DEVELOPMENT OF THE APOLLO MISSION 17 CONTROL NETWORK*

William D. Cannell
Missile Support Department
Defense Mapping Agency Aerospace Center
St. Louis, Missouri 63118

Charles M. Ross
Missile Support Department
Defense Mapping Agency Aerospace Center
St. Louis, Missouri 63118

BIOGRAPHICAL SKETCH

William D. Cannell is a Physical Science Project Officer in the Defense Mapping Agency Aerospace Center (DMAAC), Missile Support Department, Techniques Office. He is the Project Officer for all lunar activities in the department. He has a B.S. in mathematics and physics from Washington University, St. Louis, Missouri and a M.A. in astronomy from the University of Virginia, Charlottesville, Virginia. Mr. Cannell was chief of the Lunar Observation Office located at Lowell Observatory in Flagstaff, Arizona from 1961 to 1967.

Charles M. Ross is a Cartographer in the Defense Mapping Agency Aerospace Center (DMAAC), Missile Support Department, Analytical Division, Production Management Office. He is responsible for all lunar production in the division. He has a B.A. in geology from Southern Illinois University, Carbondale, Illinois. Mr. Ross began analytical triangulations with lunar orbital photography in 1967 using lunar Orbiter 3 material. Since that time, he has been intimately involved in all lunar triangulations at DMAAC.

ABSTRACT

With the return of the mapping photographic materials from the Apollo Mission 17, the National Aeronautics and Space Administration (NASA) initiated a data reduction assignment of that mission which would contribute to the unified selenodetic network. The data reduction was accomplished for NASA by the Defense Mapping Agency Aerospace Center.

The triangulation involved was accomplished with 408 near vertical photographs acquired during eight orbital revolutions.

This paper describes the techniques utilized for this reduction including the exploitation of the auxillary sensor data. An evaluation of the results of this reduction are provided and a comparison is made with the Apollo 15 solutions.

* The work described in this paper was performed by the Defense Mapping Agency Aerospace Center for the National Aeronautics and Space Administration under contract No. W-13,408.

INTRODUCTION

Triangulation efforts using Metric Camera System photography began in 1971 with the acquisition of Apollo Mission 15 materials. The return of the mapping materials from Apollo Mission 17 provided the third and final set of data of this type that will be incorporated into the planned Apollo Control Network. In early 1973 the National Aeronautics and Space Administration initiated an Apollo 17 data reduction assignment to the Defense Mapping Agency Aerospace Center (DMAAC).

The photogrammetric data generation and solutions contained in the DMAAC Apollo 17 Metric Camera System Data Reduction proposal provided for: (1) an initial evaluation phase and (2) documentation of the complete reduction. The initial test and evaluation of Apollo Mission 17 metric vertical photography and support data was performed and reported on April 1974.[1] Procedures used in the test will be referenced in this paper, but no attempt will be made to redefine the techniques and methods which were developed and described in the Apollo 15 Initial Metric System Evaluation Report.[2] This paper contains a description of the complete reduction including the stellar and mapping camera data preprocessing phases, analytical triangulation solutions, evaluation of the developed selenographics and comparison of the results with those of Apollo Mission 15.

APOLLO MISSION 17 REDUCTION PLAN

The Apollo 17 near vertical mapping camera photography covers approximately 3,900,000 square kilometers extending 247° from 155°W in a westward direction to 42°W. All photo materials received from NASA were reviewed to determine the total number of exposures, the correspondence of the mapping and stellar exposures, the number of measurable exposures, and the availability of altimeter observations. From this, the following information was determined.

Total number of mapping camera exposures	3289
Number of usable near vertical exposures	1593
Number of usable oblique exposures	359
Total number of stellar camera exposures	3595
Number of usable stellar exposures	2571
Number of usable near vertical exposures with usable stellar and laser altimeter observations	1345

Based on this review of the near vertical photographs, a selection of all or parts or eight revolutions was made to provide comprehensive Apollo Mission 17 coverage of the moon's surface, provide an evaluation of the ephemeris positions, and to supplement the area covered by Apollo Mission 15.

The even numbered photographs, which provided 56 percent forward overlap, were used to obtain the desired lunar coverage. Exceptions to the criterion of 56 percent forward overlap between alternate photographs were encountered when changes in the spacecraft altitude resulted in changes in the photographic scale. To maintain this desired overlap every photograph was used from exposure 180 through 232 and exposures 1821 and 1825 and every third photograph from exposure 276 through 303. Every photograph between exposure 232 through 256 and 2030 through 2050 was used because the blurred image of a lens cover obscured part of the lunar imagery. The final coverage selection resulted in the use of 408 terrain photographs. The side overlap between adjacent revolutions ranged from 10 to 95 percent. Table 1 lists the selected photographs and Figure 1 shows the area of coverage.

The Apollo 17 reduction was planned by revolutions (strips) with the general sequence of the triangulation phases as follows:

A. Stellar reductions were performed on a strip basis.

B. Selected point and image measurements were made on photographs of each strip. (Points identified on Apollo 15 photograph would be used, if practical.)

C. Quality control checks on the data from each revolution were made using the Rigorous Analytical Block Orientation (RABO) Program.

D. Strip solutions were performed using the Simultaneous Adjustment of Photogrammetric and Geodetic Observations (SAPGO) Program.

E. Common points were evaluated in sidelap areas.

F. Assembled strips in an Analytical (SAPGO) Block Solution.

G. Accomplished an analytical triangulation with data from the adjusted block.

STELLAR DERIVED ORIENTATIONS

The stellar derived orientations were developed in three phases: star identification, star mensuration, and data processing.

The imagery on the Apollo Mission 17 stellar exposures was not as well defined as the stellar images from Apollo Mission 15. The general degradation was caused by a slight over-exposure resulting from extraneous light reflecting into the stellar camera lens. For each of 332 of the 408 terrain exposures used in the reduction, a companion stellar photograph was measured. Table 1 lists the exposures measured. Each measured stellar photograph contained approximately 25 well distributed stars. Of the 76 stellar exposures for which orientations were not developed, 65 were excessively over-exposed and the remaining 11 had the stellar imager obscured by the camera lens cap. Typical standard deviations for the mapping and stellar orientation angles relative to the celestial coordinate system were:

	$\sigma(\omega)$	$\sigma(\phi)$	$\sigma(\kappa)$
Stellar Camera	1".8	1".7	12".6
Mapping Camera	6".8 (Roll)	12".3 (Pitch)	3".6 (Yaw)

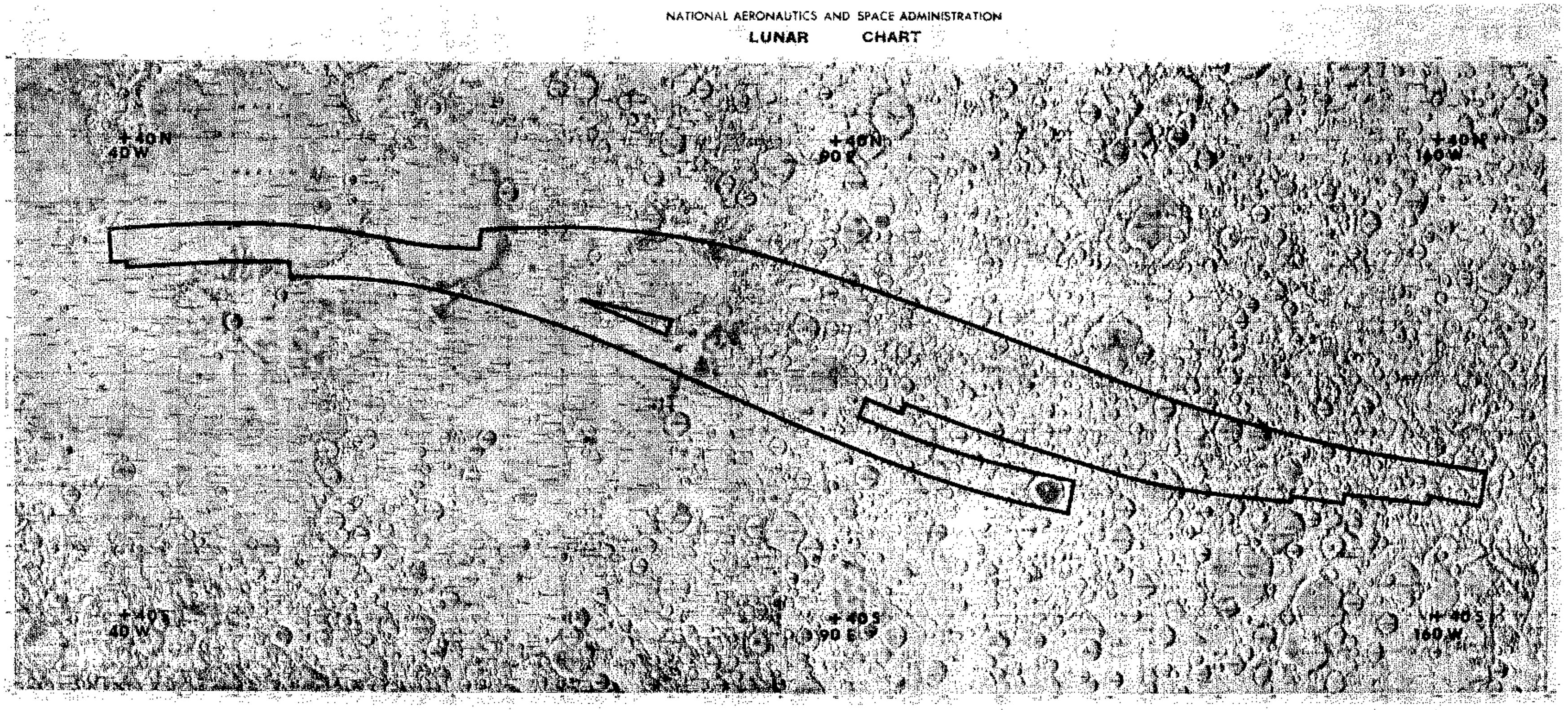

FIGURE 1. LIMITS OF SELECTED APOLLO 17 CAMERA SYSTEM COVERAGE.

The stellar derived orientations were examined for consistency by plotting the first differences in the mapping camera orientation angles between alternate exposures. Figures 2 and 2.1 show typical changes in the angles versus exposure numbers. Graphs of this type, for all photographic sequences, were examined as a quality control check. Departures from the normal trends in these curves were viewed as being potentially inconsistent orientation data.

The stellar orientations were also compared with the inertial measurement unit (IMU) values tabulated in the photo support data. A plot showing the differences between IMU and stellar derived orientation angles for even numbered exposures is shown in Figures 3 through 3.2 with the delta (Δ) angles referenced to the stellar values. Breaks in the graphs for revolutions 14, 29, and 38 are due to incomplete IMU data. Each of the orientation elements exhibited differences of as much as eight minutes during a revolution but with a variation about an envelope of two to three minutes. Variations in the delta angles reflect acceleration of the spacecraft to maintain a local vertical pointing of the mapping camera. The spacecraft was being maneuvered from an oblique to vertical position during revolution 62 as reflected by the radical angular changes.

IMAGE POINT SELECTION AND REDUCTION

To organize image point selection reference strips of photographs were chosen on which a basic pattern of lunar surface features could be defined. These strips were chosen to provide maximum coverage of the lunar surface.

Lunar features were selected and marked on the photographs such that each photograph contained approximately 30 image points, where every other photograph was used. Where every photograph was used each photo contained approximately 18 image points. The points were normally associated with the discrete images of small craters. The image points were marked using the Wild PUG II stereoscopic point transfer instrument. The features were observed stereoscopically on film positives enlarged two times and marked on one photograph of the stereo pair with a 30 micrometer drill. The marked image coordinates were transferred from the selected strips to all sidelapping strips and measured on the used photographs. In many cases the distribution of the images transferred to sidelapping strips was not geometrically acceptable and had to be supplemented by selecting and marking additional points. Images used in the Apollo Mission 15 vertical reduction were used in the Apollo 17 reduction when they helped strip geometry.

Mensuration of the pass points was accomplished with the Nistri TA3/P stereocomparator using the enlarged film positives. A point was first monoscopically measured and recorded on the reference photograph, then stereoscopically transferred and measured on every corresponding exposure in the forward and sidelapping directions. The measuring procedure was repeated at least four times, twice in normal stereo and twice in pseudo-stereo (depth appears as height), and then monoscopic measurements were made of the four reseau intersections nearest the image measurement on each photograph. The stereo and pseudo-stereo readings were averaged to minimize reader bias. The removal of this bias produces a smaller standard deviation when the data is merged into a single solution.

REVOLUTION 2

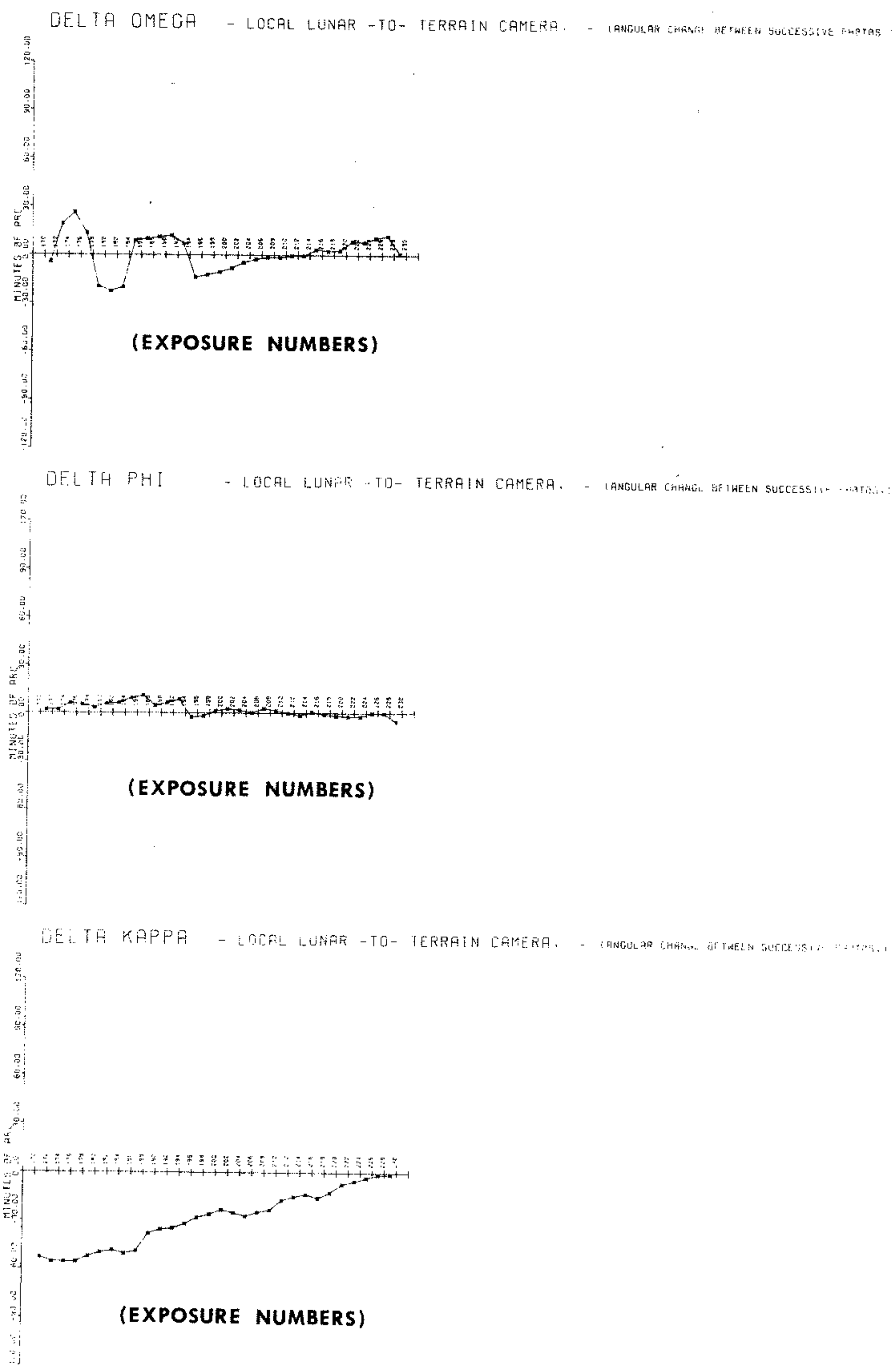

FIGURE 2. FIRST DIFFERENCES IN MAPPING CAMERA ORIENTATION ANGLES.

REVOLUTION 38

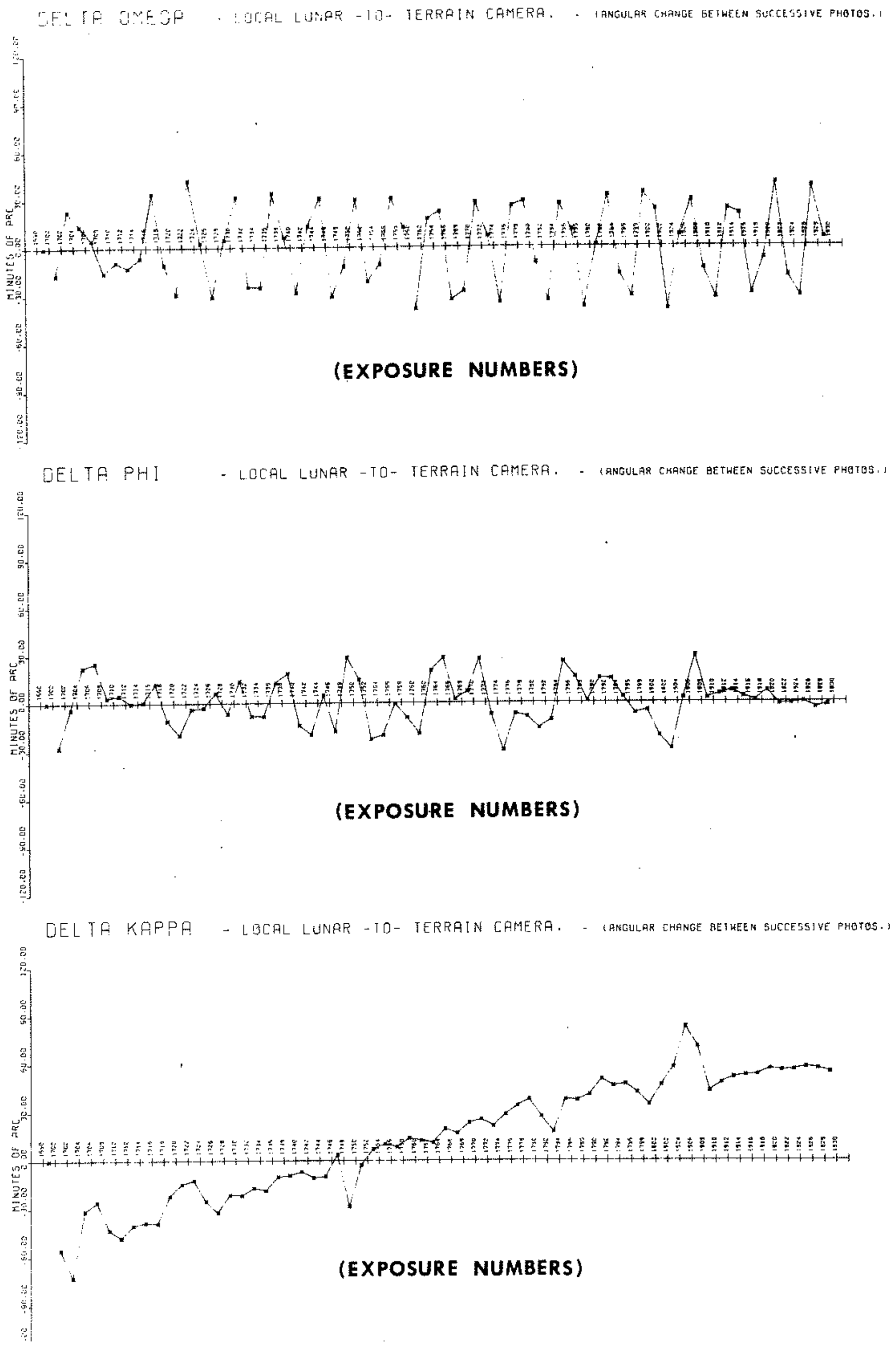

FIGURE 2.1 FIRST DIFFERENCES IN MAPPING CAMERA ORIENTATION ANGLES.

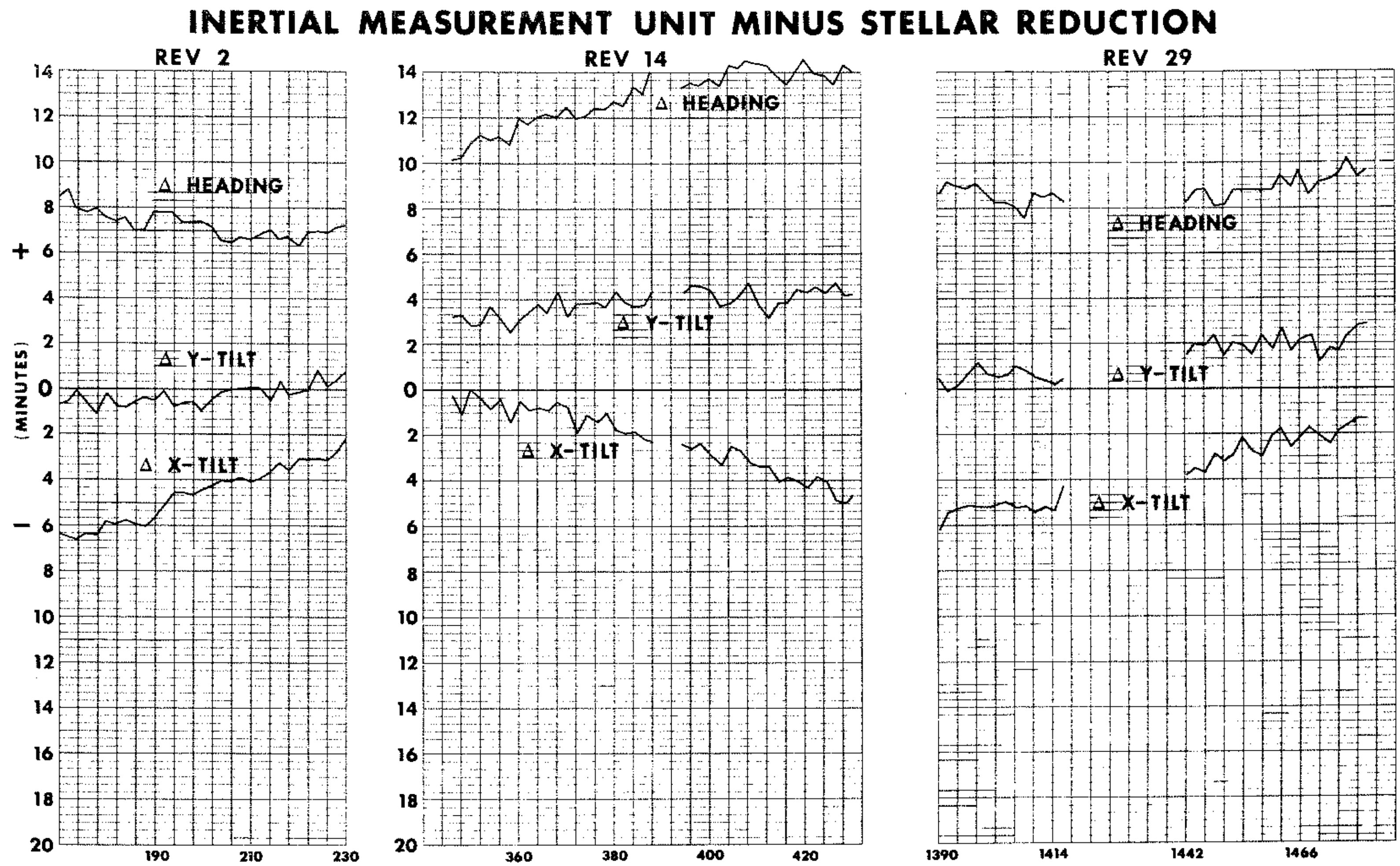

FIGURE 3. DIFFERENCES BETWEEN INERTIAL MEASUREMENT UNIT AND STELLAR DERIVED ORIENTATION ANGLES.

(EXPOSURE NUMBER)

APPENDIX B

INERTIAL MEASUREMENT UNIT MINUS STELLAR REDUCTION

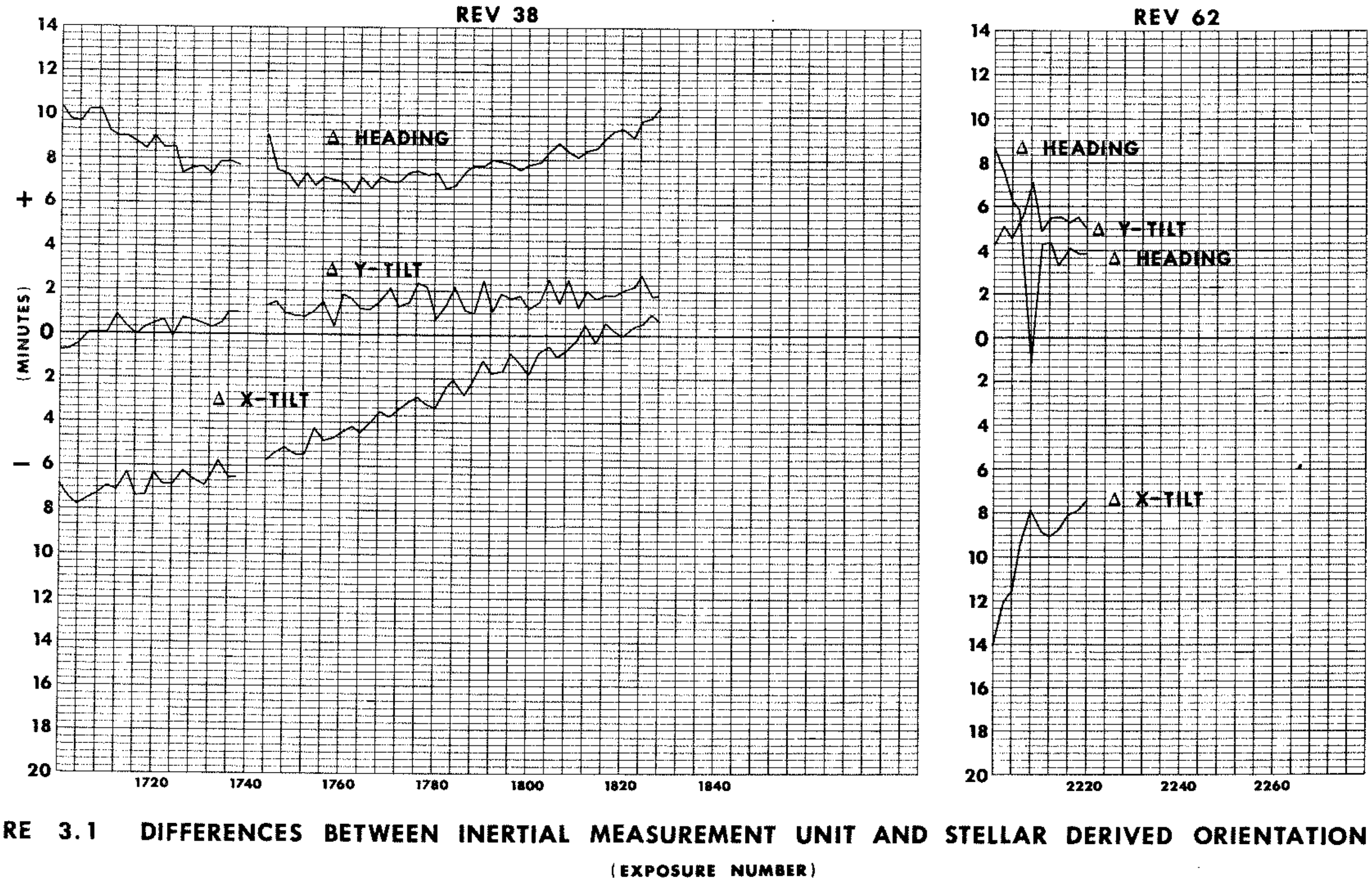

FIGURE 3.1 DIFFERENCES BETWEEN INERTIAL MEASUREMENT UNIT AND STELLAR DERIVED ORIENTATION ANGLES.

APPENDIX B(1)

INERTIAL MEASUREMENT UNIT MINUS STELLAR REDUCTION

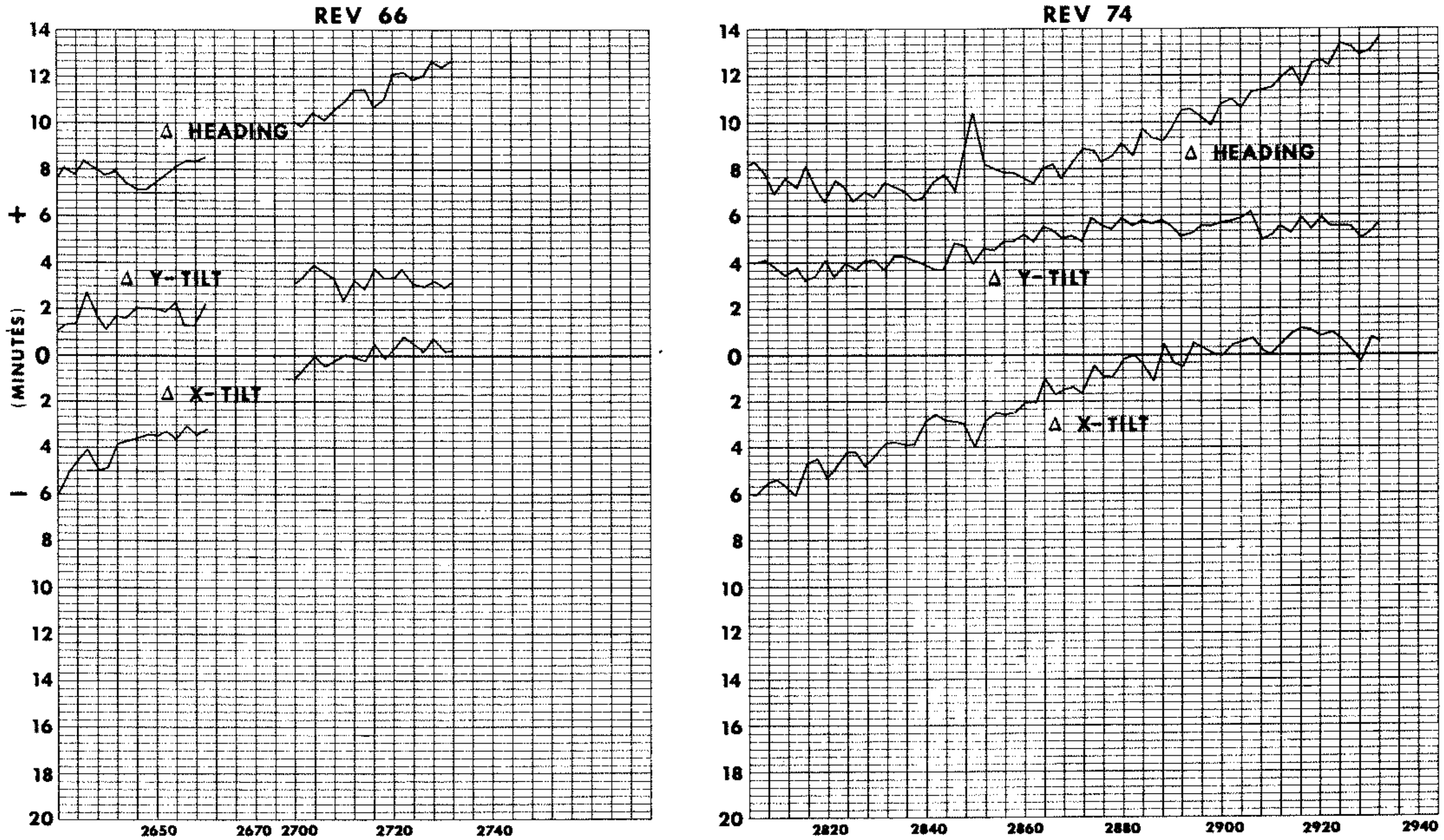

FIGURE 3.2 DIFFERENCES BETWEEN INERTIAL MEASUREMENT UNIT AND STELLAR DERIVED ORIENTATION ANGLES.

(EXPOSURE NUMBER)

APPENDIX B(2)

Second generation contact negatives were used to perform measurements necessary to relate the image measurements to the camera system. The four nearest reseau intersections were used to correct the fiducials for film deformation prior to adjusting the measured fiducials to the calibrated values. The standard deviations of these adjustments ranged from 2.4 to 7.5 micrometers. The measured coordinates for all image points and their four nearest reseau intersections, camera calibration data and the coefficients of the fiducial adjustment were used in a computer program to obtain corrected image coordinates in the camera system for each exposure.

The altimeter image coordinates were obtained thru use of an "on line" TA3/PA automated stereocomparator program.[2] The TA3/PA was programmed to slew to the computed altimeter image coordinate. The altimeter point was then measured stereoscopically by the same process used for measuring any image point.

Laser Altimeter Slant Range values were not recorded in the photo support data for the last 38 exposures in Revolution 2 or the first 18 exposures in Revolution 14. Observations of the altimeter position were not made on these exposures or on exposures where the recorded slant range value differed radically from those on adjoining exposures. An additional 56 altimeter observations were not included in the reduction due to the lack of detail at the point of measurement. These observations, however, were scattered throughout the reduction and represented a normal loss of data using this quality of imagery. Table 2 lists those exposures for which an Altimeter Slant Range was derived.

ANALYTICAL TRIANGULATION

A. Strip Triangulation

Each strip or subsection of a strip was analytically triangulated with the Relative Analytical Block Orientation (RABO)[2] Program. Input to the RABO consisted of the corrected image coordinates of surface features and altimeter locations, the camera position for each exposure, and the stellar derived orientation angles. The lunar fixed selenocentric position vectors and orientation angles obtained from SATLUM[3] were input to the RABO in the Universal Space Rectangular (USR) System[5]. These strip RABO solutions were used as a quality control edit to detect image measurement blunders and to provide an estimate of the average mensuration accuracy for the image coordinates. The standard deviations of the image measurement residuals from these solutions ranged from 3.1μm to 6.0μm. In general, the lower standard deviations were associated with those photographs displaying medium sun angles. Very high or very low sun angles caused standard deviations of image measurements to be higher.

The Simultaneous Adjustment of Photogrammetric and Geodetic Observations (SAPGO) Program[4] was used to compute an initial solution with the photographs of each revolution. The lunar fixed orientation angles obtained from the stellar reductions were constrained to 30 seconds of arc in each component. Lunar fixed orientation angles were obtained from the photo support data for the terrain exposures that did not have acceptable companion stellar exposures. These orientations were constrained to 5 degrees of arc in each component. The exposure station positions were constrained to 200 meters in X, Y, and Z (USR) and altimeter distances were constrained to 50 meters. Based on results of the RABO solutions an apriori standard deviation of 7μm for image coordinates was used. Figures 4 and 4.1 show the horizontal and vertical adjustments made to the initial camera positions in the strip SAPGO solutions for three sample revolutions.

Selenographic coordinates of the same lunar features were derived independently in two or more SAPGO strip solutions and compared. From this analysis the mean positional bias between the common points of sidelapping strips was computed by using one revolution as a standard and comparing all other revolutions to this standard. Table 3 shows the systematic biases between revolutions.

The analysis of these differences of common points between strips (with the mean systematic biases removed) showed an elimination of non-linear discrepancies over the length of the strip solution. As in the Apollo 15 reduction, these results supported the assumption that the periodic changes of the exterior orientation parameters in the triangulation were caused by the spacecraft ephemeris positions.

B. Block Triangulation

The SAPGO computer program was also utilized for the block triangulation solution. The present program data storage capabilities of 700 exposures and 6,000 surface coordinates was large enough for the total block solution. The program in this case performed a simultaneous solution with essentially the same data set found in the strip SAPGO solutions. All the exposures used in the strips were used in the block.

From the analysis of the strip SAPGO solutions the following decisions were made for further data reduction work. First, revolutions 66 and 74 were selected to provide the absolute positional datum for the total Apollo 17 block reduction. The reasons for making this choice were (1) the solution indicated that all input parameters were more compatible for these strips than the others; (2) comparisons of common points showed that these revolutions approximated the mean position of the strips in the block. Camera positions (derived from the spacecraft ephemeris) for all revolutions were allowed to adjust in the solutions in order to achieve compatibility with image measurements and attitude information. Altimeter data for the camera stations was constrained to achieve the best possible fit to the spacecraft ephemeris, at least to the extent that the apriori constraints of the other parameters were not violated. The camera station constraints were applied in a local coordinate system in order to provide an altitude constraint for each revolution.

The positional constraints assigned to x, y, and z (local coordinate system) components were as follows:

Revolution	Constraint in Meters	
	x, y	z
2	1500	1500
14	500	500
29	300	225
38	100	100
49 (partial)	500	200
62 (partial)	100	150
66 (partial)	100	75
74	100	75

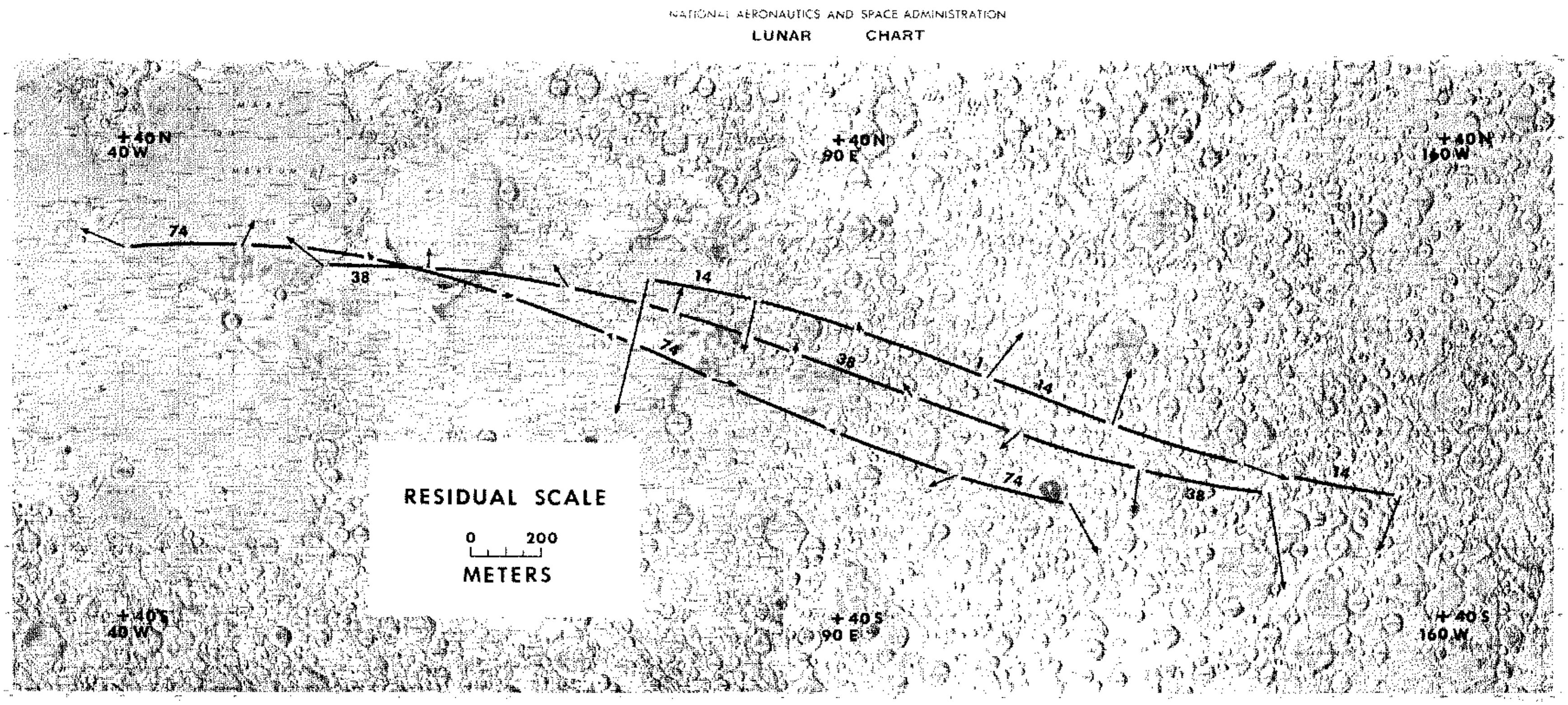

FIGURE 4. HORIZONTAL ADJUSTMENT OF STRIP SAPGO SOLUTION.

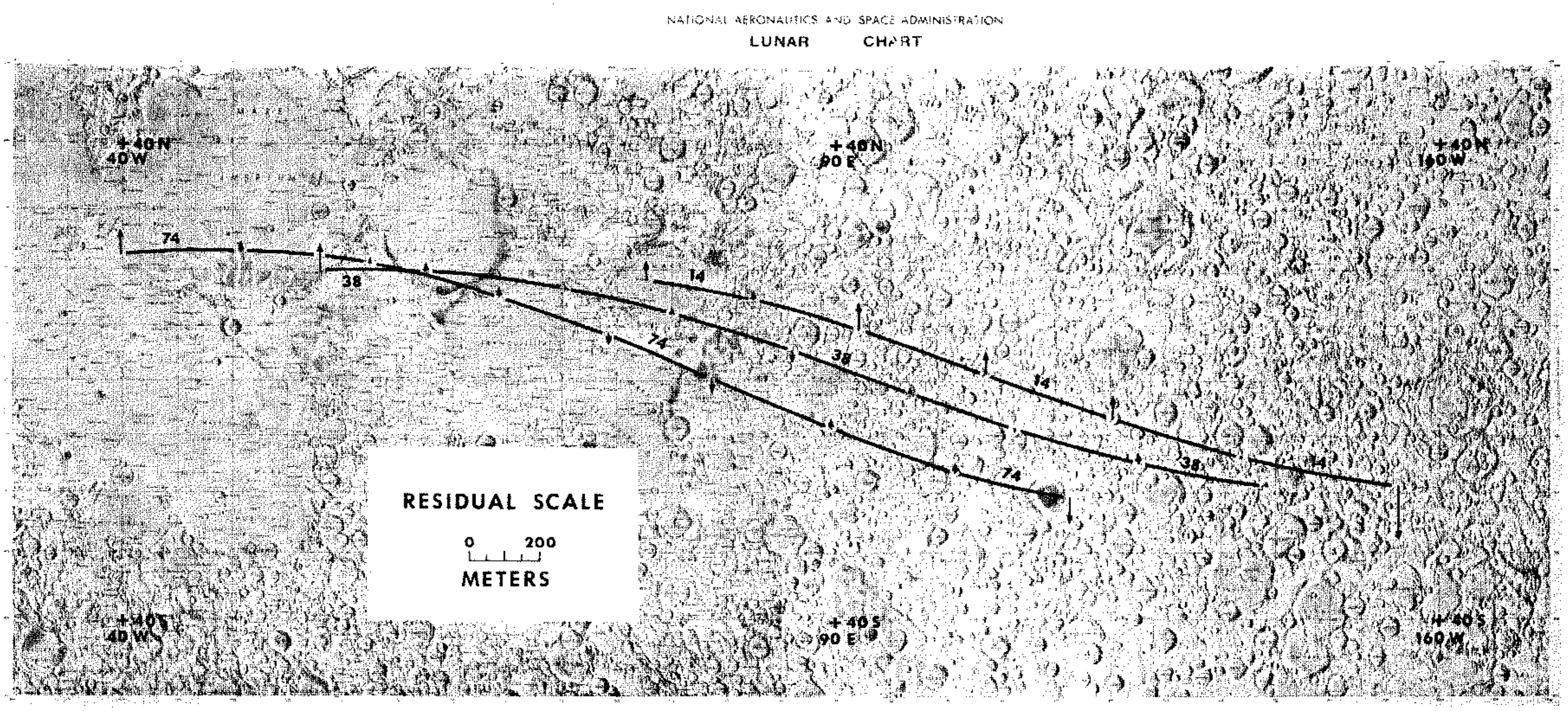

FIGURE 4.1 VERTICAL ADJUSTMENT OF STRIP SAPGO SOLUTION.

The constraints placed on the angular orientations derived from the SATLUM Program[3] were 30" of arc, while those obtained from the spacecraft ephemeris (for terrain exposures without companion stellar exposures) were 5^{0} of arc. An average standard deviation of 8 micrometers was selected as representative of the reliability of the image measurements in the block. This value approximates a combination of within-strip and cross-strip identification and mensuration accuracy. The altimeter slant range values were held to 50 meters.

In the final simultaneous block SAPGO solution, the standard deviation of the image-measurement residuals was computed to be 6.6 micrometers. Changes to the orientation parameters were within the apriori constraints. Figures 5 and 5.1 illustrate the horizontal and vertical changes in the camera positions. The solution provided selenographic coordinates for 3945 lunar features and adjusted exterior orientation parameters (positions and attitudes) for the 408 photographs in the solution. Of the 3945 feature positions computed, 889 were common to the Apollo Mission 15 reduction. Figure 6 shows the area of common vertical photographic coverage between the Apollo Mission 15 and Apollo Mission 17 reduction.

The validity of the corrections made to the parameters of exterior orientation was checked by independently deriving selenographic coordinates for common surface features. For a feature measured on photographs of two overlapping revolutions two sets of selenographic coordinates were available, one set from each revolution with each set based on the corrected exterior orientation parameters for its revolution in the block. All pass points were derived and compared in this manner.

A computer program was used to calculate the positional differences between sets of common points, to plot these differences, and to compute the standard deviations of the differences in terms of latitude, longitude, and height. Table 4 shows the results of these calculations. The results of the analysis of the block indicated that the positional relativity achieved in the block was in proportion with that projected from the assumed accuracies of the input parameters.

The laser altimeter slant range values provided in the photo support data were compared to the slant range derived in the block solution. The mean difference between these two sets of observations was ±10 meters. Of the 291 altimeter points used in the Apollo 17 block solution, 17 exceeded the 50 meter constraint. The largest of these was 89 meters. All 17 points were retained even though the lack of a better fit was attributable to the marginal quality of the photographic imagery. Ninety percent of the derived altimeter slant range values varied less than 40 meters from their computed values.

POSITIONAL EVALUATION

A. Relative Accuracy of Coordinates Relative to Revolutions 66 and 74

As previously discussed, the surface positions were independently derived from each respective revolution in the block using the adjusted exterior orientation parameters. The standard deviations presented in Table 4 give a range from 16 to 25 meters (CE 39%) horizontally and from 14 to 26 meters (LE 68%) vertically. These values were used to obtain an estimate of the accuracy of the surface coordinates to the datum of the block solution established by Revolutions 66 and 74. Assuming the contribution from any two revolutions to be equal and uncorrelated, the variances of any derived coordinate relative to the datum established by these two revolutions is;[5]

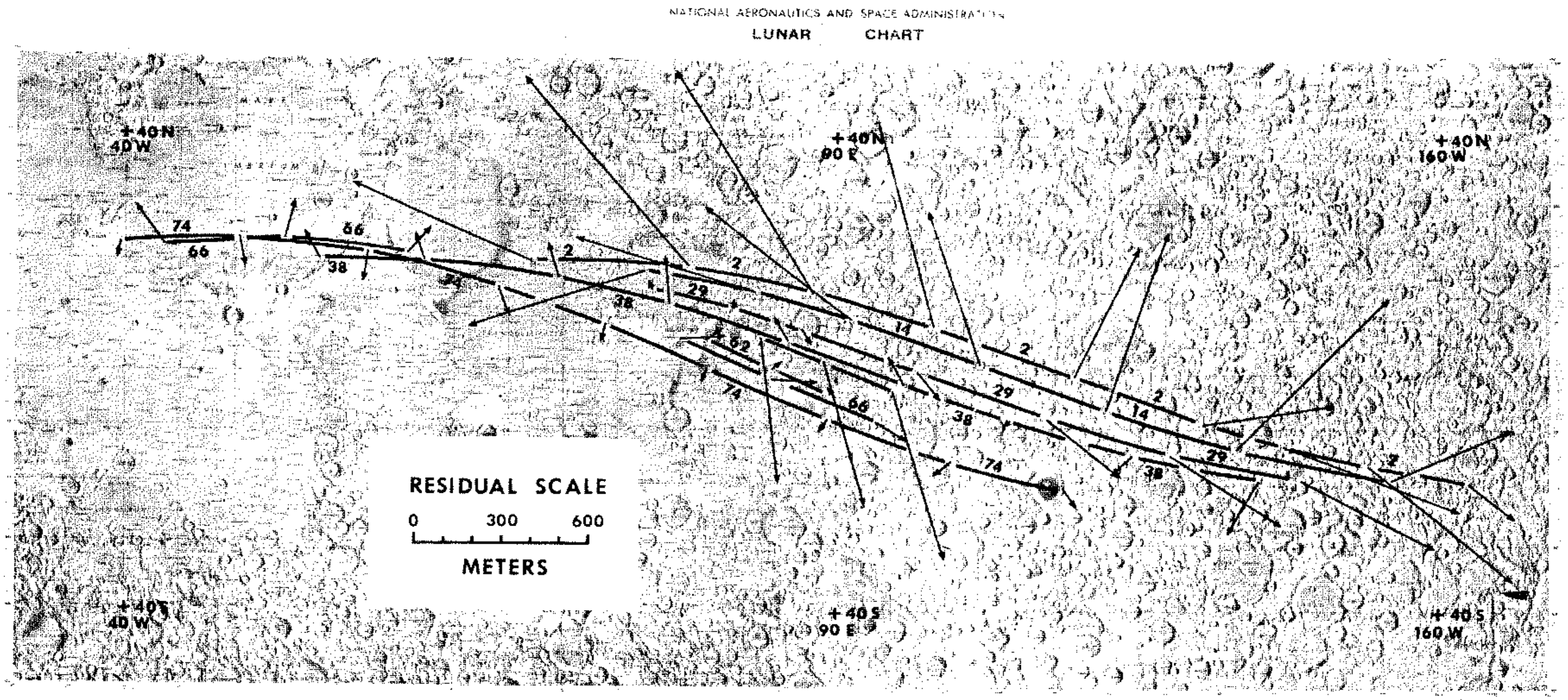

FIGURE 5. HORIZONTAL CHANGE TO CAMERA POSITIONS FINAL BLOCK SOLUTION.

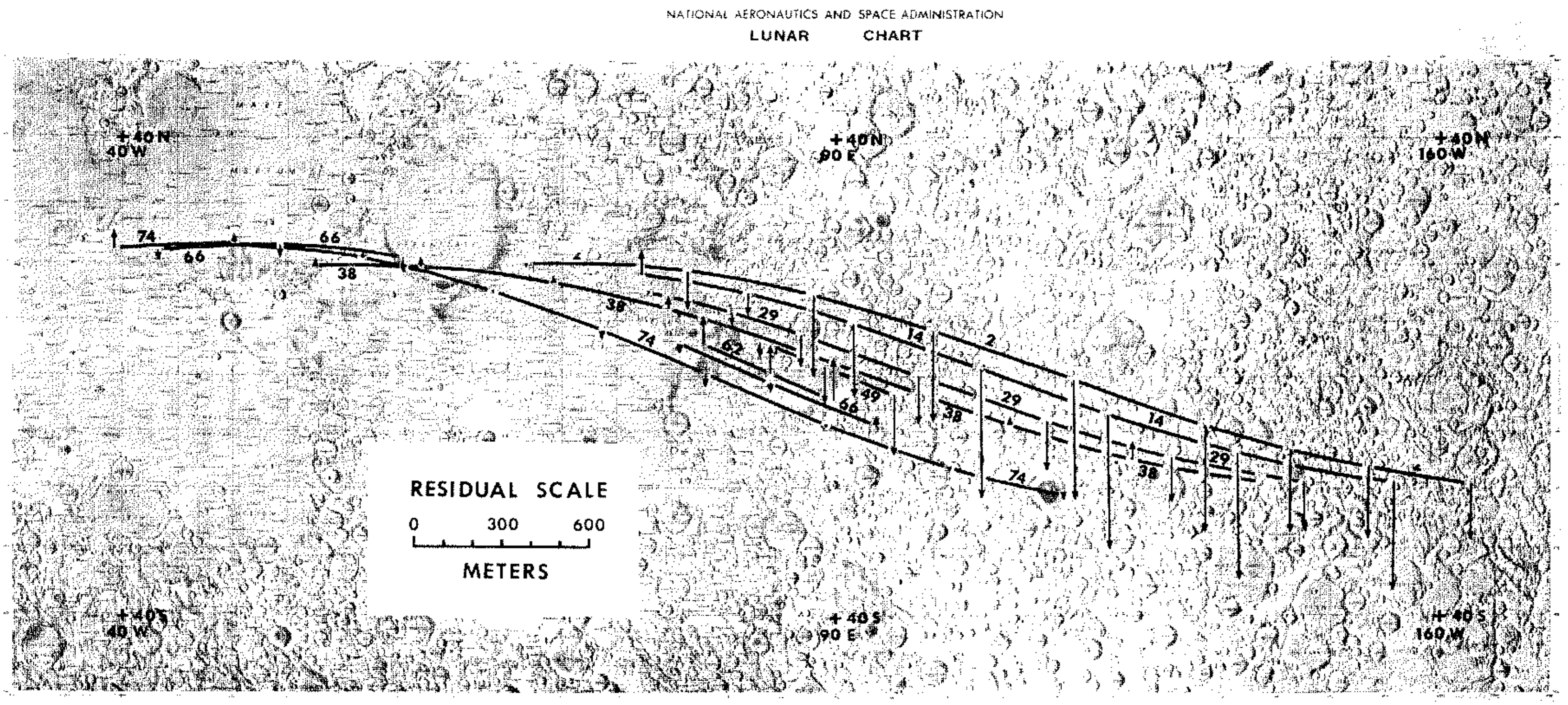

FIGURE 5.1 VERTICAL CHANGE TO CAMERA POSITIONS FINAL BLOCK SOLUTION.

$$\sigma_{\phi i}^2 = \sigma_\phi^2 / 2 \qquad \text{(a.1.)}$$

where $\sigma_{\phi i}^2$ is the variance in latitude of the coordinates derived from any two strips, each contributing equally, and σ_ϕ^2 is the variance in latitude of the common point comparison in Table 4. The same formulas were used for the longitude and height computations.

Applying equation (a.1.) to the standard deviations in Table 4, the root mean square of the latitude, longitude, and height was computed. The latitude and longitude was combined by $(\sigma_\phi + \sigma_\lambda)/2$[6]. The estimated relative circular standard error and the standard vertical error were each computed as 21 meters.

B. Relative Accuracy Between Coordinates

The relative accuracy between any two surface points is dependent upon the accuracy of each point relative to the triangulation datum and the accuracy of that datum relative to the coordinate system which is oriented with respect to the principal axis of inertia and the center of mass of the moon.

The Apollo 17 derived datum may be related to the true datum by seven parameters (one for scale, three for orientation, and three for translation). An error in scale or orientation will contribute to the relative error between surface coordinates. This may be written in simplified form as:[5]

$$\sigma_T^2 = \sigma_i^2 + \sigma_j^2 + \sigma_p^2 \qquad \text{(b.1.)}$$

where σ_T^2 is the relative variance between the two points.
σ_i^2 and σ_j^2 are the variances relative to the Apollo 17 reduction, and
σ_p^2 is the variance of scale and orientation.

The i and j are assumed equal and uncorrelated, therefore:

$$\sigma_T^2 = 2\sigma_i^2 + \sigma_p^2 \qquad \text{(b.2.)}$$

One other condition was imposed in equation (b.2.) to account for the condition that σ_p^2 is a function of the distance between the coordinates being evaluated. The estimated effect of this condition is introduced by modifying equation (b.2.) to:

$$\sigma_T^2 = 2\sigma_i^2 + \left(\frac{d}{D}\,\sigma_p\right)^2 \qquad \text{(b.3.)}$$

where d is the actual distance between the two coordinates, and
D is the total distance covered by the triangulation (7400 km).

To obtain some appreciation for this estimate of accuracy between coordinates, computations were made using equation (b.3.) and varying the distance (d) between coordinates. The values used for σ_p^2 were the assumed standard deviations of 100 meters horizontally and 75 meters vertically for Revolutions 66 and 74 in the block triangulation.

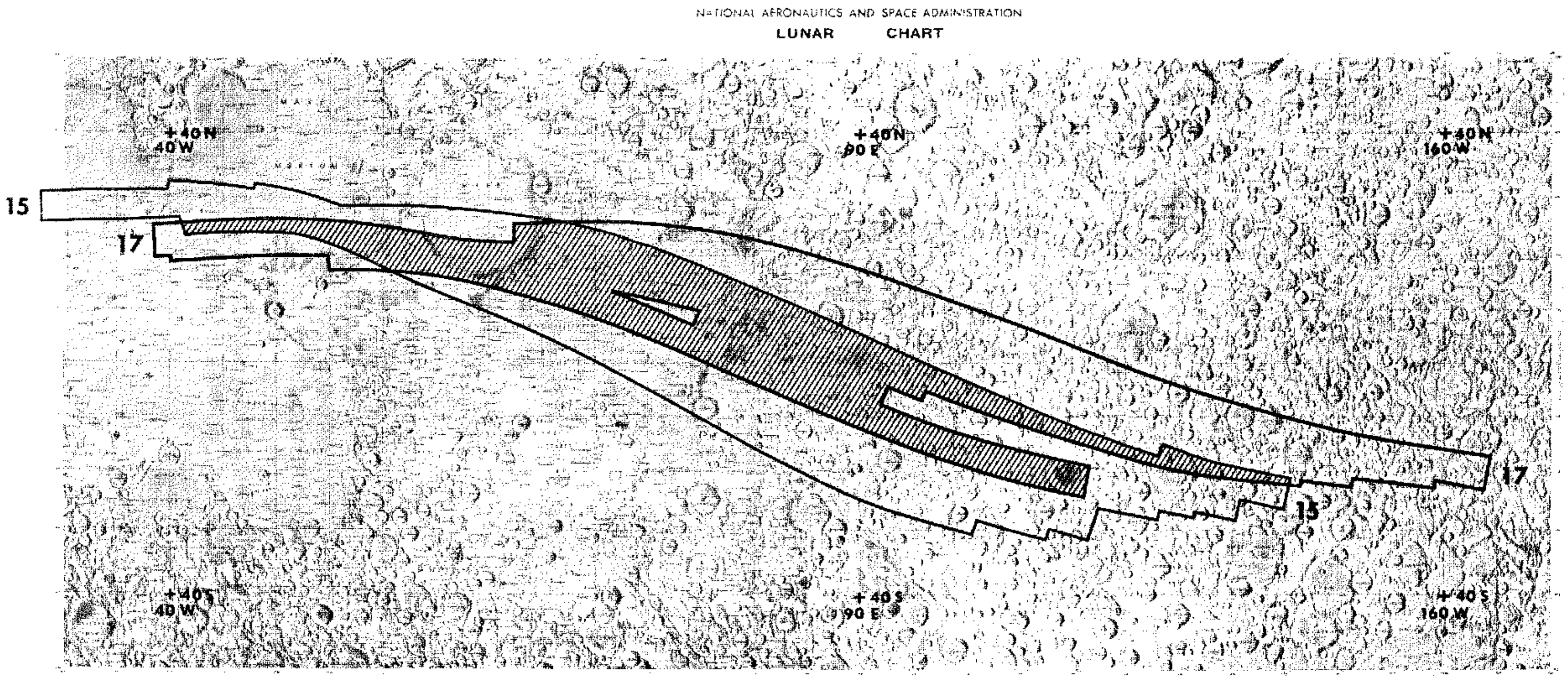

FIGURE 6. COMMON VERTICAL PHOTOGRAPHIC COVERAGE BETWEEN APOLLO MISSIONS 15 AND 17.

The values used for σ_i^2 were the circular and vertical accuracies estimated for the block solution. Table 5 gives the results of the computations.

C. Absolute Positional Accuracy of Coordinates

The absolute accuracy of any coordinate derived from the block reduction is dependent upon the relative accuracy of that coordinate to the triangulation datum and the accuracy of this datum in an absolute sense. The relative accuracy based on a strip to strip evaluation was previously discussed but the relationship of the triangulation datum to the absolute datum can only be estimated at this time. Analysis of the discrepancies between the strip solutions given in Table 3 would yield an average bias of approximately 260 meters. These biases could be used as an indication of the Apollo 17 spacecraft ephemeris accuracy in terms of an absolute evaluation. However, due to the lack of sufficient data on which to base an evaluation of the spacecraft ephemeris position relative to the principal axes of inertia and the center of mass of the moon, no absolute evaluation is presented at this time.

RELATIVE POSITIONING OF APOLLO MISSIONS 15 AND 17

Selections of lunar images identified in the reduction of the Apollo Mission 15 metric vertical photographs were used in the triangulation of Apollo Mission 17. Selenographic coordinates of the points common to the triangulations were compared, the positional mean bias computed, and the differences plotted. The computed differences reflect ephemeris bias depicted by the revolutions used to establish the respective triangulation datums.

The relationship between the Apollo 15 and Apollo 17 triangulation datums was determined with 889 points. The Apollo 17 positions derived approximately 600 meters to the northeast of the Apollo 15 positions. A change in azimuth of the positional mean bias was attributed to the lack of laser altimeter constraints for the Apollo 15 triangulation in this area. The vertical differences vary with Apollo 17 being 200 meters lower than Apollo 15 at the eastern end - zero at the center - and 200 meters higher at the western end. Figures 7 and 7.1 illustrate the positional relationship of the two datums.

CONCLUSION

Completion of the Apollo Mission 17 Control Network provided coverage for approximately ten percent of the lunar surface, five percent of which was in addition to that of Apollo 15. Available altimeter data provided for auxiliary sensor constraints throughout the triangulation. Refinement in data reduction procedures, and revolution relativity of the lunar ephemerides, were evidenced by the improved positional constraints in the Apollo 17 reduction. Point positional data from this solution has provided mapping control for the 1:250,000 scale lunar mapping program.

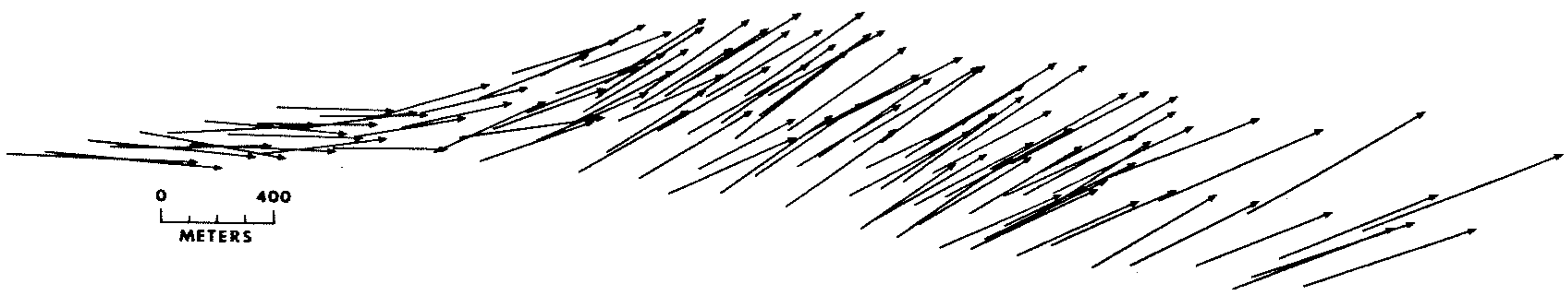

FIGURE 7. HORIZONTAL POSITION COMPARISON OF APOLLO 15 TO THE APOLLO 17 BLOCK SOLUTION.

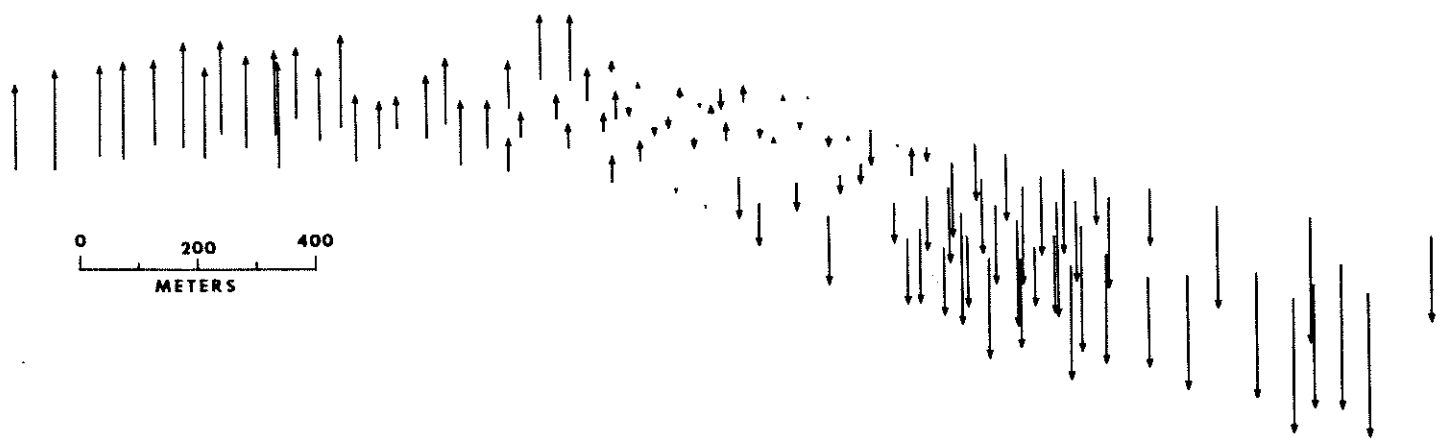

FIGURE 7.1 VERTICAL POSITION COMPARISON OF APOLLO 15 TO THE APOLLO 17 BLOCK SOLUTION.

TABLE 1

PHOTOGRAPHS SELECTED FOR DATA REDUCTION

Revolution	Vertical Exposure	Stellar Exposure
2	170-180 181-256* 258-276 279-306**	152-162 163-213*
14	328-430	318-412
29	1384-1480	1372-1462
38	1692-1820 1821,1822 1824,1825 1826,1828	1682-1802 1803,1804 1806,1807 1808,1810
49	2030-2050*	
62	2200-2220	2182-2202
66	2630-2660 2700-2732	2612-2642 2682-2714
74	2796-2932	2786-2914

Even numbered exposures were used unless noted
* Every exposure used
** Every third exposure used

TABLE 2

EXPOSURES WITH DERIVED ALTIMETER SLANT RANGE

Revolution	Exposure
2	172,176-180 181-218,220-229*
14	346-354,358 362-380,394 398-422
29	1386-1392,1396 1400-1416 1442-1448,1452,1454 1458,1464-1480
38	1694,1696,1700,1704 1706,1710-1716,1720 1726,1730,1734-1738 1744,1750-1760 1764-1776,1780-1798 1802-1818,1821,1822 1824,1825,1826
49	2031-2034,2036-2050*
62	2200-2212,2216-2220
66	2630-2644,2648-2660 2700-2730
74	2796,2798,2804-2828 2832-2850,2854-2902 2902-2932

Even numbered exposures were used unless noted
* Every exposure used

TABLE 3

MEAN SYSTEMATIC BIASES BETWEEN COMMON SURFACE COORDINATES

DERIVED IN INDEPENDENT STRIP SAPGO SOLUTIONS

Standard Revolution	Comparison Revolution	Number of Common Coordinates	Mean Biases (Meters)		
			Latitude	Longitude	Height
2	14	303	49	60	-54
2	29	30	408	-31	-155
29	14	128	-618	104	270
29	38	245	-243	189	-187
29	49	21	218	-157	-70
38	14	30	-333	-213	370
38	49	82	454	-125	183
38	62	9	74	-56	-64
38	66	17	-104	-54	68
62	49	19	321	-23	370
66	62	54	-79	103	-118
74	2	12	-736	555	113
74	38	54	-160	-38	-32
74	62	15	-16	-104	-127
74	66 1st Part	62	39	-209	-38
74	66 2nd Part	110	-290	-60	83

TABLE 4

STANDARD DEVIATIONS COMPUTED FROM COMPARISONS

OF COORDINATES COMMON TO TWO OR MORE STRIPS

Standard Revolution	Comparison Revolution	Common Coordinates	Standard Deviations (Meters) Lat (68%)	Long (68%)	Horizontal CE(39%)	Vertical LE(68%)
2	14	239	25	17	21	26
29	2	23	22	18	20	21
29	14	123	18	15	17	21
29	38	212	20	15	18	22
29	49	13	26	21	24	18
38	2	58	27	19	23	24
38	14	23	21	17	19	20
38	49	69	30	18	25	25
38	62	6	25	21	25	24
38	66 2nd Part	9	14	20	17	20
62	49	15	20	19	20	22
66	62	50	24	19	21	18
74	2	9	31	19	25	18
74	38	47	19	18	19	14
74	62	11	31	17	25	17
74	66 1st Part	50	22	17	20	24
74	66 2nd Part	105	18	13	16	15

TABLE 5

ESTIMATED RELATIVE ACCURACY BETWEEN
POINTS SEPARATED BY VARIOUS DISTANCES

Distance Between Points (KM)	Point to Point Relative Accuracy (M)	
	Horizontal (39%)	Vertical (68%)
0	30	30
1000	36	31
3000	65	42
5000	100	58
7000	137	76
7400	144	80

ACKNOWLEDGMENT

The authors wish to acknowledge the technical assistance of Mr. George Jokerst and Mr. Robert Hodge. Also, the production efforts of those persons under Mr. George Peo's supervision are recognized and in particular the work of Ms Linda Dutton and Mr. Robert Maes who were totally responsible for processing the stellar and terrain photo measures throughout the completion of the project. All have made significant contributions.

BIBLIOGRAPHY

1. Defense Mapping Agency Aerospace Center, Apollo 17 Metric System Initial Evaluation Report, St. Louis, Missouri, April 1974.

2. Aeronautical Chart and Information Center, Apollo 15 Initial Metric System Evaluation Report, St. Louis, Missouri, March 1972.

3. Defense Mapping Agency Aerospace Center, Apollo 15 Stellar Reduction Report, St. Louis, Missouri, June 1973.

4. Wong, K. W. and Elphingstone, G. M., Simultaneous Adjustment of Photogrammetric and Geodetic Observations, Presented Paper at ASP Annual Meeting, Washington, D.C., March 1971.

5. Defense Mapping Agency Aerospace Center, Development of the Apollo 15 Control Network, St. Louis, Missouri, August 1973.

6. Aeronautical Chart and Information Center, Principles of Error Theory and Cartographic Applications, Technical Report No. 96, St. Louis, Missouri, February 1962.