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FINAL REPORT

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ABSTRACT

This document describes the results of a comprehensive study aimed at assisting NASA Headquarters in its task of planning R&D programs and developing an operational capability to acquire, process and disseminate remotely-sensed earth resources data to appropriate experimenters and users.

A review is presented of the basic objectives and requirements of the major government support agencies and experimenter groups associated with the Earth Resources Program, as well as the sensor and auxiliary equipments associated with the Manned Spacecraft Center aircraft survey program. Data flow models are developed which depict the processing of typical data from each sensor class through the associated MSC ground data processing facility.

Future trends in the Earth Resources Program are delineated, with emphasis on the Houston aircraft program, its eventual coordination with spacecraft collection activities, and its attendant ground data processing requirements. Priority techniques, systems and facilities growth requirements are identified. Development plans are presented to permit the timely research, development, construction and test of required data processing equipment and facilities.

Recommendations and conclusions concerning future effort aimed at furthering the growth of the earth resources data processing facilities at the Manned Spacecraft Center are developed.

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DEPT. OF INTERIOR

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U.S. NAVAL OCEANOGRAPHIC OFFICE

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SECTION 3

THE MSC EARTH RESOURCES AIRCRAFT PROGRAM

FOREWORD

This section describes the current MSC Earth Resources Aircraft Program. After a brief discussion of the mission and an historical review of the program from its inception to the present time, a summary of user/experimenter requirements is presented. This is followed by a survey of data acquisition equipment, including aircraft and sensors. General data processing requirements are then considered, and data flows for various classes of sensors are treated. The section ends with some observations on program effectiveness and a suggestion for improved communications and information feedback between experimenter/user groups and the Program Office at Houston.

Detailed descriptions of sensor equipment and data processing flow paths are given in Appendices D and E, respectively.

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3.1 PROGRAM MISSION AND HISTORY

Before examining the history of the program, it is appropriate to reiterate the original assignment of functional responsibility as given in the charter of the Earth Resources Division at MSC.

3.1.1 Mission

"The Earth Resources Division shall provide a technical and management organizational focus for earth resources and meteorological applications activities within the Science and Applications Directorate and at MSC. In providing this focus, the Division will carry out the following functions:

a) Manage and participate in the planning and execution of the Center's activities in the Earth Resources Program.

b) Interface with and support OSSA as appropriate in the planning and execution of the program.

c) Manage the relationships between the Center and user agencies and principal investigators involved in the program.

d) Develop techniques for the application of spaceborne remote sensors to a variety of earth applications and research.

e) Conceive and develop experiments and conduct research associated with the Earth Resources Program.

f) Plan and manage the implementation of instrumentation for earth resources test aircraft and laboratories.

g) Plan, manage, and participate in the implementation of test programs conducted with test aircraft.

h) Study, propose, and provide earth resources sensor packages for space flight.

i) Manage and participate in the analysis of earth resources data from aircraft and space flights."

From the above statement, it is apparent that the Earth Resources Program is essentially dual in nature, designed to:

- Provide a continuing data collection and processing capability, utilizing various types of remote sensors, in response to the needs of a large group of government and university experimenters and users.

- Maintain a continuing program of equipment and system research and development, leading to sensors and processing techniques suitable for space applications.

An examination of on-going activities makes it also apparent that the program is growing: new sensors are being developed, techniques are in a constant state of refinement, and the volume of data collected is becoming increasingly more massive. Consequently, data processing capability must grow in pace with data volume; at the same time, processing techniques must become more sophisticated to satisfy the anticipated increasing demand for detailed, specific information.

It follows that facilities for data dissemination also must increase in size in order to permit other earth resource users to have access to the accrued information. The comprehensive and varied data generated by the Earth Resources Program is too valuable to restrict its use to a few experimenters and, ultimately, the merit of the program derives from the ability to service a broad community of users.

As the program develops, complex and costly facilities, such as instrument calibration laboratories, will be required. Such facilities could also be used by other organizations engaged in earth resources investigations for calibration and standardization of their equipment. To duplicate such laboratories around the country would be expensive and, unless the volume requirements placed on centralized facilities become excessive, the proliferation of these facilities would not be particularly cost-effective.

These growth considerations are treated more fully in Section 4. However, in order to view them properly, it is necessary to first examine the historical development and current magnitude of the Houston operation, the services it provides, and the specific equipments and data processing techniques at its disposal.

3.1.2 History

The aircraft flight program began in June of 1964 utilizing the NASA 926 vehicle, a Convair 240A, which had been acquired originally for testing various electronic systems for the Apollo Program. Only two sensors, an RC-8 camera and a T-11 camera, formed the initial equipment complement. Table 3-1 summarizes mission history from 1964 through early 1969. NASA 927, a Lockheed Electra NP3A, was acquired on loan from the Navy in December 1965 and became operational in May 1967. These two aircraft have been used to acquire data from both low and intermediate altitudes.

Instruments that have flown to date include mapping cameras, multi-band cameras, infrared and ultraviolet scanners, microwave radiometers and imagers, and radar scatterometers. A detailed listing and discussion of these sensors appears in Section 3.3 and Appendix D.

The aircraft program has been a relatively minor activity at the Manned Spacecraft Center during the past five years. In 1964, only three missions were flown; the following year, there were 13 missions. In 1966, activity increased to 21 flights. This annual level of activity has been more or less maintained during the ensuing years, but the expectation is that it will soon begin to expand significantly. Funding for the program has been provided primarily by the NASA Office of Space Science and Applications. Expenditures have been utilized for the acquisition of sensor equipment, for aircraft modification and sensor integration, and for data processing and instrument studies. Table 3-2 summarizes the funds expended through the end of 1968.

TABLE 3-1

EARTH RESOURCES AIRCRAFT PROGRAM MISSION HISTORY

Year	Total Missions	Aircraft	EXPERIMENTS IN EACH DISCIPLINE					
			Agriculture	Forestry	Geology	Geography	Hydrology	Oceanography
1964*	3	NASA 926	--	--	3	--	--	1
1965	13	NASA 926	11	1	19	2	1	2
1966	21	NASA 926	13	1	24	5	9	8
1967	22	NASA 926 NASA 927**	10 1	4 0	17 4	10 2	7 6	8 3
1968	18	NASA 926 NASA 927	9 2	1 0	9 4	11 2	16 8	8 4
1969	2***	NASA 926	--	--	--	4	1	--

NOTES: * First mission flown June 30, 1964

** NASA 927 began operations on May 11, 1967 with Mission No. 47

*** As of January 31, 1969

TABLE 3-2

EARTH RESOURCES AIRCRAFT PROGRAM FUNDING

Fiscal Year	Funds Expended*
1965	$200,000
1966	$840,000
1967	$2,700,000
1968	$5,971,000
1969**	$7,995,000

NOTES: * Based on Report for the Subcommittee on NASA Oversight of the Committee on Science and Astronautics, U.S. House of Representatives, December 31, 1968 (Karth Report)

** As of December 31, 1968

3.2 USER/EXPERIMENTER REQUIREMENTS

All data collection and processing tasks performed by MSC are undertaken in response to formal requests from various user agencies. A number of scientific disciplines are involved, and it is useful to briefly review them and some of the general factors influencing experiment design, in order to appreciate the specifics of the Houston operation.

3.2.1 Disciplines and Experiment Organizations

The NASA Earth Resources Program at Houston interfaces with major government user organizations which are responsible for coordinating the efforts of many experimenters around the country. These agencies are funded, in part, by NASA for the purpose of supporting university experimenters and government scientists concerned with the earth resource disciplines. Government agencies cooperating with NASA in this program, and the corresponding disciplines served, include:

- U.S. Geological Survey (EROS and Geographical Applications Office)
  - Geography
  - Geology
  - Hydrology/Water Resources/Water Pollution
- U.S. Department of Agriculture (Agricultural Research Service)
  - Agriculture
  - Forestry/Vegetation
- U.S. Naval Oceanographic Office (Spacecraft Oceanography Project)
  - Hydrography
  - Oceanography
- Bureau of Commercial Fisheries .

In the development of research programs, part of the agency responsibility is to evaluate requests to conduct experiments, and to fund experimenters for all aspects of an approved program. Some types of experiments necessitate that the responsible organization coordinate the aircraft flights with other on-going data collection programs. Typical of these are oceanography experiments, where ships are needed to collect the auxiliary atmospheric and water information during remote sensing overflights. Without such cooperation, the cost of collecting auxiliary data in many oceanographic experiments would be prohibitive.

Many other technical and management factors must be taken into account in designing "good" experiments; the major considerations are outlined in the next few paragraphs.

3.2.2 Technical Design of Experiments

All objects on the earth's surface, including the surface itself, continually radiate electromagnetic energy, either due to their inherent temperatures or as reflectors of solar energy, or both. The fundamental concept underlying the Earth Resources Program is that spectrally-selective emission and reflection will uniquely identify all objects of interest; furthermore, these radiations can be measured by sensor equipment aboard overflying aircraft or earth-orbiting satellites.

Hence, a first requirement on the program is that appropriate sensor systems be developed. That effort begins by evaluating relevant existing systems. To support the investigations, MSC has equipped several aircraft with a variety of sensors capable of recording data throughout the ultraviolet-to-microwave spectral region. The experimenters are then concerned with assessing the data products in terms of their contributions to the signature problem. Those critiques eventually lead to new performance criteria and new experiments.

Unfortunately, all such collections are obscured by atmospheric degradations and the differing response characteristics of "identical" sensors. Furthermore, the spectral signatures are generally found to be complex functions of sun angle, look angle, type of soil, moisture content, etc. Consequently, it is imperative that rigid calibration standards be instituted and that the remotely sensed data be correlated with some form of ground truth information. In this early stage of the program, when the problem is to determine what the critical signature characteristics are, ground truth provides both a reference set of calibration measurements and a corroborating identification of the subject matter. Therefore, test sites, or calibration areas, have been developed for all the disciplines.

Although experimenters generally try to incorporate a test site as one element in any mission area, this is not always practical. An alternative approach is to obtain reference measurements by means of portable radiometers and other instruments brought to the area of interest.

MSC has considered the possibility of installing such equipment in a "Ground Truth Van" but no vehicle of this sort yet exists. As a consequence, hardly any ground truth data has been collected by NASA. Rather, the experience to date has been that some Users collect ground truth data themselves and some conduct experiments with no rigorously correlated ground truth.

Special instrumentation might be required in exceptional cases but a van containing a standard equipment complement would be useful in all experiments. For example, measurements of temperature, humidity, etc. are necessary regardless of discipline. Coupled with analysis by the scientists at the time of the overflight, the technique would provide, in effect, a "portable test site". The approach seems eminently worthwhile and should be further examined.

Because of the large number of subject, environment and sensor variables which are always present, the search for common parameters, which would permit uniform analysis anywhere in the world, is extraordinarily difficult. The hope is to discover a unique set of data combinations for each subject of interest, with minimum dependence on location.

3.2.3 Mission 73

On occasion, multi-sensor experiments require so many instruments and types of data that more complex collection programs are necessary. An example of such an effort is Mission 73, which was one of the activities performed as part of the International Participation Program, and monitored by visiting scientists from Mexico and Brazil.

The mission was designed to be multi-sensor and multi-discipline in nature and used 13 sensors mounted in 7 aircraft. Many of the aircraft were furnished by the MSC Earth Resources Program. Flights were conducted over test sites in southern California, including the Los Angeles basin, the Indio Hills, the Coachella Valley, the Imperial Valley and Salton Sea, and the Anza-Borrego desert. The airborne program collected remote sensor data from late April through mid-June, 1968, while a complex auxiliary data collection program was being conducted on the ground. Ground truth data included information from existing collection programs (e.g., those of the Weather Bureau and Los Angeles Air Pollution Control District), as well as from instruments established at the sites during the overflights.

3.2.4 Multiband Spacecraft Photography

Another useful example of a coordinated multi-discipline effort is the SO 65 experiment, which involved the Apollo 9 spacecraft. Utilizing four Hasselblad cameras recording in red, blue, green and IR bands, the program sought to investigate the effectiveness of multispectral photography from space. NASA/MSC coordinated the experiment and several corollary activities involving four remote sensing aircraft and a number of ground truth experimenter teams. It also provided one aircraft, the Convair 240 A, as a sensor platform. The geographic area covered was mainly in the south central and south western U.S. in the vicinity of Tucson, Arizona and El Paso, Texas. The test spanned roughly five days, although sensing time was much less.

While the program was carried out at the beginning of March 1969, data from the experiment is only now being analyzed; consequently, the significance of the results will not be known for some time. Nevertheless, certain important aspects of the experiment should be reviewed in the very near future, particularly since similar types of experiments will undoubtedly be planned for both ERTS-A&B and the Apollo Applications Program. Among these points of interest are the mechanics of coordination, the effect of such programs on the data processing facilities now available at Houston, and the support required for conducting similar spacecraft/aircraft/ground site experiments over much longer time intervals, e.g., one month to one year.

Primarily, detailed study of the SO 65 experiment is warranted because it is a good prototype for future programs, and because it not only was a large team effort, but was executed with extreme efficiency and coordination among the many organizational groups that were assembled together to accomplish its demanding tasks.

3.2.5 Data Collection Scheduling

Data collections must be scheduled with attention given to:

- Site locations
- Weather
- Varying perishabilities of different phenomena
- Lead times necessary in certain activities

Experiments at different sites are coordinated by location and time, so one mission may involve overflights of several sites. This is done to minimize the operating expenses accrued in flying aircraft to various parts of the country. In addition, every effort is made to perform multiple experiments per mission site, in order to gather one body of data meeting the needs of several disciplines.

With regard to weather, schedules must have sufficient short-term flexibility to permit alternative flight periods over the areas of interest. This is particularly important when a large number of people are deployed around the site to collect auxiliary data.

In addition, each scientific discipline has its own unique collection problems which are frequently associated with the perishability of the phenomena to be observed. To illustrate this more clearly, the following paragraphs describe typical problems in a few representative disciplines, stressing the impact which perishability has on data collection scheduling. No attempt has been made to treat the subject exhaustively; rather, the intent is to indicate the complexity of the problem.

3.2.5.1 Oceanography. Because of the high cost of ship time for collecting auxiliary water and atmospheric data for the short period of remote sensing overflight experiments, it is necessary to coordinate such flights with an on-going ship data collection program, in which the ship will traverse the area of interest. Since ship schedules are planned one to two years in advance, a particular remote sensing experiment over a selected site may have to wait two years, or longer, until a ship can include the area in its plan.

Consequently, some experiments may require long term advance scheduling in order to coincide with a ship plan. This problem often is further complicated by seasonal changes in the phenomena of interest.

In contrast, other phenomena may dictate an almost instantaneous aircraft response, as when observing schools of fish whose appearance in an area may be related to a particular thermal front. Still other phenomena require short period repeated coverage, such as a half-day flight every ten days for several months to record the time histories of horizontal waves on the edge of a boundary current.

3.2.5.2. Hydrology/Water Resources. Besides recording time-histories of the variable phenomena involved, many critical data collection periods arise in hydrology, water resources, and water pollution studies. For snow areas, aircraft are needed to record critical temperature levels, as when some glaciers reach temperatures between 10° and 20°F, which may occur only once or twice a year.

Similarly, critical timing is required to record the moment of breakup of river ice and associated water temperature and current patterns. Finally, extremely flexible short-term aircraft scheduling is necessary to register wet and dry land boundaries after a rainfall.

3.2.5.3 Geology. Aside from collecting reflected solar energy at various times of the day, the major short term geological phenomena of interest in remote sensing experiments involve thermal energy emitted from the earth (due to forest fires, volcanoes, hot springs, and reradiated solar energy) and land/sea interaction processes along coastlines. Some phenomena, such as forest fires and active volcanoes, require an immediate response; others, such as dormant volcanoes and hot spring areas, need time-history data to detect changes.

The study of land/seashore estuary processes, aside from catastrophies and hazards, requires careful timing to record such phenomena as tide levels and variations in off-shore currents. Time-history records are also required, in order to understand erosion, silt deposition and water mass mixing.

3.2.5.4 Agriculture/Forestry. Rapid changes in plant life require that critical timing be observed in order to acquire data during selected states in the plant growth/decay cycle. Time-history records should then be compiled throughout the cycle and examined to determine which factors are significant in terms of automatic signature analysis. Other applications, such as the monitoring of plants and crops in stress, indicate a need for very short-term, flexible aircraft scheduling.

3.2.6 Sensor Stabilization

At present, most airborne sensors are hard mounted to the vehicle. Several systems (for example, the MR-62 and MR-64 microwave radiometers) are mounted on servo controlled platforms, but these merely permit remote selection of look angles, and are not used for stabilization. IR Line Scanners generally have built-in roll compensation but are otherwise uncorrected for vehicle attitude perturbations.

Ideally, all sensors should be mounted to a single reference, with no differential motions between any two viewing apertures. In practice, this is extremely difficult to achieve, and the problem substantially worsens as more sensors are introduced.

The situation has not yet become an issue of concern in the Earth Resources Program but will have to be given serious attention in the course of resolving problems associated with Automatic Data Correlation.

3.3 DATA ACQUISITION EQUIPMENT

In order to meet its stated data collection responsibilities, MSC has acquired several aircraft and a multitude of remote sensing equipments. These are briefly treated here in order to outline the general nature of the existing capability; system details have been relegated to Appendix D so as not to obscure the overall view.

As a matter of convenience, sensors are categorized into three general groups: camera systems, infrared systems, and microwave systems. Although several of the sensors presently employed in the program are recently developed equipments, the majority are older, in some cases almost obsolete, systems that were designed years ago either for military applications or space research missions. However, all systems are closely evaluated and ineffective ones are eventually removed from the aircraft and dropped from the program.

3.3.1 Program Aircraft

Four aircraft are now available to the Earth Resources Aircraft program. Together they provide a complete range of operation from low altitude to very high altitude, and three of them possess cruising ranges in excess of 2000 miles.

Table 3-3 lists the specific vehicles and their performance characteristics of interest. Tables referenced in the next three paragraphs are organized according to sensor type but contain column entries denoting which equipments are installed in which aircraft.

3.3.2 Camera Systems

The camera systems currently used in the program are listed in Table 3-4. All but the RC-8 are used for multispectral photography. The RC-8 is a mapping camera and is often used for the

TABLE 3-3

PROGRAM AIRCRAFT

Aircraft	Type	NASA	Altitude (Feet)	Range (miles)	Cruising (mph)	Maximum (mph)
1	Convair 240 A	926	1500-15,000	1000	240	285
2*	Lockheed C130	929	1500-25,000	2500	340	370
3	Lockheed Electra NP3A	927	1500-25,000	2000	400	450
4**	General Dynamics RB57F	---	>50,000	**	**	**

NOTES: * Vehicle not available until mid-summer 1969

** Flight performance parameters are classified.

TABLE 3-4

PROGRAM CAMERA SYSTEMS

Manufacturer	Model	Description	Film Size	Field of View	Resolution (Lp/mm)	Aircraft
Chicago Aerial	KA-62	Cluster of 4 Cameras	5"	74° x 74°	53	3
Wild Heerbrug	RC-8	Single Camera	9"	74° x 74°	48	1 - 4*
Itek	2-2	9 Lenses, 1 Magazine	70mm	21° x 21°	50	1**
Hasselblad	500EL	Cluster of 6 Cameras	70mm	31° x 31°	Not Available	4
Hasselblad	-----	MF Radiom. Boresight Camera			Not Available	
Hasselblad	-----	SLAR Boresight Camera			Not Available	
Hasselblad	-----	Photopanel Camera			Not Available	

Notes: * 2 units per aircraft

** No longer used

metric calibration of radar imagery or the multispectral imagery from the other camera systems.

A large selection of spectral filters and black-and-white panchromatic and IR films are available for use with each camera, and this selection may be exploited for calibration purposes in a wide range of spectral bands. At present, this is not being pursued, but MSC is aware of the technique and plans to implement it at a later date.

The ITEK nine-lens camera was used in early experiments but has now been placed in storage.

3.3.3 Infrared Systems

The infrared sensors consist of line-scanning imagers, frequency-sampling spectrometers, and radiometers. The first type provides a two-dimensional IR image of the scanned ground area, while the last two record spectral profiles of the vehicle ground track. The sensors in use are listed in Table 3-5, together with parameters indicating their respective collection geometries. Further information is provided in Appendix D.

The Texas Instruments RS-7 system is classified, so detailed performance characteristics are unavailable.

3.3.4 Microwave Sensors

Microwave sensors presently utilized in the aircraft program are radiometers, scatterometer radars and side-looking radars. They are listed in Table 3-6, with entries that denote their collection geometries. Except for the side-looking airborne radar (SLAR), which records on five-inch film, all of these sensors provide their output data on analog magnetic tape.

Additional characteristics are given in Appendix D.

TABLE 3-5

PROGRAM INFRARED SYSTEMS

Manufacturer	Model	Description	Film Size or Modulation	Field of View	Resolution (mrad.)	Aircraft
HRB Singer	Reconofax IV	1 Channel Imager	70mm	120° Scan	2	1
Texas Instr.	RS-7	1 Channel Imager	70mm	*	*	2, 4
Texas Instr.	RS-14	2 Channel Imager	5", FM	80° Scan	1 or 3	3
Lockheed	------	Scanning Spectrometer	PCM	Fixed	6	3, 4
Block Engr'g.	------	IR Radiometer	PCM	Fixed	6	3, 4
Barnes	PRT-5	Radiation Thermometer	PCM	Fixed	35	2, 3

Note: * Performance parameters are classified

TABLE 3-6

PROGRAM MICROWAVE SYSTEMS

Manufacturer	Model	Description	Film Size or Modulation	Range or Field of View	Resolution	Aircraft
JPL	MR-62	Radiometer	FM	2°, 3°	*	1**
JPL	MR-64	Radiometer	FM	1°, 4°	*	1**
Space Gen'l.	-----	Multifreq. Radiometer	PCM	5°, 16°	*	3
Ryan Aeron.	-----	13.3 GHz Single Polarized Scatterometer Radar	FM (2 Chan.)	120° x 3°	3° +	2
Ryan Aeron.	-----	13.3 GHz Dual Polarized Scatterometer Radar	FM (4 Chan.)	120° x 3°	3° +	3
Ryan Aeron.	-----	1.6 GHz Dual Polarized Scatterometer Radar	FM (1 Chan.)	120° x 6°	6° +	3
Emerson Elec.	-----	400 MHz Dual Polarized Scattometer Radar	FM/FM (1 Chan.)	120° x 9°	9° +	3
Philco-Ford	-----	16.5 GHz SLAR	5"	10 nm	100 feet	2, 3

Notes:
- * Depends on aircraft velocity, sensor FOV and integration time
- ** No longer used
- \+ Nominal broadside resolution

3.4 DATA PROCESSING

Sensor data must be converted to usable forms before it can be analyzed by the experimenters, and very often the conversion itself is an analytical process. This leads to a multiplicity of data handling possibilities and a potential problem if large input volumes are encountered. Clearly, the Principal Investigator (PI) in any experiment is responsible for defining precisely what it is he wants and the form in which it should be delivered, but there is also a sequence of activities and PI decisions which must be coordinated. This is accomplished by the Data Management Group at MSC.

The per misssion procedure settled upon is essentially that shown in Figure 3-1. At this stage in the Earth Resources Program, sufficient experience has been accumulated with certain sensors to establish firmly the associated processing techniques and to standardize the output forms; thus, the corresponding PI instructions are not shown on the diagram.

The illustration is self-explanatory, but note that two distinct levels of processing are peformed. Initially, the collected raw data (magnetic tape recordings and photographic exposures) are routinely converted to several intermediate product forms and sent to the PI for review. In some cases, for example scatterometer processing, normal follow-on calculations and statistical summaries are performed on a sample basis to further assist the Principal Investigator in his evaluation of the usefulness of the data. He then decides which portions of the data are of particular interest and submits a request for what amounts to second-level processing; binary records of converted analog data in the time and spectral ranges of interest are transformed through additional computer calculations into detailed plots and tabulations and new photographic image products may be prepared.

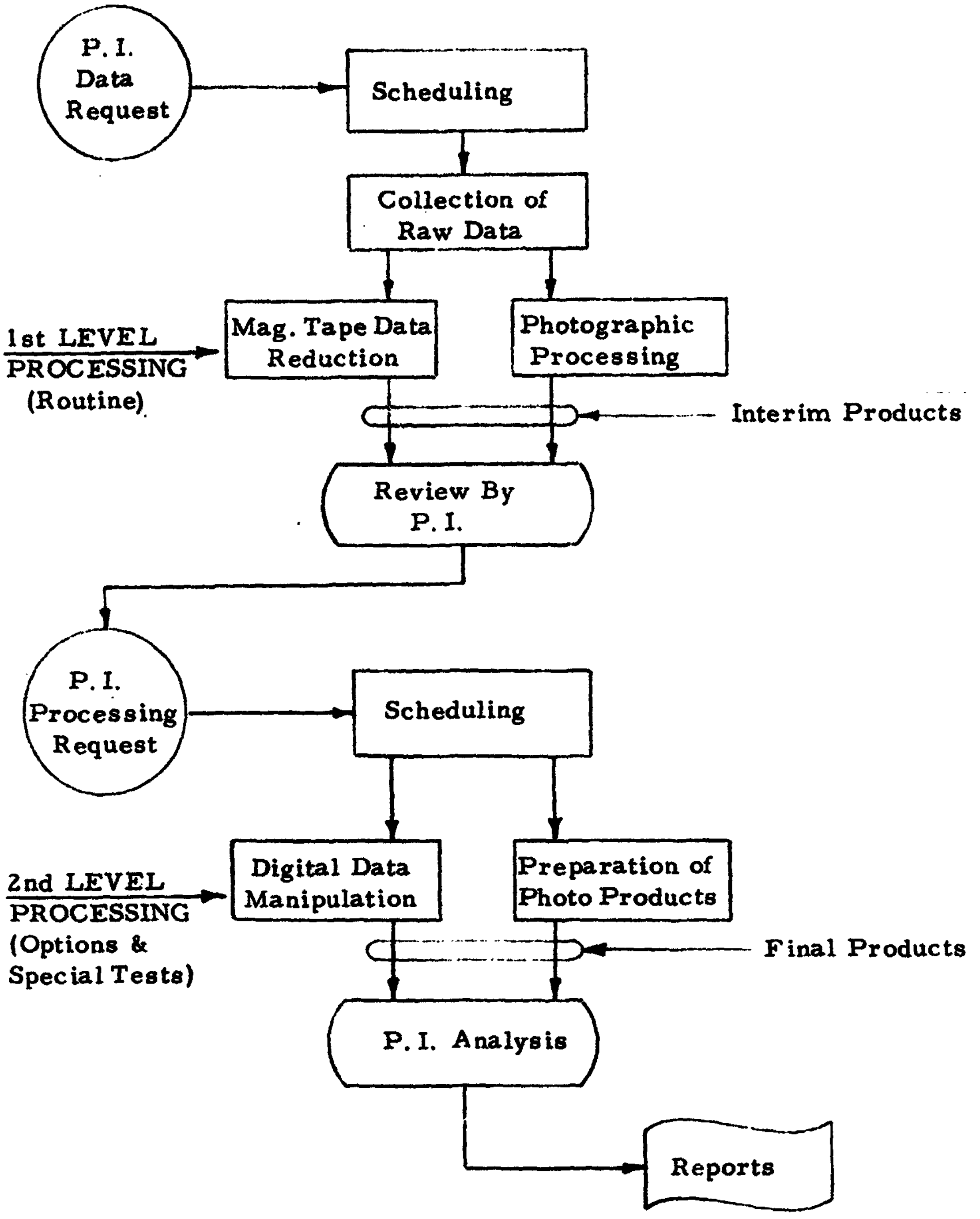


FIGURE 3-1 PER MISSION ACTIVITIES

The PI needs more information for his evaluations and analyses than processed sensor data alone can provide. He requires time and NAV data, plus boresight camera photographs to determine exactly where the prime sensors were "looking" at each instant; he often requires archival data for time-history comparisons. He may occasionally desire a copy of the analog tape in order to more closely examine raw signal characteristics. All of this material is also available from the data center.

More specific descriptions of the processing steps involved in handling both photographic materials and magnetic tape data are given in Appendix E.

In general, since the Earth Resources program is still in the sensor evaluation phase, the emphasis to date has been placed more on system flexibility than on integrated and complete data handling. Hence, processing in some cases falls short of ultimate goals (e.g., there is no automated, precise rectification of line scanner imagery) and, in others, proceeds to a reasonable point which is, however, independent of any specific application (e.g., the conversion of certain unused ancilliary data to computer-compatible formats). It is to be expected that such conditions will prevail for some time as new sensors are obtained and presently operational ones discarded. Eventually, multisensor correlations will be performed and these tasks will impose new processing requirements which do not currently exist. Consequently, at the moment there is no rigid metric control of sensor data and the only correlation parameter available is time. Again, this is reasonable at the present stage of the program.

3.5 PROGRAM EFFECTIVENESS

Any attempt to assess the effectiveness of the Earth Resources Program at MSC must be carefully prefaced with a statement of the nature of the program and of the selected criteria of effectiveness. More specifically, it cannot be too strongly emphasized that this is an evolving program. As such, it exhibits the characteristics of any evolutionary system; for example, its effectiveness continually increases, as weak elements are eliminated and strong elements are strengthened and maintained. It is the function of this portion of the report to suggest a means of identifying these weak and strong points, and thereby contribute to the acceleration of the evolutionary process.

An obvious prerequisite for evaluation of program effectiveness is the establishment of appropriate criteria in order to make value judgements. Clearly, "effectiveness" must be measured in terms of the degree to which the goals of the program are being fulfilled and, although it may not be entirely objective, the best measure of this is probably "User Satisfaction". Since all of the users will never be completely satisfied (new ones will constantly appear), user satisfaction will always be a relative term. This is no serious disadvantage, however, since the areas of valid user dissatisfaction indicate the direction in which evolution must proceed, and reduction in such dissatisfaction implies progress.

3.5.1 Criteria

The basic criterion, USER SATISFACTION, has been analyzed in Table 3-7. In a preliminary study of user's evaluations of the current state of the program, it was found that the comments could be conveniently distributed among four major categories: quality, quantity and timeliness of the data, and flexibility of the system. These categories have been further subdivided in a series of questions which, in general, are answered differently by each of the users.

It is important to note that during this R & D phase of the program, users are basically of only two types. The first of these is the scientist experimenter who is studying the problem of resource identification from data collected by remote sensors, while the second is the equipment engineer who is attacking the problem of sensors, processors and processing techniques designed to provide the experimenter with superior data.

TABLE 3-7

CRITERIA OF PROGRAM EFFECTIVENESS

	USER SATISFACTION
QUALITY OF DATA	1) Are sensors correct for purpose? 2) Are data correct for purpose? 3) Is sensor quality adequate? a) Resolution spatial spectral radiance b) Sensitivity c) Signal/Noise ratio d) Is geometric information accurate? 4) Is sensor and use standardized? 5) Are processing techniques standardized? 6) Are sensors and environment calibrated? 7) Is all ancillary information complete?
QUANTITY OF DATA	1) Does data cover an adequate spectrum? 2) Is data volume adequate?
TIMELINESS OF DATA	1) Is time interval between collection and availability sufficiently short?
FLEXIBILITY OF SYSTEM	1) Can new sensors and techniques be easily integrated into system? 2) Can new users be readily accommodated? 3) Can system respond quickly to an unexpected demand or emergency?

Universities are exemplary of the first group and MSC itself represents the second. In general, the two types of users will have quite different answers to the User Satisfaction questionnaire. Furthermore, even within the first group, requirements may differ widely; for example, the hydrographer will be satisfied with much lower resolution than the agriculturist.

Finally, as the entire Earth Resources Program evolves from the R&D phase to the operational phase, the criteria emphasis will shift. Whereas at present quality and quantity are all-important, timeliness and flexibility will gradually assume greater significance. This does not imply that the latter will replace the former. Even today, some experimenters require a degree of timeliness and flexibility and, even under a comprehensive production operation, R&D will continue.

3.5.2 Communication

The most important factor in a controlled evolutionary system is the closed loop concept. For the Earth Resources Program, the feedback loop is the communication between the data users and the data collectors. The data flow and communication channels are illustrated in Figure 3-2 where the circular symbology has been chosen to emphasize the completeness of the system and the fact that this completeness depends on the system being enclosed in a communications loop.

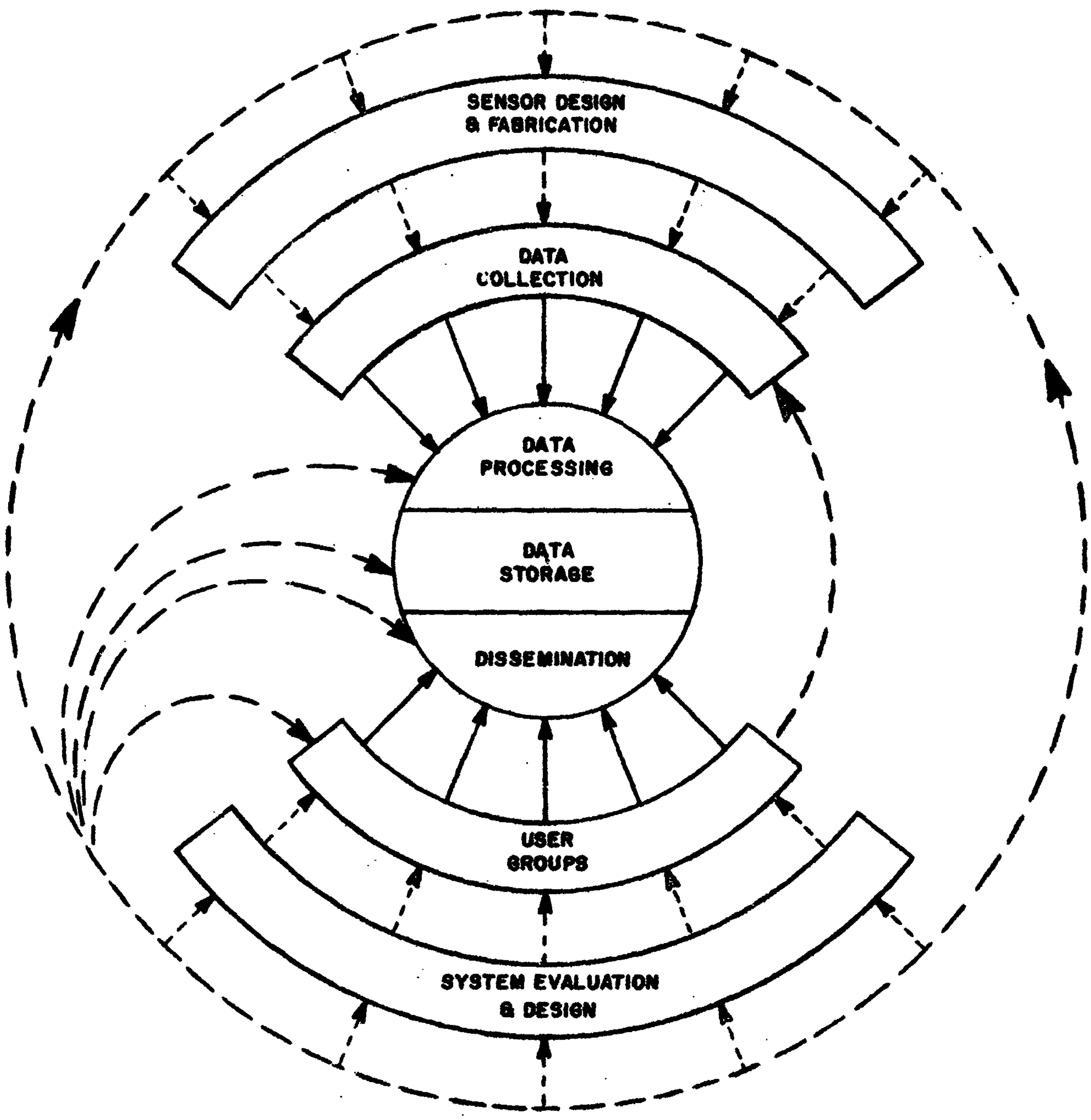


FIGURE 3-2 THE SIGNIFICANCE OF COMMUNICATION

The inside circle in the diagram, together with the inner annular segments, represents the operating system. The two outer segments, plus the communications ring, belong primarily to the R&D phase. As implied in the diagram, it is particularly important that the communication lines remain open and active, and it will be noted that the User Groups occupy the key position. They are the ultimate users of the data and they must therefore be the originators of the feedback. Unless they are expeditious in their data evaluation and in their constructive criticism of data collection and processing techniques, growth of the entire program may be hampered. It is imperative, therefore, that all parties endeavor to strenthen and maintain the communication feedback loop.

3.5.3 Detailed Evaluation of Program Effectiveness

It is beyond the scope of the present study to prepare an in-depth critique of Program Effectiveness or User Satisfaction for all experimenters at this time. To make such a critique meaningful would require literally dozens of interviews all over the country, coupled with a great many man-hours of analysis and evaluation. Even then, it is improbable that the resulting evaluation would accurately reflect the users' true opinion of the program. Nevertheless, a start can and should be made.

It was emphasized above that communication feedback is the key to rapid and fruitful evolution of the program. A useful technique which will both facilitate this feedback and provide the system designers with an up-to-date critique of program effectiveness is illustrated in Figure 3-3. The chart shown in the figure, or a similar one, should be provided to all users of MSC data with a request for prompt return. It will be noted that the chart depicts effectiveness, not capability; although the capability may be present, if user satisfaction is not being realized, the returned charts hopefully will reflect this fact.

DISCIPLINE (example) EXPERIMENTS In AGRICULTURE / CRITERIA of EFFECTIVENESS (example)	Yield Forecast	Stress nutrition too dry too wet diseases & pests A B C D	Maturity	Crop Identification genus species
DATA QUALITY Sensor Adequacy				
Data Correctness				
Resolution spatial spectral radiance				
Sensitivity				
Signal/Noise				
Geometric Accuracy				
Standardization sensor and use processing techniques				
Calibration sensors environment				
Completeness of Information				
DATA QUANTITY Spectral Adequacy Volume Adequacy				
TIMELINESS (data)				
FLEXIBILITY (system) New components and techniques New and different users Unexpected demand				
		G = Good F = Fair P = Poor		

PROGRAM EFFECTIVENESS CHART

FIGURE 3-3

The charts are arranged with the discipline and specific experiments in the left hand column and the several criteria of effectiveness across the top. At the intersection of an experiment row and a criterion column, the experimenter will enter a qualitative evaluation of the degree to which the delivered data fulfills his needs. Probably no more than a three-level evaluation (as shown on the chart) is warranted or required, but the experimenter should be encouraged to fill in as many boxes as possible, and to comment freely.

As a final step in completing the communication feedback loop, it is necessary to digest, evaluate and summarize all responses, and to develop recommendations concerning the indicated directions of improvements. If this effort is initiated in the near future on a widespread and systemmatic basis, and a spirit of cooperation is thereby engendered, the beneficial impact which would result on the Earth Resources program could be quite substantial.

SECTION 4

EVOLUTION OF THE EARTH RESOURCES PROGRAM

FOREWORD

The Earth Resources Program in general, and the program at Houston in particular, should be viewed as a "directed evolutionary system".

Unlike a natural evolutionary system, which is constantly constrained to adapt to its present environment, the directed system continually evolves toward a future prescribed environment. In common with its natural counterpart, the system must evolve gradually. As improvements occur, there should be no disruptive period when operations cease and, after their occurrence, there should be no loss of useful function.

In causing the system to evolve from one level of capability to a higher one, NASA should consider several steps which follow in logical sequence:

- Determine the present state of the system
- Establish "next level" goals
- Define the problem
- Describe a functional solution to the problem
- Discover or invent necessary techniques
- Determine feasibility of approach
- Develop hardware and software to execute techniques
- Develop the facilities to accommodate the new hardware and software.

At this point, the improved system becomes operational and NASA should revert to the first step and consider the next higher level of growth.

Section 3 and 4 of this report constitute a Program analysis which essentially proceeds through the same sequence. Section 3 describes the present state of the system and Section 4 delineates new goals (anticipated user requirements), identifies problem areas, suggests functional solutions and outlines recommended techniques and facility developments. The treatment is necessarily general, since specific new requirements have not been detailed. Nevertheless, it is certain that higher resolution imagery, obtained under better controlled conditions and reduced by superior processing techniques, will be a prime requisite. For the present, this is an adequate basis for defining the direction of future growth.

It should be noted that MSC program personnel are aware of many of these requirements and are actively planning to meet these needs.

SECTION 4 CONTENTS

SECTION 4 CONTENTS
(Cont'd.)

SECTION 4 CONTENTS (Cont'd)

TABLES

4.1 DATA ACQUISITION

The Earth Resources Program is expected to broaden considerably over the next few years, with major impact on all associated activities coordinated by MSC. This subsection provides quantitative values for aircraft mission activity and raw data volume projections through 1973, then briefly deals with the major considerations raised by changes in operational responsibilities, in the types of data acquired, and in the data sources.

4.1.1 Aircraft Program Projections

Discussions with cognizant MSC personnel have led to the mission activity and data volume projections given in Tables 4-1 and 4-2, respectively.

This information conveniently sizes the impending data collection and processing problems in terms of numbers of missions and amounts of raw data. However, many other factors must be taken into account in order to satisfactorily realize the desired capabilities.

4.1.2 New Procedures and Responsibilities

Innovations in collection procedures and the acceptance of new responsibilities in phenomena monitoring can markedly alter the volume and type of acquired data. Much more rapid processing throughput might also be demanded and it appears that some data may have to be handled in essentially real time.

This area is entirely speculative in that very little, if any, hard plans currently exist, and it would be premature to attempt to delineate them in any detail at this time. Nonetheless, some types of future activity are foreseeable and it is useful to touch on them in order to appreciate the possible scope of the program. Requirements may arise from several disciplines but, in general, they will lead to the following:

- Repeated site overflights in order to accumulate time-history data.

TABLE 4-1

PROJECTED A/C MISSION ACTIVITY

FY	CV-240A	P3A	C-130	RB57F	Total Missions	Avg. Missions Per Month
'69	10	10	4	---	24	2
'70	--	12	12	12	36	3
'71	4	15	15	20	54	4.5
'72	15	15	14	28	72	6
'73	18	17	17	36	88	7.3

AVERAGE MISSION:

- 3 Test Sites
- 2-8 Instruments (Avg. 3-4) per test site
- 72 tests and experiments
- 2-5 collection minutes per run
- 10-20 runs (Ave. 15) per site

TABLE 4-2

PROJECTED DATA PRODUCTS

F.Y.	Avg. No. Feet of Film/Mo. 35mm	70mm	5"	9 -1/2"	Mission/Yr.	Avg. Hours of Mag. Tape/Mo.
'69	4,100	1950	3900	1100	24	6
'70	6,150	2925	5,850	1650	36	9
'71	9,225	4,390	8,775	2,500	54	13.5
'72	12,300	5,850	11,700	3,300	72	18
'73	15,000	7,200	14,300	4,000	88	22

$$4 \frac{\text{min}}{\text{run}} \times 15 \frac{\text{runs}}{\text{site}} \times 3 \frac{\text{sites}}{\text{mission}} = 180 \frac{\text{min.}}{\text{mission}} = 3 \frac{\text{hrs. of tape}}{\text{mission}} \text{ Average}$$

Note: Based on NASA/MSC Memo, December 1, 1967, TF2/M147-67, "Earth Resources Data Summary Study," to TA/Deputy Director of Science and Applications, from TF2/Chief, Mission and Data Management Office.

- Multiple aircraft flights whereby data on time variant phenomena can be simultaneously collected from different altitudes and the effects tracked over long ground distances.

- Simultaneous aircraft and spacecraft overflights to acquire data for correlation analyses.

- Aircraft flights to acquire more detailed information in areas where examination of satellite-derived data has revealed something of interest.

- Collection of experimental data for the analysis of environmental hazards such as air pollution.

- "Real-time" monitoring of specific hazards such as tsunamis, floods, forest fires, etc. Note that this requires the design and implementation of a new data link system.

Time-history data collections, in particular, can impose severe constraints on aircraft scheduling. Thus, for example, providing repeated coverage of a particular wheat field every two weeks throughout the growing season will strongly limit the other uses to which the observation aircraft can be put during the same time period. Similar scheduling problems will occur while collecting time-history data over an instrumented glacier for an entire year, or recording the advance and retreat of a continental snow pattern. It will be necessary to provide enough aircraft and flight crews to perform experiments such as these, while simultaneously supporting other experiments of a more conventional nature.

As the program progresses, certain experiments will be designed to cover long flight lines over land and water to determine the need for multi-sensor combinations to reduce ambiguity in data interpretation, and to establish the quantity and location of earth surface data collection and communication relay instruments for future space programs. Similarly, as the Earth Resources Program expands in international scope, more flights will be required over regions outside the continental United States. Formidable logistics problems can be expected in conjunction with such operations, and the need for detailed long range planning will become increasingly critical.

4.1.3 New Sensors

While it is expected that some of the sensors currently in use will be discarded as collection requirements are refined, the more significant program changes will be those brought about by the introduction of new systems. At the moment, thirteen (13) such new devices have been identified. They are listed in Table 4-3. Most are applicable to aircraft usage but even systems assigned exclusively to satellites are likely to be flight tested on one of the MSC vehicles. The RB57F, for example, would be an excellent test bed.

4.1.4 New Requirements on Metric Accuracy

As techniques and tools for usably correlating time-history and/or multiple sensor data become more powerful, they will gradually be moved out of the laboratory and incorporated in the routine production processing operations. Clearly, geometric registration of all sensor collections will have to be controlled to accuracies beyond current levels because extensive manual adjustment is untenable for large data volumes. In general, automated processing will require:

- Additional information on sensor alignments.

  To measure these parameter values completely and at the desired accuracy, it will be necessary to run calibration flights over specially prepared test areas.

- Greater precision in the description of aircraft location.

  An analysis should be performed to establish worst case error budgets in light of user requirements and sensor and vehicle characteristics. It may then develop, for example, that an improved Navigation System would contribute substantially to the elimination of manual techniques in ground processing.

  Similarly, location data might be more useful in the form of difference distances relative to overflown check points rather than as latitude/longitude readings. This is the intrinsic form of collection in a doppler navigation system, and direct values would be free of errors introduced by on-board conversion calculations.

TABLE 4-3

NEW SENSOR SYSTEMS

A. SENSORS PLANNED FOR EARTH RESOURCES PROGRAM

Description	A/C	Spacecraft
4-Band Multispectral Camera	x	
Bendix Multispectral Scanner, 24 Bands (0.3 - 14 microns)	x	
Microwave Imager	x	
Goodyear 102 Side-Look Radar	x	
Short Wavelength Spectrometer (0.3-5.5 microns)	x	
SO_2 /NO_2 Correlation Spectrometer	x	
Return Beam Vidicon		x
Multi-Spectral Point Scanner		x

B. NEW SUGGESTED FUTURE SYSTEMS

Description	A/C	Spacecraft
TRW Wide Range Imaging Spectrophotometer (WISP)	x	x
FSDS Solid State Camera	x	x
Laser Profile Altimeter	x	
High Resolution Frame Camera	x	x
High Resolution Panoramic Camera	x	

* A fully implemented photo annotation system.

  All film strips should contain sufficient data for precision rectification. It is possible to obtain the necessary information by a time correlation with the Auxiliary Data tape but that function is more useful if it can be used as a two-way validity check. This is the approach now being planned using ADAS.

* Quality controlled image and analog data handling.

  This subject is discussed in detail in Section 4.3.

4.1.5 Correlation of Sensor, Subject and Environmental Data

An important trend in experimenter requirements is the increasing need to correlate the sensor output with environment and subject data in a more comprehensive manner than has been done to date. The use of auxiliary ground truth instruments to collect information, particularly radiance data, in close proximity to the subject will always be needed, but such information will not provide a detailed understanding of energy losses.

It is believed by many experimenters that before extensive "spectral signature" analyses can be proven in a research program, a detailed understanding of each element in the experiment is required. The following three subsections discuss the problem further.

4.1.5.1 The Signature Problem

The major technique being developed for the Earth Resources Program involves determination of the "spectral signature" of an object over a wide spectral band. It is assumed that this signature is unique and that, therefore, information about an object is available, provided its signature correlates 100% with the signature of a reference object about which everything is known. If, however, the spectral signature is incomplete (i.e., it consists of a few sample points within a limited band), even 100% correlation does not ensure identity between the test object and the reference object. On the other hand, even if correlation is less than unity, the probability of correct identification may be high. Hence, the problem consists essentially of two parts: a) examination of a sufficient portion of the spectrum to produce a unique signature, and b) elimination or reduction of all known sources of error so that the probability of correct identification can be maximized.

The first part of the problem forms the basis for a remote sensing program and involves the use of many sensors for recording information. It also necessitates the use of special data processing techniques to develop characteristic signatures.

Many of the simpler experiments, involving the use of narrow-band instruments to measure phenomena little affected by atmospheric or subject variables, have already been accomplished. However, the remote sensing program is now reaching the stage where broader regions of the spectrum must be collected in various combinations in order to produce unique signatures. In addition, the concept of variable parameters and errors introduced by collecting environment should be understood in order to eventually produce valid signatures.

4.1.5.2 Variable Parameters and Sources of Errors

There are many parameters and errors involved in "sensing" a remote object by detecting the electromagnetic radiation which travels from the object to the sensor. Three basic causes for the spectral signature of an object to vary from one sampling to another are:

- Variations in the Sensor System

  Signatures of a given object taken from supposedly identical sensors under identical operating conditions will vary because the sensors may actually differ in such characteristics as detectivity, spectral response, resolution, S/N, etc., and their operating conditions (e.g., electrode potentials, beam currents, magnetic field, temperatures, etc.) may also be different.

- Variations in the Environment

  Signatures of an object taken with a given sensor under several different operating conditions will vary because temperature, atmospheric pressure, atmospheric composition (e.g., water, dust, pollutants) and atmospheric structure (e.g., thickness, sloping hydrodynamic surfaces, thermal inconsistencies) have changed. Other environmental variables include sun angle and sensor/subject look angle.

- Variations in the Object(s)

  Even with all the above conditions fixed, signatures may well vary due to changes in the characteristics of the object itself. Thus, for example, two different crops at different agricultural stages of development may present nearly identical signatures; changes in surface roughness conditions, assuming identical composition and phenomena, may alter energy returns; identical crops with differing degrees of ground cover will present different signatures by virtue of contamination from soil signatures; signatures will differ with vegetation maturity and stress conditions, etc. In the last example, of course, differences are part of the information desired and are, therefore, not necessarily a source of error.

4.1.5.3 Signature Methodology

There are two fundamentally different approaches to the signature problem. The first of these attempts to obtain an "absolute" spectral signature of a subject, meaning either that the signature was obtained under a set of known and repeatable conditions, or that corrections can be applied to the recorded signature which will then match the standard for the subject. However, that implies a set of associated, accurately calibrated recordings of all sensor, meteorological, sun angle and exposure conditions. The second approach attempts to obviate the need for absolute signatures and extensive correction techniques.

By maintaining and reporting on a large number of control plots, it is assumed that all samples within the field of view having the same signature as a control object will have other characteristics in common with the control subject. This technique attempts to make subject identification independent of equipment and environment, but it still depends on view angle. Although this weakness would probably vanish for the small view angles used from a satellite, the small angular field would encompass a large area, and the additional variables of soil, surface roughness, moisture, and atmosphere would be major sources of error affecting the data. In addition, the maintenance, reporting and data processing associated with the control plot approach represents a most formidable task.

Further experiments and studies, aimed at determining which of these two basic approaches to signature determination is superior from an operational viewpoint, will represent a continuing R&D effort during the next several years.

It appears probable that early work will lean heavily on the ground truth approach, but that, as calibration techniques improve, there will be a gradual shift toward reliance on the absolute signature concept.

4.1.6 Satellite/Spacecraft Data Simulation

With the initiation of the Earth Resources Technology Satellite (ERTS) Program (ERTS-A and -B are scheduled for launch in 1971 and 1972, respectively) and with the Apollo Applications Program due to begin shortly, a comprehensive satellite/spacecraft data simulation program may represent a new direction for growth in the aircraft program in the near future. Although some information is available from past flights, the aim of the program would be to maximize the usefulness of future satellite/spacecraft data collection systems. Such a goal could be accomplished efficiently with a program designed to simulate spacecraft data collections using high altitude aircraft and appropriate sensors, and possibly also data transmission links and data encoding methods similar to those anticipated in the satellite/spacecraft programs.

The sensors would be configured to simulate anticipated space sensors, and the experiments would be designed to correlate high altitude with lower altitude overflights and conventional ground data collection. Data processing could be performed in a satellite/spacecraft data processing simulation facility, where data flow would simulate the techniques to be applied to actual spacecraft-collected data. Data analysis and preparation of products would follow a similar procedure.

Such a facility could permit alternate methods of data processing, such as electro-optical versus computer, to be set up to compare data flow rates, accuracies, and output products. It would also be used to detect problem areas in advance and permit corrective action to be taken long before the space system becomes operational.

4.1.7 Correlation of Earth Resources with Meteorology Programs

The several meteorology programs, both experimental and service-oriented, being conducted by NASA and ESSA represent a large investment in facilities and manpower. Since future earth resources experiments will involve collection of data on many more parameters, particularly those related to the atmosphere, it would appear desirable to use the capability that already exists in established and on-going meteorological programs. Such programs have well-instrumented aircraft that could be used in conjunction with earth resources aircraft in common overflights. Although such cooperation has existed on some past experiments, this type of effort will undoubtedly become more formalized and extensive in the future.

4.2 DATA STANDARDS

If the Earth Resources Program is to become truly productive, it must thoroughly standardize its operational methods. The transformation will be gradual and piecemeal, in that technical innovations will be introduced only after they are proven in R&D, and new data management procedures will not be instituted until a careful analysis has been performed in each case.

The force pressing these changes will originate in the growing heterogeneous community of users and experimenters. It will therefore exist, primitively, as a set of independent special-interest service requests. Clearly, if these disparate elemental "forces" are to be accommodated properly, they must be integrated and given coherent direction. This ultimately becomes the responsibility of the Data Management Group.

Concisely stated, the problem is to rigorously control all aspects of data collection, processing, and dissemination in order to efficiently meet the user/experimenter needs for timely, accurate information. The consistent theme in all of these considerations is the requirement for "data control," i.e., the establishment of appropriate data standards.

A first step in the solution is the definition of end-to-end performance criteria; thereafter, detailed requirements must be laid down for each operation performed from the time a mission is assigned to the time that final processing products are available.

Figure 4-1 shows the relationships among the major aspects of the problem. The next few paragraphs briefly deal with each of them.

4.2.1 Performance Criteria

Operations guidelines should be developed corresponding to each of the scientific disciplines serviced. These will take the form of end-to-end performance specifications where quantitative values are defined for such things as:

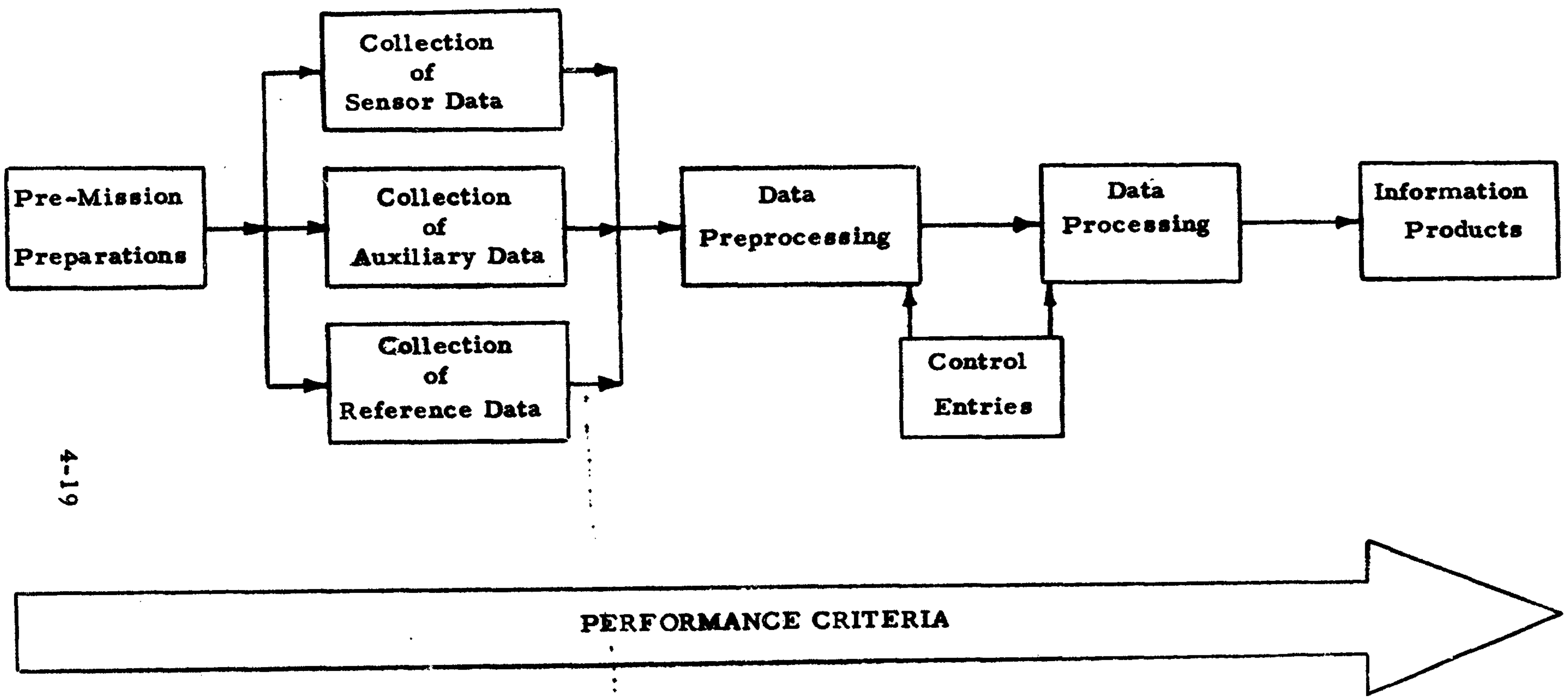


FIGURE 4-1 ASPECTS OF DATA STANDARDIZATION

- Geometric Accuracy
- Resolution
- Signal Fidelity
- Throughput Volume and Timeliness.

In order to meet the overall goals, error budgets should be established for each relevant service operation. Output products must also be defined, and they are discussed in a later paragraph.

Depending on user requirements, error(s) may or may not be tolerable. In some cases, for example geometric misalignments, the imagery might be correctable. Figure 4-2 shows the output portion of a generalized flow whereby a qualified analyst could review the hard copy, modify the imagery and add further annotations reflecting his actions or noting correlative field calibration references, etc.

In a similar manner, spatial, spectral, time base, amplitude and noise error control of electronically recorded data has implications regarding suitability of materials; thoroughness of annotation; procedures for handling, mounting, aligning and calibrating a variety of equipment; the characteristics of the vehicle used; the determination of adequate data sample intervals and parameters monitored; the need to compensate raw data so as to correct atmospheric degradations; etc.

All of these considerations must be weighed in terms of system requirements and error budget allotments, and improvements introduced where warranted.

A rigorous error analysis can have impact on details which range from the trivial to the major. For example, Memorex Corp. has just announced a new magnetic tape called Quantum. It has a stress-resistant coating which is claimed to provide recordings with three (3) times fewer permanent errors and fifteen (15) times fewer transient errors than other tapes, at 10-15 per cent higher cost. The technical advantages of the tapes may or may not be significant when converted to absolute performance, but its cost certainly has negligible impact on overall operational costs.

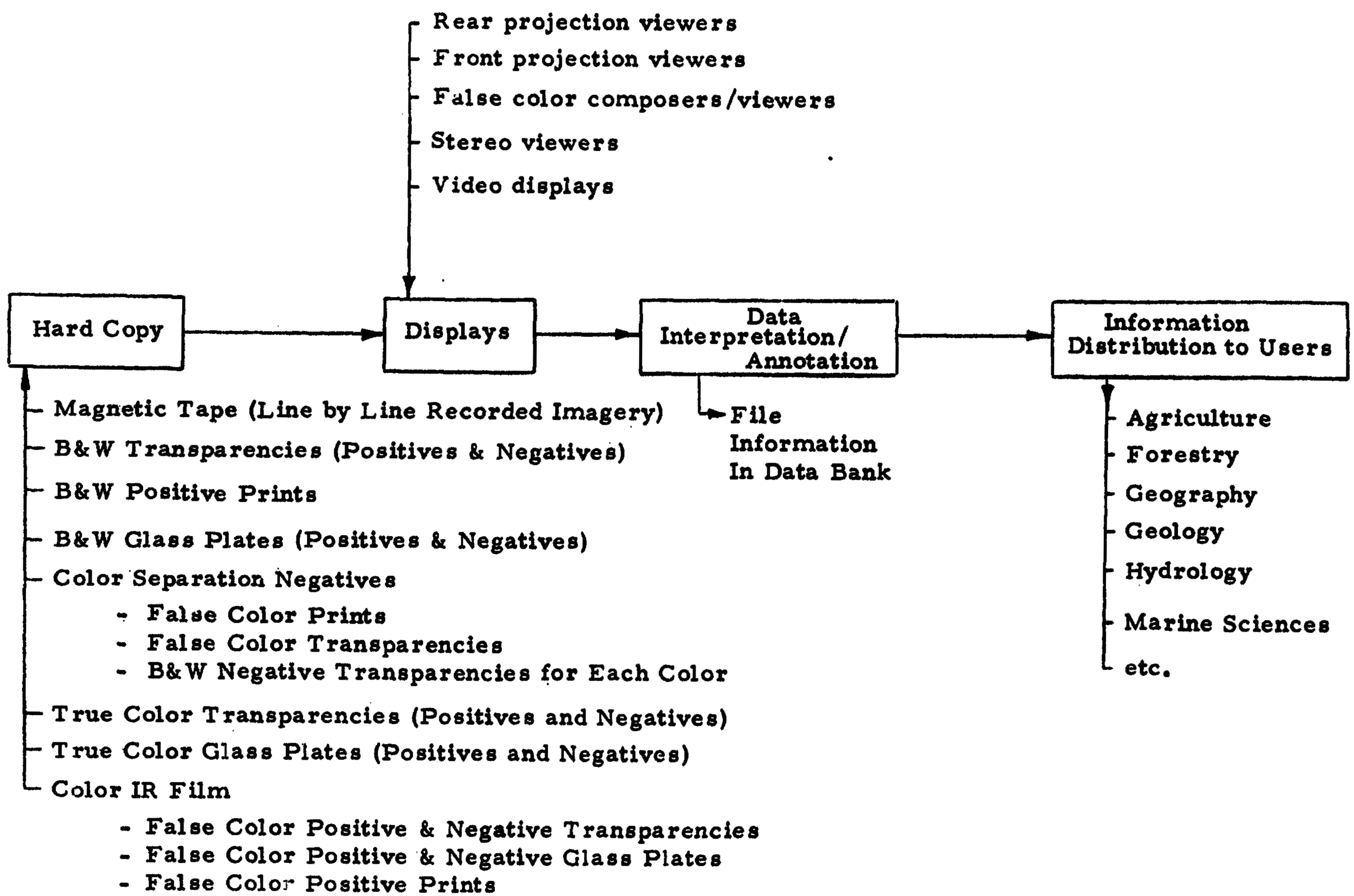


FIGURE 4-2 UTILIZATION OF INFORMATION

On the other hand, the issue of desired registration accuracy has far reaching consequences. Figure 4-3 shows the relationship between ground registration and the corresponding angular accuracy requirements at aircraft altitudes of 1000, 10,000 and 50,000 feet.

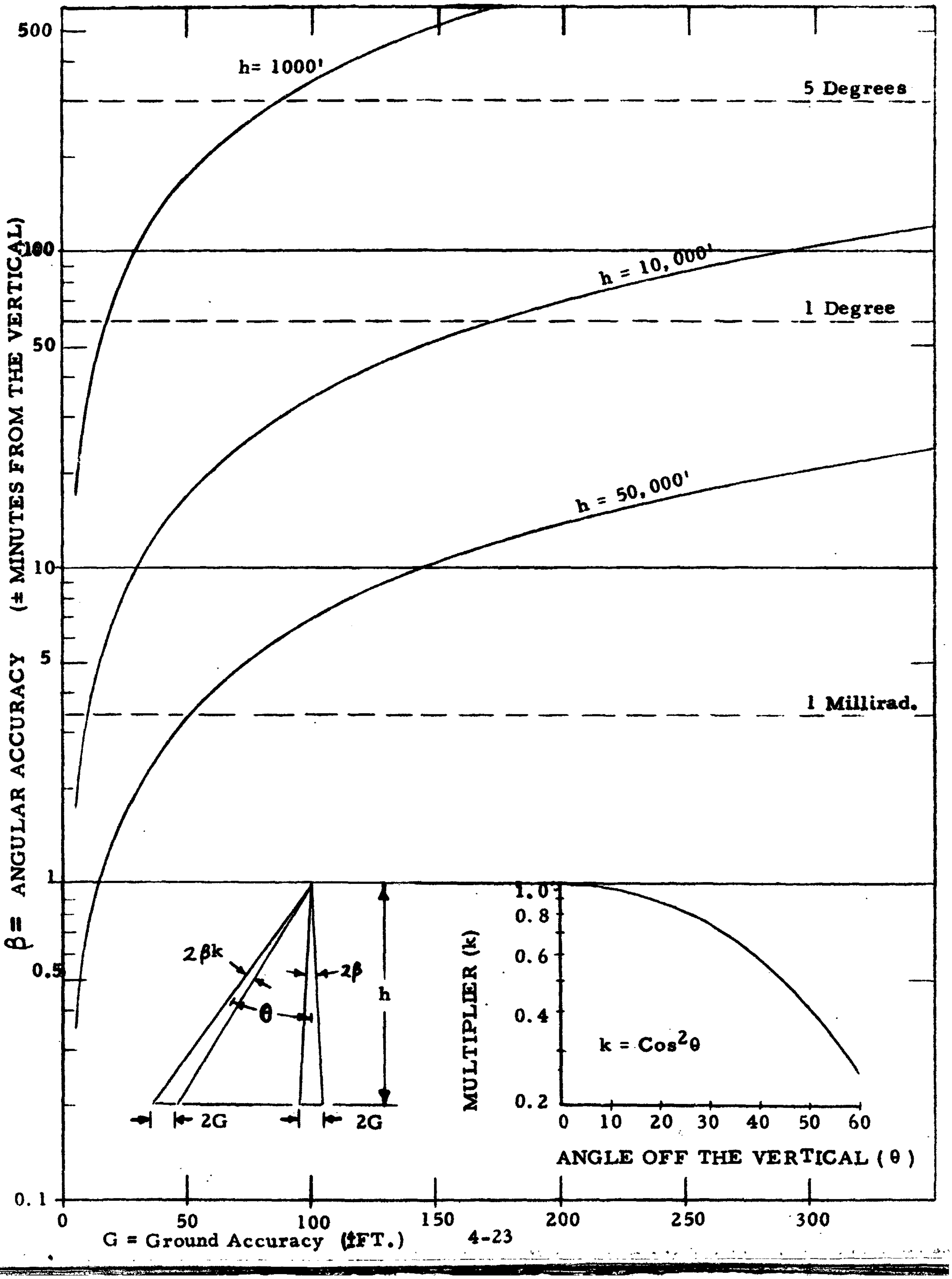
It is evident that high altitude flights will require extremely accurate knowledge of aircraft attitude, even for moderate ground registrations. For example, a ± 100 foot specification implies a taking accuracy of approximately ± 7 arc minutes at 50,000 feet. Note also that the requirement drops to coarser than 5 degrees at a 1,000 foot altitude.

Immediately involved, then, are trade-offs of equipment performance versus flight profile; more frequent attitude sampling versus additional readings of pitch, roll and yaw rates and possibly accelerations (particularly for spacecraft line-scanner corrections); the practicality of using space pyramid geometry to reconstruct attitude from the terrain imagery; the adequacy of existing image rectification equipment; etc. Questions must be raised concerning the setup, calibration and stability of sensor alignments and availability of boresighted auxiliary camera systems.

If the registration required is very precise then line and television type scanners must be further analyzed to determine whether their electronic deflection systems (in the CRT recorder and image tube, respectively) are satisfactorily linear and free from drift. If they are not, then special purpose ground processing steps must be introduced into the data flow to correct the errors; and certain equipment changes must be made.

Thus, for example, line scanner video should probably be recorded on tape only. The rectilinearization correction introduced via the CRT- film recorder will contain sweep distortion errors and if roll correction is added (which is currently the normal procedure in systems such as the RS-14), the conversion on the ground to a complete pitch/roll/yaw correction will require additional programs; yet other sensors are completely uncorrected in raw form.

FIGURE 4-3 ANGULAR ACCURACY



Furthermore, for very precise registration, TV-type scan tubes should have an etched faceplate to provide a measure of the two dimensional sweep distortion over the entire image.

Ultimately, the registration requirement should depend on the investigative application rather than the sensor resolution. Since all sensors in an aircraft undergo identical attitude and location changes, it is more practical to construct one set of corrections and apply it to all sensors than to refine it to different levels for different sensors. Furthermore, the expectation is that any particular application will require only one level of spatial accuracy for all sensor collections.

4.2.2 Pre-Mission Preparations

In actual operations planning, once the Mission Objectives have been determined, aircraft and equipment can be assigned for the overflight. However, even before that point is reached, standards are required for:

- An environmentally controlled warehouse for films and filters
- Routine maintenance of all equipment and vehicles.

Handling procedures are then necessary for:

- Selection of films and filters, based on mission objectives, aircraft and camera assignments, and the anticipated photometric conditions over the target;
- Logging out of mission and test films, and the proper routing of each;
- Sensitometric and color calibration exposures and annotation entries (Batch and Stock numbers, date and time, etc.) for both the mission and test films;
- Standard development and reference storage of test films;

* Magazine loading and logging into aircraft storage of mission films and filters.

The aircraft film sto… oom must also be environmentally controlled and, therefore, requires a set of specifications. This is again true of various compartments for detectors and calibration sources but it is more convenient to consider such requirements as part of the sensor equipment specifications.

Finally, procedures and specifications are necessary to control the checkout and optical and electrical alignment of all equipments. Depending on the precisions necessary for a particular mission, this may entail calibration overflights of specially prepared test targets.

4.2.3 Data Collection

As indicated in Figure 4-1, there are three major classes of data which must be collected on any mission. Expanded one level further, they are:

1) Prime Sensor data, from

   * Cameras
   * Infrared systems
   * Microwave systems

2) Auxiliary data, such as

   * Vehicle attitude, altitude, location ("NAV" data)
   * Calibration measurements (environmental and electrical)
   * Sensor tilt angle, mode, and other control settings
   * Boresight photography (for several sensors)

3) Reference data, including

   * Ground truth
   * Atmospheric measurements

These requirements have several significant implications regarding the establishment of collection standards.

In the first place, standardized procedures are necessary to assure that adequate total information is recorded. Figure 4-4 illustrates how extensive this can become, by depicting a typical sequence of operations and some of the attending considerations for a camera system. For adequate operational control, the given procedure would have to be further refined to include detailed instructions, such as decision criteria for selection of films, filters and exposure settings.

Of even greater importance is the observation that none of the collection procedures can be defined satisfactorily at our present level of knowledge. Much more has to be learned in each area, and the only effective way it can be done is by means of specially designed Calibration and Environmental laboratories.

4.2.3.1 Calibration Laboratories

Laboratory facilities are needed to gather calibration data on all ground-based instruments and airborne remote sensors. In addition, simulation techniques should be used to evaluate factors affecting operational performance, such as temperature, humidity, vibration, electrical biases, charge build-up, detector characteristics, etc.

In some cases, this may lead to requirements for new or tighter controls on certain parameters; in others, the existing controls may be adequate but it may become necessary to record additional signals in order to eventually correct the data.

Some of the parameters of interest that would be explored in a Camera Calibration Laboratory are given in Table 4-4. Note that spectral photometric calibrations will be needed. These are not normally determined for cameras but, in an earth resources program where spectral radiance is the key to information analysis, such measurements are vital.

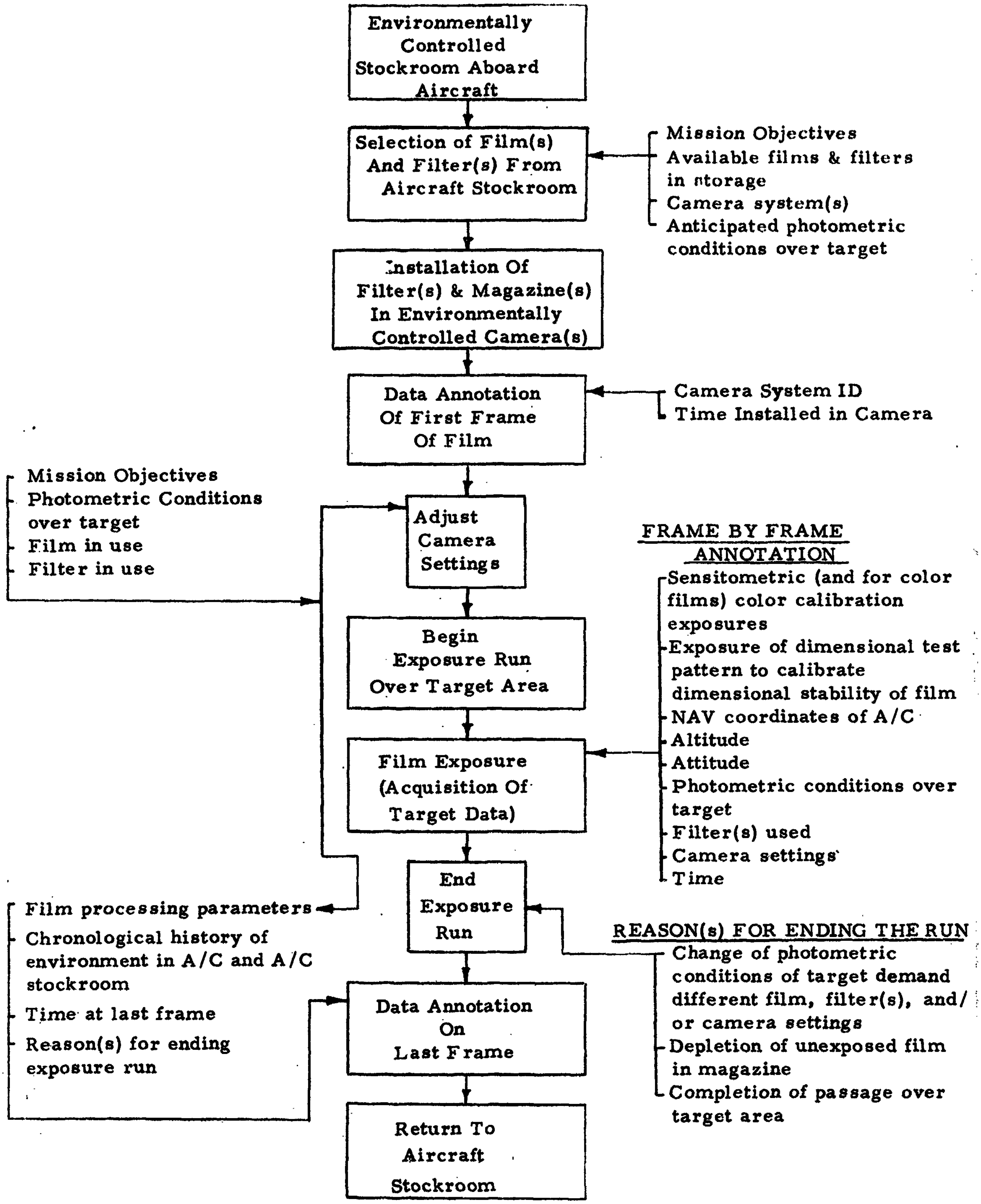


FIGURE 4-4 CAMERA DATA COLLECTION

TABLE 4-4

FUNCTIONS OF

A CAMERA CALIBRATION LABORATORY

Determination of Lens/Camera Characteristics	Variables
Metrical Information	• Temperature
• Focal Length	- Gradients
• Field Distortion	• Wavelength
• Resolution	• Air Pressure
- OTF (3 Bar Target)	- Gradients
- MTF (Sine Wave)	• Mount
• Principal Point	• Vibration
• Plate Perpendicular	• f - Stop
• Optic Axis	• Angle off Axis
• Film Flatness	
• Reseau	
Shutter/f -Stop	
• Efficiency/Photometry	
• Speed	
Spectral Photometry	
• Filter/Lens Transmittance	
- On Axis	
- Off Axis	

Similar calibrations are needed for each class of airborne and ground sensor, and detailed measurements should be made on all instruments. Since the devices range from UV through radar wavelengths and consist of entirely different mechanisms, each type of system will require careful attention both in designing an effective test facility and in actually determining the calibration parameters, techniques and procedures.

4.2.3.2 Environmental Laboratories

Since the entire Earth Resources Program is predicated on collecting electromagnetic energy through the atmosphere, it would seem appropriate to have a group of environmental laboratories capable of performing research in the various spectral bands of interest. There are many problem areas that should be investigated, ranging from the need for more accurately-determined spectral absorption coefficients, to testing instruments in environmental simulation chambers.

Since most instrumentation designed to measure spectral absorption data in the field is based on diffusion theory, there is a need to determine the coefficients more accurately. This requirement is especially true for the narrow bands used for air pollutant spectral absorption measurement. In addition, further research in atomic and molecular theory is required, and it will be necessary to test hypotheses in atmospheric environmental chambers.

Environmental laboratories could be used to simulate complex atmospheric and meteorological combinations to test the effectiveness of existing and new sensor equipment.

Research in this area could produce instrumentation for remote sensing alarm monitors, which could be used from ground-based and airborne platforms.

Further work is needed to understand scattering effects to improve remote sensing data collection. Research in polarization and with the various scattering theories (Rayleigh , Mie, Airy, Wiener, LaMer, et al) should be extended further as an aid in detecting remotely the presence of pollutants, dust, smoke, etc. The ASA rating in photography is based on Rayleigh scattering; ratings based on other scattering effects may be more appropriate for aerial photography, especially over dust and smog covered regions. Such studies also could better define film/filter combinations to penetrate smog and haze; indeed, they might even suggest combinations for determining particle/smog distribution and composition.

Each climatic region has a basic set of atmospheric conditions, and it is necessary to determine how best to collect radiance data over each area. Therefore, the spectral environmental laboratories also should consider radiance problems associated with areas such as oceans, seas, snow/ice fields, tropical rain forests, mid-latitudes, savannas and deserts, etc.

It is apparent that the entire problem of environmental laboratories will require extensive study. It is equally clear that a more complete determination of the factors influencing the performance of remote sensors is vital to the future success of the Earth Resources program.

4.2.4 Data Preprocessing

As used here, "preprocessing" refers to all ground system transforms of raw data plus those subsequent operations necessary to produce visually convenient or computer-compatible inputs to the "processing" system. It is, basically, data conditioning rather than data adjustment, and includes:

1) Quality-controlled film development
2) Decommutation and decoding of magnetic tape data
3) A/D conversions of analog recordings
4) NAV processing
5) Formatting
6) Gross screening of all film and tape data.

Obviously, standards must be adopted whereby preprocessing operations will produce no noticeable degradation in raw data quality; furthermore, judgement criteria and evaluation tests must be determined in order to permit efficient screening. The implied requirements may be conveniently summarized as follows, where each numbered statement applies to the identically numbered entry in the previous list:

1) Development of a QC Photo Laboratory;
2) Standardization of tape track and channel assignments and of data encoding techniques;
3) Establishment of A/D standards for sampling rates and digitization accuracy;
4) Development of rapid techniques for assessing and accurately correcting vehicle NAV data;
5) Definition of standard preprocessing output formats for all film and tape data;
6) Development of criteria and rapid techniques for the gross screening of input data and the rejection of unusable or non-interest portions.

4.2.5 Control Entries

Both preprocessing and processing operations will be controlled by operator instruction entries of various kinds. Eventually, all of the necessary control functions must be defined in detail; then system software and hardware can be developed to enable the selection of standard functional options and the entry of specific values for standard sets of parameters.

Standardization requirements would include at least the following:

- Mission Requirements entry (Subject ID and file reference data, site ID, on/off time intervals, etc.)

- Site Parameters entry (location, dimensions, grid spacing, etc.)

- Equipment Parameters entry (file-stored boresight offsets, electrical compensation characteristics, etc.)

- Procedure to semi-automatic extraction of rectification control parameters

- Procedure for manual adjustment of final image overlays
- Selection of output products
- Selection of other processing options and entry of other variable terms.

4.2.6 Data Processing and Information Products

A great number of detailed techniques and procedures must be established for the actual processing (i.e., reduction and adjustment) of input data. In general, standardized routines and tools must be developed in order to perform:

- Calibration corrections
- Geometric corrections
- Image enhancement
- Signature analysis.

In all areas, flexible orderly procedures must be developed and the system operator must be able to select or reject particular operations plus indicate whatever output products are desired.

It would seem advantageous to standardize outputs with regard to scale factors, projections, annotations, etc. This has the double merit of reducing output processing variables while also minimizing file storage and search operations.

4.3 DATA PROCESSING TECHNIQUES

Any discussion of technique development for the future must be rather general because earlier steps in the evolutionary cycle have not been formalized. But it is obvious that the system will be called upon to produce more and better pictures with reduced time delay. This, then, is the basis for recommending that the following techniques be studied and their development encouraged.

4.3.1 Screening

Man's ability to collect data has far outstripped his ability to make use of it. This fact is exemplified by the ever-increasing volume of unanalyzed reconnaissance imagery accumulating in military archives and by the months which elapsed between the time the Cuban photographs were taken and the embryonic launching sites were discovered.

It is the intent of the earth resources system-planners to increase this collection capability manyfold, and this increase is, in fact, necessary if the program is to succeed. Nevertheless, it is easy to visualize the entire system being strangled by its own input.

The first step in avoiding this catastrophe is the recognition of its possibility and the establishment of a timetable of probable input demands on the system. Once this is available, two possible courses of action are open:

- Continually increase the system throughput-capacity to remain ahead of the growth of input data.

- Devise techniques whereby only a fraction of the input data is processed through the entire system, the remainder being side-tracked at various points within the system.

It is not unrealistic to consider the first alternative. The growth rate of computer technology, both in hardware and software, is truly phenomenal. But this alternative includes not only geometric and value corrections of the data, but interpretation as well. And despite the "phenomenal advances", this function, comparable to that of the human eye-brain system, is still several decades away. Hence the second alternative must prevail and the "screening" function becomes an indispensible part of the program.

Screening is the function of excluding from further processing (or routing into a lower priority position) those data which are not immediately of interest. In its crudest form it can be automatic, e.g. all frames which contain no information (uniform gray level) are discarded as worthless. But automatic screening can be carried considerably further. Ocean areas and land areas can be separated out and only those of immediate interest processed in real time. The computer can be "taught" to separate forested areas from agricultural areas, etc. In other words, automation of the screening function will gradually encroach upon what has heretofore been considered man's prerogative, but it will be some time before man is completely displaced.

Study of the screening function and techniques for implementing it logically fall into four phases:

- Where, within the Central Data Processing Center, will this function maximize efficiency?
- What is the optimum mix (as a function of time) of automatic versus human screening?
- What techniques are required for automatic screening?
- What tools can be provided to facilitate screening by humans?

The answers to all four of these questions are legitimate products of a screening study. However, a few general guidelines can be established at this point.

The first (and grossest) screening function should occur as early in the processing cycle as possible, thereby reducing the load on the remainder of the system. For the present and near future, this should be a combined automatic/manual operation. Subsequent screening, at least for the immediate future, will be performed by man and the principle of "least work" must be invoked. If the function is performed too frequently, there will be little filtering at each station and a waste of manpower will occur; if too infrequently, unnecessary processing will be performed and system efficiency will be impaired.

Techniques for automatic screening have been described liberally in papers and symposiums on the subject of automatic pattern recognition. The proposed study should examine the results of all work in this field and make recommendations based on this study.

The heart of a manual screening function is a high resolution electronic display with the capability of man/machine interaction. The fourth study item will, therefore, be largely devoted to determining the state-of-the-art of such systems and either designating a system or laying out specifications for its development.

4.3.2 Geometric Data Processing

If useful spectral signatures are to be extracted from remotely-sensed data, it is mandatory that the system be capable of determining which data constitute a "set" (i.e. were derived from the same surface element) and which specific surface element a given set represents. Unfortunately, the sensor introduces geometric distortion, the absolute altitude determines the scale, and the platform attitude produces a variable scale. Hence, before the data can be correlated into sets representative of specific surface elements, the geometry must be corrected. These corrections consist of several steps as follows:

- Correction for sensor distortion
- Rectification for "taking" attitude
- Scale equalization for altitude and field-of-view.

These operations will result in all flat terrain data being converted to orthographic projections of a common scale, so that pictures of the same area will register when superimposed. It may also be desirable to make additional geometric transformations, as to a standard map projection such as Universal Transverse Mercator. "Geometric" corrections are not so obvious when the data is never reduced to geometry, but remains stored in digital form on a magnetic tape. Nevertheless, these same operations must be performed before signature extraction can be accomplished. In addition, it may be necessary to adopt a common ground element size for a set of tapes from which signatures are to be extracted.

Scale changes and simple rectification of distortions caused by taking geometry can be accomplished most expeditiously on an analogue basis using optical techniques. However, the more complex distortions due to non-linear scans in electronic sensors will probably require digital treatment.

A formal study of the complete problem of geometrical data processing is, therefore, recommended.

4.3.3 Image Enhancement

Enhancement is here defined as all processing operations on the data which modify their "values" rather than their positions. The components of value are magnitude, hue and saturation, and any or all may be altered for either of two purposes. The first purpose of image enhancement techniques is to compensate for deficiencies in the data collection system, the object being to restore the image to as near a perfect representation of the object as possible. The second application of enhancement is the deliberate introduction of some type of regular distortion, the object here being the emphasis of some characteristic of the imagery or the accentuation of subtle features which might otherwise go unnoticed.

Typical image enhancement techniques include aperture correction, unsharp masking, contouring, the introduction of false color, smear removal, and the removal of coherent noise. The literature is full of information on this subject, and a study should be initiated, the object of which is to determine which of these techniques are applicable to earth resources data processing, and to prepare and collect software for their accomplishment.

4.3.4 Signature Extraction & Correlation

There are two major facets to this problem. The first of these is the extraction of spectral signatures from a set of data on which all of the geometric, photometric and calibration corrections have been performed. And the second part of the problem lies in comparing and correlating these signatures with a library of standard signatures for the purpose of identifying the nature of the reflecting or emitting surface.

Again, the degree to which these functions are automated will increase with time. As new and better sensors are introduced, signatures will become increasingly complex (better spectral resolution) and hence more distinctive. Automatic spectral-correlation techniques must be developed, as manual library-search and visual correlation would be most tedious. Probably the automatic search should be based on a narrowing-down technique rather than an exhaustive trials approach. Signatures can be categorized into classes, orders, families, genera and species in accordance with their gross common characteristics down to their increasingly fine common features. For example, a single gross correlation test should separate vegetation from rock or soil on the basis of the presence or absence of the typical chlorophyl signature. Subsequent single tests might narrow the choice to annuals versus trees, thence to grains versus root crops, etc. It would seem that this signature classification problem should receive intensive study as a technique for system simplification and improved timeliness of output products.

Other subjects requiring study in this area include the problem of normalization and standardization of signatures, correlation techniques and their implementation, signature statistics versus signature features as correlation criteria, and the establishment of decision criteria.

4.3.5 Storage and Retrieval

The storage and retrieval function must be treated as a part of the data processing function, and its implementation must be integrally incorporated into the data processing facility. In section 4.3.1 it was pointed out that part of the screening function consisted of routing certain material into a lower priority channel, for processing at slack times. Some material, such as absolute signatures, may require frequent call-up for correlation purposes, and other material may have to be retrieved only occasionally or even only once, for studies of time-dependent changes. These requirements establish the necessity for smooth and rapid communication between the library and the active portions of the data processing facility.

The primary requirement placed on the library is accessibility, and this quality should probably be stratified into several levels. Those data which are retrieved most frequently should involve the smallest access time, whereas those for which the demand is relatively rare may take longer. Data which are always or frequently used together (as the gross classification signatures suggested in the previous section) should be consecutively accessible, i.e. a consecutive portion of a tape can be dumped quickly into computer storage for use in fairly extensive processing.

A basic characteristic of all libraries is their tendency to grow more rapidly than anticipated. This one will be no exception and the data accumulation rate will probably be phenomenal. Accommodation of this growth, without loss of function or reduction in efficiency, will be the measure of success of the original design. For these reasons, the storage and retrieval function warrants a careful and comprehensive study.

4.3.6 Data Outputs and Dissemination

Tapes, imagery and computer printouts are the ultimate products of the data processing center and the entire system will be judged on their acceptance or rejection. At present, the quality of these products appears to be more than acceptable, but quantity and turn-around time could probably be improved. Furthermore, the deluge of data is yet to come.

Requirements for tight quality control on photographic products, from film calibration through "taking" conditions and chemical processing, has been discussed elsewhere and will not be repeated here. However, the real problems will be in the areas of through-put and dissemination. Here, careful attention to priorities and close cooperation with users can partially compensate for inadequate facilities. Hence the MSC concept of having experimenters participate in and guide the actual processing will certainly mitigate these problems.

The third output, the electronic display, is actually a processing tool rather than a system output. It should have access to the in-process data at several significant points, thereby permitting the experimenter to assess the probable value of the finished product, modify the processing techniques, delete useless data, etc. This implies scan conversion from digital tapes to video signal, film scanners and, probably, a "point" and "zoom" capability. It also implies a two-way interaction capability between the operator and the system via the display, light pen and command-control. Finally, all electronic components must provide state-of-the-art resolution, linearity, and fidelity in order to ensure meaningful decisions by the experimenter.

Dissemination of the system products is, obviously, at least as important as their quality. In addition to establishment and observance of priorities and cooperation with existing users, it will probably devolve upon system management to actively seek out and educate potential users of its products. By interesting as many disciplines, arts, and technologies as possible, the program will move faster, its efficiency will increase, and its rewards will be sooner realized.

The three outputs listed are all essential parts of subsystems and, as such, will probably receive adequate attention without a separate Output Study. However, the dissemination problem is a real and important one which has been raised by some of the current experimenters. As such, it is suggested that it be studied by a qualified group, and the possibility of establishing a permanent panel on Education and Dissemination should be considered.

4.4 CENTRAL FACILITY

At present, data processing techniques are being studied at universities and in industrial laboratories all over the country. This is both necessary and desirable. Only the individual experimenter knows exactly the type and form of information he wishes to extract from the raw data. Furthermore, such independent processing studies must continue for some time possibly indefinitely. But as techniques become perfected, it will be possible to process large amounts of data in order to service a broad range of users. This can be accomplished most effectively by a large-scale Central Facility.

The assertion is justified on the basis of cost effectiveness. It is inefficient to distribute raw data to a large number of users and require them to process it to their needs in independent laboratories. Clearly, this would result in a large parallel, and hence extravagant, effort.

Furthermore, much of the value of accurate calibration and standardization would be lost. Finally, in any scheme, data collection, transmission, processing, storage and retrieval, information dissemination and all the multitude of steps in each major function will be expensive. The cost can only be justified if maximum use is made of the resulting product. This will occur only if one central agency is cognizant of as much of this product as possible, and if a concerted effort is made to seek out all potential users and make them aware of the application of this product to their needs.

But these ends are the precise goals of the Earth Resources Program - to continually free the experimenters to explore more advanced concepts and, of far greater significance, to make accurate, production processed information available to the world.

These requirements strongly recommend the establishment of a Central Facility. The next few paragraphs will examine the nature of this facility and will show that it should contain a coordinated group of laboratories, service centers and special purpose offices. Specifically, they include:

1) QC Photographic Processing Laboratory
2) Magnetic Tape Data Preprocessing Center
3) Data Exploitation Center
4) Space Data Simulation Laboratory
5) R&D Laboratory
6) Calibration and Environmental Laboratories
7) Library Center
8) Program & Systems Development Office
9) Public Relations & Education Office
10) Management Office.

Each of these sub-facilities will require extensive study and planning prior to actual development. It will be shown, in Section 4.5, "Management Considerations", that the best practical approach is to first design and build a moderate-scale interim facility, then use the accrued operational experience to plan the final configuration.

It is recommended that the Interim Facility studies be initiated at the earliest possible date. The remainder of this section is concerned with functional descriptions, so the distinctions between interim and final facilities are, temporarily, irrelevant.

4.4.1 Quality Controlled Photographic Processing Laboratory

Because each Earth Resource discipline uses photographic imagery in some form during data analysis, it is suggested that the highest priority item in the entire program is the development of a capability for producing quality-controlled photographic products. Research has proven that dimensional stability, image density, edge gradients and resolution become random variables in uncontrolled processing environments.

Table 4-5 lists the basic environment and facility elements which must be controlled and shows the degree to which the present MSC photographic processing laboratory meets these requirements. However, it does not indicate the additional requirements that must be imposed during the raw material manufacturing process or in film handling. These arise from considerations regarding:

- Uniformity in chemical quality, mix processing and thickness of the emulsion layers and base;
- Calibration of each batch of material;
- Maintenance of atmospheric environmental control during transport from the manufacturer to the Pre-Mission storage facility, then from there to the aircraft store, then to the camera, the post-exposure aircraft storage and, finally, to the processing laboratory.

Many other problems can also occur during manufacture. One example is the technique of cutting large sheets of film into strips. As the cutters move through a dry emulsion, the material splinters, landing on the film surface in a random pattern. Such double emulsion thicknesses affect the spectral sensitivity and processing of those spots.

TABLE 4-5

REQUIREMENTS FOR FACILITIES TO PRODUCE QUALITY-CONTROLLED PHOTOGRAPHIC IMAGERY

	REQUIREMENTS	CAPABILITY AT MSC
A.	Film /Copy Material	
	Controlled Storage	
	• Film/Copy Material	Yes
	• Temperature	Partial
	• Humidity	Partial
	• Dust Filtration	Partial
	• Static Electricity	
	- Atmosphere	No
	- Clothing	No
	- Materials	No
B.	Pre-flight Controls and Test (incl. Magazine Loading)	
	• Color Film Sensitometry Check	Yes
	• B&W Film Sensitometry Check	Yes
	• Copy Material Sensitometry Check	Yes
	• Temperature	Partial
	• Humidity	Partial
	• Dust Filtration	Partial
	• Static Electricity	
	-Atmosphere	No
	-Clothing	No
	-Materials	No
C.	Environmental Control For Film Transfer to A/C	No
D.	A/C Environment Controls	
	• Temperature, Humidity	Partial
	• Dust, Filtration, Static Electricity	No

TABLE 4-5 (Continued)

E. Laboratory Processing

1. Laboratory Organization

• Central Management	Partial
• Ease of Light to Darkroom Conditions	Partial
• Clean Room Design	No
• Decontamination Entrances & Exits	No
• Operators in Clean Room Clothing	No
• Emergency Shut Offs	Yes

2. Water Input Control

• Volume	Insufficient for 100% operation
• Particle Filtration	Yes
-5 micron size	No
• Temperature	Yes
• Mineral Control	No
• De-ionization for chemical mix	No

3. Chemicals, Mixing, Feed and Environment Control

• Isolated Facility	Yes
• Chemical Purity	Kit Control
• Remote Hopper Fill	No
• Automatic Hopper Mixing	No
• Volume per batch	Insufficient
• Closed loop	No
• Mix check	
- Automatic	No
- Manual	Partial
• Hypo recovery	No
• Silver recovery	No
• Bleach recovery	No
• Maintenance of mix stability and purity	Partial

TABLE 4-5 (Continued)

	• Environment	
	- Temperature	Partial
	- Humidity	Partial
	- Dust filtration and exhaust	Partial
4.	Processing Environment	
	• Temperature	Partial
	• Humidity	Partial
	• Dust Filtration	Partial
	- 5 micron particle size	No
	• Static Electricity	
	- Equipment	No
	- Atmosphere	No
	- Clothing	No
	- Materials	No
	• Laminar air flow	No
5.	Support Equipment Isolation	
	• Pumps	No
	• Heat Exchangers and Controls	No
	• Chemical flowmeters	No
	• Filters	No
	• Water conditioning and tempering devices	No
6.	Central Quality Control and Monitoring	
	• pH of solutions	No
	• Flow rates	No
	• Temperature of solutions	No
	• Temperature of wash water	No
	• Machine Processing Speed	No
	• Environment Temperature	No
	• Environment Humidity	No
	• Temperature of Film Dryers	No
	• Air particle size and count	No

TABLE 4-5 (Continued)

7. QC Process

• Original Film ("Trenton" or HTA series processors)	No
• Copy Materials ("Dalton" or HTA series processors)	No
• Archival Wash Quality	No
• System Ballast	No

Based on the eventual need for more controls before, during and after the photographic mission, on the difficulties associated with raw materials, and on the limited capability of the existing photographic control program, there is a need for a thorough study of the problem.

4.4.2 Magnetic Tape Data Preprocessing Center

This facility will be responsible for all preprocessing and gross screening operations performed on those mission inputs which are on magnetic tape. It will also provide other off-line capabilities such as film-to-tape and tape-to-film conversions, and various plotting functions.

4.4.3 Data Exploitation Center

The on-line portions of the Automatic Data Correlation System and the Signature Analysis System essentially comprise a Data Exploitation Center. This complex will:

- Accept film and tape inputs:
- Perform data reduction, calibration correction, geometric processing and correlation processing of all inputs, with reference to on-file ground data;
- Perform signature analyses of multi-spectral sensor data using references on file and/or determined from the collection itself;
- Set up master output products, under operator control.

Although this operation will initially be concerned with R&D analyses, it will eventually become the very core of the production processing activity.

4.4.4 Space Data Simulation Laboratory

A Space Data Simulation Laboratory would be designed to:

- Modify sensor films and tapes collected by high flying aircraft so as to simulate data acquired from satellite altitudes;

- Experiment with various processing techniques in order to determine the optimum methods for handling high-volume spacecraft collections.

The facility should have optical and computer techniques at its disposal.

The value of simulation has been proven for many space programs. Development of this facility would result in a more cost-effective program for the design of new sensors and data processing system components.

4.4.5 <u>R & D Laboratory</u>

The Center would also undertake research and development programs in film and tape processing. There would be two general goals:

- Improve hardware and software techniques used in processing data from existing sensors;

- Anticipate the processing requirements associated with new sensors.

These tasks should be performed in a separate facility so as not to interfere with production processing.

4.4.6 <u>Calibration and Environmental Laboratories</u>

The need for these facilities was discussed at length in Section 4.2.3 and will not be reiterated here. In general, each sensor requires calibration and more and better information is needed for each waveband regarding transmission and absorption coefficients, scattering and polarization effects, the influence of meteorological variables, etc.

It would be appropriate for study efforts to begin very soon, because long lead times will be necessary either to create new facilities or update existing ones.

4.4.7 Library Center

A Library Center is needed, which would contain:

- Data archives
- Printing and publishing facilities
- Viewing equipment for data examination and comparison by national and international users.

As a matter of convenience, the same center could assume the responsibility of copying mission processing products and distributing the material to all users and experimenters.

It is recommended that studies leading to the development of a suitable Library Center be started in the very near future.

4.4.8 Special Purpose Offices

An integrated facility would have many special purpose offices whose attentions would be focused on particular aspects of all operational and R&D programs. Three of these warrant specific mention at this time; they are the Offices for:

- Programs & Systems Development
- Public Relations & Education
- Management.

4.4.8.1 Programs & Systems Development Office

This office would manage all on-going discipline application and data collection programs.

The discipline applications function (an existing capability at MSC) would interface with experimenters and users on both a national and international scale. The data collection programs function would include not only existing aircraft and aircraft/spacecraft programs, but also the space data simulation program. In addition, it would develop collection standards for air/space remote sensing, navigation, and ground-based data.

4.4.8.2 Public Relations & Education Office

An auxiliary but important function would be provided by this office. Although the value of public relations is well understood, the function of education should be stressed. There is a need for many more scientists in the field of remote sensing applications, and a program should be developed to disseminate remote sensing information to the colleges and universities. This program could include many facets, such as providing scientific guest lecturers, preparing teaching aids and remote sensing course materials, and disseminating scientific reports.

4.4.8.3 Management Office

Any program which is to function efficiently must be under central administrative control, with all facilities and functions responsible to a centralized authority.

For a complex operation, such as the one described, to function smoothly and produce information in a timely manner, requires that there be a fully-developed management program, administered by a Management Office and including planning activities and various mechanisms for monitoring and controlling data collection, processing, dissemination and experimentation.

The topic is discussed in greater detail in the next subsection.

4.5 MANAGEMENT CONSIDERATIONS

The management of any complicated program demands that a great deal of attention be paid to a host of detail problems. However, in the broadest view, all issues can be summarized by three questions:

1) What are the program goals?
2) How well are they being realized?
3) What should be done about the existing or forseeable deficiencies?

Although the Earth Resources Program at MSC has many management sub-programs and the planners are well aware of problem areas, there are several observations which warrant mention in this document. All but one involve basic principles and are therefore important because of the influences they can exert on program development; the one other is significant because it has to do with modern management tools and their relationship to program control.

To give the discussion continuity, it will proceed through the same sequence of themes as the trilogy of questions, namely:

Goals - Effectiveness - Methodology.

4.5.1 Program Goals

It is the opinion of FSDS personnel that the Earth Resources Program has now reached a key point in its evolution, where specific goals should be re-examined and critical undertakings accelerated. A first consideration is the firming of the scientific base and a second is the interface with the nation and, ultimately, the world.

4.5.1.1 Scientific Goals

The central technical concept in the program is that subjects of interest, either on the earth's surface or in the atmosphere, can be satisfactorily monitored by sensor equipment carried in aircraft and/or spacecraft. Experiments to date have been encouraging in that they support the general validity of remote sensing, but so many variables are involved that a great deal more work is necessary before the problem will be completely understood. Needed are:

- More experimenters/users, not only from government and universities, but also from commerce and industry;

- More, and better regulated, experiments;

- New research on atmospheric and other environmental influences on "apparent" signatures;

- Improved sensors.

Of course, efforts along these lines are underway, but they are essentially piecemeal; there is no unified attack on the over-all set of problems. What is lacking is a coordinated, codified set of national earth-science goals, including statements indicating the present status of the science and where it should be going to improve the range of man's knowledge.

It will always be necessary to perform pure or undirected research, but it is much more imperative to establish directed research, both basic and applied, to solve the more pressing problems.

4.5.1.2 Interface Goals

The basic aim of the entire Earth Resources Program is to provide vital, timely information to as broad a community of users as possible. The nature of the operation immediately places it on a national scale but, certainly, if the underlying concepts are valid, earth monitoring must eventually become a cooperative international activity. That implies an approaching requirement to quickly process enormous amounts of raw sensor data and efficiently distribute the resultant information to a vast user group.

The point was made in section 4.4 that production processing and dissemination chores can best be handled by a single large-scale facility, with the added attraction that it could then conveniently assume other responsibilities by virtue of its centralized role. When the program expands to global proportions, there might be several such major facilities, all interconnected as components of a world-wide earth resources data network.

Such long-range speculations are useful in that they set directions. However, another element is required for the reference to be useful: that factor is, rate of progress.

Measured this way, it appears that the program is in danger of developing non-uniformly; that data collection activities may soon outstrip the necessary associate developments in ground conversion to usable forms. Specifically:

1) The aircraft collection program at MSC is being expanded by the addition of the RB-57 aircraft plus new sensors;

2) ERTS satellites are scheduled for launch in 1971 and 1972;

3) The Apollo Applications Program will soon be operational;

4) It appears likely that approval will be given to development of the Manned Space Station.

All of these sub-programs will produce sizeable amounts of multi-sensor earth resources data in the relatively near future. Therefore, it is crucial that a corresponding effort be started immediately to define and develop a National Data Processing Center. At least two critical studies have been initiated regarding the processing difficulties, namely, the Automatic Data Correlation System Study and the Signature Analysis System Study. However, the facility itself must be analyzed.

This is an extremely difficult task and, in the opinion of FSDS personnel, it should be undertaken in two stages. Because of the magnitude of the eventual program and the still evolving technical requirements, economic factors and political forces which will shape it, the only practical course is to begin by planning and developing a moderatelyscaled interim facility. Then operational experience with that, plus the better vantage point of a later time, can be used to refine the specifications on the final large-scale complex.

Consequently, it is strongly recommended that specific technical and budgetary planning for such an Interim Central Facility be initiated as soon as possible.

4.5.2 Program Effectiveness

If program goals are to be realized in minimum cost, then more formalized procedures must be instituted to evaluate the effectiveness of each sub-effort. Section 3.5 discussed the topic from the standpoint of determining whether the aircraft program and associated ground processing were satisfying experimenter/user needs. In addition, there is a need to evaluate the experiments themselves.

The most fundamental question to be explored is how well an experiment contributes to an understanding of any of the significant unresolved problems. Initially, the number of proposed experiments were few and the quantity of unknowns was large, so virtually any progress could be looked on as significant. Gradually, this ratio is changing, and the time has come to start considering priorities.

Experiment evaluation should therefore begin at the proposal stage. At that point, its validity should be judged on the:

- Degree to which it conforms to established national scientific goals
- Apparent merits of the technique
- Demonstrated competence of the experimenter team
- Projected cost, time constraints and complexity
- Potential conflict with, or augmentation of, other collection or processing activities.

Further management controls should be imposed to guarantee the return of post-experiment results for evaluation. All experimenters and users, whether operating in the field or at some central facility, should be obliged to file standard:

- Science reports
- Data suitability reports
- Recommendations for future experiments.

Some science areas, such as Hydrology, are better coordinated than others, in terms of having a unified national program; all of them, however, have some parts of such a program. The development of a completely integrated set of earth-science goals and a means of gauging progress toward them will take time, and should be begun at once. It must also be recognized that some disciplines, such as Hydrography and Oceanography, might most appropriately entail international participation from a very early stage in the program.

Finally, no program will be effective unless its sub-efforts are well coordinated. The previous paragraph noted the possibility of slippage between total collection and total processing capabilities. That particular problem has major repercussions, but the same principle applies on lesser levels also.

One important example is the development of new sensor systems. In order to save time and money in applying a new sensor, all preparations necessary to integrate it into the program should be complete by the time it is delivered. That includes vehicle assignment and mounting hardware, interface equipment, transmission links, recording provisions, design of first experiment(s), and suitable data processing procedures.

This can be accomplished by establishing system integration controls. It is recommended that plans be developed to formalize the scheduling of all such related R&D activities.

4.5.3 Program Methodology

Program evaluation and planning lead to reforms in specific areas of methodology. These can conveniently be categorized as:

- Vehicles and crews
- Sensors and auxiliary systems
- Data processing facilities and techniques
- Dissemination facilities and procedures
- Facility personnel
- Management techniques.

Most of these items have been discussed at length in other sections of this report; a few need further comment.

A basic factor affecting program size and cost is the flexibility of flight operations. A particularly demanding requirement is the wide-scale monitoring of unpredictable, rapidly perishable phenomena. Either such activities must be kept limited, or a greater number of aircraft and crews must be obtained.

Ground facility requirements have been discussed in Section 4.4 and Section 5 makes some estimates regarding the attached personnel, but those latter figures are developed for gross sizing purposes. They are, by no means, recommendations. Rather, the number and types of specialist personnel are issues to be resolved in the suggested facility study. The only point to be added here is that both earth scientists and principal investigators should be included: The first, to smooth the interface between experimenters and operations planners and the second, to conduct in-house data analyses and special experiments.

The most complicated, but also the most powerful, management tools needed will be computer-assisted Management Information Systems. Three types can be distinguished, their differences arising out of what it is that is being managed:

1) Program planning support
2) Simulation analysis
3) Processing control.

The first would provide status data on all program elements and would be designed to facilitate the detailed planning and scheduling of future missions and the follow-on processing tasks.

Computer-assisted operations analyses using simulation techniques have proven successful in estimating system growth, suggesting alternative processing methods and improving data-flow organization and rates.

Processing control is a complicated subject which, nonetheless, lends itself to useful generalized analysis. The discussion is far too lengthy to include here, but can be found in Appendix G.

4.6 PRIORITY GROWTH ITEMS

Section 3 of this report described the present status of the MSC aircraft survey program. This section has considered the major evolutionary trends which are developing, or need to be developed, in the Earth Resources Program as a whole, with particular emphasis on their impact on the MSC operation. It is useful to now summarize the more important of these findings and assign priority levels that seem appropriate at this time. This has been done in Table 4-6.

Programs aimed at developing many of the systems and techniques indicated are already underway at MSC, and it is expected that others will be initiated soon. Furthermore, on-going planning efforts at Houston have identified the need for many of the listed facilities. However, the intent of the present study has been to perform an independent program review and analysis. Consequently, a deliberate effort was made to avoid detailed discussion of these planning areas with NASA/Houston project personnel. To the extent that Fairchild's recommendations agree with those of MSC, the present report constitutes a reinforcement, perhaps even an amplification, of their ideas. In other instances, the recommendations herein may introduce new concepts into the program. In short, an attempt has been made to be as objective as possible, while still acknowledging existing MSC projects.

One final point needs to be made. Almost as important as the identified facilities, systems and techniques that are the program

TABLE 4-6

PRIORITY GROWTH ITEMS

(Sheet 1 of 2: Central Facility)

ITEM	PRIORITY	STATUS
QC Photo Lab.	A	-
Mag. Tape Data Preprocessing Center	B	-
Data Exploitation Center	B	-
• Auto. Data Correl. System	A	MSC Contracted
• Signature Analysis System	A	MSC Contracted
• Mgmt. Info. System	B	-
Space Data Simul. Lab.	C	-
• Space Data Simul. System	C	-
R&D Lab.	C	-
Calibr. & Environ. Labs.	B	-
Library Center	B	-
• Library System	B	-

Notes:
1. A... represents the highest priority
2. Studies are required for all items
3. All systems will eventually require hardware and software development.

TABLE 4-6 (cont.)

PRIORITY GROWTH ITEMS

(Sheet 2 of 2: Contributing Studies)

ITEM	PRIORITY	STATUS
Screening Techniques	B	-
Data Storage and Retrieval Techniques	B	-
Image Enhancement Techniques	B	MSC In-House
Calibration Techniques	A	MSC In-House
Interface Problems	B	MSC In-House
Public Relations	C	-

Note: A.... represents the highest priority.

building-blocks, is the assurance that they will be brought together, merged and operated efficiently. It is beyond the scope of the present study, and would be most inappropriate, for the Contractor to recommend suitable organizational structures. It is appropriate, however, to emphasize that the data processing and dissemination functions are critical ones, and that close cooperation among all parties is required to ensure the ultimate success of the program.

SECTION 5

DEVELOPMENT COST ESTIMATES

FOREWORD

The previous section identified a number of priority growth items which are vital to the continued development of the Earth Resources Program. Here, schedules and cost estimates associated with achieving these goals are presented.

It should be emphasized that the values given, while considered to be reasonable and of the proper order of magnitude, are neither exact nor completely definitive. Further detailed study and planning is required if costs and schedules are to be defined to the accuracy needed to proceed confidently.

SECTION 5 CONTENTS

SECTION 5 CONTENTS (Cont'd)

5.1 TECHNIQUE STUDIES

Estimates for critical scientific and system technique studies are summarized in Figure 5-1. Several of these pertain only to first-phase efforts, whereas the corresponding topics are likely to require further levels of detailed examination as the program continues. This is indicated by the dashed lines in the figure.

Projections are carried through a 40-month period in order to make this chart compatible with subsequent ones.

It is expected that many other study requirements will arise as the program develops. It should also be emphasized that some studies should be closely coordinated by NASA to assure maximum benefits. For example, considerable interaction should be encouraged between contractor teams studying the Automatic Data Correlation System, the Signature Analysis System, and Image Enhancement Techniques, in order to settle interface details and arrive at optimum display configurations.

5.2 INTERIM FACILITY

Facility costs must be separated into set-up and operating expenses but, before either can be estimated, the complex must be sized.

5.2.1 Basic Assumptions

It is assumed that the Interim Facility will have essentially all the functional capabilities desired of the final National Center, but scaled down to conform to Houston aircraft program projections. For costing purposes, only the Data Exploitation Center, Q.C. Photo Laboratory, Calibration & Environmental Laboratories and Space Data Simulation Laboratory will be considered. Ideally, the facility should also contain R. & D. photographic and computer laboratories, public relations and education offices, user applications and program offices, etc. However, these capabilities have

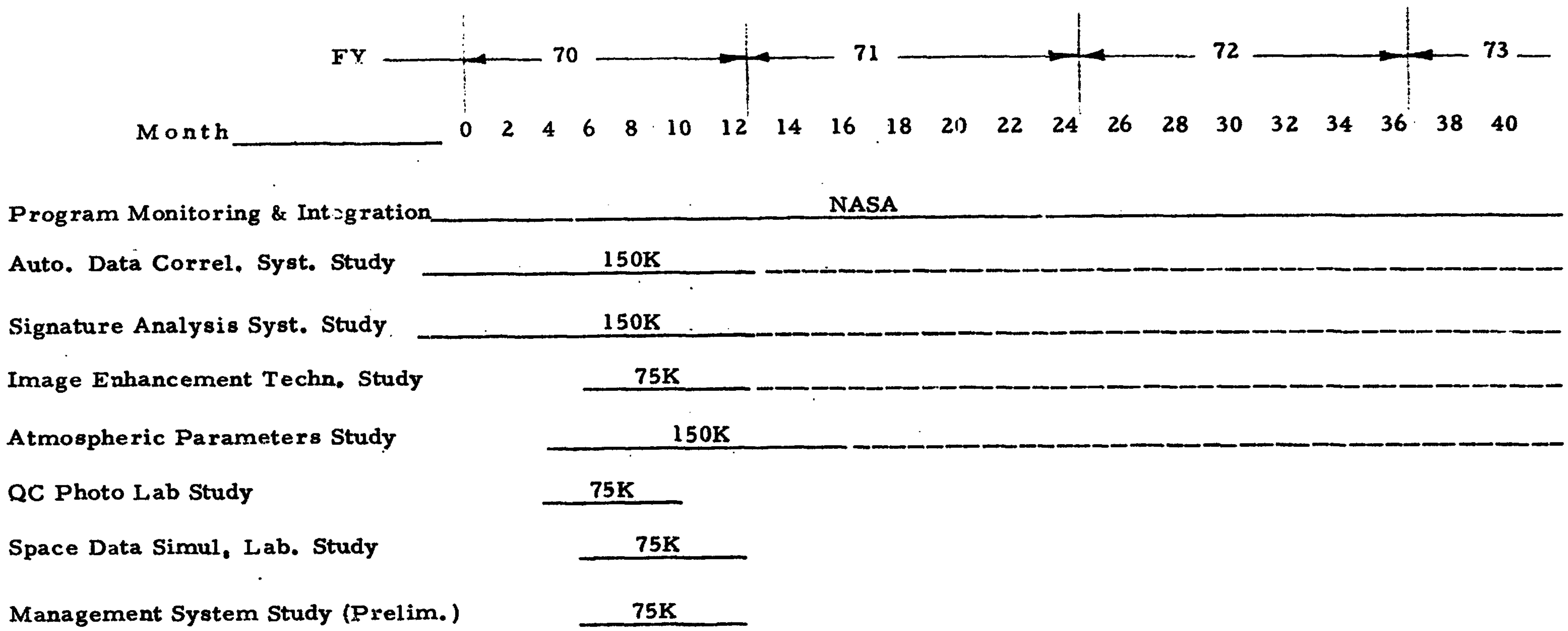


FIGURE 5-1

TECHNIQUE STUDIES ESTIMATES

not been taken into account in the analysis, either because they already exist at MSC and can readily be incorporated into the facility, or because they are of relatively low priority and might be temporarily ignored.

5.2.2 Reference Model

The reference for subsequent cost projections is the hypothetical model detailed in Table 5-1 and summarized in Table 5-2. The values given are for a Data Exploitation Center scaled for an arbitrary film throughput rate of 108,000 feet per month.

The example is valid because the ratios of analysts to support personnel, floor space and film rate, and the rates for operating expenses proved to be quite accurate in generating a ten year forecast for the largest photographic-interpretation facility in the country. It is emphasized that the costs reflect construction and operation expenditures and do not include the costs of the equipment, a photographic laboratory, or a computer facility.

5.2.3 Sizing Assumptions

The values given for the model center can be used to derive reasonable estimates for the Data Exploitation Center in the Interim Facility. Since the desired Center will be designed to work with multi-sensor inputs on both film and tape, the number of analysts required versus film rate and the space requirements per analyst are assumed to increase by 50%.

Total film input is assumed to be 5,500 feet per mission (see "Earth Resources Data Summary Study", a Dec. 1, 1967 memo to NASA/MSC TA/Deputy Director of Science and Application, from NASA/MSC TF2 Chief, Mission and Data Management Office) and, over the next few years, mission activity is expected to increase to somewhere on the order of 88 per year.

TABLE 5-1

OPERATIONAL ANALYSIS OF A MODEL DATA EXPLOITATION FACILITY

FUNCTION	PERSONNEL	FLOOR SPACE (ft^2)
Sr. Image Analysts (P. I.'s)	75	22,500
Photoreaders	75	
Clerk/Typist	30	8,000
Photo Processing	50	22,500
Collateral Data	75	8,000
R. & D. (Technical)	15	3,000
Administration	18	3,100
Contracting	3	
Reproduction	23	3,200
Editorial Staff	15	3,000
Illustrators	23	7,000
Director's Staff	16	8,000
Graphic Arts	14	6,000
Liaison	15	3,000
Job Control & Security	5	500
Couriers & Drivers	6	1,000
Secretaries & Clerks	25	3,500
Data Processing	10	5,000
Guard Force	10	500
Receptionists	4	1,200
Photogrammetrists	23	20,000
Cleaning Detail & Maintenance	10	1,000
Training	10	20,000
	550	150,000

TABLE 5-2

SUMMARY OF MODEL FACILITY CHARACTERISTICS

RATIOS

1 Analyst to	1,444	Feet of film per month
	5 2/3	Support personnel
	2,000	Sq.ft. floor space (includes support)

CONSTRUCTION COST

150,000 sq.ft. at $ 25 = $ 3,750,000

OPERATING EXPENSES

Salaries-------500 at $ 13,082 average	$ 6,541,000
Supplies & Services---at $26 2/3 per sq.ft.	$ 4,000,000
R. & D. ---------------at $ 26 2/3 per sq.ft.	$ 4,000,000
TOTAL ANNUAL COST	$14,541,000

Combining these assumptions and the reference cost factors yields the list given in Table 5-3 and the straight-line plots shown in Figures 5-2, 5-3 and 5-4.

Hence, a Data Exploitation Center which could accommodate 88 aircraft missions/year would be on the order of 130,000 square feet in size, with a total staff of about 300 people. By estimating the relative complexities and space requirements of the other constituent laboratories, the values summarized in Table 5-4 were derived.

5.2.4 Cost Estimates

Using the sizing figures, plus allowances for construction cost variations in the different sub-facilities, total set-up and operating cost estimates are as shown in Tables 5-5 and 5-6, respectively.

Additional design costs and time table estimates for sub-facility development programs are given in Figures 5-5 through 5-7.

Finally, the overall Interim Facility development program is summarized in Figure 5-8 and cumulative costs are plotted against time in Figure 5-9.

Assuming that crash programs are not instituted, and that all stages smoothly merge into the following ones, it should be possible to begin limited production processing about 46 months from the initiation date. If the latter occurs at the beginning of FY1970, a production-type facility could be fully operational by the end of FY 1973, as indicated.

Note that the program costs are quite comparable to those indicated in Appendix A, page A-18 (Volume I of this report).

TABLE 5-3

DATA EXPLOITATION CENTER REQUIREMENTS VS. MISSION GROWTH

Missions/Yr.	Ft. of Film/Mo.	P. I.'s	Support	Floor Space (ft.^{2})
24	11,000	12	68	36,000
36	16,500	18	102	54,000
54	24,750	26	148	78,000
72	33,000	35	199	105,000
88	40,200	42	238	126,000

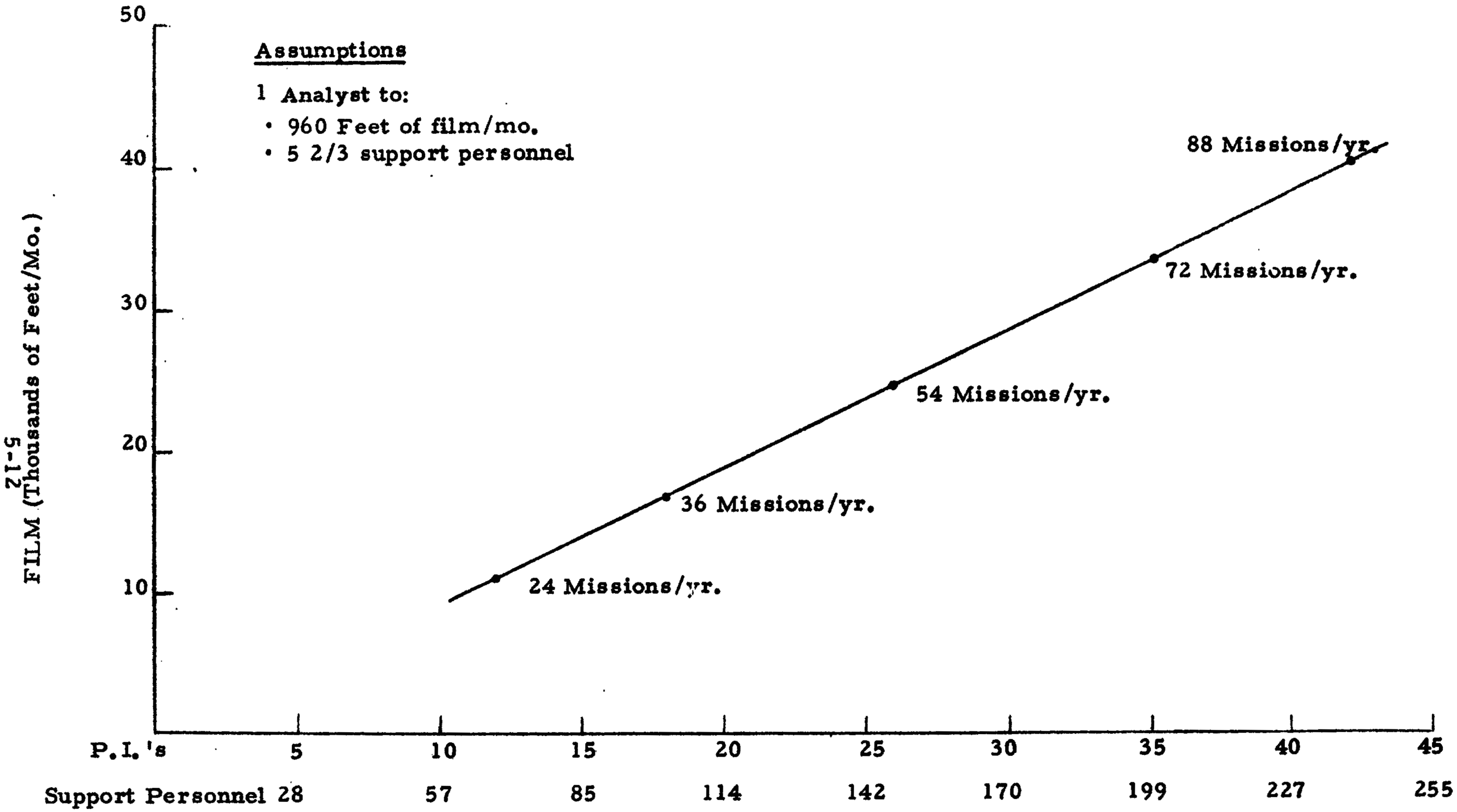


FIGURE 5-2 DATA EXPLOITATION CENTER-MANPOWER VS. FILM INPUT

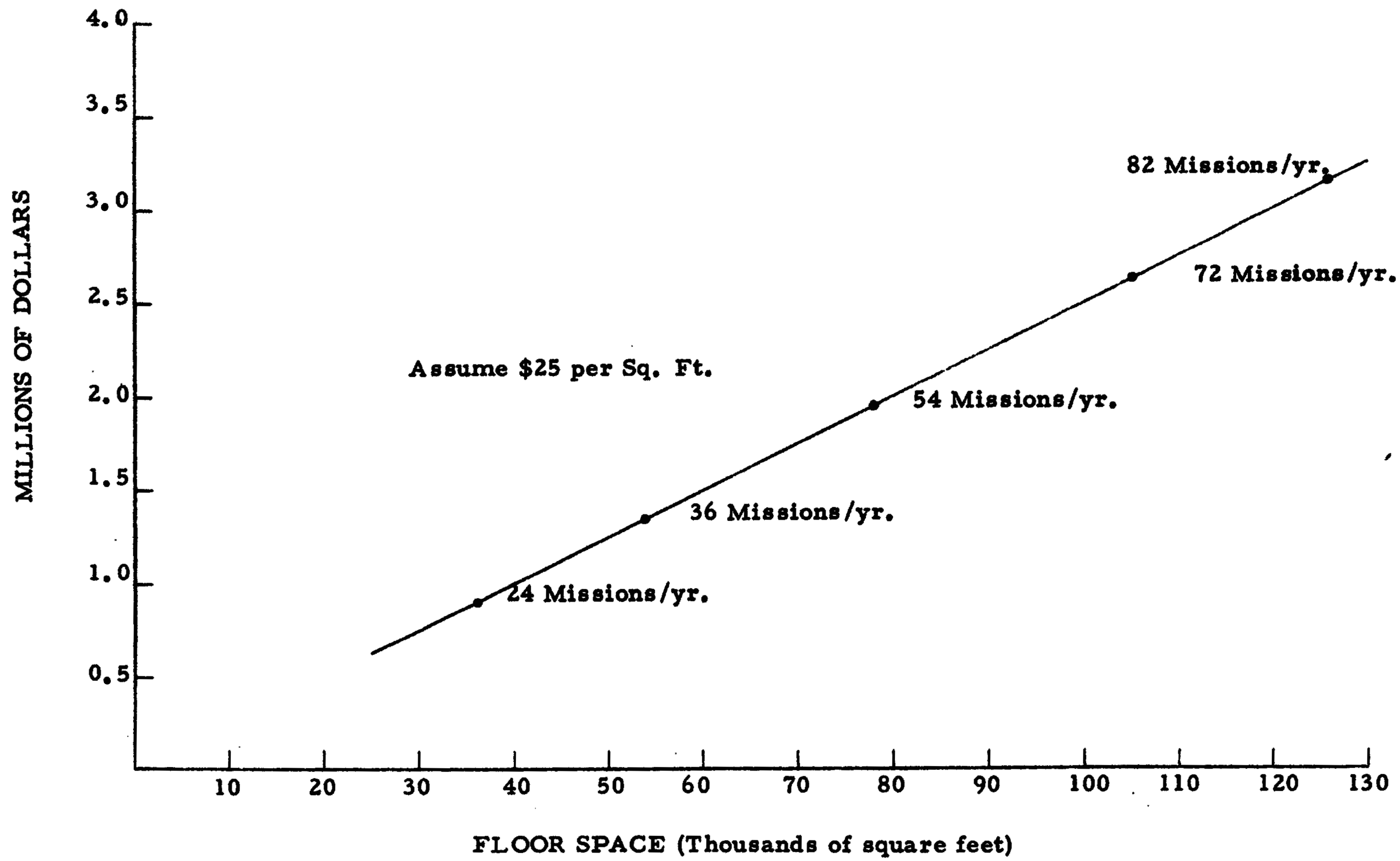


FIGURE 5-3 DATA EXPLOITATION CENTER-CONSTRUCTION COSTS

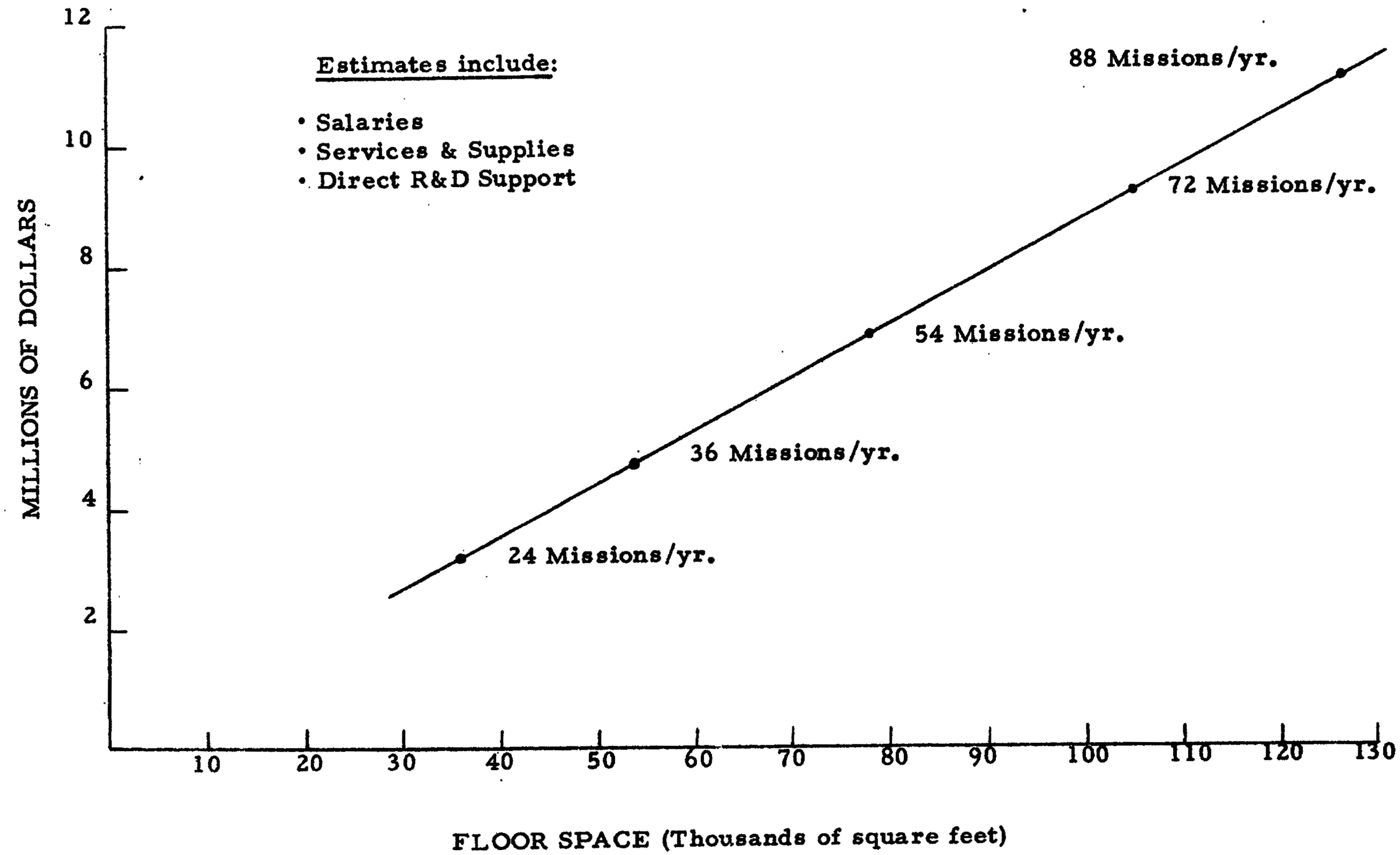


FIGURE 5-4 DATA EXPLOITATION CENTER-OPERATING COSTS

TABLE 5-4

INTERIM FACILITY SIZING ESTIMATES

	Personnel	Square Feet
Data Exploitation Center	300	130,000
Calibration & Environmental Labs.	300	50,000*
Library Center	100	60,000
Q. C. Photo Laboratory	60	50,000
Space Data Simulation Laboratory	40	20,000
	800	310,000

* Does not include field ranges.

TABLE 5-5 FACILITY COST ESTIMATES (SETUP) FOR 88 MISSIONS/YR.

Facility	Construction	Designed* Equipment	Design & Development* Hardware	Design & Development* Software	Total
Data Exploitation Center	$6.8M	$5.0M	$20.0M	$5.0M	$36.8M
Calibration & Environ. Labs.	2.0M	4.0M	5.0M	1.5M	12.5M
Library Center	2.5M	1.0M	6.0M	3.0M	12.5M
Q. C. Photo Lab.	4.0M	2.5M	0.5M		7.0M
Space Data Simulation Lab.	1.0M	1.5M	1.5M	1.0M	5.0M
				Total	$73.8M

*Also Includes { System Integration Tests / Installation and Checkout }

TABLE 5-6 FACILITY COST ESTIMATES (OPERATING) AT 88 MISSION/YR.

Facility	Salaries*	Supplies & Services**	R. & D.	Total Annual Cost
Data Exploitation Center	$3.9M	$3.6M	$3.6M	$11.1M
Calibration & Environ. Labs.	3.9M	1.2M	1.2M	6.3M
Library Center	1.3M	1.6M	0.5M	3.4M
Q. C. Photo Lab.	0.8M	1.3M	0.8M	2.9M
Space Data Simulation Lab.	0.5M	0.5M	0.7M	1.7M
	$10.4M	$8.2M	$6.8M	
			Total	$25.4M

* Based on $13,080 average.

**Based on $26-2/3 per square foot.

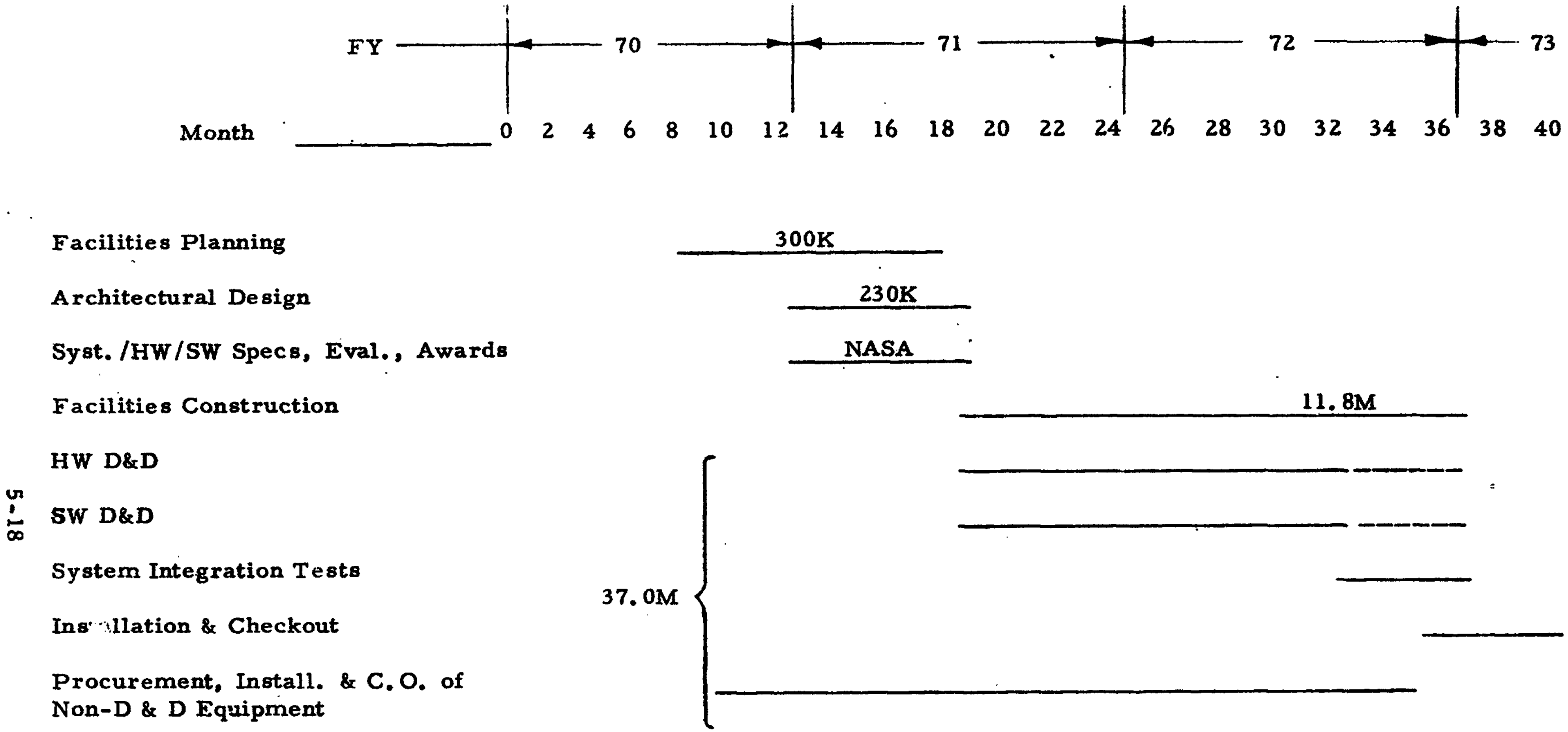


FIGURE 5-5

DATA EXPLOITATION, QC PHOTO LAB, AND SPACE DATA SIMULATION FACILITIES DEVELOPMENT

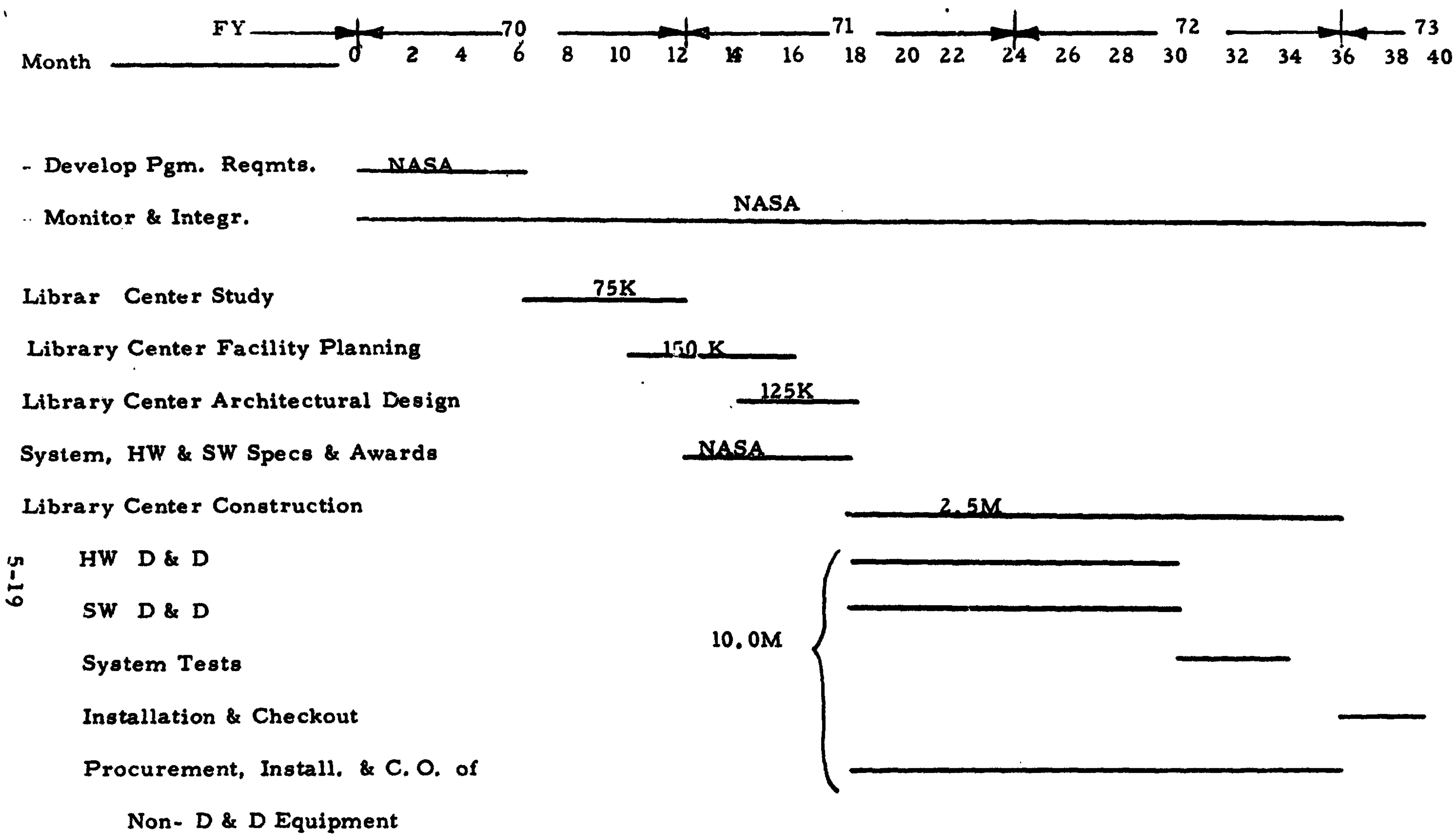


FIGURE 5-6 LIBRARY CENTER DEVELOPMENT

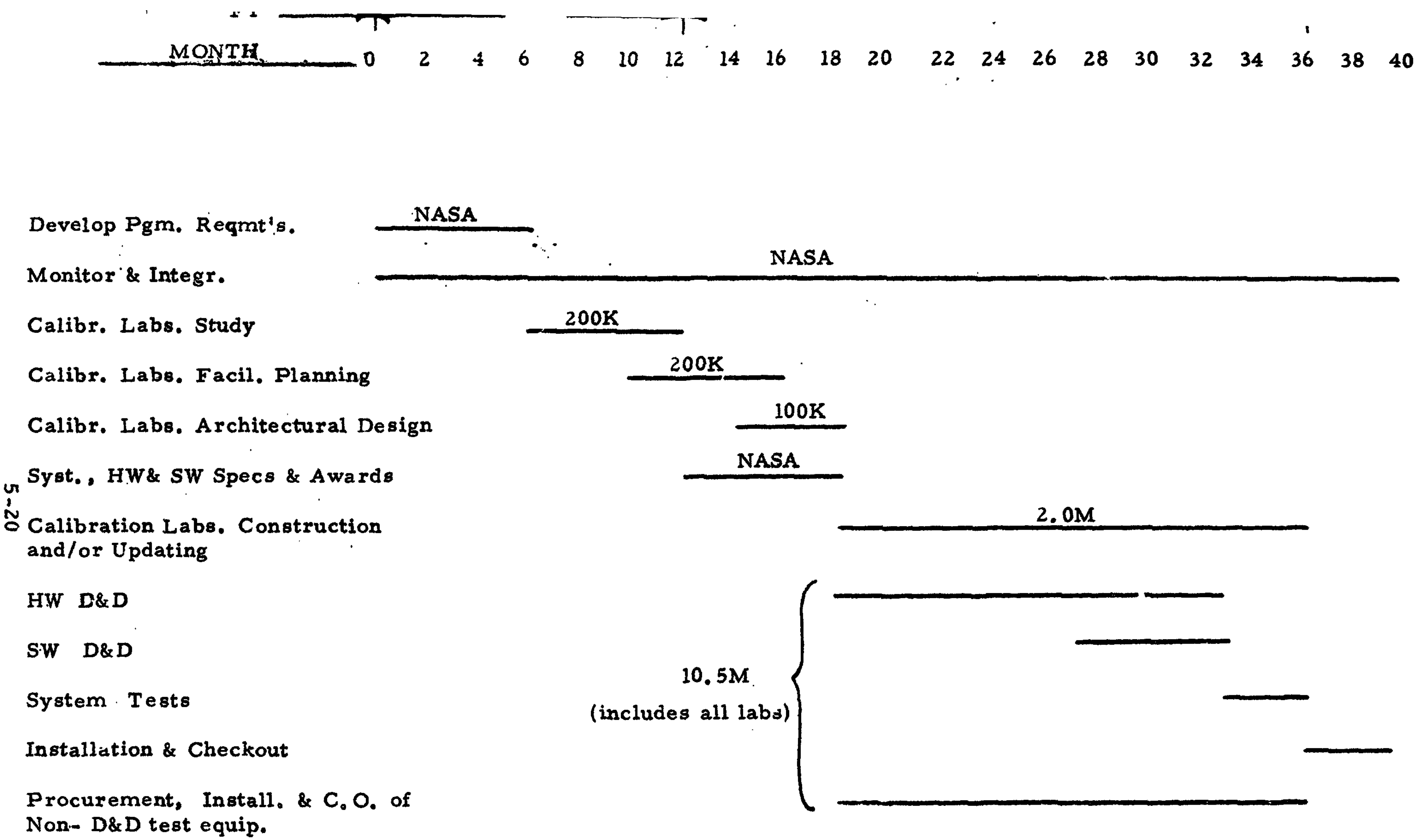


FIGURE 5-7

CALIBRATION & ENVIRONMENTAL LABORATORIES DEVELOPMENT

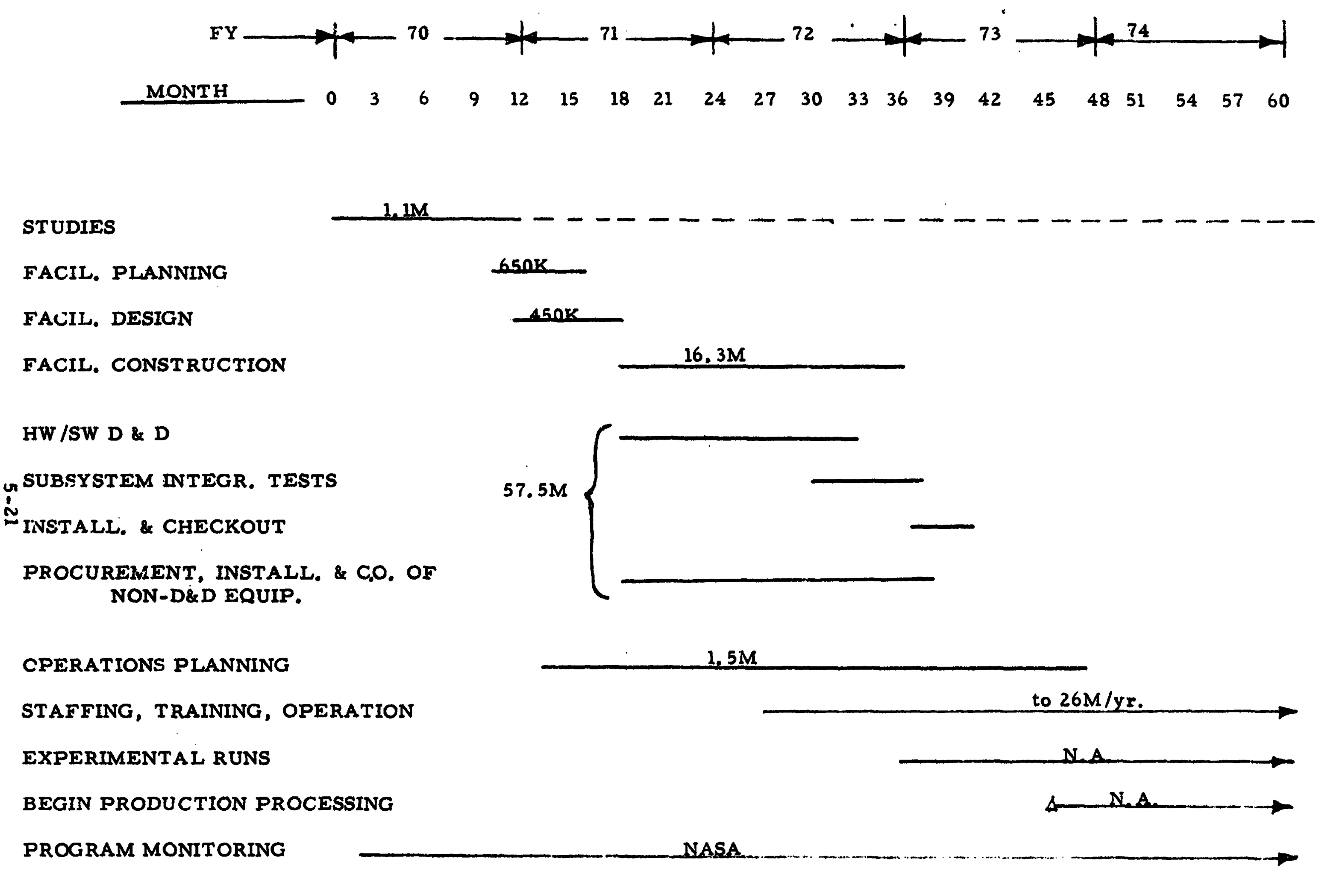


FIGURE 5-8 DEVELOPMENT PROGRAM SUMMARY

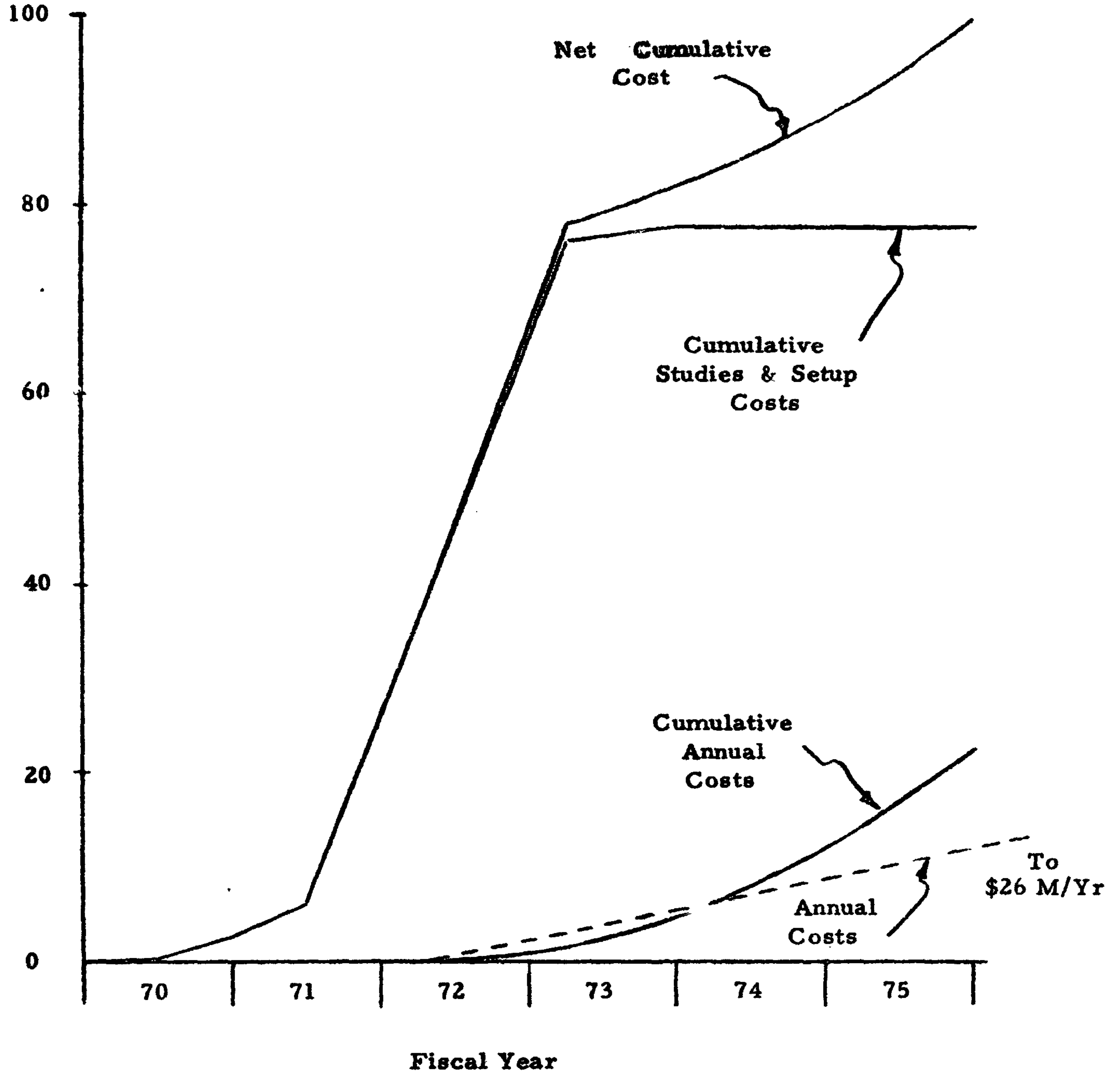


FIGURE 5-9 COST ESTIMATES

5.3 FINAL FACILITY

Development of a full-scale operational facility for earth resources data processing is an accomplishment which will require perhaps 10 years to realize. It is impossible at this time to pinpoint, with any credible accuracy, the net cost of such an undertaking, or the exact sequence of steps involved; however, a rough outline of a workable program is discernible and rough order of magnitude costs can be established.

The ultimate goal is an independent facility capable of handling all earth resources planning, processing and dissemination tasks and of providing global services, although primarily occupied with national activities. Fairchild personnel estimate that this is achievable by 1980, may cost on the order of 300 million dollars to establish, and will be an operation requiring some 4700 people, a floor space of about 1.2 million square feet, and a sustaining annual budget of approximately 140 million dollars.

APPENDIX B

SUMMARY OF USER /EXPERIMENTER DISCUSSIONS

FOREWORD

A major effort conducted during the course of the study program involved numerous visits to actual and potential experimenter/user organizations, and conversations with their earth resource program personnel. In addition, trips also were made to several other organizations closely linked with the program. Information and insights gained during these discussions have served, among other things, to:

- Acquaint FSDS project personnel with experimenter sensor and data processing requirements and plans.
- Place in perspective the roles played by various government agencies involved in the program.
- Provide insight into the relative use of aircraft and satellite vehicles in the program.
- Uncover problems associated with the experimental acquisition, processing and dissemination of remote sensor data.

Visits and discussions are summarized in a series of forms which were developed specifically for this purpose. It should be emphasized that the comments cited are those expressed by the parties visited, and do not necessarily reflect the opinions of Fairchild project personnel.

EARTH RESOURCES PROGRAM VISIT SUMMARY
(NASW-1811)

Organization Visited: School of Forestry, University of California at Berkeley

Location: Berkeley, California

Date: 13 January 1969

Interest Category: Experimenter

Organization Personnel: R.N. Colwell

FSDS Personnel: R. Neasham, E. Willett

Others Present: None

Selected Comments:

Professor Colwell discussed some of his more recent work in multi-spectral photography and photointerpretation, and in particular the programs supported by USDA funds. Professor Colwell is pursuing multi-spectral work from the visual analysis point of view. He is concentrating on determining the applicable indicator, utilizing film/filter combinations which are used to emphasize a particular phenomenon in relationship to its background. His major effort thus far has been in the forestry ecology area. He has little or no interest in digital multi-spectral signature analysis in terms of computer stored library data. He has developed several fine courses in photo-interpretation on camouflage detection film, otherwise known as Aerographic IR color, and is one of the prime investigators on Apollo 9 which will utilize the Hasselblad cameras. He currently trades photointerpretation course material with Ron Lyon at Stanford, whose prime area of investigation is in infrared geologic interpretation. Professor Colwell and his class were briefed on the utilization of Fairchild solid state electro-optical phototransistors for earth resources applications.

Prepared By: R. Neasham   Date: 14 February 1969

EARTH RESOURCES PROGRAM VISIT SUMMARY
(NASW-1811)

Organization Visited: School of Geology, Stanford University

Location: Palo Alto, California

Date: 14 January 1969

Interest Category: Experimentation

Organization Personnel: R. J. P. Lyon

FSDS Personnel: R. Neasham, E. Willett

Others Present: None

Selected Comments:

Professor Lyon is doing work on the identification of mineral structures by means of multi-spectral analysis. His present technique does not utilize unique or specific signatures, but rather is a computer-aided statistical technique; it establishes the properties of known ground truth in various spectral bands and then probabilistically evaluates the signals from unknown specimens based on the statistical characteristics of their spectral properties. He has been achieving a modest amount of success, but the computer running time is quite lengthy. Methods of more efficient computer utilization are required.

Prepared By: E. Willett Date: 23 January 1969

EARTH RESOURCES PROGRAM VISIT SUMMARY

(NASW-1811)

Organization Visited: Spacecraft Oceanography Project (SPOC), Navy Oceanographic Office

Location: Washington, D.C.

Date: 15 January 1969

Interest Category: Government agency-user/coordinator

Organization Personnel: J. Sherman, L. Brabham, V. Nobel

FSDS Personnel: N. Gutlove, R. Nelson, R. Bashe

Others Present: None

Selected Comments:

The scope of SPOC activities with MSC and the future impact of earth resources satellites was discussed. ERTS-A will be useful for studying major water composition differences, large area "doubtful shoal" problems in low latitude clear water, and sea ice. The main user of SPOC data is the Bureau of Commercial Fisheries (Dr. P. Maughan); C. Bates at the Coast Guard is concerned with sea ice studies. A radar scatterometer has been proposed for ERTS-B (to study sea state) but it has not yet been approved officially.

Because of ship costs, oceanographic experiments should be planned two to three years in advance, and allocated "block time". NASA seems receptive to this suggestion, but little has been done yet by way of implementation. For oceanographic work, a single center correlating aircraft, ship and satellite data is very desirable. J. Sherman stated that, on balance, MSC is doing a good job on the earth resources program.

Prepared by: R. Nelson/N. Gutlove Date: 25 January 1969

EARTH RESOURCES PROGRAM VISIT SUMMARY
(NASW-1811)

Organization Visited: National Academy of Sciences/National Research Council (NAS/NRC)

Location: Washington, D. C.

Date: 15 January 1969

Interest Category: Coordination

Organization Personnel: E. Risley

FSDS Personnel: N. Gutlove, R. Nelson, R. Bashe

Others Present: None

Selected Comments:

The nature of the FSDS study was discussed. Risley appreciates the significance of data processing problems, and indicated that such a study was needed. He suggested further sources of information, and provided some insight into government agency interactions in the earth resources program.

Prepared By: R. Nelson Date: 25 January 1969

EARTH RESOURCES PROGR.-.A VISIT SUMMARY
(NASW-1811)

Organization Visited: National Environmental Satellite Center (NESC), ESSA

Location: Suitland, Mo.

Date: 16 January 1969

Interest Category: Government Agency- Potential User

Organization Personnel: R. Popham, K. Nagler, W. Planet, J. Jones, P. McClain

FSDS Personnel: N. Gutlove, R. Nelson, R. Bashe

Others Present: None

Selected Comments:

At present, the ESSA interface with MSC is limited to problems of obtaining existing experimental data, but some "ground truth" is provided by hydrology groups. ESSA has a member on the ERTS-A committee, and one or two on sub-panels. There has been some problem in the past with data validation and user coordination.

When the ERTS-A program is underway, data of value to the hydrologist and oceanographer may be somewhat marginal. However, the situation should improve significantly when new sensors are flown on future ERTS satellites.

Prepared by: R. Nelson

Date: 25 January 1969

EARTH RESOURCES PROGRAM VISIT SUMMARY
(NASW-1811)

Organization Visited: U.S. Department of Agriculture (USDA)

Location: Washington, D.C.

Date: 16 January 1969

Interest Category: Government Agency- User/Coordinator

Organization Personnel: A. Park

FSDS Personnel: N. Gutlove, R. Nelson, R. Bashe

Others Present: None

Selected Comments:

For the ERTS-A, Park hopes to develop limited automatic signature comparison techniques. Ultimately, he expects to use large, fourth generation computers in an operational system. He envisions a single large center (perhaps on 25 acres of DOA land near GSFC) with the building and general facilities supported by NASA and with the people and some special facilities supplied by the user agencies. Within the center, man would work on metric quality imagery, using his capabilities for information integration, pattern recognition and decision making to interface with the computers and peripheral equipment in a synergistic relationship.

Park suggested contacting and visiting R. MacDonald (Purdue), R. Colwell (University of California at Berkely), and M. Holter (Michigan). He discussed the three RBV spectral bands agreed upon with the Department of Interior (475-575 mμ; 580-680 mμ; 690-830 mμ). He indicated the need for a computer image editor, which takes video tape as the input, displays the information (on demand) during computer processing, and permits updating (dynamically) by use of a light pen.

Prepared by: R. Nelson/N. Gutlove — Date: 25 January 1969

EARTH RESOURCES PROGRAM VISIT SUMMARY
(NASW-1811)

Organization Visited: Allied Research Associates

Location: Hyattsville, Md.

Date: 17 January 1969

Interest Category: Industrial firm-consultant

Organization Personnel: L. Goldschlak

FSDS Personnel: N. Gutlove, R. Nelson, R. Bashe

Others Present: None

Selected Comments:

The discussion centered on the ERTS-A program, and on conclusions which could be drawn from experience with Nimbus and the ESSA satellites. Stabilization, control and display functions were considered. Film processing and duplication requirements for Nimbus were reviewed, and compared with the anticipated load from the ERTS system. Computer and software requirements for Nimbus also were discussed.

Prepared by: R. Nelson/N. Gutlove Date: 30 January 1969

EARTH RESOURCES PROGRAM VISIT SUMMARY
(NASW-1811)

Organization Visited: U.S. Geological Survey (USGS), Earth Resources Observation Satellite (EROS) Project Office, Department of Interior (DOI).

Location: Washington, D.C.

Date: 17 January 1969

Interest Category: Government agency-user/experimenter/coordinator

Organization Personnel: W. Fischer

FSDS Personnel: N. Gutlove, R. Nelson, R. Bashe

Others Present: C. Sheffield (World Systems Corporation)

Selected Comments:

At the Manned Spacecraft Center, a multi-sensor correlation capability for photography and profile data is urgently needed. The aircraft program is improving with regard to the timely reduction and dissemination of data. Fischer is interested in seeing C - and L-band radars flown on the NASA aircraft for soil penetration studies.

Future needs of the USGS with respect to the aircraft program at MSC involve one aircraft experiment per year of the complexity of Experiment No. 73. Some aircraft remote sensor data is obtained by DOI aircraft; however, this is very limited in nature, and most data of interest to DOI is acquired by the MSC flight program . Fischer recommended coordination with Mr. C. Withington, the DOI liaison man at MSC .

For the ERTS-A, the center point of each frame of photography must be known with respect to a geographic coordinate system to within one or two resolution elements. If NASA does not supply data of this accuracy with each frame, USGS will extract this information by using standard photogrammetric resection methods. Boresighting among the imaging sensors and between the imaging and non-imaging sensors is particularly critical if multi-sensor data correlation techniques are to be applied. The RBV and scanner imagery requires rectification to meet cartographic and image correlation requirements. It is expected that NASA will provide registered imagery together with sensor calibration and distortion data for further processing by DOI.

Prepared by: R. Nelson/N. Gutlove Date: 12 February 1969

Selected Comments: (Cont'd.)

The main use of this information at USGS will be for inventory analysis. Certain aspects of the data processing and analysis must be accomplished at DOI; a natural and logical break in processing occurs at the conversion to orthogonality. Thus, NASA would supply non-orthogonal imagery, and USGS would convert it to an orthogonal reference frame. Insofar as the early ERTS satellites are concerned, the frame data is of primary interest to DOI; line scan data is secondary, but must be correlatable with the frame imagery.

EARTH RESOURCES PROGRAM VISIT SUMMARY
(NASW-1811)

Organization Visited: World Systems Corporation

Location: Bethesda, Md.

Date: 22 January 1969

Interest Category: Consultant to NASA/HQ

Organization Personnel: C. Sheffield

FSDS Personnel: R. Nelson

Others Present: None

Selected Comments:

Information in the files of World Systems Corporation bearing on the Earth Resources program was reviewed, and copies of several selected documents were obtained. Arrangements were made for some joint visits to appropriate experimenter/user groups, and other areas of mutual cooperation relative to the present contract were discussed.

Prepared By: R. Nelson   Date: 3 February 1969

EARTH RESOURCES PROGRAM VISIT SUMMARY
(NASW-1811)

Organization Visited: U.S. Coast and Geodetic Survey (C&GS), ESSA

Location: Rockville, Md.

Date: 22 January 1969

Interest Category: Government agency - potential user/consultant

Organization Personnel: H. S idt

FSDS Personnel: R. Nelson

Others Present: C. Sheffield (World Systems Corporation)

Selected Comments:

Because of the extreme interest which exists in the immediate problem of pointing accuracy with regard to the ERTS-A specification, which is currently under review by NASA/HQ, satellite geodesy problems occupied most of the discussion. Topics covered included techniques for achieving various degrees of satellite pointing accuracy, means for locating the vertical axis of a spacecraft and certain other aspects of vehicle attitude control. Dr. Schmidt was extremely helpful in applying his technical expertise to these areas.

Prepared By: R. Nelson　　　Date: 5 February 1969

EARTH RESOURCES PROGRAM VISIT SUMMARY
(NASW-1811)

Organization Visited: U.S. Geological Survey (USGS), Topographical Division, Geography Branch

Location: Washington, D.C.

Date: 23 January 1969

Interest Category: Government agency- user/experimenter

Organization Personnel: A. Gerlach, J. Wilson, R. Alexander, S. Moorlag

FSDS Personnel: R. Nelson

Others Present: None

Selected Comments:

Because the manned spacecraft program has priority at NASA/MSC, the delivery of aircraft data (from the earth resource survey flights) is frequently behind schedule. The film processing laboratory at MSC lacks the high order quality control, for both black and white and color materials, which is deemed necessary for a soundly-based scientific program. Multi-sensor data correlation is presently being performed at USGS for those experiments involving USGS personnel; a similar capability is also required at MSC.

For the ERTS-A program, the capability to perform meaningful land use classification studies will be limited by the spatial resolution and time sequencing of the data obtained. It is anticipated that this limitation will largely disappear as improved sensors are flown on subsequent flights. Geography Branch personnel at USGS are interested in all aspects of environmental data which can be extracted from the earth resources satellite system.

Prepared by: R. Nelson　　Date: 7 February 1969

EARTH RESOURCES PROGRAM VISIT SUMMARY
(NASW-1811)

Organization Visited: University of Michigan, Infrared and Optical Sensor Laboratory

Location: Ann Arbor, Michigan

Date: 25 February 1969

Interest Category: Experimenter

Organization Personnel: M. Holter, J. King, R. Marshall, F. Thompson

FSDS Personnel: R. Nelson, R. Wakeman, P. Tingleff

Others Present: None

Selected Comments:

Experimenter personnel believe in applying digital techniques for research, but feel that analog methods must be developed for large volume or real time operations. They expect to collect "ground truth" data over test sites within an hour after the ERTS-A passes overhead. They also recommend a ratio of 10:1 funding of ground truth to air/space data collection, rather than the reverse.

Prepared by: R. Nelson

Date: 6 March 1969

EARTH RESOURCES PROGRAM VISIT SUMMARY
(NASW-1811)

Organization Visited: Purdue University, Laboratory for Agricultural Remote Sensing (LARS)

Location: Lafayette, Indiana

Date: 26 February 1969

Interest Category: Experimenter

Organization Personnel: R. McDonald, T. Phillips

FSDS Personnel: N. Gutlove, R. Nelson, R. Wakeman, P. Tingleff, R. Bashe

Others Present: None

Selected Comments:

For the ERTS-A program, rectification and registration problems must be solved, particularly for the line scan system on overlapping orbit coverage. LARS personnel indicated they would prefer to see the RBV system (proposed for ERTS-A) flown on an aircraft before final commitments are made. The RBV will be of limited value to the Purdue group unless the third band has sufficient response in the near IR (at 0.81 μ and beyond); thermal IR data is vital for agricultural studies, and should be taken at the highest possible ground resolution.

The LARS approach starts with energy differentials from large reflective areas, and extrapolates from simultaneous ground and air data collected over control sites. This permits gross land classification, with the ultimate goal being the identification of vegetation species and evaluation of plant stress conditions. LARS personnel believe there is a need to experiment with film and tape data correlation for extraction of photometric information; they also emphasized the need to provide quality control in film processing.

The only systems providing multispectral analog data presently operative in the aircraft program are the Michigan (14 to 18-channel) and the Bendix (9-channel) scanners. MSC is developing (with Bendix) a 24-channel system which will fly soon in the aircraft program. In the existing systems, registration problems among the various scanning apertures limit the useful number of channels to some number below the full system capacity.

Prepared By: R. Wakeman, R. Nelson, N. Gutlove Date: 14 March 1969

Selected Comments: (Cont'd.)

Five University of Michigan missions (supported by MSC) will be flown for LARS this year. Each will cover a 5 to 25 square mile area, during an appropriate part of the growing season, from an altitude of 5,000 feet, with 3 milliradian resolution. They indicate that Michigan will supply Purdue with high quality tapes and low quality photography from these missions, and that only MSC supplies high quality photographic imagery.

Purdue can now handle data on a county -wide basis, with a first cut analysis available within two to seven days. They are presently using an IBM 360/44, and plan to get a 360/65 which is 7- and 9-track compatible. A real-time CRT display will be used in conjunction with the computer. LARS personnel believe some improvement can be made in automatic data reduction techniques at MSC, in view of their tremendous computational facilities.

EARTH RESOURCES PROGRAM VISIT SUMMARY
(NASW-1811)

Organization Visited: University of Kansas, Center for Research in Engineering Science (CRES)

Location: Lawrence, Kansas

Date: 27 February 69

Interest Category: Experimenter

Organization Personnel: R. Dalke, R. Harlich, R. Moore, D. Simonett

FSDS Personnel: R. Bashe, R. Nelson, P. Tingleff, R. Wakeman

Others Present: None

Selected Comments:

Effort at the University of Kansas is concentrated on radar techniques, with emphasis on target-sensor interaction and system calibration methods for extraction of quantitative data.

With regard to the aircraft survey program, CRES did not receive radar imagery until February of this year. There is general dissatisfaction with radar scatterometer processing and data, and the strong suggestion that multi-frequency radar systems be flown on the same aircraft, with a P band system (operating at 400 MC) for vegetation penetration studies. The need for time history data collection of preselected areas was stressed.

Geographic photo interpretation studies (performed by Simonett) of several sites using aircraft multi-spectral photography degraded to 100 foot ground resolution (to simulate spacecraft imagery) indicate that the ability to perform land use classification from satellite imagery will vary widely with climate, cultural adaptation, vegetation patterns and local environmental variables.

Prepared by: R. Nelson/R. Wakeman

Date: 7 March 1969

EARTH RESOURCES PROGRAM VISIT SUMMARY
(NASW-1811)

Selected Comments: (Cont'd.)

The IDECS system, in which multispectral color separations are viewed by individual scan converters and combined in a color television output presentation for interactive analysis by the system operator, requires further study as a possible tool for research and development of ERTS-A data processing techniques. CRES personnel stressed satellite collection over world-wide test sites as a basic part of the earth resources R&D program in remote sensing. Insufficient information was presented to evaluate the CRES panchromatic radar and Kandidats systems; however, there is enough potential there to warrant continued monitoring of these programs by NASA Headquarters.

EARTH RESOURCES PROGRAM VISIT SUMMARY
(NASW-1811)

Organization Visited: Department of Interior, Bureau of Commercial Fisheries (BCF)

Location: Washington, D.C.

Date: 27 March 1969

Interest Category: User/experimenter

Organization Personnel: P. Maughan, S. Astrahantseff

FSDS Personnel: R. Nelson

Others Present: None

Selected Comments:

The Bureau of Commercial Fisheries has had only two MSC aircraft experimental flights in the last two years. BCF personnel expressed concern that the Earth Resources Program at MSC is becoming more heavily involved in experimenter-oriented functions, at the expense of such service functions as scheduling, flight operations and data acquisition and dissemination.

By late Fall of this year BCF, in cooperation with the Bureau of Sports Fisheries, will have an integrated program detailing the information which they need to make mission-oriented decisions; the program will also indicate the kinds of instrumentation required to supply the data.

In general, BCF needs block time allocation to permit the MSC aircraft to remain on station to record specific phenomena of interest, as they occur. They anticipate that data returned from the presently-proposed ERTS-A sensors will be of only marginal use to BCF.

Prepared by: R. Nelson

Date: 7 April 1969

EARTH RESOURCES PROGRAM VISIT SUMMARY
(NASW-1811)

Organization Visited: Department of Interior, U.S. Geological Survey (USGS), Division of Hydrology

Location: Washington, D.C.

Date: 27 March 1969

Interest Category: Government agency- user

Organization Personnel: C. Robinove

FSDS Personnel: R. Nelson

Others Present: None

Selected Comments:

USGS hydrology problems and remote sensing R&D are more empirical, at present, than in some of the other scientific disciplines. Robinove believes the MSC aircraft program should be more flexible (e.g., common mounts for several kinds of instrumentation and fewer sensors per aircraft should be utilized); further, he believes the aircraft survey program should be pursued more vigorously. He would like to see the tight aircraft scheduling relaxed to compensate for weather and ensure data collection over test sites when the phenomena parameters and weather are suitable. More information is needed on sensor capability and performance characteristics, with particular emphasis on hydrological applications.

Prepared by: R. Nelson

Date: 8 April 1969

EARTH RESOURCES PROGRAM VISIT SUMMARY
(NASW-1811)

Organization Visited: U.S. Army Corps of Engineers, Army Engineer Waterways Experiment Station (WES)

Location: Vicksburg, Miss.

Date: 28 February 1969

Interest Category: Experimenter/User

Organization Personnel: J. Lundien, A. Williamson, Jr.

FSDS Personnel: R. Bashe

Others Present: None

Selected Comments:

WES has conducted several Earth Resources-related experimental investigations as part of their overall "Terrain Analysis by Electromagnetic Means" program. Their efforts have been partially supported by NASA-MSC.

WES has developed radar and gamma ray soil signatures. Standard pulsed radar sensors in the 0.25 to 8.0 GHz band can provide information on soil moisture content, surface vegetation and depths to subsurface interfaces. Gamma-ray signatures in the 0 to 2.82 MEV region can be used to determine soil moisture content and specific soil types.

The following WES reports describing results were obtained:

- Radar Responses to Laboratory-Prepared Soil Samples, TR3-693-2
- Laboratory Investigations in the 0 to 2.82 MEV Gamma-Ray Spectral Region, TR3-693-3.

Prepared by: R. Bashe

Date: 18 March 1969

EARTH RESOURCES PROGRAM VISIT SUMMARY
(NASW-1811)

Organization Visited: Department of Interior, USGS Photogrammetric Research Center

Location: McLean, Virginia

Date: 28 March 1969

Interest Category: Government Agency-user/experimenter

Organization Personnel: A. Colvocoresses, M. Scher, T. Hughes, E. Swasey

FSDS Personnel: R. Nelson

Others Present: None

Selected Comments:

USGS Photogrammetric Research Center personnel believe in system calibration for cartographic and rectification purposes, and hope to use high altitude aircraft at MSC to test systems for eventual space application. Calibration programs are needed for all sensors in the aircraft program, as well as for those in the spacecraft program. Colvocoresses would like to see a high resolution metrical camera included in the aircraft survey work at MSC.

The Bolsey Associates Inc. image-correlator shows promise in reducing image coordinate readout time. However, like all other such systems, the operator must use his eye in combination with an optical system reticle to select a specific image point before he directs the opto-electronic system to scan and record the scene. Therefore, the instrument is subject to the same image pointing errors as are other, less sophisticated, systems. In general, the techniques described by Photogrammetric Research Center personnel tended to confirm the assumptions made by FSDS during the course of the ERTS-A trade-off studies conducted under the present contract.

Prepared By: R. Nelson

Date: 8 April 1969

EARTH RESOURCES PROGRAM VISIT SUMMARY
(NASW-1811)

Organization Visited: Raytheon/Autometrics

Location: Alexandria, Virginia

Date: 18 April 1969

Interest Category: Industrial Contractor

Organization Personnel: R. Pascucci, G. North

FSDS Personnel: R. Nelson

Others Present: S. Moorlag (USGS, Geography Branch)

Selected Comments:

Autometrics is preparing the final report on image interpretation of Mission 73 information, in which they compared ten different image sets collected simultaneously over common subjects. Their effort consisted of a "normal" photo interpretation exercise, with no other forms of analysis applied to the photographs. Mission 73 was a complex remote sensing/"ground truth" data collection program conducted in May, 1968 over a part of Southern California; the area covered included a section of Los Angeles and adjacent territory down through the Imperial Valley and the Salton Sea. It was organized by the USGS and included aircraft from NASA/MSC, NASA/Goddard, Barringer Research Ltd., and four chartered by universities. Scientists from Brazil, Mexico, various U.S. Government agencies and several universities participated in the experiment. The kinds of imagery analyzed by Autometrics included: microwave, IR thermal, two-band Hasselblad, false color IR, RC-8 regular color, B&W IR, RC-8 B&W panchromatic, AAS-5 UV imagery and 12" mapping camera.

Prepared by: R. Nelson

Date: 30 April 1969

APPENDIX C

SUMMARY OF DISCUSSIONS BETWEEN FSDS AND MSC PERSONNEL

FOREWORD

As a necessary and vital part of the study, an investigation of the operations, procedures, equipments, problems, and future plans for the MSC Earth Resources Program was undertaken. During this investigation, several meetings took place at Houston involving MSC and FSDS personnel. A brief summary of these meetings follows.

TABLE I

Summary of FSDS Review Meetings with Earth Resources Program Office & Associated Groups At MSC, Houston, Texas

ORGANIZATION	DATE	PERSONNEL	SELECTED COMMENTS
Earth Resources Program Office (Introductory Meeting)	2/3/69 09:15	ERPO - J. Dornbach J. Overton R. Piland S. Whitley E. Zeitler FSDS R. Bashe N. Gutlove R. Nelson P. Tingleff R. Wakeman	Piland emphasized the top priority nature of the Apollo program and outlined each Apollo shot which collected information for earth applications, highlighting Apollo IX (a 4 camera Hasselblad, multi-spectral system) which will be correlated with simultaneous aircraft and ground truth data collection. He indicated the need to emphasize experimental data processing. The nature of the information sought in Earth Resources missions differs in one basic aspect from the information sought in military missions. The main emphasis in Earth Resources missions is placed upon the classification of targets, while the detection of targets is primarily emphasized in military missions. Three to four flights are approved for the AAP program. They are proposing a manned space station with an earth resources laboratory, resupplied every 3 months. Three MSC aircraft are configured for remote sensing, with an AF RB-57 scheduled to carry a sensor instrumentation pallet. FY-69, 24 missions; FY-70, 36 missions (incl. 12/RB-57 missions); by FY-73, they expect to increase their capability to 50 missions per year, plus 18 to 36 /RB-57 missions per year. At present, MSC cannot fly two aircraft at one time, due to the limited number of flight crews. Flight missions are only scheduled 3 months in advance, with a tentative schedule for the next 3 months. MSC wants more control over missions, including experimenters, ground control, and report feedback. To work more closely with fewer investigators would be highly desirable.

TABLE I (Con'td.)

ORGANIZATION	DATE	PERSONNEL		SELECTED COMMENTS
Tour-E.R. Aircraft	2/3/69 11:00	ERPO-	N. Foster J. Overton S. Whitley	A guided tour was conducted of available MSC aircraft: the P3A and Convair 240A. Many sensor systems are undergoing maintenance and re-installation. Some sensor engineers were available to discuss systems.
		FSDS-	R. Bashe N. Gutlove R. Nelson P. Tingleff R. Wakeman	
Mission Control Center	2/3/69 13:30	MCC-	M. Lowe	A tour was taken of the Mission Control Center, including large screen display capability and technology, computer facility, and staff support rooms.
		ERPO-	J. Overton S. Whitley	
		FSDS-	R. Bashe N. Gutlove R. Nelson P. Tingleff R. Wakeman	
Mission Planning & Analysis Div.	2/3/69 14:30	MPA-	R. Ernull J. Overton S. Whitley	A discussion of software planning, computer hardware used in flight simulation programs, and a new hybrid analog-digital experimental computer was held.
		FSDS-	R. Bashe N. Gutlove R. Nelson P. Tingleff R. Wakeman	

TABLE I (Cont'd.)

ORGANIZATION	DATE	PERSONNEL		SELECTED COMMENTS
Computation And Analysis Division	2/3/69 16:00	CAD- FSDS-	R. Everett R. Bashe N. Gutlove R. Nelson P. Tingleff R. Wakeman	There was a discussion of computer facility utilization. Only about 200 hours per month are presently being devoted to earth resources programs. They are experimenting with film-computer interface techniques and analog graphical plot readout.
Wave Analysis Laboratory	2/4/69 09:15	WAL- ERPO- FSDS-	M. Perry J. Overton S. Whitley E. Zeitler R. Bashe D. George N. Gutlove R. Nelson P. Tingleff R. Wakeman	The Wave Analysis Laboratory is designed to assist sensor engineers in determining if the sensor is working properly. Also, they compare time history sensor data of test sites with recorded data from new tests to determine if the new data is reasonable. The function of the lab is to provide a quick look analysis to detect gross problems rather than a complete data reduction; actually the capability for complete data reduction exists, but at a much slower rate than that of the data reduction center. They expect to expand facilities to meet planned mission expansion during next 3 years.
ERPO-Planning Discussion	2/4/69 10:15	ERPO- FSDS-	J. Overton S. Whitely E. Zeitler R. Bashe D. George N. Gutlove R. Nelson P. Tingleff R. Wakeman	ERPO plans to build up a sensor science and technology capability, for both space and aircraft missions. Data bank-accessions (photo, tape, documents) from all missions are stored in 3 locations. The R&D central Data Facility handles electronic data, multi-band photography and laboratory processing, and multi-sensor correlation. In the IR Lab, they will develop an ultra-high resolution, multi-spectral Lab-model IR radiometer; do spectral absorption parameter measurements, including atmospheric mixture combinations as well as pure compounds; and develop an integrating radiometer (1mm-100mm). ERPO is also developing a Radar Lab and a natural environment lab to do multi-spectral investigations from ground stations up to 200 MHz. They are funding the Bendix multi-spectral line scan system, which has a single aperture and is time/space synchronized with a geometric

TABLE I (Cont'd.)

ORGANIZATION	DATE	PERSONNEL		SELECTED COMMENTS
				distortion removal capability. They will buy a microwave imager similar to the Nordberg-Aerojet General instrument. They are doing studies on color IR film, film processing, scatterometer data processing, photo image display and microwave calibration and corrections.
R&D Computer Laboratory	2/4/69 14:00	C.L.- ERPO- Lockheed FSDS-	J. Overton S. Whitley S. House R. Bashe T. George N. Gutlove R. Nelson P. Tingleff R. Wakeman	The R&D Computer Laboratory is doing image correlation studies for advanced retrieval systems. They are actively engaged in a microfiche study for lunar orbitar imagery, to be established by mid-1969, with a computer retrieval of imagery in another year. The system storage contains 73,500 images at $6,000 per unit. For lunar orbiter, they need 4 units. For ERTS-A, at 9,000 photographs (inc. color and B&W composites) per day, one storage will cover 8 days; they would need 48 units per year at a cost of $288,000. This cost is not high, but the computer interface could be a major problem. They are funding a Ground Reconstitution Facility (GRE); there is a 1 year delivery time, with an overall 4 year program. The system is designed to scan and read data into a computer and reconstitute it. Major problems involve with multi-sensor correlation; this program is just starting.
MSC Photographic Lab.	2/4/69 15:30	P.L. ERPO- FSDS-	R. Underwood J. Overton S. Whitley R. Bashe T. George N. Gutlove R. Nelson R. Wakeman	There was a tour of the photographic processing laboratory. The lab is designed for production and support for manned space flight programs. They have a large volume motion picture capability; they do a large volume print business in B&W and color. The can do neither quality control, nor high resolution processing; laboratory personnel are aware of its limitations.

TABLE I (Cont'd.)

ORGANIZATION	DATE	PERSONNEL		SELECTED COMMENTS
Computer and Analysis Div.	2/4/69 15:30	CAD- FSDS-	J. Fisher P. Tingleff	This was a concurrent discussion with the FSDS computer specialist relative to the Earth Resources program. They discussed mathematical techniques and algorithms, computer hardware, run time, calibrations, etc. A major problem is the scatterometer data; the ratio of data collection time to computer running time is approximately 1:40.
Mapping Science Laboratory	2/5/69 09:15	MSL- ERPO- FSDS-	R. Musgrove A. Patteson J. Sasser J. Overton S. Whitley E. Zeitler R. Bashe D. George N. Gutlove R. Nelson P. Tingleff	This laboratory is working on lunar orbiter photography in support of the Lunar Science Institute. They are supported by Lockheed Electronics (65 men) and Autometrics-Raytheon (23 men). They work on small volume R&D mapping and photogrammetric problems; large volume efforts are performed at AMS and ACIC. They have $2.5M in photogrammetric equipment, $1.5M in other instrumentation. The operating cost of the lab is $1M per year. They will have to expand their effort to support the E.R. program. They are learning to use JPL analog/digital photo recording techniques. A tour of the facilities ensued; they have a good x-y plotter/computer tie-in; viewers are standard Itek rear projection instruments; all equipment is off-the-shelf. They have one environment controlled room for precision coordinate measurement; the accuracy is about ± 5 microns. It does not have a high volume capability; it could be improved, but the limitation is in precision coordinate measurements.

TABLE I (Cont'd.)

ORGANIZATION	DATE	PERSONNEL	SELECTED COMMENTS
ERPO-Final Review Discussion	2/5/69 11:00	ERPO- J. Overton S. Whitley E. Zeitler FSDS- R. Bashe D. George N. Gutlove R. Nelson P. Tingleff	A discussion of what additional information FSDS required transpired. It was agreed that ERPO would furnish FSDS with the following supplementary inputs: 1) Accession lists (catalogue of mission data according to type of data, where taken, sensors used, form of output, etc.) 2) Functional organization chart of center. 3) Summary of instrumentation aboard aircraft. 4) Description of computer facilities. 5) Summary of sensor characteristics. 6) Summary of some missions (sample reports). All of these inputs were delivered by 1 May 1969. Also reviewed were the following items: 1) Photographic Sciences Study (completed by Data Corp., Dayton, Ohio). 2) Exposure studies and film/filter combinations for color IR film. 3) An additional color Versamat processor is on order. This unit will make the rate at which color film can be processed equal to the rate at which B & W film is processed by the B & W Versamat unit. 4) They plan to set up existing Versamats to handle negative materials (as per Data Corporation's suggestion). 5) They plan to reduce the scatterometer data processing rate to below the existing 40x the collection rate. 6) New ways of displaying scatterometer data (two examples of these were given to FSDS personnel). 7) Temperature calibration of microwave radiometer (they have an RFP out).

TABLE I (Cont'd.)

ORGANIZATION	DATE	PERSONNEL	SELECTED COMMENTS
			8) Multisensor correlation study (common data base reduction). An RFP will be out soon. 9) They have planned signature studies with multispectral information (i.e., 24 channel scanner).

TABLE II

Summary Of Subsequent FSDS Special Meetings With MSC Earth Resources Project Personnel

ORGANIZATION	DATE	PERSONNEL	SELECTED COMMENTS
ERPO-Imagery Exploitation and Processing Discussion	3/26/69	ERPO- M. Chestnutwood, F. Pierce, J. Kraus, R. Bennett, S. Whitley German Federal Geological Survey- Dr. R. Muhlfeld FSDS- D. George, J. Libby	FSDS personnel presented some concepts for the exploitation of Earth Resources imagery. NASA attendees discussed Earth Resources program objectives, automated photo interpretation and digitizing imagery, need for a 4 channel (band) multispectral viewer, film sizes and workloads for interim Earth Resources efforts, MSC's plans for annotating film in the cameras, automated film in the cameras, automated film titling (original processed film and/or dupe film), and the film emulsions to be used for Earth Resources. Specific problem areas identified by MSC personnel were correlation of conventional imagery with radar imagery, superimposition, false color, spectral zonal, and related considerations.
MSC Photographic Laboratory	3/26/69	ERPD- R. Underwood FSDS- D. George, J. Libby	This was a visit to MSC Photo Laboratory by FSDS personnel; see Table I, appendix B for appropriate comments.
ERPO-Preliminary discussion of final report	4/30	ERPO- J. Dornback, E. Zeitler, S. Whitley FSDS- N. Gutlove, R. Neasham	There was a discussion of the status of Fairchild's program. The need to coordinate the Final Report with MSC personnel was considered. The problems of multispectral analysis were discussed. Additional information needed for the Final Report was obtained, and arrangements were made to return to MSC in June to review and coordinate that document with MSC personnel.

APPENDIX D

SENSOR EQUIPMENT DETAILS

FOREWORD

This appendix presents detailed information on sensor equipment characteristics which were felt to be too lengthy for inclusion in the main body of the report.

APPENDIX D CONTENTS

APPENDIX D CONTENTS (Cont'd.)

1. AIRCRAFT PRIME SENSOR EQUIPMENT

The various aircraft and sensor equipments available to the Houston program have been indicated in Section 3.3 of this report. However, it is convenient to regroup that information here in order to present a summary of equipments per aircraft. This is given in Table D-1.

2. CAMERA SYSTEMS

Detailed camera system characteristics are given in Table D-2.

3. INFRARED SYSTEMS

The infrared sensors are comprised of three basic equipment types: line scanning imagers, spectrometers, and radiometers. Table D-3 presents a tabular survey of the sensors with their important parameters and operating features. All the IR sensors previously listed in Table 3-5 are included with the exception of the Texas Instruments RS-7. This equipment is presently classified and no further information, beyond what appears in Table 3-5, was obtained during the course of the study.

All three of the line scanning imagers, the Reconofax IV, RS-7 and RS-14, utilize the line-scanning pattern illustrated in Figure D-1. Of the many possible scanning patterns, this is perhaps the simplest to generate and implement. Scanning of the area of interest makes use of the forward motion of the aircraft. The scanning mirror in the sensor permits the sampling of incremental areas of the scene along a straight line normal to the flight path. At any instant, the field of view is represented by a cone having a small included angle, α. The Reconofax IV is an older system that utilizes an integral scanner-recorder. Infrared radiation from objects beneath the aircraft is converted to electrical signals that are placed on 70mm film in the form of a continuous strip map by means of an optical-mechanical recorder. The modulated light output of the recorder lamp is swept by a mirror located on the scanning mirror shaft to provide precise synchronism between the incoming radiation and the strip map recording. The system provides roll stabilization of the film magazine over a large range, i.e., 60 degrees, but has no sweep distortion correction. The TI RS-14, on the other hand, provides both sweep distortion correction and roll correction. It is a unique sensor and was specifically developed, under contract with NASA, for non-military remote sensing applications.

TABLE D-1

AIRCRAFT EQUIPMENT COMPLEMENT

SENSOR	AIRCRAFT 240A	C130	NP3A	RB57F
KA-62 Cameras (4)			X	
RC-8 Cameras (2)	X	X	X	X
500 EL Cameras (6)				X
Reconofax IV	X			
RS-7		X		X
RS-14			X	
Scanning Spectrometer			X	X
IR Radiometer			X	X
PRT-5 Thermometer			X	
MR-62, MR-64 Radiometer	X			
Multifrequency Radiometer			X	
13.3 GHz Single Polarized Scatterometer		X		
13.3 GHz Dual Polarized Scatterometer			X	
1.6 GHz Dual Polarized Scatterometer			X	
400 MHz Dual Polarized Scatterometer			X	
16.5 GHz SLAR		X	X	

TABLE D-2

CAMERA SYSTEMS PRESENTLY USED IN THE

EARTH RESOURCES PROGRAM

(3 Sheets)

TABLE D-2 (Sheet 1 of 3)

Model Number	KA-62	RC-8	2-2	500 EL *
Manufacturer	Chicago Aerial	Wild Heerbrug	ITEK	Hasselblad
Type of Camera	Frame	Frame	Frame	Frame
System Description	Cluster of Four Cameras	Single Camera	Nine Lenses One Magazine	Cluster of Six Cameras
Application	Multispectral	Mapping	Multispectral	Multispectral
Focal Length	3 Inch	6 Inch	6 Inch	100mm
f-Number	4.5	5.6	2.4	3.5
Format Size (Inches)	4.5 x 4.5	9 x 9	2.25 x 2.25	2.25 x 2.25
Field of View	74° x 74°	74° x 74°	21° x 21°	31° x 31°
IMC Mode (V/H Range)	Autocycle (.05-3.6) IMC Pulse(.05-1.2)	None	Yes	None
Operational Mode (Cycling Rate)	Autocycle & Night Flash - (6 cps) IMC Pulse - (2 cps) Pulse & Night Open Shutter - (1 cps)	(0.285 cps)	(0.5 cps (MAX.)	(0.5 to 2 cps)
Power Required	28VDC, 10A. 115VAC, 400 Hz, 1 Phase	28VDC	28VDC or 115VAC	Own Rechargeable NiCd Batteries

TABLE D-2 (Sheet 2 of 3)

Model Number	KA-62	RC-8	2-2	500 EL *
Type of Shutter	Focal Plane	Rotary	3 Parallel Focal Plane Shutters	Compur Shutter Between Lens
Range of Exposure Times	1/60 to 1/3000 sec.	1/100 to 1/700 sec.	1/30, 1/60, & 1/120 sec.	1 sec. to 1/500 sec.
Range of f-Numbers		f/5.6 to f/32	f/2.4 to f/22	f/3.5 to f/32
Film Width	5 Inch	9.5 Inch	70mm	70mm
Film Capacity	250 feet	200 feet	250 feet per roll	160 frames
% Overlap		up to 80%		
Film Types Used	Plus X 3401 (used in three spectral bands from .375μ to .725μ) B&W IR 2424 (used in band from .700μ to .900μ)	Ektachrome Films: (MS-2448) (IR-8443) Plus X-2401 B&W IR-2485 High Speed Recording - 2485	Was same as KA-62	Plus X 3401 B&W IR 2424 MS-2448 IR-8443

TABLE D-2 (Sheet 3 of 3)

Model Number	KA-62	RC-8	2-2	500 EL *
Spectral Bands	.375μ -.525μ .475μ -.625μ .525μ -.725μ .700μ -.900μ	0.4μ - 0.9μ One Band	Was same as KA-62 (No longer in use)	Same as KA-62
Resolution (Line pairs per mm)	53	48		Not Yet Determined

* The Hasselblads had not been flown as of March 1969.

TABLE D-3

INFRARED SENSORS

PRESENTLY USED IN THE EARTH RESOURCES PROGRAM

(5 sheets)

TABLE D-3 (Sheet 1 of 5)

Sensor Type	IR Line Scan Imager
Model	Reconofax IV
Manufacturer	HRB Singer
Wavelength	3-5 μ, or 8 -14 μ
Recording Medium	70mm Black & White Film
Recording Method	Integral scanner-recorder; video modulated light output of recording lamp is swept by a mirror located on the scan mirror shaft.
Field of View	$\pm$ 60° scan angle.
Angular Resolution	2 milliradians, or 3 milliradians
Thermal Sensitivity	0.42 °C, or 0.28 °C
Detector Type	Indium antimonide, or Mercury-doped germanium
Calibrated Reference	None
Sweep Distortion Correction	None
Stabilization	Built-in roll stabilization system with reference gyro; corrected over $\pm$ 30 degrees.
Scan Rate	200 scans/sec.
V/H Range	0.007 - 0.4 rad/sec, or 0.01 - 0.6 rad/sec.

TABLE D-3 (Sheet 2 of 5)

Sensor Type	IR Line Scan Imager (Dual Channel)
Model	RS-14
Manufacturer	Texas Instruments
Wavelength	0.3-0.55μ, or 3-5.5μ; 8-14μ
Recording Medium	1" Magnetic tape, FM recorded. One channel selectable for recording on 5-inch Black & White film.
Recording Method	Remote, high-resolution CRT recorder
Field of View	± 40° scan angle
Angular Resolution	1 milliradian & 3 milliradians, in each channel
Thermal sensitivity	0.8°C (1 mrad), 0.25°C (3 mrad)---3-5μ 0.5°C (1mrad), 0.1°C (3 mrad) --- 8-14μ
Detector Types	Chan. 1 1 photomultiplier tube (0.3-0.55μ) or 2 indium antimonide (3-5 μ) detectors. Chan. 2 2 mercury-doped germanium (8-14μ) detectors.
Calibrated Reference	Visible for 0.3 - 0.7μ Two temperature-controlled black bodies for 1-14μ
Sweep Distortion Correction	Rectilinearization via tangent sweep velocity of the CRT recorder beam.
Stabilization	CRT has deflection compensation for ± 8° roll; derived from gyro error signal.
Scan Rate	200 scans/sec (1 mrad); 66.7 scans/sec (3 mrad)
V/H Range	0.02 - 0.2 rad/sec.

TABLE D-3 (Sheet 3 of 5)

Sensor Type	IR Scanning Spectrometer
Model	-
Manufacturer	Lockheed
Wavelength	6.5 - 13 μ (90 spectral bands, each 1% of the center frequency in width)
Recording Medium	1" Magnetic tape, PCM recorded.
Recording Method	Remote recorder with tape speed of 120 ips
Field of View	0.4° cone
Angular Resolution	7 milliradians
Spectral Resolution	1% of the instantaneous wavelength
Detector Type	Mercury-doped germanium, liquid helium cooled
Calibrated Reference*	Cooled thermoelectric reference at -40°C and an internal wavelength calibration.
Sweep Distortion Correction	Not Applicable
Stabilization	None
Scan Rate	6 Spectra/sec.
V/H Range	Not Applicable

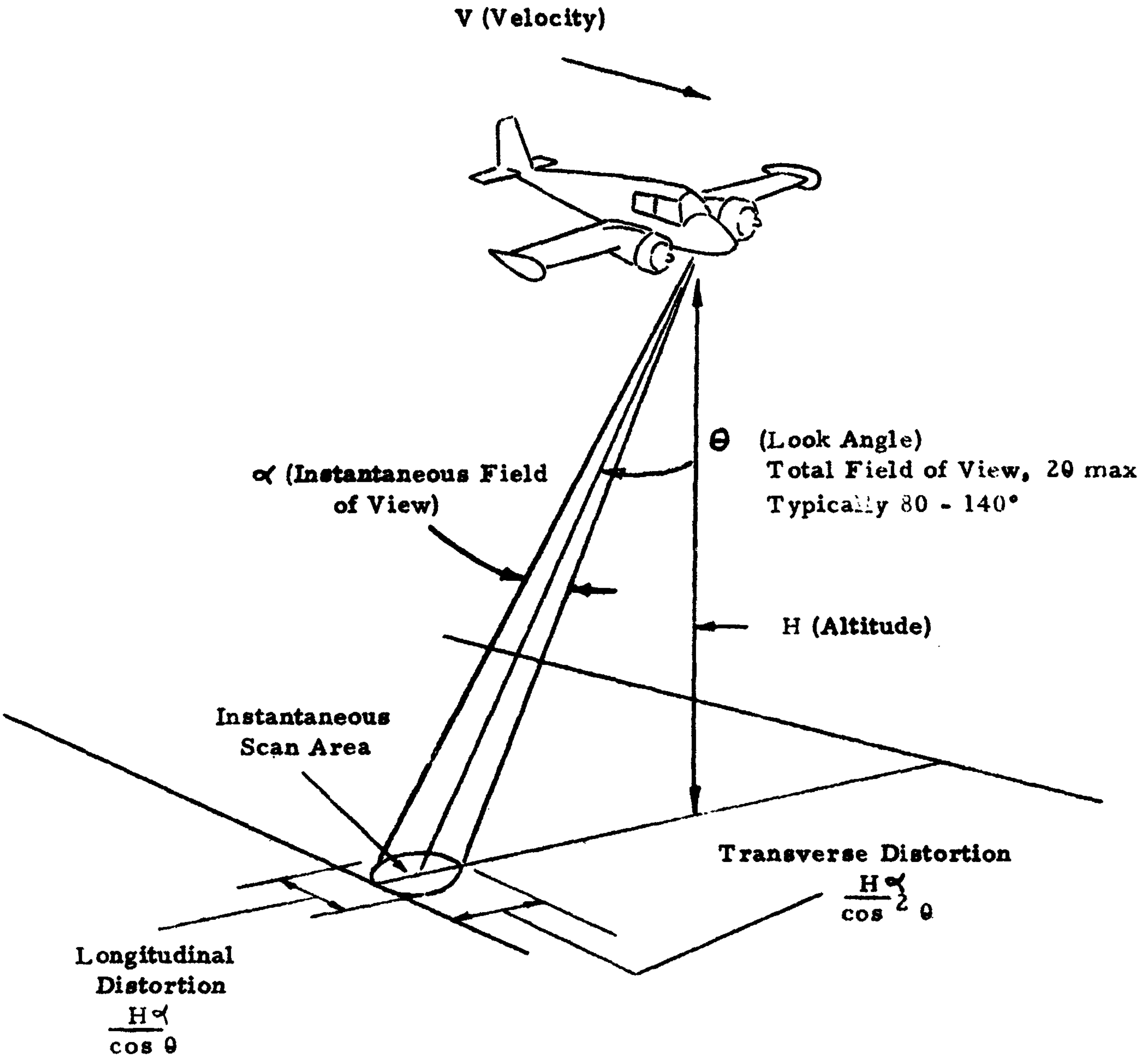
* Normally used in conjunction with the Block Radiometer. The latter provides the total radiance in the 10-12 μ region; then those measurements are used to calibrate the spectrometer data.

TABLE D-3 (Sheet 4 of 5)

Sensor Type	IR Radiometer
Model	-
Manufacturer	Block Engineering
Wavelength	10-12 μ
Recording Medium	1" Magnetic tape, PCM recorded
Recording Method	Remote recorder; output signal chopped at 600Hz.
Field of View	0.4° cone
Angular Resolution	7 milliradians
Thermal Sensitivity	0.03°C from -20°C to + 80°C
Detector Type	Mercury - doped germanium, liquid helium cooled
Calibrated reference	A conical graphite black body source.
Sweep Distortion Correction	Not Applicable
Stabilization	none
Scan Rate	Non-Scanning
V/H Range	Not Applicable

TABLE D-3 (Sheet 5 of 5)

Sensor Type	Radiation Thermometer
Model	PRT-5
Manufacturer	Barnes Engineering
Wavelength	8 - 14 μ
Recording Medium	1" Magnetic Tape
Recording Method	Remote recording of simultaneous high and low level electrical outputs.
Field of View	2° Cone
Angular Resolution	35 milliradians
Thermal Sensitivity	0.1°C from - 20°C to + 140° C
Detector Type	Immersed thermistor bolometer
Calibrated reference	Internal reference cavity at 55°C.
Sweep Distortion Correction	Not Applicable
Stabilization	None
Scan Rate	Non-Scanning
V/H Range	Not Applicable.



The scanning pattern used in the Reconofax IV, RS-7 and RS-14 imagers is a line-scanning pattern. Of the many possible scan patterns, this is the simplest to generate and implement. Scanning of the terrain makes use of the forward motion of the aircraft. A scanning mirror in the sensor permits the sampling of incremental areas of the scene along a straight line, normal to the flight path. At any instant, the field of view is represented by a cone having a small included angle.

FIGURE D-1 GROUND SCANNING GEOMETRY FOR INFRARED IMAGER

The RS-14 has special features which allow many experiments to be performed over the spectral range from 0.3 microns to 14 microns. These special capabilities are:

- Simultaneous dual - channel operation.

- Calibrated energy sources for visible or IR detectors.

- Remote recording that provides a rectilinear, 5-inch film format.

- Tape recorder outputs.

- Internal electronic compensation for aircraft roll maneuvers.

- Closed-cycle detector cooling.

- Ten-step gray scale printed on film.

- Dual detectors in either one or both channels allowing a choice of high thermal or high spatial resolution.

- In-flight selection of one of four filters. (This is in the 0.3 to 5 micron range covered by one head; a second channel covers the 8 to 14 micron range but the filters are fixed).

- Closely regulated scanner speed control.

The system features listed above indicate the flexibility and versatility of the RS-14 scanner. Without going into further detail, it is apparent that this scanner is a complex instrument which embodies a high level of sophistication in its design, and requires considerable skill in its effective use.

The Lockheed scanning IR spectrometer was designed for remote geological sensing. In operation it scans the 6.5 to 13 micron region six times per second to determine the bulk chemical composition of geological targets. The spectral resolution is one per cent of the instantaneous wavelength. A typical spectral output of the sensor is shown in Figure D-2 for two geologic phenomena. The Block Engineering IR radiometer is normally used in conjunction with the spectrometer to obtain total radiance in the 10 to 12 micron region of the spectrum, from which the spectrometer data is calibrated.

The Block radiometer is a non-scanning sensor which provides a field of view that is quite narrow, i.e., 0.4 degrees by 0.4 degrees. This matches the field of view of the Lockheed spectrometer; as noted earlier, the radiometer is normally used to calibrate the spectrometer. The Barnes PRT-5 radiation thermometer is a light-weight, battery-powered IR radiometer designed to make relatively sensitive temperature measurements in any selected range between roughly -20°C and +140°C. The unit consists of a 3.5 pound optical head and a separate, 15 pound, solid-state electronic control unit. The optical head may be hand-held, by means of a pistol grip attachment, or hard mounted. The sensor has a two-degree field of view in the standard configuration but can be converted to both a wide-field instrument, with 20-degree field of view, or to a very narrow-field version with a 0.14 degree field of view that provides a spatial resolution of 2.5 milliradians.

4.0 MICROWAVE SYSTEMS

The microwave sensors presently utilized in the aircraft program fall into three general categories: radiometers, scatterometer radars and side-looking radars. Table 3-6 shows the distribution of equipment by aircraft, with a few system parameters. A more complete listing is provided in Table D-4. Except for the side-looking airborne radar (SLAR), which records on five-inch film, all the microwave sensors provide their output data on one-inch analog magnetic tape.

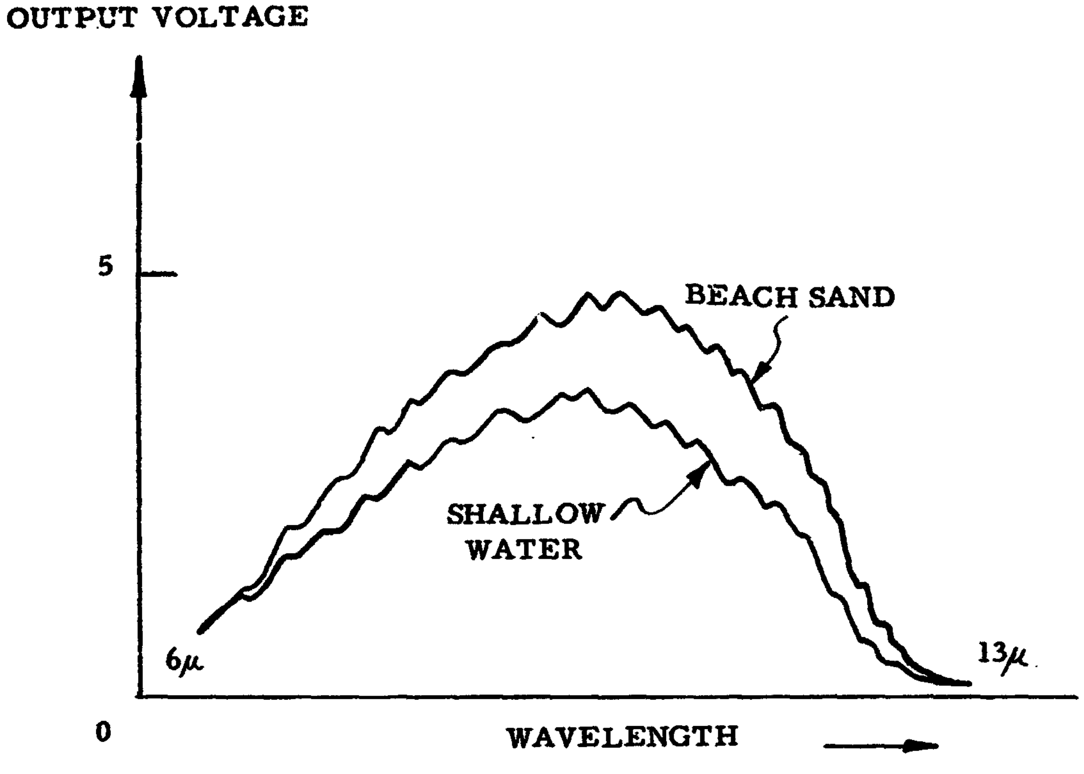


FIGURE D-2 TYPICAL SPECTRAL OUTPUT OF LOCKHEED SCANNING INFRARED SPECTROMETER

TABLE D-4

MICROWAVE SENSORS

PRESENTLY USED IN THE EARTH RESOURCES PROGRAM

(3 Sheets)

TABLE D-4 (Sheet 1 of 3 - Radiometers)

Model	MR-62	MR-64	- -
Manufacturer	JPL	JPL	Space General
Wavelength	1.4, 1.9 cm	0.88, 3.2 cm	0.96, 1.34, 1.35, 2.8, 21 cm
Recording	1" Magnetic Tape FM	1" Magnetic Tape FM	1" Magnetic Tape PCM
Field of View	2°at 1.4 cm 3°at 1.9 cm	1°at 0.88 cm 4°at 3.2 cm	16° at 21 cm 5° at all others
Spatial Resolution	Note 1	Note 1	Note 1
Integration Time	0.2 second	0.2 second	1 second
Radiometric Sensitivity	2.2 °K	2.2 °K	1°K
Calibration Sources	Note 2	Note 2	Note 3
Radiometric Temp. Range	0-500°K	0-500°K	0-500°K
Antenna Positioning	0-45° forward	0-45° forward	0-150° forward
Polarization (Linear)	V, H	V, H	V, H

Notes:

1. Depends on aircraft velocity, sensor field of view and signal integration time.
2. Argon noise temp. of 50°K/130°K for MR-62/64; secondary calibration performed before and after each flight (on the ground) by covering the antenna feed with a black-body source at ambient temperature.
3. Argon noise temp. of 125°K; two precision input temperature sources of 325°K and 450°K for secondary in-flight calibration.

TABLE D-4 (Sheet 2 of 3 - Scatterometer Radars)

Manufacturer	Ryan Aeronautical	Ryan Aeronautical	Ryan Aeronautical	Emerson Electric
Frequency	13.3 GH_z	13.3 GH_z	1.6 GH_z	400 MH_z
Polarization	V	Dual V, H	Dual V, H	Dual V, H
Analog Recording	FM 2 Chan.	FM 4 Chan.	FM 1 Chan.	FM/FM 1 Chan.
Field of View	$120° \times 3°$	$120° \times 3°$	$120° \times 6°$	$120° \times 9°$
Broadside Resol. at 1000'	53 ft.	53 ft.	91 ft.	160 ft.
Calibration Signal	12 KH_z	12 KH_z	10 KH_z	1 KH_z
σ_0 Dynamic Range	65 db	65 db	65 db	121 db
Angle of Incidence	$\pm \lvert 5-60° \rvert$	$\pm \lvert 5-60° \rvert$	$\pm \lvert 5-60° \rvert$	$\pm \lvert 0-60° \rvert$

NOTE: σ_0 = Radar target cross-section

TABLE D-4 (Sheet 3 of 3 - SLAR)

Manufacturer	Philco - Ford
Frequency	16.5 GH_z
Polarization	V, H transmit/ receive
Recording Medium	5-inch Black & White Film
Antenna Field of View	$2° \times 56°$, one side of the aricraft
Depression Angle	10-25°, adjustable in-flight
Range	10 nm
PRF	1868 pps
Resolution	range -- 100 ft. (80 nsec.pulse width) azimuth -- $<$100 ft. (unfocussed synthetic aperture)
Calibration	Internal Go/No-Go self-test
6_0 Dynamic Range	$>$ 60 db

4.1 Radiometers

The MR-62 and MR-64 are dual channel radiometers operating at 15.8 and 22.2 GHz, and 9.2 and 34.0 GHz respectively. They are mounted in the nose of the Convair 240A aircraft on a servo controlled platform which permits remote selection of look angles from the nadir (zero degrees) to 45 degrees forward of the nadir with a readout which is accurate to ± 0.5 degrees. Two polarizations, E-plane and H-plane, are also remotely selectable. The two channels in the MR-62 radiometer are cross-polarized. Both instruments are identical in basic design, utilizing superheterodyne detection and Dicke switching. The input signals from the respective antennas are compared to heated reference terminations which are temperature controlled to ± 0.1°C in the vicinity of 50°C. Dual-band noise sources are provided in each system to allow injection of calibrated noise temperatures at the input.

The Space General multi-frequency radiometer is also a passive microwave sensor that measures absolute radiometric temperature at five different frequencies at a preferred look angle and polarization. The instrument is a profile sensor and does not scan from side-to-side or from forward to rear. The motion of the aircraft moves the antenna beam across the terrain width of the beam. The antennas can be positioned to observe at any angle from the nadir up to 150 degrees from nadir. Figure D-3 shows the antenna beam orientation for such a system. The antennas are all mounted on a common plane and are located so as to have a common boresight; the common plane can be rotated for varying look angles and polarizations.

4.2 Scatterometers

The four scatterometer radars operate at 400 MHz, 1.6 GHz, and two at 13.3 GHz. These systems (except one Ryan 13.3 GHz system which operates with a single vertical polarization beam) are dual polarized sensors which can obtain simultaneous back-

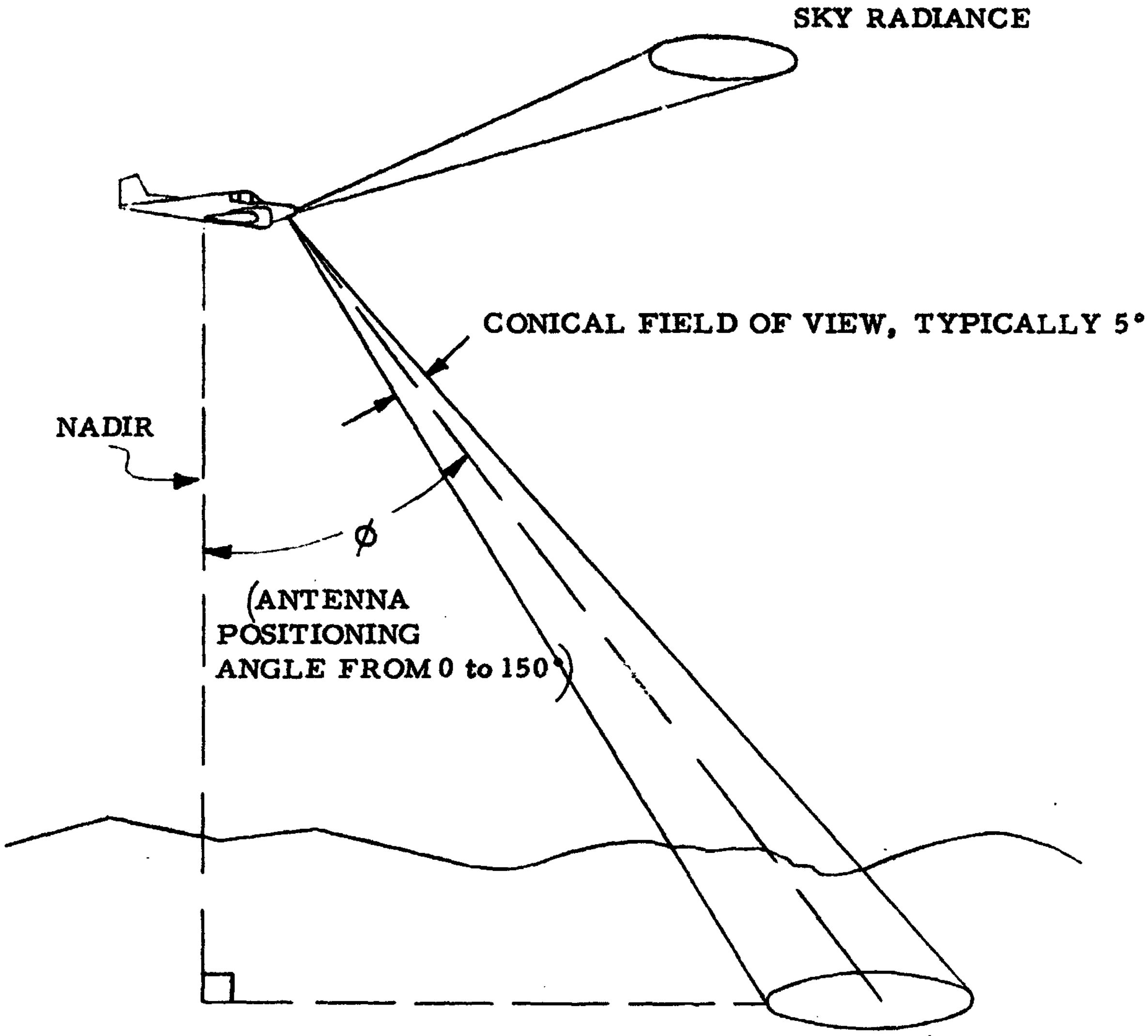
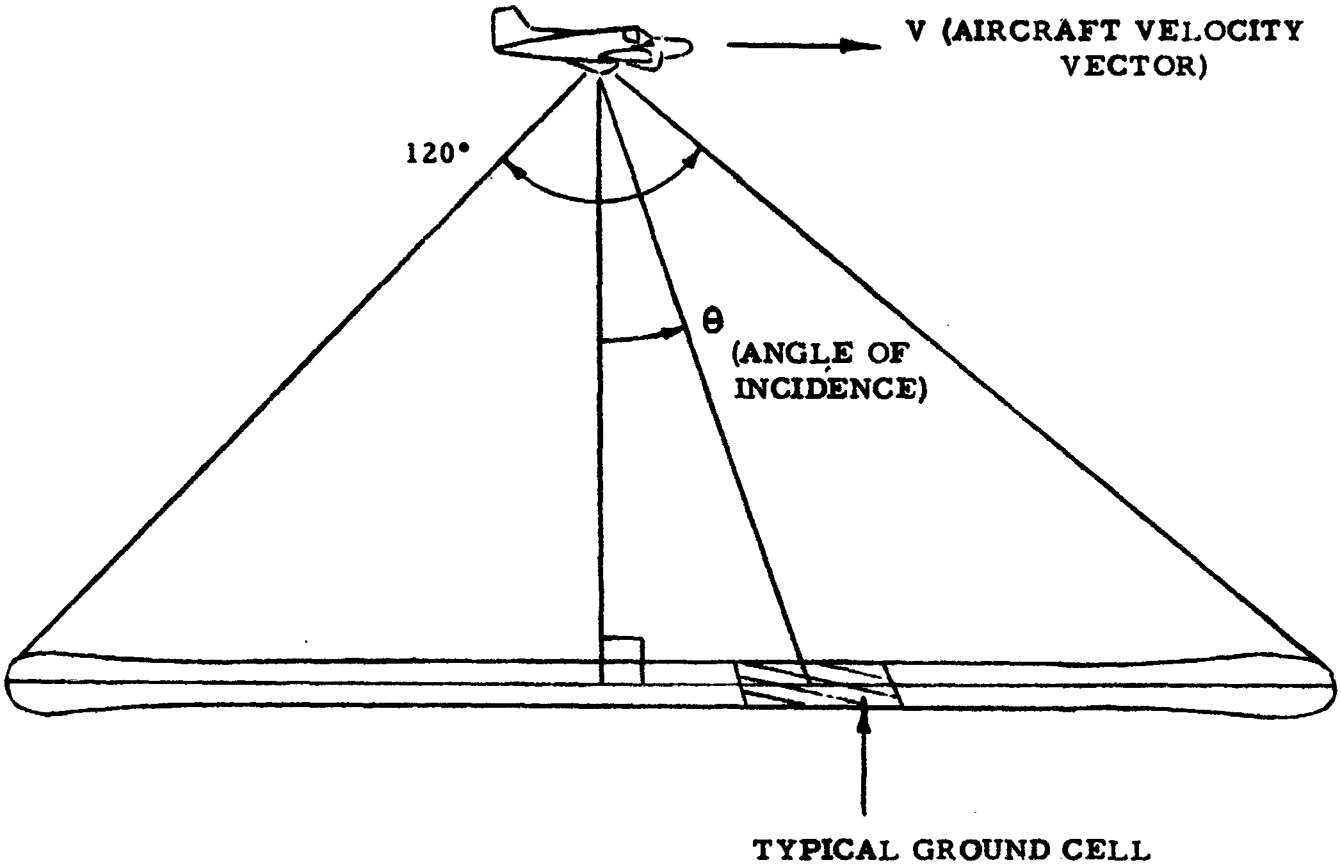


FIGURE D-3 MICROWAVE RADIOMETER ANTENNA BEAM ORIENTATION scattering data at four polarizations in all incidence angles. The four instruments incorporate the same essential principle of operation to measure the radar backscattering cross section per unit surface area, (σ_0), versus angle of incidence, (θ), of various types of terrain. The sensors utilize the relationship between the Doppler frequency and the angle of incidence of the scatterometer echo power density to measure the magnitude of σ_0 as a function of θ. The magnitude of σ_0 can be determined for angles of incidence of approximately ±5 to ±60 degrees from the vertical. Data is obtained at all angles of incidence simultaneously by recording the echo signal from the terrain in conjunction with readings of aircraft velocity and altitude. The dual polarized scatterometer antennas are arrays of slot radiators which alternately generate vertically and horizontally polarized, fan-shaped beams. The radiation patterns have nominal 3 db two-way beamwidths of about 3 degrees port-starboard and effective beamwidths of 120 degrees in the fore-aft direction. Figure D-4 shows a typical scatterometer radar antenna beam orientation.

4.3 Side Looking Airborne Radar

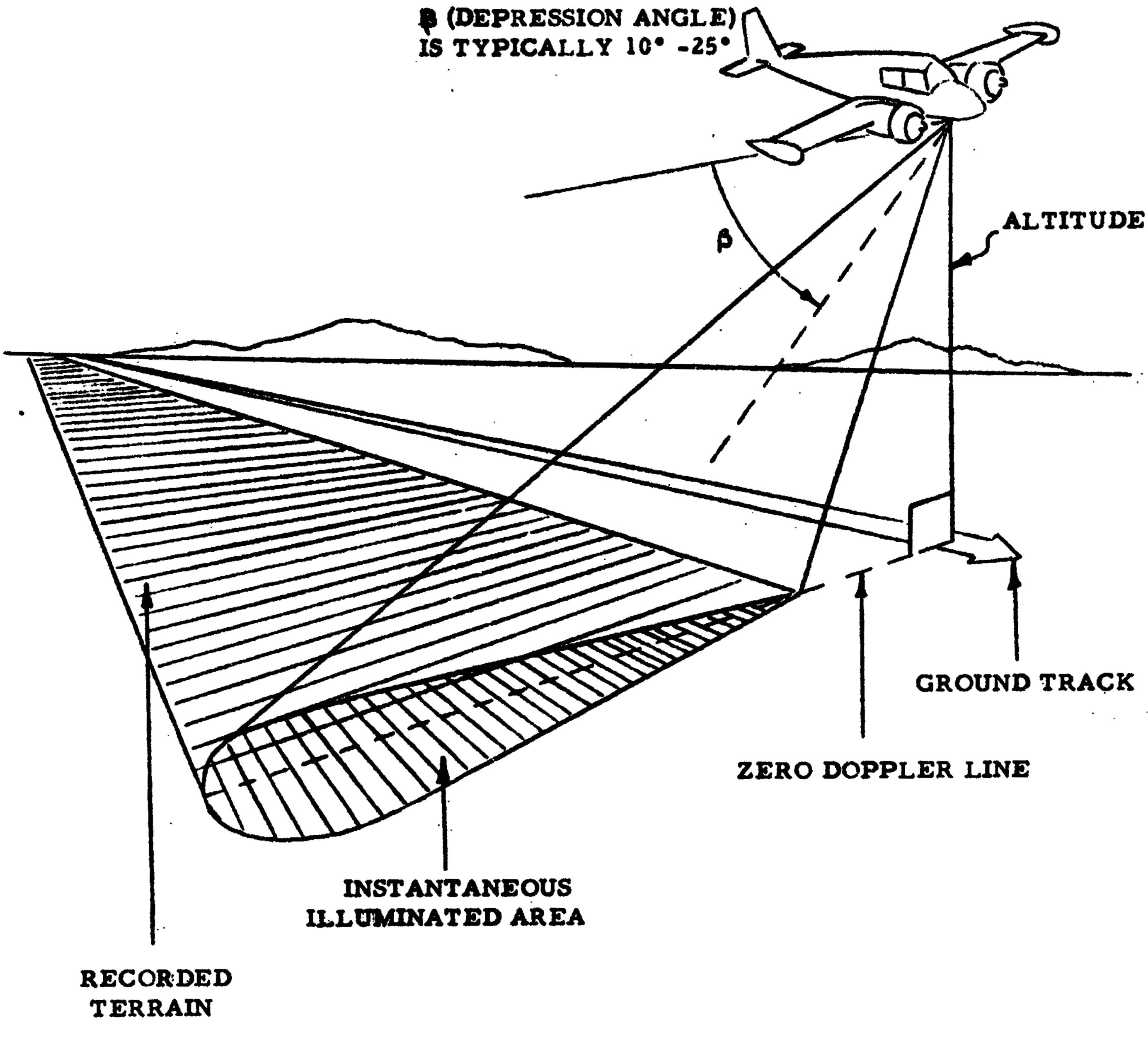
The last sensor to be discussed is the Philco-Ford side-looking airborne radar (SLAR). This sensor offers the unique capability of all-weather, day/night continuous mapping and can independently transmit and receive at horizontal or vertical polarization. Adverse climatic conditions such as snow, rain, hail or clouds are essentially transparent to the radar scanning beam.

The system directs a beam of energy at 16.5 GHz perpendicular to the flight path (see Figure D-5) and the reflected energy returns are electronically processed, then recorded as adjacent strips of the terrain. High resolution is provided by utilizing a short pulse width for range resolution (across-track) and a long, synthetically obtained antenna aperture for azimuth resolution (along-track).



RF energy is radiated by the antenna which has a wide fore-aft beam and a narrow transverse beam. The return from any particular ground cell may be separated from other ground cells by the Doppler frequency which is a function of aircraft velocity, V, and the angle of incidence, θ. For a given V, the Doppler frequency determines a particular θ, hence a particular ground cell.

FIGURE D-4 SCATTEROMETER RADAR ANTENNA BEAM ORIENTATION



The SLAR directs a beam of energy perpendicular to the flight path on one side of the aircraft. The reflected return of energy is recorded in sequence as adjacent strips of the terrain.

FIGURE D-5 SIDE-LOOKING RADAR COVERAGE

Conventional radars use long antennas to provide high azimuth resolution; the SLAR coherently sums successive radar returns and creates the equivalent of a physically long linear array antenna. The geometric relationships of this synthesis are shown in Figure D-6, where d represents the distance the aircraft travels between successive pulses in forming the aperture and is equal to the aircraft velocity (V) times the pulse repetition period (T). The situations for generating both an unfocused and focused synthetic aperture are shown. For the focused case, the target returns from a range, R, must be the same phase at each radiator in the synthetic aperture. This requires the incorporation of a programmed phase correction. The unfocused aperture can be generated quite easily, requiring basically a feedback network and delay line which has a practical maximum feedback factor of 0.94 to 0.98. This limits the number of successive returns that can be effectively summed, so aperture equivalent length and, therefore, resolution, are functions of aircraft velocity.

The system used by MSC is an unfocused synthetic aperture type. Expected azimuth resolution versus range is plotted as a family of curves in Figure D-7. The boundaries placed on the variables are as follows:

. Aircraft Velocity	210-400 knots
. Radar Range	0.5-15.0 nm
. Data Processor Feedback Factor (K)	0.94-0.97
. Display Resolution	40-60 feet.

Each member of the family consists of two curves depicting the minimum and maximum expected resolution on the recorded image film for the aforementioned boundaries of the display resolution.

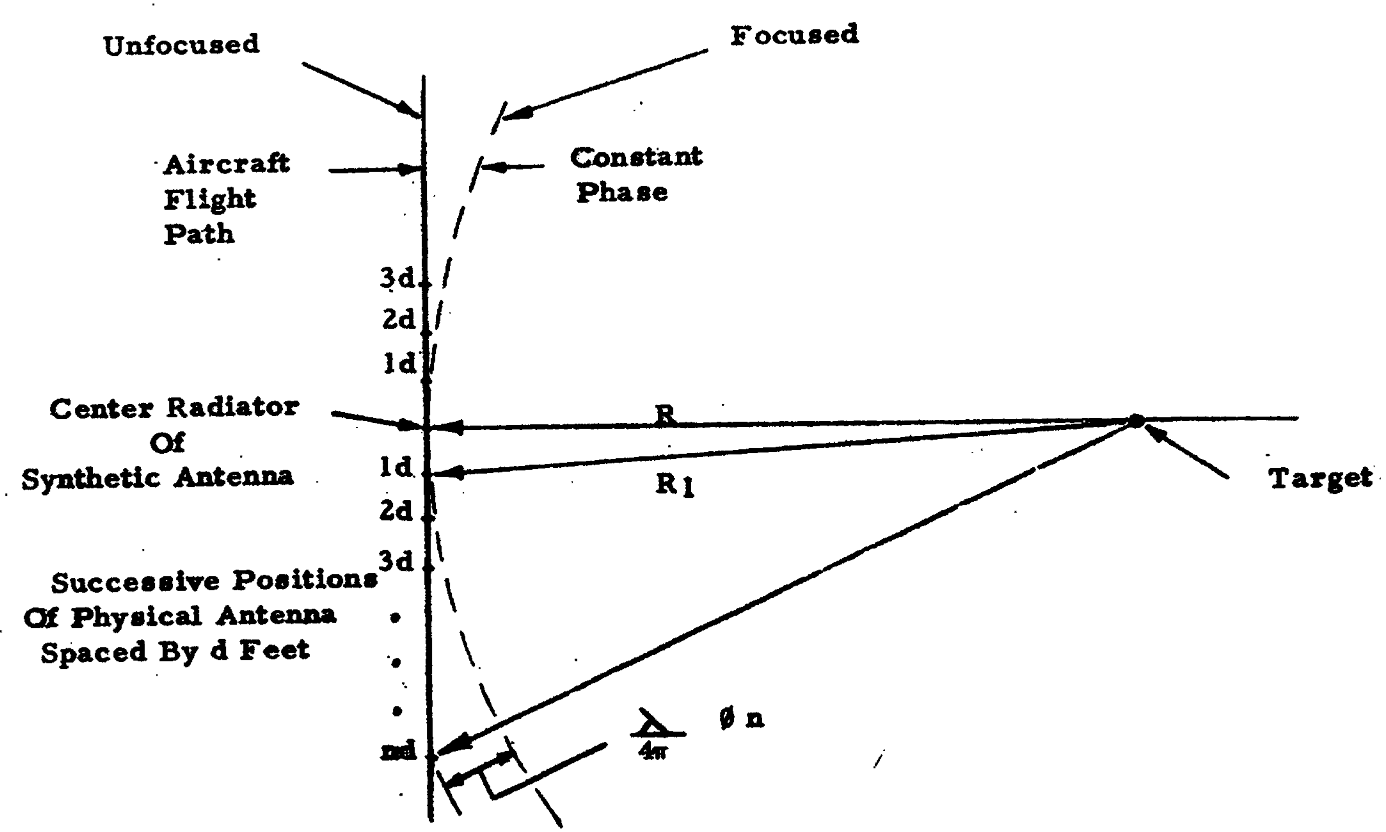


FIGURE D-6 SYNTHETIC APERTURE GENERATION

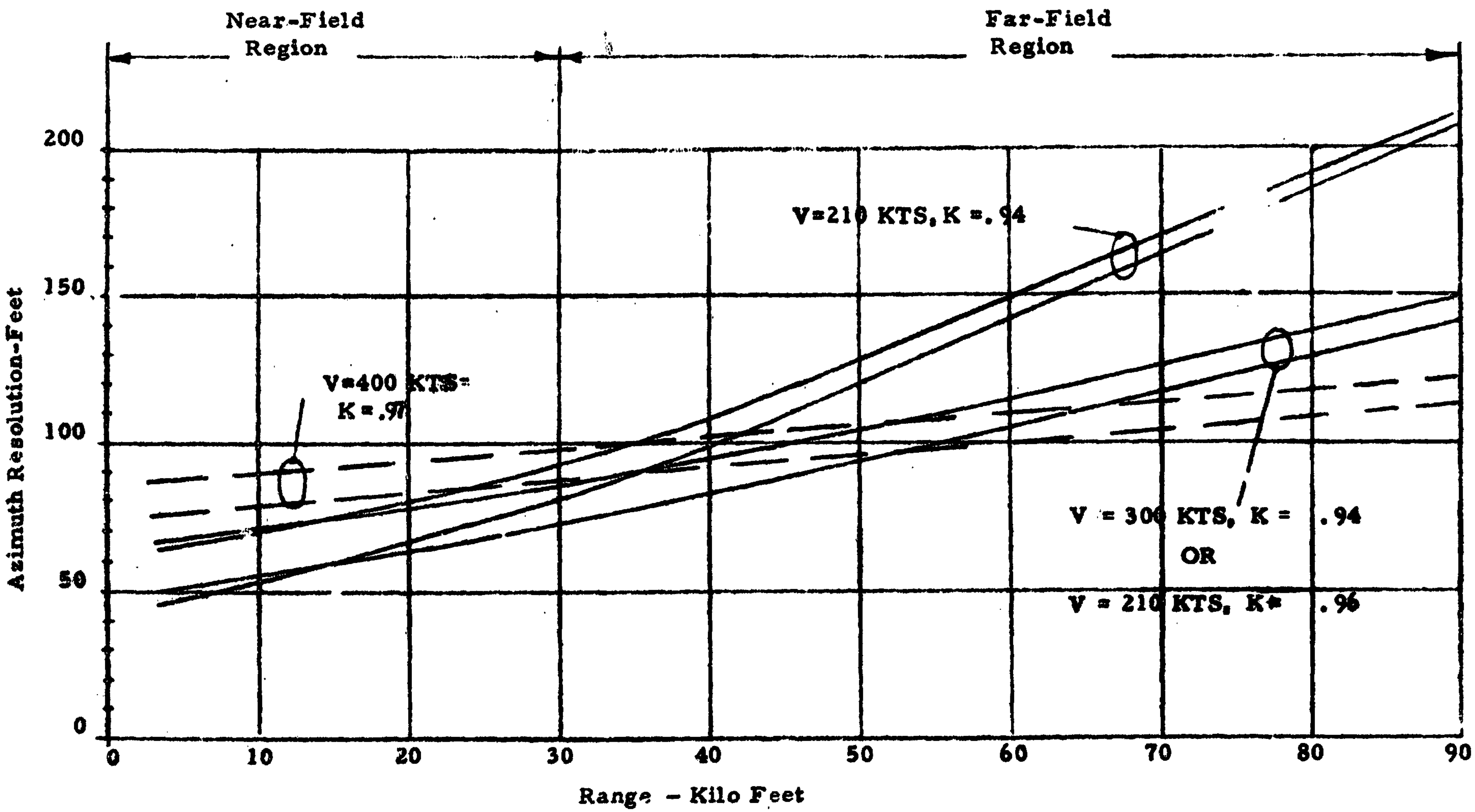


FIGURE D-7 EXPECTED RESOLUTION PERFORMANCE, 16.5 GHZ SLAR

The slant range displayed is a constant 10 nm swath. To maintain the proper ground illumination as a function of altitude, a tilt control of the antenna is provided. The range of the tilt control is approximately -10° to -25°, and the approximate tilt position can be read by the operator on a meter indication on the System Control Panel.

The system has a peak power output capability of 125 kilowatts, mapping is restricted to a swath on one side of the aircraft, and the operating altitude range is 4,000 - 30,000 feet. Data is recorded as 4 strip maps, for the 4 transmit-receive polarization combinations, on 5-inch film. In addition, the equipment includes a real-time display of the slant range sweep.

APPENDIX E

PROCESSING FLOW DETAILS

FOREWORD

This appendix provides a cursory view of the major processing steps employed to convert all sensor and auxiliary data collections into usable output forms. The discussion is limited to actual flows, and rough estimates of current throughput flow rates and volumes have been made. In some cases, a range of quantitative values is indicated because input volume and processing options can vary widely.

APPENDIX E CONTENTS

APPENDIX E CONTENTS (Cont'd)

APPENDIX E CONTENTS (Cont'd)

1. OVERVIEW OF PRESENT DATA HANDLING

Figure E-1 presents an overview of the current data handling procedures at MSC. Missions are scheduled by the Data Management Group, based on specific requests submitted by various users. After a mission is flown, its output products, in the forms of film, magnetic tape and flight logs, are delivered to the Data Group where they are logged in and inspected.

The Photo Laboratory and Data Laboratory are notified as to what data has been received and are given specific instructions regarding the processing expected. Mission film is delivered to the Photo Laboratory where it is processed, used to generate desired output products, and stored. Magnetic tapes are sent to the Earth Resources Data Research Facility where they are copied.

The originals are then sent to the Central Metric Data File for storage and the copies are released to the Data Reduction Complex for processing. In this manner, the use of the original data is minimized.

Film processing may lead to any of the following output product forms, depending on user request:

- B & W Duplicate Negative
- B & W Duplicate Positive Transparency
- B & W Paper Prints
- B & W Rectified Paper Prints
- B & W Glass Plates
- Original Color Film

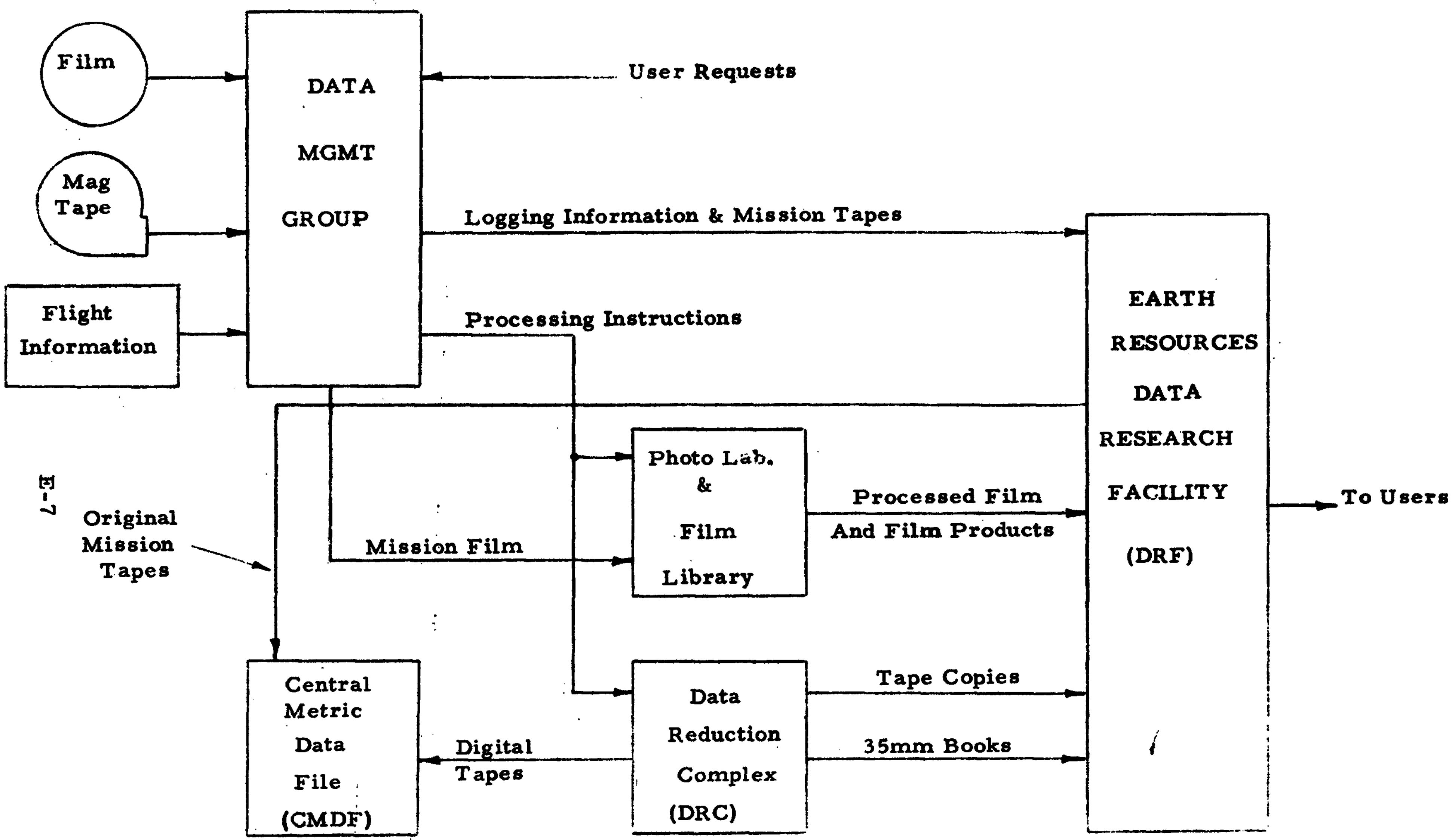


FIGURE E-1 OVERVIEW OF PRESENT DATA HANDLING

- Duplicate Positive Color Transparency
- Color Prints Type C
- Color Prints Type R

Magnetic tape data processing may result in digital tapes and 35mm microfilm plots and tabulations. The tapes are sent to the CMDF for storage but all other outputs are routed to users through the Data Research Facility. In addition to the tape duping, that section is responsible for disseminating all processing products for maintaining records as to storage locations of all mission data originals, and for the direct filing of all 35mm books from the DRC. The DRC can also produce line printer listings, strip chart oscillograms and pen recordings, and plot tapes to be used with several types of off-line plotting equipment. These data forms are generally used only internally but are available to users upon request.

A complete accession list of stored data is published twice a year and distributed, with monthly updates, to Principal Investigators and other data users. Based on that information, data processing and/or copy requests may be filed with the Data Management Group and another servicing cycle initiated.

The next two sections treat specific data flow paths within the Photo Processing Laboratory and the DRC, respectively.

1.1 Flow Rate Terminology

It is convenient to consider input data volume on the basis of a typical "per site" collection (feet of film and/or minutes of tape per average site) for each sensor. Since one "mission" may extend for several days and entail overflights of several sites, it is clear that the site take is a more fundamental unit of volume than the mission take.

Similarly, since even per site volumes vary, it is more useful to describe processing throughput in terms of flow rate (Q and M values), rather than absolute time.

Photographic processing is characterized by flow values (Q), given as either feet of film, or number of frames per unit time. If the input flow, Q_i, exceeds the capability of a particular device in the stream, data will back up unless the obstruction is cleared by adding one or more parallel paths around the device. The flow through all paths must then be matched properly to minimize throughput time. For example, if two devices having inherent capabilities Q_A and Q_B are operated in parallel, the actual flow through each, aQi and bQi respectively, should be such that

$$\frac{a}{Q_A} = \frac{b}{Q_B}$$

where $a + b = 1.$

Assuming all obstructions have been eliminated, the flow at all nodal points in the path can be maintained at the input rate. Under these conditions, the output flow, Q_o, will equal Q_i, but will be time displaced by the sum of throughput delays. These losses are due both to machine delays and to time consuming handling procedures. Therefore, the time required to process F feet of film is:

$$\frac{F}{Q_i} + \sum \text{delays}$$

For computer processing, it is convenient to use multiplier (M) descriptors where a value M = X means that the required machine time is X times as long as the corresponding data collection interval. M values are assigned to every major step in the processing flow of each sensor and the per sensor input - output figure is merely the sum of all values in the stream. A net input-output value representing total throughput of all sensor data can be more complicated to derive if suitable equipment is used to perform some steps in parallel. The solution is based on an equivalent serial path.

While it has not been possible to quantize fully all Q and M values involved in earth resources data processing at MSC, those values available are presented in the course of the discussion.

1.2 Data Categories

It is useful to consider input data as comprised of eight (8) groups, each corresponding to a unique processing flow path. Table E-1 summarizes the categorization.

2. PHOTO PROCESSING

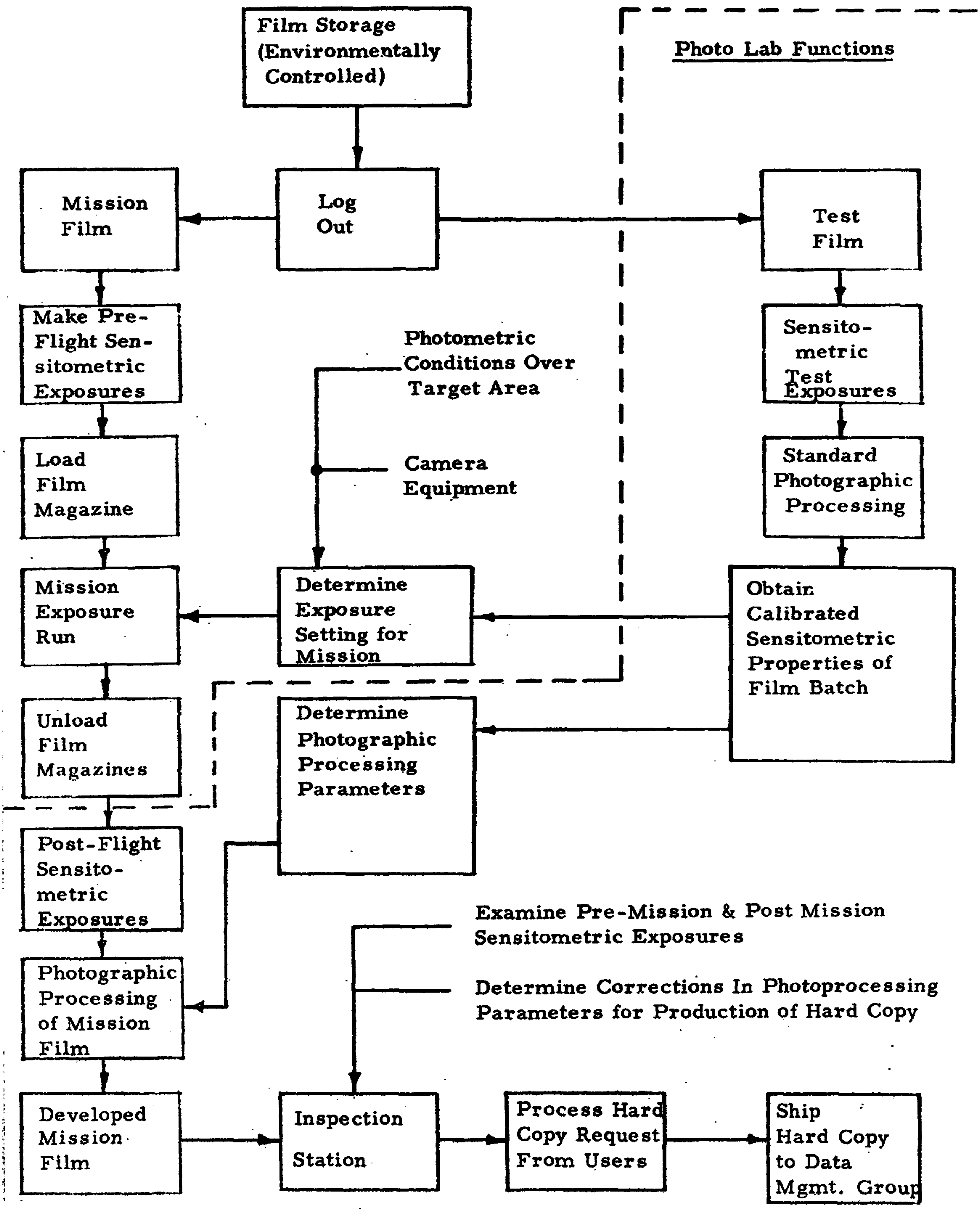
An overview of the current flow of photographic operations through the MSC photographic laboratory is presented in Figure E-2. At present, the laboratory is equipped with both color and black and white Versamat processors for developing rolls of film ranging from 35mm to 9-1/2 inches in width. Black and white, black and white IR, color, and color IR Kodak Aerial films of all types are processed according to requests from users. Although Aeroneg Color processing is available, it is seldom requested by the users.

TABLE E-1

DATA CATEGORIES

Group	Type	Film	Tape
1	Cameras and SLAR	X	
2	IR Line Scanners	X	X
3	Scatterometers		X
4	Spectrometers and Radiometers		X
5	Auxiliary Data (NAV)	X	X
6	Camera Pulses		X
7	Liquid Water Content Meter		X
	Dew Point Hygrometer		X
	Total Air Temperature		X
8	Voice Track		X
	Flight Logs	---	---

OVERVIEW OF PRESENT PHOTOPROCESSING FLOW
FIGURE E-2



The time rates of film flow through the MSC laboratory vary widely with the type of film and with the requests of the user. For example, typical flow rates through Versamat processors are 10 to 14 feet per minute for black and white films, and 3 to 5 feet per minute for color films. The MSC laboratory has a new color Versamat processor on order which will increase the typical flow rate for color films to between 10 and 14 feet per minute.

Sensitometric exposures are placed on the film both before and after the mission by an Eastman 1B sensitometer. The densities of the sensitometric exposures are examined after the mission film has been developed in order to determine the effects of environmental and handling aspects of the mission on the sensitometric properties of the film. The results of this examination are used to optimize the quality of any subsequent hard copy produced from the original mission film.

Zeiss rectifiers are used to correct geometric distortions that are present in photographs taken at oblique angles. A photographic record of the aircraft instrument panel (typically 200 feet of 35mm film) made during the mission is utilized to obtain the oblique angular parameters required as inputs to the Zeiss optical rectifiers. The fundamental flow of information from the photographic record is presented in Figure E-3. The photographic record of the instrument panel, the document that identities the mission, and the hard copy requested are shipped together to the users, who extract the navigational coordinates of any frame from the Doppler radar display on the aircraft instrument panel at the time the frame was taken.

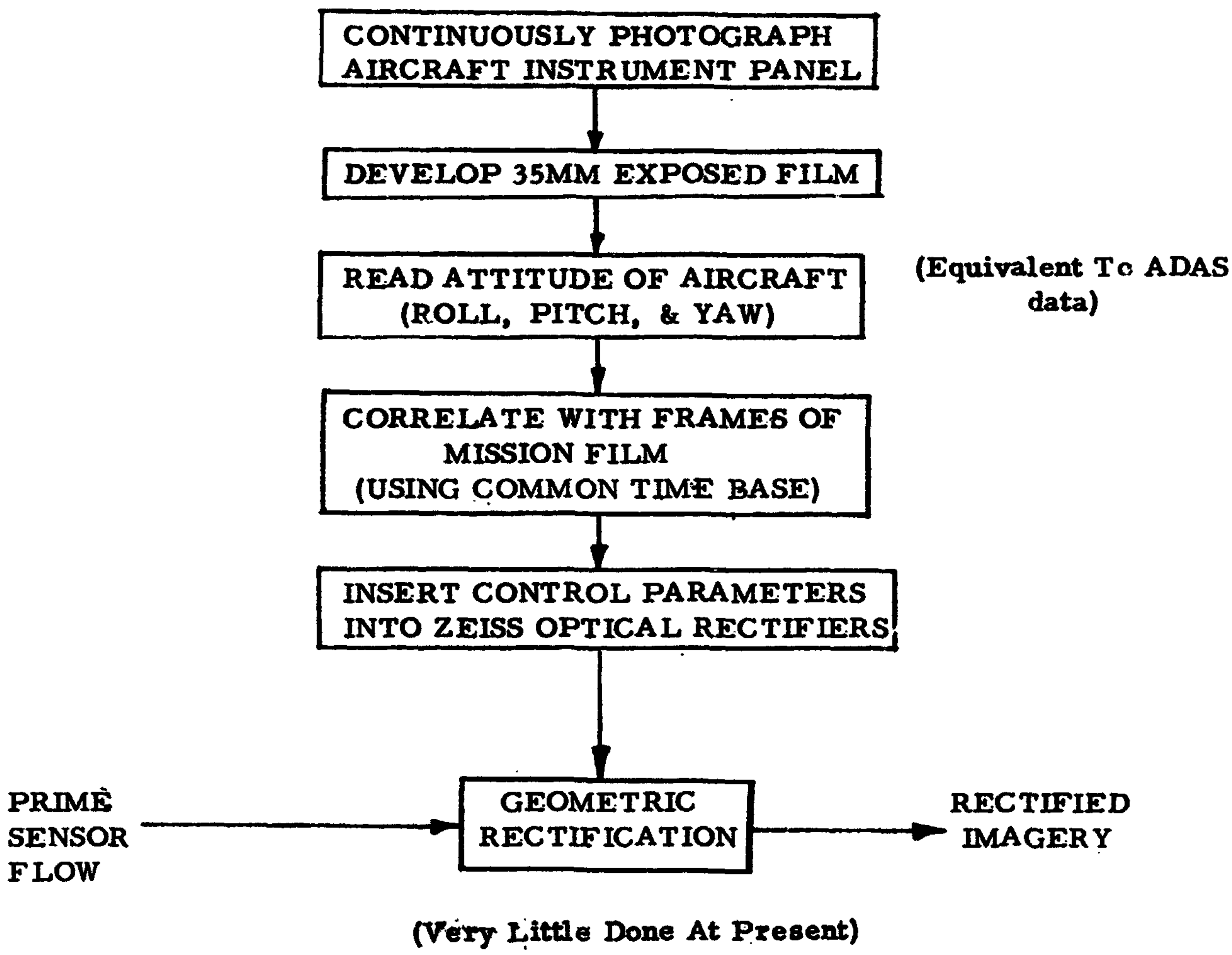


FIGURE E-3 PHOTO PANEL DATA FLOW

This method is used only for missions flown in the Convair aircraft. All other planes are equipped with ADAS systems which provide the same information.

3. MAGNETIC TAPE DATA PROCESSING

Earth Resources sensor data flow through the DRC is summarized in Figures E-4 and E-5. Magnetic tape dupes from the DRF are examined against the service request from the Data Group to determine which tapes contain the time slices of interest. A first tape is selected and mounted on a playback unit and processing commences. This is the starting point denoted by the circle, "a", in the diagram.

All flow paths consist of two major operations. The first is data conditioning, whereby analog signals are stripped from the input tape, decommutated, filtered, digitized and collected on an output "Phase I" tape in an appropriate format for subsequent processing. These steps are performed by special purpose hardware and data manipulations under the control of a CDC 3200 computer. Critical data parameters are given a time-history check and if anomalies are detected, a time-editing function is performed to delete the error entries and produce error message outputs.

Prime sensor data are handled in this manner, one at a time, but some low frequency signals can be converted in parallel. Tables E-2 and E-3 list typical AR1600 tape recorder track and channel assignments for the P3A aircraft. They are included here to convey more explicitly the nature of the raw input data. Actual track assignments can vary from mission to mission. When all sensor data of interest have been converted and loaded (circle "b"), the Phase I tape is transported to a UNIVAC 1108 system for reduction processing. As indicated in the diagram, the functional steps necessary from "c" to "d" vary significantly for data groups 3 - 7 (see Table E-1 for sensor group summaries).

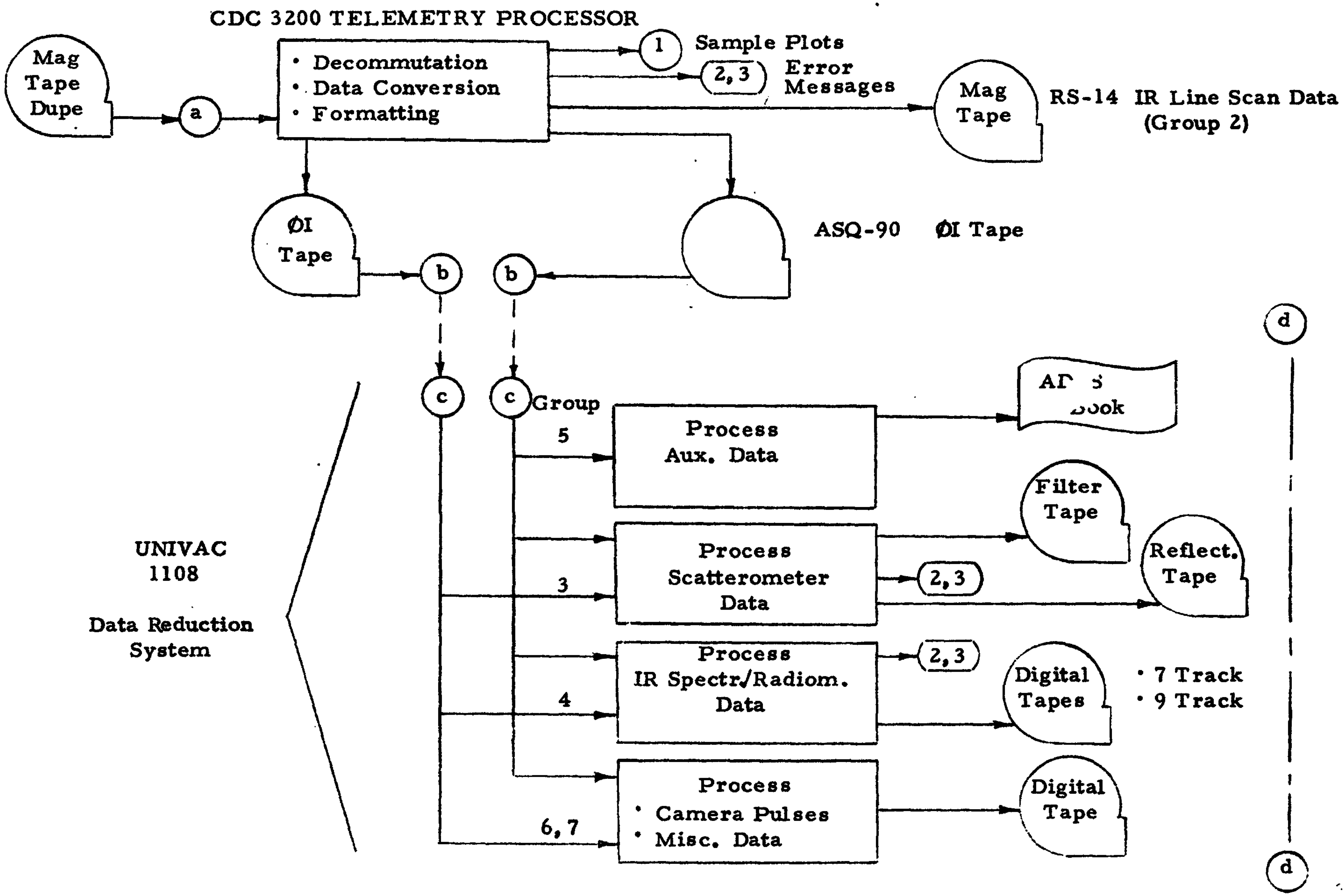


FIGURE E-4 OVERVIEW OF MAGNETIC TAPE DATA FLOW

FIGURE E-5 STANDARD DP OUTPUT FLOW

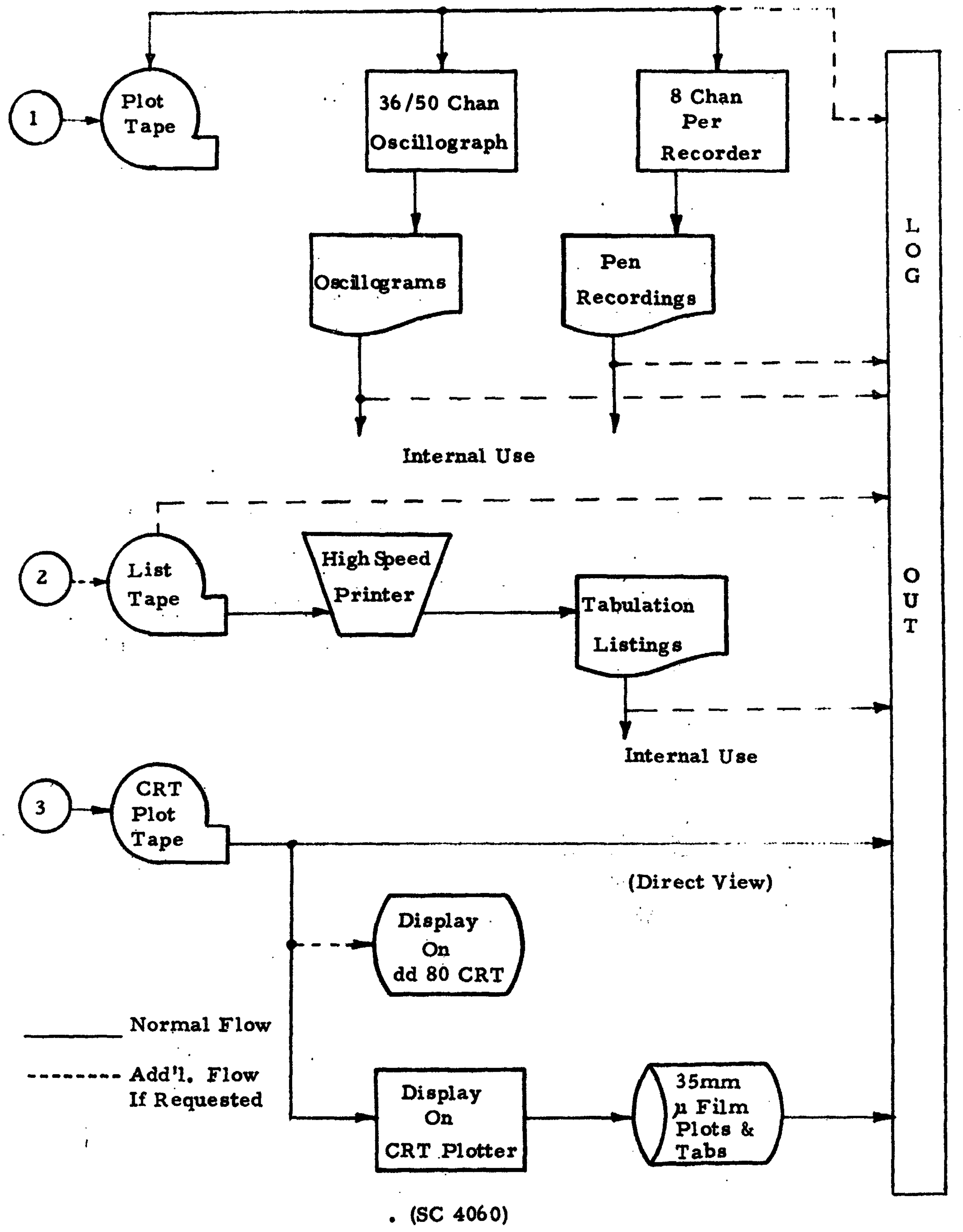


TABLE E-2

TYPICAL RECORDER TRACK ASSIGNMENTS

Track	Rec. Mode	Data
1	*WBFMGPII	RS-14 Sync
2	*WBFMGPI	13.2 GHz Scatt. Ch 1
3	DIRECT	IRIG A Time
4	WBFMGPI	13.3 GHz Scatt. Ch 2
5	WBFMGPII	ASQ-90 Wave Train
6	DIRECT	CBW 400 MHz Scatt. (11 channels)
7	WBFMGPII	PCM IR and Microwave
8	DIRECT	50 KHz Reference
9	WBFMGPI	1.6 GHz Scatt.
10	DIRECT	PBW (16 channels)
11	WBFMGPII	RS-14 Video No. 1
12	Not Used	
13	WBFMGPII	RS-14 Video No. 2
14	DIRECT	Voice

* Wide Band Frequency Modulated, Group I or II

TABLE E-3

TYPICAL PBW CHANNEL ASSIGNMENTS
(TRACK 10 DATA)

Channel	Center Frequency	Data
1	400 Hz	Not Used
2	560 Hz	Not Used
3	730 Hz	Not Used
4	960 Hz	Liquid Water Content Meter
5	1.3 KHz	IR Boresight Camera Pulse
6	1.7 KHz	Dew Point Hygrometer
7	2.3 KHz	SLAR Boresight Camera Pulse
8	3.0 KHz	Total Air Temperature
9	3.9 KHz	MF Microwave Radiometer Boresight Camera Pulse
10	5.4 KHz	PRT-5
11	7.35 KHz	Multi Spectral Camera Pulse No. 1
12	10.5 KHz	Multi Spectral Camera Pulse No. 2
13	14.5 KHz	Multi Spectral Camera Pulse No. 3
14	22.0 KHz	Multi Spectral Camera Pulse No. 4
15	30.0 KHz	RC-8 Camera No. 1 Pulse
16	40.0 KHz	RC-8 Camera No. 2 Pulse

Output products are computer compatible tapes and microfilm plots generated as noted in Figure E-5. The diagram also indicates other standard product forms which are available either internally or externally. The data flow shown in the two figures (E-4 and E-5) interface through connections 1, 2 and 3 as shown. The strip charts may be constructed by any of the appropriate off-line plotters listed in Table E-4.

The next few paragraphs briefly treat each of the specific flows for the seven analog data groups (Groups 2 - 7).

3.1 Group 2 - IR Line Scanners

Output of the RS-14 scanner is in the form of film and tape. At present, the only way to obtain imagery from the tape is to run it back through the system, and utilize the film recorder.

In the case of the RS-7 and Reconofax IV imagers, only film output is available.

3.2 Group 3 - Scatterometers

Both data conversion and data reduction involve somewhat different handling procedures for each of the three sensor types because the collections are quite different. Thus, the 400 MHz system output is recorded on 9 constant bandwidth (CB) channels on one track of the AR1600 tape recorder. These include four channels of fixed gain data (primary source), four channels of variable gain data (for special investigation) and one channel of calibration information; two analog-to-digital setups are required.

TABLE E-4

DRC OFFLINE PLOTTERS

Qty.	Type
2	36-Channel Oscillograph
14	8-Channel Pen Recorder
4	50-Channel Oscillograph
1	Cal Comp Plotter (565)
1	EAI 3440 X-Y Plotter
1	Spatial Data Systems 3-D Plotter

The 1.6 GHz system output is recorded on one track, digitized at 25,000 samples/second. The 13.3 GHz system output is recorded on two tracks and requires a special analog-to-digital program to convert each channel at 25,000 samples/second.

In addition to differences in volume and form, each set of data corresponds to a markedly different radar wavelength, so the information content changes also. However, in terms of major functional steps, all three types are processed identically. Conversion flow (a to b) has already been described; reduction flow (c to d) is shown in Figure E-6.

Power Spectral Densities are first plotted and inspected to check that the spectra appear "typical", the reference signal is present at the proper frequency, and no noise spikes at 60 Hz, 400 Hz or associated harmonics have been induced by aircraft equipment. Typical PSD's are given in Figure E-7.

Digital filtering is performed by using a Fourier Transform to compute RF reflectivity power in specific frequency bands corresponding to angles of incidence from overflown ground cells.

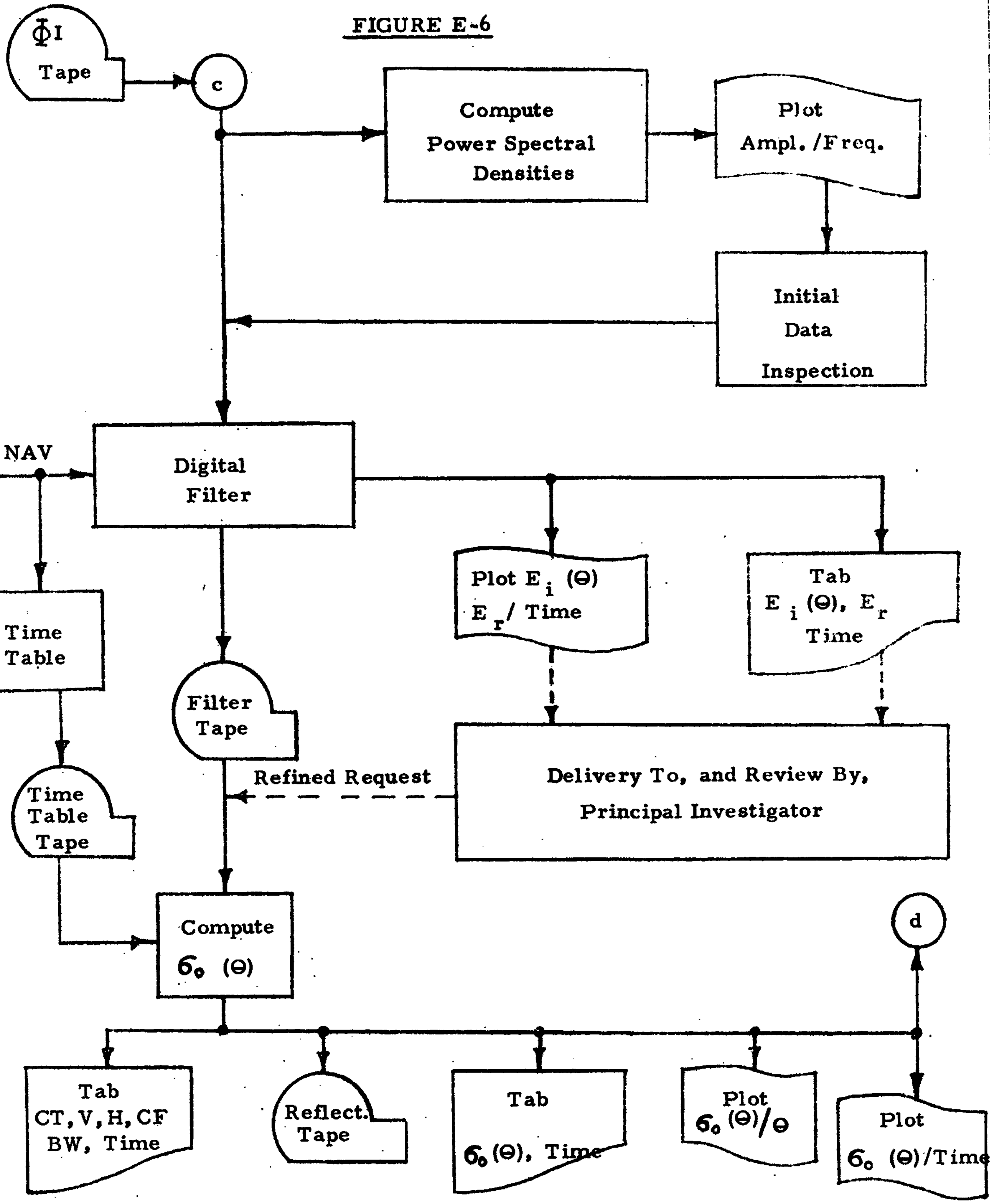
At this point, a book of sample data plots is generally prepared and delivered to the Principal Investigator who examines them and determines which data should undergo additional processing. For water overflights, this step is often bypassed and a standard sampling used.

Typical delivered products include:

- Filter Plots (digitally filtered data voltages plotted as f(t)).

SCATTEROMETER DATA REDUCTION

FIGURE E-6



E_i (Θ) = Filtered Data Voltage
E_r = Filtered Ref. Voltage
V = Aircraft Velocity

CF = Center Frequency
BW = Bandwidth
CT = Cell Time

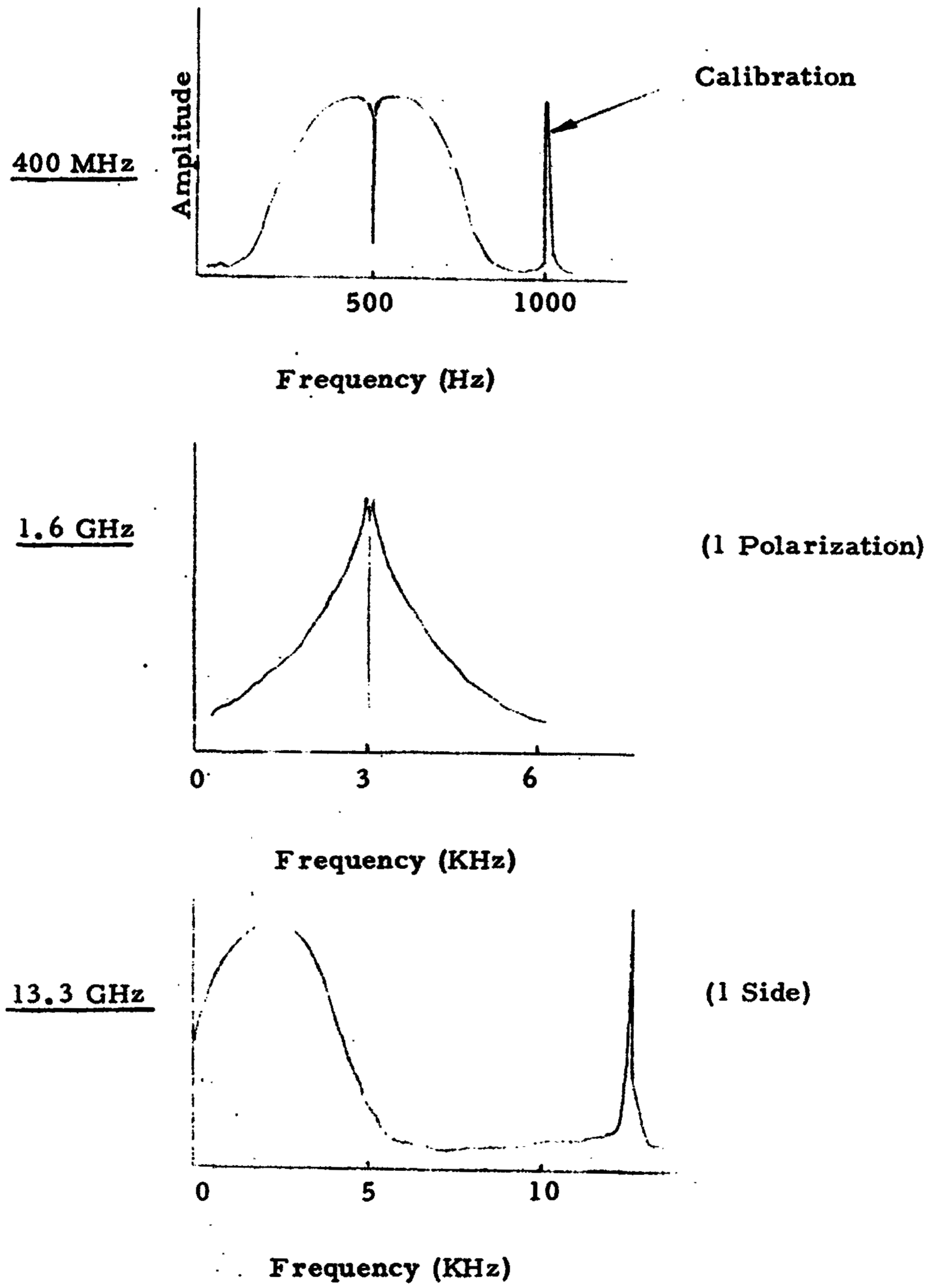


FIGURE E-7 TYPICAL SCATTEROMETER SPECTRA

- Filter Tabs (detailed listings of digitally filtered reference signal and data voltages corresponding to all incidence angles, as f(t)).

- Guidance/Navigation Plot (a time history of ground speed and vehicle height).

- Power Spectral Density Plot (a "quick" look at the general characteristics of the Doppler frequency spectrum prior to digital filtering).

Selected data is next operated on and correlated with Auxiliary Data inputs to compute radar reflectivity (σ_0) as a function of incidence angle for each ground cell; this information is plotted. Various statistics are then calculated, tabulated and plotted, including:

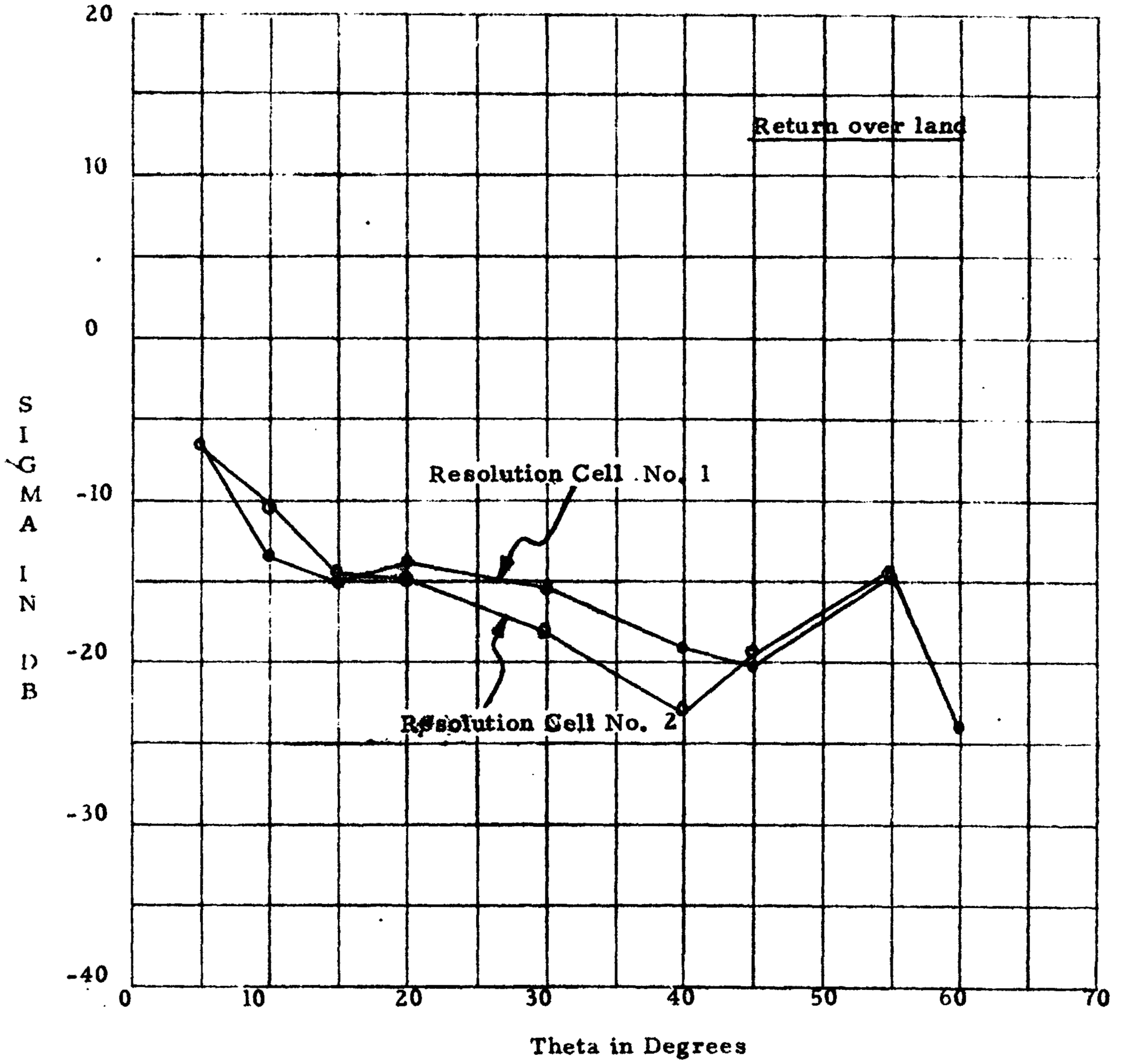
- Statistical Plots (the mean and standard deviation of σ_0 computed over a specified time interval and plotted versus incidence angle).

- Time History Plots (σ_0 for selected incidence angles as f(t)).

- σ_0 Tabs (detailed time-history listings of σ_0 for all incidence angles).

Representative samples of reflectivity plots and σ_0 time-history plots are shown in Figures E-8 and E-9 respectively.

Conversion setup time is approximately 30 minutes; conversion flow rates (Ma-b) are approximately equivalent to real time. Reduction flow rates (Mc-d) are approximately 14 times as long as real time. The throughput rates are identical for all the Group 3 scatterometer radars, regardless of operating frequency.



AFT Beam
Scatterometer **Mission** 80
Flight 7 Line 3
Run 1 Site 76

Figure E-8. Reflectivity Plots

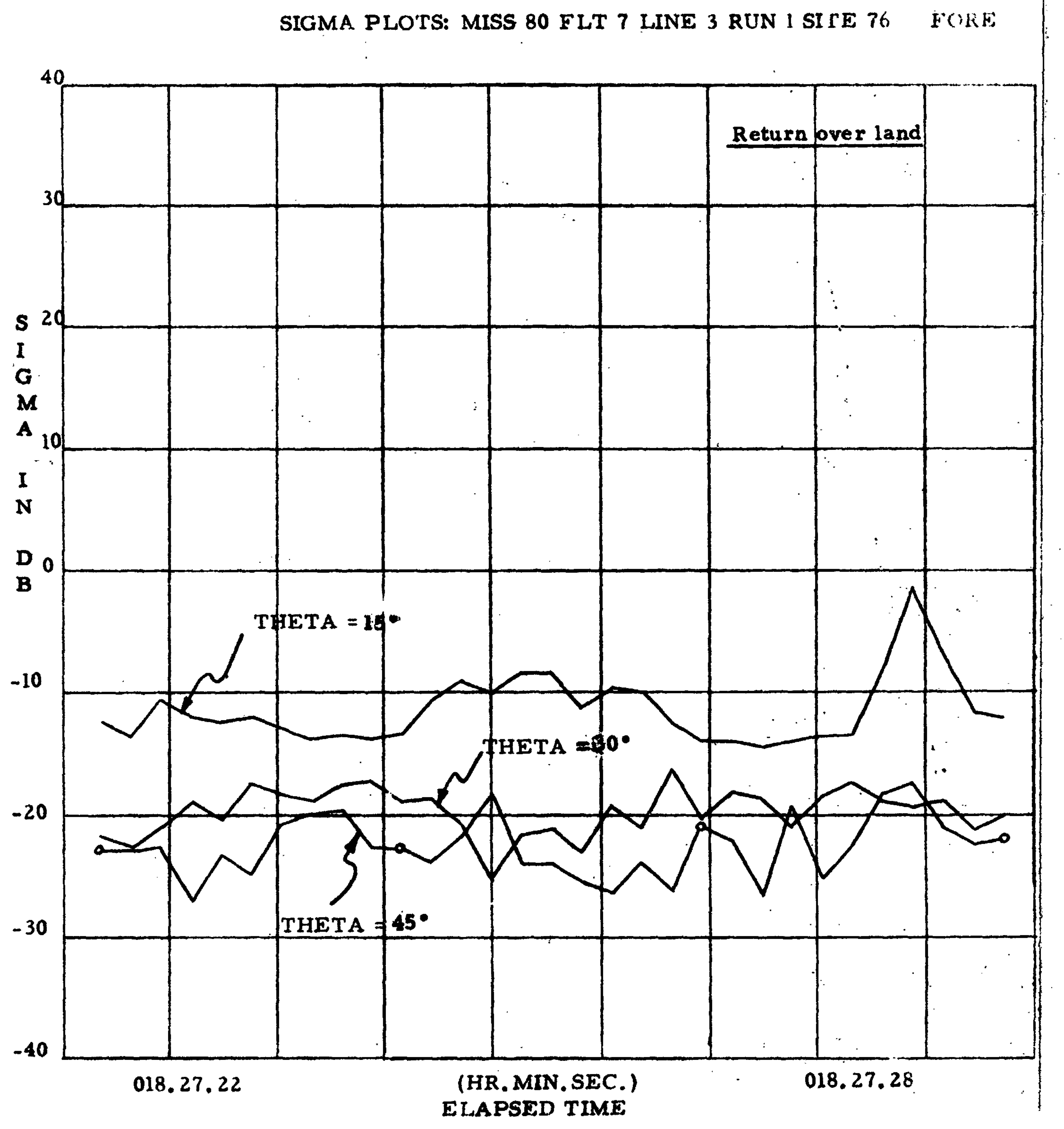


FIGURE E-9 σ_0 TIME-HISTORY PLOTS

Historically, the most time consuming element in the flow has been the Digital Filter. Initially, estimates of Mc-d ranged on the order of 40 to 80, and the figure came down as processing software was made more efficient. It appears that these programs have now been refined to a point where no further substantial improvements in reduction time are expected with this procedure.

Consequently, MSC is about to award a study which will analyze an alternative approach - that of using on-board electronic filters. The system will use approximately 20 frequency bins (10 for forward returns and 10 for aft returns) and will record all data both as single sideband modulations and as a merged PCM bit stream. On-board switching and plotting functions will also be included for preliminary data examinations. The new system is expected to substantially reduce ground throughput time. Specific details should be available in about one year.

3.3 Group 4 - IR Spectrometer/Radiometers

Data from these sensors are interleaved with other sensor data in a 100 Kbps PCM bit stream and decommutated and formatted in one computer pass in the 3200 system. Data on the Phase I tape is then reduced as shown in Figure E-10.

Six parameters are processed:

– Spectral Radiance	IRS
– Scan Marker	SMARK
– Differential Radiance	DIFRAD
– Black Body Temperature	BB TEMP
– Chopper Filter Temperature	CHFILT

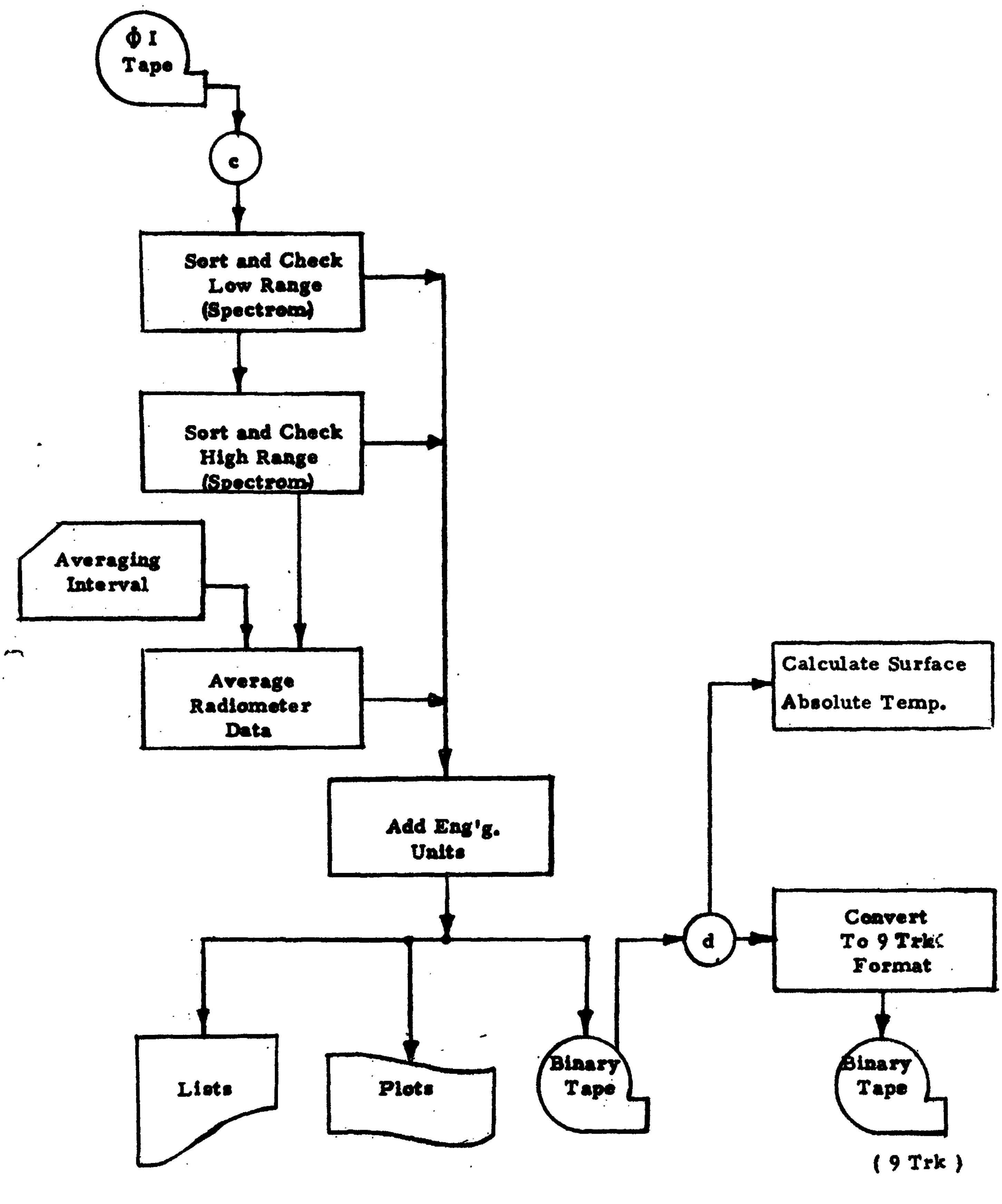


FIGURE E-10 IR SPECTROMETER/RADIOMETER DATA REDUCTION

— Case Color Temperature CCT

The first and third items include the information of interest. Spectral Radiance is plotted at 90 different wavelengths per scan, corresponding to one-half rotation of the notched-filter wheel in the sensor. Alternate scans are termed "low range" and "high range" and assigned frame numbers from 1-90 and 91-180, respectively. Therefore, 180 frames correspond to a complete rotation of the filter wheel. The SMARK signal distinguishes the low and high ranges and the last three parameters are used for calibration corrections. They and the DIFRAD values are routinely tabulated at the original sample rates. These measurements also can be averaged over any time interval and tabulated and plotted.

Sample outputs are given in Figures E-11 and E-12. Quantified data are also stored on seven track tape and can be converted to, and stored on, nine track equivalents. A recently developed program allows ground surface absolute temperatures to be calculated by comparing sensor readings from adjacent ground cells. The accuracy obtained with this technique is reported to be quite good.

Conversion setup time is approximately 15 minutes; conversion flow rate (Ma-b) is equivalent to real time. Reduction flow rate (Mc-d) is only 40% of real time. Seven-to nine-track conversion is I/O bound.

3.4 Group 5 - Auxiliary Data

Auxiliary guidance and navigation data is converted and formatted on an ASQ-90 Phase I tape rather than included as records on the sensor data Phase I tape (see Figure E-4). The next steps in the flow are as indicated in Figure E-13, and the raw input PCM format is shown in Figure E-14.

FIGURE E-11

LOW RANGE PLOT

MISSION 78 FLIGHT 2 LINE 34 RUN 1 SITE 19

H M S

LOW RANGE SCAN STARTING AT 17 43 41.351

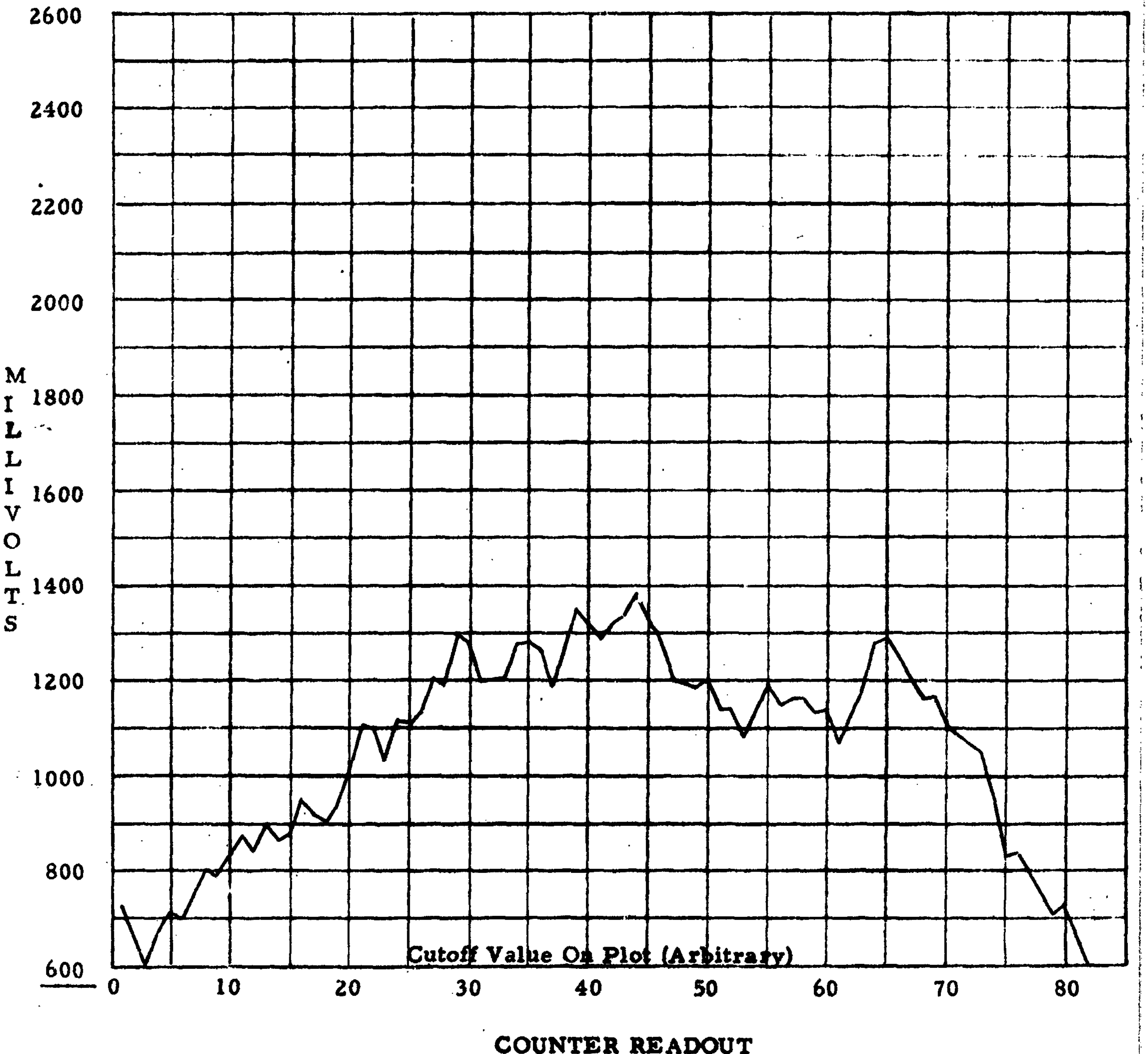
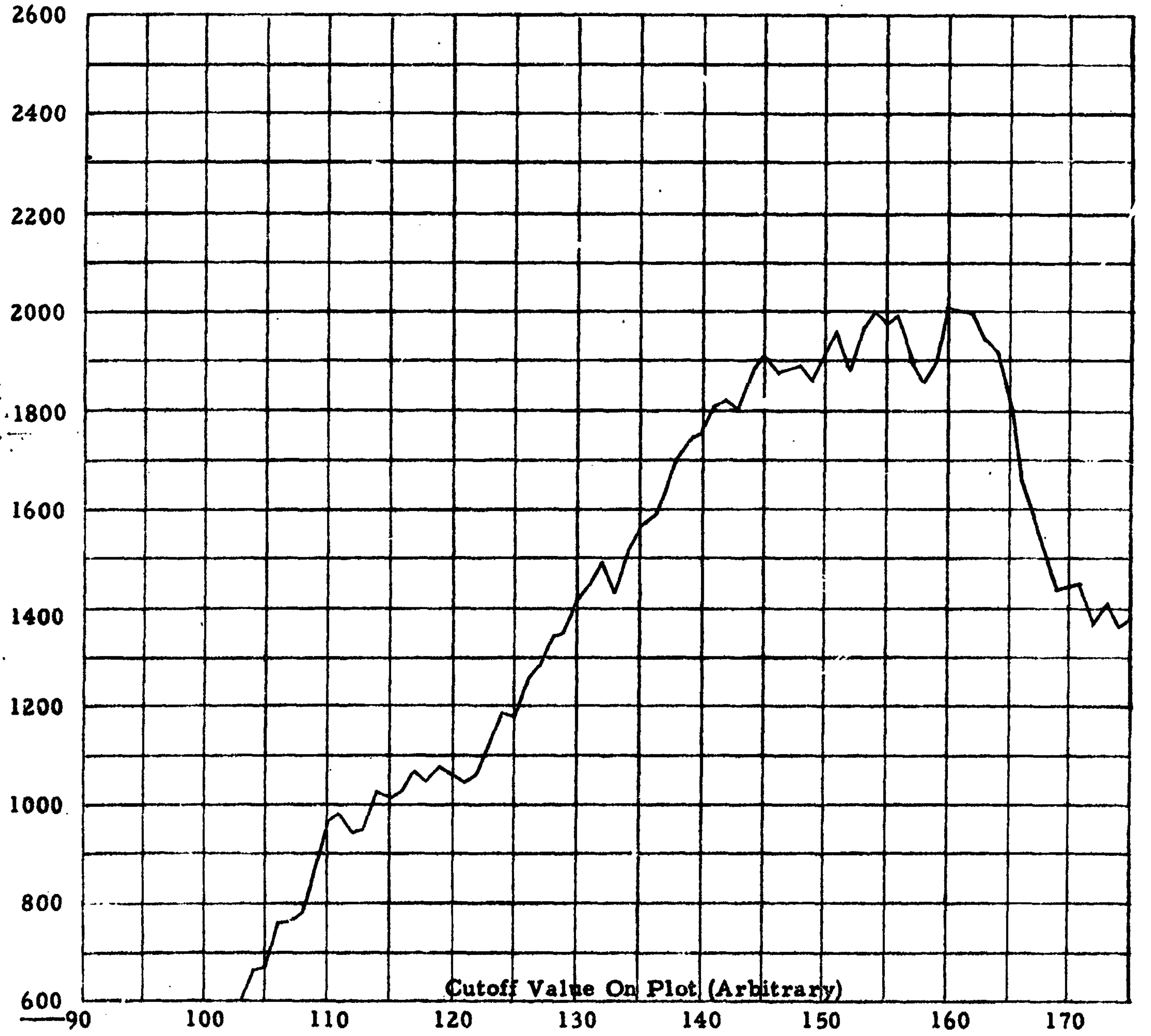


FIGURE E-12

HIGH RANGE PLOT

MISSION 78 FLIGHT 2 LINE 34 RUN 1 SITE 19

HIGH RANGE SCAN STARTING AT 17 H 43 M 41.503 S



COUNTER READOUT

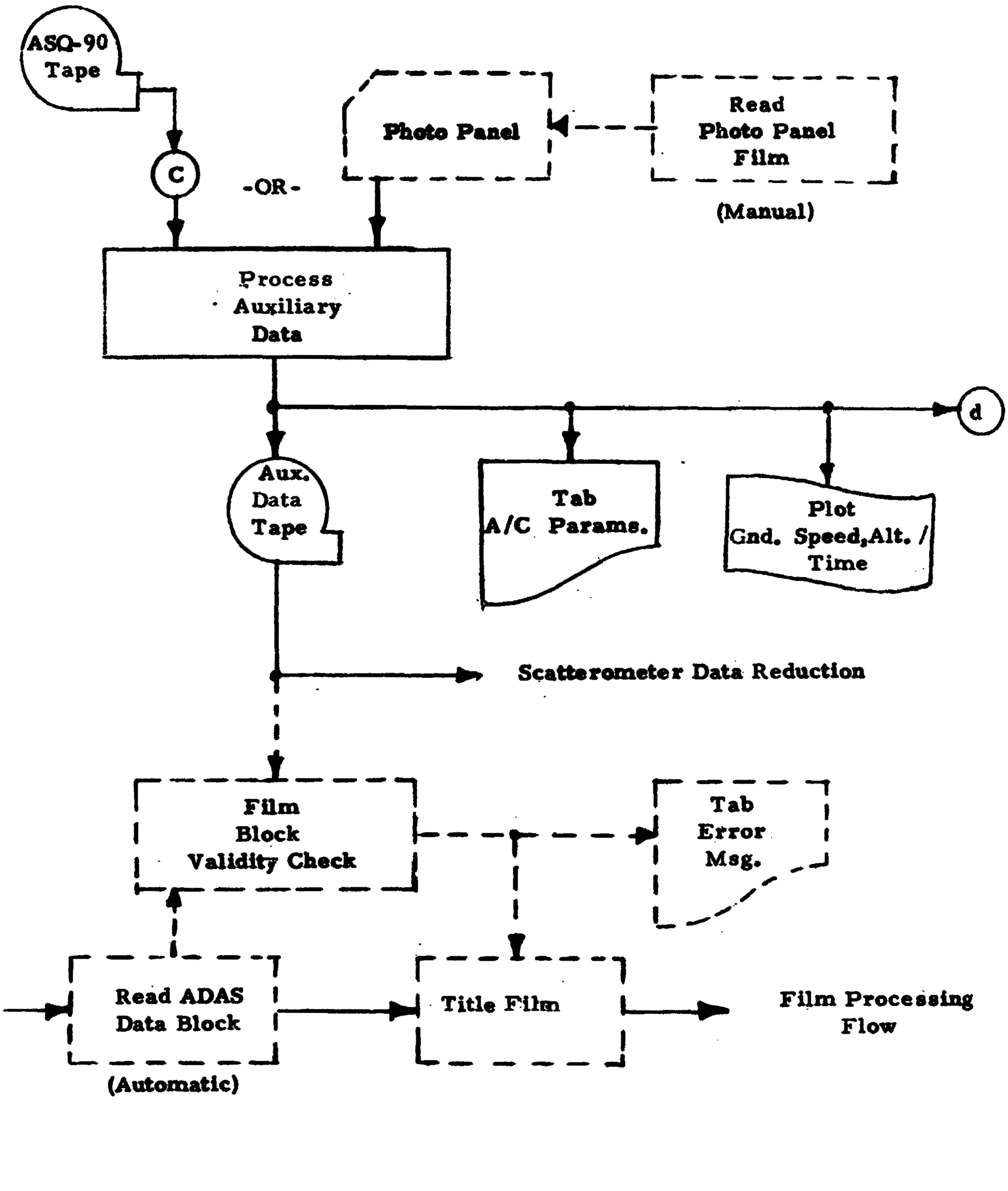


FIGURE E-13 AUXILIARY DATA REDUCTION

FIGURE E-14

ASQ-90 PCM DATA TAPE FORMAT
25 FRAMES/RECORD 3BCD CODE

24 BITS AROUND THE ORIENTATION BIT FOR AUTO READER USED FOR SYNCHRONIZATION

TIME (0)
Binary Milliseconds
from Bit Stream
TIME (24)

Frame								
25	BAROMETRIC ALTITUDE					HEADING		
	Zero	Hund's.	Thou.	T-Thou.	Tenths	Units	Tens	Hund's.
26			DRIFT			ROLL		
	Sign	Tenths	Units	Tens	Sign	Tenths	Units	Tens
27			PITCH			VELOCITY		
	Sign	Tenths	Units	Tens	Code	Units	Tens	Hund's.
28			DAY	DATE	MONTH		YEAR	
	778	Units	Tens	Units	Tens	Units	Tens	778
29				MISSION			SITE	
	778	778	Units	Tens	Hund's.	Units	Tens	Hund's.
30	FLIGHT		LINE				RUN	
	Units	Tens	Units	Tens	778	Units	Tens	Zero
31	RADAR							
	778	Mode	778	1-4	5-8	9-12	13-16	17-20
32			MINUTES	LATITUDE		DEGREES		
	Sign	Tenths	Units	Tens	Units	Tens	778	00
33			MINUTES	LONGITUDE		DEGREES		
	Sign	Tenths	Units	Tens	Units	Tens	Hund's.	778
34		RADAR ALTITUDE				PCM STATUS SYNC. O.K. 778		
	Fixed	Tens	Hund's.	Thou.	T-Thou.	00	1 Bit Slip	00
35								

Tape Width

Data Frame #1

Data Frame #2-25

Until recently, there was no tape record of Auxiliary Data and entries were made from a punch card deck. The information was obtained by visually reading successive frames on a photo panel film strip, which is a running photographic record of NAV instrument readings aboard the aircraft. Cards were then prepared by manual keypunch. The procedure is still available for backup and error checking, so the flow is included as dashed lines.

Output products are an Auxiliary Data tape and several microfilm plots and tabulations. This material is useful in scatterometer processing (see Paragraph 3.2).

The additional dashed lines on the diagram refer to an Auxiliary Data correlation function which is currently under study and may eventually be implemented. When a reliable Auxiliary Data Annotation System (ADAS) is available, a film block read/check/title function can be included in the film processing flow as shown.

Other product forms may be necessary to permit multisensor correlation studies, but these tasks are as yet undefined.

Conversion setup time is 15 minutes. Conversion flow rate (Ma-b) is equivalent to real time, while data reduction flow rate (Mc-d) is somewhat faster than real time.

3.5 Group 6 - Camera Pulses

Camera shutter pulses are recorded on proportional bandwidth channels on track 10 of the analog tape. They are available for data correlation purposes but at present are unused because each camera exposes time annotations in the ADAS Code block on the film strip. The leading edge of a recorded pulse corresponds to the beginning of the shutter opening for the boresight cameras and the midpoint of the exposure for the RC-8 cameras.

The data is stripped from the analog tape, digitized at 250 samples/second/channel, converted to a proper format for the Phase I tape and then collected routinely on an Auxiliary Data Tape. The output is a binary listing of frame number versus time for each camera. Conversion setup time is 15 minutes.

3.6 Group 7 - Miscellaneous Data

Data in this group, which includes output from a liquid water content meter and a dew point hygrometer, as well as total air temperature, is converted and routinely tabulated in appropriate engineering units versus time. Currently, it is not used.

Conversion setup time is 5 minutes. Conversion flow rate (Ma-b) and reduction flow rate (Mc-d) are both faster than real time.

3.7 Group 8 - Mission Data

Information in this group is recorded as flight log entries, plus voice comments on Track 14 of the AR1600. It includes pertinent statements regarding mission, site and run identification, run start/stop times, navigation check points, equipment settings, etc. This is used by Data Group personnel to define the requests on sensor data processing.

3.8 Summary

Conversion setup times, as well as conversion and reduction flow rates for all magnetic tape data, are summarized in Table E-5.

TABLE E-5

MAGNETIC TAPE DATA THROUGHPUT RATES

Group	Sensor/Data Type	Conversion Setup Time (minutes)	Conversion Flow Rate Ma-b	Reduction Flow Rate Mc-d
2	IR Line Scanners	NA	NA	NA
3	Scatterometers	30	1	14
4	Spectrometer/ Radiometer	15	1	0.4
5	Auxiliary Data	15	1	< 1
6	Camera Pulses	15	—	—
7	Miscellaneous	5	< 1	< 1
8	Mission Data	—	—	—

APPENDIX F

ALTERNATE METHODS OF ATTITUDE DETERMINATION

FOR

ERTS-A IMAGE RECTIFICATION

(Preliminary Trade-Off Study)

FOREWORD

Appendix F summarizes a preliminary trade-off study performed as part of the same program at the request of NASA Headquarters personnel. Basically, it presents a clarification of the problem of obtaining attitude information, to the accuracy required by certain earth resource experimenters, from the ERTS-A satellite.

Since it was performed under the present contract and has considerable bearing on the substance of the findings, it is included here for the sake of completeness.

INTRODUCTION

Various experimenters who plan to use ERTS -A RBV imagery have indicated there is a need to rectify this data form to an accuracy on the order of one resolution element. While analyzing the problem to establish methods of rectifying imagery to this accuracy, several other processing steps were found to be prerequisites to actual rectification. A critical prior step involves determination of attitude orientation and altitude for each RBV photographic set. A preliminary analysis of this task has shown that alternate techniques can be employed. One method assumes a modified design of the basic ERTS-A satellite (as defined in NASA/GSFC Specification, Final Draft copy, dated January 1969) by considering the addition of an electro-optical star mapper capable of collecting attitude data to the required accuracy. Another method employs a standard photogrammetric technique relating the RBV imagery to a correlated map of the ground. Both procedures utilize digital computers to perform high speed calculations at a ground station.

To bring the attitude determination problem into focus, FSDS was requested to perform a limited cost trade-off study comparing these two methods as part of its responsibilities under a NASA Headquarters contract, NASW-1811, "Earth Resources Data Processing Center Study". The results of that initial effort are presented in this document; the intent is to outline the problem, indicating a selected number of specific areas requiring further analysis. It is apparent that many additional factors should be considered as part of a complete study of the problem before a satisfactory solution can be developed.

Briefly, this document:

- Describes two alternate methods for determining sensor attitude to the desired accuracy.
- Outlines further difficulties encountered in rectifying optical line scan imagery (as opposed to RBV imagery), although this problem was not included in the cost trade-off results.
- Introduces the concept of data flow rate, and shows it to be a critical decision factor.
- Presents an initial analysis of the cost differences entailed in the two methods of attitude determination, for controlling RBV image rectification.

LIST OF ILLUSTRATIONS

PAGE F-4 BLANK

Reference: PLATE 1.

GENERAL ATTITUDE STABILIZATION AND CONTROL SYSTEM.

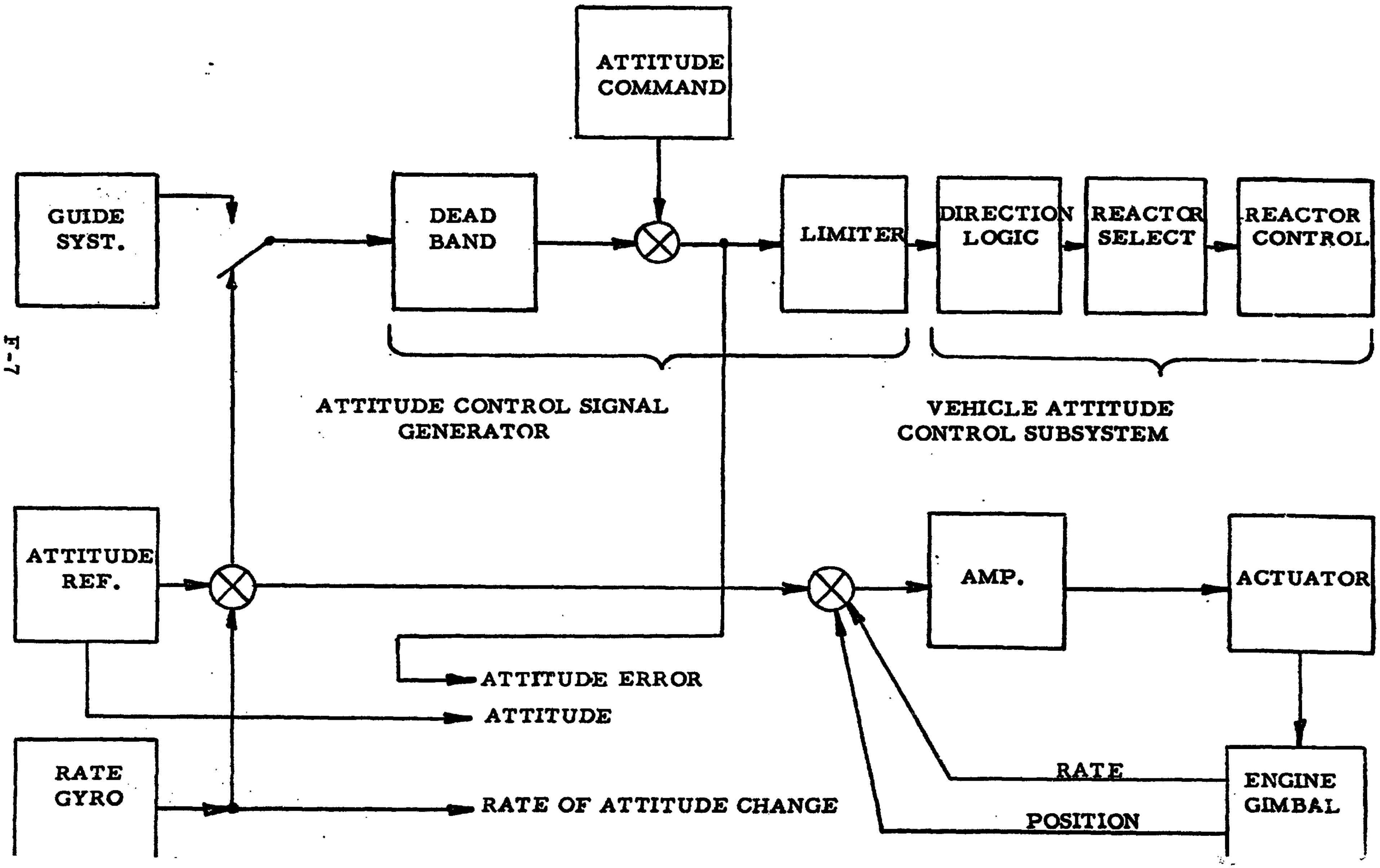
As presently outlined in the ERTS-A System Specification, the lines of sight (LOS) of the RBV camera and the optical line scan systems will be boresighted to the vehicle vertical axis without independent (i.e., self-contained) line of sight stabilization. Therefore, displacement from the nadir will be dependent on vehicle attitude during flight, and image system pointing accuracies will be directly affected by the attitude control subsystem.

The general form of satellite stabilization and control systems is shown in Plate 1. The basic attitude control is derived by a summation of the stabilization and control system attitude reference and rate gyro signals at the input of an attitude deadband. The deadband provides limit cycle amplitudes compatible with the required vertical accuracy. An error signal in excess of the set deadband is applied to a limiter which prevents the development of drive signals in excess of the specified vehicular angular rates. The combination of attitude deadband, attitude command, and limiter can be considered one form of instrumentation for an Attitude Control Signal Generator Subsystem which supplies command signals to the Vehicle Attitude Control Subsystem.

The direction logic provides reactor selection and control commands for vehicle attitude correction. Control of the vehicle for orbital and velocity changes is normally accomplished by means of a guidance system where the guidance attitude error is combined with outputs from the stabilization and control system rate gyros, and this signal is used to position the output thrust of the main engine.

PLATE 1

GENERAL ATTITUDE STABILIZATION & CONTROL SYSTEM



Reference: PLATE 2.

SPACE SYSTEM CONFIGURATIONS

Plate 2 outlines space system configurations for the present ERTS-A concept and for an expanded version incorporating a star field camera. The ERTS-A system employs an attitude sensor (presumed to be the horizon sensor type) which is implicitly specified to provide an accuracy of ±14 minutes of arc by virtue of the stated requirement for a two nautical mile (nm) positional accuracy from an orbital altitude of 500 nm. This output is used by the Control Signal Generator and Vehicle Attitude Control System to provide vehicle roll and pitch alignment of ±0.7° with maximum angular rates of 0.04°/second. These attitude accuracies apply directly to each LOS of the camera systems. Therefore, the information received at the ground station is:

- Picture data: 200' resolution
- Attitude data: $\widehat{14'}$
- Time of event: < 10 milliseconds

A better method of attitude determination is required if ground locations are to be established to within the desired 200 foot accuracy. At a 500 nm altitude, the corresponding angular deviation is approximately 20 arc seconds.

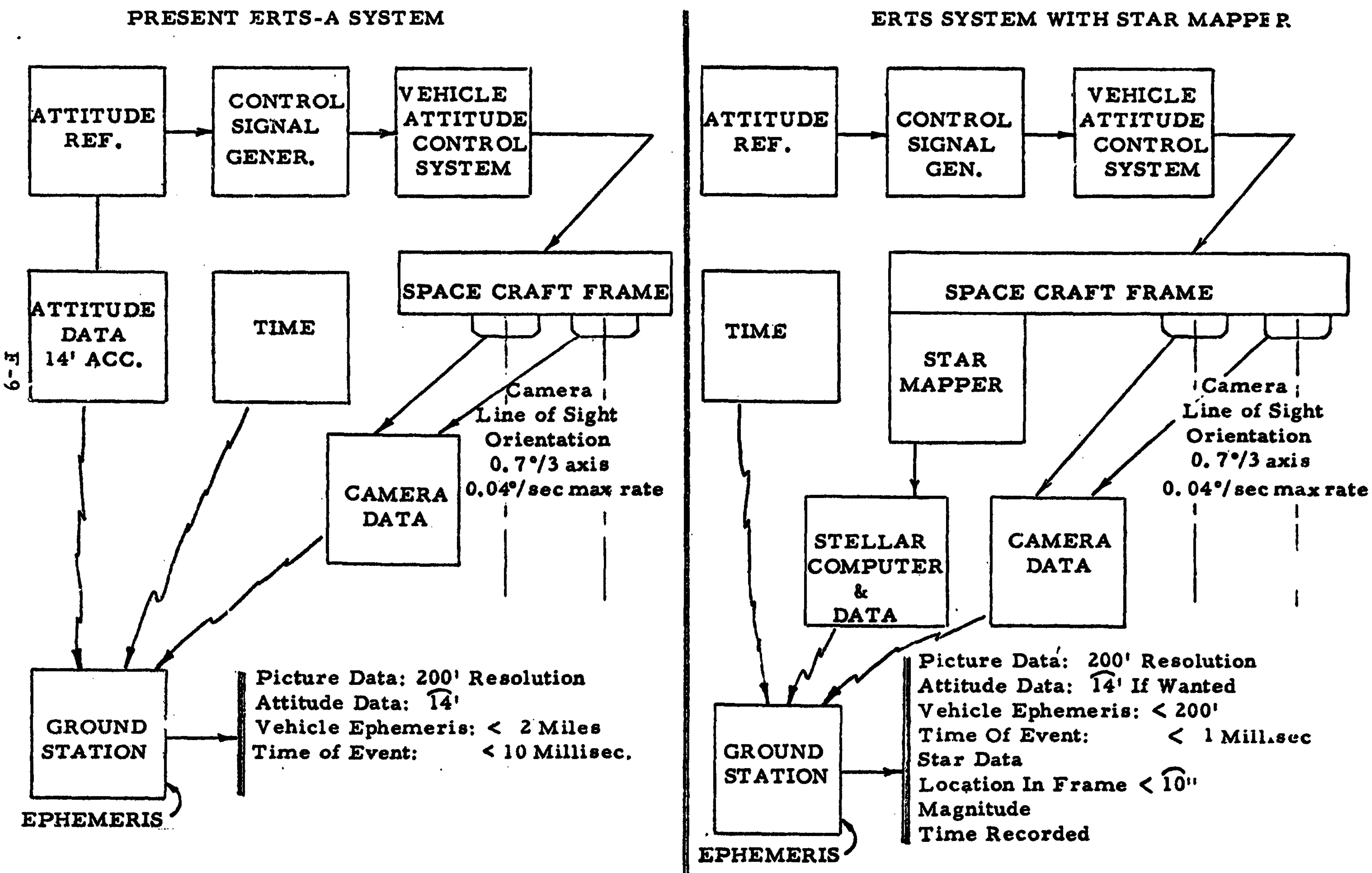
It is assumed that present vehicle performance and control techniques preclude any ability to control the vehicle to this accuracy, so the solution must lie in a method for measuring actual attitude. One approach is to add a star field camera to the spaceborne system and use its output data in the attitude calculations. The system configuration would be as shown in the right half of Plate 2. It is assumed that the vehicle attitude control system would be identical to that of the presently specified ERTS-A system.

Star mapper data would include magnitude and location of stars in the image plane, as well as time. After transmission to the ground, the star data would be compared with prestored stellar ephemeris information, thereby allowing a calculation of vehicle orientation relative to the celestial sphere. This data would be combined with orbit ephemeris data of compatible accuracy (< 200') to compute the vehicle attitude relative to a vertical axis.

The time reading would indicate the midpoint of the simultaneous RBV and star camera exposure, and would be measured to an accuracy of about one millisecond to be consistent with overall system performance.

PLATE 2

SPACE SYSTEM CONFIGURATIONS



Reference: PLATE 3.
RBV DATA HANDLING

Data transmission from the satellite is received and stored, followed by separation of RBV video data from other telemetered information and timing signals. To eliminate unnecessary and time consuming processing, the next step in an efficient flow is to display the raw RBV data to segregate unusable or otherwise uninteresting frames from usable information. Edited imagery is then corrected for RBV sweep distortions and centering and scaling misalignments caused by nonlinearity and drift in the analog deflection circuits. At this point, corrected imagery may be analyzed directly via electronic display or after conversion to hard copy.

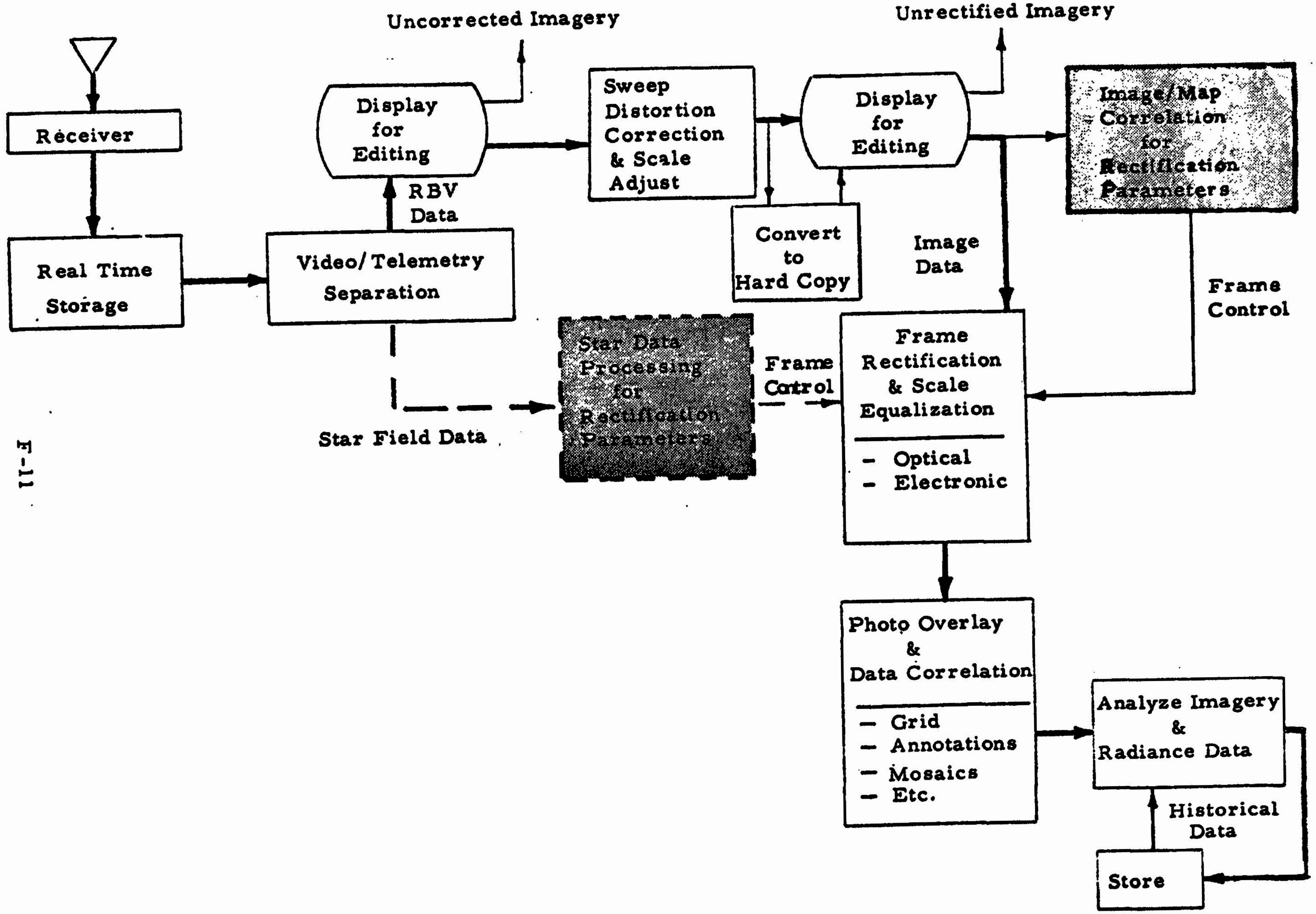
Following further editing, selected frames could be processed by a standard photogrammetric image/map correlation technique (solid line gray box) to determine the rectification parameters, (see Plate 4). Frame rectification and scale equalization could be performed either with an optomechanical instrument of special design, or by data element manipulation within a computer.

In either case, rectified hard copy would be produced which could be overlaid with a reference grid, annotated with auxiliary data, combined with other imagery to form large area mosaics, etc. The resultant product would then be suitable for detailed analysis and comparison with historical imagery of the area. Finally, selected imagery would be stored for future reference.

If star field data is available, rectification parameters can be extracted automatically (dashed line gray box), and the man could be eliminated from the flow except for editing functions (see Plate 5).

PLATE 3

RBV DATA HANDLING



Reference: PLATE 4.

RBV IMAGE/MAP CORRELATION FOR RECTIFICATION PARAMETERS

After TV distortion correction, the set of three RBV images will be used to form a composite panchromatic and/or color image. The combination of inputs yields a resolution improvement of approximately $\sqrt{N}$, where N is the number of images used. It also discloses spectral variations that are not apparent from examination of the original frames.

The imagery must be converted to hard copy via quality controlled photoprocessing, in a specially constructed and operated laboratory. The output photographs, in strip form, are rapidly compared with a reference map strip by a photogrammetrist (Pg). His tasks are to locate and mark a suitable number of points on the photograph which correspond to predetermined reference points on the map. He also identifies these points to the system so that reference coordinates can be extracted from a data list on a prestored tape at a later step in the processing.

The marked photographs are passed to a second Pg for precise measurement of the apparent coordinates. This can be accomplished by either of two techniques:

(1) The Pg uses a viewing reticle linked to a two-axis device and manually measures all point coordinates, or

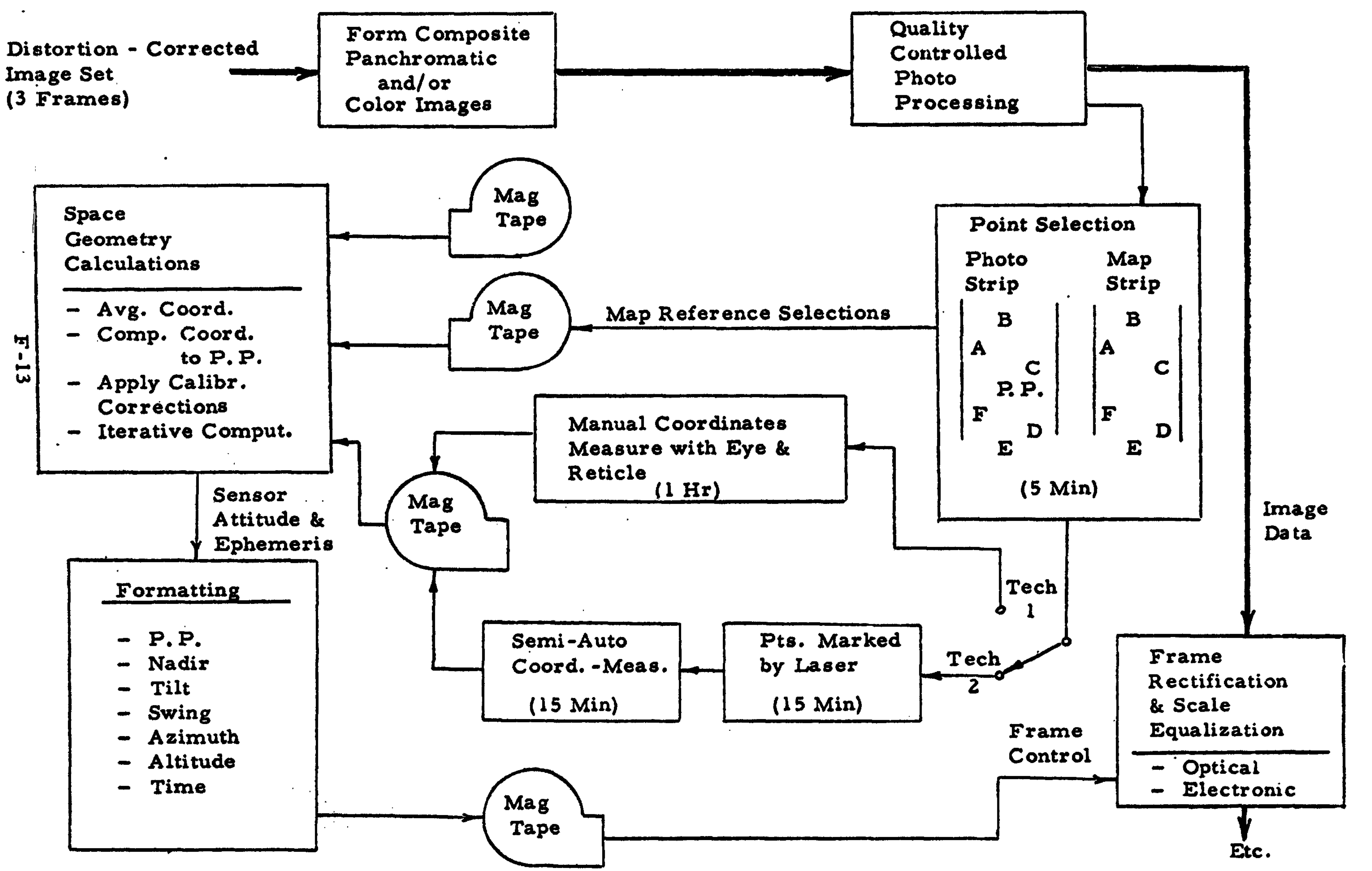
(2) The Pg could use a laser spotting device and burn the film emulsion at the points of interest; the photograph is then scanned by a semi-automatic coordinate measuring instrument.

It will be shown that technique (1) is more suited to a low volume data flow and technique (2) to a higher volume production. Once the point coordinates are established, the computer can calculate sensor attitude and location for the corresponding frame set of data. After suitable formatting, the output can be used to control image rectification.

Times required to complete key steps in the correlation process have been estimated, and are indicated on the plate. These estimates will be used later in analyzing cost factors.

PLATE 4

RBV IMAGE/MAP CORRELATION FOR RECTIFICATION PARAMETERS



Reference: PLATE 5.
STAR DATA PROCESSING FOR
RECTIFICATION PARAMETERS (RBV)

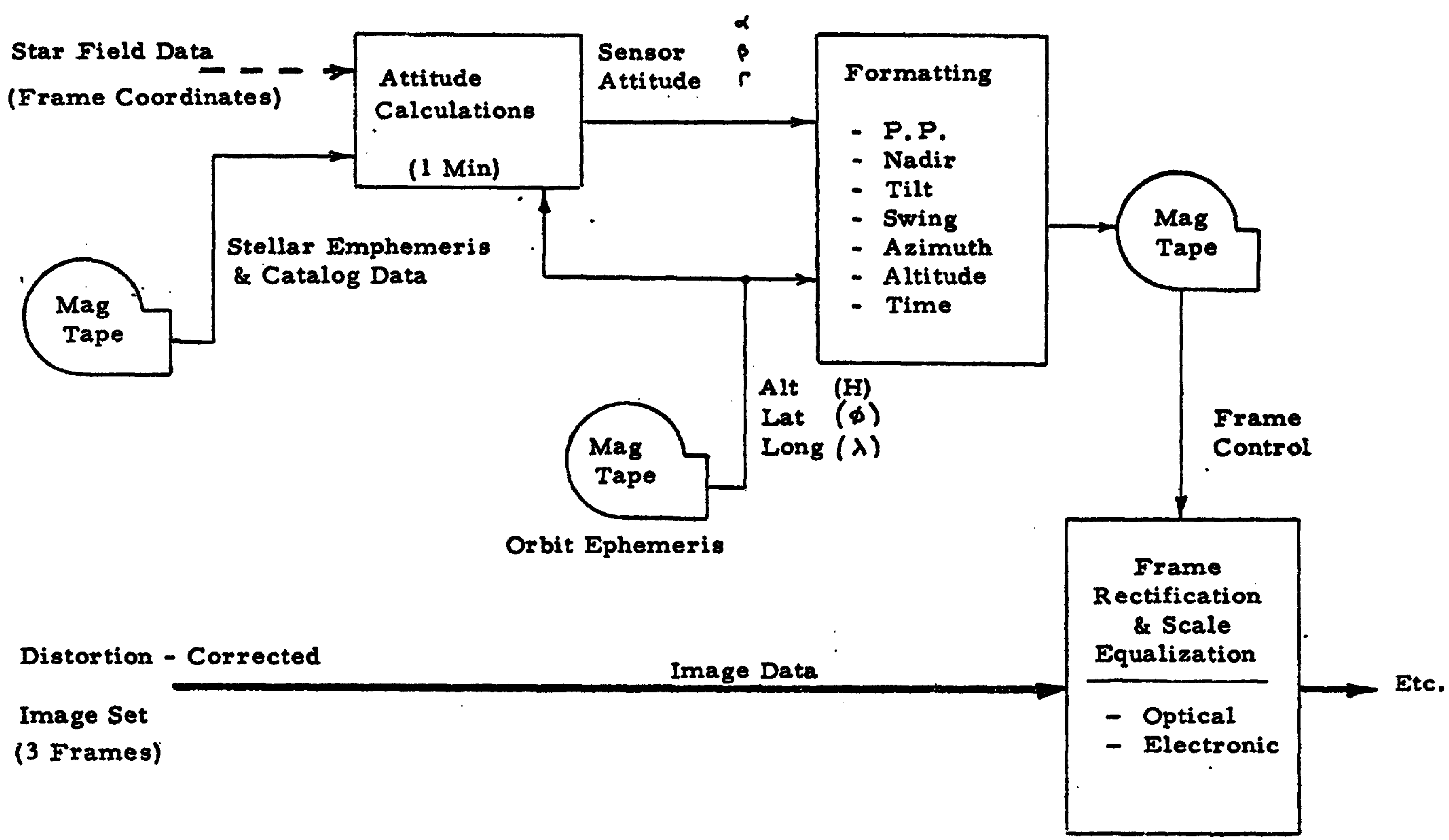
If star field data is available, rectification control parameters can be derived by automatic processing. Star coordinates on a particular frame can be matched against their reference coordinates to calculate sensor space attitude, then combined with orbit ephemeris data to form a complete set of control values.

Note that this method requires highly accurate orbit ephemeris data (200 feet or better) because it is an independent input, whereas the semi-automatic photogrammetric method involves a geometric construction that deduces location.

Formatted output data would be identical to that derived semi-automatically and, as before, would be used to control the actual rectification process.

PLATE 5

STAR DATA PROCESSING FOR RECTIFICATION PARAMETERS (RBV)



Reference: PLATE 6.

LINE SCANNER DISTORTIONS

Plate 6 presents calculations for describing distortions which are anticipated for the optical line scan system due to attitude and altitude deviations. A "frame" of line scan recording is considered to be 100 nm of ground coverage in the flight direction. The values used for the computation are "convenience numbers" taken from the ERTS-A specification. For example, since it is given that the resolution is to be better than 200', the figure of 200' was used. Therefore, although the analysis shows that there are 3000 lines for one "frame" of line scan data, it is possible that there will be more than this number of lines when the system is actually configured.

The analysis shows that line-to-line distortions are minor in nature and that it is only the accumulation of displacements caused by change of angular attitude during the period of the frame time where distortions become significant.

To summarize the chart, line-to-line distortion in roll and pitch due to the specified angular rates of the vehicle cause 1.2 arc seconds error from one line to another, or 18' ground resolution expansion or compression of the image for pitch, and 18' displacements of the image in roll per line. During one frame time, the picture could be expanded (or compressed) 54,000' for pitch rotations and shifted the same amount for roll rotations. In roll, distortion is introduced by the change in ground coverage per line, as caused by the rotation of the look angle, so that the ground coverage per line is increased 11 parts in 10,000 for roll vertical errors on the order of 0.5°.

In yaw, the line scan can be rotated up to 0.7 degree. Calculation shows that for a 0.6° yaw rotation, the ground resolution at the edge of the frame can be displaced from its nominal position ± 3000', which means that there can be a relative displacement on the order of 6000' at the edge of a frame.

Changes in altitude produce proportional changes in ground coverage such that:

Δ ground coverage = (% change in altitude x nominal ground coverage).

Therefore, for a 10% change from 500 nm altitude, ground coverage changes 10% x 100 nm = 10 nm.

PLATE 6
LINE SCANNER DISTORTIONS

ASSUMPTIONS			REFERENCE				
• Equiv. "Frame"	=	100 NM	• Scan Lines/Frame	=	100 NM x 6000/200 = 3000		
• "Frame" Time	=	25 SEC	• Line Exposure	=	25 SEC ÷ 3000	=	.008 SEC
• Resolution	=	200 FT	• Deviation/Line	=	$\widehat{150}$ "/SEC x .008	=	$\widehat{1.2}$"
• Angular Error	=	0.7°	• Deviation/Frame	=	.04 °/SEC x 25	=	1°
• Angular Rates	=	.04 °/SEC					
	=	$\widehat{150}$"/SEC					

Δ ALTITUDE

% Swath Width Change = % Altitude Change

for $\Delta H = \pm 50$ NM, $\Delta W = \frac{\pm 50}{500} \times 100$ NM $= \pm 10$ NM

PITCH	ROLL	YAW
Change in ground distance: • $H\Theta p = 15\ \Theta p$ $= 15 \times \widehat{1.2}" =$ 18 ft/line • 3000 x 18' = 54,000 ft. /frame	• Ground distance offset same as Pitch • Swath width changes by $\Theta_1 \ \Theta_R + \Theta_R^2$ For $\Theta_1 = 0.1$ (5-6°) $\Theta_R = 0.01$ (0.5 - 0.6°) Distortion is 11 parts/10,000	End of Swath displaced by $\pm \frac{w}{2} \tan \ \Theta y$ $\approx \pm 50 \text{ NM} \times \frac{0.6°}{60}$ $= \pm 3000$ ft.

Reference: PLATE 7.
LINE SCAN DATA HANDLING

Line scan rectification is more difficult than frame rectification because many successive corrections, rather than one, are necessary over the corresponding ground track areas. The particular calculations made, and the rectification device used, may be quite different for line scan than for RBV image processing. However, the data handling operations and methods are very similar, and processing with and without star field information is also possible.

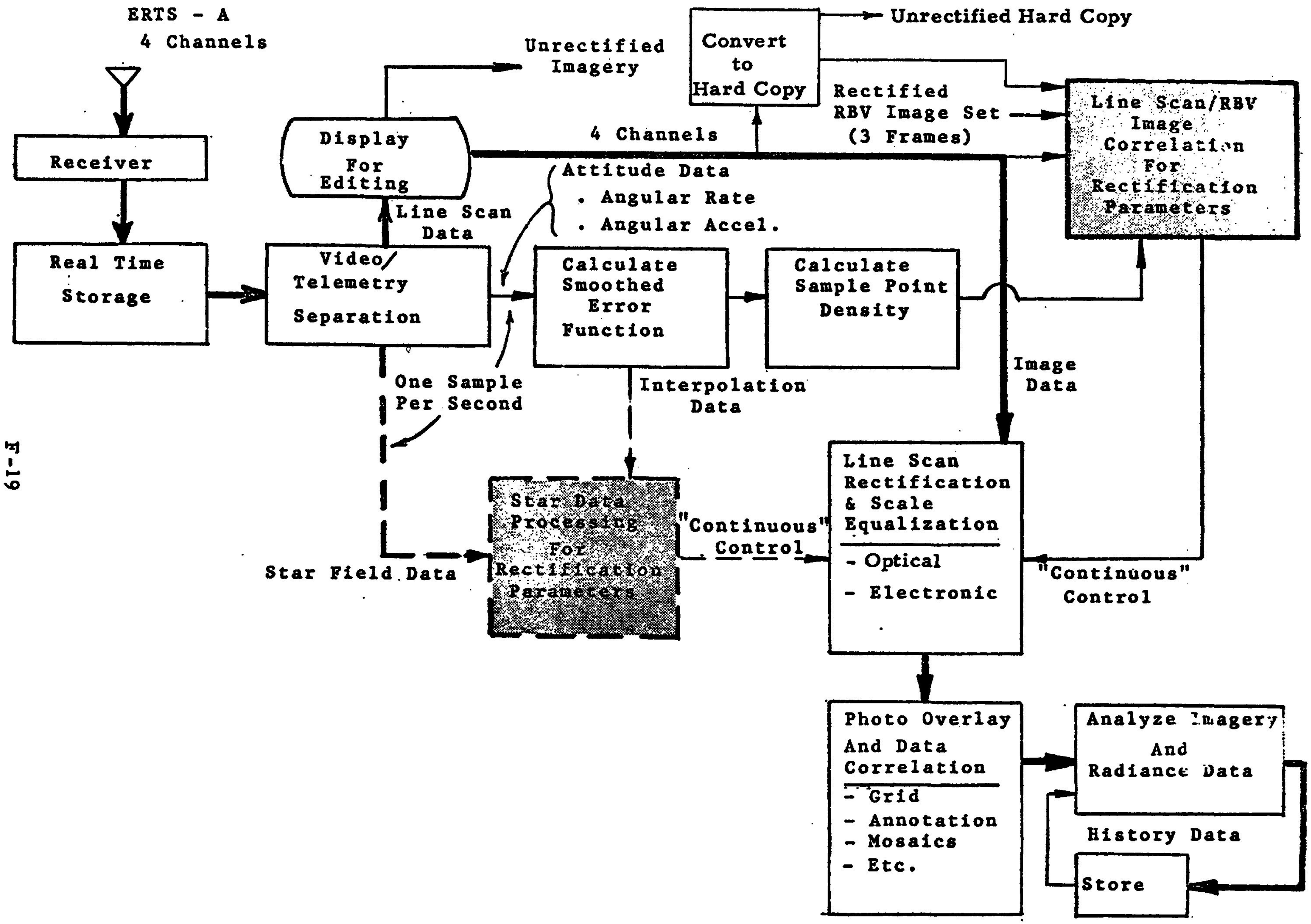
With no star field information, hard copy line scan images could be compared with the rectified RBV photographs from corresponding spectral bands (solid line gray box). The latter then serve as reference "maps" against which line scan image distances can be compared (see Plate 8). Because of the continuous variation in scanner attitude, image distance comparisons are valid only within error-limited bounds, i.e. the greater the attitude rate and acceleration, the smaller the usable inter-point distance. Under the conditions indicated in the ERTS-A specification, attitude information should be sampled at a rate on the order of once per second, including acceleration data. With this information, an adequately smoothed error function can be generated and used to calculate sample point densities along the track. This information will indicate to the photogrammetrist the number of points to be marked per unit distance in all regions of the film strip.

Line scan rectification could be performed by computer data processing or via an optomechanical device which uses a point light source and "continuous" tilt control.

If star field information is available (also at a rate of one sample per second) the procedure of determining control parameters (dashed line gray box) can be entirely automated (see Plate 9).

Post-rectification data flow would be similar to RBV image handling.

PLATE 7
LINE SCAN DATA HANDLING



Reference: PLATE 8.
LINE SCAN/RBV IMAGE CORRELATION FOR RECTIFICATION PARAMETERS

Although it would be a tedious and slow process, line scan rectification control parameters could be developed by using appropriate sets of image point coordinate measurements. Four-channel input data would first be converted to hard copy strips and processed through a quality controlled laboratory facility. It is possible that 5 strips per set would be produced, corresponding to one each of the 4 spectral bands (green, yellow, red, near IR) plus composite monochrome and/or color.

A partial set, containing spectral images from the same bands as simultaneous RBV exposures, could be run side by side with rectified RBV photographs. Using a display readout of the number of sample points per unit distance necessary in each region, a photogrammetrist would locate and mark one of the line scan strips and the corresponding RBV photo. It is convenient, but not necessary, that all markings be on the same strips. Furthermore, it is assumed that all line scan channels are identically distorted and the RBV images identically corrected.

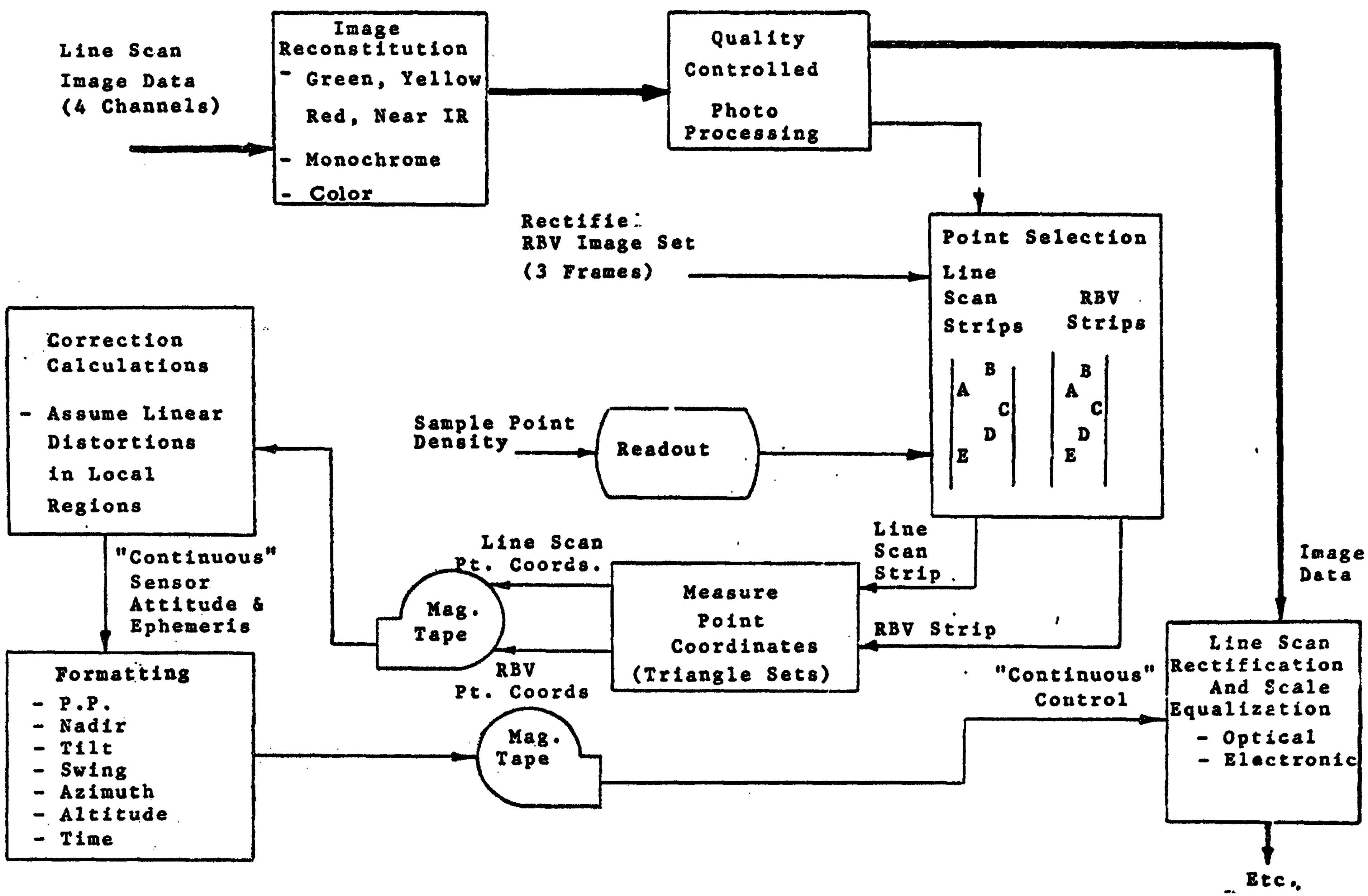
As in semi-automatic RBV processing, it would be necessary to precisely mark all points. Since there is no prior knowledge of reference point coordinates, all image points, both rectified RBV and optical line scan, would be measured. Typically, both sets of coordinate data would be "tagged" with some identifying code and loaded onto magnetic tape for eventual transfer to the computer.

If enough points are used, correction calculations can be based on an assumption that line scan image distances are linearly distorted in the measurement areas.

Output data from the computer would be formatted and loaded onto tape for off-line rectification control. The control information is "continuous" in that parameter values are updated at very short image/time intervals.

PLATE 8

LINE SCAN/RBV IMAGE CORRELATION FOR RECTIFICATION PARAMETERS



Reference: PLATE 9.

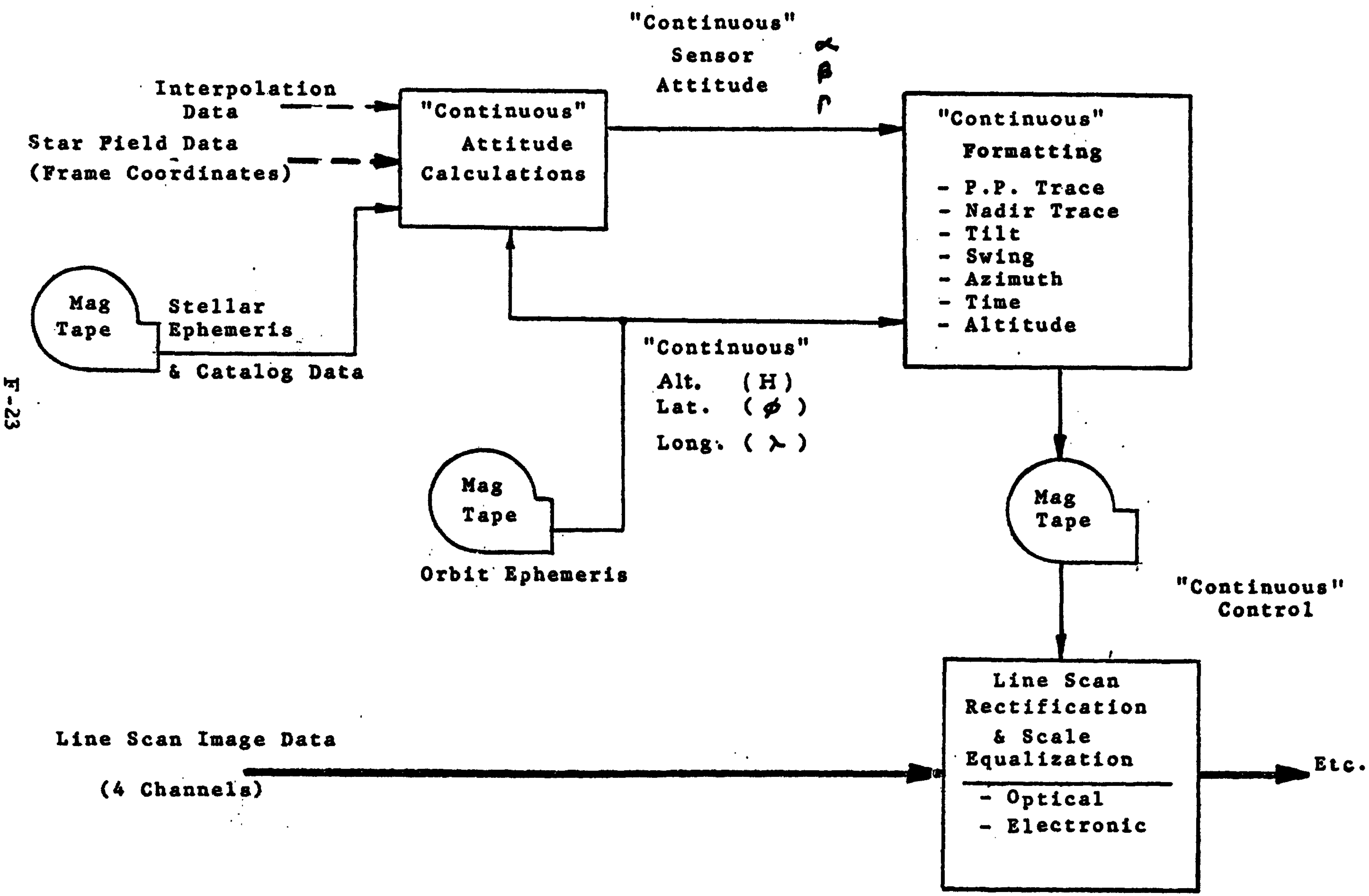
STAR DATA PROCESSING FOR RECTIFICATION PARAMETERS (LINE SCAN)

As with RBV processing, the availability of star field information would permit image corrections to be derived automatically. The first step is calculation of sensor attitude. With one second updates of star frame coordinates plus interpolation control inputs from the smoothed error calculation (see Plate 7), a "continuous" attitude determination could be made.

Remaining steps include: combining the angle values with time-coincident ephemeris data into a suitable format for rectification control, and loading the organized information onto tape.

PLATE 9

STAR DATA PROCESSING FOR RECTIFICATION PARAMETERS (Line Scan)



Reference: PLATE 16.

Δ COST FACTORS

A differential cost analysis has been performed to examine the cost impact of adding a star field camera to the satellite payload with automatic ground processing, versus the RBV alone with partial manual processing. All processing steps common to the two systems are considered to cancel one another, so differential operating costs arise only in the means used to develop the control parameters necessary for image rectification. Identical accuracy (3 - 6 arc seconds) is an assumed requirement for both methods; therefore, the salient trade-off factors are:

A. RBV ALONE

- Man-hours of photogrammetrist time required.
- Cost of special equipments and their handling capacities.
- Desired flow rate (frames/day) through the system.

B. RBV & STAR FIELD CAMERA

- Design and development (D&D) costs of the camera system.
- Data rate capability of the system (s) available from the D&D program.

It was assumed that a single D&D cost would suffice, for trade-off purposes, over the entire range of flow rates considered.

To sharpen the comparison, it is necessary first to consider the relative costs of the two semi-automatic techniques indicated on Plate 3.

PLATE 10
Δ COST FACTORS

A. RBV ALONE (ERTS-A)

- PHOTOGRAMMETRIST TIME
- SPECIAL EQUIPMENT COST & CAPACITY
- DESIRED FLOW RATE

B. RBV & STAR FIELD CAMERA

- D & D OF STAR FIELD CAMERA SYSTEM
- DATA RATE CAPABILITY

Reference: PLATE 11.

TECHNIQUE 1

PHOTOGRAMMETRIST MAKES COORDINATE ENTRIES

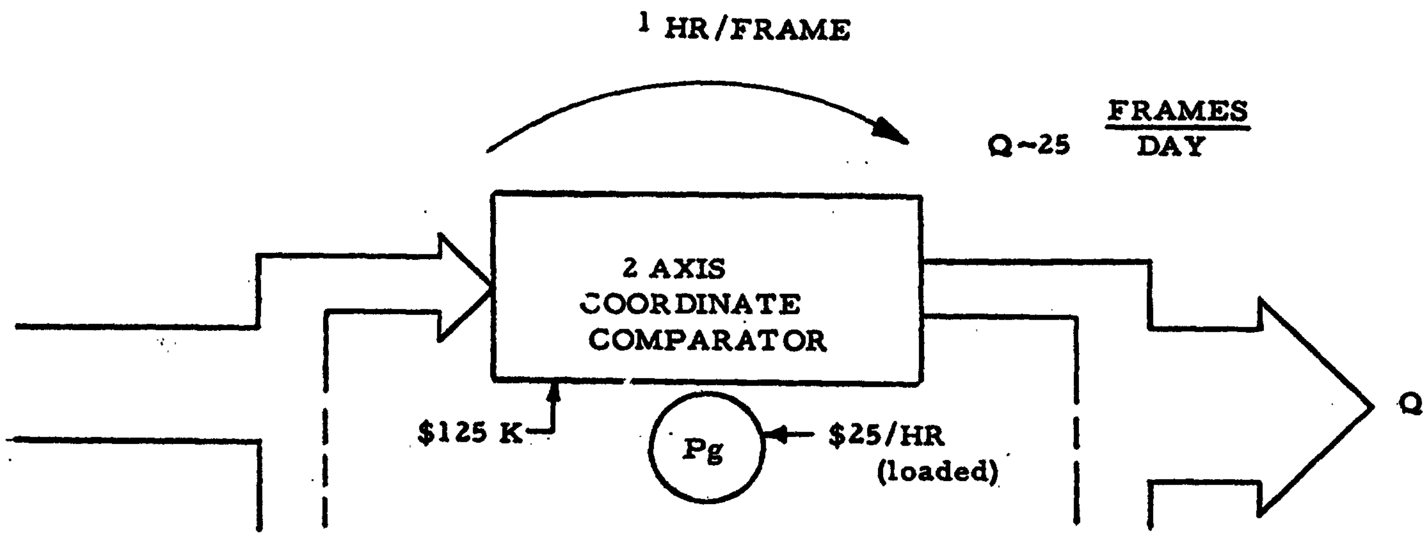
Assuming a trained photogrammetrist (Pg) can select usable reference points and accurately measure their image coordinates at a rate of about one frame per hour , the element flow capability (Qi) is approximately 25 frames/day. To accomplish this flow rate, 24 hours of Pg time plus one mensuration device, such as a two-axis coordinate comparator, are required. The equipment is available at a cost of approximately $125K; a figure of $25 per hour for Pg time, loaded to absorb miscellaneous overhead and equipment maintenance costs, also appears reasonable.

Under the above assumptions, a desired Q of 100 (i.e., flow = 100 frames/day) requires 4 x 24 = 96 man-hours of Pg service per day plus 4 sets of equipment operating full time in parallel. In any practical system, equipments will fail; therefore, either spare units are necessary to maintain flow while repairs are being made, or spare parts are required for component replacements. For this initial effort the distinction is academic, and estimates have been made on the basis of spare units only.

Total equipment costs (bottom line) are a measure of differential setup charges for this data handling technique and vary widely with Q. Differential labor charges vary directly with Q and represent recurring daily costs for this one step of the overall processing task.

PLATE 11
TECHNIQUE 1

PHOTOGRAMMETRIST MAKES COORDINATE ENTRIES



	Q= 100 N	Q= 100 COST	Q= 1000 N	Q= 1000 COST	Q= 10,000 N	Q= 10,000 COST
MAN-HRS/DAY	96	$2.4 K/DAY	960	$24 K/DAY	9600	$240 K/DAY
EQUIP.	4	500 K	40	5.00 M	400	50.0 M
SPARES	1	125 K	2	0.25 M	6	1.5 M
TOTAL EQUIP.		$625 K		$5.25 M		$51.5 M

Reference: PLATE 12.

TECHNIQUE 2

SEMI-AUTOMATIC COORDINATE ENTIRES

The technique outlined on Plate 12 would be a three-stage method, where:

1) One Pg compares distortion-corrected RBV imagery against a reference map, locates reference points, marks them on the photographs and identifies them to the system. This procedure would take about 5 minutes (it was considered part of the 1 hour task in Technique 1) and element flow capability (Qi) is approximately 288 frames/day.

2) Precisely located pin holes could be burned into the emulsion at the points of interest by a laser device under Pg control. It is estimated that this is about a 15 minute task, so Qj = 96.

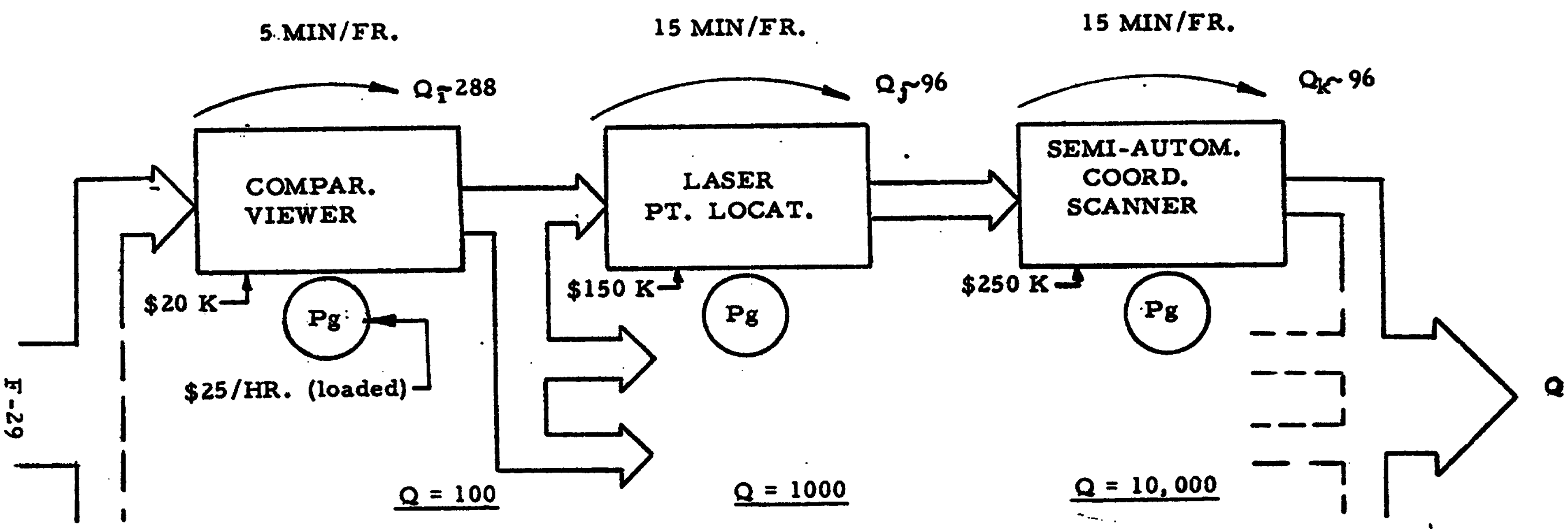
3) The film is scanned by a semi-automatic coordinate measuring device at a rate of about 15 minutes per frame, therefore, Q_k = 96.

Equipment and man-hour costs are evaluated and summarized as in Technique 1; in addition, it is assumed that a transfer of film from stage to stage is ideal, and involves no significant time loss or dollar expenditures. Note that N is the number of devices necessary to sustain Q, and S is the number of equivalent spare units. The values for N are calculated, whereas those for S represent order-of-magnitude estimates.

PLATE 12

TECHNIQUE 2

SEMI-AUTO COORD. ENTRIES



	Q = 100			Q = 1000			Q = 10,000		
	N	S	COST	N	S	COST	N	S	COST
MAN-HRS/DAY	56	-	$1.4 K/DAY	560	-	$14 K/DAY	5600	-	$140 K/DAY
COMPAR. VIEWER	1	1	40 K	4	1	0.1 M	35	2	0.74 M
LASER PT. LOC.	1	1	300 K	10	1	1.65 M	100	4	15.60 M
COORD. SCANNER	1	1	500 K	10	1	2.75 M	100	4	26.00 M
TOTAL EQUIP.			$840 K			$4.50 M			$42.34 M

Reference: PLATE 13.

ASSUMPTIONS

To summarize, differential cost estimates have been developed which were based on the following assumptions:

A. ERTS-A (RBV ALONE)

- The more economical processing technique, Technique 2, has been used for all Q in the range.
- Elemental costs are approximately as indicated.

B. FOR A SYSTEM USING THE RBV AND A STAR FIELD CAMERA

- D&D costs would be on the order of $5 M, for all Q.
- This estimate also includes the cost of developing additional telemetry and ground recording capabilities to transfer and store star field data.

C. MISCELLANEOUS

- Satellite payloads would be comparable, so that the same launch vehicle could be used for either system.
- Computer calculations, while different, would be comparable.
- Costs for corresponding software D&D would be comparable.

No attempt was made to estimate the differential cost in establishing satellite ephemeris data to the different accuracies required.

PLATE 13
ASSUMPTIONS

A. RBV ALONE

- USE TECHNIQUE 2
- APPROX. COSTS (DIRECT LABOR & EQUIPMENT) AS INDICATED

B. RBV & STAR FIELD CAMERA

- D & D COSTS ~ \$ 5 M FOR ALL Ω
- ADD'L. TELEMETRY INCL. IN ABOVE

C. MISC.

- SAME VEHICLE
- ALL COMPUTER LOADING COMPARABLE
- ALL SOFTWARE D & D COMPARABLE

Reference: PLATE 14.

Δ COSTS IN OBTAINING RECTIFICATION PARAMETERS

The stated assumptions lead to the family of curves shown in Plate 14. The horizontal line at $5 M represents the D&D cost estimate for the star field camera system and is assumed constant for all flow rates. The sloped lines represent setup charges (ordinate intersection values) plus accumulated daily operating costs; both change with Q. It is emphasized that these values are difference costs pertaining to only a small portion of the overall program expenditures, and that the latter will rise rapidly with increasing Q. In effect, the curves would move up on an absolute dollar scale but the relative values would continue to apply.

Based on price alone, the selection of technique clearly depends on the rate of data flow.

PLATE 14

Δ COSTS IN OBTAINING RECTIFICATION PARAMETERS

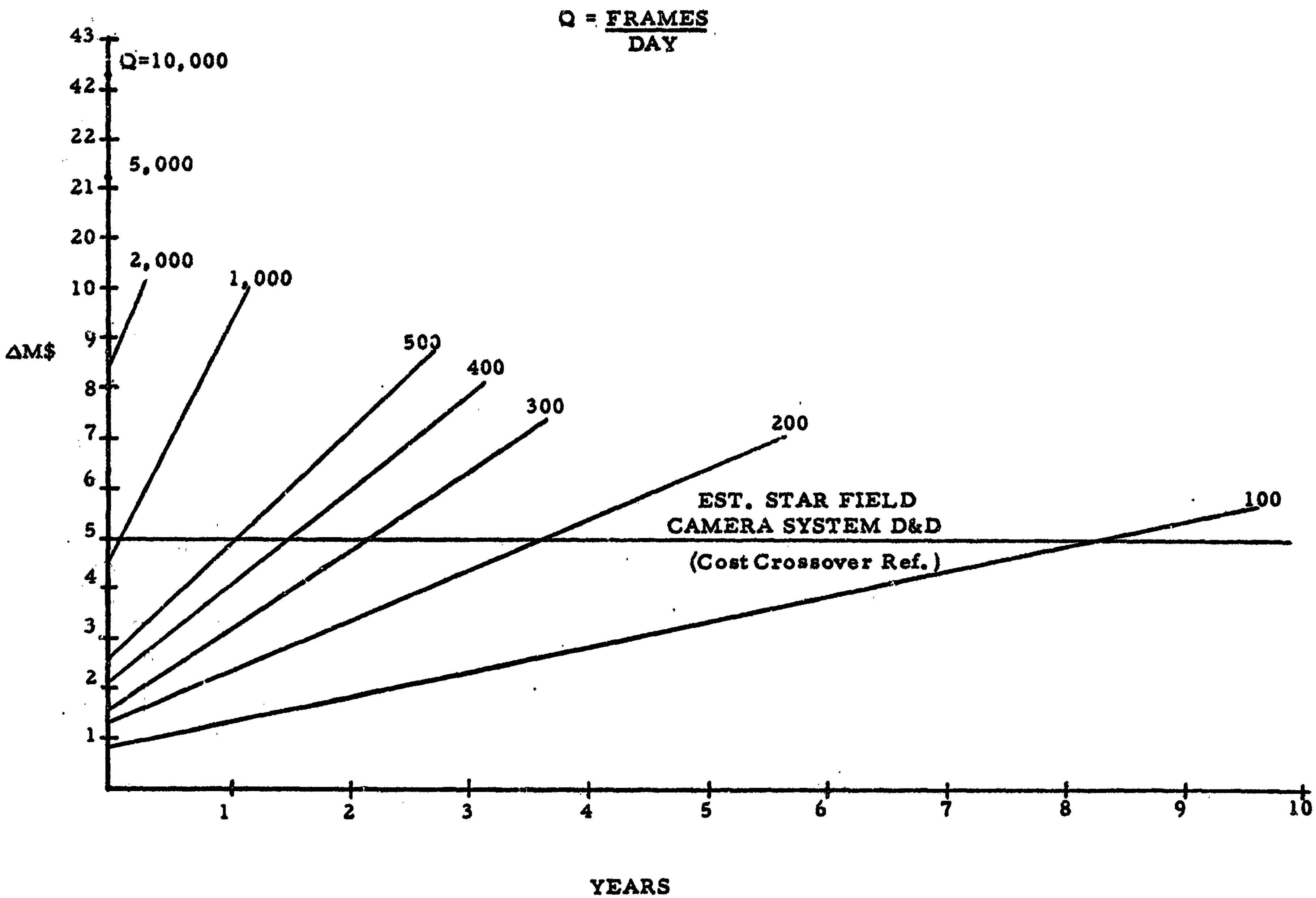


PLATE 15
PRESENTATION SUMMARY

- DATA STABILIZATION IS NECESSARY TO MEET SYSTEM RESOLUTION.
- EPHEMERIS MUST BE DETERMINED TO 200' OR BETTER FOR STAR MAPPER SYSTEM.
- PRESENT ERTS-A CONCEPT REQUIRES MAN-MACHINE PROCESSING TO EXTRACT FRAME CONTROL PARAMETERS.
- STAR MAPPER ALLOWS:
    - Entirely automatic processing
    - Image rectification in areas with no usable landmarks
- LINE SCANNER:
    - Distortions are negligible line-line but can accumulate to intolerable levels over an equivalent frame (100 NM)
    - Angular accelerations must be specified
    - Rectification is difficult and requires additional study
- CROSSOVER FOR Δ COSTS (FRAME PARAM. EXTRACTION ONLY) VARIES WIDELY WITH FLOW RATE:

Q	100	500	1,000
CROSSOVER	8.1 YEARS	1 YEAR	36 DAYS

- MAX. PRACTICAL FLOW RATE NOW UNDER STUDY

APPENDIX G

MANAGEMENT INFORMATION SYSTEMS

FOREWORD

The anticipated growth of the Earth Resources Program will create a pressing need for significant development in management systems. In addition to establishing long range goals, it is necessary to formalize planning in order to control rates of growth, acquisition of sensors and data processing hardware and software, experimental science programs, etc. It is recognized that the Earth Resources Program at MSC has numerous planning and data control programs underway; and this analysis does not attempt to delineate, circumscribe or otherwise evaluate such efforts. However, a significant area for future control is the problem of managing the processing of an increasingly large volume of information. A concept for computer-assisted management using Pert methodology is presented in this appendix. Other planning and control functions which should be considered for the future are outlined in the main body of the report.

APPENDIX G CONTENTS

APPENDIX G CONTENTS (Cont'd.)

1. COMPUTER-ASSISTED DATA MANAGEMENT SYSTEM

Since earth resources data processing is still in a developmental period, it is evident that any management information system must be highly modular in construction. It should also be recognized that some sort of management information system is always in existence whether it is on a recognized level or an unrecognized one. In general, if an existing system is permitted to evolve, it does not develop into a modular system, and it will not be responsive to changing conditions. Therefore, the intent of this section is to generate interest in the problem of management information as it relates to processing earth resources data. Rather than embark on a philosophical discussion of information systems, a definite processing information system will be formulated as a vehicle for focusing attention on the problem.

1.1 Existing System

During the course of the study, as Fairchild personnel were attempting to establish data flow rates through the Houston processing center, some difficulty was encountered in obtaining accurate information; the data presented a blend of facts gleaned from accounting records and best estimates made by system personnel. In general, it was noted that low time estimates were given by the system programmers, while relatively high estimates were given by system managers. This is certainly not an indictment of MSC, since it is a fair characterization of most processing systems which are under development. However, any attempt to forecast future processing needs based on projections from the present facts carries some uncertainty due to the quality of the data involved.

Information derived from accounting records generally suffers from these defects:

- Debugging time is not always kept distinct from program running time;
- The accounting data does not reflect interferences caused by other projects;

- The information is difficult to extract from the data;
- There is a long time lag after execution of a processing step before information is available.

Unless the quality of the processing information is improved, MSC Earth Resources Program personnel may reasonably expect unforeseen crises to arise if the data volume increases substantially.

1.2 Ideal System Characteristics

Processing of earth resources data at Houston can be expected to expand considerably in the immediate future due to an increasing sophistication on the part of the experimenter, and a sizeable increase in data volume. Processing will be further complicated by the fact that the center is not dedicated solely to processing earth resources information, and will frequently encounter interference from other NASA projects. Even if the facility processed only earth resources data, it should be noted that one mission is likely to interfere with the processing of another mission.

Therefore, the information system should have at least the following basic characteristics:

- Flexibility to adapt to rapidly changing conditions;
- Capability to detect existing and future interference with processing flows;
- Ability to provide timely and valid information.

In addition, the system should not be restricted solely to providing information, but should also exercise a degree of automatic control over processing. The secondary objectives of the system are:

- Operational scheduling;
- Immediate availability of the status of any given mission processing ;
- Accumulation of processing information;
- Ability to simulate processing flows.

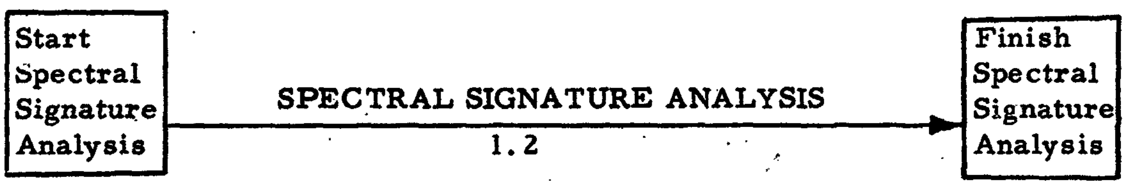
The remainder of this section is devoted to a discussion of a processing information system which is designed to the specifications outlined above.

2. BASIC SYSTEM BUILDING BLOCK

The system revolves around a collection of processing networks that are closely related to PERT networks. Since a great deal of literature is available on PERT, this section will be restricted to a very brief synopsis of PERT, to a definition of terms, and to highlighting areas where the networks differ from the usual PERT network.

2.1 PERT Synopsis

PERT networks consist of events and activities, where events are points in time and activities consume the time between events. Hence, calendar dates can be assigned to events, while time durations are assigned to activities. In the simple network shown here, the events



"start spectral signature analysis" and "finish spectral signature analysis" are connected by the activity "spectral signature analysis". In addition, the duration of the activity "spectral signature analysis" is listed as 1.2 weeks. A more complex PERT network is shown in Figure G-1.

2.2 Network Modifications

The absolute impracticality of drawing up a unique PERT network for the processing of each mission is readily apparent and it is clear that some refinements must be made before a system relying on networks is feasible. The first fact to be observed is that the pro ing

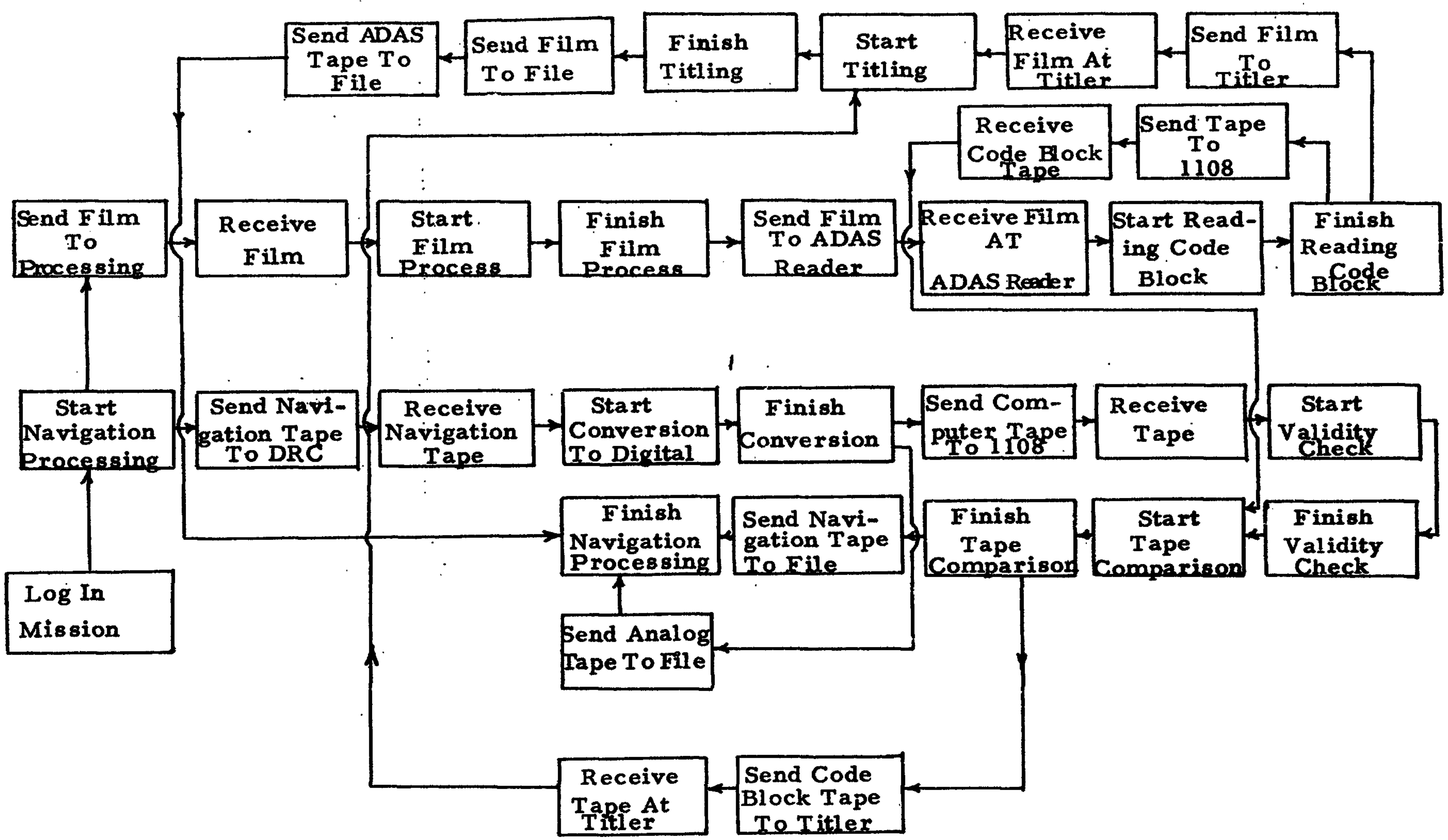


FIGURE G-1 SAMPLE NETWORK: AUXILIARY DATA PROCESSING consists of sub-networks that are unvarying in character. For example, auxiliary data processing can be expected to be of the same form for each mission; similarly, the processing of each sensor will be characterized by its unique sub-network. Therefore, it seems reasonable that mission processing may be defined by linking sub-networks of a constant form into a mission network. The flexibility of the system is derived from the concept of the sub-network in that, as the processing for any sensor becomes more sophisticated, only the sub-network associated with that sensor will require modification.

The second difficulty with the standard PERT network lies in the treatment of activity duration. For a processing network the activity duration cannot be expressed as a constant but must be expressed in a functional form depending on such variables as mission duration, data volume, etc. This duration function need not be linear; for example, classification of crops by spectral analysis may well be of the form:

$$d = A + BN_1 N_2^2 t$$

where

d = duration of the activity

A = setup time

B = a constant

N_1 = number of classes

N_2 = number of spectral channels used for the classification

t = mission duration.

The very act of establishing duration functions and comparing actual durations with predicted durations should force the secondary objective of data accumulation for the projection of future processing needs.

The third difficulty with the usual PERT network lies in the area of internal or external interferences with data processing flow. A PERT network does not identify the equipment or the place where an activity is performed, and this precludes the possibility of identifying points of interference. These work stations should be relatively easy to identify and would be such locations as the UNIVAC 1108, CDC 3800, ADAS Reader, Film Annotator, ZEISS Rectifier, etc. If the activities from all the missions in process were sorted by work station, a queue forming at any work station would be readily apparent.

Taking these factors into consideration, the original PERT building block has been modified to become the building block of the processing information system as shown below.

Start Spectral Signature Analysis	SPECTRAL SIGNATURE ANALYSIS → $d = A + BN_1 N_2^2 t$ UNIVAC 1108	Finish Spectral Signature Analysis

2.3 Definition of Terms

By way of summary, and in preparation for Section 3, terms used in the explanation of the processing system are:

EVENT - an actual accomplishment, objective or a milestone.

ACTIVITY - the process that links two events.

LIVE ACTIVITY - an activity is live if its initial event has occurred and its terminal event has not occurred.

DEAD ACTIVITY - an activity is dead if both its initial and terminal events have occurred.

DORMANT ACTIVITY - an activity is dormant if its initial event has not yet occurred.

WORK STATION - the location of equipment required to perform an activity.

CRITICAL PATH - the path through the network which consumes the longest time.

EARLIEST EXPECTED DATE (T_E) - the earliest date an event can occur. T_E is calculated from the present date and the activity durations by tracing forward through the network to the event in question.

LATEST ALLOWABLE DATE (T_L) - the latest date an event can occur without delaying the scheduled project completion date.

T_L is calculated by tracing the network backward from the completion event.

SLACK - The amount of time an activity duration can slip without affecting the scheduled project completion date.

$$\text{Slack} = T_L - T_E$$

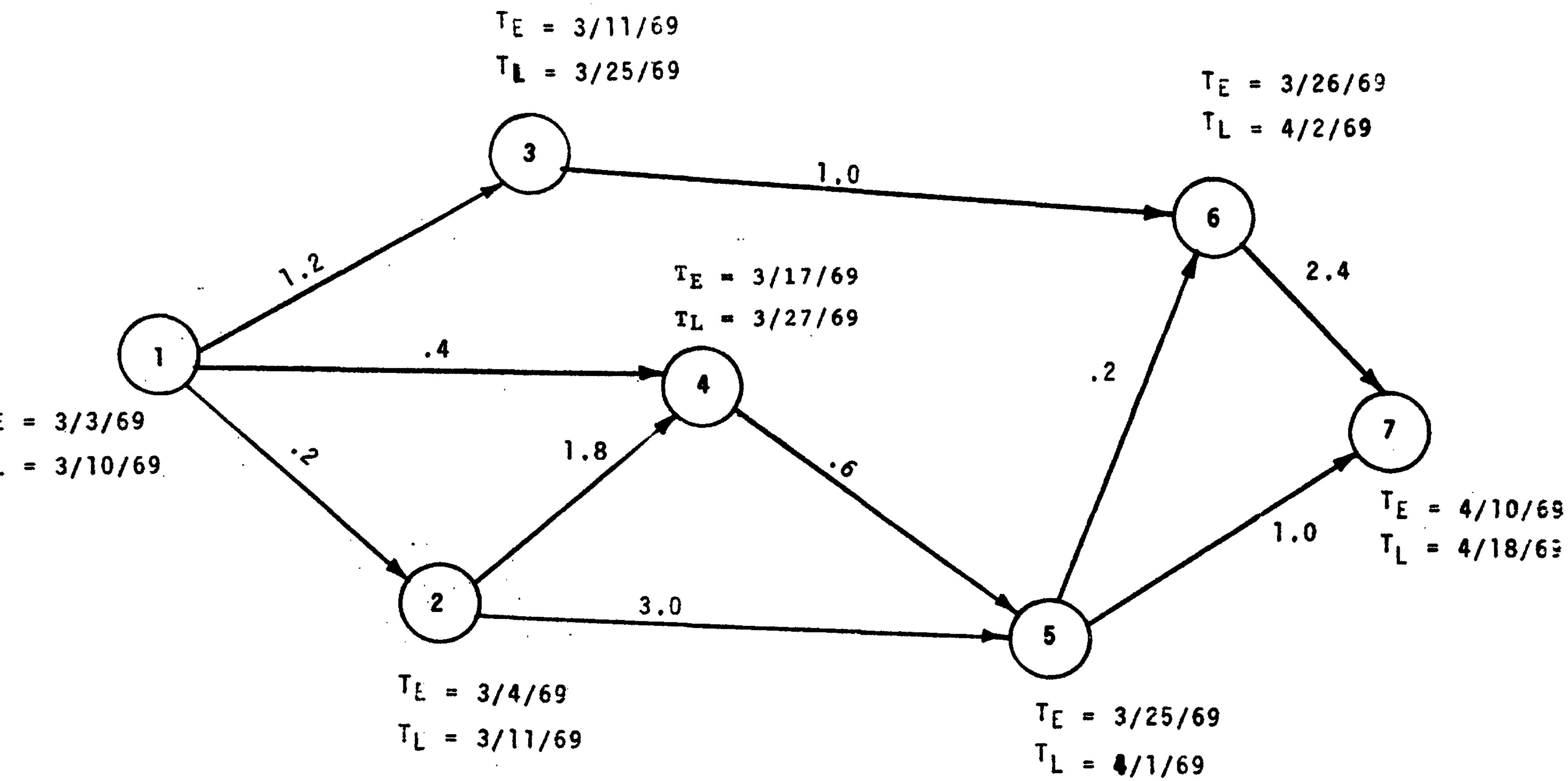
A network illustrating the concepts of T_E and T_L is shown in Figure G-2.

3. SCHEDULING PROGRAM

The foundation of the processing control system is the scheduling program which has the dual responsibilities of identifying bottlenecks in the data flow and of assigning processing priorities to activities queued up at work stations.

Bottlenecks can be expected to arise from either of two causes: (1) an attempt to shorten the mission processing time, and (2) interferences caused by processing several missions simultaneously.

In essence, the first type of bottleneck is static in character and could result in data from two parallel processing legs converging on, and saturating, a third path because phasing was lost in the shortening of one leg. Analysis of the sub-networks established for the processing flows would emphasize where such improvements are required to remove bottlenecks and this can be accomplished without implementing the scheduling program. However, a processing scheduling program is



PRESENT DATE = 3/3/69
SCHEDULED COMPLETION DATE = 4/18/69

ACTIVITY DURATIONS ARE IN TENTHS OF A FIVE DAY WORKWEEK.

FIGURE G-2 ILLUSTRATION OF T_E, T_L

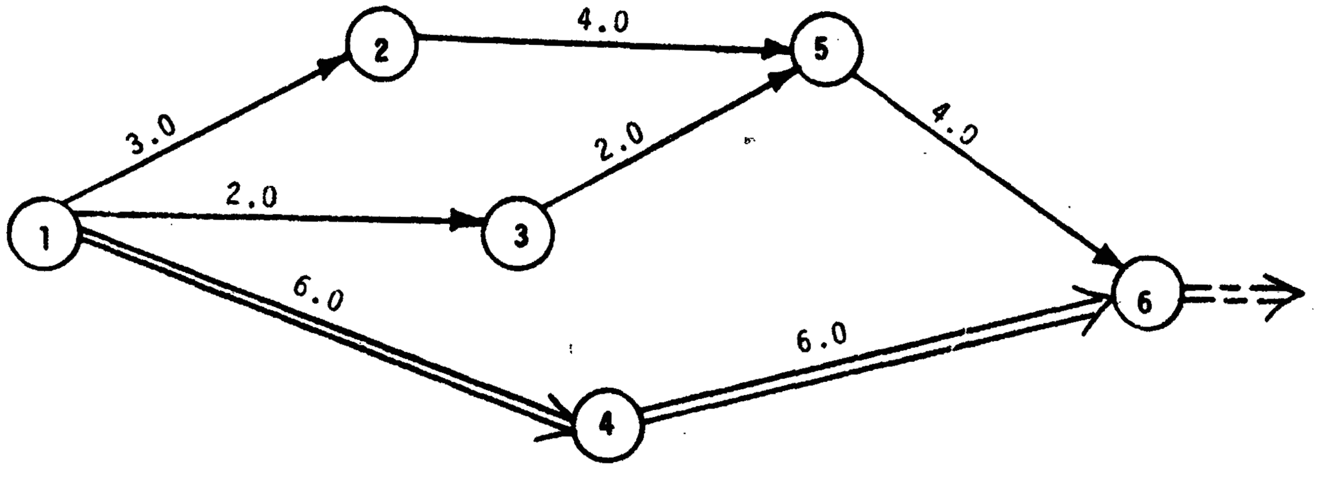
a prerequisite to study bottlenecks of the second type, dynamic interactions created by attempting to p. ess several missions concurrently. Implementation of the scheduling program can also be expected to improve the data quality used in studying the static bottlenecks.

The dynamic bottlenecks can be further broken down into two categories: (1) interference caused a delay in the completion of mission processing, and (2.) interference caused an event to be delayed but did not delay completion of the mission processing. In the remainder of this section, these delays will be labeled respectively as crucial and non-crucial delays. The purpose of cataloguing non-crucial delays is to forewarn management of dormant bottlenecks that may blossom out as crucial interferences are eliminated. Figure G-3 illustrates a crucial delay while Figure G-4 illustrates a non-crucial delay.

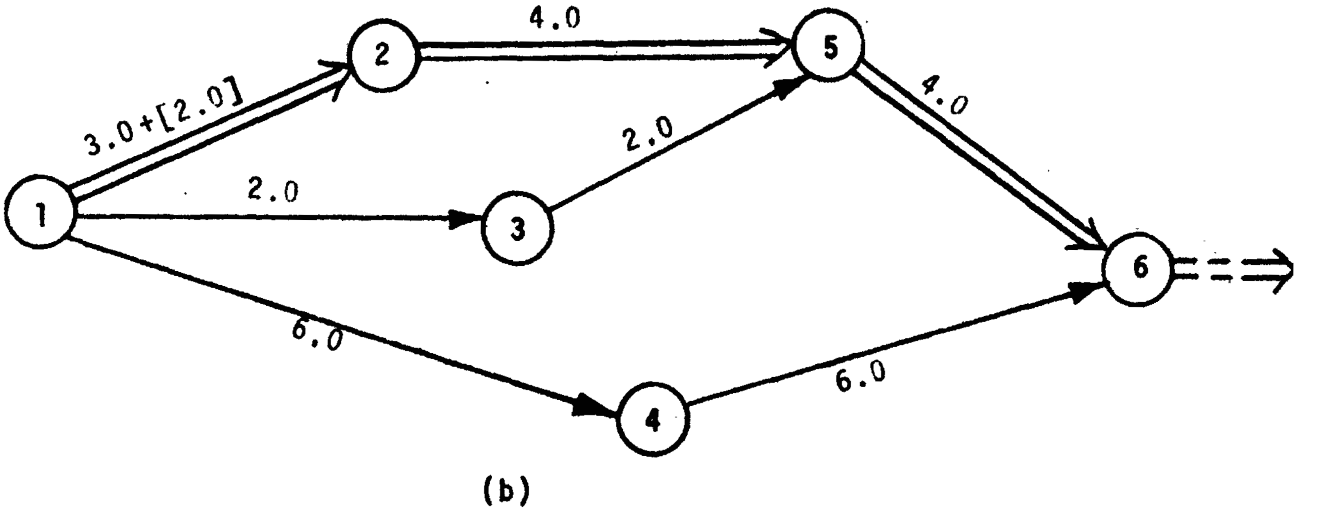
The basis of the scheduling program lies in sorting out live activities by work stations. If two activities are present at a work station, a conflict has developed and a priority must be established. At first glance, it might appear that the activity whose terminal event is furthest off-schedule (largest negative slack) should be assigned priority, but this impression is not correct. Consider, for example, the case where

FIGURE G-3

CRUCIAL DELAYS



(a)



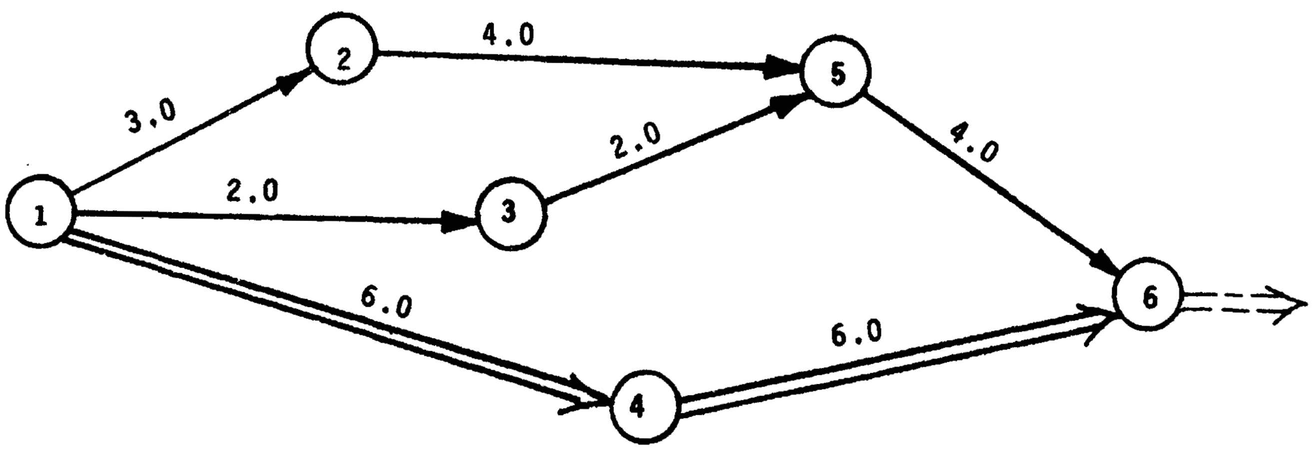
(b)

Two day interference delay in activity (1⟶2) causes a critical path change and a project delay of one day.

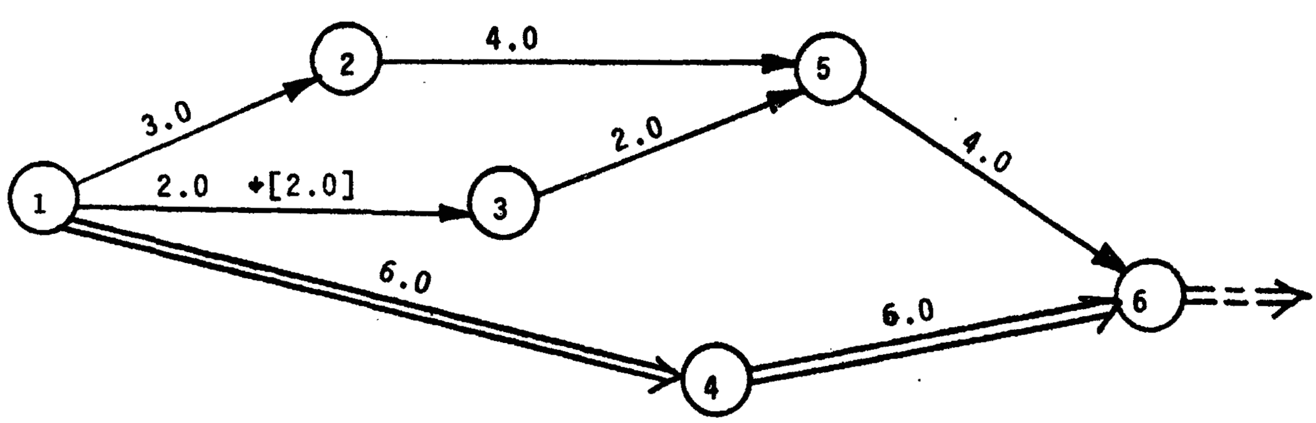
═══ Represents the critical path.

FIGURE G-4

NON-CRUCIAL DELAY



(a)



(b)

A two day interference delay in activity (1-3) delays event 3 by two days, but does not result in a project delay.

completion of mission processing is off-schedule by two weeks but the event is off-schedule by only a week. It is clear that the event can be delayed a week without postponing mission completion and that the activity should not necessarily be assigned priority. It is even possible that the activity in question is not the controlling factor in establishing the earliest expected date, T_E , of the event and that T_E may be caused by an entirely different path to the event.

Consequently, establishment of priority is a non-trivial problem and this subject will be developed in further detail in the following paragraphs.

3.1 Establishing Priorities

Let two activities i and j of respective durations t_i and t_j be queued up at a work station. If the present date is T and the earliest expected date of the terminal events are T_E (i) and T_E (j), then activity j can be processed before activity i when

$T + t_i + t_j \leq T_E$ (i). In this case, assigning priority to j will not even delay an event, let alone the mission processing.

Now suppose that $T + t_i + t_j > T_E$ (i) and

$T + t_i + t_j > T_E$ (j). In this case one event must be delayed by the scheduling program and the decision must be made as to which one. Apparently, the judgment must be based on delay of mission processing.

The function

$$f(i,j) = T_L(i) - (T + t_i + t_j) - (T_{LF}(i) - T_{EF}(i))$$

where $T_L(i)$ = latest allowable date of activity i terminal event

T = present date

t_i = duration of activity i

t_j = duration of activity j

$T_{LF}(i)$ = scheduled completion date of mission containing activity i

$T_{EF}(i)$ = earliest expected completion date of mission containing activity i

expresses the time delay in the mission of which activity i is a part when activity j receives priority. The priority assignment is based on the rule : activity j receives priority over activity i if $f(i,j) \leq f(j,i)$. This rule has the advantage of being transitive, which means that if activity j has priority over activity k, and if activity i has priority over activity j, then activity i has priority over activity k. The transitive property asserts that only one pass through the queue is required to assign the order of priorities.

For a concrete example, consider the following case:

activity i - mission 1 mission completion slack = +3 days

activity duration = 1 day

terminal event slack = 4 days.

activity j - mission 2 mission completion slack = 0 days

activity duration = 6 days

terminal event slack = 0 days.

If activity i receives priority, mission 1 processing will have a completion slack of +3 days while mission 2 processing will have a completion slack of -1 day (one day late). If activity j receives priority, mission 1 processing will have a slack of -2 days (two days late), while mission 2 will have a completion slack of 0 days. The rule will give activity i priority.

It should be emphasized that the scheduling program assigns a priority ranking to a queue formed at a work station and has nothing to do with establishing a general mission priority. Mission priorities are assigned by the managers of the processing system and they do this by determining the various completion dates for the missions. These completion dates are then used by the scheduling program to rank the queues.

Once the program has assigned priorities , it must sort the bottlenecks into crucial and non-crucial categories. If activity j has been assigned priority and $f(i,j) < 0$, then a crucial bottleneck has been identified because the completion of the mission which contains activity i has been delayed. On the other hand, if $f(i,j) > 0$ and $T + ti+tj > T_E(i)$, the delay is non-crucial and has only caused the terminal event of activity i to be postponed. Finally, if $T+ti+tj \leq T_E(i)$, no damage has been done and no note of the delay is made.

3.2 The Processing Control System

The scheduling program outlined above so far accounts only for the internal conflicts within earth resources processing and does not include external conflicts generated by other MSC projects. Since the Earth Resources program management at MSC does not control the scheduling of these projects, it is impossible for the program to include external conflicts. It is suggested that each activity be broken down into the four sub-activities shown below.

RECEIVE DATA → START PROCESS → FINISH PROCESS → SEND DATA

Any time lag between the receipt of the data and the initiation of processing that is not due to an internal conflict is assumed to be caused by an external conflict. In addition, time lags between the sending and the receiving of data are expected to provide insights into the problem of transporting data within the facility.

A rough flow chart of the processing control system of which the scheduling program is the heart is given in Figures G-5 and G-6. A tabulation of information that can, hopefully, be extracted from each file is given on page G-25.

FIGURE G-5

OPERATIONAL SYSTEM PROCESSING CONTROL

(PART I)

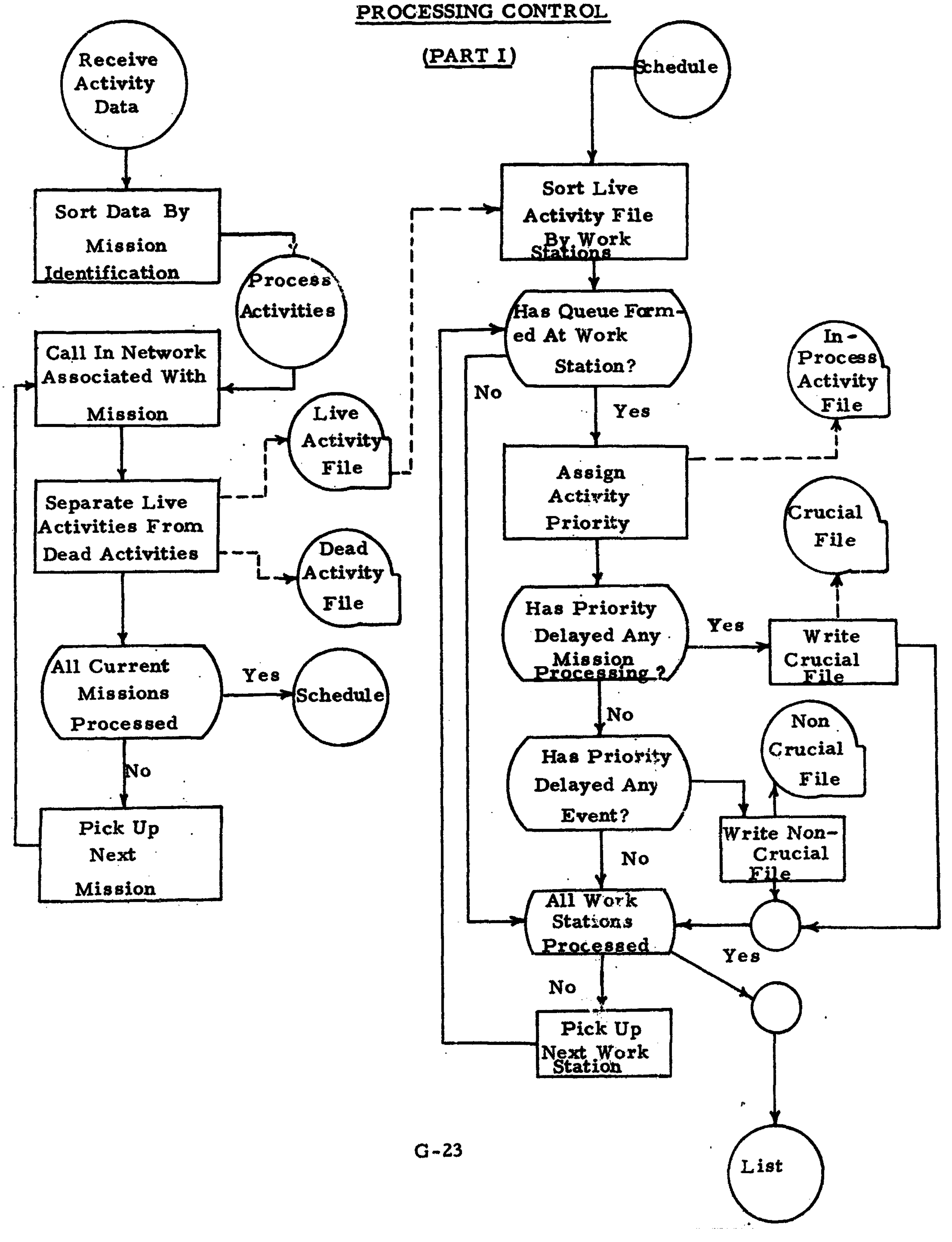
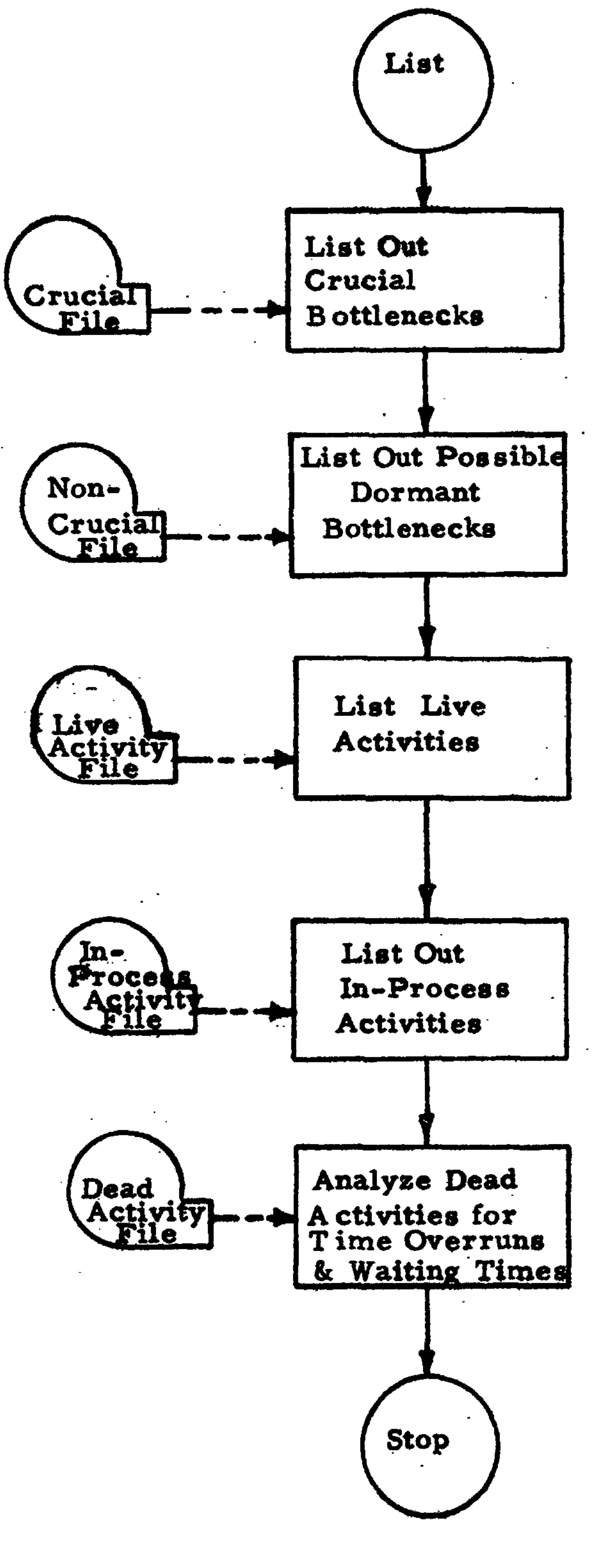


FIGURE G-6

OPERATIONAL SYSTEM PROCESSING CONTROL

(Part 2)



DEAD ACTIVITY FILE

- Accuracy, the activity duration functions.
- External conflicts.
- Data transportation problems.

LIVE ACTIVITY FILE

- Processing status of each mission.

IN-PROCESS FILE

- Activities in the execution stage.

CRUCIAL FILE

- Internal conflicts that have postponed completion of mission processing.

NON-CRUCIAL FILE

- Internal conflicts that may create delays in mission processing after crucial bottlenecks have been removed.

4. SIMULATION PROGRAM

Once the processing control system is operational, it is a relatively easy step to the simulation of the processing system. The LIST, SCHEDULE, and PROCESS ACTIVITIES programs can be borrowed from the control system and the only additional programming required is a program to simulate the progress of time. Under the assumption that each activity is completed in the time specified by its duration function, the expectation is that a simulation along the lines of Figure G-7 could be developed. The principle advantage of writing the simulation program lies in the ability to improve projections of an expanded facility.

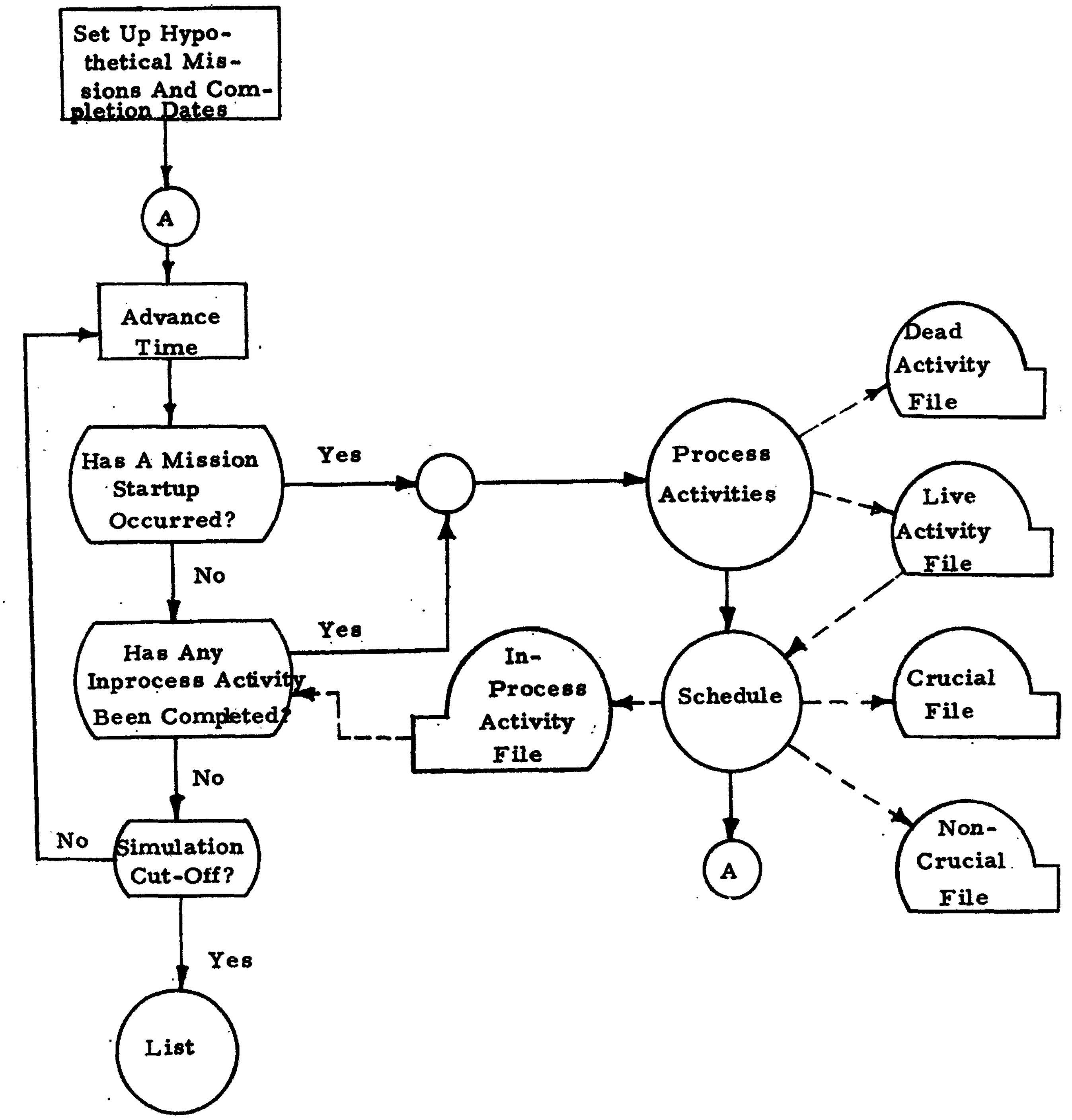
5. INFORMATION TIMELINESS AND VALIDITY

A management information system succeeds or fails depending on the timeliness and accuracy of the information provided. The cornerstone of any computerized information system is the ability to shift the paperwork burden from the operational personnel to the computer. For the processing control system, this shift could be accomplished by a variety of methods where the trade-off lies between time and money.

The most primitive method is to have the computer prepunch a card for each activity after the mission has been defined and the linkage between sub-networks has been performed. These cards would circulate with the data and the operator would send the appropriate card, after making a time entry, back to the computer room upon completion of each sub-activity. These cards could be collected once a week and run through the processing control system previously outlined. This procedure

FIGURE G-7

PROCESSING SIMULATION



would, of course, destroy the operational control generated by the scheduling program, but would still provide accurate information relative to bottlenecks and network analysis.

If the processing control system demonstrates its feasibility by the primitive method, several stages of upgrading could be undertaken. The first step might be to provide a remote time clock at each work station to remove the necessity of sending cards to the computer room. The card would be inserted into the clock and the data transmitted over lines to the punch station in the computer room. The cards could now be collected on a daily basis and some measure of operational control is restored to the scheduling program. The next difficulty that must be overcome is the transmission of priority assignments back to the work station operator.

This might be accomplished by an on-line display linked to the computer. The ultimate means of transferring information back and forth to the computer might be installation of remote terminals at the work station. The operator could log in each step of the processing and could interrogate the computer for information required to process the next step. The system managers could also use these terminals to get a status report of the mission in process.

6. SUMMARY

The purpose of this appendix has been to direct attention to both the necessity and difficulty of establishing a management information system to control the processing of earth resources data. The great danger inherent in avoiding this problem is that the sensors may provide more data than the facility is able to process or the investigator is able to analyze.

APPENDIX H

BIBLIOGRAPHY

FOREWORD

This appendix presents a selective bibliography of reference material germane to Earth Resource Program activities and problems. It is by no means all-inclusive, but does cover a broad range of specific topics of interest. For obvious reasons, very few of the listed publications date back beyond about 1962. This is not a significant deletion, because earlier works are easily found in the literature.

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