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Conceptual Design Study: Forest Fire Advanced System Technology (FFAST)

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16. Abstract

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ABSTRACT

The National Aeronautics and Space Administration's Jet Propulsion Laboratory and the United States Department of Agriculture Forest Service completed a conceptual design study that defined an integrated forest fire detection and mapping system that will be based upon technology available in the 1990s. Uncertainties in emerging and advanced technologies related to the conceptual design were identified and recommended for inclusion as preferred system components. System component technologies identified for an end-to-end system include thermal infrared, linear-array detectors, automatic georeferencing and signal processing, geosynchronous satellite communication links, and advanced data integration and display. Potential system configuration options were developed and examined for possible inclusion in the preferred system configuration. The preferred system configuration will provide increased performance and be cost effective over the system currently in use. Forest fire management user requirements and the system component emerging technologies were the basis for the system configuration design. The conceptual design study defined the preferred system configuration that warrants continued refinement and development, examined economic aspects of the current and preferred system, and provided preliminary cost estimates for follow-on system prototype development.

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SECTION 1

INTRODUCTION

In the spring of 1982, a feasibility study to examine the application of advanced technology to forest fire detection and mapping was initiated jointly with the United States Department of Agriculture (USDA) Forest Service and the Jet Propulsion Laboratory (JPL). The start of the project was the result of past efforts that JPL and the Forest Service had entered into on the Fire Logistics And Mapping Equipment (FLAME) project. The objective of the FLAME project was to bring the electronics within the existing Forest Service scanners up to date. This was necessary because the line scanners were early 1960s vintage and the increasing down time due to maintenance difficulties and scarcity of adequate replacement parts hampered full utilization.

While the improvements to the infrared (IR) line-scanning capability were dramatic and sorely needed, it was thought that an advanced system could be developed to further improve upon the current thermal infrared information system. The first step was a feasibility study carried out over a six-month period in 1983. The goal of the feasibility study was to determine the need for an improved fire detection and mapping system and the user needs in data requirements and operations. User needs were gathered by visiting the Regional Aviation and Fire Directors for the Forest Service. Since resources in fire mapping and detection are sometimes shared between the United States and Canada, several fire management personnel in the various Canadian resource agencies were also visited. The feasibility study presented and discussed a strawman system configuration that combined technology and user needs (Figure 1-1). The feasibility study recommended and outlined the implementation of the next phase for the project, a two-year, conceptual design phase to define a system that justified continued development.

This document reports the results of the conceptual design study to evaluate the application of JPL technology to forest fire detection and mapping.

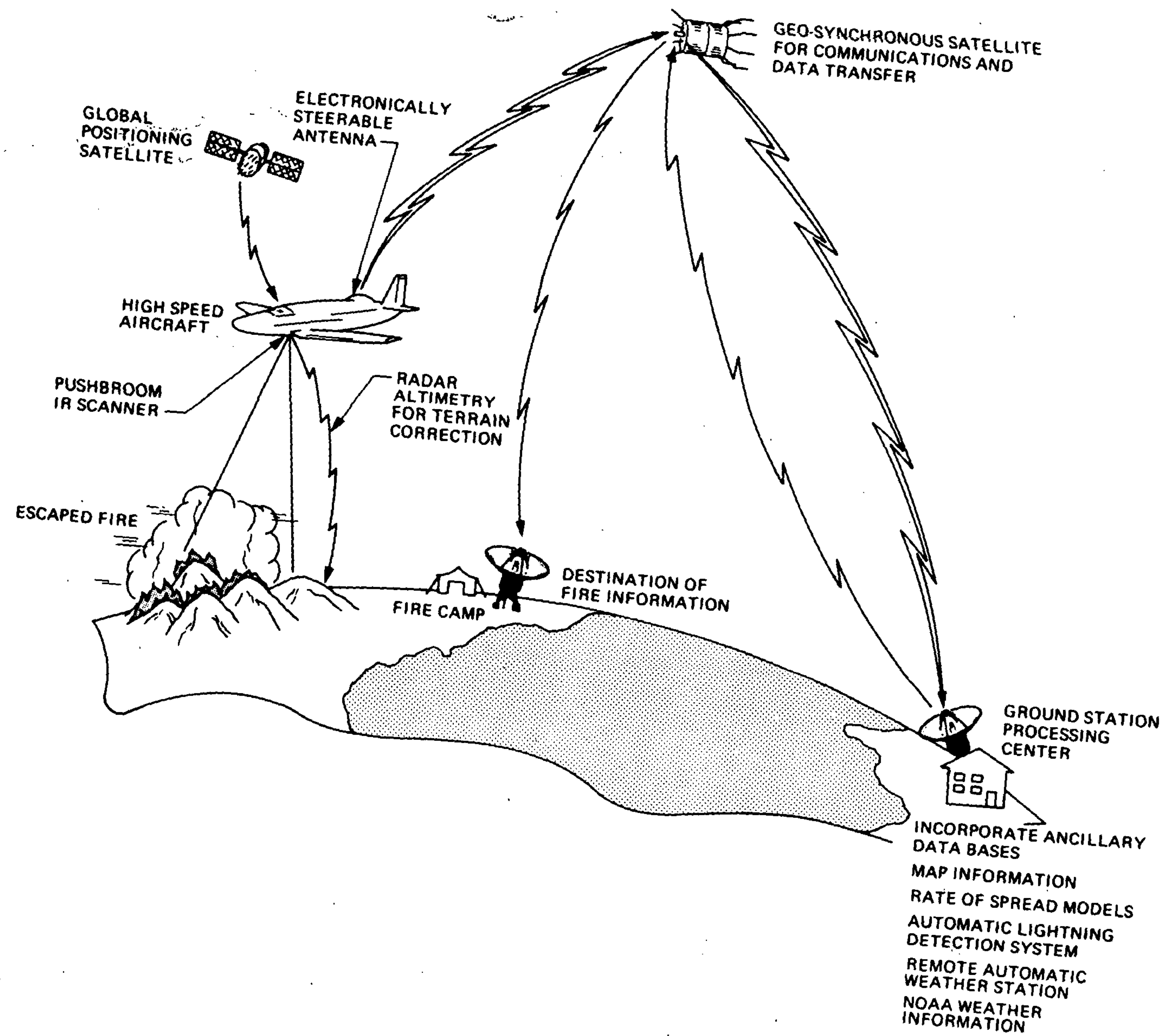


Figure 1-1. FFAST Strawman System Configuration

1.1 BACKGROUND

Thermal infrared sensing for forest fire detection and mapping has been under development by the USDA-Forest Service since the FIRESCAN Research Project began in 1962 (Hirsch, 1968). The original Forest Service airborne, infrared, line-scanning systems were based on research conducted during the FIRESCAN Project. The original systems were stand-alone IR systems designed to produce hard-copy images, onboard the aircraft, of the thermal characteristics of the terrain and fire. Timely delivery of fire imagery to a fire camp was a problem as the imagery was delivered either via drop tubes, conditions permitting, or hand delivered via ground transportation from the nearest airport.

The original scanner units became obsolete due to improvements in technology and the increasing difficulty in maintaining the units for operational readiness. Replacement parts for the scanner units were difficult to find and in some cases had to be custom built.

The FLAME project, a joint effort between the USDA-Forest Service and JPL, was charged with designing, developing, and implementing a modern, airborne, IR detection system with improved performance and flexibility over the original systems (Enmark, 1984). As a result of the FLAME project, the USDA-Forest Service Texas Instruments RS-7 scanner was replaced with a system providing increased spatial resolution, incorporation of human engineering, and real-time video display and storage. New detectors were installed to improve response time and data capture. All cabling was replaced and the controllers for the scanning unit were redesigned so that operator intervention was made easier. A new film recorder was integrated into the system as was a video frame buffer. A video monitor was supplied for real-time display of the data.

In use today by the USDA-Forest Service are two airborne thermal IR surveillance and mapping systems, the JPL line scanner (FLAME) mounted in a Beechcraft King Air, and a modified Texas Instruments RS-25 scanner mounted in a Sweringen Merlin aircraft. The two systems are the only ones in the world designed specifically for fire detection and mapping. The two systems are based at the Boise Interagency Fire Center (BIFC) in Boise, Idaho and are available for use on a nationwide basis to government agencies that request fire mapping and detection missions. Participating government agencies that use the systems include the United States Department of the Interior (USDI), Bureau of Land Management (BLM), Bureau of Indian Affairs (BIA), National Park Service (NPS), and natural resource agencies in Canada.

The airborne sensor systems in use today for forest fire mapping missions are rotating-mirror, thermal infrared line scanners that use dual-element detectors in the 3-5 and 8-12 micrometer bands. The field of view is rapidly swept across the flight line in a direction perpendicular to the aircraft's axis. The sensors are relatively large and heavy, and require large amounts of power.

1.2 FUNDING

Funding for the conceptual design study was the result of a joint effort by the NASA Technology Utilization and Industrial Affairs Division at NASA Headquarters in Washington, D.C. (NASA, 1982), and the USDA Forest Service Aviation and Fire Management, Washington Office.

The conceptual design phase was conducted during Fiscal Years (FY) 84 and 85 (see Table 1-1). The cost of the conceptual design phase was $150,000 per year for each of the two years. The USDA Forest Service Aviation and Fire Management, and NASA Technology Utilization and Industrial Affairs divided the costs equally in each of the two years.

1.3 OBJECTIVE

The objectives of the conceptual design phase were to examine in detail user requirements for tactical information on forest fire activity,

Table 1-1. Approximate Cost Contributions

Agency	Feasibility Study FY 83	Conceptual Design FY 84	Conceptual Design FY 85	Transition Year FY 86	Detailed Design FY 87-89
NASA[1]	$47 K	$75 K	$75 K	$50 K	10%[2]
USDA-FS[3]	$30 K[4]	$75 K	$75 K	$50 K	90%[2]

[1]Technology Utilization and Industry Affairs Division.

[2]Suggested percentage contribution to total cost.

[3]United States Department of Agriculture, Forest Service.

[4]Cost incurred as a function of facility use and manpower.

document functional requirements for a completed system, examine technology that will be available for application to the project objectives, and prepare a preferred system configuration. The results of the conceptual design will be applied to forest fire mapping and detection to be used by the USDA-Forest Service and cooperating agencies in the 1990s. To accomplish the objectives, uncertainties in emerging and advanced technologies related to the conceptual design were identified. Operational capabilities and characteristics as well as functional requirements were determined. Preliminary budgetary costs and schedule estimates for the planning of the detailed design and build of the complete system were developed.

1.4 APPROACH

The conceptual design was developed for an end-to-end system. Analysis of component and subsystem technologies and function were performed, including tradeoff studies and projection of technology availability. Areas of risk were identified and alternative approaches discussed. A proposed approach, task definition, schedule, and preliminary cost estimate were prepared to define the required follow-on development effort. Should the conceptual design effort lead to a detailed design and fabrication of a prototype system, it is envisioned that private industry would participate as subcontractors for supplying components making up various parts of the total system. Industry would contribute the specialized expertise that results from privately funded research and development activities. Such expertise may pertain to production processes, communication problems, and computer hardware. Early involvement of industry will facilitate the industry role in fabricating the required number of systems to meet the demand.

1.5 FFAST SYSTEM CONCEPTUAL DESIGN

The initial phases of the conceptual design effort involved reestablishing contacts with the Forest Service Regional Aviation and Fire Management Directors so that new ideas could be incorporated into the design. Gathering new ideas and user needs provided the basis for the development of the functional requirements of the system. Concurrent with the functional requirements generation, a technology assessment (see Section 4.4 and Appendix A) was performed to ascertain to what degree appropriate technology will have matured by the 1990s. A performance measure for each technology is defined and incorporated into the performance requirements for the system.

Additionally, the value analysis and tradeoff evaluation process procedures (Sections 4.2 and 4.3 respectively) were followed in order to maintain the appropriate technology level for the system and to ensure that the most economic means of design and implementation is pursued. The result was the identification of FFAST system functions that will fulfill the system functional requirements. Alternative FFAST system configurations were then developed to form the basis of the preferred system configuration. Finally, preliminary operational system capability costs and schedule estimates were developed for a prototype preferred system configuration.

SECTION 2

SYSTEM DESIGN APPROACH, DESIGN DRIVERS, AND FUNCTIONAL REQUIREMENTS

2.1 DESIGN APPROACH

There are five basic considerations behind the design philosophy of the system. The first consideration is that the new system will have improved timeliness over the current system. The new system will produce the end product within thirty minutes of the actual data collection. The second consideration is the improved accuracy the system will have over the existing system. The third consideration is the modularity of design to facilitate service, reliability, maintainability, possible upgrading, and long life of the system. The fourth consideration is the ease with which the system can be used. Extensive operator training should not be required. A user manual should only be necessary during initial training and to refresh the operator of the full capabilities of the system after a period of no usage. The fifth consideration is the use of commercially available components when possible.

2.2 DESIGN DRIVERS

User needs are the driving impetus for the conceptual design functional requirements. The user needs have been identified and derived from numerous meetings with fire management and user personnel. Prime sources have been the regional Aviation and Fire Management Directors and their staffs. User needs for information are stated in terms necessary for fire management and suppression activities. The user needs include the following:

1. Timely delivery of the fire perimeter and hot spot locations already georeferenced and transposed to the maps which are being used for fire management activities. Timely is defined as within one-half hour after the IR mapping flights. This item includes both mapping and detection needs.

2. Indications of relative fire intensity.

3. Accurate location information with accuracy-needs estimates ranging from a few feet to a few hundred feet depending upon conditions, such as weather, stage of fire, values at risk, resources available, time of day, crew positions, terrain, fuel, and fire control status.

4. Compatibility and capability to interface with a variety of data bases and computer models, available or planned.

5. Communications capability (voice and data) from ICP to anywhere in the country via satellite link into the nationwide telephone system. The number of channels or lines varies widely depending upon the fire size, stage, conditions, etc.

6. Potential for the system to be used for nonfire activities such as insect and disease surveillance, smoke monitoring, air quality, and other incident types.

7. Improved display methods for showing relationships, potential interactions, optional plans, land ownership, values at risk, etc., implying interactive video graphics, value-added processing, and data communications.

8. The application of fire location information during wildfires to validate and provide feedback to fire spread predictions and models.

9. Detection flights over selected areas during high fire danger periods or following lightning strikes detected by the Automatic Lightning Detection System (ALDS). The ALDS accuracy in predicting numbers of fires started and locations could be verified and upgraded by IR detection flights, and the combined, coordinated use of ALDS, IR and Remote Automated Weather Station (RAWS) data could greatly reduce the number of escaped lightning fires each year.

10. Potential use of system components such as laser terrain profiling for improving aircraft safety during low level operations.

11. More dependable availability of systems (users have perceived that existing systems are not always available when needed).

In order to support the conceptual system design effort, a set of functional requirements for the FFAST system was developed based upon the identified user needs, additional meetings with USDA-Forest Service personnel, and technical judgment. The functional requirements identify basic functions that are necessary to satisfy the user needs for more effectively providing information on fire activity. The functional requirements address how the system must collect, process, display, and disseminate data. The functional requirements will be used to initiate preparation of design specifications. The following subsections summarize the functional requirements.

2.3 SYSTEM FUNCTIONAL REQUIREMENTS

The system functional requirements identify the functions necessary to satisfy user needs for an improved fire detection and mapping system. The FFAST functional requirements (Dutzi, 1984) fall into two categories: (1) basic requirements, including accurate acquisition and timely georeferencing and delivery of thermal IR imagery, improved voice and data communications, improved image processing, reduction and display, and compatibility with other systems, and (2) desired attributes that may not be as clearly defined as functional requirements, including integration of distributed data bases, modeling capability, and applications of the system to other forest management areas.

The FFAST Feasibility Study (McLeod, 1983) addressed the information and communications needs of the user community for forest fire suppression and management. The users of FFAST data were defined as personnel directly involved in decision making for fire management and suppression activities. Most of the users are located at the Incident Command Post (ICP), the end destination of fire information to be generated and delivered by the

FFAST system. Some users may be located at various other USDA-Forest Service offices. Typical users include Incident Commanders and their staffs, and line personnel who are responsible for formulating tactical fire suppression plans, making decisions on deployment of fire-fighting resources, and carrying out the plans through the mop-up phase.

2.3.1 Sensors

Gathering information on fire activity has historically been accomplished in the thermal infrared portion of the spectrum due to the relatively proven technology available. The functional requirements for the data collection activity are based upon requirements for the sensors. The sensors will be multilinear or area detector arrays using dual or multiple band detectors, operating in the thermal infrared wavelength bands of 3-5 micrometers and 8-12 micrometers, and possibly other parts of the spectrum. The thermal sensors will have a minimum spatial resolution of one milliradian. The sensor will represent and relate terrain features and fire temperatures such that fires can be clearly identified. Fires will include any hot areas from 200° to 600° Celsius with temperature beyond 600° being represented at full scale. A nonlinear scale or separate scales for terrain and fire may be used. The total (cross track) field of view will be 110 degrees, with plus or minus 10 degrees added for roll. The detectors will be cooled, if required, to a minimum operating temperature of 77° Kelvin, via liquid nitrogen, thermoelectric, or refrigeration means.

The sensors will convert the detected energy into digital signals. The sensors will provide a minimum of eight-bit (256 level) output per pixel with each pixel representing a unique uniform rectangular area on the ground. At least 2000 pixels cross track for the aircraft will be acquired, processed, and stored for immediate or future processing.

The sensors and related instruments will be capable of meeting all performance requirements under environmental conditions experienced with normal aircraft operating procedures during takeoff, flight, landing, and storage. Finally the FFAST sensors will be compatible with existing and planned USDA-Forest Service aircraft.

2.3.2 Data Processing

The data-processing system hardware and software for meeting FFAST minimum functional requirements for imagery enchancement, reduction, and georeferencing will be capable of processing and delivering data to the ICP within 30 minutes of the thermal IR mission regardless of whether the system is located onboard the aircraft or in a ground-based facility.

The data-processing system will be capable of incorporating potential enhancements in integration of distributed data bases, mapping capability, and modeling capability (existing or planned) within the USDA-Forest Service (e.g., FLIPS, GEOLOC, ARC-INFO). The system will also be capable of digitizing, reducing, and storing the thermal IR output of the thermal IR sensors.

The georeferencing subsystem will be capable of adjusting the thermal IR imagery output to geographic coordinates corrected for latitude and longitude. The georeferencing subsystem will automatically locate common control points between the thermal infrared imagery and a geographic grid. Automatically registered to a geographic base, it will have a positional accuracy of 10-50 meters on the ground. The relative size of line widths on USGS Topographical Maps to meet this final georeferencing subsystem requirement is illustrated in Figure 2-1.

2.3.3 Communications

Voice and data transfer, at least 2400 baud, will be provided between any combination of aircraft, ICP, and any ground facility interfacing with the public switched telephone network. Communications equipment for the FFAST system shall be compatible with existing and planned communications systems and equipment of the USDA-Forest Service and associated user agencies. The terminals and antennas for long-range ICP communications will be lightweight, easily transportable, rugged, and easily maintainable. The voice and data communications equipment will operate under the environmental conditions encountered at the working facility where used.

	1:24,000	1:62,500	1:125,000
1/4" :	500'	1,301'	2,604'
1/8" :	250'	651'	1,308'
1/16":	125'	326'	651'
1/32":	63'	163'	326'
1/64":	31'	81'	103'

Figure 2-1. Relative Size: Line Widths on Topo Maps

Data transfer will occur between the sensor-carrying platforms to the ground facility or receiving station. The data will also be transferred from the sensor-carrying platforms to the ICP. The georeferenced and rectified thermal IR data shall be delivered to the ICP from the data-processing system within a maximum of thirty minutes after the completion of the detection or mapping mission.

Two-way voice communications capability (duplex or half-duplex) will occur between the sensor platform, the ground facility, the ICP, the cognizant USDA-Forest Service regional headquarters, and the Boise Interagency Fire Center.

2.3.4 Data Display

The data will be displayed as a hard copy in map-like format, georeferenced and rectified. The system will be capable of producing multiple copies of a map product on USGS topographic sheets at variable scales.

2.3.5 Functional Requirements Summary

The functional requirements provide a framework for the conceptual design effort. The Baseline Design Description (Section 3) will use the functional requirements as a foundation from which to develop components that will fulfill the objectives of the FFAST project.

SECTION 3

BASELINE DESIGN DESCRIPTION

The conceptual design of the FFAST project has focused upon technology that will be available and sufficiently mature by the 1990s to aid users in fire detection and mapping. This section will develop how the FFAST system will function by examining the FFAST system components that will meet the functional requirements objectives.

3.1 COLLECTION OF FIRE DATA

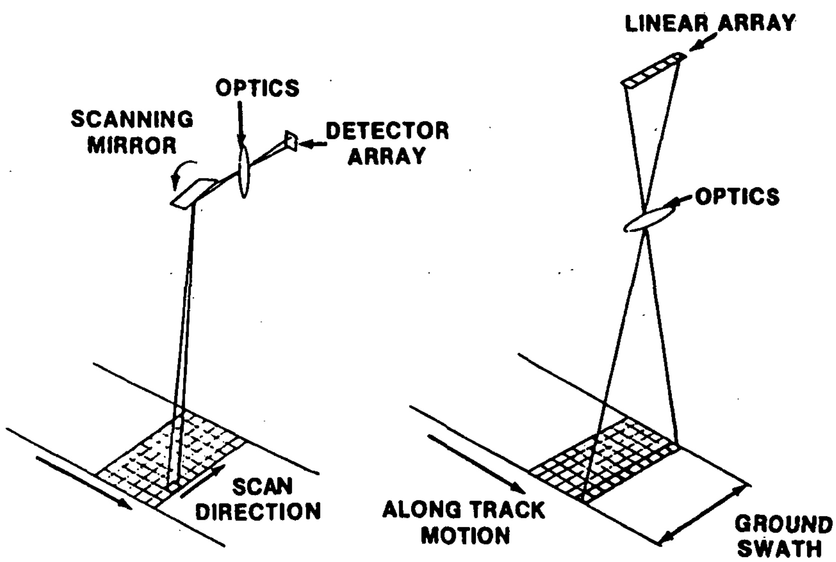
The gathering of information on fire activity has historically been accomplished in the thermal infrared portion of the spectrum. This will more than likely continue due to the relatively proven technology currently being used.

Thermal infrared sensing of forest fires and related hot spots is performed in the two prominent atmospheric transmission windows at 3-5 and 8-12 microns. Reflected solar radiation largely can be ignored in the 8-12 micron range but not always for the 3-5 micron range. During the day, highly reflective rocks can produce strong glint near 3 microns. The radiance in the 3-5 micron band is a much stronger function of temperature than at longer wavelengths for hot sources below about 200° Celsius. This means greater contrast exists in the shortwave band. Consequently, if both bands are used simultaneously, hot spots smaller than an instrument's field of view can be detected by comparing the brightness temperatures in the two bands. If there is a mix of temperatures in the field of view, the shortwave channel will always read a higher temperature. This principle is used in current IR airborne scanners and will continue to be an important feature of thermal IR detection systems.

3.1.1 Sensors

Two thermal infrared sensing methods can be useful in fulfilling the functional requirements for the collection of fire data. The current method in use is infrared line scanners that have single or dual element detectors. The field of view is rapidly swept across the flight line in a direction perpendicular to the aircraft's axis. The system scanning mirror must move fast and must be rigidly supported to produce good images. Thus, line scanners tend to be massive and built on a custom design basis. The second method is the use of linear array detectors that will be configured to sense the image from the ground swath as the system is being flown over the site of fire data collection. The linear array is oriented perpendicular to the aircraft axis and each detector traces a separate line on the ground. Figure 3-1 is a comparison of the line scanner with the linear array. The two systems will be described in this section, first the IR system presently in use by the USDA-Forest Service then the advanced linear array.

The current USDA-Forest Service infrared line scanner is the Fire Logistics Airborne Mapping Equipment (FLAME) system. The Jet Propulsion Laboratory was given the task of designing, developing, and implementing the FLAME system in order to improve performance and flexibility over the earlier Forest Service IR detection system. FLAME is a custom built system with dual band capability in the 3-5 and 8-12 micron range. The system was developed for large-scale fire detection and mapping of more than a few hundred acres. The Mercury-Cadmium-Telluride detectors have an instantaneous field of view of one milliradian and a total field of view of 110 degrees plus or minus 10 degrees. FLAME can be either DC or AC coupled for the rapid processing of images and mapping terrain features adjacent to large hot areas. The FLAME system features rectilinearization of displayed images, and hard-copy display on dry silver film, yet, geometric rectification of the image is still required. Frequent maintenance is required in addition to normal periodic maintenance. FLAME allows video display in real time, and digital-image frame storage onboard the aircraft platform. The output of the system can be enhanced with edge and hot spot markers indicated on the hard-copy image



Line Scanner

Pushbroom Scanner

Figure 3-1. Comparison of Line Scanner and Linear Array product. Liquid nitrogen cooling is required to keep the temperature of the instrument at 77° Kelvin. The large size of the system (about 300 pounds for the digital capability which includes the optics, instrument console, frame buffer, winchester disk, and film printer) and a volume of 16 cubic feet requires a sizable aircraft platform, presently a Beechcraft King Air. The FLAME system mounted inside a Beechcraft King Air is shown in Figure 3-2.

Linear-array, infrared detector systems are currently available on a custom design basis built to meet user requirements. The materials used are Mercury-Cadmium-Telluride for the 3-5 micron range currently available, and the same materials for the 8-12 micron range that are projected to be available by 1988. Element dimensions vary with up to 128-element arrays being built. The linear array light weight and small size, about 100 pounds when combined with optical storage and microcomputer processor, make such system components ideal for use in aircraft platforms smaller than those presently used by the Forest Service for IR missions.

3.1.2 Storage of Fire Data

As will be described in the Technology Assessment (Section 4.4 and Appendix A), methods of storing large amounts of digital and analog data both onboard the aircraft platform and on the ground at the Incident Command Post are numerous. The most attractive appears to be the optical disk mass storage technology. Advances in the recent years in optical disk storage make the future very promising. Digital encoded analog read-only optical disks are available today from such companies as Sony, Panasonic, Hitachi, and Reference Technology. Costs for disk players run from $3000 to $35,000 while the disks are $375 to $750. Present systems feature a capacity up to four Gbytes per disk at micro or millisecond access time, while the units are very compact and lightweight. The technology is advancing rapidly, thus, it is expected that by 1990 costs will decrease and the technology will provide read/write capability similar to existing digital magnetic disks.

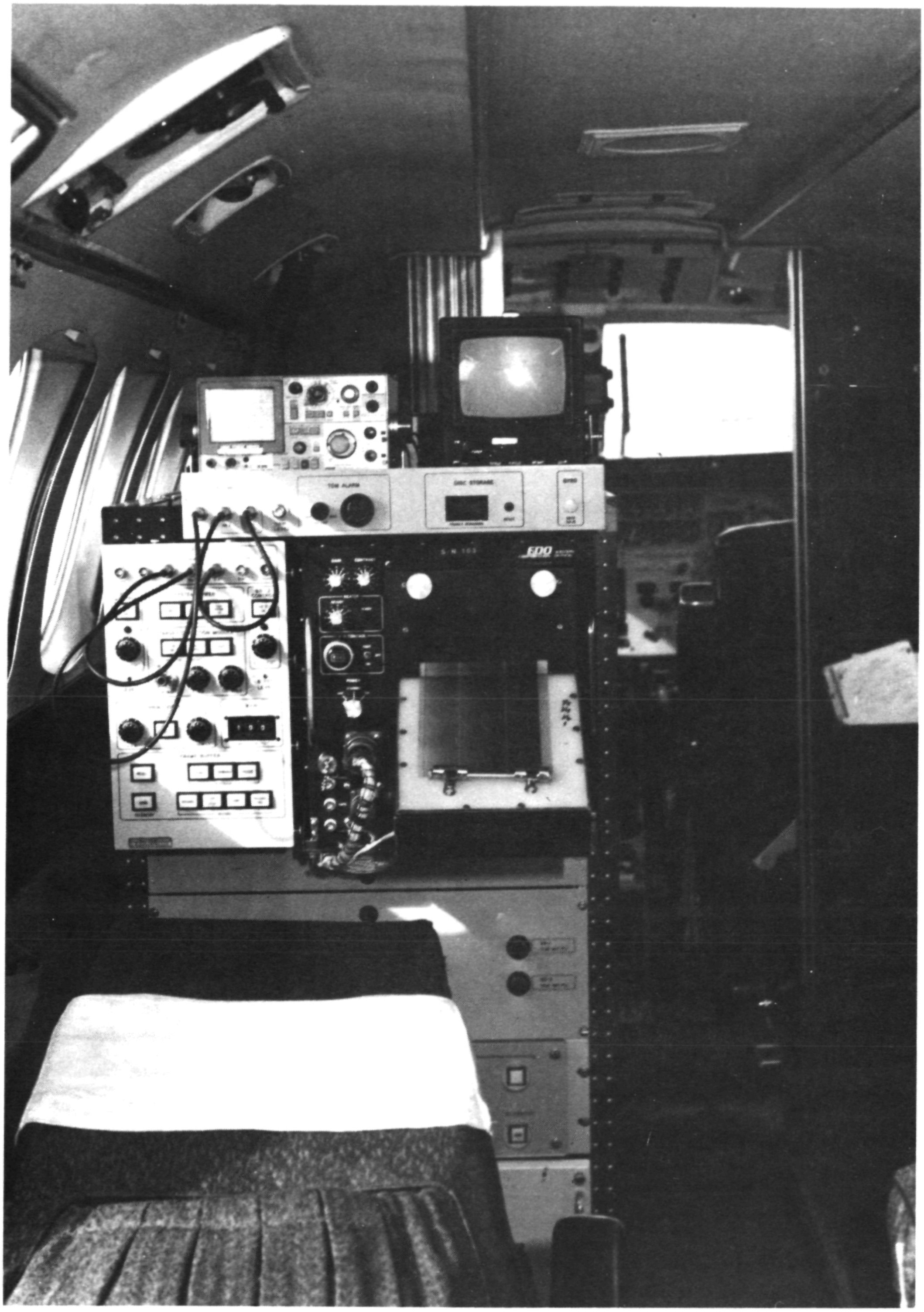


Figure 3-2. FLAME Equipment Inside Beechcraft King Air Aircraft

3.2 GEOREFERENCING OF FIRE DATA

In order to georeference fire data it is necessary to first know the position of the sensor platform (aircraft), the location of the scene imaged by the sensor system, then correlate the image data to a cartographic base (map). The georeferencing of the fire data in an automated manner is a challenge for the project. A number of technology items were identified in the Technology Assessment as possible candidates for doing georeferencing. Alternatives for georeferencing included LORAN-C, Inertial Navigation System (INS), OMEGA, TRANSIT, and NAVSTAR Global Positioning System (GPS).

The LORAN-C is attractive from the cost standpoint and provides accuracy within 600 feet and much closer via differential position calculation methods. However, high accuracy coverage is limited to within coastal areas and is nonexistent in some parts of the United States.

The INS, OMEGA, and TRANSIT systems offer other alternatives but do not meet the user functional requirements.

The Global Positioning Satellite system will be the best alternative component to position determination for the project within the time frame of the 1990s. GPS was developed by the Department of Defense as a satellite-based universal positioning and navigation system designed to provide precision three-dimensional location, velocity, and navigation information in a real-time mode. GPS provides coverage over the entire United States establishing fixes within a real-time mode of operation. Accuracies have been reported to be very good depending upon access mode to the data. Forest Service personnel in the Eastern Region have reported accuracies well within the system user requirements for forest fire detection and mapping.

The characteristics of the GPS system will meet the user functional requirements of the project. GPS will be an 18-satellite constellation, providing continuous global positioning locations, expected to be operational by late 1988. At present seven satellites are operational, five are in use and two are reserved as backups. When the 18-satellite constellation is operational excellent reliability is anticipated.

3.2.1 Global Positioning Satellite Access

Users can access the GPS data via receivers which will receive, decode, and process the two frequencies being transmitted. The transmitted code provides data needed for the user's receiver to calculate three-dimensional position information, velocity and exact time.

Various levels of position accuracy may be attained, since the GPS navigation signal is actually modulated by two different codes in phase. The long-period Precision Position Service (PPS) provides precise measurement of time, hence position, due to its higher clock rate. The PPS is so far restricted to Department of Defense users. The shorter Standard Position Service (SPS) with a lower clock rate facilitates acquisition of satellite signals by civilian users. The primary difference between PPS and SPS user hardware is the additional cost, physical dimension and power requirements of PPS receivers to include military nonjamming devices. As of January 1985, the *Department of Defense has developed and announced a new policy that will offer* access to the PPS code to selected civil users operating in the national interest. Equipment and support services will be provided under contract to the user by the government or its agent. When and how the new policy will go into effect is still undetermined.

Today GPS can be accessed by two methods available to the civilian user, by differential sensor capability and by a technique known as Satellite Emission Range Inferred Earth Surveying (SERIES). Both methods are detailed in the Technology Assessment of this report. The differential GPS will use SPS hardware to obtain access to the coded GPS navigation signal broadcast, only the accuracy capability will be expanded to positioning within 3-5 meters. With the SERIES receiver it is possible to perform simultaneous pseudo-ranging to multiple GPS satellites without knowledge of the GPS phase codes or the requirement to know the receiver position and velocity and satellite positions to begin data acquisition. Real-time accuracy of the SERIES technique will be within five meters with higher accuracy expected after processing of the data.

Both the differential GPS and the SERIES technique method of GPS access will meet the functional requirements of the system.

3.2.2 Signal Processing For Automatic Georeferencing

Georeferencing the fire data is the interface of the FFAST subsystems to create the appropriate image for display and hard copy. Although techniques are currently being developed for automatic georeferencing, there is no existing system that georeferences in a timely manner. Manual data transfer and interpretation is the current georeferencing method. It is a time-consuming process, often taking several hours. Recognizable control points in the fire area must be manually correlated to surveyed points on a cartographic base. Concurrent with manual data transfer, several computer-aided techniques can be used to enhance the accuracy and interpretability of geographic referencing. However, present computer-aided techniques can be improved upon to meet the functional requirements.

Several technologies are being developed that will enable suitably accurate automatic georeferencing. Very Large Scale Integration (VLSI) chips are the most promising of the new technologies for automatic georeferencing. VLSI chips are being developed which can process, in near real time, quantities of data large enough for any conceivable FFAST requirement. The VLSI chips are small enough to be incorporated into processing units within an aircraft. VLSI algorithms for correlating image control points to maps are being developed for referencing techniques which will prove useful as they will provide displacement from an image area being sensed.

3.3 COMMUNICATIONS

Communications is probably the single weakest link in the existing system. The inability to deliver the data reliably in a short amount of time (less than thirty minutes) has hampered incorporating the fire data into the daily fire suppression plan rather than to substantiate the plan. The most promising method of communications appears to be via satellite link. Land lines in remote areas are not readily available and VHF/UHF communications are limited to line of sight or through repeater networks.

Remote fixed service for satellite communications is currently available through the commercial sector for standard fees. A large antenna is required and the set-up can take several hours once the equipment arrives at the ICP. This, however, provides no link between the aircraft and the ICP. Remote land and aeronautical communications will be available by the 1990s and will provide service comparable to current cellular systems but on a nationwide basis. Communications between plane and ground and the ICP and control centers will be possible. The channels will be bandwidth limited to at least 2400 baud. The entire image will not need to be transmitted to the ICP, but fire intensity and fire perimeter information that is georeferenced can be transmitted over a satellite communications system. The Federal Communications Commission is currently evaluating proposals for general industry service available in the 1990s.

3.4 DISPLAY OF FIRE DATA

One of the functional requirements of the system is the interface to Forest Service practices in the display of the fire data. If the system is to be accepted and used, the output products and information must be somewhat conventional. Historically, fire perimeter information is plotted on a standard map, usually a 7-1/2 minute quad. The fire information on a map format is the display product that users require. The process of using fire information from an image, digitizing, then plotting directly on to a map with a commercially available pen plotter is readily available at a cost of around $10,000 for the size necessary to plot on 7-1/2 minute quad sheets.

Display of data on a CRT is an alternative that would meet with acceptance provided that hard copy of what was displayed on the screen was also available through photographic methods. A minimum raster for display would be 1024 x 1024 elements. CRT display units are available through a number of commercial outlets.

SECTION 4

CONCEPTUAL DESIGN PHASE

The purpose of the conceptual design was to examine in detail user requirements for tactical information on forest fire activity, functional requirements for a completed system, and technology that will be available for a completed system, and technology that will be available for application to the project objectives in the 1990s. This section describes the conceptual design activities supporting this task. The activities involve an examination of the current system, utilization of a structured problem-solving procedure (value analysis), incorporation of a method of decision making based upon the importance of advantages (Tradeoff Evaluation Process), an assessment of technology, and the development of alternative system configurations.

4.1 CURRENT IR SYSTEM CONFIGURATION

The airborne portion of the system (Figure 4-1) includes a sensor head configuration, rotating-mirror assembly, signal processing and timing circuits, a dry silver film recorder, a frame buffer capable of storing twenty 1024 x 1024 thermal images, a real-time video monitor, and a transmitter capable of transmitting the thermal imagery to a ground station. The imagery can be relayed to the ground in several ways. The method used most is physical delivery of the film product via a drop tube or by landing the plane at a nearby airstrip. The imagery is then interpreted and pertinent information is transferred to a map. Other methods in use and under development include transmitting the data to a mobile van located at the fire camp or near the fire camp. The information is then displayed on a video monitor where it is photographed and a hard copy is produced. Two separate video cameras view the thermal imagery and a map covering the same area and two images are merged to display fire information directly on the map that is displayed on a CRT. Finally, the imagery can be transmitted directly to the Operations Coordination Center (OCC) at Riverside, California where it is photographed. The fire

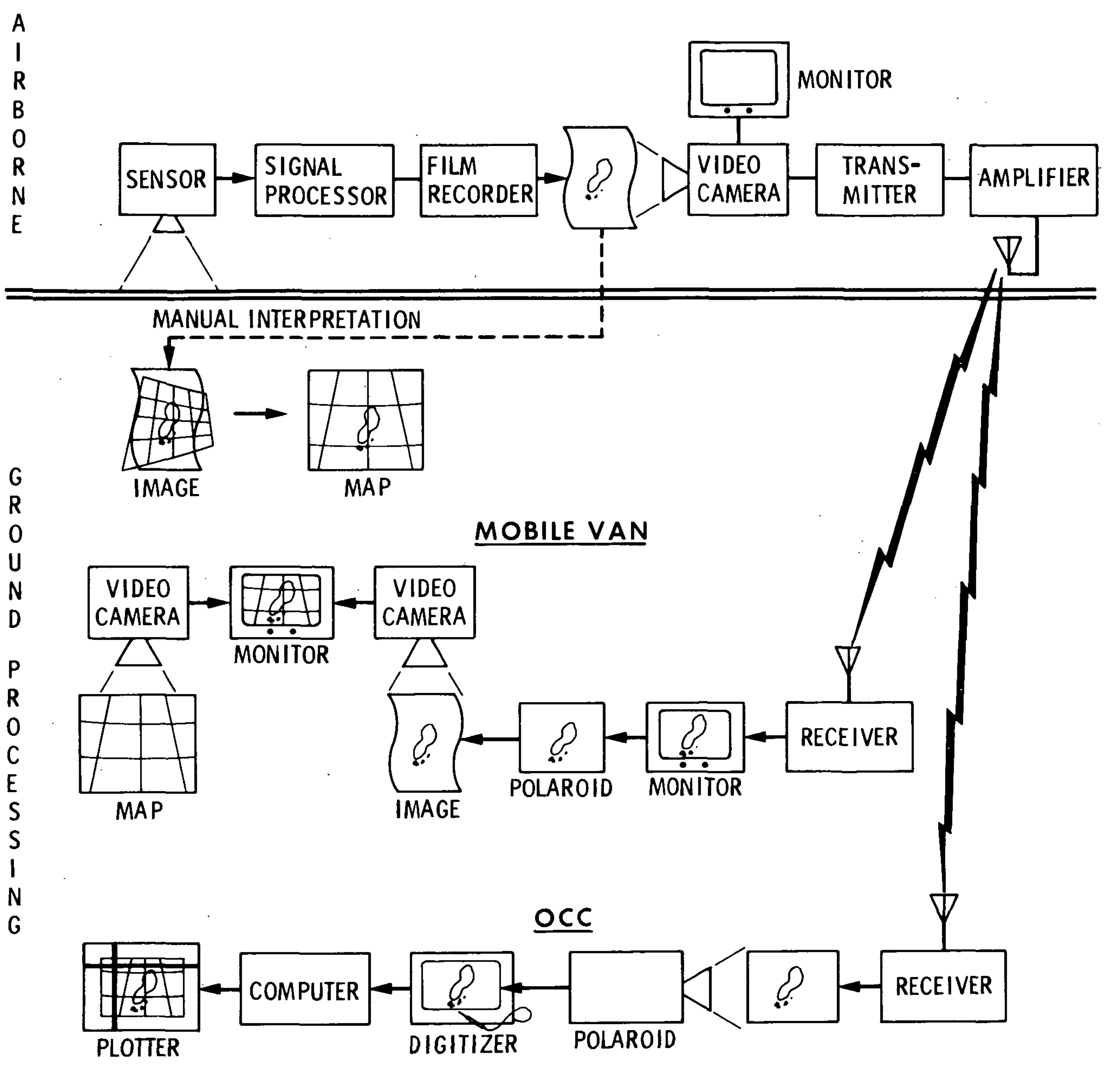


Figure 4-1. Forest Fire Mapping System Existing Configuration

perimeter is digitized from the photograph and merged with recognizable ground control points where it is then plotted directly onto a 7-1/2 minute map sheet.

The intended use of thermal infrared mapping capability is to assist in the formulation of the daily operations plans for fire suppression and control. Provided the thermal infrared data are available, a synoptic view of the incident can aid in the more effective allocation of personnel and equipment to the fire. When thermal infrared imagery is not received prior to plan formulation and dispersal of resources, the data serves only to substantiate the plan. Several deficiences in the following discussion cause this to occur frequently.

Communications between the aircraft and the ground are generally limited to line of sight. Transmission of data directly from the aircraft is then limited to an approximately 75-mile radius from the Incident Command Post (ICP), given uniformity of the terrain. There are also issues related to the amount of data needed to be transmitted down to the ground. Wide-band video links are necessary to transmit high resolution video. The more data that has to be transmitted down, the longer it takes. The second method of getting the data to the ICP is with a drop tube in which the film imagery is loaded into a brightly colored tube that also has a light and an audible alarm. If the drop tube survives the descent, the recovery can be just a few minutes. However, if the light and audible alarm are damaged and the tube lands in high grass or tumbles off a cliff, the film may not be recovered. The alternative to this method is to land the aircraft at a nearby airstrip where a courier transports the film to the fire camp. Occasionally, a courier can take longer than normal if the airstrip is some distance from the fire camp, or if in unfamiliar territory.

Once the film is received, it is taken to the ICP and examined by the fire staff. In order for the data to be of use in formulating operations plans, the imagery must be georeferenced to a standard map base. Fire targets which appear on the raw infrared imagery are located with respect to known geographic positions on the ground. With common points between the image and map, a grid is manually composed to depict the distortion surface required to correct the infrared imagery to the map. The grid is drawn on the infrared image and the corresponding grid is drawn on the map. Using the similar squares method of manual data transfer, the fire perimeter and hot spots are drawn onto the map. This method of manually georeferencing the imagery takes from one-half hour to four hours, depending upon interpreter familiarity with the area, the ruggedness of the terrain, and the ability to locate ground control points. These two main bottlenecks, communications and georeferencing, can cause considerable delay in the receipt of the infrared data.

4.2 VALUE ANALYSIS

Value analysis is a structured problem-solving procedure, currently used by the Forest Service, that defines the function which is to be performed by a part, operation, procedure, or in the case of FFAST a system. It is intended to force critical evaluation of cost per function. By definition, value analysis is "the systematic application of recognized techniques by multidisciplined team(s) which identifies the function of a product or service; establishes a worth for that function; generates alternatives through the use of creative thinking; and provides the needed function, reliably, at the lower overall cost" (USDT, FHA, 1980). Value analysis contains three basic precepts:

1. An organized review to improve value by using multidisciplined teams of specialists knowing various aspects of the problem being studied.

2. A function-oriented approach to identify the essential functions of the system, product, or service being studied and the costs associated with those functions.

3. And creative thinking which uses recognized techniques to explore alternate ways of performing the functions at a lower cost or to otherwise improve the design, service or product.

The value analysis procedure was used on FFAST with the primary program goal to have the most cost-effective infrared forest fire detection and mapping system in operation in the 1990s. The value analysis objectives are to:

1. Develop, analyze, and evaluate alternatives.

2. Determine design parameters for the most cost-effective infrared detection and mapping system for the 1990s.

4.2.1 Value Analysis Phases

The value analysis procedure is structured as a series of steps or phases with specific objectives and tasks outlined at each phase.

The first phase is the selection of the project with the primary objective to establish the identity of candidate projects and to select specific projects to achieve maximum monetary savings, or other benefits.

The second phase is that of investigation of the project. The objective of the investigation phase is to acquire knowledge of the design to be studied and to assess its major functions, cost and relative worth. The major tasks are the collection of project data, examination of sources of project data, the implementation of a search plan and the investigation of the data. The intent of this phase is to provide a thorough understanding of the system by an in-depth review of all of the pertinent factual data, and to determine the functions which are being performed and those which must be performed by the system.

The next phase speculates on all alternatives to the design by examining basic functions and cost elements, then developing a comprehensive list for each alternative. Speculation includes how the problem or task might otherwise be solved and how the basic functions could be accomplished. The purpose is to list all possible alternatives regardless of perceived or known cost. This activity affords the opportunity to explore ideas that may be overlooked during the standard selection process because of biases and engineering judgments. Alternatives are streamlined and modified, with consideration of technical and economic factors being of prime concern.

The evaluation phase is to analyze the results of the speculation phase and, through review of the various alternatives, select the best ideas for further expansion. The ideas produced prior to this phase are now critically evaluated and the final alternatives are now selected.

The final phase is that of development through collection of additional data to thoroughly analyze the best alternatives selected, to prepare cost estimates, and to change proposals, if any, which will assure feasibility if implemented. During this phase the most promising alternatives selected during the evaluation phase are further developed into detailed-change proposals. The intent is to obtain and present adequate backup data regarding design changes and costs.

4.2.2 Value Analysis Results

The value analysis procedure resulted in the decision to proceed with the FFAST conceptual design considering the conclusions of the FFAST Feasibility Study (McLeod, 1983). The goal of the feasibility study was to determine the need for an improved fire detection and mapping system and the user needs in data requirements and operations. The user needs were collected and developed into a set of user requirements, which were stated in terms of fire management and suppression activities. The user requirements include information on the following:

1. Fire location and intensity
2. Current fire behavior, at any given moment, within reason
3. Predicted fire behavior
4. Resources available to manage or suppress the fire

All information must be timely; the earlier the information is received, the greater the possibility for formulating appropriate management decisions and the larger the number of alternatives.

The FFAST Feasibility Study examined factors that would contribute to a system that matches advanced technology and functional requirements. In user needs and the relation to functional requirements, the following were identified as critical to fire operations:

1. Relative simplicity of design
2. User-friendly
3. Rapid turnaround
4. Conventional output products
5. Optionally incorporate existing data bases
6. Accurate
7. Reliable, rugged, and easily maintainable
8. Adaptable to other uses
9. Easily integrated into Forest Service practices

Concurrent with the user requirements study, a technology review was conducted to determine the suitable technology classes that would meet the requirements. The technology review addressed a variety of possible technologies including:

1. Sensor platforms
2. Line and area array sensors
3. Georeferencing
4. Advanced satellite relay communications
5. Integration technique with existing data bases
6. Image-processing techniques

Outstanding technical uncertainties were identified and a comprehensive list of alternatives for each functional area were developed.

Value analysis was used to prepare a Functional Analysis System Technique (FAST) diagram as the initial step in formalizing the functional requirements for the FFAST project. The FAST is a method for analyzing, organizing, and graphically displaying the interrelation of the basic and secondary functions of a product, design, process, procedure, or in the case of FFAST, a system. A series of FAST diagrams were prepared and modified, showing promising alternatives. Two of those diagrams are shown in Figures 4-2 and 4-3.

After the user requirements were defined, they were refined and modified to better reflect user needs. The finalized user requirements were used as the basis of the FFAST Functional Requirements Document (Dutzi, 1984). The purpose of the Functional Requirements Document was to identify the functions necessary to satisfy those user requirements necessary for an improved fire detection and mapping system.

The technology assessment for basic functions required to meet the functional requirements was developed. The technology assessment detailed generic traits of the system as well as off-the-shelf commercial components that could be used to fulfill the functional requirements. A large quantity of vendor material has been collected to support the technology assessment.

4.3 TRADEOFF EVALUATION PROCESS (TEP)

4.3.1 Tradeoff Evaluation Process Summary

The Tradeoff Evaluation Process (TEP) is a method of decision-making based upon the importance of advantages. An advantage is a favorable difference between two alternatives. The TEP requires that the situation or problem requiring a decision should be clearly defined, data collected for analysis, alternatives formulated, and the effects of the alternatives estimated. TEP divides the decision making process into three main tasks:

1. Decide the advantages of each alternative.
2. Decide the importance of each advantage.
3. Select the preferred alternative.

The first task of TEP requires the decision on the advantages of each alternative. The decision makers must decide the least preferred quantity or quality in each factor. TEP then requires decision makers to quantify or describe, for each alternative for each factor, the differences from the

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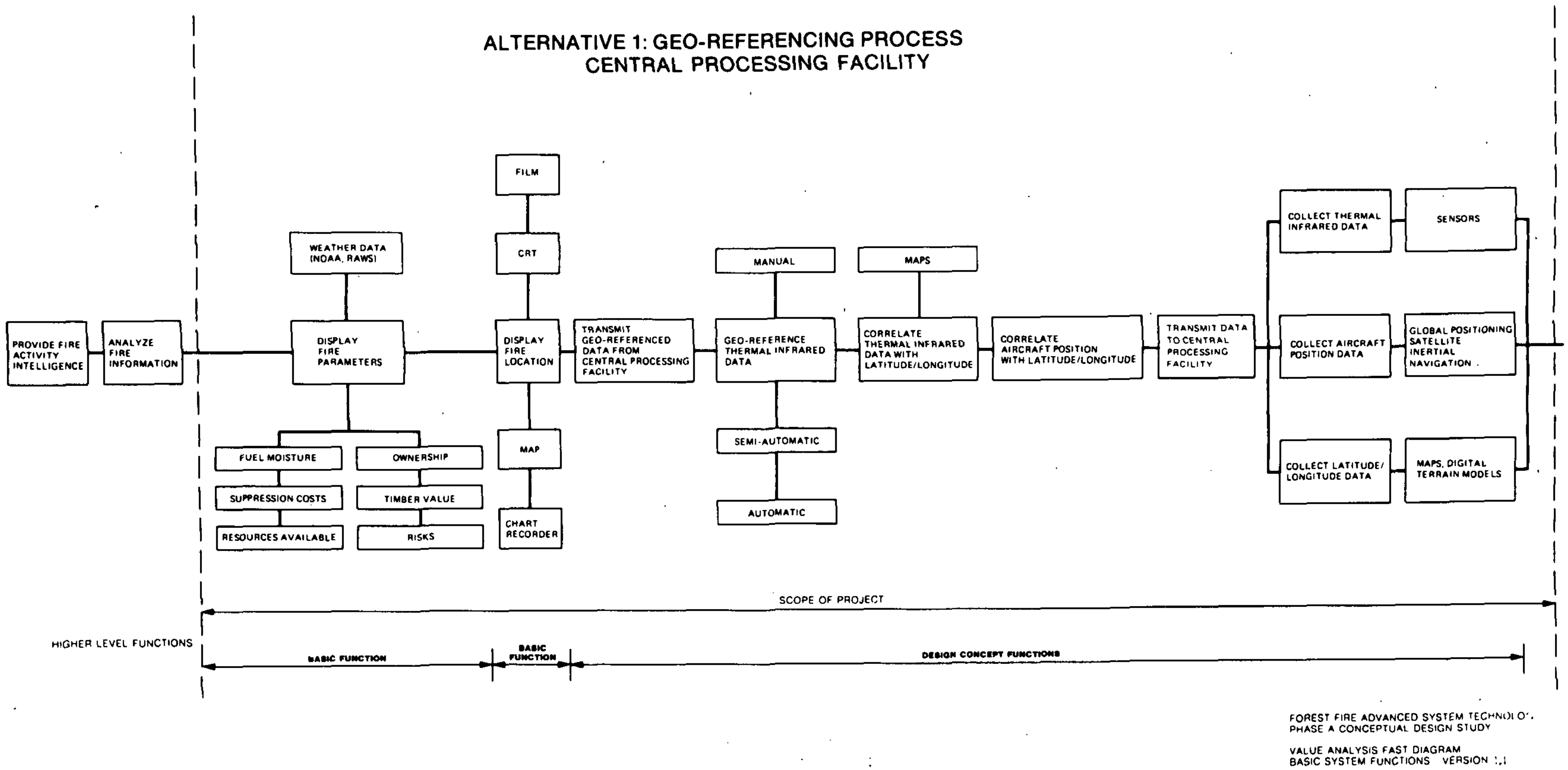
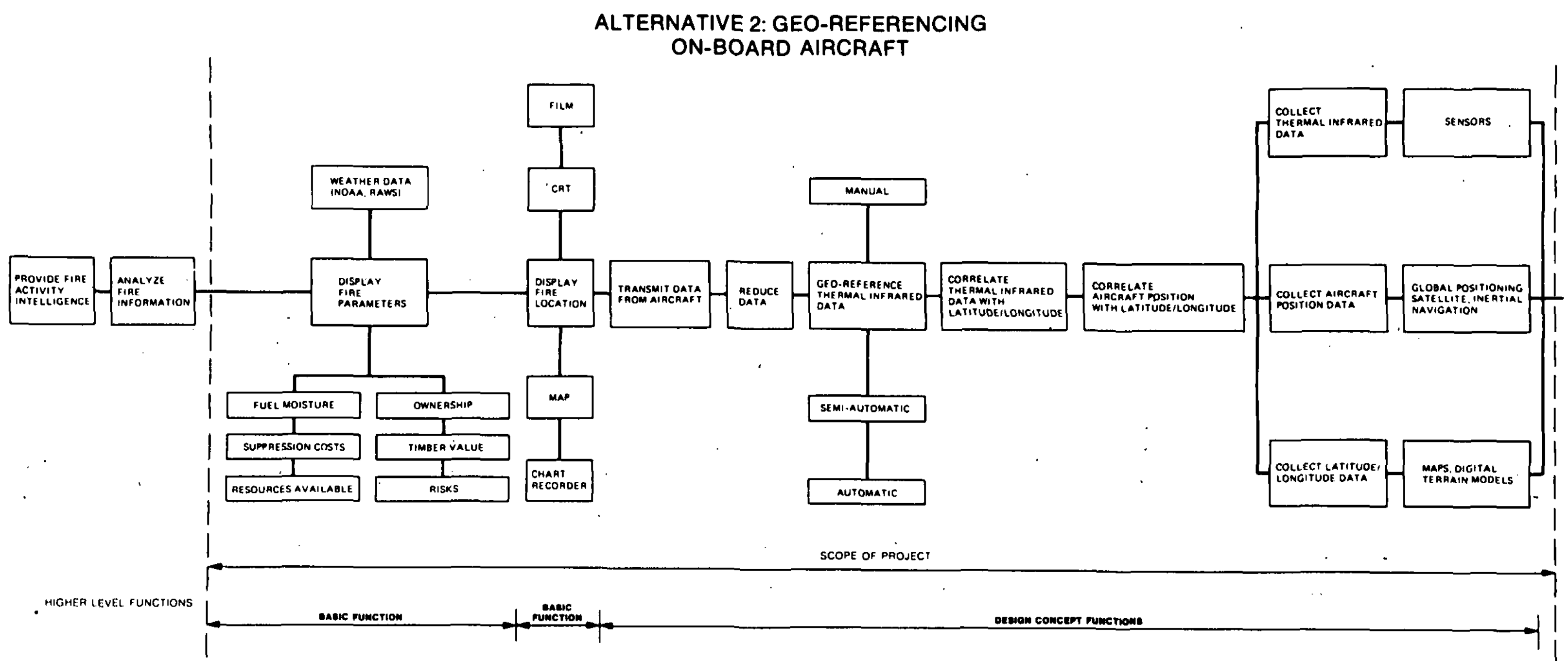


Figure 4-2. Function Analysis System Technique (FAST) Diagram - Alternative One



FOREST FIRE ADVANCED SYSTEM TECHNOLOGY
PHASE A CONCEPTUAL DESIGN STUDY

VALUE ANALYSIS FAST DIAGRAM
BASIC SYSTEM FUNCTIONS VERSION 2.0

Figure 4-3. Function Analysis System Technique (FAST) Diagram - Alternative Two least preferred quantity or quality. These favorable differences are the advantages of the alternatives.

The second task of TEP is to decide the importance of each advantage. The importance of each advantage is determined by the following process:

1. Decide the most important advantage in each factor.

2. Decide the paramount advantage, the most important of all the advantages.

3. Assign an importance factor to the paramount advantage, such as 1.0, 10, 100 or any convenient scaling factor.

4. Decide the importance of the most important advantage in each factor, compared with the paramount advantage.

5. Decide the importance of all other advantages and compare these advantages directly with the most important advantages.

The final task is to decide the preferred alternative by totaling the importance of advantages of each alternative, numerically or graphically, then reevaluating all of the facts and viewpoints for correctness.

4.3.2 Tradeoff Evaluation Process Results

Following the TEP procedure for decision making, the FFAST analysis team evaluated the alternatives for each component of the FFAST system configuration. The numerical tradeoff display of altenatives for each of the components are illustrated in Figures 4-4 through 4-8.

4.3.2.1 Collect Fire Data. The Collect Fire Data TEP result matrix, Figure 4-4, illustrates the use of comparing alternatives by the advantages of important factors. An evaluation of the matrix shows that the value analysis team considered the maintenance factor as the most important factor, listed as

COLLECT FIRE DATA - SENSOR & STORAGE									
FACTOR	ALTERNATIVES								
	LINEAR ARRAY		LINE SCANNER		A.I.S.#		LINE SCANNER WITH*		COMMENTS
AVAILABILIY (1988) ADVANTAGE	M 75		H 100	.1	H 100	.1	H 100	.1	LINE SCANNER ONLY PROVEN
COST (1988) ADVANTAGE	500K 150K	.3	650K		500K 150K	.3	650		COST OF GALILEO ARRAY (NO HARDCOPY ON A/C) VLSI-GEOREF.
WEIGHT ADVANTAGE	100 300	.4	400		100 300	.4	150 250	.3	
DIMENSIONS ADVANTAGE	5 11	.4	16		10 6	.2	6+ 10	.4	CUBIC FEET
POWER RQMTS. ADVANTAGE	L 100	.3	H		L 100	.3	H		
MAINTENANCE ADVANTAGE	L 100	1.0	H		L 100	.9	M 50	.5	A COST DRIVER COULD ELIMINATE TECH. POSITION
TOTAL IMPORTANCE OF ADVANTAGES		2.4		.1	DROPPED			1.3	

ADDITIONAL COMMENTS: OTHER FACTORS CONSIDERED WERE; COOLING: THERMAL ELECTRIC, LIQUID NITROGEN; THERMAL DYNAMIC RANGE: 200-600°C FIRES; THERMAL RESOL.: 0.1°C TERRAIN IDENT.; SPATIAL RES: 1 MR; HOT SPOT DET.: 0.5 FT^2, 0.50°C.

*IMPROVED PROCESSING AND STORAGE
#AT PRESENT ONLY AVAILABLE IN 1.2-2.4 MICRON RANGE
*WILL NOT FULFILL FUNCTIONAL REQUIREMENTS AT PRESENT

Figure 4-4. Collect Fire Data - Sensor and Storage

FACTOR	ALTERNATIVES						COMMENTS
	ON BOARD A/C		CENTRAL FACILITY		MANUAL		
ACCURACY ADVANTAGE	100 FT. 0		100 FT. 0		100 FT. 0		
COST OPERATION & MAINT. ADVANTAGE	M 50	.1	M 50	.1	L 100		
TIMELINESS ADVANTAGE	5 MIN 55 MIN	1.0	5 MIN 55 MIN	1.0	60 MIN		
COST TRANSMISSION INVEST. ADVANTAGE	5K 25K	.1	30K		0 30K	.1	
TOTAL IMPORTANCE OF ADVANTAGES		1.2		1.1		.1	

Figure 4-5. Georeferencing

FACTOR	ALTERNATIVES								
	SATELLITE AUDIO		DIRECT AUDIO		DIRECT VIDEO		HAND DELIVER		COMMENTS
COST-CAPITAL ADVANTAGE	5K 95K	.4	2K 98K	.4	100K		0 100K	.4	
TIMELINESS ADVANTAGE	5 MIN 175 MIN	1.0	5 MIN 175 MIN	1.0	10 MIN 170 MIN	.9	(180 MIN)		30 MIN. MAX IS IMPORTANT
QUALITY ADVANTAGE	H 100	.5	H 100	.5	M 50		H 100	.5	
TOTAL IMPORTANCE OF ADVANTAGES		1.9		1.9		.9		.9	1.* 2.**

* 1. AVAILABILITY IMPORTANT.

** 2. COST OF TRANSMISSION AMORTIZED OVER 5 OR 10 YEAR PERIOD NEEDED.

Figure 4-6. Communications - Transmit Data

FACTOR	ALTERNATIVES											
	DISPLAY PROCESSOR W/FILM				CRT W/FILM				PLOTTER W/MICRO			
	1		20		1		20		1		20	
COST ADVANTAGE	70K		1400K		30K 40K	.7	600K 800K	.7	15K 55K	1.0	300K 1100K	1.0
USABILITY OF PRODUCT ADVANTAGE	H 100	.8	H 100	.8	M 50		M 50		H 100	.8	H 100	.8
REPRODUCIBILITY ADVANTAGE	M 50		M 50		M 50		M 50		H 100	.2	H 100	.2
TRANSPORTABILITY WT./SIZE ADVANTAGE	500 LBS		500 LBS		150 LBS 350 LBS	.5	150 LBS 350 LBS	.5	130 LBS 370 LBS	.5	130 LBS 370 LBS	.5
TOTAL IMPORTANCE OF ADVANTAGES		.8		.8		1.2		1.2		2.5		2.5

Figure 4-7. Display Data

FACTOR	ALTERNATIVES									
	FFAST								CURRENT IR	
	A		B		C		D		HAND DELIVERY	
CAPITAL COST	850K		751K		751K		751K		0	
Advantage			99K	.1	99K	.1	99K	.1	850K	.5
TIMELINESS	<30		<30		<30		<30		240	
In Minutes										
Advantage	210	1.0	210	1.0	210	1.0	210	1.0		
MAINTENANCE	H		L		L		L		H	
Advantage				.3		.3		.3		
TOTAL IMPORTANCE OF ADVANTAGES		1.0		1.4		1.4		1.4		.5

*Costs figured on ten year, actual use basis with dedicated IR operator, 3 pilots, and four technicians.

#Total costs for ten year life of platform.

A = Line scanner, with advanced geo-referencing, communications, and display at ICP. Platform = King Air, Merlin.

B = Linear array (dual band) with advanced geo-referencing, registration, communications, and display at ICP. Platform = King Air, Merlin, or Baron.

C = Linear array with 1 Band (10-12 Microns), no terrain information, automated procedures on board aircraft, advanced communications and display. Platform = Baron.

D = Linear array (Dual Band), audio transmission of GPS and uncorrected IR digitized data of fire perimeter and intensity to central facility for registration and rectification at ground and re-transmisson to ICP Platform = Baron.

Figure 4-8. Fire Mapping and Detection Alternatives a paramount value of 1.0. Totaling the advantage ratings for each of the alternatives indicates that the linear array configuration is the best alternative desirable for the collection of fire data.

4.3.2.2 Georeferencing Data. Figure 4-5 shows the resulting matrix for the georeferencing of the data. The most important advantage of the matrix is timeliness of processing the fire data. The alternatives of onboard aircraft processing and processing at a central facility were estimated to have the best advantage at five minutes processing each. The difference between the two best alternatives is the cost of transmission investment advantage for the onboard aircraft processing, thus, the onboard processing alternative is the best alternative available for this system component.

4.3.2.3 Communication Data. The Communications matrix (Figure 4-6) shows that the timeliness was again considered to be the most important factor in the design of a forest fire detection and mapping system. The satellite audio and direct audio transmission of the fire data are rated as being equal in the timeliness factors as well as the other factors. Both means of audio transmission were considered to be better alternatives than either video transmission of the data or the hand delivery of the fire data. The technical uncertainties were not evaluated at this point. The value analysis team determined that the preferred communication system would be satellite based, since it is feasible, given the 1990 time frame of the system requirements. Recognized advantages of satellite communication are outlined in the Technology Assessment Section of this report.

4.3.2.4 Display Data. The Display Data matrix is shown in Figure 4-7. The pen plotter, using a microcomputer as the system driver, proved to be the best alternative in all the factors considered important in data display. The cost factor was the most important factor under consideration, with the usability of the product also being very important. The pen-plotter display was easily the recommended configuration of the data display component of the system.

4.3.2.5 FFAST System Alternatives. The candidate FFAST System Configuration Alternatives (Figure 4-8) were evaluated for factors considered to be of paramount importance when comparing potential system configurations. The FFAST alternative configurations, with a delivery of fire data to the ICP of less than thirty minutes, have about a three to three and a half hour advantage over the present IR system. The FFAST system configuration Option A has the disadvantage of projected high maintenance for the line scanner component of the system configuration. The Option C configuration uses a single-band linear array which is a technical uncertainty. The single-band linear array may not produce fire data that will meet the system functional requirements. The Option D configuration would utilize a ground facility to process the uncorrected IR data of the fire perimeter and intensity and then retransmit the data to the ICP. The transmission and retransmission of the fire data in Option D and the use of the processing at a ground facility are both technical uncertainties and potential inefficiencies for a FFAST system.

The Option B is the best FFAST system alternative configuration as a result of the TEP technique evaluation. The dual-band linear array component used in Option B is the best alternative of the collect fire data analysis. The advanced onboard georeferencing is the most important factor contributing to the advantage of Option B. Satellite communications are an important part of the advantage of this configuration. The size of the Option B system will allow the platform to be as small as a Baron class aircraft. Option B has the least amount of technical uncertainty, the advantage of onboard data processing, a small size, and will meet the functional requirements of an advanced forest fire detection and mapping system.

4.4 TECHNOLOGY ASSESSMENT

The purpose of the conceptual design phase is to examine in detail, user requirements for tactical information on forest fire activity, functional requirements for a completed system, and technology that will be available for application to the project in the 1990s. To allow value analysis and tradeoff evaluations to occur, an analysis was made between various subsystem components that could be used in the FFAST system configuration. The analysis, a technology assessment, addressed the following items:

1. Data Bases and Data Base Management Systems (DBMS)
2. Data display devices
3. Data-storage devices
4. Satellite communications
5. Global-positioning technologies
6. Sensor systems
7. Georeferencing technologies

The technology assessment of each of these items is in terms of its application to the FFAST system, and its projected availability as a result of continued technical evolution. Accordingly, the technology assessment implies that the FFAST system is modularized, and that new technology items can be integrated into the system configuration as they become mature and commercially available. Because of likely availability, the emphasis of the technology assessment is on nonclassified technology. Only those commercially available items that have been technically proven will be considered for possible final system integration.

It is clear from the initial assessment of current systems and operating procedures that significant improvements can be achieved by first improving communications access and positioning. Communications technologies are evolving rapidly and their integration into an advanced forest fire detection and mapping system is a function of a specific system design and then obtaining commerically available equipment.

Positioning systems are also evolving rapidly. The most significant is the United States Global Positioning Satellite System (GPS). Although developed for the Department of Defense, it is clear there will be commercial use of GPS to accuracies sufficient to meet the requirements of the forest fire detection and mapping system. As these technologies continue to evolve, commercially available systems will become increasingly less expensive and deliver more capability for potential users. Georeferencing technologies, while they are evolving, perhaps are not evolving as rapidly as other technologies with broader applications. Even within the georeferencing technology area, the major thrusts of research and development are not directly applicable to the requirements of the forest fire detection and mapping system. Although not the intent of the project, FFAST system requirements may effectively serve to help advance the state of the art in georeferencing technologies. Additional user requirements, both at the Federal level and in the commercial sector, will encourage accelerated development of georeferencing technologies. To meet the stated functional requirements of the forest fire detection and mapping systems, a significant advancement in the georeferencing technologies is required.

A wide variety of data bases exist within the USDA-Forest Service, as well as within other Federal agencies, specifically the U.S. Department of Interior (U.S. Geological Survey, Fish and Wildlife Service, and Bureau of Land Management). The variety of computer formats that are used for these data bases presents an obstacle to possible integration within the FFAST system, but one that can likely be overcome without significant technical development. The primary effort will be to make these data bases have a common or compatible computer format.

The technology assessment of data storage and display devices involves the canvassing of the many commercially available items. As in the case with the data bases, the emphasis here focuses on compatibility of the devices to effectively and efficiently message the display data in ways (CRT display, hard copy) that meet the practices of Forest Service personnel.

The technology of sensor development also is developing rapidly. The use of infrared linear and area array devices, with their small physical size, low power requirements and lack of moving parts will greatly impact the final FFAST system design. Other sensor developments, such as millimeter wave sensors, may provide the type of information that previously was only available from infrared detectors. The assessment of this technical option will indicate whether or not it can be considered a serious option for the FFAST system.

The Detailed Technology Assessment is presented in Appendix A. The technology assessments presented in the appendix vary in depth of analysis and scope, reflecting commercial availability, technical uncertainty, and potential applications to the requirements of the FFAST system. Because a technology assessment represents both a slice-in-time and forecast into the future the technical information available about items must vary.

To summarize the characteristics (size, availability, cost, performance) associated with FFAST subsystem component options and to allow easy cross comparisons between items, a Technology Evaluation Matrix has been constructed and shown in Appendix A. The purpose of this matrix is twofold:

1. To present the necessary information on the technology options in a manner that is easily comprehensible and for which quick intercomparisons between attributes can be made.

2. To provide an operating mechanism by which information gaps can be easily identified and filled.

The Technology Evaluation Matrix served as a primary guide in the TEP and value analysis procedures. Vendor material (information packets, brochures) were also available during the technology assessment.

4.5 ALTERNATIVE FFAST SYSTEM CONFIGURATIONS

Alternative FFAST system configurations have been developed with regard for future Forest Service information needs and what emerging and available technologies might be present in the 1990s. The components of the system configuration were derived from identified functions that will meet the functional requirements of an advanced forest fire detection and mapping system. The alternatives are intended as baseline configurations constructed in a modular format on which a subsequent detailed design may be built. The alternatives presented here and the technology discussed serves to aid in the refining of the total system design.

An alternative FFAST system configuration matrix summarizing the alternatives is presented in Figure 4-9.

4.5.1 Current IR System Configuration

The current Forest Service IR system configuration will be briefly described to allow a point of comparison with the FFAST system configurations.

The current fire data collection sensor system, the FLAME unit, is a line scanner with dual band (3-5 and 8-12 micron) capability. The platform size required for the FLAME unit because of weight and volume is either King Air or Merlin class. The thermal IR imagery output from the scanner, in the form of transparent film, is acquired from the aircraft and relayed to ground personnel in one of several ways. Occasionally, the IR film can be dropped via a drop tube to the ground, relying on ground personnel to spot the location of the drop. Alternatively, the imagery can be hand delivered to the ICP by a courier after the aircraft lands. The time that elapses between acquisition and delivery of the imagery varies as a function of road condition, distance, airstrip location, and location and availability of fire crew personnel. Generally, the time that elapses between image acquisition and delivery is one to four hours, and at times the imagery is never received.

After the film is received, it is taken to the ICP for review, interpretation, and transposition of the pertinent fire information to maps by ICP personnel. Fire targets which appear on the raw IR scanner film output must be located with respect to known geographic positions on the ground if the information is to be of value in tactical fire suppression planning. In the best case, georeferencing at the ICP involves the adjustment of the fire imagery to a standard geographic base. First, the interpreter identifies common points between the imagery and a map, composes a grid based on the

COMPONENT	FFAST ALTERNATIVES				CURRENT SYSTEM
	A	B	C	D	
COLLECT DATA					
LINE SCANNER	X				X
LINEAR ARRAY 1 BAND			X		
LINEAR ARRAY 2 BANDS		X		X	
DATA PROCESSING					
ADVANCED GEO-REFERENCING	X	X	X	X	
ADVANCED REGISTRATION	X	X	X	X	
AUTOMATED ON-BOARD AIRCRAFT	X	X	X		
REGISTRATION AND RECTIFICATION AT GROUND FACILITY				X	X
COMMUNICATION					
SATELLITE	X	X	X	X	
DATA DISPLAY					
ADVANCED DISPLAY AT ICP	X	X	X	X	
PLATFORM					
KING AIR	X				X
MERLIN	X				X
BARON		X	X	X	

Figure 4-9. Alternative FFAST System Configuration Matrix

selected common points, and overlays the grid on the map and image. Second, using the similar squares method of manual information transfer, the fire perimeter is sketched on the map using the grid and control points. This method of manually georeferencing the imagery takes from one to four hours, depending upon interpreter familarity with the area, ruggedness of the terrain, distortions in the imagery, nonlinearities in the image scales, and the ability to locate control points.

The imagery can also be telemetered to a mobile van which can be positioned at the ICP. The van contains a receiving station and equipment for aiding interpretation and rectification. The mobile van has only been used in southern California, but can be driven to other locations. The imagery can also be telemetered to the Operations Control Center (OCC) in Riverside, California where it can be interpreted and rectified to a map using a computer-aided system. The information can then be used at the OCC for planning. Conceivably, the mobile van could be prepositioned at fire danger areas. The transmitted imagery can usually be available at the mobile van or OCC within 30 minutes following the completion of mapping flights, depending on conditions and locations.

The georeferenced imagery is used to identify or validate fire perimeter and fire spot locations to aid in generating tactical fire suppression plans prepared for the day. In general, plans are updated every 12 hours. Maps and ancillary data used in preparing the plans are physically located at the ICP.

4.5.2 Option A System Configuration: Line Scanner, Advanced Data Processing, Satellite Communications, and Advanced Display

The Option A configuration will use a presently available, custom-built, line scanner with dual band (3-5 and 8-12 micron) capability for the collection of IR image data. The platform required for the sensor system would be the size of a King Air or Merlin class aircraft. An advanced georeferencing system will be used that incorporates the Global Positioning

Satellite system for locational determination and a differential or SERIES GPS receiver to acquire the positioning data. After the precise position of the fire image data is determined, registration of the imagery to a geographic base is done automatically via a very large scale integration registration chip. The fire perimeter and intensity data will then be telemetered via a geosynchronous communications satellite to the Incident Command Post for processing. The fire data is then used as input to a microprocessor that runs a pen plotter, producing a hard-copy display of the fire data on a map base, which is given to the users at the ICP.

4.5.3 Option B System Configuration: Linear Array, Advanced Data Processing, Satellite Communications, and Advanced Display

The Option B configuration would utilize a linear-array, IR sensor system with dual bands (3-5 and 8-12 microns) for the collection of the fire data. The system would use advanced georeferencing for the adjustment of the fire imagery to a standard geographic base. The Global Positioning Satellite system would be used to determine locational information while access to that data would be via a differential or SERIES receiver. Automatic registration of the fire imagery to a geographic base would be done on a VLSI geometric registration chip. Automated data processing would occur onboard the aircraft. The fire perimeter and intensity data would be telemetered via a geosynchronous communications satellite system. A microprocessor would be used to produce a hard-copy display from a pen plotter. The output at the ICP would be in a user-defined map format. The sensor platform required could be as small as a Baron size aircraft depending upon the final weight and size of the sensor system. Advantages of the linear-array sensor system include compact size and small weight.

4.5.4 Option C System Configuration: Single-Band Linear Array, Advanced Data Processing, Satellite Communications, and Advanced Data Display

The Option C configuration will utilize a single-band (8-12 micron) IR detector system. The use of a single band in the 8-12 micron range would eliminate false signals caused by solar radiation on highly reflective rocks that are detected in the 3-5 micron range. Although IR detector array technology is the least advanced for those devices sensitive in the 8-12 microns atmospheric window, theoretically the single band in this range would detect the required fire data. Georeferencing and registration of the fire data would be automatically processed onboard the aircraft by accessing GPS positional location data. Access of the GPS data would be by a differential or SERIES receiver onboard the aircraft. Communication of the georeferenced and registered data to the ICP would be via a geosynchronous communications satellite. The fire perimeter and fire intensity data would be displayed on the ground as a hard-copy map product of a pen plotter driven by a microprocessor. Because of the weight of the system being less than the prior option configurations, the platform for the sensor would not have to be larger than a Baron class of aircraft.

4.5.5 Option D System Configuration: Linear Array, Advanced Data Processing at Ground Facility, Satellite Communications, Advanced Data Display

The Option D configuration would use a dual-band linear array (3-5 and 8-12 microns) to collect the fire image data. The uncorrected IR data and the GPS signal would be transmitted by audio over a geosynchronous communication satellite link to a ground facility for processing. Only the fire perimeter and fire intensity would be automatically digitized onboard the aircraft. The IR data would be georeferenced and registered to map a base at the ground facility then the corrected fire perimeter and intensity data would be retransmitted via the communications satellite link to the ICP. At the ICP a microprocessor run pen plotter would produce a map product for use by the fire control personnel. The reduced weight and volume of the onboard system would allow the platform to be of the Baron class of aircraft.

4.5.6 Preferred System Configuration

The preferred system configuration (Option B), as illustrated in Figure 4-10, will meet or exceed the users' functional requirements for an

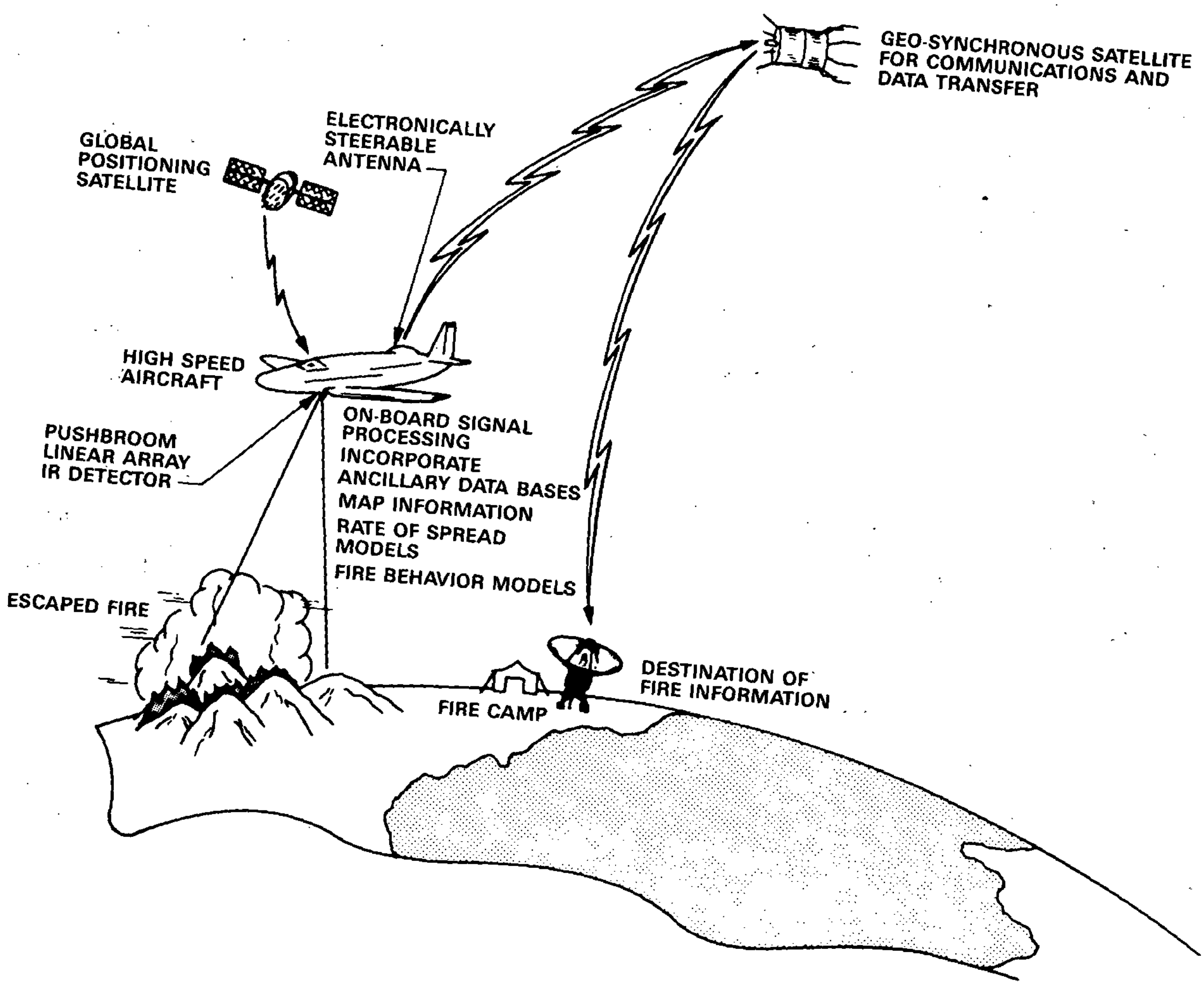


Figure 4-10. Preferred System Configuration

advanced forest fire detection and mapping system. The modular design of the preferred system provides flexibility by allowing the incorporation of both present and developing technologies at a later date. The system will rely on thermal infrared, linear-array detector technology, coupled with a Global Positioning Satellite system and onboard signal processing capabilities, to produce fire data that can be georeferenced to a common map base. The reduced size of the onboard system will allow for a smaller aircraft platform to be used. The processed data will contain fire perimeter location, hot spot detection, and fire intensity information. The processed fire data will be telemetered via mobile satellite communications to the Incident Command Post for display in a final map format for use by fire suppression personnel. Finally, the preferred system has the advantage of the least amount of technical uncertainty associated with its basic components.

The preferred system configuration addresses the dual goals of meeting the stated needs for fire management while being realistic in terms of the technology that is likely to be available by the 1990s. The technology will make it possible to acquire the requisite information and to integrate the various mapping and detection technologies into a high resolution, user-friendly system which would perform fire detection and mapping on a real-time basis. The system will also be flexible enough for expansion and multiple-use capabilities in the future.

SECTION 5

ECONOMIC ASPECTS OF THE CURRENT AND PREFERRED SYSTEM

The various operational components' costs of the current infrared system are identified and described in this section. Emphasis is placed on capturing the total cost of the system. The section contrasts the cost of the current system with that of the preferred system. The least-cost-type analysis is utilized. The economic benefit result is the difference between the cost of the preferred system and the current system.

5.1 CURRENT SYSTEM

The current system costs are summarized in Table 5-1. The following is a discussion of each component and the associated costs.

The infrared (IR) equipment is the instrumentation designed to record and process the IR data. The equipment is mounted in an aircraft and flown above a fire. Currently, there are two operational units. The most recently acquired, the FLAME unit, was purchased at a cost of $750,000. The FLAME unit is a solid-state updated version of an older Texas Instruments unit. For the purposes of this analysis, the acquisition cost of the FLAME unit has been used as the replacement cost for both units. Using a straight line depreciation over ten-years design life, an annual cost of $150,000 is obtained for both units. Maintenance totaling $31,000, exclusive of labor, was added to the annual cost. The maintenance cost was obtained from the Forest Service Aviation and Fire Management's 1984 Scanner Profit and Loss Statement (Gale, 1985).

Currently one mobile ground unit, based in southern California, is used for receiving raw IR images from the aircraft while it is over the fire. The ground unit consists of receiving equipment housed in a mobile van. A video transmitter located onboard the aircraft is also part of this equipment. The mobile ground unit costs approximately $100,000. Amortized over a ten-year period, a $10,000 annual cost is obtained. The use of the ground

Table 5-1. Current Infrared System Cost
(In Thousands of Dollars)

	Investment Cost	Annual Cost	Total Annual Cost
Fixed Cost:			
IR Equipment			
1 FLAME Unit	750		
1 Old System	750		
Maintenance (not including labor)		150	
IR Equipment		31	
Ground Unit			
Airborne Equipment	33		
Receiving Equipment	33		
Mobile Van	34		
IR Technicians			
4 Equipment Maint. & Oper.		124	
Aircraft FOR (No pilot salary)			
King Air (82% IR)	2,100		
Merlin	687		
		132	
Pilots			
4 IR Pilots		136	
Interpreters			
Training and Equipment		30	
Total Fixed Cost			613
Total Variable Cost (500 Hours IR Use)			178
Adjustment - Nonrevenue Activities (100 Hours)			87
Total Annual IR System Cost			878

unit is limited because of travel time to a fire, and the fact that only one unit exists. In lieu of the ground receiving unit, the IR imagery is hand delivered from the local airport to the ICP using ground transportation.

Four IR technicians are employed full-time to operate and maintain the current IR equipment and mobile ground unit. The cost for the technicians, including salary and travel, has been estimated at $31,000 per technician for a total of $124,000 annually (Gale, 1985).

The aircraft Fixed Ownership Rate (FOR) charge is the fixed annual cost of having an aircraft available. The FOR is the charge initially from the Government Accounting Office for major procurements. The charge includes depreciation, program management, and general administration. The Forest Service currently has two aircraft dedicated primarily to IR operations. The Sweringen Merlin operates approximately 275 hours annually in IR operations. Prorating the 275 hours for the Merlin or 85 percent of its total use to IR operations constitutes a $33,000 FOR cost. The other aircraft, a Beechcraft King Air is being replaced with a new model King Air. The King Air is the primary IR aircraft as it contains the FLAME IR unit. Both King Air aircraft were used to develop the FOR cost for the second aircraft. The 225 hours, or 82 percent of the total annual use of the old King Air, has been used for prorating the anticipated FOR charge for the new King Air. The result is a $99,000 annual cost for the King Air. Total aircraft FOR charged for the IR systems equals $132,000.

Two pilots are normally used to pilot each aircraft. The pilot pool consists of a group leader and four IR pilots who are supplemented by regional pilots as needed. Only a portion of the four IR pilots and their travel expenses was used to estimate pilot cost. The cost of pilots to crew the IR aircraft is also calculated as a fixed FOR cost. This has again been prorated by the hours spent in IR work which accounts for 500 hours out of a total of 600 hours spent in aircraft operations. At $31,000 per pilot, the total annual pilot FOR cost for IR operations is $136,000.

A cadre of IR interpreters has been trained and is available throughout the country to perform the task of transferring the infrared images to usable map form. The estimated annual cost to train and equip the IR interpreter cadre is $30,000.

The current total investment for the IR system is $1.6 million in IR hardware, and $2.8 million for the two IR aircraft (the aircraft are amortized over a 20-year period), plus an undetermined investment in the various people that are trained to operate and maintain the system. The total annual fixed cost of the IR system is $613,000.

An additional $178,000 of variable costs, based on an anticipated 500 hours of IR use, is required to operate the system (pilots are figured in the fixed cost). The overall cost has been adjusted to include $87,000 to account for 100 hours of nonrevenue-producing operations. The adjustment consists of FOR charges including pilots, and 100 hours of use. The activities for the adjustment involve such things as pilot proficiency flights, training, and flights involving maintenance. The total annual cost of the IR system including fixed, variable, and adjustment cost is $878,000.

5.2 SUPPLEMENTAL DATA

Aircraft and pilots are a major cost of the current IR system and a key to future cost. To better understand this component, more detailed data on aircraft has been prepared (See Tables 5-2, 5-3, 5-4). Over time, IR aircraft have become larger and more expensive.

Improvements in IR hardware technology will decrease the weight and volume of future IR equipment which will permit its operation in a light twin-engine aircraft of the Baron leadplane type. The equipment will be portable enough so that it would not require dedicated aircraft. Currently, IR pilots and the dedicated aircraft are costing $533,000 annually and averaging $1066 for each hour of use, or 61 percent of the total annual IR system cost.

If Forest Service Regional leadplane aircraft and pilots could be used to accomplish the IR missions a considerable savings could be realized. The data in Table 5-4, and the assessment of future IR hardware, suggest that the use of existing leadplane type aircraft would be a possibility. Seven of

Table 5-2. 1985 Infrared Aircraft

	KING AIR	MERLIN
Speed (knots)	210	250
Payload (lb)	2406	2355
Total Annual Use (hr)	275	325
Fixed Annual Cost FOR (with pilot)	$203,000	$127,000
Per Hour Cost		
FOR With Pilot	$737	$390
Use Rate	$297	$403
Total	$1037	$793

Table 5-3 Baron Aircraft (Costs in Dollars)

Speed (knots)	205	
Payload (lb)	605	
Purchase price	350,000	
Fixed Annual Cost		
GA & Misc.	3,000	
Depreciation	17,000	
FOR without pilot	(20,500)	
Pilot and expense	85,000	
FOR with pilot		105,500
Per Hour Cost (315 hr)		
FOR without pilot	(65)	
FOR with pilot		335
USE rate		150
Total		485

the current leadplane aircraft are used less than 200 hours per year and an additional seven less than 300. An additional 500 hours of IR use on these aircraft would constitute a seven percent overall increase in their total use.

Table 5-4. Leadplane Aircraft Utilization[1]

Region	Number of Aircraft	Total Hours Per Aircraft	Percent of Leadplane Use
1	2	179	71
2	2	361	7
3	3	186	40
4	2	541	8
5	6	347	18
6	5	265	20
8	2	196	22
9	2	215	7
National Total	25	297	21

[1]Source: Gale, 1983.

Table 5-3 breaks down Baron aircraft cost similarly to that in Table 5-2 for the IR aircraft. Fixed FOR and pilot costs for leadplanes are currently being covered by existing Forest Service programs. Additional use of these aircraft and pilots would constitute little additional fixed cost to the Forest Service. (If an FOR cost was charged to the IR system, it would amount to $167,750 annually or $335 per hour. The same $167,750 would be subtracted from the current leadplane cost.)

The variable cost or use rate that is directly related to the use of these aircraft is estimated at $150 per hour. This amounts to $75,000 annually and would be the only aircraft charge incurred by the IR program.

The preferred IR system configuration hardware and software cost is identified in Table 5-5. The system configuration cost in Table 5-5 constitutes one complete IR unit, exclusive of aircraft. The estimated, preferred system configuration cost is $892,000. Assuming two units are acquired with a 10-year amortization period, the annual cost is $178,400.

Table 5-5. Preferred System Configuration Hardware and Software

	Cost (In Dollars)
Linear Array	500,000
Onboard Data Storage	36,000
Georeferencing	
VLSI Chip	30,000
Satellite Access	250,000
Receiver	7,000
Communication	23,000
Data Display	
Microcomputer System	31,000
Plotter	15,000
Total Per Unit	892,000
Two Unit Annual Cost	178,400

5.3 COMPARISON OF CURRENT AND PREFERRED SYSTEM

The annual cost of the current IR system and the cost of the preferred system are summarized in Table 5-6. The cost of the preferred system has been subtracted from the cost of the current system to derive the benefit or annual savings that would be anticipated.

The cost of purchasing the preferred IR equipment is projected to be slightly less than current equipment, for an annual savings of $2600. Only one IR technician would be needed to service the equipment instead of the four currently needed, for an annual savings of $93,000.

The use of leadplane aircraft and pilots would save the Forest Service $424,000 (if a portion of the leadplane pilot and FOR were charged to the IR system, the savings is $407,250 annually). Interpreters would not be necessary with the new system because the system georeferencing locates the

Table 5-6. System Comparison Annual Cost (In Dollars)

	Current	Preferred	Benefit
IR Equipment	182,000	178,400	2,600
IR Technician	124,000	31,000	93,000
Aircraft			
FOR	132,000	0	132,000*
USE	178,000	75,000	103,000*
Adjustment	87,000	0	87,000
Pilots	136,000	34,000	102,000
(Alt. Aircraft & Pilots)	(377,000)	(209,000)	(168,000)*
Interpreters	30,000	0	30,000
Ground Unit			
1 Unit	10,000	5,800	4,200
20 Units	(200,000)	(110,200)	(89,800)#
Total Annual	878,000	326,200	551,800

* Alternative aircraft costing assumption.

\# 20 Ground units will be preferred.

images automatically by mapped coordinates. The savings on interpreters would be $30,000 annually. For comparative purposes, only one ground unit was considered initially with the preferred system. At $58,000 per unit, this constitutes an annual savings of $4200 over the current ground based unit. However, to fully utilize the capability of the preferred system, it is recommended that a total of twenty portable ground based units be purchased. The nineteen additional units would cost $1,102,000 which, amortized over ten years, is an added cost of $110,200 per year.

5.4 SUMMARY

The current IR system represents a $4.4 million investment in hardware and aircraft with an annual cost of $878,000. A comparable preferred system would require a $1,784,000 investment in hardware and software, and cost $326,200 annually to operate, providing an annual savings of $551,800. Considering the nineteen additional ground units, the investment becomes $2,886,000, and the annual cost is $436,400 still providing an annual savings of $441,600.

The preferred system will have some additional start-up costs (see Section 6), however, compared to the current system, the additional costs will be relatively small since the system is considerably less dependent on people. The system could be puchased in increments to reduce the "up front" outlay. The complete preferred system would provide for:

1. A considerable improvement in IR capability and utilization.
2. A reduction in full-time equivalents in personnel.
3. Reduced need for expensive dedicated aircraft.
4. Increased utilization of other aircraft and pilots.

The complete preferred system configuration would be expected to pay for itself in four years from the annual savings alone.

SECTION 6

SYSTEM COST ESTIMATE

6.1 SCOPE OF SYSTEM COST ESTIMATES

The objective of this section is to prepare preliminary cost estimates and basic schedules for the design, fabrication, and installation phases for the FFAST project preferred system configuration.

As stated in Section 1, the objective of the FFAST project is to implement a technologically advanced (late 1980s) forest fire detection, mapping, and management system for use by the USDA-Forest Service and cooperating agencies in the early 1990s. The preferred system configuration will provide increased performance and be cost-effective compared to the system currently in use. The system will be designed and built at JPL in conjunction with private industry. In general the system design will conform to the FFAST functional requirements as specified in JPL (Internal Document) #D-1600, May 1, 1984 (Dutzi, 1984).

Cost and schedule estimates for the detailed design and build of the system take into account the current maturity state for each subsystem component. Uncertainties in emerging and advanced technologies related to the preferred system configuration are identified. Cost projections are based upon analyzing available subsystem component technology and substituting advanced technology projections where possible. Experts were consulted to assess the advanced technology projection cost estimates in the fields of infrared detection sensing, global positioning and georeferencing, communications, and data processing.

6.2 WORK BREAKDOWN STRUCTURE

The task Work Breakdown Structure (WBS) describing the FFAST Preliminary Operational System Capability is shown in Figure 6-1. The WBS organizes the principal steps involved in the design, build, and installation of the preferred FFAST configuration. This WBS is meant as a baseline on which further developments and refinements will be made.

6.3 COST SUMMARY BY WORK BREAKDOWN STRUCTURE

The Work Breakdown Structure shown in Figure 6-1 was used to cost the system. Cost-estimates summaries by Work Breakdown Structure are presented in Table 6-1.

6.4 MASTER PROJECT SCHEDULE

The projected project period of performance will be from December 31, 1986 through December 31, 1989. The preliminary FFAST Operational System Master Project Schedule is presented in Figure 6-2.

6.5 PRIMARY COMPONENT MILESTONE CHART

The Preliminary Primary Component Milestone Chart is shown in Figure 6-3. Delay in the startup date for the mobile satellite communications technology development will affect this preliminary schedule. Thus, it should be noted that the fabrication component of the communications subtask can not be completed until the mobile satellite communications system has been developed.

6.6 PREFERRED SYSTEM CONFIGURATION COMPONENT COST AND CONTINGENCY ESTIMATES

Table 6-2 shows the total projected task costs by subsystem primary physical components along with additional cost contingency estimates for each component. The cost contingency estimates indicate the cost variability projected for each component. Cost and contingency estimates are for the design and build of one system, if more than one system was built these estimates would be affected significantly.

6.7 LABOR, SERVICES AND TRAVEL COSTS

Table 6-3 shows the FY 88 to FY 90 cost estimates for projected labor, services (including graphics, photographic reproduction, documentation), and travel.

All numbers presented in this report are as of October 31, 1985.

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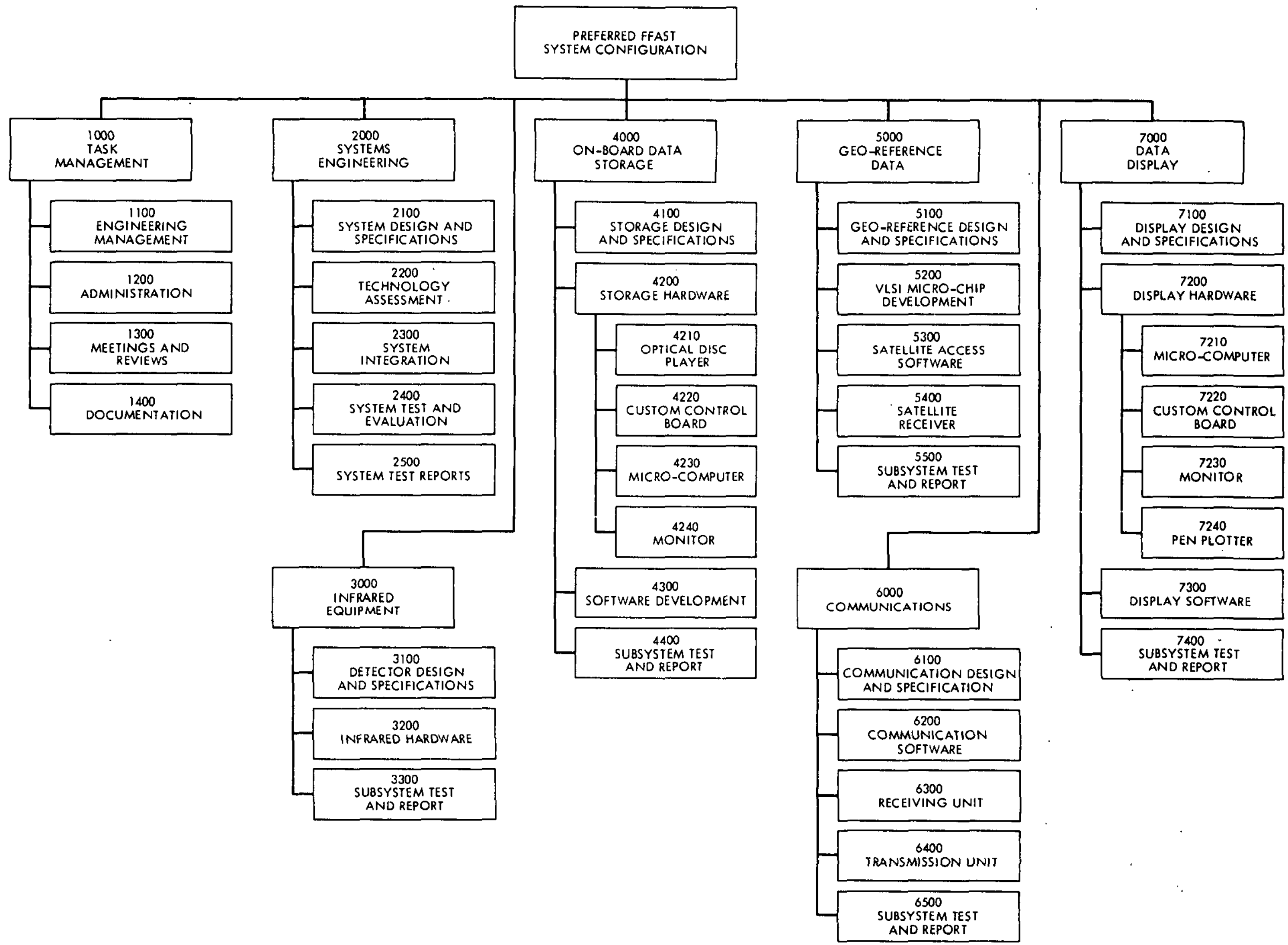

Figure 6-1. FFAST Preliminary Work Breakdown Structure Operational System

Table 6-1. FFAST Preliminary Operational System Capability (Costs by Work Breakdown Structure Element)

WBS Element	Description	Cost (In Dollars)
0000	TOTAL TASK	1,698,000
1000	TASK MANAGEMENT	276,000
1100	Engineering Management	106,000
1200	Administration	100,000
1300	Meetings and Reviews	50,000
1400	Documentation	20,000
2000	SYSTEMS ENGINEERING	248,000
2100	System Design and Specifications	50,000
2200	Technology Assessment	12,000
2300	System Integration	97,000
2400	System Test and Evaluation	60,000
2500	System Test Reports	32,000
3000	INFRARED EQUIPMENT	542,000
3100	Detector Design and Specifications	22,000
3200	Infrared Hardware	500,000
3300	Subsystem Test and Report	20,000
4000	ON-BOARD DATA STORAGE	113,000
4100	Storage Design and Specifications	20,000
4200	Storage Hardware	
4210	Optical Disc Player	20,000
4220	Custom Control Board	2,000
4230	Microcomputer	10,000
4240	Monitor	4,000
4300	Software Development	35,000
4400	Subsystem Test and Report	22,000
5000	GEOREFERENCE DATA	347,000
5100	Georeference Design and Specification	25,000
5200	VLSI Micro-chip Development	30,000
5300	Satellite Access Software	250,000
5400	Satellite Receiver	7,000
5500	Subsystem Test and Report	35,000

Table 6-1. FFAST Preliminary Operational System Capability (Costs by Work Breakdown Structure Element) (Continued)

WBS Element	Description	Cost (In Dollars)
6000	COMMUNICATION	76,000
6100	Communication Design and Specification	20,000
6200	Communication Software	17,000
6300	Receiving Unit	3,000
6400	Transmission Unit	3,000
6500	Subsystem Test and Report	33,000
7000	DATA DISPLAY	96,000
7100	Display Design and Specification	25,000
7200	Display Hardware	
7210	Microcomputer	10,000
7220	Custom Control Board	2,000
7230	Monitor	4,000
7240	Pen Plotter	15,000
7300	Display Software	15,000
7400	Subsystem Test and Report	25,000

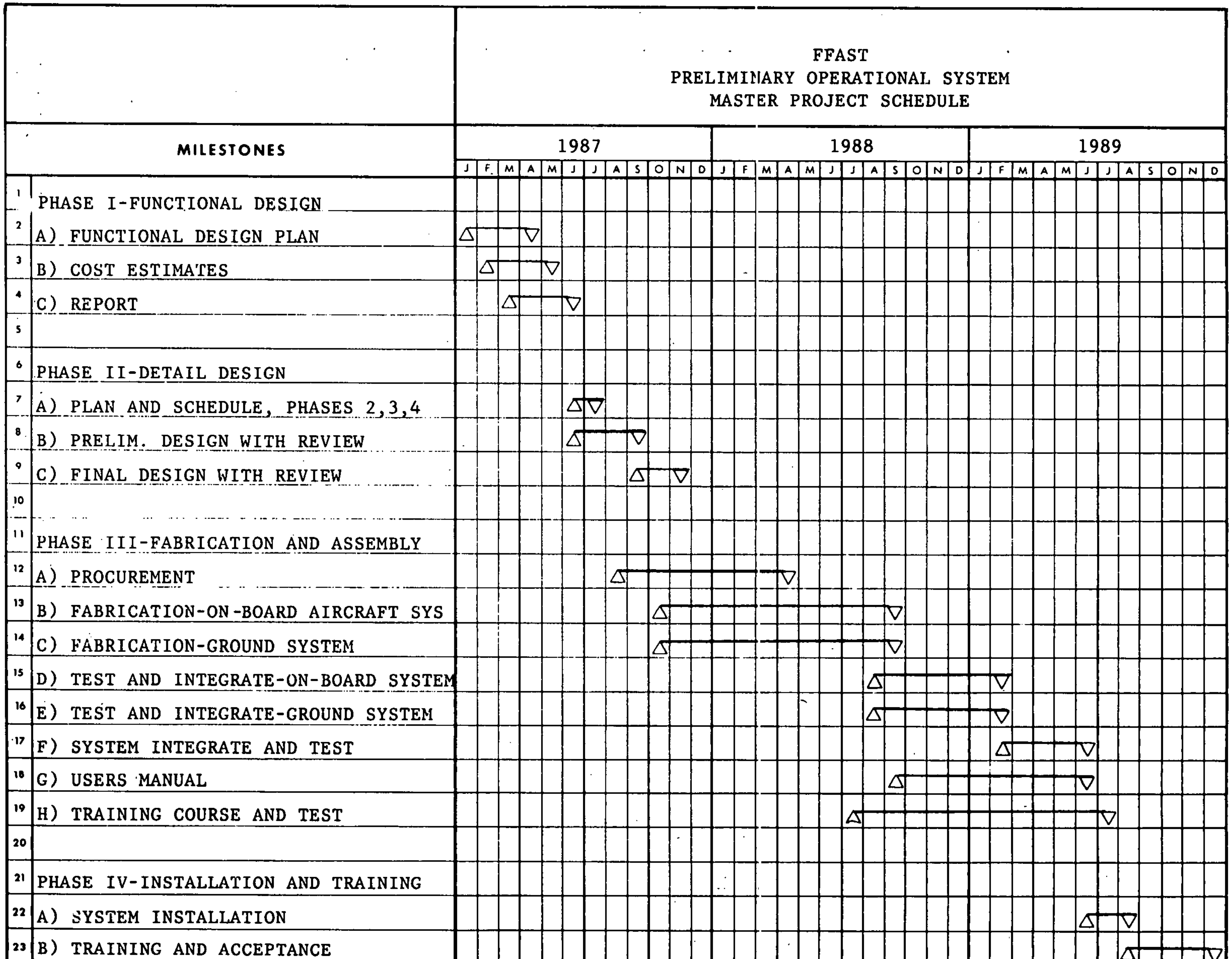

Figure 6-2. FFAST Preliminary Operational System Master Project Schedule

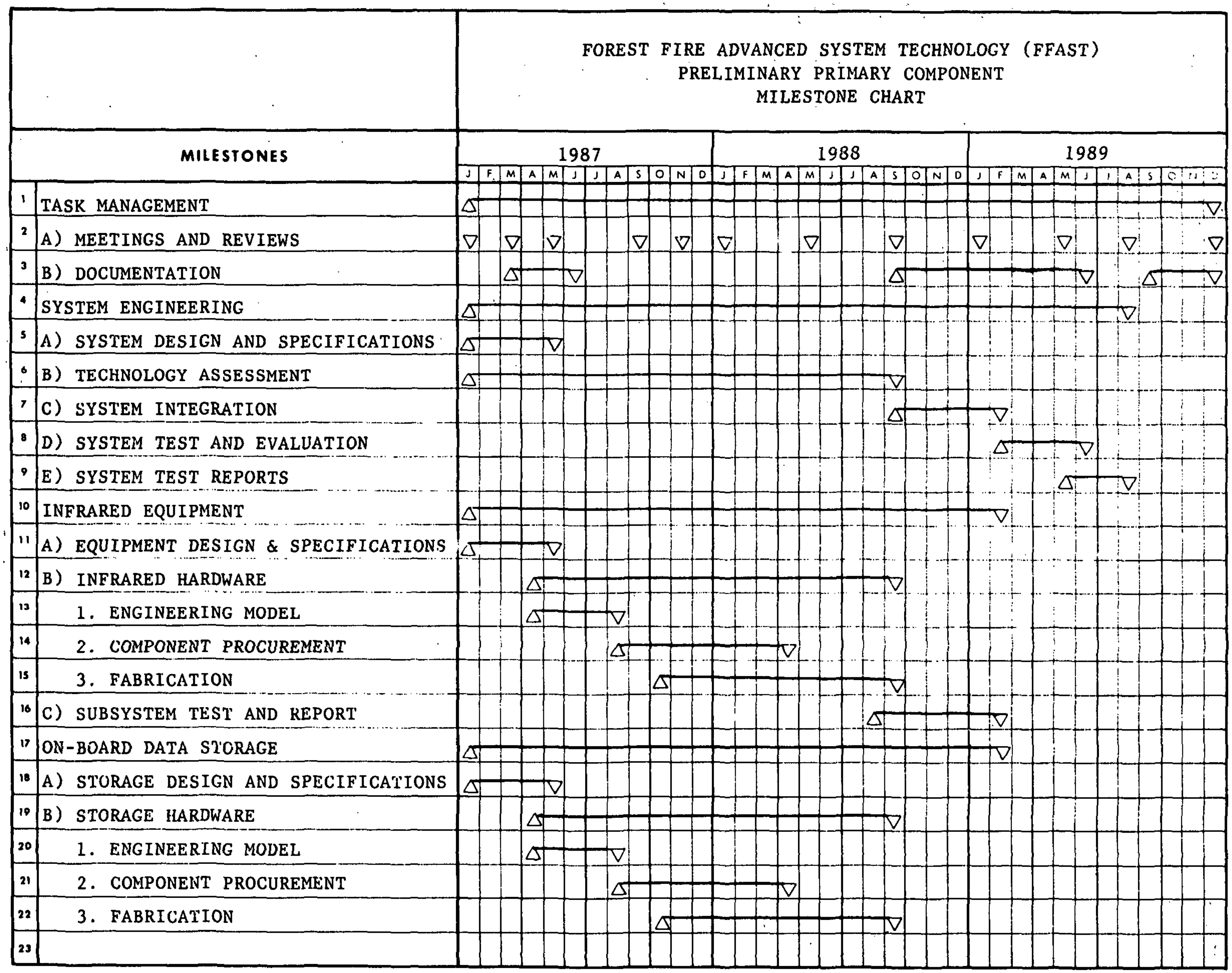

Figure 6-3. FFAST Preliminary Primary Component Milestone Chart

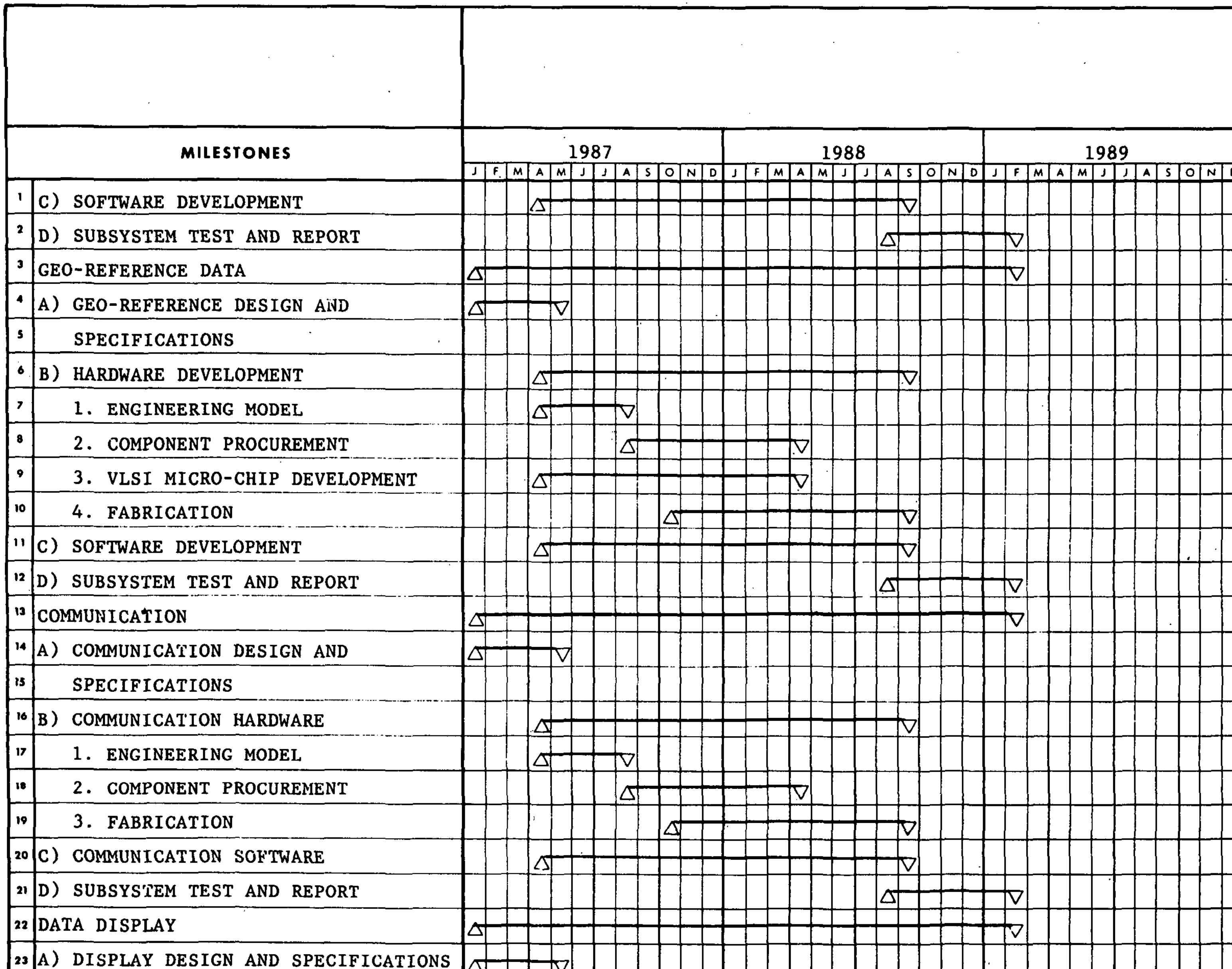

Figure 6-3. (Contd)

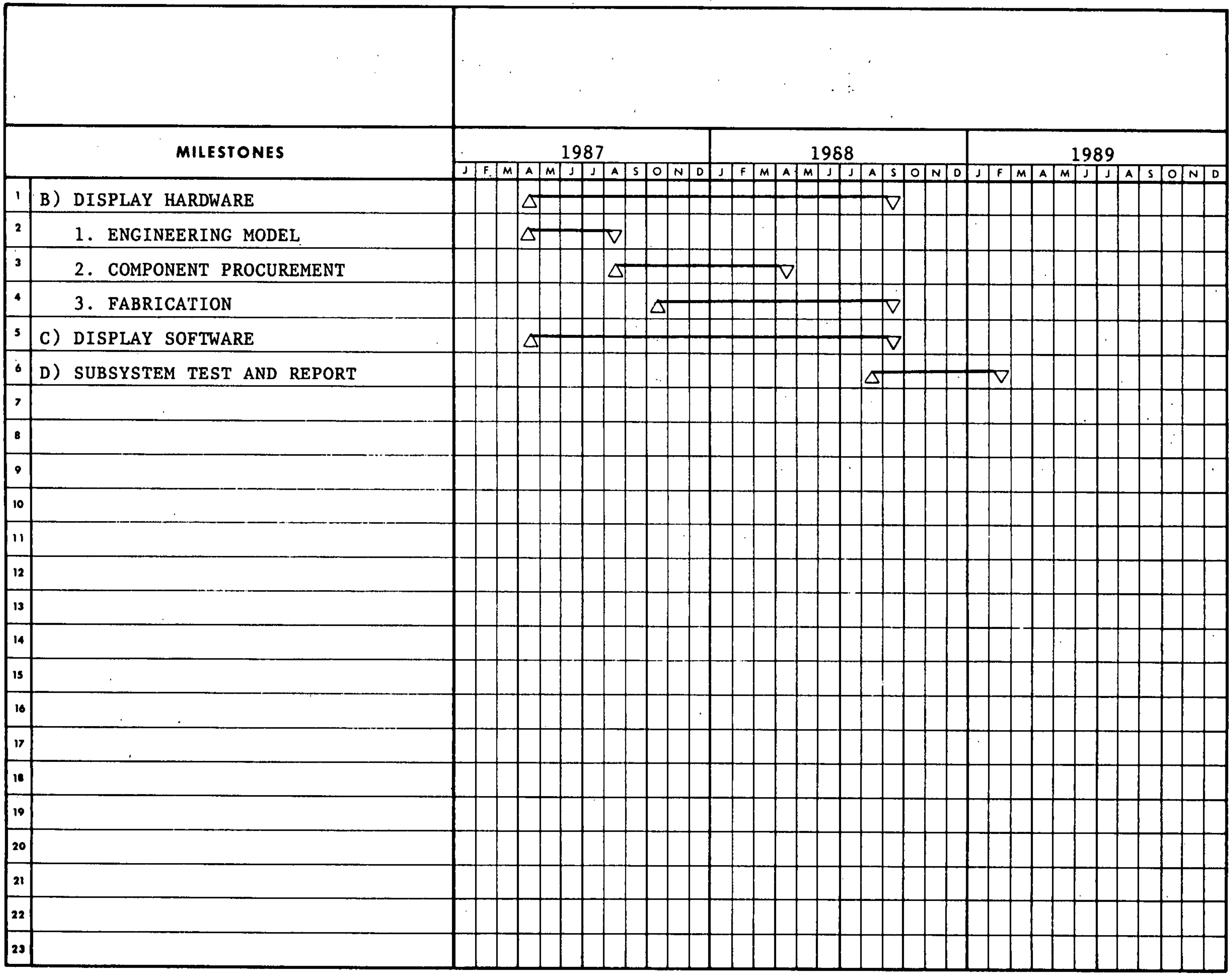

Figure 6-3. (Contd)

Table 6-2. Preferred System Configuration Component Projected Cost and Contingency Estimates by Primary Physical Component

Subsystem	Cost Estimate ($K)	Cost Contingency ($K)
Primary Components		
Data Collection:		
Thermal Infrared Linear Array Detector Equipment	500	250
On-Board Data Storage:		
Optical Disc Player	20	5
Custom Control Board	2	1
Microcomputer	10	2
Monitor	4	1
Georeference Data:		
VLSI Micro-chip	30	5
Satellite Receiver (one unit)	7	3
Communication:		
Transmission unit	3	1
Receiving unit	3	1
Data Display:		
CPU Microcomputer	10	2
Custom Control Board	2	1
Monitor	4	1
Pen Plotter	15	3
Totals	610	296

Cost Estimate + Cost Contingency = $610,000 + $296,000 = $906,000

Table 6-3 Preliminary Projected Labor, Services, and Travel Costs by Fiscal Year (In Thousands of Dollars)

	FY 88	FY 89	FY 90	Total
Cognizant Labor	191	203	216	610
JPL Burden	137	146	156	439
Services	2	5	8	15
Travel	8	8	8	24
Totals	338	362	388	1088

SECTION 7

CONCLUSIONS AND RECOMMENDATIONS

The decision to proceed with the FFAST Conceptual Design Study was based upon results of the FFAST Feasibility Study (McLeod, 1983) which evaluated the potential of advanced technology applications for improving the acquisition and use of fire information. The objective of the Conceptual Design Study was to examine how to design a forest fire detection and mapping system based upon technology that will be available in the 1990s. The Conceptual Design resulted in a preferred system configuration that is responsive to the identified needs of the USDA-Forest Service user community for improved accuracy, timeliness, reliability, maintainability, and compatibility with other systems.

System user requirements were collected from numerous meetings with personnel in the Forest Service regions. The user needs resulted in the construction of functional requirements that identify the functions necessary to satisfy user requirements for an improved fire detection and mapping system. The items identified in the Functional Requirements (Dutzi, 1984) fall into two categories: (1) basic requirements, including accurate acquisition and timely georeferencing and delivery of IR data, improved communications, improved data display, and compatibility with other systems, and (2) desired attributes that may not be as clearly defined.

The functional requirements were refined using the Value Analysis and Tradeoff Evaluation Procedures. These efforts resulted in the identification of outstanding technical uncertainties, the development of a comprehensive list of alternatives for each function, and the creation of candidate system configurations. In parallel with the refinement of the functional requirements was the development of a technology assessment for the basic functions of the system. The technology assessment resulted in the identification of generic traits and off-the-shelf commercial components for the system configuration. A large quantity of vendor material was collected to support the technology assessment.

The candidate system configurations were evaluated for technical feasibility and consistency with functional requirements. The preferred system configuration is both feasible and cost effective. Preliminary costs and schedules have been presented that show projected plans to develop a system that would incorporate existing and future technologies to fire management information needs. With the current expertise available and the benefit of past experience both in fire management and advanced technology, it is strongly recommended that the preferred system configuration be directed for further development.

SECTION 8

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APPENDIX A

TECHNOLOGY ASSESSMENT

The following has been excerpted from the Preliminary Technology Assessment, written August, 1984 (unpublished).

1 DATA BASES AND DATA BASE MANAGEMENT SYSTEMS (DBMS)

1.1 Data Bases

A variety of data bases are being considered for use in the advanced system design. The foremost of these data bases are those that are directly related to real-time tactical decision making. Also, data bases that can aid in the detection of a fire incident are also under consideration. While the advanced system will be characterized by its mapping capability, it will also be a detection system. Many existing data bases in the USDA-FS as well as other Federal agencies may be considered for incorporation into the FFAST system. The data bases that are incorporated into FFAST will have standardized formats and be computer compatible within the final FFAST system configuration. System flexibility will have to be designed to be able to integrate future data bases after implementation of FFAST.

The following is a summary of candidate data bases. The associated Technology Evaluation Matrix is Figure 4.

1.1.1 USGS Digital Line Graphs (DLG)

Data are collected from 7.5 minute source materials at scales of 1:24,000 or 1:25,000 wherever possible. If 7.5 minute sources are not available, then 15 minute sources at 1:48,000 or 1:62,500 scales are used.

The digital data are useful for the production of cartographic products, including base maps, and the data are structured to allow a series of analytical functions to be performed on them such as in a geographic information system. With these data entered as base map data, other geographically referenced data can be combined, thereby enabling automated spatial analyses to be conducted interactively.

Digital Line Graph files derived from 7.5 and 15 minute maps contain selected base categories of cartographic data in digital form. These data categories do not necessarily correspond to the traditional feature separates associated with graphic maps. The current DLG files may include one or more of the following categories:

(1) Boundaries -- Boundary data consist of political boundaries that identify states, counties, cities, and other municipalitis and administrative boundaries that identify areas such as national and state forests. Political and administrative boundaries are always collected as a single data set.

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FIGURE 4. Technology Evaluation Matrix: Data Bases

CRITERIA \ TECHNOLOGY	DLG	NHAP	TOPO MAPS	AFFIRMS	ALDS	DTM	GEOLOC
Cost	$20 to $50/ layer	$3 for b/w negative to $12 for CIR positive	$2.25 to $3.60/ quad, depending on scale	Nominal	Nominal; BLM accessible	DTT: $100/tape DEM: $100-125/ tape.	Primary cost is digitizing data
Availability	Yes	Complete U.S. coverage by mid-1985	Yes	Yes	Yes	Yes	Yes
Format	Vector		Paper			DTT: raster DEM: vector	
Computer System		N/A	N/A	Honeywell L-66	Data General 20; LLP RDP 80-02		Prime 550
Accuracy	Contour-dependent	High	High		1-2 km near sensor, 6-8 km near perimeter of sensor range	DTT: poor DEM: 1:24, 7 meters	High; down to 10 acres
Medium	9-track tape	Photographic film or paper	Paper	Paper	Paper; graphics capability	9-track tape	9-track tape
Contents	Boundaries; hydrography; transportation	Aerial photography	Topography; boundaries; hydrography; transportation; vegetation	Fire danger indices	Cloud-to-ground lightning detection and location	Digital elevation data	Topography; fuel type
Resolution		Good	Good			DTT: 208 ft. DEM: 208 ft./ 30 meters	
Compatibility	Good	Would need to be digitized	Would need to be digitized			Good	Would need to be digitized
Other	o 7.5 and 15 minute maps.	o Scales of 1:80,000 and 1:58,000; other scales possible		o Archives fire weather o Tabular output; no graphics	o Requires telephone link o BLM system o Tabular output		o Limited to So. Calif. o Graphics capability being developed

(2) Hydrography -- Hydrographic data now being collected consist of all flowing water, standing water and wetlands. Prior to 1983, hydrographic data were differentiated into two separate components: streams and water bodies. Streams represent flowing water and were digitized as a network intended for hydrologic flow modeling. Streams included the banks of double-line rivers and centerline connectors placed through double-line rivers and lakes. Water bodies include standing water such as lakes and ponds. Wetlands and coastal hydrographic data were not collected.

(3) Public Land Survey System (PLSS) -- The PLSS data describe the rectangular system of land surveys which is administered by the U.S. Bureau of Land Management. PLSS data are only collected for areas falling within the states formed from the public domain. The PLSS subdivides the public domain and represented property boundaries or references to property boundaries. These DLG data are not intended to be official or authoritative. They are presented as cartographic reference information. The only legal basis for determining boundaries remains the original survey.

(4) Transportation -- Transportation data include the major transportation systems differentiated into roads and trails, railroads, and pipeline and transmission lines. Data for all three are combined into a single data file, labeled transportation, for areas with sparse features. In areas with a dense transportation infrastructure, the data are collected in three separate sub-categories labeled: roads and trails, railroads, and pipelines and transmission lines.

The term digital line graph is employed by the USGS to describe a digital map data set in vector format in which the data are structured to one of the following levels.

(1) Level 1 -- This is the simplest structure which maintains the original (raw) data in a standardized format, coded to prescribed standards, and edited for normal input errors. The main purpose of this level is to meet three needs: (1) to provide a source of digital data quickly; (2) to provide data to users who can complete the structuring process; and (3) to provide data for plotting or display systems of low or moderate cartographic quality.

(2) Level 2 -- This structure is designed to support graphic display or plotting equipment of high cartographic quality. Level 2 DLG files contain extensive attribute codes that describe the graphic elements.

(3) Level 3 -- The third structure is used for fully topologically structured data files designed to be integrated into geographic information systems. All topological relationships have been defined for Level 3 DLG data.

These levels do not easily aggregate in an upward direction.

Cost for 7.5 minute boundary and land - net DLGs are $20 per layer; for hydrography and transportation, $50 per layer.

No DLG data set covers more than one-third of the U.S.; hydrography and transportation coverage are especially limited. DLG production currently is not a higher U.S.G.S. priority.

1.1.2 National High-Altitude Photography Program

The National High-Altitude Photography Program (NHAP) is a multi-federal agency activity (including the Forest Service) coordinated by the USGS to acquire uniform imagery to establish a nationwide high-altitude photographic data base.

Aerial survey contractors use aircraft modified to house dual 9 - x 9-inch format precision aerial mapping cameras. One camera has a 6-inch (153mm) focal length lens, uses panchromatic black-and-white Kodak 2404 film, and produces a photograph at a scale of 1:80,000 (1 inch to about 1.25 miles). The second camera has an 8-1/4-inch (210mm) focal length lens, uses Kodak 2443 color infrared film (CIR), and produces a photograph at scale of 1:58,000 (1 inch to about 0.9 miles). Each black-and-white photograph covers an area of about 130 square miles; each CIR photograph covers an area of about 68-square miles.

The aircraft fly in a north-south direction over predetermined flight lines crossing the centers of Geological Survey 7.5-minute quadrangles and operate at a constant altitude of approximately 40,000 feet above the mean terrain. Film is exposed to provide stereoscopic coverage. There are an average of three black-and-white exposures and four CIR exposures for each 7.5-minute quadrangle. Approximately 120,000 black-and-white and 175,000 color infrared photographs are required for the complete coverage of the coterminous United States.

The primary products available are 9- by 9- inch and 2X, 3X, and 4X enlargements for black-and-white and CIR photographs in film or paper print format. A film negative is available only for black-and-white photograhy in the 9- by 9- inch size. However, products can be prepared in custom formats.

Costs are separated by list or contributor. Contributor's prices are as follows:

- 9 x 9" color paper	$ 7.00
- 9 x 9" film positive	12.00
- 9 x 9" black-and-white negative	3.00
- 9 x 9" black-and-white paper	4.00

First-time coverage of the coterminous United States is expected to be complete by mid-1985. The need for second-time coverage has been expressed by the participating agencies; implementation is as of yet unscheduled. A separate Alaska High-Altitude Program (AHAP) provides 1:65,000-scale black-and-white and color infrared photographs, and was completed in fiscal year 1983.

1.1.3 Topographic Maps

Topographic Maps are comprehensive paper quadrangles produced by the USGS in scales of 1 to 24,000; 25,000; 48,000; 62,500; 63,360; 100,000; and 250,000.

Besides topography, data includes political boundaries, cultural locations such as cities, metropolitan areas and towns, transportation networks, hydrography, and vegetation types.

Maps in scales of 1:24,000 to 1:63,360 are currently $2.25 per quad. Maps in scales of 1:100,000 and 1:250,000 are $3.60 per quad.

There is total U.S. coverage in 1:250,000-scale quadrangles, and considerable coverage in scales of 1:24,000; 50,000; and 100,000 scale are for selected areas. Map production in 1:24,000-scale is continuing; complete U.S. coverage is expected by 1990. Production on a programmatic basis in other map scales has been discontinued.

1.1.4 Administrative and Forest Fire Information Retrieval and Management System

The Administrative and Forest Fire Information Retrieval and Management System (AFFIRMS), developed by the Forest Service in 1968, updated in 1978, is an interactive computer program which interfaces meteorological data collected daily within a 50 mile radius of Forest Service weather stations with selected data bases located at BIFC to rate the next day's fire danger for that station area. Fire danger ratings are distributed to the respective Forest Service station and periodically archived on magnetic disks at the National Fire Weather Data Library, Ft. Collins, Colorado. Fire weather data goes back 10-15 years, depending on the area, and serves to continually improve the fire danger rating models. (Furman, 1975)

Raw weather data (rain, wind speed, wind direction, air temerature, relative humidity, barometric pressure, fuel moisture, fuel temperature, soil temperature, and solar radiation) is collected and transmitted to BIFC by one of two means: manually operated weather stations and by Remote Automatic Weather System (RAWS) stations. Data is collected at 1:00 PM. Manually collected data is typed to BIFC; RAWS data is transmitted automatically via satellite link. (There is a stated but slow objective to implement RAWS systemwide.) (Moomey, 1984)

Weather data is then interfaced with latitude/longitude, fuel type, elevation, slope, climate class, and land ownership data bases to forecast the following next-day fire danger components: air temperature, relative humidity and fuel moisture, and energy release, lightning risk, man-cost risk, ignition, burning, rates-of-spread, and fire load indices.

(The Automatic Lightning Detection System is not a part of AFFIRMS, but data can be accessed from BLM for selected areas.)

AFFIRMS operates on a Honeywell L-66, located at BIFC.

Output is tabular; no graphics capability.

1.1.5 Automatic Lightning Detection System

The Automatic Lightning Detection System (ALDS) is the lightning detection subsystem of the USDI-BLM's Initial Attack Management System. It was designated in 1976 by the University of Arizona for use by the BLM in Alaska. The capability is now manufactured as the Lightning Location System by Lightning Location and Protection, Inc., Tucson, Arizona. Users other than the BLM with their own system include several Canadian forest fire protection agencies, various international electric power and telecommunication agencies, defense facilities, weather services, and research organizations. Lightning locations systems are used to determine the location, movement, and intensity of thunderstorms; to facilitate early detection of lightning caused fires; and to warn of impending lightning hazards.

The system components are lightning direction-finding stations, a position analyzer, and a synchronous communications link (currently via telephone networks) between the two.

Direction Finders. A direction-finder station (DF) operates as either a stand-alone system, often in conjunction with weather radar, or as part of a larger network that contains a position analyzer. A microcomputer built into the DF digitizes and stores lightning-electromagnetic signals for up to 14 return strokes in each flash to the ground, computes the angles to each stroke, and stores the results in buffer memory for subsequent output. The total number of flashes that are detected each hour, or for an operator-determined time interval, are available for display or for typing on command. The DF microcomputer can also transmit the angle and signal strength data for each discharge to a position analyzer where individual lightning locations are computed.

Position Analyzers. A position Analyzer (PA) is a preprogrammed microcomputer system which automatically computes, maps and records lightning locations in real-time using as inputs the data generated by two or more DF stations. Lightning location is computed from the intersections of simultaneous direction vectors and/or from the ratio of the signal strengths measured at two or more direction finding sites. The PA receives data from the remote DFs, calculates lightning position, and outputs the results in real time to a digital x-y plotter, a magnetic tape recorder, and/or a local data terminal. The system provides the time and location of each discharge, the number of return strokes in each flash, and the peak amplitude of the return stroke magnetic field. Remote display processors are available for plotting color TV and/or hard-copy maps of lightning locations at any number of remote sites.

The nominal range of each DF station is a circle with a radius of about 400 km. Based on vendor studies, each DF station detects at least 80-90% of all cloud-to-ground flashes that occur within the nominal angle. Lightning location accuracy is 1-2 km near the DF station, and 6-8 km at the perimeter of the DF range. The average meantime between failures of these systems is 8,000 hours per DF; 18,000 hours per PA. (Maier, 1984)

ALDS currently operates from 33 DF stations in 11 western states and eight stations in Alaska, each connected to a PA at BLM centers in Boise and Fairbanks, respectively. ALDS coverage comprises all BLM centers in Boise and Fairbanks, respectively. ALDS coverage comprises all BLM land, 95% of the western United States, and a substantial portion of Alaska. The Forest Service could access ALDS data from either facility. A primary question would be the cost-effectiveness of expanding existing ALDS coverage, or perhaps contracting with other users, to include more or all Forest Service land.

ALDS operates on Data General 20 (desktop) minicomputers. The vendor also manufactures a dedicated processor, model RDP 80-02.

The format of the typed locations can be (1) Angle-Range with respect to any origin with the distance units in kilofeet, kilometers, statute miles, or nautical miles; (2) North-South and East-West coordinates; and (3) a latitude/longitude format.

1.1.6 Digital Terrain Models

Digital terrain data currently exist in two forms: Digital Terrain Tapes and Digital Elevation Models. Both forms are computer compatible, have been easily integrated with other geograhical data bases, and are available only on 9-tract tape. Capacity per tape is computer-dependent.

Digital Terrain Tapes (DTT) are produced by the Defense mapping Agency. Each tape is a 1:250,000-scale, raster formatted, binary quadrangle; resolution is 208 ft. Coverage comprises the coterminous U.S. and Hawaii. Cost per tape is $100.

DTT has the singular disadvantage of being produced from haphazardly acquired, 30-year old data. Horizontal and vertical accuracy is considered to be poor and inconsistent, with no correction factor for error adjustment. (Brownworth, 1984)

Vector formatted Digital Elevation Models (DEM) are in scales of 1:250,000 and 1:24,000.

DEMs at 1:250,000-scale are available in planar and arc-second reference grids. Planar grids are in binary mode; resolution is 208 ft. Arc-second is both binary and ASCII (which is wider compatibility); resolution is 225 ft. Coverage is the entire U.S. and a "large portion," respectively. Elevation accuracy is contour-dependent in both grid forms. Cost per tape is $100.

1:24,000 tapes are planar grids in both binary and arc-second modes; resolution is 30 meters. Elevation accuracy is seven meters; cost per tape is $125.

The primary limitation of 1:24,00 DEMs is its spotty coverage and slow rate of production. Current area coverage is estimated to be 10-15% of the U.S., with complete coverage not expected until at least 1995.

1.1.7 Geographical Location System

The Geographical Location System (GEOLOC) evolved from the FIRESCOPE project as an effort to develop a common referencing system for tactical operations. GEOLOC uses a seven character designation to identify land parcels down to 10 acres. The smallest scale retrievable is 1:100,000. As the character designation, or cells, are assigned, it is possible to aggregate to the large scale 1:6,000. Cross indices exist for latitude/longitude, as well as Township and Range. The gridded structure of GEOLOC makes data base integration easy to implement.

Output is paper-copy topography and fuel-type text; data base exists for all of Southern California. A graphics capability is being developed. Currently, 7.5 and 15 minute Digital Elevation Models of the FIRESCOPE area have been assigned GEOLOC reference cells. Additionally, a U.S. firm, Aerial Information Systems (AIS), has been contracted to begin assessing the data needs of the participating FIRESCOPE agencies to eventually digitize and interface such data into the GEOLOC-DEM data base. Actual AIS production of a digital data base using GEOLOC reference designations is to date unknown. Area covered in this project will be limited to the FIRESCOPE (Southern California) area. (Harnden, 1984)

The principal responsibility for GEOLOC development has transferred from the Forest Service to the California Office of Emergency Services and the participating counties. There exists a GEOLOC-equivalent reference grid for each Forest Service region. There is no indication that the Forest Service at present plans to expand the GEOLOC coverage area in either its narrative or digital form.

The primary cost of implementing GEOLOC beyond the FIRESCOPE area in a format applicable to FFAST would be the hardware cost of data display and processing, and the software cost of digitizing the selected data bases.

The USGS has produced DEMs of Southern California on a cost-share basis with FIRESCOPE for $1,000 total cost per quad. Production cost has recently increased to $600 per share. There is no available information of AIS contractual cost for producing the digital data base. GEOLOC data is currently accessed from a PRIME 550; there is no graphics capability.

1.2 Data Base Management System

A data base management system serves as a centralized manager of data bases, controlling access to and integration of selected data. The following is a summary of DBMSs, the associated Technology Evaluation Matrix is Figure 5.

1.2.1 Forest Level Information Processing System

The Forest Level Information Processing System (FLIPS) is the agency-wide information management system implemented by the Forest Service. Currently, approximately one-third of the 920 FLIPS workstations are operational; full implementation is expected late 1987. Some $2 billion has been budgeted for this project. (Gale, 1984)

There are two components of FLIPS. The primary design function is as an electronic office management system (e.g., word processing, archiving), while linking each Forest Service station via electronic mail. The second function is the capability for data processing.

Each FLIPS workstation is an integratable, user friendly Data General MV 4000 or MV 8000 minicomputer. Designed system lifetime is eight years, thus, FLIPS will remain the Forest Service's information management system.

1.2.2 Map Overlay and Statistical System

The Map Overlay and Statistical System (MOSS), developd by the Fish and Wildlife Service at Ft. Collins, Colorado, is a digitized geographic information, map overlay system. Once selected map bases have been entered onto the MOSS tape, data manipulation can range from simple map display to advanced cartographic modeling.

There are three subsystems contained in MOSS: data entry (Analytical Mapping System), or (AMS); data analysis and display (also called MOSS); and the Cartographic Output System (COS) to produce high-quality map products.

MOSS can analyze both vector - and grid cell (raster) - formatted data. The cellular processing capability expands the range of data availability to include Landsat imagery and elevation and terrain models. Although actual data storage is a function of hardware capacity, tape density, and data bits used, it has been stated that a MOSS tape could store some 32,000 7.5 minute quads. (Lee, 1984)

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FIGURE 5. Technology Evaluation Matrix: Data Base Management Systems (DBMS)

CRITERIA \ TECHNOLOGY	FLIPS	MOSS	IBIS	iDIS	IDIMS	WFMAS	FLMP	IAMS
Cost	$340 million, systemwide	$120/tape; primary cost in digitizing data	$1,200	$15,000 to $17,000 (w/o PCs)		few dollars/ run	nominal; gov't publication	nominal; accessible at BIFC
Availability	Yes; full implementaton, 1987	Yes	Yes	Yes	Yes	Operational	Varying degrees of completion; mandated to be completed by 1985	Yes
Computer System	Data General MV 4000 MV 8000	Data General MV Series, desktop 20, C-350; VAX-VMS	IBM PDP mini	Intel 8086 microprocessor	VAX-11/780 HP 3000	Simulation on UNIVAC	Land use and impact simulation on UNIVAC	Data General MV Series, desktop 20
System Requirements			OS/VMS RSX-11			FLIPS accessible		ALDS requires telephone access
User Friendliness	Yes	Yes; 20 hr learning curve	No	Yes	Yes	Yes; 3-7 day learning curve	Document	Reasonable
Other	o Graphics capability. o Primarily office management application	o Analyzes vector and raster-formatted data o Tape can store 32,000 7.5 quads	o Difficult, cumbersome to use o Raster format can integrate graphical & tabular data	o Turnkey DBMS o Interface between PCs and mainframe, or stand-alone	o Manipulation, analysis, interpretation and processing of image data	o Budget efficiency tool o Tabular output; no graphics o Analysis conducted on per need basis	o Comprehensive forest use plan o Reviewed every 5 yrs o Uses timber, range, wildlife, landownership & recreational use inventory data	o Data bases: ALDS RAWS Fire fuel Terrain Fire incidence Spread models

The F&WS is currently implementing a fire management program in Alaska using MOSS (called Lightning Strike) which will integrate fuel type, land ownership, fire danger status, hydrography, and political boundaries data bases with the Automatic Lightning Detection System.

Cost per MOSS tape is $150 (or $120, without user manual). The primary cost of implementing MOSS, as with most GISs, is data entry, e.g., digitizing the selected data basis. The Forest Service, Forest Pest Management, in a 1981 test project using F&WS hardware, software and computer personnel, was able to construct and analyze a nine theme multi-resource data base* from 18 USGS 7.5 topography maps which comprise a selected county for $15,000 or $0.067 per acre. (Pence, 1983) Initial cost of creating a data base of this type would increase considerably if hardware had to be purchased or the MOSS software was converted to another computer system.

MOSS has been designed to operate on Data General C-350, MV series, and DG-20 (desktop) minicomputers. MOSS has also been integrated into a VAX-VMS computer at the EROS Data Center, Sioux Falls, South Dakota. Data can be accessed in batch or demand mode via a graphics terminal.

1.2.3 Image Based Information System

The Image Based Information System (IBIS) is a raster-based information system developed by JPL as a subset of is overall Video Image Communications and Retrieval (VICAR) image processing techniques to be applied to interface existing geo-coded data sets and information management systems with thematic maps and remotely sensed imagery.

The image formatted Data Plane is the primary data type utilized in IBIS processing. IBIS data planes may be obtained directly in image form, as in satellite imagery, or they may be derived from data compiled from statistical and cartographic sources. Regardless of data type and origin, all data planes are incorporated into a data set which is referred to as the IBIS Data Base. In order to maintain geometric consistency between all data planes included in the data base, an image plane with good radiometric or planimetric qualities is designated to be the Planimetric Base. All other data Planes are geometrically corrected to allow registration to the planimetric base.

The user of IBIS can integrate various data types to form an IBIS data base. Since the primary data structure is a raster format, image data planes are directly entered into the system. Graphical forms of data, usually obtained in cartesian reference form, must be transformed into image space prior to inclusion as a data plane. Tabular data are not transformed into image space, but are linked to the image data base through a logical interface. Logical and mathematical interfaces have been provided to link all data files in an IBIS data base superstructure. By utilizing these interfaces, information may be derived from simple associations, or from

*County boundary, forested areas, landownership, roads, major streams, towns, and three factors specific to pest management.

comparisons between two or more data files stored in an IBIS data base. (Huning, 1982) An average run costs $1,200 per procedure. IBIS operates on VAX and PDP minicomputers. IBIS is considered difficult and cumberson to use.

1.2.4 Intel Database Information System

The Intel Database Information System (iDIS) is a multi-user, multi-tasking microcomputer system developed by Intel Corporation which controls the bidirectional flow of information between mainframe computers and a network of terminals and personal computers. The configuration enables end users to access the central mainframe data base and download a subset of that data base to the iDIS system; it also allows iDIS users to create, populate, and share a local relationship data base for specific information processing needs.

The iDIS system can be configured as either a gateway in the mainframe to micro flow of data or as a stand-along processor with shared data base capabilities. The system can serve as a host controller, data base manager, a terminal/PC concentrator, and a vehicle for communication networking.

The standard iDIS 735 hardware components include the Intel 8086 16-bit microprocessor with a workspace of 768 Kbyte RAM memory; a Winchester hard disk with 35 Mbyte capacity (expandable to 105 Mbyte in 35 Mbyte increments); and an 8-inch floppy-disk drive with 2 Mbyte memory. Optional components include communications boards for remote mainframe access, user terminals, and printer.

The iDIS system supports up to nine ergonomically-advanced terminals. Each has a multi-position display screen, detachable keyboard, and two RS232C serial interfaces; it is user friendly.

Data transfer between the iDIS processor and the PC occurs at an effective transfer rate of 9600 baud if the computers are directly connected, or at 1200 baud if they are connected by dial-up links.

The iDIS system features the iDB subsystem, a full-function, mainframe DBMS implemented in the microcomputer environment. The iDB local relational DBMS supports an interactive query/update interface compatible with IBM's SQL language.

The iDB user can specify and implement a comprehensive relational data base that can be used for selecting and sorting specific data sets. Multiple users can concurrently access iDB data bases with update lockout at the relation level, while all users can simultaneously read the same relation.

The iDB manager can function as a local stand-alone DBMS, serving a network of iDIS workstations and PCs; it can also be used in conjunction with the iDIS data base extract facilities to manipulate data that has been downloaded from a mainframe host computer or uploaded from a PC.

Data can be loaded into iDB relational data bases from:

(1) Mainframe data bases.

(2) PC files.

(3) Manual (keyboard) entry.

The iDB DBMS features:

(1) Dynamic allocation off storage (up to the iDIS storage limit) with no restrictions on data sizes, table sizes, and numbers of attributes.

(2) Extensive on-line "help" facilities.

(3) Interactive data base definition and update facilities.

(4) Simultaneous multi-user access to the same data base under system integrity control.

(5) Indexing on any attribute for rapid data access.

(6) Report generation capabilities.

(7) Bulk loading and unloading utilities for rapid transfer of data among files and data bases.

(8) Integrated line editor for command modification and for correction of syntax and input conversion errors.

(9) Table and attribute names of up to 31 characters, including spaces.

(10) Renaming of a table and its attributes without dropping and recreating that table.

1.2.5 Interactive Digital Image Manipulation System

The Interactive Digital Image Manipulation System (IDIMS) developed by ESL Incorporated is a system designed for manipulation, analysis, interpretation and processing of a wide variety of image data.

The core of IDIMS is currently a VAX-11/780 or a HP3000 multiprogramming minicomputer; the distinction is primarily one of computer capacity. The VAX can be configured with up to 4 Mbytes of main memory and over 6 billion bytes of disk storage. The HP3000 is supported by up to 2 Mbytes of main memory and more than 1 billion bytes of disk storage. Data are input into either system by means of a magnetic tape, film scanner, microdensitometer or digitizing tablet. Results of processing may be viewed and photographed from a high resolution color display, or may be printed on a line printer or plotter. Final results may be recorded on film by a film recorder, printed on a plotter, or transferred back to magnetic tape. To significantly increase processing throughput, an array processor may be added.

ESL has been under contract with NASA since 1978 to develop in support of the Bureau of Land Management quantitative inventory techniques which integrate remote sensing data with existing geographic data bases to enable vegetation type mapping and productivity estimates.

Currently, geographic information operations are implemented within IDIMS using the following software packages in conjunction with IDIMS software.

Geographic Entry System. The Geographic Entry System (GES) is designed as a management information system specifically for geographic data. It supports long-term management of resources including providing information necessary to determine the effect of alternative decisions on specific issues.

Computerized GES data consists of land area boundaries, features, and descriptors in a location-oriented structure. Map-type data depicting land use, zoning information, transportation networks, school districts or locations, soil types, rainfall, and similar data are interactively entered into the GES data bank and structured as a set of map overlay files. Each data structure is designed to store six types of items: geo-blocks, overlays, areas, junction points, line segments, and control points. The structure permits computer analysis of combinations of overlays to produce computer-generated map overlay plots of specified scales and tabulated statistical data.

The GES data base is maintained in vector format which consumes less storage space than equivalent matrix or raster schemes. Conversion to image form and geometric registration are accomplished in a separate step, making the creation of the GES data base essentially independent of the imagery to be overlaid.

Earth Resources Inventory System. The Earth Resources Inventory System (ERIS) is a software package for the integration and analysis of earth resource data. The data may come from a variety of sources including the IDIMS images, aerial photointerpretation and ground-collection. It is a collection of 11 programs that use a common data file structure allowing easy access to the data files stored on the system disk(s). ERIS manipulates files and performs calculations, creates new files, and provides descriptive statistics of the contents of these files. It is primarily intended for interactive operation using a data terminal, although it can also be operated in batch mode.

The ERIS file is best understood as a table with a certain number of rows (or cases) and a certain number of columns (or variables). The cases represent some physical entities of the same type about which data has been collected, e.g., a set of trees, a set of circular one-acre plots or a set of resource strata. Each variable represents an attribute of the group of physical entities that may be either an identifier or a measure variable.

ERIS files may have a maximum of 32,767 cases and 35 variables. Up to eight-character alphanumeric names are supplied by the user for the file and for each variable in the file.

1.2.6 Forest Land Management Plan

As mandated by the 1976 National Forest Management Act, and in accordance with the National Environmental Protection Act, each national forest must have a Forest Land Management Plan (FLMP) by 1985. Additionally, each FLMP must be reviewed at least every five years, and revised every 10-15 years.

FLMPs are intended to be a comprehensive land use plan. Inventory data on timber, range, wildlife, landownership and recreational use, and value added data on soil type and hydrography, are entered into computer simulation models to assess various long-term environmental and economic impacts of different land-use scenarios. For example, given an existing inventory of timber, and soil type and hydrography, what would be the environmental and/or economic impact of increasing timber yields or recreational use over time.

FLMPs are essentially a continuing environmental impact study of each national forest, and are conducted in much the same manner. Each devised plan is open to public input and challenge.

The simulation model used, developed by the Forest Service is called FORPLAN. FORPLAN is integrated into the Univax at Ft. Collins, Colorado. FLMPs themselves are available as published documents.

Within the regulations and guidelines providedby Congress, FLMP procedures are given considerable leeway per forest. This is due largely because of the varying ecological and economic variables between forests. Consequently, there is limited consistency among Forest Service FLMPs.

FLMP applicability to FFAST appears to be limited to various fire danger projections derived from knowing land-use patterns.

1.2.7 National Fire Management Analysis System

The National Fire Management Analysis System (NFMAS) is a budgetary tool which applies traditional concepts of economic efficiency to evaluate existing fire management programs against a set of alternatives to determine the optimal program at the lowest program cost for wildfire management in a forest section, a forest, a region, and at the national level.

The general approach used in this analysis systematically evaluates a range of budget levels and fire management programs to identify an alternative which will, over time, minimize cost* plus net value change** while meeting protection and management objectives.

The specific process used to analyze the costs and effectiveness of candidate program alternatives is based on the concept that an evaluation of performance must be conducted against the range of fire related activities that are reasonably expected over time in a respective land area. Accordingly, the process was developed based on <u>expected</u> values (weighted averages). This is accomplished by integrating the effects of individual fire management functions (fuel treatment, prevention, detection, initial action) for an alternative program and systematically testing (in computer simulation) each alternative against a set of hypothetical fires. This set of fires is a statistical sample both of the locations at which fires would occur on that land-unit over time, and the range of intensities and rates of spread at which they could burn. For each fire event, a final fire size, natural-resource effects, value change and suppression costs are predicted. These predicted values for each event are then weighted by the probability of that event occurring (i.e., a fire at that location, rate-of-spread, and intensity). The expected average annual acres burned (by fire, size and intensity) and cost plus net value change are then calculated based on he annual fire frequency. Finally, these expected annual averages for each representative fire are summed for each proposed budget level or program to provide a representation of the area total.

In identifying the minimum cost plus net value change, the process uses a current of level and mix (i.e., the budget and distribution of the dollars to fuels, prevention, detection, and initial action) as a baseline. The cost plus net value change is then determined for that program mix at different budget levels and the budget associated with the minimum cost plus net value change criteria. Economic efficiency is obtained at the lowest point on a requirements/cost curve. (Forest Service, 1980)

NFMAS analysis are intended to be conducted on a per need or program-change basis. The only national analysis was conducted in 1980, and the data base is still in place. A second generation analysis is currently being taken; there is no indication when this will be completed.

To date, approximately three-fourths of the national forests are using NFMAS to identify forest fire management programs and budgets. (Chase, 1984)

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* Cost* The sum of prevention, detection, initial action, and suppression expenditures; also, the sum of the Forest Fire Protection (FFP) and Fighting Forest Fire (FFP) and Fighting Forest Fire (FFF) appropriations.

** Net Resource Value Change: The sum of the changes resulting from increases and decreases in the value of outputs from a land area as a consequence of fire. Variables considered include commercial timber, commercial forage, water uses, water storage, wildlife and fish habitat, recreational effects, and capital improvements.

Conversations with Forest Service personnel indicate the following:

1. Cost is minimal; a few dollars per run.

2. The simulation is run on a UNIVAC at Ft. Collins, Colorado. The computer model has an operational limit of 300-acre fires; beyond that an interdisciplinary team is detailed. The UNIVAC is FLIPS accessible.

3. Output is tabular only; there is no graphics capability.

4. On average, it takes three-to-seven days to learn to execute the computer program.

1.2.8 Initial Attack Management System

The Initial Attack Management System (IAMS) is the integration of the Automatic Lightning Detection System (ALDS) and Remote Automatic Weather Station (RAWS) System with several extremely large computer data bases, fire and resource management software packages, and a Bureau wide-satellite based fire-fuels mapping project. The goal of the IAMS system is to provide the local district and state fire managers all the fire related management information they need, in real time, on which to base their fire suppression decisions. In addition, this system will provide a means for short and long range fire and resource management planning and research. All of this data will be available through a network of Remote Interactive Graphics Systems (RIGS) located in each of the Bureau's district and state fire management offices. Each RIGS will be permanently connected to the central computer system located at BIFC.* (German, 1984)

The ALDS system is a very large and technicaly advanced remote sensing system that detects and plots any cloud-to-ground lightning strike occurring within the contiguous 11 western states. Each of the 32 remotely placed sensors is tied to the Boise Interagency Fire Center (BIFC) through a very complex system of telephone data equipment and telephone networks. It is here at BIFC that the raw lightning data is processed and then supplied in its final form to IAMS system. All of the ALDS data is provided to the IAMS central computer system in "real time" (less than 0.5 seconds). This "real time" data requirement increases the system complexity many fold. The IAMS system then processes, archives and distributes the lightning data to the individual fire management offices where it is displayed on maps produced by the RIGS. (See ALDS, Sec. 4.1.1.5, for additional systems information.)

The RAWS system consists of self-contained meteorological collection platforms placed throughout the 11 western states and mini computer based satellite direct readout ground station (DRGS) located at BIFC. The RAWS stations collect weather data each hour and then provide that data to BIFC through the GOES satellite system once every three hours. The

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* There is also a separate IAMS system for Alaska, centered in Fairbanks.

data is then interfaced into the IAMS system from the satellite ground station. When the full complement of weather stations is in place, the RAWS system will be providing near real-time weather data to the IAMS program from close to 650 stations. The IAMS central computer system will provide the weather data to the local fire manager, in real time, through the RIGS network.

The data bases being developed for, and implemented into the IAMS system, include fire fuels, terrain (including elevation, slope and aspect) and preplanned dispatch. The fire and resource management software packages include fire occurrence predictive packages and fire spread models. A Landsat and NOAA satellite based fuels mapping project is being performed for the IAMS system. An up-to-date electronic mail and status reporting system will be available to every other BLM fire management office on the IAMS computer system.

The system, now under a five-year procurement and implementation schedule, consists of, but is not limited to, the central computer system, individual field located desktop graphics computer systems (RIGS), data communications equipment and a complete computer facility. The central computer system, twenty three (23) of the RIGS, and the central computer facility at BIFC were procurred during FY 1983. The IAMS system, as an integrated unit, will become operational during the FY 1984 fire season. System expansion (functions, software packages and equipment) will be a continuous process, lasting for at least the five-year procurement cycle now in place.

The Forest Service can already access ALDS and RAWS data. The primary cost would be expanding the hard/software system to include all necessary Forest Service land.

RIGS operates on Data General MV4000, MV10000, and Data General 20 minicomputers.

2 DATA DISPLAY DEVICES

Data display is a rapidly evolving technology area. Driven by NASA remote sensing developments and expanding computer graphics applications, both display and storage capacity can be expected to increase, while physical dimension and production cost (at least with existing capabilities) is expected to decrease.

The following is an overview of available display processors and hardcopy devices by selected vendor and model. The information is summarized in the Technology Evaluation Matrix Figure 6. Vendor literature is available for full systems descriptions.

2.1 Display Processors

The display processor is used to temporarily store images, create the video signals which drive the display monitor, digitize video signals from video input devices, and perform intensity transformations on the image

FIGURE 6. Technology Evaluation Matrix: Data Display

TECHNOLOGY / CRITERIA	DISPLAY PROCESSORS					
	I^2S	COMTAL	RAMTEK	GOULD-DEANZA	AYDIN	ADAGE
Model Number	75	Vision One/20	RM-9465	IP 8500	AY52000	3000
Cost Current:	$60,000	$76,000		$50,000 to $150,000		$20,000 to $100,000
Projected, 1990:	Reduced	Reduced		Reduced		50% reduction
Availability Current:	Yes	Yes	Yes	Yes	Yes	Yes
Projected, 1990:						
Largest Size Image	512; 2048 memory	1024; 2048 memory	1024 memory	512; 2048 memory	1024; 2048 memory	512; 2048 memory
Colors	256^3	256^3		256^3		256^3
Physical Dimension	2 cu'	63"H x 35"W x 24"L	29"H x 12"W x 30"L	25"H x 19"W x 28"L		23"H x 19"W x 27"L
Power Requirements	750 W, max; 115 VAC	115 - 220 V	824 W; 87-128 VAC 177-256 VAC	220 V	115 VAC	1500 W, max; 115 V
Signal/Electrical Interface	IEEE/RS232	Multiple		Unibus; RS232		DEC
User Friendly	N/A					
Weight	40 lbs.	400 lbs	100 lbs	120 lbs	50 lbs	160 lbs
Reliability	Good	Good	Good	Good	Good	Good
Display Time	3 sec	0.03 sec	18 nsec	2-5 secs	2.5 secs	
Environmental Requirements	o Needs C/U driver					60°-90°F operating T
Ruggedness						
Other	o frame buffer capability developmental	o frame buffer $8,500	o color graphics	o frame buffer part of DVP		o essentially frame buffer with processor

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FIGURE 6. Technology Evaluation Matrix: Data Display (continued)

TECHNOLOGY / CRITERIA	HARDCOPY DEVICES: PHOTOGRAPHIC		HARDCOPY DEVICES: PLOTTERS		
	DUNN	POLAROID	HP	XYTEC	CHROMAJET
Model Number	635	8	7220 C	Scan-Writer	ACT II
Cost — Current:	$13,950	$7,100	$6,000		$6,150
Projected, 1990:	Reduced	50% reduction	Reduced		Reduced
Availability — Current:	Yes	Yes	Yes	1985	Yes
Projected, 1990:					
Largest Size Image	8" x 10" paper slide, transparency	8" x 10" paper or transparency	Up to 11" x 17" paper, film, vellum		8-1/2" x 11" paper or transparency
Colors			8 solid colors		8 solid; 125 shades
Physical Dimension	13"H x 17.5"W x 37"L	24"H x 16"W x 25"L 25"L	7.4"H x 19.5"W x 19"L		8.2"H x 22"W x 18"L
Power Requirements	20 W; 120 VAC	90 W; 100 to 240 VAC	100 W, max; 100 to 240 V		110 to 120 VAC; 220 to 240 VAC
Signal/Electrical Interface	RS 170, 232	RS 170, 330, 412A, 343A	RS 232; HP-IB		RS 170, 232
Weight	125 lbs	50 lbs	39		65 lbs
Reliability	Good	Good	Good		Good
Plot Time	Slides: 5-7 secs Prints: 1 min Transp: 30 sec		14"/sec		90 sec/8-1/2" x 11" copy
Clarity of Product					
Multiple Copies	Yes	Yes			
Other		• No slide capability			• Raster and character print modes

data at various stages. It can be used to perform complex arithmetic operations on images in real or near-real time. The display processor provides the essential user interface in a pictorial interactive information processing environment.

International Imaging Systems: Model 75. the Model 75 Image Processor is a general purpose image array processor. In addition, the Model 75 provides the architecture to implement a wide variety of image processing algorithms. Traditional point processing operations are accomplished in real-time (30 frames per second). Iterative or recursive spatial operations such as convolution, filtering and classification are accomplished in near-real time (a few frame times). Complex geometric operations such as rotation, rubber-sheet warping and map projections are accomplished in seconds.

Comtal: Model Vision One/20. The Vision One/20 is a stand-alone, digital image processing system. It has multi-purpose programmable processors and state-of-the-art refresh memory. As a coupled processor, the system is compatible with the numerous host computers. The Vision One/20 can be upgraded to accommodate requirements for expanded data bases, increased arithmetic capability, enhanced processing functions, and additional user stations.

Ramteck: Model RM-9465. The Ramtek Deskside 9465 is an off-the-shelf, commercial-grade raster scan display generator that drives industry compatible monochrome and color CRT monitors and large screen projectors. The system employs state-of-the-art microprocessor technology to provide solutions for a diverse range of graphics and image processing applications. The RM-9465 may be configured as an output peripheral or as an on-line interactive display system.

Gould-DeAnza: Model IP 8500. The system combines the features of four different architectures into a modular design that performs at maximum temperature and minimum related specifications. It offers additional options for extended memory, ultra-high resolution, feedback pipe-line processing, fast histogram facility, distributed processing or stand-along operation, accommodation for four users per single system, and a variety of interactive devices. Other C.P.U. interfaces can be added as required.

Aydin: Model AY52000. The AY52000 combines advanced hardware and mature software in an ergonomic workstation for use in multiple image processing applications. The complete package includes a disk, command console, and color display. The AY52000 can operate as a stand-alone computer or as a peripheral to a host computer. Host support is provided as standard. Aydin can customize display capability (more display memory, program, memory, video outputs, processors, or software) and can supply peripherals, including disk and tape drives, rackballs, joysticks, graph tablets, cameras, and hardcopy recorders.

2.2 Hardcopy Devices

Hardcopy devices create graphic output on a relatively permanent medium. The most popular media are paper, mylar-type films, and photographic films. Another class of hard-copy devices, display-screen copiers, are designed to read the analogue video signals driving a display and duplicate the image on a film or paper medium.

Dunn: Model 635. The microprocessor control of the 635 provides the user with a prompting menu system for set-up of cameras and films, as well as continuous operator feedback of camera status and conditions. The on-line diagnostic features alert the operator of fault conditions without film waste. A diversity of output is provided by the standard 8 x 10 inch film format and wide range of auxiliary format cameras.

Polaroid: Model 8. The model 8 produces Polaroid Polacolor ER Type 809 Instant 8 x 10 prints or Colorgraph Type 891 Instant 8 x 10 overhead transparencies from the output of raster scan terminals using "digital photography." Employing a proprietary digital image processor, digital photography neutralizes the inherent mismatch between CRT and film color response curves by digitizing the CRT video signal into 256 gray scale levels. An internal microprocessor then calculates a specific exposure time for each gray scale level. These calculations are made for each exposure cycle. The film is then exposed by a series of constant intensity, time-modulated light packets. Other capabilities include image reversal; negative imaging; color prints from black and white signals; black and white prints from color signals.

XYZTEK Model: Scan-Writer. The Scan-Writer is an optical scanner and pen plotter. Drawings up to E size can be scanned in less than 10 minutes; it can output as an eight-color pen plotter.

The Scan-Writer operates in the white light spectrum. A 256-step gray scale and optical filters are used for color transcription. Light intensity is determined by a preliminary document scan.

The Scan-Writer is not currently available. Production of the optical scanner is to begin mid-1985; the plotter capability will follow.

3 DATA STORAGE DEVICES

Data storage is another rapidly evolving area. Technological developments in all areas of data storage could make hardware volume as much a user criterion as data volume. Projections of capacity and format are particularly tentative at this time. Figure 7 shows the data storage devices Technology Evaluation Matrix. The following is an overview of magnetic and optical storage devices, trends in solid state memory, and an example of the range of commercial products available or being developed.

3.1 Magnetic Storage

Magnetic systems span a wide price range, with more money generally buying larger storage capacity and faster access to the data. Flexible, rigid and Winchester disks, and magnetic tape, are discussed.

FIGURE 7. Technology Evaluation Matrix: Data Storage

CRITERIA \ TECHNOLOGY	MAGNETIC STORAGE						
	WINCHESTER DISK	OTHER HARD DISK	FLOPPY DISK	CARTRIDGE TAPE	CASSETTE TAPE	REEL-TO-REEL	SOLID-STATE MEMORY
Cost per:	Drive: $15,000 to $80,000 Disks: $700 to $1,500 ea.	Drive: $10,000 to $40,000 Disk: $700 to $1,500 ea.	Drive: $650 to $3,500 Disks: Negligible	Drive: $1,000 to $3,500 Cartridge: $19-$33	Drive: $500 to $2,800 Cassette: $20-$80	Drive: $9,000 to $30,000 Reel, 2400 ft: $2100 to $3300	
Availability	Yes	Yes	Yes	Yes	Yes	Yes	
Access Speed	15-30 msec.	Typically 30 msec.	Slow	30 ips - 200 ips	15 ips to 45 ips	45 ips to 240 ips	
Physical Dimensions	5-1/4 to 14" diameter.	3-1/2 to 14" diameter.	3-1/2" to 8" diameter.	1/2" wide	0.15" wide	1/2" wide	
Power Requirements							
Ruggedness							
Interface Requirements	SMD; DEC Unibus; MMD; Priam; SCSI ANSI; Seagate	SMD; Seagate; ANSI; HP-IB	ANSI; Shugart; Seagate	SCSI; RS232;	ANSI; ECMA		
Capacity	Up to 2.5 Gbytes per disk.	Up to 630 Mbytes per disk.	10^5 to 10^6 per disk.	48K - 500K bytes per tape.	9K - 230K bytes per tape.	200K - 1.9 M bytes per tape.	
Other	o Sealed, nonremovable; reduced risk of disk surface contamination.	o Fixed or removable packs.	o Susceptible to disk surface contamination.	o Portable.	o Portable.	o Portable	o DG MV 1000-class minicomputer: 64-bit w/in 2 yrs o 1 Mbit dynamic RAM chip w/in 3 to 5 yrs; 4 Mbit by 1990 o 256 Kbit static RAM chip w/in 3 to 5 yrs

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FIGURE 7. Technology Evaluation Matrix: Data Storage (continued)

TECHNOLOGY / CRITERIA	OPTICAL STORAGE				
	ANALOG READ ONLY	ANALOG WRITE ONCE/ READ ONLY	DIGITAL/ANALOG READ ONLY	DIGITAL WRITE ONCE/ READ ONLY	MULTIPLE WRITE/SCRATCH
Cost	$3,000/player	$35,000/player $750/disk	$10,000 to $20,000/ player	$100,000/recorder $150/disk cartridge	
Availability	Yes	Yes	Late 1984	Yes	Developmental; within 2 to 3 years
Access Speed	Maximum 5 secs.	0.5 secs.	0.075 secs.	Average: 62 msec	
Physical Dimensions	6"H x 22"W x 16"L	8"H x 21"W x 19"L	8-1/2"H x 16"W x 24"L	55"H x 52"W x 32"L	
Power Requirements	110 VAC	110 VAC	120 watts; 90-132 VAC, 3 amp; 180-264 VAC, 1.5 amp	200 to 240 VAC	
Ruggedness					
Interface Requirements	RS 232	RS232	SCSI	IBM S/370, OEMI	
Capacity	54,000 color or black-and-white images per disk	24,000 color and black-and-white images per disk	4 Gbyte per disk.	4 Gbytes per disk	
Other	o Onboard microprocessor o Random access o Model: LDP 1000 A	o Model: TQ-2030	o Can store both digital encoded and standard lasers. o Model: Series 2000	o Read only units available for $5,000 to $10,000.	o Proprietary o Long-term development may be impacted by solid-state

3.1.1 Disks

Flexible, or Floppy Disks are the least expensive storage medium. They are removable, either 3-1/2", 5-1/4" or 8" in diameter, and can store from 10^5 to 10^6 bytes per disk. Their low storage capacity and slow access time make them just barely suitable for small-scale image processing; their susceptibility to disk surface contamination renders them virtually inapplicable for airborne or fire camp use. Cost of drives range from $650 to $3,500; disk cost is negligible.

Hard disks are either fixed into a system or removable. Removable disks offer a degree of portability between similar disk subsystems and are sometimes used as a means of backing up important data sets; these advantages can be mitigated by the relatively high cost of disk-packets and the danger of contamination when packs are interchanged.

Control Data makes a removable, 14"-diameter disk drive with a 12.6 GByte capacity compatible with IBM Series/1 hardware; access time averages 30 msec. Price runs $22,000-27,000 with controller; there is one drive per controller. Telefile Computer manufactures an eight 5-1/4' disk, 300 MByte per drive system for $22,000 that is compatible with Xerox Sigma and Telefile T-80 hardware. Access time averages 30 msec. 3-1/2" disk drives are available. Cost per disk ranges from $700 to $1,500.

Winchester disks are sealed, nonremovable disk packs which drastically reduce the possibility of contamination. Because of this contamination-free environment, it has become possible to construct smaller and lighter disk heads; more data can be compressed onto a surface.

Delta systems makes a 2.5 Gbyte drive compatible with CDC hardware for $50,000-74,000, with controller. There can be a maximum four drives per controller; average access time is 5 msec. Towards the other end of the capacity/price spectrum, Priam Corp. markets an 8", 188 Mbyte drive for $3,700, with controller. This Priam interfaces with SMD and Priam hardware; up to four drives can be accommodated per controller; average access time is 20 msec. Cost per disk ranges from $700 to $1,500.

3.1.2 Magnetic Tape

Disk Storage permits random access to data. Magnetic tape, by contrast, can only be accessed sequentially; access speed typically is slower. Tape is most appropriate when the data are to be stored or transported. Cartridge, cassette and reel-to-reel tapes are discussed; examples given are by tape speed.

Magatape sells a 24 track, 330 Mbyte cartridge for $3,200. Tape speed is 200 ips; density is 9,600 bpi; medium width is 0.5 inches. Under 50 ips, Kennedy makes a 38 ips, 6,400 bpi, 10 track cartridge for $1,900. These interface with DEC, Intel and IBM systems; medium width is 0.25 inches. Cost per cartridge ranes from $19 to $33.

Raymond Electronics manufactures a 20 Mbyte, 4 track cassette for $1,300. Tape speed is 30 ips; density is 10,000 bpi; medium width is 0.15

inches. Under 25 ips, for example, Techtran makes a 20 ips, 2 track, 440 Kbyte cassette for $1,300. Density is 800 bpi; medium width is 0.15 inches. Cost per cassette ranges from $20 to $80.

Cipher Data sells a 9 track, 92 Mbyte reel for $2,800. Tape speed is 240 ips; density is 1,600 bpi, 3,200 bpi; media width is 0.5 inches. Below 100 ips, Data General markets a 75 ips, 40 Mbyte, 9-track reel for $16,000. Density is 800 bpi, 1600 bpi, medium width is 0.5 inches. Cost per 2,400 ft. reel ranges from $2,100 to 3,300.

3.1.3 Solid State Memory

Development in solid-state memory progressing at an especially rapid rate. Conversations with vendors and JPL personnel indicate a 1 Mbit dynamic RAM chip may be available within the next three to five years; a 4 Mbit dynamic chip is anticipated by 1990. A 256 Kbit static RAM chip is also expected within the next three to five years. From an end-user aspect, the 32-bit microprocessor currently available in state-of-the-art minicomputers is expected to double within the next two years. (MacClean, 1984; Conway, 1984)

3.2 Optical Mass Storage

Optical storage holds the promise of being able to store the likely amount of data for FFAST implemenation in an area small enough for airborne or fire camp use. For example, the estimates for storing digital data from the approximately 54,000 1:24,000-scale topographic quads which make up the U.S. range from 10^{13} to 10^{14} bits. Currently, one optically-coded binary digital disk holds 10^{10} to 10^{11} bits. Random access memory is possible.

The following is a summary of the various types of optical storage devices.

1. Analog Read Only (Laser Disks). Each disk can hold up to 54,000 NTSC color or black-and-white images. Each image occupies a randomly accessible track on the disk, and is resistant to surface damage. Sony markets a commercial disk player, Model LDP 1000 A, for $3,000 which features onboard microprocessors for player control, a port for external computer control and inputs for external synch generators. Access time is a maximum 5 seconds.

2. Analog Write Once/Read Only. Panasonic is selling a write once system, Model TQ-2023, which can record still frames in color or black-and white. Each disk costs $750 and has a storage capacity of 24,000 images with worst case access of 0.5 seconds. record/playback units costs $35,000.

3. Digital Encoded Analog Read Only. The information content of a standard laser disk can be computed at roughly 4 Gbytes per side. Several companies are implementing systems to encode digital data into an analog signal for storage on standard laser discs. Reference Technolocy, Inc. is developing a player, the Series 2000, to read these disks offering user storage of 4 Gbytes per disk; access time is 0.075 seconds, and a maximum data transfer rate of 300 Kbytes per second. Player cost will be $10,000 to $20,000, with availability in late 1984. Disks can store both digital encoded data and standard laser disk video sequences.

4. Digital Write Once/Read Only. RCA and Xerox have both developed working systems. However, they are essentially very expensive prototypes designed for specific users and storage applications. A promising supplier of mass produced units is Storage Technology Corp., which is BETA testing player/recorders. The unit features a storage capacity of 4 Gbytes per disk, with a transfer rate of 5 Mbytes per second. Recorder/controller units will cost around $100,000 and disk cartridges $150 each. Read only units may be available for $5,000 to $10,000.

5. Multiple Write/Read. Erasible disks are at present developmental. Conversations with vendors and JPL personnel indicate commercial availability to be within the next two to four years. Continuing development and utilization of this capability may be impacted by developments in solid-state memory.

4 COMMUNICATIONS

Communications technologies for temporary remote fixed service, remote portable and mobile service, and aeronautical mobile communications are progressing rapidly. Advanced modulation techniques are using less spectrum per channel, thereby increasing the number of channels available. Specialized satellite services are being developed allowing ubiquitous mobile and portable communications for land vehicles and aircraft. Very Large Scale Integration (VLSI) chip technology is reducing the size of communications equipment while making it more reliable with greater capability. There is a multitude of potential applications of communications technologies to the forest fire mapping and detection system. Technologies are commercially available which can improve the overall communications system. The question is one of design and fiscal resources.

Technologies currently exist for transportable earth stations providing interconnect with the public switched telephone network via satellite. Land and aeronautical mobile radio communications capability is well developed, but only for relatively short-range (line-of-sight with repeater) applications. Ubiquitous coverage for airborne and terrestrial mobiles will require satellite service, which currently exist only for limited experimental applications. The Communications Technology Evaluation Matrix is presented in Figure 8.

4.1 Remote Site Fixed Communications

Telephone and data circuits can be made available to any remote location in the United States using current fixed communication satellite technology. The relatively heavy and bulky earth station antennas required for use with current communications satellites can be hauled via truck/trailer to the remote site. The earth stations can be installed and operating at a site a few hours after arrival of the equipment. Several companies provide complete, end-to-end service.

Transportable earth stations for fixed service will continue to be available in the 1990s. Technology advancements in earth station antenna design will result in much more lightweight and durable equipment in this time frame.

Commercially povided fixed remote service is generally backed by technical crews and 24-hour service centers, although these resources may not be located close enough to the fire camp to be useful in coping with an emergency breakdown. Many companies market a variety of earth station antennas designed to withstand environmental extremes (such as extreme cold).

Timeliness of transmission will probably indicate very few delays to be encountered. This will depend on grade or quality of service selected and number of channels used (all are dependent on cost).

The physical dimensions, weight and power requirements are yet to be determined, however, the equipment at present is relatively bulky.

Remote fixed service has low priority for FFAST. This technology is widely available today, and quality of service is good, but these systems are not very useful for remote emergency operations, where the Incident Command Post may remain in place for only a few days and equipment needs to be moved quickly. The equipment must be hauled via truck/trailer to the remote site from the companies/service center over roads that may be in poor condition, and set-up requires several hours. The cost is also high.

4.2 Aeronautical and Land Mobile Communications

Radio communications technology exists today and is well established for air-to-ground and ground-to-air applications for localized areas. However, ubiquitous, long-range coverage (such as for aircraft-to-BIFC) currently does not exist. This capability is feasible using mobile satellie communications tecnology, and frequency allocations exists in L-band for aeronautical mobile satellie service. This service does not currently exist.

Land mobile radio communications are well developed today. Applications are mainly for line-of-sight with repeaters (generally urban

FIGURE 8. Technology Evaluation Matrix: Communications

TECHNOLOGY / CRITERIA	REMOTE FIXED SERVICE	REMOTE LAND AND AERONAUTICAL MOBILE COMMUNICATIONS*
Cost	o Set-up charge: $1,400 plus mileage o weekly rate for terminal: $1000 o Satellite transponder: $0.70/minute o Telephone interconnect: as billed by Telco. o Power conditioner: $70 installation charge, $66/month o Data link: separate charge TBD	o Terminals: approximately $3000 o Per minute: $0.15 to $0.80 o Other charges TBD
Availability	o Currently available	o Currently not available o Will be available by 1990's
Timelinesss of transmission	o Similar to current phone and data satellite links (little delay). Depends on grade of service	o Little or no delay in transmission
Physical Dimensions and Power Requirements	o Large, heavy antennas	o Mobile radios: comparable to current cellulars systems (small) o Small, lightweight vehicle rooftop antennas
Reliability, maintainability, and durability		o Similar to current mobile radio equipment
Other		o Depends on frequency allocation and licensing in 800 MHz or L-band

*Ubiquitous coverage

areas with large numbers of users, and localized rural areas). Cost-effective, ubiquitous coverage for land and air mobiles in remote areas will require communications via satellite. This capability exists for limited experimental applications only.

The technology is feasible today. Several companies have filed to provide mobile satellite service by the 1990s; Geostar Corp., Mobile Satellite Corp. (MOBILSAT), and Skylink Corp. The Canadian government also plans to provide mobile satellite service by 1988. Other U.S. companies also appear to be interested. There is no current domestic allocation for land mobile satellite service; however, due to heavy pressure from Canada, industry and government, the FCC will probably move on a rulemaking procedure in the near future. It is reasonable to assume that mobile satellite service will be available in UHF or L-band, or both, by the mid-1990s.

The costs of mobile terminals for satellite communications is anticipated to be aproximately the same as cellular radio terminals (about $2000 - $3000) by 1990. Service charge estimates vary widely (from 15 to 80 cents per minute). Satellite access and PSTN interconnect charges are difficult to pin down at this point. Mobilsat estimates that a gateway base station (which could be located at BIFC) could cost $50,000.

The mobile communications will be similar to those available today. The reliability, maintainability and durability should be the same as for cellular radio. There should be litle or no delay in voice communications or data transmisson as it should be comparable to telephone service. The mobile radios should be comparable to current units that are passenger-compartment or trunk-mounted. The antennas will be small and light enough to be carried on the rooftop of a car.

Likely frequencies for mobile satellite communications will come from the currently designated land mobile reserve. The reserve comprises a pair of 4-MHz bands (821-825 MHz and 866:870 MHz) and a pair of 6-MHz bands (845-851 MHz and 890-896 MHz). It is unlikely, however, that the entire 20-MHz reserve will be allocated to mobile satellite service, at least by the 1990s. Satellite-to-fixed stations and fixed stations-to-satellite links can be provided in another frequency band (possibly SHF), or an all-UHF system can be employed. It is a possibility that a portion of mobile satellite service for L-band may be considered. As a baseline, the focus will be on transmission of 2400 bps in a 5 KHz channel.

Land and aeronautical mobile communications capability with ubiquitous coverage will most likely be available by the 1990s. This technology has a very high priority.

5 GLOBAL POSITIONING TECHNOLOGIES

Position accuracy, fix time and system reliability were the principal criteria by which eight position location systems were assessed and weighted. The question specifically was which systems met or approached the project requirements of better the 10 meter accuracy, in near-real time, with the greatest reliability. Of the systems considered, (GPS, Loran-C, INS, TRANSIT, VOR, TACAN, and Geostar), only GPS, TRANSIT, and Geostar have the capability (actual or potential) to warrant evaluation. The other systems had variable reliability and fix times between real-time and ten minutes; none had an absolute accuracy better than 20 meters reported, with Differential Loran in coastal conditions inapplicable to continental characteristics. Loran-C has attractive qualities: high systems reliability and real-time fixes. However, besides the inability to meet FFAST accuracy requirements, Loran-C coverage does not include all Forest Service land. Additionally, the ubiquitous capabiliy of GPS-continuous, global all-weather, 3-D position location to a potential sub-meter accuracy, and perhaps Geostar and other next-generation navigation systems, loom so advantageous as to question the commercial long-term viability of existing systems as a primary navigation device.

Figure 9 gives the associated Technology Evaluation Matrix for global postioning. Unless otherwise stated, data given are of representative models.

The following is a comparison of the candidate systems. The systems are satellite-based with near real time fix.

5.1 Transit

TRANSIT has been in operation by the DOD since 1964, and available for civilian use since 1967. The Navy is scheduled to cease TRANSIT sponsorship in 1994, but user volume is such that private or other government agency sponsorship is being discussed. TRANSIT, however, is nearing its system life expectancy; it is not a long-term alternative. The system has one constellation that is out of service and another that is faltering. At present, discrete satellite fixes are available on average only every 90 minutes. TRANSIT receivers are currently below $2000. The accuracy of TRANSIT is between 10-40 meters, depending on ionospheric variables.

5.2 Geostar

Geostar is a private-venture communications/navigation system designed to intially involve three satellites in geosynchronous orbit, one ground control station, and user transceivers. Coverage with three satellites will be limited to the continental United States.

Geostar is slated for operation sometime in 1987; capital investment, hardware development, and FCC approval of communications bandwidth (Geostar's initial product) make that date optimistic. A recent press release (MSN; June, 1984) stated Geostar had contracted with Comsat General Corp. to assist in developing detailed hardware specifications. Whether this association will accelerate Geostar's operations schedule is unknown.

Although Geostar, Inc., has yet to contract for user equipment, its literature consistently lists transceivers, including airborne versions, at around $450. (There will also be a service charge which Geostar anticipates will be comparable to current long-distance telephone rates.) Geostar with three active satellies, deduced from land-based triangulation tests, projects

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FIGURE 9. Technology Evaluation Matrix: Global Positioning

CRITERIA \ TECHNOLOGY	GPS: PPS	GPS: SPS	GPS: DIFFERENTIAL	GPS: SERIES	TRANSIT	GEOSTAR
Receiver:						
Current Cost	Contractual, DOD	$23,000 to $140,000 (for total system)		Developmental	Below $2,000	
Projected Cost, 1990	Similar to SPS	about $5,000 per receiver	Same as SPS	$5,000	Below $2,000	$450
Physical Dimension	Similar to SPS	7.5"H x 7.5"W x 13"L	Same as SPS	2"H x 11"W x 11"L	4"H x 12"W x 9"L	Hardware undeveloped; vendor anticipates hand-held models.
Power	Similar to SPS	104 - 122 VAC	Same as SPS	6 watts; 12 volts	10 watts	Hardware undeveloped.
Weight	Similar to SPS	22 lbs	Same as SPS	3 lbs	11 lbs	Hardware undeveloped.
RS 232/IEEE 488 Interface	Compatible	Compatible	Compatible	Compatible	Compatible	Hardware undeveloped
Availability	No; possibly by 1990	Yes; fully operational, 1988	Probably by 1990.	1987	Yes; scheduled to end 1994.	Uncertain
Accuracy	15 meters	o 50 meters, degraded to 100 meters.	Capable of 3-5 meters.	1-2 meters	10-40 meters, dependent on ionospheric variables.	Projecting 1-7 meters in differential.
Fix Time	Real time; continuous	Real time; continuous.	Real time; update every 5-15 minutes.	1 minute	Satellite fixes available on average every 90 minutes.	0.6 seconds
System Reliability	Good	Good	Once implemented, same as SPS		Approaching systems lifetime; poor reliability.	Will depend on ability to launch spare; low at present.
Other	o Currently restricted to U.S. military	Options: o RAM memory o Ruggedized case o Dual-drive cassette recorder	Same as SPS	o Operates independent of GPS phase codes o Antenna: 11" x 11", flat, on wing o U.S. firm	o Short-term option.	o Private venture system; hardware and business plan questionable; data are unproven vendor projections.

FIGURE 9. Technology Evaluation Matrix: Global Positioning (continued)

CRITERIA \ TECHNOLOGY	LORAN-C	INS	OMEGA	TACAN	VOR
Receiver:					
Current Cost	$1,000 - $80,000	$100,000 and up	From $14,000 w/o VLF to $120,000 w/ VLF	$25,000 to $35,000	$1,200 to $25,000
Projected Cost, 1990					
Physical Dimension	2"H x 5"W x 6"L		8"H x 8"W x 20"L	3.5"H x 5"W x 14"L	
Power	25 watts, maximum		28 VDC	27.5 VDC	
Weight	7 lbs.		26 lbs	7 lbs	
RS 232/IEEE 488 Interface	Compatible				
Availability	Yes	Yes	Yes	Yes	Yes
Accuracy	0.1 - 0.24 nmi; 20 meters reported in differential.	Function of flight time; 3 hr. flight can result in 5 nmi error.	1-2 nmi; differential Omega in development stage.	0.1 nmi; w/in 100 nmi.	Function at distance from station; w/in 25 nmi, about 0.75 nmi.
Fix Time	real time	5 to 10 minutes.	5 to 10 minutes.		Function of distance from station; w/in 25 nmi, real time.
System Reliability	Good	Two to three sets usually required.	Good	Good	Good
Other	o VOR/DME update o Accuracy affected by land conductivity. o No midwest coverage	o Self-contained navigation ability.	o Omega/VLF becoming dominant form of Omega navigation; accuracy trends still unsuitable.	o TACAN is essentially VOR/DME w/ higher capability.	o Some 1000 VOR stations in U.S., w/ an operating range of 40 to 130 nmi; receiver must be tuned to desired station.

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an accuracy between 1-7 meters. The initial Geostar configuration calls for three geosynchronous saellites and an on-orbit spare; the ground control station is to have three-computer redundancy.

5.3 Global Positioning System

The Global Positioning System (GPS) is to be an 18-satellite, three spare, continuous, global positioning location system operating in six orbital planes. GPS was developed by the DOD. The full satellite constellation is expected to be operational late 1988.

The navigation signal broadcast by a GPS satellite consists in principle of an L-band carrier modulated by a unique pseudo-random binary code. The code allows a receiver to acquire the signal from one particular satellite and measure its pseudo-range (distance plus error due to receiver clock bias) from the user. The code itself is modulated at 50 bits/s by the satellite's navigation data stream. This navigation message includes ephemeris parameters from which the user can compute the postion of the satellite. Based on the positions and pseudo-ranges of four satellites, the GPS receiver removes its own clock bias and determines the users position in 3-D. Various levels of position accuracy may be attained, since the GPS navigation signal is actually modulated by two different codes in phase quadrature. The long-period Precision Position Service (PPS) provides more precise measurement of time, hence position, due to its higher clock rate (10.23 MHz). This precision is so far to be restricted to U.S. and allied military users. The shorter Standard Position Service (SPS) with a lower clock rate (1.023 MHz) facilities acquisition of satellite signals and transfer or receiver tracking to the more precise PPS. SPS will be civilian accessible.

The primary difference between PPS and SPS user hardware is the additional cost, physical dimension and power requirements of PPS receivers to inlude military non-jamming devices. Additionally, PPS hardware information is either proprietary or classified. If PPS is eventually to be available for commercial use, it will be without these military-grade devices. Consequently, PPS and SPS hardware will be considered essentially the same.

5.3.1 Precision Positioning Service

Attainable PPS accuracy is 15 meters, real time.

The principle argument for prohibiting civilian access to PPS is the rationale to deny its accuracy to a potential enemy. There is some debate that PPS accuracy figures are already available internationally. If this is so, or becomes so, the security concern is removed. The issue may be driven by considerable industry pressure to access PPS. Best SPS accuracy is less than what is now achievable with TRANSIT, which is generally considered the minimum position accuracy for off-shore navigation.

5.3.2 Standard Position Service

Available GPS receivers are quite expensive and not representative of their projected costs when GPS becomes fully operational; the reduction rate is expected to follow TRANSIT and Loran-C curves. (Stansell, 1983) For example, Texas Instruments has been marketing a NAVSTAR system which includes an omni directional antenna and a control/display unit for $140,000. Allen Osborne Association will soon introduce a similar system for $25,000. Consensus estimates of receiver cost alone by 1990 is conistently around $5,000 with some estmates as low as $1,500. Attainable SPS accuracy will be about 50 meters, which the DOD intends to degrade to 100 meters.

GPS systems reliability can be considered the percent time a satellite redundant to the minimum four satellites needed for optimum 3-D navigation is visible over the U.S. Given the orbital planes and an 18-satellite redundant satellie will e visible some 82% of the time. If the DOD activates the three on-orbit spares, redundancy increases to 98%. (Braff, 1983)

The navigation capability of GPS has generated tremendous market interest in utilizing its accuracy potential independent of DOD restrictions. Attention has centered on using GPS in a differential mode. Additionally, ISTAC, Inc., Pasadena, California, will soon be marketing a GPS receiver configuation (SERIES) independent of DOD phase codes altogether.

The focal point of a differential capability is a GPS receiver (differential sensor) that operates from a surveyed antenna. The true value of this receiver's navigation fix is compared against the measured value and the differences become the differential corrections.

The Department of Transportation, the Coast Guard and the Institute of Navigation have for the past year been sponsoring user-vendor workshops to establish a schedule for implementing a differential capability. Discussions with persons in each organization indicate little doubt that a Differential GPS capability (includng presumably central processing units) will be operational by 1990).

Differential GPS will use standard SPS hardware; only the accuracy capability will be expanded. Accuracy between 3-5 meters, with 5 to 15 minute update requirements, is expected.

5.3.3 SERIES

SERIES (Satellite Emission Range Inferred Earth Surveying) is a technique by which it is possible to perform simultaneous pseudo ranging to multiple GPS satellites without knowledge of the GPS phase codes, or the requirement to know the receiver position and velocity and the satellite positions to begin data acquisition.

The SERIES receivers are fundamentally codeless spectral compressors where the spread spectra modulations of several GPS satellites can be simultaneously received at L-band and compressed by seven orders of magnitude into audio or sub-audio band passes. A computer extracts the frequency and phase of each satellite view. The data processing proceeds by a combination of Doppler positioning and phase ranging to levels of precision as may be required even to the millimeter level by using the L-band carriers. The compressed spectral data can be processed into positional data in the receiver or the compressed data can be buffered and transferred over a telephone-type channel.

Although the SERIES-GPS techniques is fundamentally a methodology for codeless pseudo ranging, the highest accuracy is achieved by operating airs of receivers in a differential mode so as to cancel or attenuate certain error sources. For example, the reference station in differential observations can be exploited as a satellite orbit monitoring station. Because of the nature of the non-gravitational disturbing forces on the satellites, the orbital element most affected is along the track position. By observing the closest approach event from a single station, it is possible to estimate the range to the satellites with an accuracy of approximately 50 meters. With inclusion of additional ephermeris monitoring stations, it is possible to develop the other orbital elements and finally with four regional sites a completely geometric approach to deriving the satellite positions can be obtained which avoids orbital kinematics.

The complete SERIES configuration is still developmental. Conversations with Peter MacDoran, ISTAC president, indicate the following. (Mac Doran, 1984)

1. ISTAC will be manufacturing its own hardware. MacDoran estimates receivers to cost around $5,000. The central processing unit to compute time differentials is anticipated to cost around $150,000.

2. The hardware is expected to be commercially available by 1987.

3. With a 2,000 km baseline, real-time accuracy of 5 meters is anticipated; 1-2 meter accuracy could be achievable with 1-minute post-processing.

4. Receiver: 2:H x 22'W x 11"L; Anenna: 11'W x 11"L; flat, placed on wing.

5. Average weight will be around 3 lbs.

6. Power requirements of 6 watts; 12 volts; less than 0.5 amps.

7. Receivers inerface with RS 232/488.

5.3.4 Prioritization

TRANSIT can be ruled out for consideration due to its infrequent satellite-fix capability and remaining short-term lifetime. Geostar makes some promising claims, but to date they are no more than best-case projections. Technical evaluations of the Geostar system generally conclude with serious doubts about system feasibility. In addition, the investment capital to launch the three satellites necessary for 3-D position location apears uncertain. Both concerns render their actual operations start date uncertain. As well, Geostar coverage will be limited to the continental U.S.

GPS is so far the system of choice. Its hardware and system capabilities have been tested; its operation start date is on schedule. It seems likely that some version of GPS will meet the project's requirements by 1990. GPS access can be obtained either via Differential receiver mode or the SERIES technique.

6 SENSOR SYSTEMS

6.1 Thermal Infrared Sensors

The thermal infrared bands commonly used in all thermal IR systems are approximately 3-5 micrometers and 8 to 14 micrometers. These two bands are desired because the 8-14 energy level peaks at ambient earth temperatures and the 3-5 peaks at temperatures related to fires.

Infrared systems can be classified in various ways, e.g., passive or active, imaging or non-imaging. Passive IR sensors rely upon the natural emission of radiant energy which occurs in all objects and is directly related to the temperature of the object. (Warren, 1984) Active sensors carry their own radiation source along with their receiver. A common active sensor is the millimeter-wave sensor (to be discussed) which transmits energy out and detects the energy reflected back to its receiver.

Non-imaging systems provide an indication of the temperature of an object or area in either a qualitative (light, horn, etc.), quantitative (calibrated temperature reading), or relative (deflection of meter from an uncalibrated reference) manner. Imaging systems provide an image of the scene in the field of view and the temperature of objects or areas within the scene is deduced, usually in a relative manner, by the "brightness" of those objects or areas compared to the background. An imaging system thus displays the total scene and hot objects can be located based on their relationship to the total scene. (Warren, 1984) Imaging IR systems provide an image of the covered area which is viewed at the sensor's display, on an accompanying video monitor, or on a hardcopy printout, or some combination of the above. Video compatible systems can also record the IR images for subsequent playback and may include audio annotation.

A number of sensor systems exist or are under development which may be applicable to the forest fire mapping and detection system. some of these are discussed here. It should be pointed out that the key technology elements for future systems, that is, those available in the 1990s, will be expanded capabilities at similar or reduced prices.

The following are passive, imaging, thermal IR sensors. All require a trained operator to use. The associated Technology Evaluation Matrix is shown in Figure 10.

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FIGURE 10. Technology Evaluation Matrix: Selected Sensors

CRITERIA \ TECHNOLOGY	INFRARED						MILLIMETER-WAVE SENSOR
	LINE SCANNER	LINEAR ARRAY	AREA ARRAY	TIMS	AIS	FLIR	
Cost				$30,000 to $50,000			$200,000 by 1989.
Availability	Yes; in use by Forest Service	Yes; custom design	Developmental		Yes; not commercially available	Yes; not commercially available	Prototype avail- mid-1985.
Detector Material	Hq/Cd/Te	Hq/Cd/Te	Hq/Cd/Te	Hq/Cd/Te	Hg/Cd/Te		Active sensor
Accuracy	Less than 1/2 ft. Hot spot detection at 15,000 ft at nadir						Can detect through 2 km fog bank up to 1 km.
Cooling Requirements	Liquid nitrogen	TE cooling; Joule Thomson cryostate		Liquid nitrogen			
Resolution						Ground: 5-33 meters; swath Width: 1.3-8.3 meters	Angular resolution, 0.2 to 0.3 degrees; 15 mrads eventually
Timeliness	Real time				13 msec.		Real time
Data Transfer					Tape		Tape
Weight				Suitcase portable			10 to 15 kg.
Power Requirements	AC or DC coupling						10 to 20 watts.
Physical Dimensions				Handheld			0.02 M^3.
Reliability	High			High			Good
Other	o 120° TFOV o Hardcopy o Digital image frame storage	o 3-5; 8-12; 12-17 bands o 1-30 elements per array	o 64x64 element array tested; 128 x 128 feasible	o Several commercial models o 7° x 7°-30° x 30° TFOV	o 32x32 element array o 1.2 to 2.4 band	o Six bands between 8&12 um o 80° scan angle o 2.5 mrad IFOV	o Minimum detectable temperature 1K.

6.1.1 Line Scanner

Line scanners employ a reciprocating mirror to sweep the field of view of a detector perpendicular to the aircraft motion, while utilizing this motion to displace the scan lines and so produce a two-dimensional image.

The Forest Service currently uses a thermal IR line scanner (called FLAME, developed by JPL) for its large scale (more than a few hundred acres) fire detection and mapping operations. Military and commercial line scanners are available but do not contain the dual band detectors working into target detection circuitry as required for small hot spot detection and false alarm rejection. Military systems use usually AC coupled which does not permit mapping terrain features adjacent to large hot areas and do not include rapid processing of images on board the aircraft. Commercial systems do not have the wide total field of view (TFOV) coverage.

Features of the Forest Service line scaners include a 1 millirad instantaneous field of view (IFOV); 120 degrees TFOV, ± 10 degrees for aircraft roll correction; DC or AC coupling; rectilinearization of displayed images; hardcopy on dry silver film; video display in real time; digital image frame storage; and edge and video event (hot spot) markers in hardcopy with aural-visual alarms on aircraft.

6.1.2 Multispectral Arrays

It is apparent that the commercial technology of solid-state imaging sensors frequently referred to as multispectral arrays (MSA), offer performance advantages over scanning systems. Each picture element in a MSA imager may integrate for up to one line time, whereas scanning heretofore must be sampled at each pixel time. Thus, the MSA sensor has an enormous sensitivity advantage because of its longer integration time per sample.

It does not require moving scan mirror in order to acquire an image. Consquently, MLA can have longer operating life than a scanner. Additionally, the fixed geometry from the detector arrays results in high geometric accuracies in the line direction which will simplify the image reconstruction and processing tasks.

<u>Linear Array</u>. The "simplest" of the multispectral arrays is the linear array. In the linear array system a line of sensors per spectral band is aligned perpendicular to the line of the spacecraft's motion. The image of this array is "pushed" along the ground in much the same manner as the head of a pushbroom; hence the nickname "pushbroom sensors." The important characteristics are: fixed and equal detector-to-detector spacing; a long detector-integration time, allowing very high signal/noise and imaging in very narrow spectral bands; light weight and small size compared to a scanner, allowing a pointable instrument. Production image processing will differ from that for scanners in that the N detectors per scan line per spectral band will require radiometric calibration. Geometric processing will be essentially the same as is required for a mechanical scanner because earth rotation, s/c wobble and panoramic projection effects will still occur. However, there will not be as much along-line detector geometric rectification required.

Several vendors currently can manufacture linear array detectors on a custom-design basis. Obtainable mercury-cadmium-telleride (HgCdTe) array spectral response range from these detectors is 3-5 m, 8-12 m, and 12-17 m; elements per array, and element dimensions vary. The availability of such arrays on an off-the-shelf basis is unknown.

Area Array. An area array is a next generation "pushbroom" imager. The long dimension of the array is oriented crosstrack as in the pushbroom discussed above. The spectrum of each pixel is spread by a dispersing element and imaged across the short dimension. Thus, a large number of narrow (typically 0.01 to 0.02 m) spectral bands are potentially available. Commercial area array detectors are a developmental item. Array sizes of 64 x 64 elements have been demonstrated; 128 x 128 is feasible.

6.1.3 Airborne Imaging Spectrometer

The Airborne Imaging Spectrometer (AIS) is a multispectral infrared imaging instrument utilizing a 32- x 32-element HgCdTe detector array to achieve high spatial resolution. A novel optical design provides high spectral resolution, and, in conjunction with the 32-element spatial resolution, makes optimal use of the capabilities of the area array. (Laser FocusElectro-Optics, 1983)

The confluence of the requirement for high-resolution multispectral infrared imagery and the development of IR-sensitive CCD (charge-coupled device) imaging arrays combines the technologies of TV imaging and spectroscopy to resolve capability conflicts that have resulted in implementation compromises and insufficient spatial and spectral resolutions in earlier instruments. The solid-state CCD imager has the advantages over competing sensors of wide spectral range, high geometric stability, low noise, wide dynamic range, low power and compactness, and high read-out rate. These characteristics, when coupled with high sensitivity in the spectral region of interest, result in an extremely useful tool. The AIS design was originally to incorporate one of the bands of interest here, 2.4 to 4.8 μm. However, design considerations resulted in eliminating this band, including only the 1.2 to 2.4 m band in the instrument.

With a field of view of 2 mrad/element and a spectral discrimination of 10 nm/element, the HgCdTe detector array is designed to point vertically downward from an aircraft flown at a speed of 200 kt at 3000 m altitude. The pixel pitch is 68 m square (with 77% fill factor), giving a spatial (cross-track) coverage 183 μm wide. The spectral width is 305 nm/grating position (providing a 5-nm overlap). With a CCD integration time of about 8 ms and a readout time of about 13 ms, the forward motion of the aircraft causes a displacement of the image less than one pixel, which is within the resolution of the instrument.

A magnetic tape recorder stores data acquired during a flight, and all functions of instrument and tape recorder are computer controlled. Optical alignment of the AIS is achieved with a He-Ne laser and is facilitated by the all-reflecting design. Spectral calibration is accomplished by using the IR mono-chromator swept manually through the 1.2-2.4- μm waveband. A further developed version of AIS may be suitable for forest fire mapping and detection.

6.1.4 Airborne Visible/Infrared Imaging Spectrometer

The Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) is a second-generation remote sensing instrument under development at the Jet Propulsion Laboratory as part of the Imaging Spectrometer Program sponsored by the National Aeronautics and Space Administration. AVIRIS is an opto-mechanical scanner that uses line arrays of detectors to image 550-pixel swath in 224 contiguous spectral bands from 0.4 to 2.4 μm. The instrument will be flown as a NASA facility sensor aboard a U-2 aircraft, starting in 1986. A data-processng system based on a VAX 11-780 minicomputer is under development at JPL which will provide rapid access to flight data.

Three fundamental requirements have been placed on the AVIRIS instrument that have had a major impact on its design. First, coverage is required of the entire solar-reflected portion of the spectrum transmitted by the atmosphere. This is essentially the 0.4- μm to 2.4 μm region. Second, a significant improvement in spatial coverage over AIS is required to provide broad-swath images several hundred pixels wide. Third, since the prime goal of the AVIRIS program is to provide the research community with high-quality data, it is essential that AVIRIS has been designed as an opto-mechanical scanner using line arrays of detectors of silicon (Si) for the visible portion of the spectrum and indium antimonide (InSb) for the near-IR and short wavelength infrared (SWIR). The primary drivers in this decision were the availability of very high-quality InSb line arrays, discussed in the next section, and a mature scanner technology well-suited to wide field-of-view imaging from aircraft.

6.1.5 Thermal Infrared Multispectral Scanner

The Thermal Infrared Multispectral Scanner (TIMS) was built for NASA by Daedalus. Scanner design and spectrometer/scanner fabrication was contracted for $761,000. This instrument, completed in the spring of 1982, includes six bands between 8 and 12 μm: 8.2-8.6, 8.6-9.0, 9.0-9.4, 9.4-10.2, 10.2-11.2, and 11.1-12.2 μm. It has a 2.5-mrad IFOV, and 80 degrees scan angle, selectable scan rates and V/H, and internal blackbody reference sources. Ground resolution is 5-33 meters. Swath width is 1.3-8.3 meters. Scan speeds are 7.3, 8.7, 12.0, and 25.0 scans per second. It is not known at this time the commercial likelihood of TIMS.

6.1.6 Forward Looking Infrared

Forward Looking Infrared devices (FLIR) are characterized as being operable either handheld or mounted, require cryogenic cooling usually with liquid nitrogen, and operate in the 3-5 or 8-14μm bands, or a combination of the two. Several models are commercially available, and are standard (NTSC) video compatible.

FLIRS used by the Forest Service are handheld, and may be deployed in a fixed-wing aircraft, a helicopter, or on ground vehicles or back-packs. Normal use is from a helicopter.

There are many fire-related applications where FLIR use is superior to other IR methods. For prescribed burns up to a few hundred acres, under established conditions, the FLIRS are ideal for surveillance and monitoring. They can show fire progress and status as time proceeds and can be quickly over the site of any suspected or actual unusual actions. FLIRS can view the area after the burn is completed to assure that all hot spots are known and adequately treated prior to crew release.

FLIRs used in conjunction with line scanners on active large fires can give a close-up IR "look" at crucial portions of the line. They can resolve whether the fire is contained within a firebreak or has crossed over when that may not be resolvable from line scanner imagery. They can be used to pinpoint spotting ahead of the fire perimeter and identify access conditions and routes to get to such spots. Line scanner flights may not be available (because of the limited number of aircraft and crews) more than once or sometimes twice per day on a fire. FLIR units can be used to update the last line scanner images along selected portions of the first perimeter periodically or as needed.

FLIRs are moderately expensive, from $30,000 to $50,000. Warren lists models with TFOVs ranging from 7 degrees to 30 degrees x 30 degrees, and states that FLIR field reliability so far has been excellent. (Warren, 1984)

6.2 Milimeter-Wave Imaging Sensor

JPL has been directing development of a milimeter-wave sensor capable of detecting objects the size of a military tank up to ranges of 1.5 km under conditions of light fog and smoke. Under conditions of cloud banks some 2 km thick, such objects can be detected up to a range of 1 km.

Minimum detectable temperature has been tested to be some 1K. Angular resolution (HPBW) is 0.2-0.3 degrees; surface pixel size is around 5 meters. The system has a 50 cm scanning antenna. Total system size is 0.02 M^3, weighs 10-15 kg., and operates at 10-20 watts. Processing is in real time, and reqires a mini-computer and TV display.

A prototype will be available in mid-1985; the sensor is expected to be well developed by the 1990's. Cost by 1989 is anticipated to be around $200,000 for limited production models.

7 GEO-REFERENCING TECHNIQUES

Geo-referencing is the interface of the FFAST subsystem to create the appropriate image for display and hardcopy. Although techniques are currently being developed in this area, there is no existing system which geo-rererences in a timely manner. It is the area which may require the most continuing attention. The geo-referencing Technology Evaluation Matix is shown in Figure 11.

7.1 Manual Interpretation

Manual data transfer and interpretation is the current geo-referencing method. It is a time consuming process, often taking several hours; recognizable control points in the fire area must be manually correlated to surveyed points on a cartographic base. Improvements on this existing method will have significant benefit to fire management.

7.2 Computer-Aided Interpretation

Concurrent with manual data transfer, several computer-aided techniques are employed to enhance the accuracy and interpretability of geographic referencing. Principal among these is the correlation of Loran-C or VOR position location and digital terrain data to the image being geo-referenced, thereby, increasing correlation accuracy while decreasing slope error.

7.3 Automatic Registration

Several technologies are being developed or will soon be available which, in various combinations, may enable suitable accurate, automatic geo-referencing (e.g., correlating linear array imagery and GPS location to DLGS). Technology advancements in selected other areas will offer additional automatic referencing capability.

7.3.1 Very Large Scale Integration (VLSI)

VLSI chips are being developed which can process in near real time data sufficiently vast enough for conceivably any FFAST requirement. VLSI algorithms for correlating image control points to maps are not yet available, but are being developed for some of the referencing techniques which ought to eventually prove useful; they will provide displacement from an image of a known ground control point area to the image area being searched. (Nathan, 1984) Such chips could be operational for ground use in two to three years.

7.3.2 Terrain Profilers

It may be possible to enhance terrain data accuracy using real-time terrain profilers. The USGS has been testing this ability using a laser profiler with some success. The laser profiler being tested has range resolution of a few centimeters, and has adaptable data storage capabilities. Its current limitations are operating altitude (3,000 ft.) and moisture attenuation. It is considered a fair weather apparatus; the manufacturer, ACCI Inc., Salem, MA, is uncertain of its ability to penetrate smoke. Cost

FIGURE 11. Technology Evaluation Matrix: Geo-Referencing

CRITERIA \ TECHNOLOGY	MANUAL REGISTRATION	COMPUTER-AIDED REGISTRATION				
		DIGITAL TERRAIN DATA	LORAN-C	GPS	VOR	INS
Cost: Current		Depends on type used; some limited by area coverage and would require expansion	$1,000 - $80,000	$25,000 - $140,000	$1,200 - $25,000	$100,000 and up
Projected, 1990			Reduced	$5,000		
Availability	Yes; current method used	Total U.S. coverage in 1:250,000 DTT only	Yes; long-term availability questioned	Fully operational, 1988	Yes	Yes
Accuracy	Good	Varies; DTTs poor; DLGs and DEMs good	Best: 20 m in differential mode	3-5 m is differential	Function of distance from VOR station	Function of flight time
Timeliness	Can take several hours		Real time	Real time; differential requires 5-15 min update	Function of distance from VOR station	5-10 min
Development Time						
Physical Dimension			2"H x 5"W x 6"L	7.5"H x 7.5"W x 13"L		
Weight			7 lbs	22 lbs		
Power Requirements			25W, max	104-122 VAC		
Reliability			Good	Good	Good	Good
Other		o 9-track tape	o No Midwest coverage o Accuracy affected by land conductivity	o Market expanding; hardware specs and capacity will likely change	o Receiver must be tuned to desired station	o Self contained navigation system o Accuracy could be enhanced w/ GPS

FIGURE 11. Technology Evaluation Matrix: Geo-Referencing (continued)

TECHNOLOGY / CRITERIA	AUTOMATIC REGISTRATION			
	LASER PROFILER	RADAR ALTIMETER	RADAR INTERFEROMETRY	VLSI
Cost: Current	About $65,000			
Projected, 1990				
Availability	Yes	Yes	Yes	Developmental
Accuracy	1-2 cm, average			
Timeliness	Real time.	Real time.	Real Time.	Real Time.
Development Time				
Physical Dimension				Microprocessing chip
Weight				
Power Requirements	80 W, max; 115/230 VAC or 28 VAC			
Reliability				
Other	o Used in conjunction with INS or GPS o Operating range 3000 ft. o Fair weather apparatus.		o Largely restricted to DOD use.	o Georeferencing chips could be operational within 2-3 yrs o Holds great potential for data base integration

per unit is $65,000. Radar altimetry and interferometry are also being assessed as to its applicability to real-time terrain data correction.