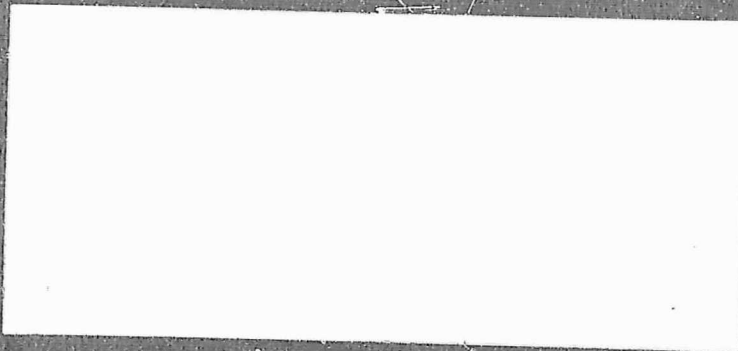


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FINAL REPORT
AUTOMATIC
DATA CORRELATION SYSTEM STUDY

Contract No.: NAS9-9842
Control No.: 2460

24 July 1970

VOLUME I : PROGRAM SUMMARY

Submitted To:

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MANNED SPACECRAFT CENTER
Houston, Texas

ABSTRACT

This document presents the results of a one year study (July 1, 1969 to June 30, 1970) to design an Automatic Data Correlation System for the Earth Resources Program at NASA Manned Spacecraft Center, Houston, Texas.

The study was devoted to the problems of correlating remotely sensed earth-surface data with other similar data and of correlating these data with the earth's surface.

A functional ground data processing system is described which is designed to handle all identified classes of remote sensor data on a large-volume, high-throughput basis. With that as a reference, a specific Pilot System configuration is recommended which, where possible, uses equipments already available at MSC.

ACKNOWLEDGEMENT

This report was prepared under NASA Contract NAS9-0842 for NASA Manned Spacecraft Center, Houston, Texas by Fairchild Space and Defense Systems (FSDS), a division of Fairchild Camera and Instrument Corporation.

Fairchild Space and Defense Systems is indebted to Mr. S. Whitley and Dr. J. Dornbach of the Earth Resources Program, MSC, and Mr. F. Doyle of USGS, for their guidance and assistance during this program.

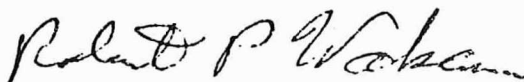
Appreciation must also be expressed to the following FSDS personnel who contributed to the study program and to the preparation of this report:

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Ira Schwartz
Ivan Steiner

Finally, a special note of gratitude is due Mr. D. McFadyan of Lockwood, Kessler and Bartlett, for the orthophotoscope education he so cooperatively provided.



Eugene Hart
Program Director



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Approved:



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Manager
Advanced Systems &
Analysis Section

PREFACE

Considerable thought was given to the form and substance of this report with two primary objectives in mind: first, to allow the reader who is interested only in the results of the Study to obtain this information with a minimum of effort and, second, to organize the material in a fashion such that the reader desiring greater detail could readily follow the paths of logic taken by the Study team.

Accordingly, the report is divided into two volumes. Volume I contains a statement of the problem; the general nature of the proposed solution; a description of the recommended Pilot System; and a compilation of the major problem areas. This should provide the information required by the first reader without belaboring him with nonessential detail.

The organization of Volume II is based on the fundamental concept rather than on specific equipments or techniques. This treatment follows logically from the general approach wherein the system was, first, functionally designed in terms of the specified inputs and the desired outputs.

Then, as the study progressed from function design to implementation, the function concept was retained. As a concrete example, the raw data may exist on a number of film types & sizes and in various analog and digital tape formats. However, all operations performed on raw data prior to geometric or correlation processing are included in the function "Preprocessing".

Clearly, this is not ideal, since it results in a given equipment appearing in several parts of the report. Nevertheless, it is the consensus of the authors that this is less disturbing than the alternative, wherein the various functions (levels of processing) are repeated in different parts of the report. Hence, the serious reader is urged to adopt this functional picture (illustrated in Figure i) and to mentally relate any subsequent part of the report to it.

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INTRODUCTION

FOREWORD

Fairchild Camera and Instrument Corporation is pleased to submit this Final Report to NASA MSC in fulfillment of NAS 9-9842, Contract for Automatic Data Correlation Study.

During the course of the Study, Fairchild personnel interviewed members of the Departments of Interior and Agriculture, members of potential user organizations outside the Federal Government and a large number of equipment manufacturers. In addition, progress and problems were reviewed and discussed regularly with personnel of the contracting agency, the NASA Manned Spacecraft Center, NASA, Houston. The material derived and reported herein is based largely on information obtained from these sources.

The Earth Resources Program is based on the proposition that wide-scale remote sensing can provide knowledge of pertinent conditions over large parts (possibly all) of the Earth's surface. It has been proposed that this information be collected by aircraft and earth-orbiting satellites containing sensors of radiant energy. Implicit in this suggestion is the fact that all objects on the earth's surface, including the surface itself, continually radiate electromagnetic energy due to their inherent temperatures, or act as reflectors of solar energy or of energies from artificial sources. Also implicit in the proposal is the concept that spectrally-selective emission and reflection will uniquely identify all objects of interest, and that these spectral signatures can be used as the primary source of identification.

A major facet of the problem of reducing this concept to practice is that of data correlation. This is the primary subject of this report.

Chronologically, the study progressed through the following four phases:

- An analysis of the possible inputs and the desired outputs, for an Automatic Data Correlation System;
- The conceptual design of a functional system capable of producing the desired outputs from the available inputs;

- An examination of the feasibility of a hardware implementation of the functional system;
- The specification of a "Pilot" system with recommendations for its directed evolution.

Section 1 poses the problem in general terms and summarizes the study findings.

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1.1 STATEMENT OF THE PROBLEM

In its most general sense, the data correlation problem is concerned with identifying those entries, on a number of sensor records, which represent a given ground element, and with relating them to the correct element.

In practice, a wide range of conditions will exist which will, in turn, result in a number of solutions ranging from trivial to extremely complex. In order of increasing complexity, the conditions are:

- Data are taken at several wavelengths, through a single set of optics (or through perfectly boresighted, identical optics) from a platform which is perfectly stabilized (or for which the instantaneous location and attitude are perfectly known). For this condition the data are automatically correlated among themselves, and their relationship to a set of earth coordinates can be readily established.
- The first part of the first condition exists, but the six degrees of freedom of the platform are not perfectly controlled or known. For this condition the data are still self-correlated but relating them to earth coordinates requires a more sophisticated system.
- The data are taken with different sensors, but from a single platform, the coordinates of which are known or controlled. This problem is much more complex since some of the sensors may collect data over an area at one instant whereas others may sense only a line or even a point at any one instant. If the platform is gyrating, these latter sensors will produce "rubber sheet" imagery which is not easily correlated with frame type imagery.
- When the above type data are sensed from a platform, the coordinates of which are not well controlled or known, the complexity of correlation increases still further. Under these conditions the problem of data-ground correlation assumes formidable proportions.

- Finally, when data are collected with a variety of sensors, covering a large range of wavelengths and mounted on different gyrating platforms which are flown months or years apart, a solution to the correlation problem will probably require a revolutionary approach.

The above data-collection conditions all affect the nature of the system input and, hence, the functional design. The desired outputs will, of course, also affect the design. Depending upon the discipline and application, the required ground resolution may vary from a few feet to a thousand feet and the required spectral resolution may vary from three points in the visible range to many points extending well into the microwave region.

Probably the most significant result of this study is the certain conclusion that no single data processing sequence can possibly be optimum for all of these widely divergent conditions and requirements.

Clearly, a process capable of reducing the accurately-controlled data for use in a discipline requiring only low resolution, such as oceanography, will be totally inadequate for a time-history evaluation of crops.

Similarly, a process capable of satisfying the latter requirement will prove unduly expensive and time consuming for those tasks where the requirements are much less stringent.

In attacking a complex problem of this type, the method depends largely on whether a study approach or an empirical approach is used. A completely legitimate approach involves an experimental attack on the simplest case. The necessary hardware is acquired, the data management problem for this simple case is solved and a pilot operation is set up. From the experience thus gained, the next step is taken, and the ultimate system is thus built up in small steps. Unfortunately, this approach frequently leads to aimless development and there comes a point where it is necessary to discard everything and start all over.

When a study approach is used, it is customary to start with the most general problem rather than with the simplest facet. Once this is solved, it becomes a simple matter to introduce shortcuts and approximations where either the quality of the input or the accuracy required

of the output makes the complete solution unnecessary or unwarranted. But of even greater importance, the solution of the most general case lays a sound foundation for the directed evolution from pilot model to the ultimate system, with a much smaller risk of running up blind alleys. The study approach was the one selected by MSC. This report contains a description of the study results and an explanation of a means for attacking the most general problem. The way is now clear to fabricate a Pilot System which will successfully handle the simpler facets of the problem, but will also be completely adaptable, through directed evolution, to the most difficult cases.

In the opinion of the authors, this is the next logical step to be taken in developing the desired capabilities. The detailed rationale leading to that conclusion is presented in Volume II, Section 5, "System Philosophy".

1.2 THE NATURE OF THE SOLUTION

As indicated in the preceding section, not one, but several solutions are required. Also, as previously indicated, if a solution for the most general (and hence most difficult) case is found, solutions for the simpler cases fall out automatically by simply omitting the unnecessary steps. The authors have, therefore, addressed themselves to the complex case where the platforms were virtually uncontrolled, the spectral regions of the several images varied widely, the images might have been acquired from different vantage points at different times, and the terrain could have had considerable relief.

Under these conditions, virtually the only possible control, tying corresponding bits of data together, is the ground detail itself. If a human were trying to extract information from a set of images, he would not go through the processes of resectioning, rectification, etc. Instead he would examine the picture detail and locate the same element on each of the images. He would then extract the density-vs-wavelength characteristic of the element and, hopefully, identify it.

Recent advances in the art of video correlation have made possible the automation of the above process, at least for images within the visible spectrum. Furthermore the correlation is accomplished at a much higher rate than could be done by a man. A typical correlator will track at a rate of 10 inches per second without deviating from the correct

instantaneous position by more than a few micrometers. Hence, for multispectral imagery, one of the images would be treated as the master and read out with some type of film scanner. The remaining images should be slaved to the master by means of video correlation so that at any one instant corresponding elements would be simultaneously read out on all images. This provides the modus operandi for data-data correlation, but does not tie the data to specific ground points.

One of the applications of the video correlator is its use in the orthophotoscope. This is a device for the automatic production of orthophotographs from overlapping imagery. An orthophotograph is equivalent to a photograph taken from a point infinitely remote, so that every point on the ground assumes its correct planimetric position, irrespective of its altitude; i. e., it is a photographic map. Several companies, both domestic and foreign, are currently manufacturing orthophotoscopes and, although at present the equipment is expensive and relatively slow (of the order of two hours for a 9" x 9" orthophoto), both the cost and the time are certain to decrease in the future.

If the orthophoto of the area of interest exists, data-ground correlation becomes a relatively simple matter. Again, by linearly scanning the orthophoto and slaving any number of other images to it by video correlation, it becomes possible to read out the slaved images at equal ground intervals regardless of the distortions or their origins.

This statement includes all distortions; not only those resulting from imperfect optics, imperfect platform control, nonlinear scan in electronic detectors and "rubber sheet" effects in line scan devices, but also the perspective distortion not compensated by any other technique.

The use of video correlators with or without orthophotoscopes, makes possible a number of interesting outputs from the Earth Resources Ground Data Processing System. These include computer-compatible tapes wherein the several pieces of information relative to each specific ground element, together with the element coordinates, are grouped together; and unrectified, uncorrected imagery wherein rectangular ground coordinates are overlaid as curved coordinates correctly compensating for the distortions. Naturally, the use of video correlation will also permit the information derived to be used to generate completely corrected images, if that degree of processing is desired.

This, then, is the general solution to the Data-Data and Data-Ground correlation problem. It is shown by the primary path on the data flow charts in the report and is proposed as the technique to follow when the taking conditions, the overflowed terrain, and the end-use all justify the precision available from this approach. Whenever one or more of these conditions is not met, bypass and alternative paths will be used in such a manner as to maximize flow rate in terms of the requirement placed on the output products.

1.3 WORK STATEMENT TASKS

The contractual Work Statement lists fifteen specific tasks to be performed during the course of the study. These have been accomplished, and each task is discussed in its appropriate section of the report. To facilitate locating these discussions within the body of the report and the appendixes, the following table has been prepared.

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CORRESPONDENCE BETWEEN WORK STATEMENT TASKS
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13. Provide equations describing functional transforms	App. B
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SECTION 2

PILOT SYSTEM DESCRIPTION

FOREWORD

The pilot version of the Automatic Data Correlation System (ADCS) is intended to be, primarily, a research and development tool. It provides all the essential functional capabilities of the advanced system, but without regard to rapid throughput of large amounts of data. As a consequence, a quite inexpensive and readily available configuration can be assembled which will allow a thorough experimentation with all stages of film and magnetic tape data handling. Furthermore, all identified Earth Resources remote sensors are accommodated.

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2.1 SYSTEM EVOLUTION

The process of selecting a pilot, or prototype, system has evolved in logical fashion with basic system functions as the embryonic starting point. Following the enumeration of basic operational functions, discussed in depth in sections 7, 8 and 9, lists of the major equipments, or subsystems, and their characteristics, were established. These lists are given in Appendix C; primary emphasis in that appendix was placed on detailing ideal subsystem requirements so that the data processing flow would be optimized while maintaining operator-ease in handling the data products. Thus, no limitation on equipment capability was imposed at that stage of the study. Rather, a liberal approach was taken to insure that no equipment limitations would be included that could either slow the processing flow or hinder the attainment of functional ease and flexibility in processing all the varied sensor output data forms that now emanate from the aircraft program, or that may eventually result as new sensors are introduced. The consequence of this effort, given in Appendix C, is a listing of major equipment requirements, condensed to include only what is judged to be the primary and important subsystem characteristics. In effect, these characteristics are the nucleus of equipment specifications which permit precise and definitive specification of the major, non-computer elements of the ultimate data correlation system. The equipment survey charts were constructed after careful screening of hundreds of pertinent developed and newly developing equipments. From these subsystem survey charts the Pilot System components, shown in Figure 2-1, were chosen.

The Pilot System of Figure 2-1 is more than just a typical system that should be studied in greater detail before any major procurement of hardware is attempted. It is the "optimum" assortment of subsystems from a family of several possible pilot arrangements, because it reflects a reasonable and prudent fiscal attitude and does not assume the unlimited availability of funding.

None of the equipments chosen for the Pilot System has all the ideal characteristics, primarily because it was required that each component of the data correlation system meet the basic demands of optimum processing flow and ease of data handling. For example, almost every equipment is found lacking when evaluated for precision roll-film transport capability. Keyboard computer entry and integral code matrix reader

features are two other requirements not presently available in commercial equipments but definitely desired in the ultimate correlation system.

The following description of the Pilot System details the generalized configuration and includes the major film-handling and tape-handling sections for: Preprocessing, Parameter Processing, and Correlation Processing. Accuracy estimates are made for the Pilot System and this is followed by a discussion of computer sizing and a flow analysis for film data. Finally, the estimated cost and availability for the pilot arrangement are delineated, with each component price listed individually. Of course, if equipments apparently available at NASA-MSD cannot be utilized, the cost for assembling a Pilot System will be considerably increased.

The study analysis indicated that present facilities at MSD are capable of performing all the identified magnetic tape data processing functions. Hence, no equipment lists or descriptions are presented here. The additional computer functions required are described elsewhere in Section 2 as well as in Sections 7, 8, 9, 10 and Appendices A and B. Since it appears likely that the corresponding software will be developed by MSD personnel, it would be inappropriate for FSDS to attempt an estimate at processing rates, software development cost, or availability.

2.2 PILOT CONFIGURATION

The Pilot System configuration, consists of components that have been chosen to fulfill the primary required functions of the ultimate production-oriented Automatic Data Correlation System. The flow path shown is the main route for data movement; as the film or tape data moves from station to station, it may be helpful to visualize a frame-by-frame, or tape reel, walk-through of the data. Such a walk-through is, unavoidably, the operational means that will be used in this first hardware configuration; the ultimate system, however, will more than likely have automatic, precision film transports as an integral part of each individual equipment, thus enabling entire rolls of film to be handled with ease and rapidity.

2.2.1 Preprocessing Equipments

The subsystems that perform preprocessing are grouped into either the film handling preprocessing section or the tape data preprocessing section as indicated in Figure 1, "System Overview". Film preprocessing is done by the following equipments: sensitometer, densitometer,

copier-enlarger, film screening viewer and multispectral viewer. Tape data preprocessing is conveniently handled by the existing CDC 3200 computer-controlled facility. Figure 2-1 outlines in block diagram form the flow of data in both areas. With the exception of the multispectral viewer, all the film preprocessing equipment is presently available in one or the other of the two well-equipped Houston laboratories: the Photo Technology Lab and the Mapping Sciences Photogrammetric Lab. The Q.C. Film Development function, which occurs throughout the correlation system, represents a film development operation that also presently exists at Houston; it is discussed in detail in subsection 7.2.

2.2.1.1 Film Sensitometer

The sensitometer, the first equipment in the flow path, is utilized to make precise, controlled exposures through a standard stepped density tablet, or wedge, onto the first and last frame of each film roll. It is probably sufficient to expose only the first and last frames; however, if necessary, each frame of photography in the input roll can be so exposed. The resulting sensitometer strips are then used for primary sensitometric tests of black-and-white and color emulsion characteristics as well as for sensitometric tests to standardize the film developing that follows in the processing cycle. Suggestions have been made that the usefulness of aerial photography could be substantially increased by equipping each camera with a similar spectral sensitometric wedge to permit quantification of reflected solar energy at the instant of exposure during the actual photographic mission. This procedure is not presently followed but requires only the exposing of a gray-scale wedge through the camera lens. It would allow the establishment of absolute irradiance standards. For example, tonal values of a particular crop could be related to a position step on the gray-scale wedge so that if solar-energy inputs varied from one flight to the next they would be reflected in the gray scale. Compensating adjustments could then be made during film development and copying to provide prints with more uniform and closely related tonal values.

The sensitometer is actually a substitute for the more desirable arrangement whereby a step wedge is illuminated by a calibrated light source within the aerial camera either immediately before or after scene-imaging. Since none of the film sensors presently used in the Earth Resources aircraft program are equipped to provide in-flight sensitometric exposures, this operation is performed as the immediate first step in the film preprocessing flow.

The important sensitometer characteristics for the Pilot System include: control of exposure time and intensity; easy and rapid calibration of exposure lamps; and good exposure uniformity and repeatability.

2. 2. 1. 2 Densitometer

After sensitometric exposures are made on the mission film, and the film developed to QC standards, the step wedge pattern on the imagery is manually scanned by the densitometer. The pre-mission and post-mission wedge exposures are measured, and the density values are then used to guide the film development. In the ultimate automatic correlation system, a code matrix reader (CMR) would read the frame data block on each individual frame and automatically identify each frame to the computer along with the measured density values of the imaged step wedge. In this manner, each frame of photography would be cataloged with its sensitometric exposure information.

2. 2. 1. 3 Copier-Enlarger

After the imagery has passed through the densitometer station, the copier - enlarger is utilized to provide the numerous copies required for subsequent processing and screening. Input film size must range from 70 mm to 9-inch; the output size will probably be standardized at 9-inch, except for boresight photography. The establishment of a stock size for these processing copies will reduce the film transport mechanism complexity in the ultimate ADCS for all subsequent film handling equipments that follow in the processing route. After sufficient copies are made, the originals can be stored as archetype data with no further risk of degradation due to developing or handling.

The preceding sensitometry provides proper exposure control and simple enhancement at this stage in the film preprocessing. These input value settings for the copier are derived from film batch reference data obtained from the unexposed mission film, prior to the mission, and from the calibration data obtained from the densitometer. Variable magnification of at least 4X is needed to handle the range of input film formats. A rapid throughput rate for the ultimate system requires motor mechanization of the equipment in three important areas: for the film transport in the format proofing housing; for the film transport on the copying stage; and for lamphouse positioning and focusing.

Following this copying operation, the new copy imagery is developed in the QC film lab and then measured for density changes in the step wedge pattern. The same densitometer utilized earlier in the flow can be used for these measurements. At this point in film preprocessing the data is ready for its first screening operation.

2.2.1.4 Film Screening Viewer

The first major screening activity takes place when the mission film is examined in the film screening viewer. Copies of the original master negatives are visually examined frame by frame. Detailed processing decisions are made at this station. Either the imagery will be discarded, held in abeyance, or passed on for further processing. The options for further processing are:

- 1) the imagery is used to produce an orthophoto;
- 2) the imagery is passed directly to the image correlator; or
- 3) rectification is performed.

For multispectral imagery, a multi-channel viewer is required. Since NASA-MSC has just funded a program to develop a new multispectral viewer, this equipment, when ready, should adequately satisfy the needs of this final preprocessing function.

2.2.2 Parameter Processing

The next step in the film process flow brings imagery to the parameter processing film section. The equivalent path for tape data is completely computer-handled and is not discussed here (see Section 8 for a discussion of the required functions). The equipments comprising this section are the optomechanical rectifier, the image correlator, the orthophotoscope, and the film scanner. The arrangement of equipments represents the most probable sequence of processing operations; other orderings subsequently may be found to be more desirable. The important point is that these particular functions should be available in the processing cycle.

2.2.2.1 Optomechanical Rectifier

This equipment, also referred to as an optical image rectifier, performs a photogrammetric rectification, rather than a computer rectification wherein the imagery is scanned out element-by-element and then transformed by digital processing. This latter approach was considered for the automatic data correlation system and discarded (for normal photographic processing) because it is wasteful and time-consuming. The optical image rectifier simply provides for the projective transformation of tilted photographs into prints that are tilt free, and speed of operation is extremely desirable.

High resolution, accuracy and reliability coupled with simple operation, are prime characteristics for the equipment. Ability to handle panoramic photography as well as frame imagery is desirable in the ultimate system because the wide coverage at low altitudes should make such imagery valuable to Earth Resources scientists in the future.

2.2.2.2 Image Correlator

The image correlator provides for correlation between sensor data and the ground in some instances, and between data and data in others. Known points on one photo, a reference map for instance, must be transferred to the second photo, either by precise measurement and recording of the film coordinates or by actual physical marking of the latter imagery. Data/ground correlation involves establishment of mutual or reciprocal point relations between frame or panoramic imagery, for example, and a reference image (ideally, but not necessarily, an orthophotomap-see Section 9); data/data correlation pertains to multispectral photography, primarily. Difficulty in correlation increases as the attempt is made to relate coordinates in line-scan or SLAR imagery to those on the orthophotomaps.

If it is found to be useful to correlate boresight photography with frame photography (see Section 8), the image correlator would require a precision film transport that handles formats and film sizes of at least 70 mm and 9-inch. In the ultimate system, CMR devices are needed in both channels to control frame flow and assure later identification of the imagery and associated measurements. The equipment

should maintain high reliability of the correlation function, and, when a loss of correlation does occur, a manual backup routine should be available to cope with the situation. In effect, what is required is extremely reliable automation of the machine-correlation procedure.

As indicated in Figure 2-1, the BAI image correlator was selected for the Pilot System. This equipment is newly developed and is essentially in breadboard form. It requires some additional development and packaging before it would be suitable for use even in the Pilot System. It should also be noted that it does not yet incorporate all the design features that are desirable for the advanced version. However, it is an adequate, and necessary, R&D tool.

2.2.2.3 Orthophotoscope

The orthophotoscope produces orthophotographs from a stereo pair of photographs; one orthophoto is derived from each frame set. These map-like photos are true orthogonal projections of the imaged terrain, and correct image displacements due to camera platform tilt as well as ground elevation differences.

Orthophotos are first prepared of all the terrain to be overflown in mission flights; they are later utilized as reference images containing ground-coherent grid marks. Automatic means are then used (in the Image Correlator) to read out any ground element from the mission data by relating it to the grid markings whose locations are accurately known. Section 5 explains in detail this new technique of ground-coherent gridding which has been developed during the course of this study contract and which, unlike other techniques devised to accomplish correlation, succeeds in correcting perspective distortion due to terrain relief.

If the resulting high accuracy location ability becomes a desirable feature for widespread use, then a large number of orthophotos will have to be constructed and placed on file. Hence, fully automatic operation in the generation of orthophotos is necessary for the ultimate system in order to assure a high production rate. The operator's work should be limited to: loading of the diapositive rolls (at present, glass plates are used); adjusting absolute orientation and scale; placing the

roll film for the orthophotographs; turning on the equipment; and general supervision of the various functions. A manual backup routine, to prevent loss of time if and when correlation failure occurs, is a desired feature.

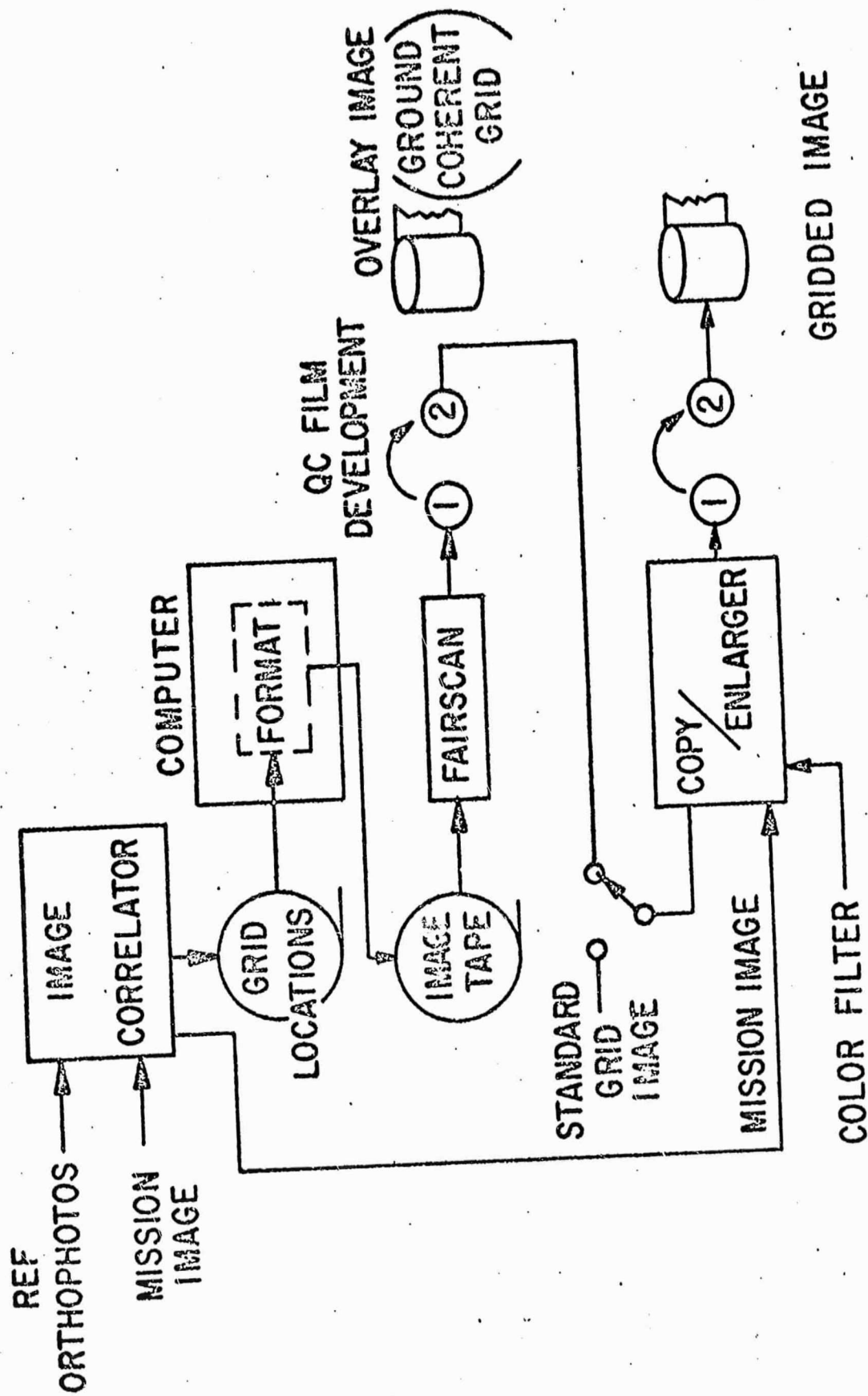
The total time to prepare an orthophoto with present equipment is approximately two hours for input imagery of 9 x 9-inch size. With the concentrated development work preceeding in many government and industrial laboratories to provide more accurate, more rapid operation, it is believed that the production time to prepare an orthophoto will decrease steadily in the next few years. A preparation time of one hour should be realizable before 1973.

After orthophotos are prepared, a reference grid would be overlayed on the image. For ease in changing this grid in the Pilot System, it is recommended that transparent plastic overlays be utilized. These overlays could be readily placed over the orthophoto and then copied to prepare the gridded reference image which is then transferred to the image correlator.

2.2.2.4 Output Image Gridding

Following image correlation, the mission imagery is gridded as detailed in Figure 2-2. The grid locations derived from correlation are formatted by computer to be compatible with the reconstitution device. The tape that is thus prepared is fed to an image reconstitution recorder, and an overlay image is reconstructed. The imagery that results, after film development, contains the ground coherent grid. This overlay image can be in the form of a transparency; it is then placed over the mission imagery and copied to produce the final output gridded image. In some cases it may be convenient to simply use a standard grid overlay; in this case a standard grid is copied onto the mission film directly, but the system must still use the image correlator in order to establish the relationship between the ground reference grid and the "standard" output grid.

The image reconstitution recorder utilized for this gridding function is capable of handling a digital tape containing the image information in



OUTPUT IMAGE GRIDDING

FIGURE 2-2.

element-by-element form. The equipment reconstitutes the picture onto standard 9 x 9-inch film. In the ultimate system, a code block encoder (CBE) would annotate each new reconstructed frame with a coded array of dots exposed during the reconstitution process; this would label the new imagery for easy subsequent identification and correlation. Precise quality control would be maintained by use of an "electronic" wedge; here a density step tablet on magnetic tape is merged with the image tape, enabling an eventual correction for machine-induced irregularities.

In addition to high scan accuracy, precise repeatability and geometric fidelity, the FAIRSCAN system provides a selectable spot size so that a reasonable match, between the reproduced photo and that of the original recording, can be attained.

2.2.3 Correlation Processing

In correlation processing, both tape and film data are manipulated to facilitate the correlation of information products. Most of the required functions will be performed by computer routines (see Section 9); the two film-handling subsystems that are needed are the film scanner and copier-enlarger, in order to construct various symbol and data overlays on mission photography.

2.2.3.1 Symbol and Data Overlays

It is recommended (cf. Section 9.7) that, as standard practice, profile sensor data be augmented by composite imagery showing a computer-calculated ground intercept track overlaid on a mapping camera photograph. Ideally, the overlay should also include a plot of the corresponding data. Figure 9-10 is a sample of effects which are currently generated at MSC.

The Pilot ADC System can continue to use ink plots but it is also within its capability to experiment with automatically controlled photographic techniques. For example, multispectral plots could be superimposed in different colors to minimize clutter, and/or the ground track representation might include variably sized symbols denoting spot size as a function of clearance altitude.

Figure 2-3 illustrates how this might be done for the adjustable symbols. A continuous track line can be considered a limiting case where the symbols are dots and their spatial separation on the image is small. Time-correlated signal waveforms can be constructed in a similar manner.

The first necessary action is a computer calculation of the ground intercept vs. time, as shown. Using known boresight information and the verified Mission NAV tape, this operation is straightforward (equations are given in Appendix A).

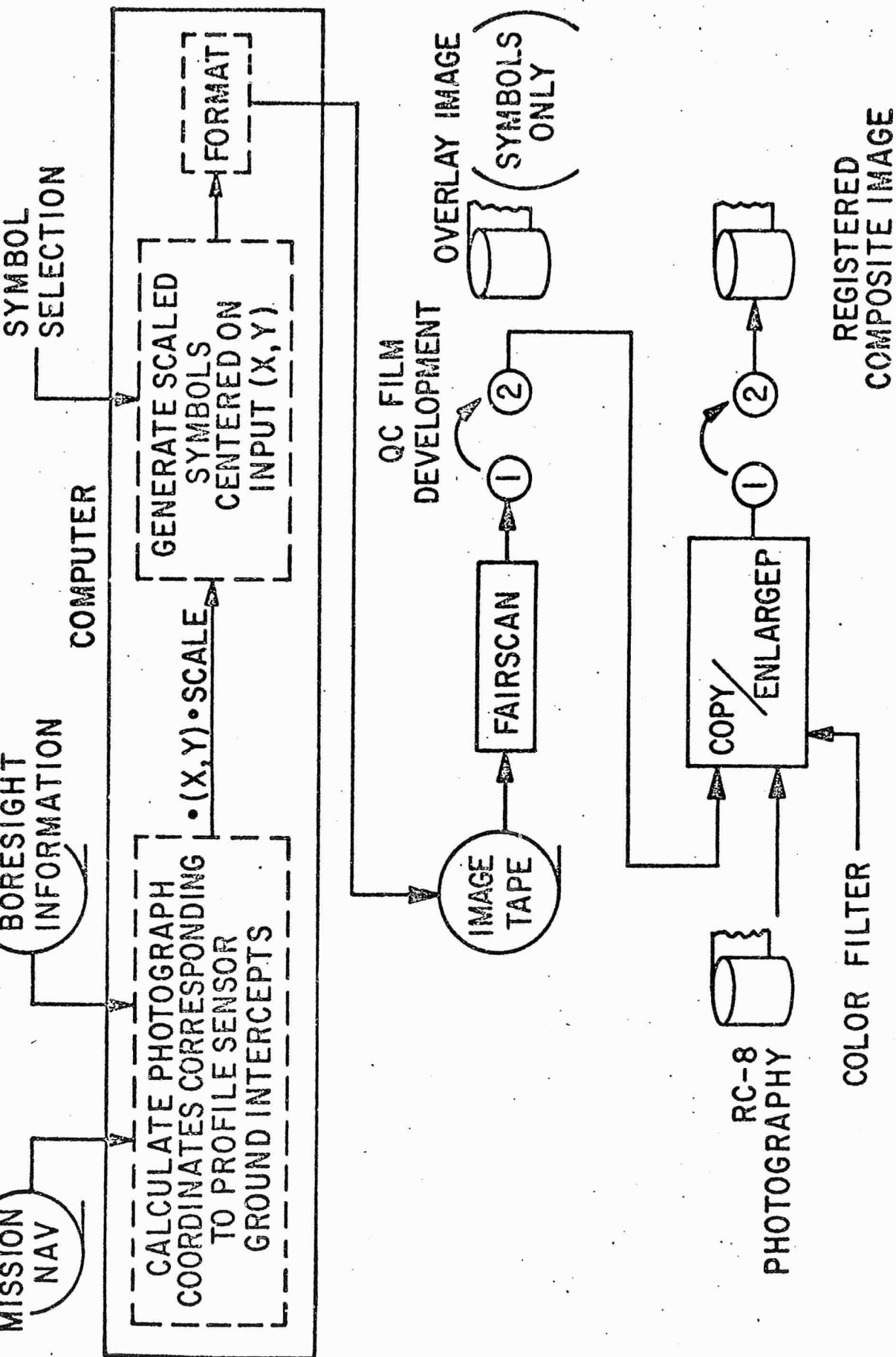
If more than one symbol is available, a selection is made and a second computer routine accepts the intercept data, in image coordinates, and constructs appropriately positioned and scaled symbol patterns. The resulting set of data is then formatted to be compatible with reconstitution scanning, and assembled on an "Image Tape".

In the Pilot System, the Image Tape will feed a FAIRSCAN unit which converts the data pattern to a corresponding overlay image exposure (i.e., it contains only the symbology and/or sensor data but no photographic background). After development, the computer-generated image may be photographically overlaid on the appropriate camera image and color filters may be freely introduced to enhance the registered composite picture.

2.2.3.2 Film Scanner/Reconstitution Recorder

The film scanner/reconstitution recorder is the final equipment used in parameter processing in the Pilot arrangement. The basic function of this equipment is to provide either digital tapes containing picture elements corresponding to input imagery scene information, or to reconstruct imagery from tapes. When used for scanning, the equipment must precisely scan the input photographs, convert the analog signal derived from the scene element density values to digital equivalents, and then record those digital values on magnetic tape.

The scanner should offer the flexibility of being able to scan opaque formats as well as transparencies. Rapid scan rate is desired without loss of good absolute linearity and registration. A variable spot size, to permit different scanning resolutions, provides the means of matching the scanner resolution more closely with the actual resolvable detail on



CONSTRUCTION OF SYMBOL OVERLAYS

FIGURE 2-3.

film. If the developed mission film is resolvable at 40 lp/mm, for example, scanning this imagery with a spot size that gives 50 lp/mm does not produce any gain in information; it does require more time to scan the photo and uses more magnetic tape, but it is necessary to use the smaller spot in order not to seriously degrade the data. Thus, a selectable spot size is important in helping optimize processing throughput time (see also the discussion in Section 8.4.1.).

2.3 COMPUTER SIZING

As indicated throughout this report, the ultimate version of the ADCS is too obscure yet to be viewable in great detail. The Pilot System is more visible, so it is possible to recommend specific equipments and address the problem of sizing the associated computer. Since it is desirable to use equipments at hand, where possible, the first consideration is the determination of whether existing or anticipated units at MSC are capable of performing the necessary system tasks.

It is now well-established that the Pilot will be a "walk-through" operation rather than a high-throughput production processor. This is quite literally the case because, as indicated previously, film-handling equipments are distributed through both the Photo Technology Laboratory and the Mapping Sciences Photogrammetric Laboratory and, presumably, the magnetic tape data preprocessing functions and ADCS computer functions will be conducted in yet some other area(s). The arrangement may be physically inconvenient but, for a first installation where the emphasis is on learning, it is adequate. The significant point that it underscores is that processing time is not critical in the Pilot System; i.e., there is no overriding demand to handle great amounts of data, or perform a large number of functional tasks, in a very short time interval. Hence, for present purposes, data load is a more relevant parameter to examine than throughput.

The scope of the problem can be further narrowed by observing that:

- 1) Preprocessing functions are essentially identical to those currently being performed, so the existing CDC 3200 facility will not be loaded any more severely than it is already;

- 2) Signature analysis functions are outside the province of the ADCS and their impact on computer requirements has been the subject of a separate study;
- 3) In the absence of a severe time constraint, large amounts of data can be manipulated by successive operations on smaller portions if there is insufficient working core available for the total load; therefore, the item of interest here is maximum anticipated record length;
- 4) The available computer is expected to be a Univac 1108. The maximum data case arises in scanning high resolution photography with a precision device. The recommended unit is the FAIRSCAN, which has a spot size small enough to produce some 1300 elements per inch of film. Thus, in one 9-inch scan line (which corresponds to one record on the output digital tape) there are approximately 12,000 data elements, each encoded to 6 bits.

It is desirable, for experimental purposes, to be able to re-pack the 12,000 x 12,000 elements from a 9 x 9-inch image into an equivalent array which has been reduced by some factor, F , in each dimension. It is also necessary, for all values of F , to format the data so as to be compatible with the Signature Analysis System.

If $F = 1$, the incoming 12,000 6-bit words can be assembled, as they arrive, into 2000 36-bit 1108 words. Assuming a configuration with at least 32K of core then, even without input packing, the working store should be adequate if the MSC Operating System occupies less than 20K of space. With packing, the margin is even more substantial and, if need be, more core modules can be added to the system.

If $F > 1$, the function requires that F^2 elements be averaged in generating each value of the output array. But this can be done by averaging successive groups of F elements on each of F lines and then averaging the derived values for corresponding groups on the successive lines. So, if core space is a problem, the input load can be held to a maximum of 12,000 6-bit words as before; i.e., one line of data-it is not necessary to simultaneously handle F lines.

Input packing might be less efficient (e. g., if $F = 7$ each group of 7 input words might be assembled into two 36-bit words, for a packing factor of only 3.5 instead of 6), but working core could still be held to under 3500 computer words of data.

Since the total number of data elements per image is so vast (after assembly it can require 4×10^6 computer words), it would be convenient if the configuration included a mass-storage subsystem. However, again, it is not necessary.

In summary, the available 1108 system should be either directly usable or easily expandable to that level, depending on the initial amount of working core. At 1108 speed, and considering the operational ground rules, processing time should pose no problem.

2.4 ACCURACY ESTIMATES

In considering accuracy standards for the Pilot System it becomes immediately apparent that overall system accuracy for film is influenced, among other things, by the scale of the photographs, the precision of the subsystem equipments, and the procedures used in compiling the orthophotos. Systematic errors can usually be minimized in the adjustment procedures, but it is the random errors which will govern the maximum attainable accuracy.

The problem of accuracy control is important; it covers such a large portion of the data collection and processing activities that it actually deserves separate and comprehensive treatment. The province of accuracy control extends all the way from individual sensor precision and vehicle attitude control to the exactness of imagery coordinate location and readout. It is clearly impossible to attempt an extensive accuracy analysis, treating all aspects of the data flow, within the context of the present contractual program, primarily because much of the information needed for such a task is not readily available from MSC. It is believed that a preliminary study would have to be completed first, before the Contractor could successfully attempt such an overall analysis. However, accuracy estimates can be made for the individual equipments that comprise the Pilot System.

Table 2-1 indicates the equipments of the Pilot System and the best available estimate of their functional accuracy. These percentage estimates represent the state-of-the-art values available in such equipments and provide a starting point in the consideration of the overall attainable system accuracy. The accuracy appraisals listed apply to the principal equipment functions that the subsystems must perform as a component of the Pilot System. For example, the sensitometer, whose function is to make exposures through a stepped density tablet onto the undeveloped mission film, is estimated for exposure repeatability and for exposure uniformity over the film area that has the step wedge image. Other ADCS equipments are treated in a similar manner.

2.5 FLOW ANALYSIS

In this section an assessment of the processing flow rate for the Pilot System equipments is provided. The discussion is limited to the specific equipments that have been described earlier in this section, and does not include computer time. The setup-time and process-time values are indicated in Table 2-2; in each case the indicated time is that needed to handle a single 9 x 9-inch frame of photography.

To determine a "total Pilot System throughput time" for a single frame of imagery, merely add together the setup and process-times for the equipments that are being utilized in the flow sequence. This has not been shown, but is relatively simple to do since the total throughput time is just the sum of all individual equipment throughput times (assuming a station-to-station transport time of zero).

2.6 ESTIMATED COST AND AVAILABILITY

With the exception of the BAI Image Correlator and the FAIRSCAN Image Analyzer System, all the component equipments of the Pilot System are, at the present time, available at MSC. Assuming these NASA equipments can be utilized in the initial configuration, the estimated cost and expected delivery to assemble the Pilot System are determined by the figures for the two subsystems mentioned above—the BAI Correlator and the Fairchild FAIRSCAN.

TABLE 2-1

PILOT SYSTEM EQUIPMENT ACCURACY ESTIMATES

<u>EQUIPMENT</u>	<u>ACCURACY APPRAISAL</u>
1. Copier - Enlarger	5% in copying size
2. Densitometer	1/4% for 8 hours operation
3. Film Scanner/Image Reconstitution Recorder	<.01% in absolute linearity & registration
4. Film Screening Viewer	5% all control functions
5. Image Correlator	.001% for transfer of coor- dinates from one image to the next
6. Optical Image Rectifier	.01% overall rectifier accuracy
7. Orthophotoscope	40 lp/mm resolution; .04% on model coordinate interval
8. Sensitometer	2% exposure repeatability; 1% uniformity.

TABLE 2-2

PILOT SYSTEM EQUIPMENT PROCESS FLOW TIME

<u>SUBSYSTEM</u>	<u>THROUGHPUT-TIME (HOURS)*</u>	
	<u>SETUP</u>	<u>PROCESSING</u>
1. Copier - Enlarger	.08	.005
2. Densitometer	.05	.03
3. Film Scanner/Image Reconstitution Recorder	.16	2.0
4. Screening Viewer	.08	.16
5. Image Correlator	.25	.50
6. Optical Image Rectifier	.16	.03
7. Orthophotoscope	.30	2.0
8. Sensitometer	.05	.03

* Throughput-time values are for equipment setup & actual process-time to handle a single 9 x 9-inch photograph.

The anticipated cost for the BAI Correlator is \$100K; estimated delivery of a unit is 6 months. The FAIRSCAN unit is estimated at \$150K, and its delivery would also be 6 months. Thus, the total major equipment expenditure needed is on the order of \$250K. Considering interface definition, specification, procurement, set-up, debugging and other associated system costs, it is felt that the Pilot System could be assembled and put into operation in 9-12 months at a total cost of about 350 thousand dollars.

SECTION 3

CONCLUSIONS AND RECOMMENDATIONS

FOREWORD

During the conduct of the study, a methodology for proceeding from a pilot correlation system to a fully automatic system evolved; in addition, a number of problem areas were identified. In essence, the conclusions reached may be summarized as follows:

- An automatic data correlation system is feasible, but the precise form and nature of the system cannot be fully determined at this time.
- It is possible to construct a pilot system, capable of exercising all preprocessing, processing and correlation functions. However, these functions would be performed primarily in a manual or semi-automatic fashion, and then only on a non-production basis.
- If constructed, such a pilot system would gradually evolve into a fully automatic system, constrained only by time and money.
- Such an evolutionary process may, after all, be the optimum way of developing an automatic correlation system, provided it is directed with the end goals in mind.

In keeping with these conclusions, the following recommendations apply:

- Proceed with implementation of the pilot system program.
- Initiate the study and the software and hardware development efforts required to ensure that all equipment and interface problems associated with construction and operation of the pilot system are solved in timely fashion.

The present section discusses the major problem areas identified during the study, and presents a timetable for their timely solution, and for the orderly development of the pilot system.

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3.1 MAJOR PROBLEM AREAS

One of the specific tasks of the Automatic Data Correlation Study was the discovery and identification of problem areas. As with any such study, the problems discovered exceed, both in quantity and difficulty, those that can be considered solved. Nevertheless, finding and defining the problem is the first step in its solution and, in several cases, it has even been possible to point out probable paths to solutions.

Although all of the problems discussed in this section are treated elsewhere in the document, they will be summarized here.

3.1.1 Multi-Sensor Correlation

This is, of course, the primary problem of the entire study and it remains partially unsolved. It has been concluded that for the highest resolution requirements, at least, the surest means of correlating images is through the use of the image detail itself. It has also been demonstrated that, for identical images, remarkable automatic correlation can be achieved. By correlating over areas large relative to a "picture element", a compensation of errors occurs so that correlation accuracy may actually be much higher than the inherent resolution would appear to allow. For example, BAI has demonstrated a video correlator with repeatability to the order of one micrometer on imagery which is certainly no better than 100 line pairs per millimeter. Furthermore, comparable accuracy has been demonstrated when the images were not identical, but represented multispectral exposures of a given area. The three bands were centered on 0.5, 0.65, and 0.8 micrometers respectively so that the densities representing a given ground element varied significantly from picture to picture. Nevertheless, correlation appeared to be equal to that for identical images. It is results of this kind that have led to the general recommendation for the use of video correlation techniques in solving the data correlation problem.

3.1.1.1 Technical Difficulties

Unfortunately, very little is yet known concerning the application of this technique to the most general problem. For the multispectral images, the density steps, though varying in magnitude from picture-to-picture, were generally in the same direction. This would not be true for foliage (for example) in a comparison of visual band imagery versus

near IR imagery. For photography versus SLAR imagery the differences might be even more pronounced. Nevertheless, the human observer finds little difficulty in correlating these quite different images. It seems likely that he uses geometric patterns rather than densities, and this approach is certainly feasible in an automatic video correlator.

Other difficulties arise if the images are not inherently congruent. Some possible cases are:

- Images are at slightly different scales
- Images were acquired from different platforms so that foreshortening effects due to terrain relief are different
- Images are acquired at different times so that shadows and seasonal effects produce significant differences.

Again, it seems reasonable to assume that, if the eye-brain system can perform the task, there is some probability of successful automation. One solution to the differential foreshortening problem, for example, is already being used in the orthophotoscope. The normally circular small areas scanned for correlation are distorted into ellipses so that both scanners "see" the same ground area. Furthermore, this effect can be automated so that the ellipses constantly seek the ellipticity and orientation which maximizes correlation. In addition to solving the perspective distortion problem, this approach is applicable to all other "gradual" distortion problems as, for example, those that result from random platform gyrations during the acquisition of data from a line-scan device or from nonlinear scans in a RBV.

When correlatability falls below a value which can be handled by a photo-interpreter, it is unlikely that successful automation can be realized and, for these cases, one of the less accurate geometric approaches must be used. However, video correlation techniques show such great promise that their development and expansion is strongly recommended for use in the Earth Resources Program.

3.1.1.2 Volume vs. Gridding Accuracy

It is an inescapable fact that the volume of data which must be handled is a very sensitive function of the required correlation accuracy. This problem is discussed quantitatively below.

One of the as yet unresolved questions regarding the suggested approach is the accuracy to which grid lines can be transferred from reference orthophotomaps to sensor images. There is reason to believe that mapping camera imagery might be spotted to accuracies of better than 0.001 inch, but no precise figure is yet available.

Unfortunately, even less is known about the ability to correlate with an orthophoto and place a grid on line-scanner or SLAR images. Since the premise of accurate grid transfers is basic to the entire system configuration, the question is a rather important one.

It also has far reaching consequences. If the overall performances stipulated by the various users are to be met, then a gridding inaccuracy must be compensated for by restricting the image width to a smaller ground distance. But then more frames would be required to cover a given ground area. Hence, the coarser the accuracy, the greater the film footage that must be handled.

Consider, for example, the effect on mapping camera photographs. The RC-8 cameras flown on the Houston aircraft have a total field of view of 74°. Therefore, the scene width on the ground is approximately 1.5 times the platform altitude (h) and, for a 9-inch image dimension:

$$G = \frac{Ah}{6} \quad (3-1)$$

where

A = Accuracy with which the grid lines are placed, in inches, on the photograph

G = Corresponding ground accuracy in same units as h.

Equation 3-1 is of interest itself, because it defines a maximum collection altitude as a function of desired ground accuracy and attainable

gridding accuracy. Thus, if gridding is, in fact, as poor as 0.01 inch on a 9-inch image and the data is to be located to 10 feet, the maximum allowable altitude is 6000 feet. But furthermore, the ground area corresponding to one frame is:

$$C_f = 2.25h^2 = 81 \left(\frac{G}{A}\right)^2 \quad (3-2)$$

Consider a requirement to photograph and grid some arbitrary ground area, say 100 x 100 nm (the equivalent of one ERTS scene). Assuming a 60% overlap in successive images for stereo photography, the number of frames (n) required is at least:

$$n_{\min.} \approx 1.1 \times 10^{10} \left(\frac{A}{G}\right)^2 \quad (3-3)$$

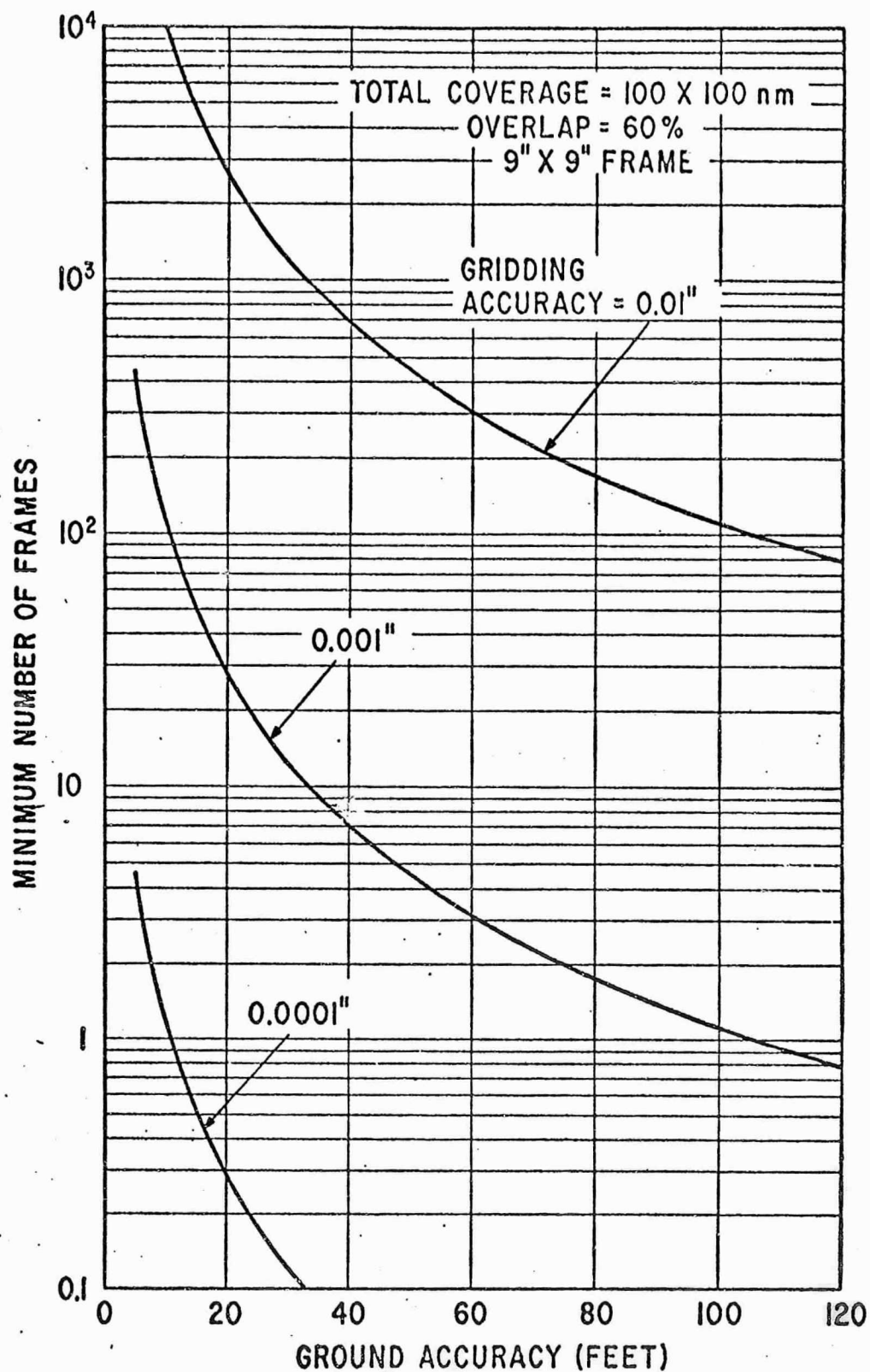
Figure 3-1 shows the striking implications of this relationship by plotting volume versus ground accuracy for grid accuracies of 0.1, 1 and 10 mils. The conclusion is quite clear--gridding accuracy must be pursued vigorously. How far, is another matter. Eventually, projected development costs and machine time needed to perform the more precise correlations will impose a practical limit. The point of maximum payoff is not yet known.

3.1.2 Production Management

This problem is conveniently divided into two parts, the first being the tools (software, displays etc.) which provide information on the system status and operation, and the second being the processing hardware itself.

3.1.2.1 Management System

An examination of Volume II shows the complete Data Correlation System to be functionally designed to a considerably greater depth than is the management system which must monitor and control it. The primary reason for this is the fact that optimization of the management system is heavily dependent on the experience gained in operating the Pilot System. Thus, while this appears to be a major problem at this time, it is anticipated that its solution will develop readily with the evolution of the processing system.



DATA VOLUME VS. GRIDDING ACCURACY

FIGURE 3-1.

3.1.2.2 Data Handling

This problem concerns both control of existing processing equipment at any point in time and planning for the next generation. It includes equipment redesign to facilitate data flow; automation of manually-performed tasks such as titling or title-reading and standardization of data formats and procedures.

In summary, although the problems of Production Management are very real, it is improbable that a formal study in this area would prove cost-effective at this time. As the Pilot System is put into operation and as succeeding generations evolve, these problems will appear in sharp relief. Quick-fix versus formal-study decisions can be made at that time.

3.1.3 Non-Existent Equipment

Another basic problem area is related to the lack of availability of various equipments required to perform the automated (and in some instances even the manual and semi-automated) preprocessing, processing and correlation functions identified as necessary for the final facility and the earlier pilot system. Specific examples of unavailable items include:

- **Special Purpose Rectifiers**

- capable of correcting for instrument and platform errors in SLAR, IR, etc. imagery.

- **Automatic Film Spotters**

- magnetic tape-controlled, off-line equipments capable of "gridding" imagery, annotating film for special analysis purposes, etc.

- **Special Effects Generators**

- capable of generating "artificial imagery," e.g., combining imagery with cartographic bases, etc. for both experimental and public relations applications.

Indeed, if the need to accommodate roll film is included as a requirement for the facility, and at present this appears to be a highly desirable feature, then even such "conventional" equipments as sensitometers, digital densitometers, and enlarger/copiers are not presently in existence.

The performance characteristics needed by non-existent equipment may be found in Appendix C. Development of this capability, whether entirely new instruments or as modifications of existing ones, represents one of the highest priority tasks in the Automatic Data Correlation program.

3.1.4 System Interfaces

Major bottlenecks may develop at any of the several interfaces of the Data Correlation System with other components of the Earth Resources Program. The most complex of these interfaces is the one with the Library Functions (see Section 10). The two-way flow of data, information, and requests which will exist between these two facilities warrants the most careful consideration, and it is recommended that this study be the subject of a specific task in a Library Facility study. Items of interest include:

- Film and tape formats
- Interim storage during processing
- Orthophoto files
- Signature files
- Standardized nomenclature and procedures.

It is anticipated that the majority of interfaces with experimenters, users and browsers will be set up to occur with the Library rather than with the processing facility (see Section 10). The exception to this general rule will be those user/experimenter personnel who actually participate in the processing by performing screening and limited analysis. Here, the interface is via the Multispectral Camera Film Viewer, closed circuit television, hard copy printouts etc. While no separate study of this interface is recommended, special emphasis on human engineering factors is required in the design and development of these equipments.

The interface between the Data Correlation System and the Signature Analysis System has received some consideration in the present study. It will receive additional attention in the design and development of the proposed Multispectral Imagery Scanning Station, but details have not yet been worked out and this interface must be kept in mind during the Pilot System design and the subsequent evolutionary system integration (see Section 9).

The last (or first) important interface is that between the data collectors and the data processors. This consists of both the Mission Planning function and the physical data-transfer function.

It has been emphasized in Section 5.5.1.1 that the Processing Manager must participate in the Mission Planning to ensure compatibility of the data collection and the processing capability. This should solve the first requirement, and the second one is covered in the Pre-processing Subsystem. Hence no additional formal studies are recommended for this interface.

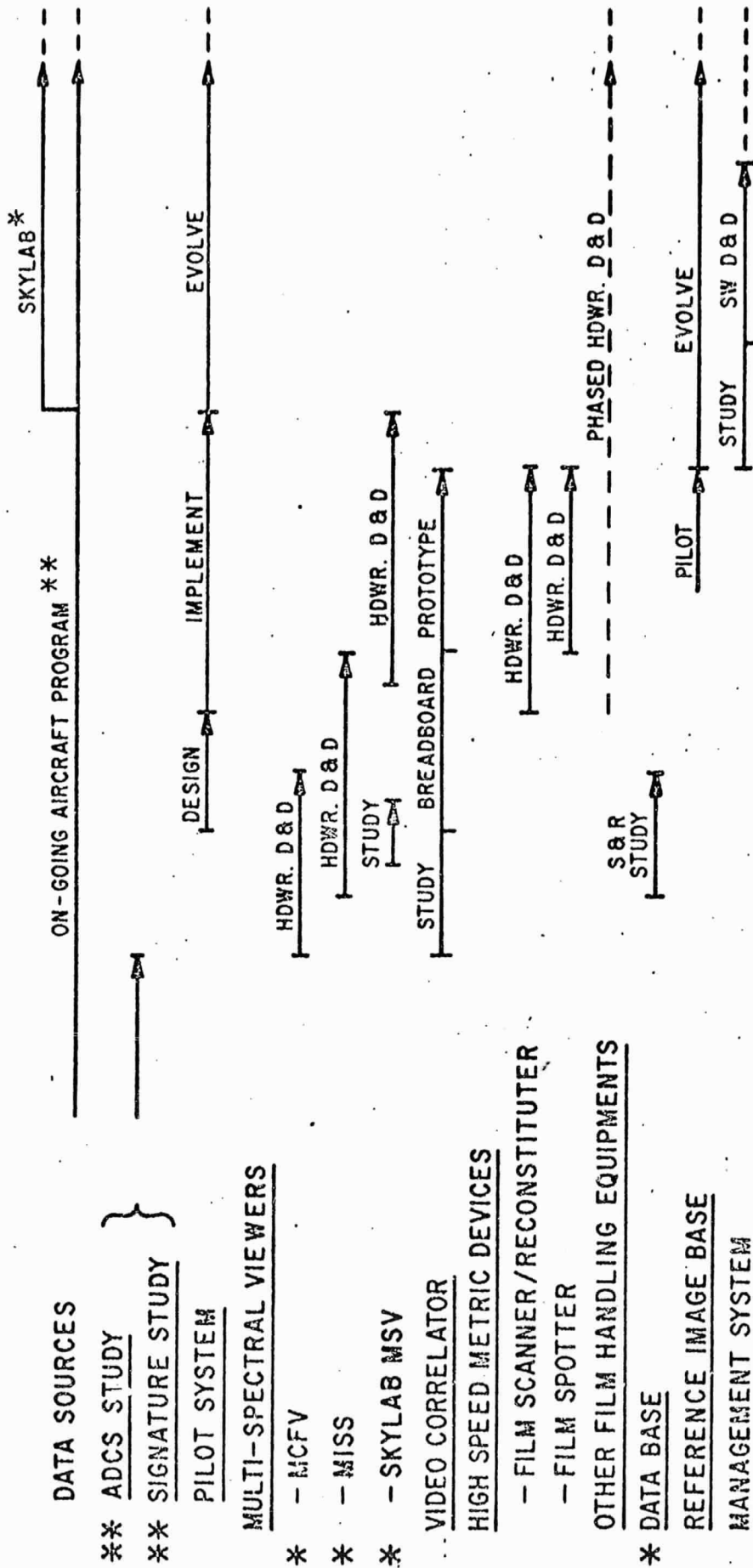
3.2 RECOMMENDED TIMETABLE

It is quite evident from the preceding discussion that a great deal of development work is necessary before the desired processing capability will be realized. Some of these activities are already being planned; in other cases, the specific needs are only now coming to light. There appears to be no instance where technical problems are insurmountable but, as usual, the level of difficulty varies widely. So does significance to the program, in terms of critical functions.

For that reason, it was felt appropriate to recommend a timetable for the remaining major efforts. Figure 3-2 summarizes the projections.

A key target date is the last quarter of 1972, when Skylab is expected to become operational. This marks a due date for delivery of one of the planned Multi-Spectral Viewers and is a realistic and relevant point in time for concluding other system development efforts.

The most difficult and most crucial element in the ADCS is the modified Image Video Correlator. Hence, it is strongly urged that the pending follow-on study be extended to include breadboard and prototype hardware development. The anticipated time span that this would require is compatible with the late 1972 goal, as shown.



RECOMMENDED TIMETABLE

FIGURE 3-2.

- * IN PLANNING STAGE NOW
- ** ACTIVE PROGRAM

A Storage and Retrieval study is expected to begin in the latter portion of 1970. This is, without a doubt, a very significant step. The investigation is needed to give a solid footing to the overall facility, and the timing is such that the results should be available at about the midpoint of a recommended Pilot System design study. That would be an excellent arrangement. It also permits a six month hiatus during which MSC personnel can absorb the results of the ADCS and Signature Studies and plan an integrated attack on the program problems.

Once the Pilot System activity begins, probably early in 1971, it should continue through design, implementation and evolution, with timing approximately as indicated. As noted in Section 3.1, virtually no existing off-the-shelf equipment is entirely satisfactory for high volume throughput processing. So the necessary D & D efforts are scattered and might best be accomplished in a series of relatively small "hardware modernization" contracts. Some of these should be let upon completion of the Pilot System design; others could be phased over several years, gradually replacing initial components of the evolving system. The only equipments warranting outright mention now are the two high speed metric devices listed. Both the Film Scanner/Reconstituter and the Film Spotter are high quality precision instruments which are vital to the system and which will present difficult development problems if they are to rapidly handle roll film imagery. Programs should be initiated as soon after the completion of the Pilot System design as is practical.

Since the key to solving the most rigorous correlation demands is automatic comparison of mission imagery with marked reference images, even the Pilot System must have a set of such material prepared. The complete task requires orthophotographs containing reference grid lines that coincide with the geographic system of Latitude parallels and Longitude meridians. This ties all data to a coherent world-wide system. However, for isolated sites, any reference images will suffice, provided all data is measured relative to them. They should, at least, be high quality rectified photographs, but not necessarily orthophotographs. Similarly, any grid will do, provided it is consistently used and its relationship to the ground is known.

The intent of these remarks is not to deny the need for properly gridded orthophotos but to point out the leeway that exists in building toward the eventual implementation. Whether the options are exercised or not, the Pilot System will require reference imagery. Preparations should begin at whatever point in time optimizes phasing with hardware deliveries and software development.

Regarding the latter, some attention should be given to the software Management System as the Pilot System begins to take shape. Then, probably about mid-1972, when most portions of the Pilot configuration are operating, a study should be undertaken to design the management software in detail.

If all projections hold, it would appear that the first "production processing" of mission data could occur sometime in mid-1973.

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