N72-18358

UNITED STATES

DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

INTERAGENCY REPORT NASA-156

GEOGRAPHIC ANALYSIS OF MULTIPLE SENSOR DATA FROM THE NASA/USGS EARTH RESOURCES PROGRAM

by

Richard F. Pascucci
Gary W. North
Rose Anne Albrizio
Barry D. Shelkin

Autometric Operation
Raytheon Company
Alexandria, Virginia

May 1969

Prepared by the Geological Survey for the National Aeronautics and Space Administration (NASA) under contract W-12589, Task No. 160-75-01-32-10. Work performed under USGS/Geographic Applications Program Contract No. 14-08-0001-11505 with Autometric Operation, Raytheon Company.

FOREWORD

This report was prepared by the Autometric Operation of Raytheon Company under U.S. Geological Survey Contract Number 14-08-0001-11505. It represents the results of a study made of multi-sensor imagery acquired by the NASA Earth Resources Aircraft Program for the Geographic Applications Program (GEOGAP) of the U.S. Geological Survey (USGS). Funding was by NASA through USGS.

In addition, to insure that the superstructure of the study rest on as broad a base as possible, frequent recourse was had to Autometric's extensive library of remote sensing imagery.

Work was begun on 15 July 1968 and completed 15 February 1969.

The authors would like to acknowledge their indebtedness, and express their thanks, to: Dr. Greg Butterworth, of IBM, for his contributions to the section, Cost Effectiveness Analysis; Dr. John W. Rouse, Jr., of Texas A & M University, for the section, Analysis of Scatterometer Data; Messrs. Frank R. Perchalski and Richard A. Bradie, of Autometric Operation, for their technical research and editorial contributions, respectively; to Mr. Harry Mallon, of the Office of Emergency Preparedness, for his perceptive comments; to Dr. Arch Gerlach, Mr. John W. Wilson, and Miss Susan Moorlag, of GEOGAP, for their helpful contributions and constructive criticism; and, above all, to Mr. Robert H. Alexander, GEOGAP program administrator, for his continuous, unstinting, and resourceful aid.

The authors:

Richard F. Pascucci - Program Manager
Gary W. North
Rose Anne Albrizio
Barry D. Shelkin - Head, Terrain Sciences Section

Technical Approval

Jay H. Simons

Jay H. Simons
Head, Interpretation and Intelligence Department

ABSTRACT

Qualitative and quantitative analyses were made of multi-sensor data acquired during aircraft missions conducted by the NASA Earth Resources Aircraft Program for the Geographic Applications Program (GEOGAP) of the U.S. Geological Survey. While the principal analysis effort was concentrated on imagery taken during Mission 73 over test sites in Southern California, data were also studied from records acquired on missions over test sites at Phoenix, Chicago, Asheville, and New Orleans. The objectives of the analyses were: 1) to determine the capabilities of ten remote sensors in identifying the elements of information necessary in conducting geographic investigations in land use analysis, urban problems, surface energy budget, and soil moisture; 2) to determine the feasibility of using these sensors for these purposes at orbital altitudes; 3) to collate and analyze ground and air data previously collected and assemble it in a format useful in the accomplishment of cost effectiveness studies.

<u>TABLE OF CONTENTS</u>

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF TABLES

LIST OF TABLES (Continued)

1. INTRODUCTION

1.1 Purpose

The purpose of this report is to present the findings made, and conclusions derived, in the course of analysis of multi-sensor data acquired during NASA Mission 73, over test site 130 in Southern California, and also from Missions 14 and 23 (test site 46, Asheville, N. C.), Mission 19 (test site 29, Phoenix), and Mission 25 (test site 43, Chicago).

1.2 Objectives

The objectives of the study were three: 1) to analyze the data, both qualitatively and quantitatively, from ten sensors, nine of which have been used in NASA missions, in order to determine their capability in identifying the elements of information required to conduct studies in land use analysis, urban problems, surface energy budget, and soil moisture; 2) to determine the feasibility of using these sensors from an orbital platform; and 3) to devise a cost-effectiveness format by means of which the Principal Investigators within the NASA Earth Resources Program can enter their data requirements, to which they have assigned weighted values, and, by comparing these with their weighted estimates of the utility of sensors and sensor combinations to acquire these data, arrive at a numerical effectiveness of each sensor set.

1.3 General Approach

1.3.1 Land Use and Urban Problems

For these two portions of the analysis, detailed lists were drawn up of the elements of information that would have to be identified on the sensor records in order to carry out the geographic studies in land use and urban problems. In a study of housing quality, for example, elements of information might include such parameters as the presence of litter, the condition of roadways, the building density, and many others. Once determined, these elements were placed in the column dimension of a two-dimensional matrix, and the sensors most used by the Principal Investigators were placed in the row dimension. The object of analysis, then, was to determine how each sensor performs in providing the information needed. In the earlier phases of the program, each analyst searched the imagery from each sensor and recorded whether or not it: 1) can identify; 2) cannot identify; or 3) can identify sometimes, in part, or relatively, each element of information. In the later phases, the sensors were ranked, by a majority decision of the analysts, on a scale of excellent, good, fair, poor, or unusable.

It was found in the course of the investigation that it was a useful heuristic procedure to actually conduct a study, such as housing quality determination, rather than to search the imagery at random. This method served to limit and direct the search and to reveal, empirically, elements of information that might have been overlooked when the lists of elements were compiled.

1.3.2 Surface Energy Budget and Soil Moisture

The positions of soil temperature and moisture measurements made during Mission 73 were plotted on a photo mosaic base map and subsequently transferred to the thermal infrared imagery that was acquired concurrently with the ground data.

It was originally intended to use positive transparencies of the thermal IR for making densitometric measurements of the ground test stations with a microdensitometer, and to attempt to relate the photographic density to soil temperature and moisture content. However, since the transparencies were not available, density was measured on the available positive prints with a calibrated photographic gray step tablet. From these data were computed the relationships: 1) photographic density as a function of temperature; 2) photographic density as a function of moisture; and 3) temperature as a function of moisture.

1.3.3 Feasibility from Spacecraft

The purpose of this section is to explore a method for determining the resolution to be expected from a sensor orbiting the earth at one hundred and fifty nautical miles. (Resolutions obtainable at other altitudes can be computed by substituting the desired altitude in the appropriate equation.) The methodology has been kept as general as possible. The sensor under primary consideration was the NASA RC-8, and the resolution obtainable was derived using a lens system with a nominal resolution of 50 lines/mm. Other remote sensing systems may be likewise evaluated using the method outlined by inputting their modulation transfer function (MTF) curves. (MTF refers to the mathematical expression that describes the transformation of information that takes place between the input and the output of a system.) The effects of different altitudes can be evaluated by changing image motion and turbulence parameters. Substitution into the method of a detector other than film would allow the evaluation of telemetered data systems. Color systems, either film or television, may be evaluated by determining the spectral response in each waveband under consideration. This is accomplished by inputting the spectral contrast attenuation of the atmosphere, the wavelength modulation of the lens and the spectral response of the film layers or detectors.

1.3.4 Quantitative Analysis of Film Quality

In the section on quantitative analysis it was attempted to derive the original resolution of the RC-8 camera using a method of edge gradient analysis. A black-and-white negative transparency was made from the imagery supplied and developed with the requisite sensitometric exposure. From this reproduction it was possible to derive the MTF of the camera/film system. The data generated, however, represents a third generation of information degradation (IR Ektachrome on color Ektachrome on Dupont 228)

It was also attempted to correlate density measurements with ground truth reflectances.

1.3.5 Cost Effectiveness Analysis

In conjunction with Dr. G. S. Butterworth, Manager of IBM's Operations and Economics Analysis Department, Gaithersburg, Maryland, a cost effectiveness format was designed that would allow the Principal Investigators under contract to GEOGAP to arrive at a quantitative economic measure of the utility of selected remote sensors in providing data useful to geographers. By asking each of the Investigators, first, to list the specific geographic information elements they were interested in studying; second, to rank these elements as to their relative importance to each other; and finally, to assess the effectiveness of each NASA sensor or sensor combination in providing that information, an overall sensor effectiveness ratio was calculated. Then, when the operational costs incurred in obtaining the data are known, as well as the other costs incidental to acquiring the film, sensors and finished products, a cost effectiveness comparison can be accomplished for each sensor alternative.

1.4 Background of the NASA Aircraft Program

The NASA Aircraft Program is part of the NASA Earth Resources Survey Program (ERSP), whose national objectives are to:

- Determine earth resources data that can be usefully acquired from space;
- Develop the best combination of instrument subsystems and procedures to acquire data for studies in:

Geography	Hydrology
Geology	Oceanography
Forestry	Cartography
Agriculture	

To help meet these objectives, NASA organized the Earth Resources Aircraft Program, now located at Ellington Air Force Base, Texas, as part of the Earth Resources Division under the Director of Science and Applications, of Manned Spacecraft Center, Houston, Texas. The group maintains and operates three aircraft equipped with a variety of remote sensing and data collection devices. Descriptions of the aircraft and their respective sensors appear in Tables I, II, III, and IV.

The Aircraft Program is structured to support Principal Investigators, who are selected by various agencies, such as USGS and USDA, to serve as directors of the research carried out under the Earth Resources Program. The funding of the remote sensing research efforts and the acquisition of the data are all handled by NASA. Each Investigator selects certain test site areas that are representative of the type of investigation he is interested in pursuing and requests flights over these sites by means of a flight request form that has been completed and approved prior to its arrival in Houston. Flight time allocations are made at

TABLE I

SENSOR EQUIPMENT - CONVAIR 240A

The Convair 240A is a low-altitude (1,500 to 15,000 feet) aircraft

Instruments	Spectrum	Format	Resolution	Field of View
Reconofax IV infrared imager	8 to 14μ	70mm film	--	--
Itek multiband camera[a]	0.4 to 0.9μ	2 1/4" x 2 1/4" film	50 lines/mm	18° by 18°
RC-8 metric camera (2)	0.4 to 0.9μ	9" x 9" film	48 lines/mm	74° by 74°

[a] Itek multiband camera and the 2 RC-8 cameras cannot be used simultaneously.

TABLE II

SENSOR EQUIPMENT - LOCKHEED ELECTRA NP3A

The Lockheed Electra NP3A is a medium-altitude (1500 to 25,000 feet) aircraft

Instruments	Spectrum	Format	Resolution	Field of View
Dual-channel infrared imager	0.3 to 5.5μ 8.0 to 14 μ	70mm film Magnetic tape	3 ft at 1000 ft alt	80°
Infrared spectrometer	6.5 to 13μ	Magnetic tape	6 ft at 1000 ft alt	0.4° by 0.4°
Infrared radiometer	10 to 12μ	Magnetic tape	6 ft at 1000 ft alt	0.4° by 0.4°
400-MHz scatterometer	400 MHz	Magnetic tape	3° by 3°	120° by 3°
13.3 GHz scatterometer	13.3 GHz	Magnetic tape	0.01° in flight direction	120° by 3°
1.6 GHz scatterometer	1.6 GHz	Magnetic tape	3° across flight line	
16.5 GHz side-looking airborne radar (SLAR)	16.5 GHz	Film	50 ft	2° by 56°
Multiple-frequency microwave radiometer	1.4;10.2;22.2; 22.3;32.4 GHz	Magnetic tape	--	1.4 GHz - 16°$\pm$ 0.5° others - 5°$\pm$ 0.2°
RC-8 metric cameras (2)	0.4 to 0.9μ	9 by 9-in film	48 lines/mm	74° by 74°
Modified KA26 camera cluster (4)	0.4 to 1.0μ	5 in film	53 lines/mm	74°

TABLE III

SENSOR EQUIPMENT - LOCKHEED HERCULES C130

The Lockheed C130 is a medium-altitude (1,500 to 25,000 feet) aircraft

Instruments	Spectrum	Format	Resolution	Field of View
RS-7 infrared imager	8 to 14μ	70mm film	--	--
13.3 GHz scatterometer	13.3 GHz	Magnetic tape	3° by 3°	120° by 3°
Multiband camera[a]	0.4 to 0.9μ	--	--	--
RC-8 metric camera (2)	0.4 to 0.9μ	9 by 9" film	48 lines/mm	74° by 74°
16.5 GHz side-looking airborne radar (SLAR)	16.5 GHz	Film	50 ft	2° by 56°

[a]To be determined

TABLE IV

SENSOR EQUIPMENT - GENERAL DYNAMICS RB57F

The RB57F is a high-altitude (greater than 50,000 feet) aircraft

Instruments	Spectrum	Format	Resolution	Field of View
RS-7 infrared imager	8 to 14μ	70mm film	--	--
RC-8 metric cameras (2)	0.4 to 0.9μ	9 by 9-inch film	48 lines/mm	74° by 74°
Infrared spectrometer	6.5 to 13μ	Magnetic tape	6 ft. at 1000 feet alt.	0.4° by 0.4°
Infrared radiometer	10 to 12μ	Magnetic tape	6 ft. at 1000 feet alt.	0.4° by 0.4°
Multiband camera[a]	0.4 by 0.9μ			

[a]To be determined

quarterly mission planning meetings, and copies of the acquired data are returned to the investigators after the flight has been accomplished and the data processed at the Manned Spacecraft Center (MSC). The investigators are required to submit a "Quick Look " review of the mission data and a 90 day report on research activities. Papers and technical reports are then produced when conclusions have been reached or contracts terminated.

1.4.1 Southern California Remote Sensing Test Operation

During the spring of 1968, USGS and NASA conducted a multi-disciplinary (Geography, Geology, Hydrology) remote sensing test program in Southern California. A series of flights, designated Mission 73, was carried out over the Los Angeles Basin, the Indio Hills, the Coachella Valley, the Imperial Valley, the Salton Sea, and the Anza-Borrego Desert. This report is concerned only with the Geographic Applications Program (GEOGAP) sites in Los Angeles, the Coachella Valley and the Imperial Valley.

The objectives of the GEOGAP exercise were:

1) to define the scientific and economic benefits to be derived from examining the resources of a region by means of remote sensors;
2) to acquire data by means of airborne sensors over an area the properties of which were being measured on the ground;
3) to demonstrate the cost/time effectiveness realized by acquiring and studying a single set of data for use by more than one team of Investigators for more than a single discipline;
4) to make recommendations on the scientific use of sensors in future space experiments; and
5) to serve as a field demonstration of remote sensing data acquisition, correlative ground data acquisition, and preliminary data analysis techniques for the NASA International Participation Program for visiting Mexican and Brazilian scientists.

The specific goals of the Mission 73 tests were to correlate multi-sensor and ground truth observations and evaluate the feasibility of sensors and sensor combinations as data-gathering components in aircraft (and eventually spacecraft) in four areas of emphasis: 1) land use; 2) urban problems; 3) surface energy budget; and 4) soil moisture. Two contrasting areas were selected for concentration of effort. One was a cross-section of Metropolitan Los Angeles, containing residental developments of wide range and quality, industrial areas, commercial districts, a variety of transportation facilities, and a classic locale for air pollution. The second was an area of irrigation agriculture, small towns, and desert in the Coachella and Imperial Valleys surrounding the Salton Sea, about 100 miles inland from the Pacific coast.[1]

Figures 1 and 2 illustrate the areas of interest, Tables V and VI show the flight schedules for the prime NASA/MSC aircraft and other supporting aircraft, and Table VII lists the characteristics of the sensors flown. Examples of multi-sensor data collected by the aircraft involved in the Southern California operations are shown in Figures 3A through 3D. For a complete summary of Mission 73, see Technical Letter, NASA-132, entitled MISSION 73 SUMMARY AND DATA CATALOG, by Richard F. Pascucci and Gary W. North of Raytheon Autometric Company.

1.4.2 NASA/USGS Principal Investigator Research Projects

Founded in January 1965 as part of the Department of the Interior's program for the utilization of remote sensing data, GEOGAP received its first operational funds from NASA in June of 1966. The program was designed to determine the potential applications of data derived from space observational vantage points and to investigate the capability of remote sensor technology for the study of geographic phenomena. The program is administered by a three-member staff under the Office of the Chief Geographer, with research being conducted by Geography departments at various colleges and universities across the country. Additional work is conducted by the Association of American Geographers (AAG). In this report, however only the following Principal Investigators and institutions will be dealt with:

Dr. Leonard W. Bowden	University of California Riverside
Dr. Norman J. Thrower	University of California Los Angeles
Dr. David S. Simonett	University of Kansas
Dr. Duane F. Marble	Northwestern University
Dr. Robert W. Peplies	East Tennessee State University
Dr. Merle C. Prunty, Jr.	University of Georgia
Dr. James P. Latham	Florida Atlantic University
Mr. Harry Mallon	Office of Emergency Preparedness

[1] Leonard W. Bowden and Robert H. Alexander, "Geographic Remote Sensing Tests in Southern California, Spring 1968," in MISSION 73 SUMMARY AND DATA CATALOG, by Richard F. Pascucci and Gary W. North, (Alexandria, Virginia. August 1968).

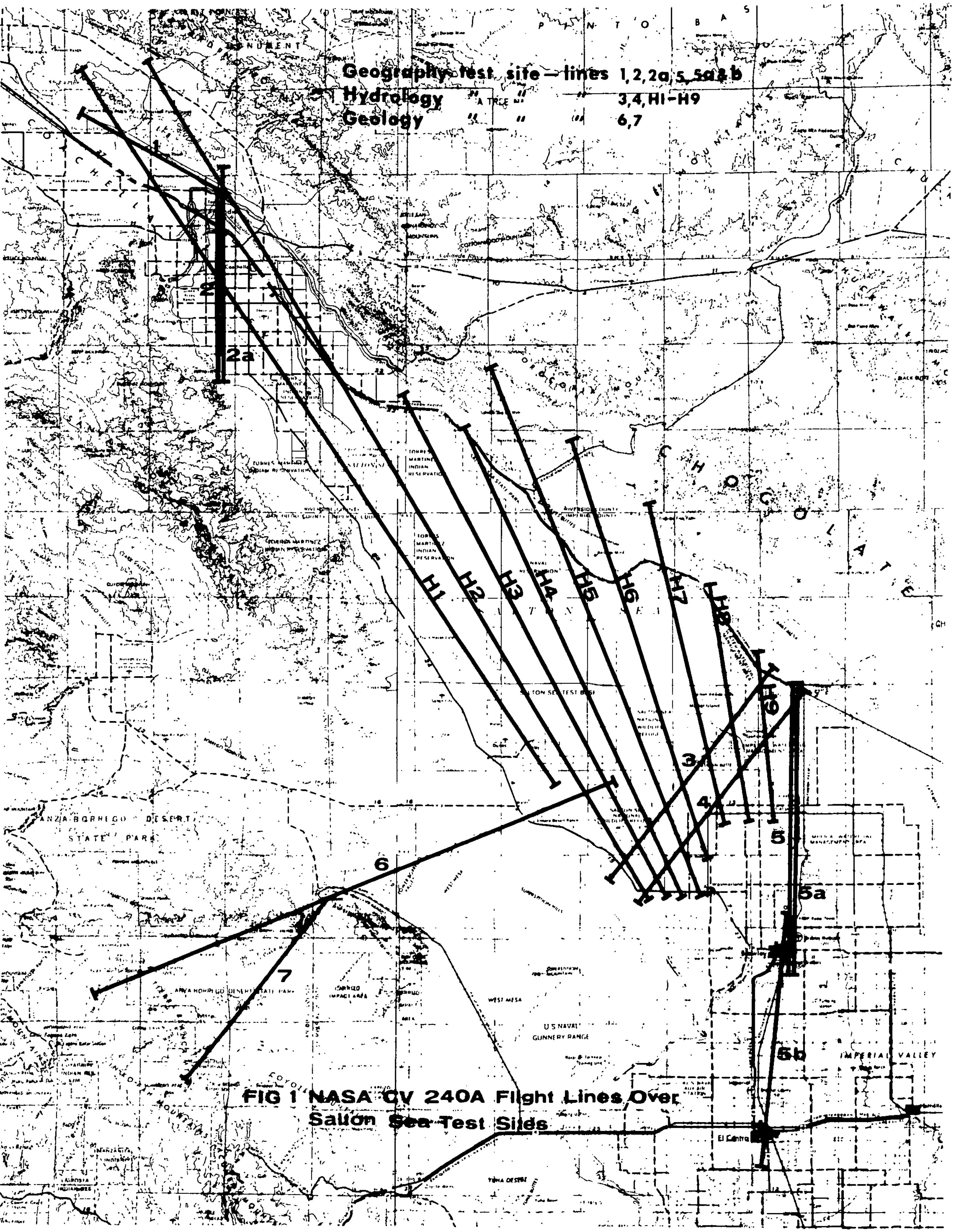


FIG 1 NASA CV 240A Flight Lines Over Salton Sea Test Sides

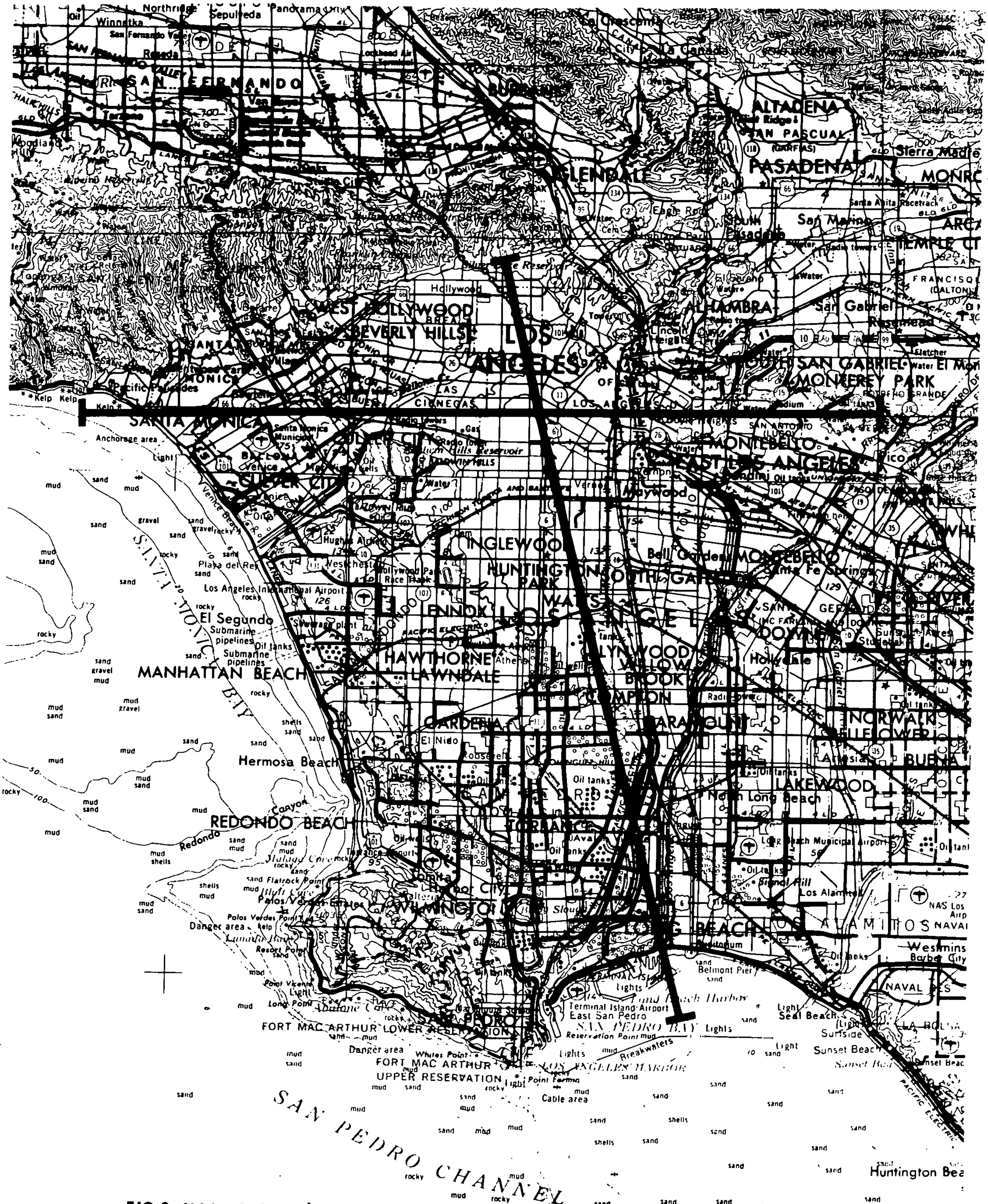


FIG 2 NASA 240A Flight Lines Over Los Angeles Test Site

TABLE V

FLIGHT SCHEDULE OF NASA CONVAIR 240A

DATE	TIME	FLIGHT LINES	ALTITUDE	SENSORS
Tuesday, May 21	1108 to 1358 L	1, 2, 2a, 5, 5a, 5b, 6, 7, 3, 4	2,000' (6 & 7 at 6,000')	Scatterometer Radiometers (MR62, MR64) Hasselblads (8442EKTO & 8443IR) RC-8 (B&W, Color IR) Reconofax IV 8-14m AAS-5
Wednesday, May 22	1845 to 2110 L	6, 7, 1, 2, 6, 7 (Mission cancelled after first two passes (6 & 7) because of IR scanner malfunction)	6,000'	Reconofax IV Radiometers AAS-5 Scatterometer
Thursday, May 23	1853 to 2055 L	6, 7, 1, 2, 6, 7	6,000'	Reconofax IV Radiometers AAS-5 Scatterometer
Thursday/Friday May 23/24	2324 to 0139 L	Radial lines over Salton Sea H-1 to H-9)	6,000'	Reconofax IV Radiometers (H-1 to H-3) AAS-5 Scatterometer
	0438 to 0630 L	6, 7, 1, 2, 6, 7	6,000'	Reconofax IV Radiometers AAS-5
Friday, May 24	1152 to 1920 L	Los Angeles lines	N-S 3,000' E-W 3,000'	RC-8 Hasselblads (8442 and 8443) Reconofax IV Radiometers AAS-5

TABLE VI

FLIGHT SCHEDULE OF SUPPORTING RESEARCH AIRCRAFT

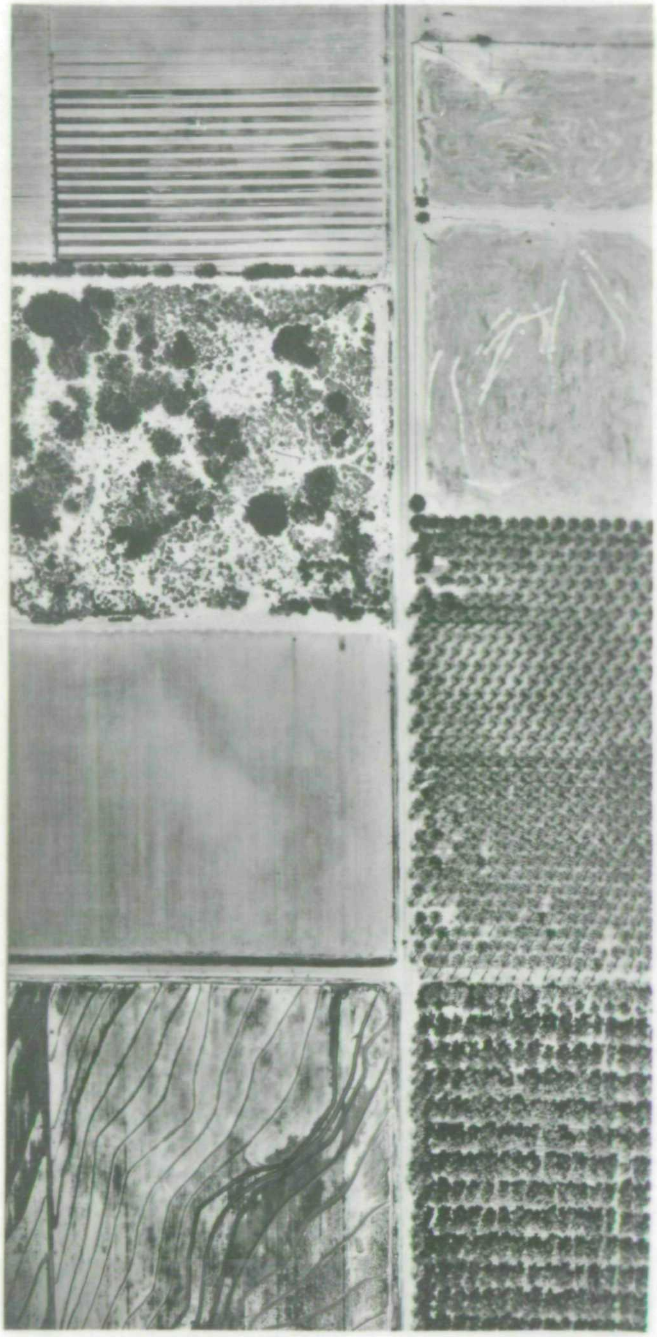
AIRCRAFT	DATE	TIME	FLIGHT LINES	ALTITUDE	SENSORS
Barringer Research Ltd. Aircraft	Tuesday, May 21	1245 - 1410	1	Restricted because of low-lying clouds	Absorption Spectrometer
	Wednesday, May 22	0830 - 1035	1, 2, 3, 4, 6	1,000' - 7,000'	
	Thursday, May 23	1205 - 1435 1630 - 1800	1, 2, 3, 4, 5, 6	1,000' - 8,500'	
	Friday, May 24	1125 - 1430 1630 - 1900	7, 8	1,000' - 10,000'	
		NOTE:	(Flt line numbers refer only to Barringer flts over Los Angeles area.		
Hugh E. Gallaher Inc. Apache	April 26 May 13 May 15	Daytime	Coachella and Imperial Valleys Los Angeles	10,000' & 20,000	12" Aerial Mapping Camera - Color IR
	May 21	1000 - 1330	1, 2, 3, 4, 5, 6, 7	10,000' & 2,000'	DVC 2400 Television Camera, Hasselblads, 12" Aerial Camera
	May 24	1500 - 1630	Los Angeles	10,000'	Same
	June 10	Daytime	Coachella and Imperial Valleys	20,000'	12" Aerial Mapping Camera
	June 12	Same	Same	Same	Same
NASA/Goddard Convair 990	June 5	Daytime	Coachella and Imperial Valleys	12,000' - 37,000'	Imaging Microwave Radiometer, Nimbus MRIR, Color IR, Aero Ektachrome
	June 7	Same	Same	50'-37,000'	
	June 11	Same	Los Angeles	Same	
Private Aircraft Owned and Operated by Harold Biell, UCR Graduate Student	May 31	Daytime	Coachella Valley	Variable	DVC 2400 Television Camera and 35mm Cameras
Private Aircraft Chartered by Dr. D. Marble	May 21	Morning	5b	500'-1500'	16mm Movies, 35mm Color IR, 35mm Ektachrome
Colorado State Univ. Aerocommander	June 5 June 7	Daytime Daytime	Coachella and Imperial Valleys	50'-22,000'	Particle counter, Barnes IT-3 IR Thermometer

TABLE VII

SENSOR CHARACTERISTICS

SENSOR	COMPANY	SPECTRUM	RESOLUTION	FIELD OF VIEW	FORMAT	LOCATION
AAS-5 Ultraviolet Imagery	HRB Singer	2900 to 5000A		80°	35mm Film	NASA/MSC Data Base
Absorption Spectrometer	Barringer Research Ltd.	Ultraviolet	Not Applicable	Unknown	Strip Chart Recorder	Barringer Research Ltd.
Conventional 12-inch Aerial Camera		Visible and Photographic Infrared		48°	9 x 9" Film	U. of Calif. (Riverside)
DVC 2400 Television Camera	Sony	Visible	Greater than 400 TV lines	Variable with zoom optics	Magnetic Tape	East Tennessee State
Hasselblad Camera	Hasselblad	Visible and Photographic Infrared	Approx. 50 L/MM	55°	70mm	NASA/MSC Data Base and U. of Tennessee
MR62, MR64, Microwave Radiometer	Raytheon	62: 9.3; 34.0 GHz 64:15.8; 22.2 GHz	1°K	Grazing angle from 0-45°	Strip chart and magnetic tape	NASA/MSC Data Base
NASA/Goddard Imaging Microwave	Aerojet General	19.35 GHz	2.5°-2.9° Beam width	50°	Magnetic Tape	NASA/GSFC
RC-8 Metric Camera	Wild Heerburgg	0.4 to 0.9μ	48 Lines/mm	74° by 74°	9 x 9 film	NASA/MSC Data Base
Reconofax IV Infrared Scanner	HRB Singer	8 to 14μ		140°	70mm film	NASA/MSC Data Base
Scatterometer 13.3 GHz	Ryan	13.3 GHz	3° by 3°	3°; grazing angle ± 60° from nadir	Magnetic Tape	NASA/MSC Data Base
Nimbus MRIR		6.4-6.9μ 10-11μ 14-16μ 5-30μ 0.2-4μ	55 km		Strip Chart	NASA/GSFC
IT-3 IR Thermometer	Barnes	Figures of merit not available at time of publication				NASA/GSFC
Particle Counter	Bausch & Lomb	See Appendix L for description				NASA/GSFC

NASA/USGS Mission #73 21 May 1968 Test Site #130 Jackson Street Flight Line Scale 1:4,000	NASA/USGS Mission #19 15 February 1966 Test Site #29 Phoenix Pass #12 Scale 1:4,700
Black-and-White	Color Ektachrome (8442)



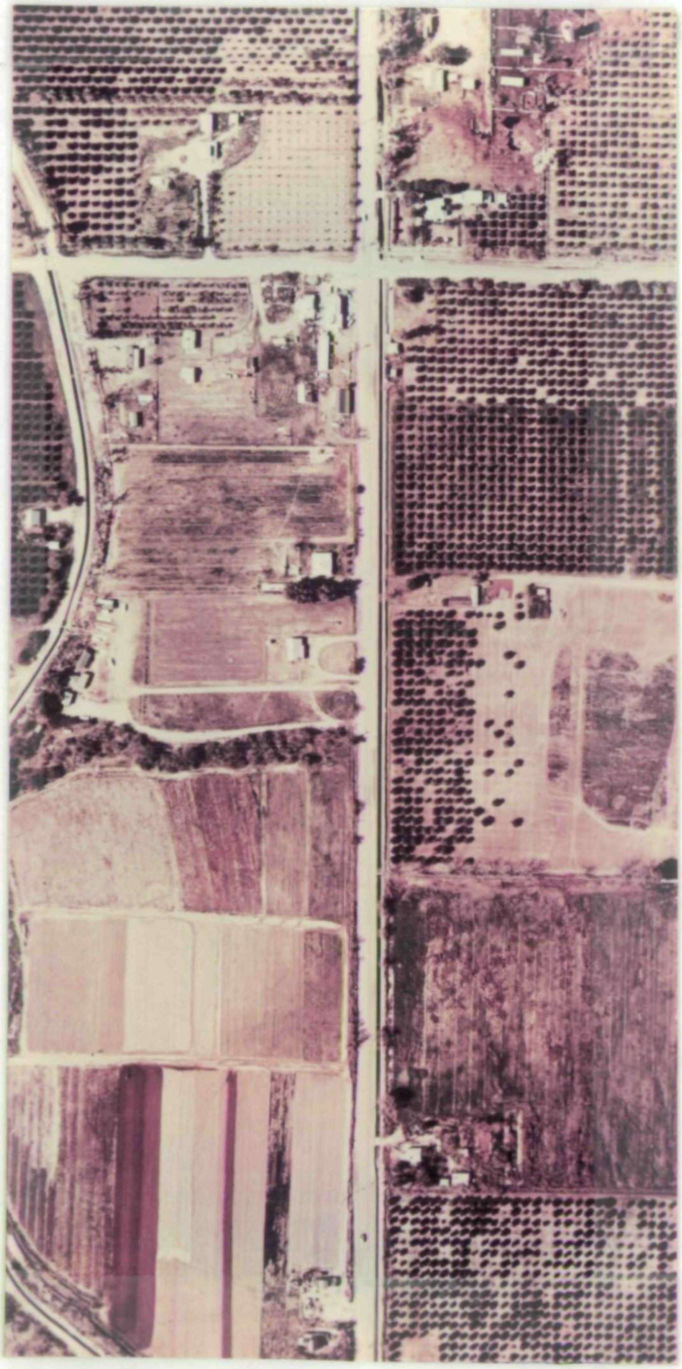
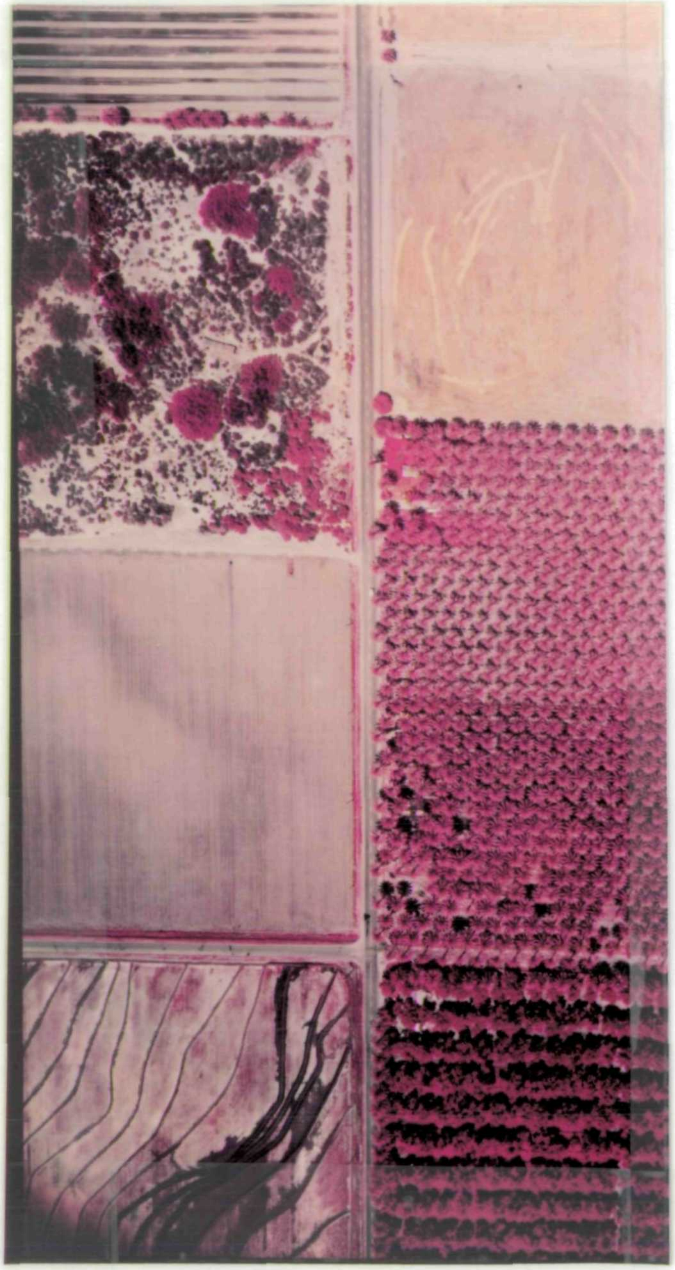


FIGURE 3A: EXAMPLES OF MULTI-SENSOR DATA

NASA/USGS Mission #73
21 May 1968
Test Site #130
Jackson Street Flight Line
Scale 1:4,000

NASA/USGS Mission #73
24 May 1968
Test Site #130
Los Angeles Pass #1
Scale 1:5,200

Color Infrared (8443)



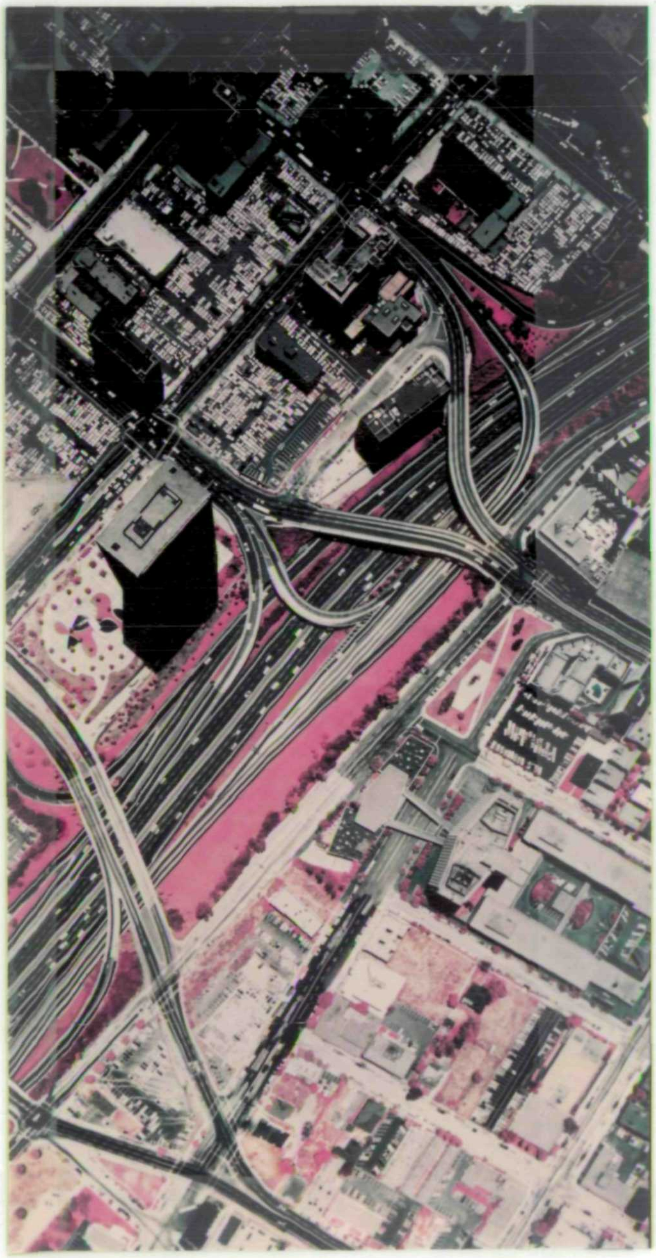
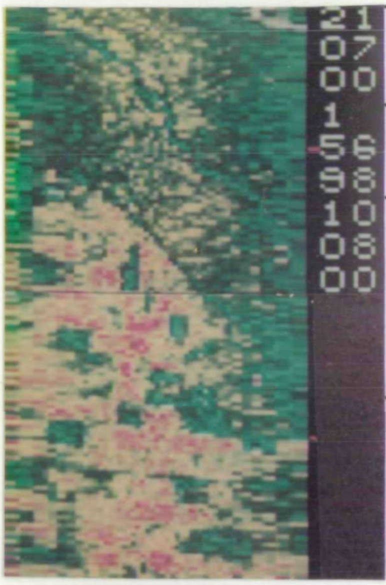


FIGURE 3B: EXAMPLES OF MULTI-SENSOR DATA

Geographic Sensor Systems

...NASA Goddard Imaging Microwave Radiometer, Side-Looking Radar (SLR), AAS-5 Ultraviolet Scanner, and Reconofax IV Thermal Infrared Scanner



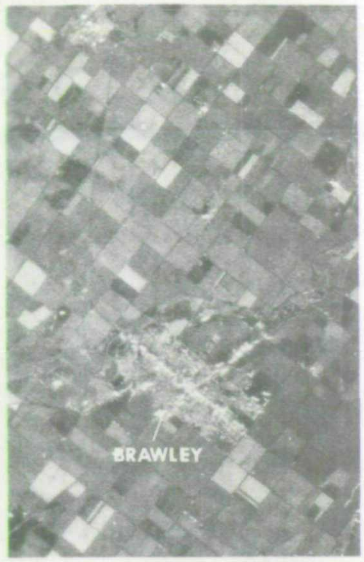
Hours
Minutes
Seconds

Day
Year

Slope
Intercept

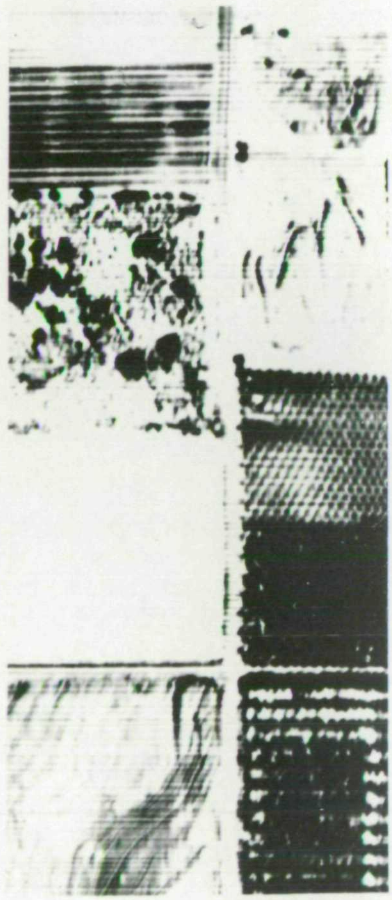
Microwave
19.35 GHz
Scale 1:262,000

SLR (X-band)
21 May 1968
Imperial Valley
Scale 1:186,000



AAS-5
.29-.5µ

RFX-IV
8-14µ



NASA/USGS Mission #73
21 May 1968
Test Site #130
Jackson Street Flight Line
Scale 1:6,100

FIGURE 3C: EXAMPLES OF MULTI-SENSOR DATA

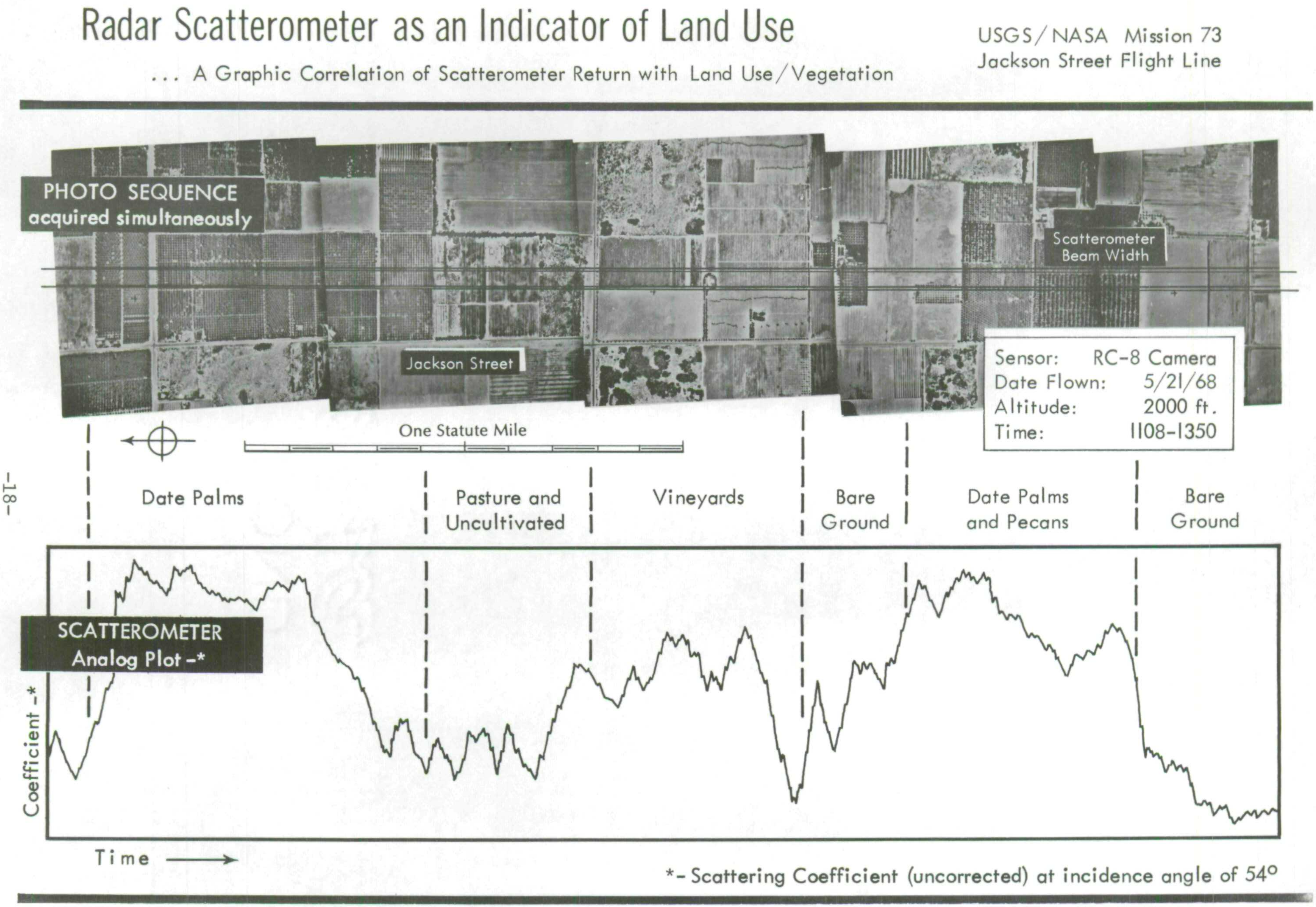


FIGURE 3D: EXAMPLES OF MULTI-SENSOR DATA

1.4.2.1 University of California - Riverside

At the University of California, Riverside (UCR), work is under way in the areas of regional studies, land use classification, soil moisture, surface energy budget, urban studies and vegetation mapping. Dr. Leonard Bowden directs the research at NASA Test Site #130 (Southern California), which was established because of its physical and cultural diversity, its critical resource problems and its high proportion of days having excellent flying weather throughout the year. Several NASA, military and commercial flights have been flown over this site, producing, perhaps, the most valuable source of data for study within the GEOGAP program. These data have also been supplemented by Gemini and Apollo photography, which makes this test site unique. Members of the UCR staff have pioneered in tests of the Kodak color infrared film (8443) for land use and housing quality studies, and the results of their film/filter combination tests are providing the data being used to construct a computerized land use classification system for the Imperial and Coachella Valleys. They are also conducting investigations in the areas of air pollution and the analysis of the effects of man on the environment of Southern California. See Table VIII for status of data pertaining to this Investigator.

1.4.2.2 University of California - Los Angeles

Students under Dr. Norman Thrower at UCLA are working on two projects. The first involves the development of a land use classification system for use in the study of urban environments, and the second is the Space Mosaic Land Use Mapping Project of a portion of southwestern United States. This work is being done with Gemini IV and V photographs, and the resulting 1:250,000 land use maps will soon be completed. These maps will then be analyzed and updated with information derived from the more recent Apollo coverage of the area. See Table IX for status of data pertaining to this Investigator.

1.4.2.3 East Tennessee State University

The Principal Investigator at East Tennessee State University (ETSU) is Dr. Robert Peplies. His work is primarily concerned with discovering the benefits that can be derived from remote sensing devices for regional analysis in the Asheville Basin of North Carolina. This area has been designated NASA Test Site #46 and was selected as being representative of a rural based economy with a wide variety of land uses. Specific studies of the area include work on rural settlement farms, population and economic traits, regional assemblages of economic-cultural types, slope failure forms, delineation of rock types from topographic expression, a study of ponds in the area, terrain morphometrics, and cultural data.

The Geography department at ETSU is unique in that it has its own Sony DVC 2400 television cameras and tape system. This unit was used during Mission 73 and, when exploited to its full advantage, could prove to be a valuable tool for the overall GEOGAP program. See Table X for status of data pertaining to this Investigator.

TABLE VIII

DATA COLLECTION AND DISTRIBUTION
UNIVERSITY OF CALIFORNIA AT RIVERSIDE

Mission	Date	Data Collected	Film	Format	Quantity	Data Distributed By NASA*	Data Analyzed By Autometric	Remarks
28	8/1/66	Reconofax IV	Tri-X	70mm	50'			
		Nikon Data Panel	Plus-X	35mm	40'			
		Magnetic Tape Data			1 Reel			
29	8/8, 12/66	RC-8	8443	9"	135'	X		
		Reconofax IV	Tri-X	70mm	50'			
		Nikon Data Panel	Plus-X	35mm	50'			
		Microwave Radiometer Strip Charts			1 Strip			
42	3/8/67	RC-8	8443	9"	60'	X		
		RC-8	8442	9"	50'	X		
56	9/6, 7-9/ 67	RC-8	8443	9"	375'			
		RS-7	5489	70mm	75'	X		
		Magnetic Tape Data			5 Reels			
73	5/21-24/68	RC-8	8401	9"	432'	X	X	
		RC-8	8443	9"	450'	X	X	
		Reconofax IV	Tri-X	70mm	200'	X	X	
		AAS-5	Tri-X	35mm	70'	X	X	
		Nikon Data Panel	Plus-X	35mm	60'			
		Microwave Radiometer Charts			10 Strips			
		Magnetic Tape Data			Several Reels			
							X	350 Frames of Hasselblad 8443 (filtered)
							X	1 roll each APQ-102 and APS-94 Radar
							X	NASA/GODDARD microwave data and TV data from E. Tenn. State

*As indicated by NASA/MSC Records (Sep 68)

TABLE IX

DATA COLLECTION AND DISTRIBUTION
UNIVERSITY OF CALIFORNIA AT LOS ANGELES

Mission	Data Collected	Film	Format	Quantity	Data Distributed By NASA*	Data Analyzed By Autometric**	Remarks
Gemini IV	Hasselblad Photographs		70mm		X	X	
Gemini V	Hasselblad Photographs		70mm		X	X	
Apollo	Hasselblad Photographs		70mm		X	X	

*As indicated by NASA/MSC Records (Sep 68)

**Viewed by Autometric Personnel at UCLA

TABLE X

DATA COLLECTION AND DISTRIBUTION
EAST TENNESSEE STATE UNIVERSITY

Mission	Date	Data Collected	Film	Format	Quantity	Data Distributed By NASA*	Data Analyzed By Autometric	Remarks
14	11/15, 17/65	Multi-Band IR	Plus-X	70mm	500'			
		RC-8	8442	9"	135'	X	X	
		RC-8	Dup.Pos.	9"	60'	X	X	
		RC-8	8443	9"	285'	X	X	
		Nikon Data Panel	Plus-X	35mm	200'			
		Magentic Tape Data (Radiometer)			5 Reels			
23	5/7, 10,19/ 66	Multi-Band IR	Plus-X	70mm	1500'	X	X	
		RC-8	Tri-X	9"	50'	X	X	
		RC-8	8442	9"	150'	X	X	
		RC-8	8443	9"	150'	X	X	
		Reconofax IV		70mm	10'	X		
		Magnetic Tape Data (Radiometer)			4 Reels	X		
						X		AAS-5 Distributed but not listed as being col-ected
34	10/10 -14 66	Multi-Band	Plus-X	70mm	1600'	X		
		Multi-Band IR		70mm	800'	X		
		RC-8	8442	9"	525'	X		
		RC-8	8443	9"	150'	X		
		Reconofax IV	TX-475	70mm	100'			
		AAS-5	TX-417	35mm	40'			
		Nikon Data Panel	Plus-X	35mm	160'			
		Microwave Radiometer Charts			17 Strips			
		Magentic Tape Data (Radiometer)			4 Reels			

*As indicated by NASA/MSC Records (Sep 68)

TABLE X (Cont'd)

DATA COLLECTION AND DISTRIBUTION
EAST TENNESSEE STATE UNIVERSITY

Mission	Date	Data Collected	Film	Format	Quantity	Data Distributed By NASA*	Data Analyzed By Autometric	Remarks
84w	9/15/65	APQ-97		9"	25'			
106w	11/10/65	APQ-97		9"	30'			
							X	Other multi-band and RC-8 imagery without logs or annotations

*As indicated by NASA/MSC Records (Sep 68)

1.4.2.4 Northwestern University

The NASA Test Sites used for urban studies are Los Angeles (Site #130), Phoenix (Site #29), New Orleans (Site #132) and Chicago (Site #43). The Principal Investigator responsible for directing activity on these sites is Dr. Duane Marble, head of the Remote Sensing Laboratory at Northwestern University.

The research conducted by Dr. Marble and his students involves investigations into the problems of urban centers and the ways in which remote sensing may prove valuable in providing data relevant to these problems. They are studying such things as the spatial relationships that play a major role in establishing the physical and functional structure of the city, the complex interactions of urban subsystems, the activities of urban planners, the lack of pertinent and reliable data about urban systems, the problems of our transportation systems, urban land use, the formulation and testing of urban models, the quality of the residential environment, air and water pollution, cost effectiveness of airborne and ground based data collection methods, movement dynamics, spectral signature versus pattern recognition, and information systems.

During Mission 73, Dr. Marble's research teams did extensive ground checking of urban sectors in Los Angeles to be used in validating information extracted from the NASA/MSC remote sensing systems. These data will be checked against data collected by such agencies as HUD, Bureau of Public Roads, Community Analysis Program of Los Angeles County Planning Commission, the U.S. Census Bureau, and others. Similar efforts have taken, or will take, place in other regional urban centers selected for study. See Table XI for status of data pertaining to this Investigator.

1.4.2.5 University of Kansas

NASA Test Sites #76 (Garden City, Kansas), #85 (Lawrence, Kansas) and #159 (Horsefly Mountain, Oregon) are administered by Dr. David Simonett, of the Center for Research in Engineering Science (CRES) at the University of Kansas.

Site #76 is a prime calibration test site for the radar and scatterometer sensor experiments. Investigations are under way in studying the influence of such crop parameters as type, height, percent ground cover, moisture content, row direction, and of the soil parameters, moisture and roughness, on the returns of side-looking radar. The site is being used to provide data for thematic land use mapping and for crop probability distribution through time. The site will eventually be used for spacecraft calibration tests.

Site #85 was selected for use in the thematic land use mapping program and also for studies relating to the discrimination of interfaces between grass, trees, cultivated land, woodland, and urban areas.

As stated in the NASA flight request form, the studies at site #159 are directed specifically to testing the value of radar in vegetation probabilistic studies, in statistical vegetation recognition, in thematic land use mapping, and, finally, in testing the degree to which radar and other sensors may usefully supplement and complement one another in land use studies. See Table XII for status of data pertaining to this Investigator.

TABLE XI

DATA COLLECTION AND DISTRIBUTION
NORTHWESTERN UNIVERSITY

Mission	Date	Data Collected	Film	Format	Quantity	Data Distributed By NASA*	Data Analyzed By Autometric	Remarks
14	11/19/65	Multi-Band IR	Plus-X	70mm	750'			
		RC-8	Tri-X	9"	75'	X		
		RC-8	8442	9"	150'	X		
		RC-8	8443	9"	150'	X		
		Nikon Data Panel	Plus-X	35mm	100'			
		Magnetic Tape (Radiometer)			6 Reels			
25	6/ 29-30/66	Multi-Band IR	Plus-X	70mm	750'	X	X	
		RC-8	Plus-X	9"	450'	X		
		RC-8	8442	9"	300'	X	X	
		RC-8	8443	9"	300'	X	X	
		Reconofax IV		70mm	55'	X		
		AAS-5	Tri-X	35mm	15'	X		
		Nikon Data Panel	Plus-X	35mm	75'			
		Magentic Tape (Radiometer)			4 Reels			
31	9/15/66	Multi-Band	Plus-X	70mm	500'	X		
		Multi-Band IR		70mm	250'	X		
		RC-8	8443	9"	150'	X		
		Reconofax IV	TX-475	70mm	25'			
		AAS-5	TX-417	35mm	25'			
		Nikon Data Panel	Plus-X	35mm	25'			
		Magnetic Tape (Radiometer)			1 Reel	X		
							X	Other Multi-Band RC-8 imagery without logs or film annotations
87w	10/10 65	APQ-97		9"	30'			
126w	7/26/66	APQ-97		9"	42'			*As indicated by NASA/MSC Records (Sep 68)

TABLE XII

DATA COLLECTION AND DISTRIBUTION
UNIVERSITY OF KANSAS

Mission	Date	Data Collected	Film	Format	Quantity	Data Distributed By NASA*	Data Analyzed By Autometric	Remarks
Site	#76:							
32		None Collected For This Site				X		Data indicated as being distributed is not listed as being collected during this mission.
54	8/5,7/67	RC-8	8443	9"	75'	X		
		Reconofax IV	TX-475	70mm	20'	X		
		AAS-5	TX-417	35mm	75'	X		
		Nikon Data Panel	Plus-X	35mm	15'			
						X		Multi-Band
61	11/13-17/67	Multi-Band	Plus-X	70mm	900'	X		
		Multi-Band IR		70mm	450'	X		
		RC-8	8443	9"	275'	X		
		Reconofax IV	Tri-X	70mm	100'	X		
		AAS-5	Tri-X	35mm	30'	X		
		Nikon Data Panel	Plus-X	35mm	50'			
		T-11	5401	9"	430'			
74	6/17, 19/68	RC-8	8442	9"	400'	X		
		RC-8	8443	9"	400'	X		
		Reconofax IV	Tri-X		50'	X		
		AAS-5	Tri-X	35mm	22'	X		
		Nikon Data Panel	Plus-X	35mm	30'			
		Magnetic Tape (Radiometer)			Several Reels			

*As indicated by NASA/MSC Records (Sep 68)

TABLE XII (Cont'd)

DATA COLLECTION AND DISTRIBUTION
UNIVERSITY OF KANSAS

Mission	Date	Data Collected	Film	Format	Quantity	Data Distributed By NASA*	Data Analyzed By Autometric	Remarks
83w	9/15/65	APQ-97		9"	32'			
127w	7/27/66	APQ-97		9"	30'			
Site	#85:							
54	8/3,7/67	RC-8	8443	9"	75'			
		Reconofax IV	TX-475	70mm	60'	X		
		AAS-5	TX-417	35mm	75'	X		
		Nikon Data Panel	Plus-X	35mm	15'			
						X		Multi-Band
61	11/12-17/67	Multi-Band	Plus-X	70mm	900'			
		Multi-Band IR		70mm	450'			
		RC-8	8442	9"	100'			
		Reconofax IV	Tri-X		100'			
		AAS-5	Tri-X	35mm	30'			
		Nikon Data Panel	Plus-X	35mm	50'			
		Microwave Radiomenter Chart			3 Strips			
74	6/17-19/68	RC-8	8442	9"	160'	X		
		Reconofax IV	Tri-X	70mm	25'	X		
		AAS-5	Tri-X	35mm	15'	X		
		Nikon Data Panel	Plus-X	35mm	15'			
		Magentic Tape			Several Reels			
81w	9/14/65	APQ-97		9"	10'			

*As indicated by NASA/MSC Records (Sep 68)

1.4.2.6 University of Georgia

At the University of Georgia, Dr. Merle Prunty is Principal Investigator for a program that is obtaining remote sensing data from controlled burning in grassland areas in order to develop a comprehensive geographical analysis of fire phenomena in Savanna areas. The NASA testing areas are called Deseret/St. Marks and designated site #165.

The long-range purposes of this research program, as stated by Dr. Prunty, are: 1) to develop an information bank that is temporally uniform and areally inclusive/extensive regarding the occurrence, distribution, type, and effects of fires on tropical Savanna grasslands; and 2) to examine findings from (1) in terms of their implications in the expansion of settlement in tropical grassland regions. See Table XIII for status of data pertaining to this Investigator.

1.4.2.7 Florida Atlantic University

At Florida Atlantic University, Dr. James Latham serves as Principal Investigator for NASA Test Site #164 (Boca Raton and Belle Glade, Florida). The research work carried out at this institution concerns multi-sensor analysis of geographical patterns of resources and land use in tropical and subtropical environments. Dr. Latham employs both traditional and electronically instrumented methods of photointerpretation with the aim of measuring and integrating data extracted from distribution patterns on the imagery, and thereby identifying and categorizing geographic land use patterns. Other research includes studies of resolution and tonal characteristics that discriminate urban and rural environments and seasonal changes of a monsoonal tropical environment. Also included in his work are electronic waveform analysis, selection of parameters for the orbital placement of earth resources satellites, determination of scale and resolution needed for identifying and measuring geographic phenomena, and analysis of Gemini photography of the Boca Raton area. See Table XIV for status of data pertaining to this Investigator.

1.4.2.8 Office of Emergency Preparedness

Mr. Harry Mallon, of the Office of Emergency Preparedness (OEP), is Principal Investigator for Test Site #132, New Orleans, La.; #133, NASA Michoud Assembly Facility; #134, NASA Slidell Computer Operations Office; and #137, NASA Mississippi Test Facility. These test sites were flown with a variety of sensors including black-and-white, color, color infrared, multiband, and thermal infrared. These and other data were analyzed by the Autometric Operation of Raytheon Company for the purpose of: 1) determining the level of detail interpretable from each type of sensor record; 2) examining industrial, urban, and other cultural activities and inspecting for unique spectral signatures; and 3) determining the applicability of each type of sensor record to functional and structural analysis and to the post-emergency analysis of earthquake damage.

The conclusions derived with respect to the specific objectives of the assessment were: 1) that, since the level of detail observed is a function of resolution and contrast, the black-and-white photography, having the largest scale,

TABLE XIII

DATA COLLECTION AND DISTRIBUTION
UNIVERSITY OF GEORGIA

Mission	Date	Data Collected	Film	Format	Quantity	Data Distributed By NASA*	Data Analyzed By Autometric	Remarks
964	1/5/68	RC-8	8443	9"	150'	X		
		Reconofax IV		70mm	15'	X		
		T-11	8442	9"	200'	X		
		Nikon Data Panel	Plus-X	35mm	25'			
		Magnetic Tape (Radiometer)			2 Reels			
67	3/1/68	RC-8	8442	9"	263'	X		
		RC-8	8443	9"	298'	X		
		RC-8	8443	9"	200'	X		
		Reconofax IV	Tri-X	70mm	75'	X		
		Nikon Data Panel	Plus-X	35mm	90'	X		
		Microwave Radiometer Chart			25 Strips	X		
						X		T-11

*As indicated by NASA/MSC Records (Sep 68)

TABLE XIV

DATA COLLECTION AND DISTRIBUTION
FLORIDA ATLANTIC UNIVERSITY

Mission	Date	Data Collected	Film	Format	Quantity	Data Distributed By NASA*	Data Analyzed By Autometric	Remarks
66	2/5-8/68	RC-8	8442	9"	200'	X		
		RC-8	8442	9"	200'	X		
		RC-8	8443	9"	200'	X		
		Reconofax IV	Tri-X	70mm	100'	X		
		T-11	5401	9"	183'			
		T-11	5401	9"	185'			
		Nikon Data Panel	Plus-X	35mm	40'			
		Microwave Radiometer Charts			11 Strips			
		Magnetic Tape Data (Radiometer)			4 Reels			

*As indicated by NASA/MSC Records (Sep 68)

proved to be the most efficient sensor where the detection of fine detail was the objective; 2) that the results of the search for exclusive spectral signatures were inconclusive; 3) that large scale and good resolution were the principal factors affecting functional and structural analysis; 4) that oblique photography is a most useful adjunct to vertical photography in determining the extent and severity of earthquake damage; 5) that color infrared and thermal infrared are the best sensors for locating, respectively, chemical and thermal water pollution; 6) that the multiband camera shows promise in determining the unique signatures of roof materials; and 7) that thermal infrared imagery shows promise of applicability in examination of tank contents for fluid level detection.

On the basis of these conclusions it was recommended: 1) that color IR, thermal IR, and multiband imagery be acquired over sites that are known to exhibit a variety of spectral signatures; 2) that the use of side-looking radar for the assessment of flood damage be investigated; 3) that the use of a trimetrogon or panoramic photographic system for providing structural and compositional data be determined; 4) that the capabilities of satellite imagery be studied; 5) that consideration be given to the establishment of an OEP data base; 6) that more consideration be given to the use of original negatives and sensitometry data in order to better quantify data reduction results; and 7) that efforts be made to convert analyzed data into a format compatible with the National Resource Evaluation Center's computer simulation programs.[2] See Table XV for status of data pertaining to this Investigator.

---

[2] Mr. Mallon's activities have been dealt with in somewhat greater detail than those of the other Principal Investigators because they are less diffuse and have been documented in a single report, prepared by Autometric Operation: Huffman, E. T., Bay, C. A., and Pascucci, R. F., Analysis of Multi-Sensor Data for Office of Emergency Preparedness Purposes, Alexandria, Virginia, December 1968.

TABLE XV

DATA COLLECTION AND DISTRIBUTION
OFFICE OF EMERGENCY PREPAREDNESS

Mission	Date	Data Collected	Film	Format	Quantity	Data Distributed By NASA*	Data Analyzed By Autometric	Remarks
Site	#132:							
40	2/24/67	RC-8	8442	9"	25'	X	X	
						X		Reconofax IV, AAS-5, and Microwave also indicated as being distributed, but not as being collected.
							X	Reconofax IV
62	12/6 67	RC-8	8443	9"	150'	X	X	
		Reconofax IV	Tri-X	70mm	25'	X	X	
		Nikon Data Panel	Plus-X	35mm	65'			
							X	Multi-Band
66	2/5-10/68	RC-8	8443	9"	100'	X	X	
		T-11	5401	9"	168'	X	X	
		Reconofax IV	Tri-X	70mm	69'	X		
						X		Nikon Data Panel
							X	Also viewed data from Mission #81 (11/11/68).
Site	#133							
40						X		RC-8, Reconofax IV, AAS-5 and Microwave Data indicated as being distributed but not collected.

*As indicated by NASA/MSC Records (Sep 68)

TABLE XV (Cont'd

DATA COLLECTION AND DISTRIBUTION
OFFICE OF EMERGENCY PREPAREDNESS

Mission	Date	Data Collected	Film	Format	Quantity	Data Distributed By NASA*	Data Analyzed By Autometric	Remarks
							X	RC-8 (8442)
							X	Reconofax IV (Tri-X)
62	12/6/	RC-8	8443	9"	150'		X	
	67	Reconofax IV	Tri-X	70mm	25'	X	X	
		Nikon Data Panel	Plus-X	35mm	65'	X		
						X	X	Multi-Band
Site	#134:							
40						X		Same As Site #133
								Mission #40
							X	RC-8 (8442)
							X	Reconofax IV (Tri-X)
62	12/6/	RC-8	8443	9"	150'		X	
	67	Reconofax IV	Tri-X	70mm	25'	X	X	
		Nikon Data Panel	Plus-X	35mm	65'	X		
						X	X	Multi-Band
Site	# 137:							
40						X		Same As Site #134
								Mission #40
							X	RC-8 (8442)
							X	Reconofax IV (Tri-X)
62	12/6/	RC-8	8443	9"	150'		X	
	67	Reconofax IV	Tri-X	70mm	25'	X	X	
		Nikon Data Panel	Plus-X	35mm	65'	X		
						X	X	Multi-Band

*As indicated by NASA/MSC Records (Sep 68)

2. DATA ANALYSIS

2.1 Land Use Classification System

2.1.1 Objective

A uniform and systematic nomenclature, while a useful tool in any endeavor, would be especially welcome to geographers working with remote sensors. It would provide, not only a common framework within which to categorize observed phenomena, but would also order and expedite the process of categorization and, therefore, the entire process of data reduction. Our objective, therefore, has been to design a land use classification system applicable to the Continental United States that will satisfy these needs.

2.1.2 Approach

The initial approach to the problem was to conduct a search of the literature in order to find the classification system best suited to the needs of geographers working with remote sensors. It quickly became apparent that the existing systems were not adequate to the needs of such geographers, since they were either limited in their coverage of subject or area, or, if comprehensive, they were compiled from the point of view of the ground surveyor, viewing the world in section, rather than from that of the remote sensor, viewing the world in plan. See Table XVI for a list of the classification systems consulted. The first reaction to this discrepancy was that the difference was in the level of resolution, the ground surveyor being able to resolve finer levels of detail than could be identified on the best large-scale vertical photography. If this were the case, all that would be necessary to make the system useful would be to move upward through the hierarchy of classification until a level was reached at which the elements of information that characterized a particular hierarchical entity could be identified on a vertical aerial photograph. The problem is not to be solved in this way, however, because the classifications for use by ground surveyors are based on conceptual, not perceptual, gradations. To the ground surveyor the system need only be conceptually logical in order to be workable. Perception does not enter his calculations because it is an *a posteriori* factor that can be taken for granted; he can always identify, say, a "Retail Store, Automotive" by looking in the showroom window. The investigator working with remote sensors, however, will be forever denied the ability to make this identification, not because the critical element of information - the automobile - is too small to be resolved by his sensor, but because it is covered by a roof. It was necessary, therefore, to devise a classification system the hierarchies of which were not only logical but perceptual.

The approach taken was logical-eclectic-empirical. The logic consisted in postulating criteria for inclusion of units in the system and for establishing a scheme of hierarchy. The criteria for admission of a land usage were two: 1) it must be of present or potential interest to a geographer; and 2) it must be verifiable, most of the time, on large-scale vertical, aerial photography. There are obvious subjective elements in both of these criteria; the only defense to be made is that each land use element included represents the best judgment of a panel of experienced geoscientists.

TABLE XVI

LAND USE CLASSIFICATION SYSTEMS CONSULTED

Bureau of the Budget, 1960, Standard Industrial Classification Manual, U.S. Government Printing Office, Washington, D. C.

Bushnell, T. M., 1951, "Use of Aerial Photography for Indiana Land Use Studies," Photogrammetric Engineering, Vol. 17, No. 5.

Center for Aerial Photographic Studies, 1968, New York State Land Use and Natural Resources Inventory, Cornell University, Ithaca, New York, 60 p.

Clawson, M., and Stewart, C. L., Land Use Information, The Johns Hopkins Press, Baltimore, Md., 402 p.

Division of Industrial Development and Planning, undated, Luray, Virginia Land Use Plan, Commonwealth of Virginia, 40 p.

Goodmen, M. J., 1959, "A Technique for the Identification of Farm Crops on Aerial Photographs," Photogrammetric Engineering, Vol. 25, No. 1.

Klimm, L. E., 1958, "Description of a Land Use Map of Pennsylvania," University of Pennsylvania, Philadelphia, Pa., 7 p.

Kohn, C. F. 1952, "An Essay Key for the Photoidentification of Farm Crops at Several Intervals During the Growing Season in Northern Illinois," Northwestern University, Evanston, Illinois, 26 p.

Reconnaissance Data Extraction Branch, 1965, Master Target List, Rome Air Development Center, Griffiss Air Force Base, New York 28 p.

Urban Renewal Administration and Bureau of Public Roads, 1965, Standard Land Use Coding Manual, U.S. Government Printing Office, Washington, D. C., 111 p.

The hierarchy was established according to the level of detail required for identification, keeping in mind a range of scales from about 1:4,000 to about 1:1,000,000.

The eclectic aspect of the approach consisted of searching out, from existing classification systems, those land uses that satisfied the criteria for inclusion. The three most fruitful sources in this search were the Master Target List, compiled by the Rome Air Development Center, which was most valuable in providing kinds of industrial land use; The New York State Land Use and Natural Resources Inventory, used by Cornell University, which was designed to be used by photointerpreters; and the NASA Flight Request Forms, in which the Principal Investigators listed or suggested the land uses in which they were most interested.

Finally, the empirical elements were supplied by Autometric geoscientists who, in analyzing sensor records from nine NASA missions[3] covering a wide range of climatologic, physiographic, and economic regions, noted many land uses that were not listed in existing systems and that would have been overlooked in a purely hypothetical approach.

The resulting land use classification system, shown in Table XVII is, we believe, the most complete one extant and potentially the most useful to geographers working within the framework of the Earth Resources Program. It should not, however, be regarded as a finished product. Quite the contrary; it would best serve its purpose if it were accepted as a point of departure and debate, a nucleus upon which to build as well as a stimulus to build.

[3] Missions 14, 19, 23, 25, 40, 62, 66, 73 and 81.

TABLE XVII

LAND USE CLASSIFICATION SYSTEM

CODE	ELEMENTS OF INFORMATION
1000	VEGETATION
1100	Agriculture (includes all farming activity)
1110	Tree Crops
1120	Field Crops (grain, fodders, etc.)
1130	Row Crops (vegetables, small fruits, etc.)
1140	Pasture
1150	Stock Feed Lot
1160	Inactive Land
1161	Fallow
1162	Reverting to Natural State
1170	Horticulture or Floriculture (nurseries, sod, and feed farms)
1180	Stock Operations
1190	Poultry Operations
11100	Specialty Farms
11110	Agricultural Storage (grain elevators, cribs etc.)
1200	Forest (>50% cover by trees >30 feet in height)
1210	Coniferous
1220	Deciduous
1230	Mixed Coniferous & Deciduous
1300	Open Forest (<50% & > 10% cover by trees > 30 feet in height)
1310	Coniferous
1320	Deciduous
1330	Mixed Coniferous & Deciduous
1400	Forest Brushland (< 50% & > 10% cover by vegetation < 30 feet in height)
1500	Brush & Grassland (weeds, mesquite, tundra growth, etc.)
1600	Savanna
	Modifiers to be subsumed under any applicable number beginning with 11-16.
0001	Species
0002	Height
0003	Moisture Content
0004	% Ground Cover
0005	Stand Density (forests)
0006	Row Direction
0007	Diseased, Dead, or Dormant
0008	Pyrogenic Area

TABLE XVII (Cont'd)

LAND USE CLASSIFICATION SYSTEM

CODE	ELEMENTS OF INFORMATION
2000	URBAN
2100	Commercial
2110	Central Business District
2120	Frame
2130	Middle City
2140	Strip Development
	Modifiers to be subsumed under any applicable number beginning with 21.
0001	Shopping Center
0002	Office Space
0003	Commercial Resort
0004	Commercial Storage
0005	Vacant
2200	Residential
2210	Suburb
2220	Fringe Zone
2230	Exurb
2240	Satellite
2250	Urban-Rural Transition Zone
	Modifiers to be subsumed under any applicable number beginning with 22.
0001	Single Family Structure
0002	Multiple Family Structure (exclusive of hotels or motels)
0003	High Density (lots less than 1/8 acre)
0004	Medium Density (lots > 1/8 < 1/2 acre)
0005	Low Density (lots > 1/2 acre)
0006	Residential Estates (greater than 5 acres)
0007	Strip Development (> 1/2 acre)
0008	Hamlet or Village
0009	Farm Labor Camp
00010	Cottages & Vacation Homes
00011	Hotel & Motel
00012	Trailer Park (> 3 trailers)
00013	Rural Non-Farm Residences

TABLE XVII (Cont'd)

LAND USE CLASSIFICATION SYSTEM

CODE	ELEMENTS OF INFORMATION
	Modifiers to be subsumed under any applicable number beginning with 22.
000001	Low Income Housing
000002	Middle Income Housing
000003	High Income Housing
2300	Industrial
2310	Extraction Industry
2311	Open Pit Mining
2312	Stripping Operation (including mining and lumbering)
2313	Shaft and Drift Mining
2314	Wells
2320	Processing Industry
2321	Chemical Processing (exclusive of water and sewage treatment)
23211	Organic
23212	Inorganic
2322	Mechanical Processing
2330	Fabrication
2330	Heavy
2332	Light
2340	Industrial Storage (POL, warehouse, open)
2350	Vacant
3000	WATER (with associated control structures)
3100	Natural Pond or Lake
3200	Artificial Pond, Lake or Reservoir
3300	Non-Navigable Streams
3400	Navigable River
3500	Canal (other than Barge Canal, see 4400)
3600	Marshland, Shrub Wetland, Wooded Wetland or Bog
3700	Intermittent Stream
3800	Ephemeral Pond or Lake
3900	Flood Control Structures (dams, dikes, levees)
4000	TRANSPORTATION
4100	Highways (with associated facilities)
4110	Limited Access Highway
4120	Lane Highway (4 lanes)

TABLE XVII (Cont'd)

LAND USE CLASSIFICATION SYSTEM

CODE	ELEMENTS OF INFORMATION
4130	Lane Highway (2-3 lanes)
4140	Urban Street
4150	Unimproved Gravel or Minor Paved Roads
4160	Interchange (ramp & cloverleaf)
4170	Service, Terminal or Freight Facility
4180	Parking Facility
4190	Bridge
41100	Tunnel
	Modifiers to be subsumed under any applicable number beginning with 41
0001	Concrete Composition
0002	Asphalt Composition
0003	Unconsolidated Road Metal
0004	Unpaved
4200	Railways
4210	Main Track
4220	Spur
4230	Marshalling Yard
4240	Station & Structures
	Modifiers to be subsumed under any applicable number beginning with 42
0001	Single Track
0002	Double Track
4300	Airfields
4310	Commercial Aircraft
4320	Non-Commercial Airfield, (private, flying farmer)
4330	Military
4400	Barge Canal
5000	RECREATIONAL
5100	Golf Course
5200	Skiing and Other Winter Sports
5300	Public and Commercial Swimming Pools
5400	Developed Beaches

TABLE XVII (Cont'd)

LAND USE CLASSIFICATION SYSTEM

CODE	ELEMENTS OF INFORMATION
5500	Marinas and Yacht Clubs
5600	Camping Grounds
5700	Stadiums
5800	Drive-In Theaters
5900	Race Tracks
51000	Amusement Parks
51100	Fairgrounds
51200	Public Parks (urban)
51300	Playgrounds
6000	CIVIC AND INSTITUTIONAL
6100	Educational Institutions
6200	Religious Institutions
6300	Health Institutions
6400	Correctional Institutions
6500	Military Bases
6600	Armories
6700	Cemeteries
7000	UTILITIES AND COMMUNICATIONS
7100	Waste Disposal
7110	Sewerage
7120	Solid Waste (dumps, junkyards & landfill)
7200	Drinking Water Supply
7210	Treatment
7220	Storage (reservoirs, including covered)
7230	Transmission (excluding under ground)
7300	Gas & Oil Transmission (above ground)
7310	Pumping Station
7320	Transmission Pipelines
7400	Electrical & Electromagnetic Transmission
7410	Electrical Power Transmission Lines
7420	Utility Lines
7430	Microwave Transmission & Navigation Station
7440	TV - Radio Transmission Tower
8000	NON-PRODUCTIVE LAND

2.2 Sensor Capability in Land Use Identification

2.2.1 Objectives

A land use classification system having been selected, the way was then open for determining the capability of sensors to provide the information necessary for the identification of each land use element of information. An element of information is herein defined as a unit of data that must be identified in order to carry out a study.

2.2.2 Approach

Eight sensors were selected for analysis on the basis of two criteria: 1) that they have already proven, or are likely to soon prove, useful in the Earth Resources Program; and 2) that they have been sufficiently well studied by Autometric personnel to allow for the passing of reliable judgments as to their capability. (All of the sensors except the laser had been thoroughly analyzed in examples from the nine NASA Missions referenced above. The laser is not a part of the NASA Aircraft Program.)

The sensors, having been agreed upon, were rated by a panel of three, with backgrounds in geoscience and military image interpretation. The experience of the men in these fields was ten years, seven years and seven years, respectively, and included the mapping from imagery of geology, hydrology, forestry, agriculture, urban features and water pollution, as well as general land use mapping. They were also involved in making the first interpretation manuals of their kind for side-looking radar and for a mechanical-optical laser recorder.

The sensors were rated on an arbitrary point scale in which 4 = excellent, 3 = good, 2 = fair, 1 = poor, and 0 = unusable. The ratings are shown in Table XVIII, opposite the elements of land use. Each rating is the result of a majority decision by the three panelists. In filling the matrix represented by Table XVIII, 1296 decisions were made by each panelist (eight [sensors] times one hundred sixty-two [land use elements]). Of this number nine hundred fifty three, or 73.5%, were unanimous. (Random unanimity would be 4%.) In no case was there disagreement by more than one category; i.e., at least two of the three decisions were always in agreement and the third never disagreed by more than one increment upwards or downwards.

Each decision was made on an open, rather than secret, basis so that, in the event of disagreement, each panelist had the opportunity to justify his vote by presenting examples in the imagery. This method fostered a lively give-and-take atmosphere and promoted a constant resort to the imagery that prevented making a decision lightly, with insufficient evidence.

In all cases decisions were made on the basis of "good quality" imagery at the scales and of the instrument and film types specified in Table XVIII. This explains the high ratings assigned to the television and laser, which were considered at operational scales. The TV system studied for this report was the Sony DVC 2400, the small hand-held camera that was used in Mission 73.

TABLE XVIII

SENSOR CAPABILITY - LAND USE

CODE	LAND USE ELEMENTS OF INFORMATION	SENSORS							
		B & W 1:10,000	COLOR (8442) 1:10,000	CIR (8443) 1:10,000	IR 1:5,000	SLR 1:100,000	UV 1:5,000	TV 1:1,000	LASER 1:2,000
1000	VEGETATION	4	4	4	3	3*	1*	4	4
1100	Agriculture (includes all farming activity)	4	4	4	3*	3*	1*	3*	4
1110	Tree Crops	4	4	4	3*	2*	0	4	4
1120	Field Crops (grain, fodders, etc.)	3	4	4	2*	1	0	3	3
1130	Row Crops (vegetables, small fruits, etc.)	3*	4*	4*	2	0	0	3*	3
1140	Pasture	2*	3*	3*	0	0	0	2	2*
1150	Stock Feed Lot	3*	3*	3*	0*	0*	0*	2*	3*
1160	Inactive Land	3*	3*	3*	1*	0*	0*	2*	2*
1161	Fallow	3*	4*	4*	1	0	0	2*	2*
1162	Reverting to Natural State	3*	3*	3*	1*	0	0	2*	3*
1170	Horticulture or Floriculture (nurseries, sod and feed farms)	2	3	3	0*	0	0	2	2
1180	Stock Operations	3	3*	3*	1*	0	0	3	3
1190	Poultry Operations	3	3*	3*	1*	0	0	3	3
11100	Specialty Farms	3*	3*	3*	1*	0	0	3*	3
11110	Inactive Farmsteads	2*	2*	2*	0	0	0	2	2
11120	Agricultural Storage (grain elevators, cribs etc.)	3	3*	3*	1*	1	0	3	3
	TOTALS	[48]	[52]	[52]	[20]	[10]	[2]	[43]	[46]
1200	Forest (>50% cover by trees >30 feet in height)	4	4	4	3*	2*	0	4	4
1210	Coniferous	3*	4	4	2	2	0	3*	4*
1220	Deciduous	3*	4	4	2	2	0	3*	4*
1230	Mixed Coniferous & Deciduous	3*	4	4	2	2	0	3*	4*
	TOTALS	[13]	[16]	[16]	[9]	[8]	[0]	[13]	[16]

*Lack of Unanimity

TABLE XVIII (Cont'd)

CODE	LAND USE ELEMENTS OF INFORMATION	SENSORS: B & W 1:10,000	COLOR (8442) 1:10,000	CIR (8443) 1:10,000	IR 1:5,000	SLR 1:100,000	UV 1:5,000	TV 1:1,000	LASER 1:2,000
1300	Open Forest (< 50% & > 10% cover by trees > 30 feet in height)								
1310	Coniferous	3*	4	4	2	2	0	3*	4*
1320	Deciduous	3*	4	4	2	2	0	3*	4*
1330	Mixed Coniferous & Deciduous	3*	4	4	2	2	0	3*	4*
	TOTALS	[12]	[16]	[16]	[8]	[8]	[0]	[12]	[16]
1400	Forest Brushland (< 50% & > 10% cover by vegetation < 30 feet in height)	3*	4*	4*	2*	2*	0	3*	3*
1500	Brush & Grassland (weeds, mesquite, tundra growth, etc.)	2*	2*	2*	1*	0*	0	2*	2
1600	Savanna	3*	4*	4*	1*	1	0	3*	3
	Modifiers to be subsumed under any applicable number beginning with 11 - 16.								
0001	Species	1	2	2	0	0	0	1	1
0002	Height	3*	3*	3*	0	0	0	1*	1*
0003	Moisture Content	0	1	1	1	0	0	0	0
0004	% Ground Cover	4	4	4	3*	2*	1*	4	4
0005	Stand Density (forests)	4	4	4	3*	3*	1	4	4
0006	Row Direction	4	4	4	3	1	0	4*	4
0007	Diseased, Dead, or Dormant	2	3	4	2*	0	0	2	2
0008	Pyrogenic Area	3	4	4	1	0*	0	2*	2
	TOTALS	[21]	[25]	[26]	[13]	[6]	[1]	[18]	[18]

* = Lack of Unanimity

TABLE XVIII (Cont'd)

CODE	LAND USE ELEMENTS OF INFORMATION	SENSORS B & W 1:10,000	Color (8442) 1:10,000	CIR (8443) 1:10,000	IR 1:5,000	SLR 1:100,000	UV 1:5,000	TV 1:1,000	Laser 1:2,000
2000	URBAN	4	4	4	4	4	3*	4	4
2100	Commercial	4	4	4	3*	1	0	4	4
2110	Central Business District	4	4	4	3	3*	1*	4	4
2120	Frame	3	3	3	2	0	0	3	3
2130	Middle City	3	3	3	2	3	1	3	3
2140	Strip Development	4	4	4	2	2	0	4	4
	TOTALS	[22]	[22]	[22]	[16]	[13]	[5]	[22]	[22]
	Modifiers to be subsumed under any applicable number beginning with 21.								
0001	Shopping Center	4	4	4	3	2	0	4	4
0002	Office Space	1*	1*	1*	0	0	0	1	0
0003	Commercial Resort	4	4	4	2*	1	0	4	4
0004	Commercial Storage	4	4	4	2	2*	0	4	3
0005	Vacant	4	4	4	2*	1	0*	4	4
	TOTALS	[17]	[17]	[17]	[9]	[6]	[0]	[17]	[15]
2200	Residential	4	4	4	3	2	1	4	4
2210	Suburb	3	4	4	2*	1*	0*	3*	3
2220	Fringe Zone	3	4	4	2*	1*	0*	4	4
2230	Exurb	3*	3*	3*	1	0	0	3	3
2240	Satellite	4	4	4	3	3	2	4	4
2250	Urban-Rural Transition Zone	4	4	4	3	3	2	4	4
	TOTALS	[21]	[23]	[23]	[14]	[10]	[5]	[22]	[22]
	Modifiers to be subsumed under any applicable number beginning with 22.								

* = Lack of Unanimity

TABLE XVIII (Cont'd)

CODE	LAND USE ELEMENTS OF INFORMATION	SENSORS B & W 1:10,000	Color (8442) 1:10,000	CIR (8443) 1:10,000	IR 1:5,000	SLR 1:100,000	UV 1:5,000	TV 1:1,000	Laser 1:2,000
0001	Single Family Structure	3	3	3	1	1*	0*	3	3
0002	Multiple Family Structure (exclusive of hotels or motels)	3	3	3	1	1*	0	3	3*
0003	High Density (lots less than 1/8 acre)	4	4	4	2*	1	1	4	4
0004	Medium Density (lots > 1/8 < 1/2 acre)	4	4	4	2*	1	1	4	4
0005	Low Density (lots > 1/2 acre)	4	4	4	3	1	1	4	4
0006	Residential Estates (greater than 5 acres)	4	4	4	3	0	0	4	4
0007	Strip Development (> 4 residences/1000 feet)	4	4	4	3	2	1	4	4
0008	Hamlet or Village	4	4	4	4*	3	0*	4	4
0009	Farm Labor Camp	3	3	3	0	0	0	3	3
00010	Cottages & Vacation Homes	3	3	3	1*	0*	0	3	3
00011	Hotel & Motel	2	2	2	0	0	0	2	2
00012	Trailer Park (> 3 trailers)	4	4	4	1	0	0	4	4
00013	Rural Non-Farm Residences	2*	2*	2*	0*	0	0	2	2
	TOTALS	[44]	[44]	[44]	[21]	[10]	[4]	[44]	[44]
	Modifiers to be subsumed under any applicable number beginning with 22.								
000001	Low Income Housing	3*	3*	4	1*	0*	0	3	3*
000002	Medium Income Housing	3*	3*	4	1*	0*	0	3	3*
000003	High Income Housing	3*	3*	4	1*	0*	0	3	3*
	TOTALS	[9]	[9]	[12]	[3]	[0]	[0]	[9]	[9]
2300	Industrial	4	4	4	3	2*	1	4	4
2310	Extraction Industry	4	4	4	3	3	0*	4	4
2311	Open Pit Mining	4	4	4	3*	3*	0	4	4
2312	Stripping Operation (including mining & lumbering)	4	4	4	3	3	1	4	4
2313	Shaft and Drift Mining	4	4	4	2	0	0	4	4
2314	Wells	4	4	4	2*	2*	0*	4	4
2320	Processing Industry	4	4	4	3	1	0	4	4
2321	Chemical Processing (exclusive of water and sewage treatment)	4	4	4	3*	1*	0	4	4

* = Lack of Unanimity

TABLE XVIII (Cont'd)

CODE	LAND USE ELEMENTS OF INFORMATION	SENSORS B & W 1:10,000	COLOR (8442) 1:10,000	CIR (8443) 1:10,000	IR 1:5,000	SLR 1:100,000	UV 1:5,000	TV 1:1,000	LASER 1:2,000
23211	Organic	4	4	4	2*	1*	0	4	4
23212	Inorganic	4	4	4	2*	1*	0	4	4
2322	Mechanical Processing	4	4	4	2	1	0	4	4
2323	Heat Processing	4	4	4	3*	1	0	4	4
2330	Fabrication	4	4	4	3	1	0	4	4
2331	Heavy	4	4	4	2	1*	0	4	4
2332	Light	1*	1*	1*	1	1	0	1*	1*
2340	Industrial Storage (POL, warehouse, open)	4	4	4	3*	2	0	4	4
2350	Vacant	4	4	4	2	1	0	4	4
	TOTALS	[65]	[65]	[65]	[42]	[25]	[2]	[65]	[65]
3000	WATER (with associated control structures)	4	4	4	4	4	0*	4	4
3100	Natural Pond or Lake	4	4	4	4	3	0	4	4
3200	Artificial Pond, Lake, or Reservoir	4	4	4	4	3	0	4	4
3300	Non-Navigable Streams	3*	3*	3*	2*	1*	0*	3*	3*
3400	Navigable River	3*	3*	3*	2*	1*	0*	3*	3*
3500	Canal (other than Barge Canal, see 4400)	4	4	4	3	1	0	4	4
3600	Marshland, Shrub Wetland, Wooded Wetland or Bog	4*	4	4	2*	2	0	3	3
3700	Intermittent Stream	3*	3	3	2	1	0	2	2
3800	Ephemeral Pond or Lake	3*	4*	4*	2*	3*	0*	3	3*
3900	Flood Control Structures (dams, dikes, levees)	4*	4*	4*	2*	1*	0	4*	4*
	TOTALS	[36]	[37]	[37]	[27]	[20]	[0]	[34]	[34]
4000	TRANSPORTATION	4	4	4	4	3	2*	4*	4
4100	Highways (with associated facilities)	4	4	4	3	3*	1*	4*	4
4110	Limited Access Highway	4	4	4	4*	2	1*	4	4
4120	Lane Highway (4 lanes)	4	4	4	1*	1	0	4	4
4130	Lane Highway (2 - 3 lanes)	4	4	4	2*	1	0	4	4
4140	Urban Street	4	4	4	3	2*	1	4	4

* = Lack of Unanimity

TABLE XVIII (Cont'd)

CODE	LAND USE ELEMENTS OF INFORMATION	SENSORS: B & W 1:10,000	COLOR (8442) 1:10,000	CIR (8443) 1:10,000	IR 1:5,000	SLR 1:100,000	UV 1:5,000	TV 1:1,000	LASER 1:2,000
4150	Unimproved Gravel or Minor Paved Roads	3*	4	4	1	0	0	3	3
4160	Interchange (ramp & cloverleaf)	4	4	4	4	3	1*	4	4
4170	Service, Terminal or Freight Facility	3*	3*	3*	1*	0	0	2*	2*
4180	Parking Facility	3	4*	4*	1	1	0	3*	3
4190	Bridge	4	4	4	4	3	1*	4	4
41100	Tunnel	4	4	4	2*	1	0	4*	4
	TOTALS	[45]	[47]	[47]	[31]	[20]	[7]	[44]	[44]
	Modifiers to be subsumed under any applicable number beginning with 41								
0001	Concrete Composition	3	3	3	2	0	0	3	3
0002	Asphalt Composition	3	3	3	2	0	0	3	3
0003	Unconsolidated Road Metal	2*	2*	3*	1	0	0	2	2
0004	Unpaved	2*	3*	3*	1	0	0	2	2
	TOTALS	[10]	[11]	[12]	[6]	[0]	[0]	[10]	[10]
4200	Railways								
4210	Main Track	4	4	4	2	2	0	4	4
4220	Spur	4	4	4	2*	2*	0	4	4
4230	Marshalling Yard	4	4	4	1*	1*	0	4	4
4240	Station & Structures	4	4	4	2	4	0	4	4
		4	4	4	1*	0	0	4	4
	TOTALS	[20]	[20]	[20]	[8]	[9]	[0]	[8]	[8]
	Modifiers to be subsumed under any applicable number beginning with 42								

* = Lack of Unanimity

TABLE XVIII (Cont'd)

CODE	LAND USE ELEMENTS OF INFORMATION	SENSORS: B & W 1:10,000	COLOR (8442) 1:10,000	CIR (8443) 1:10,000	IR 1:5,000	SLR 1:100,000	UV 1:5,000	TV 1:1,000	LASER 1:2,000
0001	Single Track	4	4	4	2*	2*	0	4	4
0002	Double Track	4	4	4	2*	2*	0	4	4
	TOTALS	[8]	[8]	[8]	[4]	[4]	[0]	[8]	[8]
4300	Airfields	4	4	4	4	4	1*	4	4
4310	Commercial Aircraft	4	4	4	3	3*	0	4	4
4320	Non-Commercial Airfield, (private, flying farmer)	4*	4*	4*	2	1	0	3*	3
4330	Military	4	4	4	3	3*	0	4	4
	TOTALS	[16]	[16]	[16]	[12]	[11]	[1]	[15]	[15]
4400	Barge Canal TOTAL	[4]	[4]	[4]	[2]	[2*]	[0]	[4]	[4]
5000	RECREATIONAL	4	4	4	2	1	0	4*	4*
5100	Golf Course	4	4	4	3	0*	0	4	4
5200	Skiing and Other Winter Sports	4*	4*	4*	1*	1*	0	4*	4
5300	Public and Commercial Swimming Pools	4	4	4	1*	0	0	4	4
5400	Developed Beaches	4	4	4	1	0	0	4	4
5500	Marinas and Yacht Clubs	4	4	4	4	2	0	4	4
5600	Camping Grounds	2	2	2	1	0	0	2	2
5700	Stadiums	4	4	4	3	2	0	4	4
5800	Drive-In Theaters	4	4	4	3	1*	0	4	4
5900	Race Tracks	4	4	4	3	2*	0	4	4
51000	Amusement Parks	4	4	4	1	0	0	4	4
51100	Fairgrounds	4*	4*	4*	1	0	0	4*	4*
51200	Public Parks (urban)	4	4	4	2*	1*	0	4	4
51300	Playgrounds	4	4	4	1*	0*	0	4	4
	TOTALS	[54]	[54]	[54]	[27]	[10]	[0]	[54]	[54]
6000	CIVIC AND INSTITUTIONAL	2	2	2	1*	0*	0	2	2
6100	Educational Institutions	3*	3*	3*	1	0	0	3	3
6200	Religious Institutions	2	2	2	0	0	0	2	2

* = Lack of Unanimity

TABLE XVIII (Cont'd)

CODE	LAND USE ELEMENTS OF INFORMATION	SENSORS: B & W 1:10,000	COLOR (8442) 1:10,000	CIR (8443) 1:10,000	IR 1: 5,000	SLR 1:100,000	UV 1:5,000	TV 1:1,000	LASER 1:2,000
6300	Health Institutions	1	1	1	0	0	0	1	1
6400	Correctional Institutions	2*	2*	2*	1*	1*	0	2	2
6500	Military Bases	4	4	4	3	3	0	4	4
6600	Armories	1*	1*	1*	0	0	0	1*	1*
6700	Cemeteries	3*	3*	3*	0*	0	0	2	2
	TOTALS	[18]	[18]	[18]	[6]	[4]	[0]	[17]	[17]
7000	UTILITIES AND COMMUNICATIONS	3	3	3	1	1	0	2	3
7100	Waste Disposal	4*	4	4	1*	0	0	4	4*
7110	Sewerage	3	4	4	1*	0	0	3	3
7120	Solid Waste (dumps, junkyards & landfill)	4*	4	4	1	0	0	3	3
	TOTALS	[14]	[15]	[15]	[4]	[1]	[0]	[12]	[13]
7200	Drinking Water Supply	2*	2*	2*	1	0	0	2	2
7210	Treatment	3*	4*	4*	1*	0	0	2	3*
7220	Storage (reservoirs, including covered)	4	4	4	3	3	0	3	3
7230	Transmission (excluding under ground)	2	2	2	0	0	0	1	2
	TOTALS	[11]	[12]	[12]	[5]	[3]	[0]	[8]	[10]
7300	Gas & Oil Transmission (above ground)	2	2	2	1	0*	0	1	2
7210	Pumping Station	3*	3*	3*	1	0*	0	2	3*
	Transmission Pipelines	3	3*	3*	1	1*	0	2	3*
	TOTALS	[8]	[8]	[8]	[3]	[1]	[0]	[5]	[8]
7400	Electrical & Electromagnetic Transmission	3	3	3	1	1	0	2	4
7410	Electrical Power Transmission Lines	3*	4*	4*	2*	2*	0	3	4
7420	Utility Lines	2	2	2	0	0	0	1	3*

* = Lack of Unanimity

TABLE XVIII (Cont'd)

		SENSORS							
CODE	LAND USE ELEMENTS OF INFORMATION	B & W 1:10,000	COLOR (8442) 1:10,000	CIR (8443) 1:10,000	IR 1:5,000	SLR 1:100,000	UV 1:5,000	TV 1:1,000	LASER 1:2,000
7430	Microwave Transmission & Navigation Station	4	4	4	1*	1*	0	3	4
7440	TV - Radio Transmission Tower	3	3	3	0	0*	0	2	3
	TOTALS	[15	[16]	[16]	[4]	[4]	[0]	[11]	[18]
8000	NON-PRODUCTIVE LAND	4	4	4	3	2	0	4	4
	GRAND TOTALS	[531]	[555]	[560]	[295]	[185]	[27]	[495]	[516]

* = Lack of Unanimity

The ratings of the black-and-white, color, and color infrared emulsions are perhaps somewhat misleading. Although in most instances each is ranked "excellent", it was the unanimous opinion of the panel that color IR is best, color next best, and black-and-white poorest of the three.

2.2.3 Passive Microwave Imager

In addition to the eight sensors discussed above the performance of two others - the microwave scatterometer and the passive microwave imager - were studied. The scatterometer, being the single non-imaging sensor of the ten under consideration, has unique interpretation problems and is discussed separately in Section 2.8

The passive microwave imager was not included in Table XVIII for three reasons: 1) it was not designed to have application to land use analysis; 2) its resolution and imaging capabilities make it apparently unsuited for such an analysis; and 3) the sample of imagery available for study, for which there was correlative data (in the form of color IR), was too small to warrant the postulation of conclusive, specific results. See Figure 4.

On the basis of the available sample, however, the following imaging capabilities (i.e., spatial, as opposed to electro-magnetic, resolution) were observed:

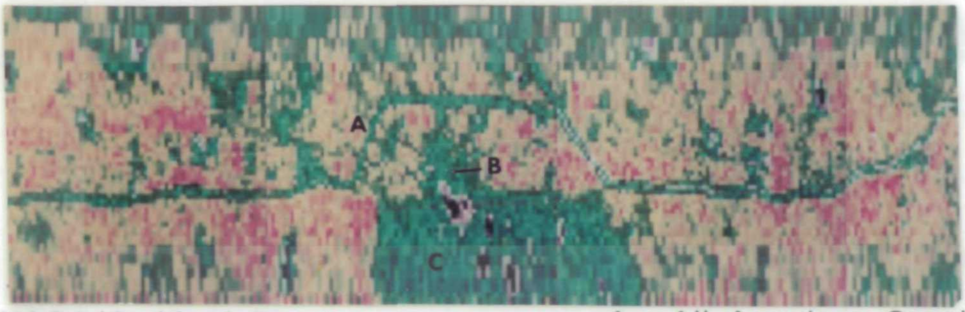
- Rivers and canals wider than thirty feet were readily observed and traced.
- Irrigated areas could be identified.
- Urban areas could be identified. (The four cold areas in the lower central portion of Figure 4 are major built-up areas.)
- The interface between residential and commercial-industrial areas could be approximately delineated.

For a more complete treatment of the capabilities of the passive microwave imager, see Edgerton, A. T., Trexler, D. T., Sakamoto, S., et al , 1969, Microwave Radiometric Studies and Ground Truth Measurements of the NASA/USGS Southern California Test Site, U.S.G.S. Contract No. 14-08-001-11425, Aerojet General Corp, El Monte, California.

2.2.4 Diseased Orchard Study (Phoenix)

In addition to the more general land use analyses conducted, a specific study was designed to examine the premise that diseased vegetation can be more effectively discerned on color infrared imagery than on color or black-and-white photography. Visual examination of several citrus orchards in the Phoenix area indicated that some disease was present, and it was decided to conduct a comparative test of the color (8442) and color infrared (8443) films' ability to detect diseased trees. Standard photographic interpretation methods and equipment were employed in the study, and each tree was categorized as either good, partially diseased, totally diseased/dead, or removed. The subjective nature of the study

NASA/Goddard
7 June 1968
Altitude: 37,000
Daytime Flight
Scale 1:262,000



NASA/Goddard Passive Microwave Imaging Radiometer

A - All American Canal
B - Calexico, California
C - Mexicali, Mexico

Line Copy of (AMS) El Centro Map
NI 11-12, Series F501 - 1:250,000

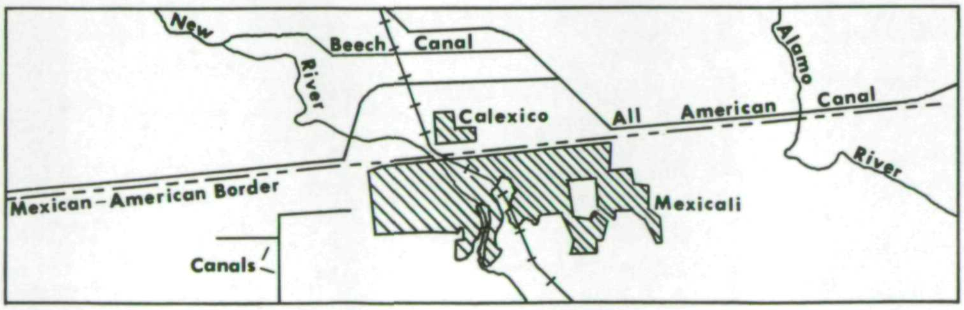


FIGURE 4: NASA/GODDARD PASSIVE MICROWAVE IMAGERY

could not be avoided since ground truth was not available (because the imagery was acquired for urban studies), and the scientist conducting this study was not familiar with citrus diseases and used only color changes and variations as the key to establishing the classifications. This section is, then, only an example of a way in which color IR can be used. Figure 5 is an illustration of the citrus grove and Figure 6 is a schematic representation of plant vigor as interpreted on the two emulsions. Below is a summary of Figure 6.

	TREE CLASS	APPARENT TONE	TOTAL	PERCENT OF TOTALS[4]
Color (8442) -	Good	Dark Green	36	11.8
	Good	Light Green	113	37.3
	Partially diseased	Brownish Yellow	110	36.2
	Completely Diseased/ Dead	Brown	28	9.2
	Removed	-	9	2.9
	Young Replant	Light Green	8	2.6
CIR (8443)	Good	Red	20	6.6
	Good	Pink	42	13.8
	Partially Diseased	Brownish Pink	172	57.0
	Completely Diseased/ Dead	Brown	55	16.5
	Removed	-	8	2.6
	Young Replant	Pink	7	2.5

Color infrared photography showed a significant increase in the number of partially diseased trees that were classified as good on the color photography.

It was then decided to make microdensitometric measurements of the selected orchard to check the subjective analysis of the photointerpreter. Figure 7 shows a representative densitometric trace of the fifth row of trees. From this, the photographic density of each tree classification was determined and the whole statistically analyzed. The results are summarized in Figure 8.

The spectral sensitivities of the film types used are given in Figure 9. The color film was filtered to eliminate wavelengths below approximately .4 microns, and the color infrared was exposed through a Wratten 12 filter that cuts off wavelengths below approximately .5 microns. The resulting transfer of color is given below.

[4]Percentages based on 304 trees. Trees covered by shadows on one emulsion or the other were not counted.

Color Infrared as an Indicator of Citrus Stress

...An Interpreted Comparison of Color Infrared and Color Ektachrome

NASA/USGS Mission #19
15 February 1966
Test Site #29
RC-8 Camera
Scale 1:2,200

Color Infrared (8443)

Color Ektachrome (8442)

ANNOTATIONS

* Row of Trees Analyzed with Microdensitometric Trace.

⌐ Limits of Studied Area

FIGURE 5:
COLOR AND COLOR INFRARED IMAGERY OF A CITRUS GROVE UNDER STRESS

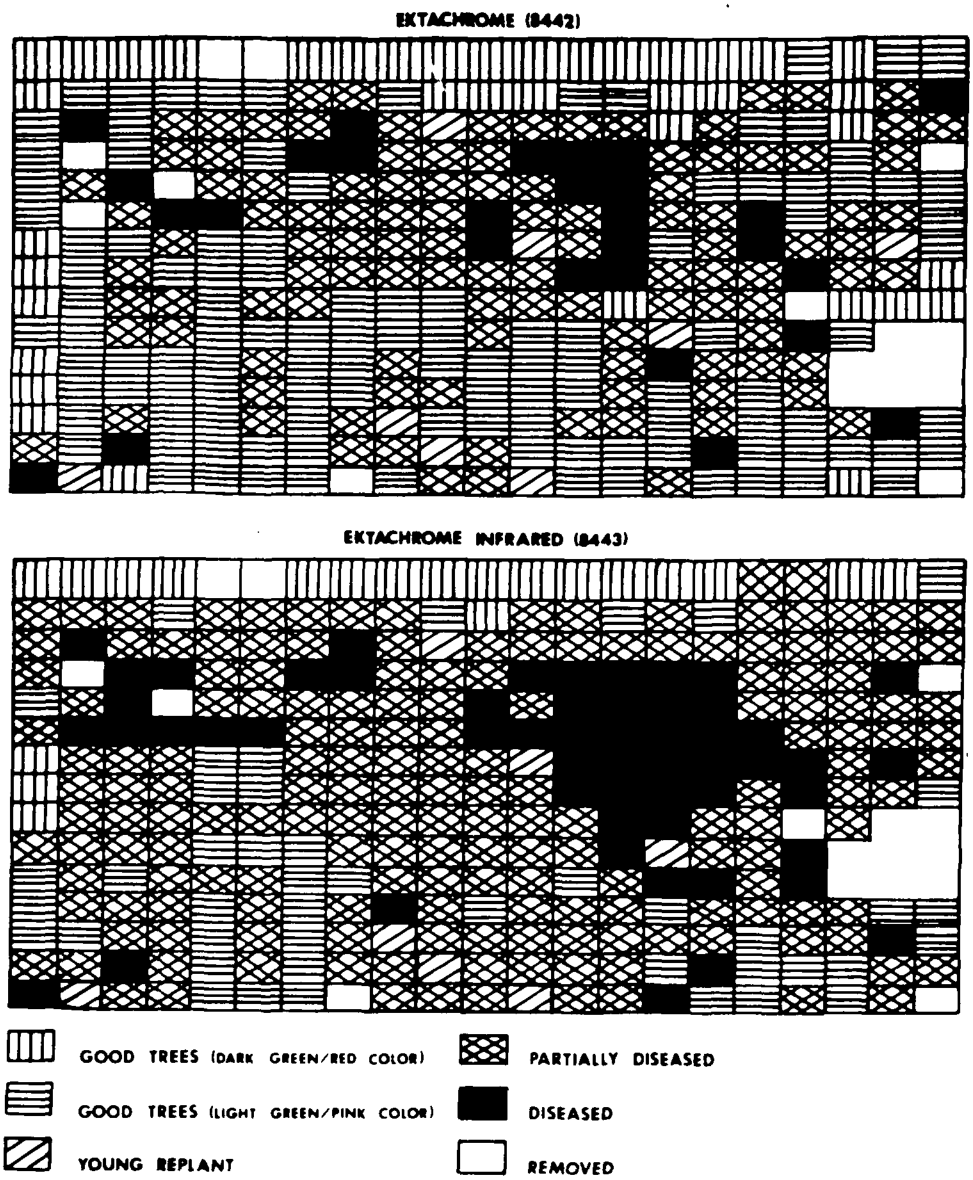
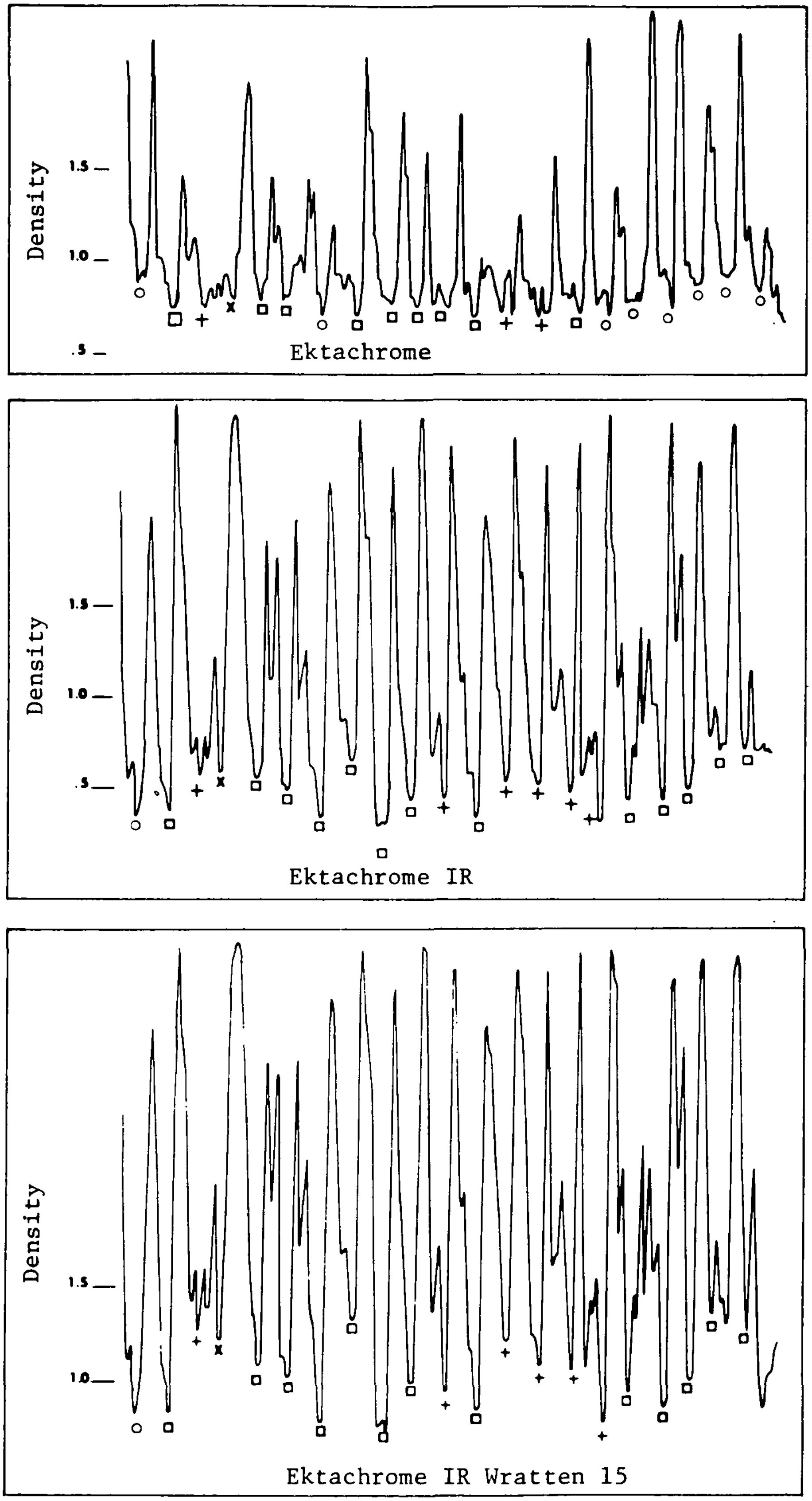


FIGURE 6 COMPARATIVE ANALYSIS OF A CITRUS GROVE UNDER STRESS



These traces were made across the fifth row (from the top) of citrus trees depicted in Figure 6.

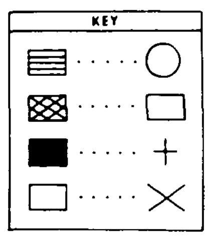


FIGURE 7 REPRESENTATIVE DENSITOMETRIC TRACE ACROSS A ROW OF CITRUS TREES

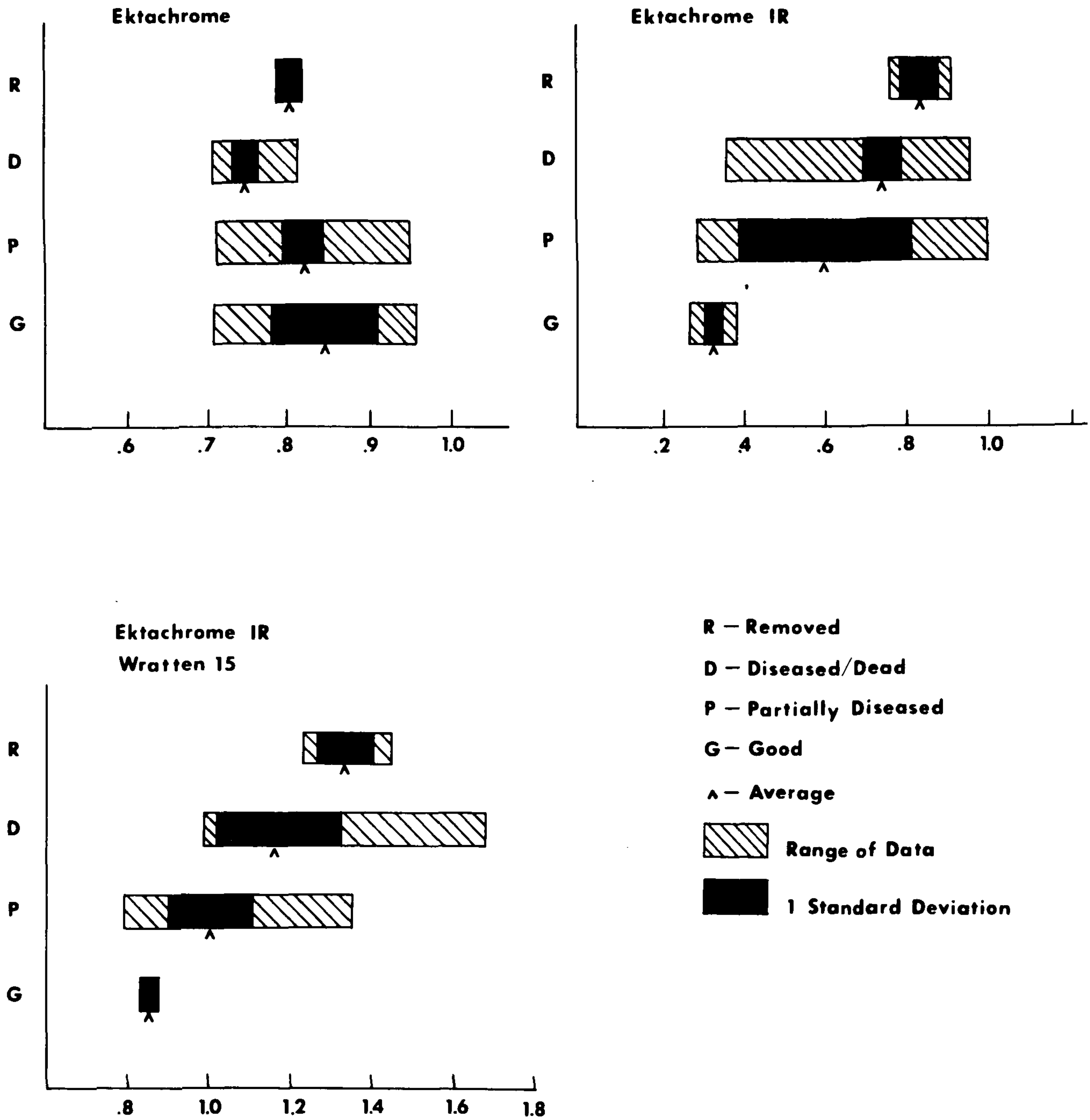
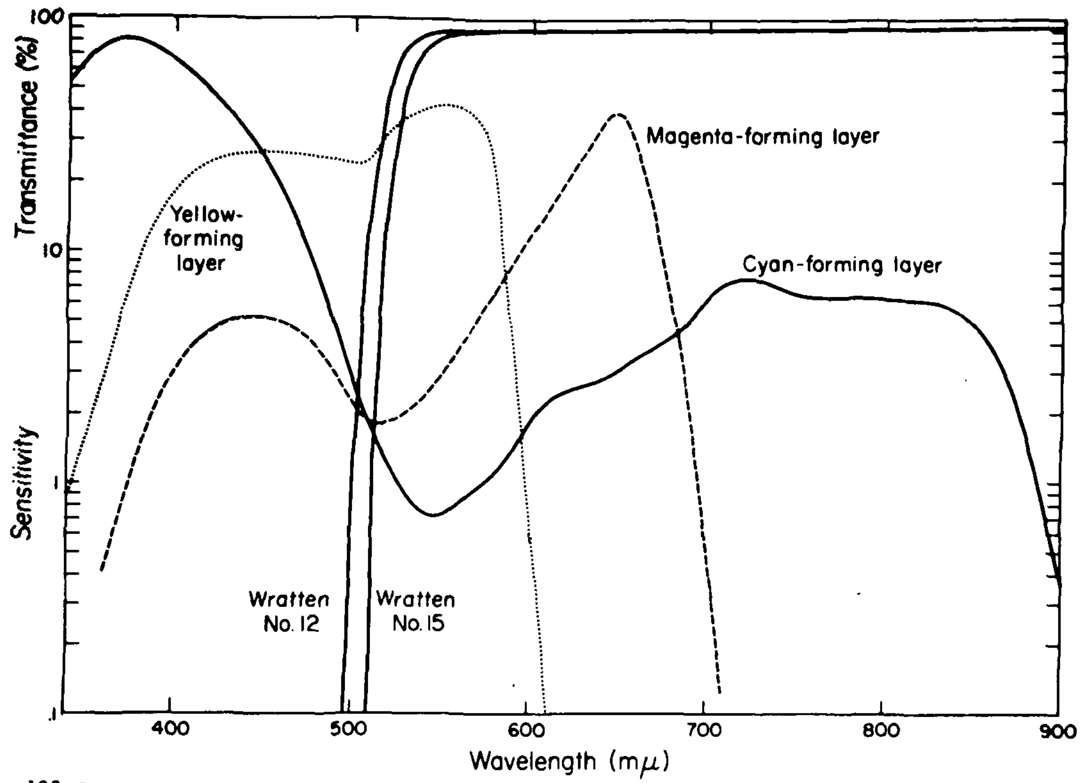
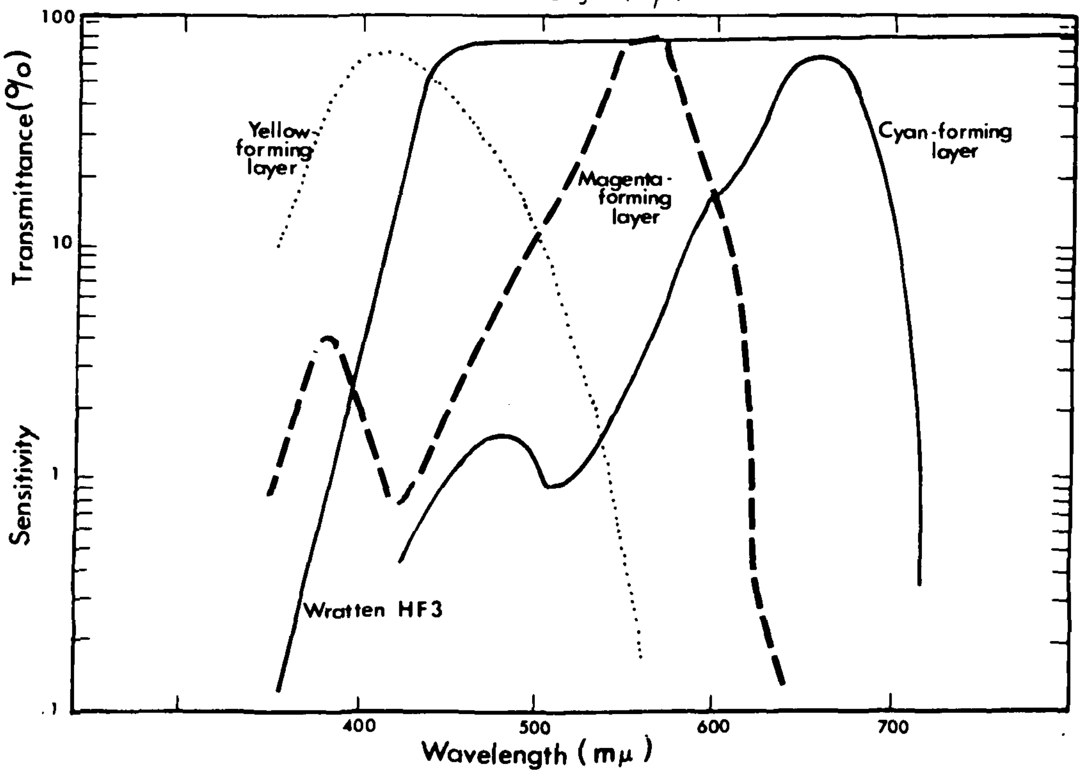


FIGURE 8 DISTRIBUTION OF DENSITY READINGS OVER ORCHARD



COLOR
EKTACHROME
INFRARED
(8443)



COLOR
EKTACHROME
(8442)

FIGURE 9 SPECTRAL SENSITIVITIES OF FILM TYPES USED IN DISEASED ORCHARD STUDY

	Spectral Region	Blue	Green	Red	Infrared
Kodak Ektachrome Aero Film	**Normal Color Film Sensitivities**	Blue	Green	Red	
	Color of the Dye Layers	Yellow	Magenta	Cyan	
	Resulting Color in Photograph	Blue	Green	Red	
Kodak Ektachrome Infrared Aero Film	Sensitivities with Yellow Filter		Green	Red	Infrared
	Color of the Dye Layers		Yellow	Magenta	Cyan
	Resulting Color in Photograph		Blue	Green	Red

Figure 10 shows the reflectance properties of healthy green vegetation. Note that the reflectance is greatest in the infrared, where about 40% of the energy is reflected, [5] compared to the reflectance within the spectral band of panchromatic photography (with haze filter .52 - .65 microns), where only about 10% of the total reflectance occurs. For diseased and dying vegetation, spectral reflectance changes drastically in the infrared. After a branch is cut or becomes diseased, the reduction of transpiration of water from the leaves immediately reduces the reflectance in the infrared.[6] The visible reflectance changes much later.

It was noticed in the course of this study that, by viewing the IR imagery through a Wratten 15 (minus blue) filter, red tone discrimination was enhanced and overall viewing appeared to improve. This is partly explained by the fact that, by eliminating the blue, the overall tone of the photograph is shifted to a region where the human eye operates more efficiently. This was corroborated by densitometric measurements which showed that density differences were enhanced by using a yellow filter. However, there was an increase in the overall density level.

----

[5] This figure is sometimes given as 50%. See Meyers, V. I., and Allen, W. A., Electro-optical Remote Sensing Method as Nondestructive Testing and Measuring Techniques in Agriculture, Applied Optics, Vol. 7, No. 9, Sept. 1968, p. 1827.

[6] Jensen, N., 1968, Optical and Photographic Reconnaissance Systems, Wiley and Sons, Inc., New York, p. 70. However, recent work by Pease indicates that there is no reduction of reflectance in the infrared of a plant under stress; the IR reflectance is simply masked by the increasing reflectance in the visible. (Pease, R. W., 1969, "Plant Tissue and the Color Infrared Record," U.S. Dept. of the Interior Contract 14-08-001-10674, University of Cal., Riverside, California.

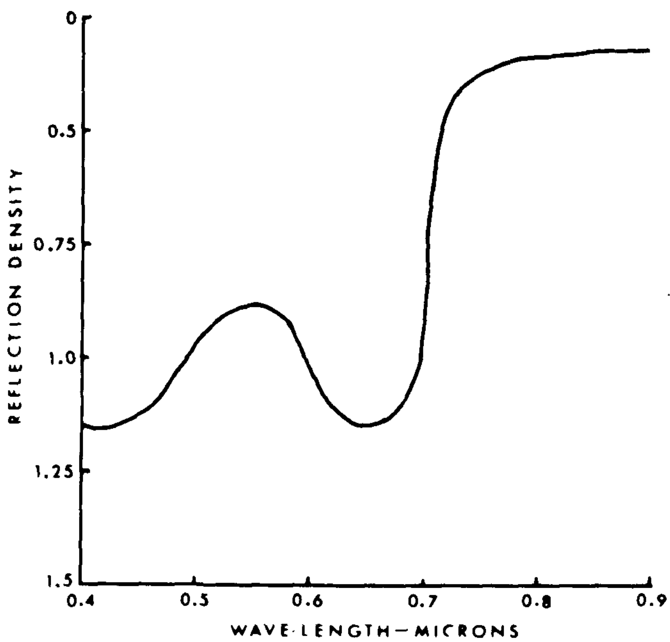


FIGURE 10 REFLECTANCE PROPERTIES OF HEALTHY GREEN VEGETATION

2.3 Sensor Capability in Urban Analysis

The United States is currently burdened by one of the greatest problems man has yet had to face - the urban crisis. As the population continues to increase and ever greater numbers of people move to the urban centers of the country, these central places can be expected to double in population in the next forty years. The effect that this will have on the quality and environment of the cities, and the effect that the cities will have, in turn, on man, is a matter of utmost concern.

In order for the citizens, planners and policy makers of the next decades to make decisions concerning the urban environment, vast amounts of data pertaining to the city must be collected, analyzed, and recast in the form of ideas, plans, and programs. Among the most important tools in this data collection effort are remote sensing devices, such as those employed on NASA/MSC remote sensing aircraft.

2.3.1 Objectives

Several GEOGAP Principal Investigators have channeled most of their efforts towards reaching a solution of urban problems. Test Sites #29, #43, #130 and #132 all include urban settlements. Duplicate copies of some of the sensor records flown by NASA over these cities were received by Autometric to be evaluated in terms of the following objectives:

1) To determine the elements of information necessary for studies of:

- Urban land use
- Transportation
- Traffic congestion
- Air pollution
- Water pollution
- Housing quality
- Barriers to growth
- Shopping intensity and patterns
- Census updating
- Time/distribution of population
- Urban-rural interface

2) To investigate the utility of remote sensors for the identification of the geographic elements of information necessary for carrying out the above studies;

3) To determine which sensor(s) can best identify these geographic elements of information;

4) To determine the relative merits of color (8442) and color infrared (8443) film in studies of housing quality.

2.3.2 Approach

The approach to objectives 1, 2, and 3 was to study the NASA/USGS data in terms of its ability to provide information necessary to conduct the various studies mentioned in 1, and to then construct a sensor capability matrix as the means for presenting the results.

The first step involved the determination of the specific elements of information necessary to conduct each geographic study in the urban environment. This was accomplished by reviewing the urban studies being conducted by the GEOGAP Investigators for certain elements and making additions whenever necessary. In many cases, imagery and studies from other sources were used to supplement the data supplied by GEOGAP.

The second step involved determining the utility of each NASA sensor in identifying each of the elements of information. The description of the way in which the Sensor Capability - Urban Analysis matrix was constructed is identical to that for the Sensor Capability - Land Use matrix, an explanation of which appears in Section 2.2.2. In filling out the matrix represented by Table XIX, three hundred and sixty-eight decisions were made by each panelist (eight [sensors] times forty-six [urban elements of information]). Of this number, two hundred and eighty, or 76%, were unanimous. (Random unanimity would have been 4%.)

Objective 3 can be satisfied by examining the matrix, element by element, or referring to the grand totals at the end. By doing this the effectiveness of each sensor, as determined by a panel of geoscientists (using the methods described in Section 2.2.2), can be determined and compared with that of the other sensors.

The approach to objective 4 was to conduct a special housing quality study using color and color infrared imagery flown over Phoenix by NASA in February 1966. The description and results of this study appear in Section 2.3.3

2.3.3 Housing Quality Study

The GEOGAP Investigators conducting studies of urban centers have been unanimous in their request for the use of filtered color infrared imagery. Since it has been suggested by several investigators that lawn quality is a surrogate for housing quality, and, since it has been further suggested that lawn vigor and condition could be more readily sensed by the color infrared, it was concluded that the color infrared would be a very useful medium for recording information indicative of housing quality.

To check this, as well as other housing quality parameters, three areas of single family housing in Phoenix, Arizona were selected for study. These areas were selected on an assumed, intuitive basis as representing, respectively, high, middle and low income neighborhoods. (Although excellent quality color infrared imagery was collected over Los Angeles during Mission 73, comparable color photography was not flown.) These test areas included four blocks of high income housing (Figure 11), a nine-block middle income development (Figure 12), and a five-block area of low income housing in the middle city (Figure 13). Tables XX through XXV represent the interpreted data relative to each housing area.

TABLE XIX

SENSOR CAPABILITY - URBAN ANALYSIS

CODE	URBAN ELEMENTS OF INFORMATION	SENSORS B & W 1:10,000	COLOR (8442) 1:10,000	CIR (8443) 1:10,000	IR 1:5,000	SLR 1:100,000	UV 1:5,000	TV 1:1,000	LASER 1:2,000
1000	TRANSPORTATION NETWORK	4	4	4	4	3	2*	4	4
1100	Roads	4	4	4	3*	1*	0	4*	4
1110	Number of Lanes	4	4	4	3*	0	0	4	4
1120	Pavement Condition	0	1	1	0	0	0	0	1*
1130	Highway Illumination Lights	2	2	2	0	1	0	1	2*
1140	Signal Lights	1*	1*	1*	0	0	0	0	2
1150	Access	4	4	4	4	3	1	4	4
1200	Railroads	4	4	4	3*	1*	0	4*	4
1210	Number of Tracks	4	4	4	1	0	0	4*	4
1300	Water	4	4	4	3*	3	0	4	4
1310	Width	4	4	4	3*	1*	0	3	4
	TOTALS	[35]	[36]	[36]	[24]	[13]	[3]	[32]	[37]
2000	TRAFFIC CONGESTION	4	4	4	2	1	0	4	4
2100	Automobiles	4	4	4	1	0	0	3*	4
2200	Trucks	4	4	4	1	0	0	3*	4
2300	Busses	4	4	4	1	0	0	3*	4
	TOTALS	[16]	[16]	[16]	[5]	[1]	[0]	[13]	[16]
3000	POLLUTION								
3100	Water								
3110	Chemical	2	3*	3	0*	0	0	1	0
3120	Thermal	1	1	1	4*	0	0	0*	0
3200	Land	4*	4	4	1	0	0	3	4*
3300	Air (Probable sources)	4	4	4	3*	1	0	4	4
	TOTALS	[11]	[12]	[12]	[8]	[1]	[0]	[8]	[8]

* = Lack of Unanimity

TABLE XIX (Cont'd)

CODE	URBAN ELEMENTS OF INFORMATION	SENSORS B & W 1:10,000	COLOR (8442) 1:10,000	CIR (8443) 1:10,000	IR 1:5,000	SLR 1:100,000	UV 1:5,000	TV 1:1,000	LASER 1:2,000
4000	HOUSING QUALITY (Socio-economic)								
4100	Dwelling Type (Single vs. multi-unit)	3	3	3	1	1*	0	3	3
4200	Building Density	4	4	4	2*	1	0	3	4
4210	Lot Size	4	4	4	1	0	0	3	4
4220	Home Size	4	4	4	1	0	0	3	4
4300	Accessory Buildings	4*	4*	4*	1*	0	0	3*	4
4400	Pools and Patios	3*	4	4	1*	0	0	3	4*
4500	Landscaping (Presence and condition)	2	3	4	1*	0	0	2	3*
4600	Litter	1	2*	2*	0	0	0	2*	3*
4700	Street Patterns	4	4	4	3	3*	1*	4	4
4710	Width	4	4	4	2	0	0	4	4
4720	Condition	0	1	1	0	0	0	0	1*
4730	Lighting	1*	1*	1*	0	0	0	1	1*
4740	Sidewalks and Curbs (Presence)	2*	3*	3*	0	0	0	2	2
4750	Traffic	4	4	4	2	1	0	4	4
4800	Community Facilities (Parks, pools, playgrounds)	4	4	4	1*	0*	0	4	4
	TOTALS	[44]	[49]	[50]	[16]	[6]	[1]	[41]	[49]
5000	BARRIERS TO GROWTH								
5100	Transportation	4	4	4	4	3	2*	4*	4
5200	Rivers	3*	3*	3*	2*	1*	0*	3*	3*
5300	Lakes	4	4	4	4	3	0	4	4
5400	Swamps	4*	4	4	2*	2	0	3	3
5500	Topography	4*	4*	4*	3	3*	0	3	3
5600	Zonal interfaces	4	4	4	3*	2*	1	4	4
	TOTALS	[23]	[23]	[23]	[18]	[14]	[3]	[21]	[21]

* = Lack of Unanimity

TABLE XIX (Cont'd)

CODE	URBAN ELEMENTS OF INFORMATION	SENSORS B & W 1:10,000	COLOR (8442) 1:10,000	CIR (8443) 1:10,000	IR 1:5,000	SLR 1:100,000	UV 1:5,000	TV 1:1,000	LASER 1:2,000
6000	SHOPPING INTENSITY & PATTERN								
6100	Number of Vehicles in Parking Lot	4	4	4	2	1	0	4	4
6200	People	1*	1*	1*	0	0	0	1	1*
	TOTALS	[5]	[5]	[5]	[2]	[1]	[0]	[5]	[5]
7000	CENSUS UPDATING								
7100	Number of Dwellings	3*	3*	3*	0*	0	0	3*	3*
8000	TIME/DISTRIBUTION OF POPULATION								
8100	Vehicles	4	4	4	2	1	0	4	4
8200	People	1*	1*	1*	0	0	0	1	1*
	TOTALS	[5]	[5]	[5]	[2]	[1]	[0]	[5]	[5]
9000	URBAN-RURAL INTERFACE	4	4	4	4	4	3*	4	4
	GRAND TOTALS	[146]	[153]	[154]	[79]	[41]	[10]	[132]	[148]

* = Lack of Unanimity

(368 Decisions - 280 unanimous or 76.1%)

Color Infrared as an Indicator of Housing Quality

...An Interpreted Comparison of Color Infrared and Color Ektachrome

NASA/USGS Mission #19
15 February 1966
Test Site #29
RC-8 Camera
Scale 1:4,400

Color Infrared (8443)

Color Ektachrome (8442)

ANNOTATIONS

A, B, C & D: Sample Housing Quality Study Blocks.

(Assumed High Income)

FIGURE 11:
ASSUMED HIGH INCOME HOUSING BLOCKS

TABLE XX

ANALYSIS OF HIGH INCOME HOUSING
COLOR

TEST SITE #29 (Phoenix)
MISSION #19
FILM TYPE: 8442
FRAMES: #6230-6232

ELEMENTS OF INFORMATION	BLOCK A	BLOCK B	BLOCK C	BLOCK D	TOTALS	PERCENTAGE
No. of Homes	16	8	8	6	38	-----
No. with Additions	5	1	2	1	9	23.6%
No. of Different Roof Colors	13	4	6	3	26	68.4%
No. with Outbuildings/Sheds	8	5	2	4	19	50 %
No. without Any Landscaping	0	0	0	0	0	-----
No. with Well Kept Front Lawns	8	3	1	4	16	42.1%
No. with Well Kept Back Lawns	4	2	0	3	9	23.6%
No. with Littered Appearances	0	0	0	0	0	-----
No. with Fencing and/or Hedges	16	8	8	6	38	100 %
No. with Swimming Pools	8	4	3	3	18	47.4%
No. with Above Ground Pools	0	0	0	0	0	-----
No. with Tennis/Handball/Basketball Courts	1	3	0	0	4	10.5%
No. with Stables	1	0	0	0	1	.26%

TEST SITE #29 (Phoenix)
MISSION #19
FILM TYPE: 8443
FRAMES: 6395-6397

TABLE XXI

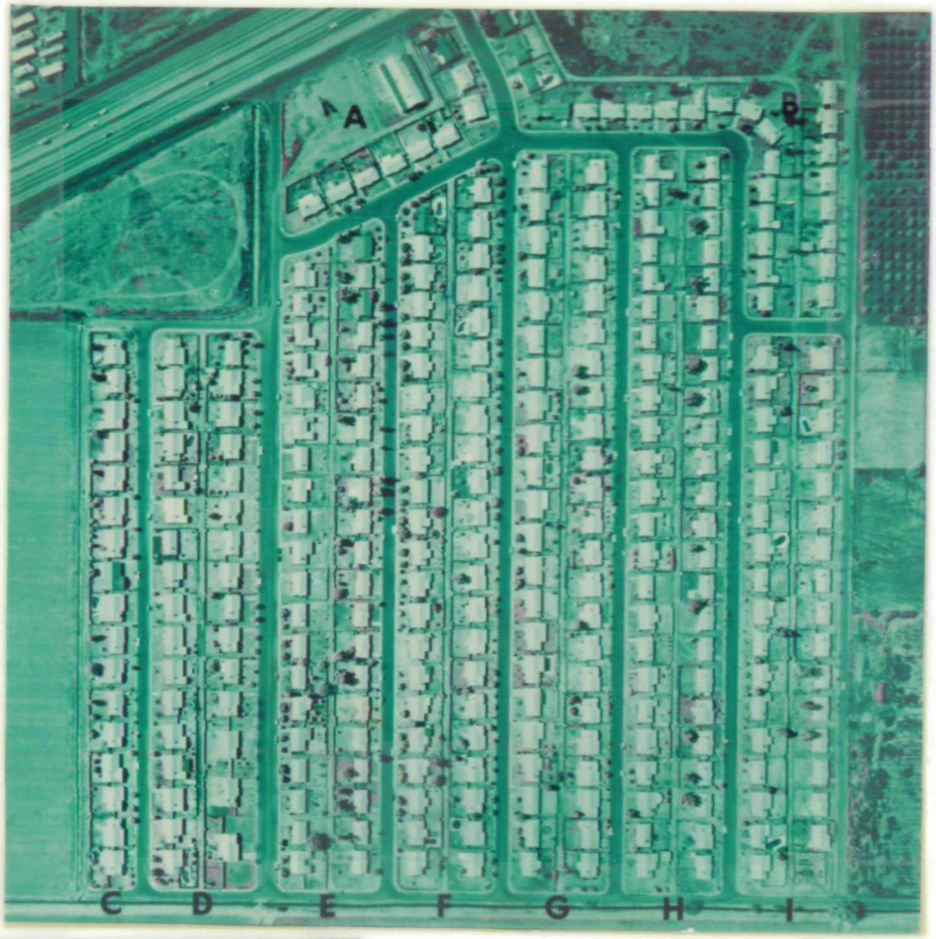
ANALYSIS OF HIGH INCOME HOUSING
COLOR IR

ELEMENTS OF INFORMATION	BLOCK A	BLOCK B	BLOCK C	BLOCK D	TOTALS	PERCENTAGE	PERCENTAGE DIFFERENCE FROM COLOR
No. of Homes	16	8	8	6	38	-----	
No. with Additions	5	1	1	2	9	23.6%	SAME
No. of Different Roof Colors	13	5	8	4	30	79.0%	+10.6%
No. with Outbuildings/Sheds	7	5	3	3	18	47.4%	- 2.6%
No. without Any Landscaping	0	0	0	0	0	-----	SAME
No. with Well Kept Front Lawns	6	3	1	4	14	36.8%	- 5.3%
No. with Well Kept Back Lawns	3	1	0	2	6	15.8%	- 7.8%
No with Littered Appearances	0	0	0	0	0	-----	SAME
No. with Fencing and/or Hedges	16	8	8	6	38	100 %	SAME
No. with Swimming Pools	8	4	3	3	18	47.4%	SAME
No. with Above Ground Pools	0	0	0	0	0	-----	SAME
No. with Tennis or Basketball/Handball	1	3	0	0	4	10.5%	SAME
No. with Stables	1	0	0	0	1	.26%	SAME

Color Infrared as an Indicator of Housing Quality

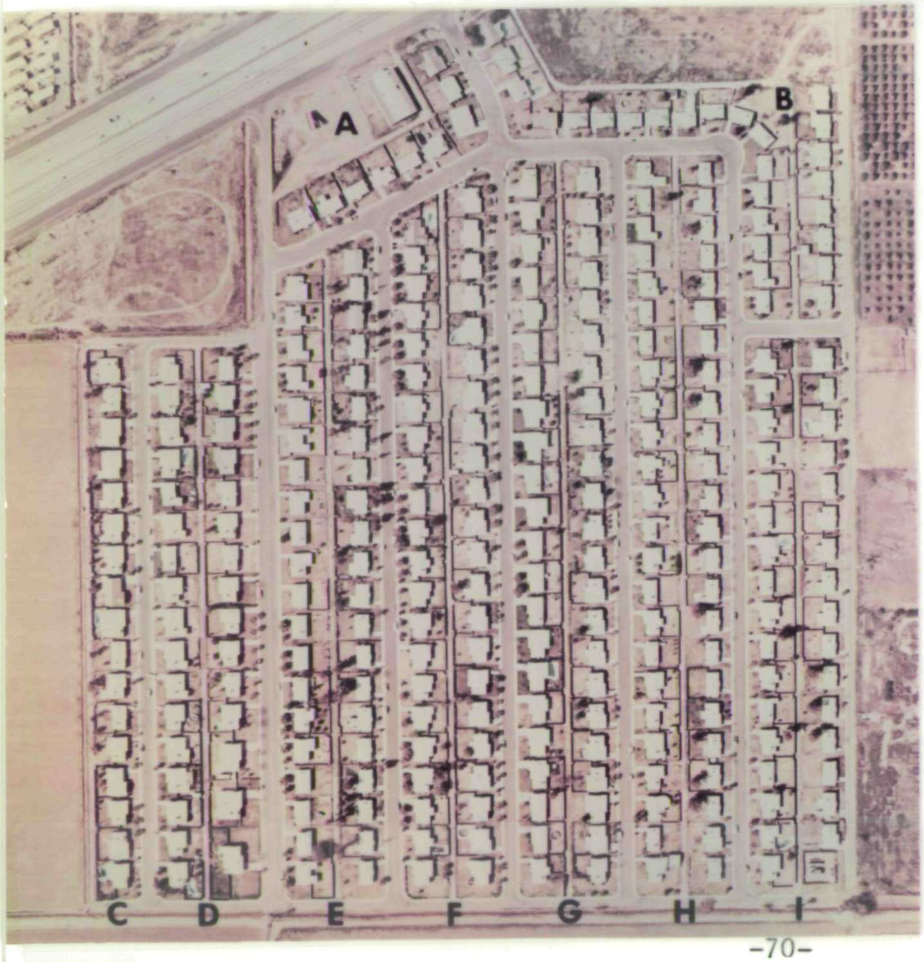
...An Interpreted Comparison of Color Infrared and Color Ektachrome

NASA/USGS Mission #19
15 February 1966
Test Site #29
RC-8 Camera
Scale 1:4,650



Color Infrared (8443)

Color Ektachrome (8442)



ANNOTATIONS

A thru I: Sample Housing Quality Study Blocks.

(Assumed Middle Income)

FIGURE 12:
ASSUMED MIDDLE
INCOME HOUSING BLOCKS

TABLE XXII

ANALYSIS OF MIDDLE INCOME HOUSING
COLOR

TEST SITE #29 (Phoenix)
MISSION #19
FILM TYPE: 8442
FRAMES: #6216-6218

ELEMENTS OF INFORMATION	BLOCK A	BLOCK B	BLOCK C	BLOCK D	BLOCK E	BLOCK F	BLOCK G	BLOCK H	BLOCK I	TOTALS	PERCENTAGE
No. of Homes	9	26	17	32	41	44	45	48	33	295	-----
No. with Additions	5	9	2	2	16*	8	8	14	9	73	24.8%
No. of Different Roof Colors	1	4	1	0	2	2	0	0	0	10	3.4%
No. with Outbuildings/Sheds	0	2	1	8	3	6	6	10	3	39	13.4%
No. without Any Landscaping	0	0	1	0	1	0	0	1	0	3	1.1%
No. with Well Kept Front Lawns	3	7	4	6	3	10	11	5	5	54	18.3%
No. with Well Kept Back Lawns	1	2	3	4	4	6	5	3	4	32	10.8%
No. with Littered Appearances	1	0	0	0	0	2	1	0	1	5	1.7%
No. with Fencing/Hedging	9	18	15	27	31	43	39	39	26	247	83.8%
No. with Swimming Pools	1	2	2	2	0	5	2	0	3	17	5.8%
No. with Above Ground Pools	0	1	0	1	1	0	1	2	0	6	2.0%
					*2 Being Built						

TABLE XXIII

ANALYSIS OF MIDDLE INCOME HOUSING
COLOR IR

TEST SITE #29 (Phoenix)
MISSION #19
FILM TYPE: 8443
FRAMES: 6384-6386

ELEMENTS OF INFORMATION	BLOCK A	BLOCK B	BLOCK C	BLOCK D	BLOCK E	BLOCK F	BLOCK G	BLOCK H	TOTALS	PERCENTAGE	PERCENTAGE DIFFERENCE FROM COLOR
No. of Homes	9	26	17	32	41	44	48	33	295	-----	
No. with Additions	7	8	2	8	14*	14	12	14	88	29.8%	+5. %
No. of Different Roof Colors	1	4	1	0	1	1	0	0	9	3. %	- .4%
No. with Outbuildings/Sheds	0	5	2	6	2	2	5	4	28	9.5%	-3.9%
No. without Any Landscaping	0	0	0	0	0	1	0	1	2	.67%	-.43%
No. with Well Kept Front Lawns	1	7	1	4*	2	3	3	4	35	11.9%	-6.4%
No. with Well Kept Back Lawns	2	2	1	4	4	4	3	4	28	9.5%	-1.3%
No. with Littered Appearances	1	0	0	1	0	2	0	1	5	1.7%	SAME
No. with Fencing and/or Hedges	7	18	13	26	34	42	32	24	234	79.5%	-4.3%
No. with Swimming Pools	1	2	2	2	0	5	0	3	17	5.8%	SAME
No. with Above Ground Pools	0	1	0	1	1	0	2	0	6	2. %	SAME

Color Infrared as an Indicator of Housing Quality

...An Interpreted Comparison of Color Infrared and Color Ektachrome

NASA/USGS Mission #19
15 February 1966
Test Site #29
RC-8 Camera
Scale 1:4,700

Color Infrared (8443)

Color Ektachrome (8442)

ANNOTATIONS

A thru E: Sample Housing Quality Study Blocks.
(Assumed Low Income)

FIGURE 13:
ASSUMED LOW INCOME HOUSING BLOCKS

TEST SITE #29 (Phoenix)
MISSION #19
FILM TYPE: 8442
FRAMES: #6188-6190

TABLE XXIV

ANALYSIS OF LOW INCOME HOUSING
COLOR

ELEMENTS OF INFORMATION	BLOCK A	BLOCK B	BLOCK C	BLOCK D	BLOCK E	TOTALS	PERCENTAGE
No. of Homes	21	19	25	26	21	112	14.3%
No. with Additions	5	4	3	2	2	16	53.5%
No. of Different Roof Colors	15	9	13	15	8	60	46.8%
No. with Outbuildings/Sheds	12	8	11	12	9	52	
No. without Any Landscaping	5	4	3	3	3	18	16.1%
No. with Well Kept Front Lawns	4	0	0	2	1	7	6.2%
No. with Well Kept Back Lawns	1	0	0	0	0	1	.89%
No. with Littered Appearances	10	8	5	2	3	28	25.2%
No. with Fencing and/or Hedges	15	13	19	12	10	69	62 %
No. with Swimming Pools	0	0	0	0	0	0	-----
No. with Above Ground Pools	0	0	0	0	0	0	-----

TABLE XXV

ANALYSIS OF LOW INCOME HOUSING
COLOR IR

TEST SITE #29 (Phoenix)
MISSION #19
FILM TYPE: 8443
FRAMES: #6357-6358

ELEMENTS OF INFORMATION	BLOCK A	BLOCK B	BLOCK C	BLOCK D	BLOCK E	TOTALS	PERCENTAGE	PERCENTAGE DIFFERENCE FROM COLOR
No. of Homes	21	18	23	26	20	108	-----	
No. with Additions	4	3	3	6	2	18	16.6%	+ 2.3 %
No. of Different Roof Colors	*	--	--	--	--	--	-----	-------
No. with Outbuildings/Sheds	10	9	14	12	11	56	51.8%	+ 5.0 %
No. without Any Landscaping	4	5	2	0	5	16	14.8%	- 1.3 %
No. with Well Kept Front Lawns	1	1	0	2	0	4	3.7%	- 2.5 %
No. with Well Kept Back Lawns	0	1	1	1	0	3	2.8%	+ 1.91%
No. with Littered Appearances	13	10	6	5	7	41	37.9%	+12.7 %
No. with Fencing and/or Hedges	10	7	17	15	9	58	53.6%	- 8.4 %
No. with Swimming Pools	0	0	0	0	0	0	-----	
No. with Above Ground Pools	0	0	0	0	0	0	-----	

The elements of information that were considered fall into three categories: the first comprises the number of houses, the additions to each home, the roof colors, and any additional buildings located on the property; the second embraces lawn care, landscaping, and fencing; and the third is simply a count of luxury items, such as swimming pools, tennis courts, stables, etc.

The color Ektachrome (8442) imagery was interpreted first and the color IR next. Percentages were calculated for each element of information, following which the percent deviation between the elements found on the two emulsions was computed.

2.4 Surface Energy Budget and Soil Moisture

2.4.1 Objectives

In order to determine the capability of remote sensors in the monitoring of energy exchange variations at the earth's surface resulting from and affecting man's activities, an investigation was conducted into the interrelations of temperature and moisture with each other and with the photographic density of thermal infrared imagery.

2.4.2 Approach

2.4.2.1 Measurement of Soil Moisture and Temperature

Data concerning soil moisture and temperature were acquired during NASA Mission 73 from seventy-one ground test stations, but only thirty-four of these stations had data on both moisture and temperature. The moisture content of the soil was computed as percent by volume using the formula:

$$\frac{W_w - W_d}{V} \times 100$$

where,

W_w = wet weight of sample,

W_d = dry weight of sample,

V = volume of sample.

Soil temperatures were taken with bulb thermometers inserted horizontally into the soil at a depth of one quarter inch.

The first step in the analysis was to compute the percentile distribution of soil moisture within the test area. The results are shown in Table XXVI and in histogram form in Figure 14. In both of these illustrations the extreme aridity of the majority of the samples is brought out, as well as is the very high moisture content of a small number of samples. Figure 14 exhibits a surprisingly smooth curve, interrupted only in the 20-25% range.

The distribution of temperatures within the test area was much less systematic, as is shown in Table XXVII and Figure 15.

TABLE XXVI

PERCENTILE DISTRIBUTION OF SOIL MOISTURE

Moisture Content	No. Samples	% Samples
<1%	36	50.7
≤1<5	16	22.5
>5≤10	8	11.2
>10≤15	2	2.8
>15≤20	1	1.4
>20≤25	5	7.4
>25≤30	1	1.4
>30≤35	1	1.4
>35≤40	1	1.4
TOTALS	71	100.2

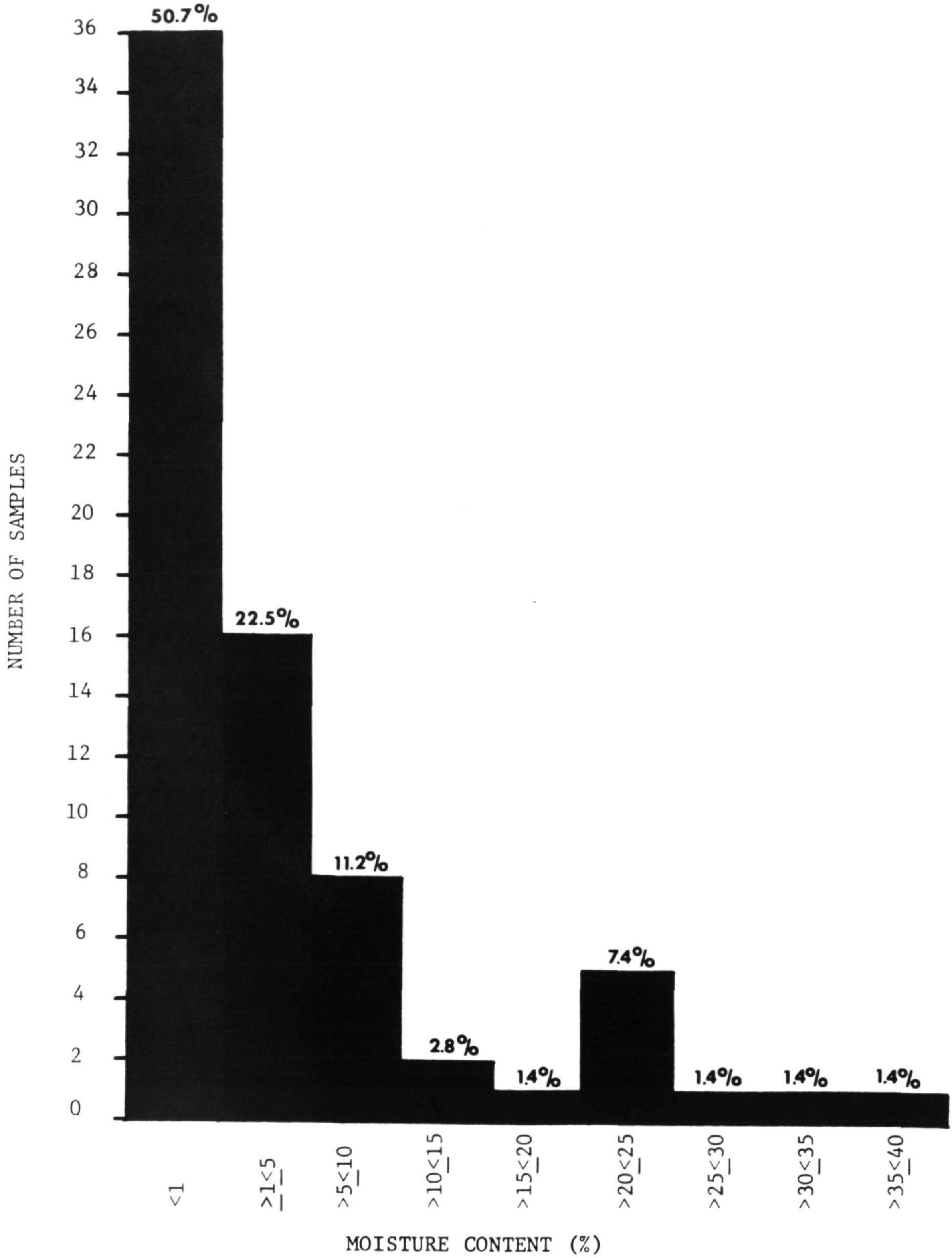


FIGURE 14 HISTOGRAM OF PERCENTILE DISTRIBUTION OF MOISTURE

TABLE XXVII

PERCENTILE DISTRIBUTION OF TEMPERATURE

Temperature (^{o}C)	No. Samples	% Samples
21-25	2	5.6
26-30	1	2.8
31-35	5	13.9
36-40	3	8.3
41-45	3	8.3
46-50	5	13.9
51-55	9	25.0
56-60	7	19.4
61-65	1	2.8
	36	100.0

2.4.2.2 Interrelations of Temperature, Photographic Density, and Moisture

It was originally planned to measure, with a microdensitometer, the photographic density of the thermal IR transparencies at the location of each of the plotted thirty-four moisture/temperature sample locations and to determine the degree of correlation between photographic density and soil moisture. The procedure could not be followed, however, because the imagery provided was in print form.

As an alternative procedure, the Kodak Photographic Step Tablet Number 2 was used. This tablet is a gray scale divided into twenty-one calibrated steps. For this study the steps were arbitrarily numbered from 1 (lowest density) to 21 (highest density) and compared visually with the image density of the thermal IR at each test point.

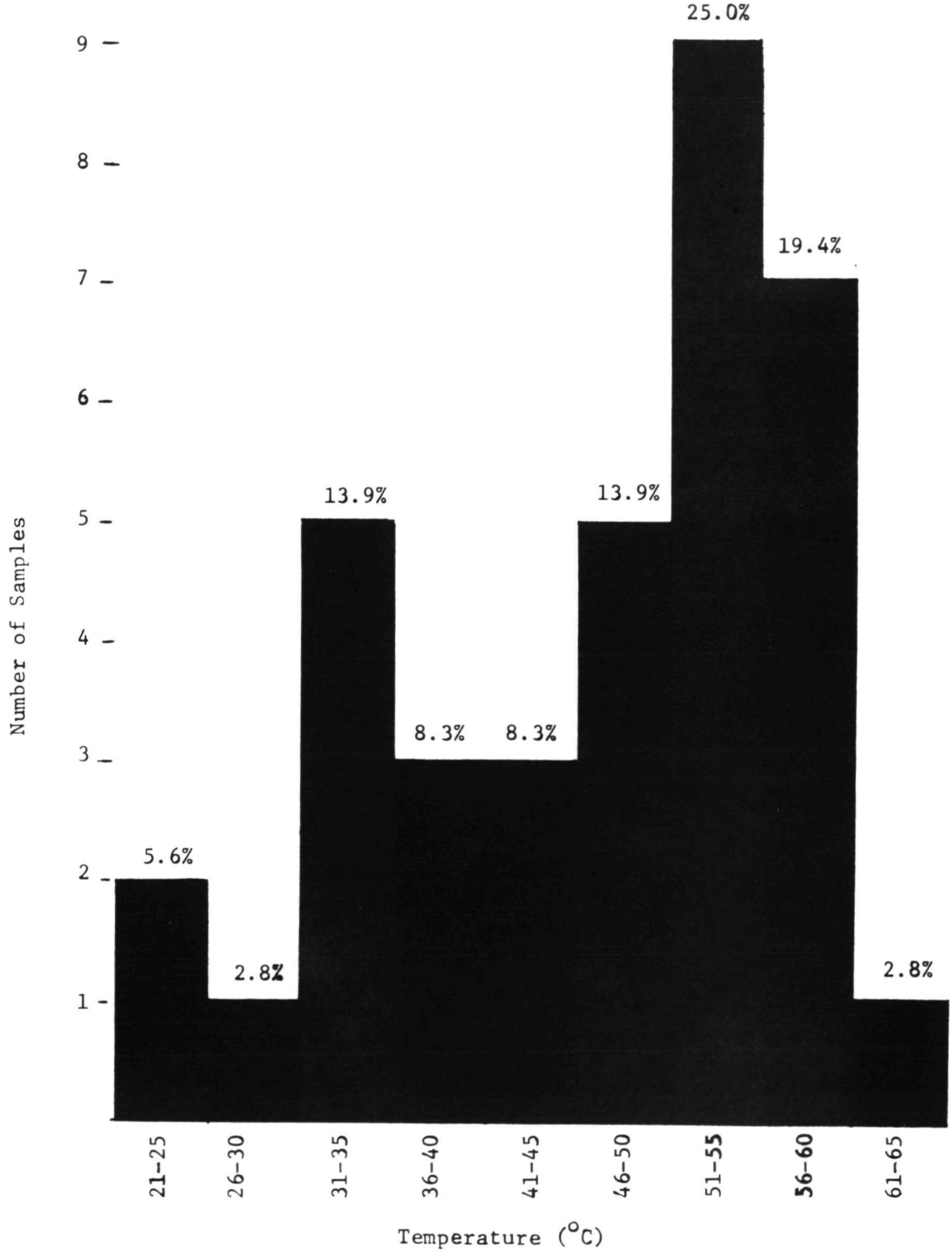


FIGURE 15 HISTOGRAM OF PERCENTILE DISTRIBUTION OF TEMPERATURE

Here an added difficulty arose - most of the fields in which the moisture samples were taken were more or less densely covered with vegetation, leaving the soil itself to be seen only in the rows between, or canopy breaks in, the crops. This made it very difficult to assess density, since the point location whose density it was desired to determine was not only very small but was also surrounded by the eye-integrated density of the background (noise), which tended to lend a bias to the observers' assessment.

Another factor that adversely affected the results was the indeterminate position of the temperature/moisture sample in respect to the top or bottom of the furrow. In many fields an alternate light-dark banding was observed, undoubtedly caused by the alternation of moist furrow bottoms with drier furrow tops. Thus, at the very beginning of the experiment, doubts were cast on the validity of the results.

Table XXVIII shows the density readings for each temperature-moisture test station. The data from four of the thirty-four test stations have been omitted from the subsequent computations since, because of the disparate density readings obtained for them, they were considered to be unreliable. Figures 16A, 16B and 16C show the positions of the test stations plotted on thermal infrared imagery.

Statistical analyses were performed on these data and correlations established between: 1) temperature and moisture (Table XXIX); 2) density and temperature (Table XXX); and 3) density and moisture (Table XXXI).

As shown in Table XXIX, there is no apparent statistical correlation between temperature and moisture, suggesting that factors other than moisture were responsible for temperature differences, such as soil type and soil compaction.

A slight coefficient of correlation (.23) was found to exist between density and temperature, with a coefficient of non-determination of 94% (see Table XXX). Therefore, based upon the input data, density appeared to be a function of temperature only 6% of the time. A slightly larger coefficient of correlation (.39) was obtained between density and moisture. The coefficient of non-determination, 85%, indicated that, apparently, density is a function of moisture only 15% of the time (Table XXXI). See Table XXXII for a summary of the statistical parameters found.

These low correlations were not unexpected for the two reasons previously mentioned: the inaccuracy inherent in the method of density measurement; and the positional indetermination of the soil samples. Automatic gain control might also have been responsible for inaccuracies in photographic density values.

2.4.2.3 Determination of Qualitative Correlation Between Soil Moisture and Image Color and Density

Thermal IR used in conjunction with color IR proved to be the most useful sensor combination for qualitatively detecting changes in soil moisture. The most efficient method of utilizing this combination is to first examine the thermal IR. Tone changes on this sensor can usually be interpreted as being due to changes in

TABLE XXVIII

DENSITY READINGS FOR TEMPERATURE/MOISTURE STATIONS

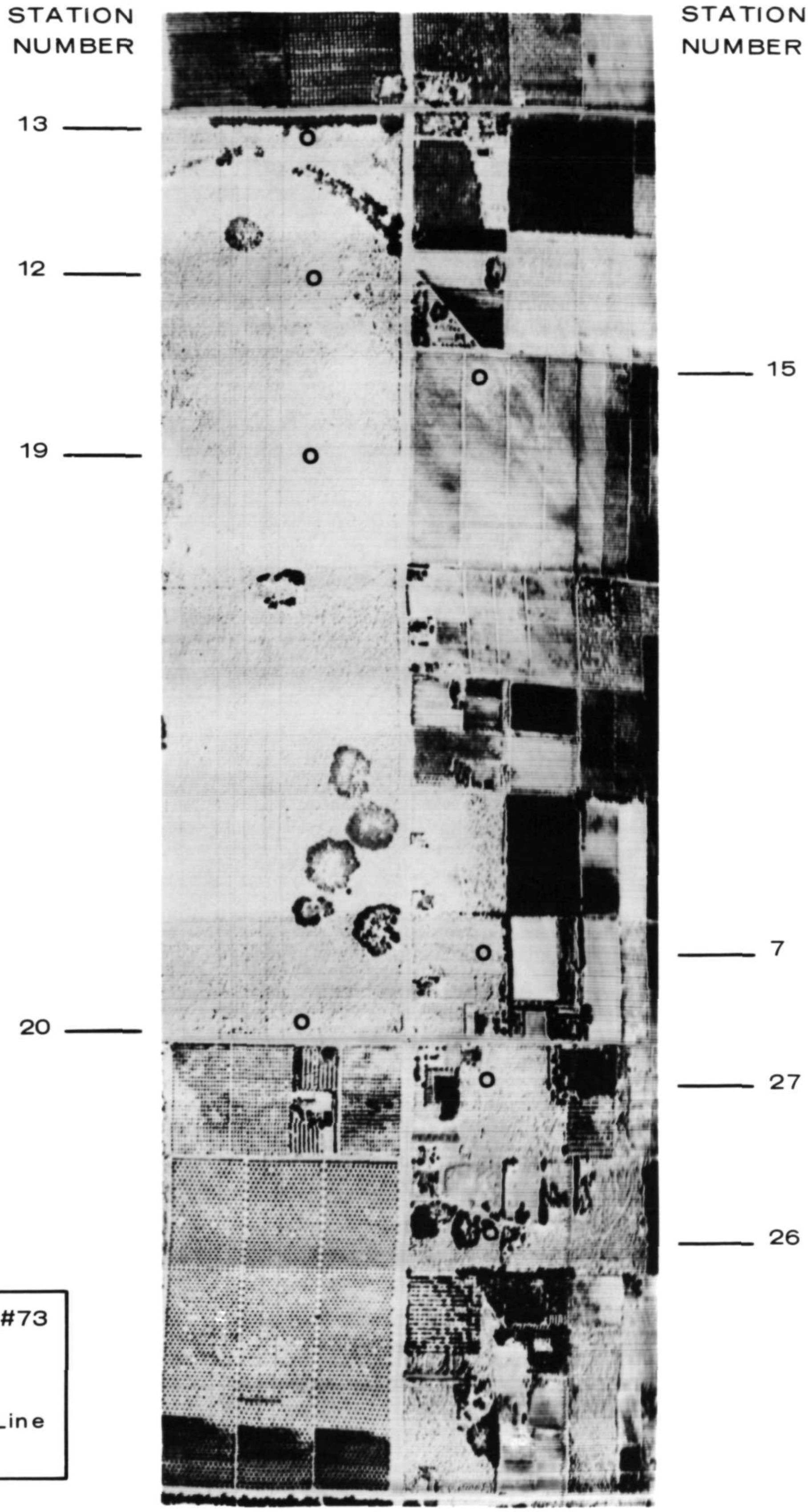
Test Station Number	Photographic Density	Temperature (°C)	Moisture (% by Volume)	
1	5	22	37.75	
2	12	25	20.52	
	4 & 16	29	25.20	(discarded)
3	12	31	32.60	
	6 & 12	33	15.55	(discarded)
4	7	33	10.65	
5	13	33	7.70	
6	10	36	0.00	
7	4	39	0.06	
8	11	40	2.09	
9	6	44	24.0	
	3 & 12	44	0.30	(discarded)
10	9	44	0.09	
11	6	46	0.30	
12	4	46	0.39	
13	3	47	0.39	
14	6	47	0.12	
15	4	48	5.52	
16	6	51	8.28	
17	2	51	0.52	
18	6	51	0.27	
19	2	51	0.18	

TABLE XXVIII (Cont'd)

Test Station Number	Photographic Density	Temperature (°C)	Moisture (% by Volume)	
20	4	51	0.15	
21	7	51	0.03	
	2 & 17	52	0.00	(discarded)
22	5	54	0.09	
23	5	54	0.00	
24	16	56	24.00	
25	5	56	.09	
26	4	56	.06	
27	3	57	.03	
28	15	58	2.31	
29	8	60	0.45	
30	5	64	.09	

Ground Sampling Stations

...Location of Temperature/Moisture Stations Plotted on Thermal IR Imagery



NASA/USGS Mission #73
21 May 1968
Test Site #130
Jackson Street Flight Line
Scale 1:6,100

FIGURE 16A:
LOCATION OF TEMPERATURE/MOISTURE STATIONS PLOTTED ON THERMAL IR IMAGERY

Ground Sampling Stations

...Location of Temperature/Moisture Stations Plotted on Thermal IR Imagery

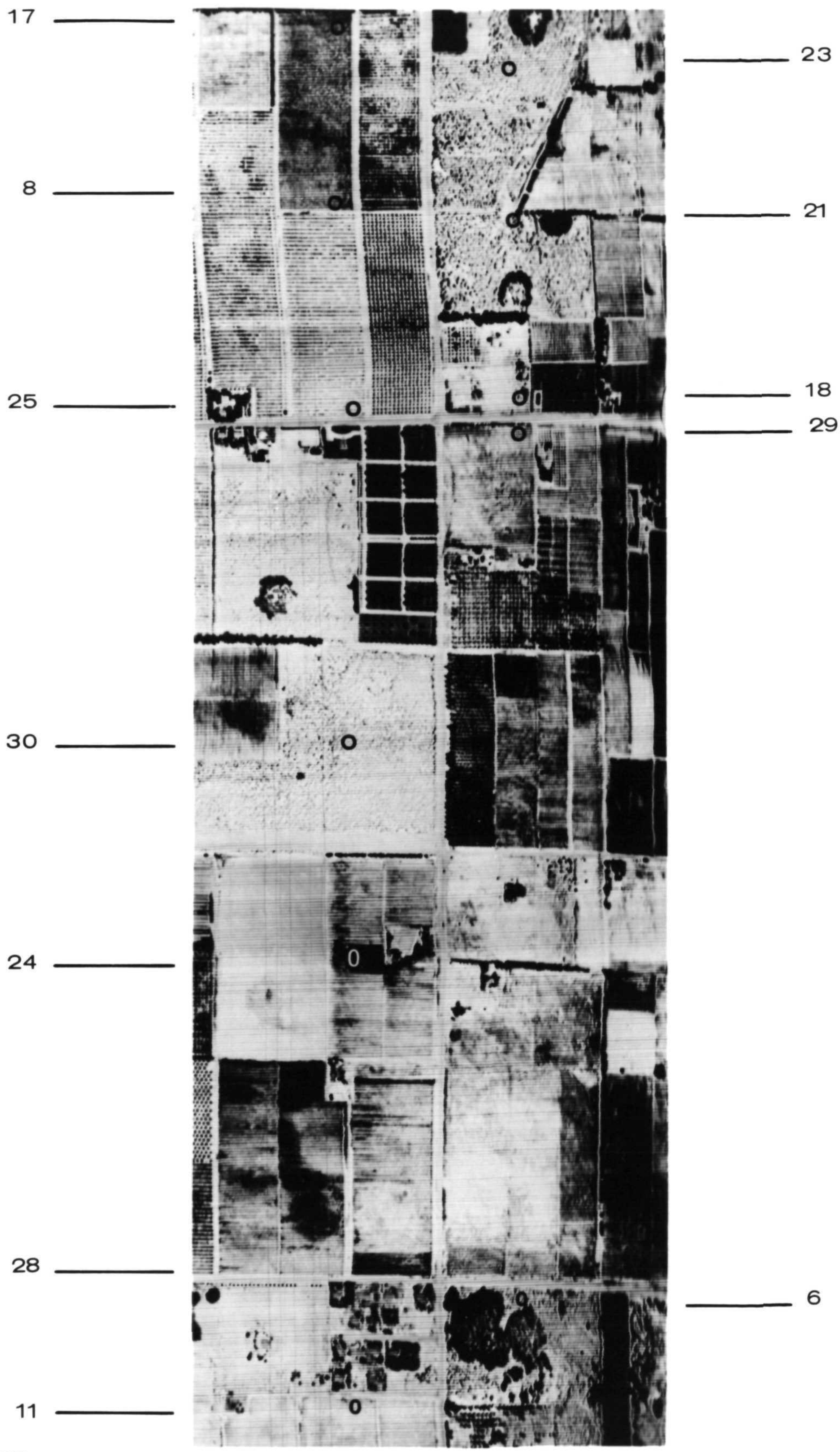


FIGURE 16B:
LOCATION OF TEMPERATURE/MOISTURE STATIONS PLOTTED ON THERMAL IR IMAGERY

Ground Sampling Stations

...Location of Temperature/Moisture Stations Plotted on Thermal IR Imagery

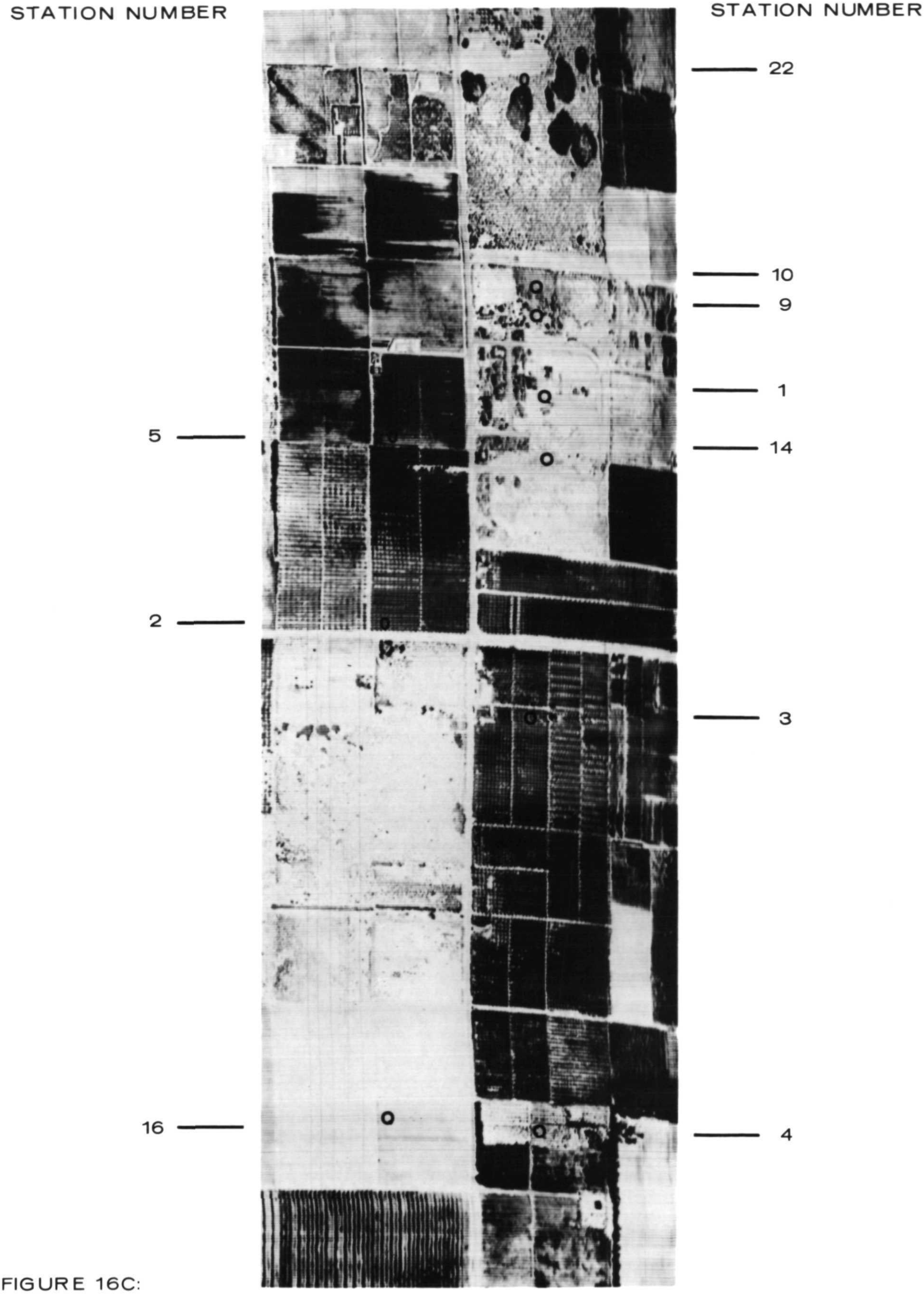


FIGURE 16C:
LOCATION OF TEMPERATURE/MOISTURE STATIONS PLOTTED ON THERMAL IR IMAGERY

TABLE XXIX

TEMPERATURE AS A FUNCTION OF MOISTURE

Temperature (^{o}C) Y	Y^2	Moisture (%) X	X^2	XY
22	484	37.75	1425.06	830.50
25	625	20.52	421.07	513.00
31	961	32.60	1062.76	1010.60
33	1089	10.65	113.42	351.45
33	1089	7.70	59.29	254.10
36	1296	0.00	0.00	0.00
39	1521	0.06	0.00	2.34
40	1600	2.09	4.37	83.60
44	1936	24.00	576.00	1056.00
44	1936	0.09	0.01	3.96
46	2116	0.30	0.09	13.80
46	2116	0.09	0.01	4.14
47	2209	0.39	0.15	18.33
47	2209	0.12	0.01	5.64
48	2304	5.52	30.41	264.96
51	2601	8.28	68.56	422.28
51	2601	0.52	0.27	26.52
51	2601	0.27	0.07	13.77
51	2601	0.18	0.03	9.18
51	2601	0.15	0.02	7.65
51	2601	0.03	0.00	1.53
54	2916	0.09	0.01	4.56
54	2916	0.00	0.00	0.00
56	3136	24.00	576.00	1344.00
56	3136	0.09	0.01	5.04
56	3136	0.06	0.00	3.36
57	3249	0.03	0.00	1.71
58	3364	2.31	5.34	133.98
60	3600	0.45	0.02	27.00
64	4096	0.09	0.01	5.76

TABLE XXX

DENSITY AS A FUNCTION OF TEMPERATURE

Density Y	Y^2	Temperature X	X^2	XY
5	25	22	484	110
12	144	25	625	300
12	144	31	961	372
7	49	33	1089	231
13	169	33	1089	429
10	100	36	1296	360
4	16	39	1521	156
11	121	40	1600	440
6	36	44	1936	264
9	81	44	1936	396
6	36	46	2116	276
4	16	46	2116	184
3	9	47	2211	141
6	36	47	2211	282
4	16	48	2304	192
6	36	51	2605	306
2	4	51	2605	102
6	36	51	2605	306
2	4	51	2605	102
4	16	51	2605	204
7	49	51	2605	357
5	25	54	2916	270

TABLE XXX (Cont'd)					
	Density Y	Y^2	Temp. X	X^2	XY
	5	25	54	2916	270
	16	256	56	3136	896
	5	25	56	3136	280
	4	16	56	3136	224
	3	9	57	3249	171
	15	225	58	3364	870
	8	64	60	3600	480
	5	25	64	4096	320
SUM	205	1813	1402	68,674	9,291

TABLE XXXI

DENSITY AS A FUNCTION OF MOISTURE

Density Y	Y^2	Moisture X	X^2	XY
5	25	37.75	1425.06	188.75
12	144	20.52	421.07	246.24
12	144	32.60	1062.76	391.20
7	49	10.65	113.42	74.55
13	169	7.70	59.29	100.10
10	100	0.00	0.00	0.00
4	16	.06	.0036	.24
11	121	2.09	4.368	22.99
6	36	24.0	576.0	144.0
9	81	.09	.0081	.81
6	36	.30	.09	1.80
4	16	.09	.0081	.36
3	9	.39	.1521	1.17
6	36	.12	.0144	.74
4	16	5.52	30.47	22.08
6	36	8.28	68.56	49.68
2	4	.52	.270	1.04
6	36	.27	.0729	1.62
2	4	.18	.0324	.36
4	16	.15	.0225	.60
7	49	.03	.0009	.21
5	25	.09	.0081	.45
5	25	0.00	0.00	.000
16	256	24.0	576.0	384.0
5	26	.09	.0081	.45
4	16	.06	.0036	.24
3	9	.03	.0009	.09
15	225	2.31	5.34	34.65
8	64	.45	.2025	3.60
5	25	.09	.0081	.45
205	1813	178.43	4343.185	1672.47

TABLE XXXII

SUMMARY OF STATISTICAL PARAMETERS

	Temperature as a Function of Moisture	Density as a Function of Temp.	Density as a Function of Moisture
Standard Error			
δy^2	1730.35	12.74	11.63
δy	41.60	3.58	3.41
Standard Deviation			
σy^2	107.26	13.48	13.74
σy	10.36	3.67	3.70
Coefficient of Correlation			
γ	0.00	0.23	0.39
Coefficient of Non-determination			
	100%	94%	85%

either vegetation or in soil moisture, after other causes have been logically eliminated. Determination as to which of the two - vegetation or moisture - is causing the change in photographic density is then accomplished by applying to the color IR image. Thus, in Figure 17A the tone change between areas A and B can be interpreted on the thermal IR as being due either to changes in vegetation or in moisture. The pattern, however, suggests irrigation, and the response of the color IR emulsion confirms this, showing no change in vegetation. Note that the thermal IR detects the irrigated area much better than does the color IR.

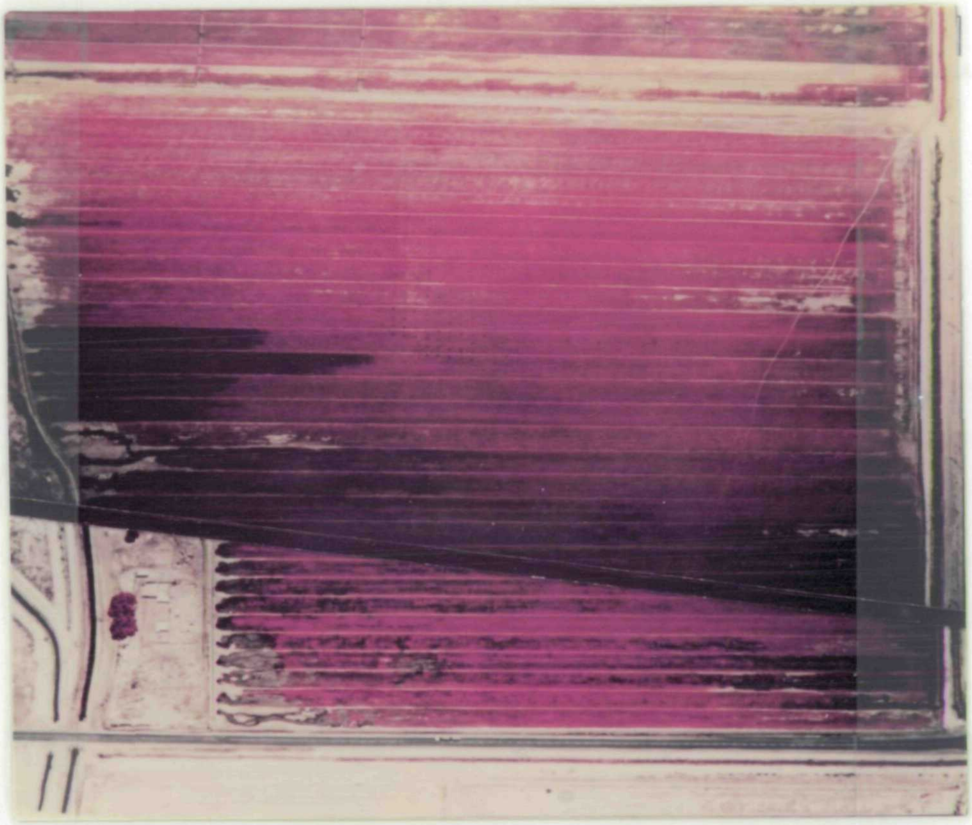
In Figure 17B, the thermal IR shows field C to be either very moist or else covered with living vegetation. The color IR reveals that the field is covered with standing water. (Fields in the Imperial Valley are subject to gradual build-up in salt content and are periodically flooded to leach the salts out.)

In Figure 17C, the thermal IR shows the gulley pattern, D, to be warmer than the surrounding area, which it drains. This is anomalous, since drainage channels usually contain more moisture than the interfluves drained by them. The color IR, however, shows the gulley bottom to be densely covered by dormant vegetation, the high emissivity of which produces the light (warm) tone on the thermal IR.

Color IR & Thermal IR as Indicators of Moisture

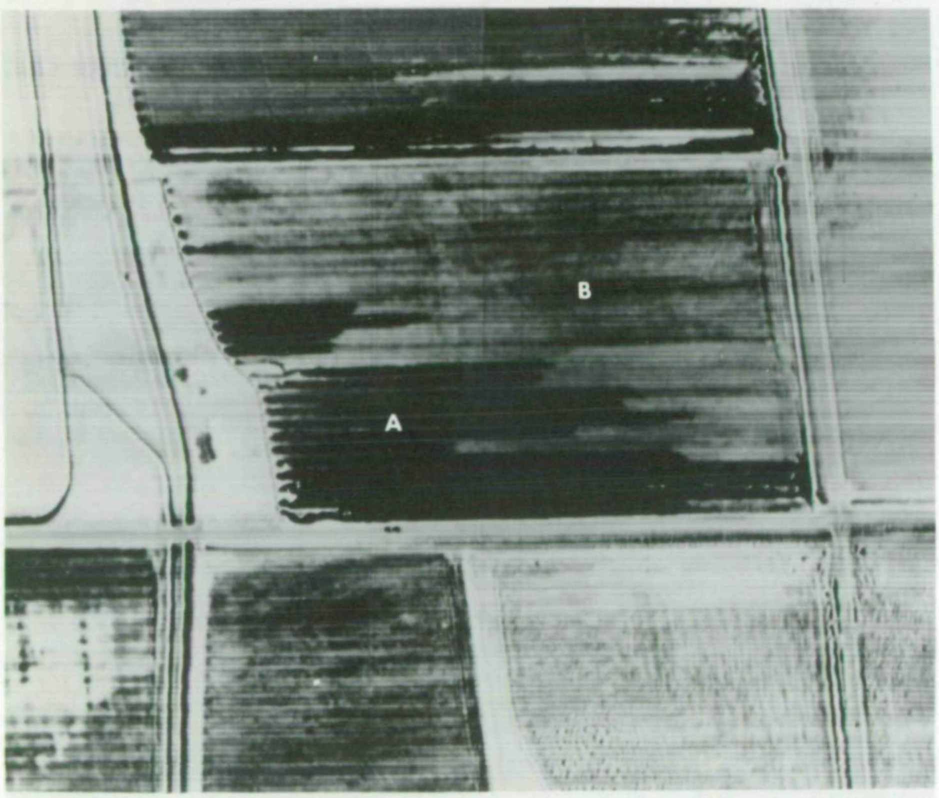
...Comparison of RC-8 Color IR and Reconofax IV Thermal IR Imagery

NASA/USGS Mission #73
21 May 1968
Test Site #130
Imperial Valley
Scale 1:7,000



Color Ektachrome (8443)

Thermal Infrared (8-14 microns)



ANNOTATIONS

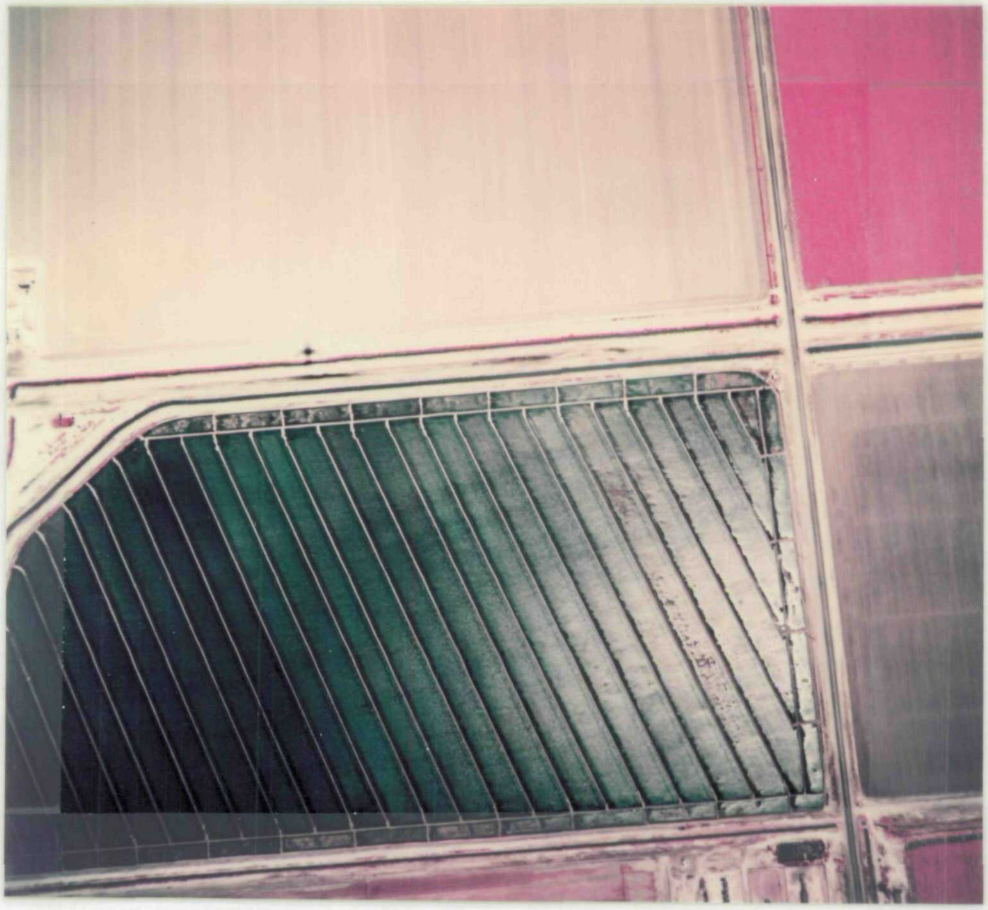
A: Irrigation in Progress
B: Alfalfa Field

FIGURE 17A:
RELATIVE SOIL MOISTURE CONTENT FROM THERMAL IR AND COLOR IR

Color IR & Thermal IR as Indicators of Moisture

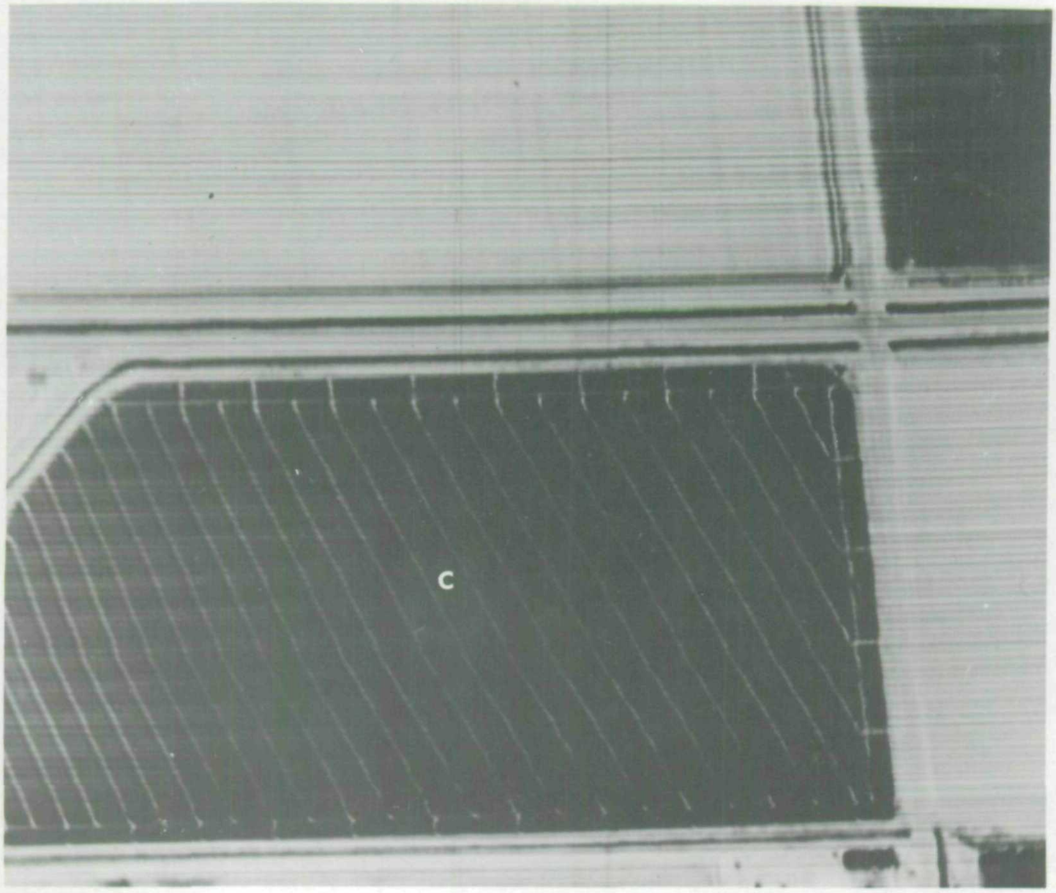
...Comparison of RC-8 Color IR and Reconofax IV Thermal IR Imagery

NASA/USGS Mission #73
21 May 1968
Test Site #130
Imperial Valley
Scale 1:7,000



Color Infrared (8443)

Thermal Infrared
(8-14 microns)



ANNOTATIONS

C: Standing Water

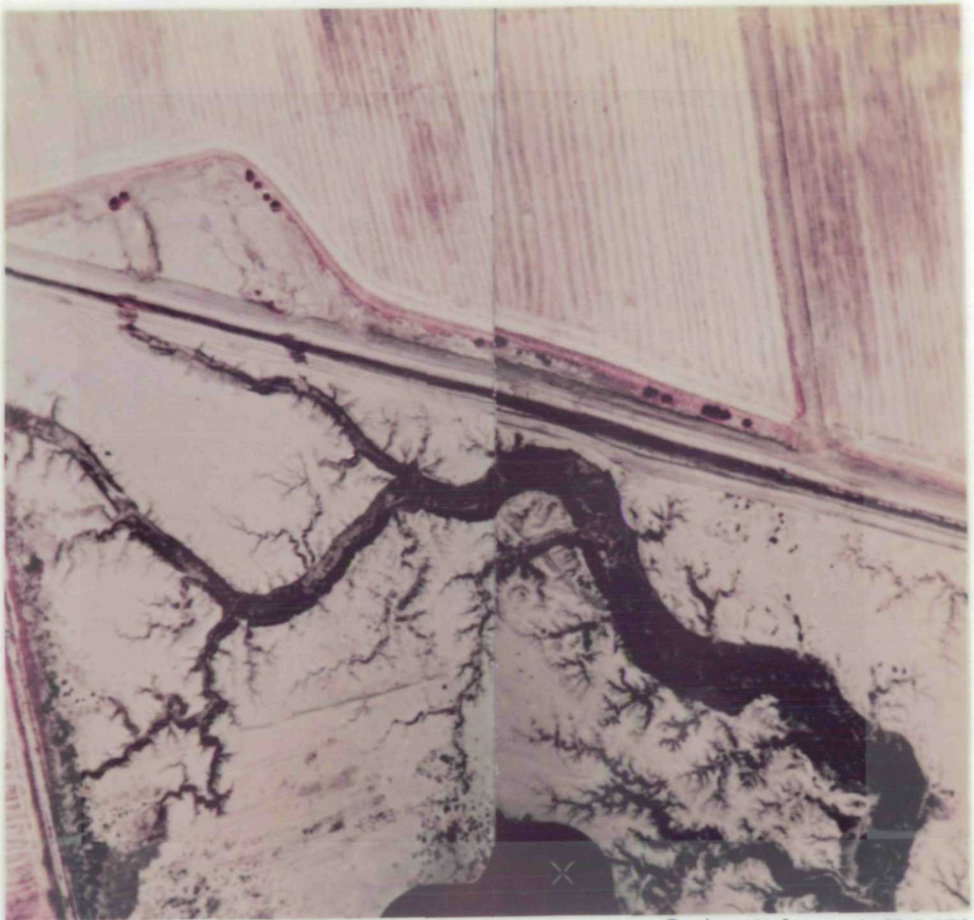
FIGURE 17B:

RELATIVE SOIL MOISTURE CONTENT FROM THERMAL IR AND COLOR IR

Color IR & Thermal IR as Indicators of Moisture

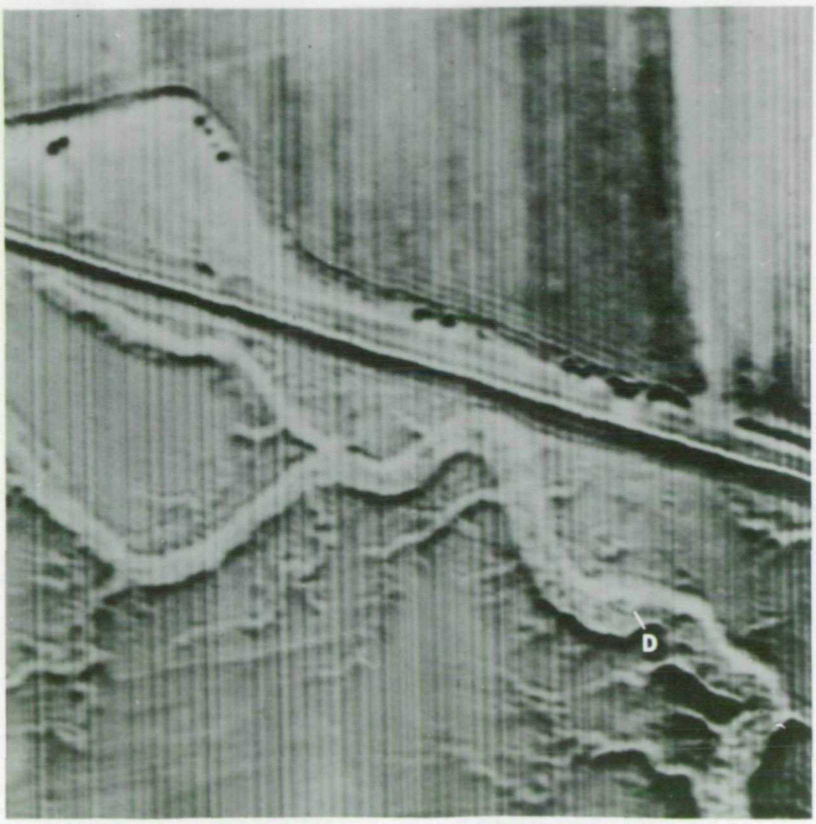
...Comparison of RC-8 Color IR and Reconofax IV Thermal IR Imagery

NASA/USGS Mission #73
21 May 1968
Test Site #130
Imperial Valley
Scale 1:7,000



Color Infrared (8443)

Thermal Infrared (8-14 microns)



ANNOTATIONS

D: Dormant Vegetation in Gulley.

FIGURE 17C:
RELATIVE SOIL MOISTURE CONTENT FROM THERMAL IR AND COLOR IR

2.5 Feasibility From Spacecraft

2.5.1 Objectives

In this section, techniques are developed for evaluating the performance of NASA's RC-8 camera at satellite altitudes using Kodak Ektachrome IR film. The methodology is kept as general as possible to allow for the substitutions of other imaging and data recording systems. The imaging situations for which sensor performance is evaluated will be related to the detection of agricultural, cultural, and urban features.

Two factors are responsible for the limitation of ground resolution obtainable from an overhead photographic system: the lens/film resolution and the atmospheric transfer process. In section 2.5.2, these factors limiting resolution from a spacecraft will be discussed.

2.5.2 Factors Limiting Resolution Obtainable From an Orbiting Photographic System.

The lens/film photographic system which is under primary consideration is the Wild Heerbrugg RC-8 camera equipped with an f/5.6, f =150 mm(6") Universal Aviogon lens (15UAg.) imaging on Kodak Ektachrome IR Aerographic film.

Resolution is defined as the ability to record fine detail. One commonly used means of determining resolution is to image a test chart containing a sequence of objects of increasingly fine detail, usually a bar target or pattern consisting of lines and spaces of equal widths. The threshold at which it is possible to barely distinguish a line-space pair is determined. The width of the line-space pair in millimeters is taken as the smallest recognizable distance. The reciprocal of this distance is the resolution in lines per millimeter.

While the resolving power, as determined by the preceding method, has the advantages of convenience and simplicity, it does not always provide an adequate index of sharpness or edge definition. For a measure of sharpness, the concepts of the optical transfer function (OTF) and modulation transfer function (MTF) are employed. This approach involves the analysis of optical images in a manner analogous to electrical signals. Brightness is considered a function of linear distance in the same manner that current or voltage varies as a function of time. Instead of frequency expressed as cycles per second, there is spatial frequency expressed as cycles per millimeter. The optical transfer function is the analogue of the frequency response of an electrical network.

The response of an optical system is determined by inputting a basic pattern and measuring and comparing the output in terms of modulation. The input pattern is usually either a point, line or edge function. The response of the system to these input functions is the point, line or edge spread function. The spread function describes the distribution of flux density in the image plane. Figure 18 shows that the edge spread function can be considered as half of the line spread function.

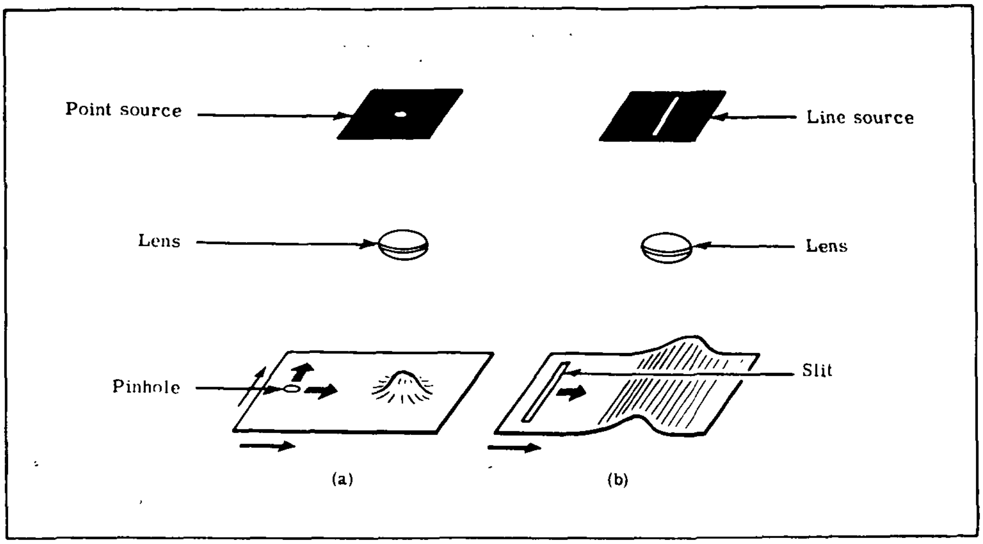


FIGURE 18 POINT AND LINE SPREAD FUNCTIONS (James, T. H, and Higgins, G. C., Fundamentals of Photographic Theory, Second Edition, Morgan and Morgan, Inc., New York, 1960, p. 229.)

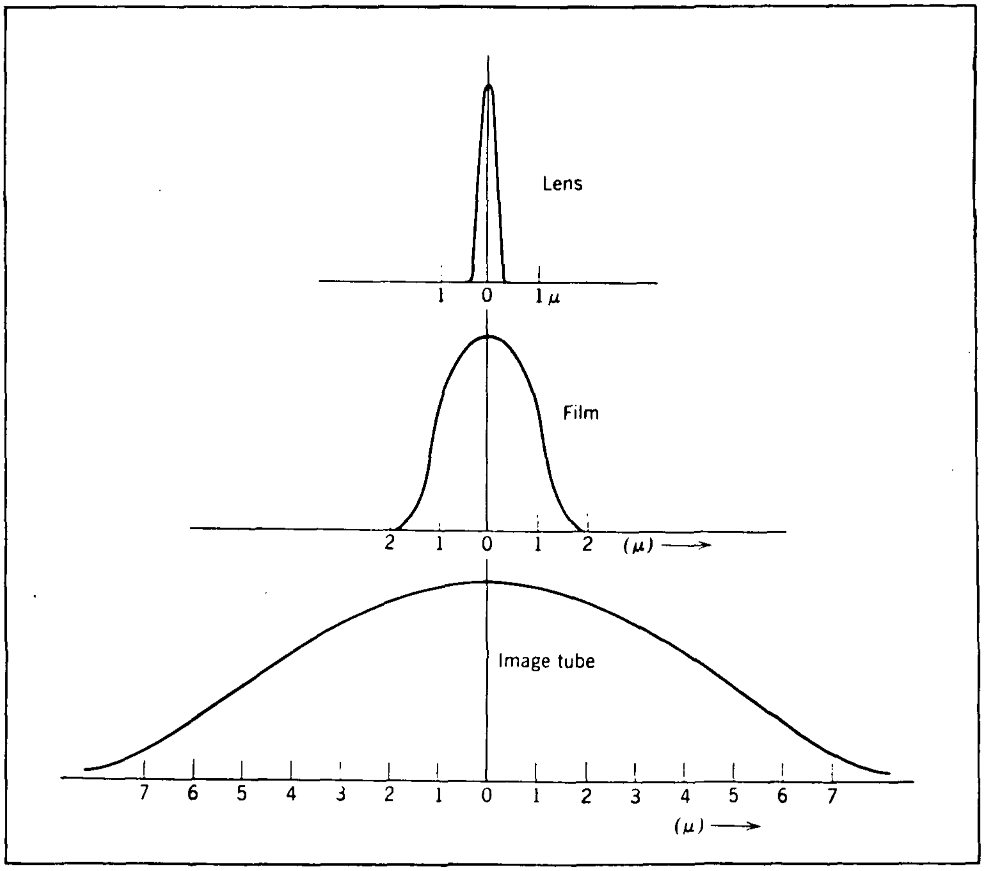


FIGURE 19 CHARACTERISTIC SPREAD FUNCTIONS

The point spread function is seldom used in the evaluation of optical systems because of problems encountered in measuring the low energy level of flux density. Instead, the line spread function is used, which can be considered as a series of point spread functions added together to form a line. In the case of imaging onto film, the image of a point or line is distorted or spread by silver grains, scattered within the emulsion, or refracted by the emulsion thickness and halation. In a like manner, the spread function of any other imaging system or part of an imaging system can be determined by putting a line or point function and deriving a spread function. Thus it is possible to express the response of an image tube, data link, or atmospheric transfer process. Figure 19 shows some characteristic spread functions. Usually the spread function can be approximated by a Gaussian distribution. In actuality, the spread function of each sensor element is a function of position from the optical axis. As a rule, only the spread function of a point on the optical axis will be symmetrical.

If a point spread function of an imaging sensor is known, the illuminance of any object can be found by a convolution process, i.e., by summing the point spread function corresponding to the points in the object. This process is illustrated in Figure 20, where the illumination of an image $i(x_1)$ is determined by an object defined by a function $o(x_2)$. The convolution integral is given by:

$$i(x_1) = \int_{-\infty}^{\infty} s(x_2)\, o(x_1 - x_2)\, dx_2 \qquad (1)$$

A more general and practical method of optical system analysis is to determine the response of the system to sinusoidal targets of varying spatial frequency. The function that describes this performance is called the optical transfer function (OTF), which expresses both amplitude and phase changes as functions of spatial frequency. The function describing only the amplitude modulation is called the modulation transfer function (MTF).

Rather than image sinusoidal test patterns, the sinusoidal response can be determined by using the Fourier transform to convert an impulse function such as a point or line function from the spatial domain to the frequency domain. An example of a function broken down into sinusoidal components is given in Figure 21. The function analyzed is a square wave. For a square wave function, the Fourier transform is a series of sine waves composed of the fundamental, having a frequency of f, and odd harmonics of frequency 3f, 5f, 7f, etc., with corresponding amplitudes of 1/3, 1/5, 1/7, etc. By adding together the various harmonics, the original function is approximated. The more harmonics present, the closer is the approximation to the original function. The intensity modulation of each component, M, is defined by:

$$M = \frac{I_{max} - I_{min}}{I_{max} + I_{min}} \qquad (2)$$

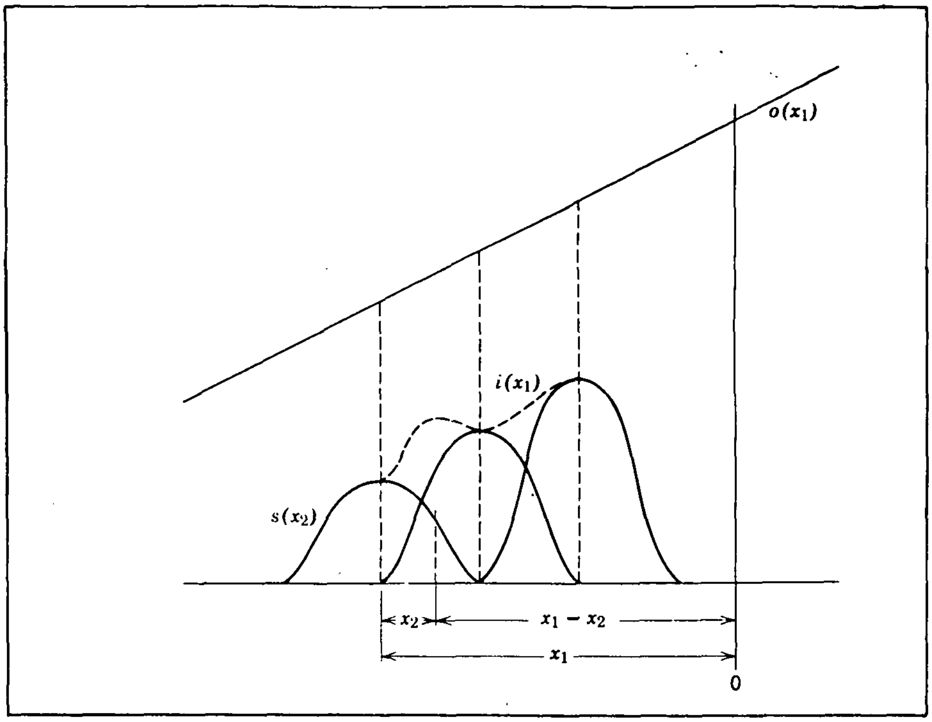


FIGURE 20 CONVOLUTION PROCESS (Perrin, F.H., Method of Appraising Photographic Systems, J. Soc. Motion Picture Television Engineers 69, p. 151-156, 1960.)

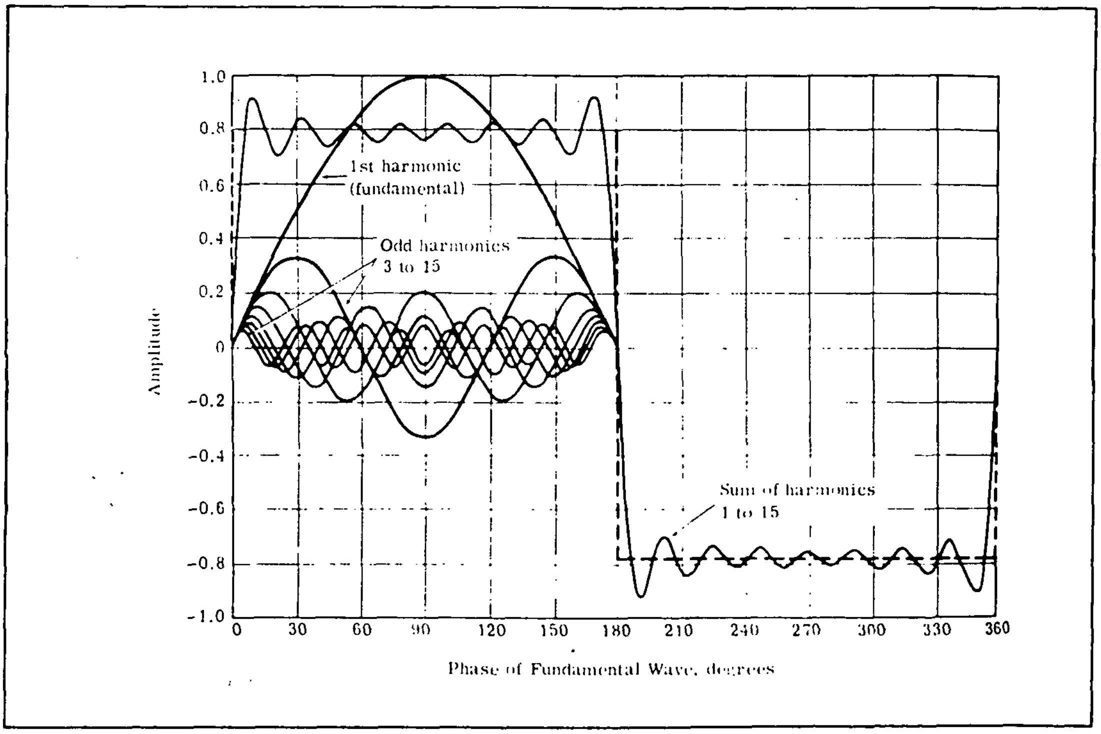


FIGURE 21 ANALYSIS OF A SQUARE WAVE INTO ITS FUNDAMENTAL AND HARMONICS

In a real system, the high spatial frequencies suffer greater attenuation resulting in an image with blurred edges. Transforming an image into its spatial frequency spectrum and computing the modulation as a function of frequency (MTF) provides a powerful tool in image analysis.

The Fourier transform, (ω), of a function $g(x)$ is defined by

$$G(\omega) = \int_{-\infty}^{\infty} g(x) e^{-iwx} dx. \qquad (3)$$

By taking the Fourier transform of equation (1), the frequency spectrum of intensity becomes

$$I(\omega) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} s(x_2)\, o(x_1-x_2)\, e^{-i\omega x} dx_2 dx_1$$

$$= \int_{-\infty}^{\infty} s(x_2)\, dx_2 \int_{-\infty}^{\infty} o(x_1-x_2)\, e^{-i\omega x_1} dx_1 dx_2.$$

Letting $x_1-x_2=u$

$$I(\omega) = \int_{-\infty}^{\infty} s(x_2)\, dx_2 \int_{-\infty}^{\infty} O(u)\, e^{-i\omega u}e^{-i\omega x}e^{-i\omega x_2}\, du.$$

$$\int_{-\infty}^{\infty} s(x_2)\, e^{-i\omega x_2}\, dx_2 \int_{-\infty}^{\infty} o(u) e^{-i\omega u} du.$$

$$I(\omega) = S(\omega)\, O(\omega). \qquad (4)$$

Thus the Fourier transform of the image $I(\omega)$ is equal to the product of the Fourier transforms of the object, $o(\omega)$ and the spread function, $S(\omega)$.

Thus, $$S(\omega) = I(\omega)/O(\omega) . \qquad (5)$$

Normalizing the Fourier transform of the spread function, $\tau(\omega)$, the optical transfer function is obtained

$$\tau(\omega) = \frac{\int_{\infty}^{\infty} s(x)\, e^{-ix} dx}{\int_{-\infty}^{\infty} s(x)\, dx} . \qquad (6)$$

The absolute value or amplitude of this complex function is the MTF. For convenience, angular frequency is converted to linear frequency and the MTF becomes

$$T(k) = |\tau(\omega/2\pi)| . \qquad (7)$$

Figure 22 shows a typical spread function and corresponding modulation transfer function for an optical system.

2.5.2.1 Image Motion Compensation

The movement of the sensor with respect to the ground is responsible for image blurring. The amount of image degradation so caused is dependent on the altitude and speed of the sensor with respect to the ground, the type of motion (linear and/or rotational), the exposure time, and the presence or absence of image motion compensation (IMC).

If the orbit of the imaging sensor is assumed as circular, the velocity can be derived from the equation

$$V^2 = GM(2/r - 1/a) \quad . \tag{8}$$

where
G = Gravitational Constant
M = Mass of the earth
GM = $1.40769256 \times 10^{16}\ ft^3/sec^2$
r = Semi-minor axis
a = Semi-major axis

For a circular orbit, r = a.

$$V^2 = GM(1/a_o). \tag{9}$$

where
a_o = radius of circular orbit = $a_e + a_h$

a_e = radius of earth at the equator = 20.9023057×10^6ft.

a_h = altitude of satellite = 150nmi = $.911415 \times 10^6$ft.

Under these conditions, orbital velocity is $V = 2.54 \times 10^4$ft/sec = 7.74262×10^3m/sec. The velocity with respect to the ground becomes

$$V = 24.3404 \times 10^3 \text{ft/sec} = 7.41897 \times 10^3 \text{m/sec}.$$

Image velocity under idealized conditions where the sensor is moving parallel to a flat earth as shown in Figure 23 is given by

$$v = VF/H \tag{10}$$

F = Focal length,
H = Sensor altitude.

In the particular case under consideration,

$$v = 13.385 \times 10^{-3} \text{ft/sec} = 4.08 \text{ mm/sec}.$$

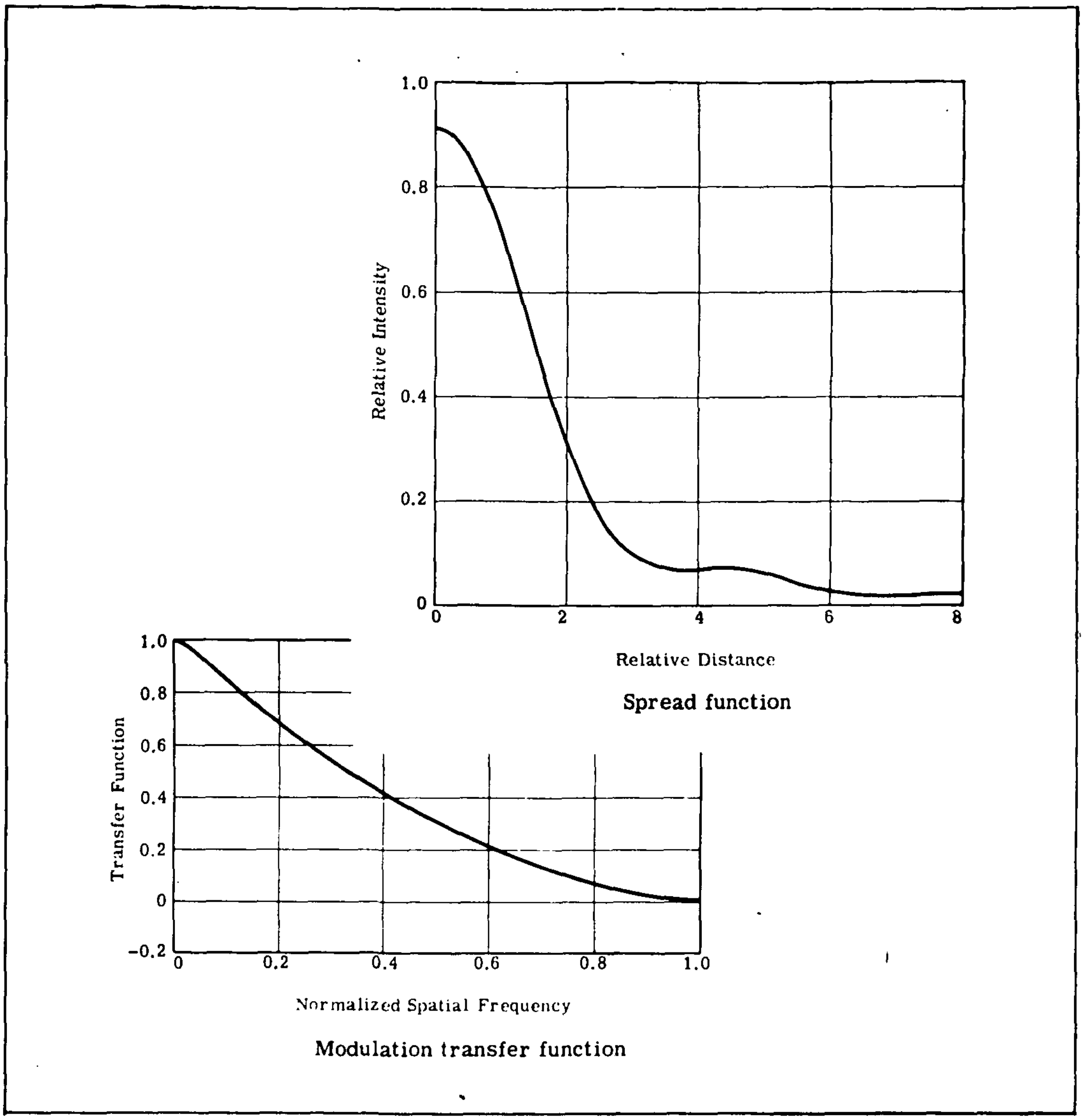


FIGURE 22 TYPICAL SPREAD FUNCTION WITH CORRESPONDING MODULATION TRANSFER FUNCTION (G. C. Brock, D. I. Harvey, R. J. Kohler, and E. P. Myskowski, "Photographic Considerations for Aerospace," Itek Corporation, Lexington, Mass., 1966.)

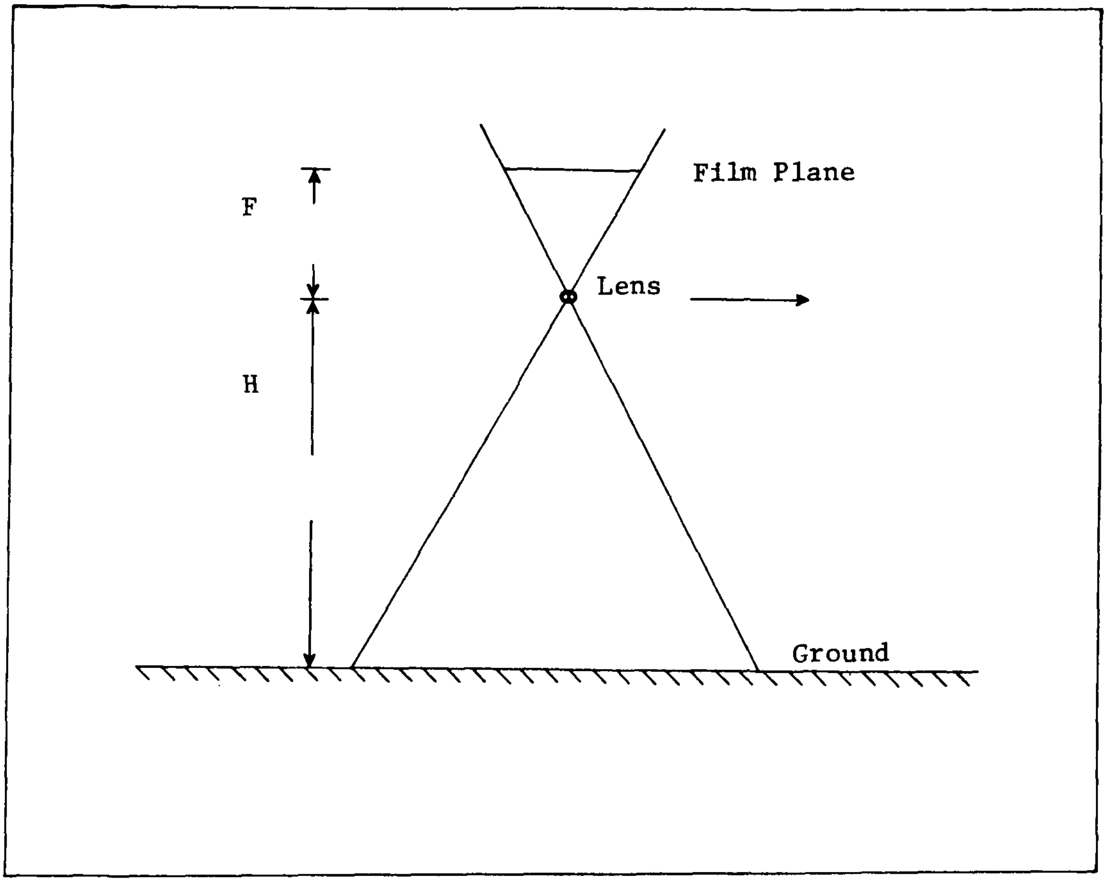


FIGURE 23 IMAGE GEOMETRY

(Taking into account the curvature of the earth, however, results in a non-uniform motion of image points.)

For an exposure of 1/100 second, the linear motion is 40 microns. This corresponds to a ground movement of 74 meters or 243 feet and a spatial frequency at the film plane of 24.5 lines/mm.

The dynamic resolution obtainable from a satellite imaging at an altitude of 150 NM with a 6" focal length and 50 lines/mm resolution can be roughly estimated by adding the static ground resolution, S_o and the amount of blur due to image motion.

$$S = S_o + \gamma V\, T_e. \tag{11}$$

S_o = static ground resolution neglecting atmospheric attenuation

$$= H/FR \tag{12}$$

H = altitude

F = focal length

R = resolution

S_o = 121.5 ft.

γ = IMC factor - (1 for no IMC)

V = ground speed

T_e = exposure time = 1/100 sec

S = 121.5 + 243 = 364.5 ft.(no image motion compensation)

The MTF for linear image motion can be determined by assuming an image with a sinusoidal luminance pattern.

$$i(x) = i_o + i_m \cos 2\pi kx. \tag{13}$$

The modulation according to equation (2) becomes

$$M_o = \frac{(i_o + i_m) - (i_o - i_m)}{(i_o + i_m) + (i_o - i_m)} = \frac{i_m}{i_o}\quad . \tag{14}$$

If the image is moving at a velocity, v, the luminous distribution is expressed by $i(x,t) = i_o + i_m \cos 2\pi\, k\, (x + vt)$. (15)

During an exposure interval, t_e, the average intensity is given by

$$\overline{i(x,t)} = (1/t_e) \int_0^{t_e} i_o + i_m \cos 2\pi\, k\, (x + vt)\, dt$$

$$= i_o + (i_m/2\pi\, kvt_e)\, (\sin 2\pi\, k\, (x + vt))_0^{t_e}$$

$$\overline{i(x,t} = i_o + (i_m/2\pi\, kvt_e)(\sin 2\pi k\, (x + vt_e) - \sin 2\pi\, kx) \quad (16)$$

Using trigonometric identities reduces equation (16) to

$$i(\overline{x,t}) = i_o + i_m \frac{\sin \pi kvt_e}{\pi kvt_e} \cos 2\pi\, k\, (x + \frac{vt_e}{2}) \quad . \quad (17)$$

Equation (17) is similar to (13) except for a phase lead of πkvt_e and a modulation,

$$M' = (i_m/i_o) \frac{(\sin \pi kvt_e)}{\pi kvt_e} \quad . \quad (18)$$

The modulation transfer function becomes

$$T_k = \left| \frac{M'}{M_o} \right| = \left| \frac{\sin \pi\, kvt_e}{\pi\, kvt_e} \right| . \quad (19)$$

The MTF is zero when $vt_e = i/k$. In the satellite system under consideration this corresponds to a cut off frequency of 24.5 lines/mm. Figure 24 shows the MTF for this situation.

Other types of motion besides linear affect the image quality. These include rotational movements due to the roll, pitch , and yaw of the spacecraft and sinusoidal vibrations caused by the opening and closing of the camera shutter and the movement of the film. These motions, however, can be mechanically compensated for by vibrational isolators or gyro-stabilized camera platform [7].

The MTF of the camera/film system can be found by cascading or multiplying the various individual transfer functions of the lens, film and image motion. Several techniques have been developed for empirically determining the lens MTF.[8] Film MTF's are now routinely determined by the manufacturer for most films. The image motion transfer function can be determined from

----

[7] cf Jensen, Op. Cit. p. 120.

[8] __________, "Modulation Transfer Function: Seminar-in-Depth" SPIE proceedings, Vol. 13, 1969.

(Also Trott, Timothy, "The Effects of Motion on Resolution," Photogrammetric Engineering, XXVI (Dec. 1960), p. 819 - 827)

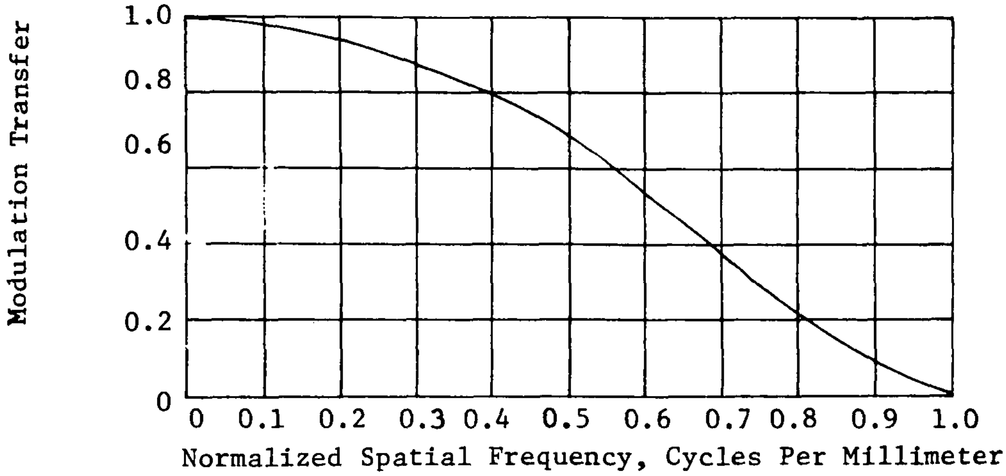


FIGURE 24 MODULATION TRANSFER FUNCTION FOR LINEAR IMAGE MOTION

equation (19). Since the actual MTF of NASA's RC-8 was not available, a nominal MTF with a resolution of 50 lines/mm was used. The MTF of Ektachrome IR is considered proprietary information by Kodak and is not available for public dissemination. Infrared Aerographic 5424 is used for the purpose of illustration.

The detection threshold is a locus of points relating the modulation and spatial frequency at which it is possible to detect three-bar targets. The detection threshold depends on the size of the silver grains, which in turn depends on the film type processing. If the resolving power for varying contrast targets is known, the threshold modulation can be computed from equation (2). For Infrared Aerographic, a resolution of 89 lines/mm for a contrast of 1,000:1 corresponds to a modulation of .999, and a resolution of 28 lines/mm for 1.6:1 corresponds to .23. The spatial frequency at which the detection threshold intersects the system MTF is a measure of system resolution. The MTF of a camera system operating under the aforementioned conditions is determined in Figure 25. In this example, system resolution is 17 lines/mm. At an altitude of 150 nautical miles, this is equivalent to a ground resolution of 357 feet, which agrees with the number derived by equation (11). It should be noted from equation (10) that an increase in focal length results in an increase in film motion and a decrease in system resolution. The effect of increasing focal length will be discussed in a later section.

In the following section (2.5.2.2) the effects of the atmosphere on the system resolution will be discussed along with a method for determining ground resolution from the spread functions of the system. In section 2.5.2.3 the atmospheric and camera transfer functions will be combined to determine the overall resolution of the system.

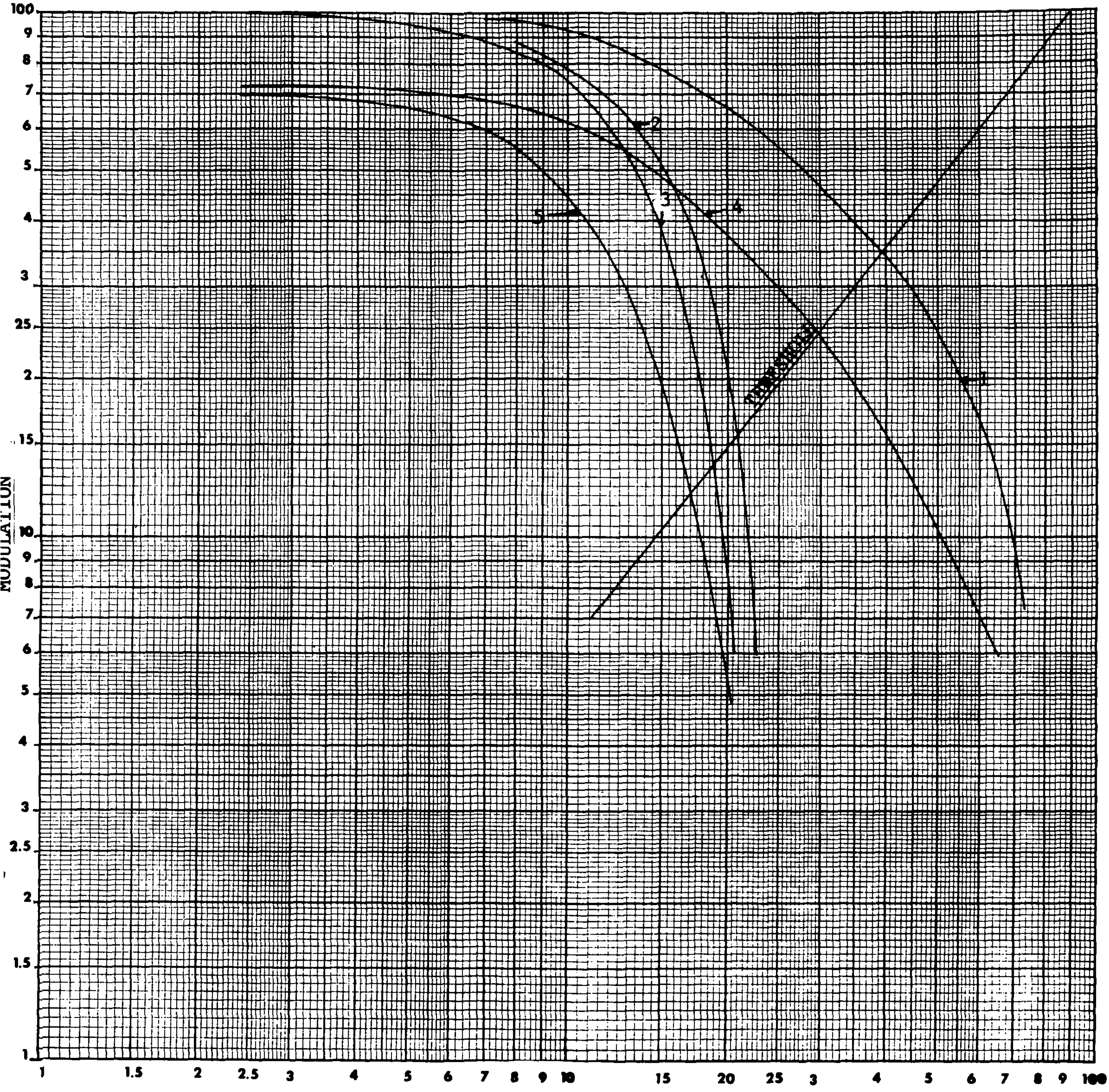
2.5.2.2 Atmospheric Transfer

The atmosphere consists of a mixture of gases. The permanent gases have a fixed proportion to the total and vary only slightly with time and location. The most important variable gases are water and ozone. Although water vapor comprises less than 2% of the gases, it absorbs six times as much solar radiation as all the other gases combined and is responsible for nearly all the absorption by gases of the terrestrial radiation.

COMPOSITION OF THE ATMOSPHERE

	Permanent Gases	Variability
Nitrogen	78.084	$\pm$0.004%
Oxygen	20.946	$\pm$0.002%
CO_2	.033	$\pm$0.001%
Other	---	--- %

	Variable Gases
Water Vapor	0-2%
Ozone	0-0.07% (ground)
	1-3 ppm (20-30 km)



1- Lens (nominal 50 1/mm)

2- Image Motion
(6" focal length at 150 nm)

3- Camera System = 1 x 2

4- Film (Type 5424)

5- Camera/Film System

FIGURE 25 MODULATION TRANSFER FUNCTION OF CAMERA/FILM SYSTEM

The distribution of atmospheric gases with respect to altitude is shown in Table XXXIII. The reduced height, H, of the atmosphere is defined as the total mass of air contained in a vertical column of unit cross-section above the point of observation divided by the density at sea level.

TABLE XXXIII

DISTRIBUTION OF THE ATMOSPHERE WITH ALTITUDE

Height (km)	Height (mi)	H (cm)	% Atmosphere beneath
0	.0	804,000	.000
5	3.1	430,000	47.000
10	6.2	211,000	74.000
15	9.4	90,000	89.000
20	12.5	45,000	94.500
30	18.8	10,000	98.800
35	21.9	4,700	99.420
40	25.0	2,500	99.690
50	31.2	790	99.902
60	37.5	220	99.973
70	43.8	57	99.993
80	50.0	10	99.999

The atmospheric phenomena affecting space photography are contrast degradation, which lowers photographic system resolution; mean refraction, which necessitates photogrammetric corrections to determine true position of ground objects; and turbulence, which causes changes in the refractive index of the atmosphere.

2.5.2.2.1 Contrast Reduction

A beam of light traversing a medium is reduced in intensity partly by absorption and partly by scattering. In the scattering process, light energy is deflected from its original path and reradiated in an altered direction. Scattering is always due to inhomogeneity within the medium. In a reconnaissance situation, atmospheric particles are responsible for light attenuation by scattering. The spectral nature of the scattered light depends on the size of the scattering particles. For a clean atmosphere chiefly composed of nitrogen and oxygen gas molecules, which are much smaller in size than the wavelength of visible light, Rayleigh scattering occurs. Under this condition, the scattering is inversely proportional to the fourth power of the wavelength. The result is a predominance of blue, since shorter wavelengths undergo greater scattering than the longer wavelengths. This phenomena explains the bluish color of the sky and atmospheric haze. Attenuation of light caused by absorption can be considered negligible in a Rayleigh atmosphere. True absorption accounts for only one-millionth of the scattered light.

A Rayleigh atmosphere seldom, if ever, exists, however. In reality, the atmosphere contains aerosol particles equal to or greater than the wavelength of light. These particles can be considered to be confined to an altitude below 15,000 ft. The following is a summary of atmospheric particle size:

ORDER OF SIZE OF ATMOSPHERIC PARTICLES[9]

Gas Molecules	10^{-4} micron
CO, CO^2	10^{-2} "
Sea Salt Nuclei (dry air)	10^{-1} "
Sea Salt Nuclei (humid air)	1 "
Fog, Cloud	1-100 microns
Dust	1 micron
Wavelength of Green Light	.5 micron

An atmosphere containing particles on the order of magnitude of the wavelength of light is termed a Mie atmosphere. In a Mie atmosphere, scattering shows less dependence on wavelength. Studies have shown that the scattering of a real atmosphere is proportional to λ-1.3 $\pm$ 0.6[10]. The relative scatter as a function of wavelength is shown in Figure 26 for a variety of atmospheric conditions. Except under extreme haze conditions a predominance of blue light scattering can be seen. The actual prediction of Mie scattering is difficult due to the variability of the distribution of Mie particles within the atmosphere. It is necessary to rely on empirically determined scattering coefficients.

The effect of scattering by the atmosphere is to impart a luminance to the atmosphere. The complicated process by which sunlight strikes the earth and is reflected back into space is outlined in Figure 27. From this diagram it can be seen that atmospheric luminance depends on the scattering of incident radiation and reflected terrain radiation.

---

9 Brock, G. C., "Physical Aspects of Air Photography", Longmans, Greenland Co., 1952, P. 197.

10 Mazurwski, M. J. and Walker, J. E., Study of Aerial Photographic Attenuation by the Atmosphere Cornell Aeronautical Laboratory, Report No. VF-1478, Page 2. (May 25, 1962).

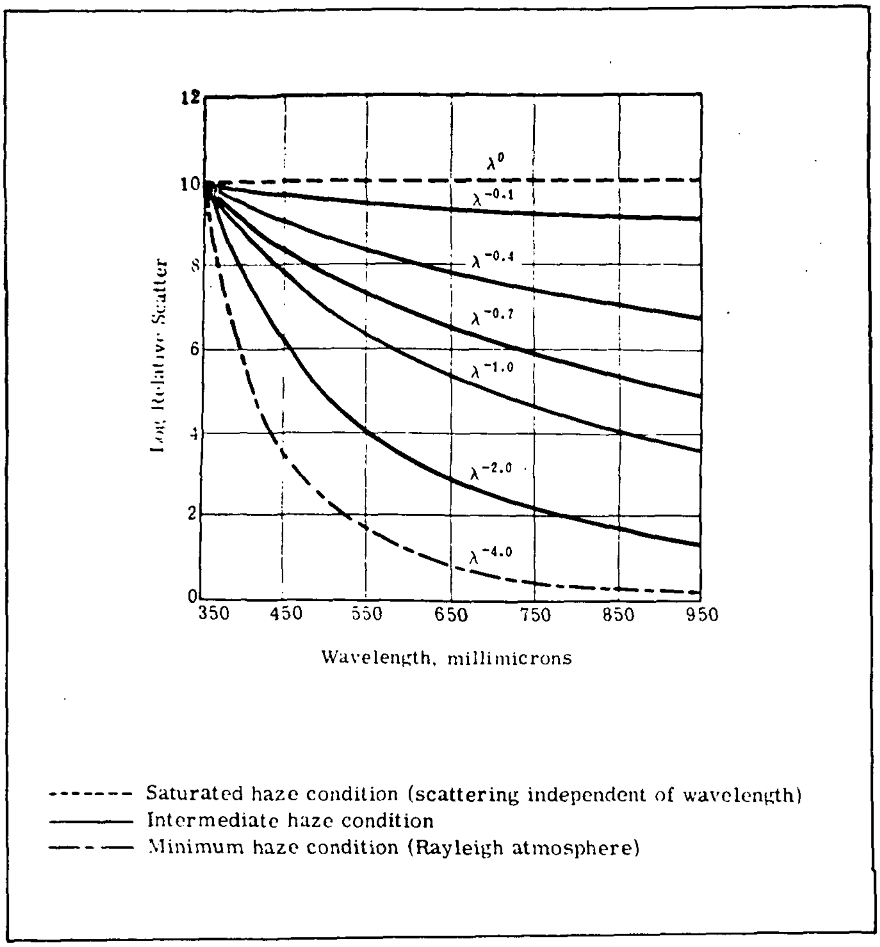
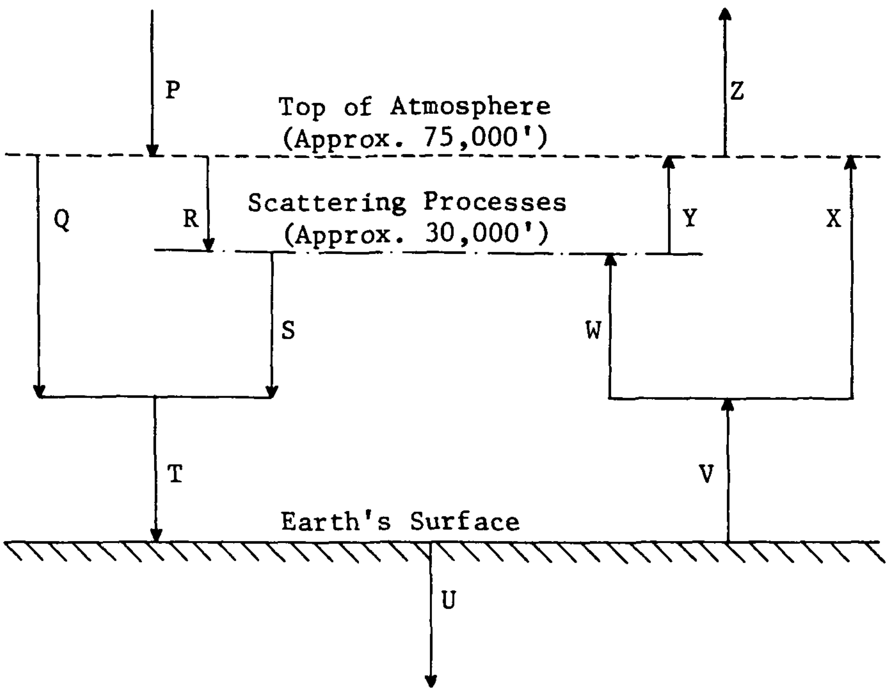


FIGURE 26 RELATIVE SCATTER AS A FUNCTION OF WAVELENGTH FOR VARIOUS MAGNITUDES OF ATMOSPHERIC HAZE (G.C. Brock, D.I. Harvey, R.J. Kohler, and E.P. Myskowski, "Photographic Considerations for Aerospace," Itek Corp., Lexington, Mass., 1966)



P Total visible solar radiation that reaches the earth's surface

Q Portion of P that reaches the earth's surface without having been scattered

R Scattered fraction of P

S Scattered light that reaches the earth's surface

T Total light reaching earth's surface

U Fraction of T absorbed by earth

V Fraction of T reflected by earth

W Scattered fraction of V

X Fraction of V that escapes into space without having been scattered

Y Scattered light that escapes into space

Z Total light from the earth that escapes into space

FIGURE 27 ENERGY BALANCE DIAGRAM (Dylewski, J.J.,Presented to Optical Society of America [Oct.23, 1963])

The effect of atmospheric attenuation and luminance on the contrast of a ground object can be expressed by

$$C_a = \frac{B_o T_a + B_a}{B_b T_a + B_a} \quad , \tag{20}$$

where C_a = apparent aerial contrast

$B_{o,b}$ = luminance of object and background in foot-lamberts

T_a = atmospheric transmission coefficient

B_a = atmospheric luminance.

Alternately, luminance can be expressed as

$$B = I_s R \quad ,$$

where I_s = incident solar illuminance in foot-candles

R = reflectance.

Thus equation (20) becomes

$$C_a = \frac{I_s R_o T_a + B_a}{I_s R_b T_a + B_a} \quad . \tag{21}$$

Equation (21) represents a simplification, since solar illuminance, transmission, and luminance are functions of wavelength. A complete description of aerial contrast would include the effects of wavelength. However, the use of a minus blue haze cutting filter minimizes these effects.

Figure 28 shows the aerial contrast above the atmosphere as a function of solar altitude. The three ground scene contrasts have a constant background reflectance of 10% incident solar illumination. From Figure 28, it can be seen that the contrast reduction by the atmosphere is a non-linear process.

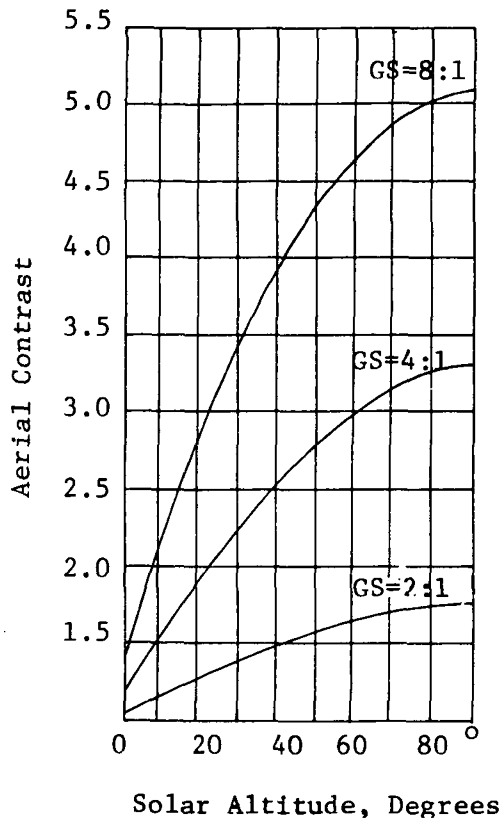


FIGURE 28 AERIAL CONTRAST ABOVE THE ATMOSPHERE AS A FUNCTION OF SOLAR ALTITUDE (G.C. Brock,et als.,"Photographic Considerations for Aerospace," Itek Corp.,Lexington,Mass., 1966.)

Figures 29A and 29 B show the contrast attenuation for a Rayleigh atmosphere. As such, they represent the minimum possible contrast attenuation for contrasts viewed through the earth's atmosphere. A comparison between Figure 29A and 29B shows that contrast attenuation increases with decreasing background terrain reflectance. It can also be seen that the effect of contrast attenuation is less in the near infrared (λ = 0.810 microns). This shows that the extended sensitivity of Ektachrome IR makes it a more efficient detector for remote sensing than Ektachrome Color.

2.5.2.2.2 Turbulence

Thermal gradients due to uneven heating and cooling of the ground and atmosphere are the major causes of turbulence. Since the index of refraction is proportional to the density, which is in turn dependent on temperature, uneven heating of the atmosphere results in a non-homogeneous index of refraction. The changes in refraction are random in nature, producing time variations in position (shimmer) and intensity (scintillation).

The effect of turbulence on space photography is dependent on the relative altitude of the turbulent layer and the imaging system. The further the turbulence is from the camera, the smaller is the angular subtense at the lens plane and the greater the imaged resolution, (Figure 30). This is intuitively evident when one considers the analogous situation of viewing an object through an uneven or wavy surface glass such as that used in shower stalls. The amount of detail which can be observed depends on the relation of the distance of the uneven surface from the object to the viewer.

Many studies of turbulent effect have been made by astronomers. The angular variations have been reported to lie between 0 and 10 seconds of arc with an average of .75 seconds on nights with good visibility. Since daytime fluctuations are at least four times greater than nighttime, for the situation of satellite imaging, the average turbulence encountered may be assumed to be 2 to 4 seconds of arc. For a particular situation, however, the actual turbulence may be greater.

The effect of turbulence is to cause a smearing of the image similar to that caused by image motion. The image spread in microns due to turbulence can be calculated by the following:

$$S_t = 3.5 \times 10^{-4} \ F \, \delta \, \frac{h_t}{H} \ . \qquad (22)$$

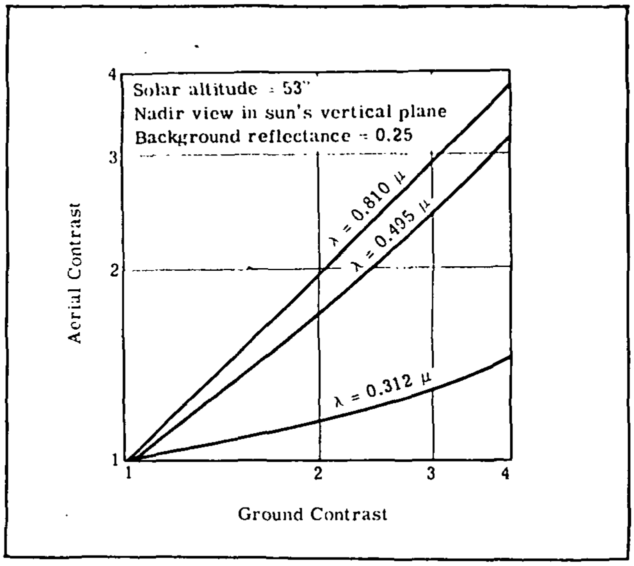


FIGURE 29A CONTRAST ATTENUATION FOR A RAYLEIGH ATMOSPHERE (G. C. Brock, D. I. Harvey, R. J. Kohler, and E. P. Myskowski, "Photographic Considerations For Aerospace," Itek Corp., Lexington, Mass., 1966.)

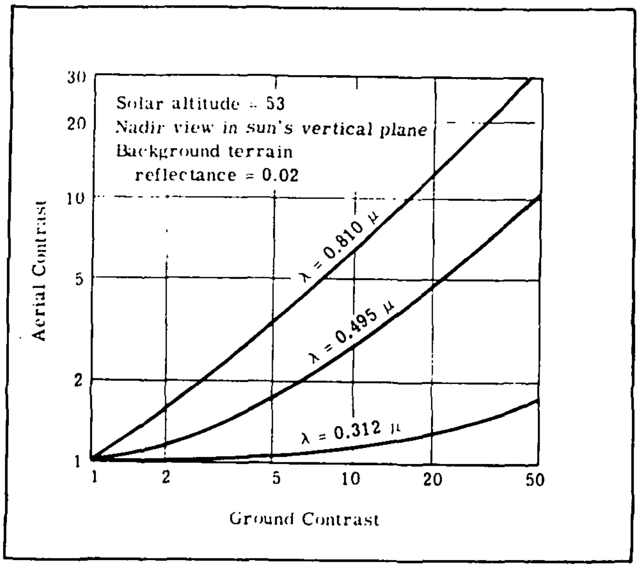


FIGURE 29B CONTRAST ATTENUATION FOR A RAYLEIGH ATMOSPHERE (G.C. Brock, D.I. Harvey, R.J. Kohler, and E.P. Myskowski, "Photographic Considerations for Aerospace," Itek Corp., Lexington, Mass., 1966.)

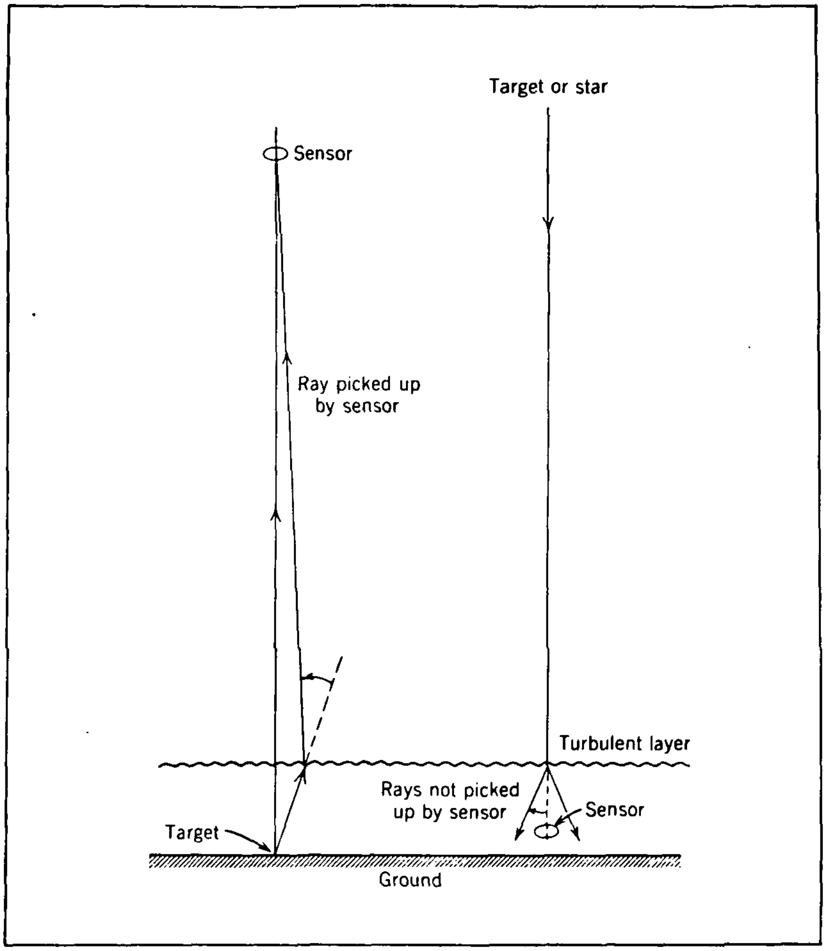


FIGURE 30 EFFECT OF NEAR AND FAR TURBULENCE ON A SENSOR (N. Jensen, "Optical and Photographic Reconnaissance Systems," John Wiley and Sons, Inc., New York, 1968.)

Where F = Focal length in feet

δ = Mean angular deviation due to turbulence (sec. of arc).

h_t = Height of turbulence in feet (assumed to occur in a single layer).

H = Camera Altitude in nm = 150 nm.

The transfer function associated with atmospheric turbulence can be derived in a manner similar to that of image motion and is given by

$$T_a = \left| \frac{\sin \pi k s_t}{\pi k s_t} \right|, \qquad (23)$$

(assuming s_t to occur within the effective exposure time).

If the equation (22) is solved for turbulence heights of 30,000 and 75,000 feet with an angular deviation of 20 seconds, the resulting image smears are 0.70 and 1.75 microns respectively. The transfer function associated with a turbulence height of 75,000 feet is given in Figure 31.

2.5.2.2.3 Atmospheric Refraction

As shown in Table XXXIII, atmospheric density varies with altitude. Corresponding to the change in density is a change in the index of refraction. The result is that objects do not appear in their true positions. Corrections for these errors must be made for precise mapping. The mathematics involved in photogrammetric corrections for refraction effects are complicated. For a thorough account of atmospheric refraction corrections see Helmut H. Schmid, "The Influence of Atmospheric Refraction on Directions Measured to and from a Satellite", AD 409-851.

2.5.2.3 Total System Resolution

The total system resolution is determined by cascading the transfer function of the camera system, Figure 25, and the atmosphere, Figure 31. This process is illustrated in Figure 32.

Contrast attenuation is independent of spatial frequency. Its effect on ground contrast is to reduce imaged contrast, as seen in Figures 29A and 29B. The modulation attenuation as computed from 29A for a wavelength of .810 microns is .96. The background reflectance value of 0.25 is within the range of reflectances for agricultural targets. The wavelength of .810 microns falls within the infrared sensitive layer of Ektachrome IR. The effective modulation due to turbulence is 1.0, within the range of the lens transfer function.

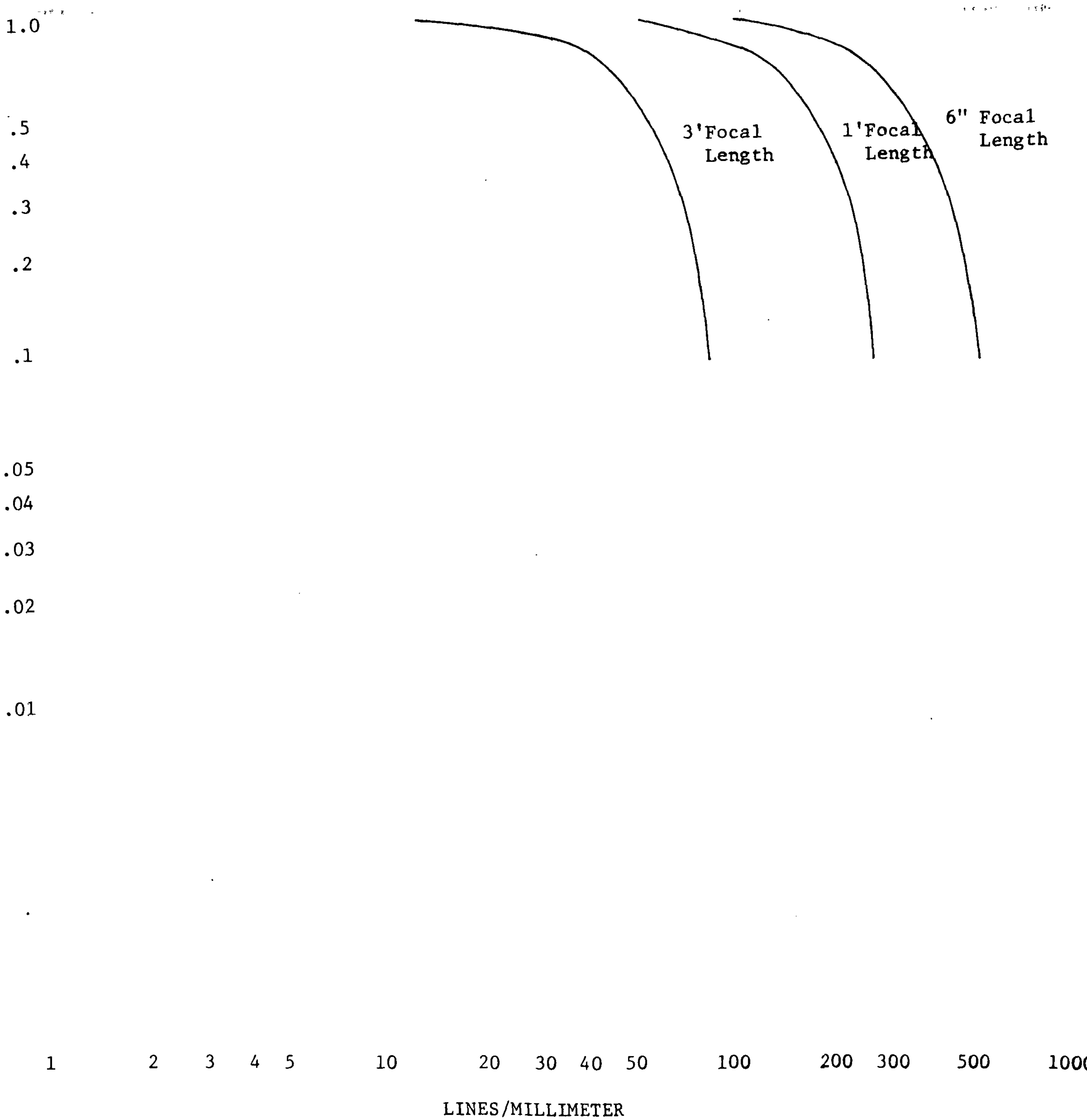
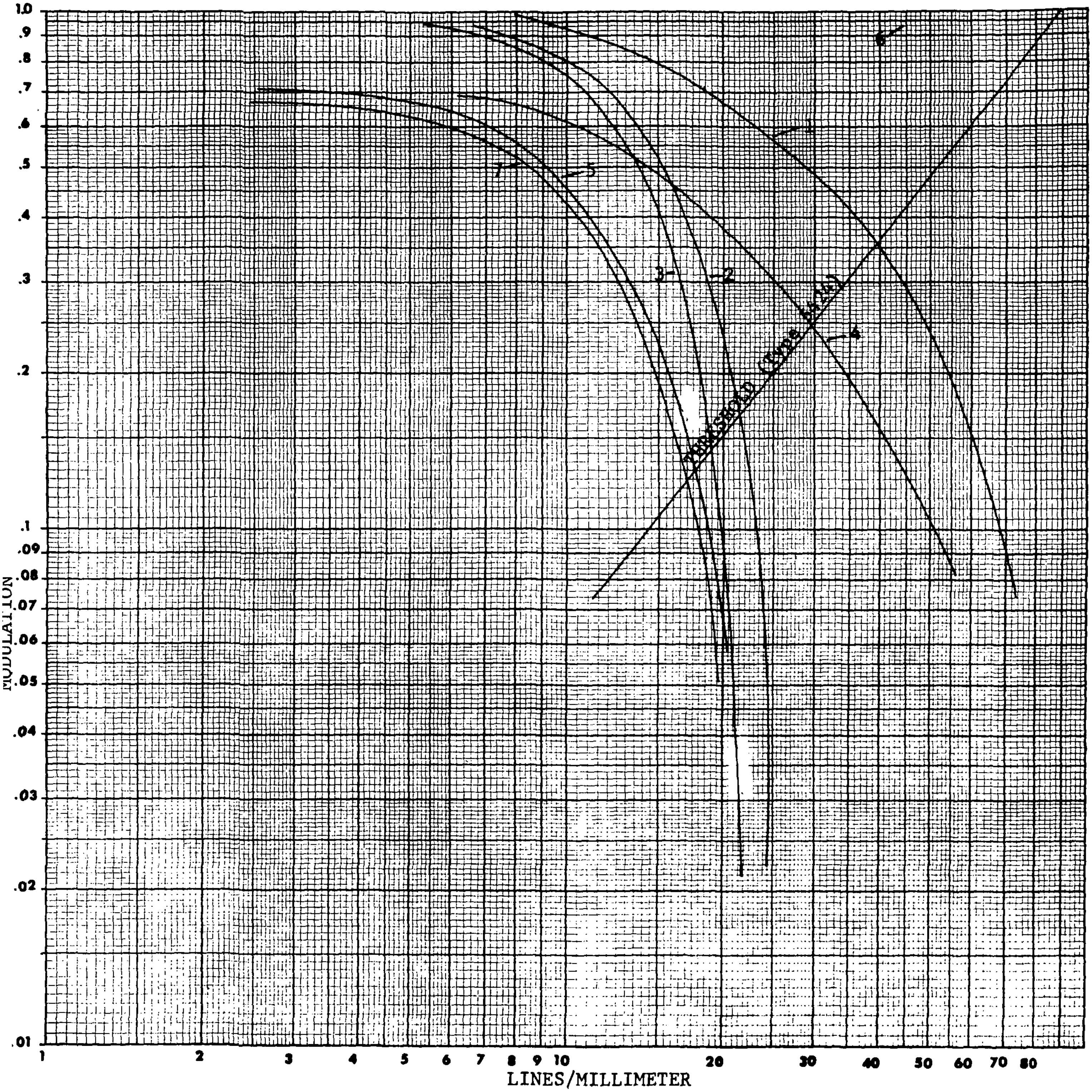


FIGURE 31 MTF DUE TO ATMOSPHERIC TURBULENCE AT AN ALTITUDE OF 150 NM AND AN EFFECTIVE TURBULENT LAYER AT 75,000'



1- lens (nominal 50 l/mm)

2- image motion

3- camera system = 1 x 2

4- film (type 5424, γ = 1.0)

5- camera/film = 3 x 4

6- atmospheric contrast attenuation (.810 microns)

7- system MTF = 5 x 6

FIGURE 32 MODULATION TRANSFER FUNCTION OF 6" FOCAL LENGTH RC-8 SYSTEM

So far the various factors influencing film MTF have been ignored. The film emulsion converts exposure to density by a non-linear process. Thus, it is necessary to generate a conversion function by exposing a calibrated step tablet. The relationship between exposure and density is the D-log E curve. The slope of this curve is called gamma and is a measure of contrast. A change in gamma will result in a change of the film MTF. An upwards or downwards shifting of the MTF depends on whether gamma is increased or decreased. The MTF for Infrared Aerographic developed to gamma = 1 is used throughout this analysis.

The film MTF is also dependent on the spectral quality of radiation used in the determination of the MTF. In this example, Infrared Aerographic is exposed to a tungsten source with a Wratten 25 filter. The resultant MTF can be considered a rough approximation of that of the cyan-forming (IR sensitive layer) of Ektachrome IR.

The total resolution as determined from Figure 32 is 16 lines/mm with a ground resolution of 382 feet. (with image motion compensation).

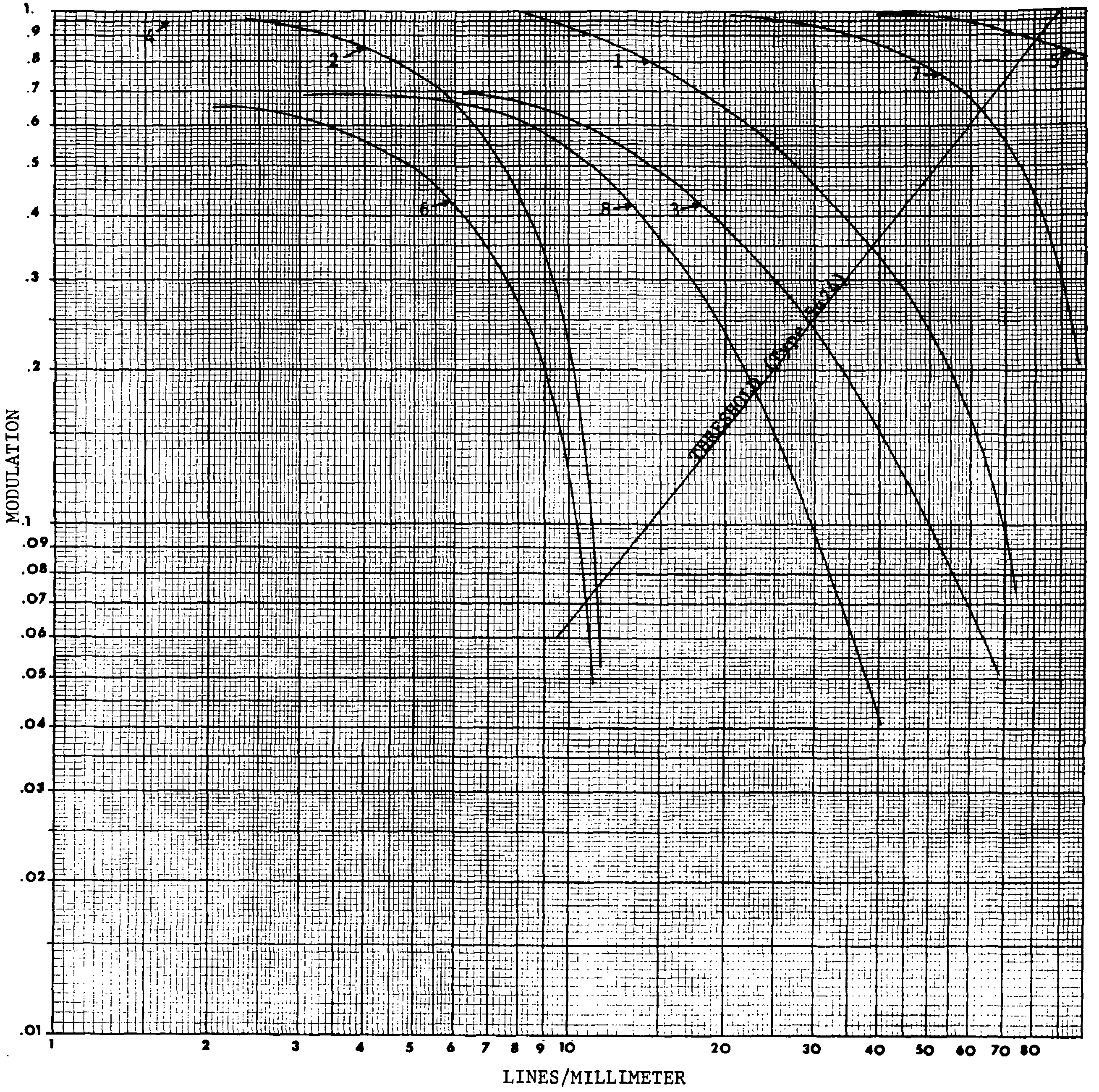
Figures 33 and 34 represent the response obtainable from the same system with a one-foot and three-foot focal length respectively. Note that the transfer functions due to image motion and atmospheric turbulence limit the resolution of the system. Without any image motion compensation, the ground resolution for a one-foot focal length system is 289' and for a three-foot focal length, 253'. Figures 33 and 34 also show the transfer function due to IMC with a residual image motion of 10%. In this case, the ground resolution obtained is 132' and 50.6' for a 1' and 3' system respectively.

Table XXXIV shows the capability of the RC-8 camera, at three of the computed resolutions, to identify the elements of information needed for a rather detailed, comprehensive land use analysis. It also shows what can be expected from the return beam vidicon at orbital altitudes. The capability of the sensors at the given resolution was arrived at in a manner similar to that used in the sensor capability matrices shown in Table XVIII and XIX.

2.6 Quantitative Analysis of Film Quality

A quantitative analysis was attempted on the color IR photography flown over Test Site 130. Two kinds of measurements were made on this emulsion-those of resolution and density.

Resolution measurements were made on a frame of color IR imagery from Mission 73 over the Data Corporation controlled test range. The method used for determining the resolution of the system as imaged on the film was edge gradient analysis. Knife edge targets on the ground were selected, including building edges and the resolution bar charts. These edges were scanned with a microdensitometer (Figure 35). Since modulation is measured in terms of exposure, it is necessary to make a black-and-white transparency of the frames, exposing it with a calibrated step wedge. Both wedge and photo were given the same processing. By scanning the step wedge with the microdensitometer, a conversion function was generated.



1- lens (nominal 50 1/mm)

2- image motion (uncompensated)

3- film (type 5424)

4- atmospheric attenuation

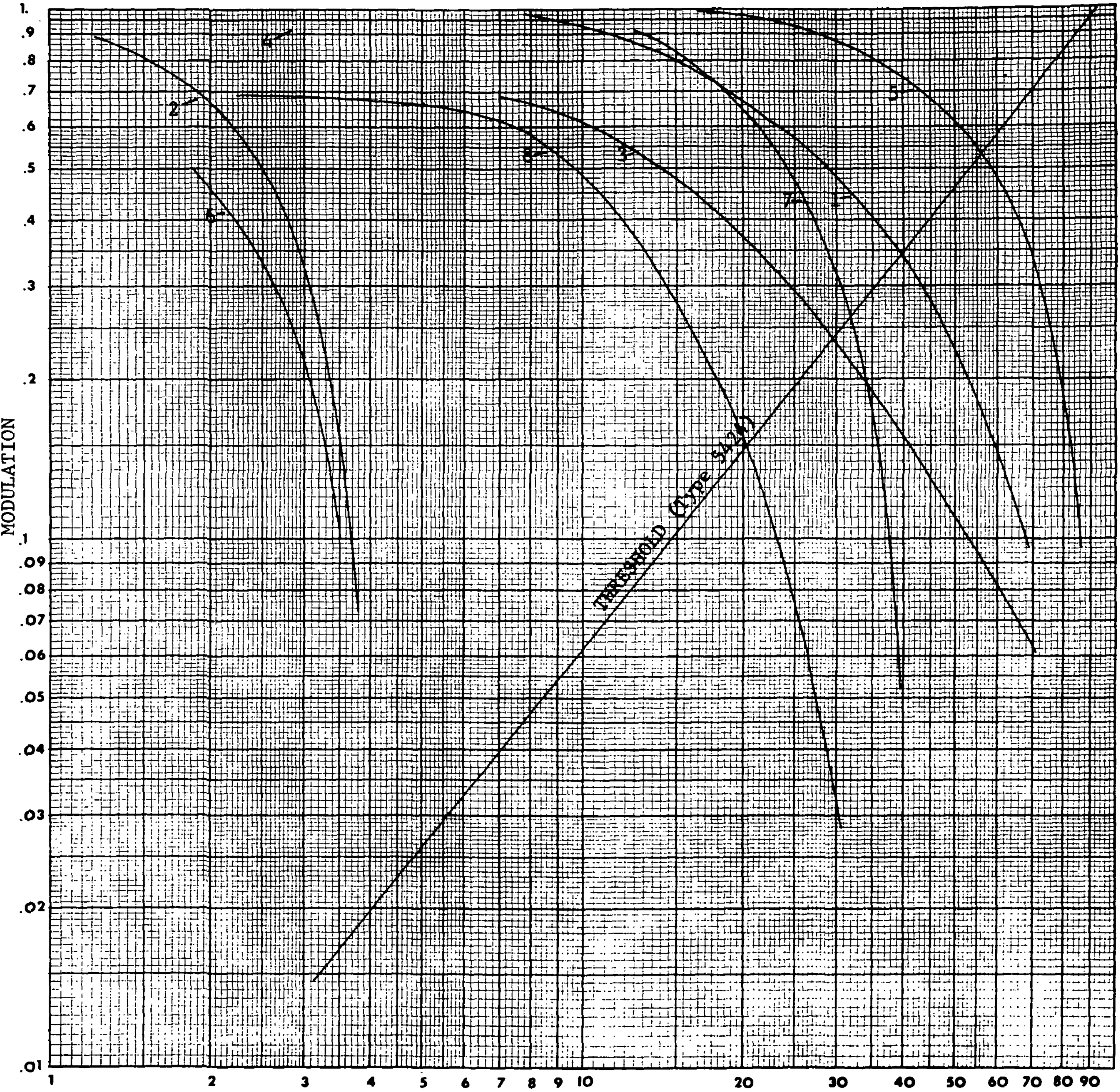
5- turbulence

6- total system = 1x2x3x4x5

7- image motion (90% compensated)

8- total IMC system = 1x3x4x5x7

FIGURE 33 MODULATION TRANSFER FUNCTION OF 1 FOOT FOCAL LENGTH SYSTEM (no IMC: resolution = 10.5 lines/mm; with IMC: resolution = 23 Lines/mm)



1- lens (nominal 50 l/mm)

2- image motion (uncompensated)

3- film (type 5424)

4- atmospheric attenuation

5- turbulence

6- total system = 1x2x3x4x5

7- image motion (90% compensated)

8- total IMC system

FIGURE 34 MODULATION TRANSFER FUNCTION OF 3FT. FOCAL LENGTH SYSTEM (No IMC: resolution = 4 lines/mm; with IMC: resolution = 20 lines/mm)

TABLE XXXIV

SENSOR CAPABILITY AT RESOLUTIONS OBTAINABLE FROM SPACE

CODE	LAND USE ELEMENTS OF INFORMATION	SENSORS: RC - 8 Res. 132' 6"f/1 Image motion compensated	SENSORS: RC - 8 Res. 253' 1'f/1 Image motion uncompensated	SENSORS: RC - 8 Res. 289' 3'f/1 Image motion uncompensated	SENSORS: RETURN BEAM VIDICON RESOLUTION 100'
1000	VEGETATION				
1100	Agriculture (includes all farming activity)				
1110	Tree Crops	X	✓	✓	X
1120	Field Crops (grain, fodders, etc.)	✓	0	0	✓
1130	Row Crops (vegetables, small fruits, etc.)	✓	0	0	X
1140	Pasture	✓	✓	0	X
1150	Stock Feed Lot	✓	0	0	✓
1160	Inactive Land	X	✓	✓	X
1161	Fallow	X	✓	✓	X
1162	Reverting to Natural State	X	✓	✓	X
1170	Horticulture or Floriculture (nurseries, sod, and feed farms)	✓	0	0	✓
1180	Stock Operations	✓	0	0	✓
1190	Poultry Operations	0	0	0	✓
11100	Specialty Farms	✓	✓	0	✓
11110	Inactive Farmsteads	X	✓	✓	X
11120	Agricultural Storage (grain elevators, cribs, etc.)	X	✓	0	X
1200	Forest (>50% cover by trees >30 feet in height)				
1210	Coniferous	X	✓	✓	X
1220	Deciduous	X	✓	✓	X
1230	Mixed Coniferous & Deciduous	X	✓	✓	X
1300	Open Forest (<50% & >10% cover by trees >30 feet in height)				

X = can identify
✓ = can identify sometimes, partially, or by inference
0 = cannot identify

TABLE XXXIV (Cont'd)

CODE	LAND USE ELEMENTS OF INFORMATION	SENSORS: RC - 8 RESOLUTION 132'	RC - 8 RESOLUTION 253'	RC - 8 RESOLUTION 289'	RETURN BEAM VIDICON RESOLUTION 100'
1310	Coniferous	X	✓	✓	X
1320	Deciduous	X	✓	✓	X
1330	Mixed Coniferous & Deciduous	X	✓	✓	X
1400	Forest Brushland (<50% & >10% cover by vegetation <30 feet in height)	X	✓	✓	X
1500	Brush & Grassland (weeds, mesquite, tundra growth,etc.)	X	✓	✓	X
1600	Savanna	✓	✓	✓	✓
	Modifiers to be subsumed under any applicable number beginning with 16.				
0001	Species	✓	0	0	✓
0002	Height	✓	✓	0	✓
0003	Moisture Content	0	0	0	✓
0004	% ground cover	X	X	✓	X
0005	Stand Density (forests)	✓	✓	0	✓
0006	Row Direction	X	X	X	X
0007	Diseased, Dead, or Dormant	✓	0	0	✓
0008	Pyrogenic Area	X	X	✓	X
2000	URBAN				
2100	Commercial				
2110	Central Business District	✓	✓	0	✓
2120	Frame	0	0	0	✓
2130	Middle City	✓	✓	0	✓
2140	Strip Development	✓	0	0	✓
	Modifiers to be subsumed under any applicable number beginning with 21.				

TABLE XXXIV (Cont'd)

CODE	LAND USE ELEMENTS OF INFORMATION	SENSORS RC - 8 RESOLUTION 132'	RC - 8 RESOLUTION 253'	RC - 8 RESOLUTION 289'	RETURN BEAM VIDICON RESOLUTION 100'
0001	Shopping Center	0	0	0	✓
0002	Office Space	0	0	0	0
0003	Commercial Resort	✓	0	0	✓
0004	Commercial Storage	✓	0	0	✓
0005	Vacant	✓	✓	0	✓
2200	Residential				
2210	Suburb	✓	0	0	✓
2220	Fringe Zone	✓	0	0	✓
2230	Exurb	✓	0	0	✓
2240	Satellite	0	0	0	0
2250	Urban-Rural Transition Zone	0	0	0	0
	Modifiers to be subsumed under any applicable number beginning with 22.				
0001	Single Family Structure	0	0	0	✓
0002	Multiple Family Structure (exclusive of hotels or motels)	0	0	0	✓
0003	High Density (lots less than 1/8 acre)	0	0	0	✓
0004	Medium Density (lots >1/8 <1/2 acre)	✓	0	0	✓
0005	Low Density (lots >1/2 acre)	✓	0	0	✓
0006	Residential Estates (greater than 5 acres)	✓	✓	✓	✓
0007	Strip Development (>4 residences/100 feet)	✓	✓	0	✓
0008	Hamlet or Village	✓	✓	0	✓
0009	Farm Labor Camp	✓	0	0	✓
00010	Cottages &Vacation Homes	0	0	0	✓
00011	Hotel & Motel	0	0	0	✓
00012	Trailer Park (>3 trailers)	0	0	0	✓
00013	Rural Non-Farm Residence	✓	0	0	✓
	Modifiers to be subsumed under any applicable number beginning with 22.				

TABLE XXXIV (Cont'd)

CODE	LAND USE ELEMENTS OF INFORMATION	SENSORS: RC - 8 RESOLUTION 132'	RC - 8 RESOLUTION 253'	RC - 8 RESOLUTION 289'	RETURN BEAM VIDICON RESOLUTION 100'
000001	Low Income Housing	0	0	0	✓
000002	Medium Income Housing	0	0	0	✓
000003	High Income Housing	0	0	0	✓
2300	Industrial				
2310	Extraction Industry	✓	0	0	✓
2311	Open Pit Mining	✓	✓	0	✓
2312	Stripping Operation (including mining & lumbering)	✓	0	0	✓
2313	Shaft and Drift Mining	0	0	0	0
2314	Wells	0	0	0	0
2320	Processing Industry				
2321	Chemical Processing (exclusive of water and sewage treatment)	0	0	0	✓
23211	Organic	0	0	0	0
23212	Inorganic	0	0	0	0
2322	Mechanical Processing	0	0	0	✓
2323	Heat Processing	0	0	0	0
2330	Fabrication				
2331	Heavy	✓	0	0	✓
2332	Light	0	0	0	0
2340	Industrial Storage (POL, warehouse, open)	✓	0	0	✓
2350	Vacant	✓	0	0	✓
3000	WATER (with associated control structures)				
3100	Natural Pond or Lake	✓	0	0	✓
3200	Artificial Pond, Lake, or Reservoir	✓	0	0	✓
3300	Non-Navigable Streams	X	X	X	X
3400	Navigable River	✓	✓	✓	✓
3500	Canal (other than Barge Canal, see 4400)	✓	0	0	✓

TABLE XXXIV (Cont'd)

CODE	LAND USE ELEMENTS OF INFORMATION	SENSORS RC - 8 RESOLUTION 132'	RC - 8 RESOLUTION 253'	RC - 8 RESOLUTION 289'	RETURN BEAM VIDICON RESOLUTION 100'
3600	Marshland, Shrub Wetland, Wooded Wetland or Bog	✓	✓	✓	✓
3700	Intermittent Stream	✓	✓	✓	X
3800	Ephemeral Pond or Lake	✓	0	0	✓
3900	Flood Control Structures (dams, dikes, levees)	✓	0	0	✓
4000	TRANSPORTATION				
4100	Highways (with associated facilities)	✓	0	0	✓
4110	Limited Access Highway	✓	0	0	✓
4120	Lane Highway (4 lanes)	✓	0	0	X
4130	Lane Highway (2-3 lanes)	✓	0	0	✓
4140	Urban Street	✓	0	0	X
4150	Unimproved Gravel or Minor Paved Roads	✓	0	0	✓
4160	Interchange (ramp & cloverleaf)	✓	0	0	✓
4170	Service, Terminal or Freight Facility	✓	0	0	✓
4180	Parking Facility	0	0	0	✓
4190	Bridge	✓	0	0	✓
41100	Tunnel	0	0	0	✓
	Modifiers to be subsumed under any applicable number beginning with 41.				
0001	Concrete Composition	✓	0	0	✓
0002	Asphalt Composition	✓	0	0	✓
0003	Unconsolidated Road Metal	✓	0	0	✓
0004	Unpaved	✓	0	0	✓
4200	Railways				
4210	Main Track	✓	0	0	✓
4220	Spur	✓	0	0	✓
4230	Marshalling Yard	✓	0	0	✓
4240	Station & Structures	0	0	0	✓
	Modifiers to be subsumed under any applicable number beginning with 42.				

TABLE XXXIV (Cont'd)

CODE	LAND USE ELEMENTS OF INFORMATION	SENSORS RC - 8 RESOLUTION 132'	RC - 8 RESOLUTION 253'	RC - 8 RESOLUTION 289'	RETURN BEAM VIDICON RESOLUTION 100'
0001	Single Track	0	0	0	✓
0002	Double Track	✓	0	0	✓
4300	Airfields				
4310	Commercial Aircraft	X	✓	✓	X
4320	Non Commercial Airfield (private, flying farmer, etc.)	✓	0	0	✓
4330	Military	X	✓	✓	X
4400	Barge Canal	✓	0	0	✓
5000	RECREATIONAL				
5100	Golf Course	✓	0	0	✓
5200	Skiing and Other Winter Sports	0	0	0	0
5300	Public and Commercial Swimming Pools	0	0	0	✓
5400	Developed Beaches	✓	0	0	✓
5500	Marinas and Yacht Clubs	0	0	0	✓
5600	Camping Grounds	0	0	0	0
5700	Stadiums	✓	0	0	✓
5800	Drive-In Theaters	0	0	0	✓
5900	Race Tracks	✓	0	0	✓
51000	Amusement Parks	0	0	0	✓
51100	Fairgrounds	0	0	0	✓
51200	Public Parks (urban)	0	0	0	✓
51300	Playgrounds	0	0	0	✓
6000	CIVIC AND INSTITUTIONAL				
6100	Educational Institutions	✓	0	0	✓
6200	Religious Institutions	0	0	0	✓
6300	Health Institution	0	0	0	0
6400	Correctional Institutions	0	0	0	0
6500	Military Bases	✓	0	0	✓
6600	Armories	0	0	0	0
6700	Cemeteries	✓	0	0	✓

TABLE XXXIV (Cont'd)

CODE	LAND USE ELEMENTS OF INFORMATION	SENSORS: RC - 8 RESOLUTION 132'	SENSORS: RC - 8 RESOLUTION 253'	SENSORS: RC - 8 RESOLUTION 289'	SENSORS: RETURN BEAM VIDICON RESOLUTION 100'
7000	UTILITIES AND COMMUNICATIONS				
7100	Waste Disposal				
7110	Sewerage	0	0	0	✓
7120	Solid Waste (dumps, junkyards & landfill)	✓	0	0	✓
7200	Drinking Water Supply				
7210	Treatment	0	0	0	✓
7220	Storage (reservoirs, including covered)	✓	0	0	✓
7230	Transmission (excluding underground)	0	0	0	0
7300	Gas & Oil Transmission (above ground)				
7310	Pumping Station	0	0	0	0
7320	Transmission Pipeline	0	0	0	0
7400	Electrical & Electromagnetic Transmission				
7410	Electrical Power Transmission Lines	0	0	0	0
7420	Utility Lines	0	0	0	0
7430	Microwave Transmission & Navigation Station	0	0	0	0
7440	TV- Radio Transmission Tower	0	0	0	0
8000	NON-PRODUCTIVE LAND	✓	✓	0	✓

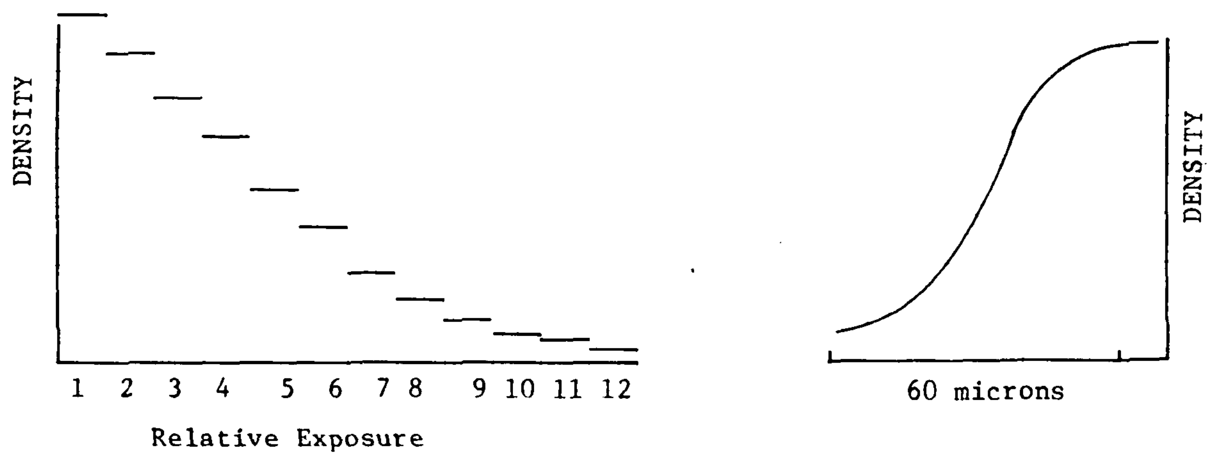


FIGURE 35 MICRODENSITOMETER EDGE TRACE WITH RELATIVE EXPOSURE CONVERSION FUNCTION

This data was fed into an IBM computer, and the Autometric program TOE was called upon to derive the MTF. Essentially the computer program TOE computes the spread function of the edge and then takes the Fourier transform of the spread function to determine the MTF. The MTFs generated were for a position off the lens axis since none of the photo frames imaged the test range on the axis. There is a considerable roll-off of resolution and light distribution (vignetting) with lens angle as shown in Figures 36 and 37.

The MTFs obtained (Figures 38A through 38D) show a rough correlation with expected resolution for their lens position. It should be borne in mind that these curves represent the response obtainable from a third generation transparency on Dupont 228. From the information supplied, it was not possible to determine the MTF of the system (camera plus atmosphere effects).

The second part of the qualitative analysis involved density measurements made on the imagery supplied by the USGS and on the black-and-white reproduction made by Autometric. Neutral density measurements were made on both the color and black-and-white imagery. In addition, color density measurements were made on the color imagery by filtering the microdensitometer with Wratten 92 (red), Wratten 93 (green), and Wratten 94 (blue) filters. A summary of these measurements is included in Table XXXV.

It was attempted to correlate these measurements with the target reflectances measured by Data Corporation. A rough correlation between reflectance and density can be seen in Table XXXV. It should be borne in mind that the ground truth measurements recorded by Data Corporation were taken of reflectance in the visual range, while sensing film records in the near infrared. It is recommended that, in the future, ground measurements be taken in the spectral range of the sensitivity of the detector.

A controlled test range, such as that deployed in Mission 73, can contribute greatly to the Geography program if correctly and selectively employed. When the original imagery cannot be obtained by the Investigator, as is the case and properly so, with the NASA policy of distribution, such ranges provide him with the only measure of his film's resolution and acutance ("T" bar target), excellent sensitometric data (gray scale target), and a measure of color reflectance (color panel target). The test ranges should not be employed indiscriminately, however, such as in those cases in which the Investigator's program does not require such data or when he has not the equipment needed to make use of it. See Figure 39 for Mission 73 imagery of the controlled test range.

2.7 Cost Effectiveness Analysis[11]

2.7.1 Objective

The objective of the format described in this section is to provide a framework for the economic evaluation of the utility of selected sensors in providing data for geographers. It is assumed that there are a definable set of outcomes that

[11] This section was prepared in conjunction with Dr. Greg Butterworth, Manager, Operations and Economic Analysis Department, IBM.

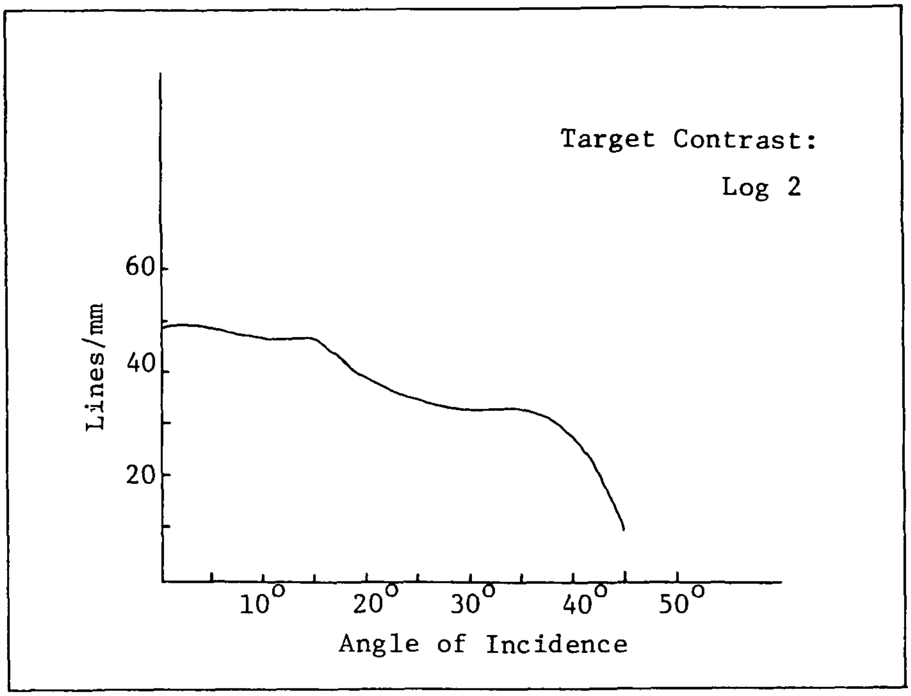


FIGURE 36 AVERAGE RESOLVING POWER OF 6" UNIVERSAL AVIOGON f/5.6

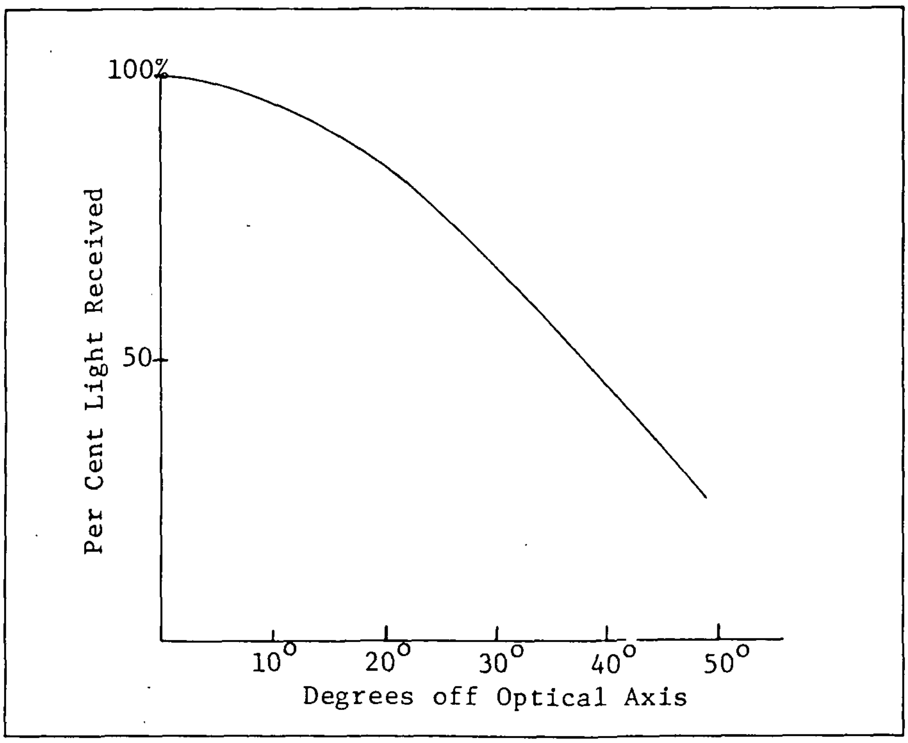


FIGURE 37 LIGHT DISTRIBUTION IN THE IMAGE PLANE OF 6" UNIVERSAL AVIOGON f/5.6

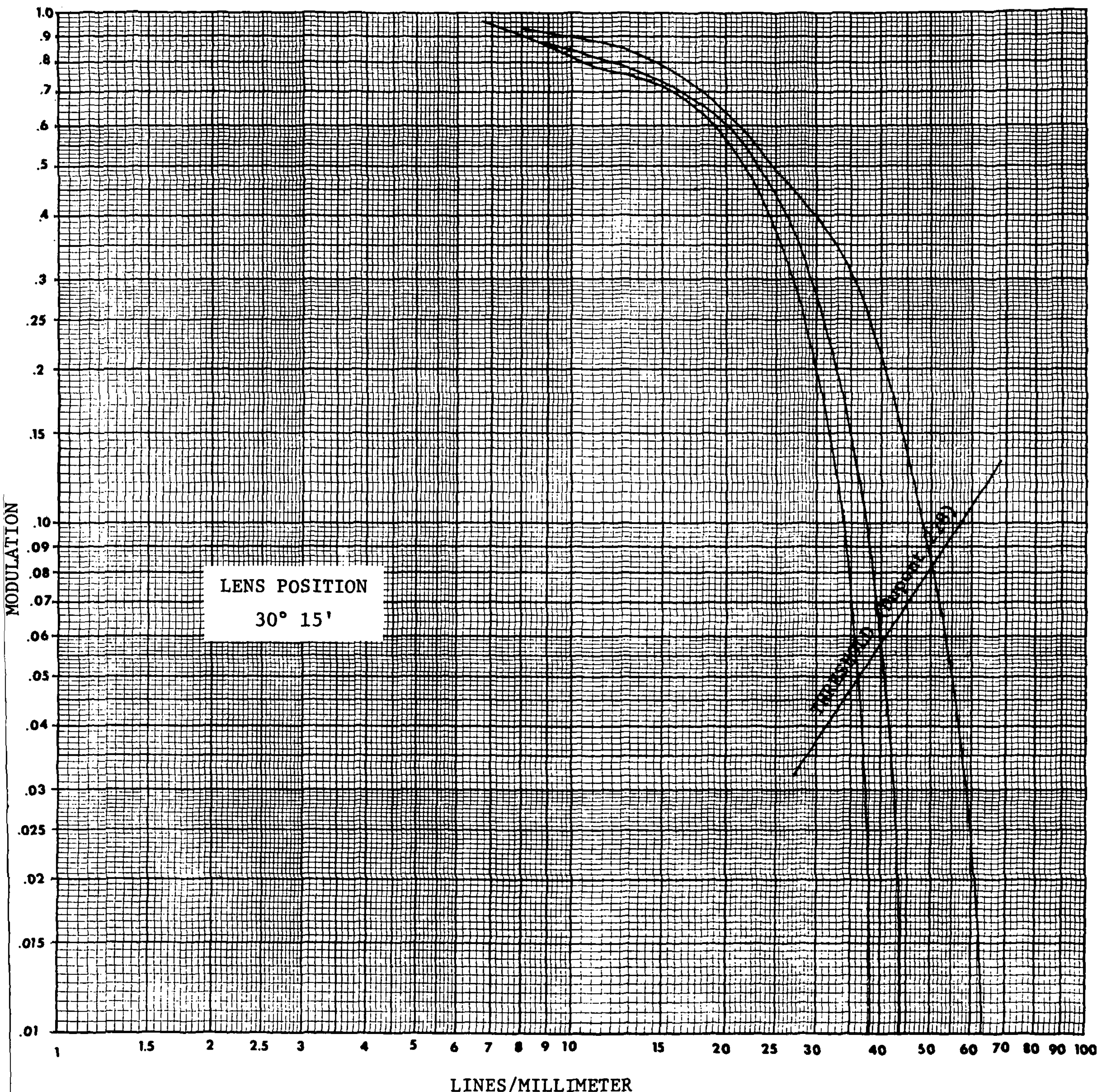


FIGURE 38A MODULATION TRANSFER FUNCTION OF RC-8 SYSTEM*
(*MTF derived from third generation transparency on Dupont 228)

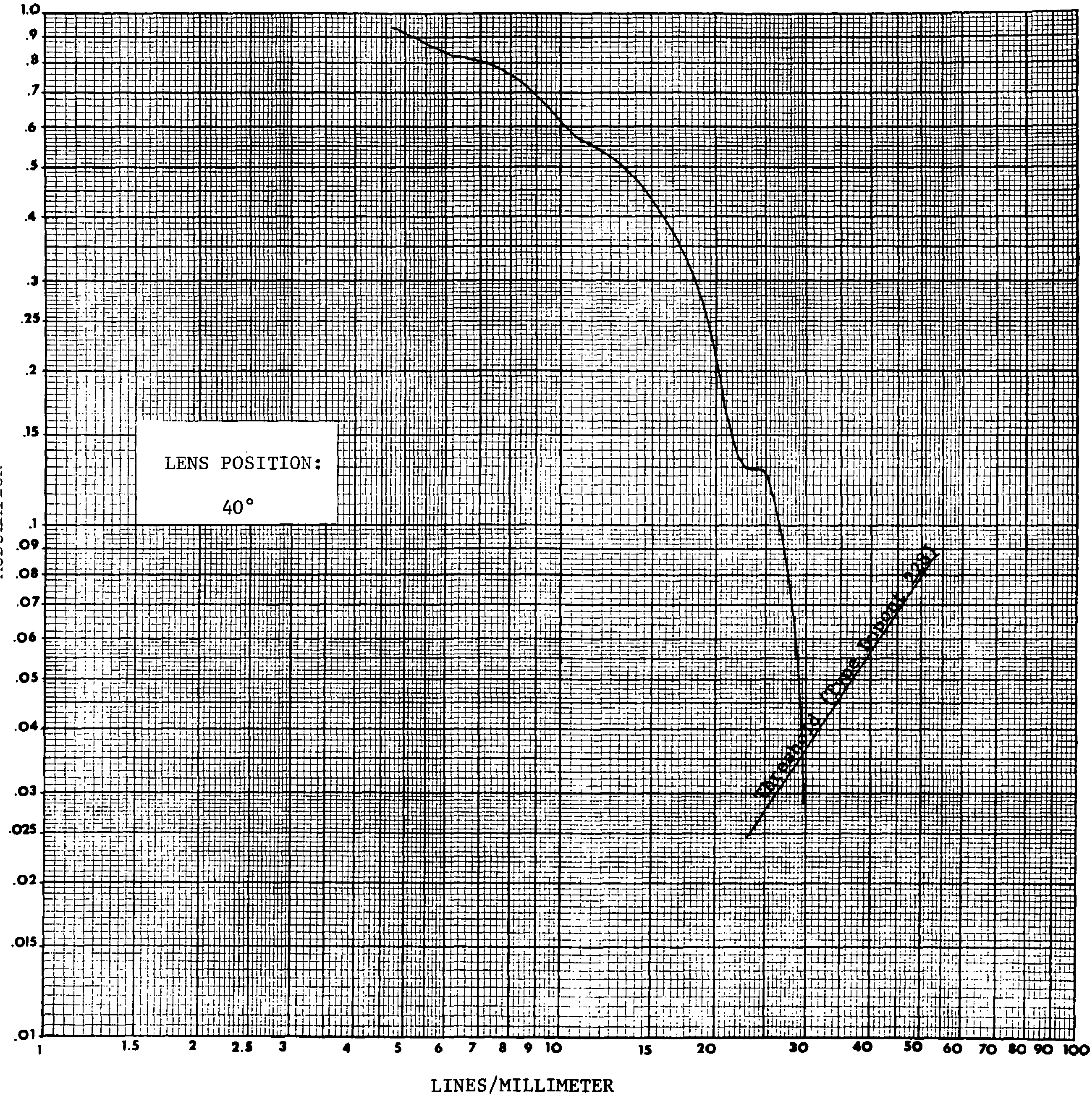


FIGURE 38B MODULATION TRANSFER FUNCTION OF RC-8 SYSTEM*

*See Figure 38A

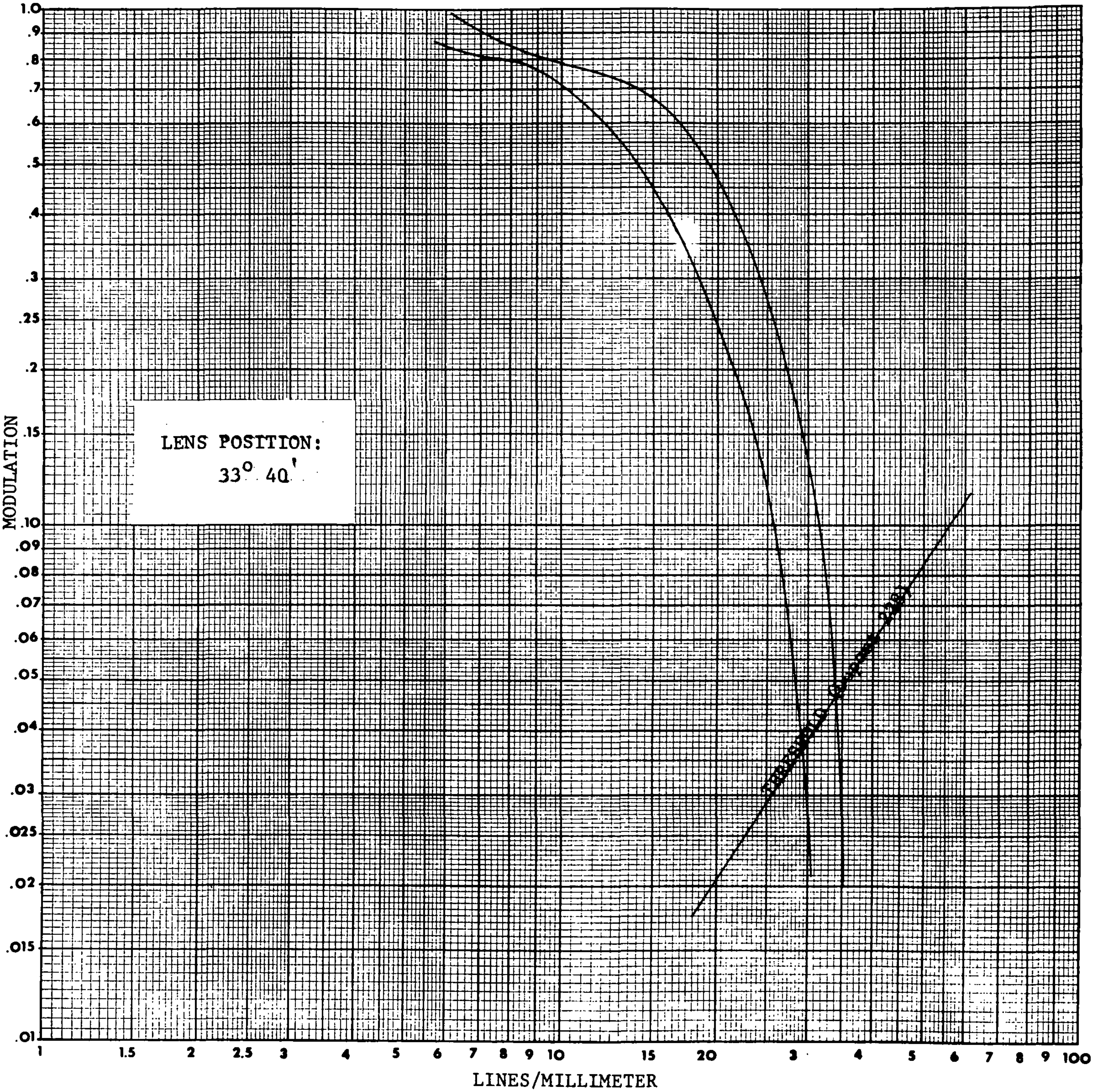


FIGURE 38C MODULATION TRANSFER FUNCTION OF RC-8 SYSTEM*

*See Figure 38A

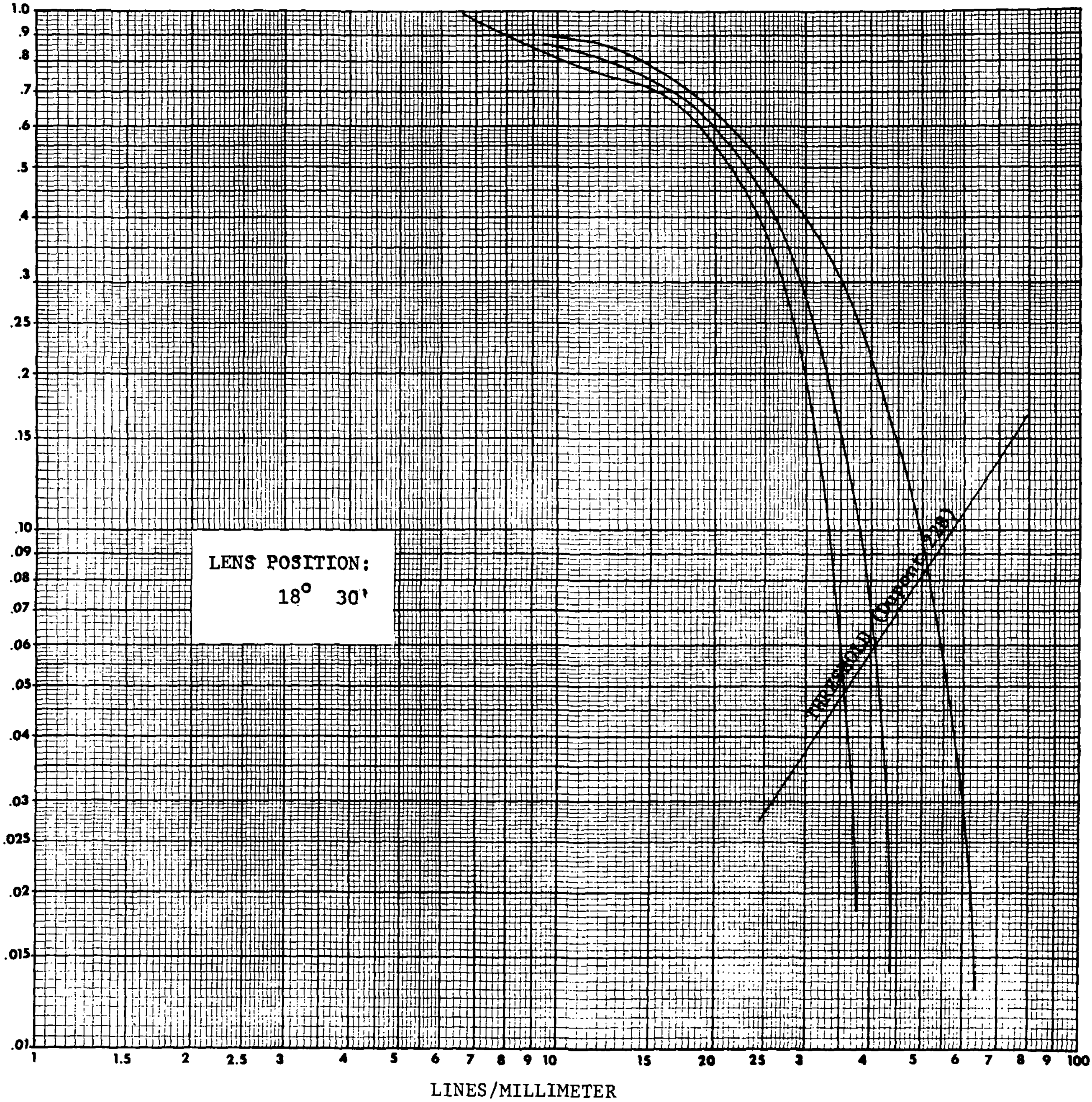


FIGURE 38D MODULATION TRANSFER FUNCTION OF RC-8 SYSTEM*

*See Figure 38A

TABLE XXXV

REFLECTANCE AND COLOR DENSITY MEASUREMENTS

	Reflectance	Color - N. Density	B & W (Neg) N. Density	Red Density (Wratten #92)	Green Density (Wratten #93)	Blue Density (Wratten #94)
Grey Scale						
1	.88	.25	1.81	1.85	1.70	1.67
2	.70	.27	1.0	1.40	1.09	1.10
3	.56	.29	.53	.66	.65	.67
4	.46	.32	.26	.34	.41	.41
5	.35	.39	.19	.26	.28	.35
6	.20	.67	.13	.24	.26	.31
7	.10	1.20	.10	.23	.23	.30
8	.03	2.00	.07	.22	.21	.28
Color Panels	1131*					
Red	.11	.38	.05	.22	.42	1.23
Blue	.12	1.15	.03	.93	1.24	1.37
Green	.099	1.71	.02	1.85	1.70	1.54
Yellow	.50	.10	.80	.21	.24	.33
Bar Targets	1124*					
Grey	.52	.35	.80			
Black	.08	1.70	.03			

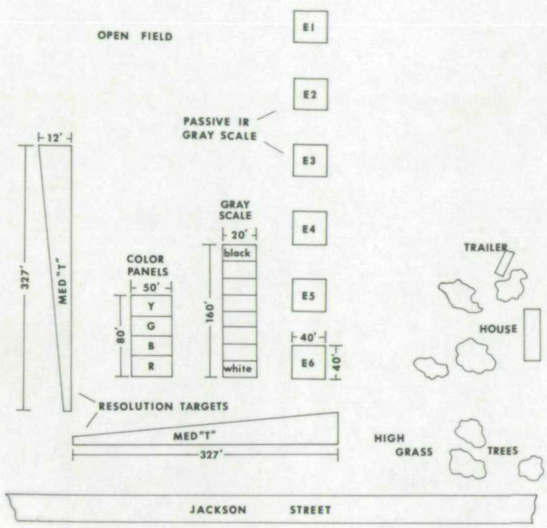
(6.5:1 Contrast)

*Ground measurements taken at 1131; time of flight 1124.

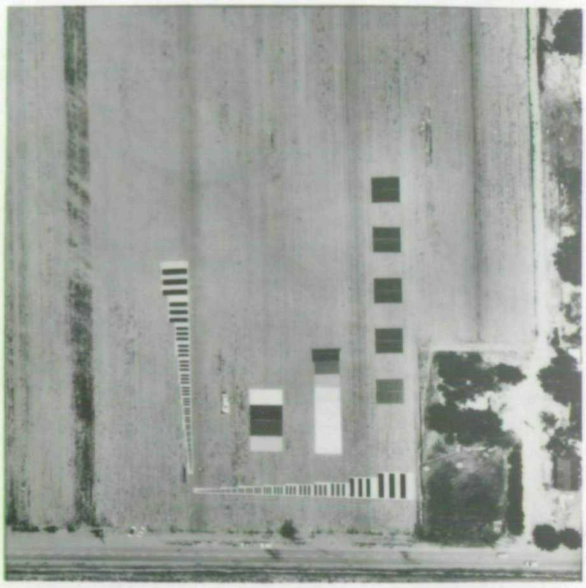
Controlled Test Range Panels

...Multi-Sensor Views and Schematic Diagram

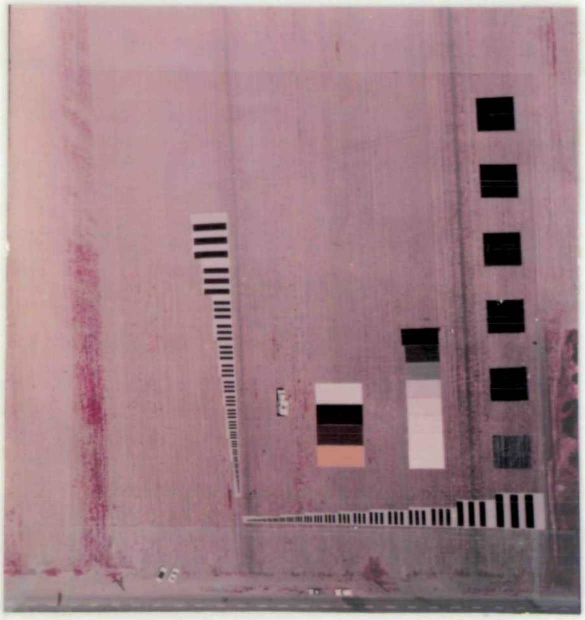
NASA/USGS Mission #73
21 May 1968
Test Site #130
Jackson Street Flight Line



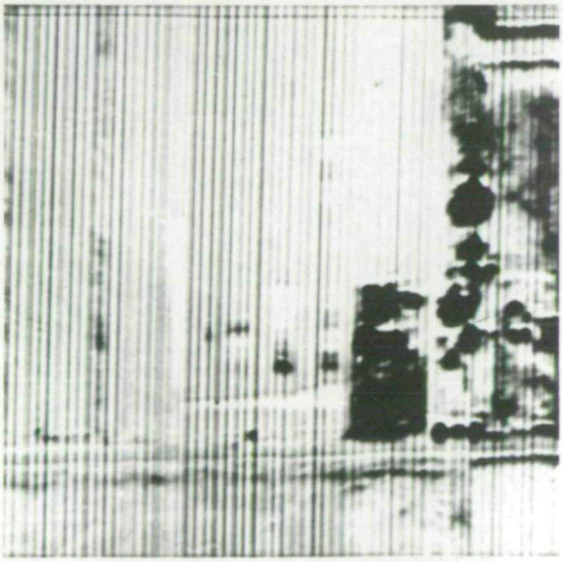
Schematic



RC-8 (Black & White)



RC-8 (Color Infrared)



Reconofax IV (Thermal Infrared)

FIGURE 39: CONTROLLED TEST RANGE TARGETS

geographers produce. It is further assumed that these outcomes are derived by assembling and analyzing some basic elements of information. A group of information elements is typically characterized by data collected by an investigator for a particular experiment, each entry on his data sheet being an information element. The information elements are, then, the fundamental data that the experimenter determines are necessary to the performance of his experiment. Recognizing that an experiment is a personal endeavor, an investigator using the format described herein would be required to structure his analytical and thought processes, or other activities relevant to this study, to this framework of information elements.

Further, it is assumed that each information element does not play an equal role in the analytical routine that produces the desired outcome. The situation frequently arises in which it would be nice to have information X, but in which it is essential to have information Y. There is some relative importance of each element. Deriving a numerical value to represent relative importance is often a subjective process, because required data are not available. However, it is a mechanism for conveying the subjective opinions of experienced persons to other disciplines, and, as such, it may even be utilized within the discipline to identify areas needing improvement.

To meet the objective stated above, some measure of the effectiveness of available sensors is required. Under the NASA Earth Resources Aircraft Program, tests have been conducted with remote sensors, and the data collected has been reviewed by Principal Investigators. Only the Principal Investigators can decide how well specific sensors provide information for their needs. It is assumed that the Principal Investigator has opinions that can produce a finer division in measure of effectiveness than (0,1) or (yes, no); probably five levels of effectiveness (exclusive of zero) can be obtained without detailed analysis. Examples of relevant effectiveness measures are given in Section 2.7.3 below.

Given the relative importance and effectiveness for each information element, the next task is to combine these values in some meaningful form to yield the effectiveness of a sensor in producing the set of information elements required by the Principal Investigator. The weighted sum technique outlined in the following section (2.7.2) provides a uniform framework for further analysis between sensors and/or Principal Investigators. A more sophisticated model is not justified because of the subjectivity and consequent lack of precision in the input data, viz., the relative importance and effectiveness values.

2.7.2 Approach

The approach adopted was to compare the effectiveness and cost of alternative methods of identifying information elements relevant to specific geographic analyses. Principal Investigators were asked to define the specific data they require and to record these data as a number of information elements. For each information element, the Principal Investigator was asked to assess the effectiveness of each sensor alternative in providing that element. An overall effectiveness is calculated as follows:

$$E_{jk} = \sum_i w_i e_{ijk}$$

where E_{jk} = Effectiveness of the k^{th} sensor(s) in providing data at an effective resolution level j.

w_i = Relative importance of the i^{th} element of information ($\sum_i w_i = 1$).

e_{ijk} = Effectiveness of the k^{th} sensor(s) in providing the i^{th} information element at an effective resolution level j.

A cost-effectiveness comparison can be accomplished if the cost of each sensor(s) alternative is known. This cost would include the procurement of the sensor(s) and film, operational costs incurred in obtaining the imagery or recorder medium, processing, and other costs incidental to acquiring the finished product in a form desired by the Principal Investigator.

To effectively involve GEOGAP and the Principal Investigator in the formulation of this cost effectiveness format, several meetings and trips were necessary.

In November, 1968, the initial draft of the format was completed and approved by the GEOGAP staff, whereupon it was decided that it should be tested by some of the investigators. Trips were then made in December to East Tennessee State and Northwestern Universities to discuss the matter. At each University the participants in the USGS/NASA research programs were asked to complete a form based on their particular project and to comment on the format itself.

This phase of the development was actually a "debugging" phase, for it was found that the approach to entering the data into the format was not consistent from investigator to investigator. Both the cost effectiveness scheme and its explanation were then revised based on the data received during the first trip.

In January, the work on the revised format was completed and discussed with GEOGAP personnel. A trip to the University of California (Riverside and Los Angeles) was then arranged and satisfactory sample data collected.

Due to conflicts in schedules and prior commitments, not all of the GEOGAP investigators had completed their forms at the time of publication of this report. The format, however, is complete and can be used by the GEOGAP staff in both cost effectiveness and sensor effectiveness studies.

2.7.3 Use of the Cost Effectiveness Matrix

Table XXXVI, along with the following comments, may be useful in conveying to the Principal Investigator the information that is needed.

Step 1 - The information elements are portrayed in the left column of the data sheet. These information elements are the lowest item in the hierarchial data structure. The particular structure shown in Table XXXVI was taken from one Principal Investigator's listing of items he needed to observe. One technique for deriving the relative importance value (w_i) is the following:

a) Assign relative importance values to the first or second level breakdown:

Water	3
Mineral	3
Transportation	5
Structures	5
Vehicles	4
Humans	3
Vegetation	4

Use any convenient numbering scheme that conveys relative magnitude of importance to the Principal Investigator. As a beginning, Transportation and Structures were considered equal in importance and more important than any other item; therefore, (5) was entered after Transportation and Structures. This established a reference for weighting the other items. The number (5) is completely arbitrary, but usually easier to work around than (7), (13), etc.

Now cross check your number allocation:

Are Water, Mineral, Humans equally important in your work?
Are Vehicles and Vegetation equal?
Do the ratios 3/5, 3/4, 4/5 seem correct?

TABLE XXXVI
Example of Data Entry

			SENSORS									
			Ground Survey		B & W 9" Format			----		B & W + IR 9" Format		
	INFORMATION ELEMENT	R_{jk}	10	1	.5'	2'	15'			.5'	2'	15'
		w_i \ jk	101	201	102	202	302			109	209	309
NATURAL	WATER (3)	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx
	Salt (5)	.040	1	1	.6	.6	.4			.8	.8	.6
	Brackish (4)	.032	1	.8	.4	.4	.2			.8	.8	.4
	Fresh (5)	.040	1	.8	.6	.6	.4			.8	.8	.6
	MINERAL (3)	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx
	Sand (4)	.030	1	1	.6	.6	.4			.8	.8	.6
	Muck (3)	.022	1	.8	.2	.2	.2			.6	.6	.4
	Coral (3)	.022	1	1	.8	.6	.4			1	1	.8
	Limestone (5)	.037	1	1	.8	.6	.4			1	1	.8
CULTURAL	TRANSPORTATION (5)	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx
	Airports (4)	.027	1	1	1	1	1			1	1	1
	Highways (5)	.034	1	1	1	1	1			1	1	1
	Secondary Roads	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx
	Concrete (5)	.009	1	.8	1	1	.8			1	1	1
	Asphalt (5)	.009	1	.8	1	1	.8			1	1	1
	Stone (3)	.005	1	.6	.8	.6	.2			1	.8	.4
	Shell (2)	.004	1	.4	.8	.4	.0			.8	.6	.2
	Parking Areas (2)	.014	1	1	1	1	.8			1	1	.8
	Bridges (3)	.021	1	1	1	1	.8			1	1	.8
	Railroads (3)	.021	1	1	1	1	1			1	1	1
	Docks (3)	.021	1	1	1	1	1			1	1	1
	Tunnels (2)	.014	1	1	1	1	.8			1	1	.8
	Canals (1)	.007	1	1	1	1	.8			1	1	1
	STRUCTURES (5)	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx
	Commercial (4)	.024	1	1	1	1	.8			1	1	.8
	Industrial (5)	.030	1	1	1	1	1			1	1	1
	Agricultural (4)	.024	1	1	1	1	1			1	1	1
	Residential (5)	.030	1	1	1	1	.8			1	1	.8
	Harbor Facilities (4)	.024	1	1	1	1	1			1	1	1
	Pumping Station (4)	.024	1	.4	.8	.6	.2			1	1	.6
	Institutions (3)	.018	1	1	1	1	.8			1	1	.8
	Levees/Dikes (2)	.012	1	1	1	1	.6			1	1	.6
	VEHICLES (4)	.148	1	.4	1	.8	.2			1	1	.6
	HUMANS (3)	.111	.8	.2	.8	.6	0			1	.8	.2
	VEGETATION (4)	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx
	Field (5)	.034	1	1	1	1	1			1	1	1
	Crop Type (4)	.027	.8	.2	.8	.6	.2			1	.8	.6
	Livestock (4)	.027	.6	.2	.6	.4	.2			.8	.6	.4
	Orchards (3)	.020	1	.8	1	1	.6			1	1	.8
	Marsh (2)	.013	1	.8	.8	.8	.6			1	1	.8
	Forest (4)	.027	1	1	1	1	1			1	1	1
		E_{jk}										
		C_{jk}										
		E/C										

b) Now proceed to the next level in the hierarchy using the same procedure:

		w_i
Salt	5	.040
Brackish	4	.031
Fresh	5	.040

c) Since this is the lowest level of breakdown for water, these values can be normalized so that $\Sigma w_i = 1$ when all values of relative importance are derived. A weight of 5 was assigned to salt. The sum of numbers assigned to the first level is 27. A weight of 3 was assigned to Water. The sub-categories of Water - Salt, Brackish and Fresh - have weightings totaling 14. The w_i for Salt, then, is calculated:

$$w_i = \frac{(5)}{(27)} \frac{(3)}{(14)} = .040$$

The remaining w_i's are derived group by group in a similar manner and entered in column w_i of the matrix. When all entries have been made, make a final check to see that $\Sigma_i w_i = 1$.

Determine the sensor alternatives to be evaluated. Alternatives include:

- Ground Survey
- 9" format, B&W
- 9" format, CIR
- 70mm format, B&W
- Radar
- 70mm format, B&W + Radar
- 70mm format, CIR + Radar + UV

An alternative is a set of sensors utilized to identify information elements needed for a specific analysis. To bound this evaluation to a reasonable level, the Principal Investigator must determine those sensor sets most useful for his analysis; evaluation of all possible sets would be overwhelming.

Step 2 - Evaluation of new technologies is usually accomplished by comparing the capability of the new technology with some base technology, which corresponds to the present methods of doing specific tasks. Basic data collection for geographic surveys of cultural phenomena have been accomplished by personal observation;

label this basic reference "ground survey". There are various grades (or levels) of ground survey data, low level referring to lower precision in identifying the information elements. Treat "ground survey" as a form of sensor for this study. In Table XXXVI the "resolutions" under Ground Survey are given as 10 and 1 and refer to high and low precision, respectively. Precision is a function of sampling density, and, if it is to be included in a cost effectiveness study, would have to be costed out.

Step 3 - Some frame of reference, a measurable parameter, is required to compare the effectiveness of various sensor sets. Since imagery is the principal product of remote sensors presently under evaluation, resolution or scale is suggested for the reference parameter. Therefore, for each sensor alternative, determine the effective resolutions of the imagery. The scale of the imagery may be used in place of resolution if so desired.

It is expected that resolution requirements will vary for different studies. For example, resolution requirements are more critical for a study that requires identification of litter or garbage in a yard than a study requiring only identification of dwellings. Each Principal Investigator is asked to indicate a range of resolutions that could yield data for his activities.

Step 4 - Enter the resolution or scale for each sensor set in the Cost Effectiveness Table.

In row R_{jk}, the undegraded resolution or scale, is entered in the first box under each sensor set. Alternative resolutions (j) are entered as needed. In row jk, the identifier for each alternative (resolution and sensor set) is entered, using two digits for k.

Step 5 - Calculate and enter effectiveness (e_{ijk}). Some guidelines are:

a) Effectiveness may be derived qualitatively or quantitatively for various situations. A recommended approach is to count the number of objects (vehicles, homes, roads, etc.) that can be identified in the imagery and compare those observed data with the ground truth (or other reference) data; a good measure of effectiveness would be:

$$e_{ijk} = \frac{\text{number of objects observed}}{\text{actual number of objects}}$$

If time or limited data preclude performing the above analysis, a more subjective scale can be utilized. Select e_{ijk} according to the following table:

e_{ijk}	Description
1	100% determination of the information element
.8	can determine most of the information element
.6	can determine over half of the information element
.4	can determine less than half of the information element
.2	can determine small amount of the information element
0	cannot determine any of the information element

Continue this procedure for all columns.

b) Check for consistency between single and multiple sensor sets. For example, one would not expect a decrease in effectiveness of a B & W camera plus an IR sensor set with respect to a B & W camera only (the B & W being at the same resolution, of course). If the added capability of IR is negligible as compared with a B & W camera alone, e_{ijk} would not be reduced because the IR data could be discarded (not used) and results would be the same as with B & W camera alone.

c) e_{ijk} must reflect the capability of the sensors, not the a priori desires of the Principal Investigators.

Step 6 - Calculate E_{jk} and enter in row E_{jk}.

Step 7 - Determine costs and enter these values in row C_{jk}. The Principal Investigator could contribute to cost data by estimating the cost of a typical ground survey that yields information elements at the selected reference resolutions. Costs of aircraft and sensors appear to be a NASA responsibility and are not available for this study.

Step 8 - Finally, if cost data are available, E/C is calculated.

(Note: Tables XXXVII through XLIIIB are cost effectiveness forms as filled out by participants in the NASA Aircraft Program and by Autometric scientists.)

TABLE XXXVII

COST EFFECTIVENESS DATA ENTRY FORM

As Completed by Principal Investigator
Data Received from NASA/MSC (Or Obtained with NASA Funds)

INFORMATION ELEMENTS (Regional Resources)	R_{jk} / w_i	SENSORS (Received from NASA): Ground Survey		CIR + 15		CIR + 15		CIR + 15 + 80B		CIR + 15 + 80B		8442 + H2		ALOTS (200")		Multi-Band 70mm		CIR(70mm) 4Filters	
				1/60,000		1/20,000		1/20,000		1/10,000		1/60,000		1/1200		1/60,000		1/32,000	
Landform Identification (5)	.116	.8	.093	.6	.070	.7	.081	.8	.093	.9	.104	.6	.070	.5	.058	.5	.058	.3	.035
Mineral Types (3)	.070	.6	.042	.1	.007	.1	.007	.1	.007	.1	.007	.1	.007	.2	.014	.1	.007	.1	.007
Erosion Action and Deposition (3)	.070	.8	.056	.5	.035	.7	.049	.8	.056	.8	.056	.5	.035	.5	.035	.4	.028	.4	.028
Structure (3)	.070	.7	.049	.4	.028	.4	.028	.4	.028	.4	.028	.4	.028	.4	.028	.4	.028	.4	.028
Soils Identification (4)	.093	.7	.065	.4	.037	.4	.037	.5	.047	.6	.056	.3	.028	.6	.056	.3	.028	.4	.037
Water (5)																			
Surface Area (5)	.045	.4	.018	.1	.005	.1	.005	.1	.005	.1	.005	.1	.005	.1	.005	.1	.005	.1	.005
Runoff (3)	.027	.3	.008	.1	.003	.1	.003	.1	.003	.1	.003	.1	.003	.1	.003	.1	.003	.1	.003
Ground Water (5)	.045	.2	.009	.1	.005	0	-	0	-	0	-	0	-	.1	.005	0	-	0	-
Vegetation (5)																			
Species (3)	.023	.8	.018	.3	.007	.4	.009	.5	.012	.6	.014	.2	.005	.9	.021	.2	.005	.7	.016
Major Types (5)	.031	.8	.025	.6	.019	.7	.022	.8	.025	.8	.025	.2	.006	.8	.025	.4	.012	.5	.016
Areal Extent (5)	.039	.6	.023	.6	.023	.4	.016	.4	.016	.2	.008	.3	.012	0	-	.4	.016	.5	.020
Health (3)	.023	.3	.007	.2	.005	.2	.005	.2	.005	.2	.005	.2	.005	.2	.005	.2	.005	.2	.005
Land Use (5)																			
Agricultural (5)	.023	1	.023	.8	.018	.6	.014	.9	.021	.9	.021	.5	.012	.8	.018	.4	.009	.8	.018
Urban (5)	.023	1	.023	.8	.018	.6	.014	.9	.021	.8	.018	.7	.016	.9	.021	.8	.018	.8	.018
Open Space (5)	.023	.8	.018	.8	.018	.6	.014	.9	.021	.8	.018	.7	.016	.9	.021	.8	.018	.8	.018
Grazing (5)	.023	.8	.018	.6	.014	.5	.012	.7	.016	.8	.018	.3	.007	.9	.021	.4	.009	.4	.009
Forest (5)	.023	.6	.014	.6	.014	.5	.012	.6	.014	.5	.012	.2	.005	.3	.007	.5	.012	.9	.021
People (5)																			
Settlements (5)	.045	.8	.036	.7	.032	.6	.027	.8	.036	.9	.041	.4	.018	0	-	.4	.018	.8	.036
Distribution (5)	.045	.4	.018	.5	.023	.4	.018	.4	.018	.3	.014	.4	.018	.1	.005	.4	.018	.5	.023
Character (3)	.026	.5	.013	.2	.005	.2	.005	.2	.005	.2	.005	.2	.005	.5	.013	.2	.005	.2	.005
Atmosphere (5)																			
Physics of - (3)	.058	.1	.006	.1	.006	0	-	0	-	0	-	0	-	0	-	0	-	0	-
Chemistry of - (3)	.058	.1	.006	.1	.006	0	-	0	-	0	-	0	-	0	-	0	-	0	-
TOTALS	.999		.588		.384		.378		.449		.458		.301		.361		.297		.348

TABLE XXXVII (Cont'd)

INFORMATION ELEMENTS (Regional Resources)	R_{jk} / w_i	SENSORS (Received from NASA): 8442 70mm 1/32,000		B & W 1/6,000		CIR + 15 1/6,000		SLR K-Band		Thermal IR 3.5-5.5µ		Thermal IR 8-14µ		Passive Micro-wave 19.3Ghz		Apollo & Gemini		Absorption Spectrometer	
Landform Identification (5)	.116	.3	.035	.6	.070	.7	.081	.5	.058	.4	.046	.4	.046	.1	.012	.5	.058	0	-
Mineral Types (3)	.070	.1	.007	.1	.007	.1	.007	.1	.007	.1	.007	.2	.014	.1	.007	.1	.007	0	-
Erosion Action and Deposition (3)	.070	.3	.021	.2	.014	.4	.028	.3	.021	.1	.007	.1	.007	.1	.007	.4	.028	0	-
Structure (3)	.070	.4	.028	.4	.028	.4	.028	.5	.035	.2	.014	.4	.028	.1	.007	.4	.028	0	-
Soils Identification (4)	.093	.3	.028	.3	.028	.4	.037	.2	.019	.2	.019	.2	.019	.1	.009	.4	.037	0	-
Water (5)																			
Surface Area (5)	.045	.1	.005	.1	.005	.1	.005	.1	.005	.1	.005	.1	.005	.1	.005	.2	.009	0	-
Runoff (3)	.027	.1	.003	.1	.003	.1	.003	.1	.003	.1	.003	.1	.003	.1	.003	.1	.003	0	-
Ground Water (5)	.045	0	-	0	-	0	-	.1	.005	.1	.005	.2	.009	.1	.005	.1	.005	0	-
Vegetation (5)																			
Species (3)	.023	.1	.002	.2	.005	.3	.007	.1	.002	.1	.002	.3	.007	.3	.007	.3	.007	0	-
Major Types (5)	.031	.2	.006	.2	.006	.6	.019	.3	.009	.3	.009	.3	.009	.3	.009	.4	.012	0	-
Areal Extent (5)	.039	.4	.016	.2	.008	.2	.008	.5	.020	.2	.008	.2	.008	.5	.020	.9	.020	0	-
Health (3)	.023	.2	.005	0	-	.2	.005	0	-	0	-	0	-	0	-	0	-	0	-
Land Use (5)																			
Agricultural (5)	.023	.6	.014	.7	.016	.8	.018	.4	.009	.4	.009	.5	.012	.2	.005	.6	.014	0	-
Urban (5)	.023	.5	.012	.4	.009	.4	.009	.6	.014	.3	.007	.3	.007	.3	.007	.1	.002	0	-
Open Space (5)	.023	.8	.018	.8	.018	.8	.018	.8	.018	.4	.009	.8	.018	.2	.005	.8	.018	0	-
Grazing (5)	.023	.4	.009	.2	.005	.5	.012	.2	.005	.1	.002	.1	.002	.2	.005	.2	.005	0	-
Forest (5)	.023	.2	.005	.1	.002	.3	.007	.3	.007	.3	.007	.2	.005	.3	.007	.5	.012	0	-
People (5)																			
Settlements (5)	.045	.4	.018	.3	.014	.4	.018	.4	.018	.3	.014	.1	.005	.2	.009	.5	.023	0	-
Distribution (5)	.045	.2	.009	.2	.009	.3	.014	.2	.009	.1	.005	.1	.005	.1	.005	.2	.009	0	-
Character (3)	.026	.2	.005	.2	.005	.2	.005	.2	.005	.2	.005	.2	.005	.2	.005	.2	.005	0	-
Atmosphere (5)																			
Physics of - (3)	.058	0	-	0	-	0	-	0	-	.3	.017	0	-	0	-	0	-	.4	.023
Chemistry of - (3)	.058	0	-	0	-	0	-	0	-	.3	.017	0	-	0	-	.1	.006	.4	.023
TOTALS	.999		.246		.252		.329		.269		.217		.214		.139		.308		.046

TABLE XXXVII (Cont'd)

INFORMATION ELEMENTS (Regional Resources)	R_{jk} / w_i	SENSORS (Desired) CIR 15 + 80B & SLR		CIR 15 + 80B & Thermal IR								
Landform Identification (5)	.116	.8	.093	.6	.070							
Mineral Types (3)	.070	.2	.014	.1	.007							
Erosion Action and Deposition (3)	.070	.8	.056	.6	.042							
Structure (3)	.070	.5	.035	.4	.028							
Soils Identification (4)	.093	.5	.047	.4	.037							
Water (5)												
Surface Area (5)	.045	.2	.009	.1	.005							
Runoff (3)	.027	.2	.005	.1	.003							
Ground Water (5)	.045	.3	.014	.2	.009							
Vegetation (5)												
Species (3)	.023	.8	.018	.6	.014							
Major Types (5)	.031	.7	.022	.7	.022							
Areal Extent (5)	.039	.9	.035	.8	.031							
Health (3)	.023	.1	.002	.3	.007							
Land Use (5)												
Agricultural (5)	.023	.8	.018	.7	.016							
Urban (5)	.023	.8	.018	.7	.016							
Open Space (5)	.023	.8	.018	.7	.016							
Grazing (5)	.023	.6	.014	.7	.016							
Forest (5)	.023	.7	.016	.7	.016							
People (5)												
Settlements (5)	.045	.7	.032	.7	.032							
Distribution (5)	.045	.9	.041	.8	.036							
Character (3)	.026	.2	.005	.1	.003							
Atmosphere (5)												
Physics of - (3)	.058	.1	.006	.3	.017							
Chemistry of - (3)	.058	.1	.006	.1	.006							
TOTALS	.999		.524		.449							

TABLE XXXVIII

COST EFFECTIVENESS DATA ENTRY FORM

As Completed by Graduate Student A

INFORMATION ELEMENTS (VEGETATION STUDIES)		w_i \ R_{jk}	SENSORS: Ground Survey 1	Ground Survey 10	Gemini Imagery (From NASA) 1/250,000	Gemini Imagery (From NASA) 1/1,000,000	Gemini (Desired) 20' Res.				
TRANSPORTATION	(5)	.042	.4 .017	1 .042	.8 .033	.6 .024	1 .042				
Airports	(5)	.042	.4 .017	1 .042	0 .000	.0 .000	1 .042				
Roads	(5)	.042	.4 .017	1 .042	0 .000	.0 .000	1 .042				
Railroads	(5)	.125	.4 .050	1 .125	.4 .050	.2 .025	1 .125				
SETTLEMENTS	(5)										
CROPLAND	(5)	.063	.4 .025	1 .063	1 .063	.8 .050	1 .063				
Irrigated	(5)	.063	.4 .025	1 .063	.6 .038	.4 .025	1 .063				
Non-Irrigated	(5)										
FOREST		.063	.6 .038	1 .063	.6 .038	.6 .038	1 .063				
True Forest	(3)	.063	.2 .013	1 .063	.4 .025	.2 .013	8 .050				
Woodland	(3)										
EXTRACTIVE		.063	.8 .050	1 .063	.8 .050	.6 .038	1 .063				
Mines	(5)	.063	.4 .025	1 .063	.6 .038	.4 .025	1 .063				
Oilfields	(5)	.125	.2 .025	1 .125	0 .000	.0 .000	4 .050				
GRAZING	(5)										
WATER BODIES	(5)	.063	1 .063	1 .063	.8 .050	.6 .038	1 .063				
Permanent	(1)	.063	1 .063	1 .063	.8 .050	.6 .038	1 .063				
Seasonal	(1)	.125	1 .125	1 .125	.8 .100	.8 .100	1 .125				
UNPRODUCTIVE	(5)										
TOTALS		1.005	.553	1.005	.535	.414	.917				

COMMENTS: Have just received the Apollo imagery and will soon be using it in comparison with the Gemini and to update present land use maps of the southwest.

TABLE XXXIX

COST EFFECTIVENESS DATA ENTRY FORM

As Completed by Graduate Student B

INFORMATION ELEMENTS (VEGETATION STUDIES)	R_{jk} / w_i	Ground Survey 1*		B & W 1/10,000		CIR + 15 1/60,000		CIR + 15 + 80B** 1/16,000		8442 1/60,000	
Forest (2)	.050	1	.050	1	.050	1	.050	1	.050	1	.050
Chaparral Brush (2)	.050	1	.050	1	.050	1	.050	1	.050	1	.050
Desert Woodland (1)	.025	1	.025	1	.025	1	.025	1	.025	1	.025
Grass & Meadows (2)	.050	1	.050	.6	.030	.8	.040	1	.050	1	.050
Desert Brush (1)	.025	1	.025	1	.025	1	.025	1	.025	1	.025
Segregation of Brush (5) Types in Chaparral ***	.125	1	.125	.2	.025	.4	.050	.8	.100	.4	.050
Identification of Forest Types in Chaparral (4)	.100	1	.100	.6	.060	.8	.080	1	.100	.6	.060
Floristic Identification of Forest Individuals (4)	.100	1	.100	.2	.020	.2	.020	.2	.020	.2	.020
Subalpine Forest (4)	.100	1	.100	1	.100	1	.100	1	.100	1	.100
Floristic Identification of Desert and Woodland Types (4)	.100	1	.100	.2	.020	.4	.040	.6	.060	.4	.040
Blight Identification (2)	.050	1	.050	0	.000	0	.000	0	.000	0	.000
Floristic Identification of Individual Broad Leafs (3)	.075	1	.075	.2	.015	.4	.030	.8	.060	.4	.030
Floristic Identification of Individual Conifers (3)	.075	1	.075	.2	.015	.2	.015	.2	.015	.2	.015
Floristic Identification of Desert Brush (1)	.025	1	.025	0	.000	0	.000	0	.000	0	.000
Identification of Riverine Vegetation (2)	.050	1	.050	.6	.030	.6	.030	1	.050	.6	.030
TOTALS	1.000		1.000		.465		.555		.705		.545

*The maxiumum level for ground survey has been eliminated since a 1.0 level can be reached with a minimum of effort.

**This film filter combination is the one desired with scales ranging from 1/10,000 - 1/100,000.

***Mapping according to floristic dominants.

TABLE XL

COST EFFECTIVENESS DATA ENTRY FORM

As Completed by Research Assistant C

INFORMATION ELEMENTS (VEGETATION STUDIES)		SENSORS (Received from NASA)(Desired)							
		Ground	Survey	CIR-12" F/L 15+80B	CIR-9" F/L +15	CIR + 15*** + 80B + Color			
	R_{jk} / w_i	1	10	1/16,000	1/10,000	1/16,000			
Crops* (5)	.263	.4 .105	1.0 .263	.8 .210	.9 .210	1.0 .263			
Fields (Non-Producing) (5)	.263	.4 .105	1.0 .263	.8 .210	.9 .210	1.0 .263			
Livestock (2)	.105	.4 .042	1.0 .105	.4 .042	.6 .063	.8 .084			
Orchards** (5)	.263	.6 .158	1.0 .263	.6 .158	.6 .158	.6 .158			
Rivers (1)	.053	1.0 .053	1.0 .053	.8 .042	.8 .042	1.0 .053			
Undeveloped (1)	.053	1.0 .053	1.0 .053	1.0 .053	1.0 .053	1.0 .053			
TOTALS	1.000	.516	1.000	.715	.736	.874			

*Vegetables, field crops and orchards can generally be imaged at .8 and in many cases defined down to a specific crop, but to date, complete crop identification has not been accomplished.

**Orchards can be broken down into citrus and deciduous categories, but citrus cannot be defined as lemons, oranges, etc.

***9" and 12" F/L

SPACECRAFT: With scales greater than 1/24,000 only gross land-use differentiation can be achieved (i.e., agriculture, urban settlement, etc.) No definite determination of degradations due to scale increase (1/10,000 to 1/100,000) has been determined.

TABLE XLI

COST EFFECTIVENESS DATA ENTRY FORM

As Completed by Graduate Student D

INFORMATION ELEMENTS (URBAN STUDIES)	R_{jk} / w_i	SENSORS (Received from NASA) Ground		Survey		CIR		CIR + 15		CIR 15 + 80B		8442		B & W		SLR		TIR	
		1		10		1/10,000		1/6,000		1/60,000		1/20,000-1/60,000		1/6,000		1/100,000		1/100,000	
Transportation (5)	.116																		
Railroads (4)	.024	.2	.005	1.0	.024	1	.024	1	.024	.8	.019	.8	.019	1	.024	.6	.014	.6	.014
Airports (2)	.012	.8	.009	1.0	.012	1	.012	1	.012	1	.012	1	.012	1	.012	.6	.007	.8	.010
Docks (1)	.006	.6	.004	1.0	.006	.8	.005	.8	.005	.4	.002	.4	.002	.8	.005	.2	.001	.2	.001
Freeways (2)	.012	.8	.010	1.0	.012	1	.012	1	.012	1	.012	1	.012	1	.012	.8	.010	1	.012
Highways (2)	.012	.4	.005	1.0	.012	1	.012	1	.012	.8	.010	1	.012	1	.012	.6	.007	.8	.010
Secondary Roads (2)	.012	.2	.002	1.0	.012	.8	.010	1	.012	.6	.007	.6	.007	1	.012	.6	.007	.6	.007
Depots (1)	.006	.2	.001	1.0	.006	.6	.004	.8	.005	.4	.002	.4	.002	.6	.004	.2	.001	.2	.001
Vehicles (2)	.012	.2	.002	1.0	.012	1	.012	1	.012	.4	.005	.6	.007	1	.012	0	-	.2	.002
Parking (3)	.018	.4	.007	1.0	.018	1	.018	1	.018	.6	.011	.8	.014	1	.018	0	-	.2	.004
Structures (5)	.116																		
Commercial (4)	.024	.4	.009	1.0	.024	.8	.019	1	.024	.6	.014	.6	.014	.6	.014	.4	.009	.4	.010
CBD (4)	.024	.4	.009	1.0	.024	.8	.019	1	.024	.8	.019	.6	.014	1	.024	.6	.014	.6	.014
Regional Shopping Ctrs. (3)	.018	.4	.007	1.0	.018	1	.018	1	.018	.8	.014	.6	.011	1	.018	.4	.007	.4	.007
Secondary Shopping Ctrs. (3)	.018	.4	.007	1.0	.018	1	.018	1	.018	.6	.011	.6	.011	.8	.014	.4	.007	.4	.007
String Developments (3)	.018	.4	.007	1.0	.018	.8	.014	1	.018	.6	.011	.6	.011	.6	.011	.4	.007	.4	.007
Isolated Stores (2)	.012	.2	.002	1.0	.012	.6	.007	.8	.010	.2	.002	.2	.002	.4	.005	0	-	0	-
Light Industry (5)	.116	.4	.046	1.0	.116	.8	.093	1	.116	.4	.046	.4	.046	.6	.070	.4	.046	.4	.046
Heavy Industry (5)	.116	.4	.046	1.0	.116	.8	.093	1	.116	.6	.070	.4	.046	.8	.093	.6	.070	.6	.070
Schools (2)	.047	.4	.018	1.0	.047	.8	.038	1	.047	.8	.038	.8	.038	1	.047	.4	.019	.4	.019
Institutions (2)	.047	.4	.018	1.0	.047	.8	.038	1	.047	.6	.028	.6	.028	.8	.038	.4	.019	.4	.019
Park Buildings (4)	.093	.4	.037	1.0	.093	.8	.074	1	.093	.6	.056	.6	.056	.8	.074	.4	.037	.4	.037
Multi-Unit Residences (5)	.116	.2	.023	1.0	.116	.6	.070	.8	.093	.6	.070	.6	.070	.6	.070	.2	.023	.4	.046
Single Family Unit Residences (5)	.116	.2	.023	1.0	.116	.6	.070	.8	.093	.8	.070	.6	.070	.6	.070	.6	.070	.6	.070

TABLE XLI (Cont'd)

INFORMATION ELEMENTS (URBAN STUDIES)	R_{jk} / w_i	SENSORS: UV		CIR + 15 (Desired)								
		-		1/6,000 and 1/30,000								
Transportation (5)	.116											
Railroads (4)	.024	0	-	1.0	.024							
Airports (2)	.012	0	-	1.0	.012							
Docks (1)	.006	0	-	.8	.005							
Freeways (2)	.012	0	-	1.0	.012							
Highways (2)	.012	0	-	1.0	.012							
Secondary Roads (2)	.012	0	-	1.0	.012							
Depots (1)	.006	0	-	.8	.005							
Vehicles (2)	.012	0	-	1.0	.012							
Parking (3)	.018	0	-	1.0	.018							
Structures (5)	.116	0	-									
Commercial (4)	.024	0	-	.8	.019							
CBD (4)	.024	0	-	1.0	.024							
Regional Shopping Ctrs. (3)	.018	0	-	1.0	.018							
Secondary Shopping Ctrs. (3)	.018	0	-	1.0	.018							
String Developments (3)	.018	0	-	1.0	.018							
Isolated Stores (2)	.012	0	-	.8	.010							
Light Industry (5)	.116	0	-	1.0	.116							
Heavy Industry (5)	.116	0	-	1.0	.116							
Schools (2)	.047	0	-	1.0	.047							
Institutions (2)	.047	0	-	1.0	.047							
Park Buildings (4)	.093	0	-	1.0	.093							
Multi-Unit Residences (5)	.116	0	-	.8	.093							
Single Family Unit Residences (5)	.116	0	-	1.0	.116							

TABLE XLI (Cont'd)

INFORMATION ELEMENTS (URBAN STUDIES)	R_{jk} / w_i	Ground 1	Survey 10	CIR 1/10,000	CIR + 15 1/6,000	CIR + 15 + 80B 1/60,000	8442 Color 1/20,000 1/60,000	B & W 1/6,000	SLR 1/100,000	TIR 1/100,000
		SENSORS (Received from NASA)								
Residential Environment Evaluation (5)	.116									
Dwelling Type (5)	.007	.2 .001	1.0 .007	.6 .004	.8 .006	.6 .004	.6 .004	.6 .004	.4 .003	.4 .003
Vegetation (5)	.007	.4 .003	1.0 .007	.8 .006	1.0 .007	.8 .006	.4 .003	.2 .001	0 -	0 -
Litter & Rubbish (5)	.007	.4 .003	1.0 .007	.6 .004	1.0 .007	0 -	0 -	.2 .001	0 -	0 -
Vacant (5)	.007	.4 .003	1.0 .007	1.0 .007	1.0 .007	.8 .006	.6 .004	.1 .001	.4 .003	.4 .003
Land Use (4)	.006	.4 .002	1.0 .006	.8 .005	1.0 .006	.8 .005	.6 .004	.6 .004	.4 .002	.4 .002
Lot Size (3)	.004	.2 .001	1.0 .004	1.0 .004	1.0 .004	.8 .003	.8 .003	1.0 .004	0 -	0 -
Home Size (2)	.003	.2 .001	1.0 .003	1.0 .003	1.0 .003	.8 .002	.8 .002	1.0 .003	0 -	0 -
Home Shape (2)	.003	.4 .001	1.0 .003	1.0 .003	1.0 .003	.6 .002	.4 .001	1.0 .003	0 -	0 -
Roof Type (2)	.003	.2 .001	.8 .002	1.0 .003	1.0 .003	.2 .001	.4 .001	.8 .002	0 -	0 -
Pools (5)	.007	0 -	.8 .006	1.0 .007	1.0 .007	.8 .006	.6 .004	.6 .004	0 -	0 -
Patios (5)	.007	0 -	.8 .006	.8 .006	1.0 .007	.6 .004	.4 .003	.4 .003	0 -	0 -
Shade Umbrellas (5)	.007	0 -	.8 .006	1.0 .007	1.0 .007	0 -	0 -	.4 .003	0 -	0 -
Play Area (Cemented) (3)	.004	0 -	.8 .003	1.0 .004	.8 .003	.2 .001	.2 .001	.2 .001	0 -	.2 .001
Street Condition (4)	.006	.4 .002	1.0 .006	.6 .004	.8 .005	.2 .001	.2 .001	.6 .004	0 -	0 -
Street Width (2)	.003	.4 .001	1.0 .003	1.0 .003	1.0 .003	1.0 .003	1.0 .003	1.0 .003	.2 .001	.2 .001
Street Pattern (4)	.006	.6 .004	1.0 .006	1.0 .006	1.0 .006	1.0 .006	1.0 .006	1.0 .006	.6 .004	.6 .004
Street Lighting (2)	.003	.4 .001	1.0 .003	.8 .002	1.0 .003	0 -	0 -	.8 .002	0 -	0 -
Street Traffic (2)	.003	.2 .001	1.0 .003	1.0 .003	1.0 .003	.6 .002	.6 .002	1.0 .003	0 -	0 -
Sidewalks (3)	.004	.2 .001	1.0 .004	.8 .003	1.0 .004	0 -	0 -	.6 .002	0 -	0 -
Curbs (3)	.004	.2 .001	1.0 .004	.6 .002	.8 .003	0 -	0 -	.4 .002	0 -	0 -
Parks (2)	.003	.4 .001	1.0 .003	1.0 .003	1.0 .003	.6 .002	.6 .002	.8 .002	.4 .001	.6 .002
Golf Courses (4)	.006	.4 .002	1.0 .006	1.0 .006	1.0 .006	.8 .005	.8 .005	1.0 .006	.6 .004	.8 .005
Community Facilities (1)	.002	.4 .001	1.0 .002	.6 .001	.8 .002	.2 .000	.2 .000	.6 .001	0 -	0 -
TOTALS	.985	.328	.986	.776	.937	.581	.551	.724	.393	.434

*The investigation realized the problem of rating a variable scale system

TABLE XLI (Cont'd)

INFORMATION ELEMENTS (URBAN STUDIES)	W_i \ R_{jk}	SENSORS: UV —	SENSORS: Desired CIR + 15 1/6,000 & 1/30,000							
Residential Environment Evaluation (5)	.116									
Dwelling Type (5)	.007	0 -	.8 .006							
Vegetation (5)	.007	0 -	1 .007							
Litter & Rubbish (5)	.007	0 -	1 .007							
Vacant (5)	.007	0 -	1 .007							
Land Use (4)	.006	0 -	.8 .005							
Lot Size (3)	.004	0 -	1 .004							
Home Size (2)	.003	0 -	1 .003							
Home Shape (2)	.003	0 -	1 .003							
Roof Type (2)	.003	0 -	1 .003							
Pools (5)	.007	0 -	1 .007							
Patios (5)	.007	0 -	1 .007							
Shade Umbrellas (5)	.007	0 -	1 .007							
Play Area (Cemented) (3)	.004	0 -	.8 .003							
Street Condition (4)	.006	0 -	1 .006							
Street Width (2)	.003	0 -	1 .003							
Street Pattern (4)	.006	0 -	1 .006							
Street Lighting (2)	.003	0 -	1 .003							
Street Traffic (2)	.003	0 -	1 .003							
Sidewalks (3)	.004	0 -	1 .004							
Curbs (3)	.004	0 -	.8 .003							
Parks (2)	.003	0 -	1 .003							
Golf Courses (4)	.006	0 -	1 .006							
Community Facilities (1)	.002	0 -	.8 .002							
TOTALS	.985	000	.955							

TABLE XLII

COST EFFECTIVENESS DATA ENTRY FORM

SHIP ROUTING IN ARCTIC AREAS

INFORMATION ELEMENTS	R_{jk} / w_i \ jk	SENSORS USED: B & W Camera		Thermal IR	SLR		Color		Imaging Laser	PPI Radar
	R_{jk}	$\frac{1}{10,000}$	$\frac{1}{100,000}$	$\frac{1}{40,000}$	$\frac{1}{100,000}$	$\frac{1}{400,000}$	$\frac{1}{10,000}$	$\frac{1}{100,000}$	$\frac{1}{3,000}$	$\frac{1}{2,000,000}$
	jk / w_i	101	201	102	103	203	104	204	105	106
WATER										
Ice Free (5)	.048	1 .048	1 .048	1 .048	1 .048	1 .048	1 .048	1 .048	1 .048	1 .048
Open (5)	.048	1 .048	1 .048	1 .048	1 .048	1 .048	1 .048	1 .048	1 .048	1 .048
Lead (5)	.048	1 .048	.8 .038	.8 .038	.8 .038	.8 .038	1 .048	1 .048	1 .048	.4 .019
Lane (4)	.038	1 .038	.8 .030	.8 .030	.8 .030	.8 .030	1 .038	1 .038	1 .038	.4 .015
Polynya (3)	.028	.8 .022	.6 .016	.8 .022	.6 .016	.4 .011	1 .028	.8 .022	.8 .022	0 000
Crack (4)	.038	.8 .030	.6 .022	.8 .030	.6 .022	.6 .022	1 .038	.8 .030	.8 .030	.2 .007
ICE DEVELOPMENT										
New (1)	.014	.6 .008	.4 .005	.4 .005	.2 .002	.2 .002	.8 .011	.6 .008	.6 .008	0 000
Nilas (1)	.014	.6 .008	.4 .005	.4 .005	.2 .002	.2 .002	.8 .011	.6 .008	.6 .008	0 000
Pancake (1)	.014	.6 .008	.4 .005	.4 .005	.2 .002	.2 .002	.8 .011	.6 .008	.6 .008	0 000
Young (2)	.029	.6 .017	.4 .011	.4 .011	.4 .011	.4 .011	.8 .023	.8 .023	.6 .017	0 000
First Year (3)	.044	.8 .035	.8 .035	.6 .026	.6 .026	.6 .026	.8 .035	.8 .035	.8 .035	.2 .008
Old Ice (5)	.073	.8 .058	.8 .058	.6 .043	.6 .043	.6 .043	.8 .058	.8 .058	.8 .058	.2 .014
Second Year (5)	.036	.8 .028	.6 .021	.4 .014	.4 .014	.4 .014	.8 .028	.8 .028	.8 .028	0 000
Multi-Year (5)	.036	.8 .028	.6 .021	.4 .014	.4 .014	.4 .014	.8 .028	.8 .028	.8 .028	0 000
Fast Ice (4)	.058	1 .058	1 .058	1 .058	1 .058	1 .058	1 .058	1 .058	1 .058	.4 .023

TABLE XLII (Cont'd)

INFORMATION ELEMENTS	R_{jk} / w_i \ jk	SENSORS USED: B & W Camera 1/10,000 (101)	B & W Camera 1/100,000 (201)	Thermal IR 1/40,000 (102)	SLR 1/100,000 (103)	SLR 1/400,000 (203)	Color 1/10,000 (104)	Color 1/100,000 (204)	Imaging Laser 1/3,000 (105)	PPI Radar 1/2,000,000 (106)
FORM OF ICE										
Floe (5)	.031	1 .031	.8 .024	.8 .024	.8 .024	.8 .024	1 .031	1 .031	1 .031	.6 .018
Giant >10km (5)	.007	1 .007	1 .007	1 .007	1 .007	.8 .005	1 .007	1 .007	1 .007	.6 .004
Vast 2-10km (5)	.007	1 .007	1 .007	1 .007	1 .007	.8 .005	1 .007	1 .007	1 .007	.6 .004
Big 500-2000m (5)	.007	1 .007	1 .007	1 .007	1 .007	.8 .005	1 .007	1 .007	1 .007	.6 .004
Medium 100 - 500m (4)	.005	1 .005	.8 .004	.8 .004	.8 .004	.6 .003	1 .005	1 .005	1 .005	.4 .002
Small 20-100m (3)	.004	1 .004	.8 .003	.8 .003	.8 .003	.6 .002	1 .004	1 .004	1 .004	0 .000
Cake < 20m (2)	.012	.8 .009	.8 .009	.6 .007	.4 .004	.4 .004	1 .012	.8 .009	.8 .009	0 .000
Floeberg (5)	.031	1 .031	.8 .024	.4 .012	.6 .018	.4 .012	1 .031	.8 .024	1 .031	.2 .006
Iceberg (5)	.031	1 .031	1 .031	.8 .024	.6 .018	.6 .018	1 .031	1 .031	1 .031	.2 .006
Ice Field (5)	.031	1 .031	1 .031	1 .031	.8 .024	.8 .024	1 .031	1 .031	1 .031	.2 .006
Ice Jam (5)	.031	1 .031	1 .031	1 .031	1 .031	1 .031	1 .031	1 .031	1 .031	.8 .024
Ridges (4)	.025	.8 .020	.6 .015	.6 .015	.6 .015	.6 .015	.8 .020	.8 .020	1 .025	0 .000
Hummocks (5)	.031	.8 .024	.6 .018	.6 .018	.6 .018	.6 .018	.8 .024	.8 .024	1 .031	0 .000
Puddles (3)	.018	1 .018	1 .018	.8 .014	.4 .007	.2 .003	1 .018	1 018	1 .018	0 .000
Rotten (1)	.006	1 .006	1 .006	.8 .004	.4 .002	.4 .002	1 .006	1 .006	1 .006	.4 .002
CONCENTRATION										
Compact/ Consolidated (5)	.065	1 .065	1 .065	1 .065	.8 .052	.8 .052	1 .065	1 .065	1 .065	.8 .052
Very Close Pack (5)	.065	1 .065	1 .065	1 .065	.8 .052	.8 .052	1 .065	1 .065	1 .065	.4 .026
Close Pack (4)	.052	1 .052	1 .052	1 .052	.8 .041	.8 .041	1 .052	1 .052	1 .052	.4 .020
Open Pack (3)	.039	1 .039	1 .039	1 .039	.8 .031	.8 .031	1 .039	1 .039	1 .039	.4 .015
Very Open Pack (2)	.026	1 .026	1 .026	1 .026	.8 .020	.8 .020	1 .026	1 .026	1 .026	.4 .010
TOTALS	.988	.899	.833	.0796	.703	.688	.937	.904	.917	.367

TABLE XLII (Cont'd)

INFORMATION ELEMENTS		R_{jk} / w_i \ jk	SENSORS DESIRED FOR SCIENTIFIC STUDIES: SCATTERO-METER		B & W CAMERA $\frac{1}{2,000,000}$		COLOR $\frac{1}{2,000,000}$	
			107		108		109	
WATER								
Ice Free	5	.048	.6	.028	1	.048	1	.048
Open	5	.048	.6	.028	1	.048	1	.048
Lead	5	.048	.2	.009	.6	.028	.6	.028
Lane	4	.038	.2	.007	.6	.022	.6	.022
Polynya	3	.028	0	.000	.2	.005	.4	.011
Crack	4	.038	0	.000	.6	.022	.6	.022
ICE DEVELOPMENT								
New	1	.014	0	.000	.2	.002	.2	.002
Nilas	1	.014	0	.000	.2	.002	.2	.002
Pancake	1	.014	0	.000	.2	.002	.2	.002
Young	2	.029	.4	.011	.2	.005	.4	.011
First Year	3	.044	.8	.035	.6	.026	.6	.026
Old Ice	5	.073	.8	.058	.6	.043	.6	.043
Second Year	5	.036	.6	.021	.2	.007	.2	.007
Multi-Year	5	.036	.6	.021	.2	.007	.2	.007
Fast Ice	4	.058	.8	.046	.8	.046	.8	.046

TABLE XLII (Cont'd)

INFORMATION ELEMENTS	w_i	R_{jk}	SENSORS DESIRED FOR SCIENTIFIC STUDIES: SCATTERO-METER		B & W CAMERA		COLOR	
					$\frac{1}{2,000,000}$		$\frac{1}{2,000,000}$	
		jk	107		108		109	
FORM OF ICE								
Floe	5	.031	0	000	.8	.024	.8	.024
Giant >10km	5	.007	0	000	1	.007	1	.007
Vast 2-10km	5	.007	0	000	1	.007	1	.007
Big 500-200km	5	.007	0	000	1	.007	1	.007
Medium 500-2000m	4	.005	0	000	1	.005	1	.005
Small 20-100m	3	.004	0	000	.8	.003	.8	.003
Cake	2	.012	0	000	.6	.007	.6	.007
Floeberg	5	.031	0	000	.6	.018	.6	.018
Iceberg	5	.031	.6	.018	.6	.018	.6	.018
Ice Field	5	.031	.6	.018	.8	.024	.8	.024
Ice Jam	5	.031	.6	.018	1	.031	1	.031
Ridges	4	.025	.6	.015	.2	.005	.2	.005
Hummocks	5	.031	.6	.018	.2	.006	.2	.006
Puddles	3	.018	.6	.010	.4	.007	.4	.007
Rotten Ice	1	.006	.4	.002	.8	.004	.8	.004
CONCENTRATION								
Compact/ Consolidated	5	.065	.6	.039	1	.065	1	.065
Very Close Pack	5	.065	.6	.039	1	.065	1	.065
Close Pack	4	.052	.6	.031	1	.052	1	.052
Open Pack	3	.039	.6	.021	1	.039	1	.039
Very Open Pack	2	.026	.6	.015	1	.026	1	.026
		.998		.466		.690		.702

Notes to Table XLII:

In compiling Table XLII, the following qualifications were observed:

1) The relatively high values (E_{jk}) for black & white camera, thermal IR, color and imaging laser, must be tempered with the knowledge that the presence of clouds is not considered in the evaluations. However, in an Arctic environment, where cloud cover is present approximately 70% of the time, the most effective sensor in terms of actual usable imagery would, in most cases, be side-looking airborne radar.

2) The slightly higher effectiveness of color to supply the Elements of Information is due to the blue tones associated with certain ice types and the ability to see these tones as other than shades of grey.

In addition, black & white and color are daytime limited. In extended periods of darkness, their utilities would be negligible, whereas the capability of side-looking airborne radar would remain unimpared, as would those of the imaging laser and thermal IR.

3) PPI radar has been included simply because the PPI is utilized as a navigation aid in most military aircraft expected to fly over an Arctic area. If cloud affected sensors were being flown and knowledge of the ice/water configuration was mandatory, the PPI would be useful as the only available acquisition medium.

4) The scales of the black & white and color film types, under Sensors Desired for Scientific Studies, are based on results of the Spacecraft Feasibility Study, Section 2.5. The sensor effectiveness values are based upon the following: extrapolations from small-scale photography viewed in the past, and inferences as to the resolution that can be expected from the sensors in a spacecraft mode.

TABLE XLIIIA

COST EFFECTIVENESS DATA ENTRY FORM
IRRIGATION CANAL ROUTE LOCATION & COST ESTIMATION (Preliminary or Feasibility)

INFORMATION ELEMENTS	w_i \ R_{jk}	SENSORS USED: Ground Survey R*	Ground Survey Rp*	Black & White 1'	Black & White 10'	Black & White 50'	Color 1'	Color 10'	Color 50'	AN-APQ 56 SLR
Topography (5)	.161									
Landforms (4)	.071	.6 .043	1 .071	1 .071	1 .071	.6 .043	1 .071	1 .071	.6 .043	.4 .028
Contours (5)	.089	1 .089	1 .089	1 .089	1 .089	0 -	1 .089	1 .089	0 -	0 -
Planimetry (5)	.161	1 .161	1 .161	1 .161	1 .161	.6 .097	1 .161	1 .161	.6 .097	.2 .032
Drainage (4)	.129									
Stream Pattern (5)	.035	.6 .021	1 .035	1 .035	1 .035	.6 .021	1 .035	1 .035	.6 .021	.4 .014
Stream Density (4)	.029	.4 .012	1 .029	1 .029	1 .029	.6 .017	1 .029	1 .029	.6 .017	.4 .012
Stream Volume (4)	.029	.8 .024	1 .029	1 .029	1 .029	.4 .012	1 .029	1 .029	.4 .012	.2 .006
Surface Water (5)	.035	.6 .021	1 .035	1 .035	1 .035	.8 .028	1 .035	1 .035	.8 .028	.2 .007
Surficial Material (4)	.129									
Material Type (5)	.023	.6 .014	1 .023	1 .023	1 .023	.6 .014	1 .023	1 .023	.8 .018	.2 .005
Permeability (3)	.014	.6 .008	1 .014	1 .014	1 .014	.6 .008	1 .014	1 .014	.6 .008	.2 .003
Predominant Grain Size (3)	.014	.6 .008	1 .014	.8 .011	.8 .011	.4 .006	.8 .011	.8 .011	.4 .006	.2 .003
Depth to Bedrock (5)	.023	.4 .009	1 .023	1 .023	1 .023	.4 .009	1 .023	1 .023	.4 .009	.2 .005
Construction Mat'l Location (3)	.014	.6 .008	1 .014	1 .014	1 .014	.6 .008	1 .014	1 .014	.6 .008	.2 .003
Foundation Conditions (4)	.019	.4 .008	1 .019	1 .019	1 .019	.4 .008	1 .019	1 .019	.4 .008	.2 .004
Landslide Potential (4)	.019	.4 .008	1 .019	1 .019	1 .019	.4 .008	1 .019	1 .019	.6 .011	.2 .004

*R = Reconnaissance - no existing imagery

*Rp = Reconnaissance - 1:20,000 scale B & W imagery available

TABLE XLIIIA (Cont'd)

IRRIGATION CANAL ROUTE & COST ESTIMATION (Preliminary or Feasibility)

INFORMATION ELEMENTS		SENSORS USED								
		Ground Survey		Black & White			Color			AN-APQ 56 SLR
	R_{ijk} / w_i	D*	Dp*	1'	10'	50'	1'	10'	50'	
Geology (4)	.129									
Rock Type (4)	.022	.8 .018	1 .022	.6 .012	.4 .009	.2 .004	.6 .012	.4 .009	.2 .004	.2 .004
Structure (3)	.017	.6 .010	1 .017	.8 .014	.8 .014	.4 .007	.8 .014	.8 .014	.4 .007	.2 .003
Permability (2)	.011	.8 .009	1 .011	.6 .007	.4 .004	.2 .002	.6 .007	.4 .004	.2 .002	.2 .002
Rippability (4)	.022	.8 .018	1 .022	.4 .009	.4 .009	.2 .004	.6 .012	.4 .009	.2 .004	.2 .004
Outcrops (5)	.028	.8 .022	1 .028	1 .028	.8 .022	.4 .011	1 .028	.8 .022	.4 .011	.2 .006
Hd/Soft Class. (5)	.028	.8 .022	1 .028	.6 .017	.4 .011	.2 .006	.6 .017	.4 .011	.2 .006	.2 .006
Vegetation (3)	.096									
Crops (5)	.040	.8 .032	1 .040	.6 .024	.4 .016	.2 .008	.8 .032	.6 .024	.4 .016	.2 .008
Forest (4)	.032	.8 .026	1 .032	.6 .019	.4 .013	.2 .006	.8 .026	.6 .019	.4 .013	.2 .006
Other (3)	.024	.8 .019	1 .024	.6 .014	.4 .010	.2 .005	.8 .019	.6 .014	.4 .010	.2 .005
Sedimentation (2)	.064									
Erosion Areas (5)	.032	.8 .026	1 .032	.6 .019	.4 .013	.2 .006	.6 .019	.4 .013	.2 .006	.2 .006
Deposition Areas (5)	.032	.8 .026	1 .032	.6 .019	.4 .013	.2 .006	.8 .026	.6 .019	.2 .006	.2 .006
Land Use (Comprehensive) (4)	.129	.8 .103	1 .129	.6 .077	.6 .077	.2 .026	.8 .103	.6 .077	.2 .026	.2 .026
	.998	.845	.998	.768	.548	.260	.830	.579	.280	.217

* D = Detailed - no existing imagery

*Dp = Detailed - 1:20,000 scale B & W imagery available

NOTES TO TABLE XLIIIA:

In compiling Table XLIIIA, the following assumptions were made:

GENERAL ASSUMPTIONS:

1) An existing source of water.
2) An area where an irrigation project is feasible.
3) 1 & 2 are more than 10 miles apart.
4) A corridor connecting 1 & 2 has not been selected.
5) 1:250,000 scale topographic maps are currently available.
6) Strip topographic maps with 10' contour interval and 1" - 2000' scale will be prepared from existing 1:20,000 scale imagery after a corridor has been selected.
7) No field check for photo-interpreted data.
8) No stream gauging records available.
9) Landforms include, but are not limited to, such features as alluvial fans, terrace level, eskers, rapids, river bars, moraines, and sand dunes.

FOR GROUND SURVEY - Assume:

1) Photos used mainly for geologic & soil mapping, vegetation, and land use inventories.
2) No subsurface investigations will be conducted.
3) Rp will satisfy all requirements, therefore all elements assigned a value of one.

AN/APQ-56 SLR resolution is: range - 50' at 18 nautical miles.
azimuth - 223' at 18 nautical miles.

Notations: 1) 0 value assigned because 10' contour interval required (Gen'l. assumption #6 cannot be realized).

1	100% determination of the information element.
.8	can determine most of the information element.
.6	can determine over half of the information element.
.4	can determine less than half of the information element.
.2	can determine a small amount of the information element.
0	cannot determine any of the information element.

TABLE XLIIIB

COST EFFECTIVENESS DATA ENTRY FORM
IRRIGATION CANAL ROUTE LOCATION & COST ESTIMATION (Detailed)

INFORMATION ELEMENTS	w_i \ R_{jk}	SENSORS USED: Ground Survey				Black & White						Color						AN-APQ 56 SLR	
		D*		Dp*		1'		10'		50'		1'		10'		50'			
Topography (5)	.161																		
Landforms (4)	.071	.8	.057	1	.071	1	.071	1	.071	.6	.043	1	.071	1	.171	.6	.043	.4	.028
Contours (5)	.089	1	.089	1	.089	1	.089	0	-	0	-	1	.089	0	-	0	-	0	-
Planimetry (5)	.161	1	.161	1	.161	1	.161	.6	.097	.2	.032	1	.161	.6	.097	.2	.032	.2	.032
Drainage (4)	.129																		
Stream Pattern (5)	.035	.8	.028	1	.035	1	.035	1	.035	.6	.021	1	.035	1	.035	.6	.021	.4	.014
Stream Density (4)	.029	.8	.023	1	.029	1	.029	1	.029	.6	.017	1	.029	1	.029	.6	.017	.4	.017
Stream Volume (4)	.029	1	.029	1	.029	.4	.012	.2	.006	0	-	.4	.012	.2	.006	0	-	0	-
Surface Water (5)	.035	.8	.028	1	.035	1	.035	.8	.028	.6	.021	1	.035	1	.035	.6	.021	.4	.017
Surficial Material (4)	.129																		
Material Type (5)	.023	.8	.018	1	.023	.6	.014	.6	.014	.4	.009	.8	.018	.6	.014	.4	.009	.2	.005
Permeability (3)	.014	.8	.011	1	.014	.4	.006	.4	.006	.2	.003	.6	.008	.4	.006	.2	.003	.2	.003
Predominant Grain Size (3)	.014	.8	.011	1	.014	.4	.006	.4	.006	.2	.003	.4	.006	.4	.006	.2	.003	.2	.003
Depth to Bedrock (5)	.023	.8	.018	1	.023	.6	.014	.6	.014	.2	.005	.6	.014	.6	.014	.2	.005	.2	.005
Construction Mat'l Location (3)	.014	.8	.011	1	.014	.8	.011	.6	.008	.2	.003	.8	.011	.6	.008	.2	.003	.2	.003
Foundation Conditions (4)	.019	.8	.015	1	.019	.6	.011	.4	.008	.2	.004	.6	.011	.4	.008	.2	.004	.2	.004
Landslide Potential (4)	.019	.6	.015	1	.019	.8	.015	.6	.015	.4	.008	.8	.015	.6	.015	.4	.008	.2	.004

* D = Detailed - no existing imagery

*Dp = Detailed - 1:20,000 scale B & W imagery available

TABLE XLIIIB (Cont'd)

COST EFFECTIVENESS DATA ENTRY FORM
IRRIGATION CANAL ROUTE LOCATION & COST ESTIMATION (Detailed)

INFORMATION ELEMENTS		SENSORS USED								
		Ground Survey		Black & White			Color			AN-APQ 56 SLR
	w_i \ R_{jk}	R*	Rp*	1'	10'	50'	1'	10'	50'	
Geology (4)	.129									
Rock Type (4)	.022	.6 .013	1 .022	1 .022	1 .022	.6 .013	1 .022	1 .022	.6 .013	.2 .004
Structure (3)	.017	.4 .007	1 .017	1 .017	1 .017	.8 .014	1 .017	1 .017	.8 .014	.4 .007
Permeability (2)	.011	.4 .004	1 .011	.8 .009	.8 .009	.4 .004	.8 .009	.8 .009	.4 .004	.2 .002
Rippability (4)	.022	.6 .013	1 .022	1 .022	1 .022	.6 .013	1 .022	1 .022	.6 .013	.2 .004
Outcrops (5)	.028	.2 .006	1 .028	1 .028	1 .028	.6 .017	1 .028	1 .028	.8 .022	.2 .006
Hd/Soft Class. (5)	.028	.6 .017	1 .028	1 .028	1 .028	.6 .017	1 .028	1 .028	.8 .022	.2 .006
Vegetation (3)	.096									
Crops (5)	.040	.6 .024	1 .040	1 .040	1 .040	.6 .024	1 .040	1 .040	.8 .032	.2 .008
Forest (4)	.032	.6 .019	1 .032	1 .032	1 .032	.6 .019	1 .032	1 .032	.8 .026	.2 .006
Other (3)	.024	.6 .014	1 .024	1 .024	1 .024	.6 .014	1 .024	1 .024	.8 .019	.2 .005
Sedimentation (2)	.064									
Erosion Areas (5)	.032	.8 .026	1 .032	1 .032	1 .032	.6 .019	1 .032	1 .032	.8 .026	.2 .006
Deposition Areas (5)	.032	.6 .019	1 .032	1 .032	1 .032	.6 .019	1 .032	1 .032	.8 .026	.2 .006
Land Use (Comprehensive) (4)	.129	.6 .077	1 .129	1 .129	1 .129	.6 .077	1 .129	1 .129	.8 .103	.2 .026
	.998	.673	.992	.993	.993	.529	.993	.993	.606	.212

R = Reconnaissance - no existing imagery

Rp = Reconnaissance - 1:20,000, scale B & W imagery available

NOTES TO TABLE XLIIIB:

In compiling Table XLIIIB, the following assumption were made:

GENERAL ASSUMPTIONS

1) An existing source of surface water.
2) An area where an irrigation project is feasible.
3) 1 & 2 are more than 10 miles apart.
4) A corridor connecting 1 & 2 has been selected.
5) 1:250,000 scale topographic maps are currently available.
6) 2' contour interval and 1" = 200' scale topographic information necessary to satisfy engineering accuracy requirements for final location and cost estimates.
7) Landforms include, but are not limited to, such features as alluvial fans, terrace levels, eskers, rapids, river bars, moraines, and sand dunes.
8) No stream gauging records available.

FOR GROUND SURVEY - Assume:

1) Topographic maps with 2' contour interval and 1" - 200' scale will be prepared as necessary by ground survey methods.
2) 1:20,000 scale imagery can produce topographic maps with 10' contour intervals.
3) Photos used mainly for geologic and soil mapping, vegetation, and land use inventories.
4) Detailed survey w/o imagery will not survey vegetation and land use on an acre by acre or unit by unit basis, even though this level of detail could be realized.
5) Subsurface investigations will be conducted as necessary to provide detailed information.
6) Dp will satisfy all requirements, therefore all elements assigned a value of one.

Notations (superscripts)

1) It is possible to achieve the same level of detail on an areal basis as Dp, but it is not generally done. (Demonstrates utility of photos.)

2) 0 value assigned because 2' contour interval required. (Gen'l. assumption #6 cannot be realized).

AN/APQ-56 SLR resolution is: range - 50' at 18 nautical miles.
azimuth - 223' at 18 nautical miles.

1	100% determination of the information element.
.8	can determine most of the information element.
.6	can determine over half of the information element.
.4	can determine less than half of the information element.
.2	can determine a small amount of the information element.
0	cannot determine any of the information element.

2.8 Radar Scatterometer Data Analysis[12]

2.8.1 Introduction

Included among several remote sensors employed in Mission 73 was a Ryan Redop 2.25 cm wavelength radar scatterometer. Previous experiments with this sensor have confirmed its applicability to determination of sea state[13] and differentiation of Arctic ice types[14]. Earlier NASA/MSC missions have employed the Ryan system to record backscatter energy from terrain; however, these data have not been analyzed. The research described in this report essentially constitutes an engineering experiment and, hence, is presented from that viewpoint. The objective of the analysis was to determine the geoscience application areas of this sensor by evaluating its performance over specific, documented regions.

This work is the first detailed analysis of the NASA/MSC scatterometer data of agricultural sites, but radar measurements of soils, crops, natural vegetation, etc., have been recorded for many years. The programs of Ohio State University,[15] Waterways Experiment Station,[16] Naval Research Laboratory,[17] and others have produced a "catalog" of backscatter characteristics.[18] However, most of these measurements were produced as information for radar system design specifications or were in other ways unsuitable for determination of general geoscience potential. Consequently, the Mission 73 radar measurements, due to the unique advantages of the particular scatterometer employed, offered the opportunity to considerably improve the "catalog" of backscatter data from natural terrain.

---

[12] This section was written by Dr. John W. Rouse, Jr., Remote Sensing Center, Texas A & M University.

[13] Rouse, J. W., Jr., MacDonald, H. C., and Waite, W. P., "Geoscience Applications of Radar Sensors", IEEE Trans. on Geoscience Electronics, Vol. GE-7, No. 1, pp. 2-19, January 1969.

[14] Rouse, J. W., Jr., "Arctic Ice Type Identification by Radar," Proceedings of the IEEE, Vol. 57, No. 4, April 1969.

[15] Cosgriff, R. L., Peake, W. H., and Taylor, R. C., "Terrain Scattering Properties for Sensor System Design," Ohio State University, Eng. Expt. Sta. Bull. 29 (3), May 1960.

[16] Lundien, J. R., "Terrain Analysis by Electromagnetic Means", U.S. Army Engineer Waterways Experiment Station Technical Report No. 3-693, September 1966.

[17] Ament, W. S., MacDonald, F. C., and Schewbridge, R. D., "Radar Terrain Reflections for Several Polarizations and Frequencies", Naval Research Laboratory, Unpublished Report, 1959.

[18] Earing, Dianne, "Target Signature Analysis Center: Data Compilation", Institute of Science and Technology, University of Michigan, July 1967.

The analysis of the radar scatterometer data from Mission 73, Site 130 was conducted at the Remote Sensing Center, Texas A & M University. It established that the radar return was sufficiently well correlated to crop type or field conditions, and that sufficient samples were recorded within each field type, to make possible the alignment of the return amplitudes from each individual field. The relative amplitude of the backscatter energy at each of several incidence angles exhibited field-type categorization potential. Unfortunately, this potential could not be fully realized in this analysis program. The initial data contained several apparent processing errors that seriously affected their reliability. Although some corrected results were available just prior to the conclusion of this work, the data were incomplete. Consequently, the full merits of the research cannot be fully determined; however, several significant features of the data were documented.

2.8.2 Radar Scatterometer

Radar scatterometers measure variation of the scattering coefficient with incidence angle. Some instruments employ as additional variables the frequency and polarization of the transmitted energy. Scatterometer measurements permit a detailed observation of radar scattering behavior, although the resolution and areal coverage are generally poorer than radar images. The NASA scatterometer used for these measurements was a 2.25 cm wavelength Ryan Redop system. This radar transmits a vertically polarized CW signal in a "fan-beam" antenna pattern. The illuminated area is 120° (± 60°) fore-aft along the aircraft line and 3° (± 1.5°) port-starboard.

The radar return was recorded on magnetic tape and subsequently processed through a set of Doppler filters. Each filter represented a discrete incidence angle within the 0° to 60° (fore and aft) beam, e.g., 5°, 10°, 15°, 20°, etc. The filter frequencies correspond to the incidence angle according to the relation:

$$f_d = \frac{2v\sin\theta}{\lambda}$$

where:

f_d = Doppler frequency

v = relative velocity of radar

θ = incidence angle

λ = wavelength

Since the entire 120° x 3° region is continuously illuminated, the scattering coefficient versus incidence angle curve fore and aft was recorded during a single overflight. By suitable processing of the return signal, a scattering coefficient versus incidence angle plot was obtained which shows the scattering coefficient variation for particular terrain "cells" along the flight line.

This is done by delaying in time the signal outputs of each Doppler filter. By appropriate choice of each time delay, the effect of viewing one spot on the terrain from several angles simultaneously is obtained. The data shown in this report are the scattering coefficient for adjacent "cells" about 30m square. Since the radar returns are recorded in quadrature, the fore- and aft-beam data are separated. The results shown in this report are from fore-beam measurements only.

2.8.3 Mission 73 - Scatterometer Experiment

Within a week of the aircraft flights during the spring of 1968, a preliminary analysis was conducted on radar scatterometer data from the geography test site in the Salton Sea area (Site 130, line 2a). The preliminary analysis employed only the analog output of the Doppler filters. These data were uncorrected for aircraft parameters. This analysis resulted in determining that the radar return has sufficient character to allow correlation of the return with the terrain features. The resolution relative to the field sizes was sufficient to provide several samples of each crop or field type. The angle dependence of the uncorrected scattering coefficient appeared to be sufficiently distinct for cataloging of certain crop types or field conditions. The "signature" of date palms was quite different than that of any other crop type, and identification of this crop could be made with a high degree of reliability. It was anticipated that subsequent n-dimensional analysis of these data would lead to disjoint categorization of many of the crop types.

Based on the preliminary analysis, a detailed study of the data from Test Site 130, line 1, 2, 2a, 5, 5a, and 5b was undertaken. In preparation for this study, NASA/MSC performed a data reduction and correction processing on the Mission 73, Site 130 measurements.

2.8.4 Measurements

The Mission 73 results used in this analysis consisted of 9 x 9 inch black-and-white aerial photography and the processed radar measurements for six lines of Site 130. The radar measurements were in three forms: 1) scattering coefficient versus incidence angle graphs for each "cell" along the flight; 2) uncorrected scattering coefficient versus time along the flight line for five incidence angles (approximately 5°, 20°, 50°, 55°, and 60°); and 3) tabulated scattering coefficient values for nine incidence angles in each "cell" along the flight line.

The photography was obtained with an approximate 10% overlap and was of good quality. The photos were examined to determine the conditions of the flight relative to the utility of the radar data. The specific findings of this review are detailed under Section 2.8.6. In general, it was discovered that excessive drift angles (greater than 4°) during parts of the overflight necessitated elimination of several terrain segments. Excessive drift angle causes the subsequent scattering coefficient versus incidence angle plots to be in error, since they do not represent a distinct "cell" on the terrain. In addition, several sections of the lines were flown so near roadways that the radar return was unrepresentative of field conditions but instead contained a composite of both the roads and the fields. Efforts to obtain "signatures" of urban regions were also hampered due to excessive drift or to the unrepresentative natures of the few usable sites.

The majority of the lines selected were flown at 1500 or 2000 feet altitude. One run of line 2 was flown at 6000 feet and was found unusable since the increased resolution size reduced the number of samples per field to less than five and the alignment was poor.

The preliminary review of the radar data indicated some problems which are described in Section 2.8.5 and 2.8.6. However, the format of the scattering coefficient versus time plots was excellent for obtaining data alignment with the 9 x 9 inch photos. In each case the alignment was obtained using only the 5° and 20° incidence angle readings. The other angles available were greater than 40° and were unusable for alignment due to excessive deviations. It was subsequently determined that the sampling rate of data obtained above approximately 40° was apparently too low to handle the Doppler frequencies in this region, and hence, a low confidence level was placed on these data.

2.8.5 Analysis Approach

Scatterometer data are optimally suited to defining the radar scattering coefficient. This parameter can be expressed as a function of several variables in the following form:

$$\sigma^\circ = f\ (\varepsilon, \Gamma, \lambda, \theta, P)$$

where:

σ° = scattering coefficient
λ = wavelength of incident signal
θ = angle of incidence
P = polarization of incident signal
ε = dielectric property of the terrain
Γ denotes surface roughness

The complex dielectric constant, ε, and the surface roughness factor, Γ, are the fixed terrain parameters which are to be determined. The system parameters, λ, θ, and P, are the variables employed to define the terrain parameters.

The Mission 73 data consists of constant wavelength and polarization with a variable incidence angle. Therefore, the analysis approach used with these data was to attempt to determine a terrain "signature" unique to each crop field type using σ° versus θ curves. This approach was previously employed using backscatter from Arctic ice and distinct "signatures" were obtained for different ice types.[19] In the Arctic analysis an individual surface roughness parameter was obtained to describe each ice-type "signature" by fitting the data to a scattering theory based on the Kirchhoff-Huygens Principle. The Mission 73 analysis was established to follow the same procedure.

The procedure was to determine the segments of the flight line for which the flight conditions, instrument conditions, and terrain conditions were such to warrant analysis. The segments on the air photo were aligned with the uncorrected scattering coefficient versus time plots to establish the exact data time correspondence with the terrain features. This alignment was considered satisfactory when the data from at least two incidence angles showed correct feature correspondence. This procedure is critical since the corrected scattering coefficient tabulations are related exclusively to the time record. For example, the alignment procedure establishes that field A is illuminated from time 18:40:05 to time 18:40:32. The tabulated scattering coefficient values for all "cells" occuring between these time bounds are therefore representative of the backscatter from field A. The average of these values is then the scattering coefficient versus incidence angle curve identifying field A. These data are then further analyzed in an attempt to identify a "signature" for field A.

Several difficulties were encountered in employing this procedure. Data released by NASA/MSC contained discrepancies which were not detectable prior to conducting relatively detailed analysis. The most serious of these apparent errors are the following: 1) time error in tabulated values of scattering coefficients; 2) absolute amplitude error for scattering coefficient values at θ_1 through θ_4 (5° to 20° incidence); and 3) sampling rate error for calculations of scattering coefficient at θ_7 through θ_9 (greater than 45° incidence). The exact cause and full extent of the latter two problems are still unknown. The third error did not seriously hamper the analysis. However, the second error was critical.

The time error in the tabulated values of the scattering coefficient was due to processing of fore-beam data as though it were aft-beam data and vice-versa. This problem was discovered during the data alignment stage of the analysis and was corrected by employing a procedure developed by Eppes.[20] In a second

---

[19] Rouse, J. W., Jr., "Arctic Ice Types Identification by Radar," <u>Proceedings of the IEEE</u>, Vol. 57, No. 4, April 1969.

[20] Eppes, T. A., "Spatial Adjustment Discrepancies in Scatterometer Data from Mission 73", Tech. Memo DAL-001, Remote Sensing Center, February 1969.

release of parts of the Mission 73 processed scatterometer data by NASA/MSC in late April 1969, the time error was corrected. The new results agreed with manually adjusted values; however, the new data disagreed with the previously released results in magnitude of the radar return.

The apparent error in the absolute values of the original tabulated scattering coefficients was discovered by comparing the resultant scattering coefficient plots to similar terrain return measured by Ohio State University and others. The scattering coefficient plots exhibit the characteristic that the value of the scattering coefficient monotonically increased as the incidence angle increased from 5° to 20°. This characteristic was previously noted in the uncorrected analog scattering coefficient plots, but was known to be unrepresentative of actual behavior due to the stage of the computer program at which these data are read out. The persistence of this characteristic of supposedly corrected data was unexplainable. The later processing of the data improved this characteristic as will be shown in Section 2.8.6.

The sampling rate error was apparently caused by failure to meet the rate required by the Sampling Theorem in the high Doppler frequency range. Reprocessing of the data did effect the data values for incidence angles above 40°, but the significance of this change is unknown.

2.8.6 Analysis Results

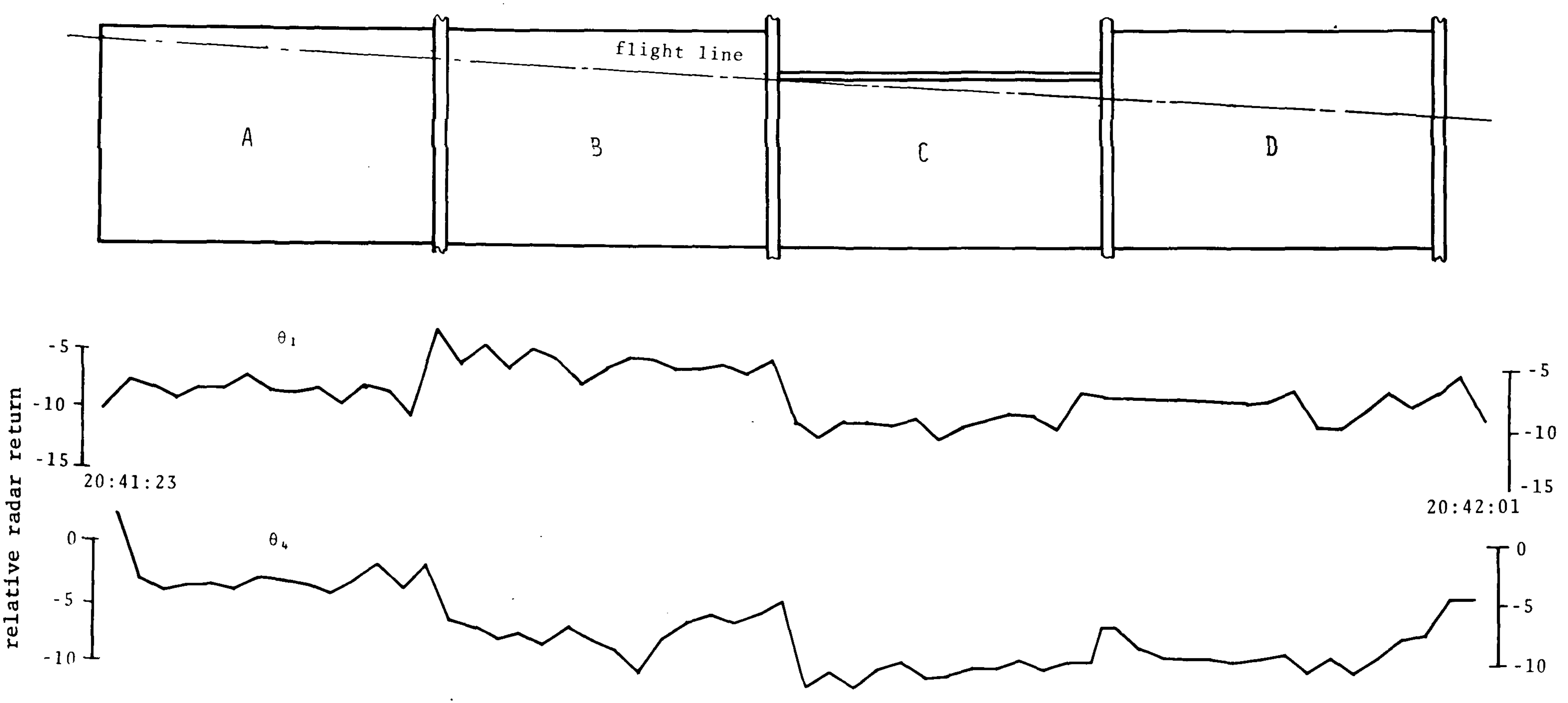
The analysis results of primary interest are from lines 5, 5a, and 5b. Line 1 was barren terrain of little interest. Line 2 and 2a contained a wide range of terrain types; however, the field sizes were small, and the alignment of the NASA/MSC digital filter output data was not accomplished with sufficient confidence to warrant advancing conclusions based upon these data. The alignment of the measurements of lines 5, 5a, and 5b was excellent.

Line 5

Line 5 extended from Niland, California to Brawley, California. The scatterometer data record was 3 minutes 25 seconds in length. The line initiates in an arid region, crosses a sparsely settled residential section, and covers a well-defined agricultural segment. The aircraft experienced excessive drift during the first 1 minute 5 seconds of the flight. This restricted the analysis to the agricultural segment only.

The alignment of the time history plots with the fields was excellent. This alignment is shown in Figure 33a and 33b. Throughout the line all fields were plowed perpendicular to the flight direction. Several roads located perpendicular to the line exhibited very distinctive radar return.

The only tabulated scattering coefficient values available for line 5 were those supplied during the initial NASA/MSC data processing. The reprocessing did not include line 5. The "signatures" of several fields are also shown in Figure 40A and 40B. Although fields of similar crop type or conditions are readily identifiable on the time history graphs, the average scattering



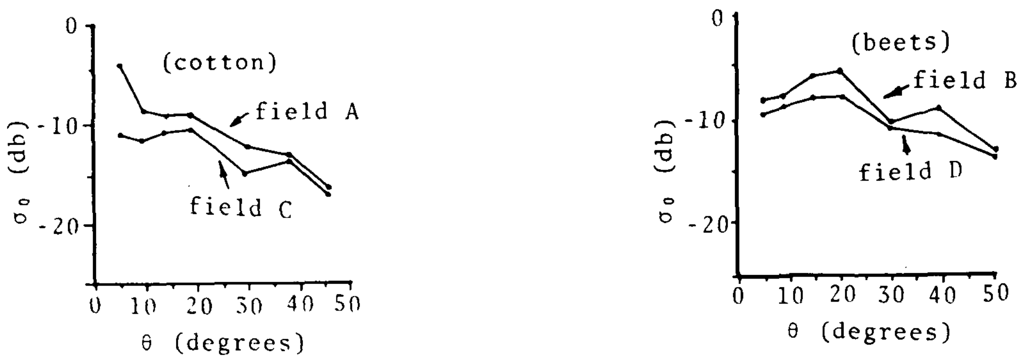


FIGURE 40A SCATTEROMETER DATA, MISSION 73, SITE 130, LINE 5.

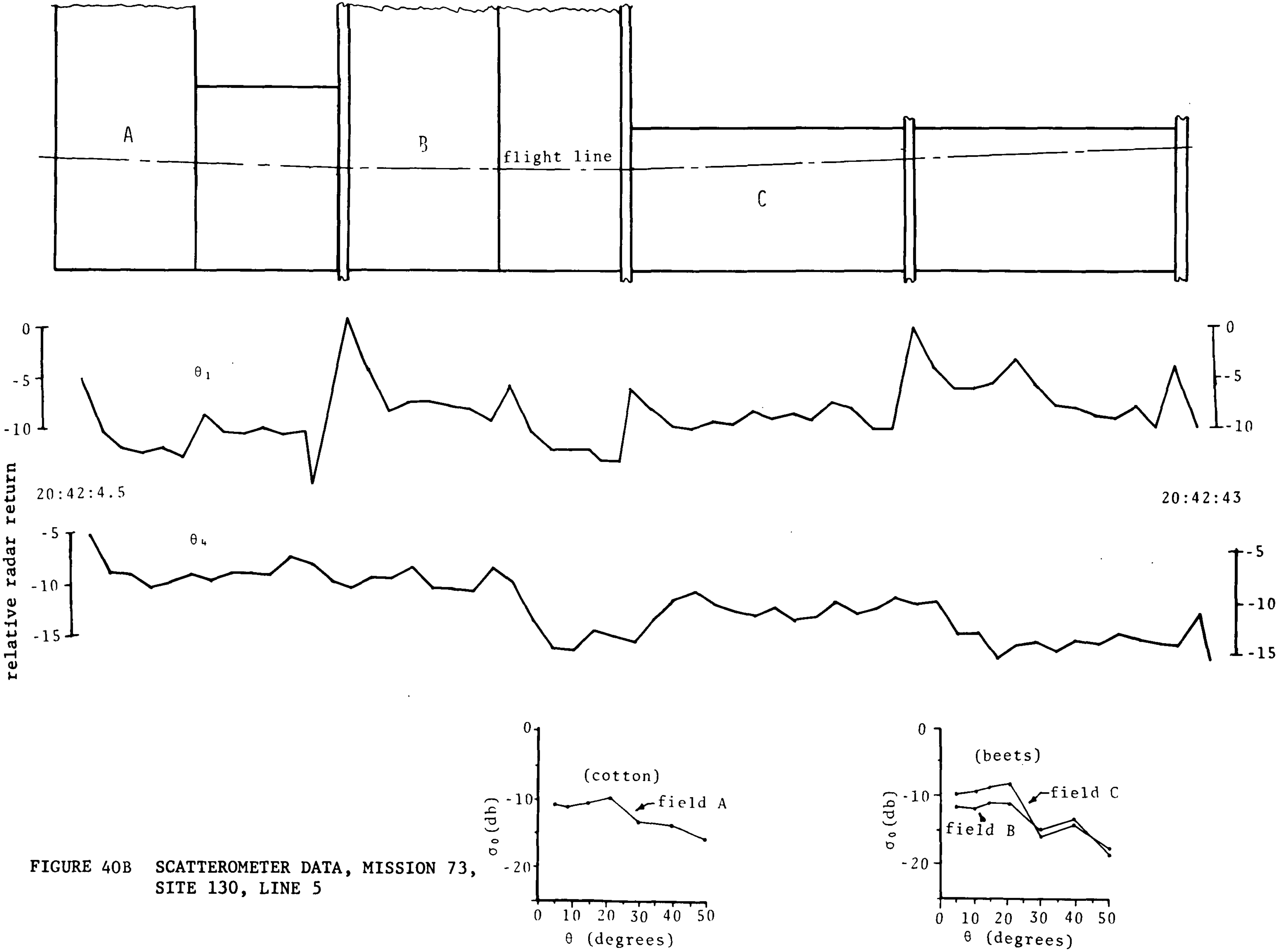


FIGURE 40B SCATTEROMETER DATA, MISSION 73, SITE 130, LINE 5 coefficient plots show unexpected characteristics that do not confirm a crop categorization potential and raise doubt as to their validity.

Line 5a

Line 5a extended from Niland, California to Brawley, California parallel to line 5. The scatterometer data covered approximately 14 n.m. in a period of 5 minutes, 25 seconds. The region is predominately agricultural in nature with several large, well-defined fields.

The flight records show that for a 22 second interval at 1 minute, 28 seconds into the line the aircraft drift angle was excessive, i.e., greater than 4°. Likewise the last 39 seconds of the run were recorded under excessive drift angle conditions. Reviewing the air photos revealed that during the first 1 minute, 20 seconds of the run the aircraft was sufficiently close to a road paralleling the flight line that the radar return would be influenced by its presence. This problem also occurred in the second of the two major agriculture segments of line 5a. In general, it is questionable that the "signatures" of any specified field in the line would be completely free of the influence of the road return.

Although the presence of the road is believed to restrict the value of these data, it was noted that very distinctive field character was present in the radar data. That is, fields of one crop type were readily distinguished from fields of other crop types. This is evident in the signature shown in Figure 41A.

Three adjacent fields in the line were found to have been illuminated sufficiently far from the road that some confidence could be placed in these data points. Although the ground truth was not available for these particular fields, each field appears to be of a different crop type or field condition.

Field A-B in Figure 41B is a homogeneous crop type, but half of the field is either under water or has recently been under water. The crop in this half is markedly retarded relative to the other half of the field. The distinction between the two halves is clearly shown by scatterometer data as shown in the illustrations, although the validity of the field A data is questionable. The second two fields (field C and D) have remarkable similar backscatter characteristics, yet based solely on the photographic data they are dissimilar field types. The similarity in the "signatures" is shown in the illustrations. This characteristic is not unexpected for certain crops. A study of radar images of Western Kansas crops showed little distinction between certain crops such as grains.[21]

---

[21] Simonett, D. S., Eagleman, J. E., Erhart, A. B., Rhodes, D. C., and Schwarz, D.E., "The Potential of Radar As a Remote Sensor in Agriculture, 1. A Study with K-Band Imagery in Western Kansas". University of Kansas, Lawrence, CRES Report 61-21, 1967.

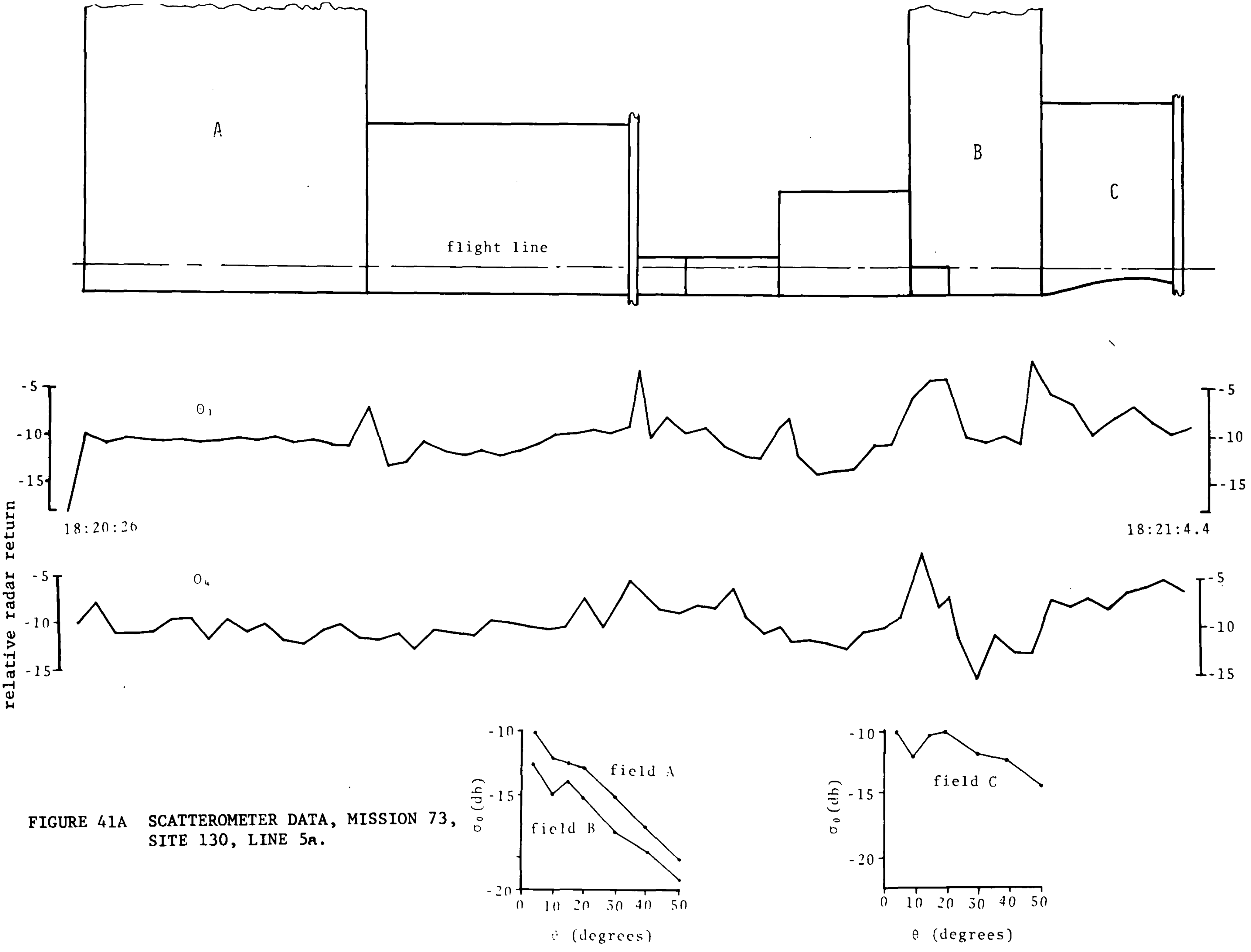


FIGURE 41A SCATTEROMETER DATA, MISSION 73, SITE 130, LINE 5a.

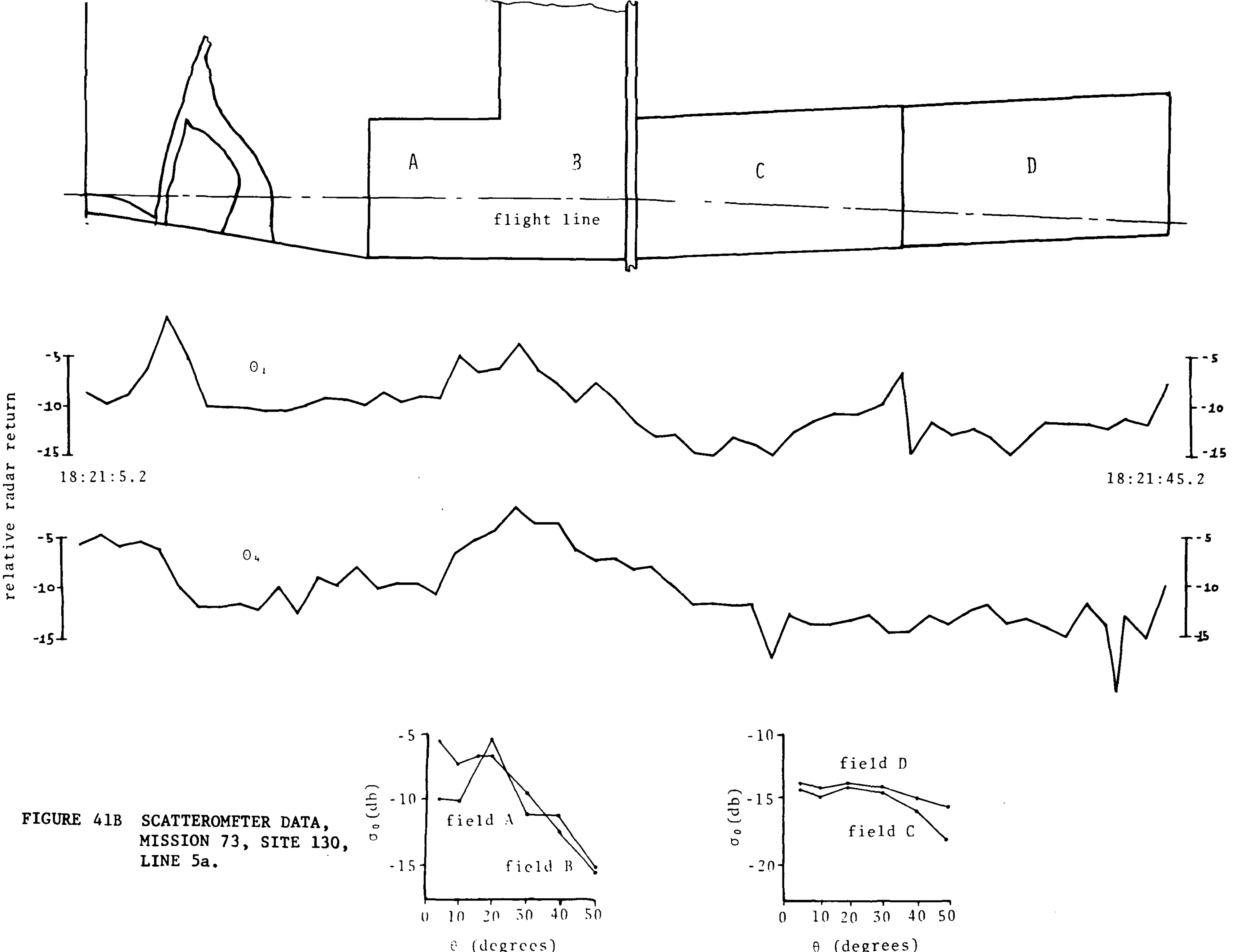


FIGURE 41B SCATTEROMETER DATA, MISSION 73, SITE 130, LINE 5a.

The average scattering coefficient plots obtained for line 5a from the initial NASA released scatterometer data suffered from the errors affecting the line 5 plots. The new data do not exhibit the pronounced uniform characteristic of the former results in which the return increased monotonically for the near vertical angles. (Field A in Figure 41B is an exception.) The tendency of these data to remain nearly constant out to 20° incidence angle is in agreement with some of the Ohio State measurements and is explainable as being due to the high frequency of incident signal and the very rough nature of the illuminated crops.

Line 5b

Line 5b extends from Brawley, California to El Centro, California in the Imperial Valley. The data recording time was 4 minutes 36 seconds. The line initiates in an urban region, passes over a well-defined agricultural region, extends through broken terrain near the center of the line, continues over another region of well-defined agricultural sites, and concludes in an urban region.

The aircraft drift angle at the beginning of the run was in excess of +5°. This excessive drift angle existed over the urban area. The scatterometer results were considered of little value over this section. Excessive drift angles were again experienced near the center of the line over the region of poorly defined agriculture sites. The drift angle was again satisfactory after this region and was less than +2° for the remainder of the run. The agricultural section of the latter half of the run was recorded under good aircraft conditions; however, a road intersected the flight line in this region and degraded the scatterometer results. Consequently, the analysis was restricted to the flight time interval 18:15:40 to 18:17:05. The time interval contained agricultural sites exclusively. The field sizes were sufficiently large that approximately 10 "cells" were available for averaging within the field.

The scatterometer data time histories for the analyzed segment showed excellent correlation with the ground photos. Since roads crossed the flight line at a rate of approximately 1 road per 10 seconds, the alignment of the time history was readily accomplished. The alignment is shown in Figures 42A and 42B.

Within the segment were approximately 15 well-defined fields. Four of these fields, denoted field type I, contain the same crop type at about the same stage of growth. The crop type was believed to be alfalfa. Two fields, denoted field type II, appear to be recently planted and were both at the same state. Two recently plowed fields (plow direction approximately 20° to the flight line) adjacent to one another were labeled field type III. Two other fields, also in a state of recent plowing, were denoted field type IV. These two fields differ from the category III type.

The classifications were made by visual inspection of the black and white aerial photography accompanying the mission. The scatterometer data time history information θ_4 (approximately 25°) gives a clear indication of the

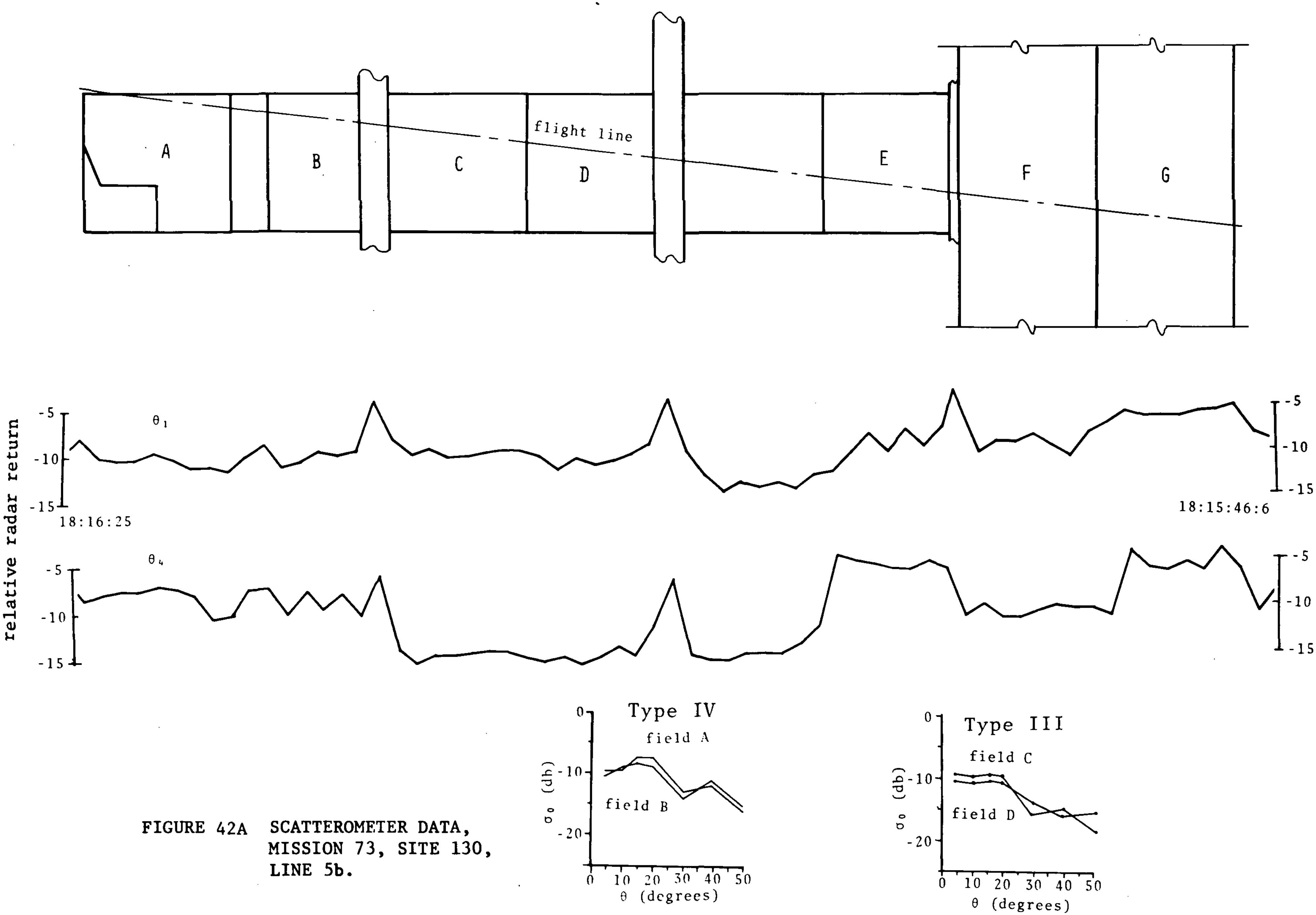
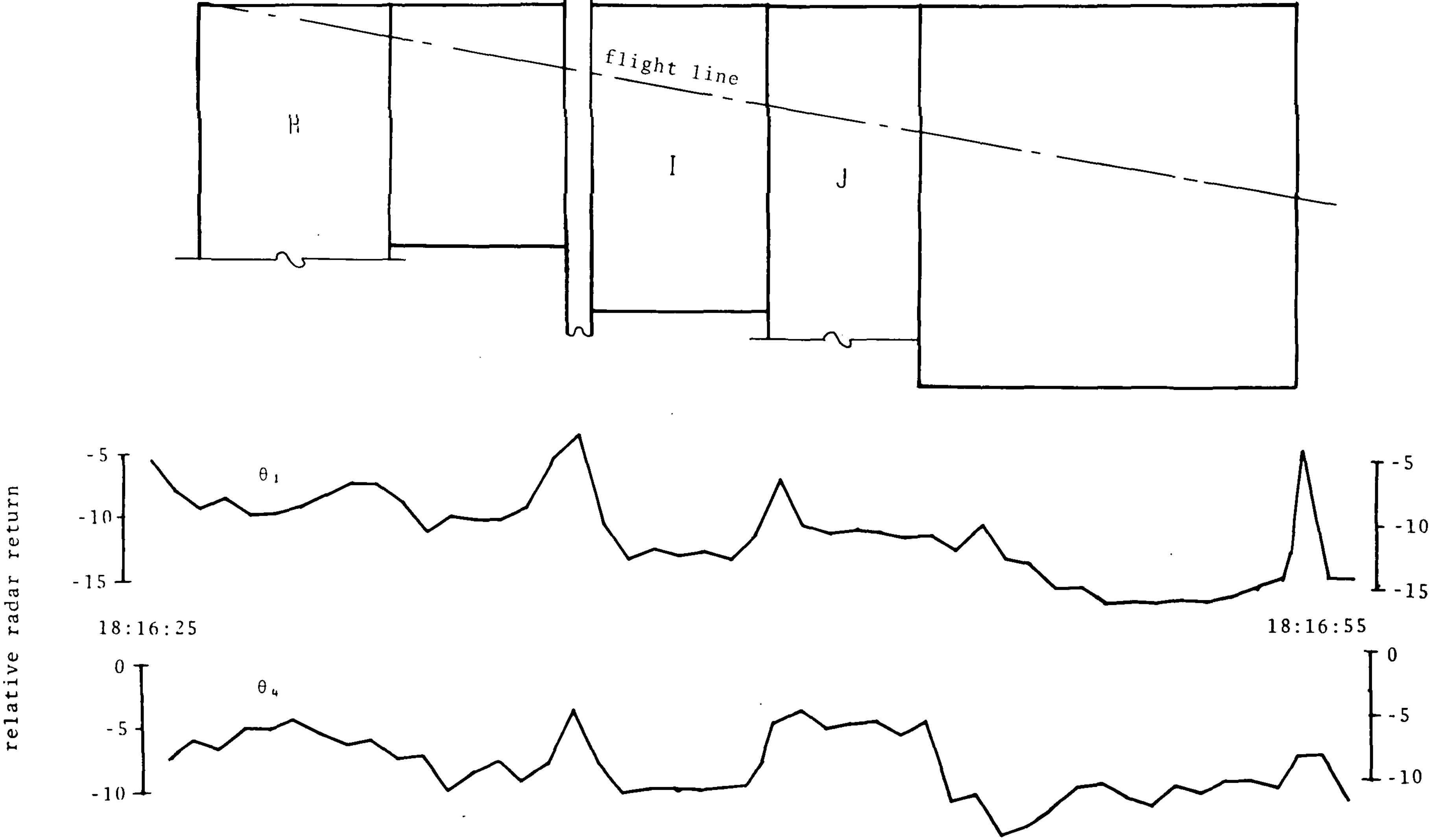


FIGURE 42A SCATTEROMETER DATA, MISSION 73, SITE 130, LINE 5b.



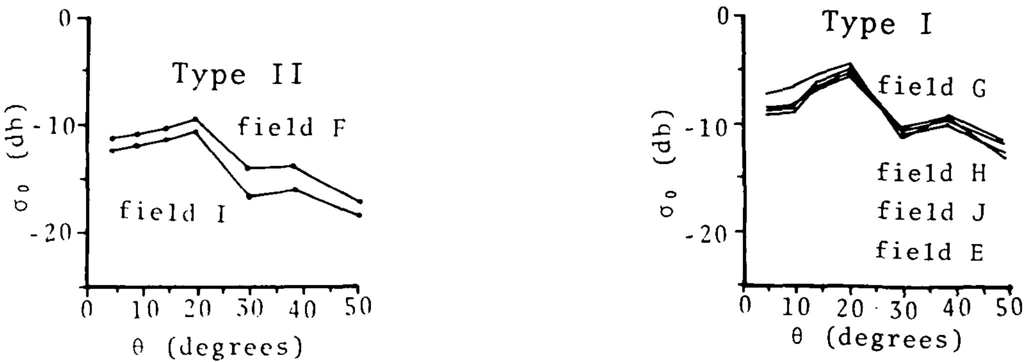


FIGURE 42B SCATTEROMETER DATA, MISSION 73, SITE 130, LINE 5b.

category I field. A return from these fields is approximately 5 db higher than any other fields in the 15-field segment. The category II fields are distinct from the category III or IV fields. Return from the category II fields varies from 3-5 db lower than the latter categories. The category III and IV fields are not distinguishable from each other on either the θ_1 or θ_4 time histories.

Figure 42A and 42B show the field type categorization from the time history graphs based on θ_1 (5°) and θ_4 (20°) returns. The subsequent transformation of these data to scattering coefficient plots does not support the expected unique "signature" classification. However, these data are from the initial data processing and are of questionable validity. Only a short segment of line 5b was included in the later reprocessing of the Mission 73 data.

Figure 43 is a comparison of the data from the first and second NASA data processing operations. The plots are from field B, line 5b (Figure 43A). The new data appear to be free of many of the characteristics which caused the original data to be questionable.

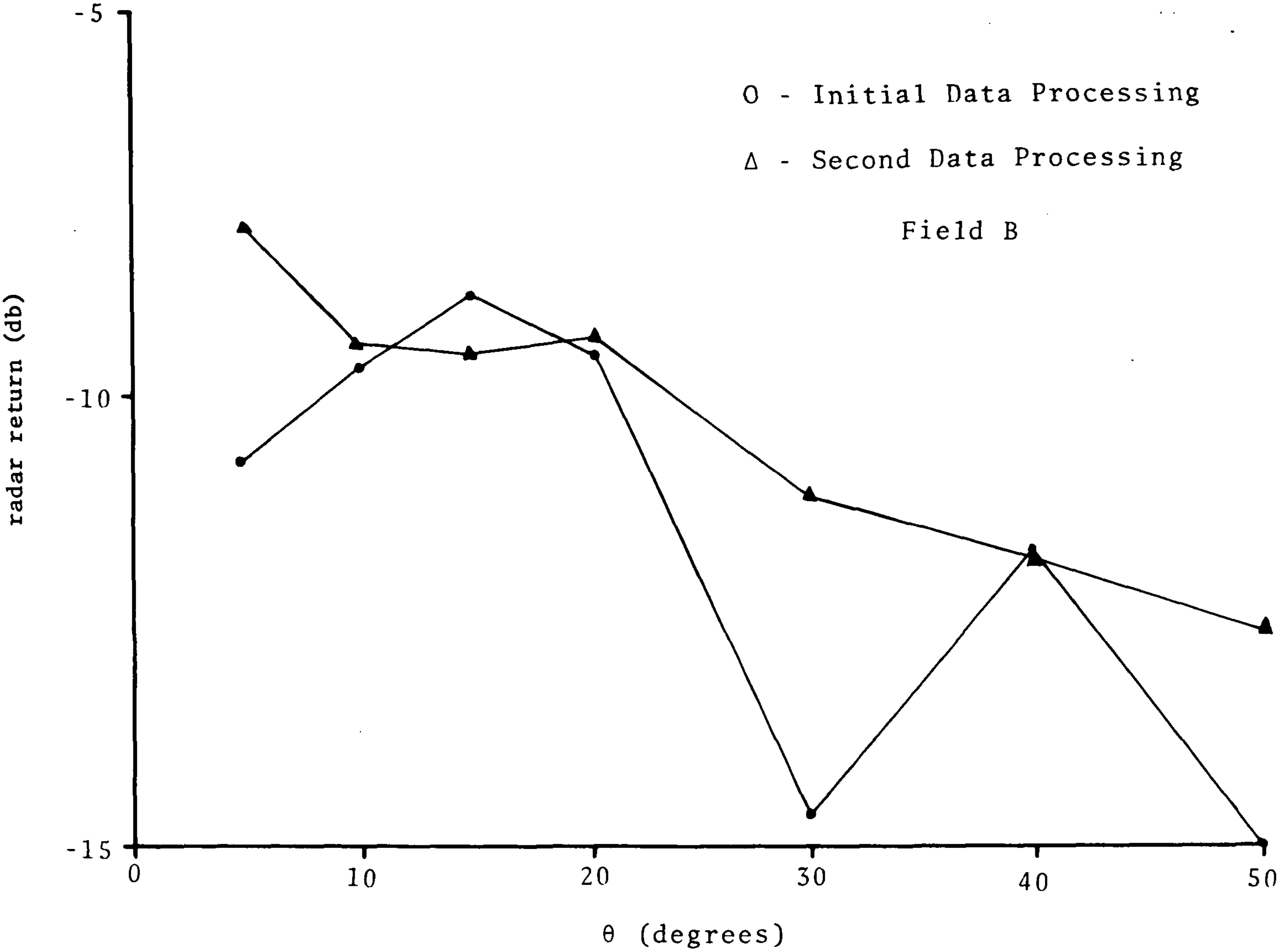


FIGURE 43 SCATTEROMETER DATA,
MISSION 73, SITE 130,
LINE 5b.

3. CONCLUSIONS AND RECOMMENDATIONS

3.1 Sensor Capability in Land Use Identification and Urban Problems Analysis

This part of the study demonstrated, with few surprises, that the capability of sensors to identify the elements of information needed for land use identification and urban problems analysis is, from best to poorest: 1) color-infrared; 2) color; 3) black-and-white; 4) laser; 5) television; 6) thermal infrared; 7) side-looking radar; and 8) ultraviolet (scanner).

The high ratings assigned to the laser and television systems are attributable to the scales at which they were studied - 1:2,000 and 1:1,000 respectively. These scales were used because they approximate the optimal scales for systems used. If used at the scales considered for the photographic sensors - 1:10,000 - their ratings would fall to approximately that of the ultraviolet. However, even at the larger scales by which they were rated, these two sensors would be of minimal value in any but the most detailed land use studies because of their small areal coverage. (It should be remembered that the television system here described is the Sony DVC 2400 camera, a small hand-held model used by East Tennessee State University. The laser, although not a sensor used in the NASA Aircraft Program, was evaluated on the basis of its possible potential utilization.)

Therefore, when these two are eliminated, along with the ultraviolet scanner, which can identify only the grossest land usages, the sensors having a practical capability for land use analysis are, in order of capability: 1) color infrared; 2) color; 3) black-and-white; 4) thermal infrared; and 5) side-looking radar. The first three can be used for both local and regional studies; the last two for regional studies only. By consulting the sensor capability matrix, a user can determine, for each sensor, at the scales given, the level of detail at which he can conduct a land use study.

Since the ultimate goal of the Earth Resources Program is to study the earth from an orbital vantage point, it is recommended that simulations be made of orbital scales and resolution. This can easily be done using the Aircraft Program's high altitude RB-57 and a camera or cameras having very short focal lengths. Scales of about 1:250,000 could be acquired in this way, and above fifty thousand feet, more than 90% of the affects of the atmosphere would be felt. Detailed analyses of such photography for the purpose of determining its utility in identifying the elements of information needed for land use and urban studies would be invaluable. Not only would analyses of this kind provide a much clearer idea of the capabilities and limitations to be expected from future ERTS imagery, but they would serve as a vehicle for establishing a base of experience in interpreting from small-scale records.

Only the photographic sensors are referred to here. It is felt that the other two sensors having application - thermal IR and SLR - have little to offer these studies from orbital altitudes in their present state of development.

3.2 Surface Energy Budget and Soil Mositure

In this case the only valid conclusions to be drawn relate not to the results of the study, but rather to the constraints under which it was performed, since the results rest on two bases of dubious validity: 1) that of having to measure photographic density by visual comparison with a calibrated gray scale step wedge; and 2) that of having inadequate positional documentation of the soil testing stations (see Section 2.4.2.2). These results, therefore, indicating very low correlations among temperature, moisture, and photographic density, can be regarded, at best, as suggestive rather than conclusive.

The most immediately apparent conclusion, then, to emerge from this portion of the study is that it is absolutely necessary that film transparencies be available for those kinds of analyses involving densitometric measurements. Ideally the original negative should be supplied for such work, but, where this is inadvisable or inadmissible, good quality transparencies with pertinent sensitometry data would be sufficient.

A second conclusion, of equal importance with the first, is that, in addition to fairly accurate planimetric locations of the sampling stations, it is necessary to have positional data in relation to micro-topography; i.e., the locations of the station in respect to the top and bottom of furrows or gulleys must be known.

The importance of research in surface energy and soil moisture detection, coupled with the inconclusive results of the present study, are the bases for recommending continuing work in this area. The sensors to be used would be thermal IR and color IR. (Although the passive microwave imager will almost certainly prove a valuable sensor for studies of this kind, there is no basis on the findings of this report to recommend it.)

The initial image acquisition flights should be conducted over areas overlain by a near-homogeneous soil mantle and having a sparse vegetation cover, such as an agricultural area before planting or after harvest. As experience is obtained, areas of increasing complexity could be attempted.

The location of the ground sampling stations should be surveyed, the accuracy of the survey varying directly as the inhomogeneity or complexity of the area. The object of accuracy is to know in what soil type a sample lies; i. e., where the point sample lies in relation to the soil demarcation line. For example, if there is a plus-or-minus error of five feet in location, all samples within five feet of a soil boundary will have to be discarded. The less the error in location, the fewer the useless samples. Also necessary is a description of the sample's position relative to the micro-topography of furrows, hummocks or other small features affecting moisture content.

Finally, it is essential to the analysis that an early-generation transparency, with detailed sensitometric data, be available.

3.3 Feasibility From Spacecraft

Under certain assumed conditions, the resolutions obtainable from the RC-8 at 150 nautical miles were computed to be 289 feet, 253 feet, and 50.6 feet. These figures result from the use of a lens having a nominal resolution of 50 lines per mm, the film response of film number 5424, a Rayleigh atmosphere, and one-foot and three-foot focal lengths, with and without image motion compensation . A scheme was provided for computing a resolution whereby values other than the ones assumed may be substituted.

The effect of color upon resolution was studied, and it was found that the high contrast (and consequently greater resolution) recorded by the cyan-forming (IR) layer of 8443 film is due to the fact that the upscattered luminance is predominantly blue.

The recommendations to provide the actual measurement of sensor resolution are as follows:

1) Determining the MTF of the sensor lens for various positions on and off the axis.

2) Conducting an investigation into the MTF of each dye layer of 8443.

3) Computerize the method described in Section 2.5 to allow rapid substitution of parameters.

4) Evaluate the effect of real targets on resolution by taking into account spectral contrast.

3.4 Quantitative Analysis of Film Quality

No conclusive results could be generated from the data and imagery provided. The MTFs for various lens positions as determined by edge gradient analysis are reasonable for a third generation transparency. The densities of ground targets and reflectance values, as given in Section 2.6, show some correlation.

It is recommended that in the future, sensitometric data (D log E curves or a gray step wedge exposed along with the film) for both original and duplicate imagery be provided.

3.5 Cost Effectiveness

The cost effectiveness format developed in the course of this study has been used, to date, only as a sensor effectiveness format. Employed in this mode, the completed format provides an excellent picture of the investigator's program, its components, and its requirements. But primarily it serves to accurately identify the capability that the investigator believes a sensor has, at a particular scale, for a particular study. "Believes" is a critical word here, because the three-digit number by which a sensor's capability is expressed in this format is the summation of the products of one-digit numbers representing only the investigator's estimate of capability. It follows, therefore, that the validity of the sensor effectiveness number is a function of the investigator's experience with that sensor. If his experience is limited to one or two examples of very good or very poor quality, the credence that his estimate commands will suffer accordingly. Conversely, if his experience with a sensor is sufficiently broad, the credibility of his estimate becomes, then, the best measure of sensor utility available.

In order to convert the sensor effectiveness data into cost effectiveness, it is necessary that costs of two types of data acquisition be known: 1) the cost of ground surveys yielding levels of detail at levels of accuracy similar to those of the sensor surveys with which they will be compared, which information could probably best be supplied by professionals in the field; and 2) the costs of data acquisition by means of the sensors or sensor sets, to include such items as the pro-rated costs of the sensors themselves and the encumbrances incurred by the aircraft, the crew, the photographic or electronic processing of the data, and any other costs incidental to acquisition. Although these figures are more difficult to obtain, they could probably be provided by NASA should NASA feel it would be cost/beneficial to perform a cost/benefit study.

As a result of the work with the cost effectiveness formats designed during this study, it is suggested that all Investigators complete the resulting forms and that they then be used for planning and evaluation purposes. It is also suggested that they be periodically updated so as to keep them current with the state-of-the-art developments pertaining to the Aircraft, Apollo, and ERTS Programs.

3.6 Scatterometer Data

The Mission 73 radar scatterometer experiment produced strong indications that backscatter from agricultural sections directly relates to the illuminated crop type or field condition, and that several types may be uniquely identified. However, the analysis was sufficiently hampered by poor data quality and/or by unsatisfactory flight parameters that complete confirmation of these indications was not possible. In general, the degree of crop type differentiation capability of the radar scatterometer was not obtained from these data; however, evidence was found that supported the contention that such capability does exist.

The analysis established factors relative to proposed future use of radar scatterometry from earth orbit altitudes. The higher altitude flights conducted during Mission 73 showed that the consequential increase in radar resolution size degraded the use of these data for crop type identification. In addition the conglomerate terrain segments averaged at these altitudes obstructed possible conclusions about soil type or moisture content. However, the 2.25 cm wavelength system employed was not expected to produce results regarding these terrain parameters. The separation of urban and rural segments was clearly accomplished even at high altitudes; however, classification of urban composition was not found to be feasible.

The study should not be interpreted as conclusive regarding the applicability of radar scatterometry to the subject disciplines. The single-frequency, single-polarization sensor employed, the questionable and incomplete data, and other factors restrict any attempt at generalization based on these findings. The added NASA capability for multi-frequency, multi-polarization measurements and the improved understanding of the data processing procedure, gained in part through this analysis program, should soon enable more positive determination of the utility of radar scatterometry in rural and urban studies.