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RADAR TRACKING SHIP PERFORMANCE DURING MA-9

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GODDARD SPACE FLIGHT CENTER
GREENBELT, MD.

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Prepared by

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RADAR TRACKING SHIP PERFORMANCE

DURING MA-9

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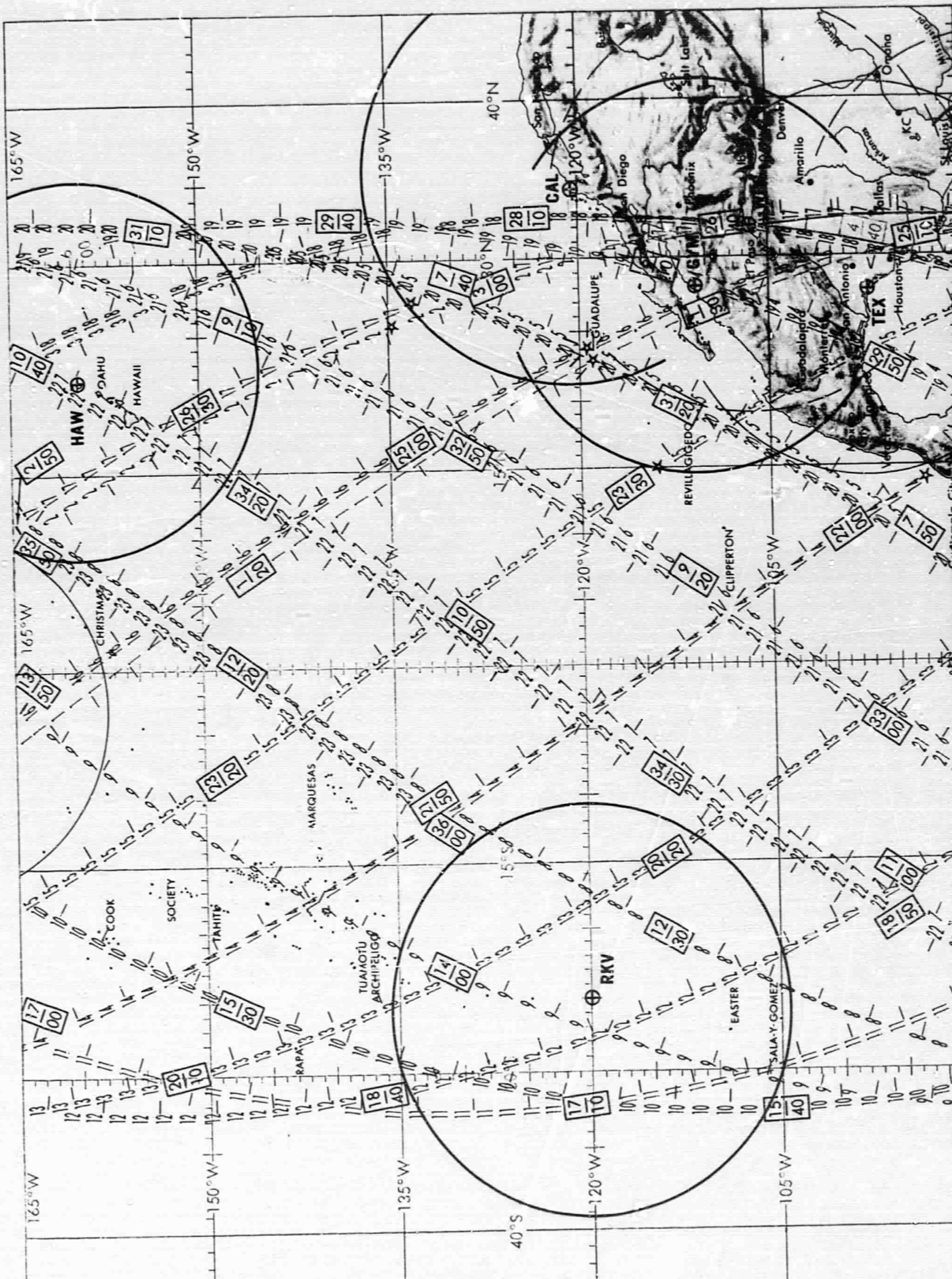

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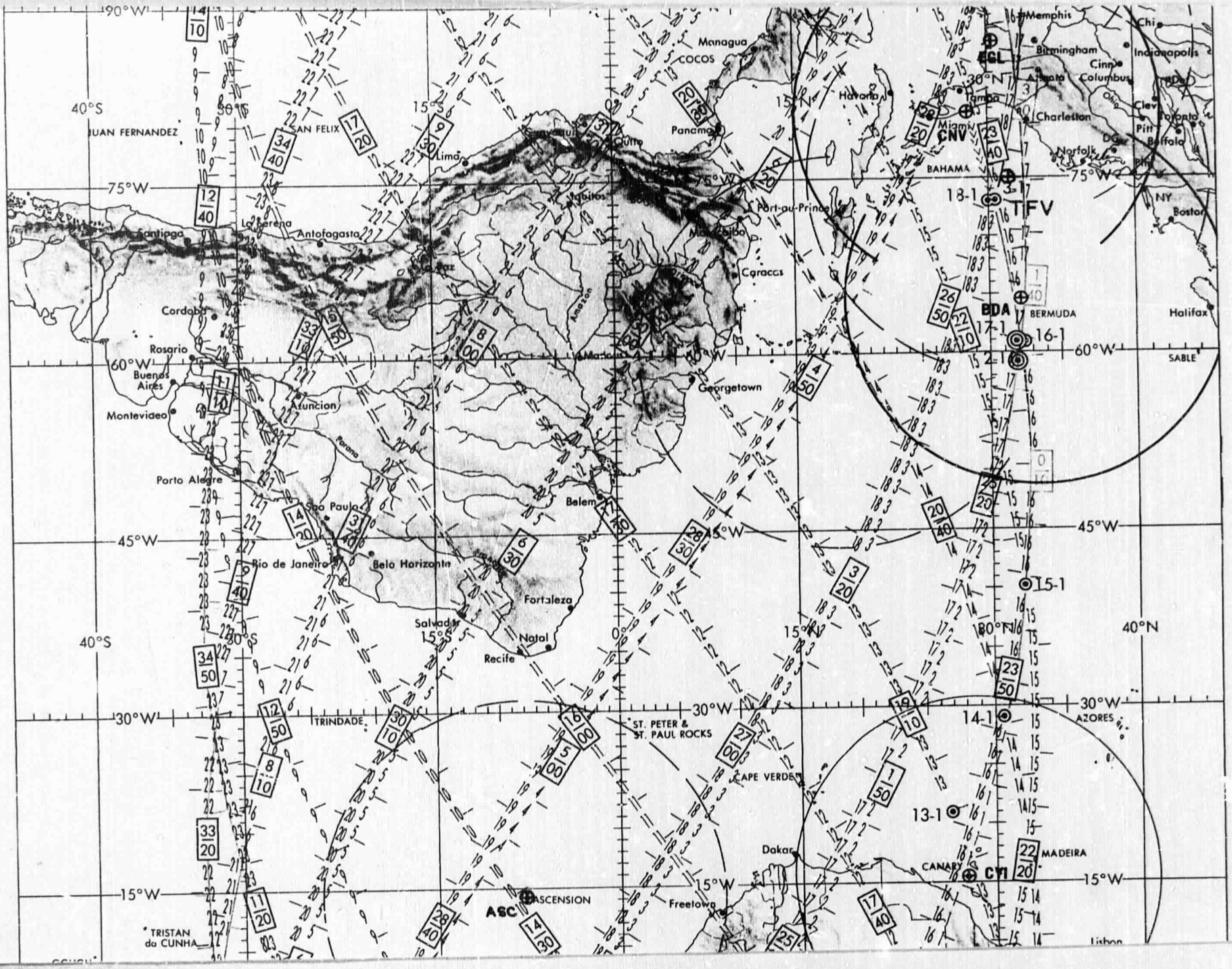

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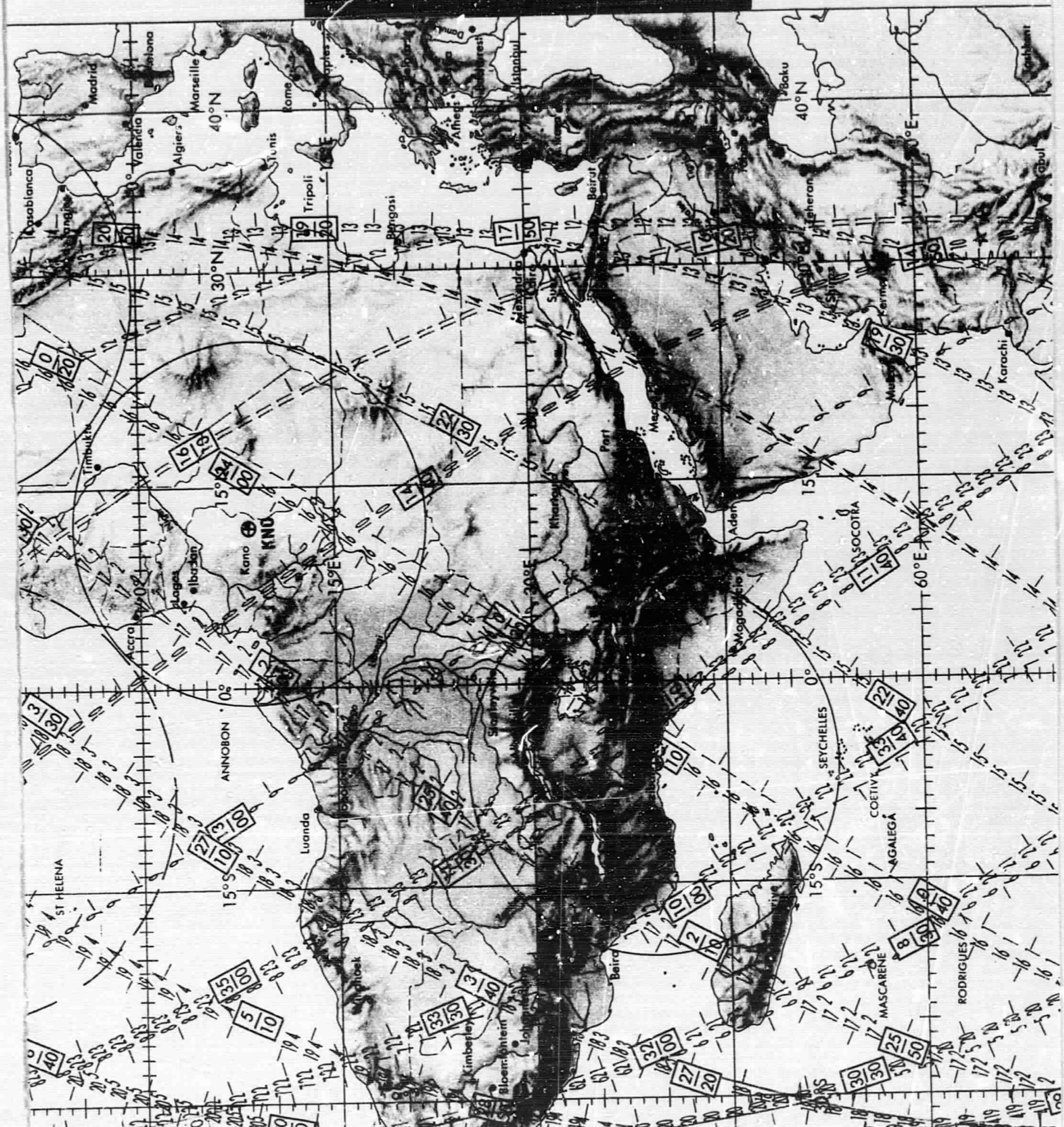

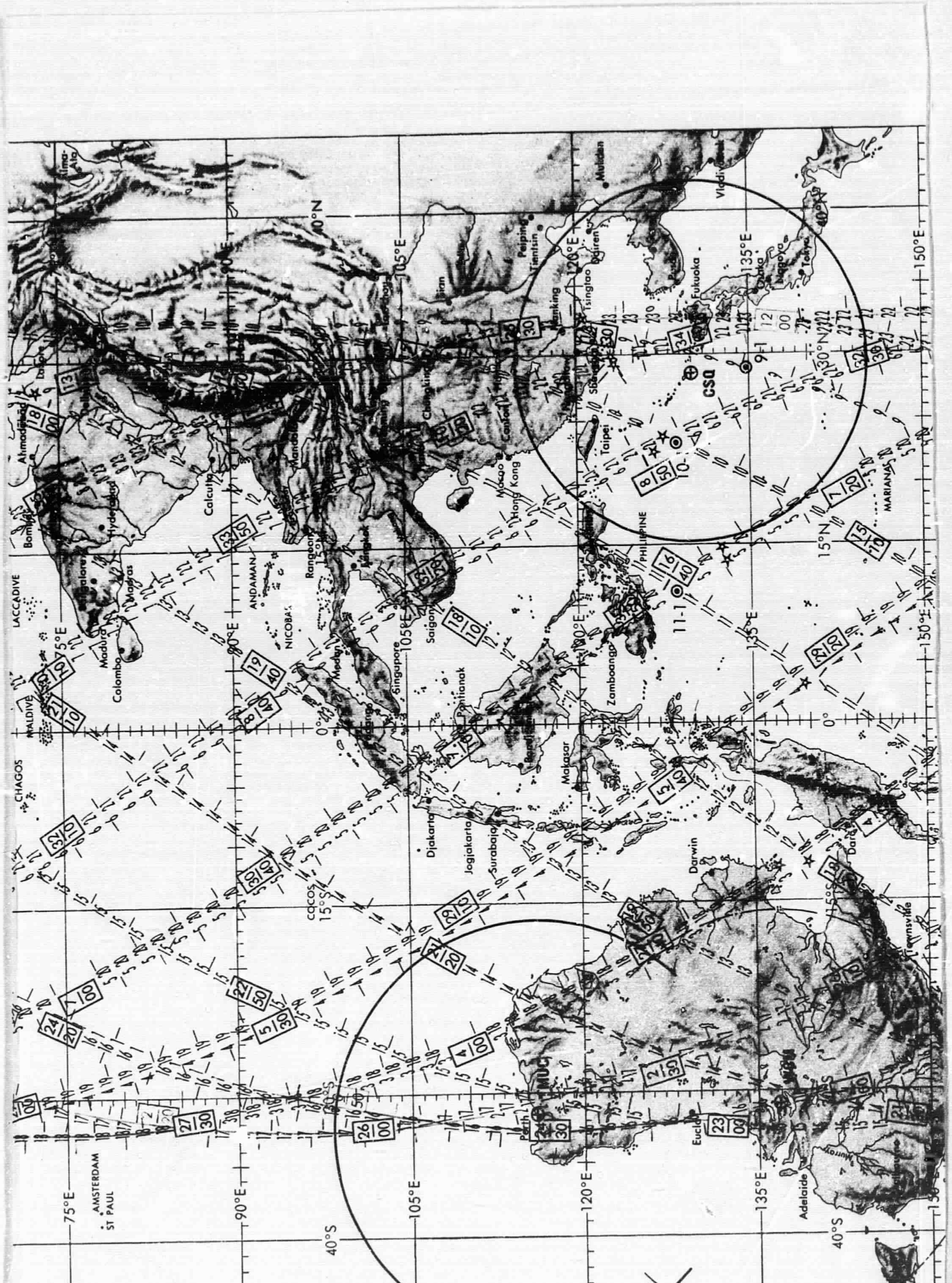

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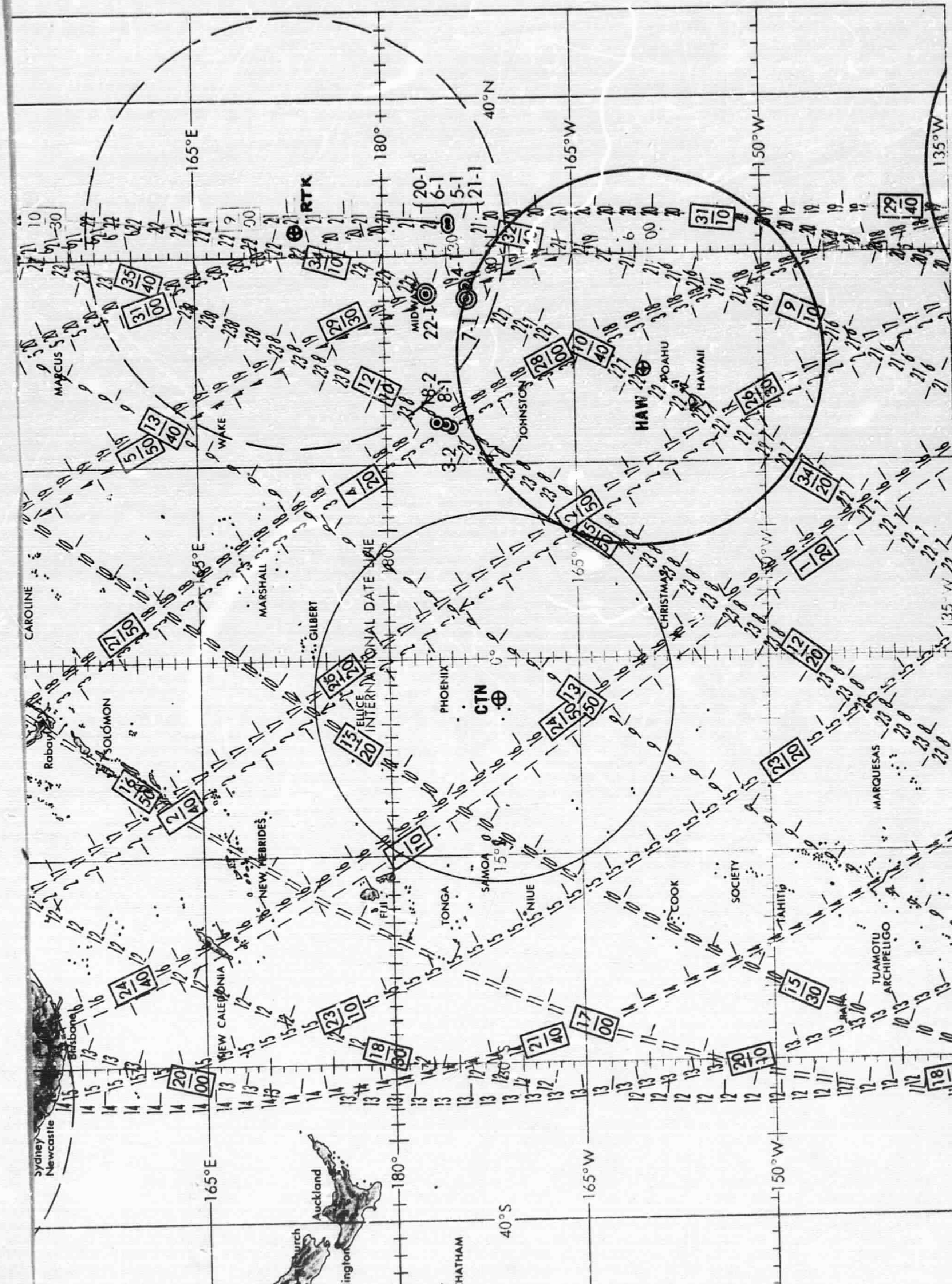

LEGEND

Command Site (coverage limits)

Mission Control Site (coverage limits)

Site with Radar only (coverage limits)

Planned Retro-sequence Initiation Points ★

Primary (Go-No Go) Landing Areas

Planned Landing Areas

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1.0 INTRODUCTION

The purpose of this report is to present the results of the support provided by the Pacific Missile Range Ship, Range Tracker and the Atlantic Missile Range Ship, Twin Falls during the Faith-7 Mercury-Atlas Mission (MA-9).

NASA was seeking two basic goals in the use of radar tracking ships:

1) To secure the critical re-entry tracking coverage required for precise landing point determination by the Goddard computers.

2) To evaluate the capabilities of existing Department of Defense vessels for the advanced Gemini and Apollo missions. The vessels have near state-of-the-art tracking, stabilization, and navigation systems, but it was predetermined that neither ship had computer capability approaching NASA requirements.

1.1 The Range Tracker was located at 31.5 degrees north latitude and 173 degrees east longitude to allow tracking during orbits 5, 6, 7, 20 and 21. Its primary objective was to provide re-entry tracking during an early termination of the mission on any of the aforementioned orbits or on orbit 22. There was no land-based station in the re-entry corridor, so the acceptable performance of the ship was extremely important. Of course, the mission was very nominal, so the spacecraft beacon was turned on to allow tracking only on orbits 7, 20, 21 and 22.

The Twin Falls was to assume an on-site position of 31.5 degrees north latitude and 75 degrees west longitude. The ship was allowed to track on orbits 2, 4, 15 and 16. In the event of an early termination, with re-entry in range of the ship's radar, it would have provided data to supplement coverage by land-based stations.

2.0 PREMISSION VALIDATION

2.1 Electronic System Tests on the Range Tracker

NASA felt that the important role that the Range Tracker would play in MA-9 warranted a premission confidence check of the complete electronic system. PMR Range Management agreed and furnished facilities and personnel for a test program. Goddard's Manned Space Flight Support Division test team went to Point Mugu, California, to perform dockside and sea trials of the Range Tracker. The NASA Group used their own instrumented aircraft to determine that the ship was able to track the plane with C-band and telemetry systems. Air-to-ground voice and other communications equipment was checked by PMR and NASA personnel. The ship's systems were found to be in working order and more refined tests were initiated. The data system was the area of greatest concern since the quantity and quality of received data would profoundly affect the Goddard computers' determination of landing point in the case of a non-nominal retrofire. Tests were designed to formulate a statistical value for overall system accuracy, using the NASA plane as the target. A description of the devised tests follows:

Simultaneous track of the aircraft by the ship's radar and a land-based FPS-16 would provide data for an evaluation of the relative accuracy of the ship's radar with respect to the land-based radar. At first the ship would remain at dockside so that the positional error could be minimized by transit survey.

Early attempts at tests were unsuccessful since the land-based radar lacked sufficient accuracy to be used as standard of comparison. Test procedures were revised so that optical triangulation (using theodolites) could be utilized to accurately locate the plane. When the tracking geometry was optimum for triangulation, the optical data was sufficiently accurate to be used as a standard. However, the transit surveying techniques employed and the incorrect usage of the ship's positional information in the PMR data reduction programs made the analysis of test results very difficult. Other problems made the test data either difficult to interpret or meaningless until shortly before the ship was to sail. Some of the problems encountered were:

1) An apparent lack of previous test results to compare with current results.

2) Inadequate coordination between the ship personnel and the PMR test data personnel.

3) Errors in the on-board G-15 computer program (used for raw data correction and formatting) and PMR 7094 test data reduction programs (used for raw data correction and data comparison).

4) A newly installed and only partially checked inertial navigation (SINS) and data systems.

Outputs of the ship's heading were found to have intermittent two (2) degree errors when the SINS analog data was fed into a multi-speed repeater-encoder unit for conversion to digital mode. Since spare parts were no longer available for this gear, the analog signal was routed to the encoders used by the RADAP-C and MK-19 stable platform.

2.2 Indicated Accuracy of the Range Tracker Test

Test results obtained during the last few days before the ship was to sail indicated that the ship's data compared with the theodolites as follows:

INERTIAL Systems	Target	RANGE ~~S/R~~ (yds)	AZ (mils)	EL (mils)
SINS (damped inertial mode)	NASA Aircraft (Range 1-5 mi)	±5.0	+2.5±.5	-2.0±.4
MK-19	"	±2.0	+2.5±.5	-2.0±.5
SINS (D.I. Mode)	PMR Aircraft (Range 100 mi)	50-70	+1.3±.5	+.8±.4
SINS (Stellar Mode)	"	50-70	-.3±.3	±.6
MK-19	"	50-70	+4.5±.5	+1.0±.5

(These values are averaged for several test runs.)

The final tests were conducted with a PMR aircraft at high altitude to minimize errors in position, but an unknown beacon delay apparently caused a range bias. The results given are raw (recorded) outputs of range, azimuth, elevation, roll, pitch and yaw, which were corrected at the PMR 7094. The deltas were then differenced and the results summarized.

The actual real time data route included data correction and formatting in the on-board G-15 computer. The limited capacity of the G-15 necessitated a tangential plane transformation from the SINS indicated position to the assigned position (used by Goddard computers). The error introduced by the shortcut transformation should have varied with distance, but should not have degraded the data seriously if the ship stayed within a 2-3 mile circle. Problems developed in the on-board computer and programs with the result that this portion of the system was not adequately tested. However, the answers seemed to be reasonable.

The ship was considered to be ready for mission support after the problems were corrected.[1]

2.3 Data System and Communication Line Checks

Goddard conducted several Computer and Data Flow Integrated Subsystem (CADFISS) tests to evaluate the status of radar encoders, data systems and communication lines. Cues were sent to each ship in turn by the Goddard computers and the radars were slewed in a prescribed manner. The data received at Goddard was analyzed to detect errors. Both ships demonstrated the ability to generate and transmit meaningful data to GSFC. Results thus validated the new data routes. It should be noted here that the Twin Falls data was transmitted to the AMR IP 7094 computer for correction and formatting. It was generally conceded that the on-board RCA 4101 lacked sufficient reliability to make corrections. Thus this data could not be considered to be in real time because the IP 7094 was not always immediately available.

The data lines from both ships in the pre-mission simulations and during the mission appeared very solid.

[1] Some tests showed the possibility of a 3 mil bias in the MK-19 stable platform, which was not completely confirmed by further testing.

3.0 TESTING ENROUTE TO SITE AND MISSION SUPPORT

3.1 Preparation at Sea (Range Tracker)[2]

May 6, 1963

The writer boarded the USNS Range Tracker at 0830 in Honolulu, Hawaii. All shipboard equipment was green with the following exceptions:

a. The multi-speed repeaters were dismantled while a new power supply was being installed. Work was completed in the evening.

b. The log periodic communications antenna had sustained a structural failure while enroute to Hawaii. The necessary parts were fabricated and repairs were completed on the following day.

In addition, the acquisition-aid servos had been returned and it was necessary to realign the acquisition aid and radar servos system. NASA Instrumented Aircraft 232 (which had rendezvoused with the ship at Hawaii) was employed that afternoon to verify that the servos system had been properly aligned.

Support of NCG 465G (simulation) during the night and early morning by the ship's personnel was excellent. All stations were manned and ready from beginning of the countdown until completion of the simulation. It was later learned the RTK was not required to support simulations after the simulated liftoff.

[2]The following text is reproduced from a report from W.C. Bryant, the Goddard observer on the Range Tracker during MA-9. No reports are available from the Twin Falls.

May 7, 1963

The ship departed Honolulu at 1600 local time. Most of the day was spent preparing for the trip. Some maintenance was done in preparation for NCG-465F. Reliable communications could not be established, however, in time to support the simulation because of the poor propagation in that area.

May 8, 1963

The NASA Aircraft rendezvoused with the RTK at 23° 57.7'N and 167° 57.5'W early that morning. An attempt was made to check the air/ground voice relay circuit. Eventually a short conversation was held between the aircraft and Hawaii via the ship. However, communications were poor and it was felt that the quality and reliability of the relay were questionable.

With communications restored, the ship participated in NCG-465E (simulation) again with excellent results.

May 10, 1963

As the ship passed Midway Island, a comparison was made between the SINS position and the chart location of Midway. This was done because a definite difference in both magnitude and direction had existed between the SINS positions and the Loran-C positions since leaving Honolulu. The comparison showed an error in longitude that was over an order of magnitude larger than the latitude error. Since a good positional updating had been obtained by the Star Tracker only a few hours earlier, the error could not have been caused by gyro drift.

After several hours the source of error had not been found and it was decided to steam back to Midway for further tests. Additional positional checks at Midway indicated that the Star Tracker stable platform was tilted and introduced a positional error during updating. A mathematical correction was inserted in the SINS computer for compensation.

To obtain a more accurate standard the ship proceeded to an island which is the location of a Loran-C master station and its position is known more accurately than Midway's. The ship's position was determined by tracking the Loran-C tower on the island with the radar. The mathematical correction was refined and a series of positional checks indicated that the error had been minimized.

<u>May 11, 1963</u>

The ship crossed the International data line at 0800. (To avoid confusion, this report will neglect the change in dates.) Once the ship had passed the island, it moved into a bad Loran-C area and positional checks between SINS and Loran-C became meaningless. Comparisons with hand-held sextants indicated that the sins was in the "ball park".

Support of NCG 465B (simulation) went very smoothly.

<u>May 12, 1963</u>

The ship arrived at the assigned position (31° 30'N, 173°00W) at 0800. The air-ground voice relay was tested using Canton

Island UHF broadcasting through the ship to Hawaii on HF. Results were much improved over the previous test with the NASA aircraft.

<u>May 13, 1963</u>

A phase shift error developed in the FPS-16 radar, which caused the servos to correct in the wrong direction when in auto track and thus to drive the radar off target. An aircraft from Midway was dispatched to rendezvous with the ship to help correct the radar. An electronic tube was replaced and several crystals reset to correct the problem. Dynamic track of the aircraft verified that the radar was operational.

3.2 Mission Support[2]

<u>May 14, 1963</u>

All stations were manned and ready at the start of the countdown for NCG-465 (MA-9). Just a few minutes prior to the beginning of the RTK CADFISS test, a resistor in the output circuit of the G-15 computer burned out. An additional paper tape punch had been installed to reduce the physical separation between the G-15 computer and teletype equipment and thereby reduce the real time error. It was suspected that this punch had been defective and had caused the burnt out resistor and so it was removed. During the remainder of the mission all data was transmitted with three(3) minutes delay in real time.

The G-15 was not repaired in time to participate in the scheduled CADFISS test. A special CADFISS test was run later in the countdown and all tests were passed successfully.

At approximately 1430Z, NCG 465 was rescheduled for 1300Z, May 15, 1963.

May 15, 1963

All stations were manned and ready at the beginning of the countdown for NCG-465 (MA-9). Support of CADFISS was on schedule and all tests were passed successfully.

Shortly before launch, a random bit drop-out in elevation was noted in the FPS-16 radar. The problem was traced to a bad module contact in the elevation shift register circuit and corrected.

The RTK went to standby status at 0040 GMT.

At T+4:15 the ship reverted to critical coverage. During the CADFISS test prior to Orbit 5 the Packard-Bell timing Module went out. It was not corrected in time to allow track of Orbit 5.

3.3 Orbit Six

During the pass over the ship during orbit 6, telemetry acquired and tracked the capsule on the low link. All "H" times are the 1° elevation times given in the Goddard acquisition message.

H time = 8:57:55 Ground Elapsed Time (GET)

H - :20	TM contact (AOS) (TM=telemetry)
H - :10	TM auto azimuth track
H + 2:13	TM full auto track
H + 6:25	TM loss of signal (LOS)

The timing problem was corrected by replacing several bad modules and a special CADFISS test was run at H +9:30:00. All tests were passed successfully.

3.4 Orbit Seven

TM and the C-band beacon were turned on for the pass over the RTK during Orbit 7.

H time = 10:13:15 GET

H - :40	TM AOS
H - :35	TM auto azimuth tracks
H + :20	TM full auto track
H + 2:13	Radar auto beacon track
H + 5:14	Radar LOS
H + 6:59	TM LOS

The capsule C-band beacon was weak with heavy modulation. This was also reported by several other sites.

A total of 26 valid data points were transmitted and received at GSFC.

3.5 Orbit Eight

The RTK acquired and tracked TM low link as the capsule passed over the ship on Orbit 8.

H time = 12:04:57 GET

H - :25	TM AOS
H - :20	TM LOS
H + 5:56	TM auto track

The ship went to standby status at 1308 GET.

Critical coverage was resumed at 27:56 GET. Participation in a CADFISS test was cancelled due to a computer printer problem at Goddard. At 28:18 GET the radar pulse coder became inoperative. A HP-212 pulse generator was substituted and used for the remainder of the mission. Work continued on the pulse coder, but it was not repaired in time.

3.6 Orbit Twenty

As the spacecraft passed over the ship during orbit 20, a voice relay was attempted from the capsule via the RTK to MCC. This was unsuccessful due to a 1700 KC tone on the Scama loop which keyed the HF transmitter and kept the VOX relay open.

H time = 31:00:04 GET

H - :50	TM AOS
H - :25	TM auto azimuth track
H + 1:15	TM full auto track

H + 1:49 Radar auto track

H + 6:32 TM LOS

Again the beacon return was heavily modulated, though improved over other passes. Twenty-eight valid data points were recorded and transmitted to Goddard.

3.7 Orbit Twenty-one

TMLO and C-band beacon were turned on for the pass over the ship on Orbit 21.

H time = 32:33:23 GET

H - :35 TM AOS

H - :30 TM auto azimuth track

H + :20 TM full auto track

H + 1:46 Radar auto track

H + 4:30 Radar LOS

H + 6:35 TM LOS

The beacon return was heavily modulated, through improved over other passes. Twenty-eight valid data points were recorded and transmitted to Goddard.

3.8 Orbit Twenty-two

MCC requested that the ship relay weather information about the landing area to the capsule. The astro was contacted on UHF prior to its pass over the ship, but it is not known whether the astro received the weather message. MCC also requested that the ship relay the TM blackout time to the Cape as soon as it was determined. This was done.

H time = 34:07:18 GET

H - :30	TM AOS
H - :15	TM auto azimuth
H + :59	TM blackout
H + 2:29	Radar auto track
H + 3:15	Radar LOS

TM blackout occurred before the acquisition aid went to auto track in elevation and before the radar had AOS. In all the other passes the radar had not acquired until the acquisition aid was in full auto track.

With the radar still slaved to the acquisition aid, the nominal re-entry trajectory (with the times corrected from the acq. msg.) from the data acquisition plan was used to position the radar. Using this scheme the radar acquired the capsule 1½ minutes after TM blackout and after point of closest approach.

Six valid data points were recorded and transmitted to Goddard.

Broken skies existed over the ship throughout the mission period and it was not possible to sustain constant stellar track with the SINS Star Tracker. However, intermittent track during the orbital phase should have provided enough information to give a good ship position. (This concludes Mr. Bryant's report)

4.0 DATA ANALYSIS

The radar data for the Range Tracker is presented in three stages. The first stage shows the differences between the values of range, azimuth and elevation measured by the Range Tracker and the values computed by integrating the vectors referenced to Cape Canaveral on a pass preceding the ship.[3]

At this point, the differences represent total errors, including errors in ship's position, radar biases, the initial vector, integration, drag model, density, etc. To obtain the total errors, the Cape 4th orbit vector was integrated to the Range Tracker 7th orbit observations and the Cape Canaveral 18th orbit vector was integrated to the Range Tracker 20th orbit, 21st orbit and re-entry observations.

The Cape 4th orbit vector proved to be a very good estimate of the orbit as only a relatively small correction was needed after 10 orbits of integration when the orbit entered Woomera on the 14th. The result of using this vector with the Range Tracker on the 7th shows very good agreement (Figure [illegible]-5-1)

[3] The vectors referenced to the time of passage over the longitude of Cape Canaveral include all reasonable radar data received during the 225 minutes preceding this point at Cape Canaveral. These vectors represent the weighted least squares "best fit" and differential correction determined from this data.

The use of the ship's data would change the orbit by .95 mile in position and 60 ft/sec in velocity. This compares fairly well with a single-station Verlort solution and the standard deviations of the Range Tracker are slightly better than those of a Verlort.

The Cape 18th vector was integrated in real-time for computation of the time to fire retro-rockets and the impact point (which was extremely good). However, the Cape 18th vector did not agree well with the observations at Hawaii on the 21st orbit and, as can be seen in graphs 5-2, 3, 4, did not agree with the Range Tracker observations on the 20th, 21st and re-entry.

As the second stage, therefore, the observations of the Cape 18th orbit vector were differentially corrected at Hawaii on the 21st orbit and the resultant vector was integrated for comparison with the Range Tracker. To prove the validity of the solution the vector was integrated to the time of retro-fire and retro-fire was applied at the time it was performed in the MA-9 mission. The change in the calculated impace point was only 2 miles different from the real time solution. Based upon this apparent position bias, a new location for the ship was computed of longitude 172° 58' 53.5" east, latitude 31° 29' north. After repositioning the difference between the Hawaii 21st vector and the Range Tracker observation on orbits 20, 21 and re-entry were computed. The differences are plotted in graphs 5-7, 8, and 9. These plots show excellent agreement between the Hawaii 21st orbit vector and the new ship's position and observations in all but the angular measurements on re-entry. The cause of this discrepancy is not clear.

This new position determined for the Range Tracker on second day tracking was also evaluated for the one set of observations on the first day, the 7th orbit. These results are plotted in graph 5-10. The position degraded the solution and therefore the second day's position is not considered valid for the first day. A problem in relocation of ship is that they can and do move from day to day and even pass to pass.

The Twin Falls was located at 75°W longitude and $31^{\circ}30'$ N Latitude roughly between Cape Canaveral and Bermuda. The ship tracked on orbits 2, 4, 15 and 16 as shown in figures 5-11, 12, 13 and 14. The observations were evaluated using vectors determined in real time at Cape Canaveral and Bermuda. The Twin Falls had a very low RMS value (noise) which was equivalent to a land-based radar. The fairly large difference, especailly for the short integration of vector involved, could be due to either radar biases or error in the ship's position. The latter is the most likely but no relocation of the ship was performed because the pattern was not very consistent. Graphs 6-1, 2, 3, 4, 5, 6, 7 and 8 present the nominal values of range, azimuth and elevation as computed for the ships. These are intended to indicate the general quality of the pass and are not exact values.

The third stage of the study is a comparison of the landing points as computed by the real time program and those determined after the fact by a slightly more sophisticated postflight program. Table 1 presents the more important findings. Line 1 is the landing point which was computed in real time and the one at which the astronaut was recovered. The recovery forces reported that the landing point was within 2 miles of the target point. It should be noted this was probably the most perfect re-entry yet experienced. Landing point determination with the re-entry data from the Range Tracker was attempted in the real time program with the results shown on lines 2 and 3. It is obvious that the solution was not convergent. Line 4 shows the results using the postflight program with the same data used on line 1. The results essentially agree. Lines 5 and 6 show the landing point determined using postflight program with the Range Tracker re-entry data alone at the oribinal and relocated positions. The impact point was in error 200 miles. The next test was to determine the quality of the Hawaii 21st orbit to see if it was of sufficient quality to use as a comparison with the Range Tracker Data. The advantage in using this data is that it was taken near in time to the Range Tracker 20th and 21st orbit data. Line 7 shows that the 18th orbit data plus Hawaii 21st orbit data gives a valid landing point less than 2 miles different from the real time solution. The same test was made with the Range Tracker 20th and 21st orbit data at its oribinal location and relocated.

Relocation improved the landing point determined using the 18th orbit data and Range Tracker 20th and 21st data by 4 and 5 miles respectively as shown on lines 8 through 19. Lines 16 through 19 show the results determined using a single-station ship solution. This demonstrates the weakness of this type of solution with errors of 64 to 111 miles in landing point. This test was not done with the relocated position since the landing point would have moved the amount of the relocation.

Table 2 contains a tabulation of the RMS errors for the ship observations. The RMS values for the RTK fall between a land-based FPS-16 and a verlort which is probably to be expected for an FPS-16 on a ship in motion. The TFV, however, had RMS values as good as most land-based FPS-16's.

Table 3 illustrates the change in orbit which would have resulted if the single-station vector from the ship's observations had been used instead of the vector determined in the real-time program.

Table 4 is a summary of the messages transmitted by the ships.

The following is a short orbit-by-orbit discussion of the ships data:

4.1 Orbit #2

The Twin Falls transmitted 54 observations of which 6 were valid and 5 above 3^{o}. This data would not yield a converged solution. The differences between the data and the estimate of the orbit are shown in Graph 5-11.

4.2 Orbit #4

The Twin Falls transmitted 40 observations of which 21 were valid and 13 above 3^{o}. Postflight analysis indicated this data, if used, would have caused a position change of 2.3 nautical miles and a velocity change of 110.7 feet/second in the estimate of the orbit. The residuals are plotted on Graph 5-12.

4.3 Orbit #7

The Range Tracker transmitted 26 observations, all valid and all above 3^{o}. This data was not used in real time. Graph 5-11 shows the data compared to the computed orbit. Postflight analysis indicates, if used, the data would have caused a position change of .95 nautical miles and a velocity change of 60.0 feet/second in the estimate of the orbit. The residuals are plotted in Graph 5-1.

4.4 Orbit #15

The Twin Falls transmitted 52 observations of which 22 were valid and 15 above 3^{o}. Post analysis indicated that, if used, the data would have caused a position change of 4.0 nautical miles and a velocity change of 22.5 feet/second in the estimate of the orbit. The difference between the observation and the computed orbit are shown in Graph 5-13.

4.5 Orbit #16

The Twin Falls Transmitted 67 observations of which 34 were valid and 28 above 3^{o}. Postflight analysis indicated this data would have caused a position change of 5.6 nautical miles and a velocity change of 39.2 feet/second in the estimate of the orbit. The residuals are plotted in Graph 5-14.

4.6 Orbit #20

The Range Tracker transmitted 29 observations of which 28 were valid and all were above 3^{o}. This data was not used on-line in real-time. Off-line tests in real-time indicated it would have caused a position change of 4.9 nautical miles and a velocity change of 6.2 feet/second in the estimate of the orbit. Graph 5-2 shows the differences between the data and the computed orbit.

4.7 Orbit #21

The Range Tracker transmitted 28 observations, all valid and above 3^{o}. This data was not used in real-time on-line. Off-line computation indicate it would have caused a position change of 7.1 nautical miles and a velocity change of 26.7 feet/second in the estimate of the orbit. Graph 5-3 shows the difference between data and the computed orbit.

4.8 Orbit #22 - Re-entry

The Range Tracker transmitted 20 observations, Six observations were valid and all were above 3^{0}. All observations were made during the period of blackout. The capsule was on the horizon at -1^{o} elevation at 23 hr 11 min 31 sec GMT at a range of 1164 n.m. It was at 3.5^{o} at 23 hr 12 min 08 sec, at a range of 86.3 n.m. Blackout times were from 23 hr 12 min 30 sec to 23 hr 16 min 42 sec.

Observations were transmitted from 23 hr 14 min 05 sec to 23 hr 15 min 59 sec with the period of valid track being from 23 hr 14 min 11 sec to 23 hr 14 min 41 sec. The maximum elevation of the pass occurred at approximately 23 hr 13 min 17 sec at 29^{o}.

With the 6 valid observations, differential correction was attempted off-line which changed position by 5.7 nautical miles and velocity by 3220 feet/second. This gave a final impact point of 26.8^{o}S latitude and 128^{o}W longitude.

Later analysis of the data with a more sophisticated postflight analysis program gave an impact point of 25.4^{o}N latitude and 173.5^{o}W longitude, with a low degree of convergence.

5.0 SUMMARY

The tracking data obtained by both ships was of good quality as shown by the RMS values. The accuracy seemed to indicate the lack of knowledge of the ship's exact position, with the possible exception of the re-entry track, which appears to have some other bias in it which caused a poor impact calculation.

Both ships did a commendable job with the equipments at their disposal. The Range Tracker was poorly positioned with respect to signal attenuation on re-entry, but that was NASA's error.

6.0 CONCLUSION

The two ships evaluated during MA-9 were demonstrated as capable of performing the mission for which they were designed. However, the requirements of manned space flight impose these conditions which neither ship could completely meet:

a. Accurate determination of ship's position.

b. Correction for ship's motion, position, and flexure to .5 mil or better in angular measurement.

c. Computer capability on-board to generate acquisition points, reacquisition information, and scan patterns.

d. A systematic procedure for validating component and system performance on a weekly basis and adequate spare parts to maintain the integrity of the system for extended periods at sea.

e. An absolute requirement for periodically returning to a home port for a complete check of alignment and total system accuracy.

f. Test procedures should be standardized, and a test director appointed with authority to control all phases of the testing.

TABLE [illegible]-1

IMPACT POINT CALCULATIONS

	ANCHOR POINT OF VECTOR	DATA USED	PROGRAM UTILIZED	RTK POSITION	TIME TO FIRE	DELTA TIME TO FIRE (sec.)		IMPACT ERROR N. M.	(DEG.)	(DEG.)
1.	CNV-18	18th Orbit	Real time	---	47:03:43	---			-176.49	+27.37
2.	RTK-22	1st D.C. Re-entry	"	Original	---	---		484.47	-168.35 (2)	+22.99 (2)
3.	RTK-22	2nd D.C. Re-entry	"	Original	---	---		2425.09	-127.99 (2)	-26.83 (2)
4.	CNV-18	18th Orbit	Post-Flight	---	47:03:43 (1)			0.60	-176.49	+27.36
5.	RTK-22	Re-entry	"	Original	---	---		192.28	-173.42	+25.44
6.	RTK-22	Re-entry	"	Re-located	---	---		191.82	-173.45	+25.42
7.	HAW-21	18th Orbit +HAW-21	"	---	47:03:43 (1)	---		1.62	-176.46	+27.36
8.	RTK-20	18th Orbit +RTK -20	"	Original	47:03:42	-1			(3)	(3)
9.	"	"	"	"	47:03:43 (1)	---		6.79	-176.36	+27.33
10.	"	"	"	Re-located	47:03:43	0			(3)	(3)
11.	"	"	"	"	47:03:43 (1)	---		3.94	-176.42	+27.34
12.	RTK-21	18th Orbit +RTK -21	"	Original	47:03:41	-2			(3)	(3)
13.	"	"	"	"	47:03:43 (1)	---		9.23	-176.32	+27.31
14.	"	"	"	Re-Located	47:03:42	-1			(3)	(3)
15.	"	"	"	"	47:03:43 (1)	---		4.39	-176.41	+27.34
16.	RTK-20	RTK-20	" (4)	Original	47:03:18	-25			(3)	(3)
17.	"	"	" (4)	"	47:03:43 (1)	---		110.79	-174.43	+26.69
18.	RTK-21	RTK-21	" (4)	"	47:03:29	-14			(3)	(3)
19.	RTK-21	RTK-21	" (4)	"	47:03:43 (1)	---		64.40	-175.29	-26.98

(1) Time to fire not calculated - Mission Value Forced
(2) Solution not converged
(3) Within 2.5 miles of nominal impact point as required by iteration for time to fire

TABLE [redacted]-2

STANDARD DEVIATIONS OF SHIP'S OBSERVATIONS

SHIP	ORBIT NO.	STANDARD DEVIATION RANGE (YARDS)	STANDARD DEVIATION AZIMUTH (MILS)	STANDARD DEVIATION ELEVATION (MILS)
RTK	7	16.6	.70	1.08
	20	15.2	.67	1.13
	21	16.0	.66	1.34
	22 (reentry)	95.86	4.00	10.31
TFV	2	--	--	--
	4	10.0	.24	.44
	15	9.3	.35	.34
	16	7.8	.32	.42

TABLE 3

CHANGES IN ORBIT ESTIMATE DUE TO SHIP'S DATA

SITE	PASS	Δr, N. MILES	ΔV, FT/SEC
RTK	7	.95	60.0
	20	4.93	6.2
	21	7.08	26.7
	22(reentry)	5.71	3220.0
TFV	2		
	4	2.31	110.7
	15	4.04	22.5
	16	5.61	39.2

TABLE 3-4

SUMMARY OF SHIP'S TRANSMISSION

Time Message Received	Site	No. of Lines	Valid	Valid above 3°	AOS Acquisition of Signal			LOS Loss of Signal			El at A.O. Valid Track	El at L.O. Valid Track	Range at A.O. Valid Track n.m.	Range L.O. Valid Track	Max Elev Deg.
					HRS.	MIN.	SEC.	HRS.	MIN.	SEC.	DEG.	DEG.	N.M.	N.M.	
Pass 7	RTK	26	26	26	23	38	07	23	40	37	36.3	7.0	152	500	59.0
Pass 20		29	28	28	20	06	05	20	08	53	13.7	8.4	313	366	59.8
Pass 21		28	28	28	21	39	22	21	42	04	13.5	10.3	314	375	48.7
Pass 22		20	6	6	23	14	05	23	15	59	20.9	9.6	117	214	20.9
Pass 2	TFV	54	6	5	14	39	28	14	45	04	7.0	4.6	482	560	7.0
Pass 4		40	21	13	17	46	16	17	52	16	8.0	3.5	491	681	8.0
Pass 15		52	22	15	11	09	47	11	15	11	6.6	4.0	492	788	7.5
Pass 16		67	34	28	12	42	11	12	48	41	53.5	2.8	108	635	55.6

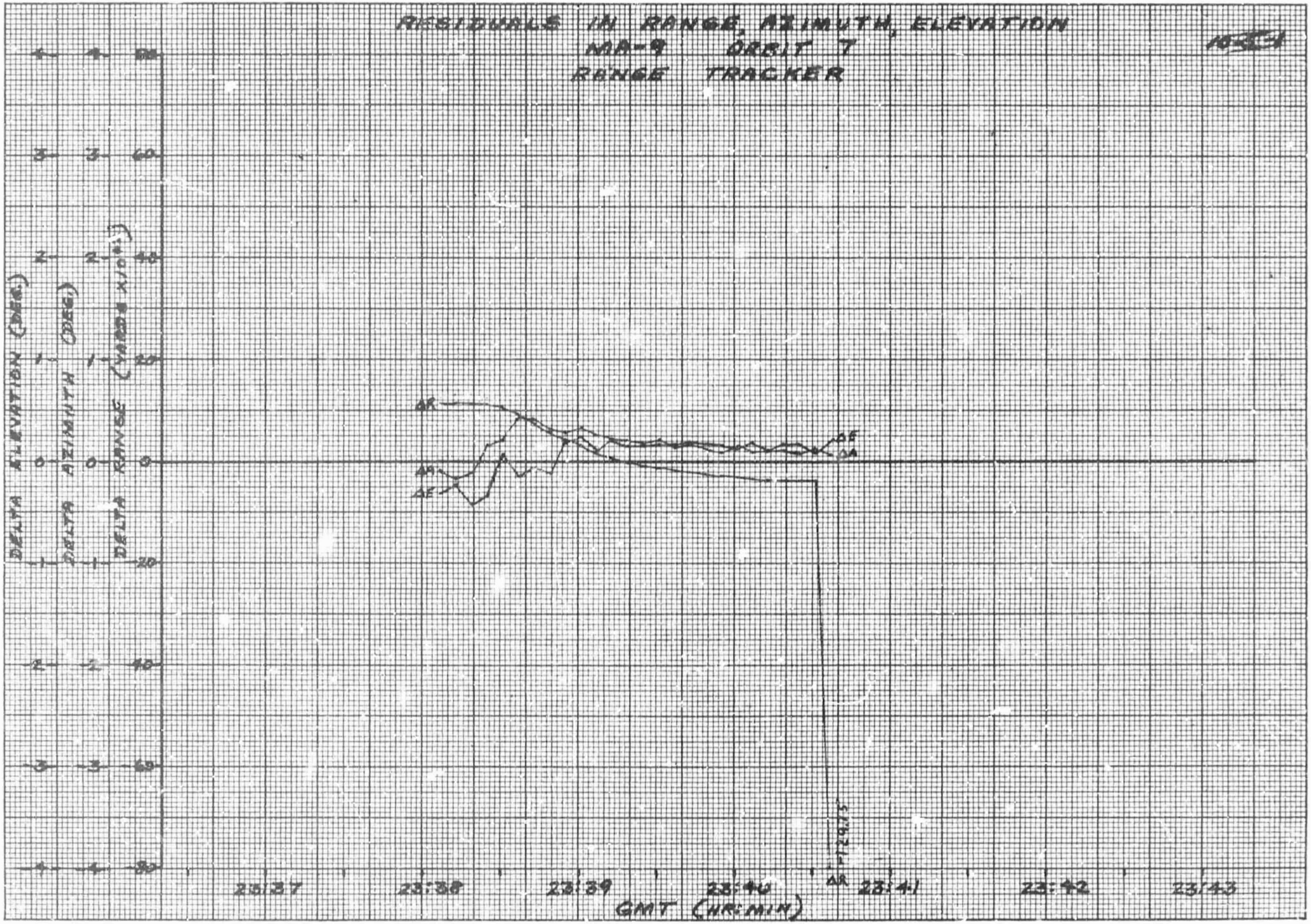
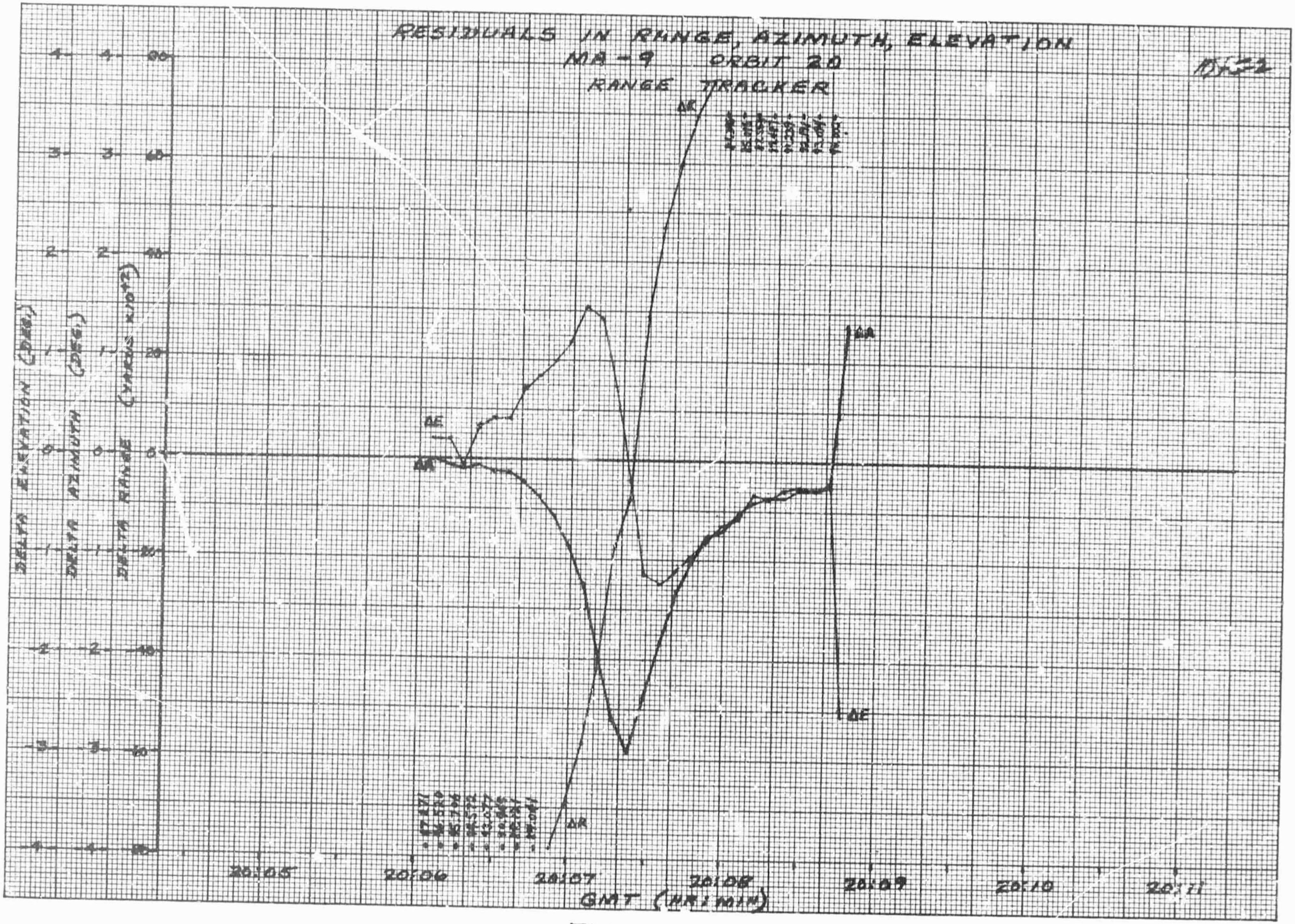

RESIDUALS IN RANGE, AZIMUTH, ELEVATION
MA-9 ORBIT 7
RANGE TRACKER
DELTA ELEVATION (DEG.)
DELTA AZIMUTH (DEG.)
DELTA RANGE (YARDS X10)
ΔR
ΔA
ΔE
-129.75
23:37
23:38
23:39
23:40
23:41
23:42
23:43
GMT (HR:MIN)

FIG 5-1



RESIDUALS IN RANGE, AZIMUTH, ELEVATION
MA-9 ORBIT 20
RANGE TRACKER
DELTA ELEVATION (DEG.)
DELTA AZIMUTH (DEG.)
DELTA RANGE (YARDS X10+2)
ΔE
ΔR
ΔA
20:05
20:06
20:07
20:08
20:09
20:10
20:11
GMT (HR:MIN)

FIG 5-2

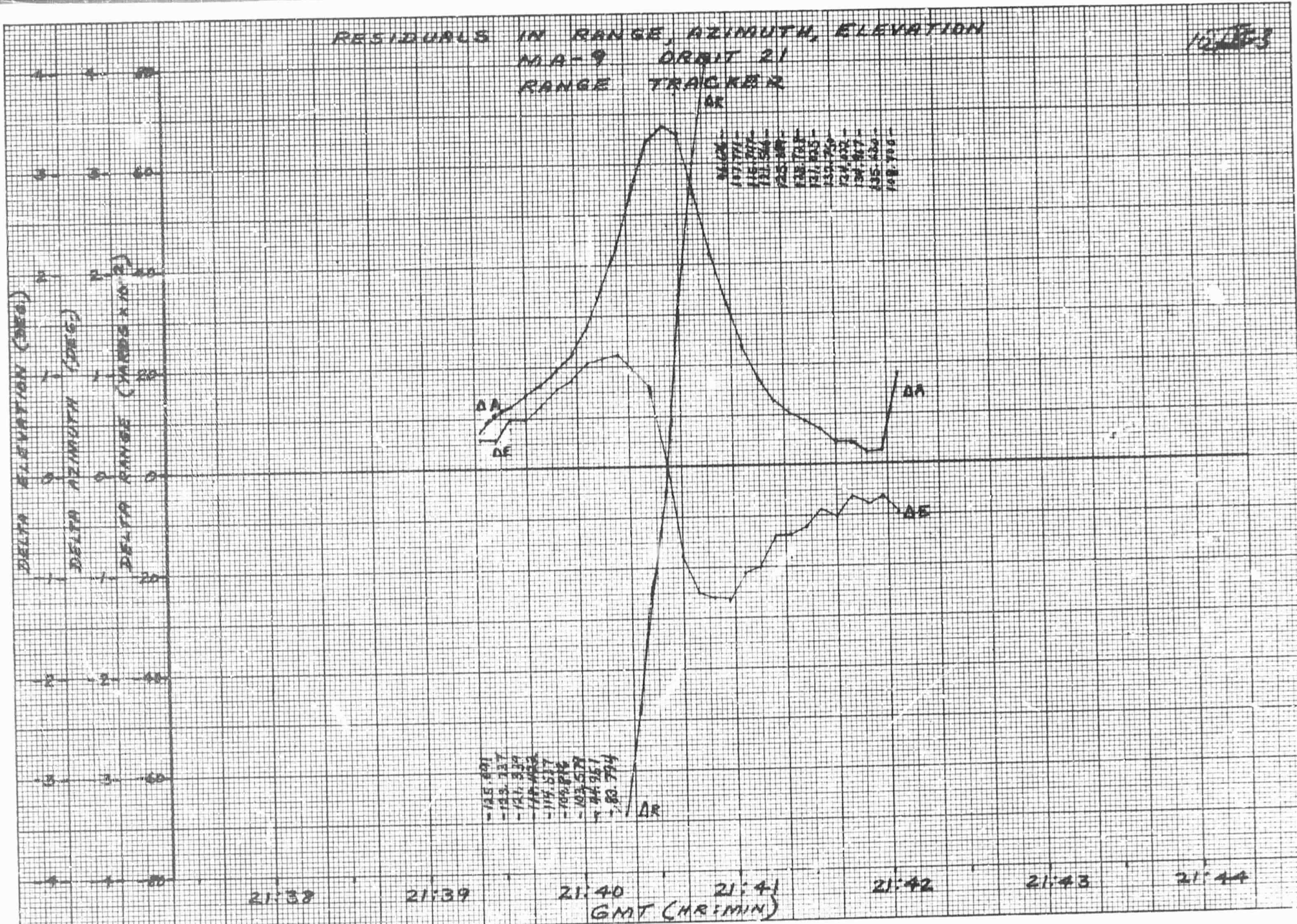

RESIDUALS IN RANGE, AZIMUTH, ELEVATION
MA-9 ORBIT 21
RANGE TRACKER
DELTA ELEVATION (DEG)
DELTA AZIMUTH (DEG)
DELTA RANGE (YARDS x 10^2)
ΔA
ΔE
ΔR
21:38
21:39
21:40
21:41
21:42
21:43
21:44
GMT (HR:MIN)

FIG 5-3

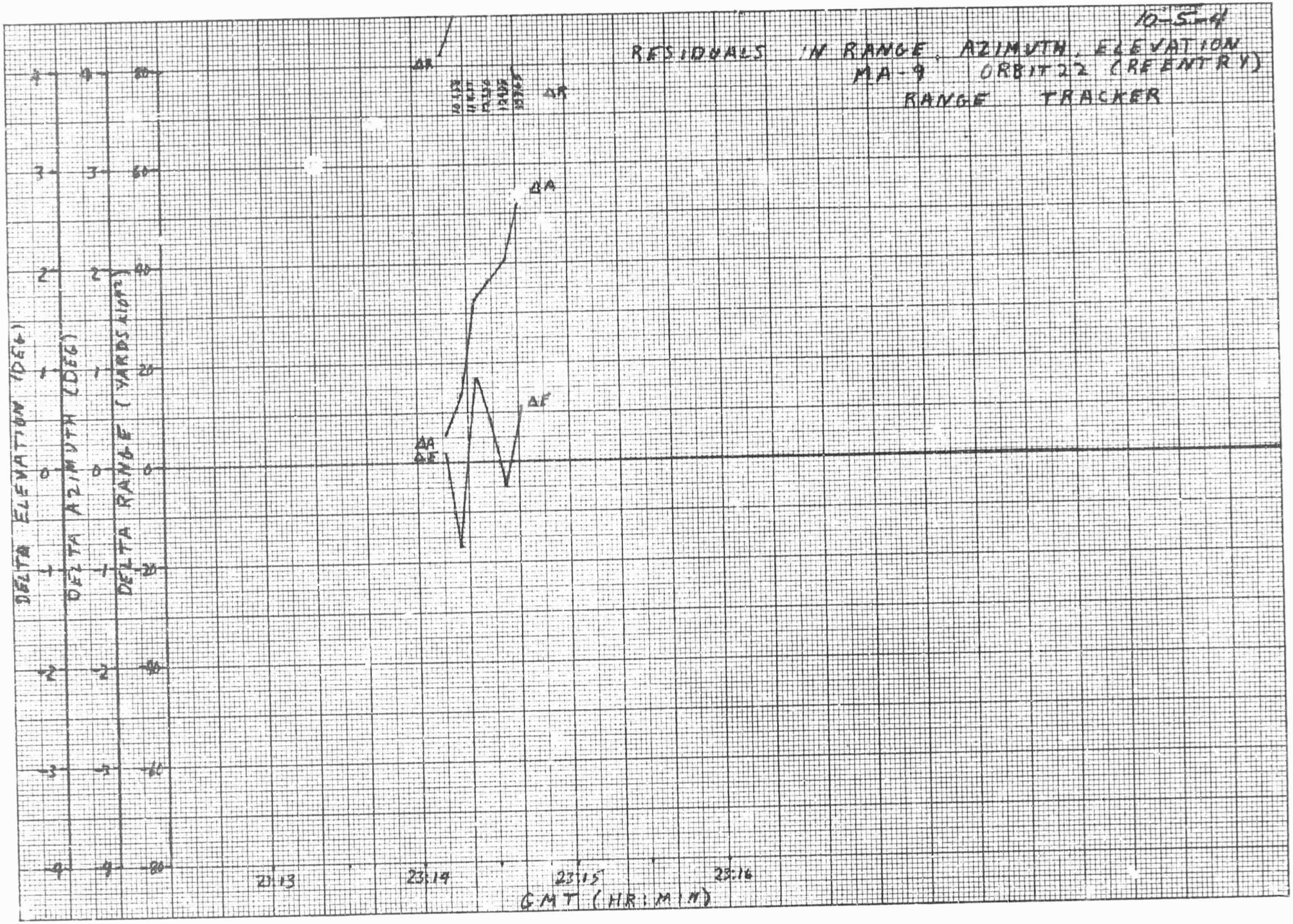

10-5-4
RESIDUALS IN RANGE, AZIMUTH, ELEVATION
MA-9 ORBIT 22 (REENTRY)
RANGE TRACKER
ΔR
ΔA
ΔE
DELTA ELEVATION (DEG)
DELTA AZIMUTH (DEG)
DELTA RANGE (YARDS ×10²)
23:13
23:14
23:15
23:16
GMT (HR:MIN)

FIG 5-4

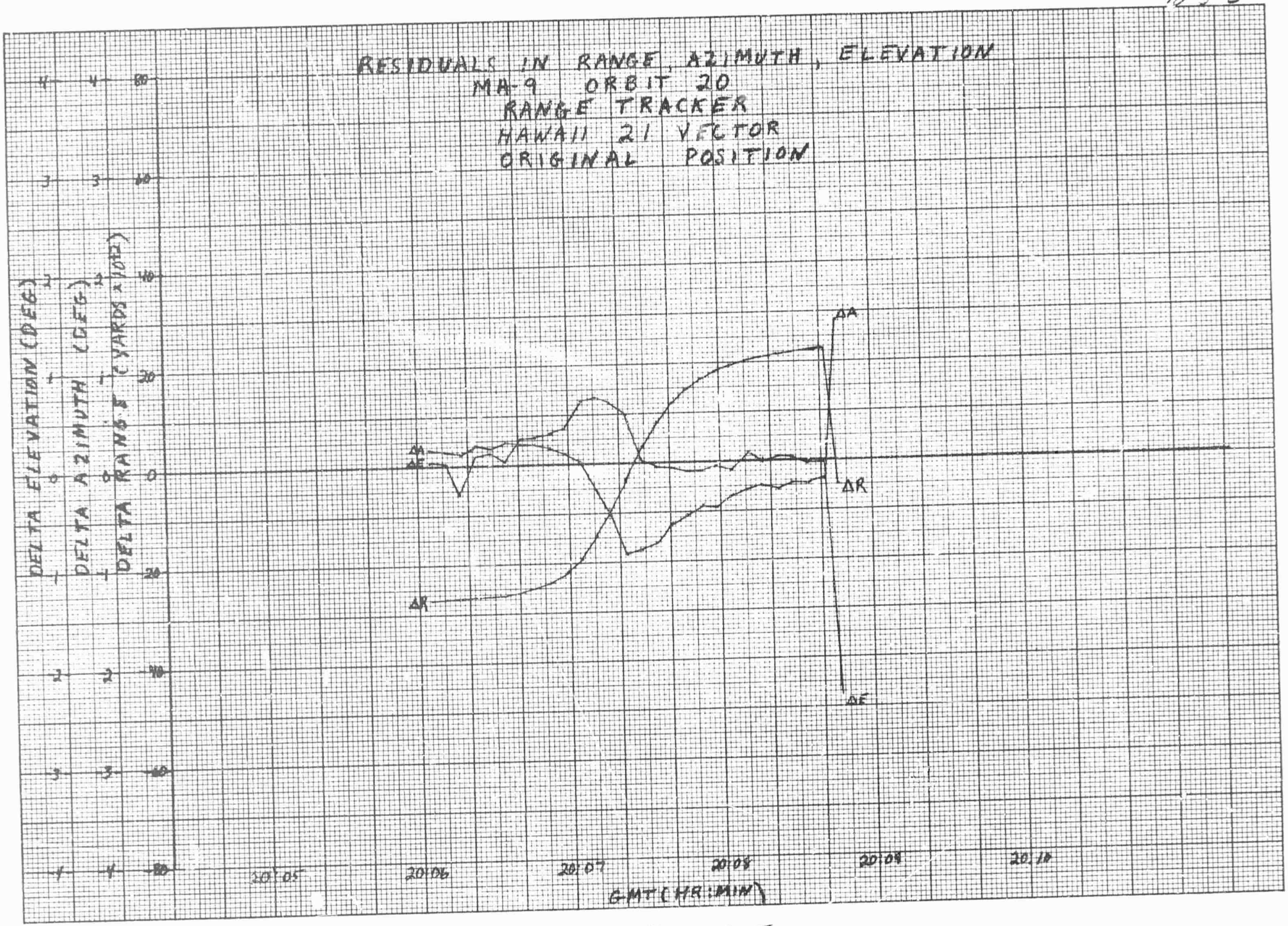
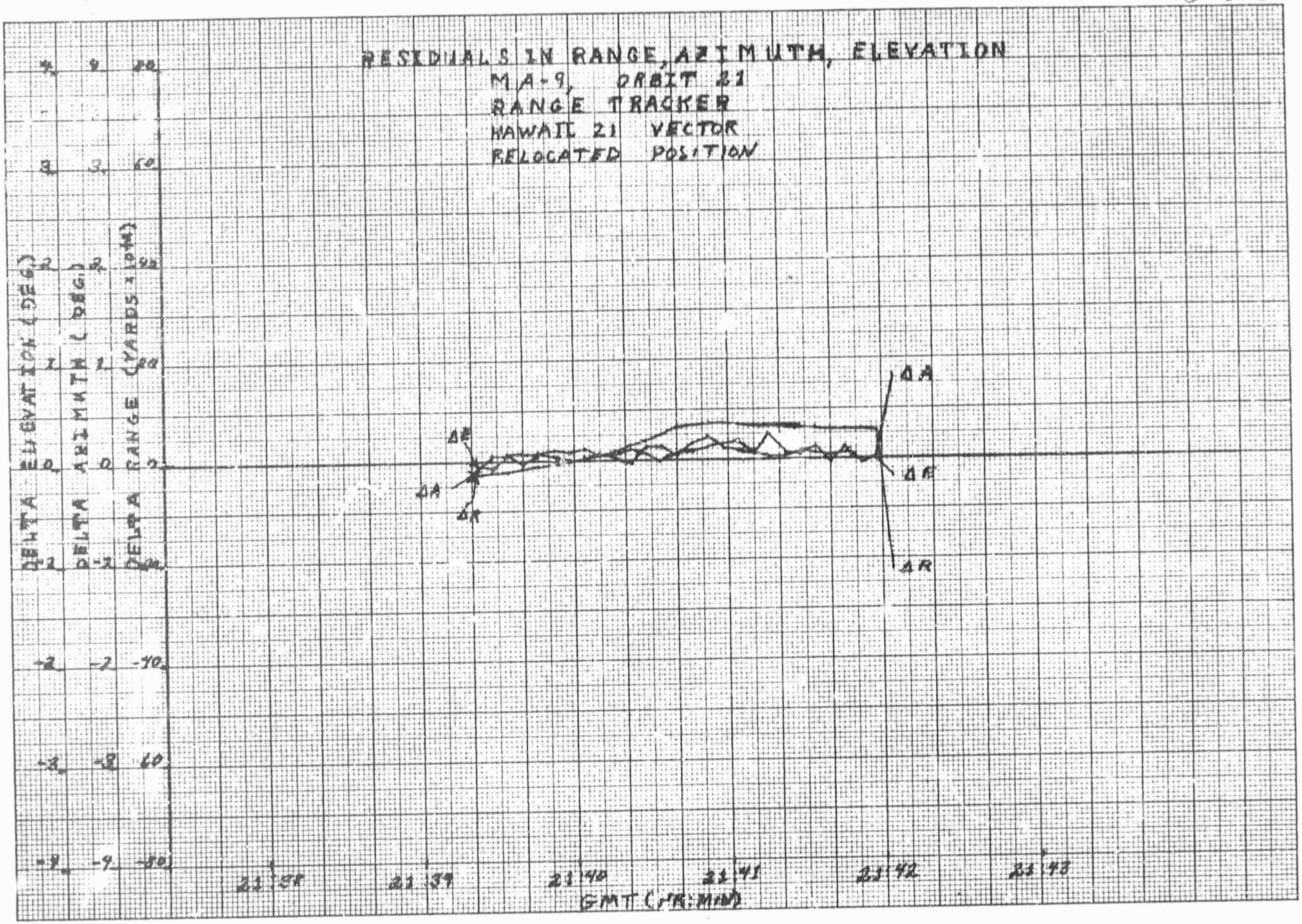

RESIDUALS IN RANGE, AZIMUTH, ELEVATION
MA-9 ORBIT 20
RANGE TRACKER
HAWAII 21 VECTOR
ORIGINAL POSITION
DELTA ELEVATION (DEG)
DELTA AZIMUTH (DEG)
DELTA RANGE (YARDS x 10E2)
ΔA
ΔE
ΔR
20:05
20:06
20:07
20:08
20:09
20:10
GMT (HR:MIN)

FIG 5-5



RESIDUALS IN RANGE, AZIMUTH, ELEVATION
MA-9, ORBIT 21
RANGE TRACKER
HAWAII 21 VECTOR
RELOCATED POSITION
DELTA ELEVATION (DEG)
DELTA AZIMUTH (DEG)
DELTA RANGE (YARDS x 10⁴)
ΔA
ΔE
ΔR
21:38
21:39
21:40
21:41
21:42
21:43
GMT (HR:MIN)

FIG 5-8

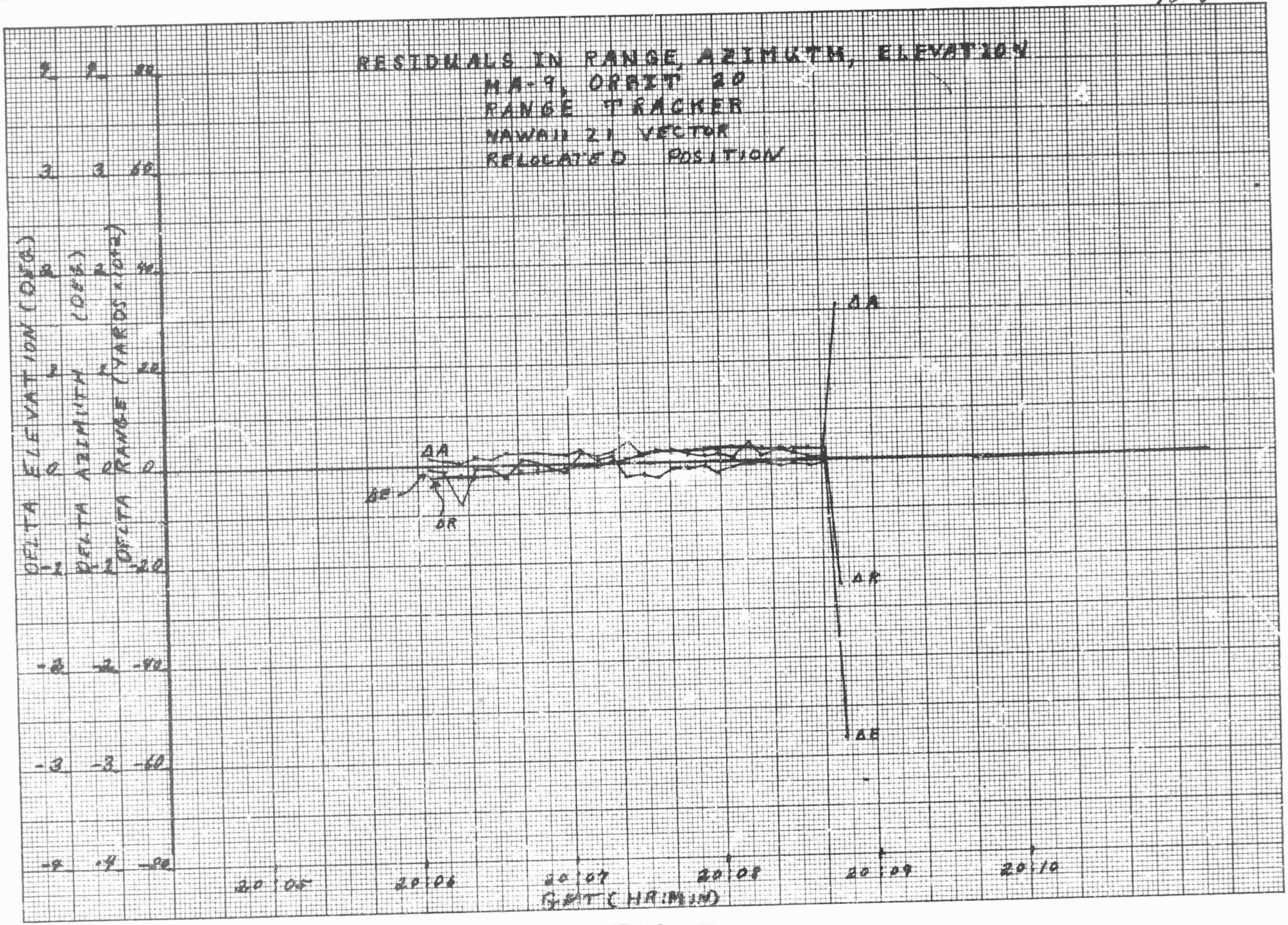
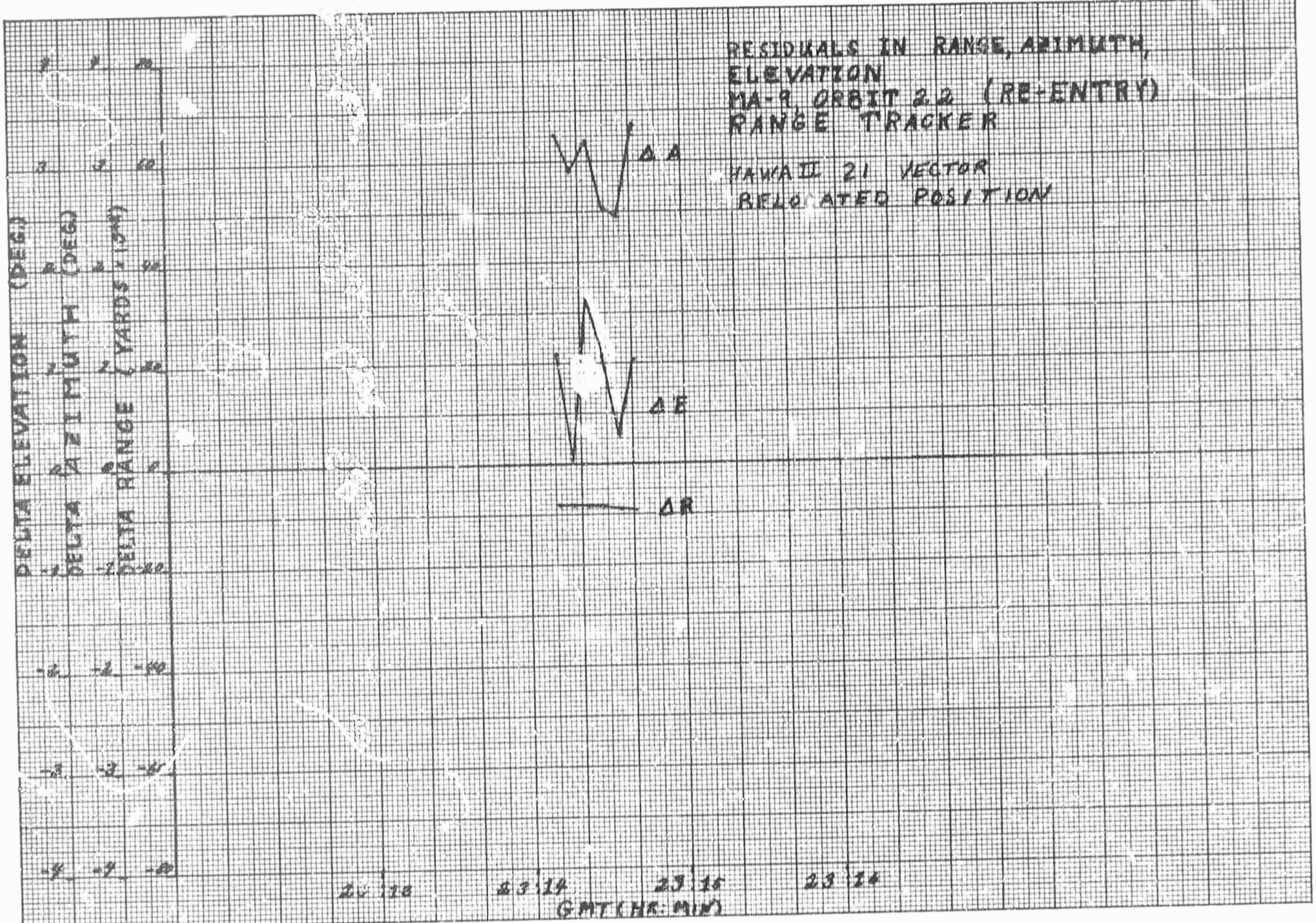

RESIDUALS IN RANGE, AZIMUTH, ELEVATION
MA-9, ORBIT 20
RANGE TRACKER
HAWAII 21 VECTOR
RELOCATED POSITION
DELTA ELEVATION (DEG.)
DELTA AZIMUTH (DEG.)
DELTA RANGE (YARDS x10+2)
ΔA
ΔE
ΔR
20:05
20:06
20:07
20:08
20:09
20:10
GMT (HR:MIN)

FIG 5-7


RESIDUALS IN RANGE, AZIMUTH, ELEVATION
MA-9, ORBIT 22 (RE-ENTRY)
RANGE TRACKER
HAWAII 21 VECTOR
RELOCATED POSITION
ΔA
ΔE
ΔR
DELTA ELEVATION (DEG.)
DELTA AZIMUTH (DEG)
DELTA RANGE (YARDS x 10³)
23:13
23:14
23:15
23:16
GMT(HR:MIN)

10-5-10

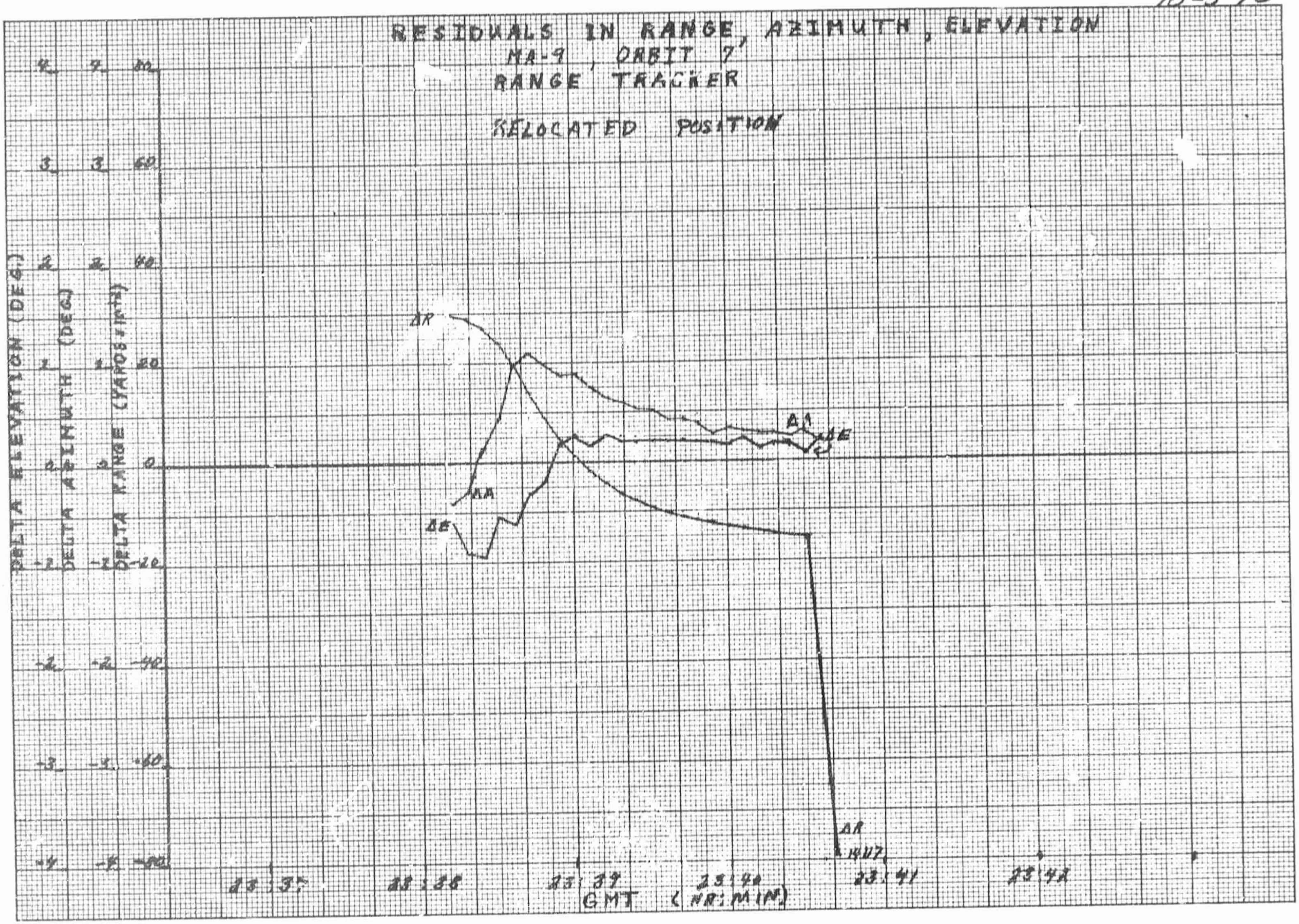


FIG. 5-10

10-5-11

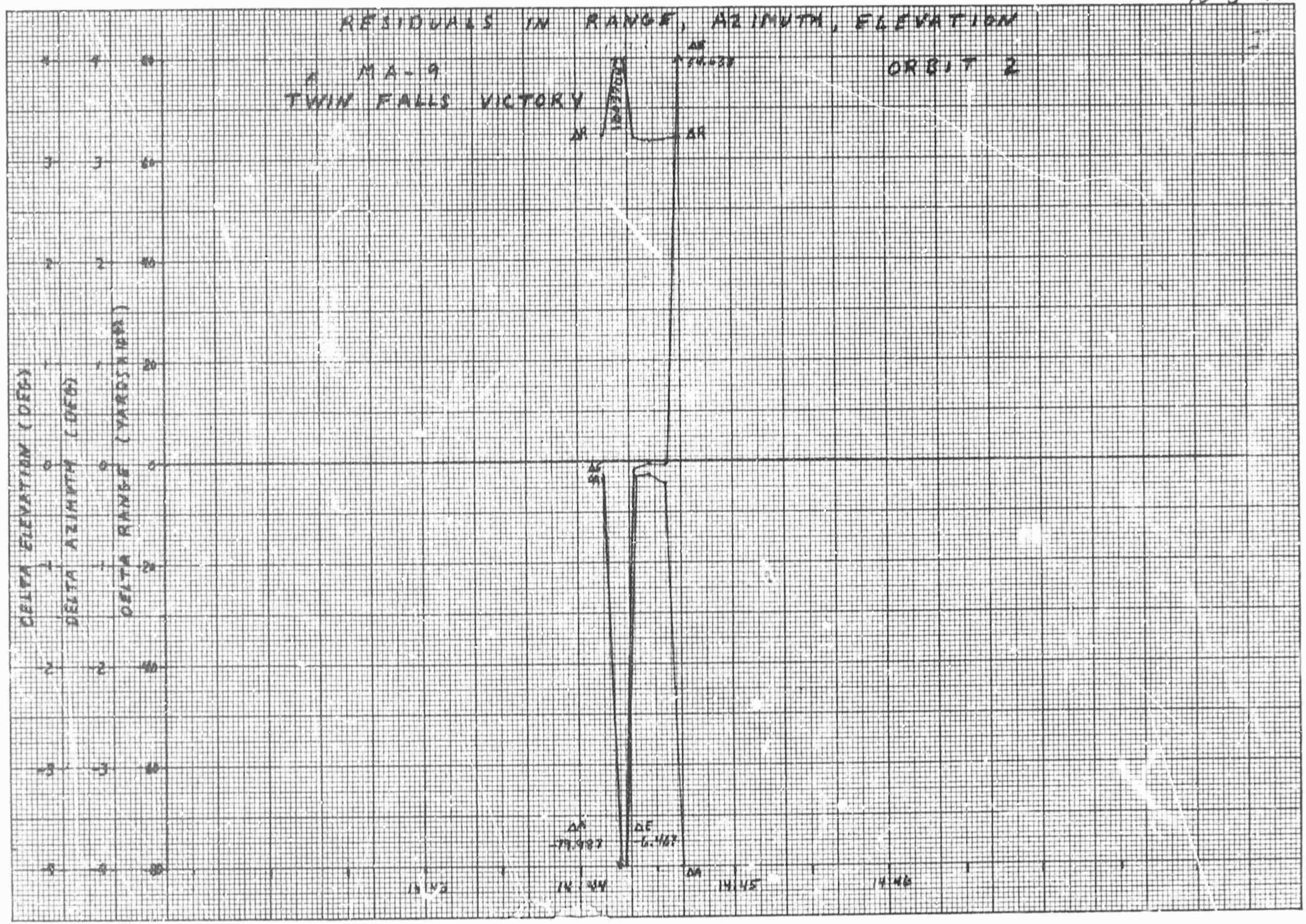


FIG 5-11

10-5-12

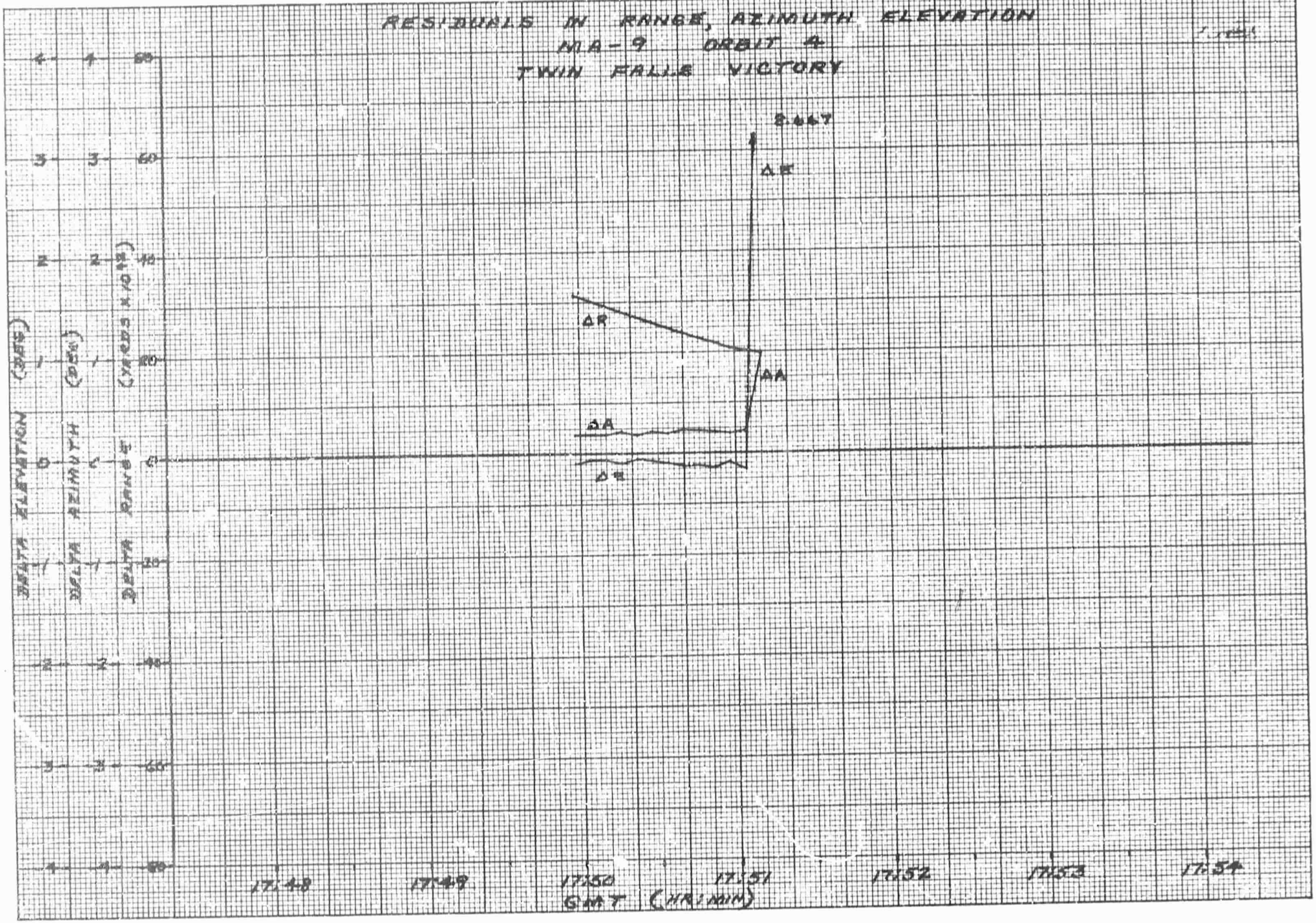
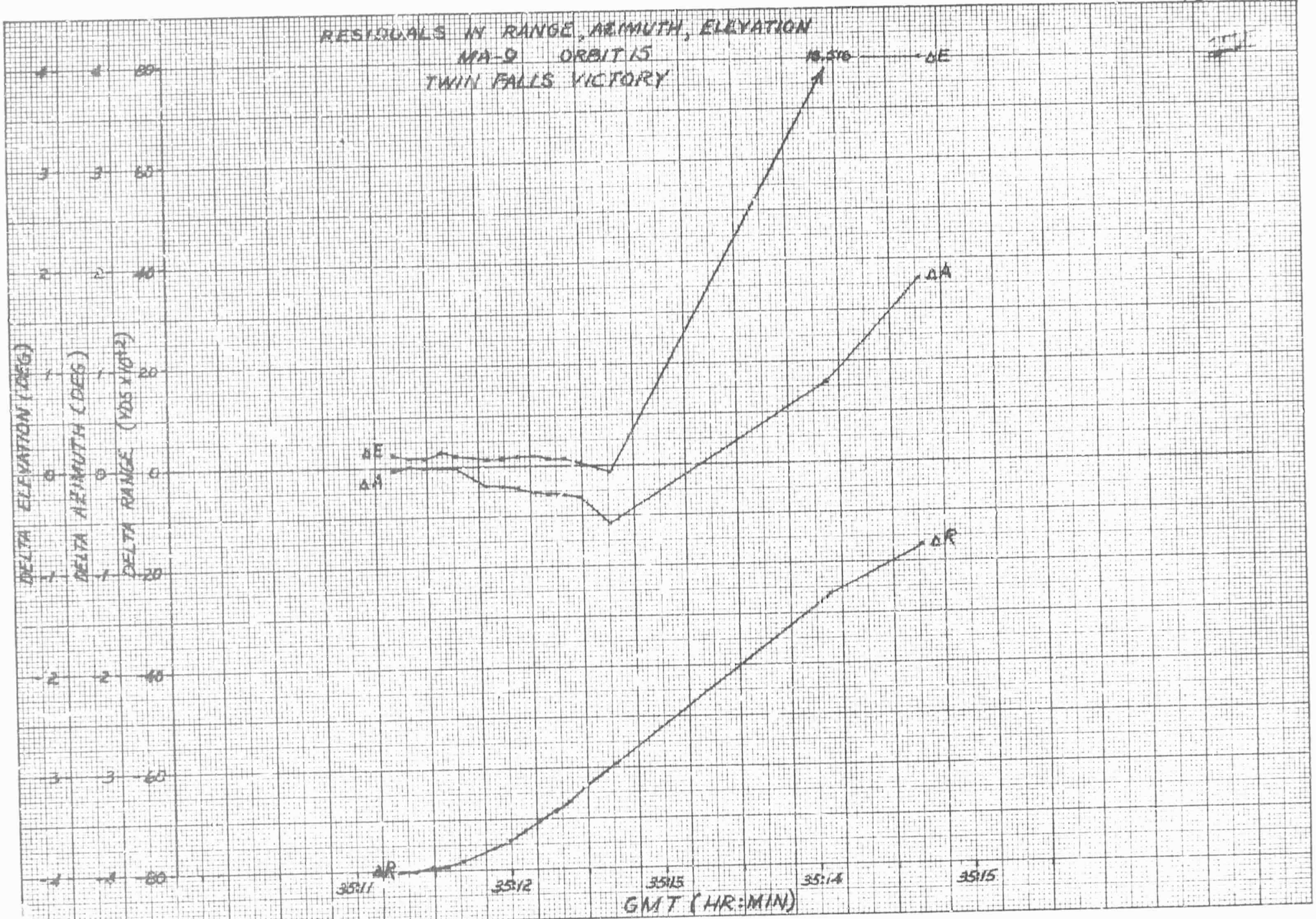


FIG 5-12


RESIDUALS IN RANGE, AZIMUTH, ELEVATION
MA-9 ORBIT 15
TWIN FALLS VICTORY
ΔE
ΔA
ΔR
DELTA ELEVATION (DEG)
DELTA AZIMUTH (DEG)
DELTA RANGE (YDS x 10^2)
4
3
2
1
0
-1
-2
-3
-4
80
60
40
20
0
-20
-40
-60
-80
35:11
35:12
35:13
35:14
35:15
GMT (HR:MIN)

10-5-14

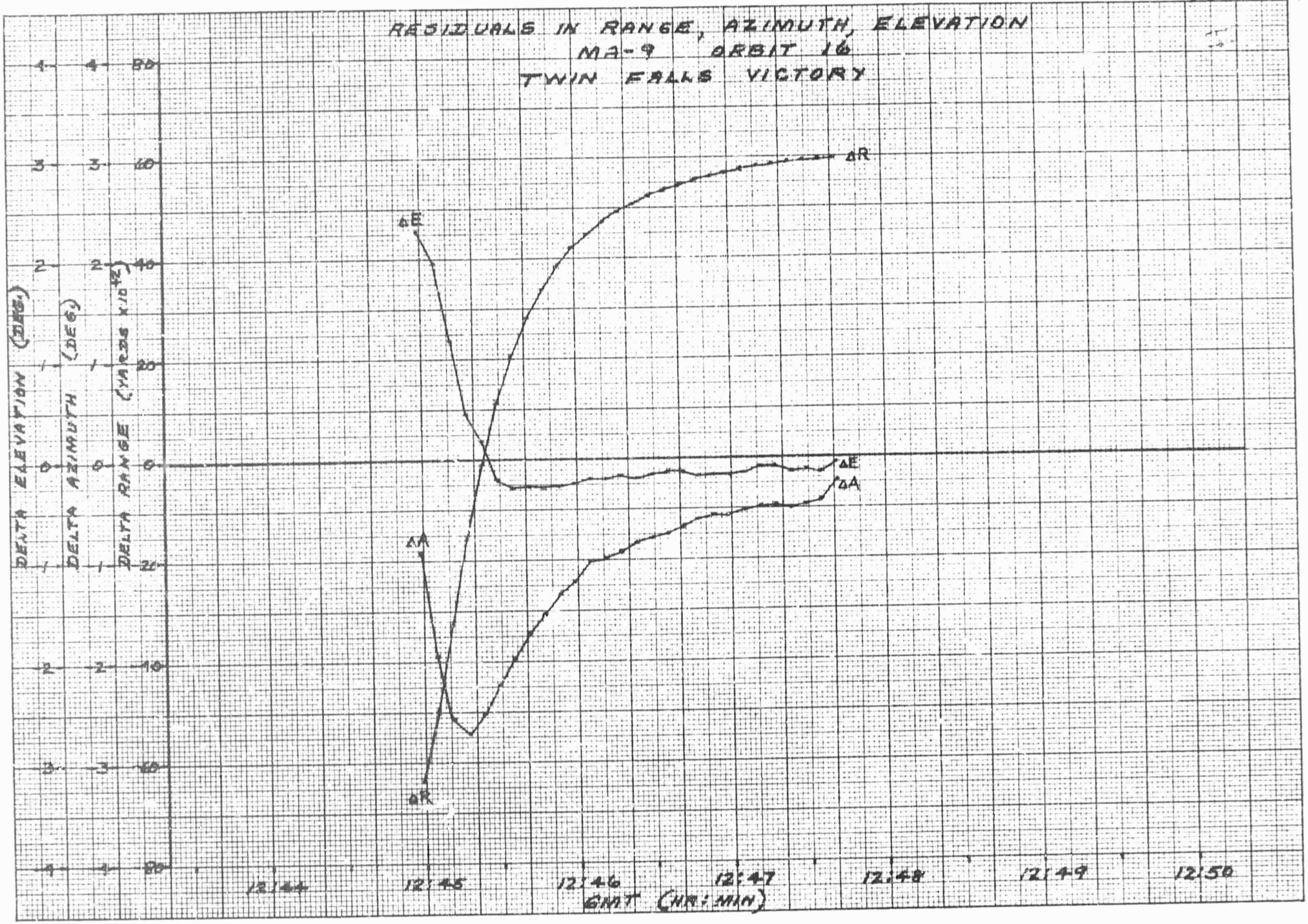
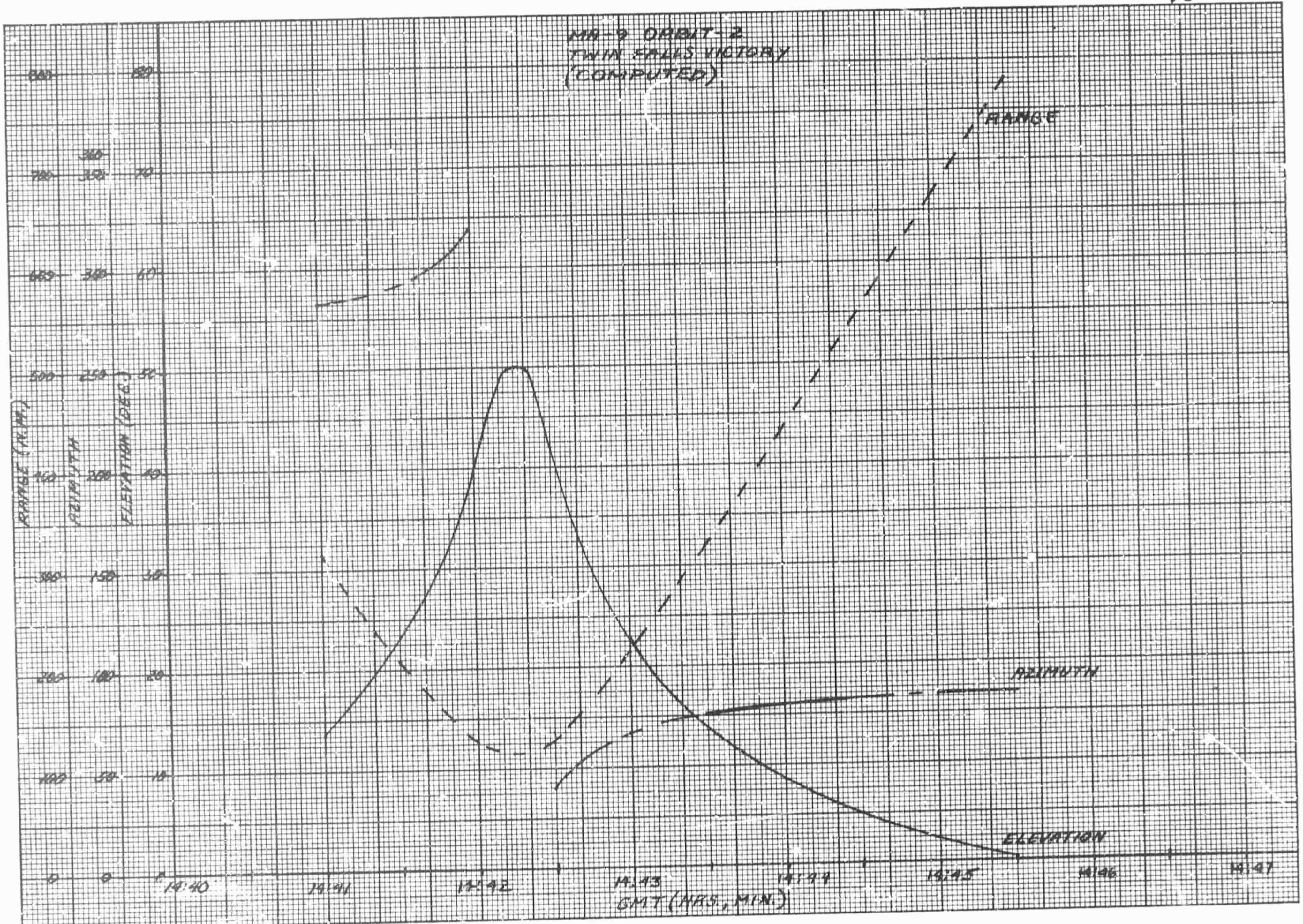


FIG 5-14

10-6-1



MA-9 ORBIT-2
TWIN FALLS VICTORY
(COMPUTED)
RANGE
AZIMUTH
ELEVATION
RANGE (N.M.)
AZIMUTH
ELEVATION (DEG.)
800
700
600
500
400
300
200
100
0
360
350
300
250
200
150
100
50
0
80
70
60
50
40
30
20
10
0
14:40
14:41
14:42
14:43
14:44
14:45
14:46
14:47
GMT (HRS, MIN.)

10-6-2

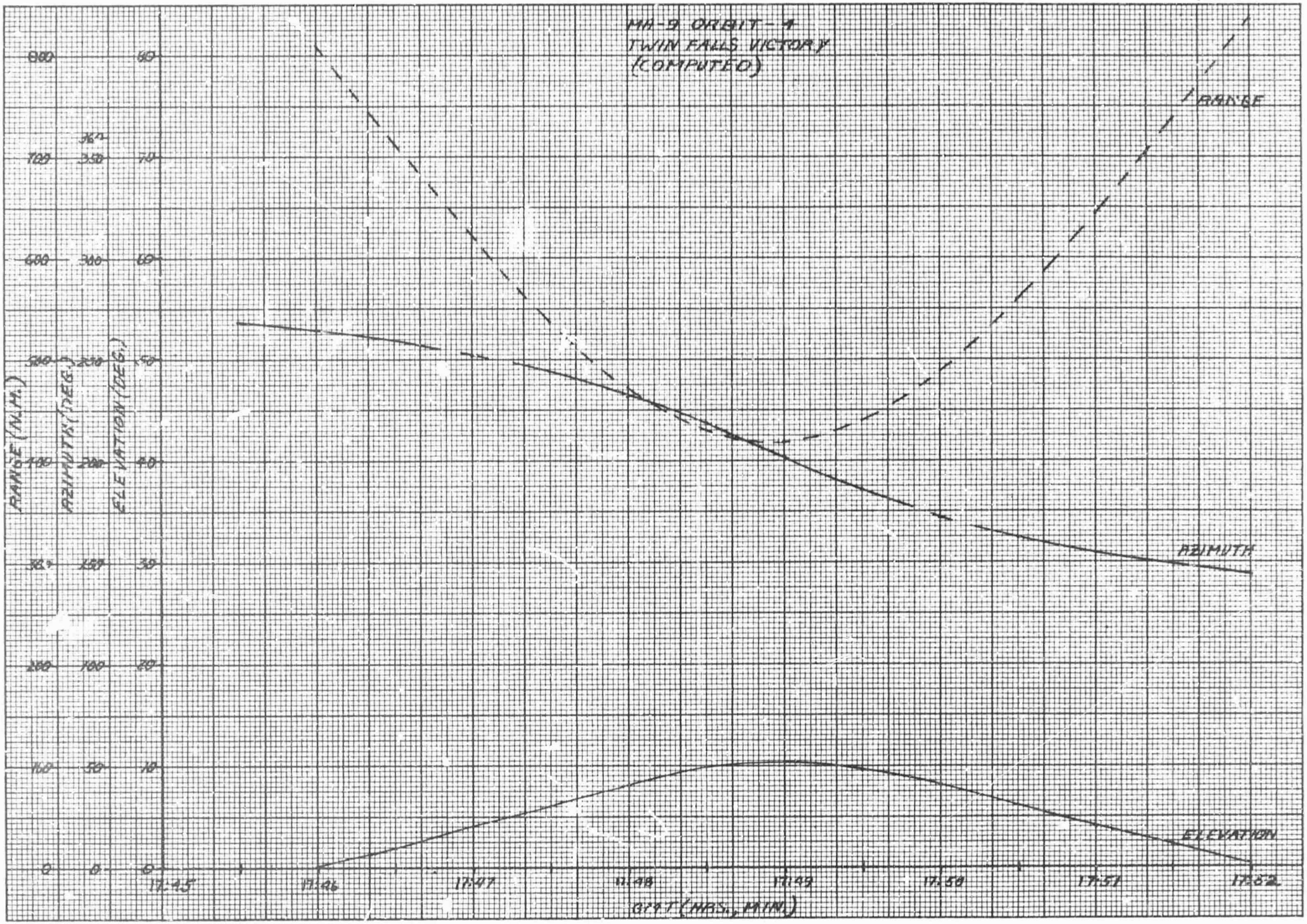

MA-9 ORBIT-4
TWIN FALLS VICTORY
(COMPUTED)
RANGE
AZIMUTH
ELEVATION
RANGE (N.M.)
AZIMUTH (DEG.)
ELEVATION (DEG.)
GMT (HRS., MIN.)
17:45
17:46
17:47
17:48
17:49
17:50
17:51
17:52

FIG 6-7

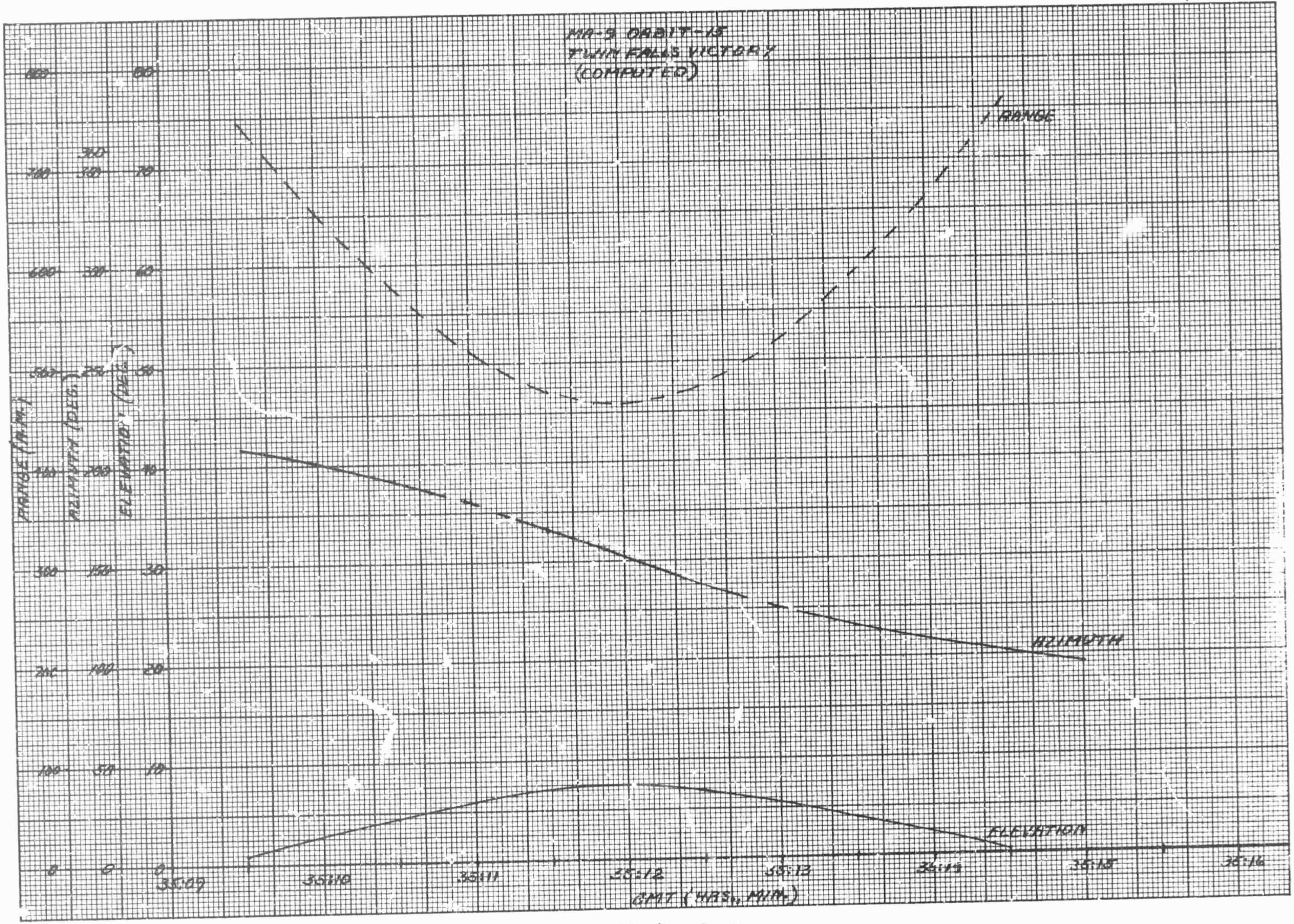
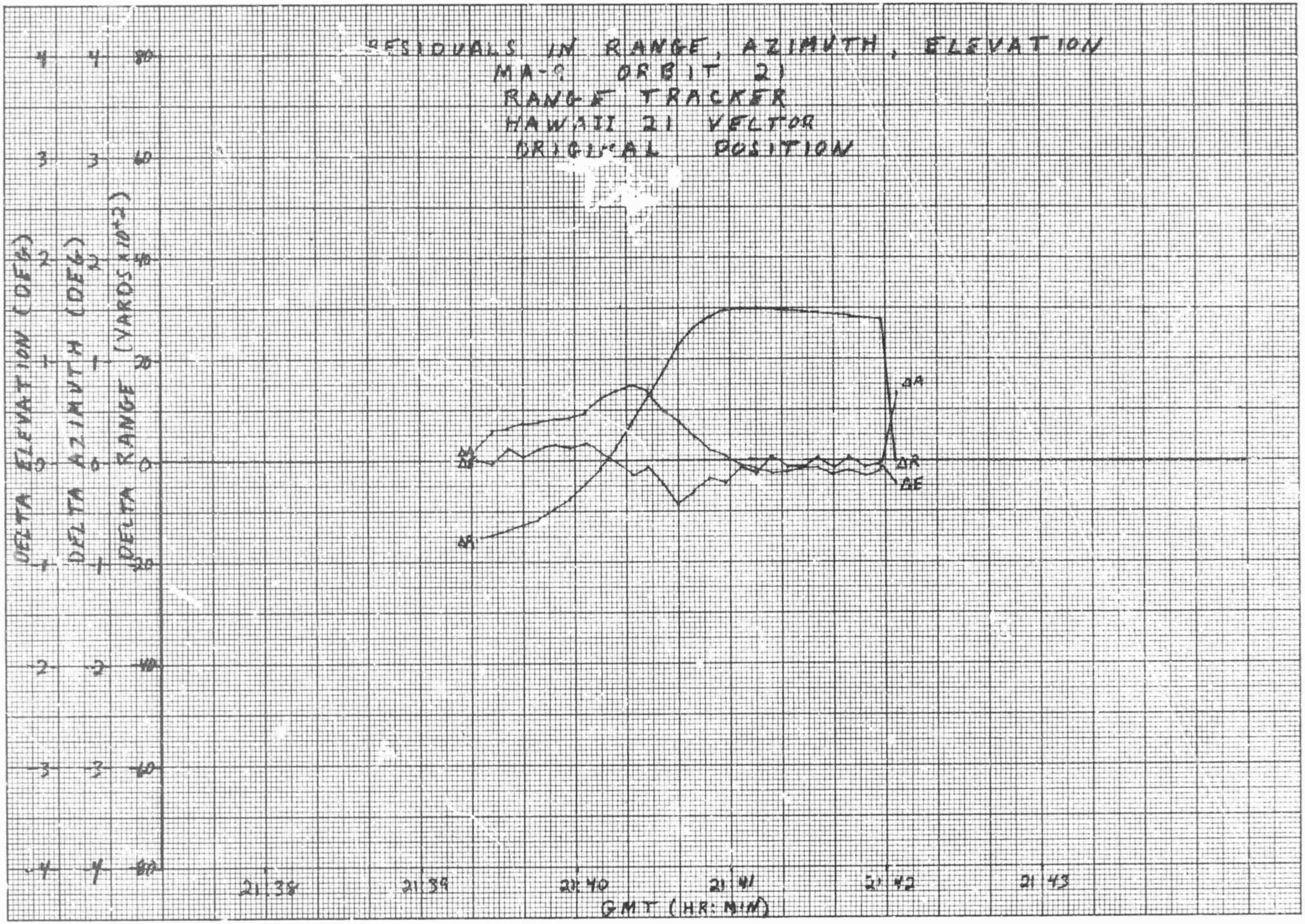

MA-9 ORBIT-15
TWIN FALLS VICTORY
(COMPUTED)
RANGE
AZIMUTH
ELEVATION
RANGE (N.M.)
AZIMUTH (DEG.)
ELEVATION (DEG.)
GMT (HRS., MIN.)
35:09
35:10
35:11
35:12
35:13
35:14
35:15
35:16

FIG. 6-3

10-5-6


RESIDUALS IN RANGE, AZIMUTH, ELEVATION
MA-9 ORBIT 21
RANGE TRACKER
HAWAII 21 VECTOR
ORIGINAL POSITION
DELTA ELEVATION (DEG)
DELTA AZIMUTH (DEG)
DELTA RANGE (YARDS x10+2)
4
3
2
1
0
-1
-2
-3
-4
80
60
40
20
-20
-40
-60
-80
ΔA
ΔE
ΔR
21:38
21:39
21:40
21:41
21:42
21:43
GMT (HR: MIN)

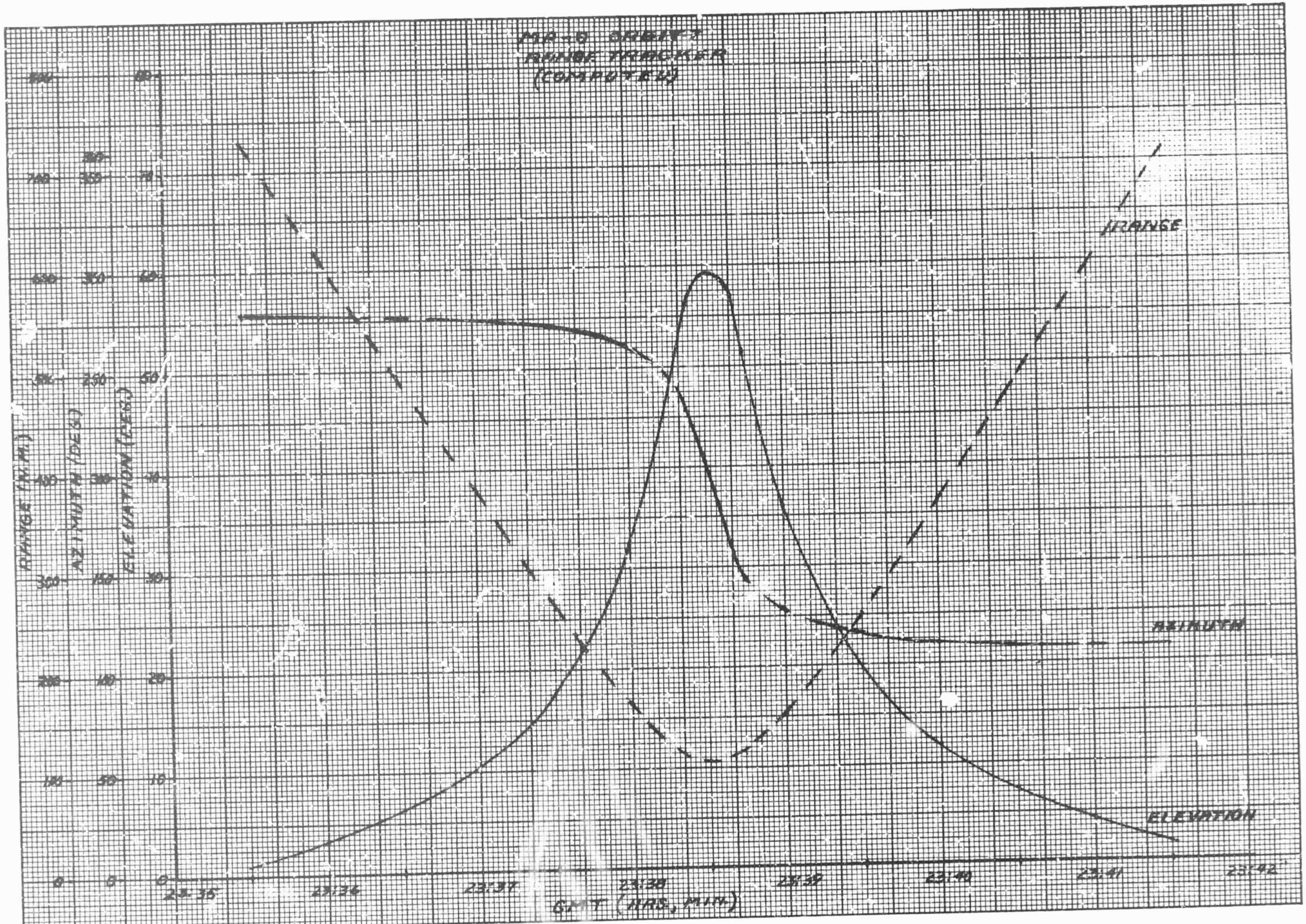

MA-6 ORBIT 3
RANGE TRACKER
(COMPUTED)
RANGE (N.M.)
AZIMUTH (DEG)
ELEVATION (DEG)
RANGE
AZIMUTH
ELEVATION
GMT (HRS, MIN)
23:35
23:36
23:37
23:38
23:39
23:40
23:41
23:42

FIG. 6-5

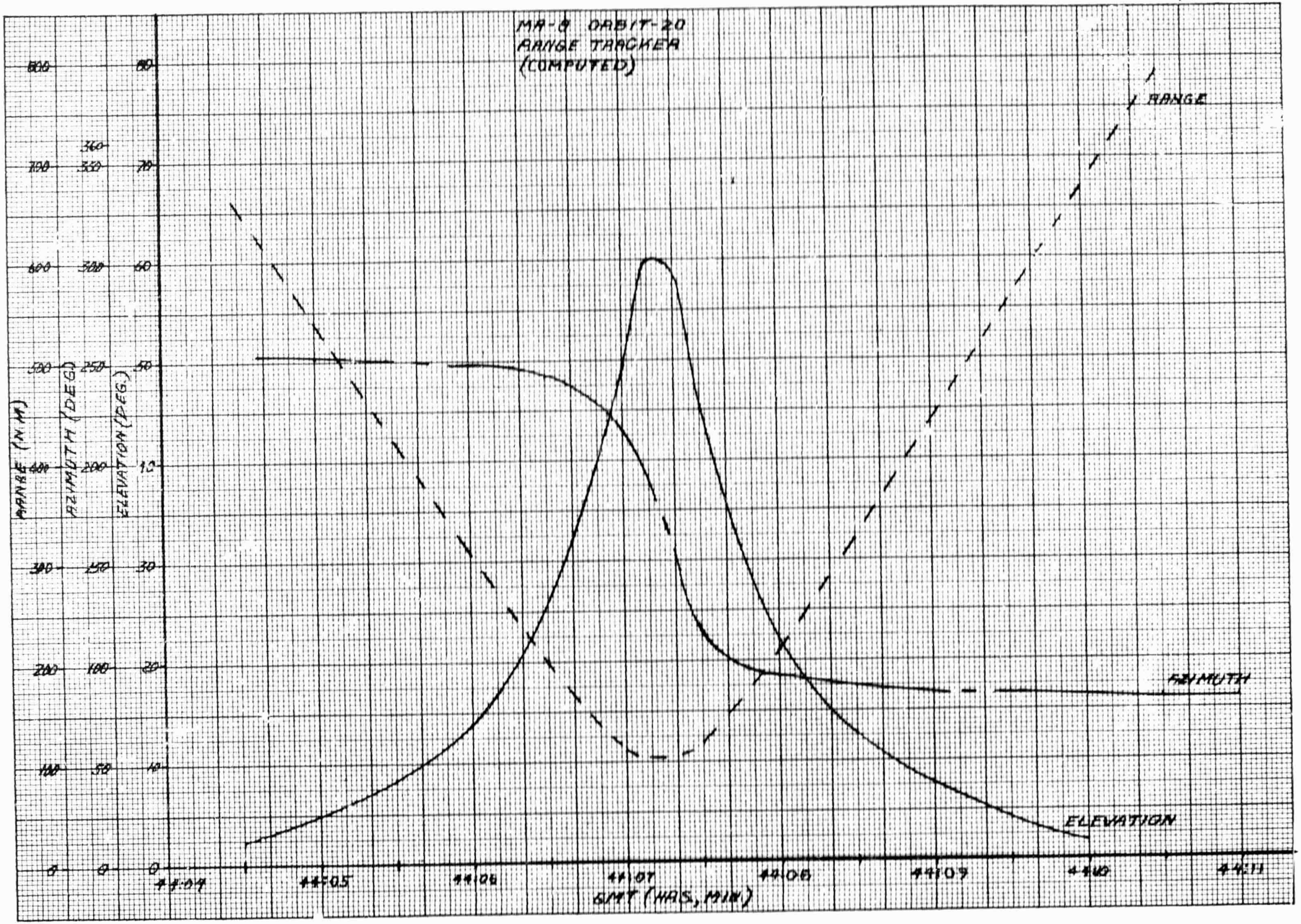

MA-8 ORBIT-20
RANGE TRACKER
(COMPUTED)
RANGE
AZIMUTH
ELEVATION
RANGE (N.M)
AZIMUTH (DEG)
ELEVATION (DEG)
GMT (HRS, MIN)
44:04
44:05
44:06
44:07
44:08
44:09
44:10
44:11

FIG 6-6

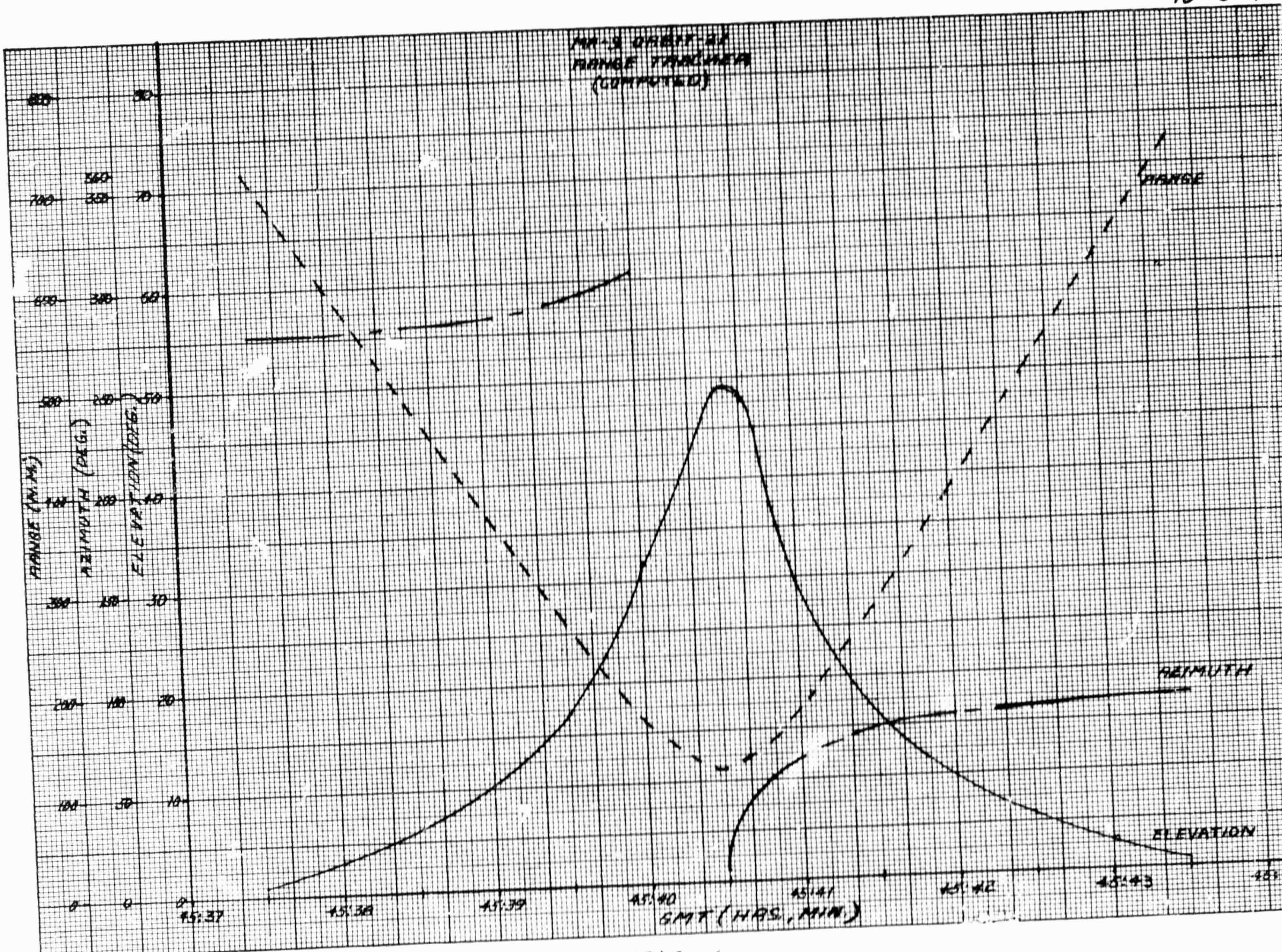

MA-9 ORBIT-21
RANGE TRACKER
(COMPUTED)
RANGE (N.M.)
AZIMUTH (DEG.)
ELEVATION (DEG.)
RANGE
AZIMUTH
ELEVATION
45:37
45:38
45:39
45:40
45:41
45:42
45:43
45:44
GMT (HRS, MIN.)

FIG 6-7

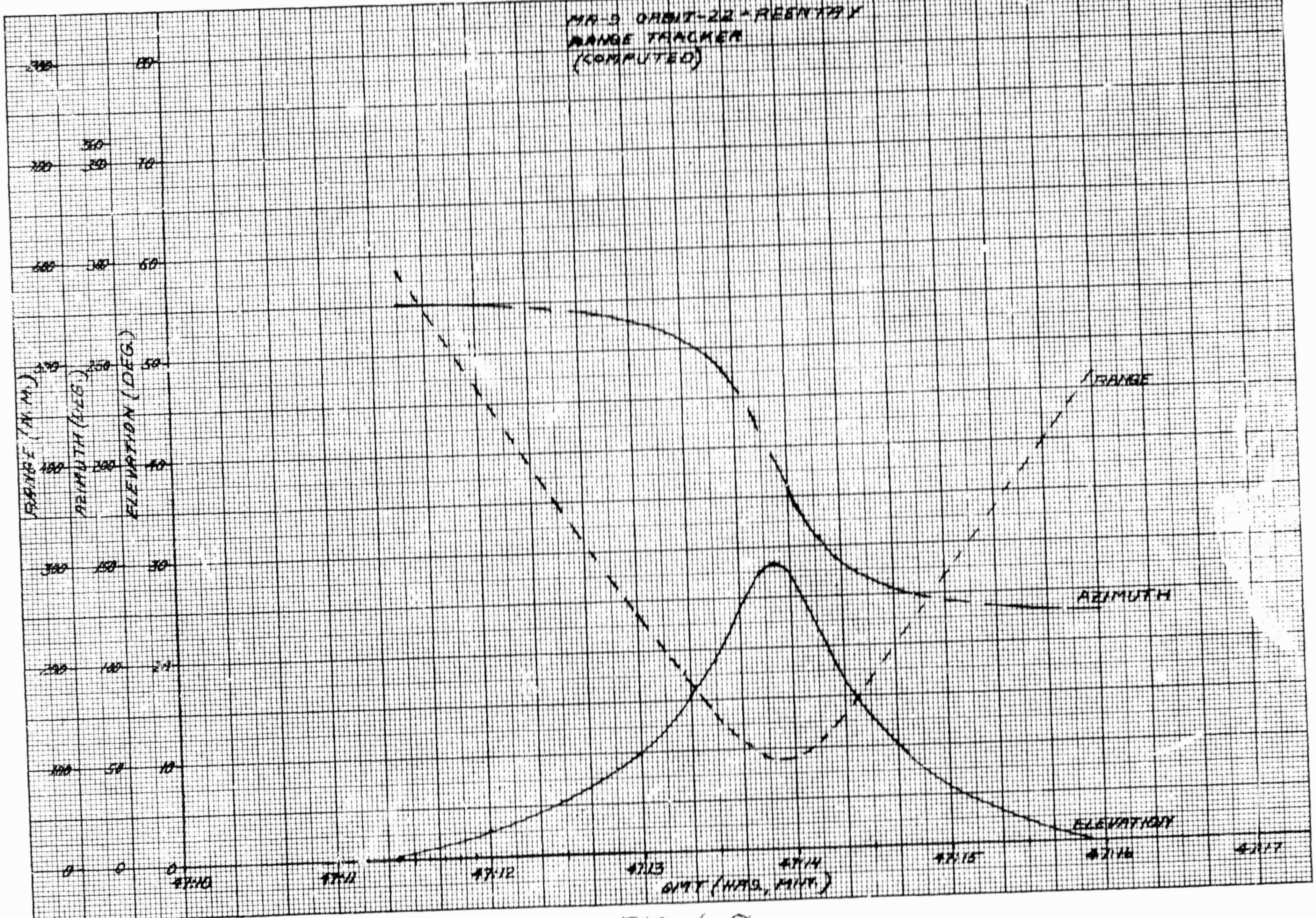

MA-9 ORBIT-22 - REENTRY
RANGE TRACKER
(COMPUTED)
RANGE (N.M.)
AZIMUTH (DEG.)
ELEVATION (DEG.)
RANGE
AZIMUTH
ELEVATION
47:10
47:11
47:12
47:13
47:14
47:15
47:16
47:17
GMT (HRS, MIN.)

FIG 6-8