BELLCOMM, INC.

TR-66-340-3

Lunar Orbiter Photographic Data Analysis For Apollo Landing Hazard Appraisal

July 27, 1966

C. S. Sherrerd

Work performed for Manned Space Flight, National Aeronautics and Space Administration under Contract NASw-417.

BELLCOMM, INC.

TABLE OF CONTENTS

ABSTRACT

The Apollo Program has need for the quantitative analysis of Lunar Orbiter photography. This report presents performance objectives for a computer-based system to assist in this analysis. The software performance is outlined in terms of function, data flow, and output products.

Processing rates sufficient to meet the needs of the Apollo Program can be achieved with newly available general purpose computers. It is recommended that the system be developed in two stages. A minimal system should be ready to process Lunar Orbiter data shortly after it becomes available. Then the capability of the system should be augmented to achieve the full performance objectives. The total effort required for software development to meet the objectives is of the order of 20 to 35 man years.

In order to support the second stage of development, it is recommended that further engineering analysis be performed in the following areas:

1) Data sampling strategy

2) Noise filtering

3) Calibration of the lunar photometric function

4) Hazard criteria

5) Minimization of operating time

BELLCOMM, INC.

LUNAR ORBITER PHOTOGRAPHIC DATA ANALYSIS FOR APOLLO LANDING HAZARD APPRAISAL

A computer-based system will process Lunar Orbiter photographic data to obtain Apollo landing site hazard statistics. Such hazard statistics are needed to assist in the process of selection of the final candidate Apollo landing sites.

The effective processing of Lunar Orbiter photographic data to obtain Apollo landing site hazard statistics cannot be done entirely manually; the amount of processing required is very high, and a computer-based system is necessary. In fact, the data rates and processing requirements are sufficiently high that the most recent state-of-the-art computers should be used. However, it can be done, provided a system can be procured by the time Lunar Orbiter photographic data is available.

This report presents performance objectives and a proposed overall design of a computer-based system for such photographic data processing. The extent to which these objectives must be met will depend on the results of a series of detailed analyses which must first be carried out on the noise and spectrum distortion characteristics of the Lunar Orbiter photographic system, the adequacy of high resolution of lunar surface, photometric analysis techniques, and the measurements needed to evaluate the safety of LEM landings.

1.0 Apollo Landing Site Selection Requirements

The primary objective of both the Surveyor and Lunar Orbiter projects is to gather information about certain areas of the lunar surface which can serve as a basis for selection of the landing sites of manned Apollo missions. A number of areas of the lunar surface have been selected as possible candidate landing areas in accordance with mission constraints and their potential safety. It is highly desirous to obtain detailed information on these candidate sites of potential landing hazards: lunar soil load bearing strength, average slope with respect to the local gravitational gradient, and the presence of boulders, etc. which might damage a landing LEM.

The Lunar Orbiter project is intended to provide local slope information on the several candidate landing sites, and the Surveyor project is intended to provide lunar soil characteristics information and information on how different are similar-appearing lunar surface areas. The two projects, in conjunction with each other, are to provide landing hazard information on the several candidate sites, such information to be used in the final site selection.

1.1 Selection Procedures

A screening group, first on the basis of the best of earth-based photographs of the lunar surface and later on the basis of Surveyor and Orbiter data, will reject most of the obviously hazardous areas. Then, using Orbiter photo data, hazard statistics will be computed for coarsely sampled areas for further rejection of the most hazardous areas. Then the candidate landing sites not yet rejected will be sampled intensely and hazard statistics computed. The net result will be a final list of "least hazardous" candidate sites from which the Site Selection Board will make the final selection.

1.2 Site Description Data Requirements

An Apollo landing site (candidate or final selection) is defined in this report as an area on the lunar surface which represents the 95% confidence prediction ellipse of a LEM landing about a point landing target. Current estimates of the uncertainty in a LEM landing indicate that a site should be from 3 to 8 km in radius, depending on the guidance and navigation modes (yet to be determined).

Based on the current LEM design, an acceptable Apollo landing site is a circular area of this size whose slope gradients are such that no matter where within the area a LEM might land, with no matter what orientation, the maximum tilt of the LEM axis is less than 12° from the local gravitational normal vector (taking soil sinkage of the LEM feet into account), and the highest point under the LEM body extends no more than 0.62 meters above the plane of the landing pads. The LEM landing stage has four legs arranged in a square, with one meter diameter circular feet spaced 8.2 meters on the diagonal (5.8 meters on the side).

This implies that in order to determine whether a given candidate Apollo landing site is or is not acceptable requires much detailed knowledge about both the surface topography and soil mechanics of that area.

Topographic data is to be obtained on candidate Apollo landing sites through photographic analysis. Earth-based photographs have been used to select several possible candidate sites. Lunar Orbiter medium-resolution stereo photographs will be examined visually, and those candidate sites, if any, whose average surface slopes are excessive, are to be rejected. For those sites not rejected, detailed topographic data is to be obtained from the high-resolution Lunar Orbiter photographs.

Soil mechanics data is to be obtained by the Surveyor project. This data is to be of two types: actual soil mechanics data of certain specific sites, and information on the dependence of soil mechanics upon the visible properties of lunar surface areas.

1.3 Lunar Orbiter Data Processing Requirements

All photographs of the Lunar Orbiter project are to be reproduced on earth for visual examination. Stereo examination of the overlapping areas covered by the medium-resolution photographs is to be done.

In addition, the high-resolution photographic data for selected areas (candidate sites) is to be processed quite thoroughly in order to obtain landing site acceptability criteria. This processing, which is sufficiently extensive as to require the assistance of computers, is to include digitization of the photographic data, photographic system distortion corrections, brightness-to-topography conversions, and computations of landing hazard statistics.

2.0 LUNAR ORBITER PROJECT DATA FLOW

Figure I, attached, ("Lunar Orbiter Photo Data Analysis for Apollo Landing Hazard Appraisal") depicts the flow of Lunar Orbiter photographic data. For discussion purposes this flow can be considered in four steps: the reception and recording of the telemetry and video signals from the satellite at the Deep Space Instrumentation Facilities (Goldstone, Arizona; Madrid, Spain; and Canberra, Australia); processing of photographs and analog video tape recordings at Eastman Kodak (Rochester, N. Y.), USAF-ACIC (Aeronautical Chart and Information Center, St. Louis, Mo.), AMS (Army Map Service) and NASA-LRC (Langley Research Center, Hampton, Virginia); computer processing, for Apollo landing hazard appraisal, at NASA-MSC (Manned Spacecraft Center, Houston, Texas); and the use of Lunar Orbiter photographic data for other purposes.

2.1 Orbiter-to-DSIF

At each of the three DSIF sites, the original video signal will be demodulated and fed into GRE (Ground Recording Equipment) for photographic reproduction, line by line. The resulting film will be shipped to Eastman Kodak to be developed and assembled into complete frames. The resulting frames will then be shipped to NASA-LRC and sent from there to NASA-MSC, NASA-Bellcomm, ACIC, AMS, and USGS.

Also at the DSIF sites, it is planned that analog video tape recordings be made of the incoming telemetry and video signals, if the required tape recorders can be shipped and installed in time. Ampex FR-900 tape units, or the equivalent, are proposed. These tape recordings, after processing at NASA-LRC, are to be the basis for computer processing at NASA-MSC for Apollo landing hazard statistics.

2.2 Photographs and Analog Tape Recordings

The video tape recordings planned at the DSIF sites will not involve complete demodulation of the vestigial side-band signal, but only a spectrum shift to fit the spectrum capabilities of the video tape recording equipment. At NASA-LRC, these tapes will be played back, the vestigial side-band carrier will be reconstructed, complete demodulation (including fold-back filtering) will be effected, and new video tape recordings will be made. At the same time, timing information from the original telemetry will be extracted and re-recorded on an auxiliary channel of the new video tapes. These new video tapes will then be shipped to NASA-MSC for computer processing.

In the meantime, the developed and assembled photographs will be shipped from Eastman Kodak to NASA-LRC, and from NASA-LRC to NASA-MSC, Bellcomm, USGS, ACIC, and AMS. At both ACIC and AMS, the medium-resolution frames will be subjected to detailed stereographic analysis, and topographic contours and profiles will be generated, to the appropriate degree of resolution, of the lunar surface areas of interest to Apollo. These contours and profiles will be shipped to NASA-MSC to augment the computer processing for Apollo landing hazard appraisal.

It is possible that some of the original telemetry video signals will not be tape recorded (e.g., because of equipment failure), but will be available in photographic form; therefore, a facility should be maintained to digitize the data from these photographs. It is proposed that microdensitometer equipment at ACIC be used for this purpose, although much less data can be processed in this manner than would be practical using tape recordings.

2.3 Computer Processing for Landing Hazard Determination

The computer-based system requirements for processing Lunar Orbiter photographic data for Apollo landing hazard appraisals of possible landing sites are discussed in sections 4.0 and 5.0, below. A preliminary design of the required computer-based system is included, plus overall operating procedural requirements.

2.4 Other Uses of Orbiter Photographic Data

Several uses of Lunar Orbiter photographic data have been suggested in addition to that of assisting in Apollo landing site selection and evaluation. Among such uses are: mapping of the lunar surface by ACIC and AMS, geological and geophysical studies of the moon by USGS (United States Geological Survey), and studies of lunar surface characteristics for future manned space exploration mission planning by NASA-OMSF, NASA-MSC, and NASA-Bellcomm.

This memorandum is concerned only with the computer processing of Lunar Orbiter data for Apollo landing site selection and evaluation.

3.0 Photographic Data Noise Correction

When photographic data is to be used, not for identification of objects and surface features, as much as for measurement, it is essential that the photographic data represent as accurately as possible the true photographic properties (brightness levels) of the surface area. However, as is to be expected of physically realized remote photographic data systems, the Lunar Orbiter system contains several sources of noise and distortion. The effects of these sources, though not severe, must be removed from the photographic data in order for accurate topographic information to be obtained. Specifically seven possible sources of noise in the Lunar Orbiter system are identified in this section, with suggested programmed models for at least partially correcting the data for them. System calibration data requirements for determining the appropriate values of the several parameters of such noise correction models are also identified.*

3.1 Sources of Photographic Distortion and Noise

3.1.1 Geometric and View Angle Distortions

If the main optical axis of the camera system is not perfectly normal to the local surface plane, the surface area

*See Bellcomm, Inc., TM-65-1012-9, "The Lunar Orbiter Photographic Data Channel", F. S. Flatow, November 1, 1965.

which is photographed onto a rectangular exposure frame is not perfectly rectangular but distorted. Furthermore, since the surface being photographed is not planar but a section of a spheriod (the moon), these areas will at best approximate spherical rectangles or near-spherical rectangles. Since topographic surface analysis is desired, geometric correction may be required so that the resulting photographic image will represent corresponding lunar surface topography relative to the local gravitational field without distortion.

3.1.2 Lens, Film and Readout Geometric Distortion

In addition to geometric distortions due to optical axis tilt and to the sphericity of the lunar surface areas being photographed, geometric distortion might be introduced into the photographic image by film warping and by abberations and imperfections in the camera lens and read-out systems. In the lunar orbiter, such distortions as those due to film warp may turn out to be negligible at low resolution, but significant geometric distortions might be introduced by the lens and by the scanning and read-out system. For example, timing variations in the line sweep of the scanner would cause geometric distortions of distance represented along each scan line, causing jitter in the alignment of surface features vertically crossing adjacent scan lines.

3.1.3 Vignetting

Vignetting is a distortion in illumination of a photographic film frame due to limitations in the light-collecting capability of any directional camera lens system. Essentially, the further away from the main optical axis of a photograph be the point on the lunar surface being photographed, the less the amount of light which is focused in the corresponding point on the photographic image. A photograph of a uniformly reflecting surface area would be darker around the edges than near the center. Hence, due to vignetting, the relationship between film brightness and surface brightness varies over the photograph.

3.1.4 Blur

Image blur in the Lunar Orbiter photographic system can arise due to four sources, as illustrated in Figure II: (1) Incomplete image motion compensation, (2) incomplete optical focusing of image on film, including the lens spread function, (3) film emulsion embossing effects, and (4) light beam thickness and scattering effects during scanning and read-out. Blue effect (1) would be of uniform magnitude and single-directional over all areas of each resulting photograph,* but might vary from photography to photograph. Effect (2) would vary radially away from the center of each photograph. Effect (3) would depend only on exposure of local areas of the film. Effect (4) would vary somewhat over each framelet but would not vary from framelet to framelet or from photograph to photograph.

The totality of these blue effects must become known, either from calibration test measurements or by estimates based on engineering knowledge of the photographic system. Also, the factors upon which the variations of these blue effects over each framelet and from framelet to framelet depend must be identified, and their values must be available quantitatively to the processing program. These factors might include spacecraft altitude, image motion compensation, telemetry, which framelet of the 116 framelets per photograph pair (86 per high-resolution frame, 36 per medium resolution frame, and 4 between frames) is being processed, and position in the framelet.

Blut is a linear process, equivalent to frequency attenuation or frequency distortion in two dimensions. It is correctable by an appropriate filtering process.

3.1.5 Density-to-Exposure Transmissivity Non-Linearity

The analog photographic data signal transmitted from the Lunar Orbiter represents the total current output of the Orbiter readout photocell due to a narrow beam of light passing through a local spot on the film during readout. However, it is desired to use digital data values to represent the total brightness of light reflected by that small area on the lunar surface to which the local spots on the film photographically correspond. Although the readout photocell's output current and the lunar surface reflectivity brightness are isotonically related, their relationship is not linear.

The relationship of the readout photocell's output electrical energy to total light energy reflected from each local spot of the lunar surface, which is often referred to as the film transmissivity, involves three separate effects taken together. These three separate effects are:

---

*If the blur is caused by a pitch error, it will vary across the photograph.

(1) the relationship of the readout photocell's output current for each spot to the density of that spot on the film;

(2) the relationship of the density of each spot on the film, after development, to the latent image formed in the emulsion as a result of exposure; and

(3) the relationship, during exposure, of the latent image to the total energy of the incident focused light.

Modification of the Lunar Orbiter photographic data to correct for these relationships can be done in a single step. Hence, these three effects need not be quantitatively known separately, although the total effect of these three relationships must be measured or estimated.

3.1.6 Film and Line Scan Tube Phosphor Granularity

The randomness of size, density, and orientation of the Lunar Orbiter film emulsion and line scan tube phosphor granules has the effect of adding noise to the resulting photographic data. This noise effect can presumably be expressed in the form of an amplitude spectrum, where frequency is in terms of cycles per unit distance (say millimeters) across the image all directions. The scanner and readout process responds to this noise, and the net result can presumably be expressed in the form of a two dimensional power spectrum.* Hence the effect of granularity is an additive component of noise, i.e., those arising during modulation, transmission, demodulation, and analog-to-digital conversion.

Actually, the noise effect of film granularity depends upon film exposure. However, for the range of exposures to be encountered in Lunar Orbiter, this effect will be assumed to be approximately constant with respect to exposure. The exact power spectrum of this noise effect over the frequency band of interest must be known, either through calibration test measurements or by estimates based upon engineering knowledge of the photographic system. A current estimate, based on known characteristics of a similar type of film, is that a white noise spectrum with a measurable average power level can be used to approximate this power spectrum over the frequency band of interest.

For photographs obtained from the ground recording equipment (GRE), granularity of the GRE tube phosphor will also be present. This granularity will appear as coherent noise in the resulting photographic image. However, this effect will not be present if the photographic data is digitized directly from the transmitted video signal.

---

*The phosphor drum noise may show an assymmetric correlation structure, due to drum rotation.

3.17 Analog Signal Noise

In Figure II several sources of "analog signal noise" are identified: film scanner and readout, modulator, transmission, telemetry receiver, demodulator, tape recording and playback, and analog-to-digital conversion. These are sources which, in addition to film granularity, introduce noise which can be represented in the form of power spectra. They are distinguished from granularity runs because they are two-dimensional in nature.

It is proposed in section 3.2.1, below, that a single digital filter be used to minimize errors due to all such analog signal noise. Hence, the individual power spectra of each of these noise sources need not be quantitatively known separately. The overall power spectrum of the totality of all of these noise sources must, however, be known, either from actual calibration test measurements or from estimations based upon engineering knowledge of these noise sources.

3.2 Corrections for Photographic Distortions and Noise

An ideal approach to the correction of the orbiter photographic data to minimize the effects of the above listed sources of noise and distortion would be to apply noise filters, geometric transformations, and density-to-exposure corrections to the data in a step by step procedure which statistically removes the noise and distortions in reverse sequence of the listing in the preceding section. That is, to process these effects in the following sequence (See Figure II, reading from right to left):

(1) Analog-to-Digital conversion noise and spectrum distortion

(2) Analog tape recording and playback noise and spectrum distortion

(3) Analog signal receiver and demodulator noise and spectrum distortion

(4) Transmission noise

(5) Analog signal modulator and transmitter noise and spectrum distortion

(6) Film scanner and readout noise and spectrum distortion

(7) Scanner geometric distortion and timing jitter.

(8) Scanner blur

(9) Granularity noise

(10) Film density-exposure non-linearity

(11) Film warp distortion

(12) Film blur

(13) Lens focus blur

(14) Image-motion blur

(15) Vignetting and shutter variation

(16) Lens geometric distortion

(17) View angle geometric distortion

(18) Surface sphericity geometric distortion

To perform such noise filtering and distortion removals separately would result in excessively lengthy computer operating time. From the point of view of design and operation of the processing computer program, it is highly preferable to group these noise and distortion removals into as few steps as practical, with similar types of removals grouped together. For example, the processing of one-dimensional analog signal noise and distortion effects #1, 2, 3, 4, 5, and 6 should be grouped into one step which would involve applying a polynomial filter to the digitized data stream. As another example, the processing of blur effects and two-dimensional granularity noise (#8, 9, 13, and 14), could be grouped into one step which would involve taking weighted averages of each spot (digitized photograph element) and several adjacent spots. Such grouping of removal steps for program design considerations is recommended.

Such grouping of course means that some removal steps will not be done in proper sequence. It is believed and assumed, however, that errors and distortions not completely removed (or perhaps introduced) because of such out-of-sequencing will statistically be much smaller in magnitude of effects than the "noise level" of the state-of-the-art of knowledge concerning each of the eighteen above-listed noise and distortion sources.

Our detailed knowledge concerning these effects is and will remain for some time incomplete; corrections to be made by the computer will be at best approximations to the unknown optimum corrections which "should" be done. The computer program design should be based upon the philosophy that it is better to have an approximate solution to the right problem (overall noise and distortion removal) which can be implemented soon enough to be of value, than to have no implementation solution at all, or an exact solution whose implementation is too late to be of value or too costly in its use (computer operating time per chit).

Based upon this reasoning, a specific sequence of grouped noise and distortion effect removals is proposed in Figure III, in sequential relationship to the determination of equal brightness contours, topographic contours, and landing hazard statistics for each chit area. The six grouped effect removal steps recommended in Figure III are as follows and are discussed below:

(1) Apply a polynomial filter to the digitized data stream to remove the effects of the analog signal noise sources #1, 2, 3, 4, 5, and 6 listed above.

(2) Perform a conversion from photographic density to "true" exposure on each photographic spot to correct for both the vignetting and density exposure non-linearity noise effects #10 and 15 listed above.

(3) Take, for each photographic spot, a circularly symmetric weighted average* of the exposures of it and several adjacent spots, to minimize errors due to blur and noise sources #8, 9, 12, and 13 listed above.

(4) Compensate for the image-motion blur effect #14 plus any other coherent noise effects by a one-dimensional digital filter in the direction of relative image motion or as otherwise appropriate.**

(5) After brightness values are obtained to represent the photographic data in an efficient form for computer processing, perform a geometric transformation to remove the effects of geometric distortion sources #7, 11 and 16 listed above. A transformation to a coordinate system related to the illumination angle (see, for example, Figure V) may be included in this step.

(6) After topographic data are obtained from the surface brightness patterns, perform a second geometric transformation to remove the effects of geometric distortion sources #17 and 18 listed above.**

3.2.1 Polynomial Filter

The correction for all one-dimensional analog signal noise introduced on the photographic data stream up to and

---

*Taking a weighted average is not necessarily the most efficient way to accomplish two-dimensional digital filtering. Other methods are under study (See Leibowitz, M.A., "A Procedure for the Digital Processing of Photographs," Bellcomm, Inc., TM-65-1012-4, August 25,1965)

**Depending on the methods of implementation, it may be desirable to combine steps (3) and (4), and steps (5) and (6).

including the analog-to-digital conversion can be conveniently done by applying a single overall digital polynomial filter to the digitized data stream (successive bytes*) representing each framelet scan line. That is if

$$U_{k-m}, U_{k-m+1}, ---, U_{k-1}, U_k, U_{k+1}, U_{k+2}, ---, U_{k+n}$$

represent a series of consecutive byte values in the vicinity of the kth byte of a framelet scan line, a filter output value V_k, assigned to the kth byte is computed by the moving weighted average

$$V_k = A_0U_k + A_1U_{k-1} + --- + A_mU_{k-m} + B_1V_{k-1} + B_2V_{k-2} + --- + B_\ell V_{k-\ell} + C_1U_{k+1} + C_2U_{k+2} + --- + C_nU_{k+n}$$

(at the beginning of each scan line, a new moving weighted average must be started. The technique for starting the moving weighted average for each line is yet to be determined).

The coefficients of such a moving weighted average or digital polynomial filter are chosen so that the transfer (frequency) function of the filter is such as to minimize, by a least squares criterion, the statistically average effects of all of the analog signal noise and frequency attenuation effects. The design of this filter (determining the values of m, n, ℓ and the (ℓ+m+n+1) coefficients) involves the following:

Let G'(w) represent the power spectrum of the total analog signal noise effects, and F(w) the transfer function corresponding to the total frequency attenuation, of the several sources listed above. Let S(w) represent the power spectrum of the photographic data (as "seen" by the camera lens system) of an analog time signal. S(w) must likewise be measured or estimated. Then the desired transfer function of the polynomial filter is determined:

$$K(w) = \frac{|F(w)|^2 S(w)}{|F(w)|^2 S(w) + G'(w)} \cdot \frac{1}{F(w)}$$

Let Δt be the time increment between data bytes as digitized by the analog-to-digital converter. K(w) is approximated by a Fourier series of base angle $\theta = w\Delta t$, i.e.,

$$K(w) \doteq K(w) = \beta_o + \beta_1 \cos w\Delta t + \beta_2 \cos 2w\Delta t + ---- + \beta_m \cos m\, w\Delta t,$$

where m is sufficiently high that the Fourier series is a "good" fit to K(w). What constitutes a "good" fit is a matter of

---

*A byte is a set of bits (about 6) representing in digital form a single sample of the photographic video signal. It is to be distinguished from a computer memory word, which usually contains several bytes or date samples.

engineering judgment and depends to some extent on how well (accurately) K(w) is known. The phase component must, of course, also be considered.

From this Fourier series approximation of the filter's desired power transfer function, the coefficients of the polynomial filter are determined. Filter design is a state-of-the-art technology, and many articles and books have been written on the subject.*

3.2.2 Vignetting and Transmissivity Correction

It is proposed that corrections for the vignetting effect discussed in paragraph 3.1.3, above, plus all three transmissivity effects discussed in paragraph 3.1.5, above, be combined in a single density-to-exposure correction. A simple polynomial approximation, or a table look-up, or both, might be used. The transmissivity effect is a non-linear but monotonic increasing function of exposure vs density which can be assumed to be the same everywhere over each photograph and from photograph to photograph. The vignetting effect, on the other hand, varies radially over each photograph, although photograph-to-photograph differences do not exist. The totality of these effects, and in the case of vignetting their variation over each photograph, must be measured or estimated to provide a basis for this correction step.

3.2.3 Blur Matrix Weighted Averages

The combined blur effects discussed in paragraph 3.1.4, above, can perhaps be best compensated for statistically by use of a weighted average matrix by the data processing computer. This involves associating a brightness value, to each spot of each photograph, which is a weighted average of the brightnesses of itself and several adjacent spots, the weights representing the average brightness intensity of a given spot which is blurred over to the adjacent spots.

The weighting coefficients, which form a two dimensional matrix, will vary from photograph to photograph and over different areas within each photograph, to reflect such variations in the various blur causes as discussed in section 3.1.4. The corresponding functional variations in these weighting coefficients, and the size of the matrix (how many adjacent spots to be used) must be evaluated in order for this portion of the processing computer program to be designed.

---

*See for example "Linear Data Smoothing and Prediction in Theory and Practice", Blackman, R. B., Addison-Wesley 1965.

It may be sufficiently accurate to use a constant weighting coefficient matrix, of dimension 20 x 20 or less, over each small photographic segment used as a processing unit (i.e., chit). However, the reasonableness of such an approximating simplification must be evaluated from calibration test measurements or a quantitative analysis of these several blur causes.

3.2.4 Readout and Lens Distortion Geometric Correction

Once the photographic brightness data has been modified to compensate for analog signal and photographic noise and blur effects, it is appropriate to compensate for the geometric bias distortions introduced by the photographic system. However, the best means of performing this geometric correction depends upon the configuration of the distortions, which must be determined from calibration test measurements or from engineering analysis of the system. Readout bias distortion probably involves horizontally symmetric distortions in each scan line of each framelet, plus vertical distortion in the positions of the several scan lines. Lens distortions, on the other hand, is apt to be irregular, depending on the position of the framelet in the frame.

3.3 Photographic System Calibration Requirements

In order for the several sources of noise and distortion in the Lunar Orbiter photographic system to be properly compensated for by the photographic data processing computer program, their effects must be quantitatively evaluated, either through calibration test measurements or by estimates based upon engineering analysis of the system. The order of magnitude of these several effects must be ascertained in order that an evaluation can be made as to which effects are sufficiently significant to warrant their compensation by the processing computer program. Then, for those noise effects which are significant, their actual values and variations must be quantitatively ascertained in order for proper design of the processing computer program logic and algorithm parameters.

Specifically, the quantitative specifications which are required are as follows:

(1) The total combined effect of the analog signal noise sources, expressed as a power spectrum over the bandwidth of the data signal. The ordinate of this spectrum, i.e., noise "power", must be related to the square of the units of the brightness levels digitized by the analog-to-digital converter,

which in turn must be related to the square of the units of film density as "seen" by the scanner and readout subsystem.

The analog signal noise sources to be thus filtered are:

(a) Film granularity

(b) Film scanner and read-out

(c) Signal modulator and transmitter in orbiter

(d) Deep space transmission

(e) Signal receiver and demodulator

(f) Analog tape recording and playback

(g) Analog-to-Digital converter

(2) The relationship of film density, as "seen" by the scanner and readout subsystem, to the lumens per unit solid angle (i.e., steradian), at the camera lens, of light reflected from the lunar surface. Vignetting effects must be expressed as a function of position in an exposure frame, and is required for both the high resolution and medium resolution lens subsystem.

(3) The combined blur effects discussed in sections 3.1.4 and 3.2.3, above. Blur is to be represented in units of a pure ratio of light energy per unit film area diffused from a single point (spot on an exposure frame) to adjacent spots in all directions about that point. How this two-dimensional spread function varies throughout an exposure frame must be ascertained for both the high and medium resolution subsystems. The dependence of blur due to improper lens focusing upon orbiter altitude above the lunar surface must also be known, if pictures are taken outside the nominal altitude.

(4) The combined geometric distortions of the exposure frame due to both the lens and the readout systems. Relative distances, within the exposure frame, of these distortions are required for both the high and medium resolution lens subsystems.

Validation of the computer program should be considered, in order to assure that the final implemented soft-ware system works properly. It is suggested that carefully prepared simulated photographic data be generated and used for this purpose. It is also suggested that Ranger lunar photographic data be obtained if possible, to a form similar to that of Lunar Orbiter data when encoded and read into computer memory, and the results compared with the JPL analysis of the same photographic data.

4.0 COMPUTER-BASED SYSTEM REQUIREMENTS

Processing of the Lunar Orbiter Photographic data for the computation of average Apollo landing hazard statistics in pre-selected candidate Apollo landing sites involves several stages of computer operations: photographic data read-in and selection, distortion and noise correction, brightness-to-topography conversion, and landing hazard statistics computation. An overall sequence chart of these computer operations is given in Figure III.

In the following paragraphs the major computer processing requirements of these stages are discussed. These requirements are presented in conjunction with a preliminary overall design of the computer-based system in order to provide a basis for an upper bound estimate of the cost and complexity of the required system. This preliminary design is based on a lack of complete system analysis and design optimization; in paragraph 5.0, below, the analysis and engineering studies, which must be made before the computer-based system can be fully implemented, are summarized.

4.1 Data Sampling Stage

The operations of the data read-in and selection stage are shown in Figure III. They are illustrated as being separate from those of the other stages, with different computers involved. This distinction is for illustration purposes only and need not actually be the case. However, the computer speed and memory capacity requirements of the operations of this first stage are considerably more stringent than those of the succeeding stages, and it might be necessary to perform these operations on two or more different machines in order to be able to procure the required computer operating time.

The following paragraphs outline the major technical aspects of this data processing stage.

4.1.1 Quantity of Photographic Data

The Lunar Orbiter photographic data system is described in Bellcomm, Inc. TM-65-1012-9, "The Lunar Orbiter Photographic Data Channel," by F. S. Flatow, November 1, 1965.

The data is transmitted as a frequency modulated analog signal representing scannings line by line, of narrow strips called framelets. Eighty-six framelets cover each high-resolution frame, and 26 framelets cover each medium-resolution frame, with five per cent overlap between adjacent framelets. Each framelet is represented by 17,000 scan lines from film edge to film edge, which contain both photographic data and header and edge strip portions of the orbiter film. Each scan line is transmitted in 1250 ± 13 usec, consisting of several μsec of line sync and other signal time followed by 1105 ± 11 μsec of photographic data. Adjacent framelets are read in opposite directions; i.e., from "bottom" to "top" or from "top" to "bottom", although each line of every framelet is read in the same direction, i.e., from "left" to "right". The entire file is read backwards from the direction of film motion during the photographic mission. Approximately 40 minutes is required for complete readout of each exposure (a high-resolution frame plus one medium resolution frame.)

For each Lunar Orbiter mission, enough film is provided for up to 196 exposures. The number of exposures taken of meaningful surface photography, however, is subject to the mission plan. Some film movement is required at least every 8 hours, due to constraints imposed by the film developing process, whether the film is exposed or not. Hence, the number of meaningful exposures per Lunar Orbiter mission will be less than 196.

Both the total amount of photographic data associated with each exposure, and the data rate during analog tape playback, are sufficiently high to preclude completely processing all of the data, or processing any data in real time, even with the fastest computer available today. For example, if the 1105 usec of data of each scan line is sampled and digitized at 620 kc, a total of $116 \times 686 \times 17{,}000 = 1.353 \times 10^9$ spots of photographic data is associated with each exposure, which includes $86 \times 686 \times 17{,}000 = 1.003 \times 10^9$ spots of high resolution photographic data. Within a reasonable amount of computer operating time, it is therefore feasible to at best process only a small amount of the total data (i.e.,only certain sampled or manually pre-selected small areas which appear to be of special interest or which reasonably form a sample representative of each exposure's total lunar surface area). Of course, the processing computer program logic should be quite flexible in terms of providing several options of sampling strategy. Since the data rate is so high, it is also necessary to process even this small percent of total data in two or more passes, the first pass being to select, read, and store on digital tape or drum the data to be processed, and the succeeding pass(es) to do the actual processing.

4.1.2 Data Sampling Rate Considerations

The rate at which the 1105 μ-sec of video signal is sampled and digitized by an analog-to-digital converter for computer processing has yet to be determined. Ordinarily, by a standard theorem in information theory, this rate must be at least at the "Nyquist frequency" of twice the highest frequency of the signal in order that all of the information contained in the signal can be preserved.

In this case, the signal is contained in a video spectrum of between 0 kc and 230 kc (i.e. a 230 kc bandwidth) which is transmitted in the form of vestigial sideband FM in a band of 80 kc to 390 kc with a suppressed subcarrier of 310 kc. Hence, if the signal, as demodulated, is sampled directly, the Nyquist frequency is 2 x 230 = 460 kc.

How much above the Nyquist rate the data must be sampled in order to best reconstruct the information in the signal depends upon the noise characteristics, which are not fully known at this time (see paragraph 3.1.7, below). A sampling rate as high as twice the Nyquist frequency is appropriate with some types of noise characteristics. On the other hand, it might be satisfactory in this case to sample at a rate lower than "that which best preserves the information contained in the signal".* To do so means that the resolution of the photographic data is degraded. However, some degradation might be permissible provided it is not such as to seriously affect the accuracies of the final landing hazard appraisal statistics computed by the program.

It is desirable to keep the sampling rate low, so as to keep low the number of "bytes" or picture elements per exposure or per processing subarea ("chit") which the computer must process. The lower be the sampling rate, the more be the "noise" (degradation of resolution) introduced by losing information in the sampling. But, a trade-off in the number of bytes per chit (and hence the computer operating time required for processing this data) and degradation in resolution due to

*When a sampling rate below the Nyquist rate is used, a filter should be used before the sampler, to prevent the high frequency energy from "folding over" into the low frequency band.

sampling, can be made. These tradeoff possibilities must be carefully studied before the choice of sampling rate and the decision of use of a fold-over filter can be made.

The following is a table showing the number of samples or bytes which will represent each 1105 usec line interval of data at each of several sampling rates under consideration:

Sampling Rate (kc)	Bytes Per Scan Line of 1105 ± 11 usec		
	(1105-11) usec	(1105) usec	(1105+11) usec
920	1006	1017	1027
780	854	862	871
715	783	790	798
690	754	762	770
620	679	686	693
460	504	508	513
400	438	442	447

A sampling rate of 715 kc, if satisfactory, has the additional "advantage" that the lunar surface area represented by each byte is "square." Specifically, for a camera altitude of 40 km, each high-resolution scan line "covers" a surface area of 0.241 meters in width and 191 meters horizontal. If a "square" surface area is to be represented by each byte, the sampling rate must be 715 kc.

4.1.3 Choice of Byte Size

The choice of byte-size, i.e. number of binary digits used to represent the signal power in each data sample (and hence the number of levels of brightness used to represent the data) depends mainly upon the average signal-to-noise ratio, and the data sampling rate. Experience with the Ranger photographs suggests a byte size of 5 or 6 bits. The rms signal-to-noise ratio of Ranger photographic data was measured at 35 to 40 db, and a byte size of 6 bits was used. 6 bits proved to be slightly inadequate; 7 bits would have been most appropriate. The signal-to-noise ratio for Lunar Orbiter photographic data, on the other hand, is expected to be lower, i.e. about 28 db. Hence, a 6-bit byte will certainly be adequate, and a 5-bit byte might be satisfactory. This should be carefully studied. Until this choice is made, however, a byte size of 6 bits will be assumed as appropriate.

In performing computations on the data, it may be necessary to use higher precision in intermediate steps to avoid excessive round-off errors.

4.1.4 Selection of Processing Subareas (Chits)

Since the total amount of photographic data per high-resolution frame is very large, processing is feasible only on a sampling basis. That is, only the data of several small lunar surface area units (called "chits") which represent a sampling of the entire exposure area can be processed in a reasonable amount of computer time.

Sampling of a candidate Apollo landing site for landing hazard appraisal depends on whether the subsequent processing is for support of site selection (screening of several candidate sites) or full evaluation of the finally selected site. In the latter case, full processing of all of the chit areas which cover the finally selected site should be done. For site screening, however, a sampling of chits in each candidate site should be sufficient.

Since statistical interpretation of the results shall be used for site screening, this sampling of each site by several chits should be such as to reasonably constitute a "random sampling." Ordinarily this would call for monte carlo randomization techniques to determine each sampling pattern, particularly if the area (candidate sites) data is structured or patterned in any way. But it is reasonable to assume, for this purpose here, that the lunar surface data is not structured, and that a patterned sampling of candidate sites by chits is satisfactory. A patterned sampling has the advantages of computational convenience and of providing assurance that all portions of each candidate site are equally sampled.

Hence it is recommended that for site screening purposes only chits of every n^{th} framelet (of the high-resolution coverage of each candidate Apollo landing site being appraised for screening) be processed, and only every n^{th} chit of each such framelet. In other words, a square grid of chits is the suggested sampling strategy. The value of n (5, 6, 7, 8, 9, or 10) should be chosen in accordance with the data read-in timing and buffer storage considerations discussed below, which in turn depend upon the data sampling rate which is used.

Three general criteria should be followed in choice of the size and shape of the chit processing subareas. First, a chit should be an area sufficiently small to permit computer processing as a unit (i.e., should be such that its data can be contained in the computer memory and whose total processing time is considerably less than the computer's mean free time between errors). Secondly, it should on the other hand be large enough to be a meaningful unit of photography as a basis for landing hazard appraisal (i.e., at least one order of magnitude larger than the area of the square defined by the four LEM feet.) Thirdly, it whould be of convenient size and shape for mosaicking, i.e., completely covering a larger area (for example, full coverage of the final selected Apollo landing site) by separate processing of several adjacent (slightly overlapping) chits.

The first criterion can be interpreted to imply that the total computer memory required to contain the chit data should be less than one core memory bank of 32,000 words. Assuming a packing of 6 bytes per computer memory word, this implies a total of less than 200,000 bytes.

The second criterion implies a chit whose smaller dimension represents at least 60 meters on the lunar surface for high-resolution data at a 40 km camera altitude.

The third criterion implies a rectangular (or square) shape, with the length (direction along scan lines) being an integer fraction (1, 1/2, 1/3, or 1/4, etc.) of the length of full scan lines plus 5% for overlap between adjacent chits of a mosaic coverage, and a length/width ratio not exceeding 3 (to limit the total perimeter length).

Based upon these criteria, the following table gives recommended chit definitions for each of the sampling rates considered in paragraph 4.1.2, above. These chit definitions are for high resolution data with a camera altitude of 40 km. A packing of 6 bytes per computer word is assumed. It is suggested that the same chit definition be used (in terms of number of bytes per scan line in width and number of scan lines in height) for medium resolution processing as high resolution processing).

	Sampling Rate (kc)	-	1240	920	780	715	620	460	400
	Bytes Per Scan Line (1105 usec)	-	1372	1017	862	790	686	508	442
Length of Chit	Fraction of Scan Line	1	1/2*	1/2*	1/2*	1/2*	1	1	1
	Number of Bytes	-	710	534	450	420	686	508	442
	Meters (High Resolution)	191	99	100	100	102	191	191	191
	Meters (Low Resolution)	1384	716	727	724	736	1384	1384	1384
Height of Chit	Number of Scan Lines	1	280	280	420	420	280	280	420
	Meters (High Resolution)	.241	68	68	105	105	68	68	105
	Meters (Low Resolution)	1.941	544	544	816	816	544	544	816
	Total Number of Bytes (thousands)	-	198.8	149.5	189.0	176.4	192.1	142.2	185.6
Number of Computer Memory Words	Total (thousands)	-	33.32	24.92	31.50	29.40	32.20	23.80	31.08
	Per Scan Line (1105 usec)	-	119	89	75	70	115	85	74
Number of Chits/Framelet	Along Vertical	-	66*	66*	44*	44*	66*	66*	44*
	Along Horizontal	-	2	2	2	2	1	1	1
	Total	-	132*	132*	88*	88*	66*	66*	44*
Byte Length/Height Ratio	High Resolution	-	0.577	0.780	0.920	1.00	1.15	1.56	1.79
	Low Resolution	-	0.519	0.702	0.828	0.894	1.04	1.40	1.61
Chit Length/Height Ratio (Lunar Surface Area)	High Resolution	-	1.45	1.47	0.95	0.97	2.81	2.81	1.82
	Low Resolution	-	1.32	1.34	0.89	0.90	2.55	2.55	1.70

*With at least 5% overlap between adjacent chits.

4.1.5 Buffer Storage Requirements

A computer word of 36 bits permits 6 bytes per computer word for initial storage, and the data should be read into the computer from the analog-to-digital converter assembled into such full 6-byte words to minimize data buffering requirements.

The input data rate places severe constraints on the capabilities of a computer to place into buffer storage all data of each of several chits being processed. In any one "run" (playback, analog-to-digital conversion, and computer read-in) to the video tape recording, not every chit can be completely extracted. If magnetic drums are used as buffer storage, the data of several consecutive chits could be stored,* up to the capacity of the drums available, after which no further chits can be stored until the drums are emptied by transfer to digital tape. If digital tapes are used directly as the buffer storage, at most every m^{th} chit can be stored, m being a function of the data sampling rate and chit size. Of course, all (consecutive) chits could be stored by making m "runs" with the video tape. Even then, however, only a fraction of all possible chits in a mission can reasonably be stored and processed; several thousand reels of digital tape and perhaps as many hours of computer time would be required for buffer storage and complete processing of all of the high-resolution photographic data of a complete Lunar Orbiter mission.

The table in paragraph 4.1.4, above, lists the total number of computer memory words required for chit data pertaining to various sampling rates. For example, considering a sampling rate of 715 kc and using 6-bit bytes, a total of 29,400 memory words are required per chit, being 420 blocks (scan lines) of 70 words each. If digital tape were used directly as buffer storage, the data would be read into memory in 70-word groups at the rate of 1250 μsec per group, but would be written out onto digital tape at a much slower rate. If tape records were also 70 words each, the maximum rate of recording would be 8.38 msec per 70-word tape record.** This leads to a value of m of 7.

---

*The exact timing of the chit transmissions must be carefully planned to avoid overwriting previous data, when magnetic drums are used.

**For the UNISERVO VIII-C tape units of the Univac 1108 computer, the tape record writing time is (4.00 + n/16) msec per record of length of n 6-byte words.

4.1.6 Framelet Sync Detection

The video tape being digitized does not contain framelet start (sync) information, although there is timing information on an auxiliary channel accurate to within the time of a few scan lines. In order for the computer to determine the beginning of a particular framelet in which it is to read the data of one or more selected chits, it must examine the edge data preceeding that framelet, perform some rudimentary pattern recognition logic to detect the first scan line of actual photographic data, and then count succeeding scan lines down to the desired chit's first scan line.

During this framelet sync logic, the 9-levels-of-gray film density calibration pattern must be detected and read for use in the subsequent photometric processing of the data. The logic required for this pattern recognition might be rather complex in either case. It is further complicated by the fact that adjacent framelets are scanned backwards, i.e., from "top" to "bottom" or from "bottom" to "top." This means that the edge containing this 9-levels-of-gray calibration pattern changes from framelet to adjacent framelet. It also means that the data of chits in the "backward-scanned" framelets must be read into buffer storage in backward line order to reverse it.

Manual input data required for this computer scan and read-in includes specification of the desired chits to be processed (or the chit selection strategy), the framelets containing these chits, the time during playback of these framelets, and which framelets are scanned "backwards."

4.2 Photographic Distortion and Noise Correction Stages

In paragraph 3.2, above, the requirements for photographic distortion and noise correction stages are explored, and several steps, logically related to the several noise sources identified in paragraph 3.1, above, are described. These steps are also shown in Figure III, interleaved with the data manipulation and interpretation steps necessary to produce the desired computer's outputs.

In actual practice, it might be practical to combine some of these steps. For example, the polynomial filter, vignetting and transmissivity correction, and blur matrix weighted averages stages discussed in paragraphs 3.2.1, 3.2.2, and 3.2.3, respectively, might be combined into a single moving two-dimensional weighted averaging step, the weights of which must be computed dynamically such as to implement in one step the total effect of the three steps taken separately. As another example, the camera tilt and surface sphericity distortion geometric correction step discussed in paragraph 3.2.5 might well be incorporated intrinsically into the process of integration of the photometric function, as is suggested in paragraph 4.4.3, below.

Nevertheless, these distortion and noise removal steps are treated in this memorandum as separate steps, to be done in a specific sequence, for several reasons:

(1) to keep logically separate the removal of brightness level noise effects from the removal of geometric distortion effects,

(2) to serve as a useful basis for the analysis work, recommended in paragraph 5.1, below, which is required to evaluate the need for and the proper extent of removal of each of the several individual noise effects, and

(3) to enable the determination of the proper filter coefficient values and the ways in which these coefficient values vary spatially.

4.3 Matrix-to-Contours Grid Conversion Stages

An algorithm may be required by which the computer will convert information defining a two-dimensional grid from matrix form to the form of a set of equal-value contour lines. For example, the output of the brightness-to-topography conversion stage discussed in paragraph 4.4, below, is a matrix of points in a grid covering a chit area, and a relative lunar geoidal elevation value associated with each grid point. An elevation contour map, however, is one of the desired visual outputs of the computer.

Contour map generation involves two-dimensional statistical smoothing of the values associated with each grid point, as well as a conversion of the grid information into a different form. One suggested approach to the design of such an algorithm would be to consider, along all grid lines in both directions, moving local successive groups of grid points, fit a simple polynomial to each group by standard least squares regression techniques, and solve such polynomials to determine the points along each grid line where the thrusly smoothed elevations cross an integer-valued elevation (contour interval) or reaches a local maximum or minimum. Then, given such an array of contour interval points, connecting neighboring points of equal contour interval values results in segmented lines comprising the desired contour line map. Of course, the degree of fineness of smoothing which can be done along each grid line, and the minimum reasonable size of contour interval which can be used, is severely constrained by the noise and jitter, both in grid point values and their geometric locations, which is intrinsic to the grid data itself.

Other approaches have been suggested and attempted. The formulation of contour line maps by computers is not a trivial task, and the algorithm to be used should be carefully optimized for this application. The degree of smoothing appropriate, and hence the order of such local polynomials, the number of successive points used for the regression fitting, the successive overlapping of successive moving groups, and the desired contour interval values must be studied and determined.

It might be the case that the noise in the data is to high to permit more than the crudest of contouring in some cases.

4.4 Brightness-to-Topography Conversion Stage

The ability of a computer to obtain local lunar surface elevation information from monoscopic orbital photographs is based upon a unique observed photographic property of the lunar surface: for a given angle between incident solar light and viewer (optic) axis, and for a given local rock darkness (albedo), the brightness of reflected light is very closely correlated with the component of the local slope gradient, relative to the viewing (optic) axis, in the plane defined by the light source (sun), viewer (camera lens), and local surface area. This dependence of brightness on slope has been extensively investigated, and a model for the functional form of the dependence has been empirically developed. (See references in (1).) Furthermore, this empirical lunar "photometric function" has been successfully applied to the Ranger photographs.[(2)]

Kosofsky[(3)] and Watson[(1)] have discussed applying such photometrics to lunar orbiter high-resolution photographic data with a computer to obtain local surface elevations. Along the lines of these discussions, the brightness-to-slope conversion stage of lunar orbiter photographic data processing involves the following steps.

4.4.1 Calibration Profiles from Stereographic Medium-Resolution Coverage

The lunar photometric function for determining local slopes from brightness values requires pre-known values of local surface albedo and yields slope components at each point on the lunar surface in one direction (i.e., along the "photometric plane" line defined by the intersection of the lunar surface with the plane determined by the sun, the orbiter camera lens, and the local surface point). Local relative elevations can be obtained by integrating, along each photometric plane line, the local slope values implied from photographic brightness values by the photometric function.

In order that local elevations thus obtained can be properly calibrated, some topographic information if available, even at a much lower level of resolution, should be used. Approximate elevations, along some of the photometric plane lines along which the photometric function is integrated, could be compared with the results of the numerical integration, to calibrate the

---

(1) Watson, Kenneth, "Photoclinometry From Spacecraft Imagery," U. S. Geological Survey Report (draft version dated February 1966).

(2) Rindfleisch, T., "A Photometric Method for Deriving Topographic Information," JPL Technical Report No. 32-786, September 15, 1965.

(3) Kosofsky, L. J., "Extracting Topographic Information From Lunar Orbiter Photographs", paper presented at the semi-annual Convention of American Society of Photometry, September 22, 1965, and to appear in March 1966 issue of "Photogrammetric Engineering".

value(s) used for local albedo. In fact, such comparison could possibly lead to reasonable estimates of how local albedo varies over each area of interest (i.e., chit of high resolution data). Also, approximate elevations along paths which cross the several photometric plane lines of slope integration could be used to properly relate the elevations along the integration lines with each other to complete the local topography in all directions. The computer operations involved in this calibration are discussed in paragraphs 4.4.4 and 4.4.5 below.

Processing of lunar surface photographic data from the Ranger missions did not involve such calibration, because the required approximate elevation data did not exist (see Rindfleisch, op. cit.). A single constant albedo value was assumed to be applicable over the entire area of each photograph; the single average value used was that obtained from earth-based photographic coverage of the overall lunar surface area in which the area of the Ranger photographic coverage lies. No corrections were made or could be made for albedo variations within each photograph's area. Also, the fitting or smoothing of elevation values computed along adjacent photometric plane lines of integration was not nor could not be calibrated with observed overall cross topography.

In the case of Lunar Orbiter photographic data processing, however, local relative elevation information exists and can be extracted from the medium-resolution photographic data by stereographic analysis. Hence, it is recommended that elevation profiles from the medium-resolution photographic data be obtained, fed into the computer, and used as a basis for the above-discussed high-resolution topographic calibration.

The requirements for medium-resolution elevation profiles is illustrated by Figure IV. Check profiles are required along several paths, all of which converge at the zero phase point (shadow, on the lunar surface, of the camera lens). Cross profiles are required along several paths which are approximately perpendicular to the check profiles. The several check (also cross) profile paths should be spaced between 30 and 80 meters, which is sufficiently close to assure several of each crossing any chit being processed, and sufficiently apart to be consistent with the inherent resolution of the medium-resolution frames used for stereographic examination. The profile paths should completely cross the area covered by the high-resolution frame being analyzed, unless it is known with certainty that certain subareas of the high-resolution frame will never be processed.

The data representing each check and cross profile must be in a form which can be inserted into the computer. The beginning and end points of each profile path must be specified, either in the local coordinate system defined by the high-resolution frame, or in a local coordinate system which can be related by the computer to the high-resolution frame. This coordinate system need not, for this purpose, be that of a lunar surface mapping grid; relative locations only are needed. Also, elevations at various points along each check and cross profile need only be relative to the elevation at the beginning point of the profile; absolute elevations in a lunar surface mapping grid are not of concern to Apollo landing hazard appraisal. Along each profile relative elevation values can be given at equally spaced intervals, or only at points where relative elevations are integer numbers of meters, or in other forms as convenient.

Note: The accuracy of such stereo profiles in areas of overlap between medium-resolution framelets (from which the medium-resolution frames are assembled) is questionable and should be investigated in terms of the above use of these profiles locally within a high-resolution chit area.

4.4.2 Reconstruction of Surface Reflectivity

Before the computer can properly integrate the lunar photometric function along photometric plane lines, the light reflectivity of each local surface "spot" as actually "seen" by the camera lens must be reconstructed from the byte numbers encoded by the analog-to-digital converter. This reconstruction, the several steps of which are outlined below, involve the noise correction steps discussed in paragraphs 3.2.1, 3.2.2, and 3.2.3, above, plus a conversion from film exposure to surface reflectivity. The actual computer algorithm used for this reconstruction should combine these steps where applicable. Background information for this latter conversion is found, for example, in JPL Technical Report 32-384, "Ranger Preflight Science Analysis and the Lunar Photometric Model", Herriman, A. G., Washburn, H. W., and Willingham, D. E., revised March 11, 1963.

Step 1: Reconstruction of film opacity from the byte values associated with each film "spot". This step involves statistical correction of the byte values data stream to remove much of the effects of analog signal noise which occurs during scanning, signal modulation, transmission, demodulation, tape recording and play-back, and analog-to-digital conversion (encoding). See paragraphs 3.1.7 and 3.2.1, above, for discussion of such noise sources and their "removal". This step further involves relating byte values, statistically corrected for analog signal noise, to local film spot average opacity. This relationship is a function of the characteristics of the scanner optics and photocell and must be accurately known.

Step 2: Reconstruction of film exposure from film opacity. This step involves the transmissivity of the film and the film granularity characteristics. See paragraphs 3.1.5, 3.1.6, and 3.2.2, above, for discussion of such reconstruction.

Note: The second part of Step 1 and this Step 2 require exposure calibrations based on the 9-levels-of-gray calibration edge data on the film, since the film transmissivity function varies from framelet to framelet. For each framelet, the associated exposure calibration function must be determined from such edge data, to determine the film exposure to byte values relationship which applies throughout that framelet.

Step 3: Reconstruction of light intensity at lens from film exposure. This step involves removal of the exposure and geometric distortions of the photographic image which are introduced by the lens system, such as vignetting and lens blur (lens spread function) effects. It also involves proper conversion of units, i.e., from film exposure values in such units as meter-candle-seconds, averaged with respect to light wave length over the sensitivity spectrum of the film, to light intensity at the lens, in such units as meter-candles, likewise averaged over the sensitivity spectrum of the film. Vignetting and lens blur effects and their corrections are discussed in paragraphs 3.1.3, 3.1.4, 3.2.2, and 3.2.3, above. The proper exposure to intensity units conversion factor must be ascertained through analysis of the lens system and from lens system calibration test results. Furthermore, if the light source used to generate the 9-levels-of-gray edge data, which is used to relate byte values to exposure values, has a power spectrum quite different from that of solar light in the same wave length region of film sensitivity, then this difference must be taken into account in ascertaining this necessary units conversion factor.

Step 4: Reconstruction of surface reflectivity from light intensity at lens. This step is geometric and requires knowledge of the range of the orbiter lens from the local lunar surface areas. For an orbiter altitude of about 40 km, a single average value of this range probably can be used for all spots in a given chit without introducing significant errors, to avoid iteration of this step with the integration of the photometric function discussed below for precise local range computations. This step involves reconstruction of the average intensity of light reflected by a local surface area "spot" in the direction of the camera lens from the light intensity at the lens. It also involves knowledge of the solar light intensity incident on each local lunar surface area "spot" averaged over the sensitivity spectrum of the film. This is assumed to be a constant for a given orbiter mission, to be determined; strictly speaking it is a function of the sun-moon distance, which in turn depends upon the season of the year and the phase of the moon at the time of the mission.

4.4.3 Integration of the Photometric Function

Integration of the photometric function of reflectivity-to-slope correspondence gives, for specific albedo values, profiles of surface elevation along "photometric plane" line paths. Specifically, these surface elevation profiles are in terms of relative camera-lens-to-surface variations, rather than in terms of elevations relative to a lunar geoid. Hence a geometric conversion of such relative range profiles to relative* geoidal elevation profiles is necessary. One current reference for the details of this photometric function integration is the U.S.G.S. report by Kenneth Watson, "Photoclinometry From Spacecraft Imagery," draft version dated February 1966.

Elevation profiles obtained by such integration of reflectivity values are only along paths, called "photometric plane" lines in the above discussions, which cross each chit area in such a manner as to converge toward the "zero phase point," i.e., the point of "shadow" of the camera lens on the lunar surface. This "zero phase point," for most lunar orbiter missions, will lie well outside the areas photographed, as illustrated in Figure V. These "photometric plane" lines will, for the orbiter missions currently planned, be directed approximately perpendicular to the scan lines, i.e., forming angles between 70° and 110° with the scan lines. It is suggested that across each chit area the number of "photometric plane" lines of reflectivity-to-slope integration be such as for approximately one-meter spacings; one-meter spacing is consistent with the intrinsic accuracy (resolution) of the high-resolution photographic data and yet will provide sufficiently "fine-grained" elevation data for subsequent LEM landing hazard appraisal calculations.

It is important that the computer algorithm used for locating such "photometric plane" lines and for determining the reflectivity values along each line be optimized with respect to computer operating time. The approach is to locate each "photometric plane" line geometrically, and to determine surface

---

*Relative, for example, to the (unknown) geoidal elevation of the beginning point of each profile.

reflectivity values along each line by interpolating from nearby brightness values. Another approach is to distort the reflectivity matrix representation of the chit area geometrically from the scan-line, orbit-motion coordinate system to a coordinate system formed by the scan lines and the "photometric plane" lines directly.

4.4.4 Albedo Calibration by Check Profiles

Since the photometric function relating surface reflectivity to local slope is highly sensitive to albedo, its integration requires accurate knowledge of the proper local albedo values. An average albedo value for the overall area covered by each high-resolution frame can be obtained from earth-based photographs taken at full moon and must be available to the computer as a basis for this photometric computation. Local variations in albedo values within the surface area of each chit can be ascertained, however, only by use of the check profiles discussed in paragraph 4.4.1, above. Along each check profile, the photometric function is initially integrated using the overall averagw albedo value of that chit's area. The resulting elevation profile is then compared with the check elevation profile, and the major discrepancies between the two sets of elevations, attributed to local albedo value variations, are obtained, possibly involving iteration of two or more photometric function integrations along each check profile, each time using best-guess-so-far albedo variation values, associated with local regions of the chit area, to be used during integration of the photometric function along all of the "photometric plane" line paths.

A common indexing system is required to permit combination of photogrammetric data with photometric data. Since the photogrammetry will be accomplished using the low resolution frames and the photometry will ultimately use the high resolution frames, the natural co-ordinate systems are quite different. Manual cross indexing of critical tie-points, based on the lunar surface imagery will probably be required.

4.4.5 Topography Calibration by Cross Profiles

Elevation profiles obtained by the above methods do not by themselves give a complete topography of the entire surface area of each chit. Elevations along each "photometric plane" line, relative to the elevation of the beginning point of each line, must be calibrated across the several "photometric phase" lines. This can be done by use of the cross profiles discussed in paragraph 4.4.1, above.

The cross profiles present low-resolution elevation data along each cross profile path, relative to the elevation of the beginning point of each cross profile path. Applying least squares statistical estimation techniques to the discrepancies, at the points of intersection of cross profile paths and "photometric plane" lines, between the elevations values of the cross profiles and those of the photometric function integrations, estimates of the relative* elevations of the starting points of the "photometric plane" lines can be

---

*Relative to average elevation of the chit area.

determined. This completes the chit area topography determination in two-dimensions. From this topography data, relative elevation contours can be obtained, as discussed in paragraph 4.3, above, for subsequent use in LEM landing hazard appraisal calculations.

4.5 Hazard Statistics Computation Stage

Appraisal of Apollo LEM landing hazards based upon surface topography shall be in terms of two ways in which the astronauts and the ascent stage could possibly be damaged during a LEM landing: toppling over; and being jolted by a surface protuberance violently crushing the landing thrust engine or the heat shield. Whether or not such damage is actually encountered during any specific LEM landing depends upon several unknown factors: the terrain confuguration in the landing area, the velocity vector of the LEM upon first contact with the surface, the lunar surface soil characteristics, and the mass and location of the center of mass of the LEM-ascent stage system upon contact.

Little is known at this time* about the lunar surface soil characteristics in candidate Apollo landing sites. For this reason an adequate model for prediction of landing dynamics is not available, even though this problem has been and is being intensively studied.** Hence, sufficient information does not exist to permit design of a computer program to produce, from Lunar Orbiter photographic data, an overall a priori probability of a landing catastrophe.

Nevertheless, some statistics are proposed, for the computer program to compute by a simulation procedure, which should be quite useful in manual evaluation of candidate landing sites. Based on a monte-carlo simulation of several LEM landings, in a high resolution chit area whose topography has been ascertained by the procedures discussed above, two types of "hazard factors" are suggested: one type simply reflecting the final tilt of a LEM once landed, and one estimating the amount of crushing of the LEM main landing thrust engine cone by a surface protuberance. The ways in which these two factors can be related to landing hazard probabilities cannot be fully evaluated until soil mechanics data is obtained of the lunar surface and it is known to what extent the lunar surface is non-yielding. At such a time, the results of landing dynamics studies, such as by Bendix* and by others (Bellcomm, MSC), will enable proper interpretation of these two hazard factors to landing hazard probabilities.

---

*Surveyor 1 data is not used in this report.

**See for example Bendix Report MM-64-8, October 1965, "Final Report of Lunar Landing Dyanmics Systems Investigation."

4.5.1 Static Landing Tilt Hazard Factors

For each simulated LEM landing, the elevations of the surface points corresponding to the four LEM feet define two possible planes of final LEM at-rest position. For the more tilted of these two planes, two tilt angles should be determined: The greatest of the four tilts considering as axes of tilt the edges of the square formed by the LEM feet; and the greater of the two tilts considering as axes of tilt the diagonals of this square. These two "edge tilt" and "cross tilt" hazard factors depend solely on the elevations of the four LEM feet landing points for each simulated landing, and do not take into account possible landing dynamic characteristics nor soil characteristics such as sinkage or slip.

4.5.2 Vertical Bottoming Hazard Factor

For each simulated LEM landing, the elevation of the surface point at the center of the square formed by the four LEM feet, relative to the elevation of the center of the stable square diagonal (the intersection of the possible at-rest LEM feet planes) should be determined. If this center-point elevation is sufficiently high to crush the LEM descent engine skirt beyond design limits, possible damage to the ascent stage through jolting might occur. Hence the amount of descent engine cone crushing, assuming a hard surface, is a meaningful quantity for each simulated LEM Landing. The highest point under the heat shield should also be determined (relative to the steepest tilt plane).

4.5.3 Dynamic Landing Factors

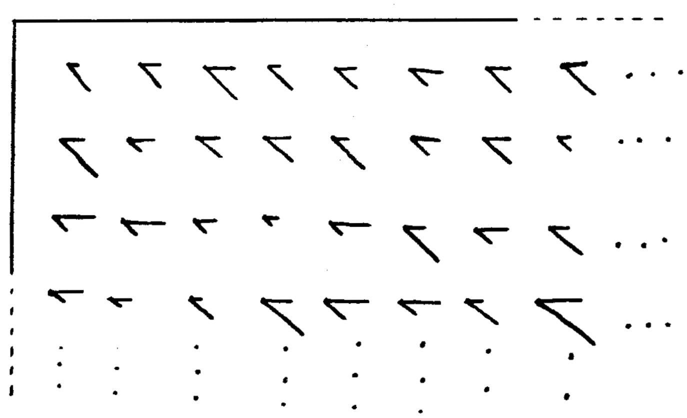
At the time of this writing, our knowledge of lunar soil characteristics (load bearing strength, composition, etc.) is insufficient to design a refined, realistic model for the computer to evaluate dynamic landing hazard factors. Hence, any model used in the early version of the computer program will of necessity be based on landing dynamics assumptions which might turn out to be incorrect. Nevertheless, it is important that as soon as lunar surface soil mechanics data becomes available, full landing dynamics must be evaluated at least to the point where the relationships between the above two static landing hazard factors and landing hazard probabilities are ascertained.

4.5.4 Hazard Statistics Outputs

Desired outputs of the computer relating to landing hazards are of three types, as follows:

(1) Optional printouts, for each of the simulated LEM landings in a chit, of the following: (a) location of the simulated LEM landing in the chit (see Paragraph 4.5.5, below); (b) orientation of the simulated LEM landing relative to the chit coordinate axes (see Paragraph 4.5.5, below); (c) edge tilt factor (see Paragraph 4.5.1, above); (d) cross tilt factor (see Paragraph 4.5.1, above); and (e) vertical bottoming hazard factors (see Paragraph 4.5.2 above).

(2) A plot of the chit area showing, at each spot where several LEM landings were simulated, the worst values of the edge and cross tilt factors of the several simulated landings; (short vectors whose length indicates magnitude of tilt factor are suggested, such as illustrated by:)



Also at each simulated landing spot, it is suggested that the worst values of vertical bottoming hazard factor and dynamic landing hazard factor be indicated in numerical form.

(3) Using the results of all of the simulated LEM landings in a chit area, plots of histograms of the several hazard statistics listed in (1) above, with the median and upper 95-percentile values indicated on each histogram plot in numerical form.

4.5.5 Simulated Landings Sampling Structure

The proposed simulation of LEM landings and the associated landing hazard factor computations shall be done on a per-chit-area basis, with the primary output being estimates of the median and upper 95-percentile values of the seven hazard factors listed above, for all landings considered in a given chit area. Strategies for sampling chits in a larger lunar surface area under investigation (i.e., a candidate Apollo landing site) are discussed in Paragraph 2.3, above.

Within a given chit area, it is proposed that several LEM landings be simulated, with the location and orientation of these simulated landings in the chit area such as to constitute a "random sample" reasonably well to form a basis for statistical estimates of the above identified landing hazard factors.

Ordinarily, monte carlo randomization techniques would be required, for determining the simulated landing locations and orientations, in order to assure that statistically the results will indeed reasonably represent a random sample. This would be particularly true if there is any probability that the original data being sampled (the lunar surface topographic data in this case) is structured or patterned in any way.

In this case, however, it is reasonable to assume, for the purpose of selecting simulated landing locations and orientations, a total absence of patterned structuring of lunar surface topography, and to ignore the patterned structuring of the data due to the data system noise effects not removed by the filtering techniques suggested in Paragraph 3.2, above. Under this assumption that the data itself is intrinsically randomized, then monte carlo sampling techniques are unnecessary: a patterned sampling of the chit area will result in what might be reasonably considered as a "random sample". This being the case, then a patterned sampling of the chit area has the additional advantages of computational convenience and assurance that all subareas of each chit are equally weighted (sampled) in contribution to the statistical estimates of the seven landing hazard factors described above.

It is therefore recommended that a patterned structure of locations and orientations of simulated LEM landings in a chit area be used. It is suggested that several locations be chosen in an $\underline{n}$ by $\underline{n}$ rectangular grid covering a chit area, and at each location the six orientations of 0°, 15°, 30°, 45°, 60°, and 75°, relative to the rectangular grid, be used. This results in $6n^2$ simulated LEM landings per chit area. Values of n between 6 and 50 are suggested.

Other sampling patterns may be preferable, and the choice of the pattern, orientations, and value of n should be analyzed, taking into consideration the LEM physical dimensions relative to the intrinsic accuracies of the topographic data being sampled.

4.6 Visual Outputs

Several visual outputs of this Lunar Orbiter photographic data processing are desired for each chit. These visual outputs, being reconstructed photographs and plots of lunar surface characteristics, could conveniently be obtained through the use of a SC4020 microfilm plotter or equivalent, and are of value in both landing site selection and final landing site analysis. These visual outputs are:

1. a reconstruction of the chit photography after the noise and distortion effects discussed in paragraphs 3.1.2 through 3.1.7, above, are removed (see Paragraph 3.2.1 through 3.2.4 and 4.4.1 and 4.4.2).*

2. An elevation contour map of the chit area (see Paragraph 4.3).

3. the chit area vector diagram and histogram plots, discussed in Paragraph 4.5.4, above, of LEM landing hazard statistics.

In addition to these visual outputs, the computer should produce, for printout, indications of when key milestone stages in the processing are reached and the key data generated and available at these milestone stages. Also to be printed out should be the seven LEM landing hazard factors, discussed in Paragraph 4.5, above, for each of the several simulated LEM landings in each chit area (see Paragraph 4.5.1, Section 1), above. Milestone indications should be printed directly on-line. Data printouts should be made off-line with optional selections by the computer operator.

---

*This type of output requires grey tone reproduction. The SC 4020 does not have such a capability; hence a different camera display system will be needed.

4.7 Operating Procedures and Manual Data Insertion

Exact formats of all data to be manually inserted into the computer, and detailed procedures for operating the computer-based system for Lunar Orbiter photographic data analysis, can be specified only as the computer program detailed design is completed. However, the following paragraphs briefly list the major types of data to be inserted and some of the major operational features which will be required.

4.7.1 Manual Operations Prior to Computer Analysis

Manual operations prior to computer analysis are discussed in Paragraphs 2.2, 2.3, and 4.4.1, above. Briefly, these operations are:

(1) Development and assembly of photographs reproduced at the DSIF sites by the ground recording equipment (GRE's).

(2) Demodulation and re-recording of analog (video) tapes of orbiter-to-earth photographic data signal, <u>or</u>, if original analog tapes are not available from the DSIF's, generation of tape-recorded digitization of the photographic data through the use of a microdensitometer on the assembled photographs.

(3) Determination and specification of the chit areas to be analyzed by computer processing.

(4) Assembly, and preparation for computer insertion, of the orbiter mission data required for the computer data processing.

(5) Obtaining, from stereographic analysis of the low-resolution photographs, of the check and cross profiles required for photometric function albedo and cross topography calibration.

4.7.2 Data Input and Sort Computer Pass

The computer-based system requirements for this stage of data processing are described in Paragraph 4.1, above. Briefly, the operating procedures involved are:

(1) Insert into the computer the mission data, specification of chits to be processed, and check and cross profile data. Required mission data include orbiter altitude above lunar surface at time of photography, angle relative to local gravitational vertical of the optic axis, the solar incident light angle at the lunar surface, average albedo value for the chit's surface area, timing information, and calibration data of the camera lens system. The sun-moon distance might also be required.

(2) Play analog (video) tape signal through analog-to-digital converter into computer, which reads, sorts, performs preliminary noise filtering on, and stores on digital tape the data of the chits to be processed and the mission and profile data associated with each chit.

4.7.3 Topography and Hazard Computations Computer Pass

This stage of data processing is done on a per-chit basis. For each chit, the data, stored on digital tape (or drum) as a result of the preceeding stage, is read back into the computer for the remainder of noise filtering, conversion to topography, and determination of the desired hazard statistics. If the mission and stereographic profile data applicable to a particular chit's analysis is not read in the previous stage and stored on digital tape along with the chit's photographic data itself, then it must be read in this stage. Manual operating procedures of this stage involve monitoring the computer's operation, calling for the operational printouts as desired, and processing the visual outputs (microfilm pictures and plots).

If options are available to the operator for parameters or alternate algorithms for some of the computations of this stage, those options must, of course, be specified to the computer.

5.0 RECOMMENDATIONS FOR ANALYSIS AND DEVELOPMENT

Before such a computer-based system as outlined in this memorandum can be fully implemented, much analysis work is required to determine which aspects of the noise filtering is required, what algorithms are appropriate, what refinements in the mathematical models underlying those algorithms can be made, and what the data sampling rates, contour intervals, and simulated LEM landing sampling pattern should be. In the following paragraphs these required analyses are recapitulated. Then, the recommendation is made that this analysis be done in parallel with computer program implementation to minimize the calandar time to final system acquisition.

5.1 Analysis Requirements

Five general areas of computer program design are identified as requiring engineering analysis, before full program development can be completed:

5.1.1 Data Sampling Rate and Byte, Chit Sizes

The most appropriate rate at which the analog-to-digital converter samples and encodes the incoming analog (video) photographic data stream (see paragraph 4.12, above), together with the choice of byte size (see paragraph 4.13, above), and the choice of chit size, shape, and sampling strategies (see paragraph 4.14, above), must be studied and ascertained. The optimum sampling rate, usually somewhat higher than the Nyquist rate, depends upon the signal-to-noise ratio of the signal, the character of the signal and noise, and the processing to be done on the sampled data in digital form. Hence this problem is closely related to the filter design discussed as follows.

5.1.2 Noise Filtering

Evaluations must be made of the need for, and the proper extent of, removal of each of the several individual noise effects discussed in paragraphs 3.1 and 3.2, above. This requires determining, through calibration tests on the photographic system, the characteristics and magnitudes of each of these several noise sources in terms of errors in the final landing hazard statistics to be computed by the computer. This also involves estimates of computer operating time required for removal of various percentages of the effects of each of these noise effects. Then, tradeoffs must be made as to just how much of each of these several noise effects shall be removed by the computer.

Generally, the more of the effects of a particular noise source is removed, the more is the required computer time. Hence, tradeoffs are possible between computer time and filter effectiveness. Compromises are possible, for example, in: the number of "A," "B," and "C" terms used in the digital polynomial filter (see paragraph 3.2.1, above); or in how many points, both horizontally and vertically, are used in the blur matrix weighted averages (see paragraph 3.2.3, above). These tradeoffs of computer time for noise removal should be made in terms of the level of errors introduced in the final landing hazard statistics by not completely removing each particular noise effect.

NOTE: This analysis of the required noise filtering should also be done for the eventuality that analog (video) tapes of the photographic data are not available, and a microdensitometer, scanning assembled photographs, is used instead as a means of digitizing the photographic data for insertion into the computer. Since the resolution of the photographic data will be worse with microdensitometer scanning (as it must be in order to avoid pattern interference between the original scan lines and those of the microdensitometer), the noise characteristics, and hence appropriate filtering, will be quite different.

5.1.3 Calibration of the Photometric Function

The technique of determing lunar surface slope gradients from photographic reflectivity, as discussed in paragraph 4.4, above, represents a new technology and is at a threshold of state-of-the-art. For example, the exact form of the photometric function, and the character of variations in appropriate albedo values, are not known as yet at the 1-meter level of resolution. Hence the appropriateness of using the current versions of the photometric function (obtained from earth-based lunar photography) and chit-wide average albedo values, as discussed in paragraph 4.4.3, must be evaluated. Also, the algorithms which are optimum for albedo calibration by check profiles (see paragraph 4.4.4, above) depend upon how albedo varies at high resolution.

This required calibration of the photometric function may require actual data from the first lunar orbiter and surveyor missions. Calibration of the photometric function at medium-resolution could be done with the Orbiter's first mission data, by directly comparing check profiles from stereographic examination of the medium-resolution frames with the same profiles by integrating the photometric function with the same (medium-resolution) data. Calibration of the photometric function at high-resolution could be done by comparing local topography as ascertained by Surveyor with profiles of the same local area as computed with the current version of the photometric function from the high-resolution data.

5.1.4 LEM Toppling Hazard Factor

The landing hazard factors of a LEM toppling or bottoming upon landing suggested in paragraph 4.5, above, is based upon a model of landing dynamics which in turn is based upon incomplete knowledge of lunar surface characteristics. As soon as such knowledge is acquired, either from the Luna or as a result of Surveyor, this model, or perhaps even the entire concept of dynamic landing hazards, should be evaluated and modified accordingly. The meaningfulness of the factors suggested above as computed from the photographic data of the early Lunar Orbiter missions should also be evaluated when possible.

5.1.5 Other Algorithms

Total computer operating time is a significant consideration in the design of the computer program for the above-discussed Lunar Orbiterphotographic data processing. Some analysis work will be necessary to optimize several of the key processing algorithms, lest operating time per chit be excessive.

Examples of key processing algorithms which should be optimized are as follows:

(1) Framelet sync detection (see paragraph 4.1.3.

(2) Framelet 9-levels-of gray edge data detection and read (see paragraphs 4.1.3 and 4.4.2).

(3) Vignetting and transmissivity correction (see paragraphs 3.2.2 and 4.4.2).

(4) Blur matrix weighted averaging (see paragraph 3.2.3).

(5) Elevation contours from grid of values, if required (see Paragraph 4.3)

(6) Cross and check (stereographic) profiles data storage and access (see paragraphs 4.4.1, 4.4.4, and 4.4.5).

(7) Determination of paths of integration of photometric function and surface reflectivity values along them (see paragraph 4.4.3).

(8) Iteration of photometric function integration for local albedo variations (see paragraph 4.4.4).

(9) Topography calibration across photometric profiles (see paragraph 4.4.5).

(10) Static landing tilt hazard factors computation (see paragraph 4.5.1).

(11) Vertical bottoming hazard factor computation (see paragraph 4.5.2).

(12) Simulated LEM landings sampling strategy (see paragraph 4.5.5).

5.2 Development Recommendations

It is anticipated that the first successful Lunar Orbiter mission will provide photographic data to be analyzed, for guidance to the Surveyor project, prior to the time the computer-based system discussed above can be fully implemented. It will be over a year after the first Lunar Orbiter mission, however, before the processing of the data from the latter missions for final Apollo landing site evaluation is done. Not all of the features of the above described computer-based system are manditory for the first Orbiter mission, and it would not be a serious handicap to Apollo landing site selection and evaluation if some of the features were not available until late in the Orbiter mission series.

It is therefore recommended that the required analysis effort discussed above be done in parallel with the computer program development effort, and that the computer program be developed in two stages. For example, it is suggested that the initial version of the computer program be limited to data read-in and sort, reflectivity-to-topography conversion, and static landing hazard statistics computation, with no noise filtering, and with no photogrammetric calibrations *via* cross and check profiles (i.e., assume a constant albedo value over each chit's area). (It is important, however, that any such initial version of the computer program be designed and implemented such as to avoid much reprogramming when the necessary subroutines for the noise filtering and photogramnetric calibrations be added later on.) Then when the required analysis effort has resulted in the design of optimum algorithms for noise filtering, photometric calibration, and dynamic landing hazard factor determination, the appropriate subroutines should be added to the computer program to form the second version of the computer-based system for use in final Apollo landing site selection and evaluation.

This recommendation is based, not only upon procurement considerations (which are indeed severe constraints on the computer program development), but also on the fact that experience in use of the initial version of the computer program in processing the photographic data of the first successful Lunar Orbiter mission will be necessary for the completion of some of the required analysis effort discussed above. For example, final evaluation of the adequacy of the proposed model for photometric function integration must be based upon comparisons of medium resolution photographic data elevation profiles produced by stereographic examinations with those produced by the computer with constant albedo assumptions. Also, experience of actual computer operating time for processing of each chit's data will be useful in making some of the necessary algorithm design tradeoffs such as algorithm complexity vs extent of noise filtering, contour line spacings and number of simulated LEM landings vs accuracy of final results, etc.

6.0 SUMMARY

Photographic data from the Lunar Orbiter project is expected to play a major role in Apollo landing site selection. Stereographic examination of the medium resolution photographs and manual examination of the non-stereoscopic high resolution photographs will result in much information concerning average slope gradients and uniformities of local areas of the lunar surface. Nevertheless, the computation of Apollo landing hazard statistics (average tipping and other damage probabilities) for tentative landing sites requires computer analysis, inasmuch as the amount of computation involved precludes manual means. Also, the removal of noise and distortions introduced by the Lunar Orbiter photographic and telemetry systems requires computer processing.

Such computer processing of Lunar Orbiter photographic data is feasible with current state-of-the-art computers. The input data rates are relatively high, and the amount of processing to be done per photograph is relatively large. Hence, the extent to which such computer processing of Lunar Orbiter data can be done in support of the Apollo project depends on the throughput capabilities of the computers used. If a computer is used of the capabilities of, for example, the Univac 1108, Burroughs 5500, CDC 6600, IBM 360/75, or GE 645, a sufficient amount of processing can be done sufficiently rapidly to be of value to Apollo.

A computer based system, employing a computer of such a throughput capability, is proposed to process Lunar Orbiter photographic data in support of Apollo. The processing includes data sampling, noise and distortion correction, brightness-to-topography conversion, and average Apollo landing hazard statistics determination. Such processing could be of value both in preliminary screening of tentative landing sites and in providing the Site Selection Board with landing hazard data for consideration in final site selection. Detailed topographic information, for use by the astronauts, of the actual landing site may also result from this processing.

The procurement of the computer program(s) required for this processing is by no means a trivial task. Many aspects of the processing requirements explored herein must be analyzed in detail, and much algorithm design optimization is necessary. It is proposed, however, that a certain specific amount of the programming be started immediately and done in parallel with such analysis in order to shorten somewhat the total length of time required for development. It is estimated that the total effort required for this procurement, including specification of requirements, analysis, design, coding, debugging, checkout, and documentation, will be between 20 and 35 man years.

Burt H. Liebowitz/for

1031-CSS C. S. Sherrerd

REFERENCES

The following documents are referenced in this memorandum:

1. Bendix Report MM-64-8, "Final Report of Lunar Landing Dynamics Systems Investigation", October 1964.

2. Flatow, F. S., "The Lunar Orbiter Photographic Data Channel", Bellcomm, Inc., TM-65-1012-9, November 1, 1965

3. Kosofsky, L. J., "Extracting Topographic Information from Lunar Orbiter Photographs", paper presented at the semi-annual convention of American Society of Photometry, September 22, 1965, and to appear in March 1966 issue of "Photogrammetric Engineering".

4. Rindfleisch, T., "A Photometric Method For Deriving Topographic Information", JPL Technical Report No. 32-786, September 15, 1965.

5. Watson, Kenneth, "Photoclinometry From Spacecraft Imagery", U. S. Geological Survey Report (draft version dated February 1966).

6. Leibowitz, M. A., "A Procedure for Reducing the Time Required for the Digital Processing of Photographs", Bellcomm, Incl, TM-65-1012-4, August 25, 1965.

Other documents which might be of general interest to the reader include:

1. The Boeing Co. Report D2-100293-1, "Picture Data Systems Analysis", December 7, 1964.

2. Bundick, W. T., Green, C. H., and Brummer, E. A., "The Lunar Orbiter Telecommunications System", NASA-LRC Report, Draft version November 2, 1965.

3. Herriman, A. G., Washburn, H. W., and Willingham, D. E., "Ranger Preflight Science Analysis and the Lunar Photometric Model", JPL Technical Report No. 32-384, Revised version March 11, 1963.

4. Kosofsky, Leon J., and Broome, G. Calvin, "Lunar Orbiter: A Photographic Satellite", NASA-LRC Report, presented at the Spring Convention of the Society of Motion Picture and Television Engineers, March 28-April 2, 1965.

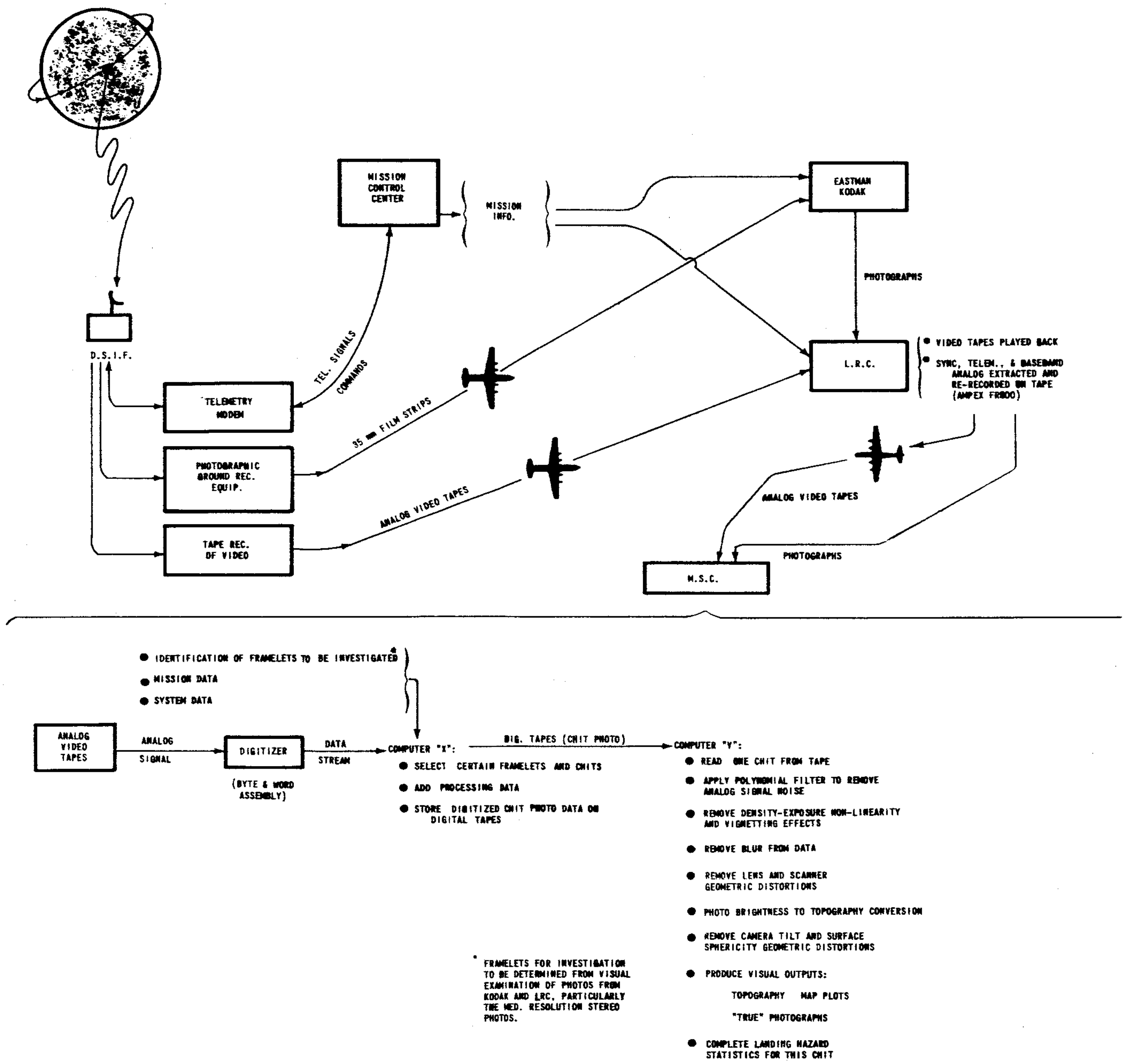
5. Lloyd, D. D., and Fudali, R. F., "Lunar Orbiter Mission Planning", Bellcomm, Inc., TR-65-211-1, January 25, 1965.

6. Nelson, C. H., "Summary of Photographic Data System Calibration, Lunar Orbiter Project", NASA-LRC Report, February 25, 1966.

7. Taback, I., and Brummer, E. A., "The Lunar Orbiter", NASA-LRC Report, presented at the AIAA Unmanned Spacecraft Meeting, March 1-3, 1965.

FIGURE I

LUNAR ORBITER PHOTO DATA ANALYSIS FOR APOLLO LANDING HAZARD APPRAISAL



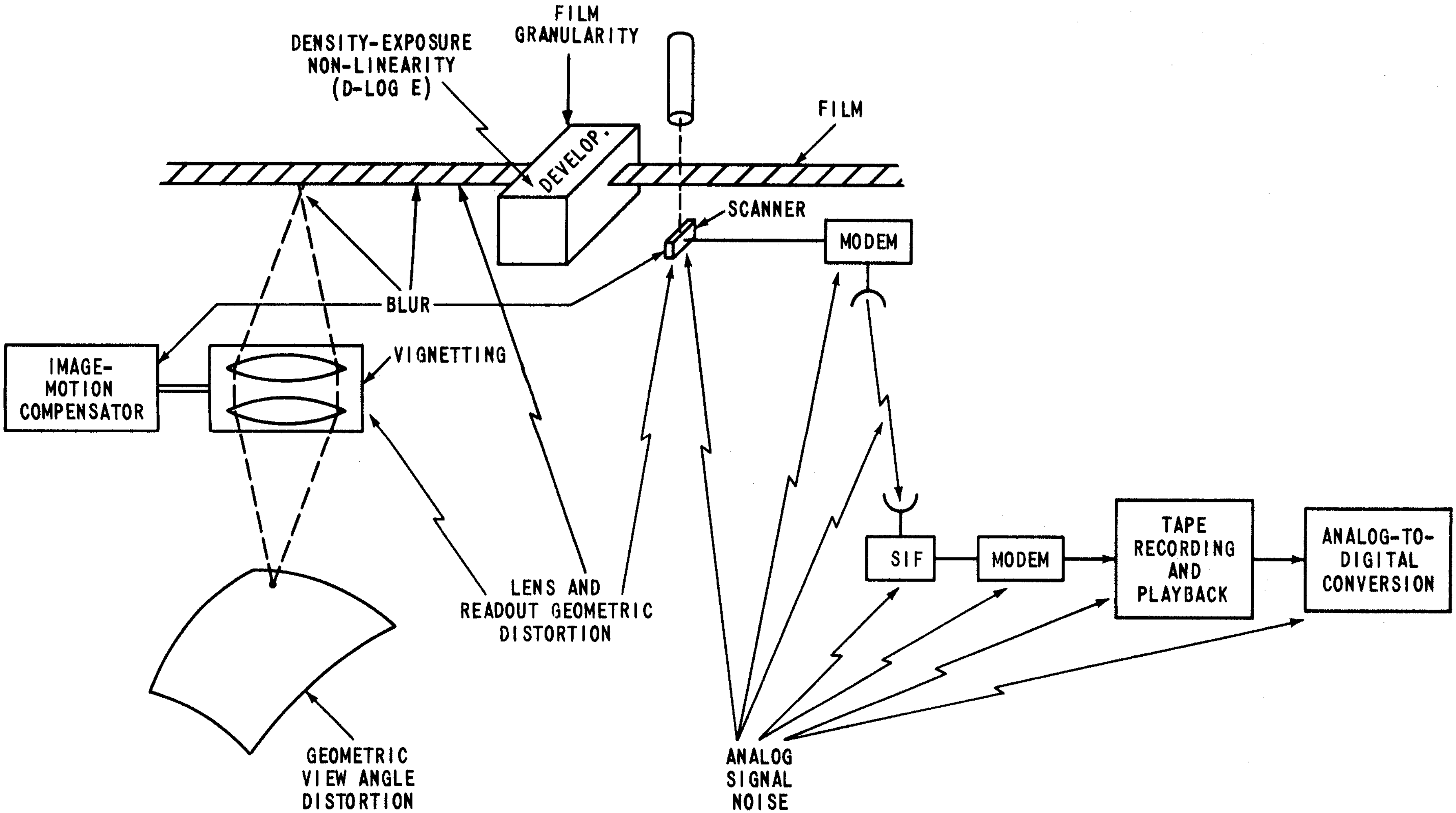


FIGURE II-MAJOR PHOTOGRAPHIC DISTORTION AND NOISE SOURCES

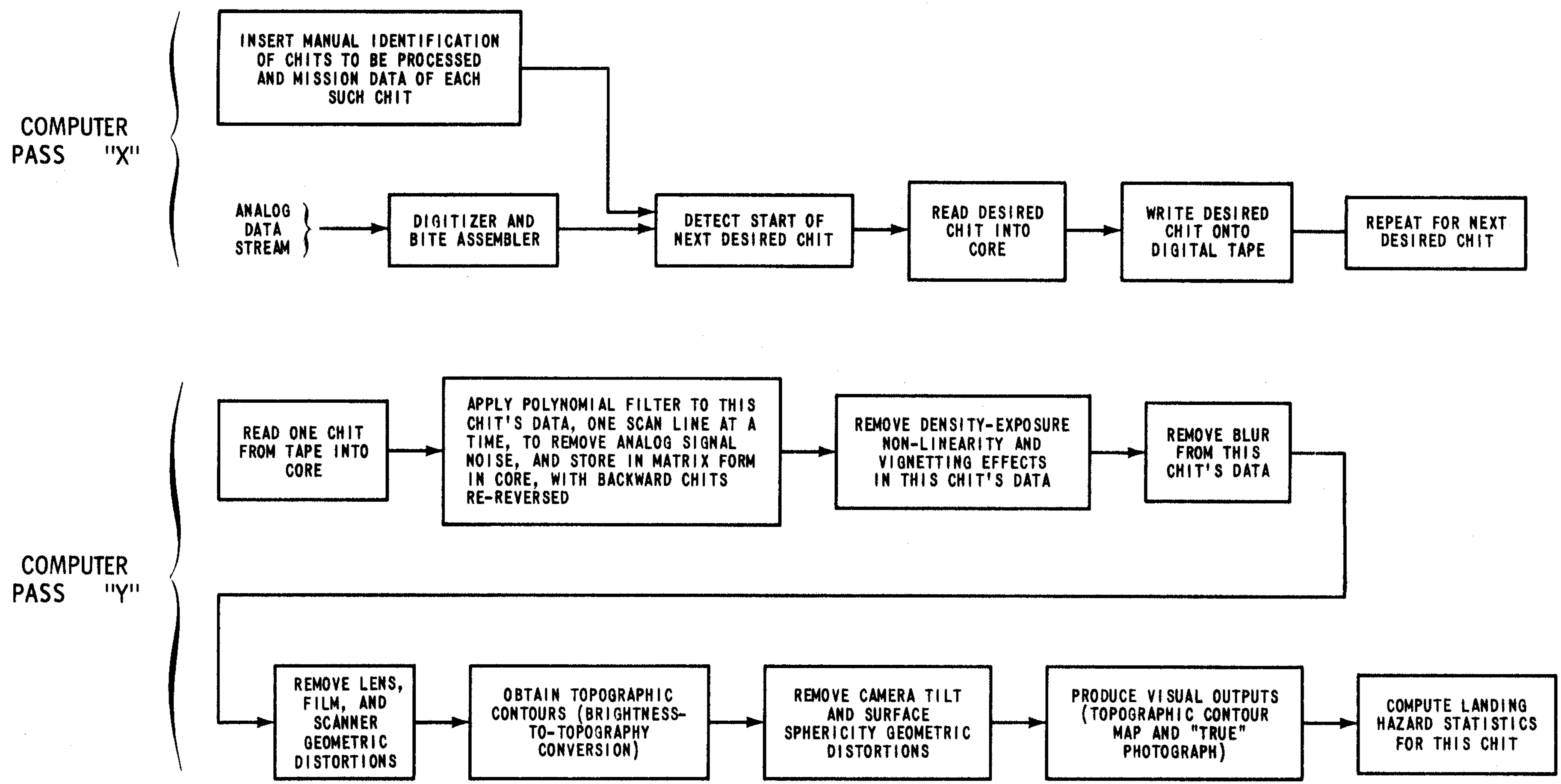


FIGURE III – COMPUTER - BASED DATA PROCESSING OVERALL SEQUENCE CHART

FIGURE IV - REQUIREMENTS FOR MEDIUM - RESOLUTION (STEREOGRAPHIC) CROSS AND CHECK ELEVATION PROFILES

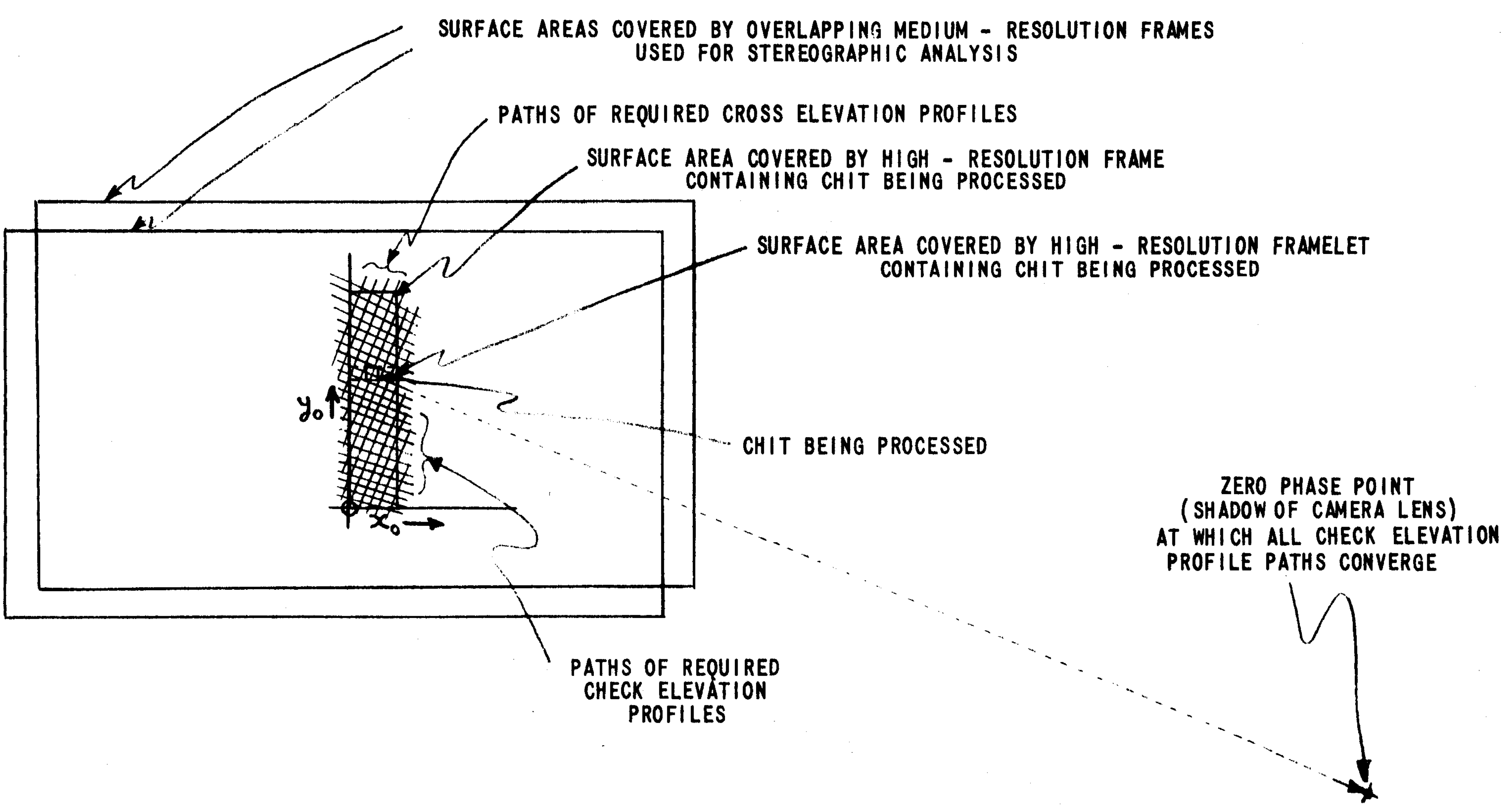
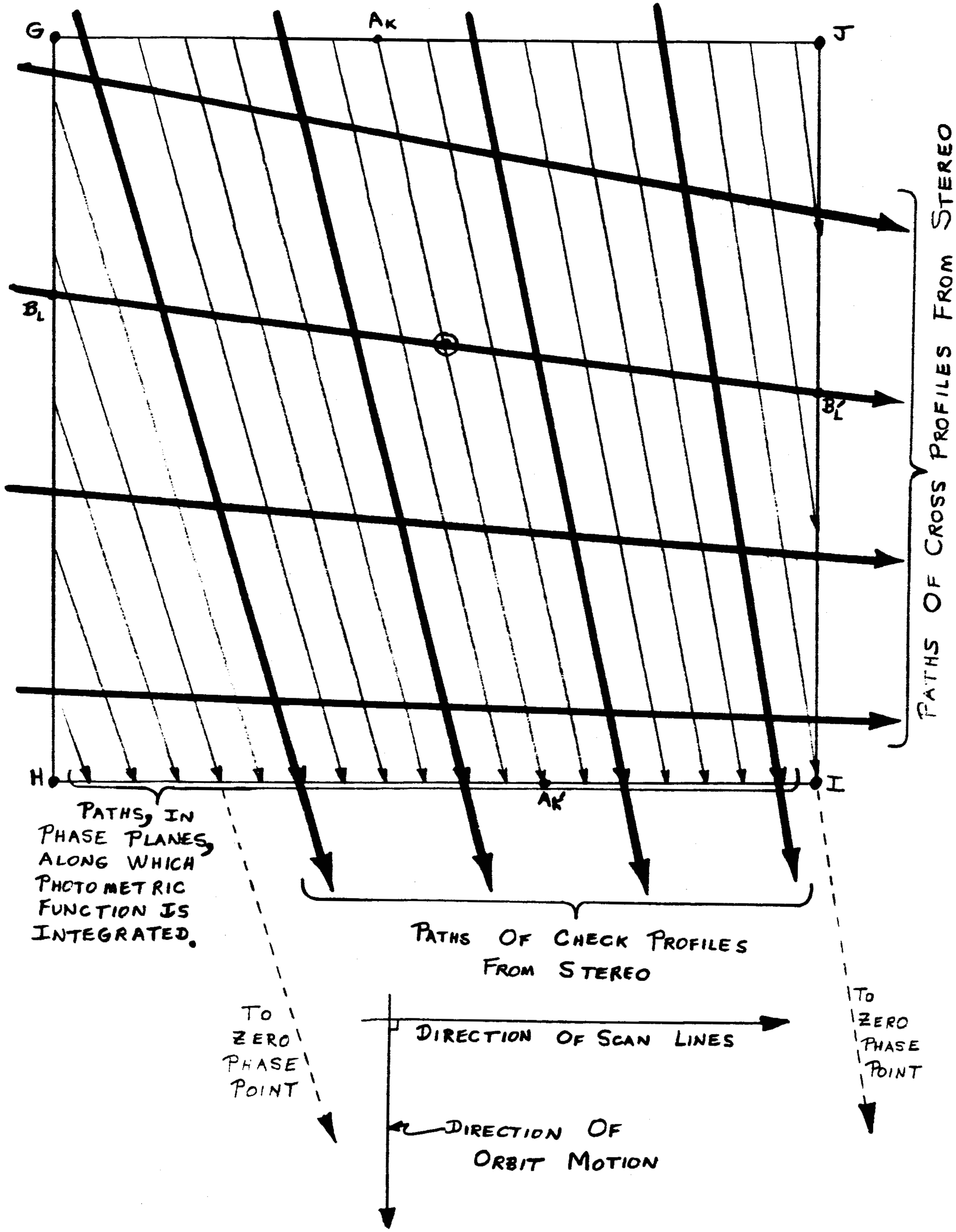


Figure V

GEOMETRY OF SURFACE-REFLECTIVITY-TO-TOPOGRAPHY CONVERSION



CBB 11 March 66