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PROJECT FIRE SCAN--FIRE MAPPING FINAL REPORT

by

Robert L. Bjornsen
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THE USE AND SYSTEM REQUIREMENTS OF INFRARED SCANNERS IN MAPPING WILDFIRES

Intermountain Forest and Range Experiment Station
Northern Forest Fire Laboratory
Missoula, Montana

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Prepared for
OFFICE OF CIVIL DEFENSE
OFFICE OF THE SECRETARY OF THE ARMY
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Work Order OCD-OS-62-174
(Evaluation of an Airborne Infrared Mapper)
and
Work Order OCD-PS-66-17, Work Unit 2521A
(Preliminary System Development)

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ABSTRACT

An airborne infrared line scanner sensitive to the 3- to-5-micron spectral region mapped 38 forest fires during the 1963, 1964, and 1966 fire seasons. The imagery obtained provided information about the fire perimeter, relative intensity of burning areas, and spot fire location under conditions when smoke or darkness prevented visual reconnaissance. This report describes the operational methods, the equipment used, and gives many examples of imagery collected.

The radiometric and electronic characteristics peculiar to fire mapping applications are discussed. A unique dual Polaroid recording camera was developed to provide quickly available imagery for air drop to fire headquarters.

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In May 1964, Work Order No. OCD-OS-62-174 was amended (Amendment #8) and the revision provided a breakdown of the existing scope of work by subtasks and added studies to the scope:

> "In consultation and cooperation with the Office of Civil Defense, Office of the Secretary of the Army, the Department of Agriculture, Forest Service, shall conduct the following specific studies:
>
> <u>Subtask 2521A (I) - Feasibility Study of Airborne Infrared Device for Fire Detection and Mapping.</u> Determine the feasibility of using an airborne infrared device for fire detection and mapping in forest areas.
>
> <u>Subtask 2521A (II) - ARPA Task No. 1</u> Measure detection probability with an infrared scanner on small charcoal fires from a fixed elevated position at vertical angles from 50-60 degrees.
>
> <u>Subtask 2521A (III) - ARPA Task No. 2</u> Measure detection probability as a function of vertical angle from an airborne scanner on small charcoal fires in forests of the white pine-cedar-hemlock type in northern Idaho and in the Douglas-fir type found on the western slopes of the Cascade Mountains.
>
> <u>Subtask 2521A (IV) - ARPA Task No. 3</u> Measure detection probability on real fires utilizing an airborne scanner in systematic search of forested areas."

In the fall of 1964, due to individual interests of the OCD and ARPA, the project was divided into two sections—fire mapping and fire detection. Subsequently, the fire detection subtasks II, III, and IV of OCD-OS-62-174 were replaced by ARPA Order #636.

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Amendment #10 dated August 21, 1964, to Work Order No. OCD-OS-62-174 added the following to the scope of Work:

"Subtask 2521A(V) - Preliminary System Development

a. Analyze intelligence requirements and collect data and determine operational requirements for mapping rural fires.

b. Analyze nuclear war environment requirements and determine operational requirements to support Civil Defense operations.

c. Analyze telemetry-ground readout system requirements and develop preliminary specifications.

d. Perform mapping missions in suburban wildfire analysis for applicability to Civil Defense operations, and develop procedures of employment of IR systems in suburban wildfire situations.

e. Develop methods of measuring rate of spread of fire."

Work Order OCD-PS-66-17, Work Unit 2521A, was negotiated in September 1965. The Department of Agriculture was to furnish the following services to the Department of the Army, Office of Civil Defense:

"a. Analyze intelligence requirements and collect data and determine operational requirements for mapping rural fires.

b. Evaluate HRB-Singer pre-prototype airborne infrared scanner.

c. Analyze telemetry-ground readout system requirements and develop preliminary specifications.

d. Perform mapping missions in suburban wildfire analysis for applicability to CD operations and develop procedures of employment of Infrared systems in suburban wildfire situations.

e. Develop methods of measuring rate of spread of fire."

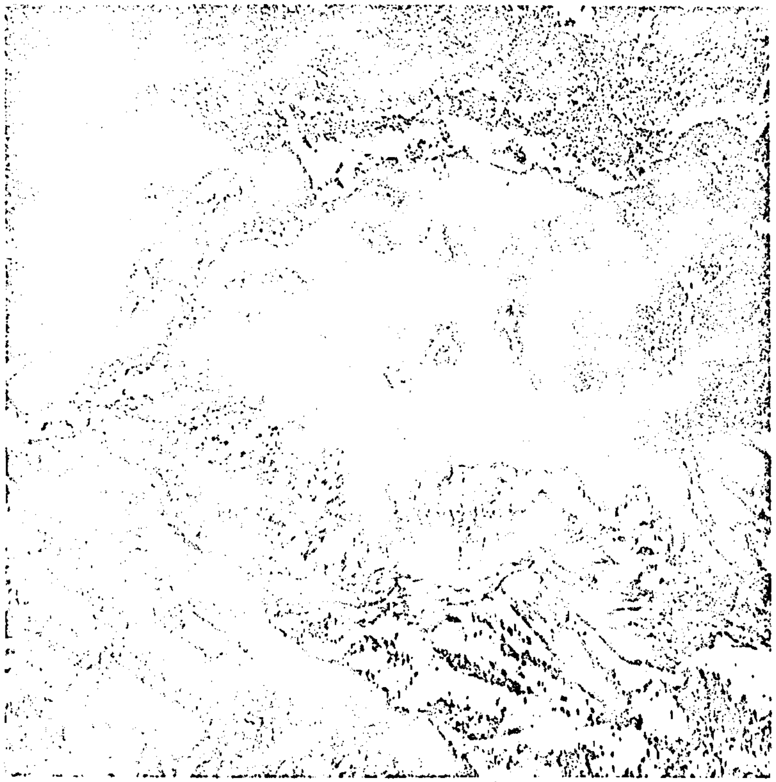
A

B

Figure 1.--Photographs of Kelly Creek Prescribed Fire, 1962: A, Oblique photographs; B, infrared map.

Based on this test, an operational feasibility study was initiated to determine detailed equipment requirements, operational methods, and training needed to implement infrared mapping of wild land fires.

The AAS/5 infrared detection set fell far short of meeting our requirements for an operational system. Imagery was recorded on 35-mm. Panchromatic film. The processing and printing required, prior to obtaining useful data, resulted in an intolerably long time lag between gathering of intelligence and making it available to the user. The angular resolution of the system was inadequate to record the terrain detail required for effective interpretation. The 80° scan angle was inadequate to provide the coverage needed in fire mapping operations. And finally, the dynamic range of the system was inadequate to handle the extreme contrast between normal terrain temperature variations and the very hot areas associated with a going fire.



A

B

Figure 2.--Gravel Creek Fire, 1963: A, Conventional aerial photograph made prior to the fire and used for identifying terrain features on infrared imagery; and B, infrared image of fire clearly showing location of small spot fires outside of main fire perimeter.

During the summer of 1963, this modified scanner was flown over nine fires. On two of these we dropped the Polaroid film immediately to an infrared interpreter in the fire camp. The intelligence obtained was employed by the fire suppression forces. The 1963 tests demonstrated the desirability of the immediate readout Polaroid prints, and the suitability of the air drop delivery method on relative small, back-country fires.

The limited experience gained during 1963 indicated the need for an expanded fire mapping study to answer the following questions:

1. What are the intelligence requirements for the suppression of large fires, and how many of these requirements can be satisfied with infrared scanning techniques?

2. Is the image dropping method of delivery suitable for all fire situations or will a telemetering capability be required?

3. Will fire mapping be used primarily in the initial stages of fire control? will it be required during control operations? and what is its utility during mopup?

4. At what altitude should fire mapping missions be flown?

5. At what times of day should IR missions be flown?

6. What are the performance requirements for an operational fire mapper?

7. What will be the reaction of trained fire control officers to this new tool? how will they employ it? and what is their evaluation of its utility?

In January 1964, preliminary criteria for an infrared fire mapping set were prepared at the request of the Office of Civil Defense (see Appendix I).

In preparation for the 1964 fire season, the infrared equipment used during the 1963 season was installed in a Forest Service Aero Commander to be used exclusively for fire mapping. Provisions were made for dispatching the unit to dangerous fire situations anywhere in the country. A cadre of Forest Service personnel from throughout the West were trained as infrared interpreters so their services would be available to support the small laboratory team.

During 1964, the infrared-equipped aircraft mapped 16 fires ranging in size from 10 acres to 215,000 acres. We flew 33 daytime and 16 nighttime flights. On 12 of the fires, the intelligence gathered was employed by fire suppression forces. The situations encountered ranged from flat country grass fires to wilderness area fires in rugged terrain and heavy timber, to the rural-urban complex involving both brush fields and private structures. We worked closely with Forest Service fire suppression teams, State fire suppression agencies, the California Disaster Office, and the Los Angeles County Fire Department. The wide range of conditions encountered during this season provided a sound basis for determining equipment requirements, personnel needs, and expected system performance.

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We needed to know the expected number of fires to be mapped during any year, and the number of fires that can reasonably be expected to occur concurrently before we could prepare final system specifications. An analysis was made of the U.S. Forest Service fire records during the past 20 years to obtain this information.

In late 1964, a contract was negotiated between the Office of Civil Defense and HRB-Singer, Incorporated to design and fabricate an infrared fire mapping unit in accordance with preliminary design criteria prepared at the Northern Forest Fire Laboratory. We received the new scanner (HRB-Singer Reconofax XI)[4] in the spring of 1965. The Aero Commander was modified for the installation of this new unit and preliminary flight tests were conducted during 1965.

4/ Reference footnote 3.

There were several deficiencies present in the new prototype unit. The amplifiers were unstable at high gain settings. The available gain was inadequate to make nighttime imagery. Amplifier saturation caused serious overshoot problems. The packaging of the electronics was not suitable for field servicing. These shortcomings had to be corrected before adequate operational tests could be made.

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The equipment was returned to the manufacturer with detailed recommendations for modification. The needed modifications were performed during the winter of 1965. In the spring of 1966, the system was reinstalled in the Aero Commander and turned over to the U.S. Forest Service, Division of Fire Control, for field evaluation. Subsequent test results were highly encouraging.

INTELLIGENCE REQUIREMENTS FOR WILD LAND FIRE SUPPRESSION

Effective fire suppression decisions must be based on the dynamic characteristics of the fire perimeter, its relation to fuels, weather, topography, values threatened, and the availability of suppression forces. The mission of infrared fire mapping should be to furnish the location of the fire perimeters at periodic intervals, rapidly enough and in sufficient detail to allow the fire control officers to make informed decisions (Appendix II).

The most important requirement is a picture of the fire edge in relation to ground features such as ridgetops, valley bottoms, streams and prominent landmarks with sufficient detail to determine the precise location of the fire edge, hot spots, spot fires, fuel type changes, and fuel breaks. A complete description of the fire and its behavior must include the following:

1. The extent and location of the entire fire edge, including both smoldering and flaming fronts.

2. The relative intensity along various portions of the fronts and the rate of spread.

3. The size and location of spot fires outside the main fire edge.

4. The location, size, and intensity of isolated hot spots within the main fire perimeter, especially those adjacent to the fire edge.

5. The location and adequacy of all firebreaks, both natural and man-made.

6. The size and location of unburned patches of fuel of 5 or more acres within the fire perimeter.

7. The existence and location of major fuel type changes for a distance of 1 or more miles outside the fire edge, i.e., changes between grass and brush, timber and brush, conifer and hardwood, blowdown and standing timber, water and land, rocks and timber, and rural or urban developments.

8. The location and extent of structural improvements such as residences, bridges, factories, schools, and urban communities with respect to the fire front.

In figure 2 (Gravel Creek Fire) many of these characteristics can be seen in the infrared image.

Fire intelligence is a highly perishable commodity. During the active stages of a fire's behavior, even the most complete description of its characteristics 4 hours ago may be of little operational value. The fire boss charged with the responsibility for strategy decisions must know what the fire is doing now. One of the prime requisites for any fire surveillance system is an ability to deliver fire intelligence to the fire staff at the scene of the fire at the time when major strategic decisions must be made.

Since infrared mapping systems produce a thermal image of the terrain being scanned, it is easy to differentiate between a hot fire and the surrounding terrain. Identifying fuel and topographic features is a much more difficult task. Before proceeding with a detailed discussion of the capabilities and limitations of infrared scanners for collecting fire intelligence, it may be helpful to discuss some of the characteristics of infrared scanners and the factors affecting their ability to depict surface features.

INFRARED LINE SCANNERS

The infrared line scanners employed in fire mapping operations consist of a telescope with a suitable detector at its focal point. A rotating scanning mirror placed in front of the objective of the telescope causes the optical system to scan a line perpendicular to the aircraft flight path (fig. 3). As the aircraft moves forward along the track, sequential lines are scanned in a contiguous manner. The output of the detector is amplified, converted to light, and printed on film. The printing device exposes a line across the film in synchronism with the rotating scanning mirror—X-axis. Film motion, in a direction perpendicular to the scan line at a velocity proportional to aircraft velocity and altitude, provides the Y-axis of the image (fig. 4). The scale of the resulting image is a function of the scan angle recorded and the altitude of the aircraft. The spatial resolution is determined by the focal length of the optical system, the size of the detector, the minimum spot size obtainable in the printer, and the height of the aircraft above ground. The spectral response of the system is determined by detector characteristics and filters employed. Distortions inherent in these systems are discussed in Appendix III.

Figure 3.—Schematic of an infrared scanner.

Figure 4.—Line scan coverage technique.

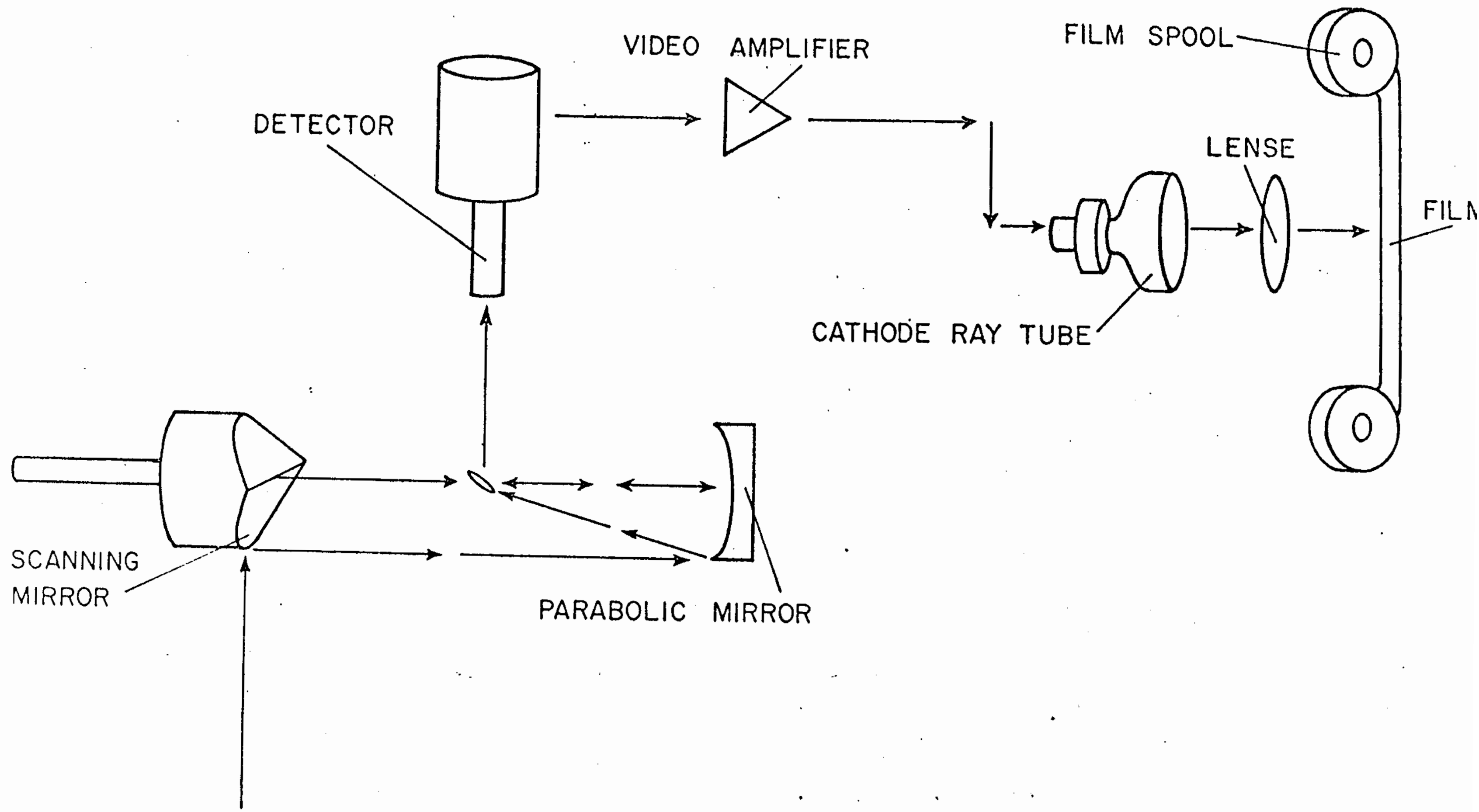

Figure 3.--Schematic of an infrared scanner.

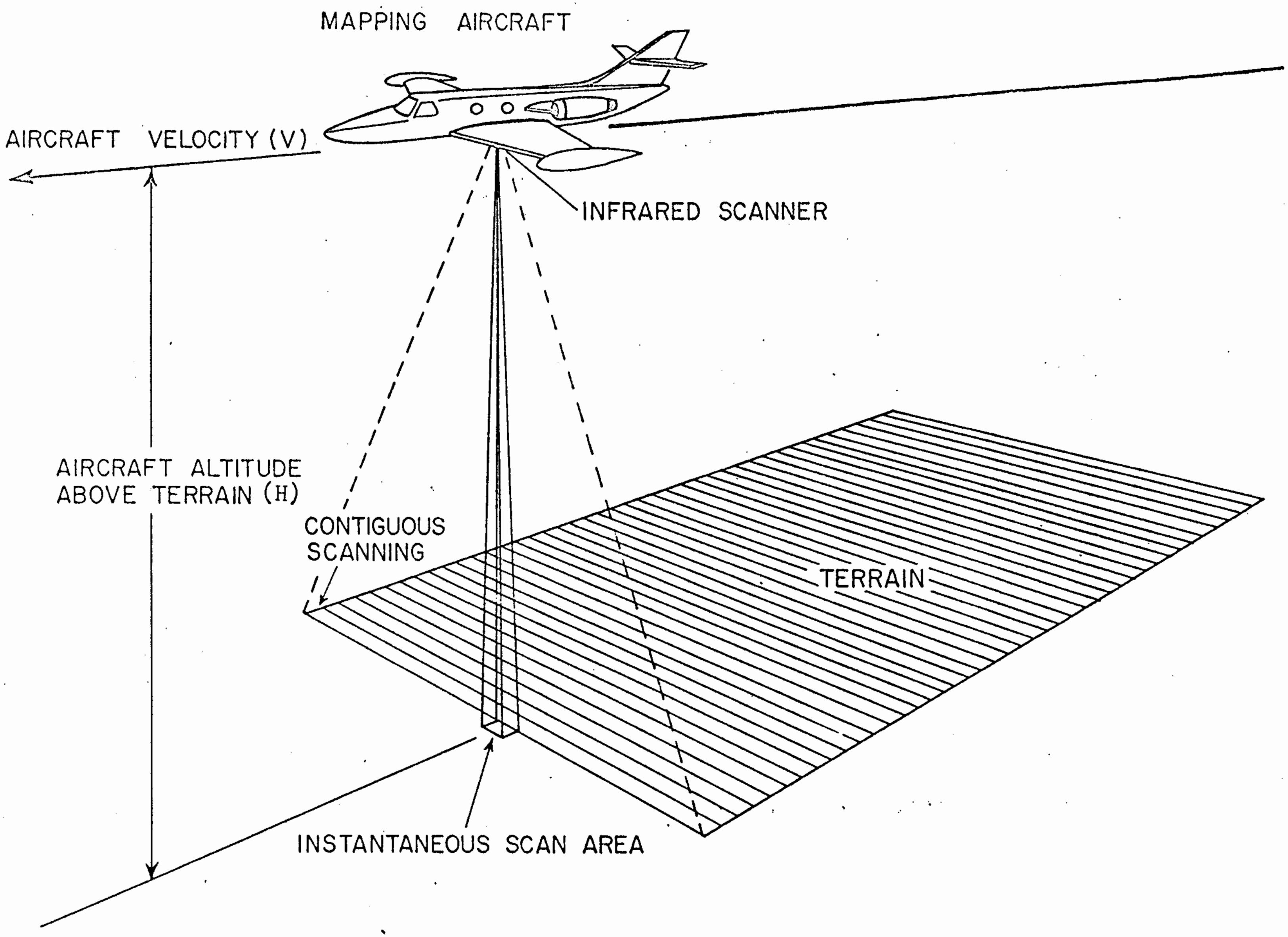

Figure 4.--Line scan coverage technique.

INFRARED IMAGERY

The tone of any spot in an IR image is a function (usually nonlinear) of the energy arriving at the scanner aperature from the ground. On a positive image light tones indicate more energy, dark tones indicate less. The tones on imagery made during the hours of darkness depend on the temperature of the terrain being scanned and the variations in surface emissivity, i.e., the tonal contrast is representative of the apparent radiant temperature. During daylight hours, the image tone depends on the energy radiated from the surface and the reflected solar energy; it is a function of detector spectral response, solar insolation, surface spectral reflectance, surface temperature, and surface emissivity. For an object to be detectable on infrared imagery, the energy radiated or reflected from it must be sufficiently different from the energy radiated or reflected from the surrounding terrain to produce a signal equal to or greater than the noise equivalent temperature of the system.

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The temperature of some terrestial features, such as large bodies of water, vary seasonally but show very small diurnal variations. Most other objects exhibit both seasonal and diurnal variation in temperature. Objects of very low thermal mass follow diurnal air temperature variations quite closely, while objects of much higher thermal mass tend to lag behind the changes in ambient temperatures. These characteristics tend to produce diurnal fluctuations in the tonal contrast of objects recorded on thermal infrared imagery. This effect can be most dramatically demonstrated by examining the diurnal temperature variations of three objects: (1) A land area, (2) a rapidly moving river, and (3) a bridge across the river.

During a bright, clear day in summer the temperature of the bridge will rise as insolation increases. There will be some lag between the surface temperature of the bridge and the changes in insolation. As we approach darkness, and insolation decreases, the temperature of the bridge will gradually decrease. During the hours of darkness, radiant exchange between the bridge and the sky will further reduce the bridge temperature. The next morning, as the insolation increases, the bridge temperature will again rise. The river temperature will remain constant throughout the period. The land surface temperature also changes from day to night, but at a slower rate than the bridge. Imagery made during one diurnal cycle goes through a complete reversal of tonal scale. There are two periods when the land-to-water and bridge-to-water tonal differences completely disappear.

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Since these tonal shifts depend on insolation and nighttime radiative cooling, cloud cover and seasonal variations in insolation will strongly affect the rates at which tonal changes occur. Although this water-land-bridge combination produces the most striking effects, the same shifts occur in all objects. The foregoing discussions assume a spectral response in the thermal infrared only. During daylight hours, these effects are further compounded by solar reflection and variations in surface reflectivity and emissivity.

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INTELLIGENCE GATHERING CAPABILITY OF INFRARED SCANNERS

Performance capability of infrared scanning systems is generally specified in terms of angular and temperature resolutions. Secondary considerations are the velocity-to-height ratio (V/H) and total field of view which govern the field coverage rate. Even if precise laboratory measurements are made of the above parameters, it is very difficult to predict field performance.

If we are to predict an infrared system's performance at such a complex task, the parameters of angular and temperature resolution are inadequate. There are at least six different definitions of "angular resolution" and three of "temperature resolution" which could apply but none have been generally accepted as a standard, and none are adequate to describe scanning system performance.

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The best available figure of merit (FM) of scanning systems is discussed in HRB-Singer's Report 1751.20-R-1, "Basic Design Considerations for an Infrared Scanning System."

$$\text{Figure of Merit (FM)} = \frac{\underline{\text{System Modulation Transfer Function MTF}}}{\text{System Noise Equivalent Temperature NET}}$$

The MTF is essentially the input spatial frequency that is reproduced at the output of the system. In general, it is not an analytic function; however, it is calculable and easily specified for any system. It is more precisely defined than "angular resolution." The NET is that temperature difference which would give a signal at the detector equal to the system RMS (root mean square) noise. This is an <u>effective</u> radiometric temperature defined for each system by an explicit function:

$$T = f(E)$$

where E is the total radiant energy to which the detector responds. This figure of merit is dependent only on the internal components of the system and is independent of the field at which the scanner is looking.

With the known MTF and NET, and given an exact description of the terrain field's radiant intensity distribution, one can calculate exactly what will be displayed on the image photograph. However, at present, no one can provide the necessary radiometric description of forested environments.

The complexity of the terrain radiometric field can be demonstrated. The energy (same as E above) from all observable sources to which a scanner responds and which is emanating from every point (x,y) in the forest can be written functionally as follows:

$$E(x,y) = \int_0^\infty P(\lambda)\, U(\lambda) [\epsilon(\lambda,\alpha,x,y) N_1(\lambda,T(x,y)) + R(\lambda,\alpha,\beta,x,y) N_1(\lambda,T_i)] \, d\lambda$$

$P(\lambda)$ is the relative spectral response of a system and is known. $U(\lambda)$ is the atmospheric transmission and is strongly dependent on meteorological conditions. It is possible for E to vary 50 percent due to relative humidity alone.

The emissivity, $\epsilon(\lambda,\alpha,x,y)$, can be determined only emperically by direct observation of every material of interest and under all conceivable conditions. ϵ will vary from material to material with surface roughness, moisture content, observation angle, wavelength, chemical composition, and impurities, etc. $N_1(\lambda,T(x,y))$ is the analytic Planck equation and is calculable only if the temperature is known of every point to be observed. Generally, differences in energy, E, will depend more strongly on ϵ in the 8- to 14-micron region where differences between materials at ambient temperatures are more easily observed. Fires are more easily observed in the 3- to 6-micron region where differences in $N_1(T)$ generally account for the greater differences in E. $R(\lambda,\alpha,\beta,x,y)$ is the reflectivity of each point in the field. Same comments as on emissivity apply; also, R is strongly dependent on the illumination angle, β.

$N_i(\lambda,T_i)$ is the surface illumination from extraneous sources such as the sun. N_i is not difficult to estimate (on clear days) but isn't as simple as N_1 above. At night we assume $N_i=0$.

From the above considerations, the dismay of a scientist can be anticipated when he is asked, "Can this scanner see a dirt road in a grass field?" The only possible answer is "it might." If the following are known, a better GUESS could be given. Is the dirt smooth and hard packed? Is the grass green and standing? Has the sun been shining for the past several hours? Is the sun shining now? Did it rain last night? Do you wish to observe the road from a low altitude? If the answers to the above questions are "yes" then the <u>chances</u> of observing the road are <u>probably</u> better. How much better—who knows? Only if the exact composition and physical state of the road and grass field are given, and only if previous emperical data are available for those conditions, can reliable yes-no answers be given. Invariably, however, problems and questions of this type are qualitatively specified. At best, the answers <u>must</u> be qualified.

A V/H capability of .25 radians per second is adequate to meet fire mapping needs. A system angular resolution of 4 milliradians and a temperature resolution of 2° K. is the absolute minimum for fire mapping, i.e., most of the information required can be obtained under optimum conditions. With an angular resolution of 1 milliradian and a NET of 1/2° K. we feel that under most conditions the needed fire intelligence can be obtained.

The tabulation in Table 1 is our "best guess" comparison of the adequacy of two different systems in meeting the requirements for fire intelligence.

Table 1.—Estimated performance of fire mapping systems

	Operational altitude	Estimated performance*: $\Delta\alpha$=4 milliradians ΔT=2° K.	Estimated performance*: $\Delta\alpha$=1 milliradian ΔT=1/2° K.
	Feet		
I. Fire Edge			
1. Overall perimeter	10,000 max.	Adequate	Adequate
2. Flaming front	10,000 max.	Adequate	Adequate
3. Rate of spread	≤ 10,000	Adequate	Adequate
4. Intensity (size)	10,000 max.	Adequate	Adequate
5. Firelines & breaks	4,000 min.	Poor	Probably adequate: ΔT=1/10° K. would improve chances tremendously
6. Spot fires ahead of front	10,000	Poor, depends on timber cover and spot fire intensity and size	Much better, probably adequate. Still a matter of statistical chance
II. Fuels			
1. Hot spots within 300' of fire edge	4,000 min.	Adequate	Adequate
2. Unburned fuels ≥ 5 acres	10,000	Very poor	Moderate; very dependent on ΔT; also prior knowledge of local area
3. Fuel types outside of fire	10,000	Poor	Probably adequate with prior knowledge of local area
III. Structural Improvements	10,000	Adequate on basis of association with local surroundings	Very good

*Distances on ground are only determined with ±4 feet per 1,000 feet of altitude with 4-milliradian systems, and ±1 foot per 1,000 feet with 1-milliradian systems.

THE PROTOTYPE FIRE MAPPING SYSTEM

The fire mapping system, developed under OCD Contract No. OCD-OS-62-174, was designed to meet the criteria prepared by Project Fire Scan (reference Appendix I). The system consists of three major subsystems:

1. The Reconofax XI[5/] infrared scanner and remote control unit;
2. a test oscilloscope; and
3. a real-time viewer and Polaroid camera assembly.

5/ For detailed information on the original Reconofax XI scanning system see: Sobel, III, J. A. 1965. Prototype airborne infrared fire mapping set (U). HRB-Singer Final Research Report, Contract #OCD-PS-65-54, OCD Subtask #2524B. 59 pp., illus. (Classified).

RECONOFAX XI SCANNER

The infrared scanner unit (fig. 5) contains the rotating optics, the detector-dewar-preamp assembly, the glow tube modulator assembly, and the 70 mm. film cassette. The film cassette is easily removed for film processing (through a panel in the side of the scanner). The port door (shown open in fig. 5) automatically closes when the scanner is not operating. The scanner remote control unit (fig. 6) contains the video processing circuits and the system power controls.

Figure 5.—Reconofax XI infrared fire mapping scanner.

Figure 6.—Reconofax XI (mod 2) infrared scanner remote control unit.

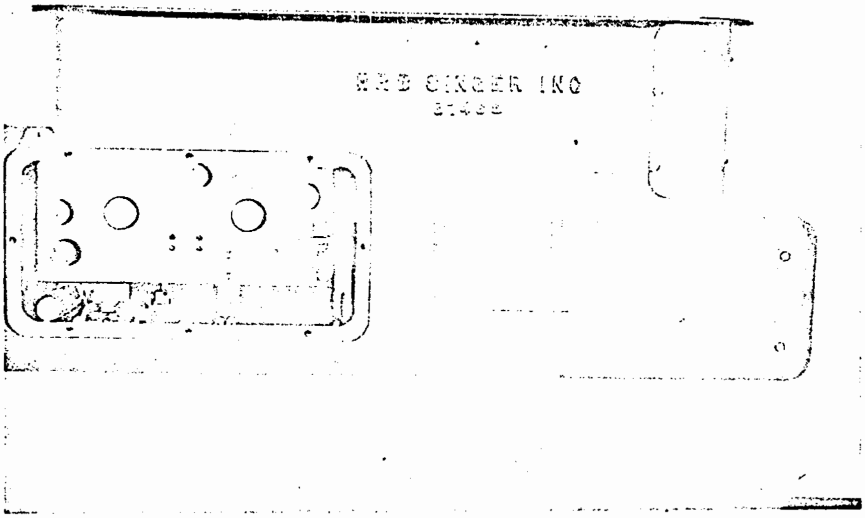

Figure 5.--Reconofax XI infrared fire mapping scanner.

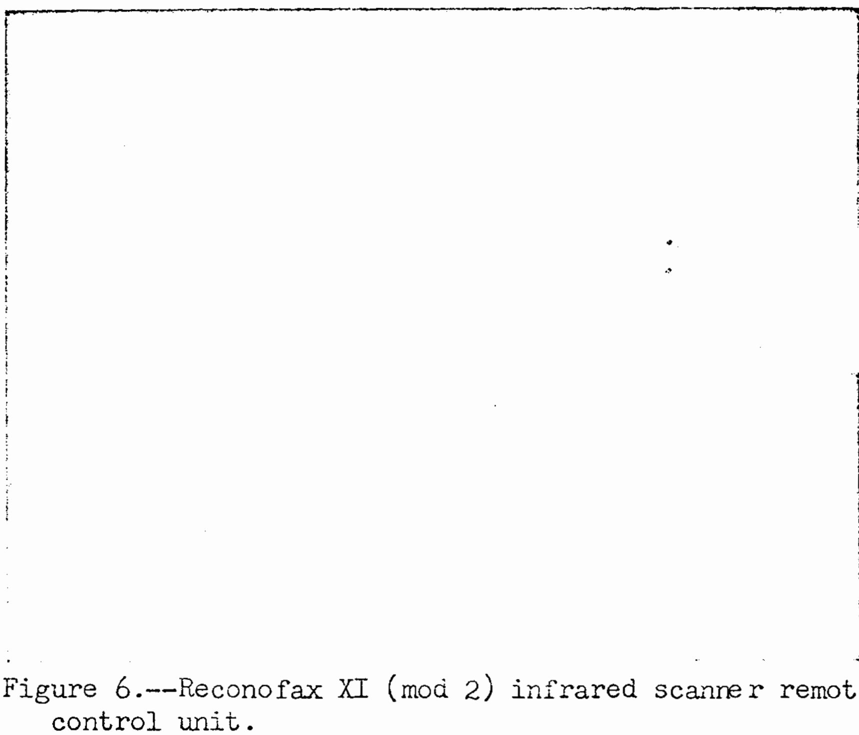

Figure 6.--Reconofax XI (mod 2) infrared scanner remote control unit.

The test oscilloscope originally supplied with the system was a 3-inch Tektronix Model 321[6] operating directly from the

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6/ Reference footnote 3.

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aircraft 28 v. d.c.

The Reconofax XI infrared scanner, delivered to the Northern Forest Fire Laboratory in June 1965, was too unreliable for flight testing. The scanner was returned to the factory for temporary repairs in late August 1965. Upon return, tests on a few fires in California, followed by Laboratory tests, furnished enough information to prepare an evaluation report[7]. The report listed

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7/ "First Evaluation of the Reconofax XI," Northern Forest Fire Laboratory in-house report, November 5, 1965.

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39 recommended changes.

A contract was negotiated with HRB-Singer, Incorporated to modify the system in accordance with the recommendations in the report. Twenty-three of the 39 items were chosen as feasible and reasonable, considering the time and money available.

REAL-TIME VIEWER

While the Reconofax XI system was at the factory, the real-time viewer (fig. 7) was delivered to the Northern Forest Fire Laboratory for evaluation. The real-time viewer (B-scan) contained a single-frame Polaroid camera photographing a high resolution cathode ray tube (CRT). The construction of the viewer was considerably better than the original scanner.

Figure 7.—Real-time viewer with dual Polaroid camera attached.

The viewer was received without an internal high-voltage power supply. Because the normal supply had failed at the factory, the manufacturer furnished an external laboratory power supply for preliminary tests.

A dual phosphor (P-7) CRT[8/] was supplied with the viewer to permit monitoring and photographing a single tube. The CRT manufacturer specifies a minimum spot size of .003 inch for the P-7 phosphor. The spot size was nearer .006 inch when installed in the printer. A .001 inch spot size is required to retain the desired scanner resolution.

8/ A P-7 cathode ray tube has a dual phosphor coating with two spectral peaks. A medium-short persistance peak at 4400 Å is suitable for photographing when used with a blue filter. A long persistance peak at 5580 Å with an amber filter is adequate for B-scan viewing.

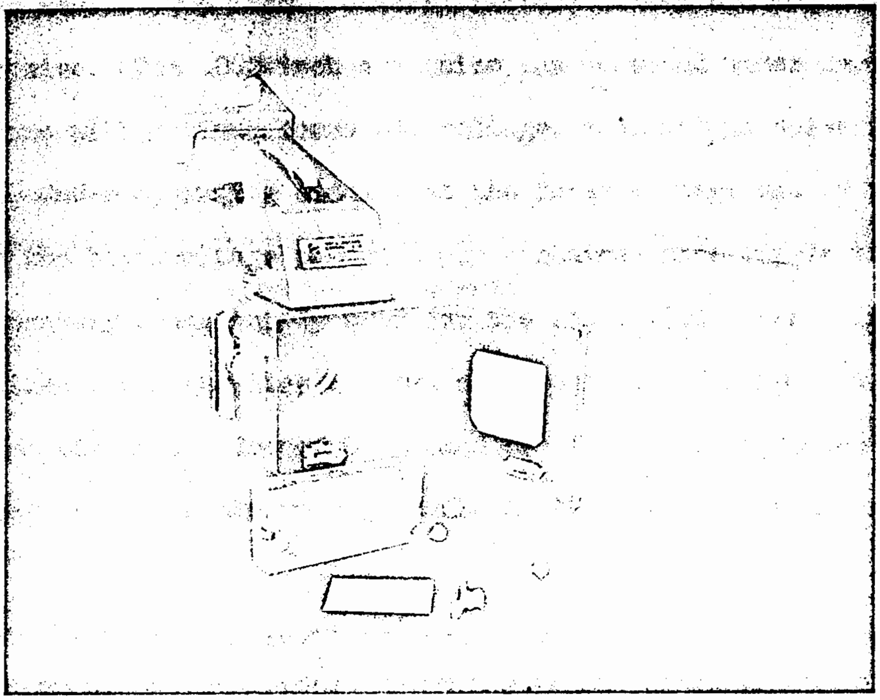

Figure 7.--Real-time viewer with dual Polaroid camera attached.

When it was found the required resolution could not be achieved with the dual phosphor CRT, the manufacturer supplied a P-11 phosphor CRT for replacement. The best laboratory measurement of spot size was .002 inch. Under actual operation the spot size was nearer .005 inch. Several factors caused the degradation in spot size. The .002-inch spot size was measured under controlled conditions with optimum focus voltage, and minimum noise and ripple. Under operating conditions the focus voltage was 75 volts low and the high-voltage power supply contained more ripple than the laboratory power supply used for the controlled tests. The low-voltage power supplies created noise spikes and ripple in the video circuits. Ground loops and poor wire routing added noise and ripple to the video. Each condition increases the spot size.

CRT pincushion distortion[9] was about 1/16 inch when it was received. A permanent magnet pincushion corrector was purchased for $35.00 and installed on the CRT deflection yoke. Line curvature was not noticeable after the corrector was alined and locked in place.

9/ Pincushion distortion occurs when the distance traveled by an electron varies as the electron beam is moved across the face of the cathode ray tube. The amount of deviation, or curvature, from a straight line is used here as a measure of pincushion distortion. For further details reference: Jenkins, Francis A., and White, Harvey E. Fundamentals of optics, p. 143. ED. 2, 647 pp., illus. New York: McGraw-Hill. 1950.

The input to the viewer video amplifier was a.c. coupled without d.c. restoration (refer to Appendix IV). Blocking occurs on the viewer imagery whenever the hot signal is large enough to alter the background reference level (indicated by arrows on fig. 8). Smaller video changes cause signals adjacent to the fire to loose contrast and detail. The variable voltage clipping in the scanner control unit was used successfully to reduce the large signal amplitudes.

Figure 8.—Infrared fire imagery showing d.c. level shifts.

CAMERA

The viewer was furnished with a single frame Polaroid camera (Tektronix Model C-12).[10] Northern Forest Fire Laboratory personnel

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[10] Reference footnote 3.

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developed a unique camera, utilizing parts from the C-12, to meet the requirements for immediate and continuous positive prints of fire imagery (figs. 9 and 10.)

Figure 9.—Dual Polaroid camera with film back open.

Figure 10.—Dual Polaroid camera with data slate door open.

Figure 8.--Infrared fire imagery showing d.c. level shifts.

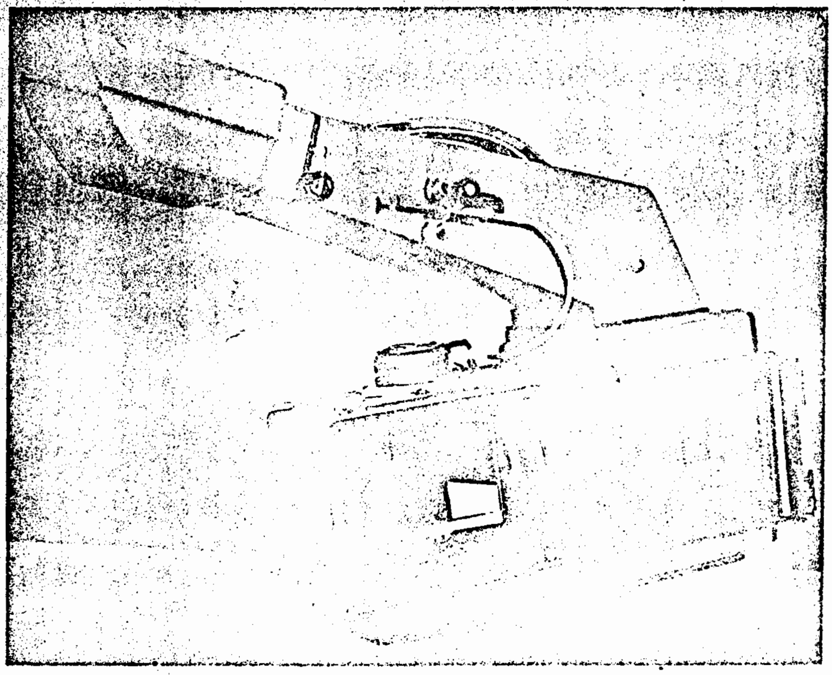

Figure 9.—Dual Polaroid camera with film back open.

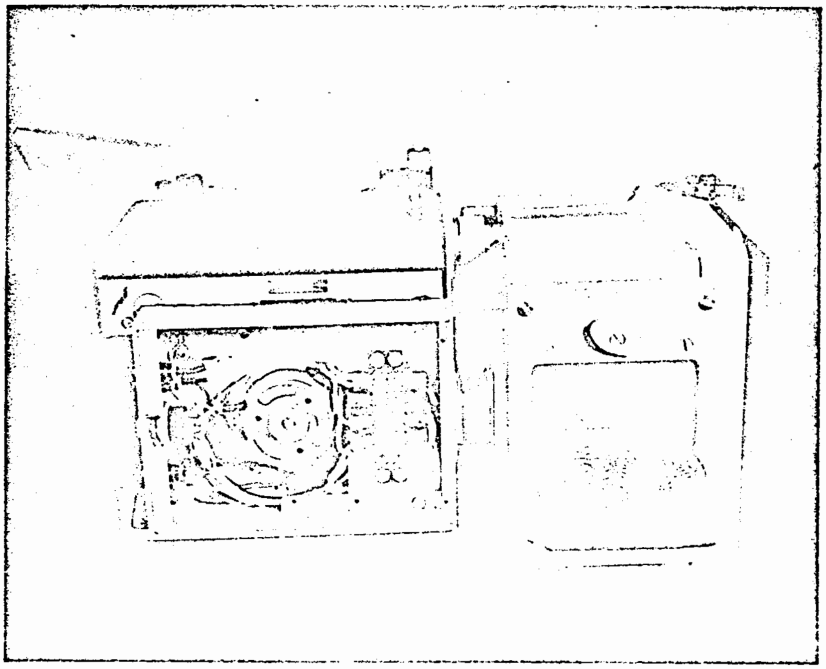

Figure 10.—Dual Polaroid camera with data slate door open.

The dual Polaroid camera system contains a "flipping" mirror and lens assembly that projects the viewer cathode ray tube image sequentially onto two Polaroid film packs. Control signals for the camera are obtained from the viewer. The rear frame of the Tektronix Type C-12 camera was replaced by a new unit containing the flipping mirror and two Polaroid film packs. The flipping mirror is two first-surface mirrors mounted back-to-back and rotated to image the CRT face, first to one film pack and then the other. The mirror is driven in both directions by two rotary solenoids powered by the camera relay in the real-time viewer. (The camera relay is operated by the vertical sweep.) A panel on the back of the camera contains (1) two amber lamps to indicate the film pack being exposed, (2) a green lamp to indicate when the shutter is open, and (3) a reset button to control the start of a frame by restarting the viewer vertical sweep.

A slate unit (fig. 10) records sequential frame numbers, time of day, and written information on the imagery. The slating mechanism is mounted on the base plate of the C-12 camera and is imaged through a beam splitter onto a 1/2-inch area along the edge of the film. The slating unit folds down for access to the clock and writing surface.

Considerable effort was spent in making the camera compact. All wiring is internal with connections made automatically as the camera is closed. Camera focus, aperature, and shutter speed controls were not changed. Standard Polaroid film packs are easily loaded from either side of the camera. The installation on the real-time viewer is the same as mounting a camera on an oscilloscope.

MONITOR

Initial planning incorporated the system monitor into the printer as a dual purpose viewer. When the dual phosphor CRT was replaced with the short persistance CRT, a new monitor was required. By choosing a standard oscilloscope for the monitor, the separate test oscilloscope could be eliminated. A Tektronix Type 422[11/] portable oscilloscope (fig. 11) with a P-7 phosphor

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11/ Reference footnote 3.

CRT was chosen for its compactness, versatility, and power requirements. The scope was modified to permit intensity modulating the cathode for B-scan operation. Vertical and horizontal sweeps were obtained from the viewer. The cathode may be disconnected for A-scan operation, or both B-scan and A-scan may be viewed simultaneously.

Figure 11.—Monitor oscilloscope.

Two viewer modifications were made to provide signals for the monitor scope. First, a new video amplifier was installed; and second, another horizontal sweep amplifier was installed.

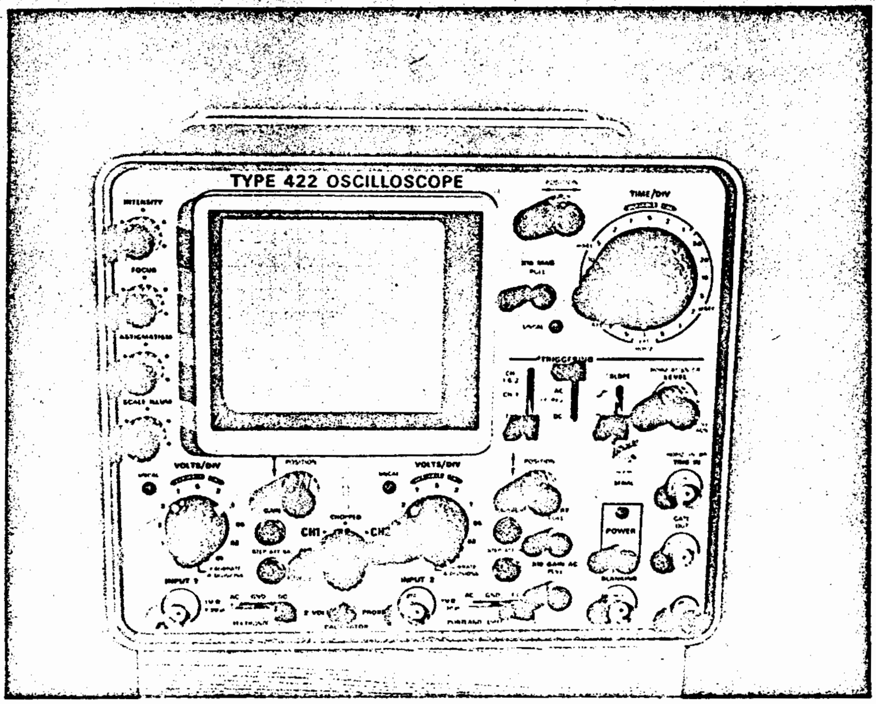

Figure 11.--Monitor oscilloscope.

MODIFIED RECONOFAX XI

In June 1966, the Reconofax XI (mod 2) scanner was returned to the Northern Forest Fire Laboratory for 6 weeks of extensive testing. The scanner and remote control assembly (fig. 6) had been thoroughly modified. All wiring was replaced, new printed circuits installed, and internal packaging completely changed. The result was a reliable scanner system.

The modifications included a redesign of the video circuits to reduce the problems caused by large fire signals. D.c. amplifiers separated by a.c. coupling with accurate d.c. restoration reduced reference level shifts (Appendix IV). Amplifier gain was increased to 94 db for higher film contrast on low-level terrain signals. The 3 db bandwidth was fixed at approximately 650 kHz to enhance small terrain features. Large fire signals cause film and CRT phosphor saturation and reference level shifts, creating loss of fire perimeter and adjacent terrain detail. The amplitudes of high energy fire signals can be restricted by voltage clipping circuits. Two methods of voltage clipping were used to reduce the effects of excessive signal:

1. A fixed voltage clipping level was built into the video amplifiers. No incoming signal can cause an output which exceeds this clipping level. This eliminates the halation effects on the film caused by large signals as long as the d.c. reference is retained.

Form
INT 1600-12 (9/66)

2. A variable voltage clipping circuit was added, permitting adjustment of the maximum signal level to meet changing terrain conditions. The variable voltage clipping circuit is unnecessary and can be removed from future systems having adequate fixed voltage clipping.

SYSTEM EVALUATION

The Reconofax XI scanner, real-time viewer, and monitor were combined for a series of laboratory tests. Angular resolution was measured using a hot, black source with 1-, 2-, and 4-mil aperatures collimated and folded into the scanner. Angular resolution at the output of the preamp was between 1 and 2 milliradians, as measured from Polaroid pictures of an A-scan trace.

Total system angular resolution was determined by printing resolution targets on both 70 mm. and Polaroid film. Resolution on the 70 mm. film was between 3 and 4 milliradians. Inadequate focus of the CRT restricted the resolution of Polaroid film to about 4 milliradians in the 60° scan position and 8 milliradians in the 120° scan position.

Form
INT 1600-12 (9/66)

Temperature resolution was measured as a noise equivalent temperature (NET) equal approximately to 2° K. The source for measuring NET was a single hot target equal to approximately one angular resolution element measured against an ambient temperature background. Target temperatures between 30° C. and 70° C. provided signals within the linear portion of the amplifier gain curve. Then

$$NET = \frac{T_t - T_b}{E_{spk}/E_{nrms}}$$

where: T_t = the target temperature,

T_b = the background temperature,

E_{spk} = the peak signal voltage, and

E_{nrms} = the true rms value of the background noise without the target.

Contrast and intensity controls worked very well. The coarse and fine attenuation (contrast) controls permit excellent adjustments of signal amplitudes on both 70 mm. film and the B-scan. The contrast control on the B-scan is used only for initial set up. Separate intensity (brightness) controls for the 70 mm. and the B-scan permit individual d.c. adjustments to compensate for equipment drift.

Form
INT 1600-12 (9/66)

A new problem with the scanner viewing angle became evident during the evaluation tests. The d.c. restoration level is disturbed by large fires seen by the scanner outside the desired 120° field of view. A black streak across the image results (see arrows fig. 8). The scanning mirror always "sees" more than the desired 120° field of view unless vignetting is permitted. Small metal shields on the aircraft, restricting the total field of view to 120°, temporarily reduced the effects of this problem. Some vignetting of the desired signal occurs, but is not severe enough to be objectionable.

The scanner, real-time viewer, and monitor oscilloscope were installed in a U.S. Forest Service Aero Commander 500-B aircraft (fig. 12). The aircraft has a special scanning slot cut in the bottom of the fuselage for the Reconofax XI scanner.

Figure 12.—Final installation of the fire mapping system in the Aero Commander aircraft. The scanner is behind the seat in the lower right of the picture.

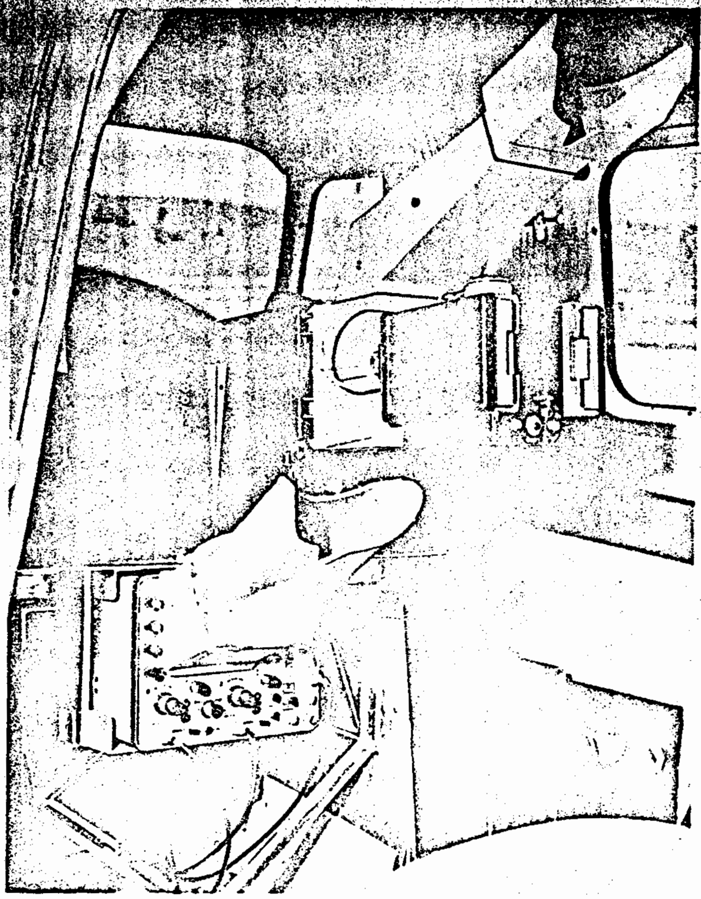

Figure 12.--Final installation of the fire mapping system in the Aero Commander aircraft. The scanner is behind the seat in the lower right of the picture.

Angular and thermal requirements for fire mapping systems are not well defined. Local test flights were flown to demonstrate system performance for comparison with the original design criteria (Appendix I). Both day and night flights over resolution charts, airports, and urban areas were made to aid subjective decisions on system performance. Automobiles in parking lots, trailer courts, and aircraft engine nacelles were used to determine angular resolution after resolution charts were not resolvable. Water temperature gradients in a river and in factory cooling ponds were used to judge temperature resolution. The results were:

1. The system angular resolution was 3 to 4 mr. and was poorer than the desired minimum (Appendix I).

2. The angular resolution of the 70 mm. and Polaroid film in the 60° position was approximately equal.

3. System temperature resolution of the 70 mm. and Polaroid film was about equal and adequate for most fire mapping missions.

There were no wildfires available locally during the test period, so the system was put into operation without prior evaluation over a fire.

The fire mapping system was released to the Division of Fire Control, U.S. Forest Service, on July 13, 1966. It consisted of:

1. A Reconofax XI (mod 2) infrared scanner and remote control unit.

2. A B-scan, real-time printer with a dual Polaroid camera attachment.

3. A monitor oscilloscope.

4. Miscellaneous associated materials required to permit system operation.

OPERATIONAL CONSIDERATIONS

NAVIGATION

Any fires requiring infrared mapping will be partially or totally obscured by a dense smoke pall. In most cases, the smoke pall covers only the area over and immediately adjacent to the fire. This situation normally occurs when a fire is located in the bottom of a drainage and the smoke is trapped by a temperature inversion. In cases of this type the pilot can usually aline the aircraft with the fire by using reference points visible outside the smoked-in area. When it becomes necessary to fly over a particular portion of the fire, some secondary means of navigation may be needed.

In severe cases, the smoke pall may cover several hundred square miles. This condition was encountered in 1964 at the Coyote Fire near Santa Barbara, California, in 1965 in the multiple fire situations in West Virginia and Nevada, and in 1966 at the Oxbow Fire near Eugene, Oregon. Under these conditions, radio navigation aids must be used to assist in aircraft alinement.

In many areas in the western United States, where wild land fires are a problem, the distance to standard radio navigation facilities (OMNI, DME) is too great for them to be used for accurate navigation. Under these circumstances other systems such as Doppler radar or inertial devices should be provided. An adequate navigation system in combination with a real-time infrared viewer will provide the capability for alining the aircraft with portions of the fire of primary interest. If a real-time display of the infrared imagery is available, the problem of determining the position of the aircraft with respect to the fire front is greatly simplified, and the time required to obtain adequate coverage will be minimized. Unfortunately, the performance characteristics of presently available, real-time viewers leave a great deal to be desired in luminosity and resolution. Their performance is marginal at best.

ALTITUDE SELECTION

The altitudes selected for the initial surveillance flight should be high enough to permit coverage of the entire fire width on one pass, with adequate allowance for navigation errors. If the scale of the imagery produced at this altitude is inadequate to provide the detailed information needed on portions of the fire, subsequent passes can be flown at lower altitudes. The selection of altitudes for followup missions must be a compromise based on resolution requirements, number of passes to complete the data gathering, navigational errors, and adequate terrain clearance for safe operations.

GROUND SPEED

The ground speed of the aircraft must be accurately determined prior to the beginning of a pass. If a Doppler radar is available, this information is quite easily obtained. If not, the pilot can use standard navigational procedures to determine the expected ground speed over the target. Ground speed information is needed to adjust the printer V/H for correct aspect ratio on the imagery. Unless an accurate ground speed measurement is available, it is mandatory that passes be made in opposite directions or in two directions at right angles to each other over the fire. By comparing imagery thus made, any errors in V/H setting become readily apparent (fig. 13).

Figure 13.—Improper V/H adjustments causing A, elongation, and B, compression of fire area on infrared imagery.

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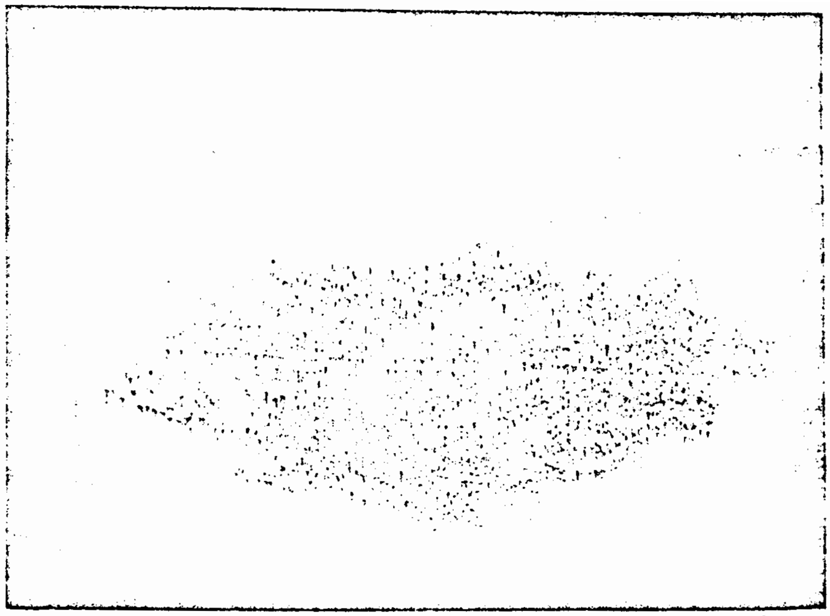
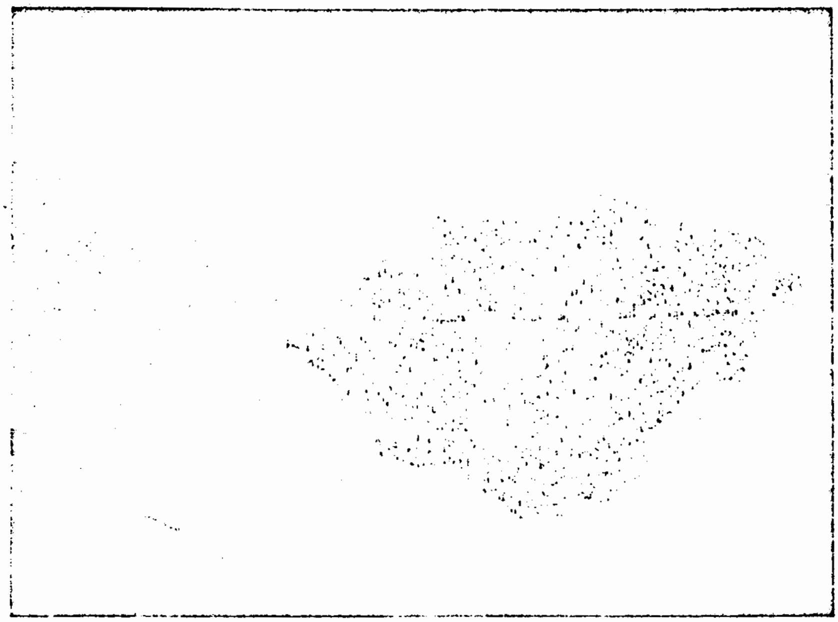


A



B

Figure 13.--Improper V/H adjustments causing A, elongation, and B, compression of fire area on infrared imagery.

FLIGHT SCHEDULING

The prime consideration in scheduling infrared fire mapping flights is to provide the fire staff with current information in time to assist in formulating fire attack plans for the next shift. In general, during the uncontrolled stage of the fire the desirable flight times are 0400, 1000, 1400 to 1600, and 2000 to 2200 hours. Allowance must be made in scheduling for the time required from collection of imagery to delivery of interpreted intelligence to the fire camp. The hours immediately before and after sunrise and sunset should be avoided since thermal washout, low sun angle, and rapidly changing conditions make it extremely difficult to obtain good terrain detail on infrared imagery. Once the fire has been contained it is the concensus that two flights per day should provide adequate intelligence.

Form
INT 1600-12 (9/66)

IMAGERY DELIVERY

Imagery has no operational value until it is delivered to the fire camp and interpreted. Two methods of image delivery used throughout this program were (1) air drop from the scanning aircraft, and (2) delivery by ground transportation from the nearest airport. These methods do not require complex and expensive telemetering ground stations at the fire camp. The air drop method is simple and fast, but it has several serious limitations. It is often difficult to find a suitable drop zone if the area adjacent to the fire camp is obscured by smoke. Quite often, helicopter and retardant aircraft traffic in the vicinity of the fire camp causes serious delays. The air drop operation involves an element of risk when the fire camp is located in canyon bottoms. Delivering the imagery from the nearest airport often involves intolerable delays.

The intelligence information is frequently needed at both the main fire camp and at zone camps around the fire perimeter. A telemetering system for instantaneous transmission of imagery to several locations simultaneously would have great operational value.

1963 and 1964 FIELD SEASONS[12]

12/ For the 1965 activities, refer to the section: THE PROTOTYPE FIRE MAPPING SYSTEM.

TRAINING AND FIELD TESTING

The modified AAS/5 scanner, with a single Polaroid camera, was used during this period. Table 2 summarizes fire mapping missions performed during the 1963 and 1964 field seasons. Over 800 pieces of imagery were produced in a wide variety of fuel types and burning conditions. Table 5 in Appendix V supplies a detailed breakdown of operational performance for individual missions during the 1964 fire season. In addition to operational missions over 80 training missions were flown to test equipment and develop crew proficiency.

Table 2.—Summary of wildfire mapping missions performed during Project Fire Scan test program

Year	Number fires	Number flights Day	Number flights Night	Average fire size	Number imagery drops	No. fires IR intelligence provided	Fuel types encountered
				Acres			
1963	7	15	1	11,300	8	3	Fir-spruce Grass Pine Sagebrush
1964	16	33	16	19,800	19	12	Pine Fir-spruce Oak-brush Grass Sagebrush

Form
INT 1600-12 (9/66)

PERIMETER INTELLIGENCE

Infrared imagery was used to determine the perimeter location on 10 uncontrolled wildfires; on 7 of these fires it would have been impossible to accurately map the fire perimeter using conventional reconnaissance methods. On 3 of the 10 fires, IR was the sole source of fire perimeter information. IR reconnaissance became an integral part of the strategic and tactical fire control planning.

The quality of the IR imagery varied widely. On one fire, equipment failure prevented collection of usable imagery. Even with poor quality imagery we were able to plot the fire perimeter with enough accuracy to meet the minimum requirements for large fire strategic and tactical control planning.

Form
INT 1600-12 (9/66)

INTENSITY INTELLIGENCE

As seen in figures 14 and 15, fire imagery graphically portrays the relative heat intensity of burning forest fuels. On 13 of the fires mapped, this intensity intelligence was shown to command personnel. In every case the information proved of value in deploying air and ground forces to suppress priority hot spots along the perimeter. The Candle Mountain Fire on the Helena National Forest (Region 1) demonstrated the value of IR intensity intelligence; this fire originated from lightning in a roadless, subalpine timber stand of spruce, fir, and lodgepole. Although fire spread was stopped at 1700 hours on July 23, a comparison of imagery obtained at 2200 hours on July 23 with that obtained at 0530 hours on July 24 showed little change in intensity during the intervening hours of darkness (figs. 16 and 17).

Figure 14.—IR imagery of Nuns Canyon Fire, 1964.

Figure 15.—IR imagery of Coyote Fire, 1964.

Figure 16.—IR imagery of Candle Mountain Fire, 2200 hours on July 23, 1964.

Figure 17.—IR imagery of Candle Mountain Fire, 0530 hours on July 24, 1964.

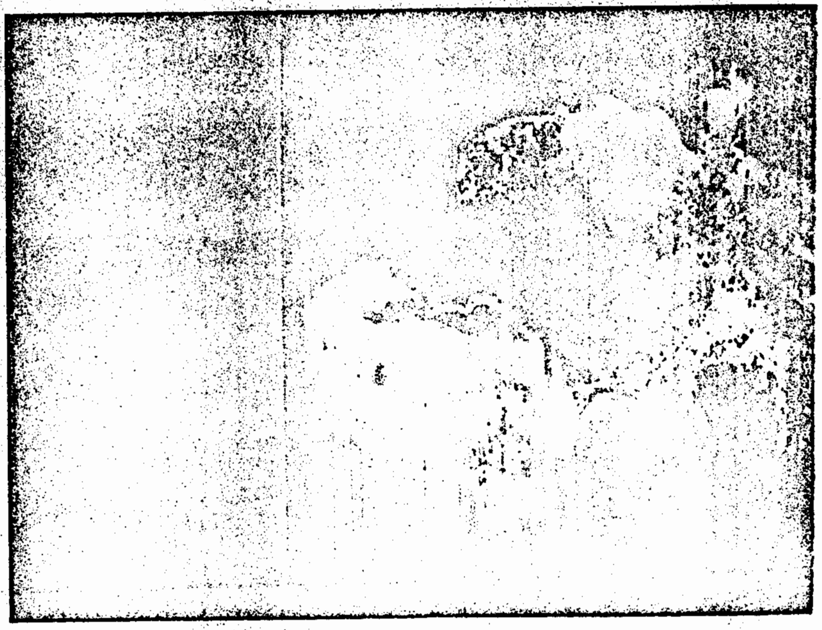


Figure 14.--IR imagery of Nuns Canyon Fire, 1964.

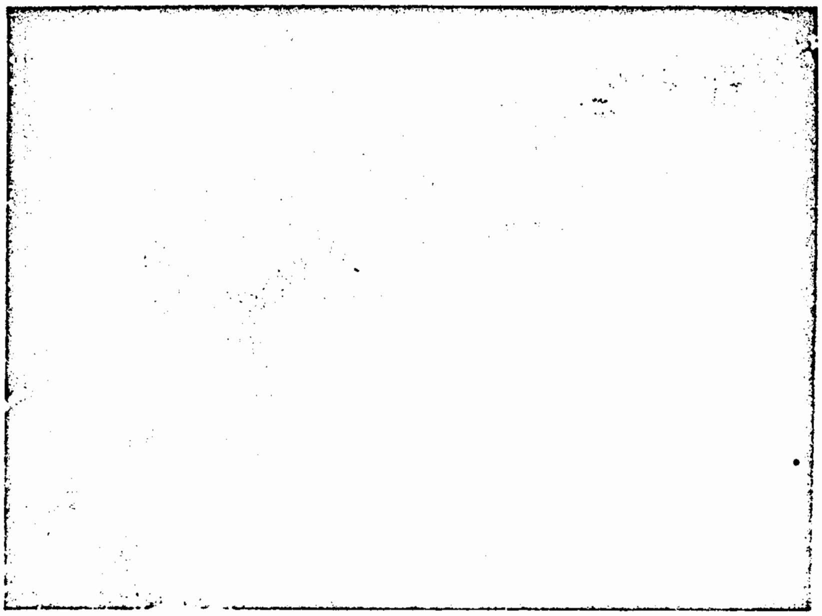


Figure 15.--IR imagery of Coyote Fire, 1964.

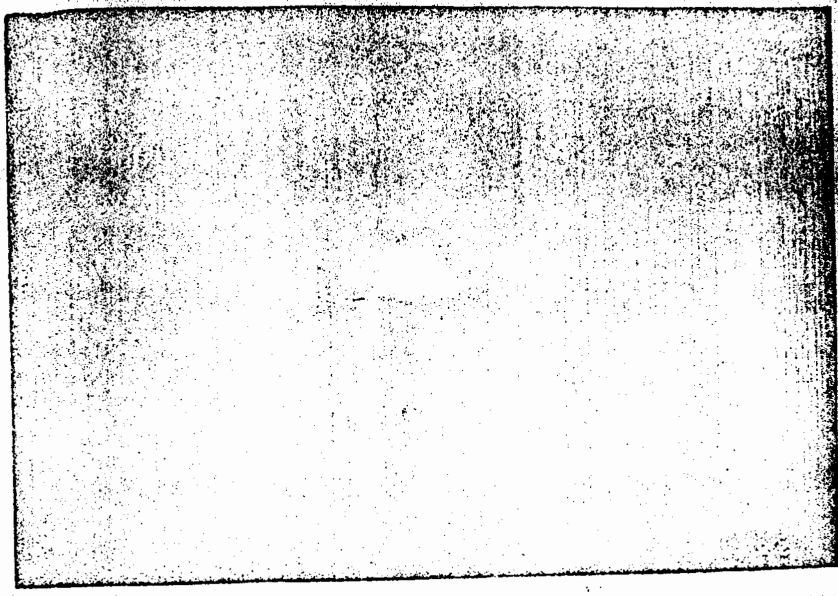


Figure 16.--IR imagery of Candle Mountain Fire, 2200 hours on July 23, 1964.

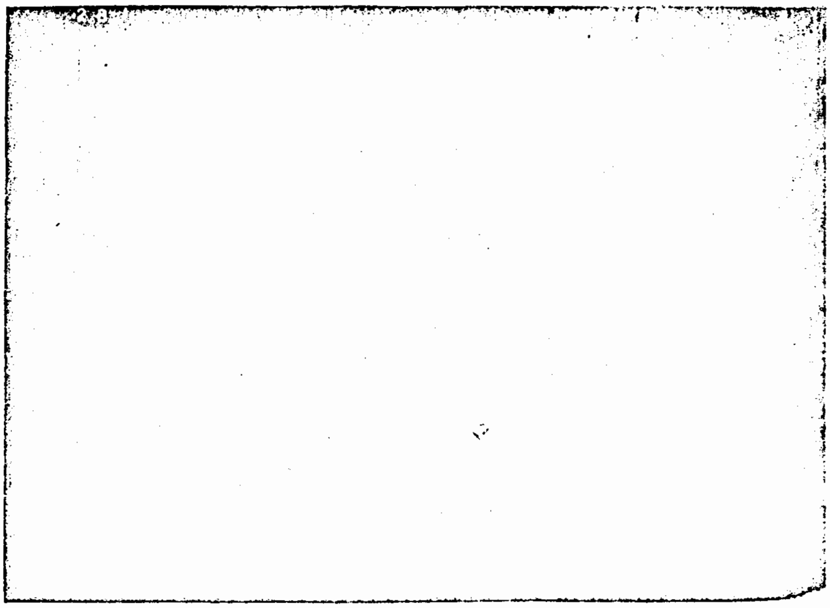


Figure 17.--IR imagery of Candle Mountain Fire, 0530 hours on July 24, 1964.

Visual reconnaissance made at first light on July 24 showed very little smoke rising from the burned area. This situation might have called for releasing manpower, particularly since the fire perimeter had not increased during a 12-hour period of cooler temperatures and higher humidity. Based on intensity intelligence obtained from the IR, command personnel decided not to release line workers during the day shift and to pursue vigorous mopup.

SPOT FIRE INTELLIGENCE

Spot fires were encountered on three of the fires mapped. On two of the fires spotting did not constitute a major threat; but on the third, one of three spot fires had not been detected by the ground forces (fig. 18). During the mapping mission, the location of the undetected spot fire was radioed to suppression forces. They were able to take control action before it became a serious problem. On each of the three fires, IR imagery clearly depicted the presence of spot fires. Smoke often prevents early spot fire detection using visual reconnaissance.

Figure 18.—IR imagery of Crazy Creek Fire, 1964.

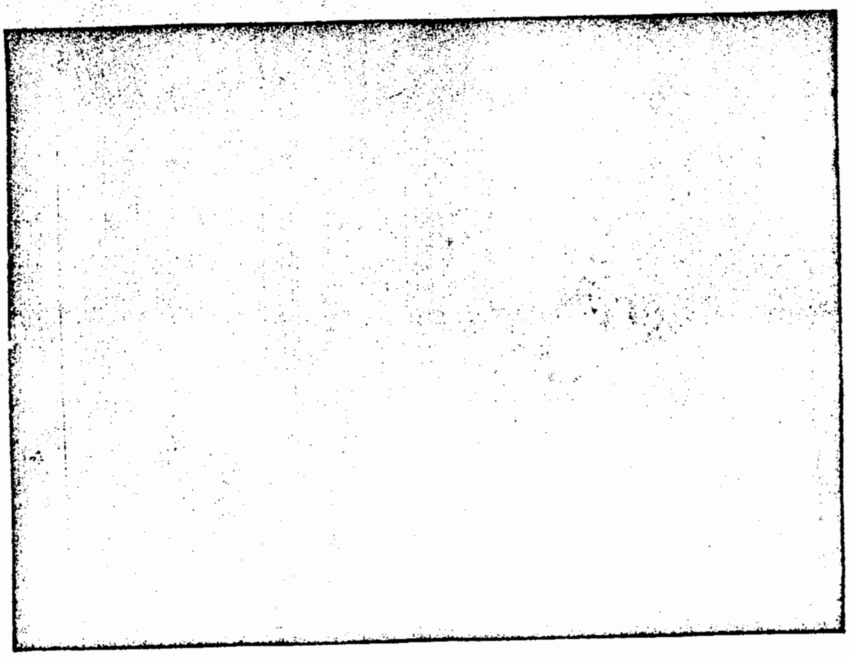


Figure 18.--IR imagery of Crazy Creek Fire, 1964.

MOPUP

Mapping of above-ground burning fuels was performed on 11 wildfires during mopup (after control had been affected). IR imagery obtained during mopup of these fires proved of value in tactical employment of manpower and equipment. Figure 19 shows hot spots on approximately 6-1/2 miles of cold fire perimeter. Using the imagery, it was possible to deploy forces to portions of the perimeter where burning fuels still persisted.

Figure 19.—IR imagery of Coyote Fire, 1964, during mopup.

Often, burning fuels at this stage consist of hot coals which give off very little smoke to aid in visual detection. These hot coals are a source of firebrands that could be wind borne into unburned fuels outside the fire perimeter. Detection of hot spots by conventional visual means on fires like the Coyote Fire, where over 70 miles of perimeter existed, requires a very large expenditure of manpower. IR mapping eliminates this problem.

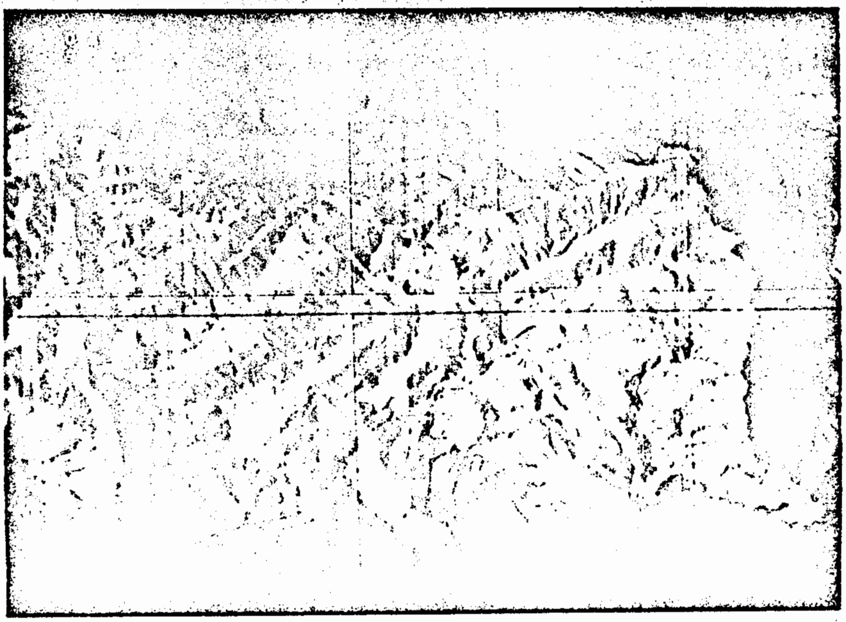


Figure 19.--IR imagery of Coyote Fire, 1964, during mopup.

INTERPRETATION

An average of 40 minutes was required to transfer fire intelligence from IR imagery to aerial photos and/or maps. Interpretation time, plus an average of 1 hour for each flight, resulted in an average of 1 hour and 40 minutes from the first imagery run over the fire to delivery of the completed map.

On most fires, intelligence was transferred from the imagery to aerial photos and finally to topographic or planimetric base maps. This method uses corresponding grids for transposing the fire perimeter from imagery to its appropriate location on a photo and finally to a map. The grid method proved well adapted for use in areas where there were no prominent changes in vegetative type or man-made features.

On three fires there were enough recognizable features to eliminate the intermediate step, i.e., use of a photo. This method was simpler and quicker; however, its use is restricted to areas where numerous changes in vegetative types are found or where there are recognizable man-made features, e.g., logging roads, clearcut logging units, orchards, rural and suburban habitation (fig. 20).

Figure 20.—IR imagery of man-made features adjacent to the Mill Creek Fire, 1964: A, Orchard; and B, road.

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INT 1600-12 (9/66)

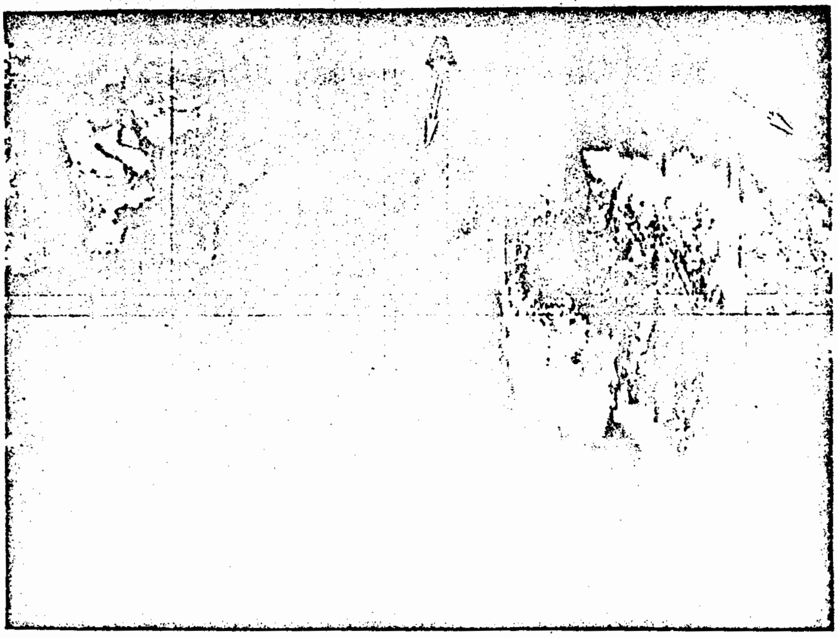


Figure 20.--IR imagery of man-made features adjacent to the Mill Creek Fire, 1964: A, Orchard; and B, road.

Imagery obtained during the first 2 hours after sunrise and 2 hours before sunset was difficult to interpret because the scanner operator could not compensate for rapid changes in thermal contrast. Figures 21 and 22 show how the early morning sun on south slopes obscures portions of the fire perimeter while terrain features on contrasting north slopes are difficult to distinguish. When equipment settings are made to accommodate south slope conditions, they usually produce an adverse contrast on north slopes (or vice versa).

Figure 21.—Degradation of IR imagery by the early morning sun, Big Creek Fire, 1964.

Figure 22.—Degradation of IR imagery by the early morning sun, Willow Tree Fire, 1964.

IMAGERY DROPPING

On seven fires we used the equipment shown in figures 23, 24, and 25 to drop imagery to the ground interpreter. This method is cheap and effective. A total of 28 imagery drops were made—21 during the day and 7 at night. All drops were successfully retrieved. Our experience on training and operational missions showed drops could be consistently placed within a clearing 500 feet in diameter. The average day drop was made at 200 feet over terrain and the average night drop at 500 feet.

Figure 23.—Side view of drop tube ejector assembly.

Figure 24.—Ejector assembly with drop tube fully inserted.

Figure 25.—Night drop tube components.

Figure 21.--Degradation of IR imagery by the early morning sun, Big Creek Fire, 1964.

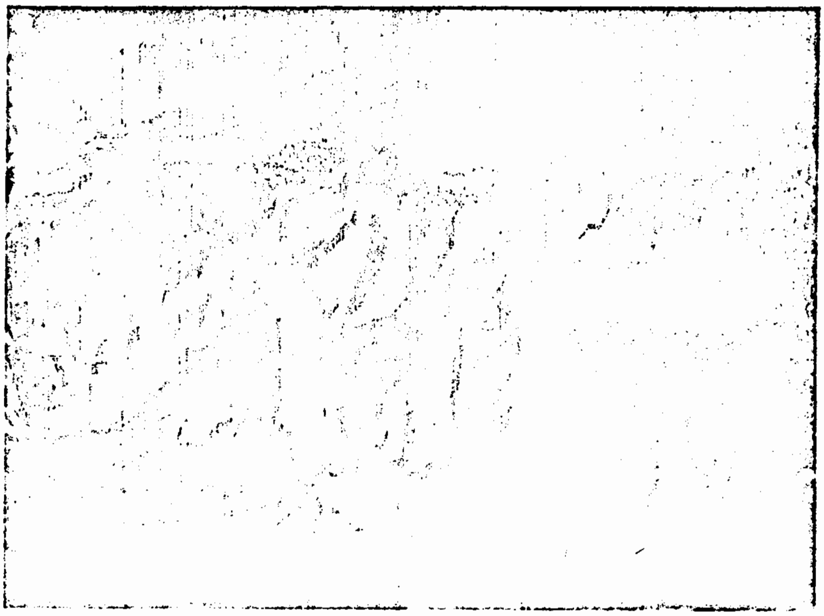


Figure 22.--Degradation of IR imagery by the early morning sun, Willow Tree Fire, 1964.

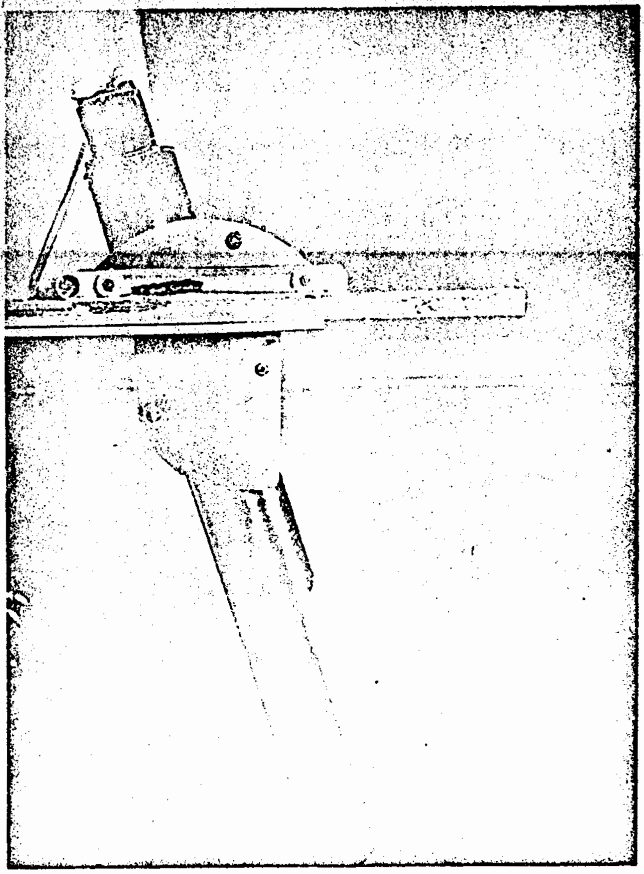


Figure 23.--Side view of drop tube ejector assembly.

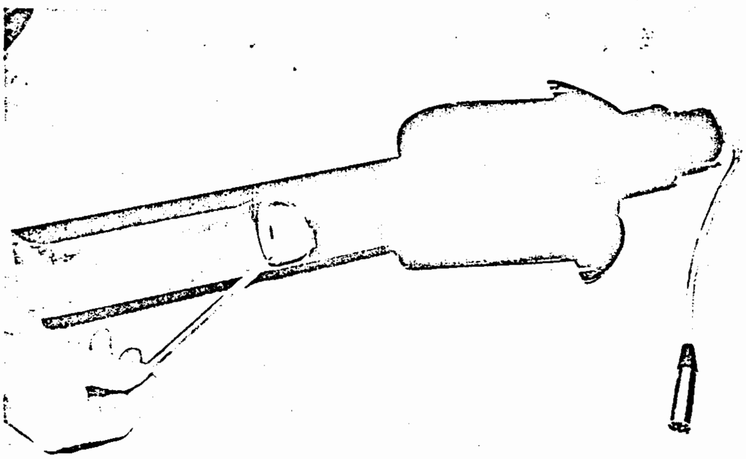


Figure 24.--Ejector assembly with drop tube fully inserted.

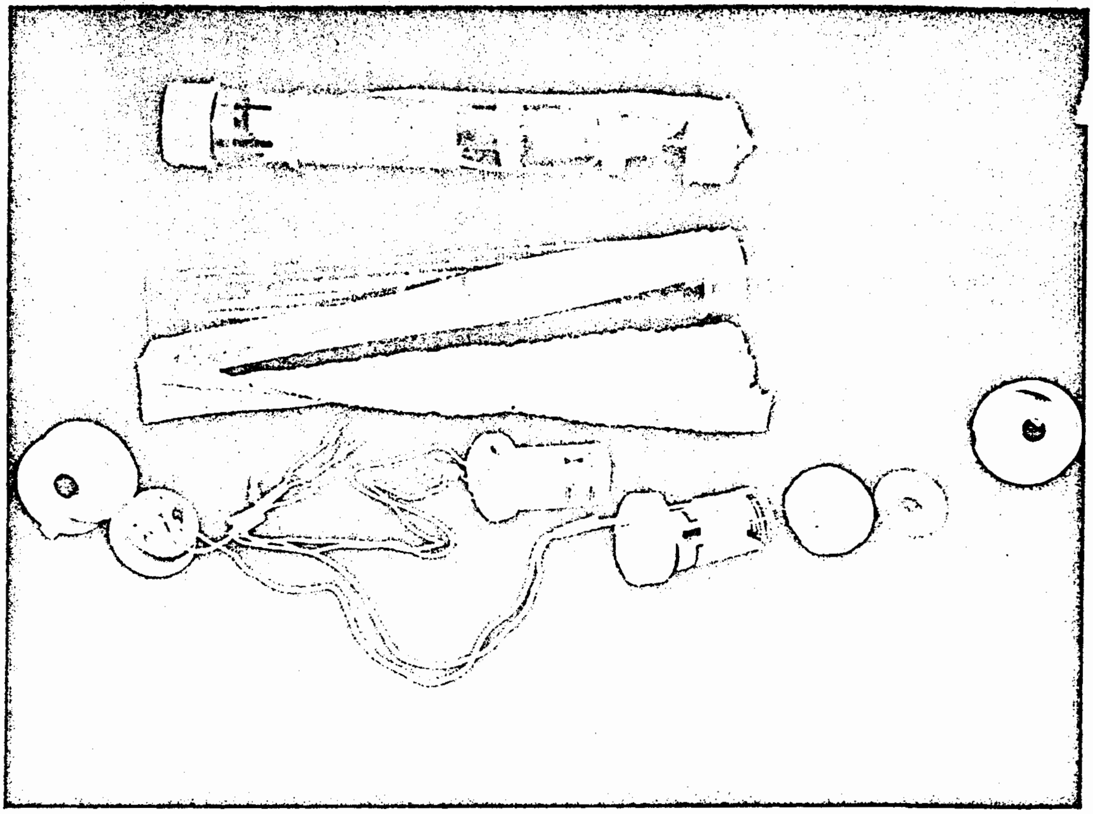


Figure 25.—Night drop tube components.

FIRE COMMAND INTERVIEWS

Command personnel were vitally interested in obtaining intelligence on perimeter location, rate of fire spread, spot fires, fire intensity, and location of interior unburned or scorched areas. Considerable emphasis was placed on the need for information on intensity and delineation of unburned areas.

Maps and aerial photos were selected as the preferred media for portraying intelligence at command headquarters and for tactical line overhead use. The ability to see dozer-built control lines on fire imagery was considered important; handlines and pumper unit locations were less important.

Average desired frequency for obtaining perimeter intelligence was five times per day during the uncontrolled stage and twice a day during the controlled (or mopup) stage. Preferred time of day (or night) coincided with planning schedules for changing shifts and for obtaining "heat of the day" intelligence. Most interviewees felt the fire boss and plans chief should physically view the fire at least twice a day.

Responses of fire staff personnel.—The following are on-the-scene comments of command personnel:

"First really complete picture of the perimeter of the fire."

"IR intelligence gave the fire manager a good positive idea of where hot spots were located and situation tactics called for at that time."

Form
INT 1600-12 (9/66)

"Southern California's large fire IR intelligence requirements call for high-altitude (small-scale) imagery."

"IR intelligence would have been particularly useful during the fluid stages of the fire when the flanks were spreading faster than suppression forces could cope with them."

"IR intelligence valuable for determining hot spots on edge of line for concentrating manpower and equipment, particularly on the day shift."

RESULTS OF THE 1966 SEASON

The fire mapping system (Reconofax XI) was placed in operation and field reports indicated a successful season. Twenty-one flights over 15 fires, plus 5 training missions, were flown to evaluate the system's operational capabilities.

Figure 26 is a side-by-side comparison of 70 mm. and Polaroid fire imagery (the images are of different passes over the same fire). Several problems are apparent from the imagery:

1. The black lines across the film occur on both images at the same place and are caused by fires outside the 120° field of view (refer to page 35). Figure 27 shows the fire within the 120° field of view and the lines are missing.

2. Accurate adjustment of V/H is difficult over wild, unknown terrain (note the compression of the river in the Polaroid image).

3. Occassionally, fire images have fuzzy or poorly defined boundaries (the left side of the fire near the center). The reason for the fuzzy perimeters has not been explained. Possible reasons are flames over the adjacent terrain, hot gases or particles ahead of the fire, or heating of the materials ahead of the hot area.

Figure 26.—Composite photograph comparing 70 mm. and Polaroid fire imagery.

Figure 27.—Polaroid pictures of sequential imagery of the total fire shown in figure 26.

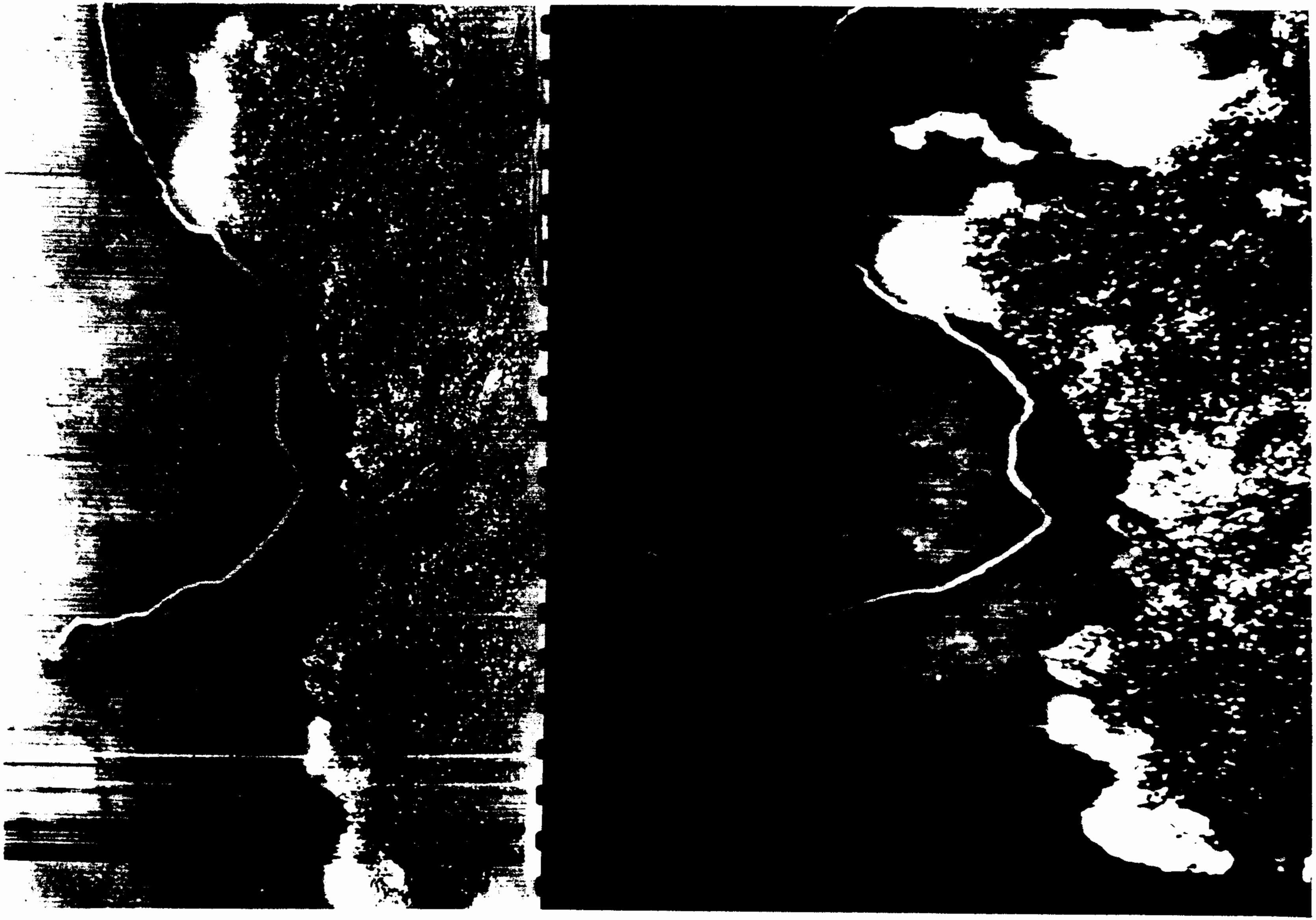


Figure 26.—Composite photograph comparing 70 mm. and Polaroid fire imagery.

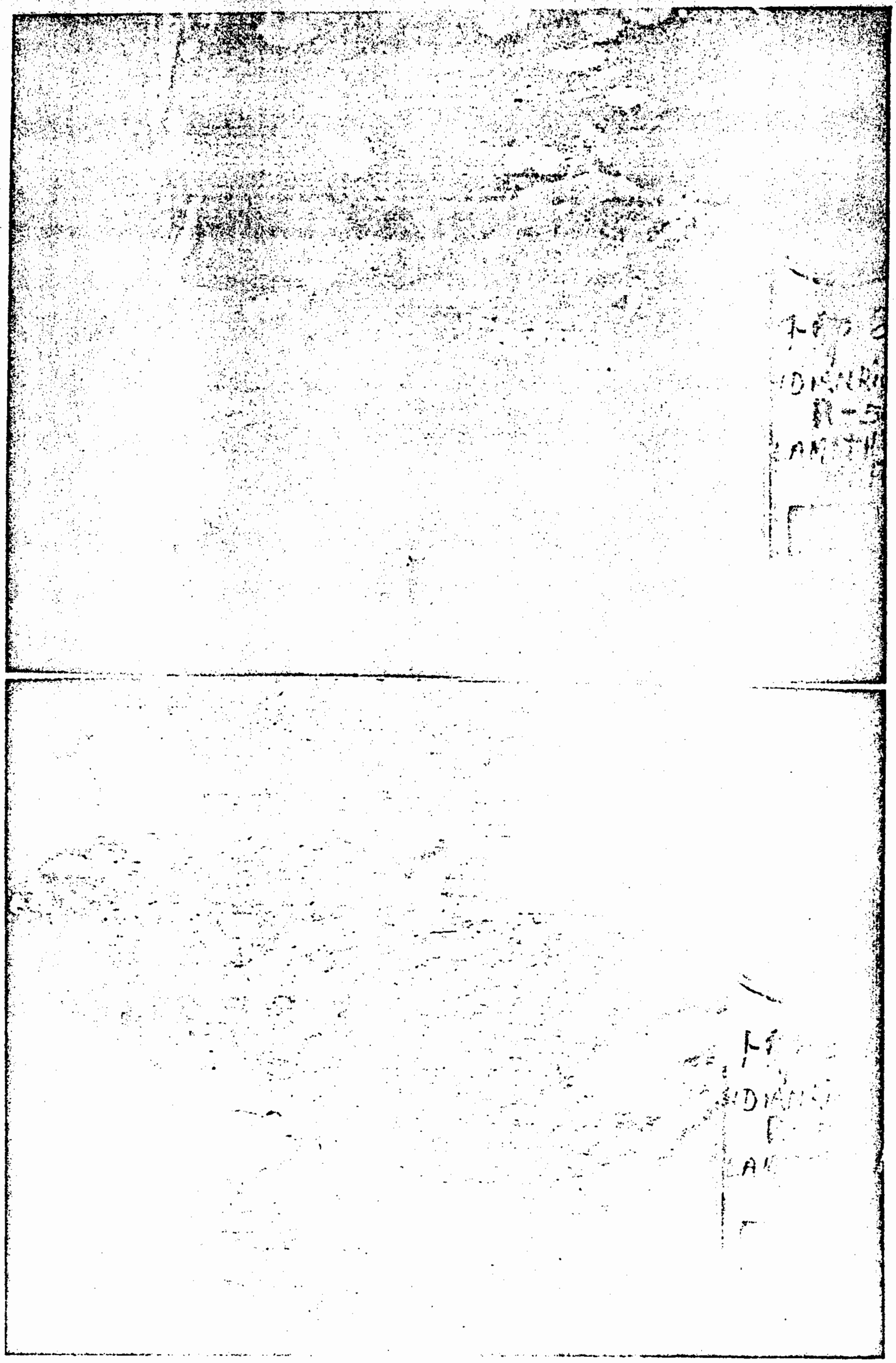


Figure 27.--Polaroid pictures of sequential imagery of the total fire shown in figure 26.

The 1966 operational testing brought out changes that should be made to the system:

1. The high-voltage power supply in the viewer failed twice and was replaced by a heavy auxiliary power supply. A new power supply for high altitude operation is recommended to reduce weight and ripple.

2. The focus voltage for the viewer CRT is inadequate for a sharp electronic focus. A new power supply is required.

3. The frame counter in the camera slating unit counts each vertical sweep of the viewer. Sequential numbering of the Polaroid prints could be obtained if the counter were connected in series with the shutter-flash switch.

4. The d.c. restoration should be corrected to eliminate the shift in film intensity caused by fires outside the 120° field of view. Increasing the scanner dead time, reducing the d.c. restoration clamp time, or vignetting the receiving aperature are possible solutions.

5. The amplifiers in the viewer and monitor are a.c. coupled without d.c. restoration and are severely upset by large signals. D.c. restoration should be included in all a.c.-coupled video amplifiers.

6. Film striations on much of the imagery make interpretation impossible. A better 70 mm. film drive is required.

LARGE FIRE OCCURRENCE

The concensus of fire control experts in various parts of the country was that in the west (U.S. Forest Service Regions 1 through 6), where fuel types are highly combustible and weather conditions frequently produce extreme fire danger, any fire 100 acres (Class D and larger) could effectively use infrared fire mapping. By contrast, in the eastern United States (U.S. Forest Service Regions 8 and 9), where fuel types and weather conditions are not as hazardous, they felt the average fire would not need IR fire mapping until it reached 300 acres (Class E or larger).

We analysed fire statistics gathered by the U.S. Forest Service (USFS Form 5100-29) to determine the expected annual workload for an infrared fire mapping unit. Since these data had already been prepunched on IBM cards it was a rather simple matter to examine all fires in the National Forests through the 20-year period from 1944 to 1963. Figure 28 indicates the number of fires per year that would have required infrared fire mapping. On the average, 156 fires per year is a normal expected load.

Figure 28.—Large fire occurrence 1944-1963, U.S. Forest Service Regions 1 through 9.

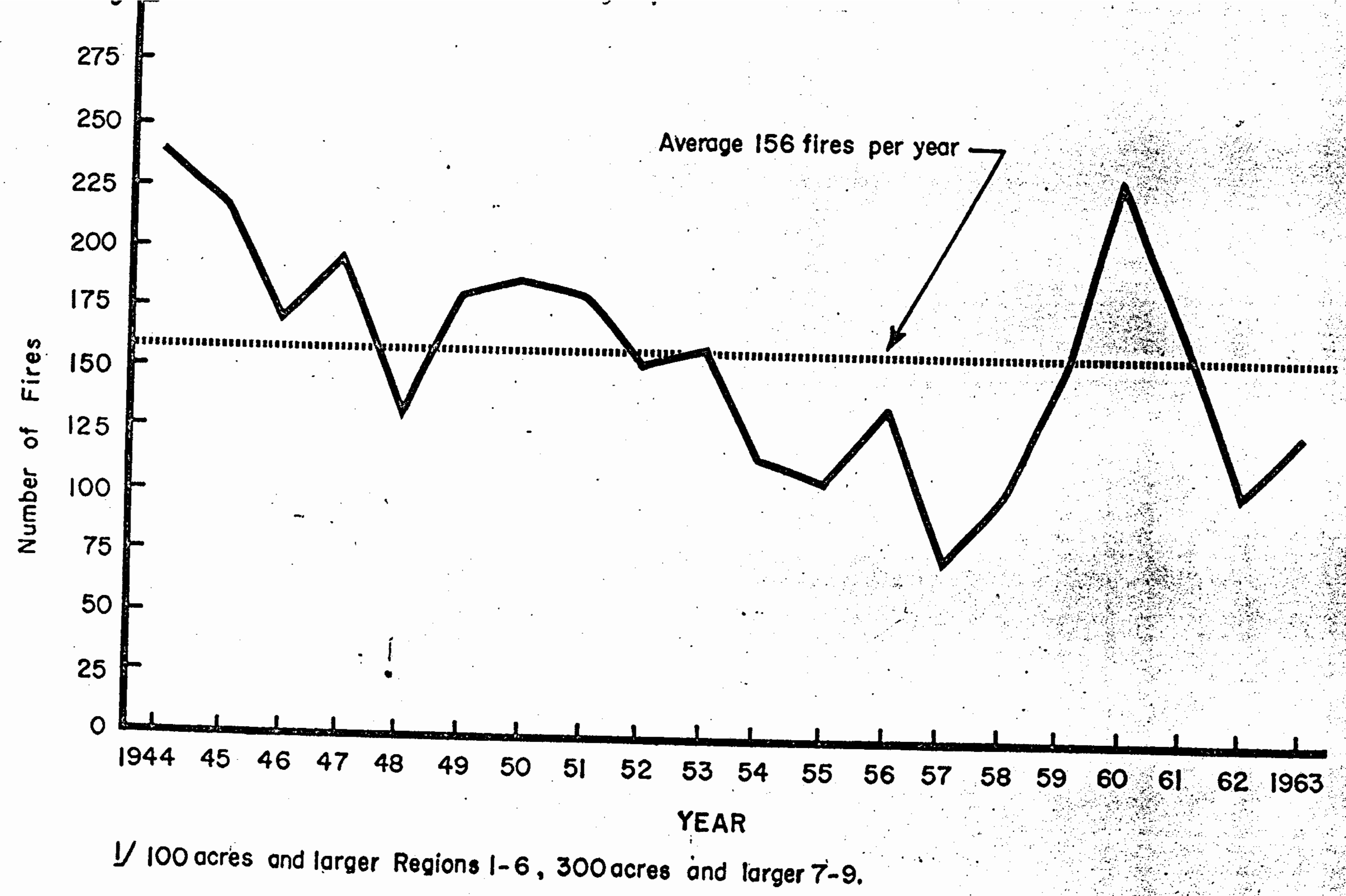


Figure 28.--Large fire occurrence 1944-1963, U.S. Forest Service Regions 1 through 9.

Western National Forest peak fire seasons extend from May 15 to September 30 with overlap between geographic regions. By contrast, the peak seasons for eastern[13/] National Forests occur in early

13/ U.S. Forest Service Region 7 was combined with Region 9 in 1965.

spring and late fall. "Peak season" was arbitrarily defined as the period when one or more large fires occurred during a given 15-day period.

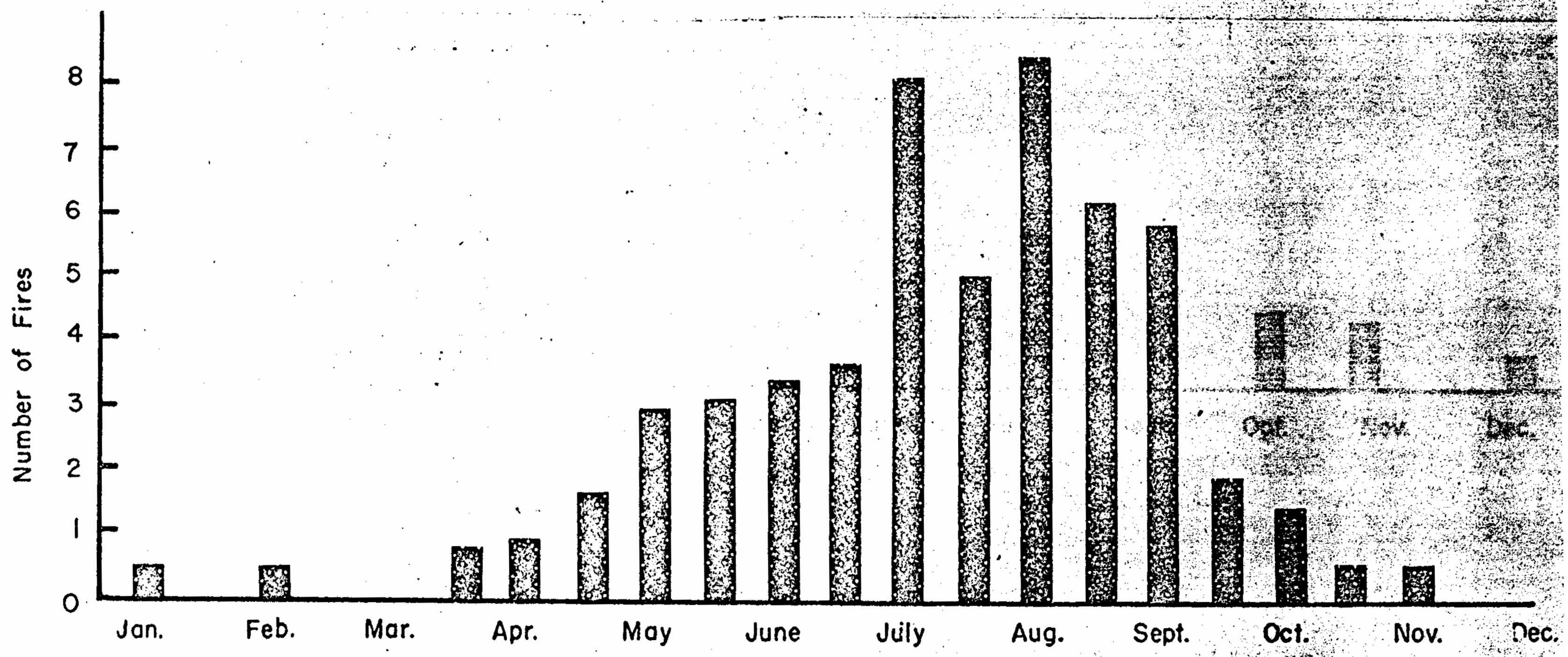
Data collected on large fire occurrence have been summarized in Table 4, Appendix V. Occurrence by 15-day periods was tabulated and the arithmetic average computed to show expected monthly fire load for western and eastern National Forests (figs. 29 and 30).

Figure 29.—Large fire occurrence, U.S. Forest Service Regions 1 through 6.

Figure 30.—Large fire occurrence, U.S. Forest Service Regions 8 and 9.

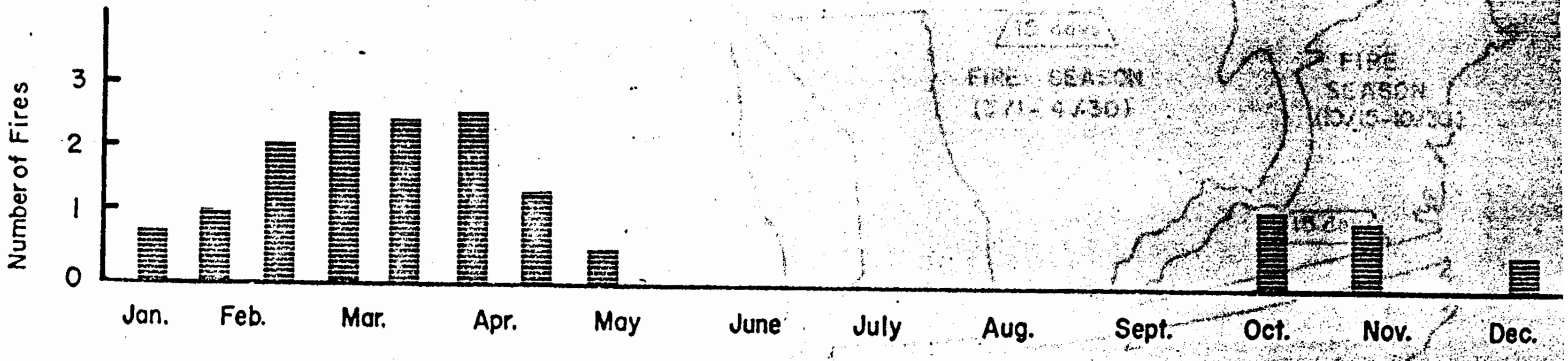
The number of days when one or more large fires occurred was determined from the monthly fire load data. Figure 31 shows distribution of large fire occurrence days within peak fire seasons.

Figure 31.—Average number of days per year on which large wildfires have occurred, 1944-1963.



1/ For fires 100 acres and larger.

Figure 29.--Large fire occurrence, U.S. Forest Service Regions 1 through 6.



1/ For fires 300 acres and larger.

Figure 30.--Large fire occurrence, U.S. Forest Service Regions 8 and 9.

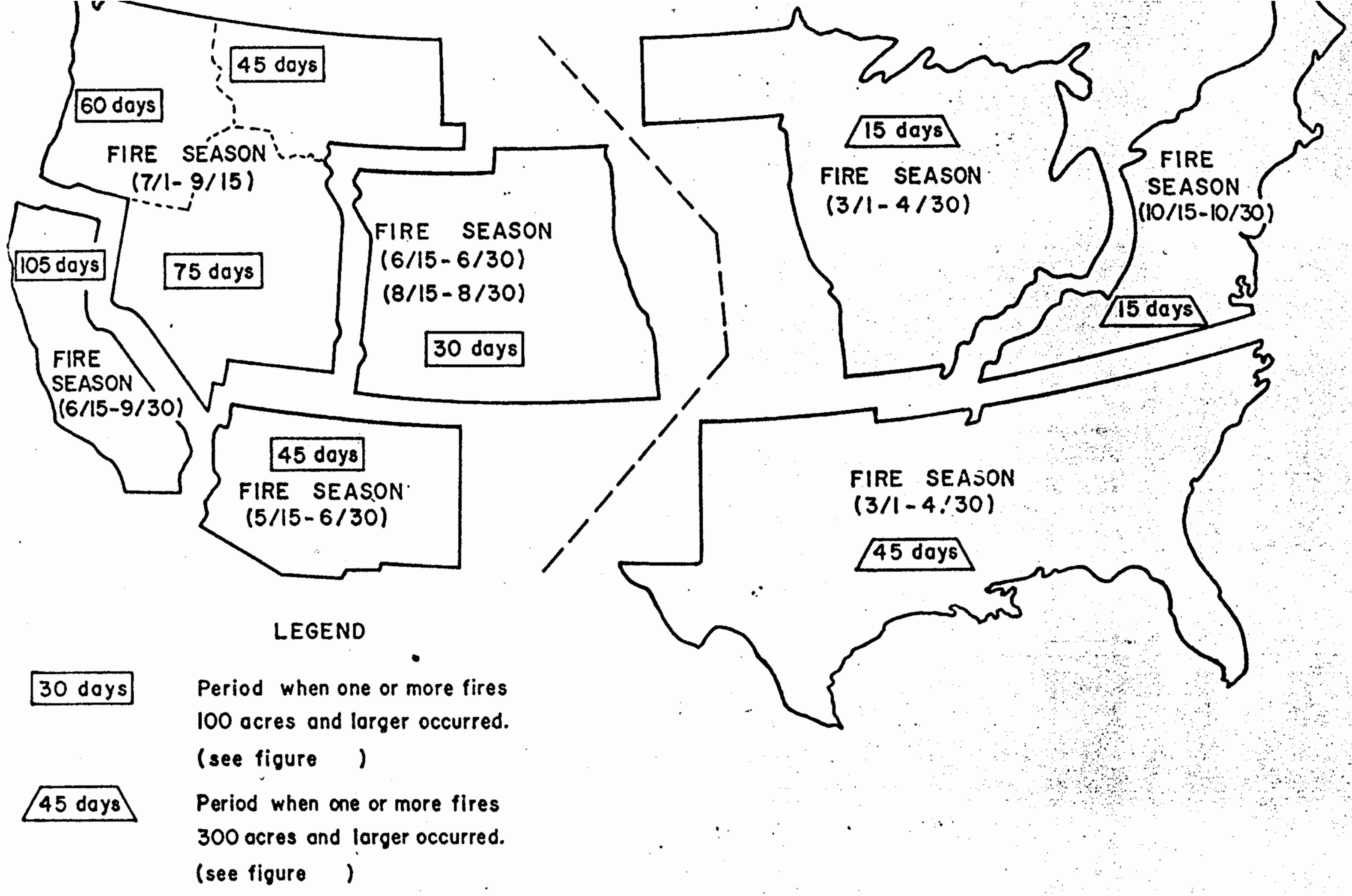


Figure 31.--Average number of days per year on which large wildfires have occurred, 1944-1963.

Table 3.—Summary of Class D and E fires 1944-1963, U.S. Forest Service Regions 1 through 9[1/]

Region	Average number of fires	Average fire length	Total days to control and mopup	Average fire size
		Days		Acres
1	11.4	10.0	114	620
2	8.6	5.8	50	410
3	18.1	7.4	133	290
4	25.5	4.7	120	1,550
5	50.0	5.8	290	1,750
6	17.7	10.1	189	260
7	2.6	6.5	17	2,500
8	17.1	2.8	48	550
9	5.3	2.1	11	1,060

1/ For fires 100 acres and larger in Regions 1 through 6; 300 acres and larger in Regions 7 through 9.

The data summarized in this section should provide the necessary information to determine the number of infrared scanners required to meet the U.S. Forest Service annual expected fire load. Since the actual number of units required will depend strongly on operational procedures, we felt it was beyond the scope of this report to recommend the number of units to be acquired.

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SUMMARY

An infrared scanner operated by U.S. Forest Service personnel consistently and reliably provided fire intelligence when visual surveillance was ineffective. Infrared imagery of uncontrolled wildfires provided information about the location and extent of the fire perimeter, the existence and location of spot fires outside the main fire perimeter, and the relative intensity along various portions of the fire front. During the mopup and final control operations it proved to be an extremely valuable tool for locating the lingering hot spots. Infrared intelligence enabled fire control officers to make more effective use of the suppression forces available.

During the 1964 fire season, 800 pieces of fire imagery were produced on 23 wild and 15 prescribed fires ranging in size from 10 acres to 215,000 acres. Many of them were obscured by dense smoke palls. In no case was there any degradation of image quality caused by smoke.

In 1966, a prototype infrared scanner employing a liquid nitrogen cooled InSb detector, an internal 70 mm. crater lamp recorder, and an external cathode ray tube recorder equipped with a dual Polaroid camera, was evaluated and found to be satisfactory for performing operational fire mapping missions.

On the average, there are 156 fires per year large enough to require infrared surveillance. Fire occurrence follows seasonal patterns that differ widely from one part of the country to another. It should be possible to effectively use infrared equipment by shifting scanners from one geographic location to another as the fire season progresses.

The reaction of fire control officers to infrared mapping has been overwhelmingly enthusiastic. In almost every case, infrared intelligence affected the decisions made and resulted in a reduction in fire suppression costs. No quantitative cost analysis of infrared fire mapping was made; until such a study is done, no meaningful cost effectiveness predictions are possible.

APPENDIX I

FOREST SERVICE - U. S. DEPARTMENT OF AGRICULTURE

Intermountain Forest and Range Experiment Station
Northern Forest Fire Laboratory
Missoula, Montana

January 29, 1964

DESIGN CRITERIA

FOR

A PROTOTYPE AIRBORNE INFRARED FIRE SURVEILLANCE SET

INTRODUCTION

An experimental program has been conducted by the U.S. Forest Service in cooperation with the Office of Civil Defense to determine whether airborne infrared line scanners can provide surveillance information on fires of 1/10 acre to several thousand acres in size when smoke or darkness prohibits the collection of this information by other means. After 2 years of flight tests with a modified military scanner, results indicate the desirability of developing a prototype scanner specifically designed to meet the requirements of forest fire and civil defense applications. This specification outlines the general requirements for a prototype fire mapping scanner to be installed and operated in a light twin-engine aircraft.

OPERATION

The equipment shall be designed to be operated by personnel with no previous electronic training. Equipment operators will be selected from forestry and civilian defense personnel with at least a high school education and above average alertness and dexterity.

The equipment will be operated in light twin-engine aircraft at altitudes from 2,000 feet to 15,000 feet above terrain and at air speeds from 100 knots to 180 knots. Under these conditions the equipment must be capable of producing high quality imagery of terrain, fire perimeter, and small spot fires, with sufficient detail so that a skilled infrared imagery interpreter can precisely determine the location of the fire perimeter with respect to terrain and man-made features such as roads, bulldozer constructed firelines, etc.

The output of the scanner shall be displayed on a B-scan monitor suitable for assisting the pilot in positioning the aircraft over the fire area. The scanner must be capable of recording terrain detail along the perimeter of extremely hot fires.

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PERFORMANCE REQUIREMENTS

Scan angle.—120°

Roll stabilization.—±10°

Angular resolution.—Optical system resolution shall be as high as is obtainable with state-of-the-art equipment. A 1-milliradian system resolution capability is desirable. A 2-milliradian system resolution capability is the minimum acceptable.

Temperature resolution.—2° C. maximum in the spectral region from 4.5 to 5.5 microns.

V/H.—0.13 per second maximum.

Dynamic range.—Dynamic range shall be adequate to handle the signal from hot fire targets without incurring saturation while the system gain is set for terrain mapping. Previous experiments have shown that a logarithmic attenuator with a 3-decade range is adequate for this function.

Display.—An A-scan monitor shall be provided to assist the operator in determining overall system performance.

A B-scan monitor shall be provided with provision for either 60° or 120° display angle.

Recording.—A Polaroid camera shall be provided to photograph the B-scan monitor. Any alternate proposal whereby processed positive imagery can be made available rapidly will be considered.

Provision for external recording.—Suitable connectors shall be installed to supply video, sync, and V/H signals to auxiliary recording and telemetering equipment.

Power requirements.—28 v. d.c., 30 amp. maximum.

Size and weight.—Size and weight shall be consistent with installation in the aircraft mentioned below while still permitting space and weight capabilities for a pilot and two scanner operators.

OTHER DESIGN CONSIDERATIONS

Installation.—This system shall be designed to permit installation in a light twin-engine aircraft such as an Aero Commander, Cessna 310, Beechcraft G-50, etc., with a minimum amount of structural modification to the aircraft. Once the initial modification has been made, installation or removal of the equipment shall not require more than two men or more than 30 minutes' time.

Detector cooling.—The use of liquid gas for detector cooling is undesirable because of logistic difficulties. The elimination of the necessity for detector cooling would be the most desirable approach; however, since at present this does not appear feasible, the use of closed cycle coolers should be considered and the cost and complexity weighed against the undesirable characteristics of liquefied gases.

Maintenance.—The equipment will be maintained by forestry and civilian defense personnel skilled in normal electronic equipment maintenance. Wherever possible, modular construction shall be employed to permit in-field servicing by replacement. Solid state devices shall be used in place of vacuum tubes wherever system performance will not be jeopardized.

The equipment shall be designed to completely eliminate any need for precise optical adjustments in the field. In no case shall any specialized optical equipment be required for the maintenance of this device.

Future production.—This prototype scanner shall be designed to be compatible with production methods so that costs can be minimized in production quantities.

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APPENDIX II

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UNITED STATES GOVERNMENT
MEMORANDUM

Department of Agriculture-Forest Service
Washington, D.C. 20250

TO : Jack Barrows, Director
Division of Forest Fire Research

File No.: 4400 (5100)

FROM : Merle S. Lowden, Director
Division of Fire Control

Date: December 1, 1965

SUBJECT: Forest Fire Research (Infrared Mapping) Your reference:

As was suggested at our November 10 meeting, use of infrared imagery to map forest fires is at a stage of development where we should identify more specifically the information these techniques can record and furnish to the fire boss.

Infrared imagery provides the fire boss with a new tool to accurately map the fire edge under adverse conditions of smoke, smog, and darkness. This is progress, but knowledge of fire edge location alone is not adequate for effective fire control decision making. Effective decisions are also based on information concerning the dynamic characteristics of the fire perimeter and its relation to fuels, weather, topography, and values threatened. Thus, the mission of infrared fire mapping should be to furnish the above information, except weather, in sufficient detail to allow the fire boss to make informed decisions to control the fire. It will be necessary to capture this information more frequently, efficiently and economically than has been possible previously. In determining the degree of detail required of infrared imagery we must emphasize that under adverse conditions of smoke, smog, or darkness, infrared mapping presents the only obvious alternative means of gathering intelligence to laborious ground reconnaissance. The first and foremost requirement is a picture of the fire edge tied exactly to ground features. Ridge tops, valley bottoms, streams and prominent points should be discernible in sufficient detail to determine the precise location of fire edge, hot spots, spot fires, fuel type changes, and fuel breaks. In addition, the following degree of detail in infrared imagery is required for fire suppression decision-making when accompanied by maps showing topography, fuels, and physical features.

Fire Edge Characteristics - The following must be discernible:

1. The entire fire edge including smoldering edge, and flaming fronts.

2. Fire intensity and rates of spread on various sections of the fire.

3. Except under closed forest canopies, all constructed lines and natural breaks.

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4. Spot fires outside the fire edge from smoldering to full flaming spot fires.

5. Size and location of spot fires.

<u>Relationship of Fire Edge to Fuels</u> - The following should be discernible:

1. Snags and hot spots burning inside the fire but within 300 feet of the fire edge. It is desirable but not necessary to distinguish between snags and hot spots.

2. Unburned patches of fuel of more than 5 acres in size within the fire.

3. Major fuel type changes for a distance of one or more miles outside the edge of the fire, i.e.; Changes between grass and brush; timber and brush; conifer and hardwood; blowdown and standing timber; water and land; rocks and timber; rural and urban.

4. Fire breaks outside the edge of the fire, e.g., country roads, highways, streams not hidden by forest canopy, and prepared fire breaks.

<u>Relationship of Fire Edge to Values Threatened</u>

1. Structural improvements such as residences, bridges, factories, schools, and urban communities should be discernible.

Some of the foregoing details may seem demanding for existing or contemplated infrared mapping capability. Since these are the intelligence requirements for acceptable fire control, the objective should be to meet these demands as nearly as possible. Moreover, the capability to gather fire information in a single integrated reconnaissance operation would enhance fire control during a nuclear attack, especially in areas where detailed maps are unavailable.

/s/ Merle S. Lowden

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APPENDIX III

DISTORTION

Familiarity with the geometric distortions encountered in line scanning is essential to successful image interpretation. The spectral sensitivity of the line scanner is determined by the detector and the filter employed, but the geometric distortions are inherent in the scanner design and independent of the spectral region selected.

Glow Tube Printer

Figure 32 is a schematic drawing of a line scanner employing a glow tube printer. A suitable detector is placed at the focal point of a parabolic mirror. The scanning function is provided by a flat mirror rotating at relatively high speed. A pair of microscope objectives are directly coupled to the scanning mirror shaft and oriented so that their axes are parallel to the path of the principle rays striking the scanning mirror. Energy from the terrain being scanned strikes the detector, producing an electrical signal whose amplitude is proportional to the intensity of the incident energy. This signal is amplified and modulates the intensity of a glow tube with output in the visible spectrum. The light from the glow tube is deflected by a mirror, passed through the microscope objective, and focused on panchromatic film. The direct coupling of the scanning mirror and the microscope objectives insures a direct correlation between the position of the focused spot on the film and the point on the ground producing the radiation incident on the detector. As the mirror rotates, a line is scanned across the ground perpendicular to the aircraft flight path and a corresponding line is printed on the film by the microscope objective. The angular coverage displayed on the image is fixed by the geometry of the printer and the width of the film.

Figure 32.—Schematic of a line scanner employing a glow tube printer.

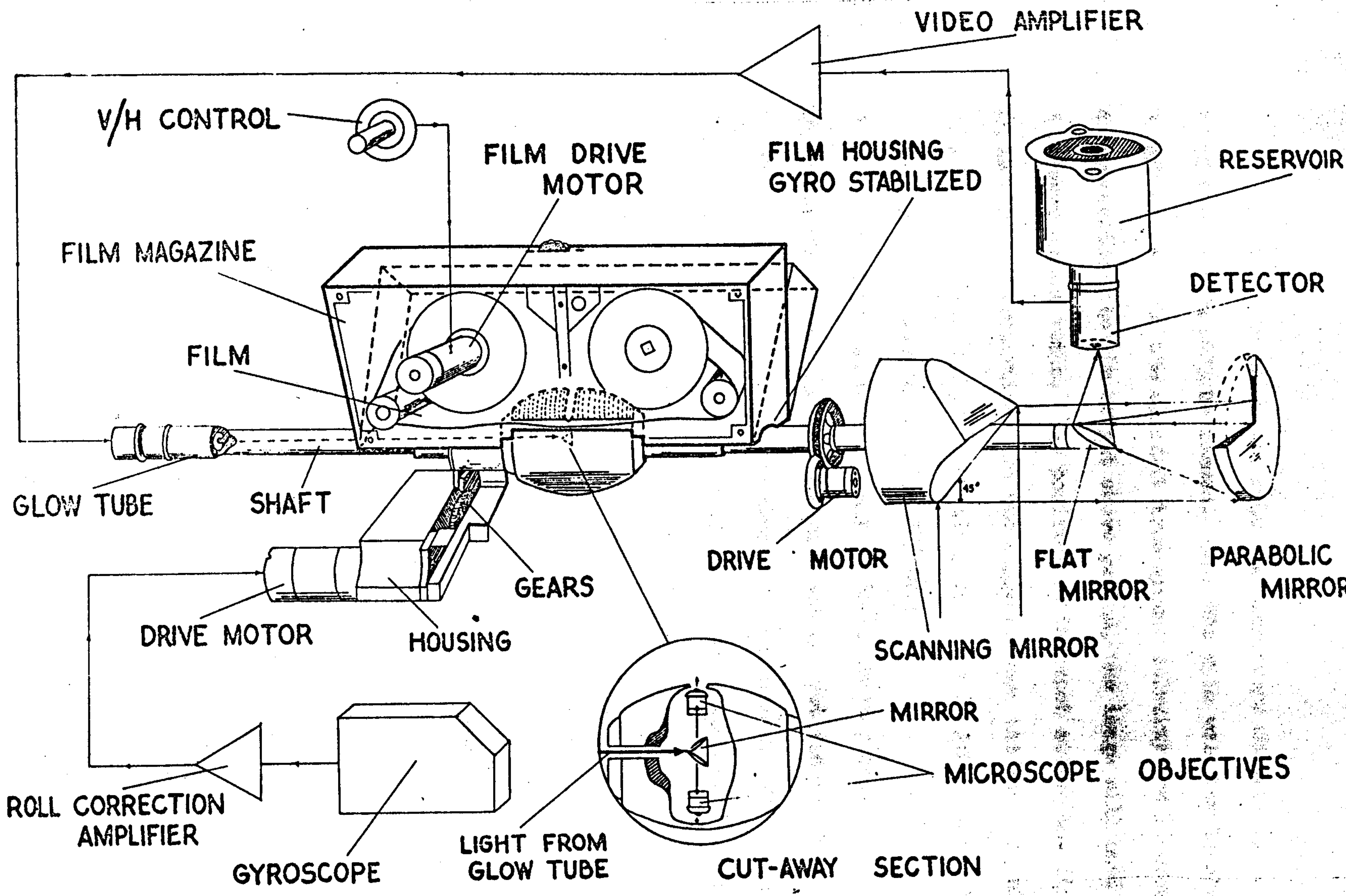

Figure 32.--Schematic of a line scanner employing a glow tube printer.

If the film is pulled past the microscope objective, an image of the terrain will be formed. When the film velocity is directly proportional to the aircraft true ground velocity and inversely proportional to its height above ground, the image will have proper aspect ratio. The position of the spot across the film is directly proportional to the angle between the scanning mirror and the nadir. The position along the film is proportional to true ground distance along the flight path.

Note that the position across the film is proportional to the angle and not to true ground distance, yet the position along the film is proportional to true ground distance. The result is an image with a distortion similar to that encountered in normal photography in one direction, but with no distortion in the other direction.

To compensate for aircraft roll, a roll-stabilized recording magazine is employed. As the aircraft rolls, the recording magazine is held level and the angular correspondence between scanning mirror position and the nadir is maintained on the recording.

The glow tube printer has the advantage of simplicity and positive synchronization between the scanner and the printer. It has the disadvantage of being extremely difficult to rectilinearize.

Cathode Ray Tube Printer

The second method of recording line scan imagery employs a cathode ray tube printer (fig. 33). The drive motor, scanning mirror, parabolic mirror, detector, video amplifier, and gyro stabilizer are identical to those used with the glow tube printer.

Figure 33.—Schematic of a line scanner employing a cathode ray tube printer.

An electron beam is swept across the face of a cathode ray tube. Magnetic pickups attached to the mirror synchronize the start of the sweep with the scanning mirror. The sweep duration is made equal to the time required for the scanning mirror to rotate through the desired display angle. The cathode ray tube's intensity is modulated by the amplified detector signal and the trace is imaged on the film. As in the case of the glow tube printer, the film is pulled past the scan line. Roll stabilization is achieved by varying the time at which the scan starts rather than by gyro stabilizing the recording magazine.

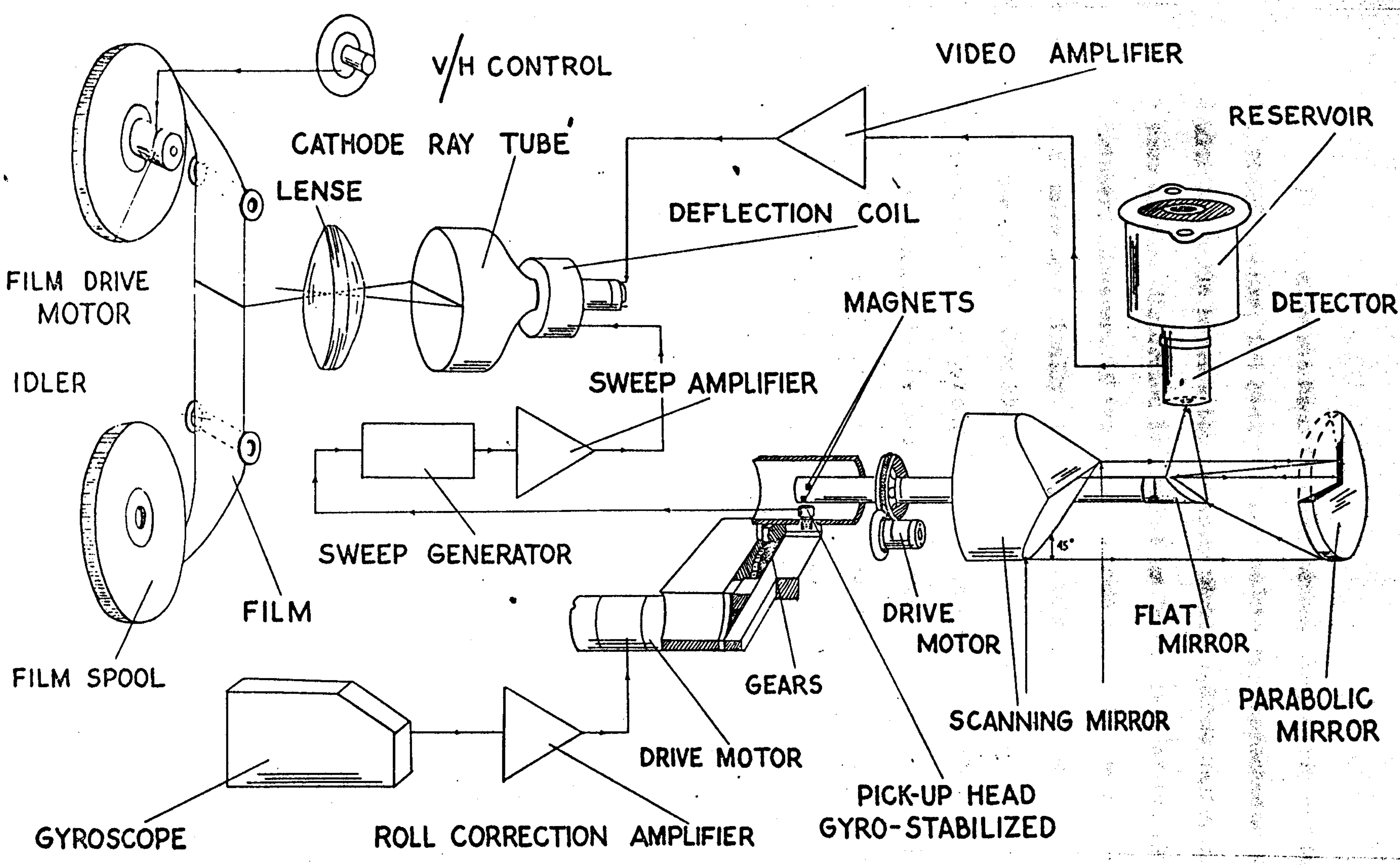

Figure 33.--Schematic of a line scanner employing a cathode ray tube printer.

If the electron beam is swept across the cathode ray tube in a linear manner, the spot position on the film correlates directly with the angle between the scanning mirror and the nadir, and the same angular distortion is present as in the case of the glow tube printer. However, if the sweep is made nonlinear (rectilinearized) and, more specifically, if the sweep wave form is the tangent of the scan angle, then the position of the spot on the film will correspond to true ground position rather than to the scan angle. A true planimetric presentation is obtained.

The disadvantages of the cathode ray tube printer are numerous and will be discussed in detail later in this section.

Resolution

Regardless of which printing method is employed, the minimum resolvable spot size directly under the aircraft is determined by the focal length of the parabola, the size of the detector, the minimum spot size obtainable in the printer, and the height of the aircraft above the ground.[14] The maximum practically obtainable resolution is an order of magnitude poorer than conventional 1:15,840 aerial photography.

14/ Assuming the quality of the parabola and the flat mirrors is sufficient to insure a blur circle much smaller then size of the detector.

Distortions Inherent in Line Scanning

The size of the minimum resolvable elements at positions other than the nadir can be calculated as follows:

$$P = \beta \; h \sec \theta$$

and

$$F = \beta \; h \sec^2 \theta \qquad \text{(fig. 34).}$$

Figure 34.—Aircraft scanning geometry.

It is common practice to correct the imagery for roll, but no correction is usually employed for pitch or yaw. If there is cross wind at the time the imagery is made, the aircraft heading and aircraft track will not coincide. Because of this, all points except those at the nadir will be skewed in the direction of the aircraft crab (fig. 35). Any turns of the aircraft during the imagery run will cause straight roads parallel to the flight track to appear curved (fig. 36).

Figure 35.—This rectilinearized image shows the effect of aircraft crab. Note that the roads crossing the flight path do not form right angles with the road directly under the flight path.

Figure 36.—This run was made in the opposite direction to figure 35. Notice that the roads are skewed in the opposite direction. Note the apparent curvature in the road at the left side of the image. This was produced by turning the aircraft during the run.

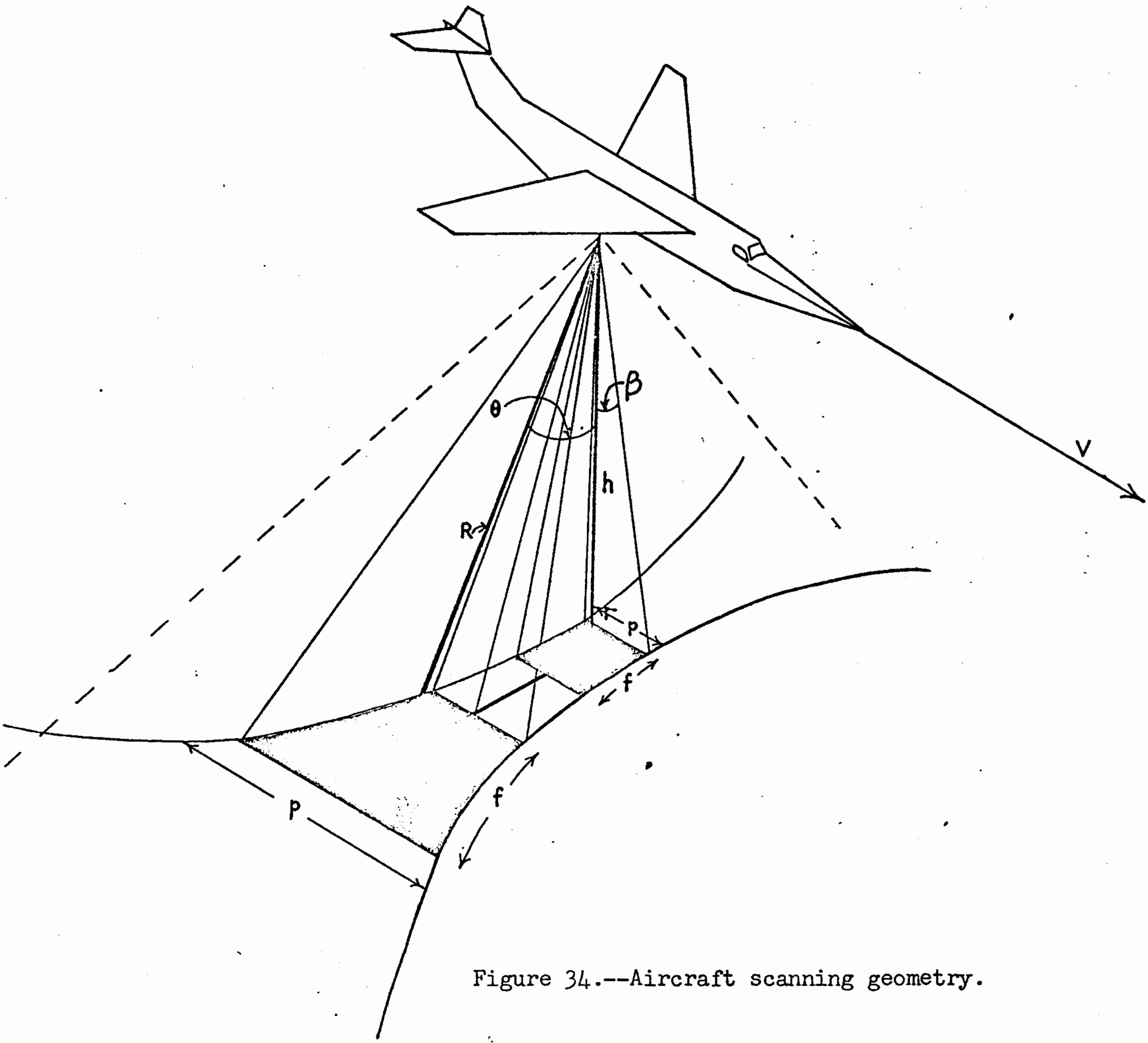

Figure 34.--Aircraft scanning geometry.

Figure 35.--This rectilinearized image shows the effect of aircraft crab. Note that the roads crossing the flight path do not form right angles with the road directly under the flight path.

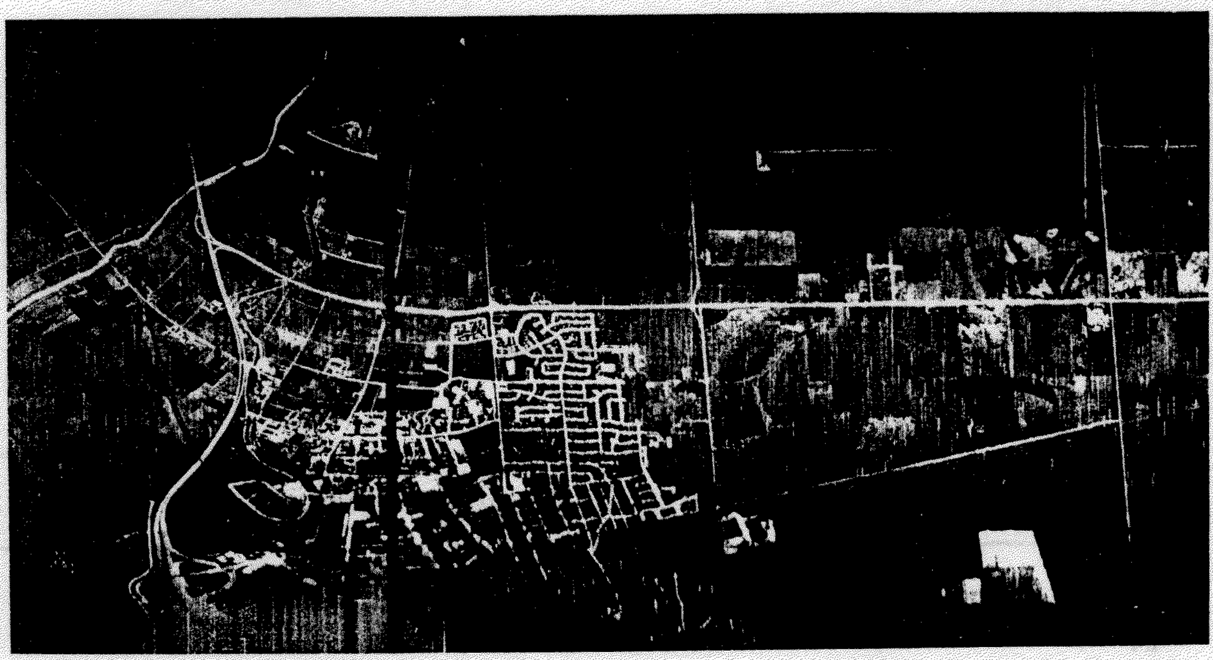

Figure 36.--This run was made in the opposite direction to figure35. Notice the roads are skewed in the opposite direction. Note the apparent curvature in the road at the left side of the image. This was produced by turning the aircraft during the run.

In practice, it is extremely difficult to determine true aircraft ground speed and true height above terrain. Since these are not generally known accurately, the film velocity in most cases will not be correct, and the scale along the flight path will be different from the scale across the flight path.

Distortion Without Tangent Correction

If the imagery is made without rectilinearization, the aspect ratio will be correct at the nadir or at two points equidistant from the nadir. Since the scale along the flight path is directly proportional to true ground distance, and the scale across the imagery is proportional to angle, it is impossible to maintain true aspect ratio throughout the entire image. A compromise is necessary and is usually made by selecting the film velocity so that true aspect ratio is maintained at either 30° or 45° from the nadir. This compromise results in minimum distortion over the largest portion of the image. If this aspect ratio distortion is ignored while attempting to perform even simple image interpretation, serious errors can result. A straight road crossing the flight path at an oblique angle will appear to be S-shaped (fig. 37).

Figure 37.—Infrared image showing distortion features.

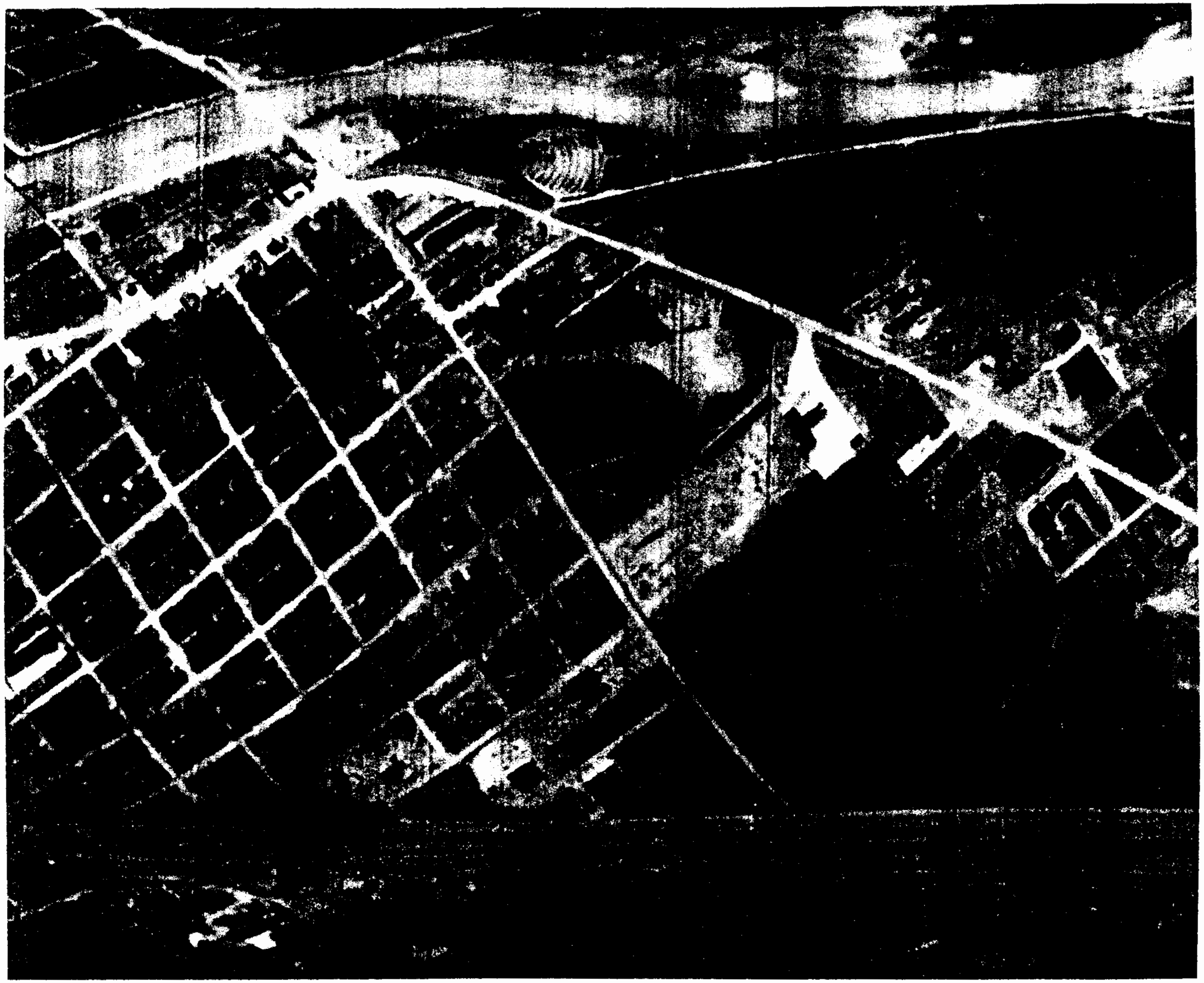

Figure 37.--Infrared image showing distortion features.

Distortions Peculiar to Cathode Ray Tube Printers

The cathode ray tube printer can be rectilinearized quite easily, but it has several serious disadvantages. It is inherently more complex, but much more important from the imagery interpreter's standpoint are distortions that often result from electronic circuit drifts.

The angular coverage recorded on the image is determined by the angular velocity of the scanning mirror and the time duration of the sweep wave form used to deflect the cathode ray tube electron beam. It is a simple matter to change the time duration of the sweep to provide any desired angular coverage. This is worthwhile for providing versatility, but any drift in the electronics can easily result in an unintentional change in coverage angle. If careful checks are not made prior to image interpretation, these drifts could result in serious errors.

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The ability to rectilinearize the imagery by developing a tangent sweep wave form is an asset of the cathode ray tube printer. But, again, the possibility of electronic circuit drifts may result in a sweep wave form that does not accurately follow the tangent curve, and an unpredictable distortion may result. The tangent wave form required to rectilinearize the imagery results in nonlinear velocity of the electron beam across the face of the cathode ray tube. This nonlinear velocity produces a nonuniformity in brightness across the scan line. In order to produce usable imagery it is necessary to correct for this change in brightness. If this correction is exactly made, no problem arises. Again, if electronic circuit drifts occur, this correction may be improper and serious shifts in tone across the imagery may result.

SUMMARY

Once we realize the number of ways in which angular and tonal distortions can be introduced into line scan imagery, we may wonder whether a device with so many problems can produce any usable results.

Line scan technology will some day advance enough to produce truly stable equipment. In the meantime, we may use the wealth of information that line scanners can provide, but with care. Always check the imagery against conventional photography so you know what distortion is present. Transfer points of interest from imagery to aerial photos before making measurements.

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APPENDIX IV

VIDEO ELECTRONICS FOR FIRE MAPPERS

The electronics in most thermal scanners are inadequate for mapping large forest fires. Signal processing that causes overshoot, ringing, and signal level shift can aid in identifying low energy targets. The same signal processing used with high energy targets, such as forest fires, will cause partial or complete loss of terrain detail near hot spots. Forest fire mapping requires electronic processing of variable amplitude and width signals without loss of adjacent terrain detail. Amplifiers must have fast recovery, minimize overshoot, and retain the original terrain background reference level.

All thermal imaging systems require signal amplification (or gain) to record small detected signals. Direct-coupled amplifiers are desirable for this application. But high-gain, direct-coupled amplifiers are inherently unstable and drift severely with temperature. The drift can be reduced by a.c. coupling, but a.c. coupling destroys the terrain reference required for fire mapping.

The problems with a.c. coupling can be investigated by studying the effects of terrain and fire signals (fig. 40) on the electronic transfer characteristic of an amplifier. A simplified a.c.-coupled amplifier with a synchronous clamp switch is shown in figure 38. The shape of the transfer characteristic (fig. 39) is very important to the results printed on film. Assume a transfer curve with a linear portion, as shown in figure 40.

Figure 38.—A.c.-coupled amplifier.

Figure 39.—Typical amplifier transfer curve.

Figure 40.—Typical detector signals: A, Simulated terrain signal; B, with small pulse; C, with larger signal; and D, with very large signal.

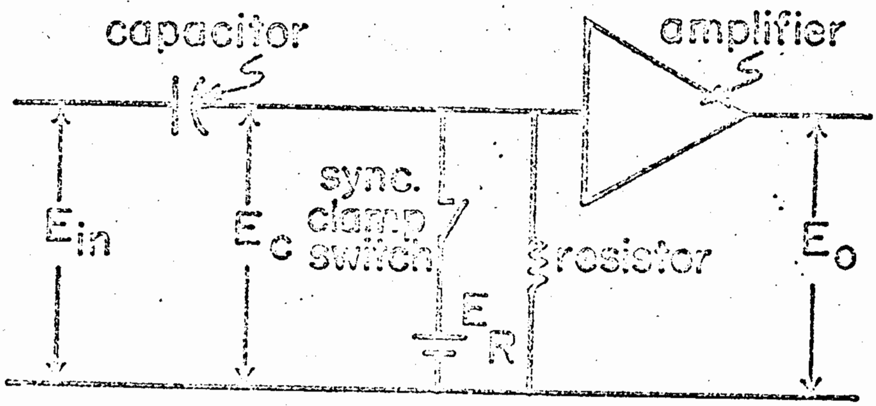

Figure 38.--A.c.-coupled amplifier.

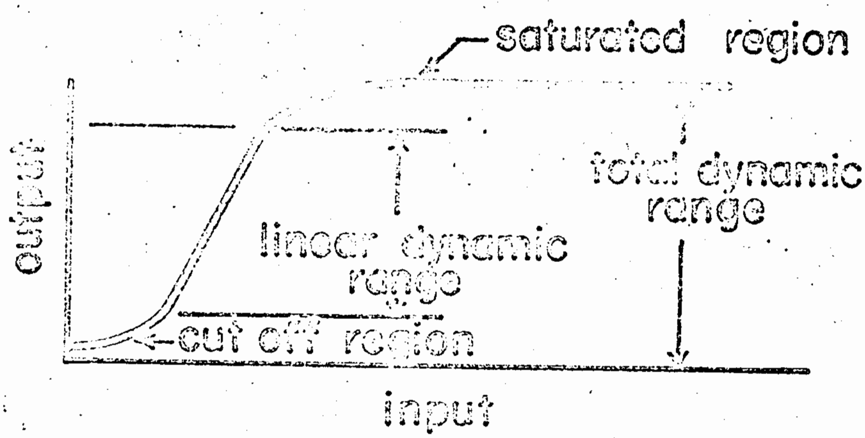

Figure 39.--Typical amplifier transfer curve.

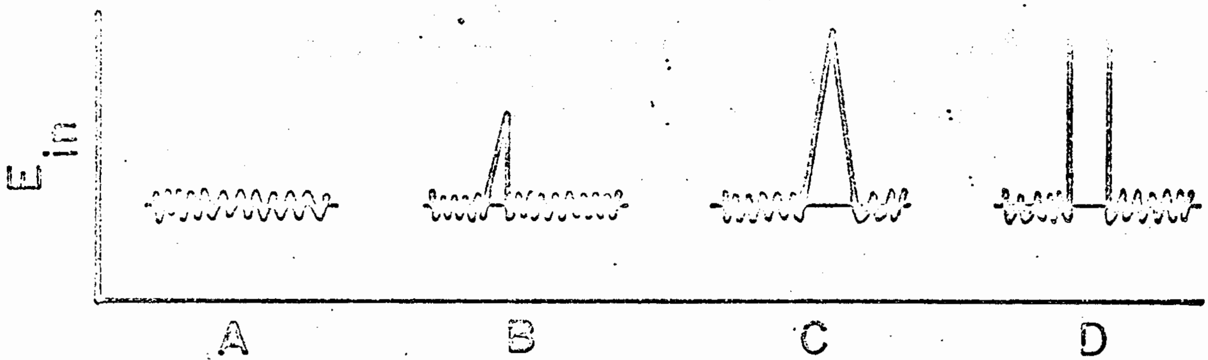

Figure 40.--Typical detector signals: A, Simulated terrain signal; B, with small pulse; C, with larger signal; and D, with very large signal.

The typical input signal contains a series of maxima and minima corresponding to hot (maxima) and cold (minima) terrain temperatures (fig. 40A). Figures 40B through D show signals corresponding to fires of various energies and sizes superimposed on the terrain signals. Applying the signals from figure 40 to a capacitor removes the d.c. reference level. Terrain signals that were used to establish film gray scales are forced below the reference level by an amount equal to one-half the area under the fire signal (fig. 41). As the fire signal changes in height and width, the area under the curve changes and the reference level is displaced up or down accordingly. The result is a continuing change in gray scales for the duration of the large signals.

Figure 41.—Typical signal after a.c. coupling: A, Simulated terrain signal; B, no reference change with small pulse; C and D, terrain base line shifts from reference level as the signal area changes.

Returning to the transfer characteristics, figure 39, we see the linear region becomes the "linear dynamic range" of the amplifier. The total dynamic range, or the information available for printing on film, is the distance between the ordinates of the curve at cutoff and saturation.

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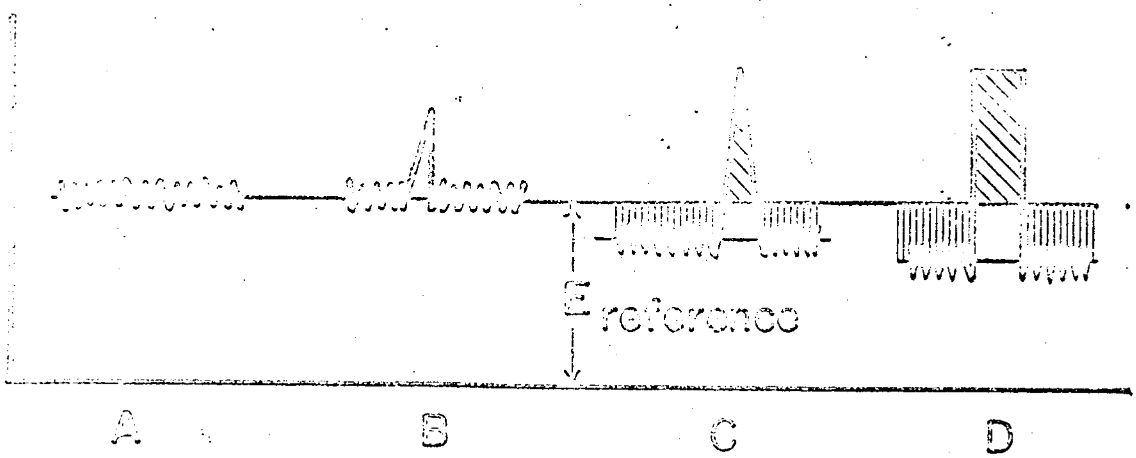

Figure 41.--Typical signal after a.c. coupling: A, Simulated terrain signal; B, no reference change with small pulse; C and D, terrain base line shifts from reference level as the signal area changes.

Fire signals have a positive polarity with reference to terrain signals. The linear dynamic range of the amplifier can best be used by setting the bias point (Q-point) near cutoff (allowing for background fluctuations and temperature drift). Figure 42A shows a low amplitude background signal amplified on the linear portion of a transfer curve. The average value of the input signal is zero and the signal is amplified around the reference (or bias) point. Figure 42B shows a very narrow, high amplitude pulse on the terrain background signal. The area under the pulse is small and does not change the reference level. Figures 42C through E show changes in background level produced by various pulse widths and heights. As the area under the pulse is increased, the terrain signal reference is forced toward cutoff. Further increase in the pulse area causes the gain to reduce and presents a graying (reduced contrast) effect on the film. If the area is increased sufficiently to force the level beyond cutoff, the background signal will be completely lost. Signals from forest fires exceed the cutoff limits.

Figure 42.—Effects of a.c. coupling on the transfer curve of a typical amplifier: A, Terrain signal; B, large, narrow target; C, low, wide target; D, high, wide target; E, low, very wide target; and F, target with d.c. restoration.

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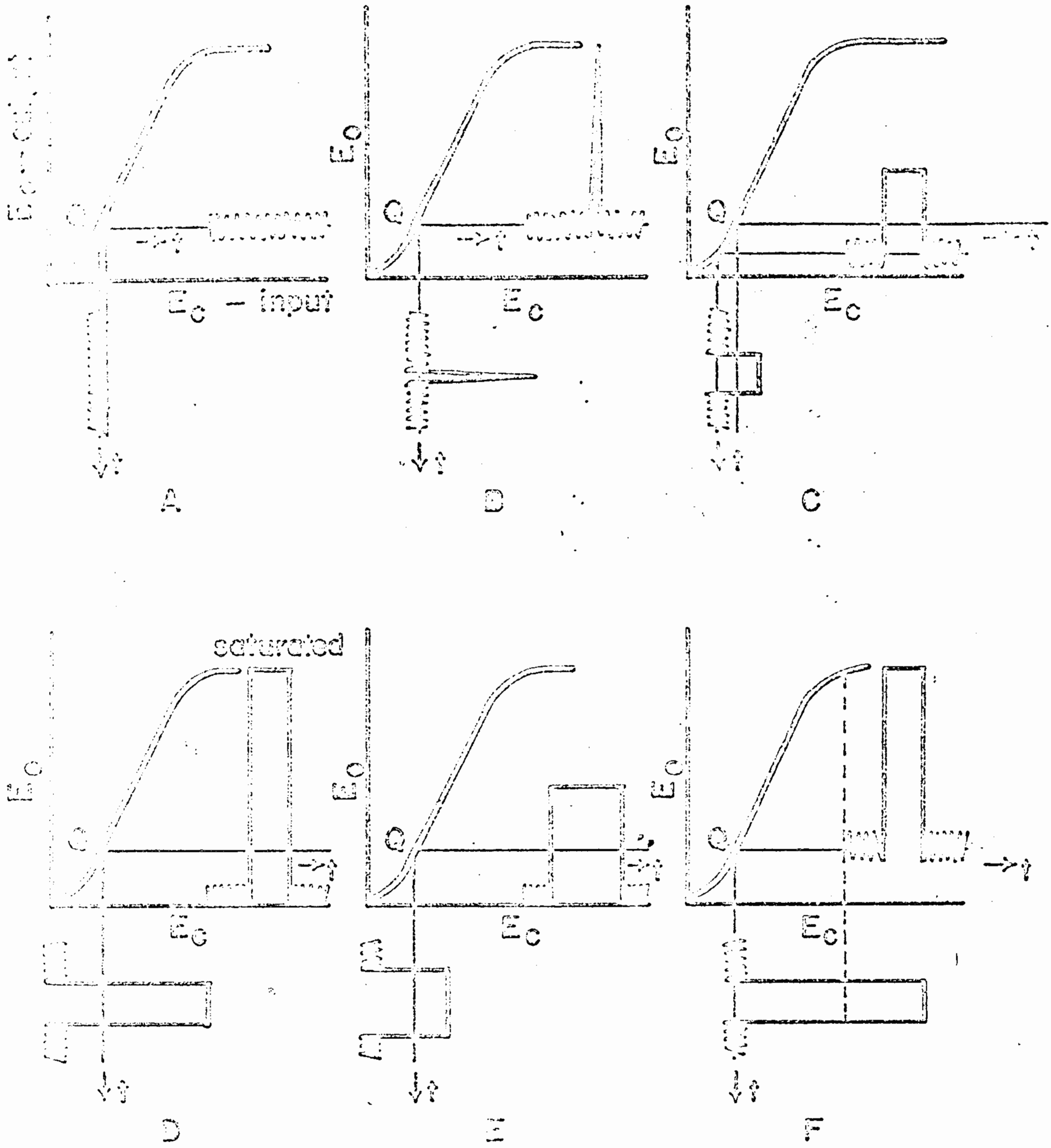

Figure 42.--Effects of a.c. coupling on the transfer curve of a typical amplifier: A, Terrain signal; B, large, narrow target; C, low, wide target; D, high, wide target; E, low, very wide target; and F, target with d.c. restoration.

When the signal amplitude exceeds the transfer characteristic saturation point, further increase in the input signal will not change the output signal. The signal is said to be clipped or limited; hence, a voltage clipping circuit. The solution to loss of d.c. reference seems simple—clamp the terrain signals to a given reference and allow the large signals to be clipped (fig. 42F). With an ideal restoration circuit, the reference level can be clamped and maintained for any fire signal. In the real world the restoration circuit becomes complicated. Signal amplitudes must be large enough to clamp before a.c. coupling can be used.

Restoration is accomplished by closing the synchronous clamp switch (fig. 38) and shorting the reference point to ground. (Another point, other than ground, may be selected by setting E_R to some reference level determined by the circuit requirements.) The selection of the reference time creates problems; fortunately, in most scanning systems there is a "dead" time when the detector and optics are looking at the inside of the scanner. The scanner temperature is relatively stable and forms a reasonable reference. To insure restoration during the dead time, the switch must be synchronously timed to the optics rotation. A synchronous gate signal is used to close the switch during a portion of the dead time, discharging the capacitor to ground and forcing each scan (horizontal sweep) to start from the same reference. The portion of the dead time selected must be void of any external or varying signals or the clamp reference will be destroyed.

Adequate low frequency response is required or overshoot will become a problem. Figure 43 shows the effect of insufficient low frequency response as the tilt on the top of the wave. The area A_1, enclosed between the input signal and the tilted wave shape, must equal the area A_2. A_2 is overshoot and will return 63 percent of the distance toward zero in one time constant.

$$\tau = 1/2 \pi f_1$$

where τ = one time constant

f_1 = low frequency bandwidth.

The area A_2 is more noticeable on imagery than A_1. It appears as a dark area adjacent to hot fire targets and slowly recovers to the brightness of the original terrain features. If the fire area is large, the area A_2 will be large and may destroy all of the terrain features on the triling edge of the fire. Figure 16 shows the results of insufficient low frequency response.

Figure 43.—Effect of insufficient low frequency response; A, input; and B, output.

Form
INT 1600-12 (9/66)

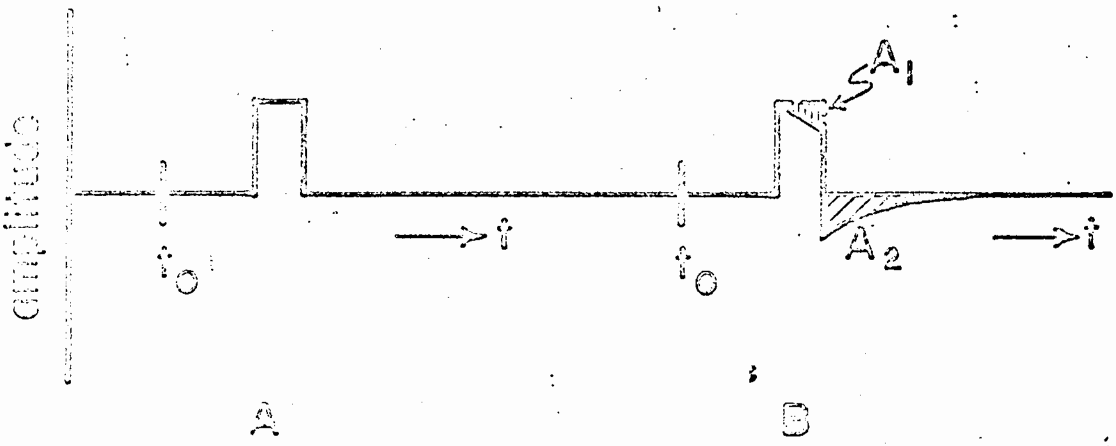

Figure 43.--Effect of insufficient low frequency response; A, input; and B, output.

Rapid recovery of the system after hot targets occur is required. An under-damped system causing ringing (fig. 44) will appear on the imagery as alternate black and white areas following the target as each maxima and minima occur. Any high amplitude target or pulse can cause ringing. Ringing is often used to identify small hot targets by multiple spots following the real target, but destroys adjacent terrain detail. It should not be used for fire mapping systems where terrain information is important. Ringing can be eliminated by adequately damping oscillatory components.

Figure 44.—Ringing: A, Input; and B, output.

Slow recovery occurs when the system is severely over-damped. The target is elongated (fig. 45), and the adjacent area to the fire will appear the same color as the fire. The fire edge will not be discernible.

Figure 45.—Target elongation: A, Input; and B, output.

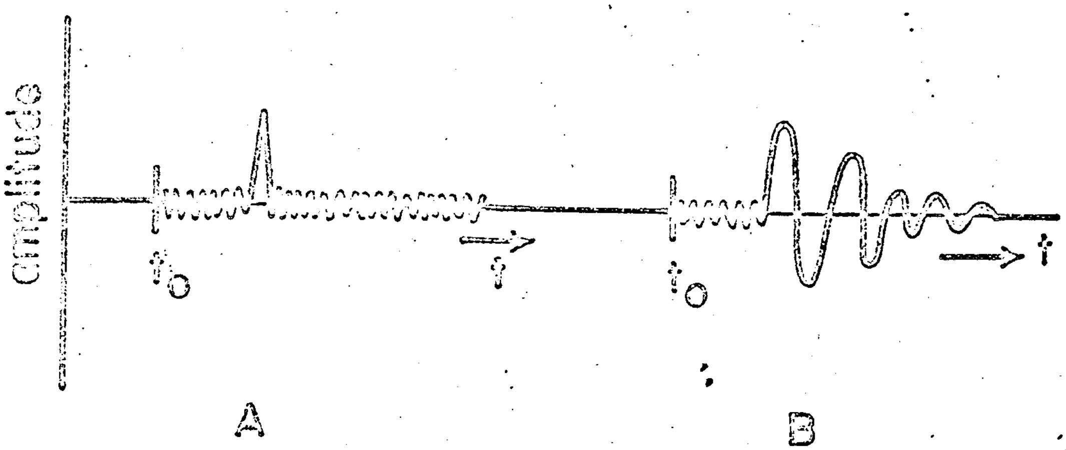

Figure 44.--Ringing: A, Input; and B, output.

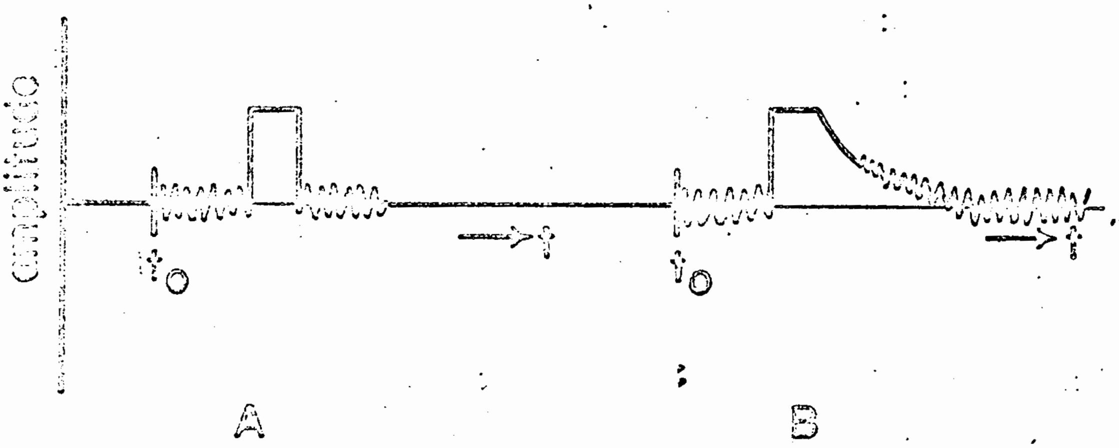

Figure 45.--Target elongation: A, Input; and B, output.

APPENDIX V

Table 4.--Summary of fire occurrence 1944-63, Forest Service Regions 1-9[1/]

Year	Regions									Total number fires
	1	2	3	4	5	6	7	8	9	
1944	20	8	10	49	78	26	3	35	9	238
1945	32	3	13	22	71	36	0	31	9	217
1946	13	3	29	27	43	16	1	22	16	170
1947	8	7	16	50	70	11	2	27	4	195
1948	1	9	19	35	38	3	1	18	9	133
1949	14	9	7	28	71	30	0	15	7	181
1950	6	12	38	14	81	12	1	20	2	186
1951	5	8	20	17	78	29	0	20	3	180
1952	5	10	3	11	33	21	25	31	13	152
1953	20	5	25	18	53	3	12	18	6	160
1954	2	7	17	13	45	3	2	20	5	114
1955	3	10	16	8	47	7	0	14	1	106
1956	5	11	53	24	28	2	0	9	5	137
1957	5	0	7	16	35	4	0	4	1	72
1958	13	11	4	27	21	19	0	5	2	102
1959	10	4	15	31	59	22	0	7	2	150
1960	22	22	21	45	51	54	0	13	1	229
1961	29	3	22	37	42	33	0	2	2	170
1962	3	12	12	20	31	13	0	5	6	102
1963	6	17	15	17	25	13	5	26	3	127

1/ For fires 100 acres and larger, Regions 1-6.
For fires 300 acres and larger, Regions 7-9.

Table 5--1964 infrared fire

Name of fire	State	Dates of fire	IR unit on fire	Fire characteristic on arrival	Fuel type	Fire size: When called	Fire size: Final	Number sorties: Per day	Number sorties: Per mission	Number sorties: Runs per	Number sorties: Day	Number sorties: Night	Initial getaway time
			Days			Acres		Average					Minutes
Parsnip	Montana	7/13-14	2	Running	Lodgepole blowdown	120	150	2	3	11	2	1	45
Candle Mountain 1/	Montana	7/23-24	2	Creeping	Lodgepole	10	11	2	3	12	2	1	20
Crazy Creek 1/	Montana	7/27	1	Running	Subalpine	8	15	3	3	7	3	0	55
Willow Tree	Washington	8/9	1	Creeping	Sagebrush	1,500	2,370	2	2	10	2	0	75
Crab Tree	California	8/10-12	2	Spotting	Brush & timber	1,500	2,360	2.5	5	8.8	2	3	105
Switchback	Oregon	8/13	1	Creeping	Grass & sagebrush	50	50	1	1	9	1	0	30
Big Creek	Nevada	8/16	1	Creeping	Sagebrush & grass	5,500	6,000	2	2	4.5	2	0	105
Keas Canyon	Nevada	8/17-19	3	Running	Grass & sagebrush	300	10,350	1.7	9.8	9.2	4	1	20
Boulder-Magee	Nevada	8/19	1/3	Creeping	Grass	215,000	215,000	1	1	7	1	0	15
Summit	California	8/26-28	2	Running	Oak & brush	2,000	20,000	2	2	11.5	2	2	20
French Gulch	California	9/17	1/3	Running	Brush	2	10	1	1	5	1	0	40
Price 1/	California	9/18	1	Running	Grass & brush	20	300	3	3	14.3	1	2	10
Nuns Canyon	California	9/19	1	Running	Oak & brush	500	3,000	3	3	8	2	1	60
Mill Creek	California	9/23	1	Creeping	Oak & brush	250	300	2	2	14	2	0	10
Coyote	California	9/24-28	4	Running & spotting	Chaparral	26,000	67,000	2.5	10	9.9	5	5	20
[illegible]	California	10/20	1/3	Running	Grass & timber	700	800	1	1	6	1	0	80
Total			23			253,460	327,716	31.7	51.8	145.2	33	16	710
Average			1.44	Running--50% Creeping--37.5% Other--12.5%		15,841	20,482	2.0	3.2	9.1	2.1	1	44.4

1/ Headquarters were not located on roads.

2/ Does not apply

…pping operation summary

Average sortie time over target	Average drop re-trieval time	Average IR interpre-tation time	Day sortie visibility	Use of scan angle 60°	Use of scan angle 120°	Distance to fire from nearest airport	Average distance, aircraft to ground	Imagery drops Day	Imagery drops Night	Map drops Day	All mapping by IR unit Day	All mapping by IR unit Night	Navigation problems	IR mosaic required
Minutes	Minutes	Minutes		Percent		Miles	Miles							
105	15	30	Clear	60.6	39.4	60	2	2	0	0	No	Yes	No	No
50	INA 2/	40	Clear	76.3	23.6	15	INA	0	0	0	No	Yes	No	No
30	05	10	Clear	79.6	20.4	19	2	1	1	0	No	Yes	No	No
60	05	60	Clear	0	100.0	35	2	1	0	0	No	No	No	No
48	05	100	Clear	36.4	63.6	20	3	6	5	0	No	Yes	No	No
30	INA	40	Clear	80	20	15	INA	0	0	0	No	No	No	No
40	05	30	Smoke	0	100.0	8	2	1	0	0	No	No	No	Yes
63	05	40	Smoke	6.2	93.8	70	INA	0	0	3	Yes	No	No	Yes
40	INA	20	Clear	28.6	71.4	45	INA	0	0	0	No	No	No	Yes
67	INA	80	Smoke	30.5	69.5	50	1	0	0	0	No	No	No	Yes
20	INA	20	Clear	100.0	0	10	INA	0	0	0	Yes	No	No	No
95	INA	30	Smoke	13.6	81.4	15	INA	0	0	0	Yes	Yes	No	No
60	05	25	Smoke	0	100	10	1	1	1	0	Yes	Yes	No	Yes
75	INA	30	Smoke	25	75	30	INA	0	0	0	No	No	No	No
68	INA	50	Smoke & fog	0	100	15	15	0	0	0	No	Yes	Yes	Yes
25	INA	20	Smog	0	100	90	INA	0	0	0	No	No	No	No
868		625				507		12	7	3				
54.2		39.1	Clear--50% Smoke--33% Smoke & fog--6% Smog--6%	33.9	66.1	31.7		.8	.4	.2	25%	45%	No--94% Yes--06%	No--63% Yes--37%