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AN OVERVIEW OF THE LANDSAT-D PROJECT WITH EMPHASIS ON THE FLIGHT SEGMENT

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I. INTRODUCTION

In the third quarter of 1981, a new, experimental Earth-resources monitoring system, Landsat-D, is scheduled for launch. The characteristics of this system have been under consideration since about 1970 through a series of study efforts and with the guidance of several advisory groups composed of representatives of federal, state, and local agencies, private industry, and university personnel. From these studies and efforts evolved an Earth-resources monitoring system, Landsat-D, that includes several technological advances over the capabilities provided by Landsats 1, 2, and 3. In essence, the Landsat-D system is designed to be a complete, highly automated data gathering and processing system that should substantially contribute to more effective remote sensing of Earth resources and to the management of these resources on a local, regional, continental, and global basis.

The four major objectives of the Landsat-D project and program are:

1. To assess the capability of the thematic mapper (TM) to provide improved information for Earth-resources management.

2. To provide a transition for both domestic and foreign users from the multispectral scanner subsystem (MSS) data to the higher resolution and data rate of the TM.

3. To provide system-level feasibility demonstrations in concert with User Agencies to define the need for, and characteristics of, an operational system.

4. To encourage continued foreign participation in the program.

The purpose of this paper is to provide an overview of the Landsat-D project and the present status in terms of the configuration and assembly of the various components comprising the overall Landsat-D system. The two major segments are the flight segment and the ground segment. Although descriptions of the components in both segments are provided, emphasis is placed on describing flight segment.

II. FLIGHT SEGMENT

The flight segment of the Landsat-D system is being designed to be compatible with the operations of the Shuttle Transportation System (STS). An artist's rendition of the Landsat-D flight segment is shown in Figure 1. A backup spacecraft and payload will be developed for Landsat-D that is commonly called Landsat-D (prime). It will be prepared for launch, as needed, by the second quarter of 1982.

The launch vehicle for Landsat-D will be a Delta 3910 rocket. It will carry the Landsat-D payload to an orbital altitude slightly above 700 km. This altitude is compatible with the retrieval and replacement capabilities planned in conjunction with the STS during the Landsat-D project timeframe. The Landsat-D payload, including the spacecraft, instruments, and other equipment, is expected to weigh nearly 1630 kg (≈ 3600 lb). The present launch capability of the Delta 3910 is 1723 kg (3800 lb). This leaves a weight margin of approximately 5 percent. Between now and the launch of Landsat-D, every effort will be made to protect this margin or increase it.

It is expected that the Landsat-D flight segment will be placed into one of two Sun-synchronous orbits. Figure 2 shows the coverage patterns for these orbits. The orbit described in Figure 2a

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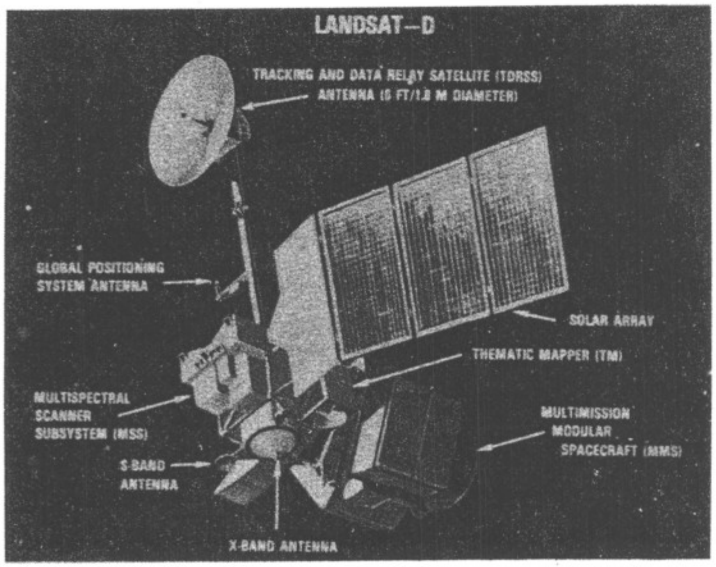

Figure 1. Expected Configuration of the Landsat-D Flight Segment (March 1979).

is the closest approximation permitted by orbital mechanics to the "minimum-drift" orbit associated with Landsats 1 through 3. It is essentially an "inventory" type of orbit that, pending minimum cloudcover, can permit large areas to be observed and image mosaics to be prepared with minimum surface-cover change during the observing period. The orbit described in Figure 2b is more what is termed a "skipping" orbit. It permits samples of observations (scenes) over very large areas to be acquired in a minimum amount of time. This approach is more compatible with the sampling methodology employed in the joint NASA, Department of Commerce, and Department of Agriculture Large-Area Crop Inventory Experiment (LACIE). The advantages of the orbit in Figure 2a are most realizable in lower latitudes in which clear skies tend to persist for longer periods of time (e.g., areas within large semipermanent atmospheric high-pressure regions). The advantages of the orbit described in Figure 2b are most realized in the higher latitudes (above 45 (degrees) because of the orbit sidelap coverage. Barring cloudcover, observations would be available at least every 9 to 11 days at latitudes higher than 45 degrees. The decision as to which orbit will be used should be made by the summer of 1979 so that complete systems and error-budget studies can be completed.

The spacecraft component of the Landsat-D flight segment will be the Multimission Modular Spacecraft (MMS). The spacecraft performs the basic functions of providing power, attitude control, and the command and data-handling systems. To the user community associated with image processing and applications, the major interest area is the attitude-control system because it affects the complexity of data processing involved in the geodetic accuracy of Thematic Mapper Observations (pixels), image rectification, and the registration of data from one scene to another.

The MMS has improved attitude-control capability over previous systems. The pointing accuracy is specified to be 0.01 degrees (1-sigma value), and the stability is 10^{-6} degrees/second (1-sigma value). These performance values should be compared to the 0.7-degree pointing accuracy and 0.01-degree/second stability values associated with Landsats 1 through 3 in order to appreciate the advantages afforded by the MMS in this area.

The solar panels depicted in Figure 1 will provide ample power. The individual outboard panels are approximately 1.5 by 2.3 meters in dimension. The solar array is to be capable of providing 790 watts of average power at the end of the Landsat-D mission, in contrast to the conservative estimate of 760 watts of average power that may be needed to sustain the operations of the various components, including the Earth-observing instruments.

One of the most complex subsystems on Landsat-D is the communications subsystem. This subsystem is designed to overcome some major problems that have long been associated with data-gathering missions in space. If one examines the history of subsystem failures in space, it is interesting to note that the great majority of them have been mechanical failures.

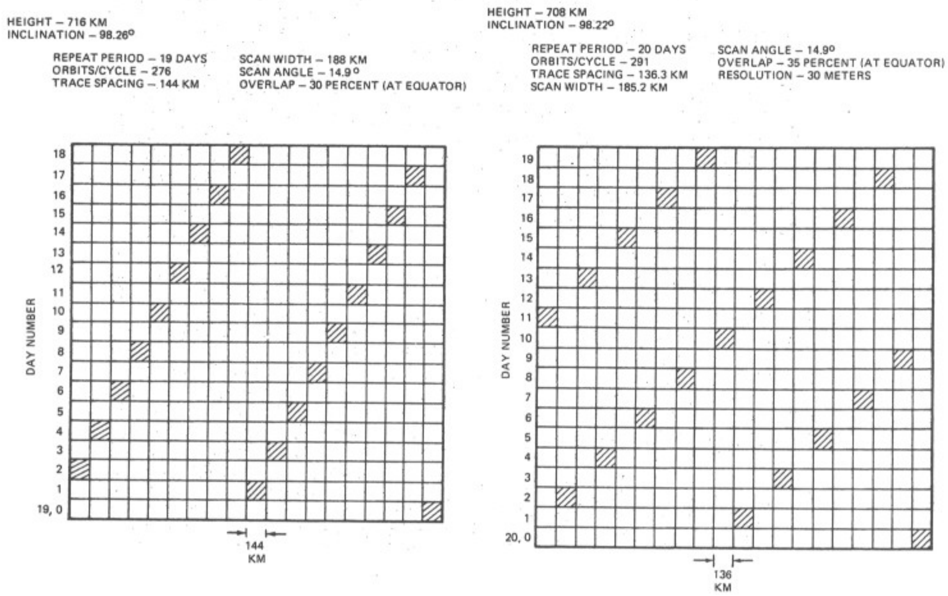

Figure 2. Coverage Patterns of Two Sun-Synchronous Orbits.

Noticeable among them is the failure of tape recorders used to record and transmit remote-sensor data. All three of the previous Landsat vehicles have suffered from this problem. The user community has been principally affected only in their requirement for foreign coverage. All domestic requirements have been met with real-time transmission of data.

With the launch of Landsat-D, the era of tape-recorder failure will be over. A few months before the launch of Landsat-D, a new global satellite-to-satellite-to-ground communications system, called the Tracking and Data-Relay Satellite System (TDRSS), will have been placed in geosynchronous orbit. For this system, it is projected that two satellites will be positioned at 41°W and 171°W to provide virtually global data transmission to the ground in real time. A troublesome zone-of-exclusion problem in the coverage over India may be solved by using, or taking advantage of, a ground receiving station in India and subsequent retransmission of the data to the United States. At this writing, a final disposition of this problem has not beem made.

Landsat-D will have the necessary Ku-band (≈ 15-GHz frequency) transmitter to communicate with TDRSS, and all of the data stream from both TM and MSS can be transmitted by this system. Simultaneously, Landsat-D must be capable of directly transmitting data to the ground over X-band (8.025 to 8.4 GHz) and S-band (2206 to 2300 MHz) communications links. The TM uses X-band, and the MSS uses S-band. Thus, a foreign ground station currently equipped to receive MSS will continue to be able to do so from the MSS on Landsat-D. However, that station will not be able to receive the TM data without station modification.

TDRSS data will be received at an appropriate facility located at White Sands, New Mexico. From there, the data will be transmitted by a communications satellite to the data-processing center at the Goddard Space Flight Center (GSFC) (Figure 3). Engineering solutions to the problem of precision pointing of antennas and very high-density data up to 300 megabits/second led to the TDRSS selection of Ku-band, but that decision forced the selection of a site with an exceedingly clear atmosphere. Thus, the need to transmit data to White Sands from the TDRSS and rapidly retransmit the data from White Sands to the data-processing center at GSFC led to the implementation of the communications satellite.

Landsat-D will fly a position-location device that receives and processes data from the Global Positioning System (GPS).[1] The GPS experiment is expected to provide very accurate position location, nominally 10 meters for the portion of the orbit when Landsat-D is in view of the GPS satellites currently available. The complete

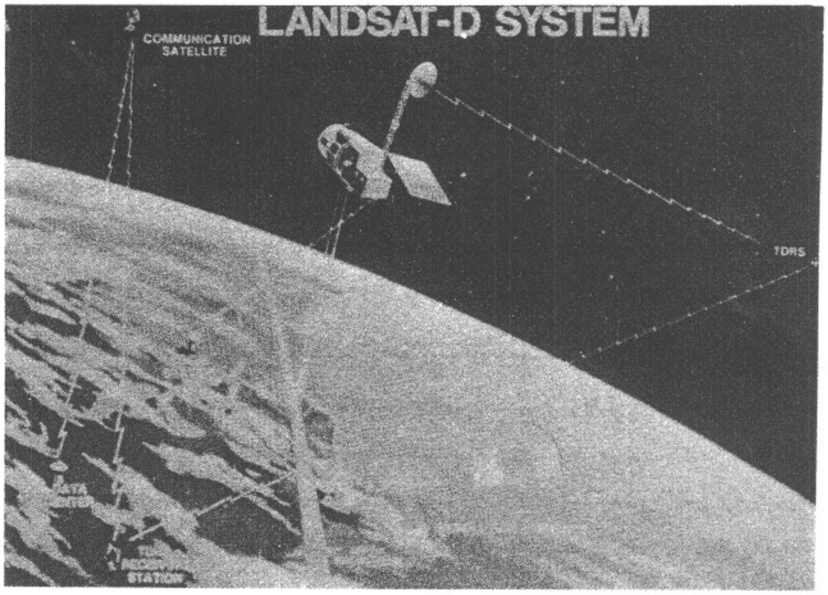

Figure 3. Overall Communications Flow for Landsat-D.

GPS will eventually employ 24 satellites, using doppler techniques to provide the 10-meter accuracy on a global basis. In the initial stages, Landsat-D will be able to use only six of the 24 satellites. Because these six are more or less in a cluster, they will be in view for only part of the orbit. GPS should provide more accurate data than standard tracking networks and contribute substantially to more autonomous operations of satellites and improved onboard data processing in the future.

III. EARTH-OBSERVING PAYLOAD AND APPLICATIONS

The instrument payload (Table 1) consists of the familiar MSS of Landsats 1 and 2; that is, it is the four-band instrument and does not have the fifth band (thermal infrared) that was included on Landsat-3. The TM provides narrower bands similar to those on the MSS and adds a 0.45 to 0.52, 1.55 to 1.75, and 2.08 to 2.35 μm bands, plus the thermal band (10.5 to 12.5 μm). Table 1 lists the spectral intervals and radiometric sensitivity of each of the sensors. Table 2 provides the radiometric performance requirements for the TM. A more in-depth description of the TM is provided by Blanchard and Weinstein.[2]

There is one fundamental difference between the two instruments (TM and MSS) in terms of basic design. The MSS scans and obtains data in one direction only. The TM, however, scans and obtains data in both directions. The TM approach is necessary for reducing the scan rate and for providing the dwell time needed to produce improved radiometric accuracy. Figure 4 illustrates the scanning strategy of the TM. Figure 5 sketches the optics configuration for the TM.

In addition to the obvious improvement in spatial resolution noted in Table 1, an equally, if not more, important change is in the quantizing level of TM. Research on this aspect of multispectral classification began more than 10 years ago. In an article on information theory published by the IEEE in 1968, the probability of correct classification of terrain materials by multispectral measurements was said to be a function of measurement complexity.[3] Measurement complexity was defined as "(the number of spectral bands) x (signal quantization precision)." If one uses that multiple as a figure of merit, then:

$$MSS = 4 \times 64 = 256$$
$$TM = 7 \times 256 = 1792$$

Thus, the TM has an improvement factor of 7.

The theory, however, assumes infinite knowledge of the classes, whereas, in practice, one seldom, if ever, has perfect knowledge of the myriad of terrain features in the field of view of the sensor. Interestingly, the theory also predicts,

Table 1. Landsat-D Earth-Observing Instrumentation (March 1979)

	THEMATIC MAPPER (TM)		MULTISPECTRAL SCANNER SUBSYSTEM (MSS)	
	MICROMETERS	RADIOMETRIC SENSITIVITY (NEΔP)	MICROMETERS	RADIOMETRIC SENSITIVITY (NEΔP)
SPECTRAL BAND 1	0.45 - 0.52	0.8%	0.5 - 0.6	.57%
SPECTRAL BAND 2	0.52 - 0.60	0.5%	0.6 - 0.7	.57%
SPECTRAL BAND 3	0.63 - 0.69	0.5%	0.7 - 0.8	.65%
SPECTRAL BAND 4	0.76 - 0.90	0.5%	0.8 - 1.1	.70%
SPECTRAL BAND 5	1.55 - 1.75	1.0%		
SPECTRAL BAND 6	2.08 - 2.35	2.4%		
SPECTRAL BAND 7	10.40 - 12.50	0.5K (NEΔT)		
GROUND IFOV		30M (BANDS 1 - 6) 120M (BAND 7)	82M (BANDS 1 - 4)	
DATA RATE		85 MB/S	15 MB/S	
QUANTIZATION LEVELS		256	64	
WEIGHT		227 KG	68 KG	
SIZE		1.1 X 0.7 X 2.0M	0.35 X 0.4 X 0.9 M	
POWER		320 WATTS	50 WATTS	

Table 2. Radiometer Characteristics for the Thematic Mapper

BAND	SPECTRAL WIDTH (μM)	DYNAMIC RANGE (MW/CM^2 — STER)	LOW LEVEL INPUT (MW/CM^2 — STER)	SNR
1	0.45 — 0.52	0 — 1.00	0.28	32
2	0.52 — 0.60	0 — 2.33	0.24	35
3	0.63 — 0.69	0 — 1.35	0.13	26
4	0.76 — 0.90	0 — 3.00	0.16	32
5	1.55 — 1.75	0 — 0.60	0.08	13
6	2.08 — 2.35μM	0 — 0.43	0.05	5
7	10.40 — 12.50	260K — 320K	300K	0.5K (NET D)

- ABSOLUTE CHANNEL ACCURACY < 10% OF FULL SCALE
- BAND TO BAND RELATIVE ACCURACY < 2% OF FULL SCALE
- CHANNEL TO CHANNEL ACCURACY < 0.25% RMS OF SPECIFIED NOISE LEVELS

and research with multispectral aircraft data confirms, that there is a point of diminishing returns. If one plots in X-Y space the probability of correct classification against multispectral complexity, probability rises rapidly through a figure of merit of 1024 (4 bands) x (256 levels), starts to tail off, and reaches a plateau at 4096 (6 bands) x (256 levels). Thus, in terms of the number of bands, but not necessarily the spectral interval, the MSS would seem to have been an excellent first choice. In fact, a multitude of reports have cited the overwhelming value of bands 5 and 7 for most analyses. One might then say that the MSS has a dimensionality of two.

The foregoing information theory studies approached the problem from the viewpoint of the targets and not from the viewpoint of the sensor. Thus, in fact, MSS is deficient as a sensor. The thematic mapper might make a substantial improvement in this area because it has both additional spectral information and additional spectral accuracy. Although one might expect the TM to reach the same dimensionality as the terrain materials and, thus, be the "ideal" sensor, it is more likely to provide a factor of 2 improvement over MSS, as follows:

Feature A descriptors - Bands, 2, 4, 5, and 6

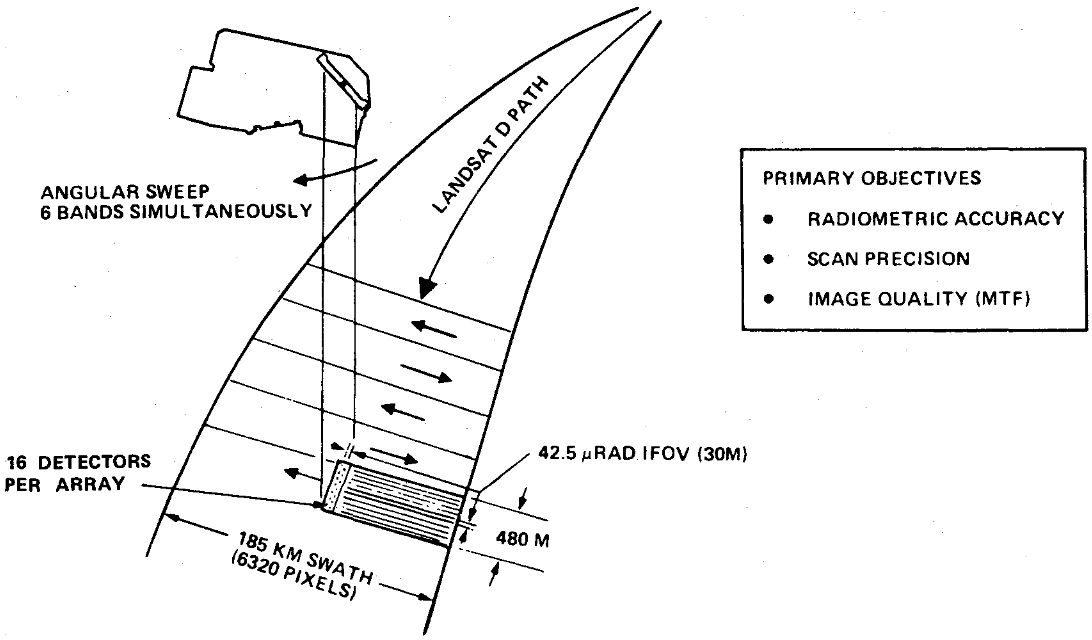

Figure 4. Scanning Characteristics of the Thematic Mapper.

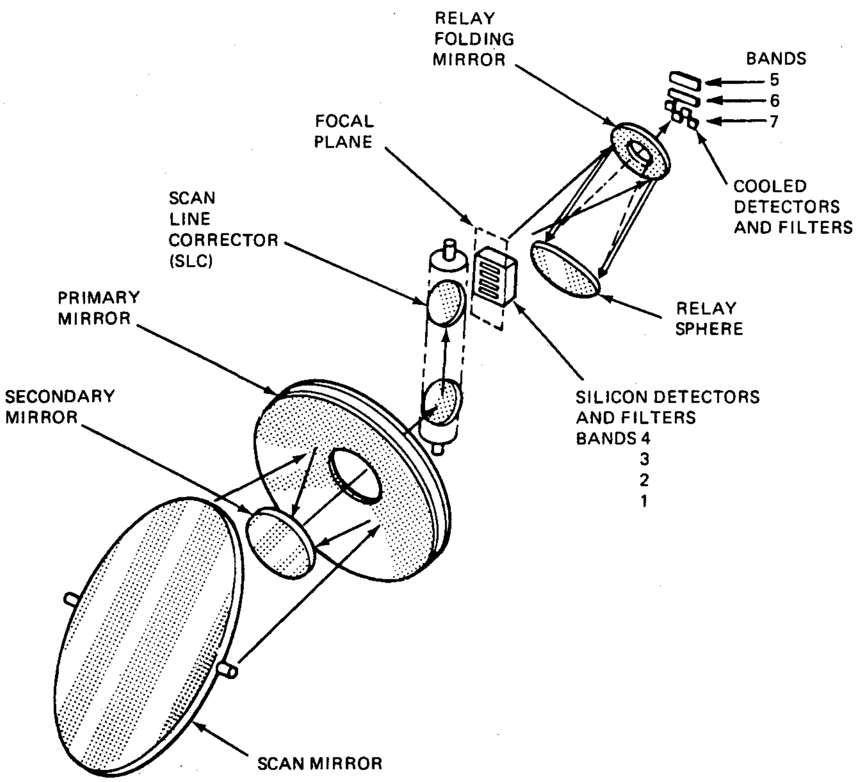

Figure 5. Thematic-Mapper Optical System.

Feature B descriptors - Bands 1, 3, 6, and 7
Feature C descriptors - Bands 2, 3, 5, and 7

thus, rarely using all seven bands in any identification task.

In terms of spatial resolution, the TM is expected to make a significant improvement over MSS in two areas. First and most obvious, mensuration will be more accurate. In practical terms, the TM will be able to measure a 10-acre field ±0.1 acre, which will satisfy the accuracy requirements for fields of that size and larger. The resolution of a sensor in mensuration terms represents the uncertainty of where the points are at each end of a line. It follows that the length of the line and, thus, the size of the field, (line A) x (line B), will yield an uncertainty in area that is a function of the resolution.

A second area in which the TM spatial resolution should make an impact will be the scale of map that can be compiled from TM observations, as well as the scale of map that can be updated by TM observations. Both officially (approved by the U.S. Geological Survey) and practically, the MSS on Landsats 1, 2, and 3 can be used to compile a planimetric map of a 1:250,000 scale and to produce a thematic map using an existing map for control at a 1:100,000 scale. For the TM, these numbers will probably be 1:100,000 for compilation and 1:25,000 for thematic work. This means that many of the states will be using the TM operationally for thematic mapping, whereas the MSS constrains them to experiments.

C. J. Tucker has recently reviewed the TM bands in terms of monitoring vegetation.[4] Table 3 summarizes the applicability of the various bands for vegetation monitoring. From the type of observations listed, it is apparent that these attributes are shared by virtually all the vegetation species in which we are interested. The resulting difficulty in using these measurements to identify the species is well-known. Although the LACIE program has been widely publicized, a procedural change in the analysis technique used very late in the review of Phase 2 results is not widely known. During these postharvest review periods, the project explored techniques for improving the accuracy of identification and measurement. The operational nature of LACIE prevented such studies until after the growing season. This latest improvement exploits time as a discriminant on the basis that multitemporal observations separate the species because of differences in timing of plant-development stages. The new TM band 1 (0.45 - 0.52), an absorption band for chlorophyll, and new TM bands 5 and 6 (1.55-1.75 and 2.08-2.35), both of which are sensitive to plant water, are expected to add additional biophase sensitivity to the measurements and make further improvements in identification accuracy. Furthermore, although MSS has already been used in plant-moisture stress analysis, the more nearly direct measurement of plant water by TM will substantially improve the quantitative assessment of such an event.

The blue band (TM 1) will permit bathymetric studies in clear water to reach new depths. Aircraft studies have shown success at depths of 20 meters with some isolated measurements at 40 meters; TM 1 should perform equally well. The new reflective infrared bands (TM 5 and 6) are expected to provide significant new information in geology. In band 5, as well as in the blue/red band ratios, we expect to map surface evidence of mineralization. In band 6 we can expect to delineate hydrothermally altered geologic zones.

In forestry, we can expect to benefit from the plant-water bands in a very important forest application; namely, predicting the susceptibility of the forest to fire. In addition, these bands should provide information on site quality, using the indirect evidence of moisture state during periods of moisture stress. An interesting improvement may be expected from the increase in spatial resolution. Forestry has perhaps the most stringent requirement for resolution among the application areas because of the need for type, stand, and classification maps. Although the TM will not approach this resolution (2 meters), we can expect to begin to see texture differences caused by stand density. In land-cover mapping, we expect to benefit from improved information about the soils and plants, as well as from larger-scale capabilities for mapping.

In water resources, both the added spectral coverage in the blue band and the increase in spectral accuracy should enhance our ability to map both surface and subsurface water features. The use of multispectral cross-correlation analyses in water produces maps of particles in water that provide information on depth, as well as particle size.

Table 3. Thematic Mapper Spectral and Radiometric Characteristics

Band	Wavelength (μm)	NEΔρ	Basic Primary Rationale for Vegetation
TM 1	0.45-0.52	0.008	Sensitivity to chlorophyll and carotinoid concentrations
TM 2	0.52-0.60	0.005	Slight sensitivity to chlorophyll, plus green region characteristics
TM 3	0.63-0.69	0.005	Sensitivity to chlorophyll
TM 4	0.76-0.90	0.005	Sensitivity to vegetational density or biomass
TM 5	1.55-1.75	0.01	Sensitivity to water in plant leaves
TM 6	2.08-2.35	0.024	Sensitivity to water in plant leaves
TM 7	10.4-12.5	0.5 K	Thermal properties

At present, the only additional information is derived from the chlorophyll bands because of the absorption of the energy by phytoplankton and/or algae. However, we expect to benefit in hydrology from the plant-water bands in the modeling of soil moisture. Landsat has demonstrated its ability to map hydrologic land use parameters, such as flood plains, and we can expect to derive useful maps of much smaller areas, perhaps as small as 200 km^2. In coastal-zone management and coastal oceanography, the benefits described in vegetation, soils, and water apply. However, Landsat is not a proper system for the dynamic phenomena of oceanography and some hydrologically significant events such as flooding. Many dynamic parameters can be detected, but the time constant for observation is exceedingly deficient.

IV. GROUND SEGMENT

The ground segment is a major part of the overall Landsat-D system. The ground segment is being assembled for NASA by the General Electric Corporation. The ground system faces substantial challenges that are largely a function of the high data rate of the TM and MSS combined (≈100 megabits/second) that must be rapidly processed. The ground segment of the Landsat-D system consists of three major subsystems. The Operations Control Center (OCC) handles all communications with the flight segment, including the commanding and scheduling of the various subsystems of the flight segment and the monitoring of their performance. The Data Management System (DMS) processes all the data from the TM and MSS into final products. The Landsat-D Assessment System (LAS) is a facility in which TM and MSS observations will be analyzed to quantify the advantages for Earth observations and applications afforded by these systems and other related components of Landsat-D. Smith and Webb[5] have made a complete review of the Landsat-D ground segment.

The DMS, the major subsystem of the ground segment, faces the major challenge of processing the high data rates noted previously. A related and key performance requirement for the DMS is to produce output products within 48 hours after receipt of TM and MSS data at GSFC. To do this, the DMS is utilizing advanced data-processing technology. For example, key components of the DMS will be two pipeline processors that are in the 10 megainstructions per second class, along with advanced minicomputers. Advanced digital tape read-and-record devices will also be used in the DMS to receive, store, and record output from the data stream generated by the TM and the MSS. For example, 42-track, 20,000 bits per inch tape recorders will be used to handle the data rate (≈ 85 megabits per second) and to record multiple scenes from the TM, which involves approximately 250 x 10^6 bytes per scene. Use of this technology in the DMS will continue the primarily digital approach (as opposed to film) to processing and archiving data established with Landsat-3 and will maintain or improve the total processing and output production time even in the face of the increased data rates.

Table 4 summarizes the input and output products for the DMS as of March 1979. The output products will be put into a long-term archive facility that will produce and deliver products on order to the general public. The long-term archive facility is expected to be the EROS Data Center in Sioux Falls, South Dakota, operated by the U.S. Department of Interior.

The LAS and OCC will also make use of the data-processing technology used in the DMS. The OCC will use three advanced minicomputer systems to perform its functions. The LAS will use one advanced minicomputer and one pipeline processor to analyze TM and MSS data. As in the DMS high speed, very high-density multitrack tape recorders will be used to record and store data and output results.

V. CONCLUSIONS

As can be ascertained from the previous paragraphs, the Landsat-D system offers many technological advances to be evaluated in terms of improved Earth-resources monitoring. The key instrument, of course, is the thematic mapper. It is expected to offer several observational advances that are expected to improve the acceptability and immediate applicability of this type of remotely sensed data. Key discipline areas that should benefit are agriculture and geology because of the increased spatial resolution and the greater number and improved location of narrower or new spectral bands relative to the multispectral scanner subsystem flown on Landsats 1, 2, and 3.

Perhaps the most important contribution that Landsat-D will provide to the user community is the learning experience in working with the nearly 100-megabit/sec data

Table 4. Input and Output Products for the Landsat-D

INPUT	OUTPUT (PUBLIC DOMAIN)
• 100 TM SCENES (IMAGE DATA) PER DAY – ALL SCENES PARTIALLY PROCESSED (RADIOMETRICALLY CORRECTED) – PUT ON HIGH DENSITY TAPES (HDT_A) – HDT_A ARCHIVED FOR SIX MONTHS AT GODDARD SPACE FLIGHT CENTER	• 200 MSS SCENES –FULLY CORRECTED (RADIOMETRICALLY AND GEOMETRICALLY) TAPES (HDT_P) – ALL SCENES TRANSMITTED TO EROS DATA CENTER SIOUX FALLS, SOUTH DAKOTA FOR LONG-TERM ARCHIVING
• 200 MSS SCENES (IMAGE DATA) PER DAY – ALL SCENES PARTIALLY PROCESSED (RADIOMETRICALLY CORRECTED) – PUT ON HIGH DENSITY TAPES (HDT_A) – HDT_A ARCHIVED FOR SIX MONTHS AT GODDARD SPACE FLIGHT CENTER	• 50 SELECTED TM SCENES – FULLY CORRECTED (RADIOMETRICALLY AND GEOMETRICALLY) TAPES (HDT_P) – ALL SCENES TRANSMITTED TO EROS DATA CENTER FOR LONG-TERM ARCHIVING – FIRST GENERATION FILM MASTERS (241 MM X 241 MM, = $1:10^6$ SCALE) SENT TO EDC – 10 TM SCENES PER DAY CAN BE PRODUCED ON COMPUTER COMPATIBLE TAPES (CCT'S)
• ANCILLARY DATA – SPACECRAFT EPHEMERIS AND ALTITUDE – RADIOMETRIC CORRECTION DATA – GEOMETRIC/GROUND CONTROL POINT DATA	
• PROCESS CONTROL DATA – PROCESSING, CONTROL, AND OPERATIONAL COMMANDS	
• DATA BASE UPDATES – AGENCY AND USER FILES, ETC.	

stream, Indeed, if experiments are conducted with TM and MSS simultaneously, the users will have that experience. There is no precedent in the history of either this comparatively new technology or its predecessor, aerial photography, to suggest that there will be any other evolutionary course except that of better and better resolution. Indeed, if one examines the published requirements of the agencies, the implications on bandwidths for the future are large even by Landsat-D standards. It may be that these requirements can be met with less than global coverage (i.e., one may be able to satisfy these requirements with sampling strategies or with regional coverage at the higher resolution). This is the trend in research today, and, if it is accepted by the agencies, Landsat-D represents a major milestone in remote sensing. We suggest that the 30-meter global coverage is the operational prototype value, and we recommend that the entire user community begin to consider a long-term commitment to designing the most cost-effective hardware and software to live in such a data environment.

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Dr. Salomonson has been with NASA and the Goddard Space Flight Center since 1968. His principal research contributions have been in the use of satellite data for meteorological studies and applications to water resources management. He has served as the Head of the Hydrospheric Sciences Branch in the Laboratory for Atmospheric Sciences since 1973. He was appointed Landsat-D Project Scientist in May of 1977.

Dr. Park has been involved with remote sensing research and NASA, User Agency, and aerospace programs for nearly two decades. He served as remote sensing coordinator for the U.S. Dept. of Agriculture in the early 1960's. In the late 1960's and early 1970's, he was the Chief Scientist for Earth Observations Programs at NASA Headquarters. In recent years he has served in private industry in efforts dealing with the applications of Landsat data and systems to a variety of applications with emphasis on agriculture.