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AIRBORNE MULTISPECTRAL DATA COLLECTION
Final Report, 28 February 1969 Through 31 December 1973

by

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ENVIRONMENTAL
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16. Abstract

This report summarizes multispectral mapping accomplishments by ERIM using the M7 airborne scanner. The ERIM-developed M7 system is described and overall results of specific data collection flight operations since June 1971 are reviewed. The mapping was conducted with the new instrument mounted in aircraft owned and operated by ERIM. The M7 system replaces the M5 multispectral scanner system—also developed by ERIM and used in the same aircraft during the 1966-1971 period. A major advantage of the M7 system is that all spectral bands of the scanner are in common spatial registration, whereas in the M5 they were not.

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PREFACE

This report briefly describes the multispectral data collection and reproduction facilities at the Environmental Research Institute of Michigan and documents the use of these facilities during the period 28 June 1971 through 31 December 1973. The work was performed primarily for the National Aeronautics and Space Administration, Lyndon B. Johnson Space Center, Houston, Texas, under Contract NAS 9-9304. NASA's use of these facilities under this same contract prior to 28 June 1971 is documented in referenced Interim Reports.

The same facilities were also used by other government and private agencies during the period and the total operation is reported herein for convenience. Because these facilities are currently operating at less than 80% capacity, additional use is solicited.

Mr. Richard Legault, ERIM vice-president who heads the Institute's Infrared and Optics Division, is Project Director, and Mr. Philip G. Hasell, Jr., is Principal Investigator. NASA's Technical Monitor for the project is currently Mr. Charles Harlan/FC2. Previous technical monitors have been J. D. Weber, W. Shaw, and J. F. Mitchell.

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1
SUMMARY

The Willow Run Laboratories (now the Environmental Research Institute of Michigan) pioneered in applying multispectral mapping techniques to earth resources with experimental hardware developments beginning in the mid sixties. WRL's experimental airborne hardware has supplied all of the multispectral scanner data processed and analyzed by Michigan, Purdue, NASA/MSC and others during the period 1966-1972. Under NASA/MSC support during FY 71, WRL extensively modified its original multispectral airborne scanner system (which had been of multipath type) to provide the same spectral bands along a single optical line of sight. This modification removed a serious restriction on the choice of spectral bands for machine processing. In the previous M5 system, only those few bands grouped in one of four separate optical paths could be processed together. After the modification, any multispectral bands recorded—whether in the ultraviolet, visible, or infrared regions—could be processed together.

A relatively small organization but one with an excellent background, ERIM is well-versed in all aspects of remote sensing and has made many contributions to advance the state of the art. Moreover, the scientific and technical interests of current as well as potential users of remotely sensed data are ably represented in the various ERIM laboratories. In addition, the staff of The University of Michigan, particularly the School of Natural Resources, is also available to participate in investigative programs. ERIM's interest and expertise in investigating earth resources problems is supported by personnel experienced in the development and operation of ground and airborne radiation measuring and recording instrumentation and also in designing, adapting, and using analog and digital computers to automatically process multispectral data. All of this diverse talent has contributed in various ways to the success of the data collection and processing work described herein.

Most of our data collection efforts were funded by government agencies and therefore the data produced belongs to the general scientific community. One of the purposes of this report is to disseminate information on the availability of ERIM-collected data that might be useful for investigations other than those for which these data were specifically collected. Such data can usually be supplied in the form of either analog tape or film merely by obtaining permission from the sponsoring agency and funding the cost of reproduction.

This report summarizes multispectral data collection using the airborne M7 system which is described in detail in Ref. [1]. Appendix A lists NASA data collection missions accomplished by ERIM from September 1968 through June 1971 using the M5 system which is described in Ref. [2]. Appendix B describes ERIM's data processing and analysis services which investigators may use in applying ERIM scanner data to earth resources problems.

2
THE MICHIGAN EXPERIMENTAL MULTISPECTRAL DATA SYSTEM

The M7 scanner, covering a wavelength range from 0.33 to 14.0 micrometers, can operate in up to 19 different spectral bands of the ultraviolet, visible, and infrared regions. Of these bands, 12 can be selected for tape recording at any one time on a 14-track analog tape machine. As many as five separate radiation reference sources may be recorded sequentially along with the ground video once each scan line. The total system, including boresight cameras, is usually operated in a Douglas C-47 aircraft.

2.1 MULTISPECTRAL SCANNER

The simplified diagrams of Fig. 1 illustrate a typical line scanner and its method of airborne use. As shown in the optical schematic at the top of the figure, the scanner basically consists of an optical telescope with its narrow field of view redirected by a rotating flat mirror. This mirror causes the system to scan in a plane perpendicular to the longitudinal axis of the aircraft. A radiation detector in the focal plane of the telescope converts the focused beam of radiation to an electrical signal. The optical system's field of view (ground resolution element) first scans laterally across the aircraft ground track through an opening in the bottom of the aircraft. Then before making the next ground scan, it scans radiation references (not shown) which are internal to the scanner. By the time the next scan begins, the aircraft has moved forward, thus subsequent line scans build upon one another to produce a continuous strip image of the terrain beneath the aircraft.

The multispectral scanner evolved from this single-channel scanner concept. This evolution required replacement of the single detector element with a system of beamsplitters, dispersing optics, and spectral filters. Figure 2 shows the optical configuration of the current M7 multispectral scanner. A key feature to note in this design is its flexibility for accepting different radiation reference sources and new detector assemblies. Weight and space savings were sacrificed to provide this flexibility, which allows increased opportunities for adaptation to a diverse number of data gathering modes. Such flexibility is an important attribute for a general-purpose experimental system.

The radiation intercepted by the 5-in.-diameter collecting aperture is directed into the Dall-Kirkham telescope, which has a 3-in.-diameter secondary mirror. The incoming radiation prevented from entering the telescope by this secondary mirror is directed upward by a folding mirror to Detector Position 1. This 3-in.-diameter collecting aperture operates over the broad band of 0.3 to 14.0 μm. To provide thermal data at this position, a focusing lens designed for the 8.0- to 14.0-μm band is used in combination with a cooled HgCdTe detector. A dichroic mirror mounted ahead of this lens diverts ultraviolet and visible radiation onto a

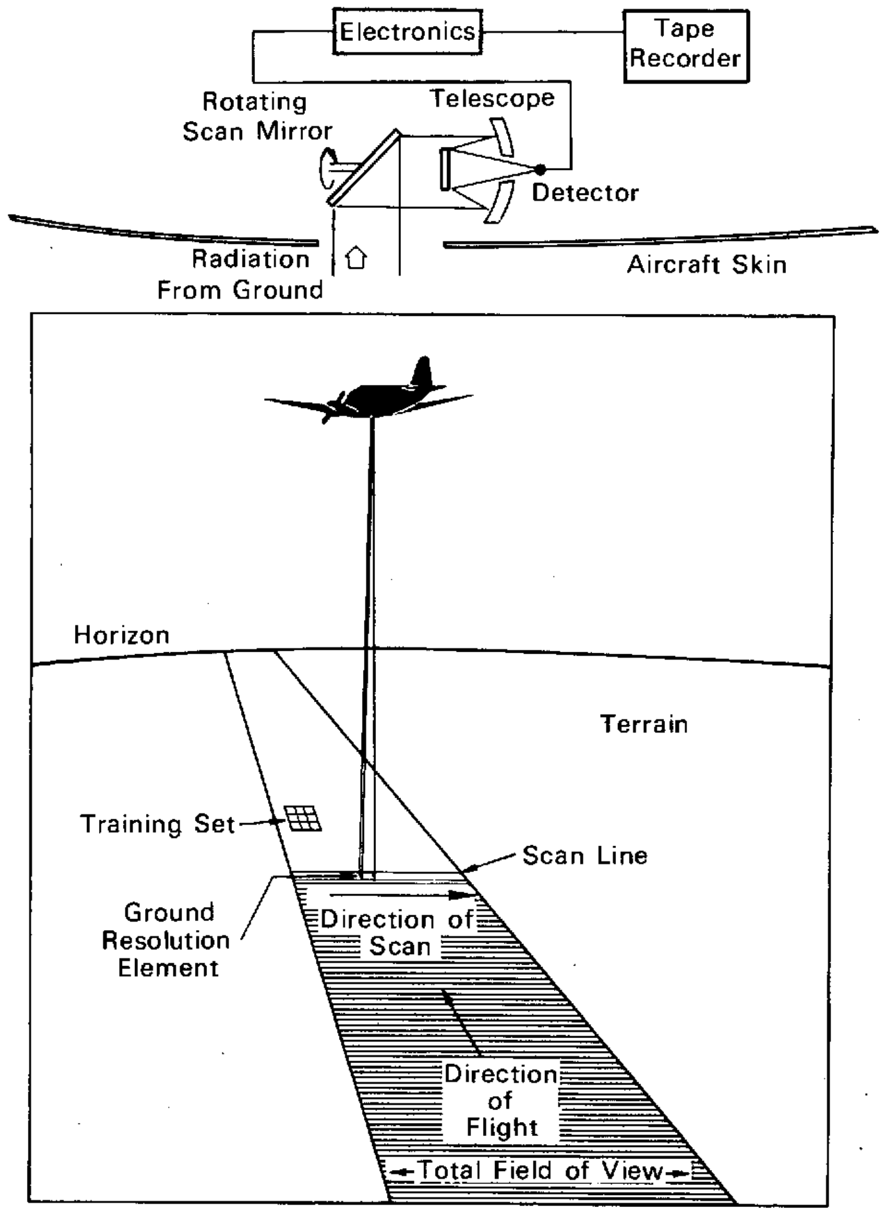

FIGURE 1. AIRBORNE MULTISPECTRAL SCANNER OPERATION

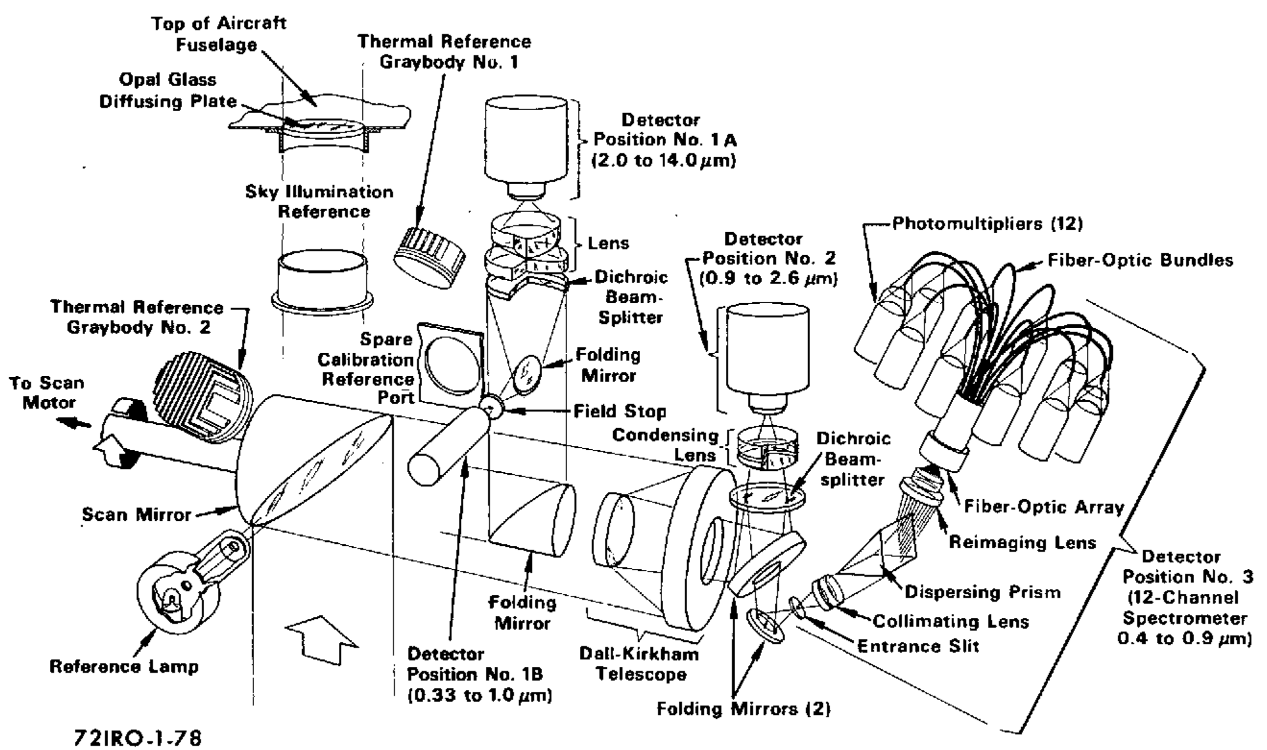

FIGURE 2. OPTICAL SCHEMATIC OF ERIM EXPERIMENTAL MULTISPECTRAL SCANNER, M7

photomultiplier detector which is filtered so the energy it receives for recording is restricted to a narrow preselected band.

The radiation collected by the effective 4-in. aperture of the Dall-Kirkham telescope is folded into a dichroic mirror which reflects radiation below 1.0μm but transmits that of longer wavelengths. The radiation thus transmitted is focused onto three separately filtered indium-arsenide detector elements in Position 2 by a lens achromatized for the 1.0- to 2.6-μm region. This dichroic and lens can be readily changed for different detector configurations.

Radiation at wavelengths shorter than 1.0μm is focused onto the entrance slit of a prism spectrometer at Detector Position 3. The spectrometer divides and directs visible and near-infrared radiation through a fiber-optic image slicer to as many as twelve photomultiplier tubes. (In the current configuration the radiation goes to nine separate photomultipliers.)

The radiation reference sources are positioned in line with the scan mirror, so that each source is "seen" and registered sequentially once each scan line. Currently, five reference sources are being used: an NBS lamp packaged to simulate a point source; one ambient and two temperature-controlled graybody thermal references that fill the collecting aperture; and a sky illumination reference consisting of an opal glass diffusing plate mounted in the top of the aircraft. Through electronic control of the lamp and graybodies and by means of attenuating optical filters for the sky illumination, the radiation from all but the ambient temperature reference sources is under operator control. During data collection, all internal sources are monitored and recorded manually by the operator. To assure their validity as references, these sources are calibrated periodically against external standards in the laboratory.

The complete airborne scanner system is diagrammed in Fig. 3. Terrain radiation enters the scanner at the bottom left; radiation detectors in the scanner assembly register this input along with that of the reference sources. The electrical signals comprising detector video outputs are amplified in preamplifiers before being transmitted to the operator console where the operator monitors them and adjusts amplifier gain to the proper level for tape recording. To confirm satisfactory recording, he is also able to monitor signals reproduced from the tape record. The system linearly transforms input radiation to voltage analogs which are recorded on the magnetic tape. The scanner system can generate video signals in up to nineteen different spectral bands over a wavelength range extending from 0.33 to 14.0 μm. Any twelve of these bands may be tape recorded at any one time on a 14-track analog tape machine; the other two tape recorder tracks are used for housekeeping purposes.

The airborne system (Fig. 3) also includes an array of boresight cameras utilizing various film-filter combinations. These aerial cameras produce film records often useful in the subsequent analysis of the scanner data.

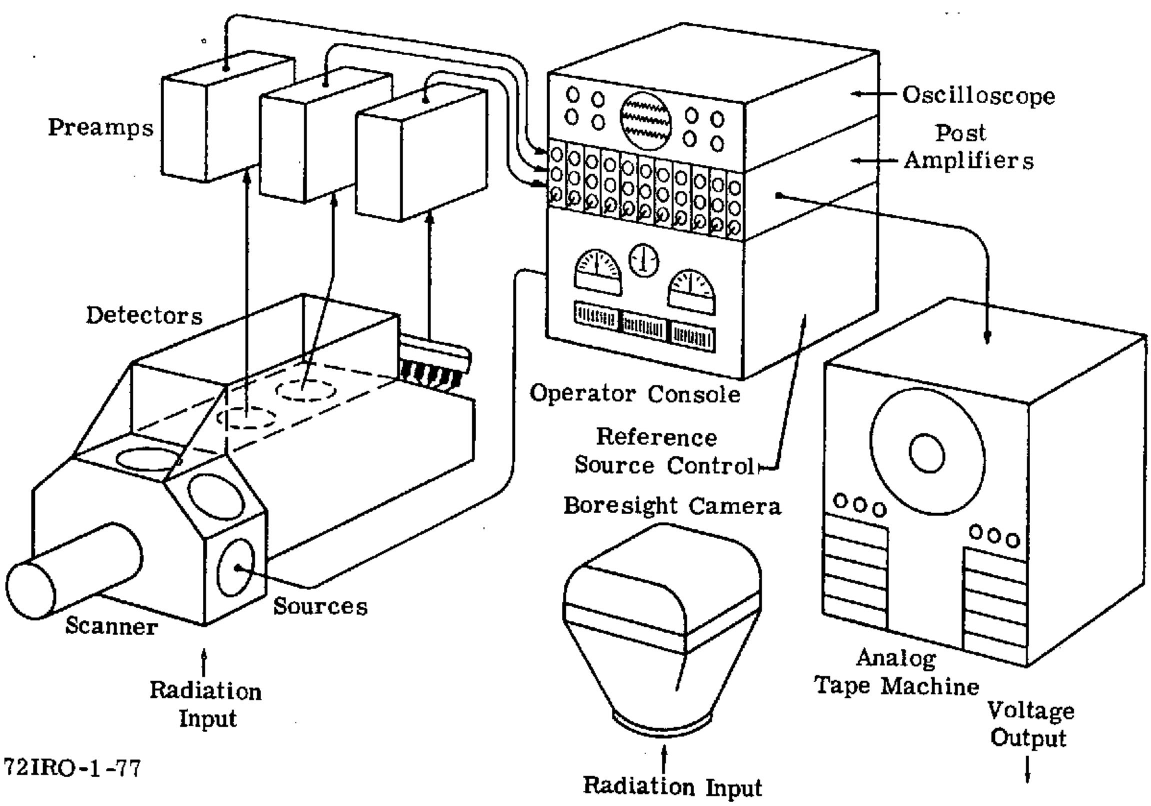

FIGURE 3. ERIM EXPERIMENTAL MULTISPECTRAL SCANNER SYSTEM

Electrical voltage representations of single linescans for the thermal and non-thermal wavelength bands are shown in Fig. 4. Note that although the detectors in all positions view, in sequence, each of the radiation references as well as the terrain (see "ground scan"), only the graybody references apply to every wavelength band. These graybody references (#1 and #2 and thermal ambient) serve as temperature calibration sources for the thermal detectors and also as a dark level source for the shorter-wavelength non-thermal detectors. The remaining sources (lamp and sky) serve as references for the non-thermal bands (as shown). For indexing purposes, synchronization references are generated by the scanner and recorded with the video signals. The marker pulse refers to the scan position relative to the internally mounted radiation references; the roll-stabilized pulse refers to ground scan nadir with aircraft roll motion removed.

Table 1 lists significant parameters of the scanner system. The scanner views the terrain during 90° of its scan, providing an external field of view (FOV) $\pm 45^{\circ}$ from nadir. A nominal 0.1°C NEΔt and a 1% NE$\Delta\rho$ are achieved.* The system operates at either of two constant scan speeds—60 or 100 scans per second. Electronic bandwidth is tape-recorder-limited to a range of dc to 90 kHz. Table 2 identifies those detector assemblies currently in use with the system. Where there is a choice of detectors, the first-listed unit is the one commonly used.

Figure 5 shows the actual scanner with its support frame and an integral bank of preamplifiers. The unit depicted weighs approximately 220 pounds (100 kg) and is 52 inches (132 cm) long.

Figure 6 is an isometric view of the ERIM C-47 aircraft that normally transports the Michigan multispectral mapping system. Figure 7, an internal view looking forward from the rear of the aircraft, shows the instrumentation installed in the aircraft. The scanner assembly, visible in the lower right-hand corner of the photo, is installed in an instrument well extending through the floor of the aircraft. A similar well on the port side of the aircraft houses the photographic cameras. Immediately to the right and above the scanner is a rack of spare detector assemblies. These units are all prealigned and may be substituted for like units installed in the scanner. Such substitutions are made as operational parameters dictate or in case of an in-flight failure. Supporting electronics as well as scanner operator positions are forward of the scanner's location in the aircraft. The usual crew complement consists of a test director, the scanner operator, the camera operator, plus a normal aircraft flight crew of three. The total weight of the multispectral system is about 1200 pounds (544 kg), or about half the instrumentation payload the C-47 can carry. Thus other systems may be installed and operated in conjunction with the multispectral mapping functions.

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*NEΔT = Noise Equivalent change in Temperature
NE$\Delta\rho$ = Noise Equivalent change in reflection

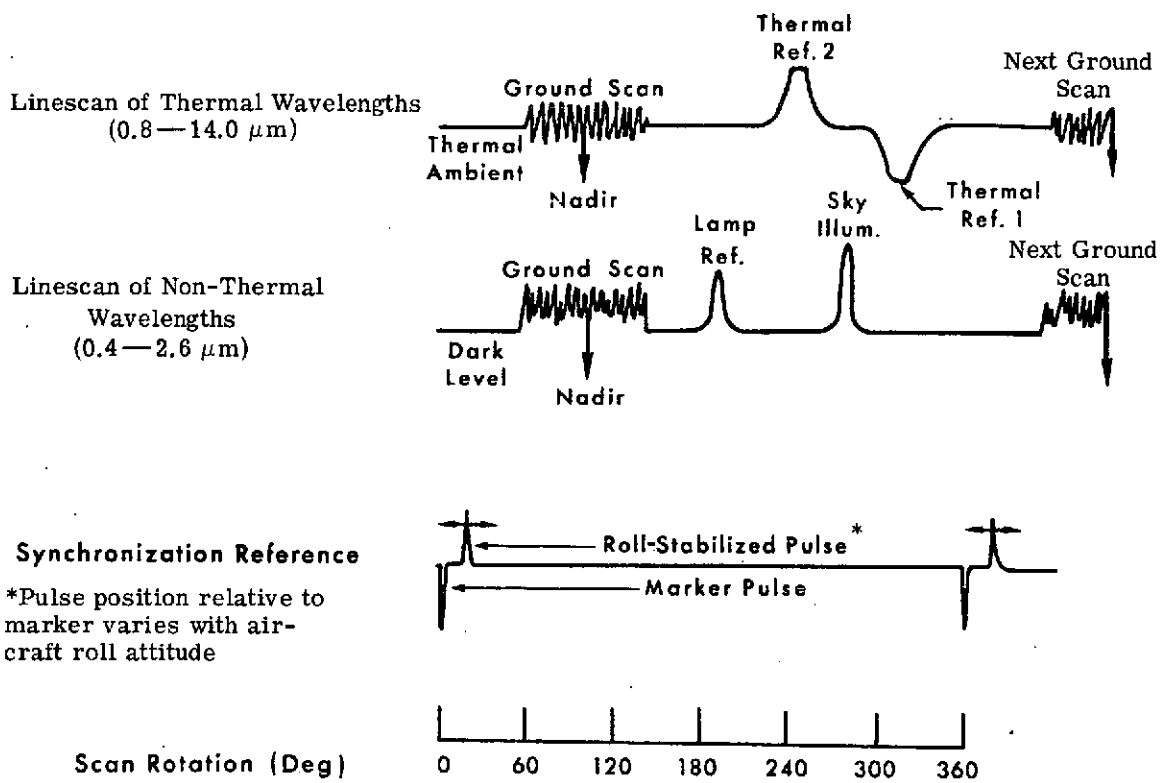

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FIGURE 4. SCANNER VOLTAGE OUTPUT VERSUS TIME

TABLE 1. M7 SCANNER PERFORMANCE CHARACTERISTICS

12 Spectral Bands in UV, Visible and IR Regions
90° External FOV ($\pm 45^{\circ}$ from nadir)
2 mrad Max. Spatial Resolution
0.1°C Nominal Thermal Resolution
1% Nominal Reflectance Resolution
Five Radiation Reference Ports
5 in. Diameter Collector Optics
Scan Rate of 60 or 100 scans/sec
DC to 90 kHz Electronic Bandwidth
Roll-Stabilized Imagery

TABLE 2. DETECTOR CONFIGURATIONS FOR ERIM M7 SCANNER

Detector Position 1‡ (0.3μm-15.0μm)

Position 1A (2.0μm-14μm)*		
Detector	Band (μm)	IFOV (mrad)
HgCdTe 1-3	2.0-11.8**	3.1 × 3.1
	or	
HgCdTe 1-2	2.0-15.0**	6.6 × 6.6
	or	
HgCdTe 2-2	2.0**-10.9	21 × 28
	9.4-12.1	21 × 21
	or	
HgCdTe 3-1	2.0**-9.1	20 × 20
	8.7-10.7	20 × 20
	9.9-14.0	20 × 20
	or	
HgCdTe 1-5	2.0-12.0**	3.3 × 3.3

Position 1B (0.3μm-0.7μm)*		
Detector	Band (μm)	IFOV (mrad)
UVPM 1-3	†	3.0 × 3.0

Detector Position 2‡

(1.1μm-14μm)*		
Detector	Band (μm)	IFOV (mrad)
InAs 3-5	2.0-2.6	2.0 × 4.0
	1.5-1.8	2.0 × 4.0
	1.0-1.4	2.0 × 4.0
	or	
InSb 3-6	2.0-2.6	2.0 × 4.0
	1.0-1.4	2.0 × 4.0
	or	
InAs 3-6	2.0-2.6	2.0 × 4.0
	1.5-1.8	2.0 × 4.0
	1.0-1.4	2.0 × 4.0
	or	
HgCdTe 2-3	2.0-2.6	2.6 × 2.6
	1.0-1.8	2.6 × 2.6
	or	
InAs 1-2	1.0-2.6	3.0 × 3.0
	or	
HgCdTe 1-2	2.0-15.0	4.0 × 4.0

Detector Position 3‡

(0.4μm-1.1μm)*		
Detector	Band (μm)	IFOV (mrad)
PM 9-1	0.83-1.15	2.5 × 2.5
	0.72-0.94	2.5 × 2.5
	0.65-0.80	2.5 × 2.5
	0.60-0.70	2.5 × 2.5
	0.55-0.64	2.5 × 2.5
	0.52-0.59	2.5 × 2.5
	0.49-0.55	2.5 × 2.5
	0.45-0.51	2.5 × 2.5
	0.40-0.47	2.5 × 2.5
	or	
PM 12-1	0.67-0.94	2 × 2
	0.62-0.70	2 × 2
	0.58-0.64	2 × 2
	0.55-0.60	2 × 2
	0.52-0.57	2 × 2
	0.50-0.54	2 × 2
	0.48-0.52	2 × 2
	0.46-0.49	2 × 2
	0.41-0.48	2 × 2

Notes: *Bandpass established by replaceable dichroic mirror.

**Bandpass established by external optical filter.

†Any band between 0.3μm and 0.7μm may be selected by external optical filter.

‡Any one of the detectors shown may be installed in the position shown. Any 12 channels of a given configuration may be selected for FM recording on magnetic tape.

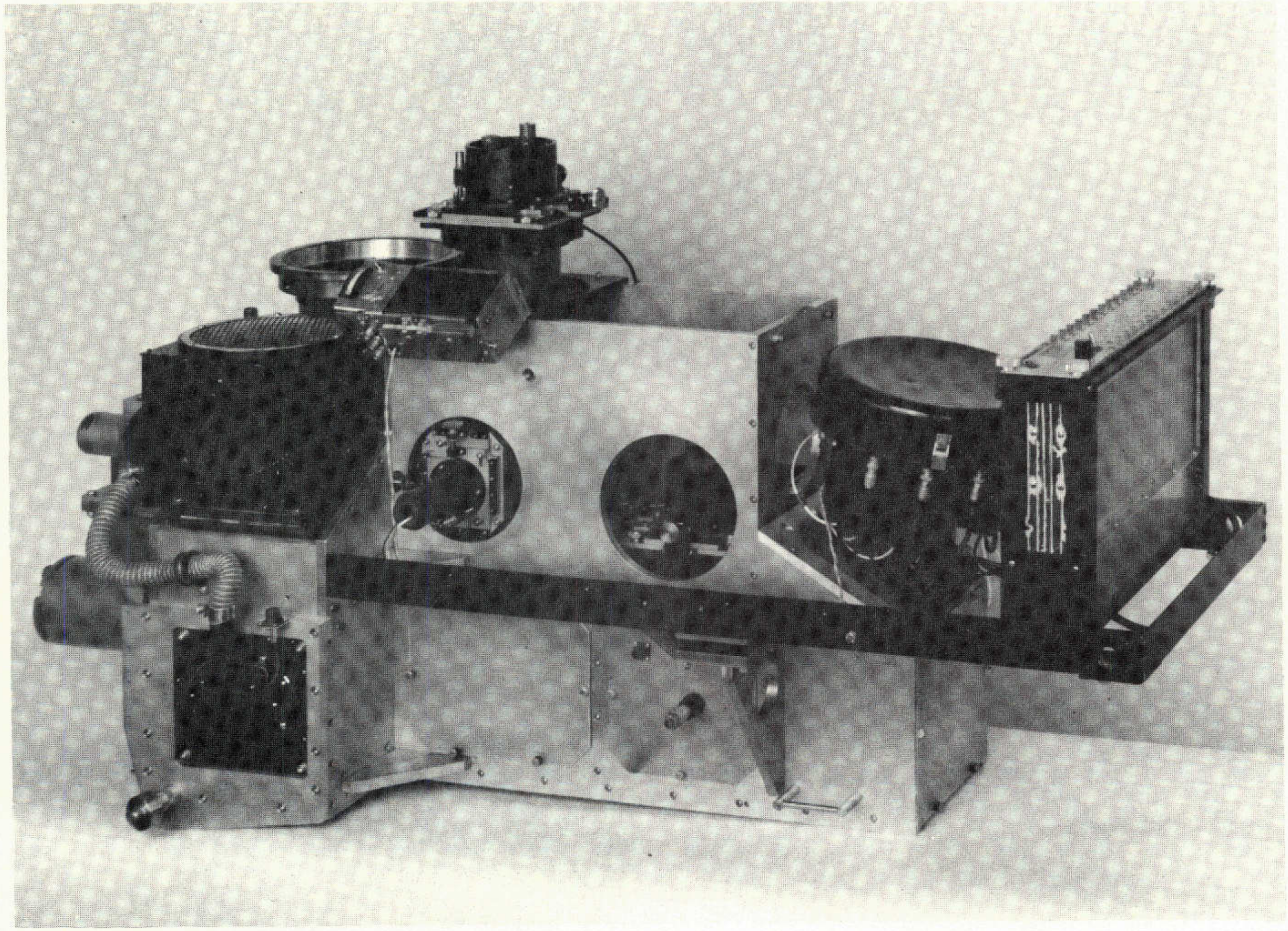

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FIGURE 5. M7 MULTISPECTRAL SCANNER WITH SUPPORT FRAME AND PREAMPLIFIER

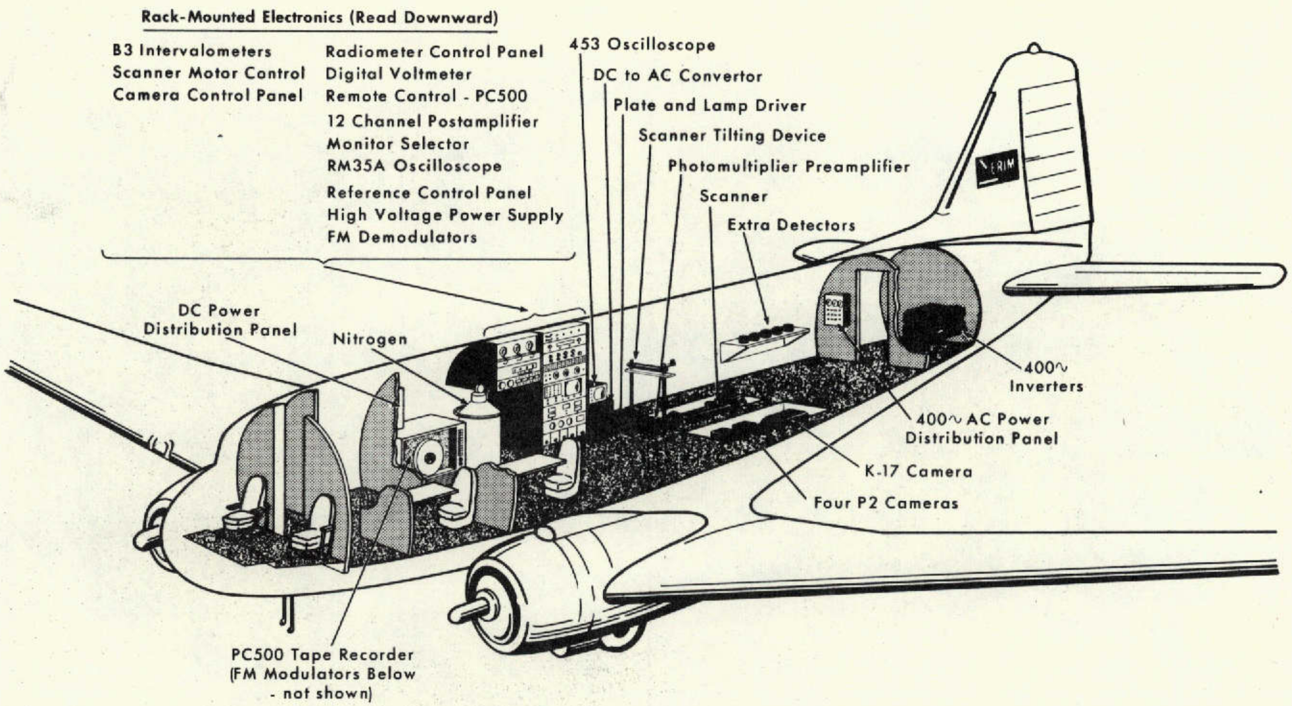

FIGURE 6. ERIM C-47 REMOTE SENSING AIRCRAFT

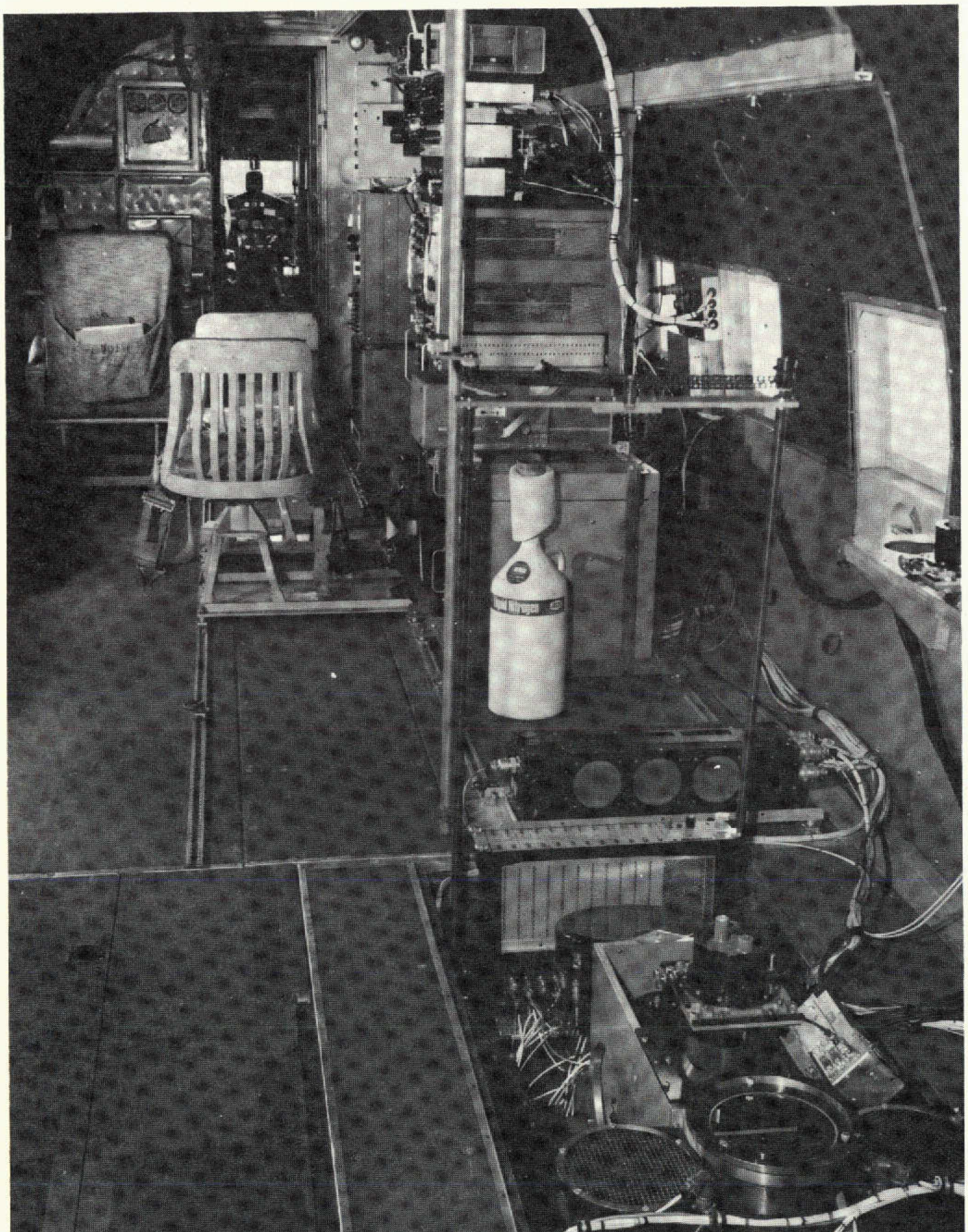

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FIGURE 7. AIRCRAFT INTERIOR SHOWING M7 SCANNER INSTALLATION

Multispectral scanner data achieves their greatest potential when machine-processed by either analog or digital means. Both of these techniques are employed at ERIM. Prior to such processing, however, visual review of the data is frequently useful. To accomplish this, the magnetic tapes are played back onto photographic film to form continuous stripmaps. Figure 8 shows, in eleven spectral bands, a short portion of such a strip map. The scene is located in the Black Hills of South Dakota. A topographic map section included as Fig. 8(a) shows the area of coverage. These data were collected in May, 1972 on a combined forestry and geology mission; altitude was 5000 ft above the terrain. Visible in the imagery are such cultural features as roads and the town of Deadwood, South Dakota. The light-toned area near the left end of the imagery is mostly bare soil and rock on the terraced side of a mountain slope; this scar is the result of a fire that occurred in about 1960. The darker-toned areas are chiefly coniferous forests consisting primarily of ponderosa pine. Power-line cuts through the forests are clearly discernible.

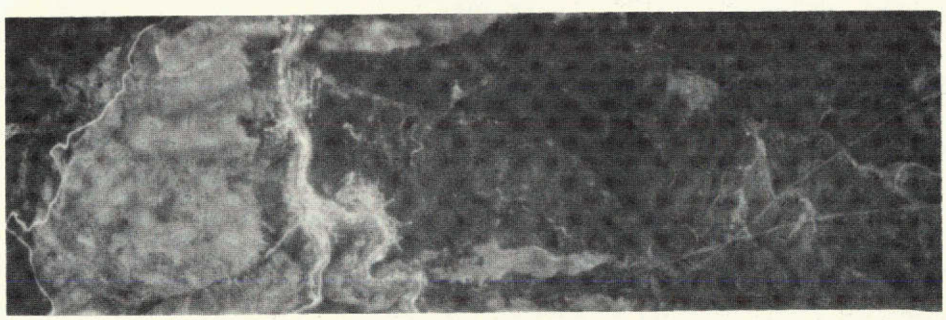
Besides continued development of new detector assemblies and electronic components to improve scanner performance, we are investigating several other techniques. One is a provision for scanning across the aircraft track in an oblique instead of a vertical plane in order to "see" more vegetation and less ground. The proportion of soil relative to crop in a common resolution element has been a problem in remotely identifying farm crops in the past, and the oblique view technique may benefit other applications also. Another new technique of potential benefit is one of actively scanning in selected wavelength bands and recording these in conjunction with certain passively scanned bands; laser radiation sources have been coupled with line scanners to provide this capability. Still another technique being explored is one of registering selected spectral bands in dual polarized outputs. Since the polarization of reflected radiation is known to cause variations in signal level along a scan line, such variations can be used to advantage as an aid in remote identification of certain reflecting surfaces.

2.2 AERIAL CAMERAS

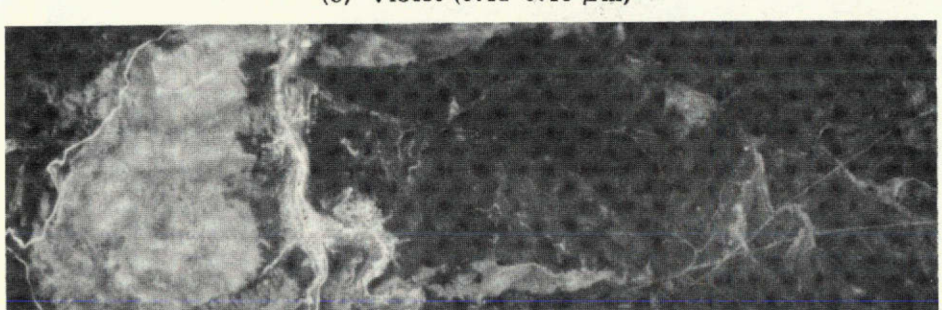
The ERIM aerial camera inventory consists of two K17 cameras, three KB8 or P220 cameras, and five P2 cameras—all of military type. The characteristics of these cameras are noted in Table 2. Although five cameras are the maximum number possible, we attempt to limit aerial camera coverage on any given mission to that afforded by three (one of each type) or fewer cameras. Performance characteristics of these cameras are listed in Table 3. All cameras are mounted directly to the airframe; in-flight leveling is through manual adjustments. No stabilization, image motion compensation, or automatic exposure control is available for any of the cameras. The camera operator has in-flight access to the cameras for magazine changes and exposure adjustments.

(a) USGS Topographic Map Section

(b) Ultraviolet (0.33–0.38 μm)



(c) Violet (0.41–0.48 μm)



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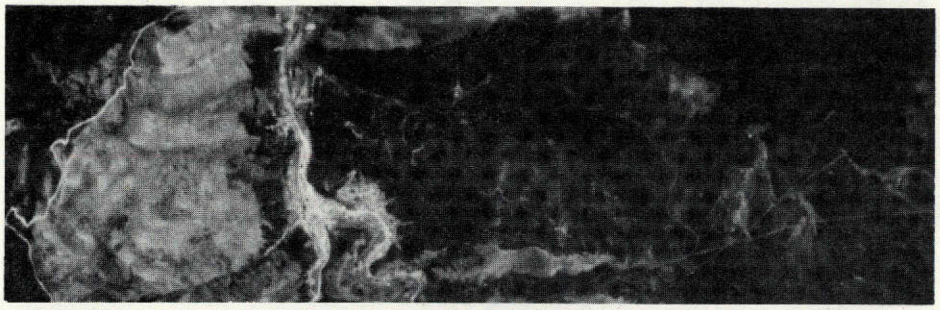
(d) Blue (0.46–0.49 μm)

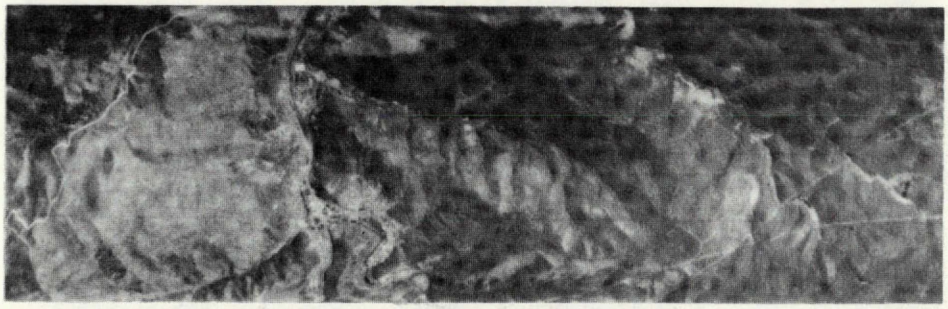
FIGURE 8. MULTISPECTRAL IMAGERY DISPLAY. Black Hills, South Dakota. 21 May 1972, 1100 hr, 5000 ft altitude.



(e) Green (0.50-0.54 μm)

(f) Yellow (0.55-0.60 μm)

(g) Red (0.62-0.70 μm)



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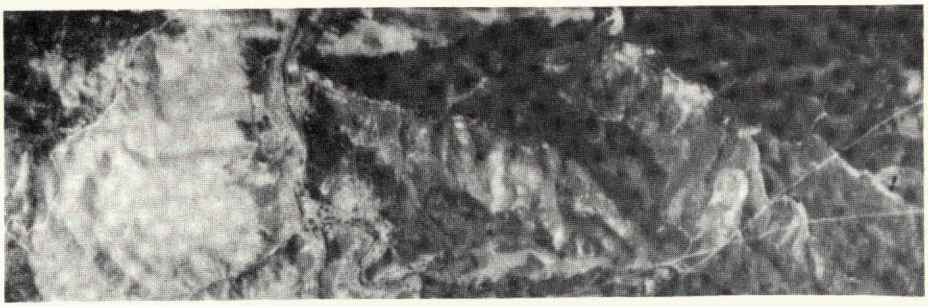
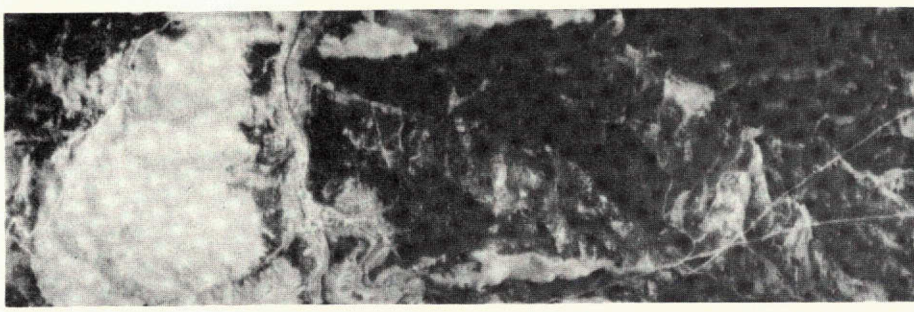
(h) Near Infrared (0.67-0.94 μm)

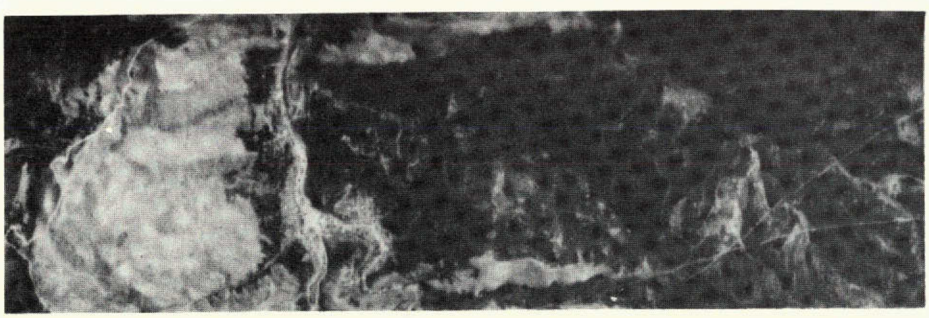
FIGURE 8. MULTISPECTRAL IMAGERY DISPLAY. Black Hills, South Dakota. 21 May 1972, 1100 hr, 5000 ft altitude. (Continued)



(i) Infrared (1.0-1.4 μm)



(j) Infrared (1.5-1.8 μm)



(k) Infrared (2.0-2.6 μm)

72IRO-9-579 (l) Thermal Infrared (9.3-11.7 μm)

FIGURE 8. MULTISPECTRAL IMAGERY DISPLAY. Black Hills, South Dakota. 21 May 1972, 1100 hr, 5000 ft altitude. (Concluded)

TABLE 3. PERFORMANCE CHARACTERISTICS OF AERIAL CAMERAS

	K17D*	KB8A*/P220	P2*
Magazine type	A5A	LA97A	LA97A
Film capacity	9.5 in. × 200 ft	70mm × 50 ft	70mm×50 ft
No. of exposures	250	230	230
Max. cycling rate	1/3 cycle/sec	5 cycles/sec	5 cycles/sec
Shutter speeds	1/50-1/400 sec	1/500-1/2000 sec	1/500-1/2000 sec
Max. AWAR†	25 lines/mm	42 lines/mm	30 lines/mm
Focal length	6 in.	38 mm	3 in.
Max. aperture	f/6.3	f/4.5	f/2.8
Angle of view	73°44'	73°44'	41°06'

*Military type

†Area-Weighted Average Resolution

ERIM stocks panchromatic (Kodak type 2403) and infrared black-and-white film (Kodak type 2424) for all these cameras. Color (Kodak type S0397) and color infrared (Kodak type 2443) film is stocked in the 70mm size only. None of the cameras has a color-corrected lens; nonetheless, all produce apparently acceptable color fidelity. The use of color film in the K17 is not recommended because of the slow lens; however, under bright illumination conditions, acceptable color work has been produced with this camera.

A variety of filters are available for these cameras. The following film/filter combinations are most often used:

Film Type	Filter
2403	W12, W15, 25A
2424	25A, 87C, 89B
S0397	1A, 2B
2443	W12, W15

Most of the filters are glass-mounted. The viewport in the aircraft is covered with plexiglass, the optical transmission of which is uniform for film-sensitive wavelengths.

The ERIM photo laboratory processes all black-and-white film; color film is sent to the Mead Corporation in Dayton, Ohio for processing.

2.3 DELIVERABLE DATA

The following items comprise the usual data ERIM delivers to the sponsor in connection with a multispectral mapping mission:

(1) Mission Plan and cost estimate—These preflight items are based on site coverage and the sponsor's data requirements, as indicated to the Principal Investigator and reflected in the Flight Request.

(2) Mission Report—Documents details of mission accomplishment and provides collateral data the investigator will need in analyzing the mission data supplied him.

(3) Scanner imagery of four selected channels—Reproduced on 70mm filmstrips from the original magnetic tapes.

(4) All aerial camera film imagery obtained on the mission.

If magnetic tapes are required by the customer, they are delivered as analog duplicates; the original tapes are retained on file at ERIM. These tapes contain, in analog form, up to 12 channels of multispectral scanner imagery and the reference signals recorded therewith. The aerial camera imagery is delivered in the form of original film transparencies. Further reproduction of mission data—such as additional scanner channels on film or on digitized tapes—are considered a part of data processing and hence not normally included in the data collection package.

From the date of initial request until the last piece of data is processed, a data collection mission normally takes about three calendar months. Initially, the ERIM test conductor works with the contract sponsor and the specific data user to evolve a plan for accomplishing the mission in a manner commensurate with available funds and data needs. The upshot of these negotiations is an acceptable Mission Plan with an associated estimate of costs; this plan is usually finalized a week or two before mission start. The mission itself usually takes a week, including transit time, weather standby time, and actual flight time.

After mission completion, approximately two weeks are required to process the aerial camera film and to duplicate the analog tapes (if such duplication is required). To reproduce four channels of scanner imagery on film and to process that film takes approximately one month. By the time all film data are reviewed and labeled and a Mission Report prepared for transmittal to the sponsor, a total of three months time will have elapsed since the initial request. However, non-routine missions can be completed in one-third this time—if they are infrequent and adequately justified.

Because much of the work following data collection can be accomplished in parallel, ERIM can fly an average of a mission a week between periods of required aircraft maintenance—which must follow every 100 hours of flight time. (Periodic maintenance and calibration of the airborne instrumentation is scheduled to coincide with aircraft maintenance periods.) One week of downtime usually suffices for all such maintenance, although this period may be extended by unforeseen failures in aircraft or instrumentation equipment.

2.4 SCANNER DATA PROCESSING AND ANALYSIS

After the terrain has been mapped in as many as twelve different spectral bands and the data stored on magnetic tape, machine processing of the multispectral data should help the investigator reach his objective with minimal effort. With the imagery in electrical form from tape playback, the separate channels can be amplified, sliced, ratioed, and combined in different ways to implement almost any function that can be described mathematically. The processing results can be displayed in statistical tabulations, computer paper printouts, in coded gray scale or color film printouts, or in any other display that accepts electrical inputs. Processing and analysis personnel at ERIM are experienced in working with investigators to extract the most information from the data and to help explain why the results appear as they do.

Specific processing and analysis services available at ERIM are described in Appendix B.

3
ACCOMPLISHMENTS USING THE M7 SCANNER SYSTEM

Between 28 June 1971 and 15 November 1973, WRL/ERIM successfully completed 84 data collection missions at sites scattered across the continental United States from New York to California and from Florida to North Dakota (see map, Fig. 9). Each mission required from one to six flights over a particular test site and was completed during a single field operation or short time period. In all, over 12,000 flightline miles (nmi) of data were collected; thus the average per mission was about 140 nmi. Table 4 summarizes missions flown, giving leading particulars on each one.

The 167 separate data collection flights which comprised these missions are listed in Table 5. Site locations and the number of spectral bands of scanner and aerial camera data collected on each flight are shown in the table. All raw data and data records are filed for reference by flight date and time. ERIM retains the original scanner analog magnetic tapes and flight data records for future reference. Prints of all black-and-white film imagery from each flight are also on file at ERIM.

Other accomplishments during the period include improvements in the scanner's performance, adoption of new radiation detectors to provide additional spectral bands, and the repackaging of scanner radiation references to insure more reliable operation. Further, the scanner system was calibrated radiometrically 12 times and spectrally 5 times during the period. This calibration and performance information is available to recipients of multispectral data.

A list of sites covered by the M5 scanner system in multispectral data collection missions for the time period of March 1966 through June 1971 is presented in Refs. [3] and [4]. A description of the M5 system and its performance is included in Ref. [2].

TABLE 4. SUMMARY OF MISSIONS COMPLETED: JUNE '71—NOVEMBER '73

NASA Mission No.	Flight Period	Site	Discipline	User Organization	Data Miles (nmi)	NASA Project No.
	1971					
40M	28 June-7 July	Corn Belt, Ind.	Agriculture	WRL/Purdue	362	SR&T
40M	7 July	Lansing Ag. Farm, Mich.	Agriculture	WRL/MSU	24	SR&T
41M	12-21 July	Corn Belt, Ind.	Agriculture	WRL/Purdue	375	SR&T
42M	27 July-5 Aug	Corn Belt, Ind.	Agriculture	WRL/Purdue	384	SR&T
42M	6 Aug	Lansing Ag. Farm, Mich.	Agriculture	WRL/MSU	212	SR&T
43M	11-17 Aug	Corn Belt, Ind.	Agriculture	WRL/Purdue	346	SR&T
43M	17 Aug	Lansing Ag. Farm, Mich.	Agriculture	WRL/MSU	24	SR&T
44M	26-29 Aug	Corn Belt, Ind.	Agriculture	WRL/Purdue	345	SR&T
45M	14-15 Sept	Corn Belt, Ind.	Agriculture	WRL/Purdue	316	SR&T
	15 Sept	Ferry Field, Mich.	Steam Leak	WRL	1	
	17-18 Sept	Genesee Co., Mich.	Land Use	WRL	127	
46M	21 Sept	Lansing Ag. Farm, Mich.	Agriculture	WRL/MSU	27	SR&T
46M	24 Sept-6 Oct	Corn Belt, Ind.	Agriculture	WRL/Purdue	416	SR&T
	29 Sept-1 Oct	Eglin AFB, Fla.	Military	WRL	50	
53M	3-5 Nov	Atlanta, Ga.	Forestry	WRL/USFS	90	SR&T
51M	11-12 Nov	HATS (Houston), Texas	Multi	NASA/MSC	150	SR&T
	1972					
	4 May	SE Michigan	Test	WRL	16	
54M	5 May	SE Michigan	Land Use	WRL	79	SR&T
55M	11 May	Baltimore, Md.	Urban Study	WRL/U. of Calif.	144	SR&T
	12 May	Cambridge, Md.	Military	WRL	19	
	12 May	Wallops Sta., Va.	Multi	NASA	24	
56M	19 May	Woodworth, N. D.	Game Mgmt.	WRL/NPWRC	134	ERTS (255)
	21 May	Black Hills, S. D.	Geology	WRL/BuMines	72	
56M	24-25 May	Black Hills, S. D.	Forestry	WRL/USFS	52	ERTS (226)
57M	5 June	Ann Arbor, Mich.	Forestry	WRL	62	SR&T
58M	17-18 June	Lake Ontario, N. Y.	Hydrology	WRL	175	SR&T
	20 June	Lake Ontario, N. Y.	Hydrology	WRL/EPA	154	
59M	28-30 June	Mill Creek, Okl.	Geology	WRL/USGS	181	SR&T
60M	22-24 July	No. Great Plains, S. D.	Multi	S. Dak. St. U.	151	ERTS (119)
60M	28 July	Woodworth, N. D.	Game Mgmt.	WRL/NPWRC	120	ERTS (255)
	31 July	Lake Ontario, N. Y.	Hydrology	WRL/EPA	168	
	4 Aug	Charlotte, Mich.	Agriculture	WRL	40	
61M	9-10 Aug	Wabash Basin, Ind.	Multi	Purdue	197	ERTS (049)
62M	16 Aug	NY Bight, N. Y.	Hydrology	WRL	47	ERTS (081)
62M	18-19 Aug	SE Florida	Hydrology	WRL	124	ERTS (081)

62M	19 Aug	Tampa Bay, Fla.	Hydrology	WRL	106	ERTS (081)
63M	13-25 Aug	Eaton Co., Mich.	Multi	WRL	251	ERTS (136, 321)
	28 Aug	Lake Michigan	Hydrology	WRL/Mich.	43	
63M	29 Aug	Oakland Co., Mich.	Land Use	WRL	69	ERTS (086)
	29 Aug	Southern Michigan	Hydrology	WRL/Mich	58	
	30 Aug-5 Sept	Genesee Co., Mich	Land Use	WRL	108	
64M	7 Sept	Lake Ontario, N. Y.	Hydrology	WRL	88	ERTS (114)
	13 Sept	Ford Lake, Mich.	Hydrology	WRL	11	
65M	14 Sept	Michigan Oakworm	Forestry	WRL/MSU	36	ERTS (321)
65M	14 Sept-19 Oct	Eaton Co., Mich	Multi	WRL/MSU	56	ERTS (321)
	30 Sept-1 Oct	Halloran Springs, Calif.	Geology	WRL/DOT	70	
66M	30 Sept-1 Oct	So. California	Geology	WRL/USGS	202	ERTS (648)
67M	17 Oct	Wabash Basin, Ind.	Multi	LARS (Purdue)	60	ERTS (049)
68M	16 Nov	SE Florida	Hydrology	WRL	112	ERTS (081)
68M	17 Nov	Tampa Bay, Fla.	Hydrology	WRL	72	ERTS (081)
	1973					
71M	2 Jan	Wabash Basin, Ind.	Multi	LARS (Purdue)	24	ERTS (049)
	10-12 Jan	So. Michigan	Hydrology	ERIM/Mich.	96	
	25 Jan	Lake Michigan	Hydrology	ERIM/Mich.	72	
72M/78M	20-23 Mar	Washtenaw Co., Mich.	Forestry	ERIM	120	SR&T (X190)
75M	24-25 Mar	Lake Ontario, N. Y.	Hydrology	ERIM	231	ERTS (114)
73M/76M	5 May	So. Michigan	Radar	ERIM	415	ERTS (072)

BuMines - U. S. Bureau of Mines

DOT - U. S. Department of Transportation

EPA - Environmental Protection Agency

HATS - Houston Area Test Site

LARS - Purdue University Laboratory for Remote Sensing

MSC - Manned Spacecraft Center (NASA) — now Johnson Space Center

MSU - Michigan State University

NOAA - National Oceanic and Atmospheric Administration

NPWRC - Northern Prairie Wildlife Research Center

USGS - U. S. Geological Survey

SR&T Supporting Research and Technology

EREP Earth Resources Experiment Package

ERTS Earth Resources Technology Satellite

TABLE 4. SUMMARY OF MISSIONS COMPLETED: JUNE '71—NOVEMBER '73 (Continued)

NASA Mission No.	Flight Period	Site	Discipline	User Organization	Data Miles (nmi)	NASA Project No.
1973 (Continued)						
74M/77M	6 April	NY Bight, N. Y.	Hydrology	ERIM	48	ERTS (081)
77M	7 April	Lower NY Bay, N. Y.	Hydrology	NOAA	384	SR&T (X180)
	11 April	Monroe, Mich.	Hydrology	ERIM	84	
72M/78M	11 April	Grand Traverse, Mich.	Forestry	ERIM	49	SR&T (X190)
	13 April	So. Michigan	Hydrology	ERIM/Mich.	72	
79M	19-20 April	Chelsea, Kansas	Geology	BuMines	312	SR&T (X185)
78M/80M	4 May	Wabash Basin, Ind.	Multi	LARS (Purdue)	150	ERTS (049)
81M	12 May	Woodworth, N. D.	Game Mngt.	NPWRC	144	EREP (486)
	24 May	So. Michigan	Land Use	ERIM	48	
	31 May-22 June	Genesee Co., Mich.	Land Use	ERIM	216	
82M	18-25 June	Eaton Co., Mich.	Agriculture	ERIM/MSU	100	ERTS (321)
81M	10 June	Wabash Basin, Ind.	Multi	LARS (Purdue)	24	EREP (397)
	11 June	Lake Michigan	Hydrology	ERIM/Mich.	72	
	3 July	Genesee Co., Mich.	Land Use	ERIM	48	
83M	5-7 July	Indiana/Illinois	Agriculture	JSC	340	SR&T (X212)
	2 Aug	WR Ramp, Mich.	Test	ERIM	20	
84M	4 Aug	Lenawee Co., Mich.	Agriculture	ERIM	250	SR&T (X188)
85M	5 Aug	So. Michigan	Agriculture	ERIM/MSU	170	EREP (410) (456) (472)
	10 Aug	Two Rivers, Wis.	Hydrology	Argonne N. L.	40	
85M	12 Aug	Woodworth, N. D.	Game Mngt.	NPWRC	160	EREP (486)
85M	20-21 Aug	Indiana/Illinois	Agriculture	JSC	240	SR&T (X212)
	22-28 Aug	Genesee Co., Mich.	Land Use	ERIM	144	
85M	6 Sept	So. Michigan	Agriculture	ERIM	44	ERTS (136)
85M	7 Sept	L. Mich. & NW Mich.	Multi	ERIM/MSU	68	EREP (450) ERTS (321)
85M	10-11 Sept	L. Ontario	Hydrology	ERIM	180	EREP (427)
	13 Sept	L. Michigan	Hydrology	Argonne N. L.	40	
85M	18 Sept	L. Michigan	Multi	ERIM	24	EREP (450)
88M	3 Oct	Huntington Co., Ind.	Radar	ERIM	40	SR&T (X216)

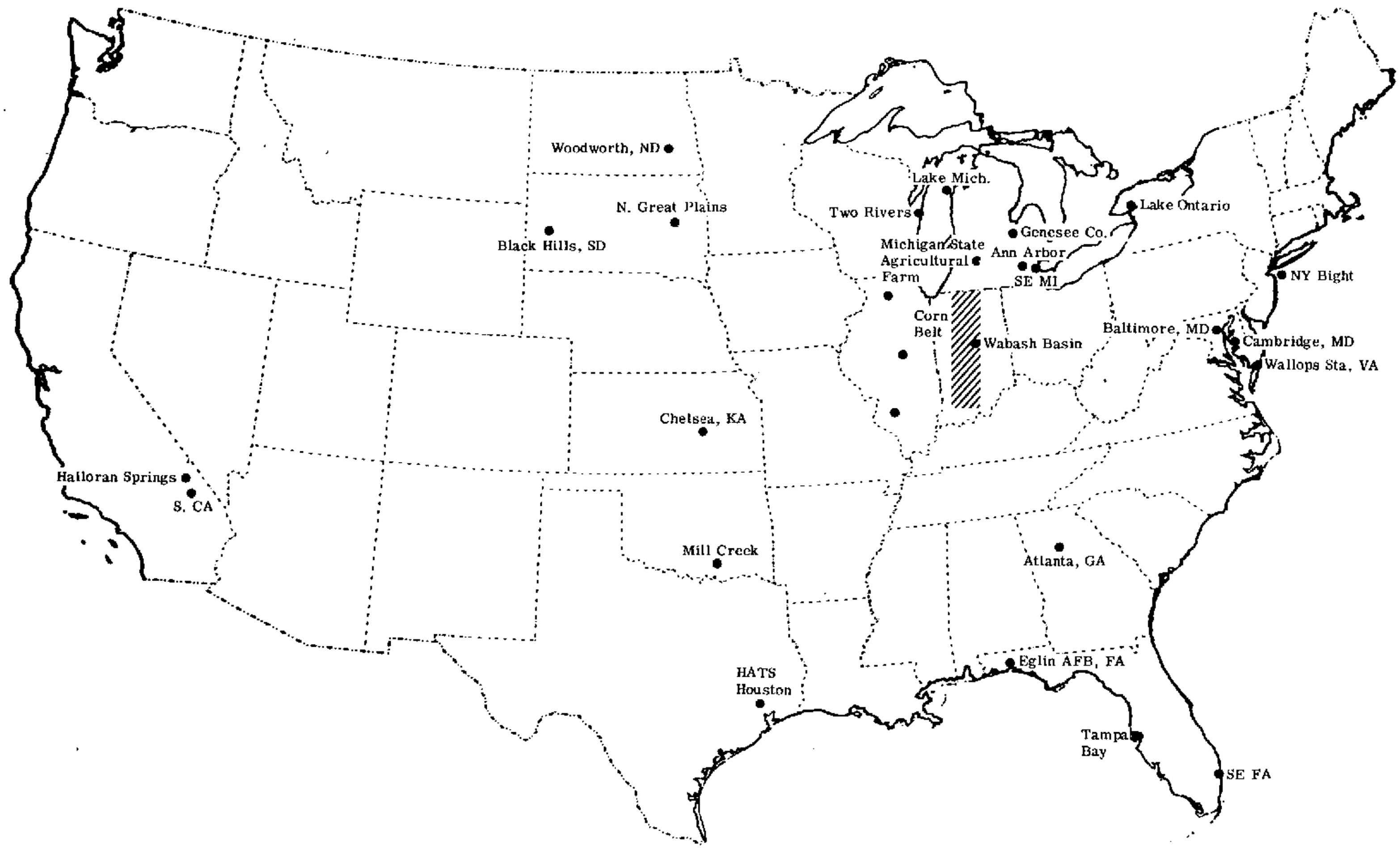


FIGURE 9. SITES OF RECENT MULTISPECTRAL DATA COLLECTION FLIGHTS

TABLE 5. SUMMARY OF MULTISPECTRAL IMAGERY COLLECTED ON EACH FLIGHT OF EACH MISSION

NASA Mission No.	Flight Date	Local Flight Time	Location of Site	Number of Scanner Spectral Bands: Ultraviolet (0.3-0.4μm)	Visible (0.4-0.7μm)	Infrared (0.7-3.5μm)	Thermal IR (3.5-15.0μm)	Aerial Camera Film/Filter Combinations: Black & White	Color
	1971								
40M	28 June	1130	W. Indiana	1	7	4	2	2	1
40M	28 June	1300	W. Indiana	0	7	4	1	1	1
40M	29 June	1000	W. Indiana	1	7	4	2	2	1
40M	29 June	1130	W. Indiana	0	7	4	1	1	1
40M	30 June	0900	W. Indiana	0	7	4	1	2	1
40M	30 June	1230	W. Indiana	1	7	4	2	1	1
40M	7 July	0900	W. Indiana	1	7	4	2	2	1
40M	7 July	1400	Central Michigan	1	7	4	2	2	1
41M	12 July	1130	W. Indiana	1	7	4	2	1	1
41M	12 July	1300	W. Indiana	0	7	4	1	1	1
41M	13 July	1300	W. Indiana	1	7	4	2	1	1
41M	16 July	0900	W. Indiana	1	7	4	2	1	1
41M	16 July	1000	W. Indiana	0	7	4	1	1	1
41M	16 July	1230	W. Indiana	1	7	4	2	1	1
41M	21 July	1130	W. Indiana	0	7	4	1	1	1
42M	27 July	0900	W. Indiana	0	7	4	1	1	1
42M	27 July	1130	W. Indiana	0	7	4	1	1	1
42M	27 July	1230	W. Indiana	1	7	4	2	1	1
42M	29 July	1000	W. Indiana	1	7	4	2	1	1
42M	29 July	1130	W. Indiana	0	7	4	1	1	1
42M	31 July	1130	W. Indiana	1	7	4	2	1	1
42M	31 July	1300	W. Indiana	0	7	4	1	1	1
42M	5 Aug.	1130	W. Indiana	1	7	4	2	1	1
42M	5 Aug.	1300	W. Indiana	0	7	4	1	1	1
42M	6 Aug.	0900	Central Michigan	1	7	4	2	1	1
42M	6 Aug.	1400	Central Michigan	1	7	4	2	1	1
43M	11 Aug.	1000	W. Indiana	1	7	4	2	1	1
43M	11 Aug.	1130	W. Indiana	0	7	4	1	1	1
43M	12 Aug.	0900	W. Indiana	0	7	4	1	1	1
43M	12 Aug.	1130	W. Indiana	1	7	4	2	1	1
43M	12 Aug.	1230	W. Indiana	1	7	4	2	1	1
43M	13 Aug.	1130	W. Indiana	0	7	4	1	1	1
43M	13 Aug.	1300	W. Indiana	1	7	4	2	1	1
43M	17 Aug.	1130	W. Indiana	0	7	4	1	1	1
43M	17 Aug.	1400	Central Michigan	1	7	4	2	1	1
44M	26 Aug.	1130	W. Indiana	0	7	4	1	1	1
44M	28 Aug.	0900	W. Indiana.	0	7	4	1	1	1
44M	28 Aug.	1000	W. Indiana	0	7	4	1	1	1
44M	28 Aug.	1230	W. Indiana	0	7	4	1	1	1
44M	28 Aug.	1130	W. Indiana	0	7	4	1	1	1
44M	29 Aug.	1130	W. Indiana	0	7	4	1	1	1
44M	29 Aug.	1300	W. Indiana	0	7	4	1	1	1
44M	29 Aug.	1330	W. Indiana	0	7	4	1	1	1

45M	14 Sept.	1000	W. Indiana	0	7	4	1	1	1
45M	14 Sept.	1130	W. Indiana	0	7	4	1	1	1
45M	14 Sept.	1300	W. Indiana	0	7	4	1	1	1
45M	15 Sept.	0900	W. Indiana	0	7	4	1	1	1
45M	15 Sept.	1130	W. Indiana	0	7	4	1	1	1
45M	15 Sept.	1230	W. Indiana	0	7	4	1	1	1
	15 Sept.	1645	S. Michigan	0	7	2	2	0	0
	17 Sept.	1530	S. Michigan	0	7	4	1	1	1
	17 Sept.	1830	S. Michigan	1	0	0	2	0	0
	18 Sept.	1330	S. Michigan	0	7	4	1	1	1
46M	21 Sept.	1400	Central Michigan	1	7	4	2	1	1
46M	24 Sept.	1000	W. Indiana	0	7	4	1	1	1
46M	24 Sept.	1130	W. Indiana	0	7	4	1	1	1
46M	24 Sept.	1300	W. Indiana	0	7	4	1	1	1
46M	29 Sept.	0800	Florida	0	7	4	4	2	0
46M	29 Sept.	1200	Florida	0	7	4	4	2	0
46M	29 Sept.	1600	Florida	0	7	4	4	2	0
	1 Oct.	0400	Florida	0	0	0	4	0	0
46M	5 Oct.	0900	W. Indiana	0	7	4	1	1	1
46M	5 Oct.	1230	W. Indiana	0	7	4	1	1	1
46M	6 Oct.	0900	W. Indiana	0	7	4	1	1	1
46M	28 Oct.	0930	SE Michigan	0	7	4	1	1	0
53M	3 Nov.	1330	N. Georgia	0	7	4	1	0	1
53M	4 Nov.	0930	N. Georgia	0	7	4	1	0	1
53M	5 Nov.	0900	N. Georgia	0	7	4	1	0	1
51M	11 Nov.	1000	E. Texas	0	7	4	1	0	1
51M	12 Nov.	1000	E. Texas	0	7	4	1	0	1
	1972								
54M	4 May	1330	SE Michigan	0	7	4	1	4	1
54M	5 May	1000	SE Michigan	0	8	3	1	3	1
55M	11 May	0515	Central Maryland	0	8	3	1	4	0
55M	11 May	1015	Central Maryland	0	8	3	1	4	0
55M	11 May	1345	Central Maryland	0	8	3	1	4	0
55M	12 May	0900	SE Maryland	0	8	3	1	3	1
55M	12 May	1100	SE Virginia	0	8	3	1	1	2
55M	12 May	2140	SE Virginia	0	0	0	2	0	0
56M	19 May	0730	N. Dakota	1	7	4	1	1	3
56M	21 May	1100	S. Dakota	1	5	4	2	2	2
56M	24 May	0830	S. Dakota	0	6	5	1	2	1
56M	25 May	0745	S. Dakota	0	6	5	1	2	1
57M	5 June	1000	SE Michigan	1	6	4	1	2	2
58M	17 June	1200	Lake Ontario	0	7	4	2	2	1
58M	18 June	0400	Lake Ontario	0	0	0	2	0	0
	20 June	0845	Lake Ontario	1	8	2	1	2	2
59M	28 June	1200	Oklahoma	1	6	4	4	3	1
59M	30 June	0530	Oklahoma	1	6	4	4	2	0
60M	22 July	1015	S. Dakota	0	6	5	1	4	1
60M	23 July	1015	S. Dakota	0	6	5	1	4	1
60M	24 July	1015	S. Dakota	0	6	5	1	4	1

TABLE 5. SUMMARY OF MULTISPECTRAL IMAGERY COLLECTED ON EACH FLIGHT OF EACH MISSION (Continued)

NASA Mission No.	Flight Date	Local Flight Time	Location of Site	Number of Scanner Spectral Bands				Aerial Camera Film/Filter Combinations	
				Ultraviolet (0.3-0.4μm)	Visible (0.4-0.7μm)	Infrared (0.7-3.5μm)	Thermal IR (3.5-15.0μm)	Black & White	Color
60M	28 July	1700	N. Dakota	1	7	4	1	1	3
60M	31 July	1400	Lake Ontario	1	8	2	1	1	4
60M	4 Aug.	0930	Central Michigan	0	6	4	1	2	1
61M	9 Aug.	0830	Indiana	0	8	3	1	2	2
61M	10 Aug.	1030	Indiana	0	8	3	1	2	2
63M	13 Aug.	0930	Central Michigan	0	7	4	1	1	2
62M	16 Aug	0900	NY Bight	1	8	2	1	1	2
62M	18 Aug.	0900	SE Florida	1	8	2	1	1	2
62M	19 Aug.	0900	Florida	1	8	2	1	1	2
63M	25 Aug.	1000	Central Michigan	0	7	4	1	1	2
63M	28 Aug.	0830	Lake Michigan	1	7	3	1	1	2
63M	29 Aug.	0830	SE Michigan	0	7	4	1	1	2
63M	29 Aug.	1400	SE Michigan	1	7	3	1	1	2
63M	30 Aug.	1030	SE Michigan	1	7	3	1	2	1
63M	5 Sept.	0900	SE Michigan	1	7	3	1	1	2
64M	7 Sept.	0830	Lake Ontario	1	8	2	1	1	2
64M	13 Sept.	1300	SE Michigan	0	7	4	1	0	0
65M	14 Sept.	1300	Central Michigan	0	7	4	1	2	2
65M	30 Sept.	1000	SE California	1	6	3	2	2	2
66M	30 Sept.	1200	SE California	1	5	3	3	2	2
66M	1 Oct.	0500	SE California	0	1	0	3	0	0
66M	1 Cct.	0700	SE California	0	6	3	3	2	0
67M	17 Oct.	1000	Indiana	0	8	3	1	2	2
65M	19 Oct.	0930	Central Michigan	1	6	3	2	1	2
68M	16 Nov.	0900	SE Florida	1	8	2	1	2	1
68M	17 Nov.	0900	Florida	1	8	2	1	2	1
	1973								
71M	2 Jan.	1000	Indianapolis, Ind.	0	8	3	1	1	2
	10 Jan.	0900	So. Michigan	1	7	3	1	1	2
	12 Jan.	1400	So. Michigan	1	7	3	1	1	2
	25 Jan.	0900	Lake Michigan	1	7	3	1	1	2
	20 Mar.	1030	Local Michigan	0	8	3	1	2	2
	23 Mar.	0930	Local Michigan	0	8	3	1	3	0
75M	24 Mar.	0930	L. Ontario, N. Y.	1	8	2	1	1	3
75M	25 Mar.	1000	L. Ontario, N. Y.	1	8	2	1	1	3
73/76M	5 Apr.	1930	So. Michigan		radar X and L bands with dual polarizations				
74/77M	6 Apr.	1300	NY Bight, N. Y.	1	8	2	1	1	2
77M	7 Apr.	0800	Lower NY Bay, N. Y.	1	8	2	1	1	2
77M	7 Apr.	1300	Lower NY Bay, N. Y.	1	8	2	1	1	2
	11 Apr.	0830	Monroe, Mich.	1	8	2	1	2	1
	11 Apr.	1100	Grand Traverse, Mich.	1	7	3	1	2	2
	13 Apr.	1300	Water Resources, Mich.	1	7	3	1	1	2
79M	19 Apr.	1130	Chelsea, Kansas	1	6	4	1	2	2
79M	20 Apr.	0600	Chelsea, Kansas	1	6	4	1	1	2

78/80M	4 May	0930	Wabash Basin, Ind.	0	7	3	1	2	2
81M	12 May	0730	Woodworth, N. D.	1	7	3	1	1	2
	24 May	1000	Local Michigan	1	7	2	1	3	0
	31 May	0930	Genesee Co., Mich.	1	7	3	1	1	2
	7 June	0930	Genesee Co., Mich.	1	7	3	1	1	2
82M	8 June	0930	Eaton Co., Mich.	1	7	3	1	1	2
81M	10 June	0830	Wabash Basin, Ind.	0	8	3	1	1	2
	11 June	1000	L. Michigan	1	7	3	1	1	2
	14 June	0500	Genesee Co., Mich.	1	7	3	1	0	0
	22 June	0930	Genesee Co., Mich.	1	7	3	1	1	2
82M	25 June	1015	Eaton Co., Mich.	0	8	3	1	1	2
	3 July	1030	Genesee Co., Mich.	1	7	3	1	1	2
83M	5 July	0900	Indiana/Illinois	0	8	3	1	1	2
83M	6 July	0900	Indiana/Illinois	0	8	3	1	1	2
83M	7 July	0815	Indiana/Illinois	0	8	3	1	1	2
	2 Aug.	1500	WR Ramp, Mich.	0	7	4	1	0	0
84M	4 Aug.	0930	So. Michigan	0	7	4	1	1	2
85M	5 Aug.	0830	So. Michigan	0	8	3	1	1	2
	10 Aug.	1615	Two Rivers, Wisc.	1	8	2	1	3	1
85M	12 Aug.	0830	Woodworth, N. D.	0	7	4	1	1	2
85M	20 Aug.	1200	Indiana/Illinois	0	8	3	1	1	2
85M	21 Aug.	0900	Indiana/Illinois	0	8	3	1	1	2
	22 Aug.	0830	Genesee Co., Mich.	0	7	4	1	1	2
	28 Aug.	1330	Genesee Co., Mich.	0	7	4	1	1	2
85M	6 Sept.	1000	So. Michigan	0	7	4	1	1	2
85M	7 Sept.	1600	L. Mich. & NW Mich.	1	7	2	1	1	2
85M	10 Sept.	1200	L. Ontario	0	7	4	1	1	2
85M	11 Sept.	0545	L. Ontario	0	7	4	1	0	0
	13 Sept.	1200	L. Michigan	1	7	3	1	2	1
87M	18 Sept.	1000	L. Michigan	1	7	2	1	1	1
88M	3 Oct.		Huntington Co., Ind.		radar X and L bands with dual polarizations				

4
TYPICAL COSTS OF DATA COLLECTION

The relatively high cost of multispectral data collection is a concern to any organization contemplating the use of such data in new applications. When experimental equipment is employed, data collection costs are high for the following reasons:

(1) High engineering costs because of continuing performance refinement and feature development

(2) High technician costs because of custom fabrications and difficult maintenance of complex developmental equipment

(3) High component costs because of small-quantity, state-of-the-art procurements

(4) The size, weight, and power requirements of experimental airborne instrumentation necessitate a large aircraft.

If a multispectral instrument were to be designed in a simple, fixed configuration and installed in a smaller aircraft which could be kept operationally active, it is reasonable to expect that the cost of data collection could be reduced to about 50% of ERIM's current costs. Given the current state-of-the-art, however, such a system may not be adequate to explore new applications; nor is it likely to allow concurrent operation of other sensors in conjunction with the multispectral scanner.

Instead, ERIM is equipped not only for straightforward investigations and semi-operational data collection but also for probing and proving the feasibility of new applications. The M7 multispectral scanner has a highly flexible configuration; and the aircraft which transports it can and has simultaneously carried additional sensors such as mapping radars, air sampling devices, microwave radiometers, metric cameras, and laser devices.

Table 6 characterizes a typical multispectral mission, describing the scope of the mission and showing a breakdown of labor and material costs incurred in operating and maintaining the airplane and associated instrumentation for data collection and reproduction. Table 7 gives some year-by-year statistics on the operational use of the WRL/ERIM experimental system, breaking down annual program costs on the basis of flight hours and data miles.

The seven-year cost history covered by Table 7 is all-inclusive in that the annual figures given are based upon the total cost to each sponsor and include flight planning, sensor installations, mission accomplishment, data reproduction and documentation, data distribution, as well as maintenance of both the instrumentation and the aircraft. (Because this maintenance expense is often absorbed in overhead by competitive organizations, ERIM's figures tend to look high by comparison.)

TABLE 6. PARAMETERS OF A TYPICAL MULTISPECTRAL MISSION

Total time at site and in transit:	5 days	
Transit time (roundtrip flights):	6 hours	
Data flight time:	7 hours	
Data collection distance:	300 nautical miles (nmi)	
Scanner channels recorded:	12 on analog magnetic tape	
Scanner channels reproduced:	4 on 70mm film	
Aerial camera coverage:	3 film/filter combinations	
		Airplane/Instrumentation Share
Labor & Material Costs:	$23K (combined total)	40/60
Labor (74%)	17K (subtotal)	29/71
—Planning (9%)	2K	45/55
—Mission Execution (13%)	3K	50/50
—Data Reproduction (13%)	3K	0/100
—Maintenance (35%)	8K	50/50
—Administration (4%)	1K	0/100
Material & Services (26%)	6K (subtotal)	43/57
—Expendable Mat'ls (9%)	2K	45/55
—Maint. Materials (9%)	2K	35/65
—Admin. & Travel (8%)	2K	50/50

TABLE 7. MULTISPECTRAL DATA COLLECTION STATISTICS (1966-73)

Period of Performance	Total Data Miles (nmi)	Total Flight Hours	Total* Expense	Average Cost per nmi of data	Average Cost per hr of flight	Total No. Missions	NASA Share of Total Business (%)
1966	2500	196	---	---	---	--	0
1967	2350	152	---	---	---	--	0
1968	1150	109	---	---	---	17	20
1969	8516	362	$470K	$55	$1300	32	70
1970	3909	327	$572K	$146	$1750	34	75
1971	5080	302	$604K	$120	$2000	27	75
1972	3301	248	$550K	$167	$2200	34	75
1973	4469	236	$570K	$128	$2400	34	70
Avg. per yr.	3909	242	$553K	$123	$1930	30	48

*This expense is the total cost to sponsors for multispectral data collection, including aircraft and instrumentation maintenance and operation, instrument modifications, administration and management, overhead, etc. In some instances, the expense also included the cost of installing and operating other sensors associated with a mission. For example, in 1973 there were two missions using the ERIM X and L band radar system.

At ERIM, costs for mission accomplishment amount to only about 25% of total mission expense. The big expense with aircraft and airborne equipment, particularly for experimental equipment, is the amount of downtime required for every flight hour of use; thus equipment maintenance and calibration between flights amounts to about half the cost of a data collection mission. The remaining costs (≈25%) are associated with flight planning, data reproduction and distribution, and mission documentation.

Appendix A
SUMMARY OF NASA-SPONSORED MISSIONS USING M5 DATA COLLECTION SYSTEM
(Sept. 1968—June 1971)

NASA Mission No.	Site	Application	Ground Track Miles	Scheduled	Flown
				1968	
1M	Purdue, Ind.	Agriculture	330	23 Sep	26 Sep
2M	Tenn. Valley	Forestry	100	14 Oct	14 Oct
				1969	
3M	San Diego, Cal.	Ag./Geol./Ocean	170	8-10 Mar	8-12 Mar
4M	Purdue, Ind.	Agriculture	330	12-16 May	13-27 May
5M	Purdue, Ind.	Agriculture	330	23-27 Jun	25-26 Jun
6M	Oregon Coast	Oceanography	2840	30 Jun-11 Jul	3-13 Jul
6M	Wind River, Ore.	Forestry	84	14-16 Jul	14-15 Jul
6M	Bucks Lake, Cal.	Forestry	40	17-18 Jul	16 Jul
6M	Black Hills, S. D.	Forestry	164	21-22 Jul	21-22 Jul
6M	Missouri River (S. D.)	Geology	160	23 Jul	23 Jul
7M	Ann Arbor	Forestry	40	24-25 Jul	4 Aug
7M	Purdue, Ind.	Agriculture	350	4-8 Aug	5-6 Aug
7M	Lake Michigan	Oceanography	50	8 Aug	11 Aug
7M	Ann Arbor	Forestry	40	11-15 Aug	13 Aug
8M	Washtenaw Co., Mich.	Agriculture	80	11-15 Aug	3 Sep
8M	Oregon Coast	Oceanography	1760	8-19 Sep	14-24 Sep
8M	Wind River, Ore.	Forestry	32	22-23 Sep	26 Sep
8M	Moses Lake, Wash.	Water Resources	40	24 Sep	25 Sep
8M	Bucks Lake, Cal.	Forestry	20	25 Sep	24 Oct
8M	Mill Creek, Okla.	Geology	225	29-30 Sep	28 Oct standby
8M	Ann Arbor	Forestry	40	2-3 Oct	26 Nov
9M	Purdue, Ind.	Agriculture	330	6-10 Oct	5-6 Nov
10 M	Purdue, Ind.	Agriculture	250	8-12 Dec	17 Dec
				1970	
11M	Biscayne/Keys, Fla.	Geological Survey	200	9-13 Mar	10-11 Mar
11M	Alafia/Peace, Fla.	Geological Survey	200	16-20 Mar	12-22 Mar standby
12M	Purdue, Ind.	Agriculture	240	13-17 Apr	6 May
13M	Ann Arbor	Forestry	80	4-8 May	8-28 May standby
14M	North Dakota	Geological Survey	200	18-22 May	22-23 May
15M	Ann Arbor	Forestry	80	8-12 Jun	8 Jun
15M	Washtenaw Co., Mich.	Agriculture	110	15-19 Jun	20 Jun
16M	Mill Creek, Okla.	Geology	300	22-26 Jun	23-26 Jun
17M	Purdue, Ind.	Agriculture	330	29 Jun-3 Jul	30 Jun-1 Jul
18M	Ann Arbor	Forestry	80	20-24 Jul	6-7 Jul
19M	North Dakota	Geological Survey	240	27-31 Jul	31 Jul
19M	Manitou, Colo.	Forestry	60	3-7 Aug	28-29 Jul
20M	Purdue, Ind.	Agriculture	330	10-14 Aug	11-13 Aug
20M	Washtenaw Co., Mich.	Agriculture	110	17-21 Aug	21 Aug
20M	Ann Arbor	Forestry	30	24-28 Aug	5 Aug
21M	Catheart Mt., Me.	Geological Survey	30	25-28 Aug	27 Aug
22M	Alafia/Peace, Fla.	Geological Survey	200	14-18 Sep	18-21 Sep

NASA Mission No.	Site	Application	Ground Track Miles	Scheduled	Flown
22M	Tenn. Valley	Forestry	100	21-23 Sep	21-23 Sep standby
23M	Purdue, Ind.	Agriculture	330	21-25 Sep	5-9 Oct standby
24M	Ann Arbor	Forestry	30	28 Sep-2 Oct	29 Sep-2 Oct
25M	Purdue, Ind.	Agriculture	330	9-23 Oct	19-23 Oct standby
26M	Ann Arbor	Forestry	30	12-16 Oct	16 Oct
27M	Purdue, Ind.	Agriculture	330	7-11 Dec	9-24 Dec standby
28M	Indiana Gr. Belt	Agriculture	70	24 Aug	24 Aug
28M	Indiana Gr. Belt	Agriculture	70	1-4 Sep	5 Sep
28M	Indiana Gr. Belt	Agriculture	70	7-11 Sep	11 Sep
29M	Chesapeake Bay	Oceanography	300	2-6 Nov	4-6 Nov
31M	Pisgah Crater, Cal.	Geology	40	26-30 Oct	29-30 Oct
				1971	
32M	Weslaco, Tex.	Agriculture	100	1-3 Mar	2 Feb and 3-4 Mar
33M	Purdue, Ind.	Agriculture	330	15-19 Mar	cancelled by NASA
34M	Tenn. Valley	Forestry	100	25-26 Feb	11 Mar
35M	Houston Area Test	Water Pollution	300	4-5 Mar	8-9 Mar
36M	Purdue, Ind.	Agriculture	330	5-9 Apr	cancelled by NASA
37M	No. High Plains, S. D.	Soil Limitations	100	17-21 May	cancelled by NASA
38M	Corn Belt, Ind.	Agriculture	300	17-28 May	17 and 21-22 May
39M	Ann Arbor	Forestry	80	31 May-4 Jun	cancelled by NASA

Appendix B
MULTISPECTRAL DATA PROCESSING AND ANALYSIS AT ERIM

While most techniques described herein apply to the processing of scanner data recorded on analog magnetic tape, they will also apply to ERTS and SKYLAB satellite data. In the satellite case, it is necessary, of course, to generate analog or digital tapes from data supplied.

Type I processing techniques described below are generally, though not always, applied to single-channel data. For ERTS and SKYLAB data processing, many of the imagery production and false-color film techniques mentioned will probably be implemented by NASA. The more sophisticated Type II techniques discussed in Section B.2 will be of primary interest to data users.

B.1 TYPE I PROCESSING

B.1.1 PREPARATION OF IMAGERY

Preparation of imagery from tape-recorded video information is one of the most basic forms of processing. This process displays video information on 70mm filmstrip negatives in a form which can be correlated with photography and other images. In all continuous filmstrip imagery produced at ERIM, a calibrated relationship is established between the video signal voltage from the magnetic tape and the film tone; this is done by periodically introducing a 16-step linear voltage scale in place of the video signal. There are several processing options, as described below.

B.1.1.1 Normal Tape Voltage to Film Tone Print

In the normal reproduction of filmstrip imagery, the lightest film gray-scale tone is clamped electrically to the signal representing the darkest or coldest reference source in the video signal, and the voltage gain is adjusted to place the signals representing the brightest or hottest objects of interest at the level of the darkest film gray-scale tone. This provision takes full advantage of the film dynamic range, but places the signal extreme in the nonlinear portion of the film transfer characteristics.

B.1.1.2 Special Tape Voltage to Film Tone Print

For calibration purposes, the video signal level can be clamped electrically to the signal representing the darkest (or "coldest") reference source. The video voltage can then be shifted in dc level and adjusted in gain to produce any preselected range of film gray-scale tone. Calibration reference levels, usually set to match the expected signal extremes, may be lost in the film print. To avoid this, the signal levels of interest (including calibration sources) can be placed within the linear region of the film grayscale. Or, for ease of data analysis, small signal variations can be expanded over a wide gray-scale range.

B.1.1.3 Mixed Video Filmstrip

The video signals from two or more video channels may be mixed before the imagery is printed—provided that such signals are in registration. Since the signals may be mixed in any proportion, color film, false-color IR film, or ERTS-A spectral channels may be simulated. After mixing, the signal may be printed with either normal or enhanced grayscale, as discussed above.

B.1.1.4 Amplitude Gating of Tape Voltage to Film Tone Print

As an aid in data analysis, either an upper or lower voltage threshold level, or both, can be set in playback after electrical clamping so that signals outside these limits will not be printed on film. Again, some calibration information may be lost since the reference sources are usually adjusted to match the signal extremes.

B.1.1.5 False-Color Films

As an alternative to black and white imagery, false-color films may be produced to portray, in color, information from three bands. The process is similar to the color reversal process of color photography. Individual imagery separations are first converted to positive transparencies, which are then printed on color ozalid material in the three subtractive colors: yellow, magenta, and cyan. To produce the color film, the three sets of ozalid material are overlaid. Because there is no restriction on the type of data set which may be combined to produce the false-color print, imagery from the nonphotographic regions may be included to enhance certain data aspects.

B.1.1.6 Correction of Yaw and Scanner Geometry Distortions

All scanner imagery has distortion in it caused by the constant angular rate at which the scanning process covers the ground. Since imagery is produced with a simple, linear sweep on the printing CRT, the resultant image is compressed at the edges relative to a display in which ground feet per inch of film is constant.

This problem may be overcome by a nonlinear sweep of tan ϕ form, where ϕ is the angle of scan relative to nadir. Circuitry to implement the tan ϕ function is now in operation and can be used to generate partially rectified imagery—that is, imagery from which the scan-induced distortion has been removed.

Yaw distortions in the data can be similarly removed by special purpose circuitry. The correction removes dc-yaw or "crab-angle" distortion from the data. It is accomplished by first measuring the yaw angle from a piece of normally produced imagery, and then correcting for the yaw by rotating the CRT trace with respect to the film. The success of this technique depends on a priori knowledge—from a topographic map or photography—of scene compositional characteristics.

Roll corrections are made in all scanner imagery by generating and recording a roll-corrected sync pulse in the aircraft, and then using this pulse in data playback.

B.1.2 CONTOURING AND QUANTIZATION

Both contouring and quantization are single-band processing techniques that display data to an interpreter in a form slightly different from conventional imagery. In quantization, the data are displayed as a set of gray levels on film, each level corresponding to equal ranges of input signals as defined by the operator. In contouring, signal amplitude may be color-coded to enhance contrast.

B.1.2.1 Quantization

As a further processing step, individual signals may be subjected to quantizing. By breaking the signal range into any number of discrete levels, a black and white filmstrip can be produced having a finite number of gray levels. By noting at which levels calibration information appears, the range of each level can be calibrated. The widths of quantizing intervals may be as small as the noise level on the data, although this frequently leads to more levels than can be conveniently printed on film. (The eye can easily distinguish as many as 16 levels on a conventional filmstrip.) The main use of quantized filmstrips is to obtain a calibrated display of data without resort to densitometry. Accomplished by analysis of the electrical video signal before it is printed on film, quantization avoids the need to deal with nonlinear film and CRT transfer characteristics.

B.1.2.2 Contoured Separations

The method of producing contoured separations is similar to that of producing quantized data. But instead of printing out a series of gray steps on film corresponding to video signals within certain quantizing intervals, only video signals present in a particular quantizing interval are printed out as black on a clear film background. By setting the width of a quantizing interval equal to the noise on the signal and then printing data in all quantizing levels sequentially on film, nearly all of the information about a scene can be extracted from a series of black and clear filmstrips having the same scale as the video filmstrip. Calibration information registered in the quantizing intervals permits calibration of each interval in terms of temperature, voltage, and radiance.

B.1.2.3 Color-Coded Contouring

Once the contour separations have been made, color coding may be added to accentuate radiance or temperature differences. The color coding is accomplished by printing each separation on a different colored ozalid foil. This step produces colored separations which may be overlaid to yield a color-coded contour display. The number of ozalid colors available and their contrast on the film upon which the ozalid overlay is photographed limit the number of data levels that can be meaningfully displayed to about 8 or 10; these may be chosen from any portion of the contouring separations.

Since all levels remain calibrated in the color-coding process, each color in the final display may be tied to a range of temperatures or radiances.

B.1.3 ANALOG TAPE DUPLICATION AND DIGITAL TAPE PREPARATION

All multispectral data are recorded in the aircraft on 1-in. magnetic instrumentation tape. Frequently, users who have access to data processing facilities request either duplicate analog tapes of data or digitized data for their own analysis. Properties of these two data formats are discussed below.

B.1.3.1 Duplicate Analog Tapes

The duplicate analog tape is simply a copy of the original data tape. All channels are commonly transferred from the original to the duplicate. The video and synchronizing data are recorded in IRIG* standard FM with 216-kHz center carrier (at 60 ips) and ±30% deviation. The synchronizing signal consists of two pulses of opposite polarity and close proximity, the first pulse being the non-roll-corrected sync, while the second is the roll-corrected sync. Since all tapes are supplied wound fully forward, they must be completely rewound before playing. Unless specifically noted, all channels on the duplicate correspond to the same channels on the original.

B.1.3.2 Digital Tapes

Digitized data suitable for digital computer processing may be supplied in one of two formats. All data are digitized to 9-bit accuracy (8 bits plus sign). Flexible control of the A/D conversion process allows sampling of the data once every resolution element, once every

*Inter-Range Instrumentation Group

other resolution element, and so on. Also, scan lines of data may be skipped. Unusual sampling formats may also be accommodated. Normal formats are as follows: sample each resolution element twice; sample each resolution element once; sample every other or every fourth resolution element. Any number of lines up to nine may be skipped.

Of the two formats available, the one commonly used for all processing at ERIM consists of the following information written as 48-bit words on 7-track (six bits and even parity), 1/2-in. digital tape. The first record is the binary title record containing the title (in standard alphanumeric form) and three numbers denoting, respectively, the number of data channels, the number of points per scan line, and an integer that tags the data as bipolar or unipolar. The second record is a binary record consisting of all the data from the first digitized scan line. These data are packed in words, with the first three octal digits (9 bits) corresponding to the value of the first channel at the first point. The next three octal digits denote the value of channel 2 at point 1. This process is continued until all the channels have been covered for point 1; then the process is repeated for point 2. Point 2 data starts where point 1 data ends, which may be in the middle of a word. The number of words per record is then

$$N = \frac{16}{3} N_{chan} \times N_{ss}$$

where N = total words per record

N_{chan} = number of channels

N_{ss} = number of points per scan

Note that the two numbers N_{chan} and N_{ss} are stored in the title. At the end of the digitized data, an "end of file" is written. In the event that a file continues over more than one tape, "end of tape" is written at the end of each tape.

The second format available at ERIM is similar to the first with two important exceptions: data are organized in card image format on the tape (short records); and data at 200 or 556 bpi can be supplied. The first two records of this format are the title and other numerical information written in binary coded decimal (BCD). The remaining records are binary records containing the data. Eighty-one 48-bit words are written in each record. The first word is a control word. Thus, each scan line of original data is covered in several records. A new record always begins with a new scan line. The numbers N_{chan} and N_{ss} serve to straighten out the packing. Further, each 81-word, 48-bit record may be converted into a 108-word, 36-bit record via relatively simple machine language programming. End-of-file and end-of-tape conventions are the same as for the first format.

Consultation with data-processing personnel at ERIM is recommended before specifying which format is to be used. This will assure format compatibility with a particular machine.

Areas to be digitized can be specified by marking data locations on a print of scanner imagery. Facilities will soon be available to put scan line numbering information on the filmstrip so that a precise specification of areas to be digitized (in terms of starting and stopping line number) will be possible. Data normally digitized include calibration and dark level information, which will be supplied in bipolar form unless otherwise specified. A graymap printout of video data alone will also be supplied. Line and point numbers on the map correspond to line and point numbers on the tape.

B.2 TYPE II PROCESSING

Type II processing comprises the more sophisticated analysis and pattern recognition operations usually applied to simultaneous multispectral data. These operations may be further divided into (1) signature analysis and calibration and (2) multispectral recognition.

B.2.1 SIGNATURE ANALYSIS AND CALIBRATION

This work, dealing with the extraction and analysis of signatures as a preparatory step before multispectral recognition, has four general categories: reflectance panel signature extraction, signature extraction of scene objects, analysis to determine optimum channels for multispectral recognition operations, and analysis of data to determine the presence of angle effects.

B.2.1.1 Reflectance Panel Signature Extraction

Standard 20 × 40 ft canvas reflectance panels are usually deployed during flight missions to permit calibration of the data collected in terms of equivalent directional reflectance. In order to calibrate scanner data in this manner, the voltage signatures of the panels are first extracted, and curves of scanner voltage versus reflectance are plotted for each spectral channel. Then voltage statistics of the area to be calibrated are obtained, and the curves generated previously are used to convert the voltage signature to a reflectance signature. Because of panel size and scanning system spatial resolution, useful panel signatures cannot be obtained at flight altitudes above 1000 ft.

B.2.1.2 Extraction of Signatures from Scene Objects or Areas

Signals received from various objects and materials on the ground exhibit spectral reflectance and emittance variations for a variety of reasons. Thus, in many applications, it is desirable for analysis purposes to obtain statistical descriptions of these multispectral signals and their variations. Facilities exist at ERIM for obtaining such descriptions from scene objects or areas selected for detailed study.* The following types of information can be digitally computed:

(1) mean signal in each spectral channel and the corresponding variances for (a) each selected scan line that contains the material of interest, (b) each scan angle at which the material is observed and sampled, and (c) all samples considered as a group
(2) covariances and correlations between signals in the various spectral channels
(3) eigenvalues and eigenvectors of each variance/covariance matrix or distribution
(4) weighted combinations of statistics from several objects or areas
(5) measures of the amount of separation between such distributions for any set of spectral channels

The data computed have the following features:

(1) Corrections are first made for scan-angle-dependent variations introduced into the data by the scanner.
(2) Calibration information is simultaneously computed.
(3) According to customer preference, results can take one or more of the following forms: computer printouts, punched cards, magnetic tapes, and computer-generated histogram plots.

B.2.1.3 Analysis to Determine Best Channels for Multispectral Recognition

In multispectral data-processing operations, particularly those in which recognition of scene objects is based upon their spectral signatures, it is often desirable to know which channels of a given set of data are most useful for discriminating terrain features. We have developed an analysis program to compute the best single channel, best pair of channels, best three channels, and so on. The performance measure is the average pairwise probability of misclassification of all signatures fed into the program. We chose this measure rather than a distance measure (which would have been computationally simpler) so we can obtain, at each step, a measure of the performance of a maximum likelihood pattern classifier. Required as program inputs are the signatures of the objects to be separated and weights denoting the relative importance of various parts of objects. The program output is a rank ordering of channels, with a performance measure at each step.

* The Target Signature Analysis Center (TSAC) at ERIM, operated under sponsorship of the Air Force Avionics Laboratory, collects optical properties-of-materials data, provides analytical programs, and publishes data compilations.

B.2.1.4 Angle Effects: Analysis and Correction

Because of peculiarities in data collection (particularly flightline orientation with respect to the sun), a pronounced variation of average scene radiance with scan angle is often present in multispectral data. This angle effect seriously degrades multispectral recognition in classification of data sets because the voltage signature representing a scene object varies with that object's position in the field of view.

The presence of angle effects is not always easy to determine by examination of imagery. Even if the signals are examined on an oscilloscope and found to have angle effects, a quantitative measure is needed. Analysis programs are available to determine whether the angle effects are sizable enough to affect recognition processing; we recommend their use on data to be processed.

Any angle effects can usually be corrected by selectively applying special preprocessing steps, the efficacy of which can be explored without actually making a recognition map. After a reasonable preprocessing approach is formulated, processing of the data continues on either the digital or special-purpose analog computer.

B.2.2 MULTISPECTRAL RECOGNITION OPERATIONS

Here, basically, we attempt to recognize scene objects using spectral signature information only. Recognition processing begins with the selection of training sets representing verified signatures of objects of interest. The computer is given this signature information; then it is asked to classify an unknown scene based on the similarity of scene spectral signatures to those in the training sets. The measure of such similarity—a likelihood ratio—is computed for each scene point for each object to be recognized. A threshold circuit then decides which of the training set objects is most likely present in the scene.

Likelihood ratio processing is implemented in two ways at ERIM. In one, the CDC-1604B digital computer may be used to generate recognition maps from digitized data. These maps may be printed out either in black and white (with different objects represented by various typewriter symbols), or in color (with different objects represented by symbols of different color —red, green, blue, and black are available).

In the other implementation of likelihood ratio processing, a special-purpose analog computer, SPARC, is used to generate recognition maps. SPARC works with taped data from the aircraft at real-time rates and produces recognition maps directly comparable with imagery. Recognition maps of this type consist of black areas on a clear film background; by means of the same false-color ozalid process described in Section B.1.2, they may be color-coded to form a color composite recognition map.

User representatives will often find it constructive to discuss proposed processing work with ERIM data processing and analysis personnel who from wide experience can offer many helpful suggestions. When multispectral data is to be processed at ERIM, a number of essential inputs are required from the customer (i.e., user organization) to insure optimum results.

(1) Designation of area to be processed. This can often be done initially through imagery inspection, but the final decision as to the most suitable area should rest on an oscilloscope examination of the data or other close analysis.

(2) Assembly of training sets. Such sets may be identified on either aerial photography or scanner imagery. Their size (in linear dimensions) will vary with flight altitude. A good rule of thumb in selecting a training set is that it should include at least 20 resolution elements. (A resolution element is approximately 3h ft square, where h is the scanner altitude in thousands of feet.) For very small objects, training sets can be smaller, but then the specification of what comprises each set must be carefully made to insure good results.

(3) Availability of adequate ground truth. In order to establish training sets and make interim assessments of processing success, data-processing personnel must be provided with ground truth information that they can correlate with the imagery obtained.

NOTE: The recognition operation tends to be repetitious and often tedious. If the user does not plan to be present during processing, he should arrange to leave ground truth information with ERIM personnel.

(4) Display parameters and purposes. The user should give some thought to how he intends to display the results. Various options include recognition maps in combination with imagery, recognition maps with color photography, and lantern or 35mm slides. ERIM's capable photographic laboratory and technical illustration department are skilled in all aspects of display preparation to suit the user's need.

(5) Realistic scheduling. Because of advance scheduling on the SPARC computer, we recommend that processing plans be made well ahead. Special requests for specific time periods will receive careful consideration, but it should be remembered that the SPARC is usable only on a non-interference basis with Air Force work (the Air Force sponsored SPARC's original construction). Normally, however, there is no interference problem.

(6) Constructive comment. The customer is encouraged to communicate to ERIM any helpful comments concerning data collection procedures or, after data processing, relative to the results achieved.

When processing has been completed, ERIM supplies the customer with a data package that includes a report which documents SPARC operations. This report usually contains imagery samples, discusses processing theory and its application to the problem at hand, mentions any pertinent data anomalies, and reviews SPARC's processing performance.

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