environment during ascent, on orbit, and re-entry.

Aerodynamic Coefficient Identification Package. Successfully obtained flight mechanics data for Orbiter development during ascent.

STS-3

Pre-entry Thermal Conditioning. Determined initial and maximum re-entry temperatures at various points on Orbiter, and determined thermal soakback tests. Hydraulic temperatures were well above re-entry interface requirements and thermal soakback effects were minimal.

Thermal Control System Performance. Determined efficiency of Thermal Control System on a variety of hardware such as aft primary and Vernier Reaction Control System, Star Tracker, and Flash Evaporator System feed water line heater. Data were gathered successfully without any anomalies.

Orbiter Entry Aerodynamic Response. Performed a series of programmed test inputs and aerosurface stick input maneuvers, and a structural programmed test input for the purpose of gathering data to determine aerodynamic characteristics of Orbiter during hypersonic and supersonic flight. Results from this test agreed with results from STS-2 on strongest derivatives.

Window Cavity Conditioning. See STS-1 (Window Conditioning and Viewing)

Flutter Boundary Evaluation. See STS-2

Main Propulsion System Inerting. Determined and verified time required to vacuum inert Main Propulsion System propellant lines on orbit. First inerting went as planned but due to a drop in hydrogen feed system pressure at beginning of second vacuum inerting, it was verified that some hydrogen had remained in feed system. Results demonstrated the possible need for a normal procedure required second inerting rather than having a second interting as a contingency operation.

Cryogenic Heat Leak Demonstration. Determined boil-off rates during orbit, and compared them to specification boil-off rates. Boil-off rates were found to be within specifications.

Remote Manipulator System Thermal Environment. Obtained data to determine temperature of Remote Manipulator System at various positions and various Orbiter attitudes. Remote Manipulator System heaters were able to maintain temperature within specified operating range of Remote Manipulator System during cold case evaluation.

Remote Manipulator System Payload Handling Performance. Analyzed capabilities of the Remote Manipulator System to deploy and birth a satellite, analyzed Remote Manipulator System control system while the system had a load, and displayed grapple/rigidization performance of Remote Manipulator System end effector. The Plasma Diagnostics Package was deployed and berthed multiple times with no problems, grappling/rigidization in both manual and automodes were accomplished without Remote Manipulator System wrist camera, and power was transferred to payload without difficulty.

Remote Manipulator System Unloaded Performance. Tested the unloaded Remote Manipulator System, including the software stop and the Primary Reaction Control System. All parts of test were completed and acceptable data were gathered. Payload Bay Door Performance. Provided door and longeron deformation measurements for correlations with analysis and verified door closure performance capability. All mission test objectives were completed, and door closure was demonstrated successfully.

Radiator Inherent Thermal Capacity. Evaluated capacity of radiator and its coolant mass to act as a backup for either the Flash Evaporator System or ammonia boiler subsystem and absorb heat during re-entry. Coolant flowed through radiators for 51 minutes, absorbing 44,500 British thermal units.

Guidance, Navigation, and Control, Flight Control System, and Reaction Control System Maneuvering Performance. Performed a Vernier Reaction Control System Minimum Deadband Test, a Passive Gravity Gradient Test, and a Vernier Reaction Control System Plume Impingement Test. Vernier Reaction Control System Plume Impingement Test generally confirmed preflight predictions of reduced thrust from some of the vernier jets, and results from Vernier Reaction Control System Minimum Deadband test were nominal during the 0.033 degree part of test.

Inertial Measurement Unit Performance and Alignment Verification. Calibrated, aligned, and verified forward and aft Crew Optical Alignment System stations. Each station was calibrated within tolerances, and data gathered indicated that Crew Optical Alignment System calibration was repeatable within expected accuracy.

Autoland. Flight tested the Autoland System from a nominal engage altitude of 3,048 m (10,000 ft) to approximately 43 m (140 ft) where manual operations took over. Autoland System performed well during flight, and was cleared for testing to touchdown on further flights.

Orbiter Rollout Control. Tested Orbiter's braking as means to control rollout. The braking portion of braking and steering capability test was deleted by flight crew, but the nosewheel steering portion of test was satisfactorily completed.

Backup Orbital Navigation. Obtained Star Tracker data on stars occulted by Earth during a night pass so a backup navigation system that required only star occultation measurements could be devised. Six occultations were obtained from the star Alhena, and data were considered complete.

On-Orbit Tactical Air Command and Navigation System Navigation. Determined that the system could be used as an on-orbit navigational aid, and verified the landing site system performance. For the first time, data acquisition at high negative range rates and tracking at near maximum range were demonstrated.

Tile Gap Heating Effects. See STS-2.

Catalytic Surface Effects. See STS-2.

Dynamic, Acoustic and Thermal Environment. See STS-2.

Aerodynamic Coefficient Identification Package. See STS-1.

Induced Environment Contamination Monitor. See STS-2 for description. Most measurements taken were found to be similar to those on STS-2, the dew/point humidity monitor indicated 0% during ascent, measurements indicated considerably lower concentration levels for entire range of particles than on STS-2, and no evidence of engine or Auxiliary Power Unit exhaust products in cargo bay were found.

STS-4

Pre-entry Thermal Conditioning. Tested and obtained data on systems requiring thermal re-entry with hope that the amount of conditioning could be lessened or eliminated. A real-time re-ordering of attitudes was required, but good data were recorded.

Thermal Control System Performance. Tested and obtained data on ability of Thermal Control System to maintain temperatures within specified limits at given points throughout Orbiter. The system performed well during flight, but several areas on Orbiter were found to have temperatures significantly different from those predicted.

Auxiliary Power Unit Tank/Fuel Line Temperature Decay. Tested whether Auxiliary Power Unit fuel and water lines would start freezing within 3 hours after heaters were turned off in an environment similar to that prior to re-entry. Test was ended after 1 hour and 51 minutes when the limit of 3°C (38°F) was reached on the Auxiliary Power Unit one service line thermostat. This demonstrated that fuel and water lines begin to freeze well before 3 hours.

Orbiter Entry Aerodynamic Response. Implemented and gathered data on a series of pushover pull-up maneuvers, lateral directional programmed test inputs, a longitudinal stick maneuver, and a structural programmed test input between re-entry interface and landing. All maneuvers were completed and were compared to the Aerodynamic Design Data Book. Significant updates were made in reducing uncertainties in Reaction Control System jet firings, lift-to-drag ratios, and effect of elevon position on aileron effectiveness above Mach 10.

Flutter Boundary Evaluation. See STS-2

Flight Debris Investigation. Successfully collected data to determine sources of materials causing damage to Orbiter during launch and re-entry. Data were used to attempt to reduce risk of Orbiter damage during launch and re-entry for future flights.

Main Propulsion System Inerting. Determined time required to vacuum inert the Main Propulsion System propellant lines on orbit and verified that propellants were not frozen and trapped in Main Propulsion System propellant lines. Main Propulsion System hydrogen and oxygen feed system lines were evacuated in 12 minutes. A repeat evacuation was unnecessary.

Hydraulic System Operation-01. Obtained data to show that on-orbit circulation pump operations were not needed for thermal control on many forthcoming missions. The demonstration was successful and results allowed for an additional power amount of approximately 2,000 watts to be allocated to other uses.

Hydraulic System Operation-02. Obtained data for systems two and three circulation pump operation in timer control mode test during the tail sun solar inertial attitude hold. Test went as expected and good data were obtained. An unexpected interaction between hydraulic line and other local systems hardware was discovered.

Power Reactant Storage and Distribution Subsystem Performance. Performed low-density stratification test and gathered data on flow capabilities of oxygen (O_2) and hydrogen (H_2) tanks. The O_2 tank met all demand flow requirement, but H_2 tank could not handle all flow requirements. H_2 tank number three made up the difference in demand flow when it was needed.

Elevon Position Observations. Visually observed that when left unattended, elevons drifted into a "rest" position.The left inboard elevon and both right elevons drifted toward an "up" rest position while left outboard elevon drifted to a "down" rest position.

Remote Manipulator System Unloaded Performance. Tested and verified functions of Remote Manipulator System and associated subsystems without a load. Adequate data were acquired for electronic, closed-caption television and digital-to-analog converter analysis.

Contamination Monitoring. Defined contamination environment of Orbiter during ascent, on-orbit, and re-entry phases of flight. All instruments operated correctly and contamination levels were found to be consistent with those for previous missions.

Remote Manipulator System Payload Handling Performance. Evaluated characteristics of Remote Manipulator System while loaded with a payload. Remote Manipulator System performed as expected, and the crew was satisfied with the operation of the system.

Radiator Coating Bond Verification. Determined whether the extent to which the silver Teflon® coating debonded from radiator surfaces in near vacuum of space. Acceptable video was obtained to make a proper evaluation of radiator debonding except for the portside radiator panel number one.

Airlock and Extravehicular Activity (EVA) Systems Demonstration. Verified basic EVA capability by demonstrating satisfactory performance of EVA preparations, extravehicular mobility unit operation in airlock, and post-EVA operations. All test objectives were met with the exception of demonstrating procedures to prepare the extravehicular mobility unit for a second EVA, including extravehicular mobility unit recharge.

Radiator Performance Test. Obtained radiator performance data when forward radiator panels were stowed. All attitudes except -ZLV and -ZSI stowed radiator performance was adequate to maintain radiator outlet temperature less than 5°C (41°F), the Flash Evaporator System start temperature.

Vapor Phase Compression Freezer Performance. Recorded freezer temperature during cool down after being turned off for 6 hours, checked for temperature stability by recording temperature daily, and prepared and inserted a water sample to be frozen and returned. Performance of refrigerator/freezer was successful, and proved that vapor compression refrigeration using Freon(r) was feasible for use in zero gravity.

S-Band and Ultra High Frequency Communications Performance. Obtained in-flight samples of Orbiter antenna-gain patterns and correlated that data with ground-based data. The antenna pattern cut for a single ground station yielded only 1% or 2% of a full spherical antenna pattern.

Approach and Landing-Autoland. Engaged Autoland System, acquired and flew outer glide slope down to 610 m (2,000 ft). Everything was nominal and Autoland System flew the outer glide slope very well.

Star Tracker Operations During Water Dumps. Determined whether Star Trackers could acquire and track stars during water dump periods. The -Z tracker was able to successfully acquire and track stars during dump periods, but the -Y Star Tracker was not.

Fwd Crew Optical Alignment System Calibration. Performed the calibration of the +X Crew Optical Alignment System and statistically verified whether Crew Optical Alignment System is suitable for inertial measurement unit backup alignment. The crew had difficulty centering the star in Crew Optical Alignment System reticle. There was a 0.2 degree data scatter across first four missions, probably due to structural deviations and hysteresis across missions.

Navigation Base Stability. Determined whether shuttle navigation base was sufficiently stable to permit inertial measurement unit/Star Tracker alignments after prolonged cold-soak periods. Navigation base remained stable and undistorted for alignment at extreme thermal conditions, and there were no thermal constraints to doing alignments on future flights.

Backup Orbital Navigation. Obtained Star Tracker data on stars that were occulted by Earth during a night pass. Results indicated that occultations were obtained on all of the stars. Guidance, Navigation, and Control, Flight Control System, and Reaction Control System Maneuvering Performance. Successfully tested to see if Reaction Control System could be programmed to hold Orbiter within a ± 0.1 degree/axis attitude deadband, and performed a passive gravity gradient attitude hold. Propellant usage was more than double the pre-flight predictions for the test.

On-Orbit Tactical Air Command and Navigation System Navigation. Determined system's maximum capability with optimal attitude and/or antenna selection. Only six of the 13 additional overseas stations were obtained, but optimal attitude signal test was successful.

Dynamic, Acoustic and Thermal Environment. See STS-2.

Aerodynamic Coefficient Identification Package. See STS-1.

Induced Environment Contamination Monitor. See STS-2 for description. Data were successfully gathered and contamination levels were similar to those on previous missions. More data were needed on decay time of events.

STS-5

Ascent Performance Data Collection. Successfully collected data during ascent for further verification of ascent aerodynamics, ascent aero heating, ascent structural capability, ascent compartment vents, vibration acoustic evaluation, and External Tank and Solid Rocket Booster aero heating.

Entry/Approach and Landing Verification. Successfully collected data during re-entry approach and landing phases for verification of structural, thermal, dynamic, and systems performance.

Nonsymmetrical/ Cold Orbital Maneuvering System Pod Trajectory Control Sensor Tests. Completed test requiring sequence of two attitude holds to demonstrate nonsymmetrical thermal conditions followed by cold mid and aft body and Orbital Maneuvering System conditions to verify the system's heaters, hydraulic system, and main landing gear capabilities.

Aft Reaction Control System Three-Engine Soakback Test. Performed thermal conditioning and a simultaneous Aft Reaction Control System three adjacent engine test fire to determine soakback effects on structural and Reaction Control System subsystem components.

Aft Reaction Control System Single-Engine Duty Cycle Soakback Test. Performed thermal conditioning and a duty cycle test firing of a single Aft Reaction Control System engine to determine soakback effects on structural and subsystem components.

Vernier Reaction Control System Single Engine Soakback Test. After a temperature stabilization period, a single aft Vernier Reaction Control System engine firing assessed thermal soakback effects on Orbiter structure and subsystems.

Entry Aerodynamic Test Number One. Completed a series of maneuvers during re-entry and terminal area energy management phases to obtain aerodynamic response data to induced motion during critical re-entry periods to evaluate aerodynamic stability and control effectiveness.

Aerothermal Test Number One. Data were collected on re-entry alpha profiles of less than 40° for extraction of aerodynamic data and cross-range capability development.

Ascent Aerodynamic Verification. Successfully collected data on ascent aerodynamics to allow for verification of aerodynamic database with sufficient confidence to remove wind placards on shuttle.

Ascent Plume Heating. Collected convective and radiative plume heating data during ascent due to Space Shuttle Main Engines and Solid Rocket Boosters. Data collected in conjunction with orbital flight test data were used to calibrate thermal math model for use in extrapolating to uninstrumented areas and operational flight conditions.

External Tank and Solid Rocket Booster Ascent Heating. Collected External Tank and Solid Rocket Booster aerodynamic and plume heating data that were used to expand orbital flight test database for math model extrapolation to operational flight conditions required for External Tank and Solid Rocket Booster hardware design verification.

Ascent Structural Capability Evaluation. Tested launch system's ability to meet program's injected weight requirements during a nominal liftoff and ascent. Data were used to determine flight loads, demonstrate structural system operational capability, determine stress/temperature response of critical structural components, and determine unacceptable dynamic effects on launch system.

Reinforced Carbon-Carbon Life Evaluation. Collected data during re-entry to support mission life determinations of nose cap and wing leading edge reinforced carbon-carbon and to verify analytical mass loss predictions and mission life for other reinforced carbon-carbon parts.

Ascent Compartment Venting Evaluation. Data were successfully collected during ascent to verify, under operational conditions, the capability of vent system to maintain compartment pressure within structural design limits.

Descent Compartment Venting Evaluation. Successfully collected data during descent to verify, under operational conditions, the capability of the vent system to maintain compartment pressure within structural design limits.

Entry Structural Capability Evaluation. Collected data during re-entry, approach, and landing to verify the adequacy of structure near design conditions, demonstrate structural system operational capability, determine flight loads, and verify stress/temperature response of critical structural components. Data were successfully acquired during re-entry, approach, and landing.

Vibration and Acoustic Environment Evaluation. Successfully obtained vibration and acoustic data during ascent to verify design life of secondary structure and components and to define operational vibro/acoustic input environment to payloads and Payload Development and Retrieval System.

Ascent Flutter Boundary Evaluation. Collected data during ascent for use in expanding the Orbital Flight Test database sufficiently by in-flight excitation of wing and tail during maximum dynamic pressure regions of ascent trajectories. Data gained from this test were used to verify adequate ascent flutter boundaries for expected operational flight profiles.

External Tank Thermal Protection System Performance. Successfully obtained photographs of External Tank after separation to determine Thermal Protection System charring patterns, identify regions where Thermal Protection System material spallation could be occurring, and to evaluate overall External Tank Thermal Protection System performance.

Solid Rocket Booster Recovery. Successfully tested and verified Solid Rocket Booster separation and recovery systems by demonstrating separation, re-entry, and water impact capability.

Flight Debris Investigation. Successfully obtained flight data to aid in determining sources of debris that could damage Thermal Protection System tiles or Orbiter windows during launch and ascent.

Airframe Unsymmetrical Distortion Test. Collected data to determine airframe distortion when a side-to-side thermal gradient exists.

Power Reactant Supply and Distribution Stratification Test. Collected data to verify the power reactant supply and distribution subsystem performance at various reactant levels under worst-case flow demand and low acceleration conditions.

Cold Orbital Maneuvering System Engine Start. Successfully demonstrated capability of an Orbital Maneuvering System engine to restart under zero gravity, hard vacuum, and worst-case engine conditions.

Hydraulic/Active Thermal Control System Interaction Test. Obtained data to allow for thermal model verification and to evaluate capability of hydraulic systems to remove heat from the Freon(r) coolant loop. Test was successfully completed and data gained from test helped determine feasibility of proposed contingency procedures for heat removal in case of flash evaporator failure.

Payload Bay Door Centerline Latch Performance. Successfully collected data to determine torque required to close payload bay door centerline latches on orbit.

Orbiter Braking Test. Obtained data on Orbiter's braking capability by demonstrating hard braking at high ground speeds.

Stowed Radiator Performance. Successfully collected radiator performance data with the forward radiators stowed. Data collected were used to evaluate heat rejection capability for normal and contingency use and to verify thermal analysis.

Waste Collection System Modification Evaluation. Evaluated effectiveness of modifications that were made to Waste Collection System.

Shuttle Launch Support System Communications Performance. Demonstrated basic Shuttle to Shuttle Launch Support System compatibility by an on-orbit test to verify performance data obtained from ground testing and from analytical predictions.

S-Band/Ultra High Frequency Antenna Tests. Collected data to determine Orbiter S-band and ultra-high-frequency antenna patterns.

Orbiter/Detached-Payload Communications. Obtained data to verify performance of Orbiter/NASA payload radio frequency links, command and telemetry channels, demonstrate ability of Orbiter to receive pulse control modulation data from a detached payload and interleave it with Orbiter's operational instrumentation pulse control modulation data channel, and demonstrate ability to downlink S-band frequency modulation from an attached payload through Orbiter to a ground station.

Lightweight headset Evaluation. Evaluated use, functionality, and comfort of a new lightweight communications headset.

Air Data Subsystem Performance. Tested capability of air data subsystem to provide accurate data at speeds above nominal design requirement. The left air data probe was deployed during re-entry at an altitude and airspeed corresponding to Mach 5.0.

Digital Autopilot Performance in Local Vertical Local Horizontal Mode. Demonstrated capabilities of Digital Autopilot with local vertical local horizontal mode by performing different attitude holds requiring rotation about each Orbiter axis in sequence.

Aft Station Crew Optical Alignment System Calibration. Determined Crew Optical Alignment System line of sight bias for contingency inertial measurement unit alignment and for comparison with previous flight data by performing an aft station Crew Optical Alignment System calibration.

Star Tracker Threshold Level Verification. Determined whether Star Tracker threshold levels were properly calibrated and were able to properly discriminate between stars of differing magnitudes by varying the Star Tracker's threshold level settings while making star acquisition attempts.

Orbiter Experiment Tile Gap Heating Evaluation. Investigated increased heating during re-entry that is produced due to turbulent airflow caused by the gap and other discontinuities between Thermal Protection System tiles. Data gained from this experiment were used to evaluate Thermal Protection System design, and to create a design that lowered heating rates.

Catalytic Surface Effects. Verified predictions of catalytic reactions on convective heat transfer for a possible weight reduction in Thermal Protection System. Instrumented tiles on Orbiter were coated with a highly efficient catalytic overlay for this experiment.

Dynamic, Acoustic and Thermal Environments Evaluation. Obtained data to improve techniques associated with predictions of dynamic, acoustic, and thermal environments and associated payload response in Orbiter's cargo area. Data obtained from this test served as the basis for further payload development.

Atomic Oxygen Interaction Studies. Evaluated interactions of atomic oxygen with materials to be used by NASA for spacecraft. Found Mylar®, Tedlar®, and Kapton® films had mass loss, silver turned nonconductive, and there was a complete loss of osmium from its nonreactive substrates.

Aerodynamic Coefficient Identification Package. Collected aerodynamic data in hypersonic and transonic flight regimes to establish a database to verify ground-based tests. No new problems were evident. The old problem of a periodic shift in housekeeping data was still present except in X-axis angular accelerometer.

STS-6

Elevon Position Observation. See STS-4.

Entry Aerodynamic Test No. 2. Provided a comparison of stability and control flight data with Aerodynamic Design Data Book, corresponding uncertainties, and previous flights. Data gathered added to the knowledge of Orbiter's capabilities during re-entry, and supported expanding center-of-gravity range to operational limits.

Light Weight Tank External Tank (ET) Impact Assessment. Obtained ET tracking data during re-entry and breakup to evaluate lightweight tank ET impact control. Data indicated that ET impact was within preflight predicted 3-sigma dispersion ellipse.

External Tank and Solid Rocket Booster Ascent Performance. See STS-5.

Reinforced Carbon-Carbon Life Evaluation. See STS-5.

External Tank Thermal Protection System Performance. See STS-5.

Solid Rocket Booster Recovery. See STS-5.

Orbiter Braking Test No. 2. Successfully obtained data on Orbiter's braking ability by demonstrating hard braking at high ground speeds.

Extravehicular Mobility Unit/Extravehicular Activity (EVA) Evaluation. Tested and evaluated extravehicular mobility unit during preparation and actual EVA. The extravehicular mobility unit performed successfully during all phase of EVA.

S-Band Antenna Performance. Obtained in-flight samples of Orbiter S-Band antenna patterns. Successfully obtained data, but found good accuracy appeared to be unobtainable.

Automatic Voice Recognition System. Successfully obtained zero-gravity voice samples for simulation tests of automatic voice recognition in orbit.

Orbiter/Detached-Payload S-Band Communications. Verified and assessed S-band radio frequency links between Orbiter and a detached payload.

Air Data Subsystem Performance. Demonstrated capability of air data subsystem to provide accurate data at speeds in excess of nominal design requirements. Both probes were deployed at Mach 5.0, nominal deployment being Mach 3.5, and no anomalies or damage was found.

Improved Crew Optical Sight. Selected and flew an off-the-shelf device to see if it had sufficient capability to view proximity operations targets at Orbiter starlight levels. Device was found to have inadequate sensitivity, and it was recommended that the improved crew optical sight being used at the time be retained, and a more sensitive device be developed and tested in-house.

Aft Station Crew Optical Alignment System Calibration. See STS-5.

Rendezvous Maneuver and Ground Navigation Test. Targeted and executed several typical rendezvous maneuvers to evaluate ground capabilities. Valuable information was gained for preparation of later rendezvous.

STS-7

Entry Aerodynamics #3. See STS-6 (Entry Aerodynamic Test No. 2) for description. Provided good supporting data for the STS-6 Flight Assessment Deltas including trends indicating more effective rudder and yaw jets than predicted, but less effective aileron at Mach numbers below 7.5.

Ascent Aerodynamic Verification. See STS-5.

External Tank and Solid Rocket Booster Ascent Performance. See STS-5.

Reinforced Carbon-Carbon Life Evaluation. See STS-5.

External Tank Thermal Protection System Performance. See STS-5.

Solid Rocket Booster Recovery. See STS-5.

Postlanding Bus Tie. Successfully measured electrical transients when a "good" main bus was connected to a "dead" main bus and the reconnect of the AC bus to inverter resulting in simultaneous restart of associated pumps/meters. Attempted to simplify ascent bus tie procedure using results obtained.

Payload Development and Retrieval System Performance. Demonstrated the Payload Development and Retrieval capability to deploy, release, capture, and berth a free-flying, stabilized payload. The Remote Manipulator System was able to successfully deploy and retrieve Shuttle Pallet Satellite-01.

Reaction Control System Plume Inpingement. Obtained forces and moments on a free-flying satellite due to plume inpingement from the Reaction Control System jets. Video recordings revealed that the satellite was perturbed by the plume.

10.2 PSIA Cabin Pressure Control. Evaluated the manual partial pressure of oxygen and cabin pressure control procedures at 10.2 psia cabin conditions relative to temperature transient effects on partial pressure of oxygen sensors, and obtained flight data to evaluate the air cooling of avionics equipment at reduced cabin pressure. Depressurization and re-pressurization of the cabin to 10.2 and 14.7 psia respectively worked as planned.

Ku-Band Communication System Functional Test. Verified functions of Ku-Band communication subsystem and ground command/monitor capability to maximum extent possible without an operational Tracking Data Relay Satellite. Critical Ku-Band functions performed without any anomalies except for several data processing errors.

Rendezvous Radar/Sensors Performance. Provided performance data on Ku-Band rendezvous radar during proximity operations. The crew was pleased with radar performance in all areas except inertial line-of-sight data.

Proximity Operations. Successfully evaluated proximity operations techniques required for separation, station keeping, final approach, and capture of a free-flying payload and evaluated various sensors needed to support the activities.

STS-8

OV-099 (Challenger) Cold Canopy Test. Determined differences in insulation performance between Columbia and Challenger configuration. Data that were obtained confirmed that a more rapid cool-down rate occurred for Challenger configuration as compared to Columbia configuration.

Crew Module Thermal Evaluation. Obtained Challenger crew module temperature data for comparison with Columbia data. Enabled a better understanding of TG-15000 insulation.

Middeck Locker Temperature Survey. Determined how accurately the mathematical model followed measured temperatures to assure that heat generated from one experiment did not affect experiments in neighboring lockers. Results showed that locker temperatures followed ambient trends closely.

Entry Aerodynamic Test No. 4. See STS-6 (Entry Aerodynamic Test No. 2) for description. Stability and control data supported STS-6 Flight Assessment Deltas with the only difference being the trim characteristics of the vehicle with up body flap below Mach 16.

External Tank and Solid Rocket Booster Ascent Performance. See STS-5.

Ascent Structural Capability Evaluation. See STS-5.

Reinforced Carbon-Carbon Life Evaluation. See STS-5.

Ascent Compartment Venting Evaluation. See STS-5.

Descent Compartment Venting Evaluation. See STS-5.

Entry Structural Capability Evaluation. See STS-5.

Prevention of Coupled Structure Propulsion Instability (POGO) Stability Performance. Verified that the vehicle had an adequate POGO stability margin throughout the ranges of Space Shuttle Main Engine power levels, shuttle structural configuration, payload mountings, and weight. No dynamic instability was detected by any of the nine POGO sensors.

Solid Rocket Booster Recovery. See STS-5.

Crew Compartment Structure Deflection Investigation. Determined compartment alignment shift from ground to zero-gravity flight.

Payload Development and Retrieval System Payload Handling Performance. Evaluated hardware-software and man-machine interface characteristics, confirmed loaded Remote Manipulator System envelopes, verified ground-based simulations, and evaluated visual cues needed for payload handling. The Remote Manipulator System performed as expected during testing on three separate flight days.

S-Band/Tracking and Data Relay Satellite Communication Link Performance Test No. 2. Exercised different operational configurations of Orbiter's S-band communication system to prepare for establishing flight readiness for Tracking and Data Relay Satellite System-mode operations.

Ku-Band Communications Link Performance Test No. 2. Tested different operational configurations of Orbiter's K-Band communications system to prepare for flight readiness for K-Band communication via Tracking and Data Relay Satellite.

Ku-Band Communications and Tracking Performance. Evaluated ability of the antenna auto-track system to properly track the Tracking and Data Relay Satellite when the shuttle attitude relative to Tracking and Data Relay Satellite was rapidly changing, and K-band link behavior in regions where antenna line-of-sight begins to become obscured by the spacecraft. Tracking rate and boundary tests were successful.

Orbiter S-Band and Ku-Band/Tracking and Data Relay Satellite System Operations Proficiency Test No. 2. Provided operators of the data acquisition system, through routine use of the communication system, sufficient opportunities to determine performance under a variety of conditions and to become proficient in its operation. Gained valuable hands-on experience, and found some procedural problems.

Ku-Band Side Lobe Detection. Determined that the side lobe of Orbiter Ku-Band antenna can detect Tracking and Data Relay Satellite-radiated signal, thus preventing acquisition. It was demonstrated that under worst-case conditions, side lobe detection was possible but had a low probability of occurrence, and Ku-Band system can automatically recover from an aborted acquisition attempt.

On-Orbit Tactical Air Command and Navigation System Navigation. Brought the on-orbit Tactical Air Command and Navigation System to an early maturity to provide a cost-effective backup to the Tracking and Data Relay Satellite by obtaining data from selected ground stations. Data showed excellent Tactical Air Command and Navigation System range coverage on every orbit, and verified performance of the modified line replaceable unit.

Star Tracker Sunlit Earth Horizon Limit Test. Acquired/tracked a star closer than 30 degrees to the horizon to demonstrate off-limit capability. Results of Star Tracker were better that expected, and no Star Tracker constraints were issued as a result.

Heat Pipe Radiator Experiment. Tested on-orbit startup and orbital response of high-capacity monogrove heat pipe when subjected to a heat load. The heat pipe performed better than expected.

Evaluation of Oxygen Interaction with Materials. See STS-5 (Atomic Oxygen Interaction Studies) for description. Thin-film specimens tested had higher relativities than on previous flights.

Get Away Special:

Cosmic Ray Upset Experiment. Designed to resolve many of the questions concerning upsets, or change in logic state, of a computer memory cell caused by single particles.

STS-9

Entry Aerodynamic Test No. 5. A series of programmed test inputs were initiated during re-entry and Terminal Area Energy Management phases to obtain aerodynamic response data. Flight Assessment Deltas were similar to previous flights, and Orbiter's flight characteristics were more accurately defined.

SRB Recovery. See STS-5

Ku-Band Communication Link Performance Test No. 3. Verified operational Ku-Band capability by demonstrating return link high data rate capability. The K-Band system was configured as required and had 100% data quality for the received 48 MB of data.

On-Orbit Tactical Air Command and Navigation System Navigation. See STS-8 for description. Verified quality and availability at higher geographic latitudes around the world.

Spacelab Tests. A number of tests were conducted to verify performance of Spacelab during its first flight. A list of the completed tests includes:

Spacelab Tests:

Ascent Environment Verification

Activation Tests

Nominal Spacelab Heating Test

Controlled Contamination Monitoring- Deep Space Attitude

Controlled Contamination Monitoring- Half-Orbit

Cold Thermal Attitude Test

Hot Thermal Attitude Test

Command and Data Management System Tests

Habitability Subsystem Test

Low Frequency Acceleration Test

Electrical Power System Validation

Scientific Airlock Functional Test

Deactivation/Transition Verification

Entry Conditions Response

On-Orbit Environment Test

Module Atmosphere Verification

STS-41B

Crew Module Thermal Evaluation. See STS-8.

Entry Aerodynamic Test No. 7. See STS-9 (Entry Aerodynamic Test No. 5) for description. No anomalies with maneuvers occurred during flight.

Entry with Lateral Offset Test No. 4. Obtained aerodynamic response data with a lateral center of gravity offset at Mach 3.5. No adverse effects were noticed.

External Tank and Solid Rocket Booster Ascent Performance. See STS-5.

Ascent Structural Capability Evaluation. See STS-5.

Reinforced Carbon-Carbon Life Evaluation. See STS-5.

Ascent Compartment Venting Evaluation. See STS-5.

Descent Compartment Venting Evaluation. See STS-5.

Prevention of Coupled Structure Propulsion Instability (POGO) Stability Performance. See STS-8.

External Tank Thermal Protection System Performance. See STS-5.

Solid Rocket Booster Recovery. See STS-5.

Elevon Trailing Edge Heating Evaluation. Successfully determined heating environment and Thermal Protection System performance at the inboard to outboard elevon interface.

Crew Compartment Structure Deflection Investigation. See STS-8.

Orbital Maneuvering System to Reaction Control System Interconnect Test. Verified Orbital Maneuvering System/Reaction Control System interconnect capability under adverse flight maneuvering. Results showed that there were no limitations on Orbital Maneuvering System propellant supplied to Reaction Control System through interconnect down to at least 45% level.

Manipulator Foot Restraint Evaluation. Successfully verified and demonstrated man-machine interface capabilities between manipulator foot restraint, electromagnetic control, and Remote Manipulator System. All non-machine interfaces were demonstrated to be operationally ready.

Tracking and Data Relay Satellite Navigation Test. Verified Tracking and Data Relay Satellite capability to provide primary ground network support for operational shuttle ground navigation.

Shuttle Launch Support System Communications Performance. See STS-5.

Extravehicular Activity (EVA) Fluid Transfer Connector Demonstration. Demonstrated an EVA-suited crew member's capability to make a redundant seal connection to a valve and operate the valve. All tools operated nominally.

Get Away Special:

Cosmic Ray Upset Experiment. See STS-8.

STS-41C

External Tank and Solid Rocket Booster Ascent Performance. See STS-5.

Entry Aerodynamic Test No. 9. See STS-6 (Entry Aerodynamic Test No. 2) for description. The accessibility of the aft operational center of gravity limit was clearly verified from an aerodynamic control standpoint.

Reinforced Carbon-Carbon Life Evaluation. See STS-5.

Solid Rocket Booster Recovery. See STS-5.

Direct Insertion External Tank (ET) Tracking for the Eastern Test Range. Provided ET entry tracking data of ET rupture and breakup. Helped provide greater confidence in ET impact footprint size prediction and an increased flexibility in impact targeting.

Manned Maneuvering Unit Satellite Support Capabilities Demonstration. Demonstrated ability of an extravehicular activity crew member to approach and repair a free-flying satellite with Orbiter station keeping away from satellite. The manned maneuvering unit performed well and useful data were gathered as the crew member was able to approach and stabilize the rotating spacecraft.

Shuttle to Mir Rendezvous Systems Performance. Provided performance data on rendezvous radar, Star Tracker, Crew Optical Alignment System, Improved Crew Optical Sight, the software used in a rendezvous and terminal braking, as well as a demonstration of closed-loop performance of entire system. Data were obtained from two rendezvous operations during flight.

Evaluation of Linhof Aero Technika Camera System. Evaluated use of a new camera to support oceanography, meteorology, and geology science investigation. The camera was found to be easy to use.

STS-41D

External Tank and Solid Rocket Booster Ascent Performance. See STS-5

Entry Aerodynamic Test No. 10. See STS-9 (Entry Aerodynamic Test No. 5) for description. Elevon schedule flown showed no adverse effects and helped reduce forward center-of-gravity restrictions from an aerodynamic standpoint.

Entry Structural Capability Evaluation. See STS-5

Solid Rocket Booster Recovery. See STS-5

Upper Stage Plume Damage Verification. Acquired upper stage solid rocket motor exhaust plume data to upgrade plume damage models. Results worked to reduce performance penalties incurred in providing the delta V maneuver required for safe separation.

Crew Compartment Structure Deflection Investigation. See STS-8.

Evaluation of Waste Collection System Bag Liner. Tested and evaluated a new bag liner for the Waste Collection System. Bag liner worked as designed and was used on subsequent missions.

Payload Bay Door Installation and Rigging Verification. Determined zero-gravity effects on payload bay door alignment and evaluated any differences in 1*g* and zero-gravity door alignment. Data were gathered for one payload bay door at both initial door opening and final door closing.

First Production Unit Remote Manipulator System Tests. Tested first production Remote Manipulator System to assure its operational capability. All operations of Remote Manipulator System were within expected performance limits.

Shuttle Launch Support System Communications Performance. See STS-5

Ku-Band Interference. Tried to obtain in-flight data concerning source of interference found on STS-41B and STS-41C. None of the tests caused radar interference to occur again but a period of interference at 90-minute intervals for 2 to 3 minutes occurred when the antenna was pointed at center of the Earth.

Characterization of Surface-Originated Vehicle Glow. Studied surface-originated vehicle glow, which indicated optical emissions originating on surfaces facing the direction of orbital motion and this characterized the different surface glow.

Office of Aeronautics and Space Technology-1 Experiments:

> Solar Array Experiment. Performed first demonstration in space of a large, lightweight solar array that could be retracted and re-stowed after deployment to obtain data that could be applied for use aboard future spacecraft. Array performance was excellent with additional "shopping list" tests being completed in addition to planned tests.
>
> Dynamic Augmentation Experiment. Gathered information on solar array's structural vibrations and worked to validate an on-orbit method of defining and evaluating dynamic characteristics of large space system structures.
>
> Solar Cell Calibration Facility. Aimed to evaluate and validate solar cell calibration techniques that were used at the time by NASA's Jet Propulsion Laboratory by comparing performance of cells on orbit with same cells flown on a high-altitude balloon flight.

STS-41G

External Tank and Solid Rocket Booster Ascent Performance. See STS-5.

Entry Aerodynamic Test No. 13. See STS-9 (Entry Aerodynamic Test No. 5) for description.

Reinforced Carbon-Carbon Life Evaluation. See STS-5.

Solid Rocket Booster Recovery. See STS-5.

Crew Compartment Structure Deflection Investigation. See STS-8.

On-Orbit Tactical Air Command and Navigation System Navigation. Certified Tactical Air Command and Navigation System software certified and verified operational navigation support capability for critical on-orbit phases, and provided an assessment of the feasibility of using Tactical Air Command and Navigation System data in a Mission Control Center environment for state vector determination. The data supported orbit determination functions.

S-Band Performance Test. Compared performance of the Orbiter-to-Tracking and Data Relay Satellite System S-Band High Data Rate return link to performance of the Orbiter-to-Tracking and Data Relay Satellite System Low Data Rate return link. Data helped determine the percent loss of coverage when using S-Band Orbiter-to-Tracking and Data Relay Satellite System High Data Rate.

VISET (Space Vision System Experiment Development Tests). Successfully completed a Canadian test of a new Space Vision System designed to improve guidance information provided to crew during satellite and assembly operations. Targets on the Earth Radiation Budget Satellite and cameras in payload bay and on the Remote Manipulator System were used to complete the test.

ACOMEX (Advanced Composite Materials Experiment). This Canadian test examined samples of composite materials attached to the Remote Manipulator System for deterioration while exposed to conditions of space. Effects on materials of prolonged exposure in space were observed by the crew, and materials were further tested on the ground after flight.

Evaluation of Oxygen Interaction with Materials. See STS-5 (Atomic Oxygen Interaction Studies) for description.

Get Away Special:

Cosmic Ray Upset Experiment. See STS-8 for description.

STS-51A

External Tank and Solid Rocket Booster Ascent Performance. See STS-5.

Entry Aerodynamic Test No. 15 See STS-6 (Entry Aerodynamic Test No. 2) for description.

Solid Rocket Booster Recovery. See STS-5.

Crew Compartment Structure Deflection Investigation. See STS-8.

Ground Spacecraft Tracking and Data Network Throughout Test. Tested ability of numerous ground stations to successfully track an Orbiter and relay information and data. All operations were successful except for Hawaii, which had a minor communication line problem that could be easily fixed.

On-Orbit Tactical Air Command and Navigation System Navigation. See STS-41G.

STS-51D

Entry Aerodynamic Test. See STS-9 (Entry Aerodynamic Test No. 5) for description.

Much data were obtained concerning sideslip, aileron, rudder coefficients, side-firing Reaction Control System jets, and the rolling and yawing moments the Reaction Control System jets create.

Entry Structural Capability Evaluation. See STS-5.

Direct Insertion External Tank Tracking for the Eastern Test Range. See STS-41C.

Crew Compartment Structure Deflection Investigation. See STS-8.

On-Orbit Tactical Air Command and Navigation System Navigation. See STS-41G.

STS-51B

Ascent Structural Capability Evaluation. See STS-5.

Reinforced Carbon-Carbon Life Evaluation. See STS-5.

Entry Structural Capability Evaluation. See STS-5.

Vibration and Acoustic Environment Evaluation. See STS-5.

Prevention of Coupled Structure Propulsion Instability (POGO) Stability Performance. See STS-8.

External Tank Thermal Protection System Performance. See STS-5.

Shuttle/Payload Low Frequency Environment. Obtained low frequency (0-50 Hz) payload/Orbiter interface data to enable development of computerized techniques in predicting low-frequency payload loads and responses. Acceleration inputs were analyzed to verify predicted inputs and to prove or disprove shuttle structural dynamic math models and forcing functions.

Elevon Trailing Edge Heating Evaluation. See STS-41B.

STS-51G

Ascent Structural Capability Evaluation. See STS-5.

Entry Structural Capability Evaluation. See STS-5.

Solid Rocket Booster Recovery. See STS-5.

Waste/Supply Water Dumps. Successfully performed in-flight verification of new water dump nozzle by using Remote Manipulator System's end effector camera to view the dumps.

STS-51F

Entry Aerodynamic Test. See STS-9 (Entry Aerodynamic Test No. 5) for description.

Ascent Structural Capability Evaluation. See STS-5.

Reinforced Carbon-Carbon Life Evaluation. See STS-5.

Entry Structural Capability Evaluation. See STS-5.

Vibration and Acoustic Environment Evaluation. See STS-5.

Prevention of Coupled Structure Propulsion Instability (POGO) Stability Performance. See STS-8.

External Tank Thermal Protection System Performance. See STS-5.

Shuttle/Payload Low Frequency Environment. See STS-51B.

Elevon Trailing Edge Heating Evaluation. See STS-41B.

On-Orbit Tactical Air Command and Navigation System Navigation. See STS-41G.

Spacelab Tests. A number of tests were conducted to verify performance of Spacelab during flight. A list of manifested tests include:

Spacelab tests:

- Ascent Environment Measurement and Recording
- Transition and Activation Tests
- Acquire/Downlink Spacelab Verification Flight Instrumentation Data On-Orbit
- Instrument Pointing System Activation and Deployment
- Instrument Pointing System Target Acquisition Test
- Instrument Pointing System Quiescent Stability Measurement and Disturbance Effects Test
- Instrument Pointing System Tracking/Pointing with Orbiter in Free Drift
- Instrument Pointing System Solar Offset Pointing Test
- Instrument Pointing System Scan Mode Test
- Instrument Pointing System Gyro Drift/Noise Test
- Instrument Pointing System Manual Pointing Control Operation Test
- Instrument Pointing System Contingency Stowage Test
- Instrument Pointing System Deactivation and Transition Tests
- Controlled Contamination Monitoring-Half Orbit
- Deactivation and Transition Tests
- Descent Environment Measurement and Recording

STS-51I

Entry Aerodynamic Test. See STS-9 (Entry Aerodynamic Test No. 5) for description.

Ascent Structural Capability Evaluation. See STS-5.

Entry Structural Capability Evaluation. See STS-5.

Waste Collection System Airflow Measurements. Obtained preflight and postflight baseline 1*g* airflow data from Waste Collection System to compare with data taken on orbit. Data on airflow characteristics during a mission, and measurements of the two-phase flow capabilities of Waste Collection System at the time were provided.

Radiator Performance. Obtained radiator performance data in specific attitudes and for specific vehicles to assist in correlating and validating the operational radiator database. Data were used by flight controllers to predict radiator performance in all attitudes to determine flash evaporator water requirements and radiator only cooling constraints.

On-Orbit Tactical Air Command and Navigation System Navigation. See STS-41G.

STS-61A

Ascent Structural Capability Evaluation. See STS-5.

Reinforced Carbon-Carbon Life Evaluation. See STS-5.

Entry Structural Capability Evaluation. See STS-5.

Vibration and Acoustic Environment Evaluation. See STS-5.

Prevention of Coupled Structure Propulsion Instability (POGO) Stability Performance. See STS-8.

External Tank Thermal Protection System Performance. See STS-5.

Crew Compartment Structure Deflection Investigation. See STS-8.

Shuttle/Payload Low Frequency Environment. See STS-51B.

Waste/Supply Water Dumps. See STS-51G.

Radiator Performance. See STS-51I.

STS-61B

Ascent Structural Capability Evaluation. See STS-5.

Entry Structural Capability Evaluation. See STS-5.

Upper Stage Plume Damage Verification. See STS-41D.

Waste/Supply Water Dumps. See STS-51G.

Radiator Performance. See STS-51I.

STS Orbiter Attitude Control Translational Thrusting. Obtained data necessary to complete database of vehicle thrusting to maintain attitude during various unbiased attitude holds. Data were used in flight design process to refine predicted trajectory, and were used in real time to improve trajectory prediction in the Mission Operations computer.

STS-61C

Ascent Wing Aerodynamic Distributed Load Verification on OV-102 (Columbia). Collected wing, vertical tail, and payload bay door ascent aerodynamic distribution loads data. Data obtained were used to allow refinement of mated vehicle aerodynamic database, which permitted a reduction in mated vehicle aerodynamic force and moment uncertainties.

Ascent Structural Capability Evaluation. See STS-5.

Ascent Flutter Boundary Evaluation. See STS-5.

External Tank Thermal Protection System Performance. See STS-5.

Crew Compartment Structure Deflection Investigation. See STS-8.

Orbiter Experiment Shuttle Infrared Leeside Temperature Sensing. Obtained flight leeside heating and flow-field data on a full-scale vehicle in a true re-entry environment. Data gained were used for comparison with wind tunnel test results and theoretical predictions, and to gain a better understanding of aeroheating for more efficient heat shield designs.

Orbiter Experiment Shuttle Upper Atmosphere Mass Spectrometer. Measured air density and identified constituents in upper atmosphere. Data gained were used to calculate aerodynamic force coefficients and derivatives in flight over the re-entry trajectory from free molecular flow to continuum flow, and were used to evaluate design predictions.

Orbiter Experiment Shuttle Entry Air Data System. Obtained more precise measurements of air data, angles of attack, and sideslip at speeds and accuracies not available with baselined air data system. Data obtained during re-entry were analyzed, used to improve design of re-entry vehicles, and reduced life cycle costs by demonstrating new design concepts in actual re-entry environments.

STS-26

Ascent Structural Capability Evaluation. See STS-5.

Ascent Compartment Venting Evaluation. See STS-5.

Descent Compartment Venting Evaluation. See STS-5.

Entry Structural Capability Evaluation. See STS-5.

Vibration and Acoustic Environment Evaluation. See STS-5.

Prevention of Coupled Structure Propulsion Instability (POGO) Stability Performance. See STS-8.

Direct Insertion External Tank Tracking for the Eastern Test Range. See STS-41C.

Shuttle/Payload Low Frequency Environment. See STS-51B.

STS-27

Ascent Structural Capability Evaluation. See STS-5.

Ascent Compartment Venting Evaluation. See STS-5.

Descent Compartment Venting Evaluation. See STS-5.

Entry Structural Capability Evaluation. See STS-5.

Vibration and Acoustic Environment Evaluation. See STS-5.

Prevention of Coupled Structure Propulsion Instability (POGO) Stability Performance. See STS-8.

Text and Graphics System. Provided a significant confidence test and evaluation of Text and Graphics System under zero gravity, and generated data for comparison with data from 1*g* test conditions. Text and Graphics System performance was evaluated, which included heater function, paper path operation, and buildup of paper emulsion residue.

Secure Closed Caption Television System Test. Tested a contingency use device designed to allow classified closed-caption television images to be downlinked to the ground by the Orbiter Communications System.

STS-29

External Tank Thermal Protection System Performance. See STS-5.

Direct Insertion External Tank Tracking for the Eastern Test Range. See STS-41C.

Ascent Debris. Assessed presence and source of possible Solid Rocket Booster debris during launch and ascent. Used a high-speed 16mm motion picture camera for views of Solid Rocket Boosters.

Hot Nosewheel Steering Runway Evaluation. Tested modified nosewheel steering system, confirmed nosewheel steering safety, reliability, and controllability during high-speed use, gained operational steering response data at high speeds, and eliminated tire model uncertainty.

Text and Graphics System. See STS-27.

Ascent Structural Capability Evaluation. See STS-5.

Ascent Compartment Venting Evaluation. See STS-5.

Descent Compartment Venting Evaluation. See STS-5.

Entry Structural Capability Evaluation. See STS-5.

Vibration and Acoustic Environment Evaluation. See STS-5.

Prevention of Coupled Structure Propulsion Instability (POGO) Stability Performance. See STS-8.

Shuttle/Payload Low Frequency Environment. See STS-51B.

STS-30

Vibration and Acoustic Environment Evaluation. See STS-5.

Prevention of Coupled Structure Propulsion Instability (POGO) Stability Performance. See STS-8.

Ascent Debris. See STS-29.

Aft Bulkhead Thermal Blanket Evaluation. Conducted inspections and obtained photography of thermal blankets on aft bulkhead of cargo bay due to unexplained blanket anomalies noted in previous postflight inspections. No damage was observed but some blanket bulging was noted.

Hot Nosewheel Steering Runway Evaluation. See STS-29.

Camcorder Demonstration. Evaluated unique hardware aspects of a camcorder as well as crew usage and interaction. Various factors affecting camera performance were evaluated such as low light level operation, macro zoom capability, and fiber optics accessories.

Tracking and Data Relay Satellite to Tracking and Data Relay Satellite Handover. Tested the capability of the Orbiter to handover from Tracking and Data Relay Satellite West and Tracking and Data Relay Satellite East during on-orbit operations. The test was successfully completed using both the S-band and Ku-Band.

Ku-Band antenna Friction. Successfully provided Ku-Band antenna gimbal friction data after eight high-speed scans. Analysis indicated minimal antenna friction.

Heads Up Display Backup to Crew Optical Alignment System. Verified the suitability of heads up display as a sighting device for inertial measurement unit alignments in all modes of Crew Optical Alignment System operation. The crew commented that the reticle was better than Crew Optical Alignment System, and that both the left and right heads up display compared favorably.

Crosswind Landing Performance. Required that the crew perform a manually controlled landing in the presence of a 90° crosswind component of 10 to 15 knots steady state. Experiment demonstrated shuttle and crew's capability to manually land in the presence of a crosswind.

STS-28

Cold Soak of Observation Window. Obtained data in a cold environment to determine observation-window-seal thermal response on Columbia following removal of the emergency egress system after STS-9. Based on analysis of data from STS-3 and this flight, the removal of the emergency egress system did not significantly affect canopy or observation window temperatures, but the configuration at the time was somewhat cooler than the previous configuration.

Ascent Wing Aerodynamic Distributed Load Verification on OV-102 (Columbia). See STS-61C.

Ascent Structural Capability Evaluation. See STS-5.

Reinforced Carbon-Carbon Life Evaluation. See STS-5.

External Tank Thermal Protection System Performance. See STS-5.

Aft Bulkhead Thermal Blanket Evaluation. See STS-30 for description. No damage was found on redesigned blankets and no visible blanket contamination was reported, but damage was found on two unmodified blankets.

Orbiter Experiment Shuttle Infrared Leeside Temperature Sensing. See STS-61C.

Orbiter Experiment Shuttle Entry Air Data System. See STS-61C.

STS-34

Ascent Structural Capability Evaluation. See STS-5.

Entry Structural Capability Evaluation. See STS-5.

Prevention of Coupled Structure Propulsion Instability (POGO) Stability Performance. See STS-8.

External Tank Thermal Protection System Performance. See STS-5.

Hot Nosewheel Steering Runway Evaluation. See STS-29.

Camcorder Demonstration. See STS-30 for description. The crew recorded and downlinked a variety of scenes including middeck operations, Earth views, and fiber scope views.

Tracking and Data Relay Satellite to Tracking and Data Relay Satellite Handover. See STS-30 for description. S-band portion of test was successfully completed.

Text and Graphics System. See STS-29 for description. The crew reported outstanding image quality, but there were operational difficulties that needed to be resolved.

Gravity Gradient Attitude Control. See STS-31. The guidance, navigation, and control community was pleased with Orbiter's performance during the test.

STS-33

Ascent Structural Capability Evaluation. See STS-5.

Ascent Compartment Venting Evaluation. See STS-5.

Descent Compartment Venting Evaluation. See STS-5.

Entry Structural Capability Evaluation. See STS-5.

Vibration and Acoustic Environment Evaluation. See STS-5.

Prevention of Coupled Structure Propulsion Instability (POGO) Stability Performance. See STS-8.

Camcorder Demonstration. See STS-30.

Inertial Measurement Unit Reference Recovery Techniques. Tested inertial measurement unit reference recovery techniques on orbit using Crew Optical Alignment System and universal pointing software. Crew evaluations and torquing angles obtained from normal guidance, navigation, and control downlist were obtained.

Solid Rocket Booster Rate Gyro Relocation. Defined a flight test program to evaluate performance of Solid Rocket Booster rate gyro assembly located in Orbiter vehicle midbody. Data were recorded during flight.

STS-32

Ascent Wing Aerodynamic Distributed Load Verification on OV-102 (Columbia). See STS-61C.

Entry Aerodynamic Control Surfaces Test. See STS-9 (Entry Aerodynamic Test No. 5) for description.

Ascent Structural Capability Evaluation. See STS-5.

Entry Structural Capability Evaluation. See STS-5.

Prevention of Coupled Structure Propulsion Instability (POGO) Stability Performance. See STS-8.

External Tank Thermal Protection System Performance. See STS-5.

Remote Manipulator System Operating Loads and Data During Long-Duration Exposure Facility Retrieve. Recorded Remote Manipulator System strain gauge readings, motor rates, joint angles, and hand controller positions during normal Long-Duration Exposure Facility retrieve and berthing operations. Provided opportunity to validate adequacy of the system to handle large payloads.

Direct Drive Remote Manipulator System Exercise. Gathered data on integrity of Remote Manipulator System joints and brakes. This was accomplished by performing an operational checklist, direct drive test, which exercised/drove each joint in turn for evaluation of joint action and braking.

Tracking and Data Relay Satellite to Tracking and Data Relay Satellite Handover. See STS-30.

Gravity Gradient Attitude Control. See STS-31.

Orbiter Experiment Shuttle Infrared Leeside Temperature Sensing. See STS-61C.

Orbiter Experiment Shuttle Entry Air Data System. See STS-61C.

OV-102 (Columbia) Acceleration Data Collection to Support Microgravity Disturbances. Collected accelerometer data during mission events such as thruster firings and crew exercise activities to assess effect on microgravity experiments and dynamic response of Orbiter to vibrations.

STS-36

Two ascent-phase Development Test Objectives were completed.

STS-31

Entry Aerodynamic Control Surfaces Test (part 2). See STS-9 (Entry Aerodynamic Test No. 5) for description.

Ascent Structural Capability Evaluation. See STS-5.

Ascent Compartment Venting Evaluation. See STS-5.

Entry Structural Capability Evaluation. See STS-5.

Vibration and Acoustic Environment Evaluation. See STS-5.

Direct External Tank Insertion - Hawaii/North American Air Defense Command Tracking. See STS-41C (Direct Insertion External Tank Tracking for the Eastern Test Range) for description.

Cabin Growth. Successfully obtained data to verify adequacy of Pole Crew Escape System operational position of crew cabin attach system.

Carbon Brake System Evaluation (Test Condition 1). Evaluated Orbiter Carbon Brake System performance through a series of landing rollout brake tests on lakebed and concrete surfaces.

Microbial Filter Resin Checkout. Verified that the new resin in Orbiter water system's microbial filter introduced proper concentrations of iodine into potable water produced by fuel cells.

Gravity Gradient Attitude Control. Tested to find a precise attitude that balanced aerodynamic, angular momentum, and gravity gradient force and determined amplitude of steady state attitude oscillations and sensitivity of those oscillations to attitude and rate errors at gravity gradient initiation. Results showed that the Orbiter reacted the same way in both the higher orbit STS-31 flew and the lower orbits normally flown.

STS-41

Forward Reaction Control System Flight Test. A series of Forward Reaction Control System flight test maneuvers were initiated during re-entry to obtain flight data showing aerodynamic effects created when Forward Reaction Control System side firing thrusters were used as a means of eliminating Reaction Control System propellant. Data gained were used to verify and validate wind tunnel data, and verify the safety of performing a Forward Reaction Control System dump during a Glide Return to Landing Site or Transoceanic Abort Landing abort.

Ascent Structural Capability Evaluation. See STS-5.

Ascent Compartment Venting Evaluation. See STS-5.

Descent Compartment Venting Evaluation. See STS-5.

Entry Structural Capability Evaluation. See STS-5.

External Tank Thermal Protection System Performance. See STS-5.

Shuttle/Payload Low Frequency Environment. See STS-51B.

Carbon Brake System Test (Test Condition 2). See STS-31 for description.

Heads Up Display Backup to Crew Optical Alignment System. See STS-30. The crew found Heads Up Display to be easier to use and more comfortable, and recommended Heads Up Display to be used as the primary instrument for these types of operations.

Payload and General Support Computer Electroluminescent Display Evaluation. Evaluated a new Payload and General Support Computer configuration, which included an electroluminescent display that was much brighter and had a wider viewing angle. The crew found the new display to be much easier to read than the old liquid crystal display.

Space Station Cursor Control Device Evaluation. Evaluated human performance under spaceflight conditions of cursor control devices, which were under consideration for space station use at the time. The Macintosh portable computer built-in trackball and a Felix cursor pointing device were tested during flight

STS-38

Ascent Structural Capability Evaluation. See STS-5.

Ascent Flutter Boundary Evaluation. See STS-5.

Heads Up Display Backup to Crew Optical Alignment System. See STS-30.

STS-35

Ascent Wing Aerodynamic Distributed Load Verification on OV-102. See STS-61C.

Entry Aerodynamic Control Surfaces Test (part 3). See STS-9 (Entry Aerodynamic Test No. 5) for description.

Ascent Structural Capability Evaluation. See STS-5.

Entry Structural Capability Evaluation. See STS-5.

External Tank Thermal Protection System Performance. See STS-5.

Improved Waste Collection System Evaluation. Evaluated operational capabilities of the Whitmore Improved Waste Collection System under spaceflight conditions. The crew reported Improved Waste Collection System performed well during flight.

In-flight Trash Compaction. Assessed feasibility of the incorporation of a trash compaction system to perform in-flight compaction and stowage of discarded crew-related debris. The hand-operated trash compaction system stowed within a middeck locker was used frequently and performed well during flight.

Orbiter Experiment Shuttle Upper Atmosphere Mass Spectrometer. See STS-61C.

Orbiter Experiment Shuttle Entry Air Data System. See STS-61C.

Orbiter Experiment Aerothermal Instrumentation Package. Provided measurements of aerodynamic surface pressure and temperature during atmospheric re-entry on Orbiter's leeside wing, fuselage, and vertical tail. Measurements comprised of Reaction Control System/aerodynamic flow-field interactions, vortex-induced heating to side fuselage, and "ground-truth" data in support of the shuttle infrared temperature sensing experiment.

STS-37

Entry Aerodynamic Control Surfaces Test (part 4). See STS-9 (Entry Aerodynamic Test No. 5) for description.

Ascent Structural Capability Evaluation. See STS-5.

Entry Structural Capability Evaluation. See STS-5.

Ascent Flutter Boundary Evaluation. See STS-5.

External Tank Thermal Protection System Performance. See STS-5.

Direct External Tank Insertion - Hawaii/North American Air Defense Command Tracking. See STS-41C (Direct Insertion External Tank Tracking for the Eastern Test Range) for description.

Carbon Brake System Test (Test Condition 4). See STS-31 for description. The carbon brakes operated flawlessly with little wear.

Video Tape Recorder Demonstration. Evaluated operational characteristics of off-the-shelf video cassette recorders in zero gravity since the video tape recorder that had been developed for the Orbiter used technology that had been surpassed by commercially available video cassette recorders. The video tape recorder flown on the flight worked well and proved that it could interface with Orbiter's system.

Advanced 5000 Series Glove Evaluation. Evaluated fit, function, and thermal protection capabilities of an advance 5000 series extravehicular mobility unit during operational extravehicular activity. The gloves were used by

Astronaut Jerry Ross and, based on the results, the glove was not recommended at that time as a replacement for the glove being used.

Video Tape Recorder Demonstration Enhancement. Enhanced the video tape recorder demonstration by evaluating and taking advantage of state-of-the-art camera and liquid crystal display technology as well as evaluating the video tape recorder. The Pulnix camera and liquid crystal display monitor were successfully evaluated by the crew.

Mid-Range Targeted Stationkeeping (Test condition 4 only). Determined how accurately Orbiter could intercept a point and maintain position behind the target, and determined how well angular rates normal to the line-of-site could be minimized. The deployed Gamma Ray Observatory was successfully used as the target.

Space Station Extravehicular Activity (EVA) Translation Evaluation (Includes new Remote Manipulator System Limp Mode test). Provided on-orbit evaluation of EVA translation rates and techniques while performing representative space station tasks such as hand-over-hand translation along Orbiter sill, translations along a non-rigid translation aid, translation with a hand-held item, and maneuvering a crew member in a manipulator foot restraint with the Remote Manipulator System accelerations.

Space Station Freedom Extravehicular Activity (EVA) Loads Data Acquisition (Crew Load Instrumented Pallet). Performed EVA tests to measure the crew induced and applied loads, which were encountered by handrails, foot restraints, crew and equipment transfer/translation aid carts and rails, and truss structure during representative Space Station Freedom EVA assembly and maintenance tasks.

Space Station Heatpipe Advanced Radiator Element II Middeck Priming Experiment. Evaluated new designs incorporated into sections of the Space Station Heatpipe Advanced Radiator Element radiator panel by verifying priming capabilities and bubble management capabilities of model manifold test sections following repeated forced de-priming of test articles. Results indicated that the new design worked as expected.

Targeting and Reflective Alignment Concept Application for Remote Manipulator System Alignment/Deflection Measurements. Provided on-orbit evaluation of the effectiveness of targeting and reflective alignment concept for observing and measuring Remote Manipulator System deflections and as an aid for precise positioning of Remote Manipulator System. Targeting and reflective alignment concept alignment was easily obtained, and the Remote Manipulator System was found to be acceptable as a work platform.

STS-39

Ascent Structural Capability Evaluation. See STS-5.

Ascent Compartment Venting Evaluation. See STS-5.

Descent Compartment Venting Evaluation. See STS-5.

Entry Structural Capability Evaluation. See STS-5.

Vibration and Acoustic Environment Evaluation. See STS-5.

External Tank Thermal Protection System Performance. See STS-5. Not scheduled but was completed by the crew.

Carbon Brake Systems Test, condition 3. See STS-31 for description.

STS-40

Ascent Wing Aerodynamic Distributed Load Verification on OV-102 (Columbia). See STS-61C.

Entry Aerodynamic Control Surfaces Test (Part 5). See STS-9 (Entry Aerodynamic Test No. 5) for description. Five of the eight programmed test inputs were completed.

Ascent Structural Capability Evaluation. See STS-5.

Entry Structural Capability Evaluation. See STS-5.

External Tank Thermal Protection System Performance. See STS-5.

Hot Nosewheel Steering Runway Evaluation. See STS-29.

Camcorder Demonstration. See STS-30 for description.

On-Orbit Cabin Air Cleaner Evaluation. Tested a proposed system to be used to filter cabin air. Successfully evaluated air velocity produced by the fan, noise generation, general air quality, and analyzed debris collected on filters after completion of the mission.

Water Separator Filter Performance Evaluation. Due to water separator failures of previous flights because of debris accumulation and buildup, a filter was designed to be a fix for the problem if it worked as planned. Filter performance was evaluated and recorded on videotape for postflight evaluation.

Heads Up Display Backup to Crew Optical Alignment System. See STS-30.

Vent Uplink Capability. Tested capability to uplink a ground-determined vent to Orbiter's on-board navigation software during a flight. Test worked to include the vent in future on-board propagation models and applications to result in more accurate state vectors, which would in turn reduce state vector uplinks on orbit.

Orbiter Experiment Shuttle Infrared Leeside Temperature Sensing. See STS-61C.

Orbiter Experiment Shuttle Upper Atmosphere Mass Spectrometer. See STS-61C.

Orbiter Experiment Shuttle Entry Air Data System. See STS-61C.

Orbiter Experiment Orbital Acceleration Research Experiment. Provided accurate measurements of aerodynamic acceleration in the nano-g range along Orbiter's principal axes during re-entry. Measurements obtained increased database for fundamental aerothermodynamic flow phenomena in upper atmosphere, along with confirmation of aerodynamics of Orbiter measurements enabled predictions of aerodynamics for advanced re-entry missions, and provided data at Orbital altitudes to expand technology used for orbital drag prediction for design of future space systems.

Orbiter Experiment Aerothermal Instrumentation Package. See STS-35.

Get Away Special:

> The Effect of Cosmic Radiation on Floppy Disks. Student experiment investigated static computer memory (floppy disks) to determine whether cosmically charged particle would produce changes in data integrity or structure.

STS-43

Alternate Mode Digital Autopilot Performance Evaluation. Successfully demonstrated in-flight operation of alternate mode autopilot by performing representative maneuvers in various control modes to allow an initial level of confidence in the system.

Payload General Support Computers/Portable Audio Data Monitor Air/Ground Communications Demonstration. Demonstrated operational capability of the integrated Payload General Support Computers/Portable Audio Data Monitor system to uplink and downlink data files via Orbiter voice communications link. Hardware, software, and related procedure for both flight and Mission Control Center systems were tested successfully.

STS-48

Ascent Structural Capability Evaluation. See STS-5.

Ascent Compartment Venting Evaluation. See STS-5.

Descent Compartment Venting Evaluation. See STS-5.

Vibration and Acoustic Environment Evaluation. See STS-5.

Electronic Still Photography Test. See STS-42 for description. The Electronic Still Camera performed well during flight and pictures were downlinked on orbit.

Payload and General Support Computers Single Event Upset Monitoring. See STS-46.

STS-44

Ascent Structural Capability Evaluation. See STS-5.

Entry Structural Capability Evaluation. See STS-5.

Edwards Lakebed Runway Bearing Strength Assessment for Orbiter Landings. Tested and obtained data to confirm decreasing rolling friction as function of dynamic load from nose gear touchdown to stop, confirm trolling drag decrease for Edwards lakebed runway complex with the onset of dry year conditions since 1983, and establish a correlation between Orbiter main landing gear and load cart rut penetrations and simulation studies. Tests were successfully completed by the crew when brakes were not applied until Orbiter had slowed to 15 knots.

STS-42

Entry Aerodynamic Control Surfaces Test (Part 6). See STS-9 (Entry Aerodynamic Test No. 5) for description.

Ascent Structural Capability Evaluation. See STS-5.

Ascent Compartment Venting Evaluation. See STS-5.

Descent Compartment Venting Evaluation. See STS-5.

Entry Structural Capability Evaluation. See STS-5.

Vibration and Acoustic Environment Evaluation. See STS-5.

External Tank Thermal Protection System Performance. See STS-5.

Shuttle/Payload Low Frequency Environment. See STS-51B.

Electronic Still Photography Test (Test 3 without downlink). Successfully tested effectiveness of Electronic Still Camera during on-orbit operations, and tested on-orbit image processing capability.

STS-45

Forward Reaction Control System Flight Test - Control Surface Effects. See STS-41 for description. Data gained were also used to study jet impingement effects of Forward Reaction Control System on control surface effectiveness.

Ascent Structural Capability Evaluation. See STS-5.

Exernal Tank Thermal Protection System Performance. See STS-5.

Video Tape Recorder Demonstration. See STS-37.

Electronic Still Photography Test (Without the Playback Downlink Unit and the Downlink Capability). See STS-42.

Ku-Band antenna Friction. See STS-30.

STS-49

Ascent Structural Capability Evaluation. See STS-5.

Ascent Compartment Venting Evaluation. See STS-5.

Descent Compartment Venting Evaluation. See STS-5.

Entry Structural Capability Evaluation. See STS-5.

Waste/Supply Water Dumps. See STS-51G.

Carbon Brake System Test (Test Condition 6). See STS-31 for description.

Orbiter Drag Chute System (Test 1). See STS-47 for description. The chute was deployed as planned and all operational areas of the chute operated properly.

Electronic Still Photography Test (with downlink). See STS-42 for description. The Electronic Still Camera performed well during flight.

Laser Range and Range Rate Device. See STS-46 for description. The device performed excellently for rendezvous and proximity operations during flight.

STS-50

Ascent Wing Aerodynamic Distributed Load Verification on OV-102. See STS-61C.

Ascent Structural Capability Evaluation. See STS-5.

Entry Structural Capability Evaluation. See STS-5.

External Tank Thermal Protection System Performance. See STS-5.

Shuttle/Payload Low Frequency Environment. See STS-51B.

On-Orbit Power Reactant Storage and Distribution Cryogenic Hydrogen (H2) Boiloff. Successfully collected data to determine accurate power reactant storage and distribution H2 boiloff rates, since discrepancies were thought to exist between predicted and actual on-orbit data, so that long-duration utilization flights to Space Station Freedom could be accomplished.

Carbon Brake System Test (Test Condition 5). See STS-31.

Orbiter Drag Chute System Test (Test 0). See STS-47 for description. The drag chute was deployed, and data obtained concluded it performed satisfactorily.

Modify Environmental Control and Life Support System Supply Air Ducting to Provide Chilled Air to Suited Crewmembers. See STS-46.

Orbiter Experiment Orbital Acceleration Research Experiment (Priorities 2 and 3). See STS-40 for description. The instrument performed satisfactorily during flight.

OV-102 (Columbia) Acceleration Data Collection to Support Microgravity Disturbances. See STS-32.

STS-46

Entry Aerodynamic Control Surfaces Test - Alternate Elevon Schedule (Part 2). See STS-9 (Entry Aerodynamic Test No. 5) for description. Tests were completed using an automated elevon schedule instead of an alternate schedule due to problems encountered on STS-50.

Entry Structural Capability Evaluation. See STS-5.

External Tank Thermal Protection System Performance. See STS-5 for description. Although not scheduled this flight, the crew took pictures of the External Tank after separation and completed the test.

Waste/Supply Water Dumps. See STS-51G.

Payload and General Support Computers Single Event Upset Monitoring. Determined the Random Access Memory susceptibility to Single Event Upset caused by cosmic radiation. Data gained from tests were used to attempt to reduce effects of cosmic radiation on Payload and General Support Computers operations.

Modify Environmental Control and Life Support System Supply Air Ducting to Provide Chilled Air to Suited Crewmembers. Evaluated hardware modifications that directed cool Atmospheric Revitalization System supply air to crew during launch, re-entry, and landing orbital phases. The crew noted that without proper venting from the suit, the modifications did not relieve any of the heat problems.

Laser Range and Range Rate Device. Demonstrated and tested the capability of hand-held laser devices to provide Orbiter flight crew with range and range rate data for rendezvous, proximity operations, and deploy operations. Laser range and range rate device was used with no apparent anomalies during Tethered Satellite System-1 deployment.

STS-47

Entry Aerodynamic Control Surfaces Test - Alternate Elevon Schedule (Test 3). See STS-9 (Entry Aerodynamic Test No. 5) for description. The aileron trim was as expected for each programmed test input.

Ascent Structural Capability Evaluation. See STS-5.

Ascent Compartment Venting Evaluation. See STS-5.

Descent Compartment Venting Evaluation. See STS-5.

Entry Structural Capability Evaluation. See STS-5.

External Tank Thermal Protection System Performance. See STS-5.

Orbiter Drag Chute System (Test 2). Evaluated Orbiter Drag Chute System performance through a series of landings with increasing deployment speeds. The chute deployed nominally; however, just after disreef and prior to nose gear touchdown, the chute pulled Orbiter to the left of the centerline.

Water Separator Filter Performance Evaluation. See STS-40. Filter operated satisfactorily most of flight.

STS-52

Ascent Wing Aerodynamic Distributed Load Verification on OV-102. See STS-61C.

Entry Aerodynamic Control Surfaces Test - Alternate Elevon Schedule (Part 4). See STS-9 (Entry Aerodynamic Test No. 5) for description. All six programmed test inputs were performed.

Ascent Structural Capability Evaluation. See STS-5.

Entry Structural Capability Evaluation. See STS-5.

External Tank Thermal Protection System Performance. See STS-5.

Orbiter Drag Chute (Nose in the air deployment after initiation of de-rotation with crosswind < 5 knots and touchdown near centerline). See STS-47 for description.

Extended Duration Orbiter Waste Collection System Fan Separator Evaluation. Verified the design worthiness of new Extended Duration Orbiter Waste Collection System Fan Separator under zero-gravity conditions for a prolonged period, and worked to verify that the new design would correct past fan separator deficiencies. Video showed proper operations with slug flow device.

Interim Portable Onboard Printer. Successfully evaluated operational capability of portable onboard printer to print text and graphics via Orbiter S-band communication link to payload and general support computer, the ability of the portable onboard printer to be an interim backup to Text and Graphics System hardcopier and teleprinter, and acceptability of the printer for operational support.

Laser Range and Range Rate (short range device only). See STS-46 for description.

Plume Impingement Model Verification. Impinged the Canadian target assembly with one or more Primary Reaction Control System engines to determine its range, attitude, and induced velocity. Flight data gained were used to support test validation of Orbiter Reaction Control System plume impingement math model.

Advanced Portable Computer Evaluation (with no Mac-to-Mac transfers). Successfully evaluated advanced portable computer technology with a series of flight tests to define portable computer requirements needed to support future shuttle and space station crews.

Space Vision System Experiment. Canadian test evaluated operational details and performance of an experimental version of the Space Vision System designed for use on shuttle and for construction of the space station. Testing was conducted using the Canadian Assembly Satellite as a target as various maneuvers were made with the Remote Manipulator System using Space Vision System data.

Payload On-Orbit Low Frequency Environment. Obtained on-orbit payload acceleration data from Primary Reaction Control System jet firings using the Space Acceleration Measurement System.

STS-53

External Tank Thermal Protection System Performance. See STS-5.

Orbiter Drag Chute System (Special test condition: post de-rotation [nose in air] deployment after initiation of de-rotation with crosswind < 5 knots and touchdown near centerline). See STS-47 for description.

Payload and General Support Computers Single Event Upset Monitoring. See STS-46.

STS-54

Ascent Structural Capability Evaluation. See STS-5.

Ascent Compartment Venting Evaluation. See STS-5.

Descent Compartment Venting Evaluation. See STS-5.

Entry Structural Capability Evaluation. See STS-5.

External Tank Thermal Protection System Performance. See STS-5.

Fuel Cell On-Orbit Shutdown/Restart (Fuel Cell 2). See STS-51 for description. Fuel Cell No. 2 was successfully shut down and restarted during flight.

Orbiter Drag Chute System (Nose-in-the-air deployment after initiation of de-rotation with average crosswind =5 knots and touchdown near centerline). See STS-47 for description. The drag chute was deployed, and the system performed satisfactorily.

Electronic Still Photography Test (without downlink; with 50mm to 300mm zoom lens replacing the 300mm lens). See STS-42.

Payload and General Support Computers Single Event Upset Monitoring. See STS-46.

Extended Duration Orbiter Waste Collection System Evaluation. Worked to verify design of new Extended Duration Orbiter Waste Collection System under zero-gravity conditions for a prolonged period on Columbia or Endeavour. Evaluation was conducted on Endeavour, and was completed satisfactorily.

Atmospheric Effects on Star Tracker Performance. Collected data on Star Trackers' ability to accurately acquire stars through Earth's atmospheric layer, documented extent of atmospheric effects, and identified any potential impacts to operational procedures for inertial measurement unit alignments on stars acquired in atmospheric layer.

Extravehicular Activity Operations Procedures/Training. See STS-51.

Frequency Interference Measurement. Collected data on interference in the 400- to 470-MHz frequency band and used the data to attempt to determine optimum Extravehicular Activity and Wireless Crew Communications System frequency bands, and worked to determine whether interference mitigation circuitry must be included in Extravehicular Activity and Wireless Crew Communications System hardware. Data were obtained for analysis.

STS-56

Entry Aerodynamic Control Surfaces Test - Alternate Elevon Schedule (Part 5). See STS-9 (Entry Aerodynamic Test No. 5) for description. All six programmed test inputs were performed.

Ascent Structural Capability Evaluation. See STS-5.

Ascent Compartment Venting Evaluation. See STS-5.

Descent Compartment Venting Evaluation. See STS-5.

Vibration and Acoustic Environment Evaluation. See STS-5.

External Tank Thermal Protection System Performance. See STS-5.

Orbiter/Payload Acceleration and Acoustics Environment Data. See STS-51B (Shuttle/Payload Low Frequency Environment).

Orbiter Drag Chute System (Nose-in-the-air deployment after initiation of de-rotation with crosswind < 5 knots and touchdown near centerline). See STS-47 for description.

Payload and General Support Computers Single Event Upset Monitoring. See STS-46.

Laser Range and Range Rate Device. See STS-46 for description. Used during Shuttle Pointed Autonomous Research Tool for Astronomy deployment and retrieval.

Frequency Interference Measurement. See STS-54.

STS-55

Ascent Wing Aerodynamic Distributed Load Verification on OV-102. See STS-61C.

Entry Aerodynamic Control Surfaces Test - Alternate Elevon Schedule (Part 6). See STS-9 (Entry Aerodynamic Test No. 5) for description. The mission management team adjusted elevon schedule to the automatic schedule rather than the alternate schedule.

Ascent Structural Capability Evaluation. See STS-5.

Entry Structural Capability Evaluation. See STS-5.

External Tank Thermal Protection System Performance. See STS-5.

Orbiter Drag Chute System (Nose-in-the-air deployment after initiation of de-rotation with crosswind <10 knots and touchdown near centerline). See STS-47 for description.

Thermal Impulse Printer System Demonstration. See STS-51 for description. Thermal Impulse Printer System performed satisfactorily after Ku-Band transmission anomaly was understood to be a configuration problem and was fixed.

STS-57

Ascent Structural Capability Evaluation. See STS-5.

Ascent Compartment Venting Evaluation. See STS-5.

Descent Compartment Venting Evaluation. See STS-5.

Entry Structural Capability Evaluation. See STS-5.

External Tank Thermal Protection System Performance. See STS-5.

Auxiliary Power Unit Shutdown Test (Sequence A). Explored hypothesis that delays between shutting down individual Auxiliary Power Units on ascent could lead to "backdriving" of non-operational hydraulic system's speedbrake hydraulic motor, and provided a database of hydraulic system performance for continued engineering and maintenance of Orbiter hardware. No hydraulic motor backdrive symptoms or any anomalous pressure hang-ups were detected during shutdown sequence on this flight.

Orbiter Drag chute System (Special Test Condition: Post de-rotation [nose-in-the-air] deployment using 90% reefed chute). See STS-47 for description.

Extended Duration Orbiter Waste Collection System Evaluation. See STS-54.

Extravehicular Activity (EVA) Hardware for Future Scheduled Extravehicular Activity (EVA) Missions (14.7 prebreathe protocol). See STS-51 for description.

Extravehicular Activity Operations Procedures/Training (14.7 Prebreathe Protocol). See STS-51.

Get Away Special:

Liquid Gauging Technology Experiment. Demonstrated two in-orbit methods--Periodic Volume Stimulus and Foreign Mass Injection Method--of gauging liquids in tanks.

STS-51

Ascent Structural Capability Evaluation. See STS-5.

Ascent Compartment Venting Evaluation. See STS-5.

Descent Compartment Venting Evaluation. See STS-5.

Vibration and Acoustic Environment Evaluation. See STS-5.

External Tank Thermal Protection System Performance. See STS-5.

Orbiter/Payload Acceleration and Acoustics Environment Data. See STS-51B (Shuttle/Payload Low Frequency Environment).

Fuel Cell on Orbit Shutdown/Restart. Obtained data to verify capability to restart a fuel cell on orbit, determine magnitude of voltage degradation, and tested how fast fuel cell will cool down so that long-duration utilization flights to Space Station Freedom would be successful. Fuel cell no. 1 was successfully shut down and then restarted after 24 hours.

Orbiter Drag Chute System (Special test condition: post de-rotation [nose-in-the-air] deployment with five ribbons removed from the chute). See STS-47 for description.

Payload and General Support Computers Single Event Upset Monitoring. See STS-46.

Thermal Impulse Printer System Demonstration. Evaluated operational capability of Thermal Impulse Printer System to uplink text and graphics via Orbiter voice/Ku-Band communication link, and evaluated Thermal Impulse Printer System as an alternative to the on-board Text and Graphics System hardcopier and teleprinter. Thermal Impulse Printer System was operated successfully during flight.

Extravehicular Activity (EVA) Hardware for Future Scheduled Extravehicular Activity (EVA) Missions (Test 3, 4, 6, and 7). Evaluated and demonstrated mission-critical EVA hardware using associated operational techniques and candidate techniques that could not be accurately represented in the 1*g* EVA environment prior to scheduled EVAs. All objectives were met, and EVA tools were operated successfully.

STS Orbiter Attitude Control Translational Thrusting. See STS-61B.

Laser Range and Range Rate Device. See STS-46 for description. The Laser Range and Range Rate device was used extensively during Orbiting Retrievable Far and Extreme Ultraviolet Spectrometer-Shuttle Pallet Satellite retrieval and it was found that the device compared well to Ku-Band radar and performed better than Ku-Band radar when within 46 m (150 ft).

Payload Bay Mounted Rendezvous Laser (Trajectory Control Sensor). Worked to demonstrate capability of trajectory control sensor to provide Orbiter crew with rendezvous data required for precise on-orbit rendezvous, proximity operations, and payload berthing or deployment operations. Continuous mode was inoperative during flight, but data were gained when the trajectory control sensor was switched to pulse mode.

Global Positioning System (GPS) On-Orbit Demonstration. Provided a qualitative assessment of GPS position and velocity data provided by a GPS receiver located on shuttle flight deck. GPS successfully demonstrated real-time absolute and relative global positioning in an orbital dynamic environment as well as provided Shuttle Pallet Satellite and Orbiter GPS data, and found that Orbiter GPS data showed good comparison with expected trajectories.

Orbiter Data for Real-Time Navigation Evaluation. Successfully supported trajectory control sensor and Global Positioning System (GPS) testing by increasing accuracy of trajectory control sensor by providing Orbiter attitude information to the laser software in real time, and collected Orbiter and payload bay GPS state vector information in real time.

Extravehicular Activity (EVA) Operations Procedures/Training. Successfully isolated and demonstrated specific differences between training facility simulations and operations in actual EVA environment, and broadened EVA procedures and training experience bases and proficiency in preparation for future EVAs such as Hubble Space Telescope and space station assembly and maintenance.

STS-58

Ascent Wing Aerodynamic Distributed Load Verification on OV-102. See STS-61C.

Forward Reaction Control System Flight Test - Control Surface Effects. See STS-41 (Forward Reaction Control System FlightTest) for description. Data gained were also used to study jet impingement effects of Forward Reaction Control System on control surface effectiveness.

Ascent Structural Capability Evaluation. See STS-5.

Entry Structural Capability Evaluation. See STS-5.

Vibration and Acoustic Environment Evaluation. See STS-5.

External Tank Thermal Protection System Performance. See STS-5.

Orbiter/Payload Acceleration and Acoustics Environment Data. See STS-51B (Shuttle/Payload Low Frequency Environment).

On-Orbit Power Reactant Storage and Distribution Cryogenic Hydrogen (H_2) Boiloff (perform on a maximum of 7 days). See STS-50 for description. Found that boiloff rates were 45% less than predicted values. Results compared well with STS-50 results, and indicated 90-day on-orbit capability had nearly been obtained.

Auxiliary Power Unit Shutdown Test (Sequence A). See STS-57 for description. The shutdown sequence was altered during ascent, and no backdriving of the power drive unit was detected.

Orbiter Drag Chute System (Special test condition: post de-rotation [nose-in-the-air] deployment with five ribbons removed from the chute). See STS-47 for description.

Portable In-Flight Landing Operations Trainer. Worked to verify that the Portable In-Flight Landing Operations Trainer simulator assisted shuttle commander and pilot in maintaining the highest level of proficiency for end-of-mission approach and landing during extended-duration Orbiter flights. The crew operated the trainer, and results were positive.

Orbiter Experiment Orbital Acceleration Research Experiment (Powered from cabin payload bus). See STS-40 for description.

OV-102 (Columbia) Acceleration Data Collection to Support Microgravity Disturbances. See STS-32.

Window Impact Observation. Collected window impact data by observing and noting window damage caused by on-orbit particulate impacts in an effort to identify source of window damage.

STS-61

Ascent Structural Capability Evaluation. See STS-5.

Ascent Compartment Venting Evaluation. See STS-5.

Descent Compartment Venting Evaluation. See STS-5.

Entry Structural Capability Evaluation. See STS-5.

External Tank Thermal Protection System Performance. See STS-5.

Orbiter Drag Chute System (Special test condition: initiation of de-rotation [nose-in-the-air]). See STS-47 for description.

Electronic Still Camera Photography Test (with downlink). See STS-42 for description. The electronic still camera was used to document Hubble Space Telescope anomalies throughout the flight.

Payload and General Support Computers Single Event Upset Monitoring (Configuration 1 and 2). See STS-46.

Portable In-Flight Landing Operations Trainer. See STS-58.

Laser Range and Range Rate Device. See STS-46 for description. Laser Range and Rate Device was used during Hubble Space Telescope rendezvous activities, solar array jettison, and Hubble deployment activities.

Global Positioning System (GPS) Development Flight Test. Demonstrated performance and operation of GPS during Orbiter ascent, on-orbit, re-entry, and landing phases using a modified military GPS receiver processor and existing Orbiter antennas. This flight test supported operational use of GPS as a shuttle navigation aid.

Waste and Supply Water Dump at 10.2 Pounds Per Square Inch Absolute (psia). Determined whether shuttle waste and supply water dumps could successfully be accomplished at 10.2 psia on backside of storage tanks so Space Station Freedom overboard dump nozzle design could be validated. Test was completed, and the dumps were videotaped.

Window Impact Observation. See STS-58 for description.

STS-60

Ascent Structural Capability Evaluation. See STS-5.

Ascent Compartment Venting Evaluation. See STS-5.

Descent Compartment Venting Evaluation. See STS-5.

Entry Structural Capability Evaluation. See STS-5.

External Tank Thermal Protection System Performance. See STS-5.

Shuttle/Payload Low Frequency Environment. See STS-51B.

Auxiliary Power Unit Shutdown Test (Sequence B). See STS-57 for description. No power drive unit backdriving was detected and all pressure slope changes corresponded to switching-valve changes of state as expected.

Payload and General Support Computers Single Event Upset Monitoring. See STS-46.

Cabin Temperature Survey. Successfully compiled a temperature profile of crew cabin in a variety of Orbiter attitudes and configurations to support possible temperature control changes. Data were used in an attempt to improve crew comfort while maintaining proper equipment cooling.

Window Impact Observation. See STS-58 for description.

Stirling Orbiter Refrigerator/Freezer. Test was a demonstration to obtain necessary information and characterization about operation of Stirling refrigerator/freezer technology in microgravity. The Stirling refrigerator/freezer operated satisfactorily other than a minor problem.

Get Away Specials:

> The Orbiter Stability Experiment. Measured vibration spectrum of Orbiter structure that is present during normal Orbiter and crew operations.
>
> The Capillary Pumped Loop Experiment. Gave an in-orbit demonstration of the working principle and performances of a two-phase capillary pumped loop, a two-phase vapor quality sensor, and a two-phase multichannel condenser profile. Even though only 9 of the 67 planned tests were completed, it was found that ground-verified start-up procedures would not work reliably in zero gravity.

STS-62

Subsonic Aerodynamics Verification (Part 1). See STS-59.

Ascent Structural Capability Evaluation. See STS-5.

Entry Structural Capability Evaluation. See STS-5.

External Tank Thermal Protection System Performance. See STS-5.

Orbiter/Payload Acceleration and Acoustics Environment Data. See STS-51B (Shuttle/Payload Low Frequency Environment).

On-Orbit Power Reactant Storage and Distribution Cryogenic Hydrogen (H_2) Boiloff. See STS-50 for description.

Orbiter Drag Chute System (Special test condition: deployment at initiation of de-rotation with nose in the air). See STS-47 for description. The special test condition of test was met.

Auxiliary Power Unit Shutdown Test (Sequence A). See STS-57 for description. No backdriving of the power drive unit was detected.

Payload and General Support Computers Single Event Upset Monitoring (Configuration 1 and 2 with a minimum of four 8- to 12-hour data takes). See STS-46.

Cabin Temperature Survey. See STS-60.

Portable In-Flight Landing Operations Trainer. See STS-58.

Thermo-electric Liquid Cooling System Evaluation. See STS-59 for description. Crew reported Thermo-electric Liquid Cooling System Evaluation performed well during ascent, re-entry, and landing.

Ku-Band Communications Adapter Demonstration. Successfully demonstrated capability of Ku-Band communications adapter to provide high-speed bi-directional computer communications via shuttle Ku-Band communications system.

Orbiter Experiment Orbital Acceleration Research Experiment. See STS-40 for description.

Payload On-Orbit Low Frequency Environment. See STS-52 for description. Data were obtained from thruster firings.

Window Impact Observation. See STS-58 for description.

STS-59

Subsonic Aerodynamics Verification (Part 1). Successfully performed a series of flight test maneuvers during approach and landing phase to obtain aerodynamic response data. Data gained from this test evaluated the effectiveness of the rudder surface with applications to crosswind landings and were used to evaluate handling qualities of Orbiter during approach.

Ascent Structural Capability Evaluation. See STS-5.

Ascent Compartment Venting Evaluation. See STS-5.

External Tank Thermal Protection System Performance. See STS-5.

Auxiliary Power Unit Shutdown Test (Sequence A). See STS-57 for description. An alternate shutdown sequence was used, and no speedbrake power drive unit backdriving was detected.

Payload and General Support Computers Single Event Upset Monitoring (Configuration 1 and 2). See STS-46.

Cabin Temperature Survey. See STS-60.

Thermo-electric Liquid Cooling System Evaluation (Commander and Pilot). Provided an in-flight evaluation of Thermo-electric Liquid Cooling System Evaluation that worked to provide increased thermal comfort to the crew. Liquid Cooling System was a replacement for the Personal Suit Ventilation System, which was used at the time.

Window Impact Observation. See STS-58 for description. A micrometeorite impact crater was noted on egress hatch window.

STS-65

Entry Aerodynamics Control Surfaces Test - Alternate Elevon Schedule (Part 7). See STS-9 (Entry Aerodynamic Test No. 5) for description. All five programmed test inputs were performed.

Subsonic Aerodynamics Verification (Part 2). See STS-59.

Ascent Structural Capability Evaluation. See STS-5.

Entry Structural Capability Evaluation. See STS-5.

External Tank Thermal Protection System Performance. See STS-5.

Orbiter/Payload Acceleration and Acoustics Environment Data. See STS-51B (Shuttle/Payload Low Frequency Environment).

Auxiliary Power Unit Shutdown Test (Sequence A). See STS-57 for description. No backdriving of the power drive unit was detected.

Portable In-Flight Landing Operations Trainer. See STS-58.

Thermo-electric Liquid Cooling System Evaluation (for commander and pilot). See STS-59 for description.

Microgravity Measurement Device Evaluation. Evaluated effectiveness of exercise isolation systems and evaluated ease of use of Microgravity Measuring Device System. Data were gained from tests and were eventually used in development of International Space Station exercise hardware.

STS-64

Subsonic Aerodynamics Verification. See STS-59.

Ascent Structural Capability Evaluation. See STS-5.

Ascent Compartment Venting Evaluation. See STS-5.

Descent Compartment Venting Evaluation. See STS-5.

Entry Structural Capability Evaluation. See STS-5.

External Tank Thermal Protection System Performance. See STS-5.

Orbiter/Payload Acceleration and Acoustics Environment Data. See STS-51B (Shuttle/Payload Low Frequency Environment).

Auxiliary Power Unit Shutdown Test (Sequence A). See STS-57 for description. No backdriving of power drive unit or anomalous pressure hang-ups were detected.

Landing Gear Loads and Brake Stability Evaluation (Data Collection Only). See STS-63.

Simplified Aid for Extravehicular Activity Rescue (SAFER) Flight Test. Performed a crewed flight test in a zero-gravity orbital extravehicular activity environment with a developmental version of a mini manned maneuvering unit to establish time, propellant, and controllability requirements to fly to fuel tank and return to cargo bay, and verify overall SAFER performance for Space Station Freedom human-overboard self-rescue. All SAFER systems performed nominally.

Cabin Temperature Survey. See STS-60.

Extravehicular Activity (EVA) Hardware for Future Scheduled Extravehicular Activity (EVA) Missions (Test 8). See STS-51 for description. The test was completed during the Simplified Aid for Extravehicular Activity Rescue EVA.

Extravehicular Mobility Unit Electronic Cuff Checklist. See STS-63 for description. Some problems with touch-screen response and page transfer between payload and general support computer and Electronic Cuff Checklist 2 during flight occurred.

Thermo-electric Liquid Cooling System Evaluation (for two crew members). See STS-59 for description.

Laser Range and Range Rate Device. See STS-46 for description. Used during Shuttle Pointed Autonomous Research Tool for Astronomy deployment and retrieval.

Payload Bay Mounted Rendezvous Laser (Trajectory Control Sensor). See STS-51 for description. Operated successfully during Shuttle Pointed Autonomous Research Tool for Astronomy retrieval after a problem occurred during its deployment.

Orbiter Data for Real-Time Navigation Evaluation. See STS-51 for description. Supported Laser Range and Range Rate Device and Tools for Rendezvous and Docking tests.

Target of Opportunity Navigation Sensors. See STS-63.

Tools for Rendezvous and Docking (Tests 1 and 2). See STS-63 for description. Requirements of test were fulfilled with completion of Laser Range and Range Rate Device, Payload Bay Mounted Rendezvous Laser, and Orbiter Data for Real-Time Navigation evaluation development test objectives.

The Shuttle Plume Impingement Flight Experiment. Used an instrument package carried by the Remote Manipulator System to study behavior and characteristics of exhaust plumes during Reaction Control System thruster firings in an attempt to determine effects of Reaction Control System thruster firings on other large space structures.

STS-68

Entry Aerodynamic Control Surfaces Test - Alternate Elevon Schedule (Part 8). See STS-9 (Entry Aerodynamic Test No. 5) for description. All five programmed test inputs were performed.

Subsonic Aerodynamics Verification (Part 2). See STS-59.

Ascent Structural Capability Evaluation. See STS-5.

Ascent Compartment Venting Evaluation. See STS-5.

Descent Compartment Venting Evaluation. See STS-5.

Entry Structural Capability Evaluation. See STS-5.

External Tank Thermal Protection System Performance. See STS-5.

Auxiliary Power Unit Shutdown Test (Sequence B). See STS-57 for description. No backdriving of power drive unit was detected.

Orbiter Drag Chute System (Test 4). See STS-47 for description.

Payload and General Support Computers Single Event Upset Monitoring (Configuration 2). See STS-46.

Cabin Temperature Survey. See STS-60.

Thermo-electric Liquid Cooling System Evaluation (without recorders). See STS-59 for description.

Global Positioning System (GPS) Development Flight Test (Configuration 1). See STS-61.

Orbiter Evaluation of Reduced Merritt Island Launch Area S-Band Uplink Power During Ascent (500W). See STS-66.

Window Impact Observation. See STS-58 for description.

STS-66

Subsonic Aerodynamics Verification (Part 2). See STS-59.

Ascent Structural Capability Evaluation. See STS-5.

Entry Structural Capability Evaluation. See STS-5.

External Tank Thermal Protection System Performance. See STS-5.

Auxiliary Power Unit Shutdown Test (Sequence A). See STS-57 for description. No backdriving of power drive unit or anomalous pressure hang-ups were detected.

Cabin Temperature Survey. See STS-60.

On-Orbit Fit Check of the Recumbent Seating System on OV-104 (Atlantis). Worked to verify ability to attach major Recumbent Seating System components to matching Orbiter interfaces on Atlantis when crew compartment was subjected to on-orbit deformations that occur during flight. Gave actual in-flight data that were needed for Mir docking missions.

Laser Range and Range Rate Device. See STS-46 for description. Used during Space Shuttle Pallet Satellite operations.

Orbiter Data for Real-Time Navigation Evaluation. See STS-51 for description.

Notch Filter. Worked to demonstrate that notch filters implemented lessened effect of structural bending on Digital Autopilot's estimate of Orbiter rotation rate, that Digital Autopilot performance was acceptable with notch filters active and, due to the importance of notch filters in Shuttle-Mir missions, gained actual flight experience working with notch filters.

Mir Approach Demonstration (Objectives 1 through 4). See STS-63.

Tools for Rendezvous and Docking (Tests 1 and 4). See STS-63.

Orbiter Evaluation of Reduced Merritt Island Launch Area S-Band Uplink Power During Ascent (200W). Evaluated effect of reducing Merritt Island Launch Area uplink power from the ground during Orbiter ascent due to a change in the amplifier that was being used because of NASA ground station maintenance cost reduction.

STS-63

Ascent Structural Capability Evaluation. See STS-5.

Ascent Compartment Venting Evaluation. See STS-5.

Descent Compartment Venting Evaluation. See STS-5.

Entry Structural Capability Evaluation. See STS-5.

Shuttle/Payload Low Frequency Environment. See STS-51B.

Auxiliary Power Unit Shutdown Test (Sequence B). See STS-57 for description. No backdriving of power drive unit or anomalous pressure hang-ups were detected.

Landing Gear Loads and Brake Stability Evaluation (Data Collection Only). Successfully collected data on landing gear system performance relative to loads, tire wear, and brake system dynamic stability. Verified performance of the carbon brake system from a dynamics stability standpoint on each flight of Discovery.

Portable In-Flight Landing Operations Trainer. See STS-58.

Extravehicular Activity Hardware for Future Schedule Extravehicular Activity Missions (14.7 prebreathe protocol), Test 9. See STS-51 for description.

Extravehicular Mobility Unit Electronic Cuff Checklist (14.7 prebreathe protocol). Successfully performed a crewed flight evaluation in orbital extravehicular activity (EVA) environment of an Electronic Cuff Checklist development unit so key design and performance requirements could be established prior to development and production of new units. Test found that further refinement was needed to tolerate cold temperatures.

Payload Bay Mounted Rendezvous Laser (Trajectory Control Sensor). See STS-51 for description. Data were collected during Mir approach, and during Shuttle Pointed Autonomous Research Tool for Astronomy deployment and retrieval.

Target of Opportunity Navigation Sensors. Worked to prove out rendezvous scenarios such as navigational merit of tracking spacecraft such as the space station with artificial light using Star Tracker, effect on navigation data when using Star Tracker to track sunlit spacecraft after its image size exceeded Star Tracker limit value, and effects on navigation data using the rendezvous radar to track spacecraft after their subtended angle became large enough to cause the radar beam to wander between multiple return locations.

Extravehicular Mobility Unit Thermal Comfort Evaluations (14.7 prebreathe protocol) Tests (1 and 2). Evaluated and demonstrated extravehicular mobility unit thermal comfort issues and potential extravehicular mobility unit thermal improvements. Thermal comfort was successfully evaluated in cold environment.

Mir Approach Demonstration (Objectives 2, 4, 5). Tested proximity operations techniques, flying a limited corridor approach and flying along positive radius vector designed to limit plume effects on Mir. All objectives were completed during Mir approach and backaway.

Tools for Rendezvous and Docking (Test 1, 3, 4). Evaluated performance of the integration of the sensors, payload and general support computers, software, and support equipment to create an efficient system that aided crew during rendezvous, proximity operations, and docking (including Remote Manipulator System activity). Tools provided the complement and configuration of tools for flight, and included the Laser Range and Range Rate Device, Trajectory Control Sensor, and the Orbiter Data for Real-Time Navigation evaluation, which were tied together through the Rendezvous Proximity Operations Program software in payload and general support computers.

Near Field Targeting and Reflective Alignment System. Performed in-flight evaluation of a calibration and measurement system, which could be used to reference a ground-controlled robot operating in Spacehab facility. Test was performed with Spacehab experiment Charlotte, and the crew reported that the activities were nominal.

Photographic and Video Survey of Mir Space Station. Successfully conducted a photographic and video survey of Russian space station Mir from shuttle to verify configuration and overall condition of Mir, inspect Mir for micrometeoroid or orbital impact debris damage, document shuttle docking approach and separation views, assess relative motion of Mir and shuttle, and analyze plume impingement.

Extravehicular Activity Operations Procedures/Training (14.7 Prebreathe Protocol). See STS-51.

Shuttle-Mir Very High Frequency Voice Link Verification. Demonstrated compatibility of the Shuttle and MIR Very High Frequency systems during proximity operations using a shuttle amateur radio experiment antenna.

STS-67

Entry Aerodynamic Control Surfaces Test - Alternate Elevon Schedule (Part 9). See STS-9 (Entry Aerodynamic Test No. 5) for description. All five programmed test inputs were performed.

Ascent Structural Capability Evaluation. See STS-5.

Entry Structural Capability Evaluation. See STS-5.

External Tank Thermal Protection System Performance. See STS-5.

Auxiliary Power Unit Shutdown Test (Sequence A). See STS-57 for description. No backdriving of power drive unit was detected.

Portable In-Flight Landing Operations Trainer. See STS-58.

Global Positioning System (GPS) Development Flight Test (Configuration 1). See STS-61.

Orbiter Evaluation of Tracking and Data Relay Satellite Acquisition in Despread Bypass Mode. Tested implementation and verified engineering test results of a proposed procedure to minimize S-band communication outage during powered flight phase due to elimination of Bermuda ground station. Window Impact Observation. See STS-58 for description.

STS-71

Ascent Structural Capability Evaluation. See STS-5.

External Tank Thermal Protection System Performance. See STS-5.

Auxiliary Power Unit Shutdown Test (Sequence B). See STS-57 for description. No backdriving of power drive unit was detected.

Payload and General Support Computers Single Event Upset Monitoring (Configuration 2). See STS-46.

Orbiter Space Vision System Flight Video Taping. See STS-69. Videotaping using Orbiter Space Vision System was successful and, due to varying Orbiter attitudes, many different lighting and shadowing conditions were observed.

Target of Opportunity Navigation Sensors. See STS-63.

Photographic and Video Survey of Mir Space Station. See STS-63.

Mated Shuttle and Mir Free Drift Experiment. Demonstrated capability to maintain a gravity gradient attitude while docked to Mir without assistance of an active control system. The mated shuttle and Mir showed good stability with minimal thruster firings.

Androgynous Peripheral Assembly System Thermal Data (Configuration 1). Collected thermal data to support expansion and correlation of Androgynous Peripheral Assembly System mathematical model, and to help eliminate mathematical uncertainties for more accurate predictions for later flights. Docking mechanism temperatures were as expected.

STS-70

Ascent Structural Capability Evaluation. See STS-5.

Ascent Compartment Venting Evaluation. See STS-5.

Descent Compartment Venting Evaluation. See STS-5.

Entry Structural Capability Evaluation. See STS-5.

External Tank Thermal Protection System Performance. See STS-5.

Orbiter/Payload Acceleration and Acoustics Environment Data. See STS-51B (Shuttle/Payload Low Frequency Environment).

Auxiliary Power Unit Shutdown Test (Sequence A). See STS-57 for description. No backdriving of rudder speedbrake power drive unit was detected.

Landing Gear Loads and Brake Stability Evaluation (Data Collection Only). See STS-63.

Payload and General Support Computers Single Event Upset Monitoring (Configuration 2). See STS-46.

STS Orbiter Attitude Control Translational Thrusting. See STS-61B.

STS-69

Ascent Structural Capability Evaluation. See STS-5.

Ascent Compartment Venting Evaluation. See STS-5.

Descent Compartment Venting Evaluation. See STS-5.

Entry Structural Capability Evaluation. See STS-5.

External Tank Thermal Protection System Performance. See STS-5.

Auxiliary Power Unit Shutdown Test (Sequence A). See STS-57 for description. No backdriving of power drive unit was detected.

Water Spray Boiler Electrical Heater Capability. Collected data on performance of Water Spray Boiler Electric Heater modifications to assure it met design specifications, and to gain data for verification and enhancement of Water Spray Boiler system capability models. No anomalous behavior was detected during flight.

Payload and General Support Computers Single Event Upset Monitoring (Configuration 2 only). See STS-46.

Portable In-Flight Landing Operations Trainer. See STS-58.

Extravehicular Activity (EVA) Hardware for Future Scheduled Extravehicular Activity (EVA) Missions, Test 10 (10.2 prebreathe protocol, 6-hour minimum duration from end of airlock depress to start of airlock repress). See STS-51.

Extravehicular Mobility Unit Electronic Cuff Checklist (10.2 prebreathe protocol). See STS-63 for description.

Ku-Band Communications Adapter Demonstration. See STS-62 for description. Ku-Band Communications Adapter performed well, and transferred large amounts of data from experiments and crew/ground messages during flight.

Global Positioning System Development Flight Test (Configuration 1 and 2). See STS-61.

Orbiter Space Vision System Flight Video Taping. Recorded camera video of targets under various on-orbit conditions to be used with Orbiter Space Vision System on the ground in a laboratory to help evaluate and characterize the system. The Remote Manipulator System provided video of the various Wake Shield Facility areas.

Manipulator Position Display as an Aid to Remote Manipulator System Operators. Performed on-orbit evaluations of Manipulator Position Display as a more efficient use of Remote Manipulator System equipment for reduced task times. Due to time constraints, not all tasks were performed.

Extravehicular Mobility Unit Thermal Comfort Evaluations (10.2 prebreathe protocol). See STS-63 for description. The crew stated that heated gloves and other extravehicular mobility unit modifications worked well.

Extravehicular Activity (EVA) Operations Procedures/Training (10.2-psia prebreathe protocol). See STS-51.

Get Away Specials:

> The Capillary Pumped Loop Experiment. See STS-60 for description. Experiment re-flight was modified to enhance the startup of its capillary system. All objectives were completed.
>
> Control Flexibility Interaction Experiment. Studied active damping control loops using a flexible plate and two piezo (pressure actuators). Data were recorded autonomously during flight.
>
> Structural Damping Evaluation of Electrorheological Fluid Filled Beams in Space. This student experiment conducted a structural damping evaluation of electrorheological fluid filled beams in space environment.
>
> Joint Damping Experiment. Studied non-linear, gravity dependent behavior of a pin-jointed truss to aid in design of future NASA missions involving precision structures. Experiment was performed during first crew sleep period when vehicle accelerations were minimal.

STS-73

Ascent Structural Capability Evaluation. See STS-5.

Entry Structural Capability Evaluation. See STS-5.

External Tank Thermal Protection System Performance. See STS-5.

Shuttle/Payload Low Frequency Environment. See STS-51B.

Auxiliary Power Unit Shutdown Test (Sequence B). See STS-57 for description. Sequence A was performed due to an early shutdown of auxiliary power unit 3, and no backdriving of power drive unit was detected.

Portable In-Flight Landing Operations Trainer. See STS-58.

Ku-Band communications Adapter Demonstration. See STS-62 for description. Many scientific files were downlinked successfully that were a valuable asset to the scientific community working on STS-73 mission.

Microgravity Measuring Device Evaluation. See STS-65.

STS-74

Ascent Structural Capability Evaluation. See STS-5.

Entry Structural Capability Evaluation. See STS-5.

External Tank Thermal Protection System Performance. See STS-5.

Orbiter Space Vision System Video Taping. See STS-69. Orbiter Space Vision System video was taken of docking module target and Mir configuration data were recorded.

Orbiter Space Vision System Flight Unit Testing. Successfully evaluated operation of Orbiter Space Vision System, an advanced and upgraded version of the then-current Space Vision System, and performance of Orbiter Space Vision System in conjunction with Orbiter closed-circuit television and crew operations on orbit.

Target of Opportunity Navigation Sensors. See STS-63.

Photographic and Video Survey of Mir Space Station. See STS-63.

Androgynous Peripheral Assembly System Thermal Data (Configuration 2). See STS-71.

STS-72

Ascent Structural Capability Evaluation. See STS-5.

Ascent Compartment Venting Evaluation. See STS-5.

Entry Structural Capability Evaluation. See STS-5.

External Tank Thermal Protection System Performance. See STS-5.

Water Spray Boiler Electrical Heater Capability. See STS-69.

Cabin Temperature Survey. See STS-60.

Extravehicular Activity (EVA) Hardware for Future Scheduled Extravehicular Activity (EVA) Missions (Test 11). See STS-51.

Extravehicular Mobility Unit Electronic Cuff Checklist. See STS-63 for description.

Global Positioning System (GPS) Development Flight Test (Configuration 1 and 2). See STS-61.

Extravehicular Mobility Unit Thermal Comfort and Extravehicular Activity Worksite Thermal Environment Evaluation (Test 3). See STS-63 for description. Evaluation of thermal effects of various suit and extravehicular mobility unity enhancements were completed.

Extravehicular Activity (EVA) Operations Procedures/Training. See STS-51.

Thermal Energy Storage-2 Experiment. Provided data for understanding long-duration behavior of thermal energy storage fluoride salts used in advanced solar dynamic power systems that use heat to produce electricity.

Get Away Special:

> The Flexible Beam Experiment. This student experiment investigated structural oscillations by exciting two cantilevered beams.

STS-75

Ascent Structural Capability Evaluation. See STS-5.

Entry Structural Capability Evaluation. See STS-5.

External Tank Thermal Protection System Performance. See STS-5.

Orbiter/Payload Acceleration and Acoustics Environment Data. See STS-51B (Shuttle/Payload Low Frequency Environment).

Portable In-Flight Landing Operations Trainer. See STS-58.

STS-76

Ascent Structural Capability Evaluation. See STS-5.

Entry Structural Capability Evaluation. See STS-5.

External Tank Thermal Protection System Performance. See STS-5.

Electronic Still Photography Test, (Configuration 2), Color Electronic Still Camera-II with downlink Payload and General Support Computers and power cable stowed in Spacehab. See STS-42 for description. Pictures were taken of the joint docked operations with Mir.

Extravehicular Activity (EVA) Hardware for Future Scheduled Extravehicular Activity (EVA) Missions (Test 12). See STS-51 for description. The common foot restraint, common safety tethers, body/equipment tethers, and thermal comfort in docked Mir environment were evaluated during an EVA that deployed Mir Environmental Effects Payload, recovered docking module camera and light, and evaluated various pieces of EVA hardware.

Orbiter Space Vision System Video Taping. See STS-69. Orbiter Space Vision System video was taken of docking module target, and Mir configuration data were recorded for model development in support of future software upgrades for Orbiter Space Vision System.

Signal Attenuation Effects of External Tank (ET) During Ascent. Calibrated and refined predicted signal attenuation due to ET obstruction/blockage for determination of communications range of Merritt Island Launch Area in the case of an abort scenario.

Photographic and Video Survey of Mir Space Station. See STS-63.

Extravehicular Activity (EVA) Operations Procedures/Training. See STS-51.

STS-77

Ascent Structural Capability Evaluation. See STS-5.

Ascent Compartment Venting Evaluation. See STS-5.

Descent Compartment Venting Evaluation. See STS-5.

Entry Structural Capability Evaluation. See STS-5.

External Tank Thermal Protection System Performance. See STS-5.

Water Spray Boiler Electrical Heater Capability. See STS-69.

Water Spray Boiler Quick Restart Capability. Determined minimum time after auxiliary power unit shutdown post ascent that auxiliary power unit controllers could be powered on without exhibiting spray cooling, and determined lag time between water spray boiler vent nozzle temperatures exceeding 50°C (122°F) and controller activation with shortened delay between auxiliary power unit shutdown and water spray boiler controller power activation. Global Positioning System Development Flight Test. See STS-61.

Global Positioning System Attitude and navigation Experiment. Collected data for Global Positioning System position as well as attitude for use on future spacecraft. All mission objectives were met as well as secondary science objectives.

Vented Tank Resupply Experiment. Tested improved methods for in-space refueling. All eight test sequences were successfully completed and they represented the first successful venting in the history of spaceflight.

Tank Pressure Control Experiment/Reduced Fill Level. Worked to provide some of the data required to develop technology for pressure control of cryogenic tankage. Experiment investigated pressure rise rates and pressure control for tanks that were approximately 40% full of oxygen.

STS-78

Ascent Structural Capability Evaluation. See STS-5.

Entry Structural Capability Evaluation. See STS-5.

External Tank Thermal Protection System Performance. See STS-5.

Shuttle/Payload Low Frequency Environment. See STS-51B.

Water Spray Boiler Quick Restart Capability. See STS-77 for description. The Water Spray Boiler demonstrated acceptable restart capabilities.

Portable In-Flight Landing Operations Trainer. See STS-58.

Vernier Reaction Control System Reboost Demonstration (Test #3 priority, Test #1 secondary). Demonstrated and examined reboost procedures, resulting jet firings, propellant usage, and jet thermal data to validate computer models and demonstrate ability to reboost the Hubble Space Telescope using only the Vernier Reaction Control System on a later mission. The Vernier Reaction Control System could perform a reboost of Hubble without damaging any of the telescope's solar arrays.

Ku-Band Communication Adapter Video Teleconference Demonstration. Tested a system upgrade of Orbiter communications adapter to allow for previously unavailable real-time computer teleconferencing and upgraded audio, video, interactive computer communication, computer file transfer, and computer application sharing. The extremely successful test included uplink of repair procedures, and numerous video conferences such as private medical, personal, family, and management demonstrations.

STS-79

Wraparound Digital Auto Pilot Flight Test Verification, Part 1. Performed a series of programmed test input flight test maneuvers during re-entry and Thermal Area Energy Management phases to verify in flight the stability and control of the Wraparound Digital Auto Pilot. The programmed test input maneuvers were successfully conducted and Wraparound Digital Auto Pilot was estimated to save 91 to 181 kg (200 to 400 pounds) of reaction control propellant over the digital autopilot being used at the time.

Ascent Structural Capability Evaluation. See STS-5.

Entry Structural Capability Evaluation. See STS-5.

External Tank Thermal Protection System Performance. See STS-5.

Trajectory Control Sensor. See STS-51 (Payload Bay Mounted Rendezvous Laser Trajectory Control Sensor) for description. Mir was tracked by trajectory control sensor during docking and undocking, but some problems were encountered during the test.

Orbiter Space Vision System Video Taping. See STS-69. Test was completed successfully.

Single String Global Positioning System (GPS). Test focused on performance and operation of GPS during Orbiter ascent, on-orbit, re-entry, and landing phases using a modified military GPS receiver processor and existing Orbiter GPS antennas.

Vernier Reaction Control System Reboost Demonstration. See STS-78 for description. The flight control systems were nominal during the test, and the crew reported the procedures were usable for a Hubble Space Telescope reboost.

Hand-Held Lidar Procedures. Tested performance of hand-held lidar docking sensor to determine if it could be used as the prime proximity operations sensor for future docking missions such as docking with Russian space station Mir and the International Space Station. The hand-held lidar operated well during rendezvous, fly-around, and separation phases of the flight.

Photographic and Video Survey of Mir Space Station. See STS-63.

STS-80

Wraparound Digital AutoPilot Flight Test Verification, Part 2. See STS-79.

External Tank Thermal Protection System Performance. See STS-5.

Portable In-Flight Landing Operations Trainer. See STS-58.

Orbiter Space Vision System Flight Video Taping. See STS-69. Various targets such as the Wake Shield Facility and Shuttle Pallet Satellite were successfully videoed during flight.

Orbiter Space Vision System Flight Unit Testing. See STS-74 for description. Test was successful and worked with Wake Shield Facility and Shuttle Pallet Satellite.

Vernier Reaction Control System Reboost Demonstration. See STS-78.

Hand-Held Lidar Procedures. See STS-79 for description. The hand-held lidar was used during operations with Russian space station Mir.

Visualization in an Experimental Water Capillary Pumped Loop. Worked to help develop a complete understanding of capillary pumped loop physics in a microgravity environment by viewing fluid flow inside evaporator.

STS-81

Wraparound Digital Auto Pilot Flight Test Verification, Part 3. See STS-79.

External Tank Thermal Protection System Performance. See STS-5.

Water Spray Boiler Quick Restart Capability. See STS-77.

Orbiter Space Vision System Flight Video Taping. See STS-69. A total of 20 data takes were recorded during flight.

Global Positioning System/Inertial Navigation System. Tested performance of a modified-for-spaceflight commercial military grade Global Positioning System/Inertial Navigation System during all shuttle flight phases that could be used for navigation on next-generation space vehicle. Obtained considerable amount of information about the system during flight, found areas that needed to be improved, and completed overall objectives.

Signal Attenuation Effects of External Tank During Ascent. See STS-76.

Single String Global Positioning System. See STS-79.

Hand-Held Lidar Procedures. See STS-79 for description. The hand-held lidar performed nominally during docking operations with Russian space station Mir.

Photographic and Video Survey of Mir Space Station. See STS-63.

STS-82

Wraparound Digital Auto Pilot Flight Test Verification (Part 4). See STS-79.

External Tank Thermal Protection System Performance (Method 4). See STS-5.

Water Spray Boiler Quick Restart Capability. See STS-77. Data from test aided in determining capability of water spray boiler to support a revolution 2 deorbit or abort-once-around.

Orbiter Evaluation of Tracking and Data Relay Satellite Acquisition In Despreader Bypass Mode. This updated version of the test worked to enhance ground controllers' performance when using despreader bypassed mode for Tracking and Data Relay Satellite acquisition. Tracking and Data Relay Satellite System acquisition was achieved in 4 seconds or less during each test.

STS-83

Wraparound Digital Auto Pilot Flight Test Verification. See STS-79.

External Tank Thermal Protection System Performance. See STS-5.

Water Spray Boiler Quick Restart Capability. See STS-77.

Portable In-Flight Landing Operations Trainer. See STS-58.

STS-84

Wraparound Digital Auto Pilot Flight Test Verification (Part 5). See STS-79.

External Tank Thermal Protection System Performance. See STS-5.

Water Spray Boiler Quick Restart Capability. See STS-77. Provided data to help determine capability of water spray boiler to support a revolution 2 deorbit and abort-once-arounds.

Orbiter Space Vision System Flight Video Taping. See STS-69. Data gained from 13 data takes were used to develop new control commands and evaluate Space Vision System procedures and techniques in support of station assembly tasks.

Global Positioning System/Inertial Navigation System. See STS-81 for description. This test was the first insight into the system's attitude reinitialization and cold-start procedures, which were needed to be operational for the system to replace Tactical Air Navigation and Inertial Measurements Unit Systems.

Single String Global Positioning System. See STS-79.

Photographic and Video Survey of Mir Space Station. See STS-63.

STS-94

Wraparound Digital Auto Pilot flight Test Verification. See STS-79. Test was considered to be a successful shuttle enhancement.

External Tank Thermal Protection System Performance. See STS-5.

Portable In-Flight Landing Operations Trainer. See STS-58.

STS-85

Wraparound Digital Auto Pilot Flight Test Verification. See STS-79.

External Tank Thermal Protection System Performance. See STS-5.

Orbiter Space Vision System Flight Video Taping. See STS-69. Conducted Space Vision System assessments from Mission Control Center during crew sleep periods, and recorded video of Orbiter separation and approach of Cryogenic Infrared Spectrometers and Telescopes for the Atmosphere-Shuttle Pallet Satellite.

Orbiter Space Vision System Flight Unit Testing. See STS-74 for description. The Orbiter Space Vision System was successfully used during International Space Station assembly simulation tasks and for payload berthing.

Single String Global Positioning System. See STS-79.

Along the Velocity Vector Proximity Operations Demonstration for International Space Station (ISS). Demonstrated piloting techniques and shuttle performance during a velocity vector approach to a small payload target using only specific nose jets. Test was successful during operations with Cryogenic Infrared Spectrometers and Telescopes for the Atmosphere-Shuttle Pallet Satellite, and obtained data for use during flights to ISS.

Remote Manipulator System Situational Awareness Displays. Tested and demonstrated the Remote Manipulator System Awareness Displays before its use during International Space Station (ISS) assembly missions. The Remote Manipulator System Awareness Displays, which were designed to determine position and attitude of payloads on ISS assembly flights, was successfully demonstrated.

Two Phase Flow Experiment. Characterized microgravity operations as well as demonstrated reliability of capillary pumped loop. Experiment operated for more than 150 hours and ran 50 different tests.

Cryogenic Flight Experiment. Tested a Joule-Thomson Cycle cryocooler designed to provide two stages of cooling. All operating principles were proven and performance requirements were demonstrated.

STS-86

External Tank Thermal Protection System Performance. See STS-5.

Extravehicular Activity (EVA) Hardware for Future Scheduled Extravehicular Activity (EVA) Missions (Test 14). See STS-51 for description. International Space Station EVA hardware such as the operational configuration of Simplified Aid for EVA Rescue, common foot restraints, and safety tethers were evaluated.

Orbiter Evaluation of Tracking and Data Relay Satellite Acquisition In Despreader Bypass Mode. See STS-82 for description. Tracking and Data Relay Satellite acquisition was achieved in about 8 seconds.

Orbiter Space Vision System Flight Video Taping. See STS-69. Videotaping was accomplished in conjunction with Photographic and Video Survey of Mir Space Station test.

Global Positioning System/Inertial Navigation System (Configuration A). See STS-81 for description. Data were obtained despite problems with the system that occurred during flight.

Signal Attenuation Effects of External Tank During Ascent. See STS-76 for description. No communication performance degradation was found.

Space Integrated Global Positioning System/Inertial Navigation System. Evaluated performance during all phases of flight of Space Integrated Global Positioning System/Inertial Navigation System, which was designed to replace shuttle's current-at-the-time Global Positioning System receiver and eventually the High Accuracy Inertial Navigation System Inertial Measurement Unit. Data were obtained during flight even though problems with the system were encountered.

S-Band Sequential Still Video Demonstration. Demonstrated capability of Shuttle S-Band System to downlink sequential still video when the Ku-Band had no coverage. The S-Band Sequential Still Video system performed well and provided excellent mission support, including allowing ground crew to see a crew-tether problem during the extravehicular activity before the Ku-Band video was available.

Photographic and Video Survey of Mir Space Station (Configuration A and B). See STS-63.

Station Docking Target Evaluation. Installed International Space Station (ISS)-designed axial docking target photometal decal on Mir to gain operational experience and enhance training techniques and aids used to simulate docking of the shuttle to the ISS.

STS-87

External Tank Thermal Protection System Performance. See STS-5.

Extravehicular Activity (EVA) Hardware for Future Scheduled Extravehicular Activity (EVA) Missions (Test 13, End-to-End Maintenance and Assembly Evaluation). See STS-51 for description. Demonstrated capability to perform International Space Station end-to-end maintenance tasks using EVA with large and small on-orbit replaceable units.

Robotics Situational Awareness Displays. See STS-85 (Remote Manipulator System Situational Awareness Displays) for description. The two displays flown were tested, and monitored by crew during appropriate tasks that were performed.

Get Away Special:

> Computer (Compact) Disc Evaluation Experiment. Investigated effects of exosphere on ability of discs to retain their information with one disc coated with a protective material and the other not coated.

STS-89

Airlock External Waterline Thermal Data. Successfully completed after undocking testing of temperature and pressure of airlock external water lines. No limits were violated during the 10 hours of attitude where Orbiter faced the sun.

Shuttle Prox-Ops with One Nose X Jet. Successfully demonstrated a final approach to Russian space station Mir using only one x-axis jet to gain actual operational experience using this technique, docking contact conditions, and development of procedures and training for future International Space Station assembly flights where this procedure was required.

Orbiter Space Vision System Flight Unit Testing. See STS-74 for description. Performance of the cameras used was nominal and consistent with previous ground checkout results.

Single String Global Positioning System. See STS-79.

Space Integration Global Positioning System/Inertial Navigation System. See STS-86 for description. The system performed better than it did during STS-86, but some errors were detected during flight.

Photographic and Video Survey of Mir Space Station. See STS-63.

STS-90

Portable In-Flight Landing Operations Trainer. See STS-58.

S-Band Sequential Still Video Demonstration. See STS-86 for description. Data were recorded in different modes during flight.

Shuttle Vibration Forces. Measured dynamic forces between the shuttle and a canister attached to shuttle sidewall during ascent. Data were collected during ascent as planned.

STS-91

Onboard Situational Awareness displays for Ascent/Entry. Tested different hardware and software displays for usability and suitability during dynamic phases of flight. Data gained were used to reduce costs and development time for upgraded cockpit displays and attempted to enhance crew situational awareness and safety margins.

Orbiter Space Vision System Flight Unit Testing. See STS-74 for description.

Single String Global Positioning System (Global Positioning System Operations Option/No Payload and General Support Computers). See STS-79.

Space Integrated Global Positioning System/Inertial Navigation System. See STS-86 for description. System performed well during flight.

Photographic and Video Survey of Mir Space Station. See STS-63.

STS-95

Orbiter Space Vision System Flight Unit Testing. See STS-74 for description. All objectives were completed with successful results as Orbiter Space Vision System operated in conjunction with Remote Manipulator System operations for the first time.

Single String Global Positioning System. See STS-79.

Space Integrated Global Positioning System/Inertial Navigation System. See STS-86 for description. System performed satisfactorily during flight, and good data were received after a cable problem was fixed.

Space-to-Space Communications Flight Demonstration. Tested replacement for the at-the-time current extravehicular activity (EVA) frequency bands due to a request by the Department of Defense. Direct communications between EVA crew members and spacecraft was demonstrated using the new communication bands.

Automatic Targeting and Reflective Alignment Concept Computer Vision System. Successfully demonstrated a new video and vision system that was designed to support mission tasks such as element-to-element assembly and berthing operations using shuttle or International Space Station (ISS) Remote Manipulator System. This new system was implemented as the Wireless Video System on shuttle and ISS.

International Space Station (ISS)/Space Shuttle – Test of Color Printer. Tested a color printer in zero gravity to be used to support operations on shuttle and ISS. Printer performed well during flight, and was able to print files remotely and handle large-scale print jobs.

Cryogenic Thermal Storage Unit Flight Experiment. Demonstrated functionality of spacecraft thermal control devices called the 60K thermal storage unit, the cryogenic capillary pumped loop, the cryogenic thermal switch, and the phase change upper end plate. Experiment achieved more than 200% of minimum mission objectives, and over 100% of nominal mission science objectives.

Hubble Space Telescope Orbital Systems Test. Demonstrated that electronic and thermodynamic equipment slated for installation on the Hubble Space Telescope worked in radiation and microgravity environment. A total of 100% of planned mission duration at 28.45-degree inclination and 556-km (300-nmi) altitude was accomplished.

Get Away Special:

> The Capillary Pumped Loop Experiment. See STS-60 for description. This modified re-flight of the experiment flown on STS-60 operated during flight.

STS-88

Structural Dynamics Model Validation. Worked to validate uncertainty with structural dynamics models when shuttle and International Space Station were docked on orbit. Data were obtained to acquire critical natural frequency data and corresponding structural damping, and results were within range of preflight predictions.

Miniature Air-To-Ground Receiver-Global Positioning System. See STS-79 (Single String Global Positioning System).

Solid State Star Tracker Size Limitation. Test characterized performance of Solid State Star Tracker with a large and bright target—the International Space Station.

STS-96

International Space Station (ISS) On-Orbit Loads Validation (hardware prepositioning tasks only). Installed equipment on ISS for future testing of ISS loads.

Heat Exchange Unit Evaluation. Evaluated effectiveness of a commercial portable heat exchange unit that used water as the refrigerant in microgravity. The unit successfully chilled the package of gelatin used for the test.

Single String Miniature Air-to-Ground Receiver Global Positioning System. See STS-79 (Single String Global Positioning System).

Space Integration Global Positioning System/Inertial Navigation System. See STS-86 for description. System performed satisfactorily during flight and navigated with four satellites during both ascent and re-entry.

Solid State Star Tracker Size Limitation. See STS-88.

Resource Transfer Line Capability Evaluation. Successfully tested installation and operation of resource transfer capability prior to its first required use with shuttle and International Space Station.

International Space Station/Space Shuttle - Test of Color Printer. See STS-95 for description. Printer performed nominally during flight.

Shuttle Vibration Forces. See STS-90.

STS-93

Shuttle Radar Topography Mission Fly Case Maneuver. Tested a technique to be used on a future mission that was designed to minimize structural loading of the 60-m (197-ft) extendible boom antenna. Required sequence of Orbiter thruster firings was performed and no anomalies were detected.

Digital video Camcorder Demonstration. Successfully tested and demonstrated new digital camcorder technology on orbit to determine eventual replacement for the then-obsolete camcorders being used.

Light Weight Flexible Solar Array Hinge Experiment. Demonstrated deployment capability of a number of hinge configurations used for purposes such as the primary mechanism used to deploy spacecraft solar arrays. All six hinges were deployed during the course of the mission with planned mission objectives being accomplished for a 100% success rate.

STS-103

Single String Global Positioning System (Payload Ground Support Computer Option) Miniature Air-To-Ground Receiver. See STS-79 for description (Single String Global Positioning System).

Space Integration Global Positioning System/Inertial Navigation System - Configuration B. See STS-86 for description. Data were obtained despite problems that occurred during flight.

STS-99

Heat Exchange Unit Evaluation. See STS-96.

Single String Global Positioning System. See STS-79.

STS-101

Single String Global Positioning System. See STS-79.

STS-106

United Space Alliance Simplified Aid for Extravehicular Activity Rescue Flight Demonstration. See STS-92.

Single String Global Positioning System. See STS-79.

STS-92

United Space Alliance (USA) Simplified Aid for Extravehicular Activity (EVA) Rescue Flight (SAFER) Demonstration. Performed an end-to-end on-orbit functional checkout of redesigned USA SAFER system. Both crew members tested the system, and both units performed nominally.

Single String Global Positioning System. See STS-79.

STS-97

Structural Dynamics Model Validation. See STS-88 for description. All operations were completed and data obtained from this test were compared with preflight predictions and were used to tune the system.

International Space Station (ISS) On-Orbit Loads Validation. Tested and measured structural dynamics of ISS to validate on-orbit load prediction models, and to reduce uncertainty in an effort to make ISS on-orbit operations safer and more efficient. Tests were completed using photogrammetry and Laser Dynamic Range Imager.

Single String Global Positioning System. See STS-79.

STS-98

International Space Station On-Orbit Loads Validation. See STS-97 for description. Data were obtained, and the instrumentation measuring load data performed well.

Shuttle Automatic Reboost Tuning. Obtained joined shuttle/International Space Station (ISS) structural dynamics data to assist with shuttle reboosts of ISS. Quality data were obtained during the test.

Incapacitated Extravehicular Activity (EVA) Crewmember Translation. Successfully tested techniques designed to allow an incapacitated EVA crew member to be returned to shuttle airlock by another EVA crew member.

Single String Global Positioning System. See STS-79.

STS-102

Structural Dynamics Model Validation. See STS-88 for description. Test performed well and data obtained from this test and shuttle automatic reboost tuning allowed for authorization for shuttle primary thruster use for attitude control and reboost maneuvers when required.

Shuttle Automatic Reboost Tuning. See STS-98 for description. International Space Station (ISS) On-Orbit Loads Validation. See STS-97 for description. Obtained photogrammetry data of US port solar area during reboost of ISS and used data from structural dynamics model validation test.

Single String Global Positioning System. See STS-79.

Crosswind Landing Performance. See STS-30.

STS-100

International Space Station (ISS) On-Orbit Loads Validation. See STS-97 for description. Photogrammetry data were collected by Orbiter's payload cameras during an ISS reboost maneuver.

Single String Global Positioning System. See STS-79.

Crew Return Vehicle Space Integrated Global Positioning. Demonstrated Crew Return Vehicle Space Integrated Global Positioning during on-orbit and re-entry operations. Crew Return Vehicle Space Integrated Global Positioning performed nominally.

STS-104

International Space Station On-Orbit Loads Validation. See STS-97 for description. The Orbiter Reaction Control System thruster firings associated with the test were completed, and data indicated that results are similar to those obtained on STS-102.

Single String Global Positioning System. See STS-79.

On Orbit Bicycle Ergometer Loads Measurement. Studied possibility of reducing the engineering conservatism by measuring the joined shuttle/International Space Station (ISS) natural frequencies, using the bicycle ergometer as the natural frequency excitation source. Experiment was successfully performed, but ISS data system data recovery was not successful during the test.

STS-105

Single String Global Positioning System. See STS-79.

Space Vision Laser Camera System. Demonstrated Space Vision System Laser Sensor's capability to enhance target tracking capability of system, thereby expanding its operational envelope and improving robustness. The Space Vision Laser Camera System was able to make a high-resolution scan of International Space Station, and was able to track targets on Multi-Purpose Logistics Module.

STS-108

Single String Global Positioning System. See STS-79.

Crew Return Vehicle Space Integrated Global Positioning. See STS-100 for description. All objectives were completed.

On Orbit Bicycle Ergometer Loads Measurement. See STS-104 for description. Test was successfully performed, and International Space Station microgravity data system was active during the test and acquired several high-quality data streams.

STS-109

Single String Global Positioning System. See STS-79.

STS-110

Shuttle Automatic Reboost Tuning. See STS-98. Single String Global Positioning System without Payload and General Support Computer. See STS-79.

STS-111

Single String Global Positioning System. See STS-79.

STS-112

Space Station Remote Manipulator System Dynamics Validation During Shuttle and International Space Station (ISS) Mated Flight. Tested dynamics and load response of Space Station Remote Manipulator System while ISS was mated with shuttle. Worked to assure stable shuttle control system performance and acceptable loads on Space Station Remote Manipulator System induced by shuttle jet firings.

Single String Global Positioning System. See STS-79.

Crosswind Landing Performance. See STS-30.

STS-114

Tile Board Survey (Orbiter Thermal Protection System Tile and Reinforced Carbon-Carbon Panel Repair Techniques). Completed testing, on orbit, of technologies developed for Orbiter tile repair.

Water Spray Boiler Hot Restart. Successfully demonstrated a new antifreeze agent used to remove freezing conditions for a hot restart of water spray boiler following auxiliary power unit shutdown. This test helped demonstrate capability of shuttle to perform an early return from orbit if needed.

STS-121

Modular Auxiliary Data System Pulse Code Modulation Unit to Solid State Recorder Telemetry Downlink. Demonstrated Modular Auxiliary Data System Pulse Code Modulation Unit hardware's ability to use a new solid state recorder to provide telemetry data during ascent and re-entry, and the ability to downlink that data.

Thermal Protection System Repair Techniques. See STS-114 (Tile Board Survey) for description. All activities were completed.

Orbiter Boom Sensor System/Shuttle Remote Manipulator System Loads Characterization with extravehicular activity (EVA) crew member. Completed testing of loads and boom motion/deflection on Orbiter Boom Sensor System/Shuttle Remote Manipulator System when an EVA crew member was attached for emergency Thermal Protection System inspection and repair.

Extravehicular Activity (EVA) Infrared Camera. Successfully demonstrated the EVA infrared camera's ability to use infrared thermography to inspect shuttle wing leading edge and reinforced carbon-carbon system on orbit during an EVA. The EVA infrared camera performed well during mission's third EVA.

Remote Manipulator System On-Orbit Loads – Heavy Payloads. Tested capability and characterized Shuttle Remote Manipulator System when non-typical loads were induced, which included a stable extravehicular activity worksite for emergency Thermal Protection System inspection and repair.

Water Spray Boiler Cooling with Water/Propylene Glycol Monomethyl Ether Antifreeze. See STS-114 for description (Water Spray Boiler Hot Restart).

STS-115

Extravehicular Activity (EVA) Infrared Camera. See STS-121 for description. All objectives were completed, and camera and inspection procedure capabilities were effectively demonstrated.

STS-123

Tile Repair Ablative Dispenser. See STS-114 (Tile Board Survey) for description. All ten tile samples were filled using tile repair ablative dispenser .

STS-126

Shuttle Reusable Solid Rocket Booster Chamber Pressure, Strain Gauge, and Acceleration Rates Data Collection. Collected additional higher-fidelity data on shuttle reusable Solid Rocket Booster use prior to end of Space Shuttle Program for use in future initiatives.

STS-119

Boundary Layer Transition Flight Experiment. Collected flight data on effects of boundary layer transition and catalytic material on the spacecraft during re-entry. Special tile equipment installed under Orbiter performed well, and data obtained will benefit hypersonic aerothermal dynamics as well as understanding of the boundary layer transition and catalytic materials.

Shuttle Reusable Solid Rocket Motor Chamber Pressure, Strain Gauge, and Acceleration Rates Data Collection. See STS-126.

STS-125

Shuttle Reusable Solid Rocket Motor Chamber Pressure, Strain Gauge, and Acceleration Rates Data Collection. See STS-126.

STS-127

DragonEye Flash Light Intensification Detection and Ranging. Tested Advanced Scientific Concepts "DragonEye" flash Light Intensification Detection and Ranging relative navigation sensor system while in proximity to International Space Station (ISS). Test reduced uncertainty regarding sensor's performance in space, and provided reference data of ISS as imaged by the sensor.

Shuttle Reusable Solid Rocket Motor Chamber Pressure, Strain Gauge, and Acceleration Rates Data Collection. See STS-126.

STS-128

TriDAR Automated Rendezvous and Docking Sensor. Demonstrated tracking capabilities and worked to mitigate risks for use of TriDAR during rendezvous and docking operations. The TriDAR system tested in proximity to International Space Station helped gain valuable information for tracking sensor technology that can be used in future space exploration vehicles.

Boundary Layer Transition Flight Experiment. See STS-119.

Shuttle Reusable Solid Rocket Motor Chamber Pressure, Strain Gauge, and Acceleration Rates Data Collection. See STS-126.

STS-129

Shuttle Reusable Solid Rocket Motor Chamber Pressure, Strain Gauge, and Acceleration Rates Data Collection. See STS-126.

STS-130

Shuttle Reusable Solid Rocket Motor Chamber Pressure, Strain Gauge, and Acceleration Rates Data Collection. See STS-126.

STS-131

TriDAR Automated Rendezvous and Docking Sensor. See STS-128.

Boundary Layer Transition Flight Experiment. See STS-119.

Shuttle Reusable Solid Rocket Motor Chamber Pressure, Strain Gauge, and Acceleration Rates Data Collection. See STS-126.

STS-132

Shuttle Reusable Solid Rocket Motor Chamber Pressure, Strain Gauge, and Acceleration Rates Data Collection. See STS-126.

STS-133

Boundary Layer Transition Flight Experiment. See STS-119 for description. Re-entry and temperature data were collected, protuberance and catalytic coating tiles survived the flight with minor glazing on protuberance tile surface, and all flight temperatures were below those predicted.

Shuttle Reusable Solid Rocket Motor Chamber Pressure, Strain Gauge, and Acceleration Rates Data Collection. See STS-126 for description. All accelerometers and strain gauges worked properly and received data. Data from left and right motors were well matched and all data were nominal compared to flight family.

DTO 701B Dragon Eye Flash LIDAR- See STS-127 for description. Second flight of the navigation sensor to be used on SpaceX’s Dragon vehicle for International Space Station approach called “DragonEye” incorporated several design and software improvements from previous experiment. Data received were valid, and were sent to sponsors for analysis.

STS-134

Astronaut Personal Eye. Worked to demonstrate development of an autonomous microvehicle to be used to support both space station intravehicular activities and extravehicular activities in the future. Test only investigated roll axis and was conducted on Flight Day 5 and Flight Day 13.

Sensor Test for Orion Relative Navigation Risk Mitigation (STORRM). Designed to demonstrate capability of relative sensors, Vision Navigation Sensor flash lidar and high-definition docking camera, developed for automated rendezvous and docking of Orion or other spacecraft. Performance was nominal with Vision Navigation System acquisition near the 5.7-km (3.5-mile) maximum capability, and the docking camera recorded excellent images of Earth, International Space Station, and stars from about 60 km (37 miles) through docking.

Boundary Layer Transition Flight Experiment. See STS-119.

Shuttle Reusable Solid Rocket Motor Chamber Pressure, Strain Gauge, and Acceleration Rates Data Collection. See STS-126 for description. Pressure data were recorded by hardware on top of Solid Rocket Motors inside forward skirt.

STS-135

The Forward Osmosis Bag. Tested Forward Osmosis Bag systemdesigned to convert dirty water into a liquid that is safe to drink using a semi-permeable membrane and a concentrated sugar solution. Possible applications for system include use for recycling waste water in long-exposure extravehicular activity suits. Experiment was to be analyzed post-flight.

TriDAR Automated Rendezvous and Docking Sensor. See STS-128 for description. The continuing demonstration of core real-time 3-D tracking technology and demonstration of new functionality such as the real-time tracking from 2-D thermal data and demonstration of advanced user interfaces were performed. TriDAR was operated during rendezvous and undocking, and was reported to have operated flawlessly during undocking and fly-around.

4.0 ACKNOWLEDGMENTS

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13. ABSTRACT *(Maximum 200 words)*
This document was compiled to provide selected highlights of the science and engineering payloads, experiments, engineering and scientific tests, and other technical activities that were carried out during the Space Shuttle era. It is very important to note that this TM highlights selected payloads and experiments to offer glimpses into the intensive scientific and engineering initiatives throughout the Space Shuttle Program. While this document is quite detailed and highly informative, it is neither comprehensive nor encyclopedic. The intention is to give readers an overview of the shuttle science and engineering payloads. In addition, selected personal observations were provided by a handful of astronauts. The data on the Space Shuttle flights highlighted in this document are in chronological order by date(s) of the mission. The summaries are high-level descriptions of the experiments/engineering tests, etc.

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