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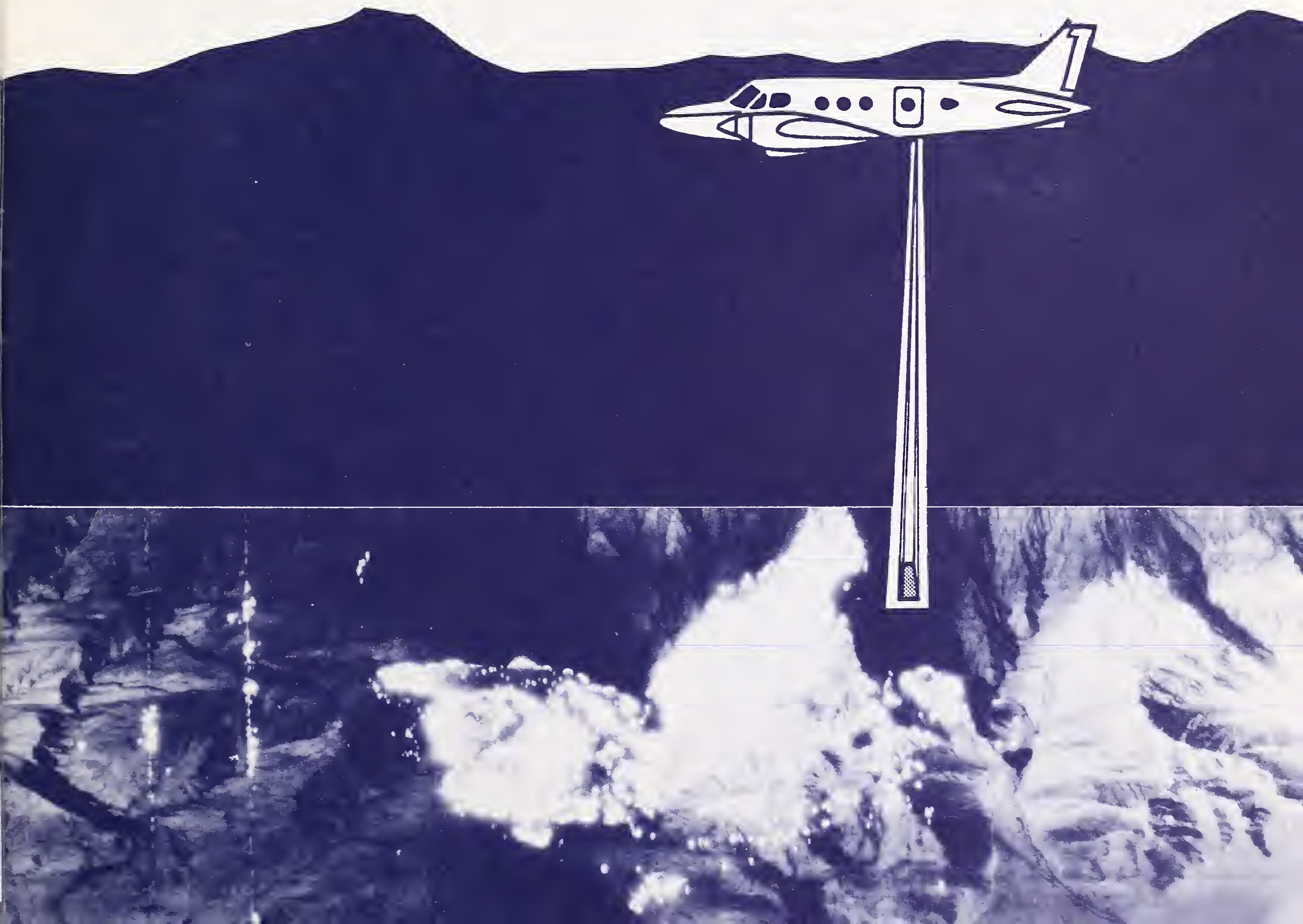
Airborne Infrared Forest Fire Surveillance--A Chronology of USDA Forest Service Research and Development

John Warren and Ralph A. Wilson



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RESEARCH SUMMARY

In the late 1940's and 1950's forest fire researchers had demonstrated that the time elapsed between ignition and detection accounted for excessive escaped fires and significant burned acreage; detection time was not materially improved with new detection methods--patrol aircraft, improved communications, and other innovations. Thus Project FIRESCAN (Research Work Unit 2105) was initiated in 1962 to work on the forest fire detection problem.

Concurrent with attempts to improve forest fire detection problems, major technological advances were occurring in electronics and photo-optics. Fast-response airborne infrared line scanners were being developed that had obvious application to forest fire detection. The development of lightning location and tracking systems was initiated.

The first research airborne infrared line scanner was acquired in 1962, and research studies were started to examine the physical problems of detecting very small radiation sources obscured by timber canopy and rugged terrain, to study and define the performance requirements of the infrared hardware, and to develop optimal fire patrol strategies and examine the cost effectiveness of airborne infrared fire detection. Studies were performed in cooperation with the Department of Defense to examine problems of common interest, gain access to state-of-art equipment, and to augment research funds. In the fall of 1962, the fire mapping capability was discovered, and the project soon divided its effort into two independent, but technically overlapping, "fire surveillance capabilities--fire detection and fire mapping."

From 1964 to 1966, a fire-mapping crew was detailed to the FIRESCAN project from National Forest Systems to expedite development of fire-mapping operational procedures. The fire-mapping system that was transferred to the Division of Fire Control in 1966, although not the ultimate in technical performance, did provide a badly needed fire intelligence capability.

The technical requirements for detecting small fires in large areas of terrain were much more difficult to resolve. Nevertheless, by 1970 a very sophisticated fire-surveillance system was developed with capability to patrol 2,000 square miles per hour and detect small fire targets with high probability. This system also included greatly improved fire-mapping capabilities.

The fire surveillance system was operationally tested by the Northern Region's Division of Fire Control, in 1971 and 1972, with only marginal success. In retrospect, the airborne forest fire detection system was conceived as a **strategic** fire detection tool; it was designed to have "very large payoff in dollar terms--or in reduction of numbers of escaped fires." The hardware and operational procedures were developed accordingly. However, fire detection is traditionally a **tactical** fire control operation--a fire starts, is detected, and initially attacked by fire control personnel. The resources and plans for implementing a new strategic fire detection system proved to be prohibitive.

By 1974 the Division of Fire Control had developed procedures and skill in using the IR mapping equipment and provision was made to transfer all technical responsibilities to the Boise Interagency Fire Center, Division of Fire Management. The fire detecting capability is available nationally, and is used in critical fire danger situations.

The timely delivery of the IR fire information to fire management personnel has continued to be a serious problem. Image transmission, processing, storage, and display systems using the latest technological advances are being developed by the IR team at BIFC.

During the research and development phase three fire surveillance aircraft with the infrared hardware were acquired; the 1965 mapping unit, the 1965 detection research "breadboard," and the 1974 operational prototype. These three units are obsolescent and are becoming increasingly difficult to maintain in operational readiness. Plans are being made to replace or upgrade these systems to provide reliable performance.

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HISTORICAL REVIEW

Work by J.S. Barrows (1951) and others during the 1940's and 1950's emphasized the need for improved fire detection capability in the Intermountain West. In certain parts of the West, up to 35 percent of the lightning fires were not being discovered until 12 hours after ignition (western zone of USDA Forest Service, Region I, 1931 to 1945, analysis of 18,000 fires.) As many as 10 percent went 72 hours before discovery. Furthermore, analysis showed that the late discoveries accounted for an inordinate number of escaped fires and significant burned acreage (Class E fires). Finally, detection time had not improved materially with "improvements" in detection methods--the introduction of improved communications, patrol aircraft, etc.

Barrows described the problem as follows:

> Once a fire starts, detection is the first requirement in control operations. The efficiency of a detection system is dependent upon its ability to cover the maximum possible area where fires may start, to discover fires quickly enough so that they will be of small size, and describe them accurately with respect to location and behavior. A system that will detect the greatest number of fires in the fastest time at the lowest cost is the major objective.

In 1962, Project FIRESCAN (Research Work Unit 2105) in the Intermountain Forest and Range Experiment Station (INT) was instituted, with Stanley N. Hirsch as project leader. An early association was established with the Electronics Research Laboratory (ERL) at Montana State University; the first cooperative study was to investigate techniques and develop a lightning location system for tracking thunderstorms (Rumpel 1965). The first lightning location efforts bore little fruit because of technical problems. (Most of these problems have been overcome, however, and a recently developed thunderstorm tracking system is currently being tested by the Fire Occurrence Work Unit (RWU 2101) with good preliminary results.)

Concurrent with attempts to improve forest fire detection, major technological advances were occurring in electronics and photo-optics. Military and commercial enterprises were developing sensitive, fast-response airborne infrared line scanners that obviously had potential application to forest fire detection.

In 1962, the project's first infrared (IR) line scanner was installed in a leased Beechcraft AT-11 aircraft. This system produced the first IR imagery of forest fires through smoke palls and of small fires under timber canopies. The technical problems encountered are discussed in detail in the publications listed in the project bibliography (see appendix). Early work concentrated on the operational requirements and utility of airborne IR forest fire detection, including:

1. Cost-effectiveness studies of detection systems by P.H. Kourtz at University of Southern California, Berkeley, Calif.; S.N. Hirsch; and Stanford Research Institute, Palo Alto, Calif.
2. Time history and radiation studies on the characteristics of small fires and obscuration of fire targets by timber canopy overstory, by R.A. Wilson, N. Noste, and B.J. Losensky.
3. Analysis of airborne IR system, performance requirements, and hardware development by F.H. Madden, R.A. Wilson, and S.N. Hirsch.
4. Development of airborne IR fire detection patrol strategy, logistics, and operations tests by P.H. Kourtz, B.J. Losensky, and R.F. Kruckeberg.

A chronological summary of these activities is shown in table 1. Initially, financial support was provided by the USDA Forest Service and the National Science Foundation. Throughout the 1960's, most commercially available IR hardware was developed under military sponsorship (and national security restrictions) and was designed to military requirements. The project undertook cooperative research studies with agencies of the Department of Defense (DOD) to examine problems of common interest, facilitate access to state-of-art equipment, and augment research funds. Cooperating agencies included the Office of Civil Defense for studies and development of techniques for mapping large fires, and the Advanced Research Projects Agency for studies to examine small hot-target identification problems. Because of the developmental nature of this work, project studies prior to 1970 were defined in approved "work agreements" with DOD in lieu of formal research problem analyses and study plans.

Table 1.--Summary of Project Fire Scan Program, 1962-1974

Year	Aircraft	Equipment	Results
1962	Beechcraft AT 11	AAS/5 scanner	First imagery through smoke. Preliminary detection of small fires under forest canopy.
1964	Beechcraft AT 11	AAS/5 (modified for Polaroid readout)	16 flights over wildfires, imagery dropped to fire camp. Data collected on detection probability versus scan angle in four coniferous types.
1964	Aero Commander 500B	AAS/5, Polaroid	49 flights over wildfires, experience in use of imagery for fire control.
	Convair T-29	AAS/5, KD-14 rapid film processor.	No data due to equipment problems.
1965	Aero Commander 500B Convair T-29	Reconofax XI scanner RS-7 scanner, Litton CRT KD-14, tape recorder.	Preliminary evaluation, no data due to equipment problems. Data collected on detection probability versus scan angle in three coniferous and three deciduous timber types.
1966	Aero Commander 500B	Reconofax XI, Dual Polaroid	System delivered to Div. Fire Control for operation.
	Convair T-29	RS-7, Litton CRT, KD-14, tape recorder, APN 81 Doppler	Data collected on detection probability versus scan angle in one coniferous and two deciduous timber types. First fire patrols.
1967	Aero Commander 500B Convair T-29	Reconofax XI, Dual Polaroid RS-7, Litton CRT, KD-14, Target discrimination module, Bendix DRA-12 Doppler	Operational. 21 fire detection patrols.
1968	Convair T-29	RS-7, Litton CRT, KD 14, TDM, DRA-12 Doppler	Equipment modified for 2-color system and to reduce size and weight for installation in smaller aircraft.
1969	Beechcraft King Air	RS-7, Litton CRT, KD-14, TDM, DRA-12 Doppler, 2-color temperature discriminator	Testing and 25 regular fire detection patrols. Two detector problems.
1970	Beechcraft King Air	Same as 1969	Detector problems solved. Successful test. 41 regular fire detection patrols and 15 large forest fires mapped.
1974	Sweringen Merlin	FFS-1 Forest Fire Surveillance (modified RS-7/RS-25)	Procured for National Forest Systems.

In the fall of 1962, the fire mapping capability was discovered while on a routine system checkout flight over a prescribed fire on the Clearwater National Forest (Hirsch 1962). The first imagery of wildfire (the Gravel Creek fire) in 1963 greatly impressed fire control staff officers. Within the next 18 months, the project divided its efforts into two independent but technically overlapping "fire surveillance" capabilities: (1) fire detection and (2) fire mapping (Hirsch 1964; Wilson and Noste 1966; Hirsch and others 1968; Wilson and others 1971).

In 1964, experimental fire mapping equipment was installed in an Aero Commander 500B aircraft. A fire-mapping crew under the leadership of Robert Bjornsen was detailed to the Northern Forest Fire Laboratory (NFFL) to develop fire-mapping operational procedures and expedite the application of this new working tool.

In 1965, the Director, Forest Fire Research, and the Director, Division of Fire Control, agreed to "identify more specifically the information these techniques can record and furnish to the fire boss." In retrospect, involving the user in the development of performance requirements and in the application phase greatly contributed to the success of the IR mapping system, which was transferred to the Division of Fire Control in 1966. The 1966 mapping system was not the ultimate in technical performance, but it was designed to provide badly needed fire intelligence and subsequently proved its worth.

The technical requirements for detecting small fires in large areas of terrain were much more difficult to resolve. In general, the optical-mechanical design of commercial/military scanners was adequate for the forest fire detection mission. However, the IR sensors, the electronic signal processing, and the fire target discrimination logic circuits required extensive study and development work to meet system objectives (Wilson and Noste 1966; Wilson 1968; Wilson and others 1971; Hirsch 1968c, 1971a).

By 1970 a very sophisticated "fire surveillance" system was developed, with capability to patrol several thousand square miles of forested terrain per hour and detect fires as small as 1 square foot with high probability and very low false alarm rates. It also provided a greatly improved capability to produce fire-mapping information. Because of its increased sensitivity and resolution, it could more easily mark spot fires around the fire perimeter, find and mark buried burning material for mopup operations, and provide cleaner and sharper imagery in a continuous strip.

During the fire seasons of 1971 and 1972, the detection system was turned over to and tested operationally (project FIDO) by the Northern Region, Division of Fire Control, with only marginal success (Elms 1972). This operational test was performed at the expense of reduced conventional detection forces on four National Forests in northern Idaho and western Montana; thus, its tactical performance was critically evaluated in specific fire management situations (namely, why did it miss this fire?).

Again, in retrospect, several observations are appropriate. First, fire detection is traditionally a **tactical** fire control operation--a fire starts, is detected, and initial attack forces are dispatched by "front line" fire control personnel. Secondly, the justification and need for improved (strategic) fire detection was a research conclusion that was not fully appreciated nor enthusiastically endorsed by fire control/management. Even though Kourtz (1971) had proved that the detection system had the potential "for very large payoff in dollar terms--or in reduction of numbers of escaped fires--", the neglected realities include: (1) goal and product oriented research must maintain close ties to the end user to be successful; (2) cost effectiveness is immaterial if implementation costs (both dollars and administrative) are prohibitive; and (3) plans for implementation are as important as the solution of the research problem.

Because the forest fire detection capability is available nationally in the airborne IR systems, it is used in critical fire danger situations. While the prototype system (the Beechcraft King Air with Texas Instruments RS-7 scanner) was being tested, the project prepared procurement specifications and monitored the purchase of a second fire surveillance system mounted in a Sweringen Merlin aircraft. These three systems (the original 1966 "mapping" system and the two high-performance "surveillance" systems) are still in use. All three are based at the Boise Interagency Fire Center.

Timely delivery of fire imagery to a fire camp has continued to be a problem since the first mapping system went operational in 1966. The aircraft were fitted with drop tubes to airdrop the imagery into fire camps during daylight hours, visibility permitting; otherwise, the imagery was delivered via ground transportation from the nearest airfield. Ground delivery costs valuable time in too many critical situations. In 1971 and 1972, effort was started to telemeter the fire imagery from the aircraft into fire camp. Briefly, the problems were: (1) the IR scanners produce data (imagery) at rates that would require wide telemetering band widths; (2) these telemetry bands are not routinely available; (3) the range and power of standard telemetry equipment severely limited the aircraft flight procedures; and (4) the costs of equipment are high.

The first low-cost telemetry system using Forest Service (narrow band) radio channels and facsimile reproduction equipment in fire camps produced fire imagery of such low quality and resolution that it was judged "unusable" by fire control staff officers. A second system, developed in 1974 for the FIRESCOPE program in southern California, was expensive, but it produced adequate imagery at fire camp. This system telemetered the composite IR video, synchronization, and roll signals via a leased military telemetry channel (restricted to southern California) to a ground station using a manual tracking directional antenna, and stored the signal on magnetic tape. The tape was then played back through a duplicate of the airborne image recorder-printer--an effective, but cumbersome and expensive procedure.

A series of studies during 1973 and 1974 in cooperation with ERL at Montana State University examined in detail the IR video signal characteristics to identify the fire and terrain mapping information specifically required to be extracted for fire control purposes. The object was to reduce the amount of data in the IR imagery and hence reduce the band width requirements of the telemetry equipment. (Perhaps the immediate need for fire intelligence could be satisfied by an automatically produced line drawing of the fire imagery which is easily transmitted to fire camp, then the IR image photos could be delivered later.) Concurrently, the telemetry system options were examined to determine the engineering trade-offs between fire information requirements, equipment availability and costs, and system complexity.

In 1974, it was apparent that the primary development work in airborne IR fire surveillance had been accomplished. Because the Division of Fire Control had developed procedures and skill in using the IR equipment for large savings in forest resource and fire suppression costs, it was decided that further technical refinements should properly be within the province of the operational organization. Thus, in 1975 administrative provisions were made to transfer the technical responsibilities and personnel from NFFL (Intermountain Forest and Range Experiment Station) to the Boise Interagency Fire Center, Division of Fire Management. This transfer was completed September 30, 1979.

Since 1975, work has continued on the telemetry "down link" and, in response to increased workload on the IR equipment, plans are in the works to update and expand the airborne IR forest fire surveillance force.

CURRENT STATUS

Fire mapping systems have been used operationally since 1964. The HRB Singer IR scanner was first mounted in an Aero Commander and later in a Beechcraft Queen Air. Subsequently, the King Air (in 1973) and the Merlin (in 1974), both with mapping and detection capabilities, were acquired. The three IR systems have been used nationally (all Forest Service Regions), internationally (Canada), and by many agencies since then. Responsibility for the operation, maintenance, etc. of the IR systems, is with the Division of Aviation and Fire Management (A&FM), Boise Interagency Fire Center.

NFFL personnel have continued support efforts and have worked in an advisory capacity to achieve an orderly implementation of the research efforts into systems hardware and operational use. Technical personnel and laboratory equipment were physically transferred to BIFC during the phaseover, and have now also been organizationally transferred to A&FM, BIFC. Thus the development work has moved systematically from research to an operational unit. The basic research results will continue to be used as a baseline during the design and development of new IR systems to replace the aging units in use.

Development efforts typically require at least three iterations: (1) a breadboard, (2) a prototype or engineering model, and (3) a production or operational unit. In the airborne infrared systems, equipment up to and including the Queen Air could be considered as experimental; the King Air as a prototype; and the Merlin as an operational system. Note that the Merlin was adapted from earlier designs and used prior technology (table 2). All three airborne systems, however, were pressed into operational use, and the decision to acquire modern, interchangeable, truly operational systems is still pending.

Table 2.--Current status of fire surveillance systems

Item	System		
	HRB Singer (Queen Air)	**T.I. RS-7 (King Air)**	**R.I. RS-25 (Merlin)**
Scanner (receiver)			
Design age	1962	1962-69	1962-73
Date acquired	1964	1965	1974
Operational date	July 1966	Summer 1971	October 1974
Source	Purchased by OCD and "given" to Forest Service.	Purchased by FS Research, used about 6 years, then transferred to NFS.	Modification of RS-7 and AAS-18 to produce RS-25.
Image producer			
Type	Polaroid	KD-14 wet chem.	EMR Dry Silver
Design age	1965	Late 50's.	1969-1970
Source	Lab prototype Built by NFFL	One of 14 military prototypes built and then dropped. Went to dry silver, then back to wet chem.	Note: a later model dry silver image producer was procured by NFFL for Firescope in 1975. Modified for wet chem. in 1975-76.

The three present airborne IR scanning systems are becoming increasingly more difficult to maintain and keep up to performance standards because of age, lack of planned cyclic replacement, changes in electronics, industry, and so on. There is a large and growing list of parts that are difficult or impossible to acquire. Also, the three systems are basically without commonality, interchangeability, or backup. Recognizing this situation, the Regional aviation and fire managers unanimously agreed to support the acquisition of new IR line scanning systems at their Oklahoma City meeting in November 1978. The recommended action is to procure four identical (or at least interchangeable to the major component level) systems--one for each of the three aircraft and one for the maintenance facility. The latter is to be used as a ready source of spares, as a test bed for proposed modifications, and for trouble-shooting replaced components. Preliminary specifications have been prepared and will be reviewed, updated, and maintained ready for upgrading to procurement level specifications when the system replacement money is available. The new systems will be based on FIRESCAN research and on the operational experience with the present three systems. The new systems will incorporate modern technology, designs, and techniques.

Image transmission, processing, storage, and display systems are now under development by the IR development and test team at BIFC. These systems will use the latest technological advances to provide rapid image transmission and reception from plane to fire command post. The first of the three iterations (experimental) has been assembled and used on real forest fires.

The operational design will greatly speed up the interpretation process and offer enhancement and display options that will greatly improve the usefulness and timeliness of fire information. It will also be available for coupling into information from other systems as described further in a discussion on the future. Figure 1 presents some of the features of the planned operational system. Procurement of the first operational system is planned for fiscal year 1981.

FUTURE PROSPECTS

The near-term (less than 5 years) plans described above will provide up-to-date airborne IR scanning systems as the primary IR fire intelligence systems for large fire mapping and detection missions. Ground image receiving/processing/storage/display systems will be available for use at the fire command post. Rapid delivery and interpretation of IR imagery for timely use by the fire boss (or incident commander) and his staff should become commonplace instead of a long-sought luxury.

Future plans call for tie-ins with computer models, such as fire rate-of-spread, and vivid interactive displays of current and predicted fire positions, electronic overlays of fire and fuelbreaks, lines to be built, and other characteristics that will aid in decisionmaking on active fires.

Voice communications via satellite from fire command post to agency headquarters (or to any telephone) will become standard for fire operations. Technical feasibility was demonstrated more than 3 years ago (Warren 1975). This will be accomplished with small-diameter (1 meter) transportable parabolic antennas and corresponding transmitting and receiving equipment. This capability may then be followed by satellite data communications and image transmission. Selective use of detection missions needs to be exploited much more in the future. With the expanding use of Remote Automatic Weather Stations (RAWS) to provide improved resolution to the National Fire-Danger Rating System (NFDRS), and the introduction of the Automatic Lightning Detection System (ALDS) to pinpoint potential fire-causing lightning strikes, a fire detection flight over the area of concern can find small, recently ignited fires and preclude some major large fires.

To sum up, the future will bring improved performance and reliability in the airborne IR systems and timely delivery and interpretation of imagery to the fire staff. In addition, the coupling of the IR information systems to other systems and to evolving computer models should multiply the benefits and the usefulness of available information.

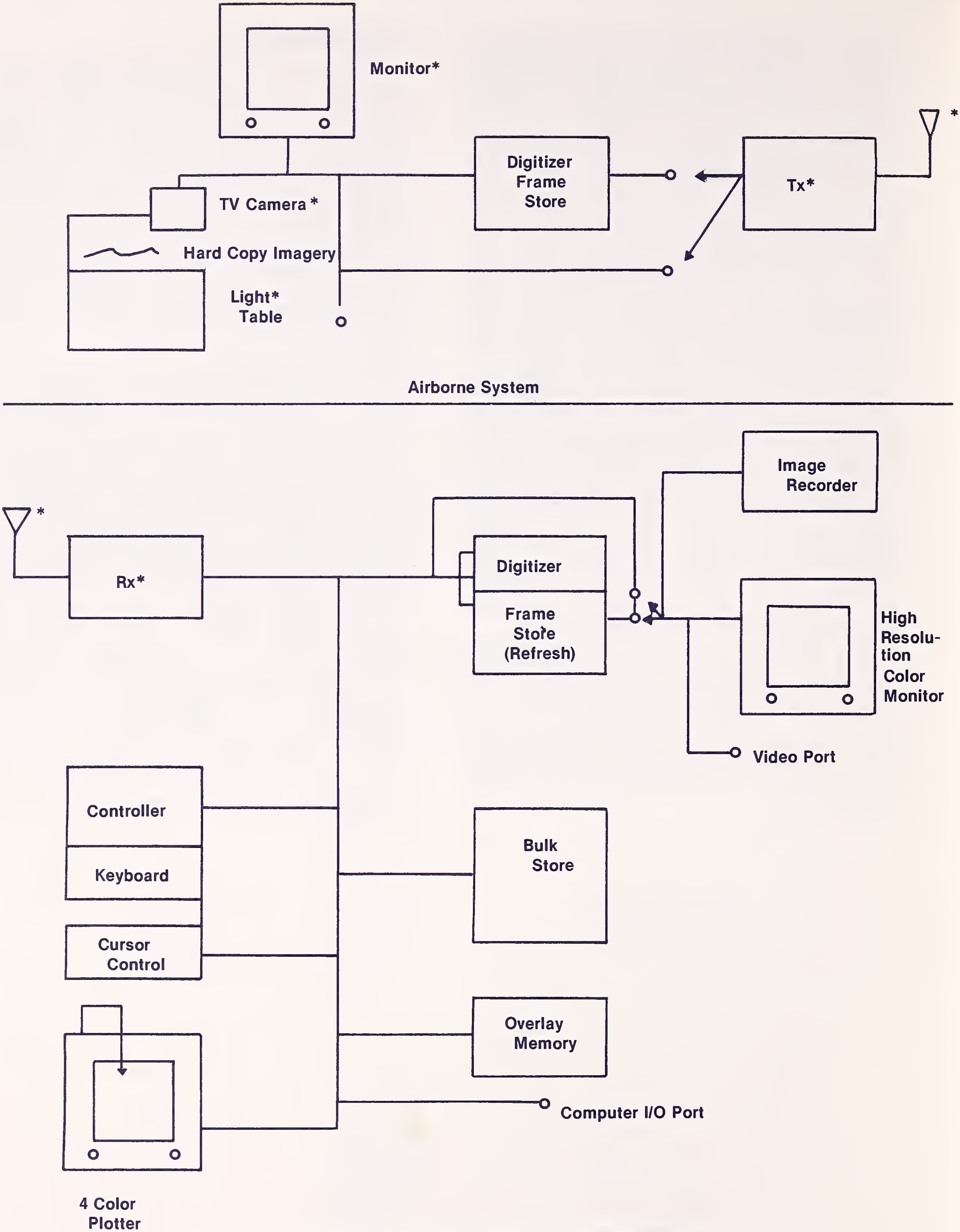

Figure 1.--Image transmission processing system.

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Provides a brief history of USDA Forest Service infrared (IR) research, current status of image systems in development, and future plans and projected uses of infrared imagery. Describes status of Forest Service IR systems research, development, testing, and usage up to the time that those functions and the IR development team were transferred from research to National Forest Systems, Division of Aviation and Fire Management, Boise Interagency Fire Center, Boise, Idaho.

KEYWORDS: infrared, airborne, surveillance, fire, mapping, detection, FIRESCAN, history

The Intermountain Station, headquartered in Ogden, Utah, is one of eight regional experiment stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

The Intermountain Station includes the States of Montana, Idaho, Utah, Nevada, and western Wyoming. About 273 million acres, or 85 percent, of the land area in the Station territory are classified as forest and rangeland. These lands include grasslands, deserts, shrublands, alpine areas, and well-stocked forests. They supply fiber for forest industries; minerals for energy and industrial development; and water for domestic and industrial consumption. They also provide recreation opportunities for millions of visitors each year.

Field programs and research work units of the Station are maintained in:

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