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Thermal Infrared Multispectral Scanner (TIMS): An Investigator's Guide to TIMS Data

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National Space Technology Laboratories

June 1, 1985

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ABSTRACT

The Thermal Infrared Multispectral Scanner (TIMS) is a NASA aircraft scanner providing six-channel spectral capability in the thermal infrared region of the electromagnetic spectrum. Operating in the atmospheric window region (8 - 12 μm) with a channel sensitivity of $\sim 0.1^{\circ}C$ TIMS may be used whenever an accurate measure of spectral radiance or brightness temperature of the earth's surface is needed. A description of this scanner is provided as well as a discussion of data acquisition and reduction.

TABLE OF CONTENTS

PAGE

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TABLE OF CONTENTS (continued)

PAGE

FIGURES AND TABLES

INTRODUCTION

The Thermal Infrared Multispectral Scanner (TIMS) is an experimental aircraft scanner providing six-channel spectral capability in the thermal infrared region of the electromagnetic spectrum. The instrument is experimental in that its full range of utility is being established through use, and improvements are being made as problems are discovered. The instrument was designed and built by Daedalus Enterprises, Inc. of Ann Arbor, Michigan, and is operated from a Lear Jet by NASA's National Space Technology Laboratories' (NSTL) Earth Resources Laboratory (ERL) located near Bay St. Louis, Mississippi. Extensive geologic use of TIMS is being made by members of the geology group at the Jet Propulsion Laboratory where the instrument concept was developed by Anne B. Kahle and Alexander F.H. Goetz. The first flights of the completed instrument were made in the summer of 1982. Investigators interested in using TIMS may propose such use through the Earth Science and Applications Division of NASA's office of Space Science and Applications. The purpose of this guide is to:

(a) Provide enough information so that potential investigators can decide whether or not TIMS provides measurements of use in their research program.

(b) Provide a new user of TIMS data enough information to begin analysis.

General Instrument Description. TIMS is a six-channel thermal infrared spectrometer. A photograph and cross-section view of the instrument are shown in Figure 1. Cross-track scanning is achieved through rotation of a 45^{o} flat scan mirror that reflects incident energy to a 19-cm diameter, 33-cm focal length parabolic primary mirror. The energy is then directed into the spectrometer section of the instrument by a flat secondary mirror. Both the primary and secondary mirrors are aluminum coated with an overcoating of silicon oxides. The optical path is shown in Figure 2. At the entrance to the spectrometer section and at the focal plane of the primary mirror is a 0.8-mm field stop aperture which defines the instrument's 2.5-mrad Instantaneous-Field-of-View (IFOV). After passing through the field stop the energy is collimated by an off-axis parabolic section mirror (M3 in Figure 2) and

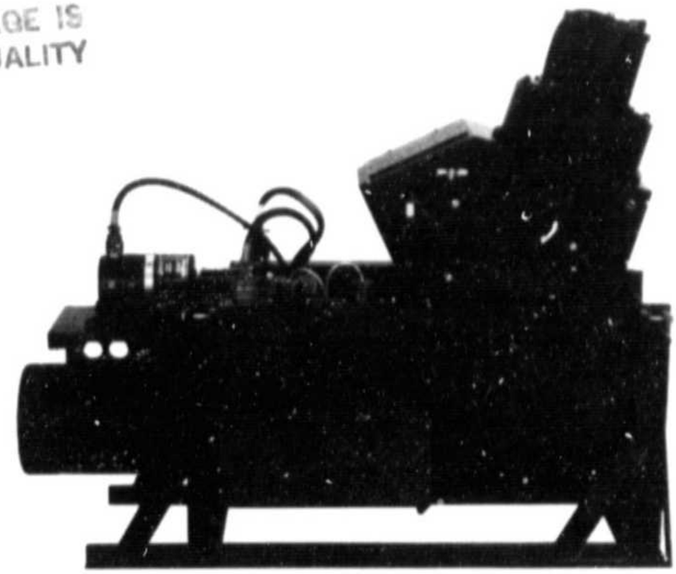

Figure 1A. External Photograph of TIMS Scan Head. (Courtesy of Daedalus Enterprises, Inc.: This media contains confidential and proprietary information of Daedalus Enterprises, Inc. Its contents may not be reproduced, copied, sold, leased, assigned, or in any manner publicly disclosed without express written consent of Daedalus Enterprises, Inc.)

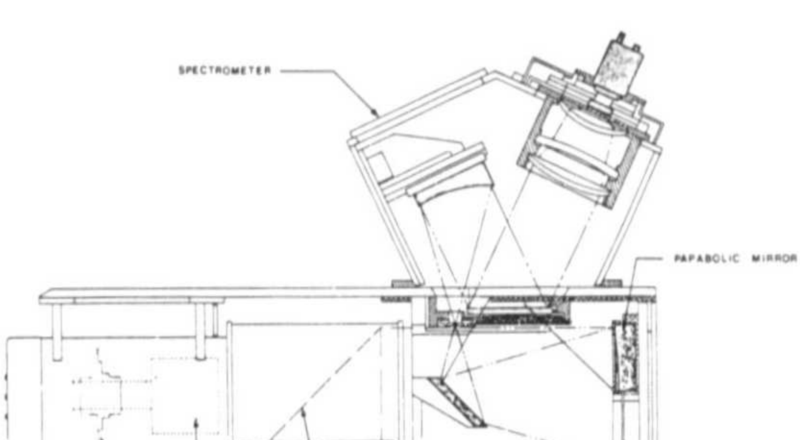

Figure 1B. Cross Section of TIMS Scan Head. (Courtesy of Daedalus Enterprises, Inc.: This media contains confidential and proprietary information of Daedalus Enterprises, Inc. Its contents may not be reproduced, copied, sold, leased, assigned, or in any manner publicly disclosed without express written consent of Daedalus Enterprises, Inc.)

directed to a replica grating of 12 grooves per millimeter with a blaze angle of 3.4°, which produces the spectral dispersion. A germanium triplet image lens (L_1 in Figure 2) is used to form an image of the field stop in the detector plane. The image size is 0.38 mm in this plane. The detector consists of a linear array of six mercury-cadmium-telluride detector elements mounted on a cold finger from the inner flask of a liquid nitrogen dewar. The width of these detectors (0.43 mm) is a little larger than the image of the field stop aperture. The length of the detectors is set by the desired bandwidth. The design channel locations and the bandwidth, Full Width at Half Maximum (FWHM) are shown in Table 1.

Table 1. Design Goals for TIMS Channel Locations and Bandwidth

Channel	Lower and Upper Limit (μm)	Bandwidth FWHM (μm)
1	8.2 - 8.6	0.4
2	8.6 - 9.0	0.4
3	9.0 - 9.4	0.4
4	9.4 - 10.2	0.8
5	10.2 - 11.2	1.0
6	11.2 - 12.2	1.0

Two thermal reference sources are mounted in the scan head so the scan mirror views one before and one after scanning across the Field-of-View (FOV). This permits line-by-line calibration of TIMS data. One of these reference sources can be heated or cooled and is used as the lower temperature reference source. The other reference source can be heated only and is used for the higher temperature reference source.

Potential Users. TIMS responds to the spectral radiance ($W/m^2 \cdot sr \cdot \mu m$) or more correctly the spectral photon radiance ($photons/s. m^2 \cdot sr \cdot \mu m$) of whatever is within the FOV (the detectors are photon detectors). These photons arise from both the surface and the intervening atmosphere. In principle the internal reference sources make possible both the relative and absolute calibration of the intercepted radiance. As a result TIMS data may be used for a wide variety of problems, alone or in conjunction with other measurements.

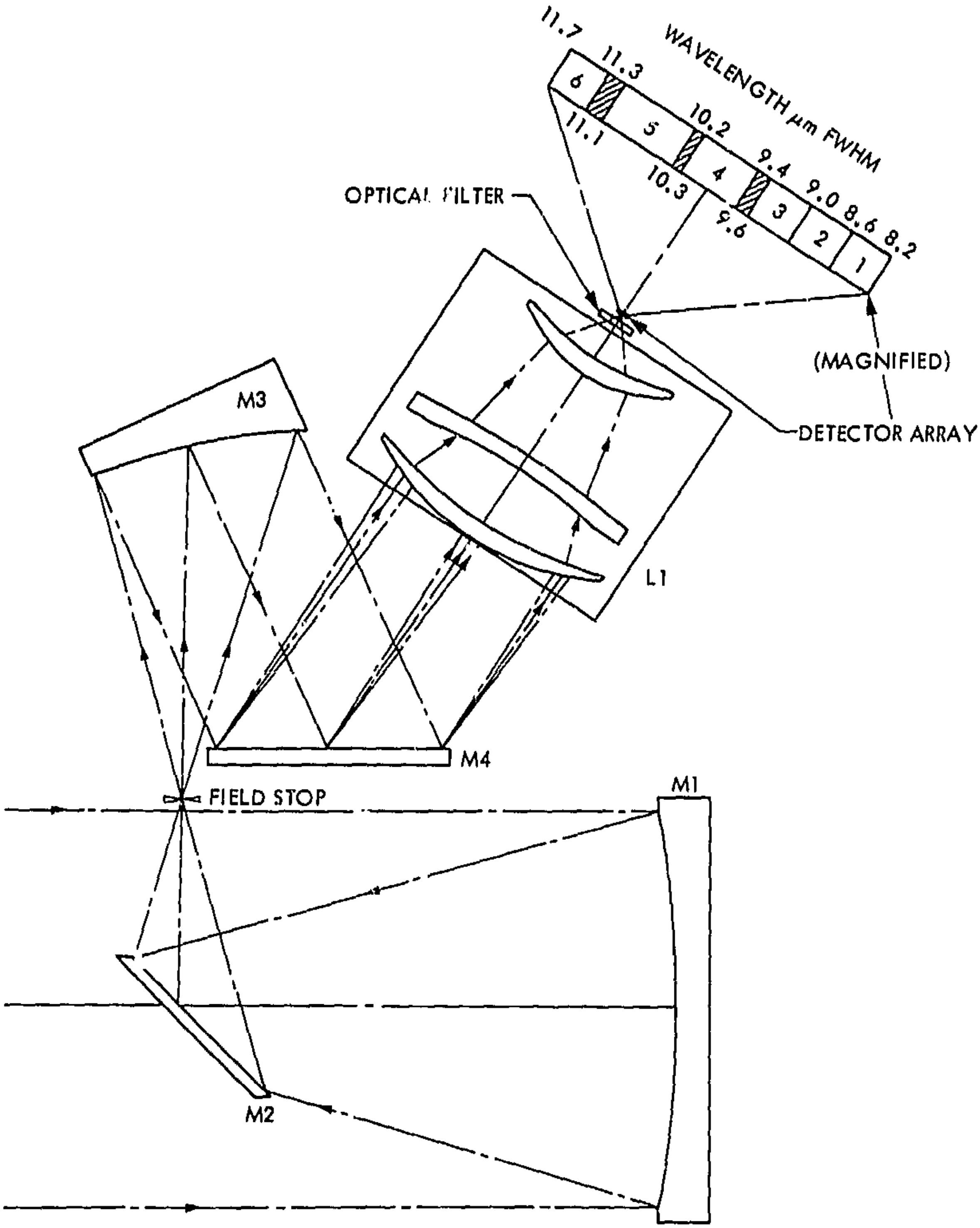

Figure 2. Schematic Optical Layout. (Courtesy of Daedalus Enterprises, Inc.: This media contains confidential and proprietary information of Daedalus Enterprises, Inc. Its contents may not be reproduced, copied, sold, leased, assigned, or in any manner publicly disclosed without express written consent of Daedalus Enterprises, Inc.)

The spectral region covered by the instrument includes diagnostic emissivity minima for silicate minerals, which vary in depth and position with crystal structure. This permits composition inference from emissivities calculated from the radiance measurements.

The excellent thermal sensitivity of the instrument (noise equivalent delta temperature NEΔT $\leq$ 0.1°C) allows it to be used for the determination of surface thermophysical properties and cultural artifacts. This sensitivity and the internal reference sources allow an accurate estimate of the brightness temperature of water and the detection of stress in plants (through changes in temperature). The instrument may be used whenever an accurate measure of the spectral radiance or brightness temperature of the earth's surface or atmosphere is required in the thermal infrared atmospheric window region (8.2 - 11.7 μm). The Reference list in Appendix A provides a listing of selected publications that illustrate some of the geologic uses of TIMS.

INSTRUMENT TECHNICAL DESCRIPTION

Spectral Response. The spectral response of each of the six TIMS spectral channels is shown graphically in Figure 3 and tabulated numerically in Appendix B. These measurements represent the response of the entire TIMS system, measured by NASA/NSTL ERL personnel using a monochromator in June 1984. The system spectral response is sensitive to detector alignment and the specific detectors used. After TIMS maintenance or modification the response may change slightly. When using TIMS data an investigator should obtain from the NASA/NSTL Earth Resources Laboaratory (ERL) the spectral response functions and other calibration information that apply for the date of data acquisition. The responses shown in Figure 3 and Appendix B apply for flights during the summer of 1984.

Various uniformly and non-uniformly mixed atmospheric gases (e.g. H_2O, CO_2, O_3) emit and absorb photons at wavelengths within the overall TIMS bandpass. The peak of ozone (O_3) absorption is the largest spectral feature of these gases and is contained within the bandpass of channel 4.

Field of View and Scan Rates. The instantaneous field-of-view (IFOV) of TIMS is 2.5 mrad, defined by the field stop shown in Figure 2. The clear field-of-view (FOV) is greater than 80° of which 76.56° is digitized in

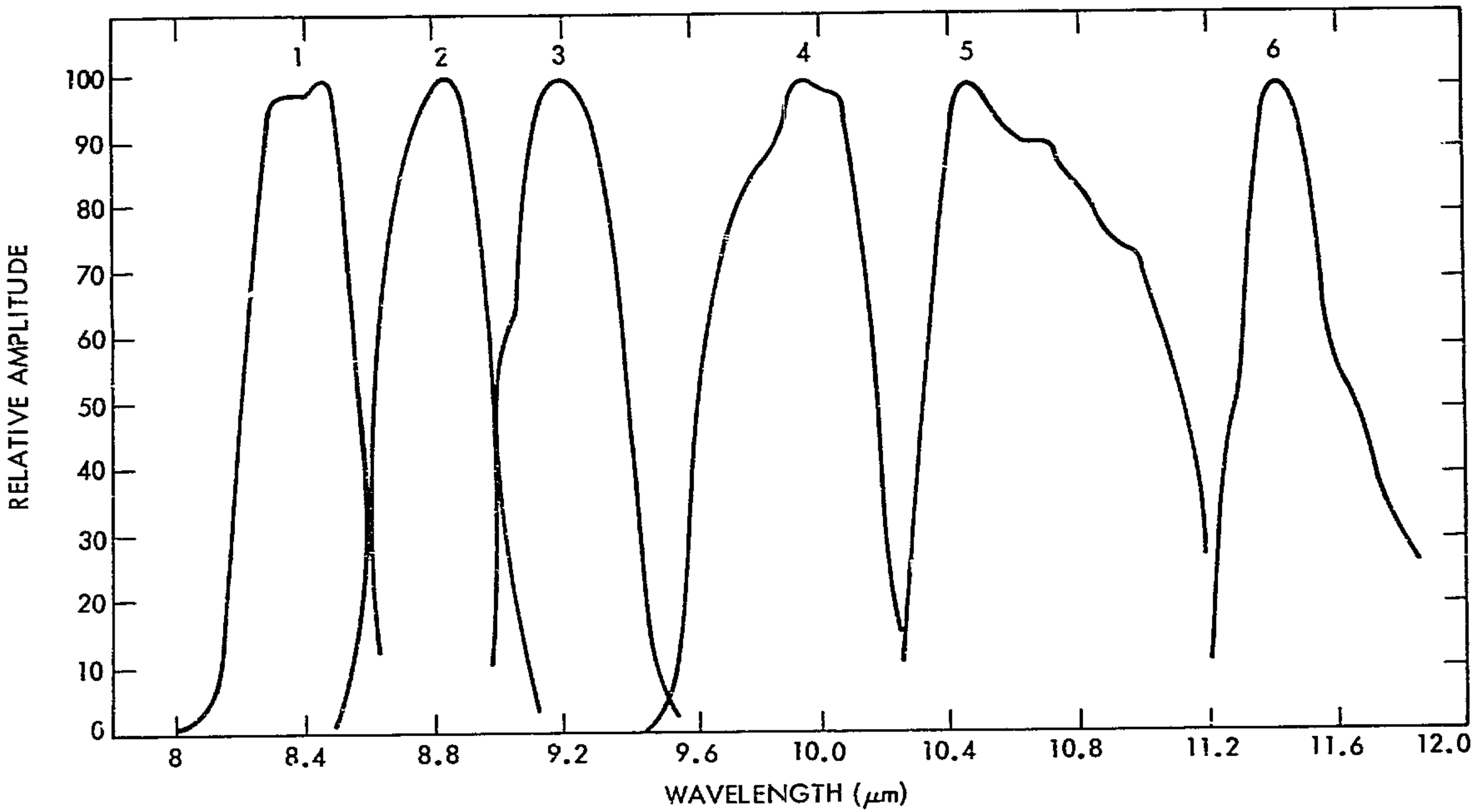

Figure 3. Normalized TIMS Spectral Response as of 6/7/84

638 eight-bit samples on any single scan. With 638 samples in 76.56° each sample is separated by 2.094 mrad. Roll correction up to ±15° is automatically provided. There is no yaw correction.

The instrument can scan at any one of four discrete rates: 7.3; 8.7; 12; and 25 scans per second. The requirements for ground resolution at nadir (IFOV * Altitude) and downtrack overlap from scan to scan can be met by selecting the altitude (above terrain) and ground speed. Both requirements should be indicated on the Aircraft Mission Request form (a copy is included as Appendix C) and discussed with NASA/NSTL ERL personnel.

Internal Reference Sources. Each reference source is a 20.3-cm (8-inch) square copper plate 0.64 cm (1/4 inches) thick coated with Krylon 1602 ultra-flat black paint. Thermistors are mounted in slots cut into the rear of these plates with two types used to cover the range -55°C to 80°C. Reference source 1 can be either heated or cooled and uses two blowers to facilitate forced air heat exchange. Reference source 2 can only be heated and is cooled by radiation and convection. Both reference sources are under microprocessor servo control to maintain their selected temperatures. Reference source 1 is sampled once at the beginning of a scan, and Reference 2 is sampled once at the end of a scan. The reference sources fill the IFOV for 4.4 degrees of scan-mirror rotation and sampling is done at the center of this interval.

Normally the aircraft instrument operator adjusts the two reference sources so they span the range of spectral radiance expected of the target. This places the reference source radiances near the bottom and top (with some margin to account for drift) of the 256 digitized values (data numbers or DN). The two reference sources can be set and read out to the nearest 0.1°C. The spread in temperature between the two reference sources and the gain setting used (see next section) depends on the investigator's purpose. A large temperature spread and a low gain setting are best for a scene with large thermal contrast (desert terrain with high relief near noon) and a smaller temperature spread and high gain setting are more appropriate for a scene with low thermal contrast (flat, near-homogeneous terrain before dawn, or water). NASA/NSTL ERL personnel can be very helpful in optimizing these choices.

Gain and Offset. The relative gain of each channel of the instrument may be set at any one of five discrete levels: 0.5, 1, 2, 4, or 8. As the numerical values indicate, the levels differ from one another by a factor of two. Any gain level may be used but the radiance equivalent of 0 and 255 DN change with the level. The appropriate gain for any investigation depends on the total range of radiance or brightness temperature the investigator wishes to record (i.e. 0 to 255 DN) and the desired radiance or brightness temperature equivalent of one DN. The choice often made is to maximize the gain consistent with keeping the entire scene on scale. Each channel has an individual offset adjustment which is set so as to center the expected radiance within dynamic range. Offsets are established by the flight operator.

Data Collection and Formats. TIMS produces data at the following rates depending on scan speed: 43.8; 52.2; 72.0, and 150 kbits/second. In flight, data are recorded on a 3937-bits/cm (10,000-bits-per-inch) tape recorder. The output data format from the instrument is given in Appendix D. A complete scan (Frame in Table D-1 of Appendix D) consists of 750 eight-bit words. Words 5 through 8 contain the scan line number, which is useful in establishing position along a flight line. Words 9 through 12 contain the date (day, month, year) and sortie number and must be entered by hand by the instrument operator at the time of data acquisition. Words 13 through 16 contain the temperatures measured by thermistors imbedded in reference sources 1 and 2 to the nearest tenth degree Celsius. These temperatures may vary slightly (a few tenths of a degree) as the reference source servo mechanisms attempt to stabilize the reference sources at their desired set temperatures. The encoded radiance from reference source 1 is found in word 101 (called "Low Temp Blackbody Video" in Appendix D, page D-4) and the radiance for reference source 2 is in word 740 (called "High Temp Blackbody Video" in Appendix D, page D-4). Between these reference radiances are the 638 scene radiance samples for the scan. This pattern is repeated for each of the 6 channels.

Technical Description Summary. Table 2 provides a summary of TIMS operating parameters.

DATA ACQUISITION AND PRODUCTS

TIMS flights are available to investigators funded by NASA and by other United States government departments or agencies. Unsolicited proposals may be sent to the NASA Earth Science and Applications Division at any time. The address for this Division and the acting Chief of the Land Processes Branch of this Division is given at the end of this section.

Table 2. TIMS Operating Parameters

Number of Channels.	6
Channel Locations Full Width at Half Maximum as of 6/7/84 . . .	CH 1 8.2 - 8.6 μm
	CH 2 8.6 - 9.0 μm
	CH 3 9.0 - 9.4 μm
	CH 4 9.6 - 10.2 μm
	CH 5 10.3 - 11.1 μm
	CH 6 11.3 - 11.7 μm
Aperture.	19 cm (7.5 in.) dia; 232 cm^2 (36 $in.^2$) collecting area
Focal Length, primary	33 cm (13 in.)
Optical Aperture (effective). . .	f/1.9
Scan Rates (selectable)	7.3; 8.7; 12; 25 scans/second
Digitized Field of View	76.56^o
Unvignetted Field of View	$>80^o$
Instantaneous Field of View . . .	2.5 mrad
Roll Correction	$\pm 15^o$
Reference Sources	2 controlled thermal plates
Digitization Accuracy	8 bit words; $\pm$1 LSB ($\pm$0.4%)
Words/Scan Line	750
Scene Words/Scan Line	638
Digitizer Gains	0.5; 1; 2; 4; 8
Bit Order	MSB first
Output Bit Rates.	43.8; 52.2; 72.0, 150 kbits/second
System Analog Bandwidth	50 kHz

Persons wishing to acquire TIMS images should contact the NASA/NSTL Aircraft Data Acquisition Manager (address and phone number given at the end of this section) who can provide advice and estimate data acquisition costs.

After funding has been approved the user should finalize the flight request (see Appendix C) and establish a firm understanding with the Aircraft Data Acquisition Manager of all relevant parameters.

Following the return of the aircraft from the image acquisition mission, the Earth Resources Laboratory (ERL) of NASA/NSTL will reformat as a computer compatible tape (CCT) the high density tape recorded on board. Nominally within a week after the mission the CCT's will be shipped to the investigator. Any of a number of CCT formats and tape densities may be requested. (See Appendix E for description of the standard ERL TIMS format). If requested, aerial photography will be ready for shipment two weeks after the mission is completed. The user will receive the original processed film. No duplicates will be generated by NASA. The mission data log with aircraft and sensor operational parameters and a printout of the CCT header information with a listing of the first few scan lines will accompany the CCT's.

Address and Phone Information

Chief Land Processes Branch of Earth Science and Applications Division
Dr. Robert E. Murphy (Acting)
NASA
Federal Building 10B
600 Independence Avenue, Southwest
Washington, D.C. 20546
Phone: Commercial (202) 453-1720
FTS 453-1720

NASA/NSTL Aircraft Data Acquisition Manager
Kenneth D. Cashion
NASA/NSTL Station
Bay St. Louis
Mississippi 39529
Phone: Commercial (601) 688-1930
FTS 494-1930

DATA REDUCTION

The format information provided in Appendices D and E permits identification of each bit of the CCT received by the user from NASA/NSTL ERL. The specific data reduction method adopted depends on the intended use of the images. No one method can be expected to satisfy all users. Most users will wish to make a panorama correction and other geometric corrections to facilitate registration of TIMS data to other data sets.

Reduction to Physical Units. The internal reference sources of TIMS permit an accurate reduction of scene DN to physical units (radiance). The purpose of this section is to describe one method of accomplishing this reduction.

Definition~:

T_1 = Low reference source temperature (K)
T_2 = High reference source temperature (K)
D_1 = Low reference source data number
D_2 = High reference source data number
R_1 = Low reference source spectral photon radiance (photons/s · m^2 · sr · μm)
R_2 = High reference source spectral photon radiance (photons/s · m^2 · sr · μm)
T_x, D_x, R_x = scene values of brightness temperature, data number and photon radiance respectively for sample x of the same scan line as the reference source values.
$S(\lambda)_i$ = the relative spectral response of channel i (see Figure 3 or Appendix B).
$P(\lambda,T)/hc$ = the Planck function intensity divided by photon energy with $P(\lambda, t)$ the Planck intensity in wavelength units, λ the wavelength, h Planck's constant, and c the velocity of light.

The object of the reduction is to translate the scene DN for each scan line into physical units using the internal reference sources and to account for any scan-to-scan differences in system operation.

TIMS is designed such that the output data numbers are linearly related to the input photon radiance, e.g.,

$$R_x = a + b\ D_x \tag{1}$$

For each scan line one can use the two internal reference sources to determine the constants a and b which relate spectral photon radiance R_x to data number D_x.

Then:

$$R_1 = \frac{\int_\lambda \frac{\lambda\ P\left(\lambda,\ T_1\right) \cdot S(\lambda)_i\ d\lambda}{hc}}{\int_\lambda S(\lambda)_i\ d\lambda}$$

$$R_2 = \frac{\int_\lambda \frac{\lambda\ P\left(\lambda,\ T_2\right) \cdot S(\lambda)_i\ d\lambda}{hc}}{\int_\lambda S(\lambda)_i\ d\lambda}$$

for each of the six spectral bands i. Given R_1 and R_2 one can solve for a and b using equation (1) with the following result:

$$a = \frac{R_2 D_1 - R_1 D_2}{D_1 - D_2}$$

$$b = \frac{R_1 - R_2}{D_1 - D_2}$$

Using equation (1) one can then, channel-by-channel and scan-by-scan, solve for R_x from D_x. R_x is then in physical units (photons/s $\cdot$ m^2 $\cdot$ sr) and to first order is independent of the TIMS system state at the time of measurement.

For some purposes the scene brightness temperature T_x is desired rather than the scene photon radiance. One cannot analytically compute T_x from R_x but a look-up table can be created using:

$$R_x = \frac{\int_{\lambda} \frac{\lambda\, P\left(\lambda,\, T_x\right) \cdot S(\lambda)_i\, d\lambda}{hc}}{\int_{\lambda} S(\lambda)_i\, d\lambda}$$

from which T_x can be found by interpolation. Computation of T_x completes reduction of TIMS DN to physical units.

Noise. Several types of random and systematic noise occur in TIMS data. Measurements made in the laboratory (1983) using an external reference blackbody indicate an RMS noise component of $0.1^{o}C$ in channels 1 to 5 and $0.2^{o}C$ in channel 6.

Random infrequent noise may be introduced in recording of TIMS data in flight and in translating the flight tapes to computer compatible tapes. Such noise may affect any bit in the eight-bit words. Such bit errors will affect an entire scan line if they occur in the reference source data numbers. Since such errors have been observed, a wise procedure is to check the reference source temperature and radiance data numbers for unusually rapid changes. Since only slow changes are expected in the reference source temperature, rapid changes must be due to one or more errors in the bits making up the word. Once identified the affected word in error may be replaced by an average of the adjacent calibration data.

Another type of noise, which is sometimes present, has been traced to a digitizer error in channel 6. The digitizer constructs the 8 bits corresponding to a word through a process of successive approximation. This process is susceptible to error (a defective chip) when the input level is changing rapidly. A common symptom of this effect is for bit errors to concentrate on topographic ridges separating topographic slopes of different temperatures. The user of TIMS data should report occurrences of this effect to the NASA/NSTL Aircraft Data Acquisition Manager so that the instrument may be repaired. Nearest neighbor interpolation may be used to "cosmetically" adjust for this error.

Another type of noise is periodic with varying amplitude and frequency. We attribute it to microphonic vibration. The vibrations appear to be associated with the aircraft environment and movement. This noise can be seen, for example, in stretched images of channel-to-channel ratios, which to first order remove the variation in scene temperature from the image. Such noise can be reduced through Fourier transform techniques which remove the periodic component.

Calibration. The accuracy of the brightness temperatures calculated from TIMS data depends on the accuracy with which the brightness temperature of the reference sources can be established. To establish this relationsnip, laboratory measurements involving two different external blackbodies have been made. The first set of measurements indicated the brightness temperature of the internal reference sources agreed with the external blackbody to within $\pm$ 1.8°C at all internal reference source temperatures checked (24 to 51°C). The second set of measurements covering a wider range (10 to 55°C) have not yet been fully reduced; however, preliminary results do not appear to agree with the first set. It may be that encoded radiance values vary somewhat with the temperature of the TIMS itself. Confirming this suspicion will require a more extensive set of laboratory measurements than has thus far been made.

APPENDIX A

SELECTED JPL-AUTHORED PUBLICATIONS DEALING WITH THE GEOLOGIC USE OF THERMAL INFRARED SPECTRAL DATA

Abrams, Michael J. and Anne B. Kahle, Recent developments in lithologic mapping using remote sensing data, Proceedings of the IUGS-Unesco Programme on Geological Applications of Remote Sensing, Seminar on Remote Sensing for Geological Mapping, Orleans, France, February 2-4, 1984.

Gillespie, Alan R., Anne B. Kahle, and Frank D. Palluconi, Mapping alluvial fans in Death Valley, California, using multichannel thermal infrared images, Geophysical Research Letters, 11, 1153-1156, 1984.

Kahle, Anne B., The new airborne Thermal Infrared Multispectral Scanner (TIMS), 1983 International Geoscience and Remote Sensing Symposium (IGARSS '83), Vol. 11, FA-4, pp. 7.1-7.6, San Francisco, California, August 31 - September 2, 1983.

Kahle, Anne B. and Alexander F.H. Goetz, Mineralogic information from a new airborne thermal infrared multispectral scanner, Science, Vol. 222, No. 4619, pp. 24-27, October 7, 1983.

Kahle, Anne B. and Lawrence C. Rowan, Evaluation of multispectral middle infrared aircraft images for lithologic mapping in the East Tintic Mountains, Utah, Geology, Vol. 8, No. 5, pp. 234-239 May 1980.

Kahle, Anne B., Daryl P. Madura, James M. Soha, Processing of multispectral thermal IR data for geologic application, JPL Publication 79-89, 1979.

Gillespie, Alan R., and Anne B. Kahle, Color enhancement of highly correlated images: I Decorrelation and HSI contrast stretches (in preparation).

APPENDIX B. NUMERICAL LISTING OF TIMS RELATIVE SPECTRAL RESPONSE*

Each band separately is normalized to 100 at the wavelength of maximum response.

Channel 1		Channel 2		Channel 3	
Wavelength(μm)	Amplitude	Wavelength(μm)	Amplitude	Wavelength(μm)	Amplitude
8.00	0.46	8.48	1.23	8.96	12.11
8.03	0.78	8.51	4.69	8.99	31.29
8.06	1.12	8.54	15.52	9.02	60.24
8.10	2.47	8.58	34.00	9.06	69.33
8.13	10.48	8.61	52.93	9.09	82.81
8.16	26.89	8.64	67.05	9.12	92.92
8.19	49.25	8.67	77.26	9.15	98.57
8.22	69.76	8.70	87.31	9.18	100.00
8.26	84.12	8.74	92.51	9.22	99.28
8.29	93.19	8.77	95.60	9.25	98.15
8.32	97.07	8.80	97.13	9.28	95.28
8.35	97.44	8.83	100.00	9.31	89.24
8.38	97.58	8.86	99.95	9.34	78.88
8.42	97.31	8.90	95.84	9.38	62.37
8.45	100.00	8.93	84.23	9.41	44.50
8.48	99.74	8.96	64.45	9.44	28.88
8.51	85.98	8.99	42.91	9.47	17.07
8.54	63.45	9.02	27.34	9.50	8.23
8.58	40.57	9.06	15.86	9.54	3.59
8.61	24.59	9.09	7.14		
8.64	13.14	9.12	3.96		

*Spectral Response measured at NSTL - 6 June 1984

APPENDIX B. (continued)

Channel 4		Channel 5		Channel 6	
Wavelength(μm)	Amplitude	Wavelength(μm)	Amplitude	Wavelength(μm)	Amplitude
9.44	0.00	10.24	14.10	11.20	11.39
9.47	0.20	10.27	25.76	11.23	30.95
9.50	2.19	10.30	42.43	11.26	45.47
9.54	8.00	10.34	60.64	11.30	54.53
9.57	22.13	10.37	77.15	11.33	74.05
9.60	40.66	10.40	90.16	11.36	89.63
9.63	57.12	10.43	98.52	11.39	98.21
9.66	67.16	10.46	100.00	11.42	100.00
9.70	73.09	10.50	98.75	11.46	98.03
9.73	78.37	10.53	95.92	11.49	92.20
9.76	83.08	10.56	93.34	11.52	82.93
9.79	85.44	10.59	92.60	11.55	67.70
9.82	87.09	10.62	90.26	11.58	58.53
9.86	89.66	10.66	90.50	11.62	54.77
9.89	93.62	10.69	90.53	11.65	51.58
9.92	98.09	10.72	89.21	11.68	46.50
9.95	100.00	10.75	86.06	11.71	40.94
9.98	99.78	10.78	84.42	11.74	35.05
10.02	98.28	10.82	82.88	11.78	31.58
10.05	98.30	10.85	78.25	11.81	29.06
10.08	93.77	10.88	76.11	11.84	26.66
10.11	85.79	10.91	74.84		
10.14	68.20	10.94	73.75		
10.18	45.46	10.98	73.99		
10.21	29.77	11.01	68.18		
10.24	16.42	11.04	64.70		
		11.07	59.79		
		11.10	54.24		
		11.14	46.71		
		11.17	35.89		
		11.20	25.54		

APPENDIX C. FLIGHT REQUEST FORM

NASA/NSTL EARTH RESOURCES LABORATORY
AIRCRAFT MISSION REQUEST

MISSION NO.: ____________ SITE: ______________________________

PROJECT TITLE: ______________________________

PRINCIPAL INVESTIGATOR: ______________________________ DATE: ____________
(Typed Name & Signature

SENSOR REQUIREMENTS: ☐ TIMS ☐ TMS ☐ MLA ☐ PHOTO ONLY

SUPPORTING AERIAL PHOTOGRAPHY: ☐ ZEISS 6" F.L. Aerial Mapping Camera

☐ Type 2443 C.I.R. Film ☐ Other ____________

SIDELAP: ____________ FORWARD OVERLAP: ____________

DESIRED ACQUISITION DATE: ____________	☐ Daytime	☐ Nighttime
ACCEPTABLE WINDOW: ____________	Sun Angle: (Time)	(State time.)

MISSION CONSTRAINTS: ______________________________

FLIGHT ALTITUDE: ____________ P.I. NOTIFICATION: ____________
(or desired resolution)

CLOUD COVER: ____________ DIRECTION OF FLIGHT: ____________

SITE COORDINATES: CHECK ONE: ☐ CORNER COORDINATES OF TEST AREA
☐ START STOP COORDINATES OF EACH FLIGHT LINE
☐ CENTER POINT COORDINATE

APPENDIX D. OUTPUT DATA FORMAT

PARAMETER	WORD NUMBER	BIT NUMBER (MSB … LSB)	IDENTIFICATION (MSB … LSB)
Last End of Frame	750	1 2 3 4 5 6 7 8	1 0 1 0 1 0 1 0
Frame Synchronization	1	1 2 3 4 5 6 7 8	1 1 1 0 1 0 1 1
	2	1 2 3 4 5 6 7 8	1 0 0 1 0 0 0 0
	3	1 2 3 4 5 6 7 8	1 0 1 0 0 1 1 0
	4	1 2 3 4 5 6 7 8	1 0 1 0 1 1 1 1
Scan Line Count (BCD)	5	1 2 3 4	1,000,000's of counts
	5	5 6 7 8	100,000's of counts
	6	1 2 3 4	10,000's of counts
	6	5 6 7 8	1,000's of counts
	7	1 2 3 4	100's of counts
	7	5 6 7 8	10's of counts
	8	5 6 7 8	1's of counts
	8	1 2 3 4	1's of counts (redundant)
Date	9	1 2 3 4	10's of days
BCD Input from Front Panel	9	5 6 7 8	1's of days
Range 00-00-0 to 99-99-9	10	1 2 3 4	10's of months
	10	5 6 7 8	1's of months
	11	1 2 3 4	1's of years
Sortie	11	5 6 7 8	100's of sorties
BCD Input from Front Panel	12	1 2 3 4	10's of sorties
Range 000 to 999	12	5 6 7 8	1's of sorties
#1 Reference (temperature)	13	1 2 3	10's of degrees
	13	4	Sign: 0=Minus °C; 1=Plus °C
	13	5 6 7 8	1's of degrees
	14	1 2 3 4	1/10's of degrees
	14	5 6 7 8	NOT USED
#2 Reference (temperature)	15	1 2 3	10's of degrees
	15	4	Sign: 0=Minus °C, 1=Plus °C
	15	5 6 7 8	1's of degrees
	16	1 2 3 4	1/10's of degrees
	16	5 6 7 8	NOT USED

PARAMETER	WORD NUMBER	BIT NUMBER (MSB … LSB)	IDENTIFICATION (MSB … LSB)
Scan Speed	17	1 2	00=7.3; 01=8.7; 10=12; 11=25 scans/sec.
	17	3 4 5 6 7 8	0,0,TH2,TH1;UH8,UH4,UH2,UH1 } IRIG TIME CODE
	18	1 2 3 4 5 6 7 8	0,TM4,TM2,TM1;UM8,UM4,UM2,UM1 } IRIG TIME CODE
	19	1 2 3 4 5 6 7 8	0,TS4,TS2,TS1;US8,US4,US2,US1 } IRIG TIME CODE
	20	1 2 3 4 5 6 7 8	NOT USED
	21	1 2 3 4 5 6 7 8	NOT USED
True Heading	22	1 2	100's of degrees
BCD Output of LTN-72	22	3 4	NOT USED
Range: 0 to 360.0°	22	5 6 7 8	10's of degrees
	23	1 2 3 4	1's of degrees
	23	5 6 7 8	1/10's of degrees
Pitch Angle	24	1 2 3 4	10's of degrees
3-Wire Synchro Output of LTN-72	24	5 6 7 8	1's of degrees
Range: 0 to 90.0° Nose Up	25	1 2 3	NOT USED
0 to 90.0° Nose Down	25	4	Sign: 0=down; 1=up
	25	5 6 7 8	1/10's of degrees
Roll Angle	26	1	100's of degrees
3-Wire #2 Synchro Output of LTN-72	26	2 3	NOT USED
Range: 0 to 180.0°Left	26	4	Sign: 0=L; 1=R
0 to 180.0° Right	26	5 6 7 8	10's of degrees
	27	1 2 3 4	1's of degrees
	27	5 6 7 8	1/10's of degrees
Present Position-Latitude	28	1 2 3 4	10's of degrees
BCD Output from LTN-72	28	5 6 7 8	1's of degrees
Range: 0 to 90° 00.0'N	29	1 2 3	10's of minutes
0 to 90° 00.0'S	29	4	Sign: 0=S; 1=N
	29	5 6 7 8	1's of minutes
	30	1 2 3 4	1/10's of minutes
	30	5	Sign: 1=valid; 0=not valid
	30	6 7 8	NOT USED

PARAMETER	WORD NUMBER	BIT NUMBER (MSB … LSB)	IDENTIFICATION (MSB … LSB)
Present Position-Longitude	31	1 2 3 4	10's of degrees
BCD Output from LTN-72	31	5 6 7 8	1's of degrees
Range: 0 to 179° 59.9'E	32	1 2 3	10's of minutes
0 to 179° 59.9'W	32	4	Sign: 0=W; 1=E
	32	5 6 7 8	1's of minutes
	33	1	100's of degrees
	33	2 3	NOT USED
	33	4	Sign: 1=valid; 0=not valid
	33	5 6 7 8	1/10's of minutes
Ground Speed	34	1 2	1000's of knots
BCD Output of LTN-72	34	3	NOT USED
Range: 0 to 2000 knots	34	4	Sign: 1=valid; 0=not valid
	34	5 6 7 8	100's of knots
	35	1 2 3 4	10's of knots
	35	5 6 7 8	1's of knots
Drift Angle	36	1 2	10's of degrees
BCD Output of LTN-72	36	3	NOT USED
Range: 0 to 39.9°	36	4	Sign: 0=L; 1-R
	36	5 6 7 8	1's of degrees
	37	1 2 3 4	1/10's of degrees
	37	5	Sign: 1=valid; 0=not valid
	37	6 7 8	NOT USED
	38		NOT USED
	.		NOT USED
	.		NOT USED
	.		NOT USED
	99		NOT USED
	100	1 5	NOT USED
Video Gain Setting	100	2 3 4	Binary 1 to 5; 1=lowest gain; 5=highest gain
Channel Number	100	6 7 8	Binary Coded

PARAMETER	WORD NUMBER	BIT NUMBER (MSB … LSB)	IDENTIFICATION (MSB … LSB)
Low Temp Blackbody Video	101	1 2 3 4 5 6 7 8	Digitized analog value
Active Image	102	1 2 3 4 5 6 7 8	Pixel #1
Active Image	103	1 2 3 4 5 6 7 8	Pixel #2
. . .	. . .	. . .	. . .
Active Image	739	1 2 3 4 5 6 7 8	Pixel #638
High Temp Blackbody Video	740	1 2 3 4 5 6 7 8	Digitized analog value
End of Frame	741	1 2 3 4 5 6 7 8	1 0 1 0 1 0 1 0 End of Frame #1
End of Frame	742	1 2 3 4 5 6 7 8	1 0 1 0 1 0 1 0 End of Frame #2
. . .	. . .	. . .	. . .
End of Frame	749	1 2 3 4 5 6 7 8	1 0 1 0 1 0 1 0 End of Frame

APPENDIX E

RELATIONSHIP BETWEEN TIMS AIRCRAFT RECORDING AND REFORMATTED COMPUTER COMPATIBLE TAPE

The relationship between the output of TIMS onboard the aircraft as given in Appendix D and the reformatted CCT is shown in Figure E-1. In addition the NSTL Earth Resources Laboratory adds to each data file a header record that describes the data in that file. The description of the format of the header record is given in Table E-1 (see page E-3). TIMS produces six channels of data for each scan. The successive channels for each scan are stored successively as seperate records as shown below:

Record Number	Data Description
1	Header record
2	Scan line 1, Channel 1
3	Scan line 1, Channel 2
4	Scan line 1, Channel 3
5	Scan line 1, Channel 4
6	Scan line 1, Channel 5
7	Scan line 1, Channel 6
8	Scan line 2, Channel 1

Requests for additional format and tape density information should initially be addressed to the NASA/NSTL Aircraft Data Acquisition Manager.

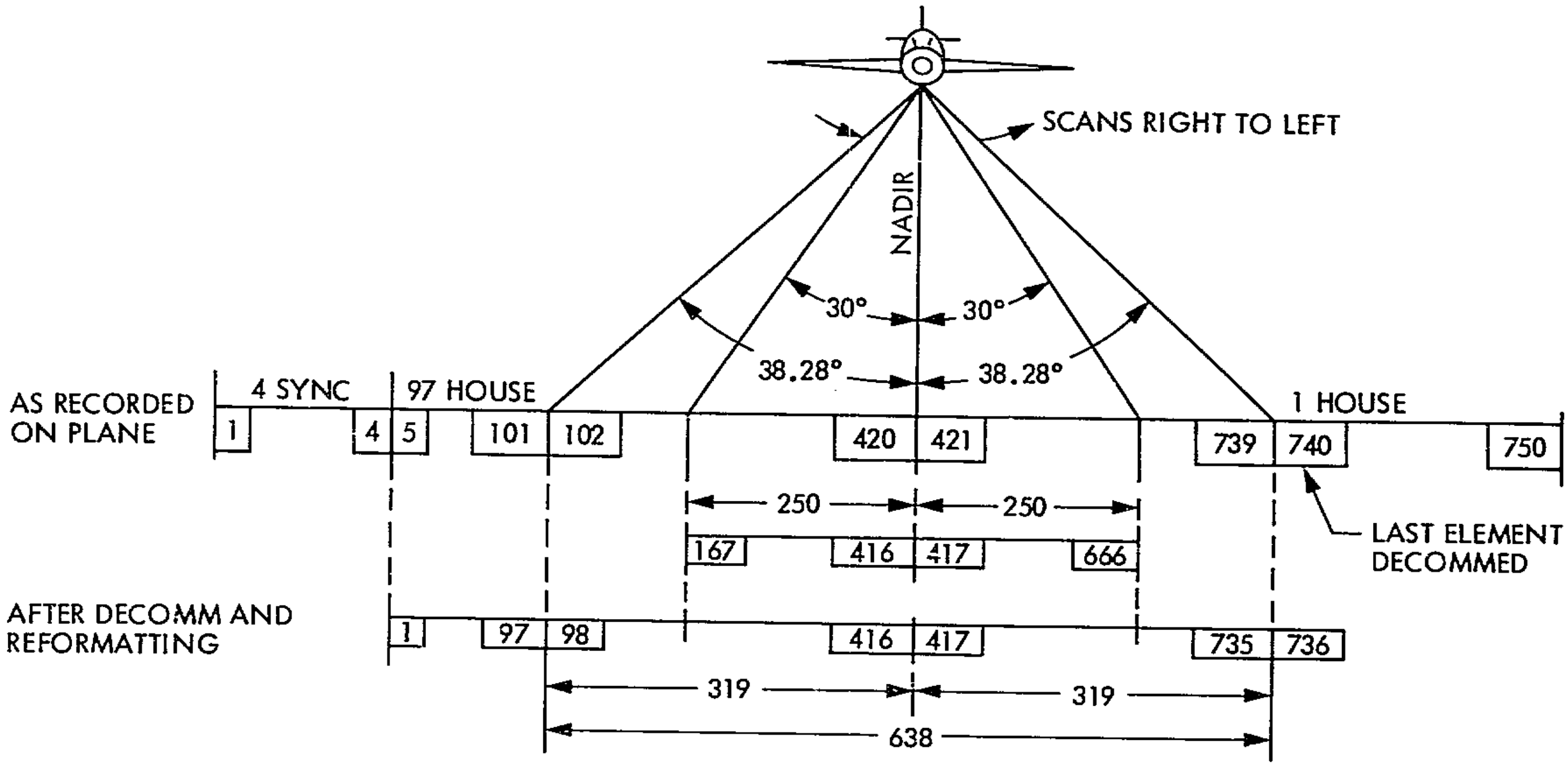

Figure E-1. Recorded vs Reformatted Data Structure

TABLE E-1. HEADER FORMAT AND DESCRIPTION

Maximum Size - 1024 Bytes (Machine-Sector-Increment-Dependent)

WORD	1	2	3	4	5	6	7	8	9	10	11
	NBIH	NBPR	IL	LL	IE	LE	NC	4321	Descriptor	Y-Offset	Descriptor
	INTEGER*4								4H	I	4H

12	13	14	15 16 17 18	19-24	25-56	57-120	121-(121 + NC)
X-Offset	Y Spot Size	X Spot Size	Transformation (Linear)	Not Used	Color Table	Comments	Descriptor for data base use
I	F	F	4F		INTEGER*4	4 lines at 64 characters each	4H each

WORDS	DESCRIPTION	WORDS	DESCRIPTION
1	NBIH - Number of bytes in header	12	X-Offset - The X coordinate system value for element IE-1
2	NBPR - Number of bytes per record (one record contains one channel for one line)	13	Y Spot Size - The picture element height
3	IL - Initial line of data file	14	X Spot Size - The picture element width
4	LL - Last line of data file	15-18	Transformation matrix (linear) from line and column (IL, LL, IE, LE) coordinates to the coordinates described in words 9 and 11 1.0.0.1. - Represents identity transformation 1.0.0.-1. - Represents data in the UTM format
5	IE - Initial picture element of scan line	19-24	Not Used
6	LE - Last picture element of scan line	25-56	Color Table
7	NC - Number of channels	57-120	Comments - 4 lines at 64 characters each
8	4321 - Header record identification	121-(121 + NC)	Descriptors for data base use
9	Descriptor - Grid descriptor for Y-axis 'NOR', LNIR', etc.		
10	Y-Offset - The Y coordinate system value for scan line IL-1		
11	Descriptor - Grid descriptor for X-axis 'EAS', 'LNIR', etc.		