NOAA Technical Memorandum NOS NGS-15

Goldstone Validation Survey - Phase I

William E. Carter
James E. Pettey

National Geodetic Survey
Rockville, Md. 20852

November 1978

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
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NOAA Geodetic publications

Classification, Standards of Accuracy, and General Specifications of Geodetic Control Surveys. Federal Geodetic Control Committee, John O. Phillips (Chairman), Department of Commerce, NOAA, NOS, 1974 reprinted annually, 12 pp (PB265442). National specifications and tables show the closures required and tolerances permitted for first-, second-, and third-order geodetic control surveys.

Specifications To Support Classification, Standards of Accuracy, and General Specifications of Geodetic Control Surveys. Federal Geodetic Control Committee, John O. Phillips (Chairman), Department of Commerce, NOAA, NOS, 1975, reprinted annually 30 pp (PB261037). This publication provides the rationale behind the original publication, "Classification, Standards of Accuracy, ..." cited above.

NOAA Technical Memorandums, NOS/NGS subseries

NOS NGS-1 Use of climatological and meteorological data in the planning and execution of National Geodetic Survey field operations. Robert J. Leffler, December 1975, 30 pp (PB249677). Availability, pertinence, uses, and procedures for using climatological and meteorological data are discussed as applicable to NGS field operations.

NOS NGS-2 Final report on responses to geodetic data questionnaire. John F. Spencer, Jr., March 1976, 39 pp (PB254641). Responses (20%) to a geodetic data questionnaire, mailed to 36,000 U.S. land surveyors, are analyzed for projecting future geodetic data needs.

NOS NGS-3 Adjustment of geodetic field data using a sequential method. Marvin C. Whiting and Allen J. Pope, March 1976, 11 pp (PB253967). A sequential adjustment is adopted for use by NGS field parties.

NOS NGS-4 Reducing the profile of sparse symmetric matrices. Richard A. Snay, June 1976, 24 pp (PB-258476). An algorithm for improving the profile of a sparse symmetric matrix is introduced and tested against the widely used reverse Cuthill-McKee algorithm.

NOS NGS-5 National Geodetic Survey data: availability, explanation, and application. Joseph F. Dracup, June 1976, 45 pp (PB258475). The summary gives data and services available from from NGS, accuracy of surveys, and uses of specific data.

(Continued at end of publication)

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Juanita M. Kreps, Secretary

National Oceanic and Atmospheric Administration
Richard A. Frank, Administrator

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Allen L. Powell, Director

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GOLDSTONE VALIDATION SURVEY - PHASE I

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ABSTRACT. Results are given for a special purpose study conducted by the National Geodetic Survey (NGS) of the National Ocean Survey (NOS) at the National Aeronautics and Space Administration/Jet Propulsion Laboratory (NASA/JPL) MARS Deep Space Station, located at the Goldstone Deep Space Communication Complex in California. The purpose was to determine the components of an approximately 330-m base line, used in space system validation studies, with an accuracy of ±1 cm. Three-dimensional geodetic techniques were employed.

The observational methods of measurement are described. Input and output of the least-squares adjustment program, HAVAGO, are listed as appendices.

INTRODUCTION

This report presents the results of a special purpose survey conducted in the immediate vicinity of the NASA MARS Deep Space Station (DSS 14). The MARS station is located at the Goldstone Deep Space Communication Complex, near Barstow, California. It is operated by the California Institute of Technology's Jet Propulsion Laboratory.

William E. Carter served as NGS Project Manager and James E. Pettey served as Special Technical Advisor for the project. Field operations were under the direction of Richard Maxey, Chief of Geodetic Party G-48.

The National Geodetic Survey, NOS, worked closely with JPL during the planning, site preparation, and field operation phases of the survey. Primary responsibility was assigned to NGS for developing a suitable survey scheme, taking the measurements, reducing the field data, and producing the final report. The Jet Propulsion Laboratory had primary responsibility for reviewing the survey scheme to ensure that it addressed all their needs, site preparation, and coordination between the survey activities and the operational activities at the MARS station. In addition, because of irresolvable scheduling conflicts, certain measurements of the telescope itself were accomplished by JPL personnel and provided to NGS for inclusion in the final computations.

PURPOSE OF THE SURVEY

The MARS 64-m antenna is regularly used for Very Long Baseline Interferometry (VLBI) observations. In an effort to compare a variety of space techniques, certain collocation experiments will be conducted at the MARS station. A special facility suitable for use by the NASA transportable laser-ranging and VLBI systems has been constructed near the MARS antenna.

The primary purpose of the survey was to determine the components (ΔX, ΔY, ΔZ) of the vector base line from the VLBI point of reference at the MARS antenna (DSS-14) to a monumented point at the new "validation" facility. The goal was to achieve an accuracy of ± 1 cm in each component, in a coordinate system defined by the FK-4 Fundamental Star Catalog, the Conventional International Origin (CIO), and Bureau International de l'Heure time and pole position values.

The survey also tied-in other points of interest in the area. (See Survey Scheme.)

BASIC FORMULATION

The components of a line connecting two stations on the Earth, expressed in a standpoint altitude-azimuth coordinate system, are

$$\Delta X_A = B \cos a \cos v$$

$$\Delta Y_A = B \sin a \cos v$$

$$\Delta Z_A = B \sin v$$

where

B is the chord distance between the stations,

a is the azimuth of line B,

v is the altitude of line B,

Subscript A indicates an altitude-azimuth reference frame.

This local coordinate system is not a very desirable reference frame in which to express the base line components because the orientation is defined by the local vertical which varies over the surface of the Earth in a very complex manner.

If the astronomic latitude and longitude of the standpoint (i.e., the direction of the local vertical with respect to the rotational axis of the Earth) are known, appropriate rotations can be made to express the base line components in an equatorial frame of reference. The components are then given by

$$\Delta X_E = B\ [\cos\lambda\ (\cos\phi\ \sin v - \sin\phi\ \cos a\ \cos v) - \sin\lambda\ \sin a\ \cos v]$$

$$\Delta Y_E = B\ [\sin\lambda\ (\cos\phi\ \sin v - \sin\phi\ \cos a\ \cos v) + \cos\lambda \sin a\ \cos v]$$

$$\Delta Z_E = B\ [\cos\phi\ \cos a\ \cos v + \sin\phi\ \sin v]$$

where

B, a, v are as previously defined,

ϕ is the astronomic latitude,

λ is the astronomic longitude,

Subscript E indicates an equatorial reference frame.

It is, of course, well known that the orientation of the physical body of the Earth with respect to the axis of rotation varies with time. This phenomenon is commonly referred to as polar motion. Polar motion causes the components of a line to be time dependent, and if multiple determinations of the components made at different epochs are to be compared, the observed values must be reduced to a common epoch. All astronomic latitudes, longitudes, and azimuths used in this survey were reduced to the Conventional International Origin using polar coordinates and time information published by the Bureau International de l'Heure.

The concepts and equations which are briefly presented above form the basis for the methods often referred to as three-dimensional geodesy. Several books and papers have been prepared on the subject, e.g., Heiskanen and Moritz (1967), Bomford (1971), and Rapp (1975). The final adjustment of the survey was made by Pettey using computer program HAVAGO. HAVAGO, developed by T. Vincenty of NGS, combines horizontal, vertical, and astronomic observations in a least-squares adjustment according to the principles of three-dimensional geodesy.

SURVEY SCHEME

The VLBI reference point at the MARS antenna is taken to be the point where the vertical (azimuth) axis intersects the plane containing the horizontal (altitude) axis. There is no physical component at this point, but rather it is a point in space that can be located only with respect to some auxiliary monumented point.

The VLBI reference point is located among the structural components of the telescope and could not be conveniently occupied for the purposes of surveying. Indeed, no point that could be conveniently occupied was found very near the desired point of measurement. It was decided to establish a temporary station, designated MARS COLLIMATION, near ground level and almost directly beneath the MARS VLBI reference points. (See fig. 1.) The Jet Propulsion Laboratory designed and installed a special observing platform and instrument support structure in the base structure of the master equatorial tower. From station MARS COLLIMATION, it was possible to look up to the master equatorial system and down to a brass station marker cemented to the floor of the support structure by use of a vertical collimator. Lines of sight from MARS COLLIMATION to stations MARS CONTROL and GOLDSTONE VALIDATION were created by JPL by boring 20-cm diameter holes at appropriate locations in the master equatorial support structure. Both MARS CONTROL and GOLDSTONE VALIDATION were located so that the lines of sight passed through existing doorways in the main telescope pedestal.

The primary reason for establishing station MARS CONTROL was to provide redundancy in the determination of the base line components. Since it was not possible to observe astronomic latitude, longitude, and azimuth from MARS COLLIMATION, it was not possible to solve for the base line components from independent determinations from each end of the line. However, the addition of MARS CONTROL allowed a comparison between the direct measurement of the GOLDSTONE VALIDATION-MARS COLLIMATION vector with the sum of the GOLDSTONE VALIDATION-MARS CONTROL and MARS CONTROL-MARS COLLIMATION vectors.

Figure 2 is a sketch of the total survey scheme. For brevity in the discussions to follow, stations will be identified by the following numeric codes:

Station Name	Identification No.
MARS 1963	[100]
ARIES 1976	[101]
GOLDSTONE VALIDATION	[102]
MARS CONTROL	[103]
MARS COLLIMATION	[104]
MARS VLBI	[105]
GOLDSTONE VALIDATION RM 1	[201]
GOLDSTONE VALIDATION RM 2	[202]
GOLDSTONE VALIDATION RM 2	[203]

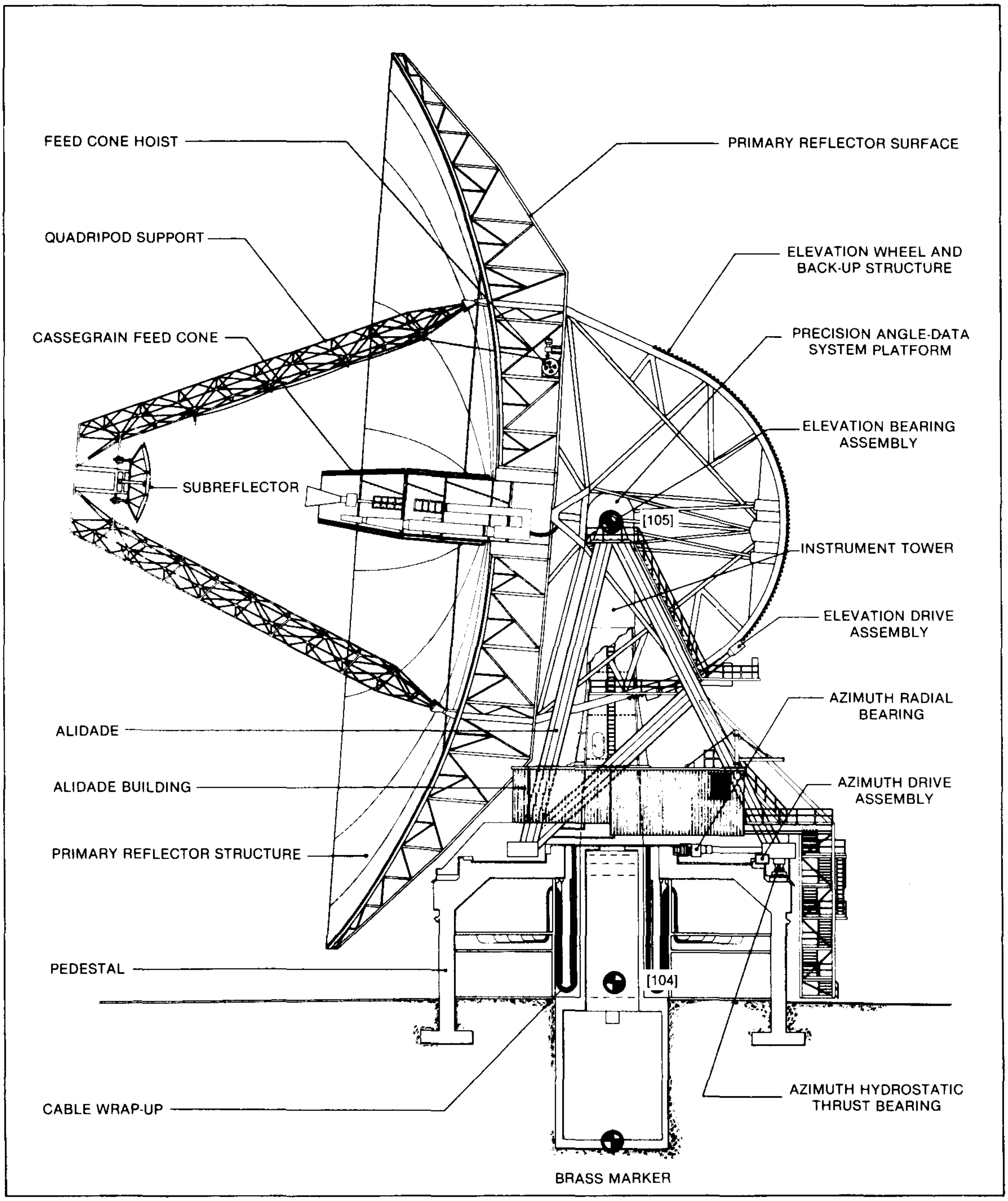

Figure 1.--Sketch taken from JPL visitor pamphlet, modified to indicate the location of temporary station MARS COLLIMATION [104], the VLBI reference point [105], and the brass marker at the base of the master equatorial support structure.

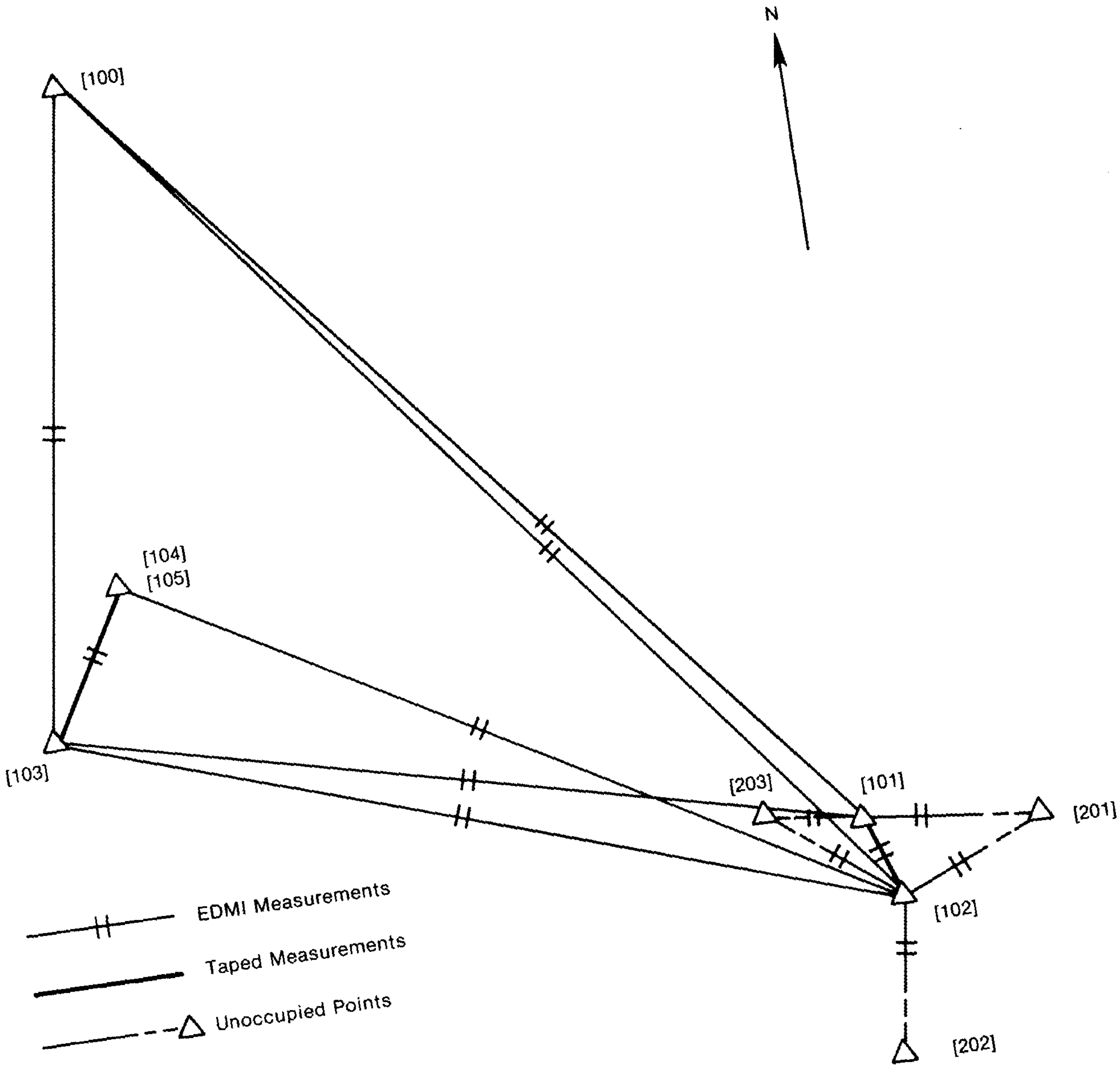

Figure 2.--Survey scheme.

NGS OBSERVATIONAL PROGRAM

To ensure that the desired accuracy of ±1 cm was achieved in each component of the vector base line [102]-[105], both redundancy and multiplicity of measurements were employed. Instruments of several different types and manufacturers minimized systematic instrumentation errors. Measurements were made by more than one observer to reduce personal biases. The observing periods were also scheduled to minimize the effects of time-dependent atmospheric anomalies.

Complete listings of all the measurements used in the adjustment are given in appendix C.

Astronomic Observations

Astronomic positions were determined explicitly for stations [100], [102], and [103] using FK-4 stars exclusively. Astronomic positions for the remaining stations were considered implicitly determined based on their close proximity to one of these three stations; i.e., to obtain the desired astronomic quantities for those stations not actually observed, geodetic positional differences were applied to the astronomic values of the nearby station.

Historically, NGS has used the Horrebow-Talcott method in the determination of latitude. This features the meridianal measurement of the small zenith distance difference of two stars culminating on opposite sides of the local zenith within a few minutes. The tight constraints on zenith distance differences and time between transits of the stars forming a pair require that a catalog containing a large number of stars be used. The SAO catalog, which contains 258,997 stars, has been used for this purpose since 1968. Even though this catalog is referred to the FK-4 system, it cannot be considered as definitively FK-4.

To avoid placing qualifications on the reference system for the astronomic latitudes the Sterneck method was adopted, for which acceptable observing lists can be developed using only the 1,500 plus FK-4 stars. The Sterneck method requires the measurement of absolute zenith distances. To minimize the influence of systematic refraction errors on the latitude results, a program involving an equal number of stars north and south of the zenith was specified. As an additional constraint, the mean declination of all stars scheduled for a nightly observation program was required to be not more than ±1° from the station's assumed latitude.

Latitude determinations for stations [100], [102], and [103] were obtained by two observers with both a Kern DKM-3A and Wild T-4 theodolite observing the same stars simultaneously. The resulting latitudes for stations [100] and [103] involved single night determinations, while observations for station [102] spanned two nights. Appendix A contains a list of the astronomic latitude determinations.

Longitude determinations were made by the meridian transit method (Hoskinson & Duerksen 1947) using the Wild T-4 theodolite and Datametrics model SP-300 digital timing system.

The following tabulation gives the number of longitude sets obtained at each station during the course of this project.

Station	No. of Sets
[100]	3
[102]	8
[103]	6

Each longitude set includes observations on seven stars. For station [100], there were an additional six sets observed in 1964. After careful analysis, all nine sets were combined to obtain the adopted station longitude.

A summary of all the astronomic longitude determinations is presented in appendix A.

Astronomic azimuths were observed from stations [100], [102], and [103]. For the few lines not directly included in the azimuth observation program, azimuth orientations were obtained through angular transfer using horizontal angles measured independently from the azimuth observations.

In the azimuth observation program with the DKM-3A theodolite, special observing techniques were used to minimize personal biases. Three observers, each observing 10 positions, were used in each nightly azimuth determination. After each 10 positions, the theodolite was rotated 120° on the supporting tribrach to remove possible theodolite eccentricities. Theodolite focussing draw tube errors were minimized by installing a circular defraction grating over the telescope objective lens. A summary of the astronomic azimuth determinations is included in appendix A.

Electromagnetic Distance Measurements

Four instruments (two MA 100 Tellurometers, one model IV Ranger, and one model 3800 Hewlett-Packard) were used in the Electromagnetic Distance Measurements (EDM) among stations [100], [101], [102], [103], and [104]. Standard point-to-point ranging techniques were used in all measurements with the MA 100 and model 3800 instruments. For the model IV Ranger measurements, a multiple path technique was used which employed a flat first-surface mirror in conjunction with a retroreflector. This allowed range measurements to be made to all stations from a single instrument setup at station [103].

To illustrate the method, consider the lines [103]-[104] and [104]-[102]. The EDM instrument was positioned over station [103]. The mirror, gimbaled for azimuth and altitude adjustments[1], was positioned over station [104], and a retroreflector was positioned over station [102]. Measurements were first made to station [104] by direct ranging to the mirror. The mirror was then reoriented to achieve retroreflection from station [102] and then the total distance of [103]-[104]-[102] was measured. The distance [104]-[102] was obtained by the simple process of subtracting the distance [103]-[104] from the overall distance [103]-[104]-[102]. Assuming that corrections for any instrument and retroreflector offsets are properly applied, the distance obtained by this differencing process is inherently free of instrumental constants. The lines [101]-[100], [101]-[102], and [102]-[100] were measured in a similar manner.

Meteorological measurements to determine the atmospheric index of refraction were taken at 15-minute intervals throughout the EDM observing periods. These measurements were made at each terminal using precise altimeters and asperated thermometers located at instrument/reflector heights. Periodic frequency measurements for each EDM instrument oscillator were taken to minimize systematic scale errors.

Additional Observations

As an additional verification of the EDM instrument measurements, two lines, [103] to [104] and [101] to [102], were measured with standardized tapes. Four invar and two steel tapes certified by the National Bureau of Standards were used in these base line measurements. Standard base line procedures were employed as detailed in the "Manual of Geodetic Triangulation" (Gossett 1971).

Reciprocal zenith distances were measured at stations [100], [101], [102], [103], and [104]. For stations [100], [102], and [103], these measurements were made in conjunction with the astronomic azimuth observations. To minimize systematic errors resulting from short term refraction anomalies, the vertical measurements were observed nightly in two sets separated by approximately two hours.

As an independent check on the zenith distance measurements, first-order spirit level observations were obtained for all ground stations.

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[1]This fixture was fabricated at the NGS Instrument and Equipment Branch, Corbin, Va., in such a manner that the geometric center of the mirror's front surface is coincident with the mechanical intersection of the axes.

The vertical distance from station [104] to station [105] was measured with two standardized steel tapes. The tapes were tensioned at 5 kg.

Station [104] (MARS COLLIMATION) was found to be slightly eccentric to the vertical axis of the telescope. A sketch showing the direction and magnitude of the offset is included in appendix A.

JPL MEASUREMENTS

Due to conflicting schedules, it was not possible for NGS to survey directly to the MARS VLBI reference point. During the survey NGS, working with JPL personnel, did relate the survey to a reference mark on the master equatorial assembly.

Jet Propulsion Laboratory subsequently measured the height of the elevation axis above this reference mark and the eccentricity of the horizontal axis relative to the vertical axis of the telescope. Appendix B contains a copy of JPL correspondence relative to these measurements.

Note that the eccentricity which is quite small actually assumes no importance to this survey, since the VLBI reference point is defined to be on the vertical axis.

CONCLUSIONS

The goals of the survey were achieved and, in fact, substantially exceeded. The components of the vectors between station GOLDSTONE VALIDATION [102] and the other stations of the survey scheme are listed in table 1.

Table 1.--Base line components

From	To	$\Delta X \pm \sigma x$	$\Delta Y \pm \sigma y$	$\Delta Z \pm \sigma z$
[102]	[100]	-166.165 ±.001	301.130 ±.002	306.849 ±.002
[102]	[101]	- 2.320 ±.001	20.675 ±.001	26.552 ±.001
[102]	[103]	-258.792 ±.001	199.452 ±.001	86.406 ±.001
[102]	[104]	-214.919 ±.001	211.848 ±.001	134.133 ±.001
[102]	[105]	-227.005 ±.001	188.002 ±.002	153.150 ±.002
[102]	[201]	56.294 ±.001	- 13.693 ±.001	19.561 ±.001
[102]	[202]	- 21.765 ±.001	- 25.429 ±.001	- 51.028 ±.001
[102]	[203]	- 33.991 ±.001	40.046 ±.001	30.886 ±.001

ΔX, ΔY, ΔZ are components of vectors between the indicated stations in meters. σx, σy, σz are the formal standard errors.

Notice that the formal standard error of each component of the GOLDSTONE VALIDATION-MARS VLBI base line [102]-[105] is ±0.002 m. Even allowing for reasonable unknown systematic errors, the components should be accurate to ±0.005 m.

The entire output of program HAVAGO is reproduced in appendix D.

REFERENCES

Bomford, G., 1971: Geodesy. Clarendon Press, Oxford, third edition, 731 pp.

Gossett, F. R., 1971: Manual of geodetic triangulation. Special Publication No. 247, U.S. Coast and Geodetic Survey (now National Ocean Survey, NOAA), Dept. of Comm., Washington, D.C., 344 pp. (NTIS accession no. COM-71-50406).

Heiskanen, W. A. and Moritz, H., 1967: Physical Geodesy, Freeman and Co., San Francisco and London, 364 pp.

Hoskinson, A. J. and Duerksen, J. A., 1947: Manual of geodetic astronomy, Special Publication No. 237, U.S. Coast and Geodetic Survey (now National Ocean Survey, NOAA), Dept. of Comm., Washington, D.C., 205 pp. (NTIS accession no. PB267465).

Rapp, R. H., 1975: Geometric Geodesy Notes, Vol. II. Ohio State University, Columbus, pp. 111-134.

APPENDIX A. NGS SUPPORTIVE DATA

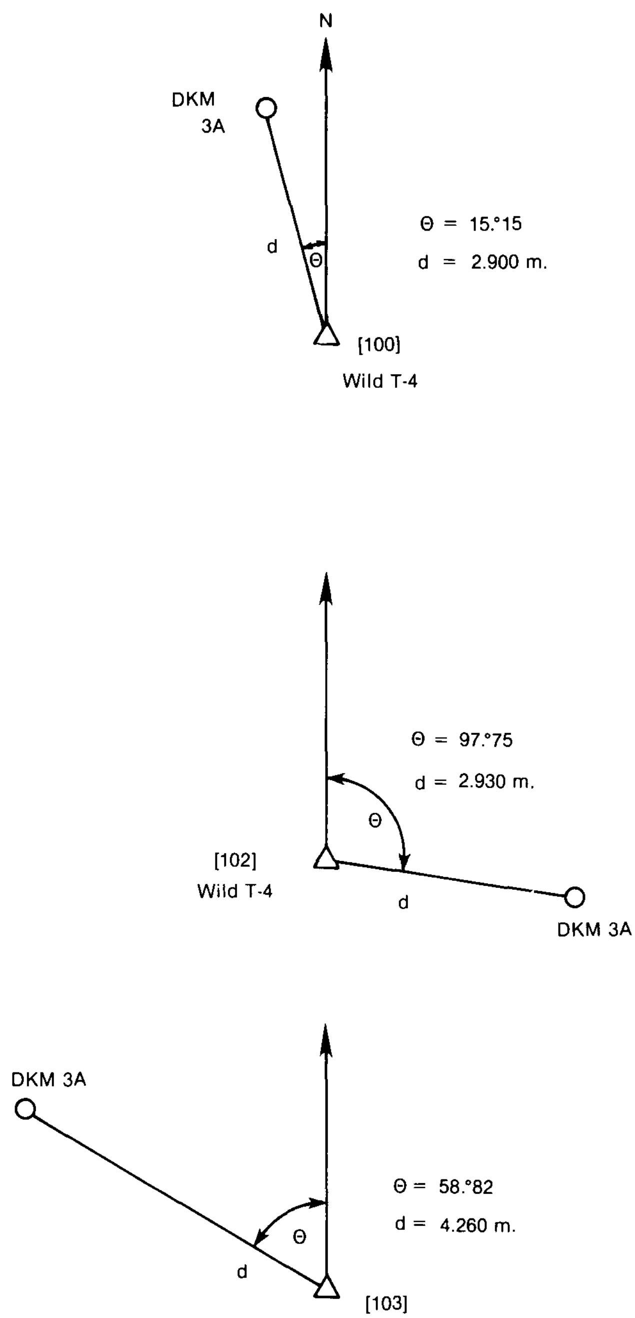

Figure 3.--Theodolite locations used for latitude observations.

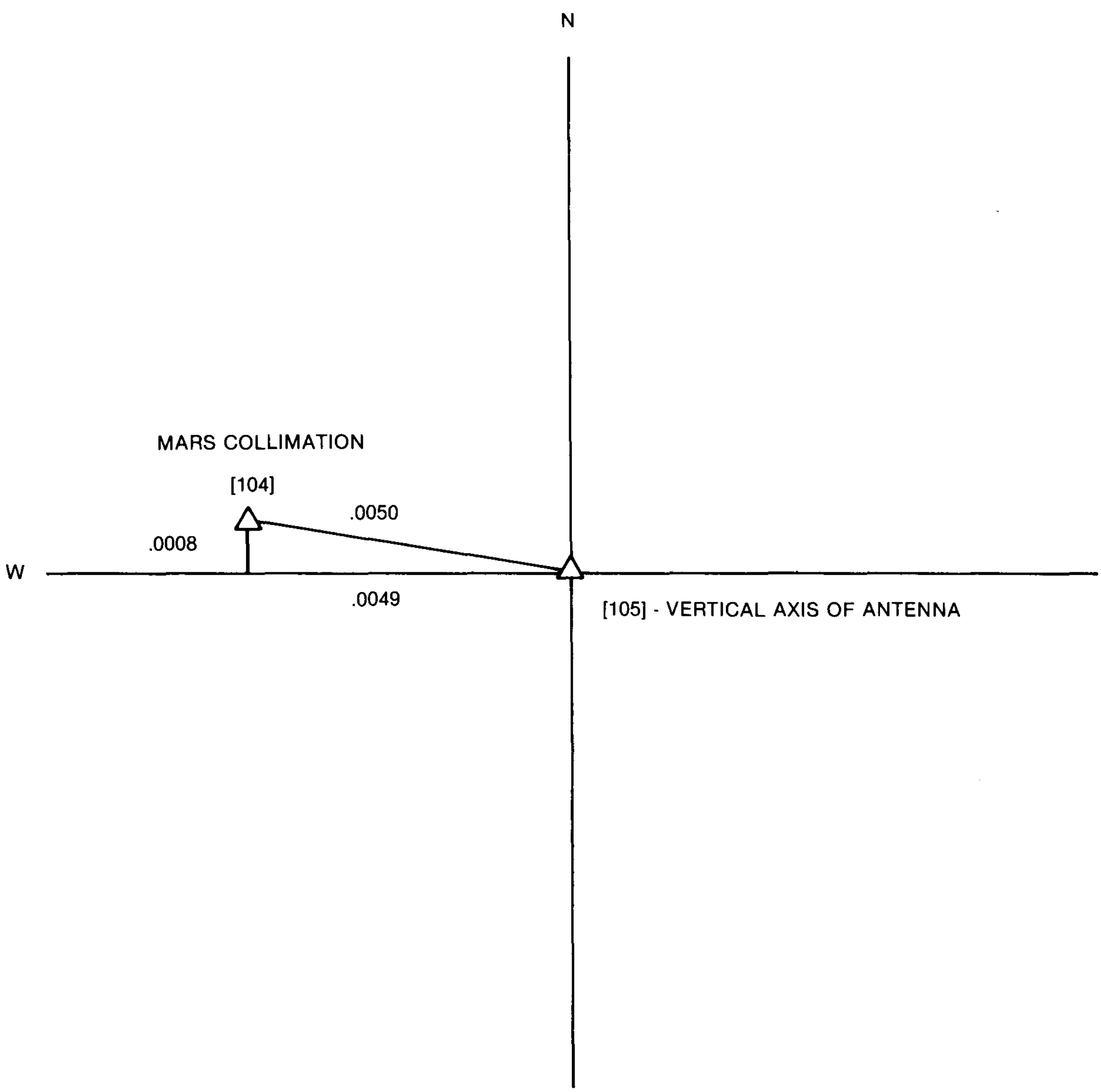

Figure 4.--Eccentricity of MARS COLLIMATION [104] from the vertical axis of the Mars telescope. (All measurements are by direct measure.)

Table 2.--Astronomic latitude results

Station	Date	Instrument	Φ (CIO) ° ' "	Adopted Φ ° '
[100]	10/11/77	DKM-3A	35 25 35.59	35 25
	10/11/77	Wild T-4	35.31	35".45
[102]	10/06/77	DKM-3A	35 25 24.41	
	10/06/77	Wild T-4	24.22	
	10/07/77	DKM-3A	24.29	35 25
	10/07/77	Wild T-4	23.91	24".21
[103]	10/12/77	DKM-3A	35 25 27.34	35 25
		Wild T-4	27.39	27".36

Table 3.--Astronomic longitude results

Station	GCD	Observer	Λ (epoch) ° ' "	Λ (CIO) "	Adopted Λ
[100]	3/05/64	VB	116 53 25.94	24.24	
	3/05/64	FB	26.32	24.63	
	3/05/64	EH	27.22	25.53	
	3/10/64	EH	27.26	25.49	
	3/10/64	EH	26.88	25.11	
	3/10/64	FB	26.02	24.25	
	10/12/77	RM	27.03	25.37	
	10/12/77	BK	26.14	24.48	116° 53'
	10/12/77	BK	26.55	24.88	24".89 ±0".17
[102]	10/06/77	RM	116 53 15.28	13.89	
	10/08/77	BK	15.39	13.90	
	10/10/77	RM	15.42	13.85	
	10/10/77	RM	15.52	13.96	
	10/10/77	RM	15.21	13.64	
	10/10/77	BK	14.94	13.37	
	10/10/77	BK	15.15	13.58	116° 53'
	10/10/77	BK	15.02	13.44	13".70 ±0".08
[103]	10/13/77	BK	116 53 28.41	26.70	
	10/13/77	RM	28.54	26.83	
	10/13/77	RM	28.10	26.38	
	10/14/77	RM	28.54	26.79	
	10/14/77	BK	27.96	26.20	116° 53'
	10/14/77	BK	28.60	26.85	26".62 ±0".11

APPENDIX B. JPL SUPPORTIVE DATA

JET PROPULSION LABORATORY *California Institute of Technology • 4800 Oak Grove Drive, Pasadena, California 91103*

30 June 1978

Dr. William E. Carter
National Geodetic Survey
U. S. Department of Commerce
National Ocean Survey
Rockville, Maryland 20852

Dear Bill:

Attached is a sketch showing the values for measurements JPL agreed to perform at DSS-14. These values relating the ME to the elevation and azimuth axes should enable you to complete Phase I and issue the DSS-14 short baseline final report.

The weather at Goldstone during the measurements was not cooperative - it is a very windy year. The accuracy of the elevation axis offset is probably ± 0.020 inches. I will be conducting the elevation axis measurements again in the future to try and improve on the accuracy. I think the values are adequate for the completion of the report and the up-coming meeting with Mr. R. Stevens.

(unrelated text removed)

Sincerely,

Ken

Kenneth P. Bartos, Supervisor
Antenna Mechanical Group

KPB:em

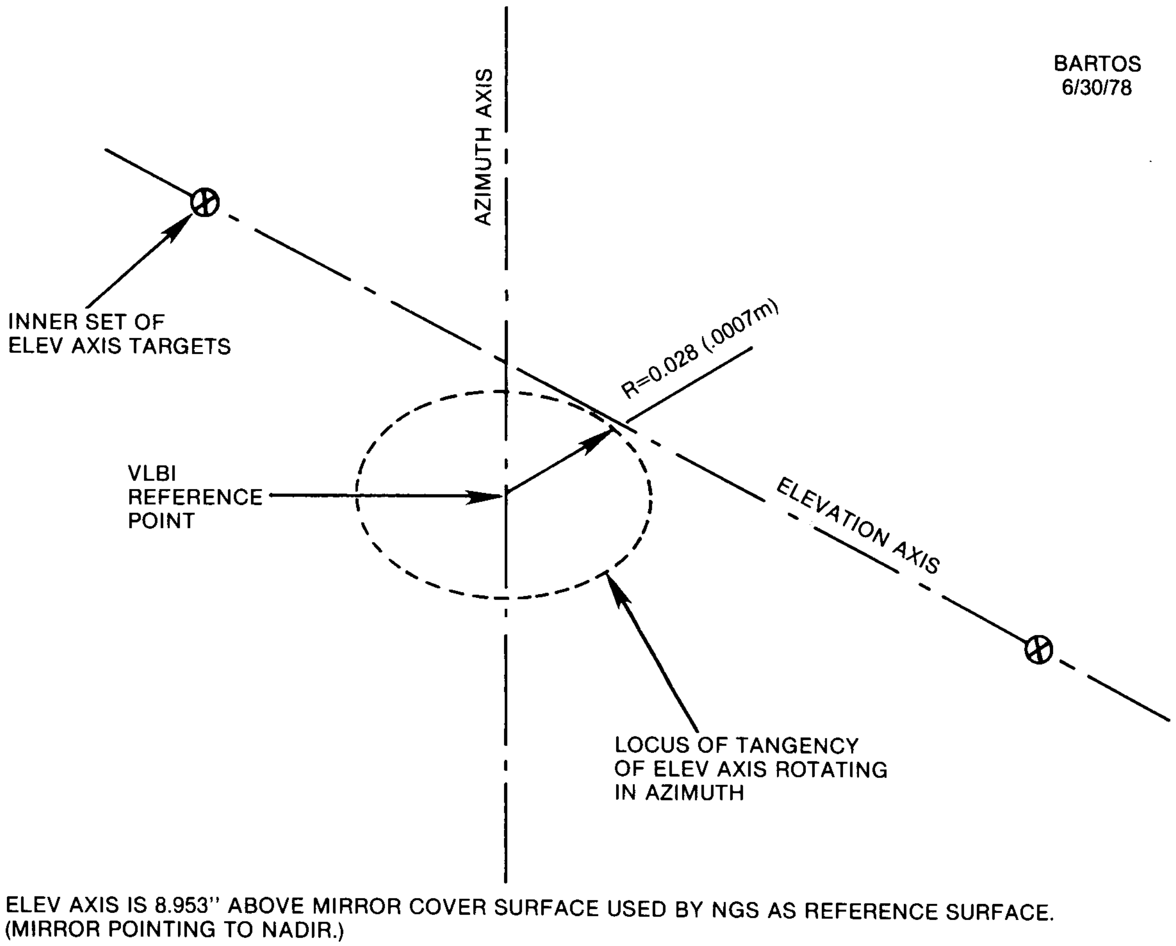

Figure 5.--Telescope elevation axis offset.

APPENDIX C.--INPUT DATA FOR ADJUSTMENT

The following computerized listing, using program HAVAGO, gives the input observational data for the Goldstone validation survey.

INPUT

STATION DATA

STATION		GEOD. LAT.	GEOD. LON.	HEIGHT	ASTR. LAT.	ASTR. LON.	S. E. (GEOD.)			S.E.(ASTR.)		CODES		
MARS 1963	100	35 25 39.81830	116 53 19.02710	993.374	35 25 35.45	116 53 24.89	0.001	0.001	0.001	0.3	0.4	1	1	1
ARIES 1976	101	35 25 29.09709	116 53 8.20789	974.344	35 25 25.24	116 53 14.15	0.0	0.0	0.0	0.3	0.4	0	0	0
GOLDSTONE VALIDATION	102	35 25 28.06809	116 53 7.75532	973.124	35 25 24.21	116 53 13.70	0.0	0.0	0.0	0.3	0.4	0	0	0
MARS CONTROL	103	35 25 31.49676	116 53 20.47860	973.624	35 25 27.36	116 53 26.62	0.0	0.0	0.0	0.3	0.4	0	0	0
MARS COLLIMATION	104	35 25 33.33962	116 53 19.14992	976.107	35 25 29.20	116 53 25.29	0.0	0.0	0.0	0.3	0.4	0	0	0
MARS VLBI	105	35 25 33.33947	116 53 19.14985	1008.915	35 25 29.20	116 53 25.29	0.0	0.0	0.0	0.3	0.4	0	0	0
GOLDSTONE VALIDATION RM 1	201	35 25 28.83473	116 53 5.52011	973.669	35 25 24.98	116 53 11.46	0.0	0.0	0.0	0.3	0.4	0	0	0
GOLDSTONE VALIDATION RM 2	202	35 25 26.10757	116 53 8.06915	970.051	35 25 22.25	116 53 14.01	0.0	0.0	0.0	0.3	0.4	0	0	0
GOLDSTONE VALIDATION RM 3	203	35 25 29.26785	116 53 9.67519	974.448	35 25 25.41	116 53 15.62	0.0	0.0	0.0	0.3	0.4	0	0	0

INPUT

DIRECTIONS

	FROM	TO	LIST	OBSERVED			MM	SEC.
1	101	103	1	0	0	0.0	0.5	0.7
2	101	100	1	37	0	16.73	0.5	0.7
3	101	102	1	236	45	44.28	0.5	1.0
4	102	103	1	0	0	0.0	0.5	1.0
5	102	100	1	33	38	13.65	0.5	1.0
6	102	101	1	51	58	37.00	0.5	1.0
7	102	103	2	0	0	0.0	0.5	0.7
8	102	100	2	33	38	13.19	0.5	0.7
9	102	101	2	51	58	36.29	0.5	1.0
10	102	103	3	0	0	0.0	0.5	0.5
11	102	104	3	11	15	6.31	0.5	0.5
12	102	100	3	33	38	13.14	0.5	0.5
13	103	100	1	0	0	0.0	0.5	0.7
14	103	101	1	95	18	28.91	0.5	0.7
15	103	102	1	100	5	35.84	0.5	0.7
16	104	102	1	0	0	0.0	0.5	0.6
17	104	103	1	91	4	28.49	0.5	0.6
18	103	100	2	0	0	0.0	0.5	0.6
19	103	104	2	22	25	16.21	0.5	0.6
20	103	102	2	100	5	38.84	0.5	0.6
21	102	103	4	0	0	0.0	1.0	1.0
22	102	203	4	19	7	45.90	1.0	1.0
23	102	201	4	139	3	23.40	1.0	1.0
24	102	202	4	259	14	12.90	1.0	1.0

INPUT

ASTRONOMIC AZIMUTHS

	FROM	TO	OBSERVED	MM	SEC.
25	100	101	140 26 20.80	0.5	1.5
26	100	101	140 26 23.18	0.5	1.5
27	100	101	140 26 23.06	0.5	1.5
28	100	101	140 26 25.32	0.5	1.5
29	100	102	141 51 28.05	0.5	1.5
30	100	102	141 51 29.17	0.5	1.5
31	100	102	141 51 28.32	0.5	1.5
32	100	102	141 51 30.96	0.5	1.5
33	100	103	188 7 36.51	0.5	1.5
34	100	103	188 7 36.45	0.5	1.5
35	100	103	188 7 36.22	0.5	1.5
36	100	103	188 7 37.99	0.5	1.5
37	102	100	321 51 39.32	0.5	1.5
38	102	100	321 51 40.47	0.5	1.5
39	102	100	321 51 37.08	0.5	1.5
40	102	100	321 51 34.22	0.5	1.5
41	102	103	288 13 22.06	0.5	1.5
42	102	103	288 13 22.36	0.5	1.5
43	102	103	288 13 18.07	0.5	1.5
44	102	103	288 13 20.97	0.5	1.5
45	103	100	8 7 32.02	0.5	1.5
46	103	100	8 7 33.35	0.5	1.5
47	103	100	8 7 31.41	0.5	1.5
48	103	100	8 7 33.55	0.5	1.5
49	103	101	103 26 5.34	0.5	1.5
50	103	102	108 13 13.94	0.5	1.5
51	103	102	108 13 13.98	0.5	1.5
52	103	102	108 13 12.95	0.5	1.5
53	103	102	108 13 13.08	0.5	1.5

INPUT

GROUPED VERTICAL ANGLES

	FROM	TO	LIST	OBSERVED			SEC.	MM	H.I.	H.T.	K1	K2
54	100	101	1	92	32	39.90	5.0	1.0	1.723	1.696	0.0	0.0
55	100	103	1	94	6	11.10	5.0	1.0	1.723	2.885	0.0	0.0
56	100	101	2	92	33	46.60	5.0	1.0	1.723	1.564	0.0	0.0
57	100	102	2	92	19	0.80	5.0	1.0	1.723	3.331	0.0	0.0
58	100	101	3	92	33	46.20	5.0	1.0	1.714	1.564	0.0	0.0
59	100	102	3	92	19	26.40	5.0	1.0	1.714	3.287	0.0	0.0
60	100	103	3	94	6	15.40	5.0	1.0	1.714	2.875	0.0	0.0
61	101	103	1	89	55	56.70	5.0	1.0	1.826	2.875	0.0	0.0
62	101	100	1	87	30	18.10	5.0	1.0	1.826	1.451	0.0	0.0
63	102	100	1	87	44	18.80	5.0	1.0	3.534	1.484	0.0	0.0
64	102	103	1	90	1	47.80	5.0	1.0	3.534	2.866	0.0	0.0
65	102	100	2	87	44	30.40	5.0	1.0	3.545	1.449	0.0	0.0
66	102	103	2	90	1	36.20	5.0	1.0	3.545	2.875	0.0	0.0
67	102	100	3	87	44	37.50	5.0	1.0	3.545	1.443	0.0	0.0
68	102	103	3	90	1	44.50	5.0	1.0	3.545	2.875	0.0	0.0
69	102	100	4	87	44	42.80	5.0	1.0	3.548	1.443	0.0	0.0
70	102	103	4	90	1	48.60	5.0	1.0	3.548	2.875	0.0	0.0
71	102	104	4	90	3	12.60	5.0	1.0	3.548	0.256	0.0	0.0
72	103	100	1	86	0	32.00	5.0	1.0	3.129	1.470	0.0	0.0
73	103	102	1	90	3	41.80	5.0	1.0	3.129	3.271	0.0	0.0
74	103	100	2	86	0	52.20	5.0	1.0	3.142	1.449	0.0	0.0
75	103	101	2	90	9	15.90	5.0	1.0	3.142	1.564	0.0	0.0
76	103	102	2	90	3	35.50	5.0	1.0	3.142	3.288	0.0	0.0
77	103	100	3	86	0	59.20	5.0	1.0	3.149	1.445	0.0	0.0
78	103	101	3	90	9	20.60	5.0	1.0	3.149	1.566	0.0	0.0
79	103	102	3	90	3	41.60	5.0	1.0	3.149	3.289	0.0	0.0
80	103	100	4	86	1	2.70	5.0	1.0	3.149	1.443	0.0	0.0
81	103	102	4	90	3	50.10	5.0	1.0	3.149	3.278	0.0	0.0
82	103	104	4	90	21	6.50	5.0	1.0	3.149	0.256	0.0	0.0
83	104	102	1	89	59	47.90	5.0	1.0	0.275	3.287	0.0	0.0
84	104	103	1	89	54	2.70	5.0	1.0	0.275	2.875	0.0	0.0

INPUT

ABSOLUTE DISTANCES

	FROM	TO	OBSERVED	MM	PPM	H.I.	H.T.
85	103	100	259.7082	1.5	2.00	3.252	1.540
86	103	101	318.3092	1.5	2.00	3.252	1.668
87	103	104	65.9581	1.5	2.00	3.252	0.300
88	102	100	460.8339	1.5	2.00	3.655	1.608
89	102	101	33.7216	1.5	2.00	3.655	1.685
90	102	103	337.9663	1.5	2.00	3.655	2.982
91	102	104	330.2310	1.5	2.00	3.655	0.300
92	102	104	330.2285	1.5	2.00	3.655	0.234
93	103	104	65.9576	1.5	2.00	3.252	0.280
94	103	104	65.9569	1.5	2.00	3.252	0.300
95	102	100	460.8301	1.5	2.00	3.655	1.549
96	102	103	337.9657	1.5	2.00	3.655	2.982
97	102	104	330.2332	1.5	2.00	3.655	0.300
98	102	104	330.2266	1.5	2.00	3.655	0.234
99	102	101	33.7198	1.5	2.00	3.655	1.685
100	100	101	429.0271	5.0	7.00	1.645	1.725
101	100	102	460.8421	5.0	7.00	1.645	3.439
102	100	103	259.7301	5.0	7.00	1.645	3.036
103	102	101	33.7159	5.0	7.00	3.476	1.725
104	102	101	33.7186	5.0	7.00	3.479	1.725
105	102	103	337.9640	5.0	7.00	3.476	3.038
106	102	103	337.9671	5.0	7.00	3.481	2.973
107	103	104	65.9580	5.0	7.00	3.074	0.355
108	103	101	318.3108	5.0	7.00	3.074	1.725
109	103	102	337.9617	5.0	7.00	3.074	3.439
110	102	100	460.8376	5.0	7.00	3.476	1.594
111	102	100	460.8377	5.0	7.00	3.481	1.540
112	102	104	330.2259	5.0	7.00	3.481	0.256
113	103	101	318.3154	5.0	2.00	3.139	1.782
114	101	102	33.7092	5.0	2.00	1.782	3.418
115	103	101	318.3179	5.0	2.00	3.139	1.782
116	101	100	429.0362	5.0	2.00	1.782	1.621
117	103	104	65.9593	5.0	2.00	3.139	0.229
118	104	102	330.2394	5.0	2.00	0.229	3.461
119	103	104	65.9594	5.0	2.00	3.139	0.229
120	104	102	330.2386	5.0	2.00	0.229	3.461
121	103	102	337.9733	5.0	2.00	3.139	3.505
122	102	100	460.8479	5.0	2.00	3.505	1.621
123	103	104	65.9625	5.0	2.00	3.139	0.326
124	103	101	318.3171	5.0	2.00	3.139	1.695
125	103	102	337.9716	5.0	2.00	3.139	3.418
126	103	100	259.7241	5.0	2.00	3.139	1.578
127	103	104	66.0034	1.0	0.0	0.0	0.0
128	101	102	33.7315	1.0	0.0	0.0	0.0
129	101	201	68.3416	1.5	2.00	1.942	0.317
130	101	203	37.4134	1.5	2.00	1.942	0.192
131	102	201	61.2151	1.5	2.00	3.655	0.189
132	102	202	61.2974	1.5	2.00	3.655	0.198
133	102	203	60.9580	1.5	2.00	3.655	0.192
134	102	201	61.2095	5.0	7.00	3.479	0.205

INPUT

ABSOLUTE DISTANCES

	FROM	TO	OBSERVED	MM	PPM	H.I.	H.T.
135	102	202	61.2801	5.0	7.00	3.479	0.208
136	102	203	60.9550	5.0	7.00	3.479	0.205

INPUT

ELEVATION DIFFERENCES

	FROM	TO	OBSERVED	S.E.
137	100	101	-19.026	0.002
138	101	102	-1.220	0.002
139	102	104	2.982	0.002
140	104	103	-2.483	0.002
141	103	102	-0.501	0.002
142	102	203	1.324	0.001
143	102	201	0.545	0.001
144	102	202	-3.073	0.001

POSITION DIFFERENCES (METERS)

	FROM	TO	LAT.	S.E.	LON.	S.E.	HEIGHT	S.E.
145	104	105	-0.0008	0.0001	-0.0049	0.0001	32.8080	0.0020

INPUT

A PRIORI STANDARD ERRORS (UNLESS OVERRIDEN BY INPUT ON OBSERVATION CARD)

	VECTOR SUM OF	
DIRECTIONS	0.5 MM	1.0 SEC.
AZIMUTHS	0.5 MM	1.5 SEC.
RECIPROCAL VERTICAL ANGLES	3.0 SEC.	1.0 MM
GROUPED VERTICAL ANGLES	3.0 SEC.	1.0 MM
ABSOLUTE DISTANCES	5.0 MM	5.0 PPM
RELATIVE DISTANCES	5.0 MM	5.0 PPM

APPENDIX D.--OUTPUT DATA FOR ADJUSTMENT

The following computerized listing, using program HAVAGO, shows the output of the three-dimensional adjustment.

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NATIONAL GEODETIC SURVEY, ROCKVILLE, MD

JOB STATISTICS

ELLIPSOID:  CLARKE 1866      A = 6378206.400    1/F = 294.9786982

GOLDSTONE VALIDATION PROJECT (PHASE I)                                   *

STANDARD ERROR OF UNIT WEIGHT =  1.12, VARIANCE =  1.25, 102 DEGREES OF FREEDOM.

NUMBER OF -
    ITERATIONS                        1
    STATIONS                          9
    UNKNOWNS                         66
    LISTS OF DIRECTIONS               8
    REFRACTION UNKNOWNS              13
    SCALE UNKNOWNS                    0
    OBSERVATIONS                    168
    DIRECTIONS                       24
    ASTR. AZIMUTHS                   29
    RECIP. VERT. ANGLES               0
    GROUPED VERT. ANGLES             31
    ABSOLUTE DISTANCES               52
    RELATIVE DISTANCES                0
    ELEVATION DIFFERENCES             8
    LAT., LON., HEIGHT DIFF.          1
    PLANE DISTANCES                   0
    OBS. ASTR. LATITUDES              9
    OBS. ASTR. LONGITUDES             9
    CONSTR. GEOD. LATITUDES           1
    CONSTR. GEOD. LONGITUDES          1
    CONSTR. GEOD. HEIGHTS             1
    ASTR. POSITION DIFFERENCES        0

DK/DH ASSUMED AS  -0.010/1000 IF K VALUES NOT INPUT.

SELECTED OPTIONS:

    NONE
```

NATIONAL GEODETIC SURVEY, ROCKVILLE, MD

ADJUSTED DATA: STATIONS

STATION		LATITUDE	SIGMA	LONGITUDE	SIGMA	HEIGHT	SIGMA
100	MARS 1963	35 25 39.81830	0.00004	116 53 19.02710	0.00004	993.374	0.001
101	ARIES 1976	35 25 29.09752	0.00005	116 53 8.20810	0.00005	974.348	0.002
102	GOLDSTONE VALIDATION	35 25 28.06849	0.00005	116 53 7.75552	0.00005	973.130	0.003
103	MARS CONTROL	35 25 31.49724	0.00005	116 53 20.47885	0.00005	973.624	0.003
104	MARS COLLIMATION	35 25 33.34008	0.00005	116 53 19.15014	0.00005	976.111	0.003
105	MARS VLBI	35 25 33.34005	0.00005	116 53 19.14995	0.00005	1008.919	0.004
201	GOLDSTONE VALIDATION RM 1	35 25 28.83467	0.00006	116 53 5.52008	0.00007	973.676	0.003
202	GOLDSTONE VALIDATION RM 2	35 25 26.10784	0.00007	116 53 8.06917	0.00007	970.055	0.003
203	GOLDSTONE VALIDATION RM 3	35 25 29.26765	0.00006	116 53 9.67489	0.00007	974.453	0.003

NATIONAL GEODETIC SURVEY, ROCKVILLE, MD

ADJUSTED DATA: DIRECTIONS

	FROM	TO	LIST	OBSERVED	V	N.V	ADJUSTED	DIST.	AZ.	V.A.
1	101	103	1	0 0 0.0	-0.31	-0.40	0 0 0.0	318.310	283 26 12.65	90 7 50.88
2	101	100	1	37 0 16.73	0.24	0.32	37 0 17.27	429.029	320 26 29.92	87 27 36.79
3	101	102	1	236 45 44.28	0.84	0.26	236 45 45.43	33.733	160 11 58.07	92 4 12.35
4	102	103	1	0 0 0.0	-0.21	-0.20	0 0 0.0	337.965	288 13 21.40	89 55 0.77
5	102	100	1	33 38 13.65	0.21	0.21	33 38 14.08	460.919	321 51 35.48	87 29 5.20
6	102	101	1	51 58 37.00	-0.09	-0.03	51 58 37.12	33.733	340 11 58.52	87 55 48.85
7	102	103	2	0 0 0.0	-0.47	-0.62	0 0 0.0	337.965	288 13 21.40	89 55 0.77
8	102	100	2	33 38 13.19	0.42	0.57	33 38 14.08	460.919	321 51 35.48	87 29 5.20
9	102	101	2	51 58 36.29	0.36	0.11	51 58 37.12	33.733	340 11 58.52	87 55 48.85
10	102	103	3	0 0 0.0	-0.55	-0.94	0 0 0.0	337.965	288 13 21.40	89 55 0.77
11	102	104	3	11 15 6.31	0.11	0.19	11 15 6.98	330.244	299 28 28.38	89 29 1.30
12	102	100	3	33 38 13.14	0.38	0.70	33 38 14.08	460.919	321 51 35.48	87 29 5.20
13	103	100	1	0 0 0.0	-1.53	-1.90	0 0 0.0	259.833	8 7 34.80	85 38 35.34
14	103	101	1	95 18 28.91	0.01	0.01	95 18 30.45	318.310	103 26 5.24	89 52 19.74
15	103	102	1	100 5 35.84	1.37	1.80	100 5 38.74	337.965	108 13 13.54	90 5 10.72
16	104	102	1	0 0 0.0	-0.27	-0.39	0 0 0.0	330.244	119 28 21.53	90 31 9.55
17	104	103	1	91 4 28.49	1.63	0.97	91 4 30.38	66.003	210 32 51.91	92 9 28.87
18	103	100	2	0 0 0.0	0.05	0.08	0 0 0.0	259.833	8 7 34.80	85 38 35.34
19	103	104	2	22 25 16.21	-0.04	-0.02	22 25 16.12	66.003	30 32 50.91	87 50 33.39
20	103	102	2	100 5 38.84	-0.04	-0.06	100 5 38.74	337.965	108 13 13.54	90 5 10.72
21	102	103	4	0 0 0.0	-0.07	-0.06	0 0 0.0	337.965	288 13 21.40	89 55 0.77
22	102	203	4	19 7 45.90	0.19	0.05	19 7 46.16	60.935	307 21 7.56	88 45 20.34
23	102	201	4	139 3 23.40	0.43	0.12	139 3 23.90	61.149	67 16 45.30	89 29 21.80
24	102	202	4	259 14 12.90	-0.00	-0.00	259 14 12.97	61.026	187 27 34.37	92 53 12.64

NATIONAL GEODETIC SURVEY, ROCKVILLE, MD

ADJUSTED DATA: ASTRONOMIC AZIMUTHS

	FROM	TO	OBSERVED	V	N.V	ADJUSTED	DIST.	V.A.
25	100	101	140 26 20.80	2.95	1.95	140 26 23.75	429.029	92 32 36.62
26	100	101	140 26 23.18	0.57	0.38	140 26 23.75	429.029	92 32 36.62
27	100	101	140 26 23.06	0.69	0.46	140 26 23.75	429.029	92 32 36.62
28	100	101	140 26 25.32	-1.57	-1.03	140 26 23.75	429.029	92 32 36.62
29	100	102	141 51 28.05	0.81	0.54	141 51 28.86	460.919	92 31 9.42
30	100	102	141 51 29.17	-0.31	-0.20	141 51 28.86	460.919	92 31 9.42
31	100	102	141 51 28.32	0.54	0.36	141 51 28.86	460.919	92 31 9.42
32	100	102	141 51 30.96	-2.10	-1.38	141 51 28.86	460.919	92 31 9.42
33	100	103	188 7 36.51	-0.52	-0.34	188 7 35.99	259.833	94 21 32.92
34	100	103	188 7 36.45	-0.46	-0.30	188 7 35.99	259.833	94 21 32.92
35	100	103	188 7 36.22	-0.23	-0.15	188 7 35.99	259.833	94 21 32.92
36	100	103	188 7 37.99	-2.00	-1.29	188 7 35.99	259.833	94 21 32.92
37	102	100	321 51 39.32	-3.84	-2.53	321 51 35.48	460.919	87 29 5.20
38	102	100	321 51 40.47	-4.99	-3.29	321 51 35.48	460.919	87 29 5.20
39	102	100	321 51 37.08	-1.60	-1.06	321 51 35.48	460.919	87 29 5.20
40	102	100	321 51 34.22	1.26	0.83	321 51 35.48	460.919	87 29 5.20
41	102	103	288 13 22.06	-0.66	-0.43	288 13 21.40	337.965	89 55 0.77
42	102	103	288 13 22.36	-0.96	-0.63	288 13 21.40	337.965	89 55 0.77
43	102	103	288 13 18.07	3.33	2.18	288 13 21.40	337.965	89 55 0.77
44	102	103	288 13 20.97	0.43	0.28	288 13 21.40	337.965	89 55 0.77
45	103	100	8 7 32.02	2.78	1.79	8 7 34.80	259.833	85 38 35.34
46	103	100	8 7 33.35	1.45	0.93	8 7 34.80	259.833	85 38 35.34
47	103	100	8 7 31.41	3.39	2.18	8 7 34.80	259.833	85 38 35.34
48	103	100	8 7 33.55	1.25	0.80	8 7 34.80	259.833	85 38 35.34
49	103	101	103 26 5.34	-0.10	-0.06	103 26 5.24	318.310	89 52 19.74
50	103	102	108 13 13.94	-0.40	-0.26	108 13 13.54	337.965	90 5 10.72
51	103	102	108 13 13.98	-0.44	-0.29	108 13 13.54	337.965	90 5 10.72
52	103	102	108 13 12.95	0.59	0.38	108 13 13.54	337.965	90 5 10.72
53	103	102	108 13 13.08	0.46	0.30	108 13 13.54	337.965	90 5 10.72

NATIONAL GEODETIC SURVEY, ROCKVILLE, MD

ADJUSTED DATA: GROUPED VERTICAL ANGLES

	FROM	TO	LIST	OBSERVED	REF/KM	V	N.V	ADJUSTED	DIST.	AZ.
54	100	101	1	92 32 26.93	18.39	1.80	0.36	92 32 36.62	429.029	140 26 23.75
55	100	103	1	94 21 31.18	18.39	-3.03	-0.60	94 21 32.92	259.833	188 7 35.99
56	100	101	2	92 32 30.24	18.10	-1.38	-0.27	92 32 36.62	429.029	140 26 23.75
57	100	102	2	92 30 59.81	18.10	1.28	0.25	92 31 9.42	460.919	141 51 28.86
58	100	101	3	92 32 34.16	0.98	2.04	0.41	92 32 36.62	429.029	140 26 23.75
59	100	102	3	92 31 9.76	0.98	-0.78	-0.16	92 31 9.42	460.919	141 51 28.86
60	100	103	3	94 21 34.69	0.98	-2.02	-0.40	94 21 32.92	259.833	188 7 35.99
61	101	103	1	90 7 16.45	66.63	13.22	2.62	90 7 50.88	318.310	283 26 12.65
62	101	100	1	87 27 17.98	66.63	-9.74	-1.94	87 27 36.79	429.029	320 26 29.92
63	102	100	1	87 29 2.12	5.05	0.76	0.15	87 29 5.20	460.919	321 51 35.48
64	102	103	1	89 55 0.11	5.05	-1.04	-0.21	89 55 0.77	337.965	288 13 21.40
65	102	100	2	87 28 53.15	30.97	-2.20	-0.44	87 29 5.20	460.919	321 51 35.46
66	102	103	2	89 54 47.29	30.97	3.02	0.60	89 55 0.77	337.965	288 13 21.40
67	102	100	3	87 28 57.56	16.16	0.20	0.04	87 29 5.20	460.919	321 51 35.48
68	102	103	3	89 54 55.59	16.16	-0.28	-0.05	89 55 0.77	337.965	288 13 21.40
69	102	100	4	87 29 1.52	9.84	-0.85	-0.17	87 29 5.20	460.919	321 51 35.48
70	102	103	4	89 54 57.86	9.84	-0.41	-0.08	89 55 0.77	337.965	288 13 21.40
71	102	104	4	89 28 56.44	9.84	1.61	0.32	89 29 1.30	330.244	299 28 28.38
72	103	100	1	85 38 38.21	0.15	-2.91	-0.57	85 38 35.34	259.833	8 7 34.80
73	103	102	1	90 5 8.46	0.15	2.21	0.44	90 5 10.72	337.965	108 13 13.54
74	103	100	2	85 38 31.48	18.05	-0.81	-0.16	85 38 35.34	259.833	8 7 34.80
75	103	101	2	89 52 13.36	18.05	0.64	0.13	89 52 19.74	318.310	103 26 5.24
76	103	102	2	90 5 4.61	18.05	0.02	0.00	90 5 10.72	337.965	108 13 13.54
77	103	100	3	85 38 29.76	15.04	1.68	0.33	85 38 35.34	259.833	8 7 34.80
78	103	101	3	89 52 14.82	15.04	0.13	0.03	89 52 19.74	318.310	103 26 5.24
79	103	102	3	90 5 7.04	15.04	-1.40	-0.28	90 5 10.72	337.965	108 13 13.54
80	103	100	4	85 38 31.68	11.32	0.73	0.14	85 38 35.34	259.833	8 7 34.80
81	103	102	4	90 5 8.83	11.32	-1.94	-0.38	90 5 10.72	337.965	108 13 13.54
82	103	104	4	87 50 22.95	11.32	9.70	1.64	87 50 33.39	66.003	30 32 50.91
83	104	102	1	90 31 9.17	0.64	0.17	0.03	90 31 9.55	330.244	119 28 21.53
84	104	103	1	92 9 29.97	0.64	-1.14	-0.19	92 9 28.87	66.003	210 32 51.91

NATIONAL GEODETIC SURVEY, ROCKVILLE, MD

ADJUSTED DATA: ABSOLUTE DISTANCES

	FROM	TO	OBSERVED	V	N.V	ADJUSTED	AZ.	V.A
85	103	100	259.8326	0.0009	0.55	259.8335	8 7 34.80	85 38 35.34
86	103	101	318.3087	0.0014	0.84	318.3101	103 26 5.24	89 52 19.74
87	103	104	66.0033	-0.0001	-0.04	66.0033	30 32 50.91	87 50 33.39
88	102	100	460.9191	0.0002	0.09	460.9192	321 51 35.48	87 29 5.20
89	102	101	33.7352	-0.0027	-1.79	33.7325	340 11 58.52	87 55 48.85
90	102	103	337.9664	-0.0015	-0.93	337.9649	288 13 21.40	89 55 0.77
91	102	104	330.2441	0.0003	0.17	330.2444	299 28 28.38	89 29 1.30
92	102	104	330.2416	0.0029	1.74	330.2444	299 28 28.38	89 29 1.30
93	103	104	66.0027	0.0006	0.39	66.0033	30 32 50.91	87 50 33.39
94	103	104	66.0021	0.0011	0.76	66.0033	30 32 50.91	87 50 33.39
95	102	100	460.9176	0.0016	0.92	460.9192	321 51 35.48	87 29 5.20
96	102	103	337.9658	-0.0009	-0.57	337.9649	288 13 21.40	89 55 0.77
97	102	104	330.2463	-0.0019	-1.17	330.2444	299 28 28.38	89 29 1.30
98	102	104	330.2397	0.0048	2.90	330.2444	299 28 28.38	89 29 1.30
99	102	101	33.7334	-0.0009	-0.59	33.7325	340 11 58.52	87 55 48.85
100	100	101	429.0305	-0.0010	-0.18	429.0295	140 26 23.75	92 32 36.62
101	100	102	460.9172	0.0020	0.34	460.9192	141 51 28.86	92 31 9.42
102	100	103	259.8320	0.0015	0.28	259.8335	188 7 35.99	94 21 32.92
103	102	101	33.7337	-0.0012	-0.23	33.7325	340 11 58.52	87 55 48.85
104	102	101	33.7364	-0.0038	-0.76	33.7325	340 11 58.52	87 55 48.85
105	102	103	337.9642	0.0007	0.13	337.9649	288 13 21.40	89 55 0.77
106	102	103	337.9673	-0.0024	-0.43	337.9649	288 13 21.40	89 55 0.77
107	103	104	66.0044	-0.0012	-0.24	66.0033	30 32 50.91	87 50 33.39
108	103	101	318.3109	-0.0008	-0.14	318.3101	103 26 5.24	89 52 19.74
109	103	102	337.9619	0.0030	0.55	337.9649	108 13 13.54	90 5 10.72
110	102	100	460.9162	0.0030	0.50	460.9192	321 51 35.48	87 29 5.20
111	102	100	460.9187	0.0005	0.09	460.9192	321 51 35.48	87 29 5.20
112	102	104	330.2392	0.0053	0.95	330.2444	299 28 28.38	89 29 1.30
113	103	101	318.3155	-0.0054	-1.06	318.3101	103 26 5.24	89 52 19.74
114	101	102	33.7286	0.0039	0.78	33.7325	160 11 58.07	92 4 12.35
115	103	101	318.3180	-0.0079	-1.56	318.3101	103 26 5.24	89 52 19.74
116	101	100	429.0432	-0.0137	-2.70	429.0295	320 26 29.92	87 27 36.79
117	103	104	66.0048	-0.0015	-0.31	66.0033	30 32 50.91	87 50 33.39
118	104	102	330.2527	-0.0082	-1.63	330.2444	119 28 21.53	90 31 9.55
119	103	104	66.0049	-0.0016	-0.33	66.0033	30 32 50.91	87 50 33.39
120	104	102	330.2519	-0.0074	-1.48	330.2444	119 28 21.53	90 31 9.55
121	103	102	337.9735	-0.0086	-1.70	337.9649	108 13 13.54	90 5 10.72
122	102	100	460.9266	-0.0074	-1.45	460.9192	321 51 35.48	87 29 5.20
123	103	104	66.0085	-0.0053	-1.06	66.0033	30 32 50.91	87 50 33.39
124	103	101	318.3170	-0.0069	-1.36	318.3101	103 26 5.24	89 52 19.74
125	103	102	337.9717	-0.0068	-1.35	337.9649	108 13 13.54	90 5 10.72
126	103	100	259.8380	-0.0045	-0.89	259.8335	8 7 34.80	85 38 35.34
127	103	104	66.0034	-0.0001	-0.15	66.0033	30 32 50.91	87 50 33.39
128	101	102	33.7315	0.0010	1.05	33.7325	160 11 58.07	92 4 12.35
129	101	201	68.3063	-0.0005	-0.36	68.3057	96 48 39.49	90 33 54.15
130	101	203	37.3773	0.0002	0.16	37.3776	278 3 52.02	89 50 19.86
131	102	201	61.1479	0.0007	0.47	61.1486	67 16 45.30	89 29 21.80
132	102	202	61.0259	0.0002	0.12	61.0261	187 27 34.37	92 53 12.64
133	102	203	60.9348	0.0001	0.06	60.9349	307 21 7.56	88 45 20.34
134	102	201	61.1511	-0.0026	-0.51	61.1486	67 16 45.30	89 29 21.80

NATIONAL GEODETIC SURVEY, ROCKVILLE, MD

ADJUSTED DATA: ABSOLUTE DISTANCES

	FROM	TO	OBSERVED	V	N.V	ADJUSTED	AZ.	V.A
135	102	202	61.0281	-0.0021	-0.41	61.0261	187 27 34.37	92 53 12.64
136	102	203	60.9381	-0.0033	-0.65	60.9349	307 21 7.56	88 45 20.34

NATIONAL GEODETIC SURVEY, ROCKVILLE, MD

ADJUSTED ELEVATION DIFFERENCES

	FROM	TO	MEASURED	V	N.V	ADJUSTED
137	100	101	-19.0262	0.0007	0.34	-19.0255
138	101	102	-1.2198	0.0014	0.70	-1.2184
139	102	104	2.9821	0.0025	1.23	2.9846
140	104	103	-2.4834	-0.0016	-0.82	-2.4850
141	103	102	-0.5009	0.0012	0.60	-0.4997
142	102	203	1.3236	0.0000	0.00	1.3236
143	102	201	0.5452	0.0000	0.00	0.5452
144	102	202	-3.0732	0.0000	0.00	-3.0732

ADJUSTED POSITION DIFFERENCES (METERS)

	FROM	TO	LAT.	V	LON.	V	H	V
145	104	105	-0.0008	-0.0000	-0.0049	-0.0000	32.8080	-0.0000

NATIONAL GEODETIC SURVEY, ROCKVILLE, MD

ADJUSTED ASTRONOMIC LATITUDES AND LONGITUDES

STATION				OBSERVED	V	N.V	ADJUSTED	SIGMA
146	100	MARS 1963	LAT	35 25 35.45	0.02	0.08	35 25 35.47	0.33
147	100	MARS 1963	LON	116 53 24.89	-0.05	-0.12	116 53 24.84	0.42
148	101	ARIES 1976	LAT	35 25 25.24	0.00	0.00	35 25 25.24	0.33
149	101	ARIES 1976	LON	116 53 14.15	0.05	0.12	116 53 14.20	0.45
150	102	GOLDSTONE VALIDATION	LAT	35 25 24.21	-0.02	-0.06	35 25 24.19	0.33
151	102	GOLDSTONE VALIDATION	LON	116 53 13.70	-0.30	-0.74	116 53 13.40	0.42
152	103	MARS CONTROL	LAT	35 25 27.36	0.02	0.06	35 25 27.38	0.33
153	103	MARS CONTROL	LON	116 53 26.62	0.35	0.87	116 53 26.97	0.42
154	104	MARS COLLIMATION	LAT	35 25 29.20	-0.03	-0.09	35 25 29.17	0.33
155	104	MARS COLLIMATION	LON	116 53 25.29	-0.06	-0.14	116 53 25.23	0.44
156	105	MARS VLBI	LAT	35 25 29.20	0.00	0.00	35 25 29.20	0.33
157	105	MARS VLBI	LON	116 53 25.29	-0.00	-0.00	116 53 25.29	0.45
158	201	GOLDSTONE VALIDATION RM 1	LAT	35 25 24.98	-0.00	-0.00	35 25 24.98	0.33
159	201	GOLDSTONE VALIDATION RM 1	LON	116 53 11.46	0.00	0.00	116 53 11.46	0.45
160	202	GOLDSTONE VALIDATION RM 2	LAT	35 25 22.25	0.00	0.00	35 25 22.25	0.33
161	202	GOLDSTONE VALIDATION RM 2	LON	116 53 14.01	-0.00	-0.00	116 53 14.01	0.45
162	203	GOLDSTONE VALIDATION RM 3	LAT	35 25 25.41	-0.00	-0.00	35 25 25.41	0.33
163	203	GOLDSTONE VALIDATION RM 3	LON	116 53 15.62	-0.00	-0.00	116 53 15.62	0.45

NATIONAL GEODETIC SURVEY, ROCKVILLE, MD

GEODETIC LATITUDE CONSTRAINTS

STATION		CONSTRAINED	V	N.V	ADJUSTED	SIGMA
164	100	35 25 39.81830	-0.00000	-0.00004	35 25 39.81830	0.00004

GEODETIC LONGITUDE CONSTRAINTS

STATION		CONSTRAINED	V	N.V	ADJUSTED	SIGMA
165	100	116 53 19.02710	-0.00000	-0.00000	116 53 19.02710	0.00004

GEODETIC HEIGHT CONSTRAINTS

STATION		CONSTRAINED	V	N.V	ADJUSTED	SIGMA
166	100	993.3740	-0.0000	-0.0	993.3740	0.001

NATIONAL GEODETIC SURVEY, ROCKVILLE, MD

ADJUSTED CARTESIAN COORDINATES

DX	DY	DZ	EPSILON	PSI	OMEGA	SCALE
0.0	0.0	0.0	0.0	0.0	0.0	0.0

STATION		X	Y	Z	TRANSFORMED COORDINATES X	Y	Z
100	MARS 1963	-2353545.879	-4641377.177	3677023.872			
101	ARIES 1976	-2353382.034	-4641657.632	3676743.576			
102	GOLDSTONE VALIDATION	-2353379.714	-4641678.307	3676717.023			
103	MARS CONTROL	-2353638.506	-4641478.855	3676803.429			
104	MARS COLLIMATION	-2353594.633	-4641466.459	3676851.156			
105	MARS VLBI	-2353606.719	-4641490.306	3676870.173			
201	GOLDSTONE VALIDATION RM 1	-2353323.420	-4641692.001	3676736.585			
202	GOLDSTONE VALIDATION RM 2	-2353401.480	-4641703.736	3676665.996			
203	GOLDSTONE VALIDATION RM 3	-2353413.706	-4641638.261	3676747.910			

NATIONAL GEODETIC SURVEY, ROCKVILLE, MD

MISCELLANEOUS DATA FOR SELECTED LINES, PART 1

FROM	TO		STANDARD ERRORS	CORRELATION COEFF. AZ.	DIST.	V.A.		STANDARD ERRORS	CORRELATION COEFF. DX	DY	DZ	DX,DY,DZ	AZ.,DIST.,V.A.	AZ.,DIST.,B.AZ. (GEODETIC)
102	100	AZ.	0.42	1.00	0.19	-0.07	DX	0.001	1.00	0.69	-0.53	-166.165	321 51 35.48	321 51 38.42
		DIST.	0.001	0.19	1.00	0.03	DY	0.002	0.69	1.00	-0.70	301.130	460.919	460.403
		V.A.	1.10	-0.07	0.03	1.00	DZ	0.002	-0.53	-0.70	1.00	306.849	87 29 5.20	141 51 31.88
102	101	AZ.	1.93	1.00	-0.02	0.01	DX	0.001	1.00	0.84	-0.82	-2.320	340 11 58.52	340 12 1.55
		DIST.	0.001	-0.02	1.00	0.07	DY	0.001	0.84	1.00	-0.74	20.675	33.733	33.705
		V.A.	11.61	0.01	0.07	1.00	DZ	0.001	-0.82	-0.74	1.00	26.552	87 55 48.85	160 12 1.29
102	103	AZ.	0.44	1.00	0.08	-0.15	DX	0.001	1.00	0.61	-0.46	-258.792	288 13 21.40	288 13 24.63
		DIST.	0.001	0.08	1.00	-0.04	DY	0.001	0.61	1.00	-0.64	199.452	337.965	337.913
		V.A.	1.02	-0.15	-0.04	1.00	DZ	0.001	-0.46	-0.64	1.00	86.406	89 55 0.77	108 13 17.25
102	104	AZ.	0.57	1.00	-0.07	-0.08	DX	0.001	1.00	0.56	-0.26	-214.919	299 28 28.38	299 28 31.54
		DIST.	0.001	-0.07	1.00	-0.00	DY	0.001	0.56	1.00	-0.63	211.848	330.244	330.181
		V.A.	1.06	-0.08	-0.00	1.00	DZ	0.001	-0.26	-0.63	1.00	134.133	89 29 1.30	119 28 24.94
102	105	AZ.	0.57	1.00	-0.07	-0.05	DX	0.001	1.00	0.77	-0.61	-227.005	299 28 30.01	299 28 32.61
		DIST.	0.001	-0.07	1.00	0.39	DY	0.002	0.77	1.00	-0.84	188.002	332.161	330.176
		V.A.	1.73	-0.05	0.39	1.00	DZ	0.002	-0.61	-0.84	1.00	153.150	83 48 55.77	119 28 26.01
102	201	AZ.	4.04	1.00	-0.21	0.02	DX	0.001	1.00	0.05	0.22	56.294	67 16 45.30	67 16 48.64
		DIST.	0.001	-0.21	1.00	0.03	DY	0.001	0.05	1.00	0.03	-13.693	61.149	61.137
		V.A.	3.81	0.02	0.03	1.00	DZ	0.001	0.22	0.03	1.00	19.561	89 29 21.80	247 16 49.94
102	202	AZ.	4.19	1.00	0.00	0.00	DX	0.001	1.00	0.11	0.22	-21.765	187 27 34.37	187 27 37.46
		DIST.	0.002	0.00	1.00	0.11	DY	0.001	0.11	1.00	0.30	-25.429	61.026	60.939
		V.A.	3.84	0.00	0.11	1.00	DZ	0.001	0.22	0.30	1.00	-51.028	92 53 12.64	7 27 37.28
102	203	AZ.	4.00	1.00	0.21	0.00	DX	0.001	1.00	0.01	-0.03	-33.991	307 21 7.56	307 21 10.64
		DIST.	0.001	0.21	1.00	0.03	DY	0.001	0.01	1.00	0.20	40.046	60.935	60.911
		V.A.	3.77	0.00	0.03	1.00	DZ	0.001	-0.03	0.20	1.00	30.886	88 45 20.34	127 21 9.53

NATIONAL GEODETIC SURVEY, ROCKVILLE, MD

MISCELLANEOUS DATA FOR SELECTED LINES, PART 2

		E Q U A T O R I A L	S Y S T E M		HORIZON SYSTEM, ORIGIN AT THE STANDPOINT					
FROM	TO	ALTITUDE	AZIMUTH	DISTANCE	DN	SIGMA	DE	SIGMA	DU	SIGMA
102	100	41 44 18.84	118 53 24.34	460.919	362.165	0.001	-284.384	0.001	20.227	0.002
102	101	51 55 10.83	96 24 8.69	33.733	31.718	0.001	-11.419	0.000	1.218	0.002
102	103	14 48 46.79	142 22 42.28	337.965	105.685	0.001	-321.015	0.001	0.490	0.002
102	104	23 57 50.56	135 24 43.95	330.244	162.486	0.001	-287.491	0.001	2.976	0.002
102	105	27 27 22.41	140 22 8.50	332.161	162.486	0.001	-287.486	0.001	35.784	0.003
102	201	18 39 24.01	346 19 41.95	61.149	23.617	0.001	56.401	0.001	0.545	0.001
102	202	-56 44 12.82	229 26 19.74	61.026	-60.433	0.002	-7.913	0.001	-3.073	0.001
102	203	30 27 21.09	130 19 29.98	60.935	36.961	0.001	-48.427	0.001	1.323	0.001

(Continued from inside front cover)

NOS NGS-6 Determination of North American Datum 1983 coordinates of map corners. T. Vincenty, October 1976, 8 pp (PB262442). Predictions of changes in coordinates of map corners are detailed.

NOS NGS-7 Recent elevation change in Southern California. S.R. Holdahl, February 1977, 19 pp (PB265-940). Velocities of elevation change were determined from Southern Calif. leveling data for 1906-62 and 1959-76 epochs.

NOS NGS-8 Establishment of calibration base lines. Joseph F. Dracup, Charles J. Fronczek, and Raymond W. Tomlinson, August 1977, 22 pp (PB277130). Specifications are given for establishing calibration base lines.

NOS NGS-9 National Geodetic Survey publications on surveying and geodesy 1976. September 1977, 17 pp (PB275181). Compilation lists publications authored by NGS staff in 1976, source availability for out-of-print Coast and Geodetic Survey publications, and subscription information on the Geodetic Control Data Automatic Mailing List.

NOS NGS-10 Use of calibration base lines. Charles J. Fronczek, December 1977, 38 pp (PB279574). Detailed explanation allows the user to evaluate electromagnetic distance measuring instruments.

NOS NGS-11 Applicability of array algebra. Richard A. Snay, February 1978, 22 pp (PB281196). Conditions required for the transformation from matrix equations into computationally more efficient array equations are considered.

NOS NGS-12 The TRAV-10 horizontal network adjustment program. Charles R. Schwarz, April 1978, 52 pp (PB283087). The design, objectives, and specifications of the horizontal control adjustment program are presented.

NOS NGS-13 Application of three-dimensional geodesy to adjustments of horizontal networks. T. Vincenty and B. R. Bowring, June 1978, 7 pp (PB286672). A method is given for adjusting measurements in three-dimensional space without reducing them to any computational surface.

NOS NGS-14 Solvability Analysis of Geodetic Networks Using Logical Geometry. Richard A. Snay, October 1978, 29 pp. No algorithm based solely on logical geometry has been found that can unerringly distinguish between solvable and unsolvable horizontal networks. For leveling networks such an algorithm is well known.

NOAA Technical Reports, NOS/NGS subseries

NOS 65 NGS 1 The statistics of residuals and the detection of outliers. Allen J. Pope, May 1976, 133 pp (PB258428). A criterion for rejection of bad geodetic data is derived on the basis of residuals from a simultaneous least-squares adjustment. Subroutine TAURE is included.

NOS 66 NGS 2 Effect of Geoceiver observations upon the classical triangulation network. R. E. Moose and S. W. Henriksen, June 1976, 65 pp (PB260921). The use of Geoceiver observations is investigated as a means of improving triangulation network adjustment results.

NOS 67 NGS 3 Algorithms for computing the geopotential using a simple-layer density model. Foster Morrison, March 1977, 41 pp (PB266967). Several algorithms are developed for computing with high accuracy the gravatational attraction of a simple-density layer at arbitrary altitudes. Computer program is included.

NOS 68 NGS 4 Test results of first-order class III leveling. Charles T. Whalen and Emery Balazs, November 1976, 30 pp (GPO# 003-017-00393-1) (PB265421). Specifications for releveling the National vertical control net were tested and the results published.

NOS 70 NGS 5 Selenocentric geodetic reference system. Frederick J. Doyle, Atef A. Elassal, and James R. Lucas, February 1977, 53 pp (PB266046). Reference system was established by simultaneous adjustment of 1,233 metric-camera photographs of the lunar surface from which 2,662 terrain points were positioned.

NOS 71 NGS 6 Application of digital filtering to satellite geodesy. C. C. Goad, May 1977, 73 pp (PB-270192). Variations in the orbit of GEOS-3 were analyzed for M tidal harmonic coefficient values which perturb the orbits of artificial satellites and the Moon.

NOS 72 NGS 7 Systems for the determination of polar motion. Soren W. Henriksen, May 1977, 55 pp (PB274698). Methods for determining polar motion are described and their advantages and disadvantages compared.

(Continued on inside back cover)

NOS 73 NGS 8 Control leveling. Charles T. Whalen, May 1978, 23 pp (GPO# 003-017-00422-8) (PB286838). The history of the National network of geodetic control, from its origin in 1878, is presented in addition to the latest observational and computational procedures.

NOS 74 NGS 9 Survey of the McDonald Observatory radial line scheme by relative lateration techniques. William E. Carter and T. Vincenty, June 1978, 33 pp (PB287427). Results of experimental application of the "ratio method" of electromagnetic distance measurements are given for high resolution crustal deformation studies in the vicinity of the McDonald Lunar Laser Ranging and Harvard Radio Astronomy Stations.

NOS 75 NGS 10 An algorithm to compute the eigenvectors of a symmetric matrix. E. Schmid, August 1978, 5 pp. Method describes computations for eigenvalues and eigenvectors of a symmetric matrix.

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