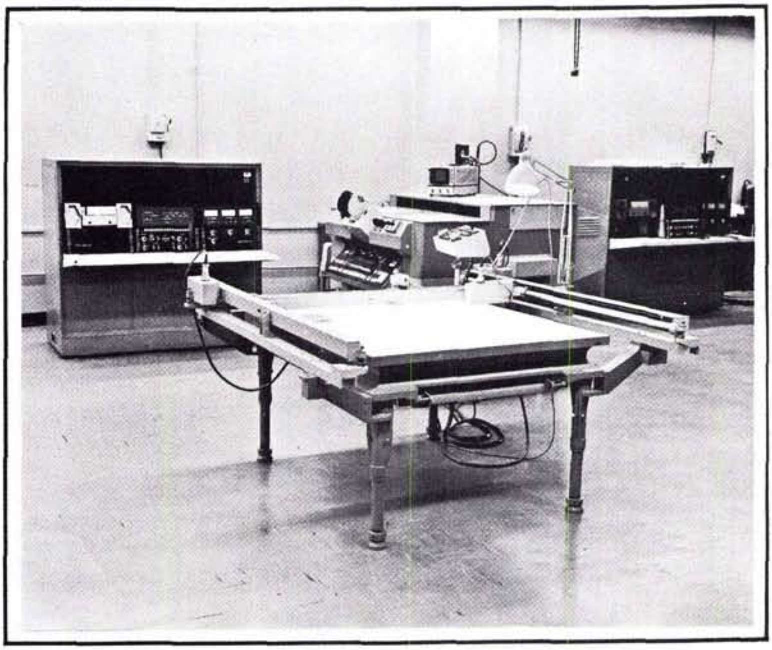

FIG. 1. Analytical plotter system used in the stereophotogrammetric reduction.

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Compilation of Lunar Pan Photos

A large-scale topographic chart is produced using convergent panoramic photos and the analytical stereoplotter.

(Abstract on page 76)

INTRODUCTION

APOLLO 15 generated a vast amount of high-resolution panoramic photography which cannot be readily utilized on conventional stereoplotters to extract topographic information. In order to demonstrate the feasibility, versatility, and accuracy achievable from this panoramic material on the AS-11B1 analytical stereoplotter[1], a stereophotogrammetric compilation of a large-scale (1:25,000) topographic chart was performed.

The AS-11B1 system shown by Figure 1 has many unique properties that enable it to handle many non-standard photogrammetric applications. These properties are:

- Ability to compensate for panoramic geometry,
- Real-time digital computer,
- Wide range of focal lengths,
- Automated stereoplotting,
- Offset model capability and
- Model deformation coefficient correction.

Thus the plotter system is capable of handling a wide range of photography from vertical frame photographs to convergent panoramic photographs. The convergent panoramic photographs do not need to be transformed or rectified prior to use in the AS-11B1 plotter. The plotter can also correct for: lunar curvature, film shrinkage, lens distortion, image motion, vehicle motion, and stereo model deformation.

Compilation Area

The compilation area selected was over the landing site of Apollo 15. It contains rugged mountains, a flat plain, a depressed rille, and various size craters. Such a wide variety of differing relief would demonstrate the capabilities of the AS-11B1 with the lunar panoramic photographs whereas the topographic chart could be used to document the surface activities of the Apollo 15 crew.

Test Materials

The photographs selected were taken from the Scientific Instrument Module (SIM) bay of Apollo 15[2] and judged to be the best representation of the Apollo 15 Lunar Module (LM) landing site as regards the light and shadows falling over the landing area. The density of the high-light and shadow areas is very critical as it is not possible to contour very dark or very bright areas because these areas show little or no information. The materials selected for this compilation, Figure 2, shows that five panoramic and two frame exposures were used to form the required models. The scale of the panoramic photography was approximately 1:170,000 and that of the frame was approximately 1:1,382,000.

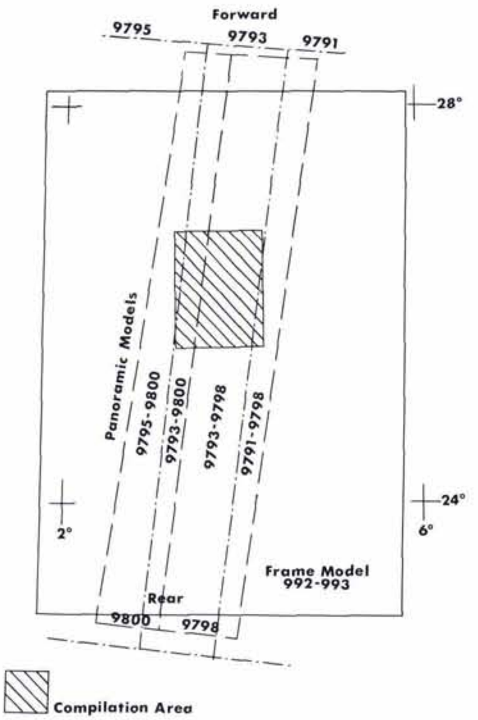

FIG. 2. Photo index showing panoramic and frame model coverage over compilation area.

1. *Panoramic photographs.*
   Forward exposures 9791, 9793, 9795.
   Rear exposures 9798, 9800.
   Revolution Number 27.
   Focal length 609.608 mm (24 inches).
   Flying height 105.127 km.
   Convergent angle 12.5 degrees.

2. *Frame photographs.*
   Exposures 992, 993.
   Revolution Number 27.
   Calibrated focal length 76.080 mm (3 inches).
   Flying height 105.127 km.

Figure 3 shows the compilation area of panoramic exposure 9793 whereas Figure 4 shows that of frame exposure 993.

Production Process

The production process consists of the segmentation of panoramic photographs and stereo-model development. It is necessary to segment the panoramic photography in order to obtain a film positive of a usable dimension.[3] The panoramic photo is $4\frac{1}{2}$ inches wide and 45 inches long. The stage plates for the AS-11B1 plotter are 9 inches wide by 18 inches long. Therefore, it is necessary to segment the panoramic photo in the long, or Y-direction, and to allow for some overlap between segments for control purposes. Figure 5 shows how the panoramic photographs were segmented. Contact film positives were used for their geometric and high-resolution qualities.

The stereo compilation was developed in two stages. First, the frame model was oriented to a TOPOCOM 1:250,000-scale map. Secondly, control for the panoramic model was derived from the frame model. Figure 6 shows this relationship. This approach was necessary due to the lack of any reliable absolute control over the selected landing site and the need to provide a control-point distribution suitable for panoramic model adjustments.

Prior to establishing the frame model, it was determined that a real-time reseau correction should be applied to each photograph through the AS-11B1 computer in order to minimize residual systematic error. The real-time reseau correction program consists of two parts. The first part provides for measuring and recording the coordinates of a calibrated grid or reseau[4] as shown in Figure 7. The second part allows the computer to calculate and output corrected values of a selected matrix of points. The cor-

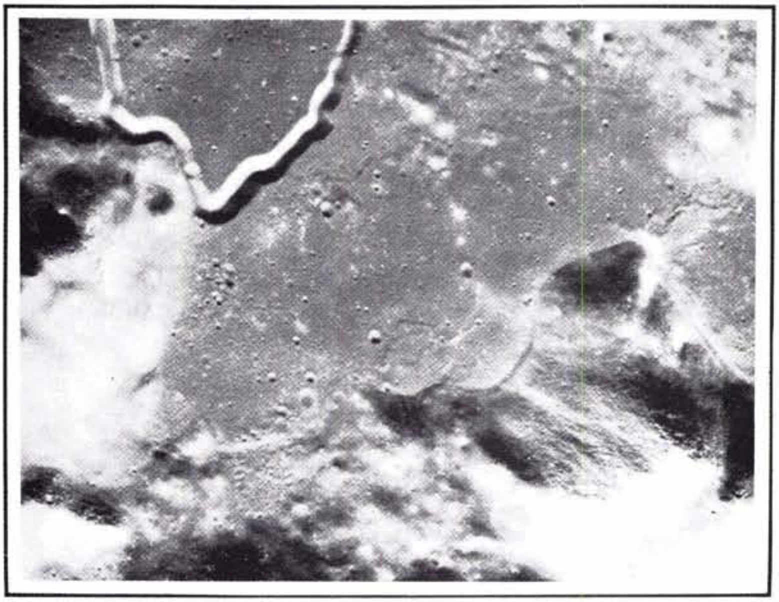

FIG. 3. A portion of a panoramic photograph over the compilation area.

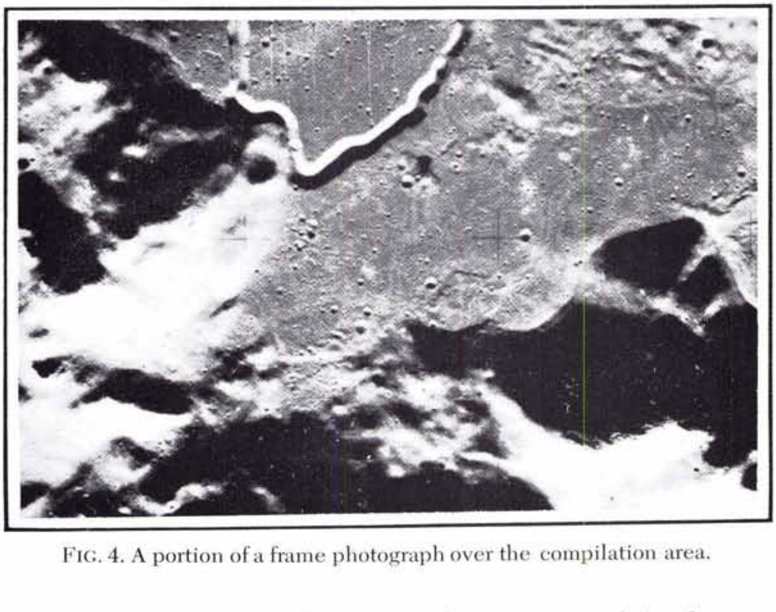

FIG. 4. A portion of a frame photograph over the compilation area.

rection utilizes on-line linear interpolation between points and the correction is applied in real time. The real-time reseau correction may be used in addition to or instead of other corrections.

A relative orientation was performed and the frame model was analyzed as to its quality. The resolution of the model was very good and the illumination of the surface was judged to be adequate with very little loss due to shadows.

The geometry of the frame system provided a vivid stereo model. The pointing precision of the instrument and the operator was initially determined by making repeated readings. This precision was calculated to range from 5 to 7 meters on the lunar surface.

Lacking any reliable absolute control, the frame model scale was controlled by the calibrated focal length and the flying height given by the laser altimeter. The TOPOCOM

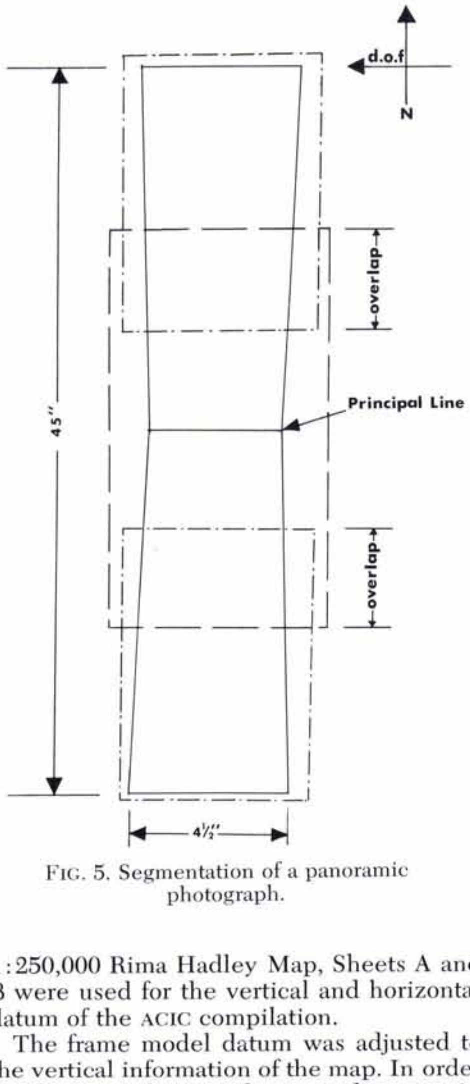

FIG. 5. Segmentation of a panoramic photograph.

1:250,000 Rima Hadley Map, Sheets A and B were used for the vertical and horizontal datum of the ACIC compilation.

The frame model datum was adjusted to the vertical information of the map. In order to derive selenographic coordinates, 11 prominent features were read in the model and identified on the source map. An off-line computer was used to perform a linear conformal adjustment. This adjustment rotated and translated the frame model into the same system as the source map. Detail points common to the frame and panoramic models were then read in the frame model and derived into this same system. These frame-derived detail points were then used as control for the panoramic models.

To establish an interior orientation of the segmented panoramic photography, it is necessary to identify an offset principal point, Figure 8, as a distance function for the AS-11B1 Plotter. Because panoramic photography has a principal *line* and not a principal *point*, it is necessary to identify the center of the image area on the principal line as being the principal point. The distance from the center of the segmented photo to the *so called* principal point is the offset distance and is identified as such to the AS-11B1 Plotter.

A relative orientation was performed with the panoramic photo pairs and the models were scaled and leveled to the frame-derived control.[5] Detail points from the frame model were then read in the panoramic models and an off-line computer was used to perform a non-conformal linear adjustment. This adjustment generated model deformation coefficients which would orient the panoramic models into the frame control system.

It was necessary to orient four stereopanoramic models in the above manner to cover the desired compilation area. Frame-derived control points were chosen such that they were common to adjacent stereo models.

COMPILATION

The Apollo 15 LM landing site, near Hadley Rille, was topographically compiled on a transverse mercator projection (source

ABSTRACT: *The Aeronautical Chart and Information Center has performed a stereophotogrammetric reduction of Apollo 15 panoramic photographs using the unique properties of the AS-11 Analytical Plotter System in a large-scale topographic compilation. A production process segments the panoramic photographs into a dimension usable by the plotter although maintaining the high resolution characteristics of the photographs. The relative orientation technique is employed for stereo-model development and off-line computational techniques are used for adjusting the stereo model to selected selenodetic control. A statistical method is used for evaluating the topographic information without the benefit of the ability to perform a field check.*

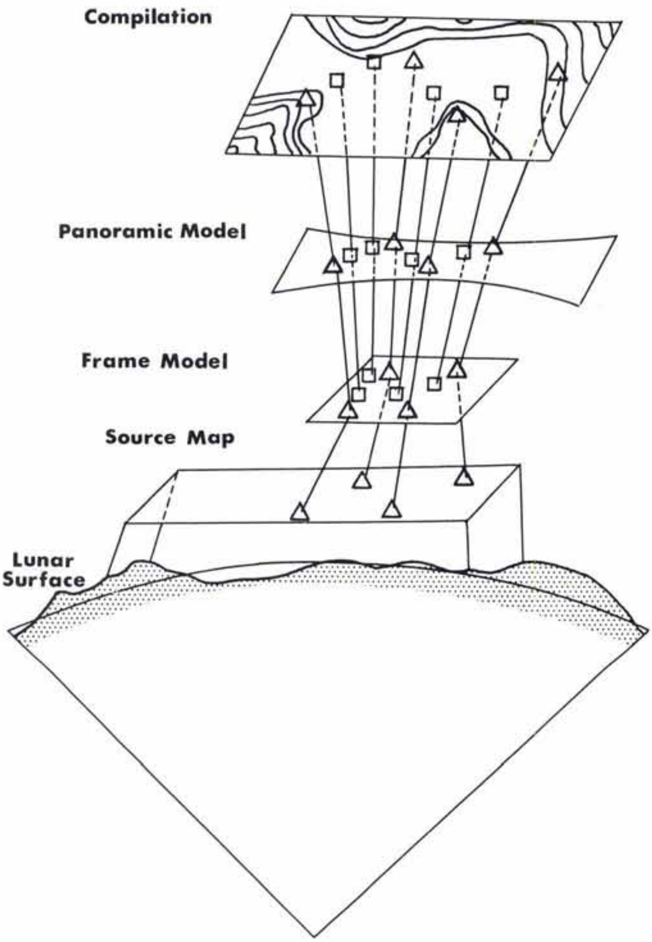

FIG. 6. Development of compilation control.

map system) at a scale of 1:25,000 with a 20-meter contour interval. Eighty percent of the compiled contours were drawn utilizing the automated capabilities of the AS-11B1 Plotter.[6] The compilation that was not compiled automatically was due to either (1) a loss of slope information in the very flat plane or (2) loss of cross correlation in the relief areas from the very brilliant sunlight. A 100-meter contour interval would have been adequate to portray the slope of the terrain. Many spot elevations were used to depict the flat plain and depression contours were used to depict craters.

The contour base was composited on an orthophoto generated on a AS-11A/Gigas Zeiss, Figure 9, utilizing 2× frame material.[7] The AS-11/GZ-1 output was enlarged to the compilation scale. Prior to the generation of the orthophoto it was anticipated that a great amount of small detail would be lost from the final product. As seen in Figure 10, the loss was minimal.

EVALUATION

An evaluation, or accuracy statement, is important for knowing the reliability of the position of features upon measuring those features. The evaluation would normally contain two parts, one, the relative accuracy and, two, the absolute accuracy of features. The relative accuracy describes the relationship of features within the borders of a chart or a specific area. The absolute accuracy describes the relationship of features when evaluated with respect to a selenodetic datum. We can talk here only of the relative accuracy due to the lack of any reliable absolute control.

One system for estimating the relativity of map features both vertically and horizontally is presented next.

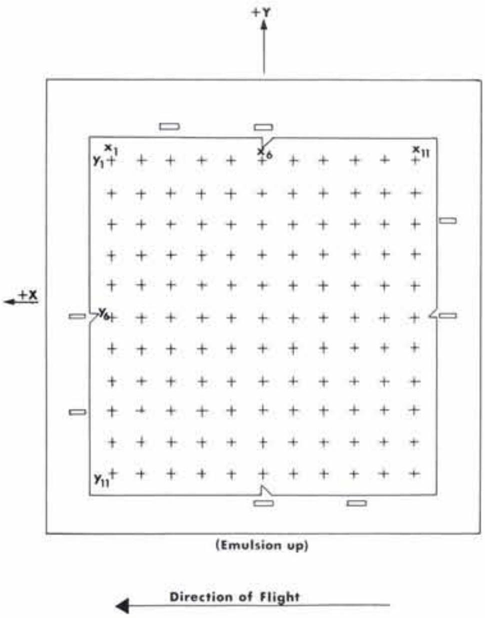

FIG. 7. Calibrated grid used on frame photographs.

VERTICAL

1. The vertical relative accuracy of features to the compilation datum is given by the formula,

$$\sigma_3 = \sqrt{[(\sigma_{RP})^2 + (\sigma_{CE})^2 + (\bar{\sigma}_{CI})^2]}$$

where σ_{RP} is the repeatability or random pointing, σ_{CE} is the random reading contour evaluation or vertical plotting precision, $\bar{\sigma}_{CI}$ is the average from off-line computation of relative vertical evaluation of center point of model. This is the vertical reliability between four models. For example,

$$\sigma_3 = \sqrt{[(3.6)^2 + (9.7)^2 + (12)^2]}$$

$\sigma_3 = \pm 15$ meters at 90 percent probability.

2. The point-to-point relative vertical accuracy (± 21 meters) of feature-to-feature can be approximated by multiplying the above found value σ_3 by the square root of 2.

HORIZONTAL

1. The horizontal relative accuracy of features to the compilation datum is given by the formula,

$$\sigma_{HR} = \sqrt{[(\sigma_P)^2 + (\bar{\sigma}_{CI})^2 + (\sigma_{AI})^2]}$$

where σ_P is the horizontal plotting accuracy, $\bar{\sigma}_{CI}$ is the average of off-line computation of relative horizontal evaluation of center points of model. This is the horizontal reliability between four models.

$$\sigma_{AI} = \tfrac{2}{3}|\sigma_I - \sigma_C|$$

where σ_I is the largest magnitude of a point near the outer edge of the compilation as evaluated by the off-line adjustment of the frame model to the scaled control, σ_C is the magnitude of a point near the center of the compilation as evaluated by the off-line adjustment of the frame model to the scaled control. As an example,

$$\sigma_{HR} = \sqrt{[(20)^2 + (14)^2 + (5)^2]}$$

$\sigma_{HR} = 25$ m at 90 percent probability.

2. The point-to-point relative horizontal accuracy (35 meters) of feature-to-feature can be approximated by multiplying the above found value σ_{HR} by the square root of 2.

CONCLUSION

It has been demonstrated that it is possible to produce a large-scale topographic chart over the lunar surface utilizing conver-

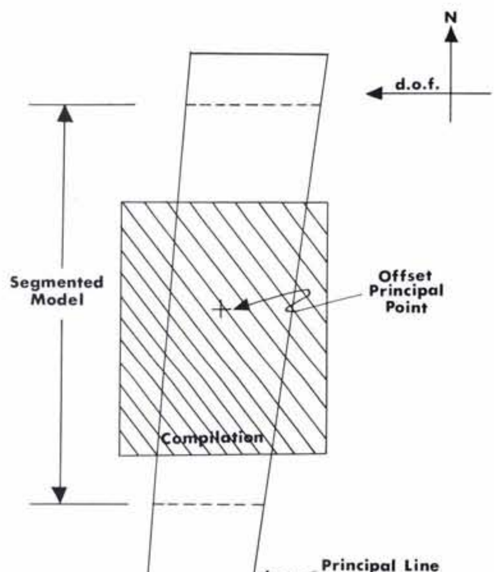

FIG. 8. A segment of a compilation with panoramic photographs.

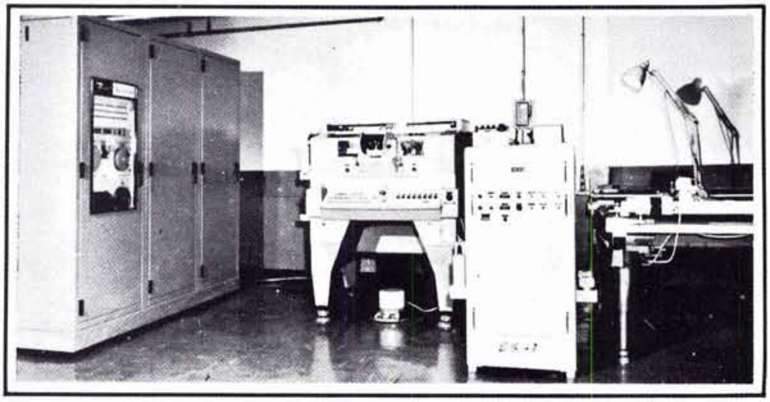

FIG. 9. AS-11A/GZ-1 used to generate ortho photo from frame photography.

gent panoramic photographs and an AS-11 11 Analytical Stereoplotter. The versatility of the AS-11B1 plotter system enabled the accurate compilation of four convergent panoramic models over the Hadley Rille region of the moon.

FIG. 10. Composite of panoramic-compiled contours and frame-generated orthophoto.

Compliments are extended to the NASA team for their planning, evaluation, and selection of the camera array and supporting instrumentation. The geometry of the frame camera and the laser altimeter enabled the accurate portrayal of a segment of the lunar surface. The stellar camera in conjunction with the other components of the SIM bay will allow a system of reliable absolute control to be developed in the near future.

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