

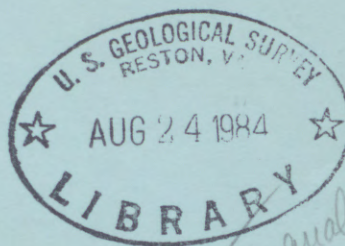
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no. 84-314



**REPORT OF THE COMMITTEE  
FOR  
"ACQUISITION AND PROCESSING OF SPACE DATA FOR MAPPING PURPOSES"  
OF WORKING GROUP IV/3  
OF  
THE INTERNATIONAL SOCIETY FOR PHOTOGRAMMETRY  
AND REMOTE SENSING (ISPRS)**



June 1984





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"ACQUISITION AND PROCESSING OF SPACE DATA FOR MAPPING PURPOSES"  
OF WORKING GROUP IV/3  
OF THE INTERNATIONAL SOCIETY FOR PHOTOGRAMMETRY  
AND REMOTE SENSING (ISPRS)

by Alden W. Krivonozhuk

Open-File Report 84-344



Open-file report  
(Geological Survey  
U.S.)

Reston, Virginia

May 1984

June 1984





UNITED STATES  
DEPARTMENT OF THE INTERIOR  
GEOLOGICAL SURVEY

Committee Report on "Mapping from Space" of the  
International Society for Photogrammetry and  
Remote Sensing (ISPRS)

by Alden P. Colvocoresses

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Open-File Report 84-314

Reston, Virginia

May 1984





# United States Department of the Interior

GEOLOGICAL SURVEY

RESTON, VA. 22092

Mail Stop 520

August 15, 1984

## Note to recipients of USGS "EC Memos"

During June 1984 the USGS published a Miscellaneous Investigation Report titled "USGS Landsat Thematic Mapper (TM) Color Combinations Washington, D.C. and Vicinity" and designated I-1616.

I-1616 includes a copy of a written report distributed as part of EC-85 but its principal content is a large sheet of multicolored graphics which includes the following:

- o Small scale (1:553,000) renditions of the 6 TM bands (thermal band omitted) plus the 20 possible combinations and the 6 possible permutations of the most promising combination.
- o Four 1:100,000-scale renditions of a portion of the area depicting 4 selected band combinations which include 2 permutations of the same combination.
- o A brief textual explanation of the graphics.

The price of I-1616 is \$6.00 plus \$1.00 postage and handling for orders under \$10.00 from within the U.S., Canada or Mexico. It may be ordered from:

U.S. Geological Survey  
Eastern Distribution Branch  
1200 South Eads Street  
Arlington, Virginia 22202

Prepayment required. Make check or money order payable to "Department of the Interior-USGS."

Foreign orders: Add surcharge of 25 percent to the net bill to cover surface transportation (except for Canada and Mexico). Air Mail shipments will be charged at full cost of service. Prepayment is required in United States funds by International money order or check drawn on a United States bank.

*Alden P. Colvocoresses*  
Alden P. Colvocoresses  
Research Cartographer  
National Mapping Division







# United States Department of the Interior

GEOLOGICAL SURVEY  
RESTON, VA. 22092

In Reply Refer To:  
WGS-Mail Stop 520

August 15, 1984

Memorandum for the Record (EC-86-Landsat/Mapsat)

By: Research Cartographer (EROS Cartography)  
National Mapping Division

Subject: Committee Report on "Mapping from Space" of the International Society  
for Photogrammetry and Remote Sensing (ISPRS)

Attached is an accepted committee report of the ISPRS titled "Acquisition and Processing of Space Data for Mapping Purposes." Because of this paper's interest to the cartographic community and the sizable contribution made by U.S. Geological Survey (USGS) personnel, it is hereby made a USGS Open-File report. Since the committee relied heavily on the technology of both Landsat and Mapsat this report is included in the Landsat/Mapsats series of EC Memos.

*Alden P. Colvocoresses*  
Alden P. Colvocoresses

## Attachments

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USGS Open-File Report 84-314

Publication authorized by the Director, U.S. Geological Survey on May 23, 1984.





## PREFACE

The committee preparing this report was authorized by the President of the International Society for Photogrammetry and Remote Sensing (ISPRS) by letter of July 30, 1982 (appendix B). Alden P. Colvocoresses of the U.S. Geological Survey was appointed chairman and the committee was organized under working Group 3 (Mapping from Spaceborne Imagery) of ISPRS Commission IV (Cartographic and Data Bank Applications of Photogrammetry and Remote Sensing).

During the 2 years of the committee's existence, the chairman has worked with a sizable number of cartographic and remote sensing specialists who make up the committee and who have provided input in the form of subject matter, comments, and reviews. Not all committee members concur fully in the final report and their reservations thereto have been noted and made a part of this report. The final report will be submitted to the XV ISPRS Congress in Rio de Janeiro in June, 1984.

Those committee members who made substantial contributions to this report are listed below:

### Committee Members

Pierre-Marie Adrien	Inter-American Development Bank
David Alspaugh	US, DMAAC
Ken Ando	US, DARPA
William Barnes	US, NASA Goddard
Fred Billingsley	US, JPL
Alden Colvocoresses	US, USGS (Chairman)
John DeNoyer	US, USGS
Ian Dowman*	UK, University College London
Wolfram Drewes	World Bank
Kadri El Araby	United Nations, Natural Resources & Energy Division
Norbert Falzon	United Nations, Natural Resources & Energy Division
Elizabeth Fleming	Canada, Department of Energy Mines & Resources
James Hammack*	US, DMAHTC
Fred Henderson*	US, Geosat Committee
David Hocking*	Australia, Photogrammetry & Remote Sensing Society
Gottfried Konecny	FRG, University of Hannover
Franz Leberl	Austria, University of Graz
Donald Light	US, USGS
Mark Macomber	US, DMAHQ
Ron Ondrejka	US, ITEK Corp.
Jack Staples	PAIGH
John Trinder	ISPRS, Commission I
George Zarzycki	Canada, Department of Energy Mines & Resources

\*Members who generally concur with the report but have requested that their reservations be appended thereto (see Appendix C).

## CONTENTS

	Page
Guidelines and Concepts .....	1
Basic Requirements .....	2
Definition of Immediate Task .....	4
Definition and Selection of Sensing Mode .....	4
Resolution and Radiometric Considerations .....	8
Satellite Orbit .....	10
Sensor System .....	11
Geometric Considerations .....	14
Data Transmission and Storage Modes .....	16
Transmission Rate Control - OMS Options .....	18
Processing Considerations .....	19
Satellite Life and Launching Mode .....	22
Economic Considerations .....	22
Political Considerations .....	25
Summary .....	26
Recommendations .....	27
References .....	28
Appendix A - Abbreviations and Acronyms .....	32
Appendix B - Letter from ISPRS President Authorizing the Committee .....	33
Appendix C - Reservations of Committee Members .....	35

## ILLUSTRATIONS

Figure 1. Landsat Receiving Stations Coverage .....	6
2. Continuous Stereo Imaging Concept .....	12
3. OMS Sensor Configuration .....	13
4. Projected Balance for Space Segment of an Orbital Mapping System .....	24

## TABLES

Table 1. Basic Modes of Earth Sensing from Space .....	5
2. Basic Parameters for Selected Electro-Optical Earth-Sensing Systems .....	7
3. OMS Epipolar Condition .....	21
4. OMS Time-of-day for Descending Node vs Optimum Conditions for Stereo Correlation .....	21
5. Balance Sheet for Space Segment of an Orbital Mapping System .....	23
6. OMS Suggested Basic Parameters .....	27

REPORT OF THE COMMITTEE  
FOR  
"ACQUISITION AND PROCESSING OF SPACE DATA FOR MAPPING PURPOSES"  
OF WORKING GROUP IV/3  
OF THE INTERNATIONAL SOCIETY FOR PHOTOGRAMMETRY  
AND REMOTE SENSING (ISPRS)

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GUIDELINES AND CONCEPTS

Subject committee was authorized and instructed to proceed by letter from the President of ISPRS dated July 30, 1982, (see Appendix B). Objectives and general guidelines for the committee are contained in this same letter. It is inferred that the committee will limit its purview to the Earth and as a minimum define a system which is suitable for precise three-dimensional mapping at a determined scale and contour interval. It is recognized that conventional line maps include information on names, road classification, boundaries, and feature identification that cannot be obtained from any space system. In fact the cartographic products which appear most compatible with space systems are image maps and derived thematic maps. Space acquired data can certainly be used for the limited revision of line maps (Fleming, 1982) and for the generation of contours (Doyle, 1982). They may also be used as a basis for the preparation of new line maps but must be augmented by pertinent auxiliary data from other sources. This committee recognizes that the image map lacks the explicit form of the line map but also recognizes that the image map, when properly made, is a valuable cartographic product that can be produced at a fraction of the cost and time of a line map. Moreover, in many types of areas the image map provides important information not available on line maps. Image or photo maps are currently produced in a wide variety of scales by both governmental and commercial agencies. These photomaps are nearly all based on aerial photography and are generally monochromatic (black and white). Aerial photography, because of its wide-angle nature, creates unwanted geometric and radiometric anomalies and the lack of color limits the information content of the image. Space-borne Earth-sensing systems are generally of a narrow-angle field-of-view, near orthographic, and this basically eliminates many of the anomalies of the aerial camera. Obtaining the color response is relatively simple with the electro-optical systems now in space, so that producing a color image map of uniform high radiometric quality is achievable (Colvocoresses, 1983b). Maintaining geometric fidelity in an image map derived from space imagery is likewise quite simple due to the orthographic view, so that many of the problems inherent in photomapping from aerial photographs do not exist with either electro-optical or film space systems. Moreover, image mapping from space readily lends itself to automation and rapid production, whereas the preparation of a line map is normally a matter of several years' effort. Thus, this committee recognizes its basic goal of defining a system which can, as a minimum, produce image maps of suitable scale which meet accepted standards for positional accuracy and produce data from which topography can be readily derived.



By accepting these guidelines, the required spatial resolution,\* which is a key parameter in any Earth-sensing system, will in turn be defined. The following sections of this report will cover both map scale and resolution considerations in detail.

## BASIC REQUIREMENTS

According to a recent report on global mapping (United Nations, 1983) only about 42% of the Earth's land areas (exclusive of Antarctica) has been topographically mapped at scales suitable to support development. This same study and others (Konecny, et al., 1979; Dowman, 1981) indicate the scales to support such development should be of 1:50,000 or larger and with contour intervals of 40 m or less. Moreover, the cited United Nations report indicates that for precise larger-scale mapping, 1:50,000 is the scale most commonly used throughout the world and 20 m is the most common contour interval for such maps. Thus there is a recognized requirement for a three-dimensional mapping capability to meet the needs of undeveloped and developing nations or other areas which are generally unmapped in the form indicated. It is interesting to note that mapping aerial photographs exist for many of the unmapped areas of the world. However ground control is generally non-existent or too sparse to support conventional mapping for such areas and the funds required to establish such control are simply not available. A space system, if properly defined, greatly reduces the need for ground control and (at least potentially) the cost of mapping. Thus the requirement is not simply for a mapping capability but for one which is more cost effective than conventional aerial methods.

The mapping of the Earth's physical surface in three dimensions is basically a one-time task, but cultural features and land use, which may be depicted in two-dimensional (planimetric) form, are subject to constant change. Their repeated coverage for revision purposes does not necessarily require a stereoscopic system but may well be accomplished with a nearly orthographic monoscopic system. The requirement for map revision generally exists for all inhabited (and some uninhabited) areas but is particularly high in rapidly developing and well-developed areas where the goal is to perform revision on a 5- to 10-year basis (Konecny et al., 1979). During the past 10 years systems such as Landsat have created a new requirement by demonstrating that land cover, land use, and particularly the areal extent of agricultural crops and forests can be monitored and mapped from space more efficiently than by any other means. There is now a recognized requirement for a space system that can monitor and map crop and forest acreage as well as other aspects of land use and land cover (United Nations, 1982). The unique characteristics of Landsat 1, 2, and 3 also permit a profound increase in geological mapping capabilities on a global basis. The recent imaging by Landsats 4 and 5 has further demonstrated that increased resolution and the "shortwave" infrared wave bands (1.55-1.75 and 2.08-2.34  $\mu\text{m}$ ) provide a further significant capability in geologic mapping (Fred Henderson, Geosat Committee, written communication, 1983). Thus the advantages of space systems to

\*Resolution throughout this paper is described in terms of the picture element (pixel) dimension on the ground. It is recognized that the resolution of film cameras is normally indicated by the ability to discriminate line pairs. Estimates on the relationship of the pixel to the line pair vary from 1.6 to 2.83 but the value of 2 is in common use and considered to be an acceptable relationship insofar as information content is concerned.

geologic mapping have in turn created a very real requirement by providing a valuable tool to assist in man's quest for mineral resources and his understanding of the Earth's structure.

Although 1:50,000 is a recognized desirable mapping scale, it is inadequate for the proper portrayal of densely developed areas, and it is larger than necessary for many barren or underdeveloped areas. For the densely developed areas where maps of scales larger than 1:50,000 are required, it is felt that aerial surveys rather than space systems should be employed. On the other hand, a space system, capable of mapping at the 1:50,000 scale, should, insofar as possible, be designed to map efficiently at scales much smaller than 1:50,000 such as 1:250,000 or even 1:1,000,000.

Another requirement is the mapping of the shallow seas. These vast areas, except for established shipping lanes, are basically unmapped in any detail, yet their economic importance is now well recognized (Borgese, 1983). Until recently their comprehensive mapping was beyond the capabilities and resources of mankind but Landsat has demonstrated that sizable portions of the shallow seas to a depth in the order of 30 m can be effectively mapped from space (Hammack, 1977). Moreover, this can be done with reasonably high spatial accuracy and with indications of water depth where suitable conditions exist.\*

An Earth-sensing system records many items, principally of a transitory nature, for which precise geodetic position may not be required. Landsat has recorded oil slicks, phytoplankton blooms, and the polar rescue operations of ice breakers, for example. However, developing positional systems such as the Global Positioning System (GPS) (Klass, 1980) permit any ship or vehicle with appropriate receivers to be geodetically located within 50 to 100 m on the Earth's surface. Thus there is a requirement to be able to describe any recorded item with a similar degree of accuracy. Moreover, isolated mapping projects must often be conducted in areas where no geodetic control is available. Relating such projects to the Earth's figure with some precision is highly desirable. Being able to do so within 50 to 100 m (in all three axes) is of obvious value and a desirable feature, if not a defined requirement.

Heretofor conventional mapping concentrated on the accurate depiction and identification of fixed land features. Through space image-mapping the discipline can be expanded so that it also encompasses the mapping and/or monitoring of:

- geologic rock, mineral and soil units, and geobotanical patterns related to underlying rocks and soils;
- transitory land features involving agricultural patterns, changes in land cover and land use; also environmental conditions such as snow and ice cover, floods, forest cuttings and burns; droughts, erosion, desertification, and the existence of certain pollutants;
- fixed and transitory bottom features in suitable shallow sea areas; and
- transitory offshore surface or near-surface conditions such as ice, turbidity patterns, oil slicks, plankton concentrations, and even shipping activity.

\*Water must be reasonably clear with a reflective non-vegetated bottom. Such conditions are common throughout tropical (and some other) areas not affected by turbid river discharge. Sun elevation must be sufficiently low to preclude specular reflection.

The mapping of fixed land features is considered fundamental and of first importance, but the others involve applications which are also of high economic interest and which may be accomplished by a well-defined mapping satellite system. These additional applications warrant consideration as long as the fixed land feature mapping is not compromised. In fact, it appears necessary to include such applications in order to justify an operational mapping satellite system. Thus the fundamental requirement is to define a space system that will support two- and three-dimensional mapping up to the 1:50,000 scale and, in so doing, provide data that can be applied to other related applications of economic, social, and scientific importance.

#### DEFINITION OF IMMEDIATE TASK

This committee, recognizing the cost and complexity of Earth-sensing systems, considers its immediate task to be the definition of a system which can be initiated at this time, placed into operation within the next 5 to 10 years and which will best meet known requirements in a cost-effective manner. This committee assumes that the basic requirements, as previously spelled out, are valid.

#### DEFINITION AND SELECTION OF SENSING MODE

This committee recognizes five basic modes of sensing the Earth from space that are relevant to the task at hand. Three of these are electro-optical, one is active microwave, and the fifth involves film cameras (Table 1). The five modes appear to be basically exclusive and one must be selected for the task at hand. The following rationale is presented as a basis for this selection.

Mode 1 has been demonstrated by Landsat for over 12 years and is a leading candidate for an electro-optical mapping satellite system. Recent studies (JPL, 1979 and 1980; ITEK, 1981) indicates this mode is highly suitable for stereo as well as monoscopic coverage and thus can perform three- as well as two-dimensional mapping. It has one geographic limitation in that the two polar regions above the 82°/83° parallels are not covered by this mode as so far defined by Landsat. A single Landsat-type satellite will cover many areas only once per 16 or 18 days and thus has limited capabilities for the monitoring and mapping of highly transitory phenomena. The acceptance of this mode is illustrated by Figure 1 which depicts the current distribution of Landsat receiving stations.

Mode 2 differs from Mode 1 in that the sensor can be directed away from the nominal vertical and orbital path. This permits increased frequency for sensing specific areas but, in so doing, precludes systematic coverage of sizable areas within a given epoch. It does however produce stereoscopic imagery of the specific areas involved by directing the sensor from separate paths to the same scene. This will enhance the interpretability of the area, but because of the geometric uncertainties involved in acquiring such stereo data, its value for topographic mapping will be quite limited. Moreover, directing the satellite or sensor towards specific areas involves disturbing forces which degrade the geometric fidelity and in turn the overall mapping capability of the system (ITEK, 1981). This mode is particularly adopted to the repetitive monitoring of selected areas as opposed to comprehensive wide area mapping. Beginning in 1985 SPOT should be demonstrating this mode and, if its effectiveness is established, a SPOT type system might well prove to be a worthwhile adjunct to a dedicated mapping system rather than the primary data source.



Table 1.--Basic modes of Earth sensing from space\*

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<u>MODE 1</u> (EO)	Sun-synchronous, systematic (fixed) coverage, mono- or stereoscopic. <u>Landsat</u> (U.S. Geological Survey, 1979; Goddard Space Flight Center, 1977), <u>Mapsat</u> (ITEK, 1981) are examples.
<u>MODE 2</u> (EO)	Sun-synchronous but selective as to imaged path. Permits more frequent coverage. <u>SPOT</u> (Chevrel, Courtois and Weill, 1981) is an example.
<u>MODE 3</u> (EO)	Geosynchronous, three or more satellites, systematic or selective coverage. <u>GOES</u> , <u>SMS</u> (Ludwig, 1975), SEOS (ITEK, 1975) are examples.
<u>MODE 4</u> (AM)	Radar--Sun-synchronous, geosynchronous or arbitrary orbit, self-generating imaging signals. <u>Seasat</u> (NOAA, 1979), <u>SIR-A</u> (Settle and Taranik, 1982) are examples.
<u>MODE 5</u> (FC)	Frame or panoramic camera, any orbit, generally film recovery. <u>LFC</u> (Doyle, 1979), <u>Metric Camera on Shuttle</u> (Konecny, et al, 1979) are examples.

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EO = Electro-Optical    AM = Active Microwave    FC = Film Camera

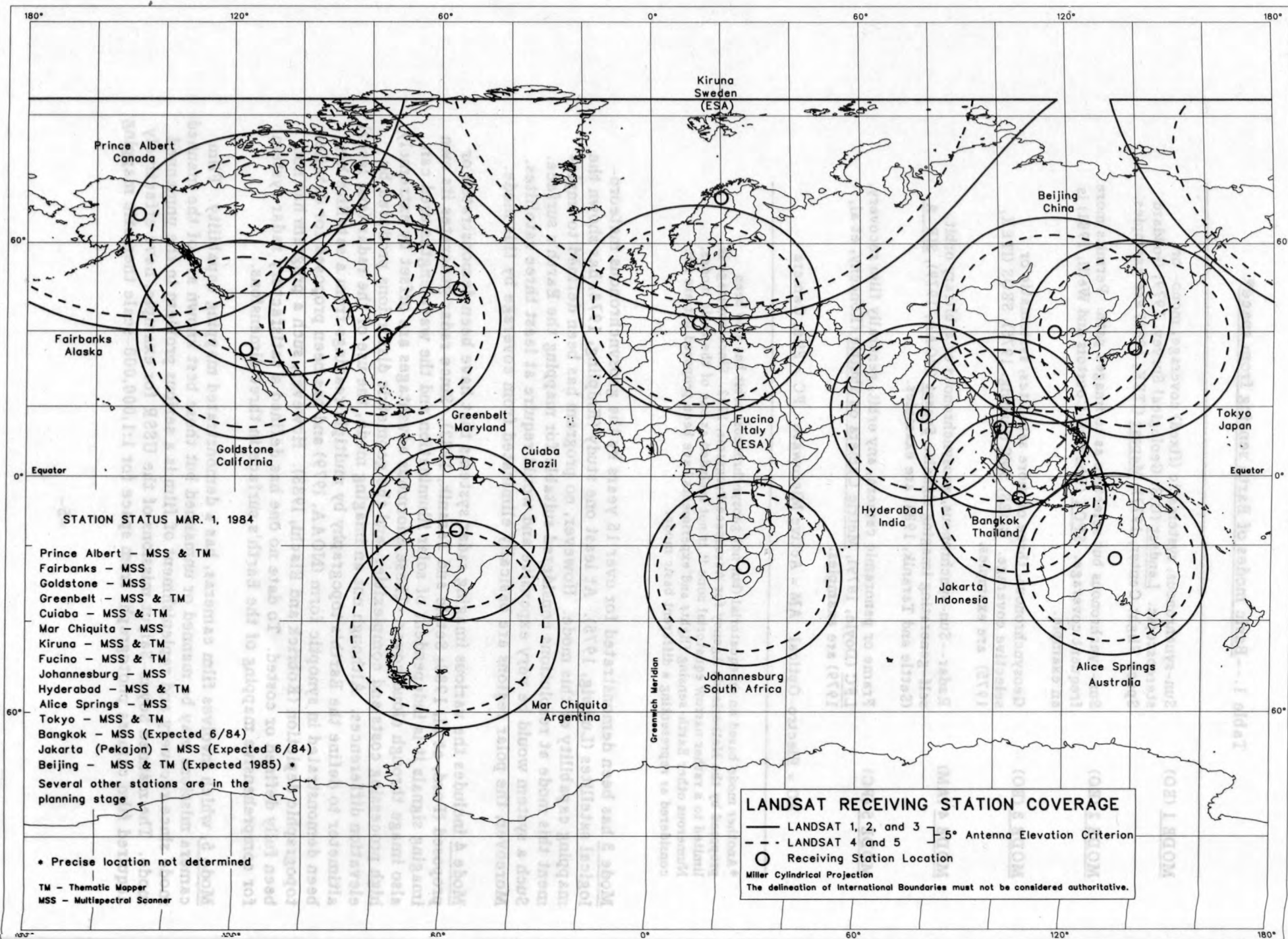
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\*Another mode based on an equatorial (but not geosynchronous) orbit has also been proposed by the Netherlands Agency for Aerospace Programs, 1982. Since coverage is limited to a rather narrow equatorial zone it is not included as one of the basic modes. Numerous other Earth-sensing flights and experiments have been proposed but are not considered as representing a different basic mode.

Mode 3 has been demonstrated for over 15 years by the geosynchronous meteorological satellites (Ludwig, 1975). At least one study (Knipling, 1974) has shown the mapping capability of this mode. However, no program has been defined to implement this mode at resolutions considered suitable for mapping the Earth's surface. Such a system would be very expensive and would require at least three satellites. Moreover, the polar regions are basically eliminated from coverage by this mode.

Mode 4 includes the various imaging radar systems that have been demonstrated or proposed (Ford, et al, 1980; Settle and Taranik, 1982). Since radar generates its own imaging signals it is independent of solar illumination and the wavelengths used can also image through cloud cover. These enormous advantages are offset by extremely high processing costs and complexities, and the geometric distortions produced by elevation differences. Although not an imaging mode, the use of the radar (and laser) altimeter to define the Earth's topography by multiple readings from a satellite has been demonstrated in synoptic form (NOAA, 1979) and has been proposed for detailed topographic depiction (Kobrick and Elachi, 1983). However, such a program has not been fully defined or costed. To date no one has defined a satisfactory radar system for comprehensive mapping of the Earth's surface in three dimensions.

Mode 5, which involves film cameras, has a demonstrated mapping capability. Film camera missions may be manned or unmanned but those best known are of the manned mode since recovery and replenishment of film is a serious problem in the unmanned mode. The manned Soyuz-Salyut missions of the USSR for example, have effectively acquired film camera photographs from space for 1:1,000,000-scale thematic mapping



purposes (United Nations, 1981). However, before any such system could be applied on a global operational basis, the enormous cost and complexities associated with manned flights must be reconciled. There is no question but that manned space flights offer usable platforms for film cameras and several Shuttle flights involving the Metric Camera (European Space Agency) and Large Format Camera (NASA) have been flown or are scheduled. The Soyuz-Salyut system which is, in effect, a manned space station of indefinite duration, may be expected to continue to photograph sizable areas between the  $51.6^\circ$  parallels which define its orbital inclination. The USSR Cosmos series, involving automated Sun-synchronous flights of 15 to 30 days, carry film cameras which have been used to record crops during the past several summers (Doyle, 1983). Both manned or unmanned (automated) film camera flights are as so far defined of limited (fixed) duration and thus the acceptable imagery acquired from any such flight is likewise limited. Manned flights, thus far, generally follow lower inclination, non Sun-synchronous orbits and provide only limited time periods of suitable illumination. The usable coverage obtained from any film camera flight is severely limited as compared to an electro-optical Sun-synchronous flight of several years' duration.

Although there are no reports available which document the determination of heights with any real precision from space-borne cameras, the geometric fidelity of film cameras, whether flown in aircraft or in space, is well known. Where suitable base-to-height ratios are applied, as with the Large Format Camera configured for space shuttle flights, it may be expected that contouring as close as 20 m may be achieved (Doyle, 1983). Film cameras may be flown on dedicated Sun-synchronous orbits of several months duration but such systems still involve the complex problems of film retrieval and are not suited to the monitoring and mapping of transitory conditions as sizable delays are involved between acquisition and the general availability of the data. The most serious problem with film systems is the basic response limitations of film itself (American Society of Photogrammetry, 1980). In many areas it is impossible to record the full dynamic range of the Earth scene with high sensitivity on film and, as is discussed in the following section, spectral band options with film are highly limited. In-flight adjustments as to aperture and/or shutter speed can be made but any given scene of high contrast will either fail to be fully recorded or, if fully recorded, will be at low sensitivity. It has been recently demonstrated (Colvocoresses, 1984) that a high-resolution digital scanner/plotter can efficiently digitize, transform, and plot an image without any apparent loss of resolution. However, the resulting digital data will still be limited to the information content of the input which in this case would be the aerial film. On the other hand electro-optical systems have a combined dynamic range and sensitivity well beyond that of film. This has been recently demonstrated by astronomers (Kristion and Blanke, 1982) who recorded the return of Halley's Comet electro-optically when it was still well beyond the imaging capability of film systems.

This committee recognizes the importance of the various modes and suggests that all five (and others) may eventually find their place as man develops a comprehensive capability to monitor, map, and better understand the physical Earth surface and its environmental factors. However, objective analysis of these five modes leads to the conclusion that only Modes 1 and 5 are now serious candidates for a global mapping satellite system. The other modes are dropped from immediate consideration for the reasons given. Mode 5 (film camera) has an obvious three-dimensional mapping capability--which is considered paramount. The disadvantages of Mode 5 are, however, fundamental and if the technical and economic feasibility of the electro-optical Mode 1 can be established, it is the logical choice. This is because Mode 1, being based on the digital mode, has the potential for data availability in near real time and can thus provide timely information on transitory phenomena. The film mode lacks this attribute and also involves the stated limitations of film itself.



The remaining body of this report deals principally with the parameters and problems associated with Mode 1, since the parameters and problems of Mode 5 are already well known and documented (Doyle, 1979; Konecny et al, 1979). For convenience the Mode 1 system described herein is referred to as the Orbital Mapping System or OMS. This report will thus evaluate Mode 1 and indicate to what extent the two modes should be supported by the concerned international community with respect to an operational Earth-sensing system having mapping capabilities.

## RESOLUTION AND RADIOMETRIC CONSIDERATIONS

Resolution is perhaps the most critical parameter for an Earth-sensing system. In the digital domain of electro-optical sensing this involves the fundamental picture element (pixel). Spatially the pixel is defined in terms of its ground dimension and, for simplicity, treated as a square abutting adjacent pixels. Studies based on Landsat and other space systems (United Nations, 1982; ITEK, 1981; Konecny et al, 1982; Colvocoresses, 1984) indicates that a pixel dimension of 10 m or smaller is required to produce a suitable image map of 1:50,000 scale and that a line map of the same scale requires source data of no larger than 5-m pixel size. The cited ITEK study and an analysis shown under Geometric Considerations indicate that 20-m contours can be derived from a 10-m-pixel system where a satisfactory base-to-height ratio and adequate geometric constraints are imposed. However, 10-m pixels are much too small for small-scale image mapping. Thus an Earth-sensing system should have the on-board capability of data compaction which would enlarge the effective resolution element to any desired multiple of 10 m and thus simplify the data storage, transmission, and processing problems for areas where the high resolution (small pixel size) is not needed. The 10-m (or smaller) pixel appears to be the size necessary to meet the basic requirement. It is interesting to note that this is the dimension selected for the high-resolution mode on SPOT and for several other proposed systems. Data rates, engineering, and political sensitivity are considerations which also affect the choice of the pixel dimension and 10 m appears to be compatible with such considerations. Recent tests with Landsat Thematic Mapper data and SPOT simulations indicate that 10-m data can be usefully portrayed at scales larger than 1:50,000. However, there is no assurance, at this time, that map accuracy and informational standards would be maintained at larger than 1:50,000 scale.

Radiometric requirements vary according to different applications and there is no way of satisfying all users with one waveband or single set of wavebands. Aerial photography has long relied on a single broad (panchromatic) wave band. However, recent authoritative reports (United Nations, 1982; NASA, 1982) clearly indicate that any Earth-sensing space system should be multispectral. Table 2 indicates the wave-bands in use or proposed for various Earth-sensing systems. Although a topographic or planimetric map can be made from only a single band, comprehensive land and shallow-sea image mapping call for more than one band. Moreover, thematic mapping of most subjects requires the multispectral approach. As the number of wave-bands increase, the cost of acquisition and processing goes up (United Nations, 1982) and per band signal strength goes down. Landsats 1, 2, and 3 have demonstrated the utility of three bands, two in the visible and one in the near infrared.\* For near-infrared wavelengths beyond 1.05  $\mu\text{m}$ , non-silicon cooled detectors must be used, which increases the complexity and cost of the satellite.

\*The other near-infrared band, 0.7 to 0.8  $\mu\text{m}$ , of the Landsat multispectral scanner had only limited application.

Table 2.--Basic parameters for selected electro-optical Earth-sensing systems

	LANDSAT 1, 2, & 3 MSS <sup>1</sup>	LANDSAT 4&5 TM	METEOR		MOMS-1	SPOT	MEOSS <sup>2</sup>	MOS-1	MOMS-2 <sup>3</sup>	MAPSAT
Status or expected launch	Flown	Flown	Flown		Flown	Late '85	April '85	'86	Proposed	Proposed
Orbital height (km)	<sup>4</sup> 919	<sup>4</sup> 705	<sup>4</sup> 650 BIK-E "Fragment" MSU-E		<sup>5</sup> 296	<sup>4</sup> 832	400	<sup>4</sup> 909	300-1000	<sup>4</sup> 919
Swath width (km)	185	185	30	85	140	60	180+	200	140-500	<sup>6</sup> 185
Resolution, pixel dimen.(m)	80	30	30	80	20	10 (pan.) 20 (color)	67-150	50	20-65	<sup>6</sup> 10
Spectral bands (µm)	0.5-0.6	0.45-0.52	0.5-0.7	0.4-0.8	5.75-6.25	0.51-0.73 (pan.) ?		0.51-0.59	0.6±0.025	0.47-0.57
	0.6-0.7	0.52-0.60	0.7-0.8	0.5-0.6	8.25-9.75	0.50-0.59 ?		0.61-0.69	0.9±0.075	0.57-0.70
	0.7-0.8	0.63-0.69	0.8-1.0	0.6-0.7		0.61-0.68		0.72-0.80	1.6±0.1	0.76-1.05
	0.8-1.05	0.76-0.90		0.7-0.8		0.79-0.89		0.80-1.10	2.2±0.1	
		1.55-1.75		0.8-1.1						
		<sup>7</sup> 10.4-12.5		1.2-1.3						
		2.08-2.35		1.5-1.8						
				2.1-2.4						
Transmission band	S	X,KU	?	?	na	X	S	X	?	S or X
and data rate (Mb/s)	15	85	?	?	<sup>8</sup> 40	25+25	8.6	8.78	?	48
Stereo mapping capability	no	no	no	no	no	limited	limited	no	yes	yes

<sup>1</sup> The Landsat MSS is also flown on Landsats 4 and 5. However, the band designations were changed from MSS 4, 5, 6, and 7 (in order shown) to MSS bands 1, 2, 3, and 4 on Landsats 4 and 5. In addition to the MSS, return beam vidicon (RBV) cameras were also flown on Landsat 1, 2, and 3. On Landsats 1 and 2 these bands recorded at 80-m resolution but had limited use. The RBV's on Landsat 3 were panchromatic, of 30-m resolution, and recorded sizable portions of the Earth's surface.

<sup>2</sup> ME OSS parameters relative to orbit, resolution and spectral bands are not fully defined.

<sup>3</sup> MOMS-2 parameters relative to platform (spacecraft), orbit, resolution and spectral band are flexible.

<sup>4</sup> Near-polar sun-synchronous orbit.

<sup>5</sup> 28.5° orbit inclination.

<sup>6</sup> Variable swath width, resolution and stereo modes.

<sup>7</sup> 120-m pixel dimension.

<sup>8</sup> No data transmission, 30-min on-board data storage.

However, recent developments (Elabd and Villani, 1982) indicate that newly developed passively cooled detectors offer a possible approach to solid-state sensing to the  $1.75\ \mu\text{m}$  wavelength. However, such sensing, as is being demonstrated by band 5 ( $1.55$  to  $1.75\ \mu\text{m}$ ) of the Landsat 4 and 5 Thematic Mappers, must first prove to be justified for a general-purpose operational mapping satellite. The  $2.08$ - $2.35\ \mu\text{m}$  Thematic Mapper band, although of demonstrated geologic importance, involves complex detectors which, based on current technology, are not compatible with the simple linear array systems being developed for the next generation of remote sensing satellites. Thermal bands ( $6$  to  $14\ \mu\text{m}$ ) are in operational use at lower resolutions but there are both engineering and scientific reasons for not including thermal band regions on the satellite designed to image the Earth in the visible and near-infrared. Thermal bands require cryogenic detection cooling and most thermal applications need to separate the solar from the non-solar effects and thus need a dawn and dusk type orbit to separate these two effects. From the above it can be seen that there are a sizable number of candidate wave bands, but at this time there are three which stand out as being essential for a general purpose operational satellite. Additional wave bands cannot be justified until additional applications have been demonstrated from the experimental satellites (such as Landsat 5) and the cost effectiveness of such bands validated. The three wave bands which now appear to be essential and fully justified for an Earth-sensing system are as follows:

Band 1 -- blue green,  $0.47$  to  $0.57\ \mu\text{m}$ .\* This band is particularly suited for water penetration and water analysis as well as recording many land features in areas of clear atmospheric conditions. Its value for shallow-sea mapping and water turbidity analysis has been well demonstrated by the analogous band 4 ( $0.5$  to  $0.6\ \mu\text{m}$ ) of the Landsat multispectral scanner (MSS). However, the limits have here been slightly lowered from those of MSS band 4 to improve water-penetration capability.

Band 2 -- red,  $0.57$  to  $0.69\ \mu\text{m}$ .\* This band provides optimum records for most natural and cultural features. It is equivalent to band 5 ( $0.6$  to  $0.7\ \mu\text{m}$ ) of the Landsat MSS, although its lower limit has been dropped to provide a stronger signal.

Band 3 -- near infrared,  $0.76$  to  $1.05\ \mu\text{m}$ .\* This band gives a high response to growing vegetation and clearly delineates water boundaries. It also has the capability of recording through considerable atmospheric obscurations such as haze, smoke, and even thin clouds. It is equivalent to band 7 ( $0.8$  to  $1.05\ \mu\text{m}$ ) of the Landsat MSS with a slightly lowered lower limit to increase signal strength.

#### SATELLITE ORBIT

For an Earth-sensing satellite, a Sun-synchronous circular orbit appears optimum. The principal variables appear to be the nominal orbital altitude above the figure of the Earth and the local Sun time for crossing the descending node (equator). The

\*The indicated limits are based principally on the results obtained from Landsats 1, 2, and 3 with minor modifications based on limited analysis of the Thematic Mapper wave bands on Landsats 4 and 5.



altitude considered for such satellites varies from 500 to 1200 km. Landsat 1, 2, and 3 orbit at 919 km; Landsats 4 and 5, at 705, and SPOT, at 832 km. Higher altitudes require larger optics and higher launching costs, but provide sizable advantages in data acquisition patterns, such as daily progression and transmission ranges. Holding the same Sun-synchronous orbital altitude provides continuity in ground coverage patterns, which is important for any mapping system. Analysis of orbital options indicates that the 919-km orbit of Landsat 1, 2, and 3, which provides daily progression and was utilized for over 10 years, is considered the most suitable (ITEK, 1981; Colvocoresses, 1976, 1977). The optimum time for crossing the descending node is set at 8:30 a.m. for reasons given under Processing Considerations.

## SENSOR SYSTEM

For an electro-optical sensor to be geometrically competitive with a calibrated mapping camera, both the sensor and the platform (satellite) must be rigidly defined geometrically. Space provides a basically disturbance-free environment, and if the satellite is free of moving parts (except for inertial wheels, gyroscopes, and balanced tape recorders), a system of very high geometric fidelity can be achieved (Bartlett, 1977; Rose and Berkery, 1981; Moore, J.V., 1980, Stabilization and Control of the International Ultraviolet Explorer Including a Summary of Flight Performance, NASA, Goddard, unpublished).

On the image plane of a camera, film can now be replaced with a vidicon tube or solid-state detectors in either two- or one-dimensional arrays which create electronic signals. The return beam vidicons (RBV's) on Landsat, however, were rather poor radiometers, had limited dynamic range, and therefore lacked the sensing capabilities of solid-state arrays. Two-dimensional arrays provide a record analogous to a film camera but in so doing fail to provide a continuous data flow, which is desirable and feasible with a space system. On the other hand one-dimensional (linear) arrays of detectors can record continuously in either monoscopic or stereoscopic mode as illustrated by Figures 2 and 3. Optical-mechanical scanners such as employed on the Landsat series also utilize solid-state detectors but because of their moving parts, scanners are not considered suitable for a system of high resolution and geometric fidelity. As mentioned in a previous section, solid-state detectors which record beyond 1.05  $\mu\text{m}$  are complex and expensive. Silicon detectors which record up to 1.05  $\mu\text{m}$  are inexpensive, reliable, readily available, and their use is therefore recommended at this time. Linear arrays, both single-band and multispectral, utilizing silicon detectors appear to be preferred on the next generation of Earth-sensing satellites. This is exemplified by the French SPOT, German MOMS, and Japanese MOS and ERS. This linear array mode is commonly referred to as a pushbroom sensor and has been well described elsewhere (Billingsley, 1982).

The optical (energy collecting and focusing) system might be either refractive or reflective. Refractors, which involve the transmission of energy through glass elements, are well known and of proven performance. Reflective optics, which are also well known in the astronomy field have the ability to collect and focus a wide range of wave bands without distortion. However, they tend to be heavy, complex, and difficult to accommodate any sizable field-of-view. At this time refractors, which are available for the indicated task, are the defined optical mode (ITEK, 1981).

Since three-dimensional mapping is considered a valid requirement, the sensor system must be capable of stereo imaging. Mapping cameras have wide fields-of-view and accomplish this by repeated (overlapping) vertical imaging of the same area from

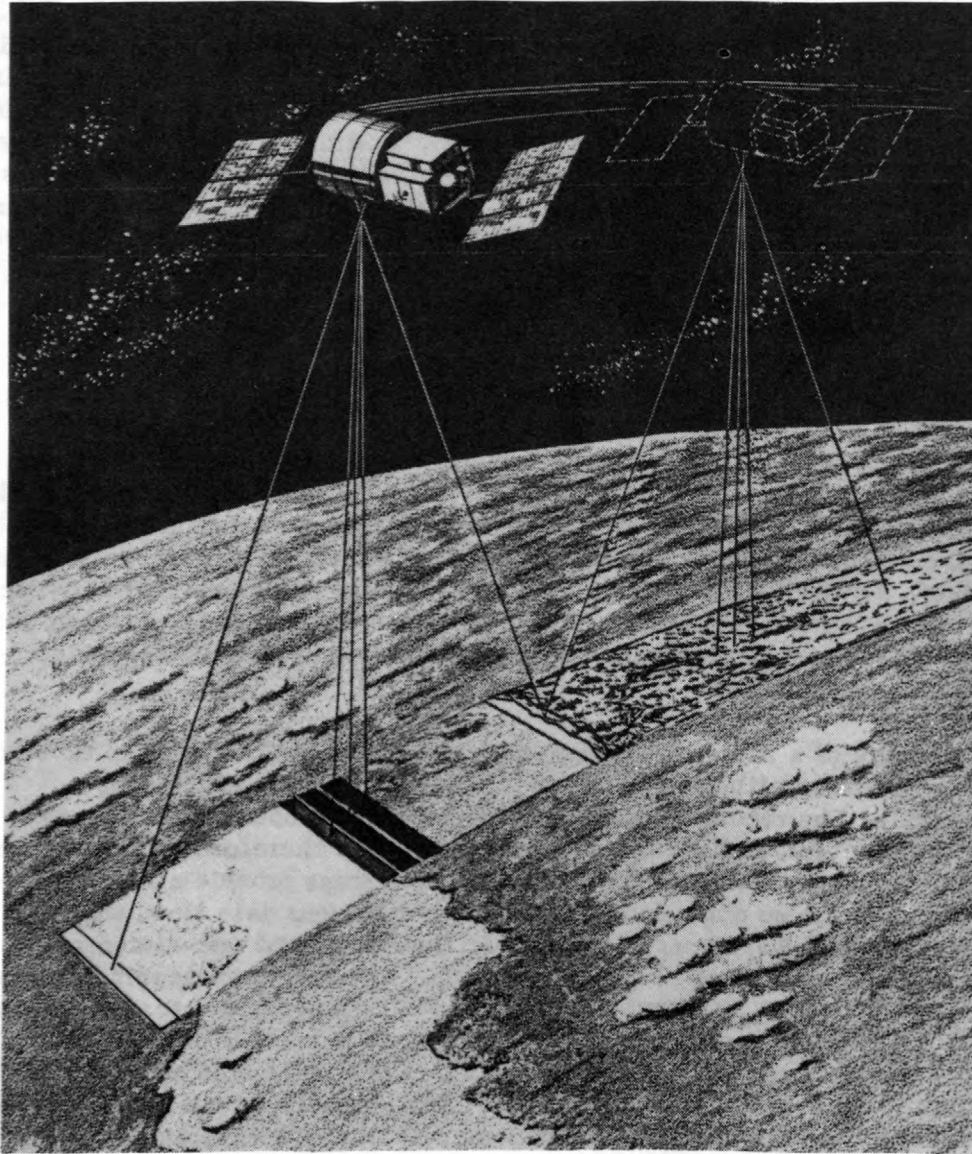
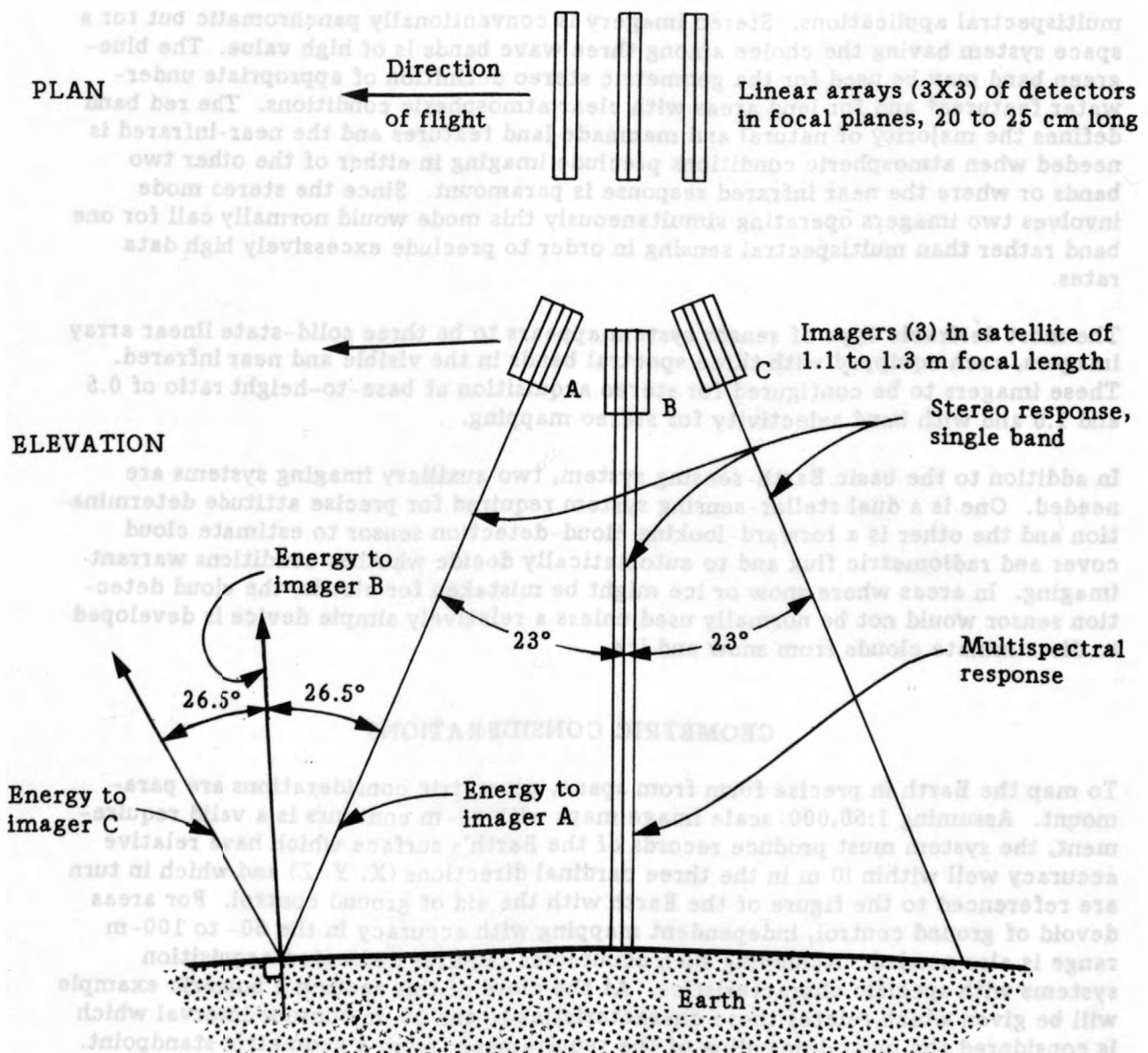


Figure 2.--Continuous stereo imaging concept.

sequential positions. The narrow field-of-view of a solid state linear-array sensor precludes this form of stereo imaging. Rotating the spacecraft, sensor or an optical mirror can accomplish stereo data acquisition from a single solid-state imager\* but, in so doing, disrupts continuity and complicates the geometric solution of the stereo model. Two, or preferably three imagers mounted in convergent mode, provide a means for obtaining continuous stereo imagery from a solid-state sensing system of narrow overall field-of-view and without the use of moving parts or changes in the basic attitude of either the spacecraft or sensor. Base-height ratios of 0.5 and 1.0 can be achieved from any reasonable altitude and at the 919 km orbit, by utilizing three imagers, one tilted  $23^\circ$  forward, one vertical and the third  $23^\circ$  aft (Figure 3).

\*An imager is referred to herein as a refractive optic with a digital image recording device such as linear arrays of solid-state detectors mounted in the focal plane of the optic.



Imagers A, B, and C are a rigid part of satellite. Imager B senses the same strip 60 seconds after A, imager C, 120 seconds after A. Any combination of A, B, and C produces stereo. Imager A and C are about 10% longer focal length to provide resolution compatible with imager B.

Figure 3.--OMS sensor configuration (not to scale).



The two indicated base-height ratios are considered necessary. The ratio of 1.0 is for relatively flat terrain where contour intervals and spot elevations of the highest precision are needed. A ratio of 0.5 is more desirable for rugged terrain where elevation precision requirements are less rigorous and the response from two stereo views must be as similar as possible to accommodate stereo correlation. Also the near-vertical view provides a basically distortion-free image for planimetric and multispectral applications. Stereo imagery is conventionally panchromatic but for a space system having the choice among three wave bands is of high value. The blue-green band may be used for the geometric stereo definition of appropriate underwater features\* and for land areas with clear atmospheric conditions. The red band defines the majority of natural and manmade land features and the near-infrared is needed when atmospheric conditions preclude imaging in either of the other two bands or where the near infrared response is paramount. Since the stereo mode involves two imagers operating simultaneously this mode would normally call for one band rather than multispectral sensing in order to preclude excessively high data rates.

The most desirable type of sensor system appears to be three solid-state linear array imagers, each equipped with three spectral bands in the visible and near infrared. These imagers to be configured for stereo acquisition at base-to-height ratio of 0.5 and 1.0 and with band selectivity for stereo mapping.

In addition to the basic Earth-sensing system, two auxiliary imaging systems are needed. One is a dual stellar-sensing system required for precise attitude determination and the other is a forward-looking cloud-detection sensor to estimate cloud cover and radiometric flux and to automatically decide whether conditions warrant imaging. In areas where snow or ice might be mistaken for clouds, the cloud detection sensor would not be normally used unless a relatively simple device is developed to discriminate clouds from snow and ice.

## GEOMETRIC CONSIDERATIONS

To map the Earth in precise form from space, geometric considerations are paramount. Assuming 1:50,000-scale image maps with 20-m contours is a valid requirement, the system must produce records of the Earth's surface which have relative accuracy well within 10 m in the three cardinal directions (X, Y, Z) and which in turn are referenced to the figure of the Earth with the aid of ground control. For areas devoid of ground control, independent mapping with accuracy in the 50- to 100-m range is also needed. Achieving such accuracies requires dedicated acquisition systems with specific characteristics. At the close of this section a numeric example will be given which relates these characteristics to the 20-m contour interval which is considered the most demanding of the requirements from a geometric standpoint. The required geometric characteristics are as follows:

- Positional determination -- The satellite position should be known to within 10 to 20 m in all three axes. Such precision will soon be possible through use of the Global Positioning System (GPS) which is currently being implemented (Klass, 1980) and the satellite must be equipped with a GPS (or equivalent) receiver.

\*Due to refraction, the base-to-height ratio for underwater features would be reduced by about 30% with a corresponding loss in heighting accuracy.

- Attitude (pointing) control -- Pointing of the sensors need not be exact but to simplify processing and ensure proper coverage, it should be kept to within  $0.1^\circ$  of the vertical to the Earth figure. This is well within the state-of-the-art for satellite control (Goddard Space Flight Center, 1977).
- Attitude determination -- This is one of the most critical considerations and requires reference to the star field for independent accurate mapping. Modern electro-optical stellar sensors can provide attitude references to within 5 to 10 arc-seconds (Deter, 1979). The lower figure, when obtained and combined with the lower positional accuracy figure of 10 m, would lead toward the lower independent ground positioning accuracy figure of 50 m. The 10 arc-second figure, which is well within the state-of-the-art, would lead toward the 100-m accuracy figure. Of course, to achieve such accuracies the stellar and Earth sensors must be rigidly oriented to each other and calibrated once in orbit. Since satellite stability is of a high order (see below), attitude determinations at 10-minute intervals are considered sufficient.
- Satellite stability -- If continuous stellar reference was obtained stability would, in theory, not be a critical problem. However, efficient processing (as described in a following section) requires a stable system. Satellites with no moving (actuated) parts, except for inertial wheels, gyroscopes, and tape recorders, now have stability in the order of  $10^{-6}$  degree per second ( $3\sigma$ ) in each axis (Goddard Space Flight Center, 1977). This means that such a satellite, when commanded to perform rotations in yaw, pitch, and roll at specified rates, will do so and, with very high probability, will deviate from such rates at no more than 1 millionth of a degree per second. Such stability can only be maintained if changes in attitude rates are of a very low order, such as are required to maintain specified attitude with respect to the rotating Earth from a satellite in near-polar circular orbit. Providing proper stability requires the elimination of mechanical scanners, directional antennas, and rotating solar panels during data acquisition. Such satellites exist for astronomic observations (Rose and Berkery, 1981), and Earth-sensing satellites with the same stability characteristics can be built today.
- Timing precision -- A continuously imaging satellite depends on precise timing for data correlation of the Earth's figure. Absolute timing to  $10^{-4}$  second is needed for such a precise mapping system. Relative timing to within  $10^{-6}$  second now exists (ITEK, 1981) and through occasional calibration, the  $10^{-4}$  second absolute time is readily achieved.
- Internal sensor geometry -- A linear array has only one significant dimension (defined as the Y direction for the OMS configuration) which involves the spacing of the detector elements. Such elements are today in the order of  $13 \mu\text{m}^*$  in size and can be centered to within one-tenth of the pixel dimension (ITEK, 1981). Moreover, any spatial deviations that might exist can be corrected through calibration since the array is fixed. Refractive optics, which are defined for this application, create some distortion and must be thermally protected. However, the full field-of-view of the optics is only about  $11^\circ$  and for such a narrow field, calibration, both before launch and in orbit, is relatively simple. The other (X) direction is defined by the satellite's heading and distances along this axis are measured by time. Since the satellite velocity is highly uniform during an imaging interval, and time is precisely measured, the X dimension is well defined.

\*During the summer of 1984 detectors as-small-as  $7 \mu\text{m}$  (center to center) were reported in technical journals.

In the event the GPS and/or stellar sensors are not available in adequate form for precise positioning and attitude, another system which is independent of both GPS and stellar sensors has been proposed by Messerschmitt-Bolkow-Blohm (Hofmann, 1982) and others (Gokhman and Billingsley, 1984). The first referenced system is known as the Stereo -- MOMS (Modular Optoelectronic Multispectral Scanner) and utilizes small arrays of detector elements which look fore and aft of the vertical linear array. Such a system theoretically provides the geometric capabilities of a wide-angle film camera to permit aerial triangulation along the orbital path, and in so doing resolves the photogrammetric orientation problem. However, the concept has yet to be demonstrated and in any case involves complex processing problems since its geometric fidelity depends on the unique recognition of ground features in two or more images as a basis for establishing exterior orientation. In theory, satellite position and attitude can also be determined from a highly stable single linear array system coupled with relatively dense ground control. This is the procedure that must be used for any height determination with a system such as SPOT by which the two SPOT positions and attitudes, which create the stereo pair, must be precisely determined from ground information. Another stereo imaging system is being developed in West Germany for launch on an Indian (Rohini) satellite. It is known as the Multispectral Electro Optical Stereo Scanner (MEOSS), (DFVLR, 1983). It involves the replacement of the film with solid state linear arrays in a Hasselblad camera. The basic parameters are listed in Table 2. If sufficient precision is applied to the satellite attitude control, the system would generate stereo data which could be directly formatted in epipolar planes. The systems principal limitations are its dependence on the relatively wide-angle optics of the Hasselblad camera, its low-inclination (non Sun-synchronous) orbit and low resolution.

Assuming the GPS and stellar sensors are available, a numeric error analysis developed by Dr. Frederick Doyle is given to show the relationship of an electro-optical Orbital Mapping System to the 20-m contour interval (see following page). Dr. Doyle has used the conservative estimate for digital correlation of stereo data of 0.5-pixel dimension. A recent study (Förstner, 1982) indicates digital correlation may be of a much higher order. Today's technology permits the definition and flying of an electro-optical Earth-sensing satellite which will meet the indicated geometric requirements for relative mapping of the Earth surface to scales as large as 1:50,000 with contour intervals as small as 20 m. For absolute mapping where no control is available the scale and contour interval would remain the same but the mapping, both horizontally and vertically, might contain a systematic error or bias of 50 to 100 m.

## DATA TRANSMISSION AND STORAGE MODES

Today 15 Landsat receiving stations exist or are under construction and others are being planned, most of which can receive in two channels at the rate of at least 15 megabits per second (15 Mb/s) per channel. By a relatively simple modification each channel can be raised to 24 Mb/s or a total of 48 Mb/s (ITEK, 1981) per station. Landsat (MSS) uses the S band (1.5 to 5.0 GHz) whereas SPOT and the Thematic Mappers on Landsat 4 and 5 utilize the X band (5.0 to 12 GHz). The question of whether operational Earth-sensing satellites should utilize the S or X band (or both) has not been settled, but future Earth-sensing systems should obviously be compatible with each other insofar as possible. In any case transmission must be compatible with receiving stations built or planned for operational use, and the 48 Mb/s data rate appears adequate and relatively economical to implement.

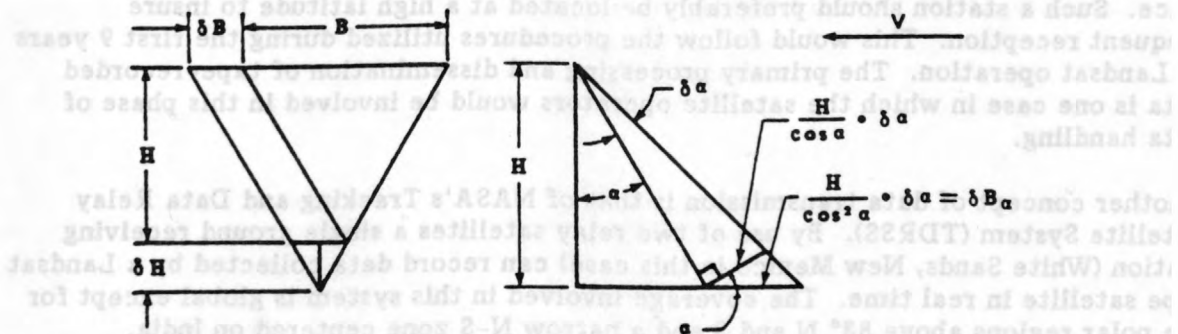


# RELATIVE ERROR ANALYSIS FOR CONTOURING ACCURACY OF OMS

Based on Analysis by Dr. Frederick Doyle

## Assumptions

1. Stereo base =  $B = H = 900,000$  m
2. Stability of satellite =  $10^{-6}$  degrees per second
3. Pixel to pixel correlation is accurate (rms) to 0.5 of the 10 m pixel dimension\*
4. Spacecraft velocity (V) is 7400 m/second (B represents 120 seconds)
5. Relative timing is accurate to  $10^{-4}$  seconds



## Error Analysis

The stereo model is assumed to have proper orientation with all Y parallax removed. Thus the errors of concern are in the X direction which is represented by the base (B).

$B = H \therefore \delta B = \delta H$ ; see figures

Pixel-to-pixel correlation error = 0.5 pixel = 5 m

Timing error:  $10^{-4}$  sec x 7400 m/sec = 0.7 m

Errors due to angular (attitude) change:

1. Roll and yaw error components in B are in the cm range and may be ignored.
2. Pitch error is illustrated by above figures where  $\alpha = 26.6$  deg. OMS is defined by a fore and aft angle of 23 deg off the vertical. In this simplified case, treating the Earth as a plane, this angle ( $\alpha$ ) becomes 26.6 deg.

$$\delta \alpha = \frac{10^{-6}}{\text{sec}} \text{ deg} \times 120 \text{ sec} \times \frac{1}{57.11 \text{ deg}} = 2.1 \times 10^{-6} \text{ rad}$$

$$\delta B_{\alpha} = \frac{H}{\cos^2 \alpha} \cdot \delta \alpha = \frac{900,000}{0.80} \times 2.1 \times 10^{-6} = \underline{2.4 \text{ m}}$$

$$\text{Mean error in H} = \delta H = \delta B = \sqrt{5^2 + 0.7^2 + 2.4^2} = \underline{5.6 \text{ m}}$$

The contour interval should be 3.3 x the mean error in H (U.S. Standards). Thus contour interval =  $5.6 \text{ m} \times 3.3 = 18.5 \text{ m}$  which rounds up to a 20-meter contour interval.

\*In some areas such as open water or very uniform forested areas stereo data will not correlate. The 0.5-pixel criterion is a conservative estimate based on the various results obtained by those who have performed digital stereo data correlation (ITER, 1981).

In addition to direct real-time transmission to receiving stations the system should have an on-board data storage capacity. This is to permit the acquisition of data beyond the range of receiving stations, which can be transmitted to a station when within its range. Tape recorders are now the best available storage mediums and, although they have a limited life, a tape recorder system should last for the designed 7-years, provided its use is properly controlled. Tape recorders (and other data-storage means) are rapidly being improved and storing the data for several thousand kilometers of an imaged path appears to be quite feasible (ITEK, 1981).

Whoever builds and operates the satellite must ensure that at least one ground station is available to receive tape-recorded data, process it into an acceptable tape format, and further transmit the data within a reasonable time and at a reasonable price. Such a station should preferably be located at a high latitude to insure frequent reception. This would follow the procedures utilized during the first 9 years of Landsat operation. The primary processing and dissemination of tape-recorded data is one case in which the satellite operators would be involved in this phase of data handling.

Another concept of data transmission is that of NASA's Tracking and Data Relay Satellite System (TDRSS). By use of two relay satellites a single ground receiving station (White Sands, New Mexico in this case) can record data collected by a Landsat type satellite in real time. The coverage involved in this system is global except for the polar regions above 83° N and S and a narrow N-S zone centered on India. Because the TDRSS involves directional antennas on the Earth-sensing satellite, only one receiving station, and one-way communications, it is not considered suitable for an international Earth-sensing system when compared to a global network of receiving stations as now exists for Landsat.

#### TRANSMISSION RATE CONTROL -- OMS OPTIONS

The maximum transmission rate for OMS has been defined at 48 Mb/s. A single linear array recording at high (10-m) resolution, 8-bit (256-level) quantization, and full (180-km) swath width generates 92.8 Mb/s (ITEK, 1981). The 48 Mb/s will obviously be exceeded in high resolution and multispectral or stereo mode unless certain data rate constraints are employed. The OMS concept includes several imaging and on-board processing options discussed below, which provides for such constraints.

- The swath width of Landsat on the Earth surface is 185 km which provides about 13% overlap between adjacent orbital paths at the Equator. By improved attitude and orbital draft control, the swath for the OMS can be reduced to 180 km without losing the equatorial overlap. Nevertheless when the high-resolution (10-m) mode is employed, the swath width will normally have to be reduced to accommodate the 48 Mb/s limit. Before considering a specific swath reduction other options should also be examined.
- Quantization of acquired signals (number of radiometric levels) is defined at 8 bits (256 levels) but, by using a forward-looking sensor to determine upcoming dynamic range and on-board non-destructive data compression the actual transmission will be at 5 bits (32 levels) or at most 6 bits (64 levels) (ITEK, 1981).

- Multispectral imaging does not require all three bands at the same resolution (Schowengerdt, 1980). One band at 10-m and the other two at 40-m resolution, for example, will result in little information loss when the data are properly processed as compared to three bands, all of 10-m resolution. However, the resultant data rate is reduced by 62.5%. This is the same principle by which color television makes use of only one high-resolution band.
- The sequential recording (as opposed to simultaneous recording) of two or more wave bands should achieve higher effective resolution than indicated by the nominal pixel size. For example, each detector which represents a 10-m pixel in the cross-track (Y) direction can be sampled every 15 m in the along-track (X) direction. If three spectral bands are involved, each sampling at 15-m intervals, but sequentially at 5 m intervals to each other, the resulting data can be reconstituted at perhaps 10-m effective resolution even though the data rate is only two thirds of what it would be if all three bands were sampled simultaneously at 10-m intervals. This concept is based on the fact that spectral wave bands in the visible and near-infrared regions are highly redundant (coherent) and a very large percentage of the recorded boundaries occur on all of the bands in these regions. Information theory states that the signal-to-noise ratio will increase as the square root of the number of coherent observations will apply to some extent (Schwartz et al, 1966). This again has been validated by Schowengerdt (1980); U.S. Geological Survey experimental work in which one high-resolution, (sharpening) band was used to increase effective resolution (Aviation Week and Space Technology, 1980); and by the deconvolution of Landsat multispectral scanner imagery (Dye, 1975).

Probably the most demanding condition would be where 10-m stereo data and 6-bit quantization are required. In this case the swath width could normally be no more than 60 km or one-third of the normal swath. Where such swath reduction is involved it would take 54 days instead of 18 (assuming no clouds) to cover an area of 180-km or greater width. An exception would be at or near the Equator where three 60-km swaths would not provide sufficient overlap to cover the 180-km normal swath. Swath width reduction is accomplished by command which directs that a specified portion of the sensed data be fed into the data transmission system but not by any changes in the satellite attitude. In any case the OMS requires a system of data control by which such parameters as resolution, sampling rates, quantization, wave bands, stereo-mode selection, and swath width are viable options. Providing such options and controls to OMS is well within the present state-of-the-art.

## PROCESSING CONSIDERATIONS

Data acquisition has heretofore comprised but a relatively small part of the topographic mapping process as compared to data processing. The orientation of stereo models and their subsequent manual exploitation is the slow and costly part of mapping which in large part has defied automation. The automation of the mapping process requires self orientation of the stereo data and then its correlation by computer rather than the human operator. The various efforts to accomplish automated correlation have been summarized (Konecny and Pape, 1981) and no less than six papers were devoted to this subject in a single recent publication (Photogrammetric Engineering and Remote Sensing, 1983). It is now possible to acquire continuous stereo data which is self-orienting, but it is unlikely that the computer can ever achieve 100% correlation of stereo data (Mahoney, 1981). As a recent



article indicates (Luczkiewicz and Piech, 1983), areas with too little detail, too much detail, or too rapid height variations simply won't correlate. Fortunately such areas are usually devoid of topographic expression or are of limited extent. Moreover, if the area so warrants, objects which create identifiable stereo response can be developed or emplaced to improve the correlation function.

One-dimensional, as opposed to two-dimensional correlation is more efficient and can generally yield results comparable to the two-dimensional mode. Today one-dimensional\* correlation is accomplished by computer after photographic models have been manually oriented and then digitally scanned along epipolar planes (American Society of Photogrammetry, 1980). Automated correlation is successful where suitable ground conditions exist and where the two stereo data sets produce unique but similar signal patterns. Such patterns generally occur when illumination response conditions are comparable. For optimum processing of stereo space data the following conditions should exist:

- The acquired data should be organized in epipolar planes which creates one-dimensional sets of self-orienting stereo data without further resampling of the data sets.
- The scene illumination and recording conditions should be such that the two sets of responses will form similar radiometric patterns.

Operational experience with automated stereo data processing is quite limited. As a previous reference (Konecny and Pape, 1981) indicates, automated stereo systems are both expensive and complex and now only suited for large mapping organizations. The U.S. Defense Mapping Agency Aerospace Center is such an organization and is probably the most experienced in this field. D. H. Alspaugh (written commun., 1983) summarizes their experiences and outlines some of the problems and accomplishments that might be expected with OMS. In summary, Alspaugh states that "OMS looks very attractive to me and I would expect if wisely deployed could satisfy a certain spectrum of global mapping needs."

Stereo data can now be acquired in such a form that it can readily be organized into the one-dimensional form associated with epipolar planes (ITEK, 1981). The degree to which this can be accomplished, as indexed to the expected geometric error sources has been previously documented (Snyder, 1982) and is summarized by Table 3. Satellites in near-polar orbit can have the Sun within 30° of a right angle to the direction of satellite heading (X direction) for about 70% of that daylight portion of the orbit which lies between 65°N and 35°S latitude and covers over 90% of the world's population (Colvocoresses, 1983a). Maintaining the Sun within 30° of a right angle to the satellite heading and at reasonable elevation (20° to 70°) provides similar response patterns to the stereo data sets. Table 4 summarizes these conditions as a function of the time for crossing the descending node (Equator). Eight-thirty a.m. local Sun time was selected as being close to that providing optimal conditions for stereo correlation (8:18 a.m.). Moreover, 8:30 a.m. is the approximate time at which Landsat 1 flew for the last 16-months of its life (February 1977 to June 1978) when

\*In current practice up to six lines (sets) of data are utilized in the correlation process but with a dedicated system this number should reduce to three. Thus, the process is not truly one dimensional, but approaches this mode and is commonly referred as one-dimensional correlation.

Table 3.--Orbital Mapping System epipolar condition. Maximum of y parallax ( $\pm$ ) in half orbit (50 minutes). Meters on the ground

	Case 1 Vertical plus Fore or Aft B/H = 0.5	Case 2 Fore and Aft B/H = 1.0
• Optimum condition:	1.3 m	0.3 m
• Attitude errors (yaw and pitch) of:		
10 arc seconds	0.7	1.6
100 arc seconds	5.0	12
• Attitude rate errors of:		
$10^{-6}$ deg/sec	11 (2)*	22 (4)*
$10^{-5}$ deg/sec	110 (22)*	230 (46)*
• Elevation differences of:		
1,000 m	2.3	0.5
10,000 m	22	1.8

\*( ) Values obtained by 10-minute rather than 50-minute stellar reference intervals.

Table 4.--Orbital Mapping System time-of-day for descending node vs optimal<sup>1</sup> conditions for stereo correlation<sup>2,3</sup>

Descending node, local Sun time	Imaging under optimum conditions, annual mean percentage	
	Half Orbit	
	(82°N to 82°S)	65°N to 35°S <sup>4</sup>
10:30 a.m.	10	20
9:30	25	40
8:30	45	65
8:18	<sup>5</sup> 48	<sup>5</sup> 69
7:30	35	55

<sup>1</sup> Sun elevation of 20° to 70° and Sun azimuth of 90°±30° to satellite heading.

<sup>2</sup> Same Sun-synchronous orbit as Landsat 1, 2, and 3 (919 km altitude, 99° inclination).

<sup>3</sup> One stereo sensor (11° FOV linear array) looking 23° fore and the other looking 23° aft along the satellite heading.

<sup>4</sup> Region encompassing over 90% of the world's population.

<sup>5</sup> To nearest percent rather than nearest 5 percent.



some of the most useful Landsat data were recorded. The 8:30 a.m. timing provides an average Sun elevation for that area of the Earth lying between 65°N and 35°S of approximately 31°. This Sun angle is considered near optimum for general purposes.

A solid-state imaging system which records stereo data that can be organized in epipolar form will greatly simplify data processing. Also careful selection of the orbital timing will produce similar response patterns on the stereo data set so that automated correlation may be optimized.

Stereo-data processing presents the most complex and challenging aspect of the OMS, but the majority of OMS data is expected to be received and processed in monoscopic, near-orthographic form. Because linear arrays are fixed in one (the cross-track) dimension, each detector creates a one-dimensional data set and their data processing is a relatively simple process as compared to the data generated from the actuated optical-mechanical scanners of Landsat. With minor modifications, Landsat receiving and processing equipment can be adapted to the OMS in its non-stereo mode. Because of the simplified data format, increasing the throughput to accommodate the 48 Mb/s of OMS from the 15 Mb/s of the Landsat multispectral scanner is not considered to be a major problem. Systems such as the Landsat Thematic Mapper and SPOT involve equal or higher data rates, and many receiving and processing facilities are currently being equipped to handle such rates.

#### SATELLITE LIFE AND LAUNCHING MODE

There is no reliable method for predicting the life of such a satellite, but various steps can be taken to increase the probability and length of survival. Obviously, the launch must be successful, and it is customary to have a back-up system ready in case of launch (or other) failure. A back-up (engineering model) should be built along with the launch model of OMS and such is included under Economic Considerations. Based on experience with similar type satellites, expected life of 7 years has been defined. In theory the satellite could be recovered and refitted by a Shuttle type system but the economic feasibility of this concept remains to be demonstrated.

The mode by which the satellite is launched must be determined prior to definition and construction. The choice is basically between an independent launch from the ground or one from an orbiting spacecraft such as the Shuttle. Relevant studies made to date are generally based on an independent launch but at this time the launching mode decision is considered to be beyond the purview of this committee.

#### ECONOMIC CONSIDERATIONS

An electro-optical Earth-sensing satellite system, such as might be used for topographic and planimetric mapping, is expensive to build, launch, and operate. One report based on 1979 U.S. dollars gives an estimate of \$120,000,000 to build, launch, and operate the space segment for seven years (ITEK, 1981). Using a 10% annual inflation figure this equates to \$194,000,000 by 1984. If one assumes that \$194,000,000 is now required to fund the space segment, its funding raises some interesting possibilities. Non-U.S. Landsat receiving stations now are charged a \$600,000 per year annual fee. However, the licensing of stations may soon become difficult to manage and control and it might be simpler to merely charge for turning on the satellite over a given area (Colvocoresses, 1982). A charge of 25 cents (U.S.) per sq km per year has been suggested and if this were fully subscribed for the land

and adjacent sea areas (exclusive of Antarctica), revenues in the order of \$50,000,000 per year would be realized since the area involved is about 200,000,000 sq. km. Such income, based on 1982 dollar values would in fact make the space system self-supporting as shown in Table 5. This table assumes inflation will continue (10% per annum) and that the expenses and income would also rise accordingly. Twenty-five cents per sq km per year would mean about \$3 million dollars per year for a country the size of the United States or Australia assuming off-shore areas were included. There is no assurance that 200,000,000 sq km of the Earth's 511,000,000 sq km surface would be subscribed on an annual basis. However Landsat has recorded many important events and conditions in areas well removed from the inhabited land areas. For example, phytoplankton blooms have been recorded several hundred miles south of Iceland, oil slicks tracked across hundreds of miles in the Gulf of Mexico, USSR rescue operations in the ice-choked arctic documented, and huge areas of Antarctica image-mapped by several governments.

The extent to which satellite service would be subscribed depends on several conditions including politics and the competition available. Nevertheless, the first reliable mapping satellite which will do the things outlined herein should be heavily subscribed perhaps up to or beyond the 200,000,000 sq km on which the above economic analysis is based. Even so there is no question but that the building and flying of the satellite constitutes a financial risk which those concerned must be willing to take. It has

Table 5.--Balance sheet for space segment of an Orbital Mapping System

- Expenses are based on a 1981 report by ITEK using 1979 U.S. Dollars inflated at 10% per annum.
- Interest is based on the issuance of 15% bonds as required and 15% interest on surplus.
- Income is based on a 25 cents per sq km or \$50 million per annum estimate of 1982--inflated at 10% per annum.

MILLIONS OF U.S. DOLLARS

	<u>Year</u>	<u>Expenses (-)</u>	<u>Income (+)</u>	<u>Interest</u>	<u>Balance (end of year)</u>	
<u>1984</u>	1	5	0	-0.9	-5.9	1
	2	20	0	-4.6	-30.5	2
	3	30	0	-10.7	-71.2	3
	4	50	0	-21.4	-142.6	4
Launch						
<u>1988</u>	5	142.0	26.6	-49.4	-307.3	5
	6	5.2	58.5	-46.1	-300.1	6
	7	5.7	107.2*	-45.0	-243.6	7
	8	6.3	117.9	-36.5	-168.5	8
	9	6.9	129.7	-25.3	-71.0	9
	10	7.6	142.6	-10.6	+53.4	10
	11	93.4	156.9	+8.0	+124.9	11
Launch						
<u>1995</u>	12	104.2	172.6	+18.7	+212.0	12
	13	10.1	189.9	+31.8	+423.6	13

\* \$50 M inflated to 1990 dollars

been suggested that instead of a uniform rate that unit area charges should vary according to various factors but such factors have not, as yet, been well defined. However, if several different governments or agencies wanted the same area covered the unit price for such an area might be raised above the nominal rate.

As Figure 4 indicates it would take 10 years before the balance sheet shows an overall profit based on the assumptions made. It is highly doubtful that industry would ever put up the money for such an enterprise without governmental guarantees or subsidies. Since governments represent the principal users of such a system they must at least participate in the financing. It is believed that mechanisms for funding such enterprises do exist, but deciding on such a mechanism is beyond the purview of this committee.

The economic considerations discussion (and tables) thus far has not considered the data reception processing and distribution problem which may be grouped as the ground segment. The previously referenced report (ITEK, 1981) estimated that the ground segment would cost \$41,500,000 to build, and \$7,800,000 per year to operate three reception stations and one complete processing and distribution center. \$2,000,000 per year is also forecast for mission planning, command and control of the

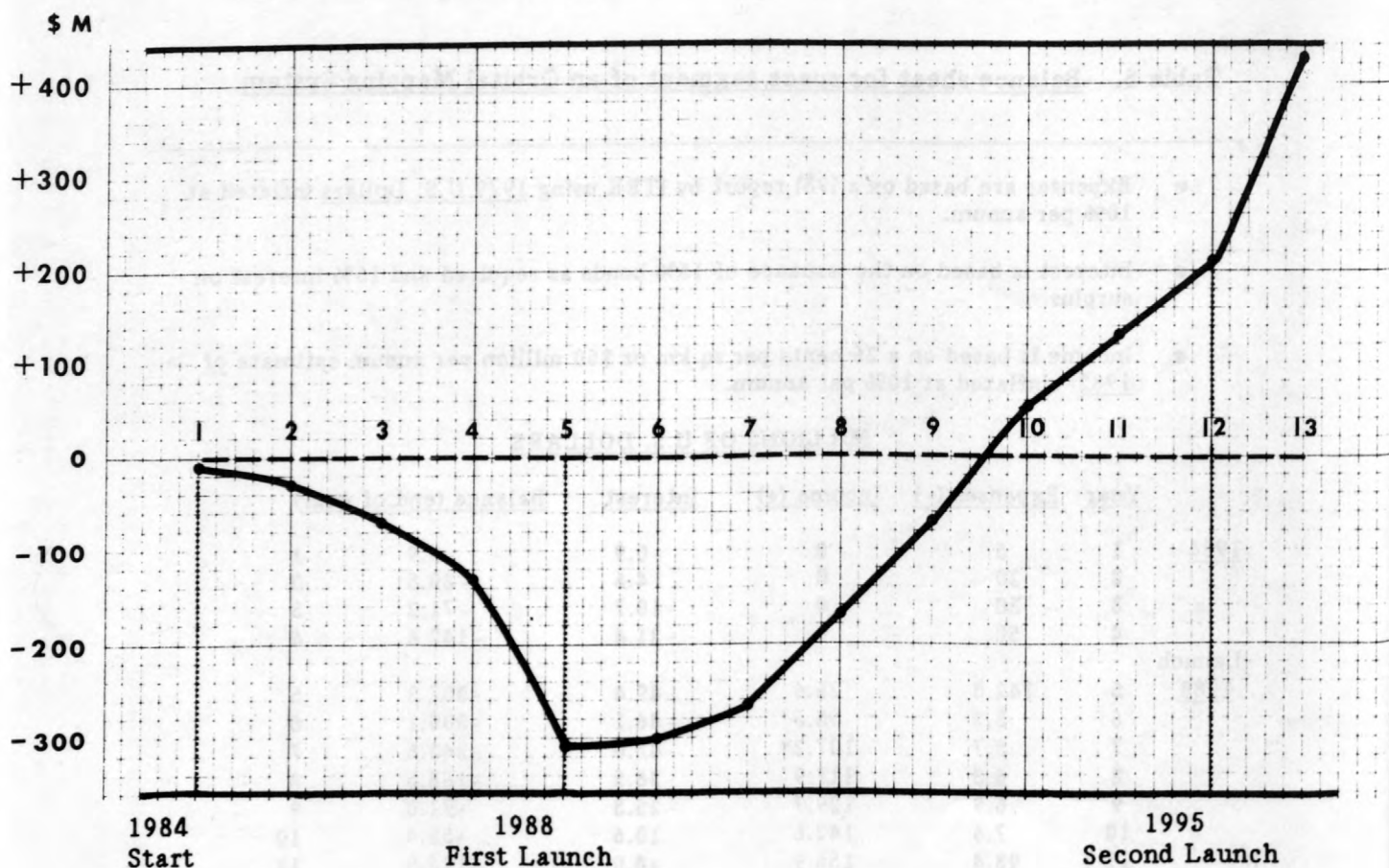


Figure 4.--Projected balance for space segment of an Orbital Mapping System.



satellite, but this sum is already included in the discussion and tables relating to the space segment. The \$41,500,000 assumes a new start and must be tempered by the following:

- Extensive Landsat receiving and processing facilities (15 to date) plus others designed for SPOT and other systems either exist or are being built and they could readily be adapted to the OMS.
- Data processing techniques, including stereo data correlation, are undergoing rapid and extensive changes.
- Sales of expected products and services, while impossible to accurately forecast and quantify, have a direct and substantial effect on the economics of the ground segment.
- Assuming suitable international agreements are made there appears to be no real requirement for more than one or two processing facilities designed specifically to process stereo data into digital elevation data or topographic (contour) map form. Such processing involves a major share of the estimated high cost for the ground segment.

For the above reasons no further economic discussion of the ground segment is made at this time other than to note that at least one receiving and processing station costing in excess of \$40,000,000 to build and \$8,000,000 per year to operate is needed and that some form of governmental support would probably be required to develop and operate this ground segment.

#### POLITICAL CONSIDERATIONS

A global mapping system is of concern to all nations and this raises political issues. The question of whether a system of 10- to 30-m resolution should operate on an unrestricted basis has already been raised (United Nations, 1983). However, the United States, Western Europe, the Soviet Union, and Japan have built or are building systems within this resolution range and there are indications that at least some of them will be flown on an open basis. The United States long supported an "open-skies" policy on such matters and indications are that many other nations subscribe to this same concept. The assumption made is that the benefit from an open Earth-sensing system will far outweigh the possible loss of sovereign rights that might be involved. The United Nations and others are deeply involved in this issue but at this time it appears obvious that systems with resolution elements as small as 10 m are soon to be flown and that restricting their use is a near impossibility. It would appear that the best protection for any nation not capable of its own Earth-sensing system is to insist on a fully open system by which they can acquire the data as quickly and as cheaply as others. This was the premise on which Landsat was flown and it appears to have resulted in more or less universal acceptance. It is noteworthy that the return beam vidicons on Landsat 3 and the Thematic Mapper on Landsat 4 involve 30-m resolution elements, and film cameras, such as those on Skylab and the Shuttle, involve the equivalent of 10-m resolution elements. Insofar as is known, no formal complaints have been made against the use of such systems.

Assuming a system of 10- to 30-m resolution will be flown on an operational basis its control (and management) is a critical issue. Ideally such control should be vested in an international body but creating a body to effectively manage such an endeavor is

a complex task which might take years or even decades to achieve. In the interim it is suggested that a nationally sponsored system be supported internationally in as much as the system promises to benefit other countries in addition to the one sponsoring the system. It is suggested that a technically oriented international organization such as the ISPRS should define what it believes to be an optimal system, which in turn should be presented to both national and international bodies concerned with implementation of an operational Earth-sensing system. Determining who should build and operate such a system is considered beyond the purview of this committee.

## SUMMARY

There is ample evidence that image maps of 1:50,000 scale and topographic data expressed by contour intervals of 40 m or smaller can be developed from space originated photographs. As long as the manned programs will carry film cameras at relatively low cost, this mode should be fully exploited. However, it does not appear likely that manned space flights will develop comprehensive global coverage suitable for mapping within the foreseeable future. Unmanned dedicated film camera flights in Sun-synchronous orbit could, perhaps in a decade, produce a reasonable set of mapping photographs but the costs (including film recovery) as known today, are exorbitant. Moreover, such a set of photographs, for the reasons given, would not have the general-purpose applications expected today of Earth-sensing satellite data. The committee believes that it is now possible to deploy an electro-optical space system which will materially contribute to the geometric mapping of the Earth's surface at scales as large as 1:50,000 and with 20 m contours. It also believes that such a system can, in large part, be automated and that the time and cost for such mapping, as compared to conventional mapping, can be greatly reduced. This committee further believes that such a system, in addition to topographic land mapping, is capable of shallow sea mapping, thematic mapping and the monitoring and analysis of transitory phenomena as has been demonstrated at lower resolution by the Landsat series. Although topographic mapping is the application which guided this system's design, its ability to monitor transitory phenomena and changes on the Earth's surface may, in fact, be of equal or greater value than the mapping application. It is further believed that concerned nations and agencies will be willing to pay for access to such a satellite in amounts which may provide for liquidation of the construction and operating costs of the space segment. The suggested parameters for such a satellite system are given in Table 6.

The committee considers the reception and processing of data and the distribution of desired products as a separate problem that must, in large part, be dealt with on the local level. However, the suggested satellite system has been defined to achieve optimum compatibility with existing receiving and processing facilities. This includes the relatively new technology by which stereo data in epipolar form can be transformed into digital elevation data and displays (maps) of the Earth's surface in various forms.



Table 6.--Suggested basic parameters for an Orbital Mapping System

- Orbit--same as Landsat 1, 2, and 3 (919 km alt) with descending node crossing at 8:30 a.m. local time
- Sensor--linear arrays, three optics looking 23° forward, vertical, and 23° aft.  
Three spectral bands:\*  
 blue green 0.47-0.57  $\mu$ m  
 red 0.57-0.69  $\mu$ m  
 near IR 0.76-1.05  $\mu$ m
- Resolution--variable - down to 10-m pixels
- Sensitivity--256 levels (8 bits) compressed on board to 6 or fewer bits (64 or fewer levels)
- Swath Width--180 km or defined portion thereof
- Transmission--S or X band, compatible with Landsat receivers but with rates up to 48 Mb/s
- Processing--digital, based on one-dimensional data sets, including stereo
- Expected life of satellite - 7 years

\*New technology and experience with the Landsat Thematic Mapper may justify changes in these wavebands or even the addition of one or more bands. However, any major changes, such as the addition of wavebands involving the cooling of detectors, would require a redefinition of the OMS. At this time such changes have not been justified.

## RECOMMENDATIONS

This committee recommends that its findings be accepted and, as suggested by the letter creating it, be forwarded to concerned national and international organizations. Such organizations should in turn confirm or propose modifications to the concept and parameters of the suggested system and, where deemed appropriate, conduct additional studies and comparisons with other mapping systems, including those based on aerial or space film cameras. It is further recommended that the ISPRS as a body, and through its affiliates at the national level, initiate an active program aimed at implementing an Orbital Mapping System at the earliest opportunity. Such action could provide the technical foundations on which national and international policy makers might arrive at a favorable decision with respect to such a system.

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## **APPENDIXES**

## APPENDIX A -- ABBREVIATIONS AND ACRONYMS

BIK	USSR acronym for electro-optical Earth-sensing system
DARPA	Defense Advanced Research Projects Agency (US)
DFVLR	Deutsche Forschungs- und Versuchsanstalt für Luft- und Raumfahrt e. V., (German, FRG)
DMAHQ	Defense Mapping Agency Headquarters (US)
DMAHTC	Defense Mapping Agency Hydrographic Topographic Center (US)
ERS	ESA resources satellite (European) or Earth resources satellite (Japanese)
ESA	European Space Agency
FOV	field of view
FRG	Federal Republic of Germany
GOES	geosynchronous operational environmental satellite (US)
GPS	global positioning system (US)
IADB	Inter-American Development Bank
ISPRS	International Society for Photogrammetry and Remote Sensing
Ku band	wave band of 15.35-17.25 GHz
Landsat	land satellite (US)
laser	light amplification by stimulated emission of radiation
LFC	large format camera (US)
MEOSS	multispectral electro optical stereo scanner (German)
MOMS	modular optoelectronic multispectral scanner (German)
MOS	marine observation satellite (Japanese)
MSS	multispectral scanner on Landsat (US)
MSU	USSR acronym for electro-optical Earth-sensing system
Mapsat	mapping satellite, proposed (US)
Mb/s	megabits per second
na	not applicable
NASA	National Aeronautics and Space Administration (US)
NOAA	National Oceanic and Atmospheric Administration (US)
OMS	orbital mapping system, proposed
PAIGH	Pan American Institute for Geography and History
pan.	panchromatic
pixel	picture element--the smallest increment for which a radiometric value is recorded in an electro-optical imaging system
radar	radio detection and ranging
RBV	return beam vidicon on Landsat 1, 2, and 3 (US)
S band	wave band of 1.5 to 5.0 GHz
SEOS	synchronous Earth observatory satellite, proposed (US)
SIR	shuttle imaging radar (US)
SMS	synchronous meteorological satellite (US)
SPOT	Système Probatoire d'Observation de la Terre (French)
Seasat	sea satellite (US)
stereo	stereographic
TM	thematic mapper on Landsat (US)
US	United States of America
USGS	United States Geological Survey
USSR	United Soviet Socialist Republics
X band	wave band of 5.0 to 12.0 GHz



INTERNATIONAL SOCIETY FOR PHOTOGRAMMETRY AND REMOTE SENSING  
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P-14-310

July 30, 1982

Dr. Alden P. Colvocoresses  
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Dear Colvo:

On November 16, 1981, you wrote me suggesting the formation of a Working Group entitled "Acquisition and Processing of Space Data for Mapping Purposes," and proposed that the Working Group be sponsored by both Commission IV and Commission I. I discussed this with Roy Mullen, President of Commission IV, who already has a Working Group IV/3 entitled "Mapping from Spaceborne Imagery" which is chaired by Ray Batson in the Branch of Astrogeologic Studies in Flagstaff, Arizona. The title of that Working Group is broad enough to encompass the activities which you propose. However, since Ray Batson is primarily interested in planetary mapping, I suggested to Roy Mullen and Ray Batson the formation of a committee under Working Group IV/3. Both agreed to this solution and to your serving as its chairman. This letter, then, is your authorization to proceed.

You will obviously want to be involved with the data acquisition system, as well as with the cartographic processing. Data acquisition is the function of Commission I and there are two Working Groups within Commission I with which you should interface. These are Working Group I/1 - "Data Quality of Aerial and Satellite Sensor Systems," chairman Dr. Roy Welch, Department of Geography, University of Georgia, Athens, Georgia 30601, U.S.A., and Working Group I/4 - "Acquisition of Remote Sensor Data from Spacecraft," chairman Dr. Robert McEwen, U.S. Geological Survey 519, Reston, VA 22092, U.S.A. You should ask them, or suggest to them, individuals who would represent Commission I in your committee.

By copy of this letter I am informing Professor John C. Trinder, President of Commission I of this suggested cooperation. I am confident that he will approve. He may even want to suggest participants to you.

I believe that the objective of your committee should be to define a system - both space and ground segments - which could contribute to the geometric mapping of the Earth's surface. I think you should address not only the

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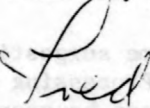
**CONGRESS DIRECTOR:**  
**PLACIDINO FAGUNDES**  
Sociedade Brasileira de Cartografia  
Rua Mexico 41 Sala 706  
Centro Rio de Janeiro, Brazil 20000

technological aspects of such a system, but also the economic and political implications, and clearly the system should be international rather than U. S. only. If a suitable report is prepared, it would be forwarded by the ISPRS Council to the appropriate levels in NASA, ESA, CNES, NASDA, and other organizations interested in satellite remote sensing.

Although the program has not yet been arranged there will be sessions at the Rio Congress devoted to satellite remote sensing. There will probably be a joint session between Commission I, Commission IV, and Commission VII. Suitable papers resulting from your committee might be presented at this session.

I wish you good fortune in the conduct of this important work.

Sincerely yours,



Frederick J. Doyle  
President



## APPENDIX C

### Reservations of Committee Members

Ian Dowman - "I agree that the OMS system proposed is very necessary to provide the possibility of continuous earth cover and data suitable for monitoring and mapping. The specifications which the report outlines and particularly those under the heading GEOMETRIC CONSIDERATIONS are highly desirable in an orbiting mapping system. However I feel that proper weight is not given to complementary systems for mapping. The Metric Camera on Spacelab, the Large Format Camera, SPOT and stereo MOMS are all sensors which will provide data for three dimensional mapping of varying degrees of accuracy and will undoubtedly play a part in extending the world-wide map coverage at small scales. These sensors are of great importance at the present time and should be supported actively by ISPRS until such time as a better system is operational."

James Hammack - "With regard to water penetration photogrammetry, it is my opinion that ten meter pixels (collected from any altitude) will not provide adequate bottom detail to support significant photogrammetric operations on a global basis. "A second factor to consider with regard to bottom depth extraction is that two spectral bands penetrating to the bottom in clear water can be processed to yield good depth data as well as a map of bottom reflectivity. This has been demonstrated by the use of bands 1 and 2 of the Thematic Mapper. The OMS as now defined provides for only one band with significant water penetration capability."

Fred Henderson - "On behalf of the geologic community I want to point out that the OMS will not meet our basic requirements for multi-spectral response. Experience with the Thematic Mapper 1.55 to 1.75  $\mu\text{m}$  and 2.08 - 2.35  $\mu\text{m}$  bands indicate such bands are essential to the proper discrimination and classification of the Earth's surface features for geologic purposes. On the other hand the delineation of the Earth's topography, as proposed, does meet one of our major geologic requirements."

David Hocking - "Consideration should be given to a more equitable charging policy possibly taking into account such things as population, number of receiving stations or charging on a per image basis with, of course, a basic minimum charge rather than the annual charge being based solely on the area of a country."







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