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TECHNICAL REPORT

TECHNIQUES APPLIED IN COMPILING THE TRANQUILLITY BASE SURFACE AND EXPERIMENT POSITIONS MAP

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PREPARED FOR
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FOREWORD

This report presents the techniques applied in compiling the Tranquillity Base Surface and Experiment Positions Map. The mathematical formulas used in recapturing the geometry of the oblique photography and constructing a transfer grid are explained in detail. Problems encountered and the errors involved are also discussed.

The Tranquillity Base Surface and Experiment Positions Map is included as an appendix.

This report was prepared by Lockheed Electronics Company, Houston Aerospace Systems Division, under contract NAS 9-5191 in response to Job Order 60-094 (Action Document 63-2616-0094.17-14 Graphic Documentation) issued by the Mapping Sciences Laboratory, Manned Spacecraft Center, Houston, Texas.

Special acknowledgement is made to Mr. K. M. Renfro, of the Lunar and Earth Sciences Department, for his valuable assistance in deriving the techniques and the mathematical formulas involved. In addition, special acknowledgement is made to Mr. G. L. Gutschewski, of NASA's Mapping Sciences Laboratory, for guidance and direction and to Mr. R. D. Esten, of Raytheon/Autometrics, who reviewed the manuscript and offered valuable suggestions to improve the overall content.

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TECHNIQUES APPLIED IN COMPILING THE TRANQUILITY BASE SURFACE AND EXPERIMENT POSITIONS MAP

A. INTRODUCTION

Three magazines of photography were taken with the 70mm Electric Hasselblad Camera by Astronauts Armstrong and Aldrin from the spacecraft and from the surface at Tranquility Base. In some frames of this photography, the scientific instruments, flag and the television camera were portrayed in their relative positions to the spacecraft. In addition, excellent detail of the lunar surface at a scale never seen before was portrayed.

After screening this photography, the feasibility of making a map using basic photogrammetric principles was discussed. The result of this discussion was to research and attempt to position the various instruments relative to the spacecraft. In addition, as much detail of the lunar surface as feasible was to be included to balance the graphic.

The resulting map, if possible to compile using basic photogrammetric principles, would serve as a working map for experiments and site documentation until a more accurate one was available.

B. RESEARCH

Most present-day authors of photogrammetry stress the use of plotting instruments in mapping. Various techniques using basic photogrammetric principles in mapping were researched for application to this problem, with little success.

The graphic resection method was the first method attempted to transfer ground detail from the photography to the base. This method proved to be unreliable with this near horizontal, ground photography.

Next, the horizontal ray projection method was attempted. This method was satisfactory but required stereo views of the detail to be transferred. In addition, it was very time consuming, because each point to be transferred had to be treated individually.

The Canadian Grid method, with some modification, was determined to be the most reliable method of transferring the photographic detail to a base.

C. METHODS USED IN ESTABLISHING RELATIVE POSITIONS

In order to establish positions of features relative to each other, a feature must be located on a base with all other features located in respect to this feature. The lunar module was used as the datum feature in this map and all other features were located relative to it.

In locating the scientific experiments plus the flag and television camera, two or more frames, portraying the lunar module and these objects were required. Frames AS11-30-5948 and AS11-40-5949 were used in fulfilling this requirement, Figs. 1 and 2.

In addition, the geometry of the camera had to be established in order to position the images in their relative ground locations.

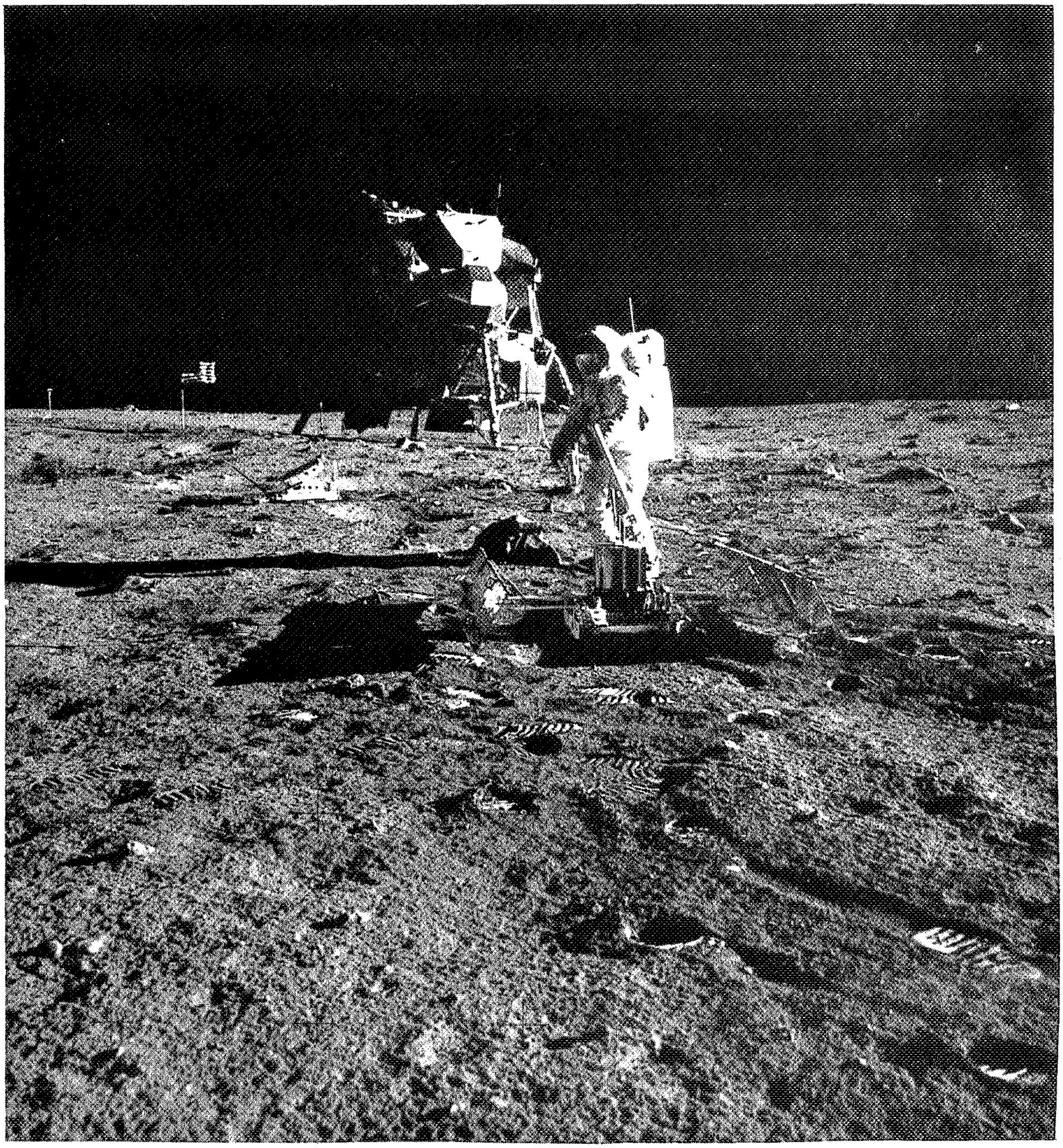

FIGURE 1. FRAME AS11-40-5949. VIEW OF THE LUNAR MODULE AND EXPERIMENTS TAKEN FROM THE LUNAR SURFACE.

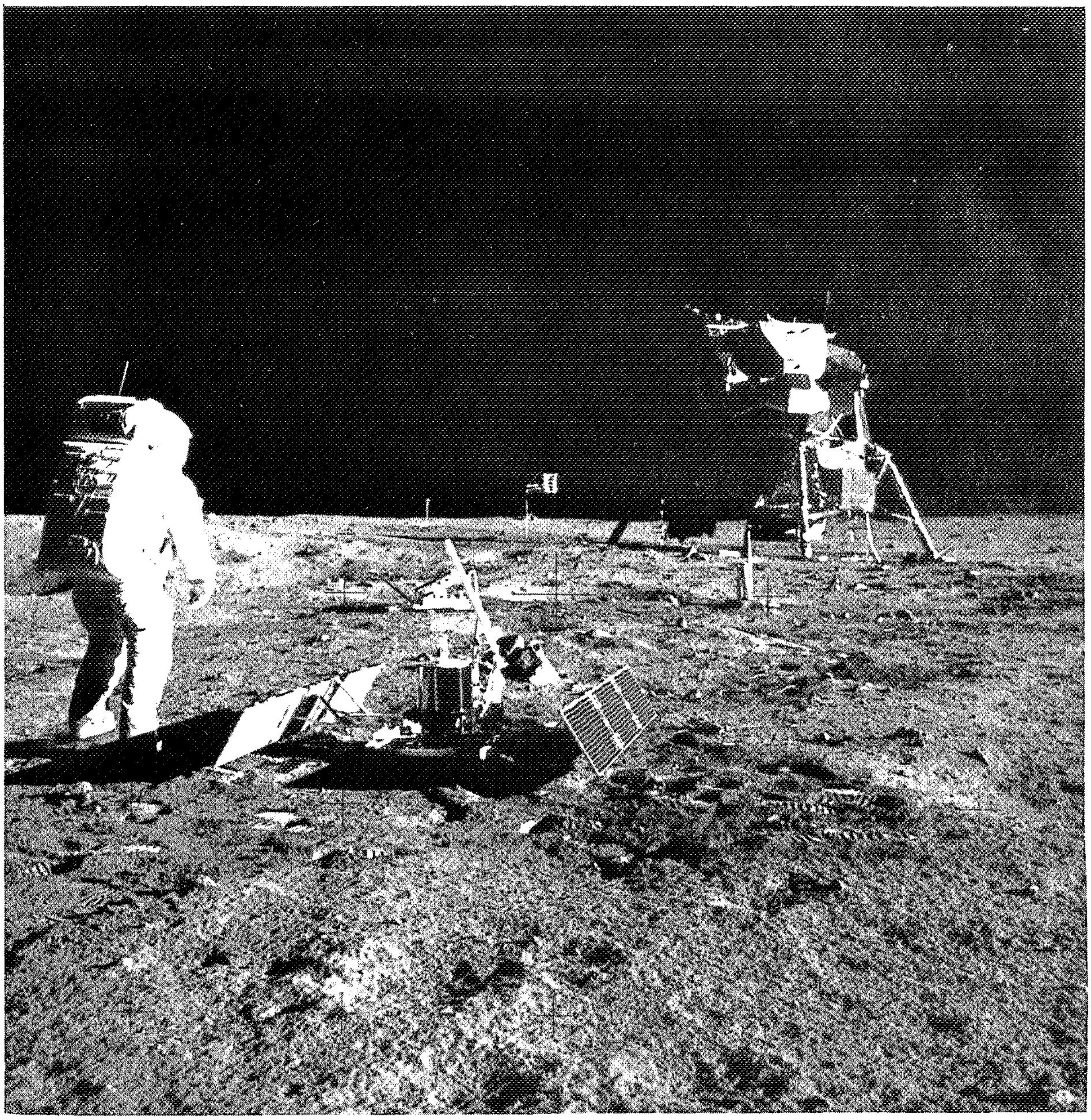

FIGURE 2. FRAME AS-11-40-5948. VIEW OF THE LUNAR MODULE AND EXPERIMENTS TAKEN FROM THE LUNAR SURFACE.

In recapturing the geometry of the oblique photograph certain basic photogrammetric techniques were applied. These included: establishing the apparent horizon, the principal point, the principal line, the depression angle, the isocenter, the nadir and the horizontal angle of images to be transferred.

The apparent horizon line was established by constructing a line tangent to the horizon on the photography. (The difference between the apparent and true horizons on this photography was negligible, so the apparent horizon was used in all measurements).

The principal point was established by intersecting the four corners of the photographs on frames without reseaux. On frames with reseaux, the central reseau marks the approximate location of the principal point.

A perpendicular drawn from the apparent horizon line through the principal point establishes the principal line of the photograph, Fig. 3.

The depression angle of the photograph was established using the following formula:

$$\theta = \arctan \frac{y_o}{f}$$

θ = depression angle

y_o = measured distance from the principal point to the horizon along the principal line

f = effective focal length

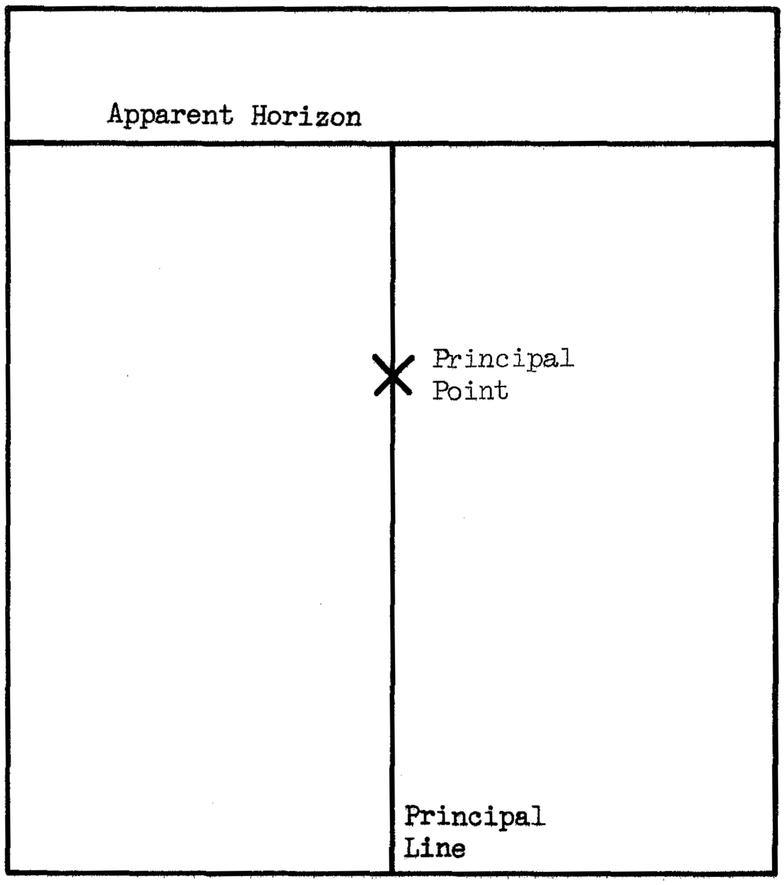

FIGURE 3. GEOMETRY OF A PHOTOGRAPH PORTRAYING APPARENT HORIZON, PRINCIPAL POINT AND PRINCIPAL LINE

Upon determining the depression angle, the tilt angle of the photography was established by subtracting the depression angle from 90°. The tilt angle was then used to establish the isocenter (the half angle distance between the principal point and the nadir, Fig. 4) using the following formula:

$$id = f \tan \tfrac{1}{2}t$$

id = distance from principal point to the isocenter along principal line, in the direction of the nadir

f = effective focal length

t = angle of tilt

The distance from principal point to nadir was calculated using the formula.

$$nd = f \tan t$$

nd = distance from the principal point to the nadir measured along the principal line

f = effective focal length

t = tilt angle

The horizontal angle (the angle at the nadir between a given point and the principal line) was established by calculating the parallax of each image point to be transferred, Fig. 5. By measuring the perpendicular distance of the image point from the principal line, and the perpendicular distance from the apparent horizon, the parallax

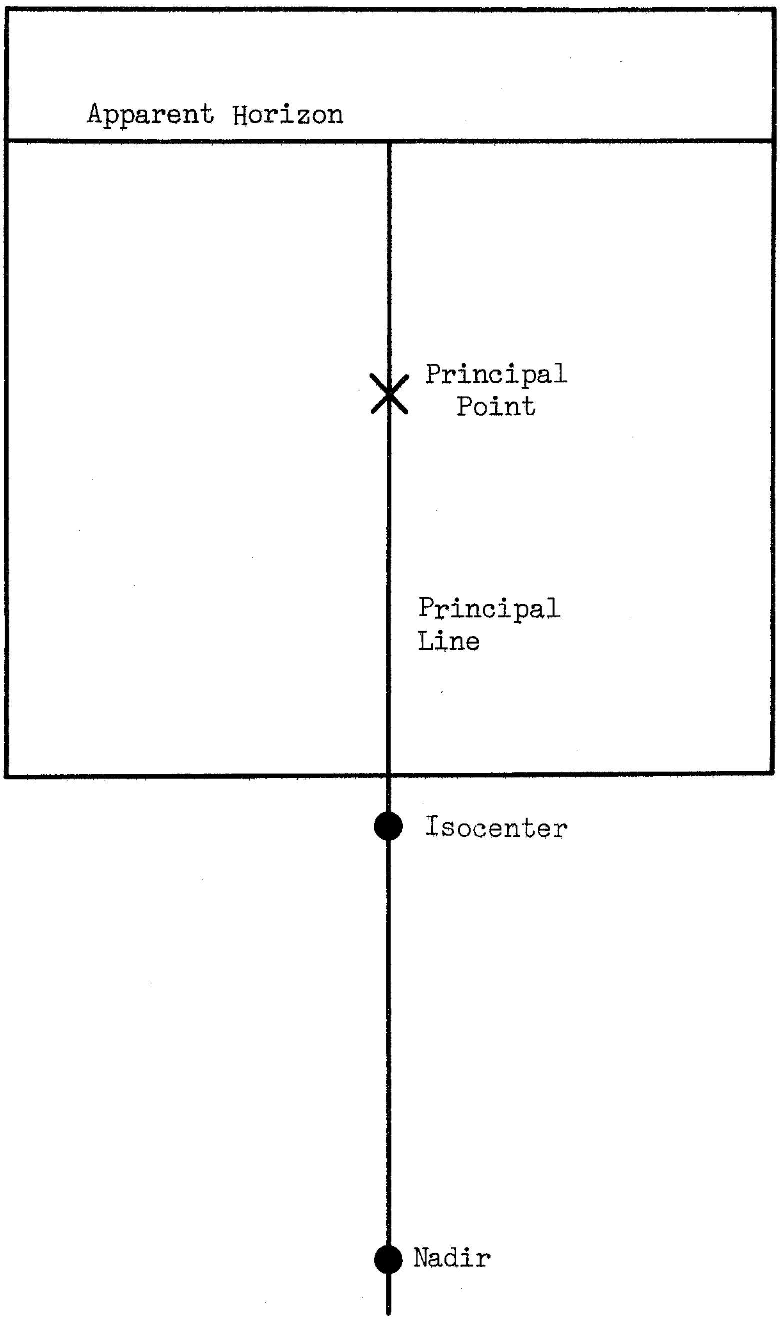

FIGURE 4. GEOMETRY OF A PHOTOGRAPH PORTRAYING THE POSITION OF THE ISOCENTER AND NADIR

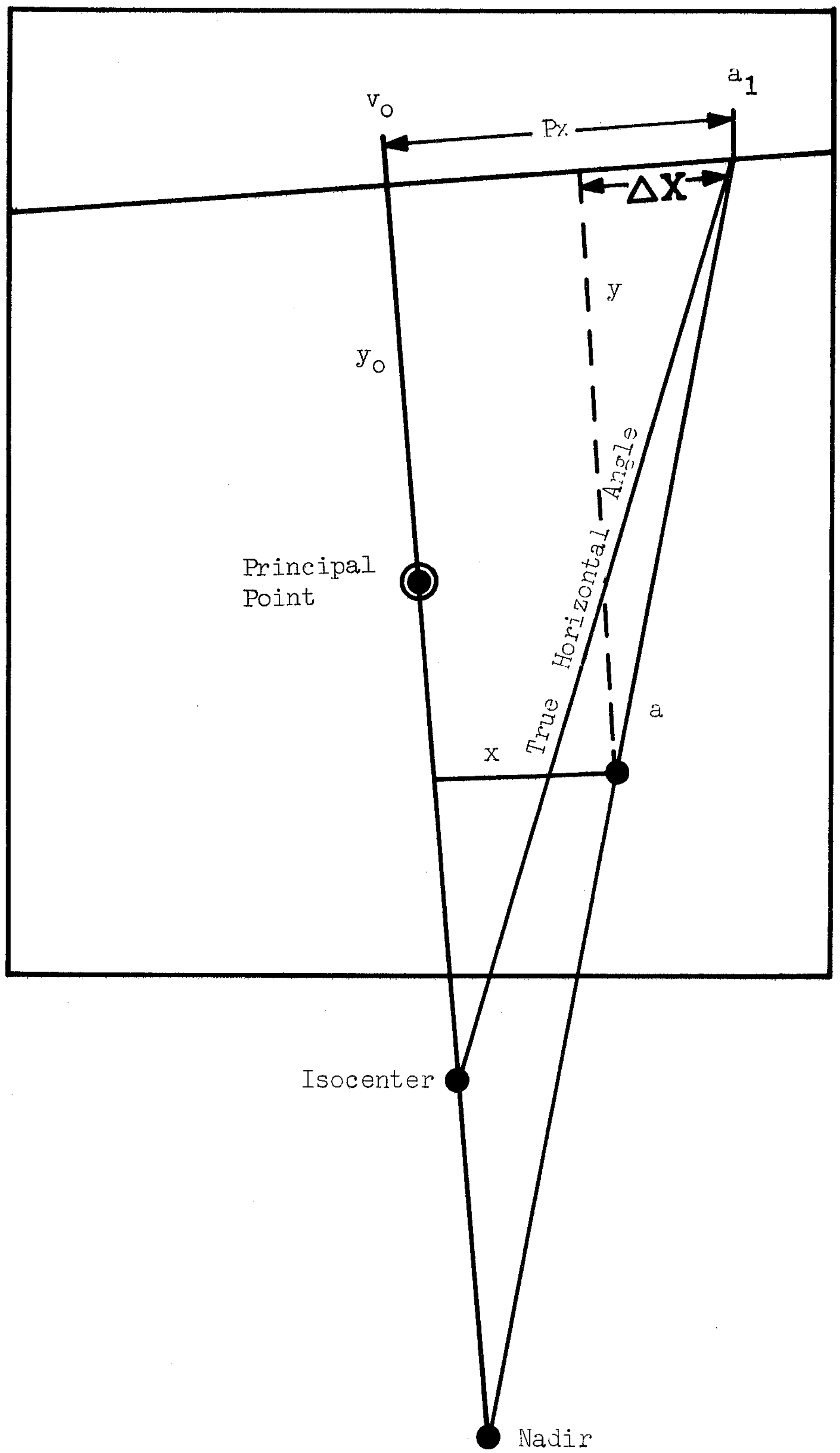

FIGURE 5. GEOMETRY OF A PHOTOGRAPH PORTRAYING THE TRUE HORIZONTAL ANGLE OF AN IMAGE POINT (a).

of the point was then established using the formula:

$$Px = \frac{x\ (f^2 + y_o^2)}{f^2 + y_o^2 - y_o y}$$

Px = distance measured from principal line along the horizon line

x = perpendicular distance from principal line to image point

y = perpendicular distance from a horizon line to image point

f = effective focal length

y_o = distance from vanishing point (intersection of horizon line and principal line) to principal point measured along the principal line

A ray constructed from the isocenter through this parallax distance on the horizon establishes a true horizontal angle.

Horizontal angles were established on the photographs AS11-40-5948 and AS11-40-5949 for the scientific instruments, flag and television camera. The constructed rays were intersected on the map base using the spacecraft legs as the controlled ray intersections. The intersection of corresponding points on each photograph determines the position of these points relative to the control points, at the equivalent scale of the control points.

After the instruments, etc., were transferred to the base, they were used as control points to align the photographs taken from the

LM spacecraft. These photographs, as shown in the panorama in Fig. 6, were used to fill in additional detail because (1) the camera station was higher and constant, and (2) the depression angle was greater than photographs taken from the surface, thereby providing a more accurate solution.

A modified Canadian grid was used to transfer lunar surface detail from the photograph to the map. In constructing this grid the depression angle was established using the formula previously explained.

The distance from the horizon to the scale line was calculated using the following formula:

$$hd = \frac{H \text{ Sec } \theta}{m}$$

hd = distance from vanishing point (intersection of horizon line and principal line) to scale line, measured in inches along the principal line

H = altitude of camera in feet

θ = depression angle

m = selected scale increments in feet

At this point a scale line was constructed parallel to the horizon line, and one inch increments were marked on the line. A line was drawn from v_o (vanishing point) through each point marked on the scale line, Fig. 7.

The result is a series of lines equal distance apart and parallel to the principal line on the lunar surface.

The distances from the nadir to selected intervals along the principal line were calculated using the following formula:

$$d = f\frac{(y_o)D - Hf}{fD + y_oH}$$

APOLLO 11 LUNAR SURFACE PANORAMA TAKEN FROM THE LM

COMPILED FROM UNRECTIFIED PHOTOGRAPHS

FIGURE 6. PANORAMA OF LUNAR SURFACE FROM SPACECRAFT

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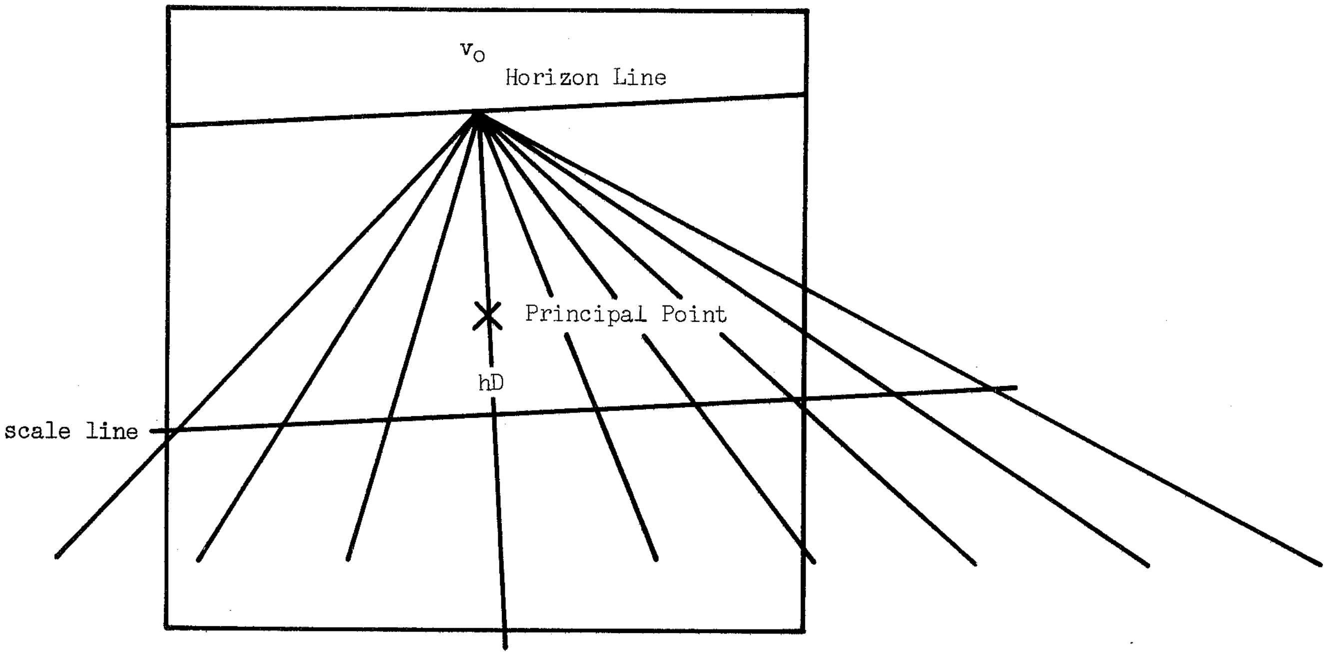

FIGURE 7. PARALLEL LINES ON A PHOTOGRAPH

d = distance from principal point along principal line in millimeters on the photograph

f = effective focal length

H = altitude of camera station

y_o = distance from the principal point to the horizon along the principal line on the photograph

D = selected distance intervals from nadir along principal line on the surface

Using 10 foot intervals, parallel lines to the horizon line were constructed at the distances calculated with the above formula, Fig. 8. This completed the modified Canadian Grid, whereby detail could be transferred from the photograph to the map base with a reasonable amount of accuracy.

The photographs taken from the LM windows were screened and the grid described above was constructed on each of the following frames: AS11-37-5461, 5488, 5549; AS11-39-5768, 5770, 5834; AS11-40-5847, and 5848, Fig. 9.

Upon completing the grid for each photograph, the horizontal angles were calculated from the isocenter to the images used as control points on the base; and rays were constructed to establish the principal line of each photograph, on the base. A 10 foot grid was constructed at the base scale to aid in the transfer of detail from the photograph to the base, and visual transfer of lunar surface detail was

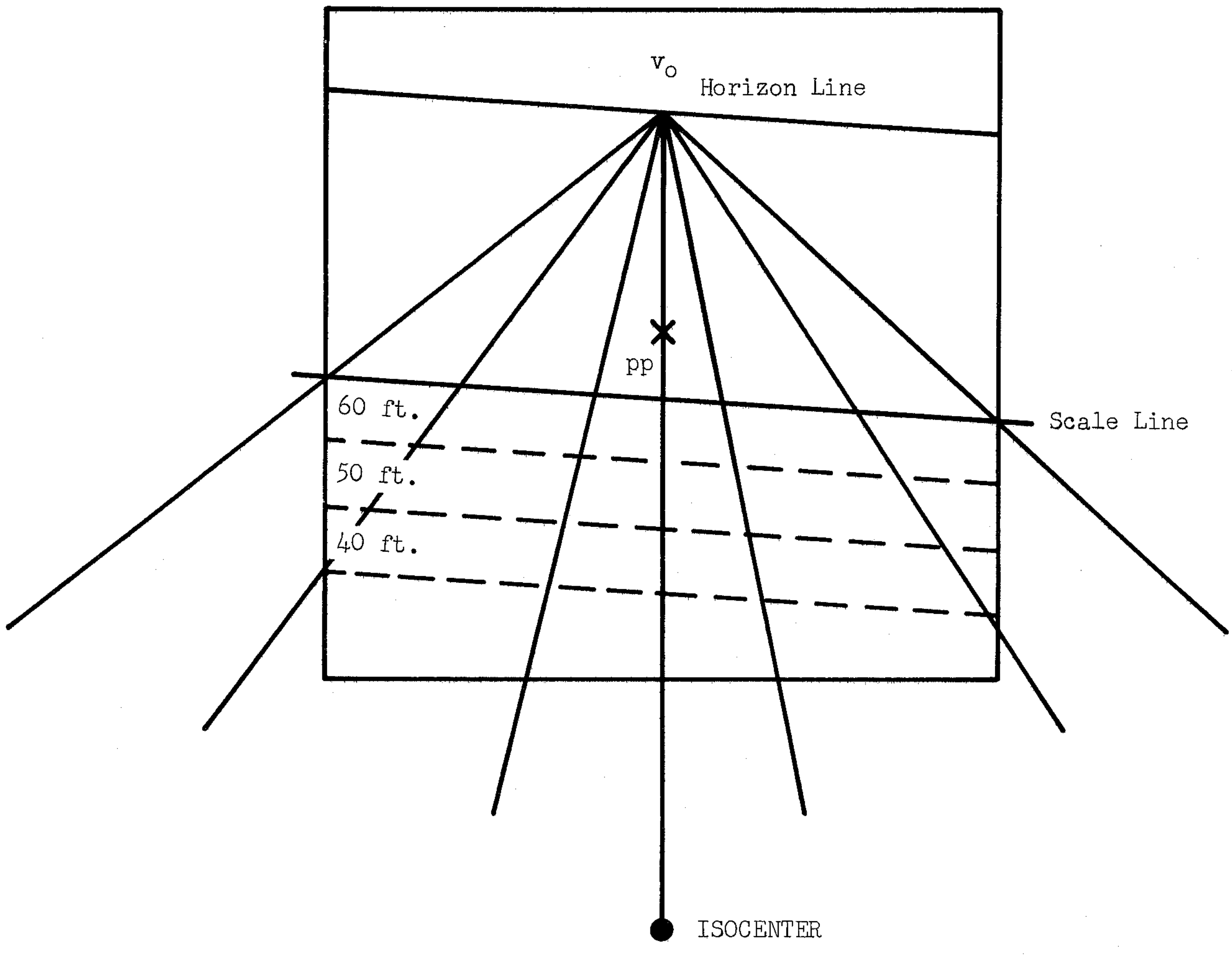

FIGURE 8. MODIFIED CANADIAN GRID

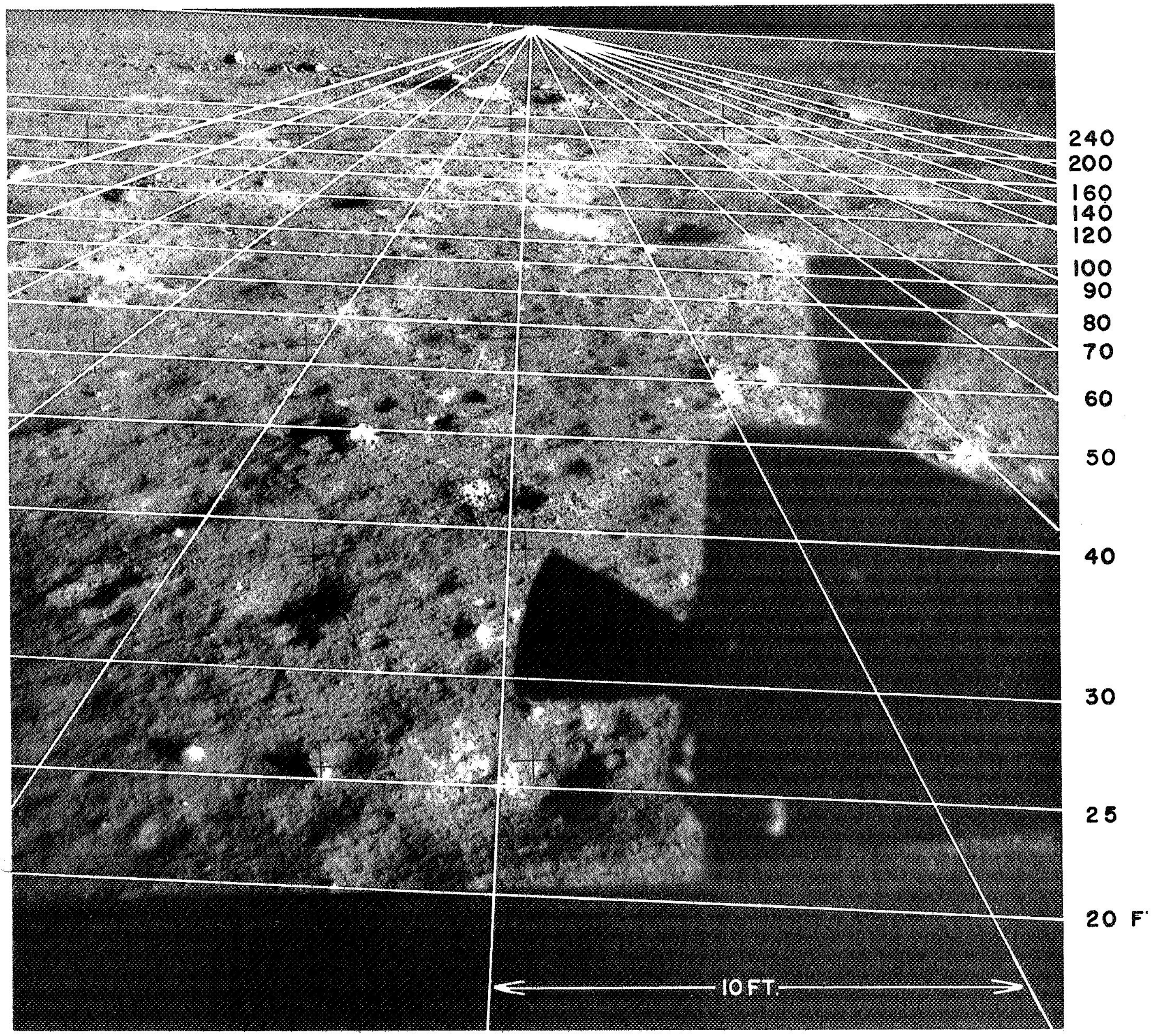

FIGURE 9. WORKING PHOTOGRAPH WITH MODIFIED CANADIAN GRID OVERLAY

accomplished using corresponding 10 foot grid squares on the photograph and on the base as transfer guides.

In the area not covered by photography from the LM window, the positioning of features was accomplished by plotting distances and azimuths from a point on the large crater (100' diameter) to the east of the LM, located from Lunar Orbiter photography. Additional detail was transferred by graphic resection from the lunar surface photography.

D. PROBLEMS ENCOUNTERED

Many problems arise in the positioning of features when constructing a surface map using the techniques described above. These techniques work favorably in areas that are relatively flat, where the vertical angles do not create a measurable error. Also, for ground photography such as this, the greater the height of the camera station (up to a certian point), the more accurate the technique will be because of the smaller relative size of errors in estimation.

In the area of Tranquillity Base the changing veritcal angle of each photograph, due to terrain roughness, created errors in the final product. Less error was encountered by using frames taken from the windows of the lunar module where the camera elevation was higher and more constant. However, since the photography taken from this position covered only approximately 180 degrees, no closure could be accomplished.

The surface photography used in the area to the east of the LM was extremely hard to control because of the changes in elevation, low height above ground of the camera, and the relative roughness of the terrain. The error due to relief is felt to be quite large in this area of the map.

The general accuracy of the map can only be estimated. In the western area of the map, the estimated positional error is $\pm$ 5% to a radial distance of 100 feet. For the eastern area, and all radial distances beyond 100 feet, the estimated positional error is $\pm$ 10%. This estimation is based upon the enlargement of Lunar Orbiter V photography and the scale of the photography used.

E. CONCLUSIONS

The positioning of features on a base using this type of photography and these techniques can be accomplished with a reasonable amount of accuracy, but the application of these techniques are tedious and time consuming. However, the resulting map provides a preliminary working map that is extremely useful for relative positioning of experiments and site documentation.

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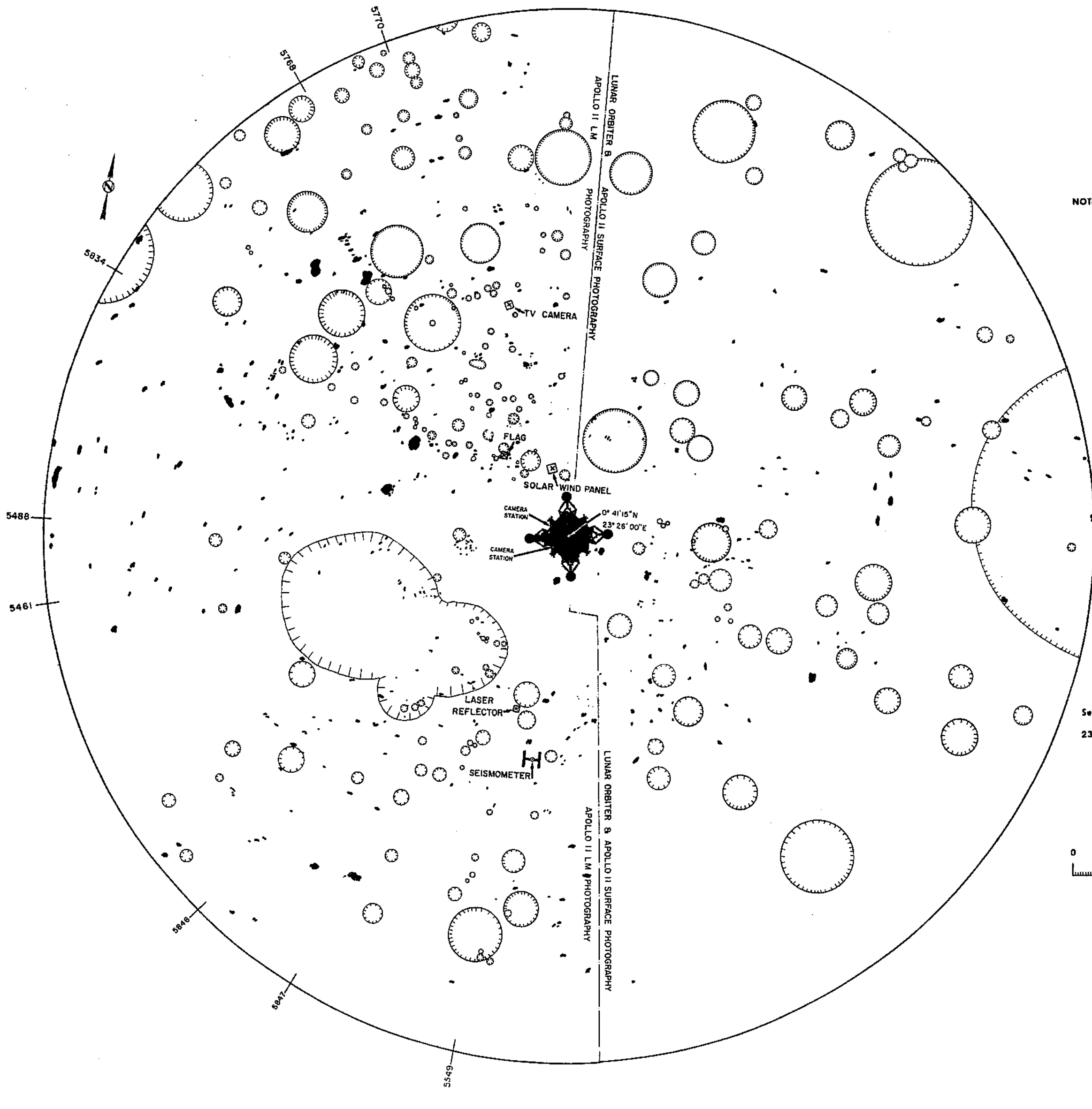
APPENDIX

TRANQUILLITY BASE

SURFACE AND EXPERIMENT LOCATIONS MAP



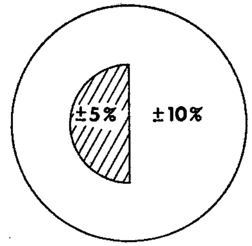
TRANQUILLITY BASE

SURFACE & EXPERIMENT LOCATIONS MAP

NOTE: Photography taken through the windows of the landed Lunar Module was used to compile the western area of the map. The numbered ticks on the perimeter of the circle represent the principal line of each photograph. The eastern area was compiled using frame 76, Lunar Orbiter V high resolution photography, supplemented by surface photography.

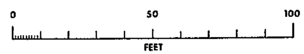
Radially from the Lunar Module, 100 feet, the estimated error is ± 5% for the western area of the map. For the eastern area and beyond 100 feet in the western area, estimated errors are ±10%.

ACCURACY DIAGRAM



Selenographic position of the landed Lunar Module is 0°41'15"N, 23°26'00"E; Reference TOPO 1:100,000

APPROXIMATE SCALE



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