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TRAJECTORY STUDIES FOR USE IN DETERMINING TRACKING REQUIREMENTS FOR PROJECT APOLLO

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Houston, Texas

March 9, 1964

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TRAJECTORY STUDIES FOR USE IN DETERMINING TRACKING REQUIREMENTS FOR PROJECT APOLLO

SUMMARY

In recent months the ground rules for the Apollo missions have become refined to the degree that a study of the tracking network is feasible. Consequently, the Manned Spacecraft Center initiated a study to assess the tracking network required to support the Apollo missions. The four mission phases in which network planning had left a need for augmentation were the following:

1. Insertion
2. Parking orbit
3. Post translunar injection
4. Reentry

For insertion tracking, one tracking ship, in combination with existing land tracking stations, is adequate for tracking insertion into the parking orbit throughout the daily launch window.

For the parking orbit phase of the mission, the assumed network appears to be adequate.

For the injection phase of the mission, it was found that to have adequate coverage for most Atlantic injections a ship or station in the vicinity of South Africa is essential. In addition, a ship in the vicinity of Guam Island would be valuable for covering many Pacific injections.

For the reentry phase of the mission, it has been determined that one ship strategically located in the Pacific can be used for essentially all reentry ranges once the proper hemisphere is specified. Since a Northern Hemisphere and a Southern Hemisphere landing site must be used during different times of the month, two tracking ships would be needed.

INTRODUCTION

This is a study of selected Project Apollo trajectories and earth parking orbits which attempts to determine the adequacy of present and planned tracking facilities, and which proposes locations for new stations to adequately support the Apollo mission.

Because of the complex nature of the Apollo mission, the tracking requirements are not as easily defined as in earth orbital missions or one-way unmanned interplanetary missions. Definitive mission ground rules for Project Apollo were not fully developed until recently; however, the mission trajectory ground rules have been established in enough detail. Now fairly definitive tracking requirements can be established for the nominal mission.

The results presented in this paper are not complete in the reentry phase since in this phase the spacecraft reentry guidance steering equations have not been clearly defined.

SYMBOLS

A	Sampling interval, seconds
T	Smoothing time interval
σ_ρ/σ_{16}	Relative accuracy of assumed tracking station to that of a good ground based FPS-16
σ_v	Standard deviation of velocity, FPS

RESULTS AND DISCUSSION

Assumptions, Limitations, and Initial Data

This study is based on the Project Apollo mission ground rules developed by Manned Spacecraft Center Apollo Mission Trajectory Sub-Panel set forth in appendix A. Some of the basic mission rules used are as follows:

1. The range safety limits are based on launch azimuths of 72° – 108°. Azimuths considered in this study are azimuths of desired inclinations for 100 nautical mile circular orbits passing through Cape Canaveral. In this study these azimuths are referred to as launch azimuths. Therefore, the "launch azimuths" which appear in this report are not to be mistaken for the initial launch azimuths of the powered flight launch phase.

2. A variable azimuth sweep of 26° was allowed (for example, 72° – 98°, 74° – 100°, 80° – 106°, 82° – 108°) which corresponds to the daily launch window.

3. The number of earth parking orbits is limited to three since the Saturn IV Booster (S-IVB) presently has a $4\frac{1}{2}$-hour limitation because of performance, systems, lifetime, and reliability considerations.

The terms insertion and injection in this paper refer respectively to entry into an earth parking orbit and entry into a translunar trajectory from an earth parking orbit. Insertion in this study was assumed to occur 1,400 nautical miles downrange from Cape Canaveral at an altitude of 100 nautical miles.

The injection points considered numbered more than 200, due to permutation of the many parameters necessary for complete problem description. Thus, injection points were considered for seven launch azimuths (68.8, 72.6, 74.7, 90, 102.7, 107.4, and 11.2), five lunar declinations (-27.5, -15, 0, 15, and 27.5), and two injection areas (Atlantic and Pacific), and three orbits, for a total of 210 points. It should be noted that 150 of these injection points are within range safety limits. The 60 injection points outside the range safety limits were used to interpolate data for 72° and 108° launch azimuths. Using these initial conditions, the translunar trajectories were computed for 4 hours following injection. It was assumed that the spacecraft would certainly be acquired and tracked after 4 hours from injection by a Deep Space Instrumentation Facility (DSIF). As a matter of fact, since the altitude of the vehicle is nearly 18,000 nautical miles 2 hours after

injection, acquisition and tracking interval times for the non-DSIF stations were computed for only 2 hours following injection, as the DSIF stations could be continuously tracking the vehicle by this time.

The probabilities for injection in each of the four parking orbits have been estimated for Atlantic and Pacific injections and are listed as follows:

Orbit No.	Atlantic	Pacific
1	0.00	0.10
2	0.70	0.70
3	0.20	0.20
4	0.10	0.00
	1.00	1.00

These probabilities consider the possibility of a nominal injection in any orbit.

Four landing locations were considered for the reentry phase. These include two land locations, one in Texas and one in Australia, and two water locations, one near Hawaii and one near Samoa.

Requirements were established to guarantee that a radar could track the vehicle. The existing DSIF requirements are the following: the elevation angle was to exceed 5°, total tracking time was to exceed 10 minutes, realistic physical constraints of the radar mounts were to be included, and no slant range limitation was to be considered. The proposed DSIF requirements are the same as the existing DSIF requirements except that no physical constraints of the radar mounts were to be considered. The requirements for non-DSIF stations were that the elevation angle was to exceed 5°, total tracking time was to exceed 3 minutes, and slant range was to be less than 32,000 nautical miles. (Implicitly, this assumes that modification kits have been added to the non-DSIF stations).

Table I presents the locations of stations assumed for this study. All stations, except the present DSIF (Goldstone (old), Woomera, and Johannesburg) stations were assumed to be equipped with x-y or polar mounts.

The spacecraft was assumed to have a C-Band beacon in addition to a unified S-Band beacon.

Mission Phases

Insertion.- Tracking of the insertion phase of the mission is considered necessary for making a GO-NO GO decision on the orbital phase of the mission based on the insertion velocity vector.

Therefore, tracking is needed throughout powered flight and for a sufficient time after powered flight to determine an accurate cut-off velocity. A velocity accuracy of approximately 12 - 16 feet per second (3 sigma) is needed to make the GO-NO GO decision. This is approximately the same accuracy as obtained by Project Mercury Bermuda short arc solution. The time available after cut-off in which to make the GO-NO GO decision will be between 30 and 90 seconds, but further studies need to be made before the exact time available can be determined.

Figure 1 shows the portions of five earth parking orbit ground tracks in the insertion area and radar coverage circles for tracking stations located at Cape Canaveral, Bermuda, Antigua, and San Salvador. Also shown are the radar coverage circles for a ship 1,800 nautical miles downrange from Cape Canaveral at three locations A, B, and C.

From figure 1 it can be seen that Cape Canaveral, San Salvador, and Bermuda always contribute to the tracking in the early part of the launch over the total azimuth range. Bermuda, Antigua, and the tracking ship must be available to track the terminal launch phase. Only Antigua and the tracking ship are effective in tracking after S-IVB cut-off.

In figure 2(a) the tracking for ships at six assumed locations are shown. These locations are at various distances downrange on the ground track of the 90° launch azimuth parking orbit. The total tracking time from insertion is plotted against launch azimuth.

Total tracking times and launch windows in degrees of azimuth as functions of various ship locations are shown in figure 2(b). From this figure it was determined that a ship located near 1,800 nautical miles downrange from Cape Canaveral was a near optimum location. In this case more than 3 minutes of tracking after insertion is obtained for differences of 28° in launch azimuth (80° - 108°).

The total tracking times from insertion for Antigua, Bermuda, and for three locations of a ship placed at a near optimum distance downrange from Cape Canaveral, are shown in figure 2(c).

From this figure it can be seen that radar tracking by Antigua is effective only for launch azimuths greater than approximately 100°. Therefore, a tracking ship is necessary to insure continuous tracking during the entire launch phase and after insertion. The ship's location will

be adjusted according to the tracking provided by land stations such as Antigua. The movement required of a ship during the monthly cycle is within the capability of a normal tracking ship.

Figure 2(d) shows total tracking time from insertion for a ship placed at a near optimum distance downrange, for Antigua, and for Bermuda as a function of launch azimuth window in degrees. It can be seen from figure 2(d) that Antigua will provide a maximum of only 1 minute of tracking after insertion (102.5° – 108°) for only 5° of the 26° range of launch azimuth. Therefore, a tracking ship will be necessary to insure coverage of the 26° range of launch azimuth.

Parking orbit.- Tracking is also needed during the parking orbit to update the S-IVB injection guidance system.

Ground based orbit determination during the parking orbit phase is necessary for checking the onboard navigation system, particularly when cloud coverage precludes observation of the earth by the vehicle.

S-IVB ullage and venting impulses impart a velocity increment to the S-IVB at approximately 15-minute intervals. The total velocity increment added in three orbits could be as high as 30 to 40 feet per second. It is necessary that measurements of this velocity increment be telemetered from the spacecraft for use in the ground based orbit determination. The station coverage assumed in this paper appears to be adequate for ground based orbit determination if the venting impulses information can be satisfactorily transmitted for use on the ground.

Figure 3 shows ground tracks for four earth parking orbits and radar coverage circles for various radar stations. Also shown are the translunar injection points for lunar declinations used in this study. The injections from the fourth orbit were not studied because of the present life expectancy of the S-IVB.

In figure 4 the time intervals during which a vehicle is tracked from insertion by the stations of figure 3 are shown for four earth parking orbits for each of five launch azimuths. Since insertion occurs 12 minutes after launch, times from launch may be obtained by adding 12 minutes to each acquisition and final contact times.

Figure 5 shows the time interval from the final radar contact in an earth parking orbit to the initiation of translunar injection thrusting.

Injection.- Tracking is needed after injection to make a GO–NO GO decision on the translunar phase of the mission.

Another reason for desiring injection tracking is associated with the use of the ground based orbit determination system to determine a

midcourse correction. Normally, the first midcourse correction will be made between 5 and 8 hours after injection. This delay is necessary since it requires a considerable length of time before a sufficient number of onboard observations can be made to determine the position and velocity with enough confidence to make the first midcourse correction. However, the ground network with the ability to have higher data rates may be able to achieve a satisfactory prediction of position and velocity before it is possible in the spacecraft. In some non-normal cases, 5 to 8 hours could be too late for making the first midcourse correction. In these cases, ground determination of the orbit established within an hour after injection could result in the saving of an otherwise aborted or altered mission.

There are a number of operational features which enter into the acquisition time requirements for post injection tracking. These are as follows:

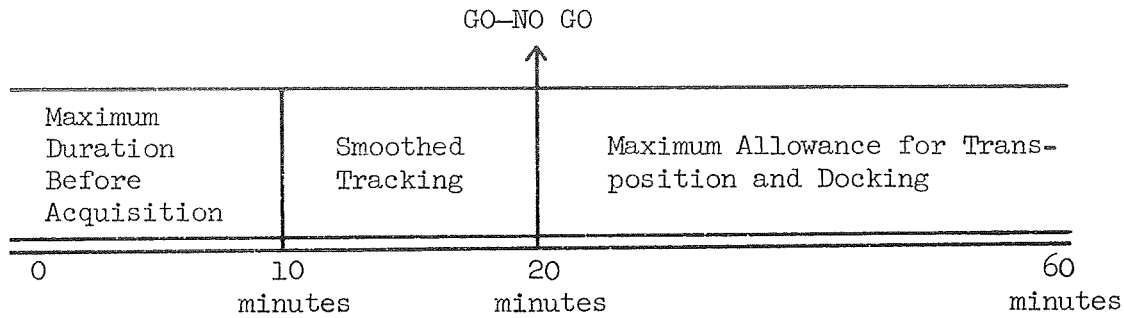
1. The S-IVB state has a vent-free mode limitation of 60 minutes after injection; therefore, the Command Module transposition and docking with the S-IVB – LEM stage should be completed before 60 minutes after injection (the S-IVB – LEM stage is used in an attitude hold mode during the transposition and docking maneuver).

2. The maximum time required for transposition and docking is estimated not to exceed 40 minutes. The present estimate of the normal time is 30 minutes. The minimum time required for transposition and docking has been estimated to never be less than 15 minutes. It is desirable to begin transposition and docking as soon as possible after injection and before venting.

3. A GO–NO GO decision is desired before transposition and docking begins. (Although it may be possible to track during transposition, tracking may be intermittent and it would be desirable to complete the tracking before transposition begins.)

4. The Command Service Module omni-directional antenna presently has a range limitation corresponding to approximately 52 minutes after injection.

It is anticipated that about 10 minutes of tracking will be required for acceptable orbit determination. With this assumption and considering 1 and 2 above, the latest time for acquisition after injection is required to be 10 minutes. The time line for this first hour after injection is shown below.



The tracking accuracy requirements are determined by the length of smoothing time available and the data rates possible. Shown in figure 19 of appendix B are the smoothing times required for various data rates to obtain a given accuracy. A velocity accuracy of 1 to 2 feet per second (one sigma) is necessary at injection.

Although it is desirable to obtain tracking and make the GO–NO GO decision as soon as possible after injection, it is believed at this time that the GO–NO GO decision may be acceptable as late as 20 minutes after injection. This is based on the following considerations:

1. The spacecraft is already above orbital speed; therefore, no decaying reentry time – critical aborts are probable.

2. The times required to return to a recovery site, if an abort occurs after injection, are long in any case and vary from about $\frac{1}{2}$ hour to 50 hours.

For this study, the injection altitude was assumed to be 650,000 feet. In actual operations, the injection altitude could vary from 650,000 to 900,000 feet. The low value was selected for this study to assure that the results obtained were conservative.

Figure 6(a) shows the extreme values of lunar declination for dates from 1968 through 1970. The total injection area available in 1970 within launch azimuth range safety limits for lunar declinations of 28.5° to -28.5° are shown in figure 6(b) for the first three orbits.

The altitude of the vehicle is shown in figure 7 as a function of time from injection. Also in figure 7 is the slant range of the vehicle at 5° elevation as a function of time from injection.

Figure 8 shows acquisition times after injection for table I stations as a function of launch azimuth. DSIF stations are always shown when tracking the vehicle. Some non-DSIF stations are not shown in this figure when they did track because others acquired earlier and lost the vehicle later.

Figure 9 shows the tracking time intervals for launch azimuths within range safety limits for each acquisition by stations in figure 8. Also shown are tracking time intervals for 72.6° and 107.4° launch azimuth.

Figure 10 shows the earliest acquisition time and the table I station that acquires the vehicle earliest after translunar injection as a function of launch azimuth. In table II it can be seen that all Atlantic injections within range safety limits are acquired by 10 minutes if table I stations are used. However, only 86.7 percent of Pacific injections are acquired by 10 minutes using table I stations. Table II shows the frequency and relative cumulative frequency (rcf) distributions of earliest acquisition times after injection of 150 translunar trajectories within range safety limits that were considered in this study. Table III is an expansion of table II and shows the same information as functions of launch azimuth, lunar declination, and earth parking orbit.

Figures 11(a) to 11(m) show how earliest acquisition time of figure 10 is affected by loss of South African stations and by replacing the South African stations with a station at Madagascar (25°10' S. latitude, 46°5' E. longitude). Figures 11(n) to 11(v) show how earliest acquisition time of figure 10 is affected by the addition of Guam (13°35' N. latitude, 144°55' E. longitude). In table II, the frequency and rcf distributions of acquisition times after injection are shown for these cases. From table II it can be seen that for Atlantic injections, the Madagascar site would be an effective substitute if the South African stations are not operational and by adding a tracking station at or near Guam to the table I stations, the percentage of acquisition for 10 minutes after injection would be 100 percent as compared to 86.7 percent with the table I stations.

Figures 12(a) to 12(i) show the loss of launch window considering table I stations alone, table I stations without South African stations, and table I stations with South African stations replaced by Madagascar. Figures 12(j) to 12(o) show the loss of launch window considering table I stations, and table I stations with the addition of Guam.

Figures 13(a) to 13(i) show the launch time available considering table I stations, table I stations without South African stations, and table I stations with South African stations replaced by Madagascar. Figures 13(j) to 13(o) show the launch time available considering table I stations, and table I stations with the addition of Guam.

In figures 12 and 13, the effect of the South African stations are depicted. It is obvious that serious loss of the launch window and available launch time would occur without a station in the vicinity of South Africa. Also the loss in launch window and launch time for the Pacific injections would effectively be eliminated by placing a station at Guam Island.

Figure 14 shows translunar trajectory ground tracks from injection to four hours after injection. Table I stations tracking the vehicle are shown at their times of acquisition and final contact.

Figure 15(a) shows the percentage of 150 translunar trajectories acquired and tracked by radar, plotted as a function of the number of radar tracking ships used in addition to table I stations. These 150 trajectories are for combinations of the following: launch azimuths of 72.6°, 74.8°, 90°, 102.7°, and 107.4°; lunar declinations of 27.5°, 15°, 0°, -15°, and -27.5°; three earth parking orbits and the Atlantic and Pacific injection areas.

From examination of figure 15(a), it is determined that acquisition is obtained within 10 minutes after injection 92 percent of the time without tracking ships. This percentage reduces to 65 percent and 18 percent for acquisition within 5 minutes after injection and at 0 minutes (injection), respectively.

In figure 15(a) it may be noted that the addition of three tracking ships increases the injection coverage to 100 percent for the 10 minute acquisition time and to 86 percent and 30 percent for the 5 minute and 0 minute (injection) acquisition times from injection. It would take approximately seven ships to obtain 100 percent coverage for acquisition 5 minutes after injection. To obtain 100 percent coverage for acquisition at injection, over 30 ships would be needed. The curve shown in figure 15(a) labelled "-6 minutes" represents tracking beginning at the initiation of injection powered flight and lasting for 3 minutes. Since the powered flight phase lasts in the order of 6 minutes, this tracking does not cover the entire powered flight phase. If tracking were required during the entire powered flight phase and 3 minutes thereafter, the number of ships required would be increased by an order of magnitude.

Figure 15(b) shows the percentage of telemetry/voice coverage for the same 150 trajectories used in figure 15(a) as a function of ships used in addition to land based stations. Four land based stations were considered in addition to table I stations. They are: Kano, Nigeria; Zanzibar, Tanganyika; Guaymas, Mexico; and Canton Island, Phoenix Islands. The acquisition requirements for telemetry/voice are that the elevation angle must exceed 0°, and 1.5 minutes of tracking are necessary.

In figure 15(b) and table V it can be seen that without tracking ships, acquisition is obtained in 96 percent, 79 percent, and 47 percent of the translunar injections for 10 minutes, 5 minutes and 0 minutes, respectively. The addition of two tracking ships would extend the coverage to almost 100 percent for the 10 minute and 5 minute cases and to 63 percent for acquisition at injection. It is estimated that 11 tracking ships would be necessary to obtain complete coverage at translunar injection for all injection opportunities.

For this study consideration was given to the mobility of the tracking ships and to the locations of the various land masses. It was assumed that ships could be moved approximately 250 miles per day and that the injection would occur in any of the first three orbits. It was also assumed that the launch could occur at any time during the daily launch window.

Figure 16 shows the transearth trajectory ground tracks for 4 hours before reentry to reentry. Table I DSIF stations are always shown when tracking the vehicle; other table I stations are shown only if they track the vehicle nearer to the reentry point than any DSIF station. This reentry point is assumed to be 66 nautical miles above the earth's surface.

Reentry.- Reentry tracking could be used to update the knowledge of position and velocity during the Apollo reentry for the following purposes:

1. In near nominal conditions, it may enable the crew to reduce the eventual impact error relevant to the intended landing position.

2. In some abnormal conditions, tracking during reentry may provide a gross indication of overshoot or undershoot conditions (stemming, for example, from undetected systematic errors in the onboard sensors). In the overshoot conditions, the crew will implement control when there is sufficient dynamic pressure to obtain significant aerodynamic control forces. Effectively, this is obtained by rolling the Command Module.

It would be desirable to obtain about 3 minutes of tracking in the orbital or near orbital velocity phase of the reentry and for reentry ranges which will vary during the month from 1,200 to 5,000 nautical miles. The maximum reentry range for the Apollo mission will not be more than 5,000 nautical miles. The minimum reentry range is never less than 1,200 nautical miles.

In addition, in the operational phases of the Apollo mission no attempt will be made to introduce direct ground control; however, the ground could be used for advice and updating of the onboard system.

In order to assess the tracking coverage available for various reentry ranges given a single tracking location, a study was performed by placing ships along the reentry ground track at various locations and determining the associated acquisition and line-of-sight times. In this manner, the optimum single-ship location was determined as a function of the initial reentry range. Figure 17 illustrates the location of all possible reentry points for a return to the two water and two land recovery sites. The location of the reentry point for a specific mission

depends upon the lunar declination, reentry trajectory inclination to the equatorial plane, and reentry range.

In order to establish the most advantageous position for a tracking ship, a study was performed which considered the various tradeoffs as a function of tracking acquisition and total tracking time. There are three important considerations in determining the eventual position of a tracking ship relative to the reentry point. First, the ship location must provide coverage during the pull-up and skip-out phases in order to allow an early evaluation of the guidance system's performance during this critical period. If a malfunction has occurred, this is the time to establish the fact inasmuch as the reentry vehicle possesses a high maneuverability potential during this period and its eventual second-entry position can still be determined with relative ease. Secondly, the ship location should be positioned so as to provide the maximum probability of acquisition even with a gross malfunctioning of the guidance and navigation systems. Finally, the ship's location must be consistent with the tracking blackout limitations. All of these requirements are met if the tracking ship can be positioned along the reentry ground track so that the command module essentially enters the tracking cone just as it leaves the blackout region that occurs during the initial reentry and pull-up phases. Since the vehicle's exact position in the reentry corridor is not known until the final midcourse correction, and since the trajectory profile is governed in the main by the corridor position (flight-path angle), it was necessary to consider the influence exercised by reentries throughout the corridor.

The tracking field-of-view was assumed to include elevation angles of 5° or more. Exit from the blackout region was arbitrarily assumed to occur when the reentry vehicle's velocity reduced below orbital velocity or when the altitude increased above 300,000 feet, whichever occurred first. The tracking data presented are based upon entry trajectories generated employing a digital simulation of the MIT reentry guidance, and are therefore representative of typical Apollo reentry profiles. The reentry trajectories were based on a CM reentry weight of 9,500 lbs. and a maximum L/D of 0.50.

Figures 18(a) to 18(c) present tracking time as a function of ship location for flight-path angles representing the middle and both extremes of the reentry corridor as well as five values of reentry range. The tracking ship location for acquisition at circular orbital velocity and at an altitude of 300,000 feet is also indicated on each figure. These figures demonstrate that moving a tracking ship downrange from the location normally required to acquire at velocities below circular orbital velocity results in only small increases in the total tracking time.

Note that, on the average, 3 minutes of tracking is available from the utilization of one ship alone. If it is assumed that tracking as soon after blackout as possible is most advantageous from the standpoint of early trajectory confirmation and, therefore, a greater maneuvering capability to correct any acquired errors, then the ship location closest to this point is most optimum.

Before the first lunar landing mission, it will be known whether the prime landing areas shall be on water or land. In either case to comply with mission flexibility, performance, and reentry range constraints, it will be necessary to have two prime areas, one in the Northern Hemisphere and one in the Southern Hemisphere. Because of the distance between these two areas, it is believed that two tracking ships would be necessary to track reentries in both the Northern and Southern Hemispheres.

It appears that a tracking station would be a desirable operational aid to update the onboard knowledge of position and velocity and in some less nominal cases it may provide the means for crew survival in that it would provide a close indication of critical overshoot or undershoot conditions.

CONCLUSIONS

This paper has presented data which may be used as an aid for evaluating existing tracking sites, proposed Apollo tracking sites, and proposed ship utilization for the support of the Apollo mission. The study indicates that in some phases of the Apollo mission, tracking ships are a highly desirable operational aid.

For insertion tracking, one tracking ship is required in combination with existing land tracking stations for tracking insertion into the parking orbit throughout the daily launch window.

For the parking orbit phase of the mission, the assumed network appears at this time to be adequate; however, in some cases a relatively long delay may be encountered between the last tracking station and the beginning of injection powered flight.

For the injection phase of the mission, it was found that a station or ship in vicinity of South Africa is essential for adequate tracking coverage from the Atlantic. In addition, a station in the vicinity of Guam Island would be valuable for many Pacific injections and would assist in coverage during the parking orbit phase of the mission.

The following results are of significant importance:

1. For acquisition of the spacecraft 10 minutes after injection, it was determined that tracking ships would not be necessary over 90 percent of the time. With the absence of a South African station, the percentage drops to 76 percent with no ships considered. If a station at Guam is added to the original stations, table I tracking ships would add little to the overall coverage percentage.

2. For acquisition within 5 minutes after injection, three tracking ships would be needed to acquire the spacecraft over 90 percent of the time.

3. The number of ships needed to acquire the spacecraft at injection for the same percentage coverage would be near 25.

4. For the reentry phase of the mission, it has been tentatively determined that one ship strategically located in the Pacific can be used for essentially all reentry ranges once the proper hemisphere is specified. Since a Northern Hemisphere and a Southern Hemisphere landing site must be used during different times of the month, two tracking ships would be needed. It may be operationally feasible to relocate the proposed Pacific injection ship and use it as one of the reentry ships.

APPENDIX A

PRELIMINARY MISSION GROUND RULES FOR USE IN APOLLO MISSION ANALYSIS

Prepared by:

NASA MANNED SPACECRAFT CENTER

MISSION ANALYSIS DIVISION

MATHEMATICAL PHYSICS BRANCH

April 22, 1963
Revised July 22, 1963
Revised August 9, 1963

APOLLO MISSION ANALYSIS SUMMARY - NOMINAL MISSION

TRAJECTORY PHASES OF THE APOLLO LUNAR LANDING MISSION

Earth Launch Phase

Range safety limits on launch azimuths.-

Operational launch azimuth limits:

Illumination constraints.-

Orbit insertion tracking requirements.-

Parking Orbit Phase

Altitude and shape.-

Duration of coast.-

Nominal parking orbit for translunar injection:

Utilization of only one daily launch window.-

Translunar Phase

Free return considerations.-

Translunar injection tracking requirements.-

Transposition initiation.-

Radiation belt:

S-IVB attitude control constraint:

Preplanned midcourse correction for pericynthion latitude adjustment.-

Lunar Parking Orbit Phase

Orbit elements and limits.-

Parking orbit duration of entire spacecraft.-

Number of LEM parking orbits before descent.-

Selection of lunar landing site.-

Lunar environmental constraints (illumination, temperature):

Landing site selenography:

Transfer Phase

LEM only vs entire spacecraft.-

Type (Hohmann, Equi-period, et cetera).-

Operational considerations (fuel, abort philosophy, communications, and flexibility):

Powered Descent Phase

Position for initiating thrust (relative to pericynthion).-

Shaping of flare thrust program.-

Operational considerations (visibility, start of flare out, final attitude, radar, abort, and crew tasks compatibility):

Hover and translation phase.-

Hover time extremes:

Translational range limits:

Lunar Launch Phase

Desired stay time.-

Launch window.-

Desired out-of-plane limit:

Phase relationship between LEM and CSM:

Trajectory shaping.-

Ascent Transfer Phase

Transfer need.-

Type and duration:

Rendezvous shaping considerations (fuel optimization vs operational constraints).-

Docking phase.-

Transearth Parking Orbit

Minimum number of parking orbits required.-

Proper orbit selection for transearth injection.-

Control of return inclination:

LEM disposition.-

Transearth Phase

Injection.-

Maximum transfer time and/or total mission time.-

SM separation and disposition.-

Time of separation:

Impact points:

Entry aiming conditions.-

Entry Phase

Range requirements.-

Landing site.-

Location:

Number:

Entry tracking shaping.-

Tracking and communication:

Entry "g" profile:

APPENDIX A

PRELIMINARY MISSION RULES ON NOMINAL TRAJECTORY PHASES

Earth Launch Phase

Range safety limits on launch azimuths shall be 72° – 108°. This results in a launch window of over 4 hours.

Operational launch azimuth limits shall have a difference of 26° (for example, 72° – 98°, 77° – 103°, 82° – 108°). This results in a launch window of at least $2\frac{1}{2}$ hours. (This is based on the requirements for insertion tracking using one ship. With this launch window at least 3 minutes of tracking is obtained after insertion.)

Tentatively, the initial launch azimuth of the 26° variation shall be the azimuth for overall optimum performance. (Further consideration shall be given to the desirability of the initial launch azimuth being that which occurs slightly before the optimum value is reached.)

Daylight launches are preferred for all missions and will probably be mandatory for the first manned lunar mission. (This restriction, which results from launch abort considerations, will eliminate one-third to one-half of the month.) If a lunar landing in earth-reflected light is required, the constraint of daylight launches will have to be reconsidered since one-half of the month would be lost for landing in earth-reflected light. The two restrictions could be additive in some cases such that most of the month might be unavailable.)

Orbit insertion tracking is considered a firm requirement since a GO–NO GO decision is necessary after insertion to determine if orbit was attained. In the NO GO case, the service module could be used to obtain an acceptable orbit for an alternate mission or for an immediate abort.

Parking Orbit Phase

The present parking orbit is a near circular orbit at 100 nautical miles.

Two injection opportunities are desired per mission, and injection shall occur at the earliest opportunity after spacecraft systems have

been checked out and the orbit determined. At the present time the S-IVB is limited to three orbit duration (4.5 hour parking orbit).

The nominal parking orbit for translunar injection shall be the earliest one consistent with system checkout times. At this time orbit number two shall be selected as the nominal injection orbit. The spacecraft system checkout time should be scheduled so as to be completed within this time restriction.

Only one daily launch window shall be used. (This shall be the one associated with maximum mission fuel economy. In most cases this will be the window associated with the minimum translunar trajectory plane inclination to the earth-moon plane. In addition, a requirement for a daylight launch may eliminate the use of the second window.)

Translunar Phase

Free return considerations.- For the first manned lunar landing mission, it is desirable that the nominal trajectory shall be of the free return type if the performance penalties are acceptable. (A free return trajectory is defined as a trajectory which would return safely to earth using the RCS propulsion system.)

For flights after the first manned lunar landing flight, it may be possible and/or desirable to use other than free return trajectories from the standpoint of fuel utilization.

Translunar injection tracking requirements.- Telemetry and voice communication are desired during the injection thrusting. Tracking is required within 10 minutes after injection. A GO-NO GO decision is required before 20 minutes after injection and before LEM transposition and docking begins. Continuous tracking is required for at least 10 minutes after acquisition.

Transposition initiation.- Transposition shall be initiated and completed between 20 minutes (2,000 nautical miles altitude) and 60 minutes (9,000 nautical miles altitude) after injection. The following constraints were used in establishing these times:

1. S-IVB venting – 1 hour of vent free flight after injection.

2. Radiation – For trajectory calculations it shall be assumed that radiation shall not be a constraint until further clarification of constraints is obtained.

3. Orbit determination – Acquisition must be obtained not later than 10 minutes after injection and tracking shall be maintained for the last 10 minutes.

Capability for three axis control of S-IVB orientation that is commanded by the Command Module must be provided to meet LEM transposition and docking requirements. S-IVB attitude hold capability once commanded should be 2 hours.

Lunar Parking Orbit Phase

Orbit elements and limits.- The lunar parking orbit shall be a near circular orbit at an altitude of about 80 nautical miles. The lunar orbit shall be selected such that the wedge angle between the CSM orbital plane and the LEM orbital plane after launch from the lunar surface shall be no more than 1/2° for the nominal mission. In actual missions consideration shall be given to the optimization of fuel distribution between the LEM and CSM. These orbital conditions satisfy the following criteria:

1. Adequate communication time.

2. Adequate phasing for abort.

3. Ascent, rendezvous, midcourse and aborts simplified by circular orbit.

Parking orbit duration of entire spacecraft.- The nominal trajectory plan shall incorporate only one pass over the landing point with the entire spacecraft at the CSM altitude. This is acceptable from the standpoint of:

1. Fuel economy

2. LEM checkout time

3. Landing site observation

Number of LEM parking orbits before descent.- Direct descent to the lunar surface following a quarter revolution in the equi-period orbit is desired; however, navigation and guidance requirements may necessitate one LEM parking orbit for eastern limb landing sites.

Selection of lunar landing site.- For the nominal trajectory planning it shall be tentatively assumed that the lunar landing site shall be in direct sunlight during the complete LEM lunar stay time. The selection of the lunar landing conditions is based on the following considerations:

1. Lunar environmental constraints

   a. Illumination

   b. Temperature

2. Landing site selenography

3. GOSS communications

4. Trajectory constraints

No constraints due to lighting or heating have been imposed on systems design. For the nominal mission trajectory, however, the lunar landing shall be tentatively planned for direct sunlight since it is very doubtful at this time if earth reflected light is adequate for lunar landing.

The lunar landing sites have been selected from an area bounded by ±5° latitude and ±45° longitude. The longitude limitation is based on adequate GOSS communications for both the CSM and the LEM. The latitude limitation is consistent with economic lunar orbit insertion from free return trajectories over the launch window available in the month. The selection of these lunar landing areas has been based predominantly on criteria furnished by the Flight Operations Division of MSC for purposes of operational planning. Due to the necessity for selecting areas to meet this criteria, these locations are not to be construed as recommended Apollo landing sites to meet engineering design and lunar surface exploration requirements.

Five landing areas were selected as based on the following criteria:

1. An equal landing feasibility within LEM operational capability anywhere within a footprint area approximated by a 20-mile diameter circle. (At this time, this criterion restricts an acceptable area to the large, rather barren Mare region although the probability exists that when more and better data of the lunar surface becomes available, acceptable 20-mile diameter areas may possibly be found on the highland or pre-mare terrain regions.) This requirement also virtually prohibits the selection of sites located near good lunar landmarks or with good landmarks along the approach trajectory. If this requirement were relaxed, better sites that do not lie in the center of Mare areas could be chosen.

2. Operational restraints limit the area under consideration to a zone covering the area from ±5° latitude and ±45° longitude.

3. To provide a maximum flexibility in launch dates, the five areas selected were to be dispersed throughout this zone to give maximum longitudinal spread.

The application of the above criteria was influenced by the following:

1. The relative importance of various processes which have shaped the lunar surface is still a matter of controversy among the scientific community. However, both the proponents of volcanic origin and of impact origin, (with the exception of T. Gold), agree that the maria are covered by extrusive igneous rocks. Both volcanic and impact theories agree that the maria will be relatively smooth at least when compared to the upland area.

2. The surface detail which is prerequisite to the landing maneuver is not directly observable at this time. The smallest objects on the lunar surface which can be seen visually at the telescope have diameters of about 0.2 mile. Low angle illumination makes possible the observation of objects as little as ten feet high but only if the object is oriented so as to cast a shadow long enough and wide enough to be resolved.

The landing areas selected are:

1. E 36°55' N 1°45'

2. E 28°22' N 1°10'

3. W 1°28' S 0°30'

4. W 13°15' N 2°45'

5. W 31°30' S 1°5'

Within the current state of knowledge of lunar surface topography and composition, all of the proposed landing areas are assumed to have similar characteristics.

Transfer Phase

The LEM shall descent to 50,000 feet altitude in an equal period (synchronous) orbit which is coplaner with the CSM orbit. This type of transfer, although somewhat expensive in fuel for a nominal mission, is preferred because (1) transfer time to pericynthion is short, (2) LEM-CSM is always within line of sight of LEM, and (3) phasing is favorable for LEM aborts to CSM.

The transfer shall be initiated at a point in the orbit such that the initial powered descent shall start at pericynthion of the equal period orbit.

Powered Descent Phase

Position for initiating thrust (relative to pericynthion).- The powered descent is initiated at pericynthion.

Shaping of flare thrust program.- Descent path must have proper shape to allow visual target acquisition as soon as possible while still allowing altitude radar to become operational early.

CSM must be in line of sight of LEM.

Hover and translation phase.-

Hover time extremes:

Touchdown should be made in 2 minutes.

Translational range limits:

Translational range shall be not less than 1 mile.

Lunar Launch Phase

Stay time.- Maximum stay time for the initial lunar missions is 24 hours on lunar surface.

Launch.- Landing site shall never be more than $\frac{1}{2}^{\circ}$ out-of-plane of CSM orbit.

Launch-at-any-time capability must be provided.

Boost.- Burnout heading angle shall result in plane change less than $\frac{1}{2}^{\circ}$.

Ascent trajectory should be designed to be compatible with backup guidance.

Plane change maneuvers should be performed at intercept with the CSM in order to provide a launch window without excessive LEM guidance complexity.

Ascent Transfer Phase

CSM intercept should take place within a central angle range $140 \leq \phi \leq 220$.

Transearth Lunar Parking Orbit

The minimum number of lunar parking orbits after LEM docking is one in order to properly determine the orbit and to checkout the onboard systems prior to committing to transearth injection. The maximum number of lunar orbits shall be based on operational considerations such as controlling the return ground track to the landing site (inclination) with as little fuel penalty as possible commensurate with crew and systems endurance and reliability.

LEM disposition.- At this time it is believed that the LEM may be left in orbit about the moon.

Transearth Phase

Service Module separation and disposition.- The Service Module must be separated before reentry in such a way that there is not a recontact problem between the Service Module and Command Module and the impact point of the Service Module is not in a highly populated area.

Entry Phase

Two primary landing locations are necessary; one in the Northern Hemisphere and one in the Southern Hemisphere at approximately the same latitude. It may be desirable to have more to insure acceptable weather in the recovery area. In general, reentry ranges should be restrained to within 1,200 and 5,000 nautical miles in order to be safely within undershoot control and maximum heat boundaries. Also ground track inclinations should be less than 40° in order that unplanned landings are constrained to the warmer latitudes. One hundred percent of the month availability for landing, considering both Northern and Southern Hemisphere terminals available, is an important goal for primary landing site selections. Texas and Australia are the current sites for land landings in that utilizing inclinations between 35° and 40° landings are possible throughout the month. These land landing sites have associated operational difficulties:

1. High probability of Service Module impact on a highly populated area.

2. Reversion to backup reentry guidance, incurs the danger of lack of terrain avoidance associated with zero control range capability.

It appears that water landings near Hawaii (Northern Hemisphere) and near the Samoa Islands (Southern Hemisphere) are good choices for water landings.

In any case, it is desirable that the return trajectory be controlled so as to pass near planned tracking sites – in certain cases, efficient utilization of a ship must be considered – and along a preplanned ground track for efficient recovery operations.

APPENDIX B

EFFECT OF RADAR ACCURACY, SMOOTHING TIME, AND SAMPLING RATE IN THE DETERMINATION OF VELOCITY ACCURACY

APPENDIX B

EFFECT OF RADAR ACCURACY, SMOOTHING TIME, AND SAMPLING RATE IN THE DETERMINATION OF VELOCITY ACCURACY

In figure 19 are shown the smoothing times required for various data rates to obtain a given accuracy. This figure is based on the determination of the velocity from radar position measurements by fitting the best parabola to the data by the method of moments. The figure is based upon a parameter $(\sigma_\rho/\sigma_{16})(4/\sigma_v)$ which indicates the relative accuracy of the tracking system used to that of a good ground based FPS-16 system (for example, the Mercury Bermuda station). For example, if an accuracy of one foot per second (one sigma) were required and a radar system five times as poor as a ground based FPS-16 system were used, a data rate of one sample every 2 seconds would have to be used to achieve the desired accuracy within 10 minutes.

This figure is presented in order to make rough estimates of the effect of sampling rate and smoothing time. In order to obtain quantitative estimates for use in selecting equipment the actual short arc methods to be used should be evaluated.

APPENDIX C

RADAR CONTOUR COVERAGE MAPS

APPENDIX C

RADAR CONTOUR COVERAGE MAPS

In figure 20 radar contour coverage maps are shown for the existing Deep Space Instrumentation Facilities (DSIF), figure 20(a) located at Woomera, Australia; Goldstone, California; and Johannesburg, South Africa. The visibility lines depict the coverage for varying altitudes for a 0° elevation angle taking into account the terrain and physical limits of the antennas. Figure 20(b) represents the coverage map of the proposed DSIF sites located at Canberra, Australia; Goldstone, California; and Madrid, Spain. The acquisition lines depict the coverage at varying altitudes for a 5° elevation angle. The deformation of the acquisition lines results from the mechanical limits of the X-Y mounted antennas. Figures 20(c) to 20(e) are overlays (transparencies) defining the 5° elevation visibility curves at varying altitudes for radars located at latitudes of 30° North or South, 15° North or South, and for equatorial sites. These overlays may be used over any of the geographical maps containing the trajectory ground tracks to determine the coverage of additional radar sites. The overlay to be selected depends on the latitude of the radar site. The overlays should be rotated 180° for radar sites in the Southern Hemisphere.

APPENDIX D

REENTRY TRAJECTORIES

APPENDIX D

REENTRY TRAJECTORIES

Figures 21(a) through 21(dd) present typical guided reentry trajectory parameters for downrange distances from 1,200 to 5,000 nautical miles and for initial conditions throughout the acceptable reentry corridor. The present MIT steering equations were used in conjunction with a three-degrees-of-freedom point-mass trajectory program to develop the subject trajectories. These trajectories are based on a maximum lift to drag ratio of 0.40.

APPENDIX E

OPERATIONAL CONSTRAINTS STUDY

APPENDIX E

OPERATIONAL CONSTRAINTS STUDY

One of the possible approaches which has been suggested to alleviate the tracking-coverage problem is elimination of certain days of the month which would otherwise require an addition to the present coverage. In other words, establishment of those mission phases and associated times which essentially demand a further augmentation of a given tracking capability during the monthly launch window beyond a certain degree of mechanization, and dismissal of them as potential launch opportunities. Although it is recognized that this measure will have to be followed to some degree, it should be cautioned that a severe reduction in operational flexibility could result from adoption of such a plan if an integrated analysis considering all mission and operational constraints were not first performed. It is the purpose of this section, therefore, to present the results of such a study for a typical 2-month period in 1968 and to show the implications involved in successive application of various launch restrictions.

Mission Rules

The following list enumerates the mission rules which were assumed in this study. They essentially define the trajectory profile that the spacecraft must follow in order to satisfy the associated mission objectives. (It should be noted that some of the mission rules have changed since this study was performed.)

1. Launch must occur during the months of April or May 1968. The selection of this particular time was arbitrary.

2. A free-return trajectory is required. The primary reason for this requirement is crew safety.

3. The selected landing site on the lunar surface is located in the area of Sinus Medii at 3°40' E longitude and 2°4' N latitude.

4. The required stay time on the moon is 24 hours.

5. The spacecraft must return to either of two earth landing sites located at:

-150° W longitude	22° N latitude
-165° W longitude	14° S latitude

Examination will show that both of these sites are located in the Pacific Ocean. These sites were chosen in cooperation with Recovery Branch Personnel and as such represent favored water-landing recovery areas providing an "any time of the month" return capability within the allowable trajectory inclination and longitudinal range limitations. A number of primary land return sites are also being considered; however, for the purposes of this study, the water returns were chosen.

6. The spacecraft must land on the moon in earth-reflected light of 50 percent of maximum brilliance or greater. This requirement is by far the most restrictive of all the mission rules since approximately $\frac{1}{2}$ of the total 2-month span is lost with its application. This restriction results in essentially the same loss if the reverse condition of landing in sunshine is required.

Operational Constraints

The operational constraints imposed for this mission are considered reasonable representatives of those expected for a typical lunar flight. The degree to which they are ultimately enforced will depend, of course, upon results obtained with various tradeoff-studies and, finally, the minimum measure of acceptable operational flexibility. The following list is in no way considered to be exhaustive but represents those constraints which can be identified at this time well enough to be used in a study of this nature.

1. The minimum acceptable daily launch window is $2\text{-}\frac{1}{2}$ hours in length. This restriction is imposed to assure an adequate margin of time should "hold" periods require delaying the lift-off.

2. The maximum azimuth variation within a particular daily launch window will be limited to 26°. The primary reason for applying this restriction is to assure a minimum of 3 minutes of tracking during orbital insertion. It is possible for a single tracking ship to cover this degree of azimuth variation if it is centrally positioned between the minimum and maximum azimuth ground tracks. Moreover, because of the non-linear variation of launch azimuth with time as one or the other range safety limits (72° to 108°) is approached, use of the full 36° variation is not operationally feasible.

3. Return equatorial inclinations will be limited to a maximum of ±40°. This restriction is applied to assure favorable recovery conditions inasmuch as contingency landings (resulting from overshoots or system failures) beyond 40° north or south latitude could result in hazardous environmental conditions for the crew, especially if actual recovery is delayed for any reason.

4. A minimum of three successive acceptable daily launch windows is required. If minor holds (due to weather, for example) require a launch rescheduling this minimum period of time allows for reasonable operational flexibility.

5. A daylight launch is required followed by a minimum of 1 hour of daylight. This requirement is based upon the daylight recovery of the crew in the event of pad aborts and a need for optical tracking of the booster.

6. Only one of the two available daily injection windows will be employed. This restriction is imposed for two reasons. First, for reasonable fuel economy, injection must generally occur out of the Pacific for a descending moon and out of the Atlantic when the moon is ascending. There is, of course, a period, when the moon is approaching or is at its most northerly or most southerly declination, when injection can occur out of either ocean. However, this period covers only a span of approximately 4 days. Secondly, logistic considerations make it unreasonable to support injection operations in both oceans simultaneously, especially if all three possible earth orbits must be covered.

Guidance and Performance Limitations

In addition to the constraints imposed for the particular mission and for operational considerations, a third class of requirements must be examined which cover guidance and performance limitations. Thus far, the only two restrictions which have been imposed insofar as this study is concerned are listed below. It is recognized that guidance and especially fuel considerations will more than likely reduce still further the final windows arrived at in this study. This part of the mission planning problem is at this time undergoing intensive investigation and most detailed results should be available soon. Suffice to say that a study of the guidance and performance limitations will result in further launch restrictions. The constraints used in this paper are as follows:

1. The permissible reentry range limits are a maximum of 5,000 and a minimum of 1,200 nautical miles.

2. The maximum allowable inclination of the translunar trajectory to the earth-moon plane used in this study is 18°. This restriction, which levels the plane-change requirement, essentially limits injection on a given day to either the Pacific or the Atlantic windows.

Study Results

The job of determining the available launch windows which satisfy the mission rules, operational constraints and guidance limitations just

enumerated involves extensive parametric analysis of results from patched-conic and lunar lighting digital programs. Figure 22, for example, demonstrates the extensive number of days lost in order to comply with just the lunar lighting requirement. Figure 23 illustrates the further reduction experienced with application of the range-safety launch azimuth limits.

When the launch lighting restrictions are applied (fig. 24), it can easily be seen that both the upper and lower limits of the Atlantic, as well as Pacific, windows are lost. Not quite so apparent, however, is the additional restriction imposed upon the available Atlantic window in the month of April. As mentioned previously, to avoid operations involving the non-linear azimuth-versus-time portion of the range-safety window, the desirable azimuth swing for an Atlantic injection, when the moon is ascending, is from 82° to 108°. A check of figure 24 will show that the launch azimuths on the 108° side of the window are lost because of the launch lighting restriction. This means that employment of the Atlantic window entails either operations with a daily window length much shorter than the minimum $2\text{-}\frac{1}{2}$ hours, or use of the non-linear 72° to 82° launch azimuths with their associated high-fuel penalties in the event of late lift-off.

Examination of figure 25 shows the loss in window size due to the maximum inclination restrictions (see fig. 28). Note that only one 4-day period is available for injections out of the Pacific in the month of April.

If the minimum $2\text{-}\frac{1}{2}$ hour daily window restriction is enforced a further reduction is realized in the April Atlantic-injection window as shown in figure 26. Finally, figure 27 associates the two-water landing return sites with individual portions of the resulting windows. Note that the beginning of the Atlantic window in May requires a return to Hawaii. Inasmuch as it is not operationally feasible to plan for a single day return to Hawaii, this day is effectively lost.

APPENDIX F

RADAR COVERAGE MAPS

APPENDIX F

RADAR COVERAGE MAPS

Figure 29 depicts radar coverage at various times after translunar injection for land based stations and ships. The tracking ships used are the following: (1) Atlantic injection area ship (20° S latitude, 37° E longitude) which will replace the South African stations since the South African stations may not be available, (2) Pacific injection area ship (5° N latitude, 177° E longitude), and (3) the insertion area ship (24° N latitude, 48° W longitude) which may be used for translunar injection tracking.

Figures 29(a) to 29(c) show how the two injection area ships could be deployed to improve the radar coverage.

TABLE I. SUMMARY OF TRACKING LOCATIONS AND SYMBOLS USED FOR FIGURES

SYMBOLS *	STATIONS	LATITUDE	LONGITUDE
■	Canberra	35° 24' S	148° 48' E
◆	Goldstone (new)	35° 23' N	116° 51' W
◀	Goldstone (old)	35° 23' N	116° 51' W
◖	Johannesburg	25° 53' S	27° 41' E
●	Madrid	40° 25' N	3° 40' W
▲	Woomera	31° 23' S	136° 53' E
○	Antigua	17° 09' N	61° 48' W
□	Ascension	07° 57' S	14° 25' W
◇	California	34° 35' N	120° 34' W
△	Cape Canaveral	28° 29' N	80° 35' W
▽	Carnarvon	24° 53' S	113° 43' E
◺	Grand Bahama Island	26° 37' N	78° 21' W
◿	Grand Canary Islands	27° 44' N	15° 36' W
◸	Hawaii	22° 08' N	159° 40' W
◿	Houston	29° 48' N	95° 27' W
◠	Pretoria	25° 57' S	28° 22' E
◡	Wallops Island	37° 50' N	75° 29' W
◇	White Sands	32° 21' N	106° 22' W

*Solid symbol represents Deep Space Instrumentation Facility.

TABLE II. - FREQUENCY AND RELATIVE CUMULATIVE FREQUENCY DISTRIBUTIONS OF EARLIEST ACQUISITION TIMES OF TRANSLUNAR TRAJECTORIES AFTER INJECTION

Minutes from Injection	Atlantic injection area						Pacific injection area			
	Table I stations (a)		Without South African stations (b)		With Madagascar (c)		Table I stations (a)		With Guam (d)	
	f	rcf (%)	f	rcf (%)	f	rcf (%)	f	rcf (%)	f	rcf (%)
26			1	100.0						
25				98.7						
24				98.7						
23			1	98.7						
22			2	97.3						
21				94.7						
20			1	94.7						
19			1	93.3			1	100.0		
18			4	92.0				98.7		
17			2	86.7			1	98.7		
16			2	84.0				97.3		
15			1	81.3				97.3		
14			2	80.0			1	97.3		
13			3	77.3			3	96.0		
12			4	73.3			3	92.0		
11			2	68.0			1	88.0		
10	1	100.0	3	65.3	2	100.0	1	86.7		
9	2	98.7	2	61.3	2	97.3	6	85.3	3	100.0
8	8	96.0	5	58.7	4	94.7	4	77.3	2	96.0
7	2	85.3	1	52.0	2	89.3	5	72.0	6	93.3
6	8	82.7	5	50.7	9	86.7	2	65.3	3	85.3
5	10	72.0	8	44.0	14	74.7	7	62.7	7	81.3
4	8	58.7	4	33.3	7	56.0	7	53.3	11	72.0
3	8	48.0	3	28.0	7	46.7	8	44.0	12	57.3
2	9	37.3	5	24.0	9	37.3	5	33.3	6	41.3
1	9	25.3	7	17.3	8	25.3	8	26.7	9	33.3
0	10	13.3	6	8.0	11	14.7	12	16.0	16	21.3
avg. min.	3.8		8.4		3.8		5.1		3.2	

[a]Assume Table I stations.

[b]Assume Table I stations without South African stations.

[c]Assume Table I stations with South African stations replaced by Madagascar.

[d]Assume Table I stations and include Guam.

TABLE III. - DISTRIBUTIONS OF EARLIEST ACQUISITION TIMES OF TRANSLUNAR TRAJECTORIES AFTER INJECTION

(a) Frequency distribution for Atlantic injection area by launch azimuth

Minutes from Injection	Table I stations (a)					Without South African stations (b)					With Madagascar (c)				
	72.6°	74.8°	90°	102.7°	107.4°	72.6°	74.8°	90°	102.7°	107.4°	72.6°	74.8°	90°	102.7°	107.4°
26										1					
25															
24															
23									1						
22							1	1							
21															
20						1									
19							1								
18						1		1	1	1					
17							1			1					
16						1			1						
15								1							
14							1		1						
13						1		1		1					
12						1	1		1	1					
11							1	1							
10					1	1			1	1					2
9		1		1			1		1			1		1	
8	3	2	2		1	1	1	2		1	2		1	1	
7	1				1	1						1			1
6	1	2	1	2	2	1	1		1	2	2	2	1	2	2
5	3	3	2	2		2	2	2	2		4	3	3	3	1
4	1	2	2	1	2	1	1	1		1	1	1	2	1	2
3	1		3	1	3			1		2	1	1	1	1	3
2	2	2	1	3	1	1	1	1	2		2	3	2	2	
1	1	2	3	2	1	1	2	3	1		1	2	3	2	
0	2	1	1	3	3	1			2	3	2	1	2	2	4
avg. min.	4.3	4.4	3.6	3.1	3.8	8.5	9.1	7.8	8.2	8.4	4.0	3.9	3.1	3.8	4.1

[a]Assume Table I stations.

[b]Assume Table I stations without South African stations.

[c]Assume Table I stations with South African stations replaced by Madagascar.

[d]Assume Table I stations and include Guam.

TABLE III. - CONTINUED

(b) Relative cumulative frequency distribution (percentage) for Atlantic injection area by launch azimuth

Minutes from Injection	Table I stations (a)					Without South African stations (b)					With Madagascar (c)				
	72.6°	74.8°	90°	102.7°	107.4°	72.6°	74.8°	90°	102.7°	107.4°	72.6°	74.8°	90°	102.7°	107.4°
26										100.0					
25										93.3					
24										93.3					
23									100.0	93.3					
22							100.0	100.0	93.3	93.3					
21							93.3	93.3	93.3	93.3					
20						100.0	93.3	93.3	93.3	93.3					
19						93.3	93.3	93.3	93.3	93.3					
18						93.3	86.7	93.3	93.3	93.3					
17						86.7	86.7	86.7	86.7	86.7					
16						86.7	80.0	86.7	86.7	80.0					
15						80.0	80.0	86.7	80.0	80.0					
14						80.0	80.0	80.0	80.0	80.0					
13						80.0	73.3	80.0	73.3	80.0					
12						73.3	73.3	73.3	73.3	73.3					
11						66.7	66.7	73.3	66.7	66.7					
10					100.0	66.7	60.0	66.7	66.7	66.7					100.0
9		100.0		100.0	93.3	60.0	60.0	66.7	60.0	60.0		100.0		100.0	86.7
8	100.0	93.3	100.0	93.3	93.3	60.0	53.3	66.7	53.3	60.0	100.0	93.3	100.0	93.3	86.7
7	80.0	80.0	86.7	93.3	86.7	53.3	46.7	53.3	53.3	53.3	86.7	93.3	93.3	86.7	86.7
6	73.3	80.0	86.7	93.3	80.0	46.7	46.7	53.3	53.3	53.3	86.7	86.7	93.3	86.7	80.0
5	66.7	66.7	80.0	80.0	66.7	40.0	40.0	53.3	46.6	40.0	73.3	73.3	86.7	73.3	66.7
4	46.7	46.7	66.7	66.7	66.7	26.7	26.7	40.0	33.3	40.0	46.7	53.3	66.7	53.3	60.0
3	40.0	33.3	53.3	60.0	53.3	20.0	20.0	33.3	33.3	33.3	40.0	46.7	53.3	46.7	46.7
2	33.3	33.3	33.3	53.3	33.3	20.0	20.0	26.7	33.3	20.0	33.3	40.0	46.7	40.0	26.7
1	20.0	20.0	26.7	33.3	26.6	13.3	13.3	20.0	20.0	20.0	20.0	20.0	33.3	26.7	26.7
0	13.3	6.7	6.7	20.0	20.0	6.7	0.0	0.0	13.3	20.0	13.3	6.7	13.3	13.3	26.7

TABLE III. - CONTINUED

(c) Frequency distribution for Atlantic injection area by lunar declination

Minutes from Injection	Table I stations (a)					Without South African stations (b)					With Madagascar (c)				
	-27.5°	-15°	0°	15°	27.5°	-27.5°	-15°	0°	15°	27.5°	-27.5°	-15°	0°	15°	27.5°
26									1						
25															
24															
23									1						
22						1	1								
21															
20						1									
19							1								
18							1	2	1						
17								1		1					
16								1	1						
15									1						
14							1			1					
13							1	1	1						
12								2	1	1					
11									2						
10		1					1		1	1		1		1	
9		1	1				1	1			1	1			
8	2	1	1	2	2			1	2	2	1	1	1	1	
7				2					1			1		1	
6		3	1	1	3		1	1		3		2	4		3
5	2	4	1	2	1	2	2	1	2	1	2	4	2	4	2
4	2		3	1	2	2				2	2		1	1	3
3		2	3	2	1		2	1				2	3	1	1
2		3	3	1	2		3	1		1		3	2	3	1
1	4		1	1	3	4		1		2	4		1		3
0	5		1	3	1	5		1			5		1	3	2
avg. min.	2.5	5.1	3.7	3.9	3.8	4.3	8.9	9.3	12.5	6.9	2.6	5.2	4.0	3.9	3.2

TABLE III. - CONTINUED

(d) Relative cumulative frequency distribution for Atlantic injection area by lunar declination

Minutes from Injection	Table I stations (a)					Without South African stations (b)					With Madagascar (c)				
	-27.5°	-15°	0°	15°	27.5°	-27.5°	-15°	0°	15°	27.5°	-27.5°	-15°	0°	15°	27.5°
26									100.0						
25									93.3						
24									93.3						
23									93.3						
22						100.0	100.0		86.7						
21						93.3	93.3		86.7						
20						93.3	93.3		86.7						
19						86.7	93.3		86.7						
18						86.7	86.7	100.0	86.7						
17						86.7	80.0	86.7	80.0	100.0					
16						86.7	80.0	80.0	80.0	93.3					
15						86.7	80.0	73.3	73.3	93.3					
14						86.7	80.0	73.3	66.7	93.3					
13						86.7	73.3	73.3	66.7	86.7					
12						86.7	66.7	66.7	60.0	86.7					
11						86.7	66.7	53.3	53.3	80.0					
10		100.0				86.7	66.7	53.3	40.0	80.0		100.0		100.0	
9		93.3	100.0			86.7	60.0	53.3	33.3	73.3	100.0	93.3		93.3	
8	100.0	86.7	93.3	100.0	100.0	86.7	53.3	46.7	33.3	73.3	93.3	86.7	100.0	93.3	
7	86.7	80.0	86.7	86.7	86.7	86.7	53.3	40.0	20.0	60.0	86.7	80.0	93.3	86.7	
6	86.7	80.0	86.7	73.3	86.7	86.7	53.3	40.0	13.3	60.0	86.7	73.3	93.3	80.0	100.0
5	86.7	60.0	80.0	66.7	66.7	86.7	46.7	33.3	13.3	40.0	86.7	60.0	66.7	80.0	80.0
4	73.3	33.3	73.3	53.3	60.0	73.3	33.3	26.7	0.0	33.3	73.3	33.3	53.3	53.3	66.7
3	60.0	33.3	53.3	46.7	46.7	60.0	33.3	26.7	0.0	20.0	60.0	33.3	46.7	46.7	46.7
2	60.0	20.0	33.3	33.3	40.0	60.0	20.0	20.0	0.0	20.0	60.0	20.0	26.7	40.0	40.0
1	60.0	0.0	13.3	26.7	26.7	60.0	0.0	13.3	0.0	13.3	60.0	0.0	13.3	20.0	33.3
0	33.3	0.0	6.7	20.0	6.7	33.3	0.0	6.7	0.0	0.0	33.3	0.0	6.6	20.0	13.3

TABLE III. - CONTINUED

(e) Frequency distribution for Atlantic injection area by parking orbit

Minutes from Injection	Table I stations (a)			Without South African stations (b)			With Madagascar (c)		
	1	2	3	1	2	3	1	2	3
26						1			
25									
24									
23						1			
22				2					
21									
20				1					
19					1				
18				1	3				
17						2			
16					1	1			
15						1			
14				1		1			
13				3					
12				1	3				
11					1	1			
10			1		1	2			2
9	1		1	1		1	1		1
8	6	1	1	3	1	1	3		1
7		1	1		1			2	
6	3	1	4	1	1	3	2	3	4
5	2	4	4	2	2	4	4	3	7
4	2	4	2	1	2	1	3	2	2
3	2	3	3	1	2		2	5	
2	3	3	3	2	1	2	3	2	4
1	3	3	3	2	2	3	2	3	3
0	3	5	2	3	3		5	5	1
avg. min.	4.3	3.0	4.2	8.4	7.8	9.0	3.6	3.1	4.6

TABLE III. - CONTINUED

(f) Relative cumulative frequency distribution for Atlantic injection area by parking orbit

Minutes from Injection	Table I stations (a)			Without South African stations (b)			With Madagascar (c)		
	1	2	3	1	2	3	1	2	3
26						100.0			
25						96.0			
24						96.0			
23						96.0			
22				100.0		92.0			
21				92.0		92.0			
20				92.0		92.0			
19				88.0	100.0	92.0			
18				88.0	96.0	92.0			
17				84.0	84.0	92.0			
16				84.0	84.0	84.0			
15				84.0	80.0	80.0			
14				84.0	80.0	76.0			
13				80.0	80.0	72.0			
12				68.0	80.0	72.0			
11				64.0	68.0	72.0			
10			100.0	64.0	64.0	68.0			100.0
9	100.0		96.0	64.0	60.0	60.0	100.0		92.0
8	96.0	100.0	92.0	60.0	60.0	56.0	96.0		88.0
7	72.0	96.0	88.0	48.0	56.0	52.0	84.0	100.0	84.0
6	72.0	92.0	84.0	48.0	52.0	52.0	84.0	92.0	84.0
5	60.0	88.0	68.0	44.0	48.0	40.0	76.0	80.0	68.0
4	52.0	72.0	52.0	36.0	40.0	24.0	60.0	68.0	40.0
3	44.0	56.0	44.0	32.0	32.0	20.0	48.0	60.0	32.0
2	36.0	44.0	32.0	28.0	24.0	20.0	40.0	40.0	32.0
1	24.0	32.0	20.0	20.0	20.0	12.0	28.0	32.0	16.0
0	12.0	20.0	8.0	12.0	12.0	0.0	20.0	20.0	4.0

TABLE III. - CONTINUED

(g) Frequency distribution for Pacific injection area by launch azimuth

Minutes from Injection	Table I stations (a)					With Guam (d)				
	72.6°	74.8°	90°	102.7°	107.4°	72.6°	74.8°	90°	102.7°	107.4°
25										
24										
23										
22										
21										
20										
19					1					
18										
17				1						
16										
15										
14					1					
13		1	2							
12	1			1	1					
11				1						
10					1					
9	1	1	1	1	2	1	1			1
8		2		1	1		2			
7	2		1	2		2		1	2	1
6			1		1	1	1	1		
5	2	2	1	1	1	2	2	1	1	1
4	1	2	1	1	2	1	2	2	2	4
3	1	1	3	2	1	1	1	4	4	2
2	1	1	1		2	1	1	1		3
1	3	2	1	2		3	2	1	2	1
0	3	3	3	2	1	3	3	4	4	2
avg. min.	3.8	4.2	4.6	5.9	7.1	3.4	3.7	2.7	2.7	3.3

TABLE III. - CONTINUED

(h) Relative cumulative frequency distribution for Pacific injection area by launch azimuth

Minutes from Injection	Table I stations (a)					With Guam (d)				
	72.6°	74.8°	90°	102.7°	107.4°	72.6°	74.8°	90°	102.7°	107.4°
25										
24										
23										
22										
21										
20										
19					100.0					
18					93.3					
17				100.0	93.3					
16				93.3	93.3					
15				93.3	93.3					
14				93.3	93.3					
13		100.0	100.0	93.3	86.7					
12	100.0	93.3	86.7	93.3	86.7					
11	93.3	93.3	86.7	86.7	80.0					
10	93.3	93.3	86.7	80.0	80.0					
9	93.3	93.3	86.7	80.0	73.3	100.0	100.0			100.0
8	86.7	86.7	80.0	73.3	60.0	93.3	93.3			93.3
7	86.7	73.3	80.0	66.7	53.3	93.3	80.0	100.0	100.0	93.3
6	73.3	73.3	73.3	53.3	53.3	80.0	80.0	93.3	86.7	86.7
5	73.3	73.3	66.7	53.3	46.7	73.3	73.3	86.7	86.7	86.7
4	60.0	60.0	60.0	46.7	40.0	60.0	60.0	80.0	80.0	80.0
3	53.3	46.7	53.3	40.0	26.7	53.3	46.7	66.7	66.7	53.3
2	46.7	40.0	33.3	26.7	20.0	46.7	40.0	40.0	40.0	40.0
1	40.0	33.3	26.7	26.7	6.7	40.0	33.3	33.3	40.0	20.0
0	20.0	20.0	20.0	13.3	6.7	20.0	20.0	26.7	26.7	13.3

TABLE III. - CONTINUED

(i) Frequency distribution for Pacific injection area by lunar declination

Minutes from Injection	Table I stations (a)					With Guam (d)				
	-27.5°	-15°	0°	15°	27.5°	-27.5°	-15°	0°	15°	27.5°
25										
24										
23										
22										
21										
20										
19				1						
18										
17				1						
16										
15										
14				1						
13				1	2					
12			1	1	1					
11			1							
10				1						
9			1	2	3					3
8		1	1	1	1				1	1
7		1	1	1	2				3	3
6			1	1					1	2
5		1	1	4	1		1	1	4	1
4	1	1	4		1	1	1	5	3	1
3	3	3	1		1	3	3	2	3	1
2	1	2	2			1	3	2		
1	3	3	1		1	3	3	2		1
0	7	3			2	7	4	3		2
avg. min.	1.2	2.7	5.5	9.6	6.7	1.2	1.8	2.5	5.1	5.4

TABLE III. - CONTINUED

(j) Relative cumulative frequency distribution for Pacific injection area by lunar declination

Minutes from Injection	Table I stations (a)					With Guam (d)				
	-27.5°	-15°	0°	15°	27.5°	-27.5°	-15°	0°	15°	27.5°
25										
24										
23										
22										
21										
20										
19				100.0						
18				93.3						
17				93.3						
16				86.7						
15				86.7						
14				86.7						
13				80.0	100.0					
12			100.0	73.3	86.7					
11			93.3	66.7	80.0					
10			86.7	66.7	80.0					
9			86.7	60.0	80.0					100.0
8		100.0	80.0	46.7	60.0				100.0	80.0
7		93.3	73.3	40.0	53.3				93.3	73.3
6		86.7	66.7	33.3	40.0				73.3	53.3
5		86.7	60.0	26.7	40.0		100.0	100.0	66.7	40.0
4	100.0	80.0	53.3	0.0	33.3	100.0	93.3	93.3	40.0	33.3
3	93.3	73.3	26.7	0.0	26.7	93.3	86.7	60.0	20.0	26.7
2	73.3	53.3	20.0	0.0	20.0	73.3	66.7	46.7	0.0	20.0
1	66.7	40.0	6.7	0.0	20.0	66.7	46.7	33.3	0.0	20.0
0	46.7	20.0	0.0	0.0	13.3	46.7	26.7	20.0	0.0	13.3

TABLE III. - CONTINUED

(k) Frequency distribution for Pacific injection area by parking orbit

Minutes from Injection	Table I stations (a)			With Guam (d)		
	1	2	3	1	2	3
25						
24						
23						
22						
21						
20						
19			1			
18						
17			1			
16						
15						
14		1				
13	1		2			
12		1	2			
11			1			
10	1					
9	1	4	1		2	1
8	1	1	2	1		1
7	1		4	2		4
6	2			1		2
5	3	3	1	3	3	1
4	2	3	2	2	5	4
3	2	2	4	4	3	5
2	2	3		2	3	1
1	4	2	2	4	3	2
0	5	5	2	6	6	4
avg. min.	3.8	4.4	7.1	2.8	2.8	3.9

TABLE III. - CONCLUDED

(1) Relative cumulative frequency distribution for Pacific injection area by parking orbit

Minutes from Injection	Table I stations (a)			With Guam (d)		
	1	2	3	1	2	3
25						
24						
23						
22						
21						
20						
19			100.0			
18			96.0			
17			96.0			
16			92.0			
15			92.0			
14		100.0	92.0			
13	100.0	96.0	92.0			
12	96.0	96.0	84.0			
11	96.0	92.0	76.0			
10	96.0	92.0	72.0			
9	92.0	92.0	72.0		100.0	100.0
8	88.0	76.0	68.0	100.0	92.0	96.0
7	84.0	72.0	60.0	96.0	92.0	92.0
6	80.0	72.0	44.0	88.0	92.0	76.0
5	72.0	72.0	44.0	84.0	92.0	68.0
4	60.0	60.0	40.0	72.0	80.0	64.0
3	52.0	48.0	32.0	64.0	60.0	48.0
2	44.0	40.0	16.0	48.0	48.0	28.0
1	36.0	28.0	16.0	40.0	36.0	24.0
0	20.0	20.0	8.0	24.0	24.0	16.0

TABLE IV.- PERCENTAGE OF 150 TRANSLUNAR TRAJECTORIES ACQUIRED AND TRACKED BY RADAR

Time from injection, min	Number of ships used in addition to Table I stations												
	0	1	2	3	4	5	6	7	8	9	10	11	12
-6	12	17	21	25	29	33	36	39	43	46	49	53	55
0	18	24	30	35	39	44	48	51	55	58	61	63	66
5	65	77	87	91	95	97	98	99	100				
10	92	98	99	100									

TABLE V.- PERCENTAGE OF 150 TRANSLUNAR TRAJECTORIES ACQUIRED AND TRACKED BY TELEMETRY/VOICE

Time from injection, min	Number of ships used in addition to Table I stations, Kano, Zanzibar, Guaymas and Canton Island												
	0	1	2	3	4	5	6	7	8	9	10	11	12
-6	46	54	61	67	72	77	81	85	89	92	95	97	99
0	47	56	63	70	76	81	85	89	93	95	98	100	
5	79	91	99	100									
10	96	99	100										

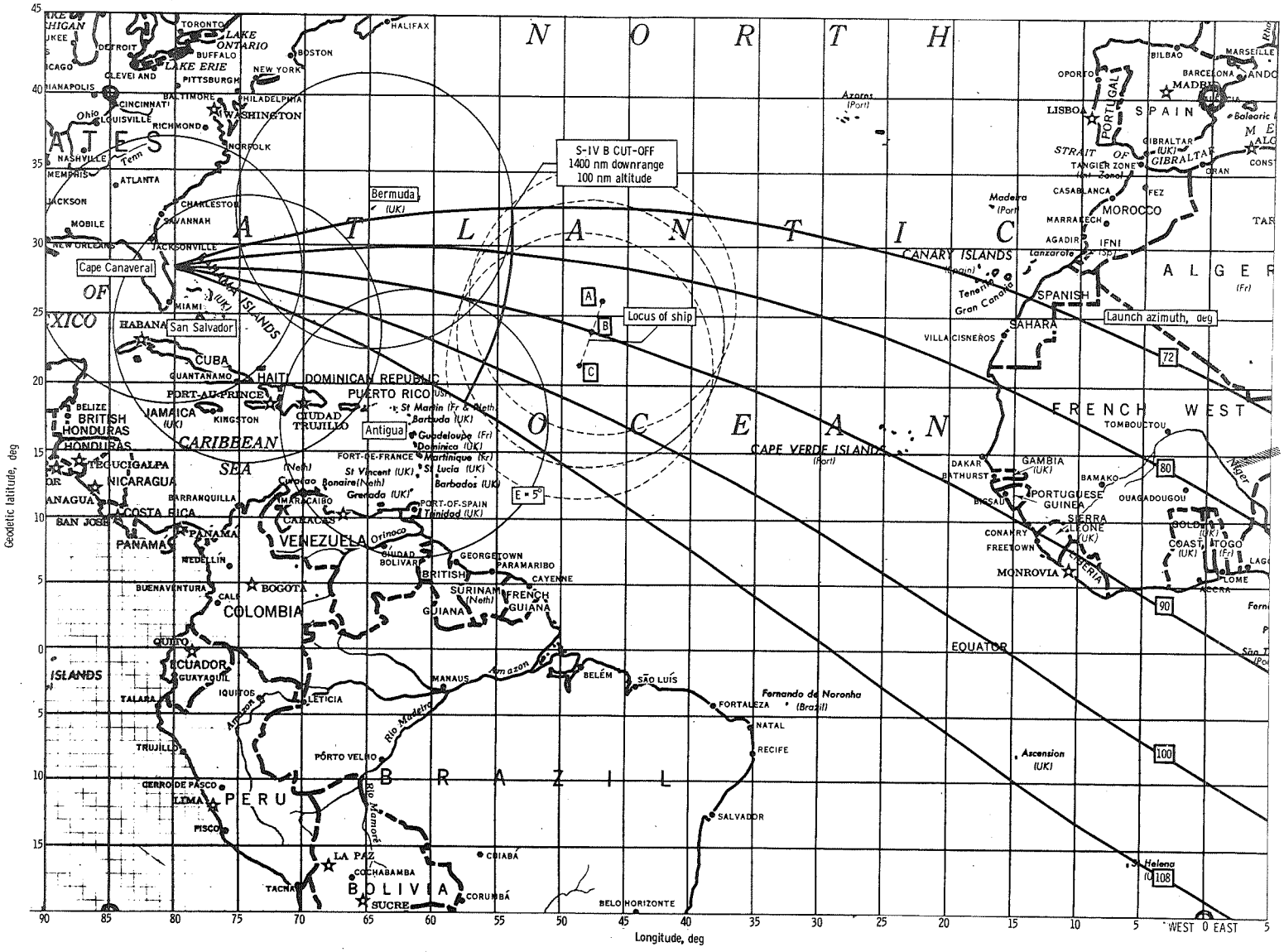
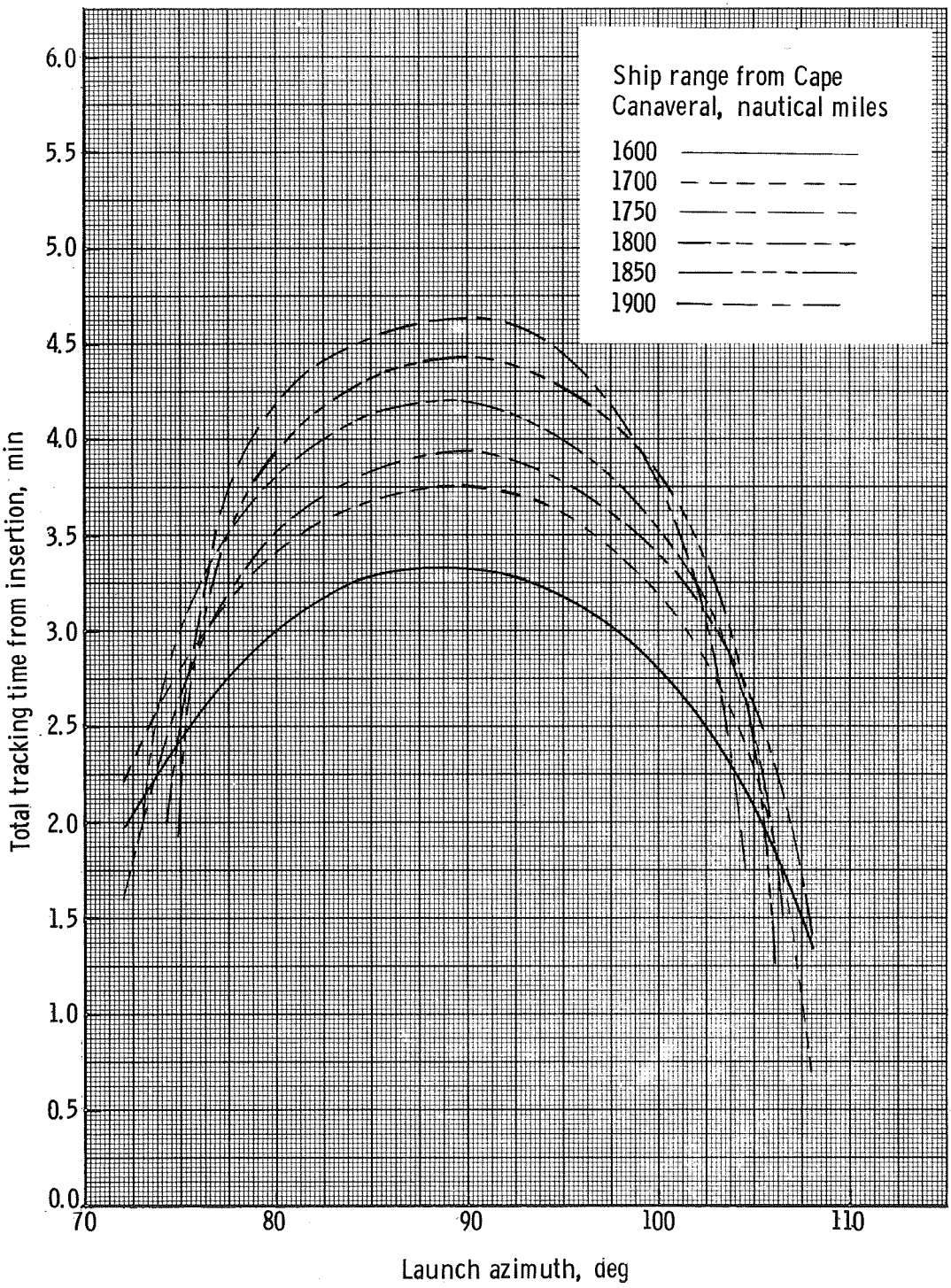
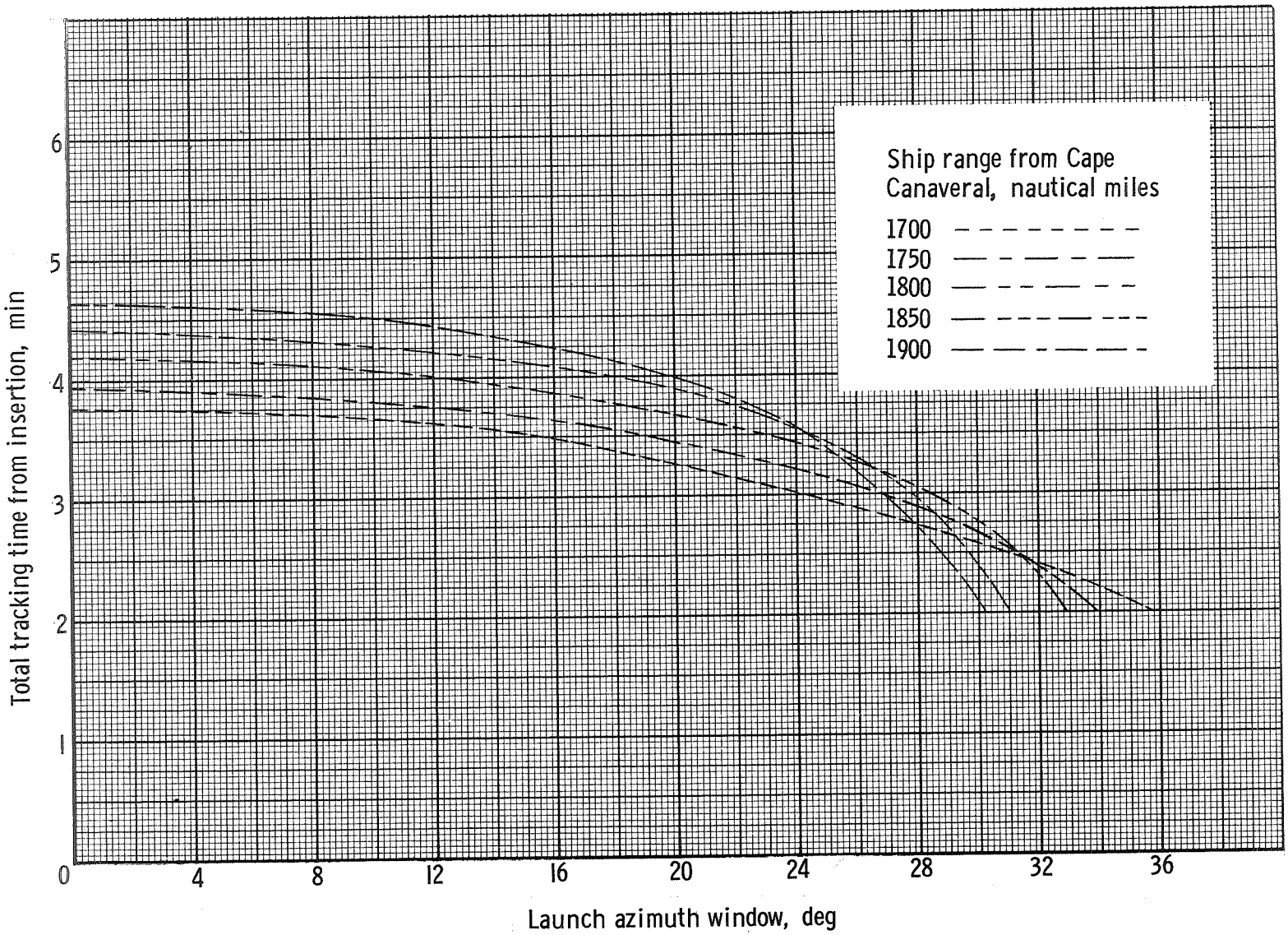


Figure 1. - Insertion area.



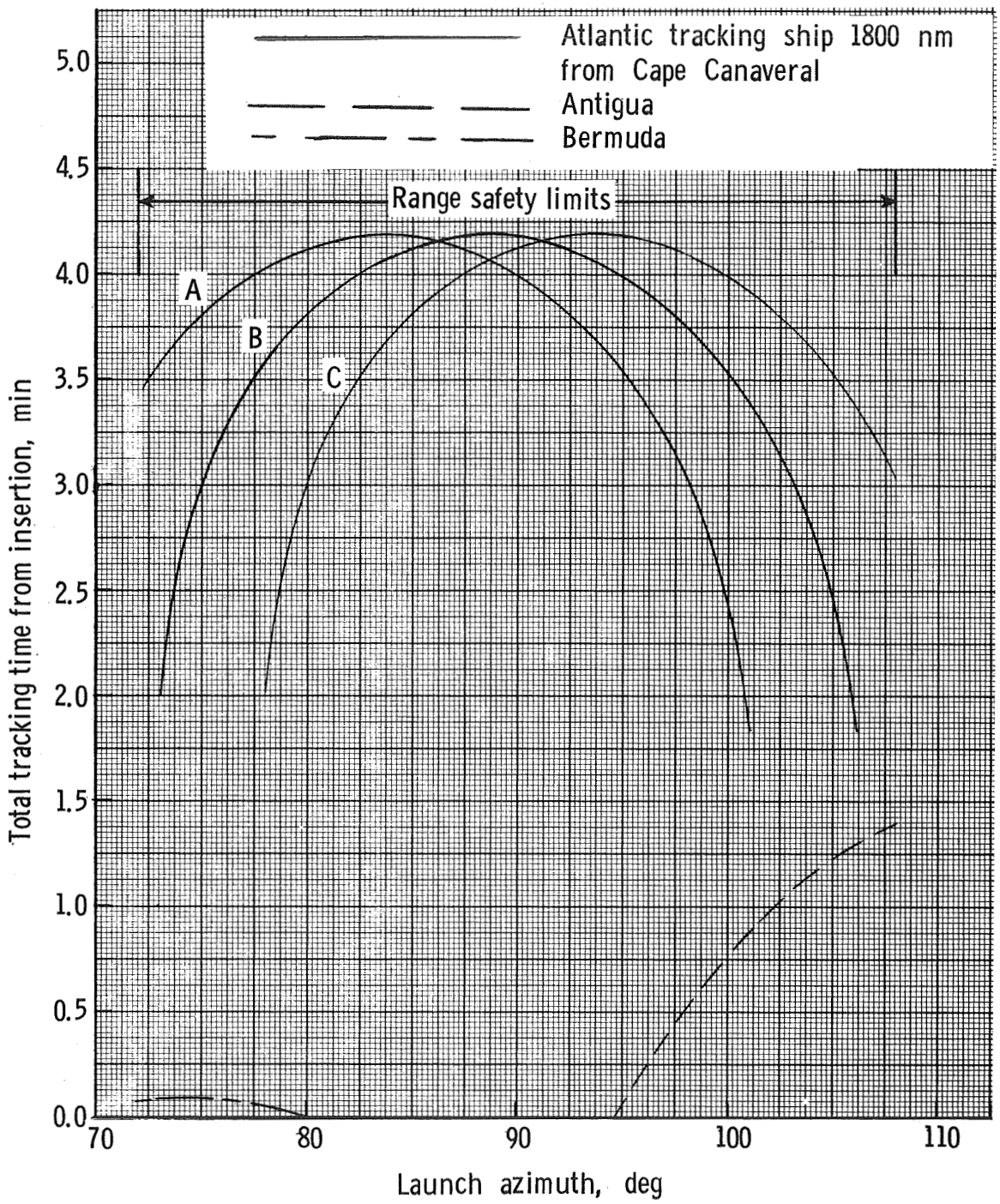
(a) Ships located on ground track of 90° launch azimuth.

Figure 2. - Apollo orbital insertion tracking coverage.



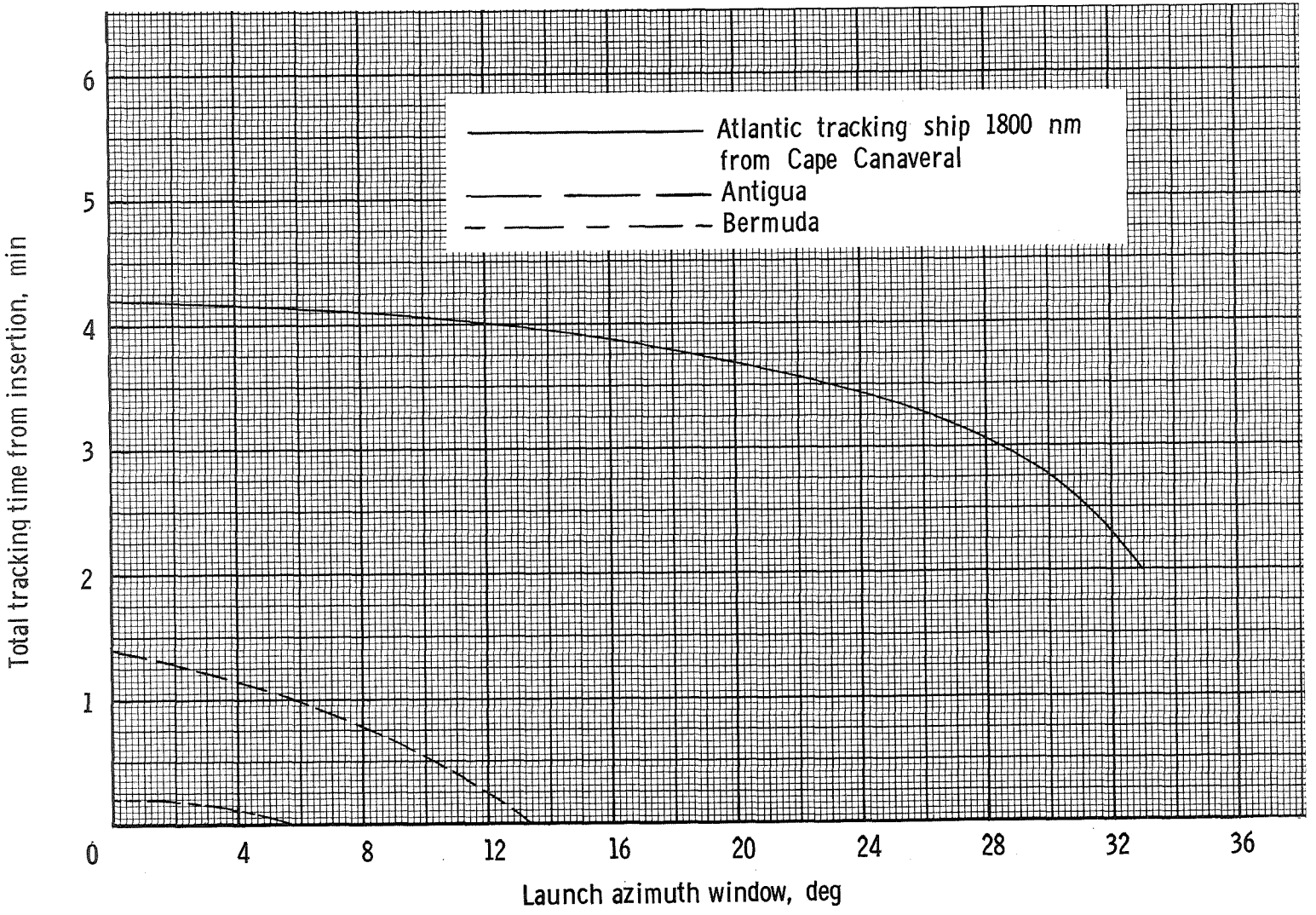
(b) Launch azimuth windows defined as a function of total tracking time for various ship positions.

Figure 2. - Continued.



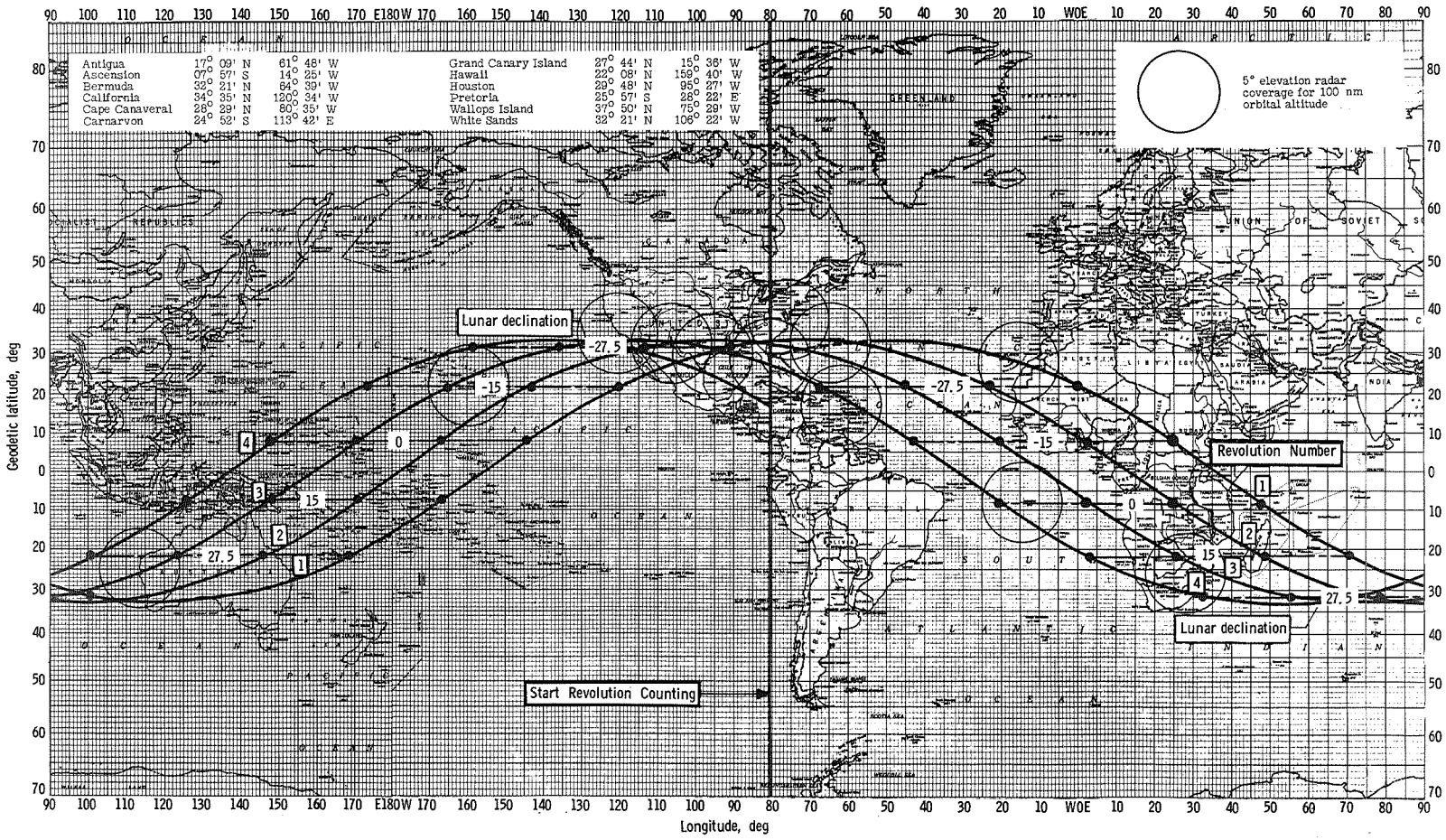
(c) Comparison of land stations and various ship locations (A, B, and C).

Figure 2. - Continued.



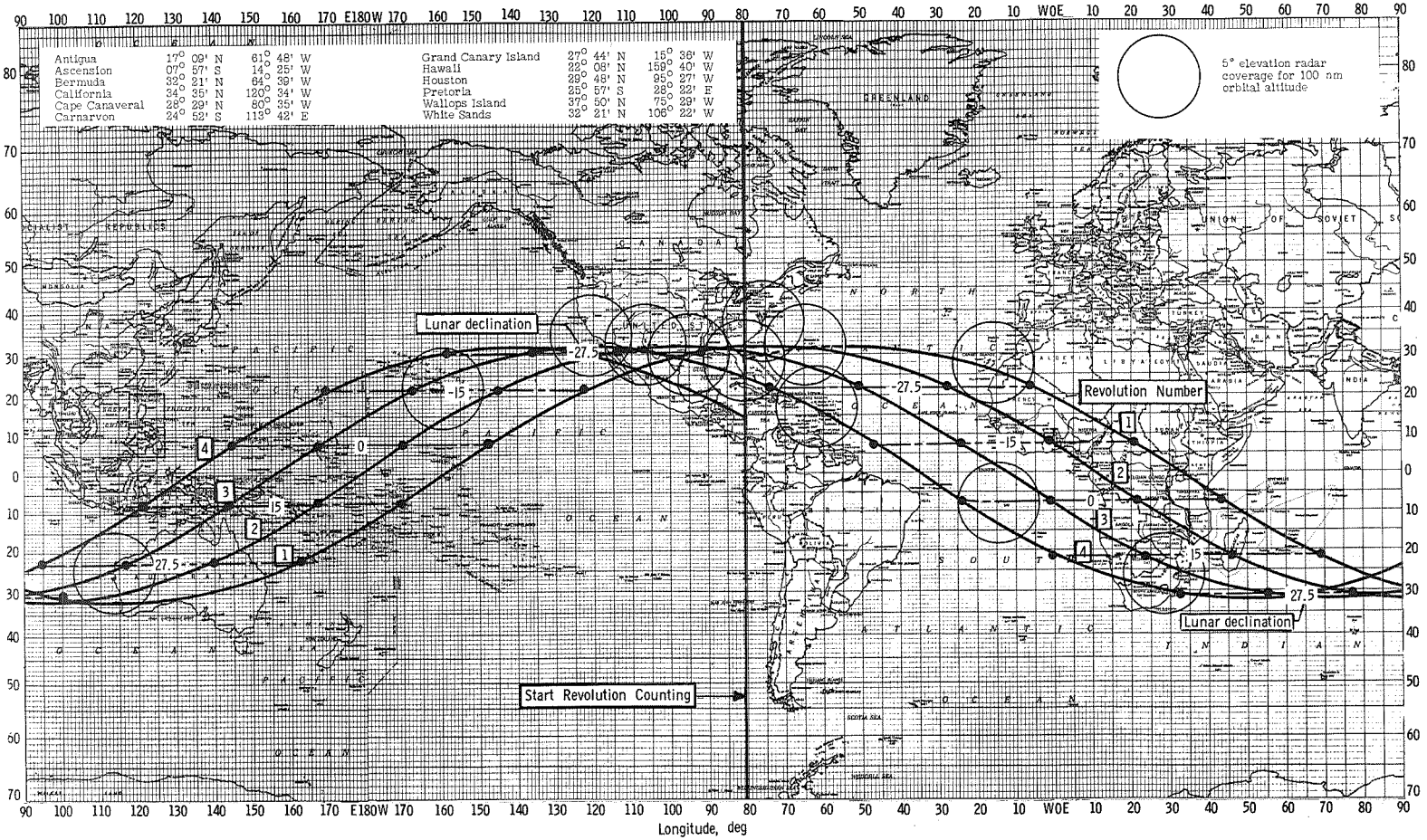
(d) Launch azimuth windows defined as a function of total tracking time for land stations and variable ship locations (A, B, and C).

Figure 2. - Concluded.



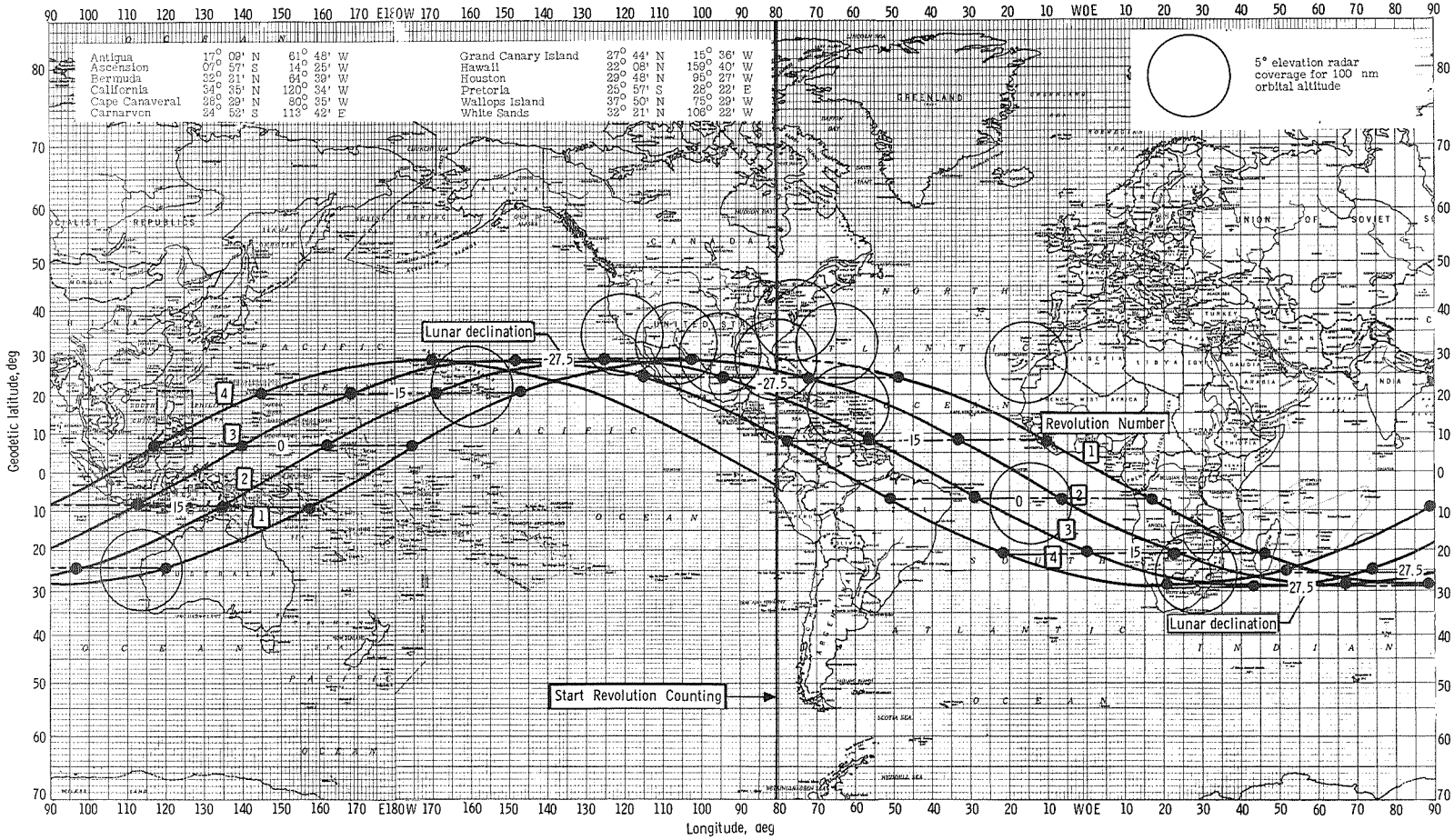
(a) Launch azimuth = 72.6°, inclination angle = 33°.

Figure 3. - Project Apollo earth parking orbit ground tracks with radar coverage circles and possible injection points.



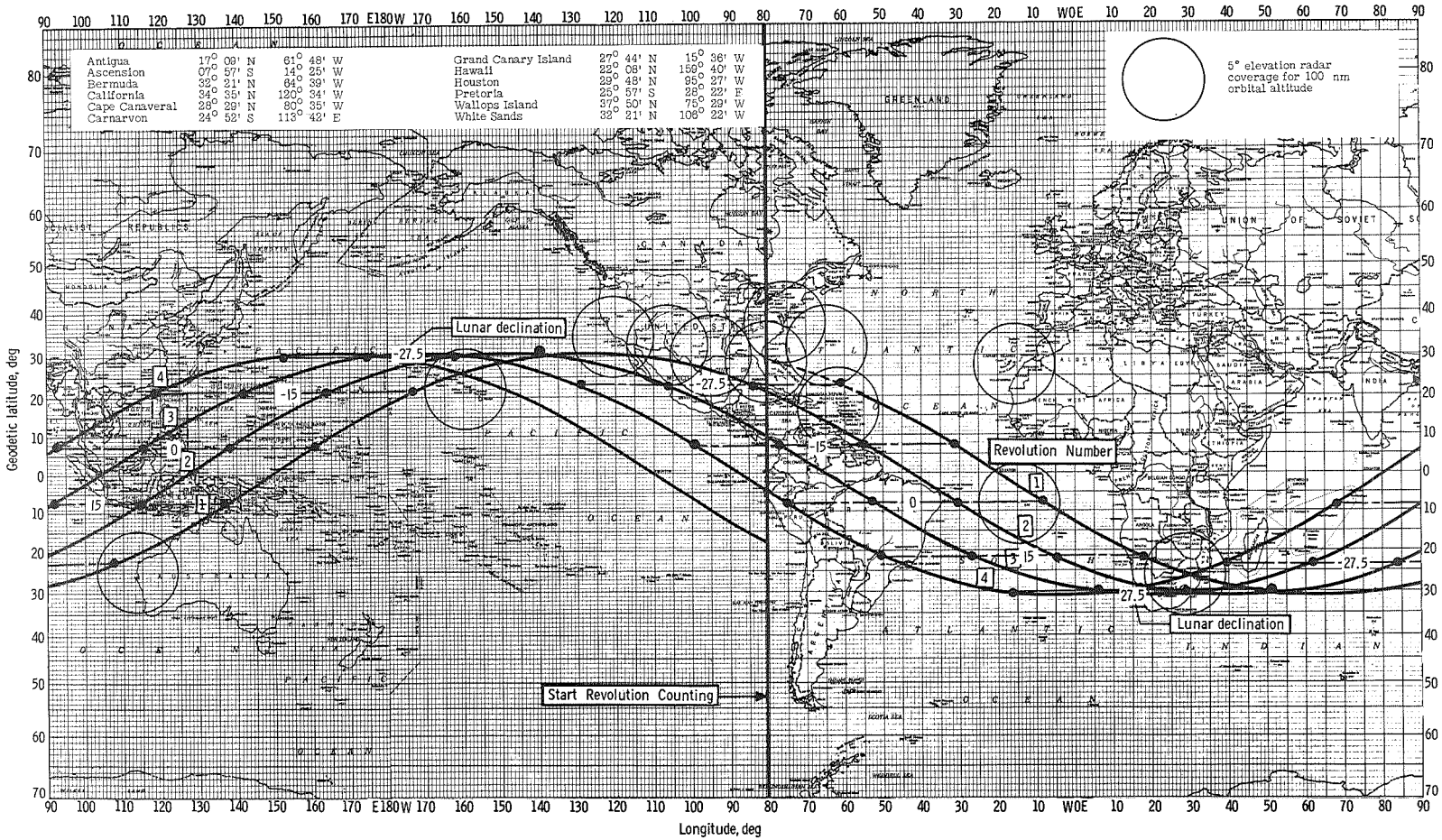
(b) Launch azimuth = 74.8°, inclination angle = 32°.

Figure 3. - Continued.



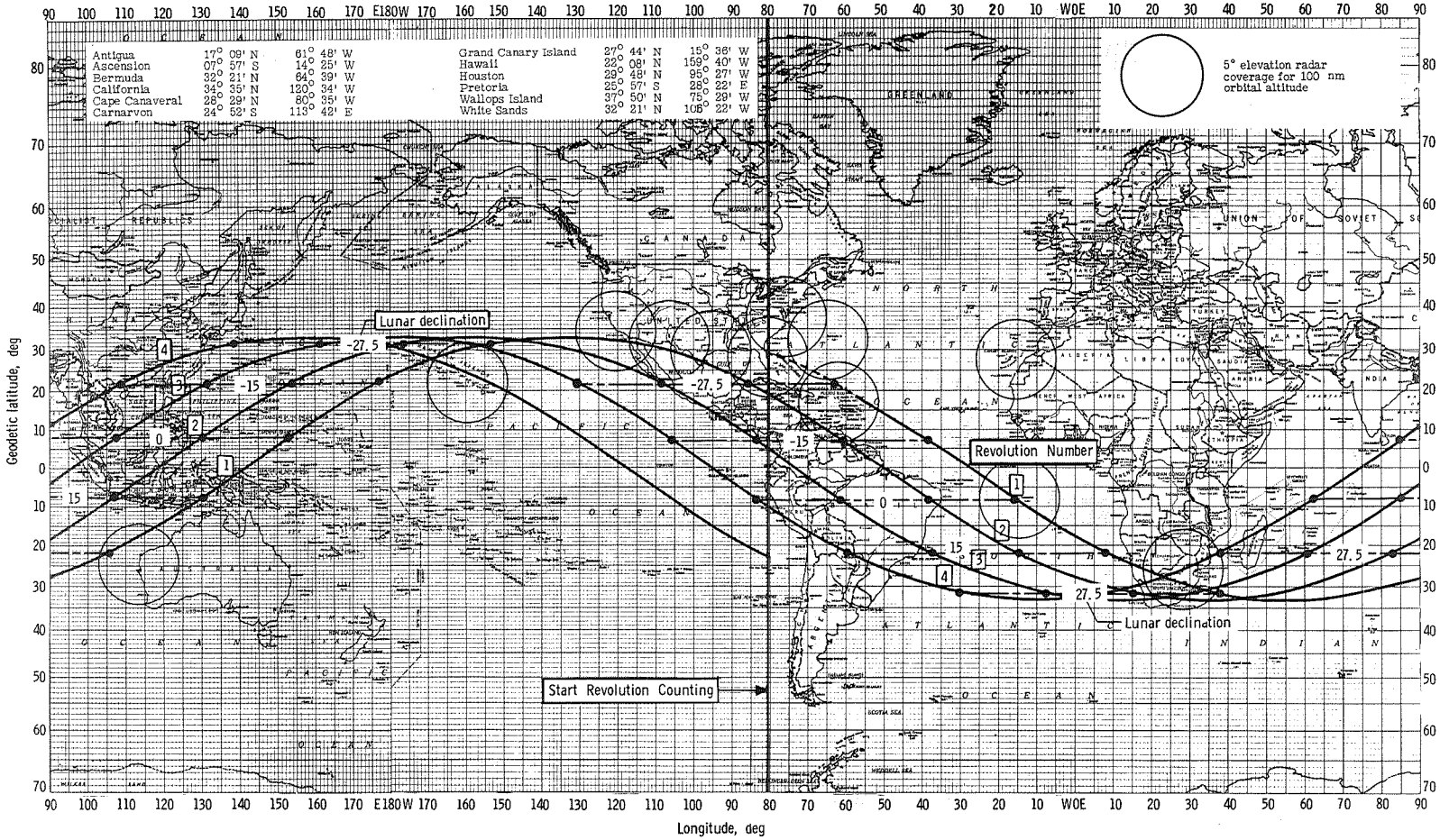
(c) Launch azimuth = 90.0°, inclination angle = 28.5°.

Figure 3. - Continued.



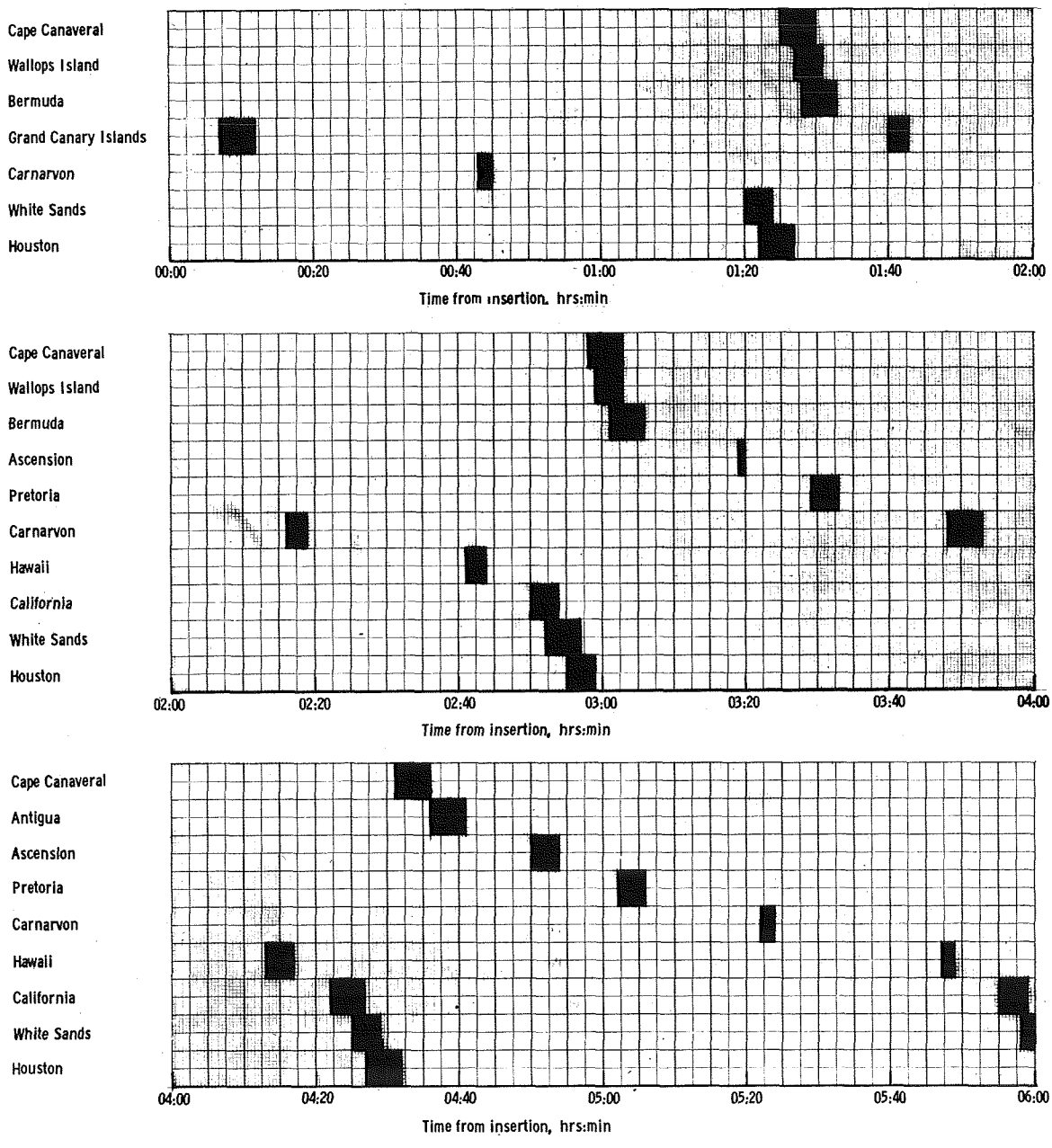
(d) Launch azimuth = 102.7°, inclination angle = 31°.

Figure 3. - Continued.



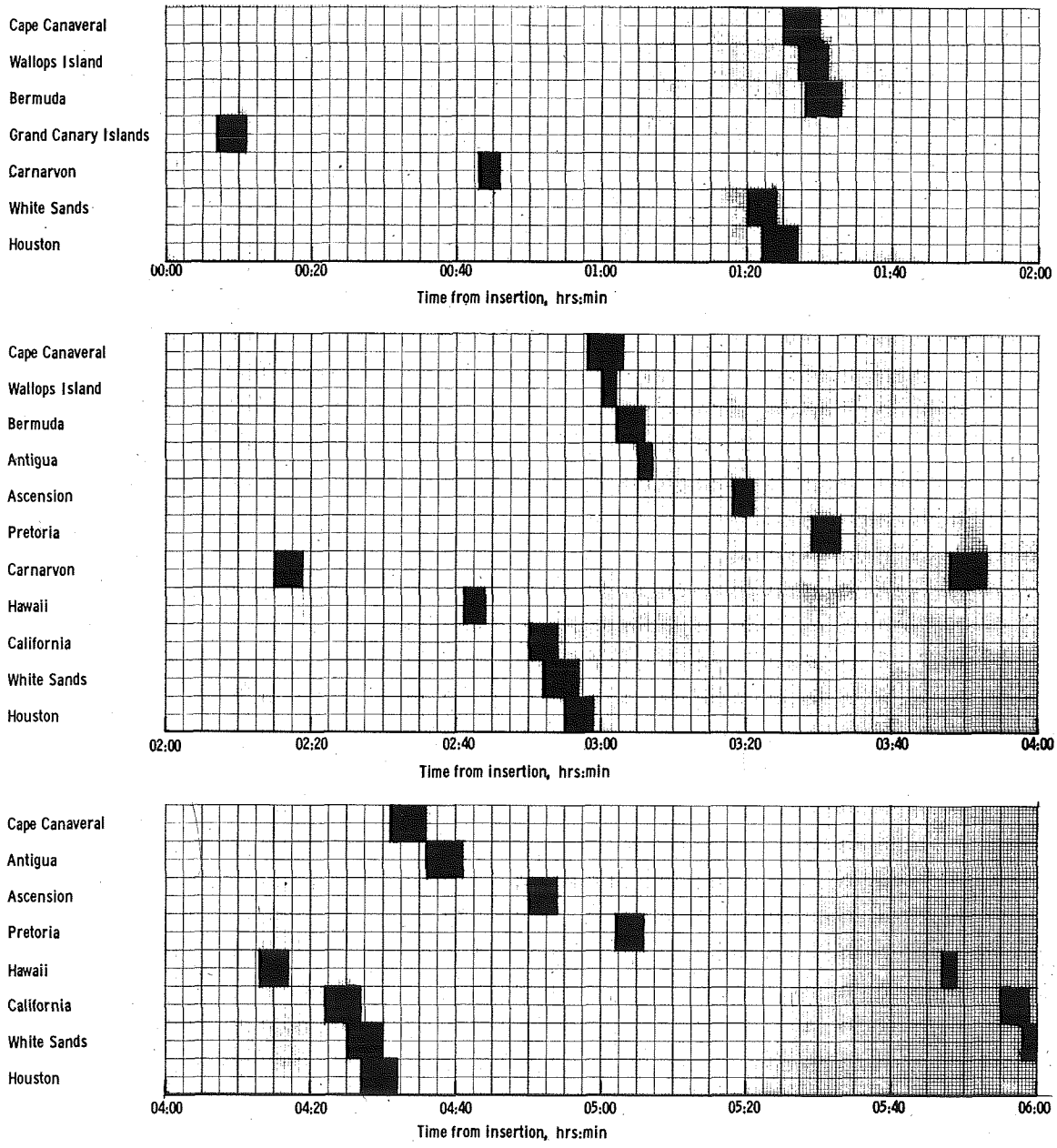
(e) Launch azimuth = 107.4°, inclination angle = 33°.

Figure 3. - Concluded.



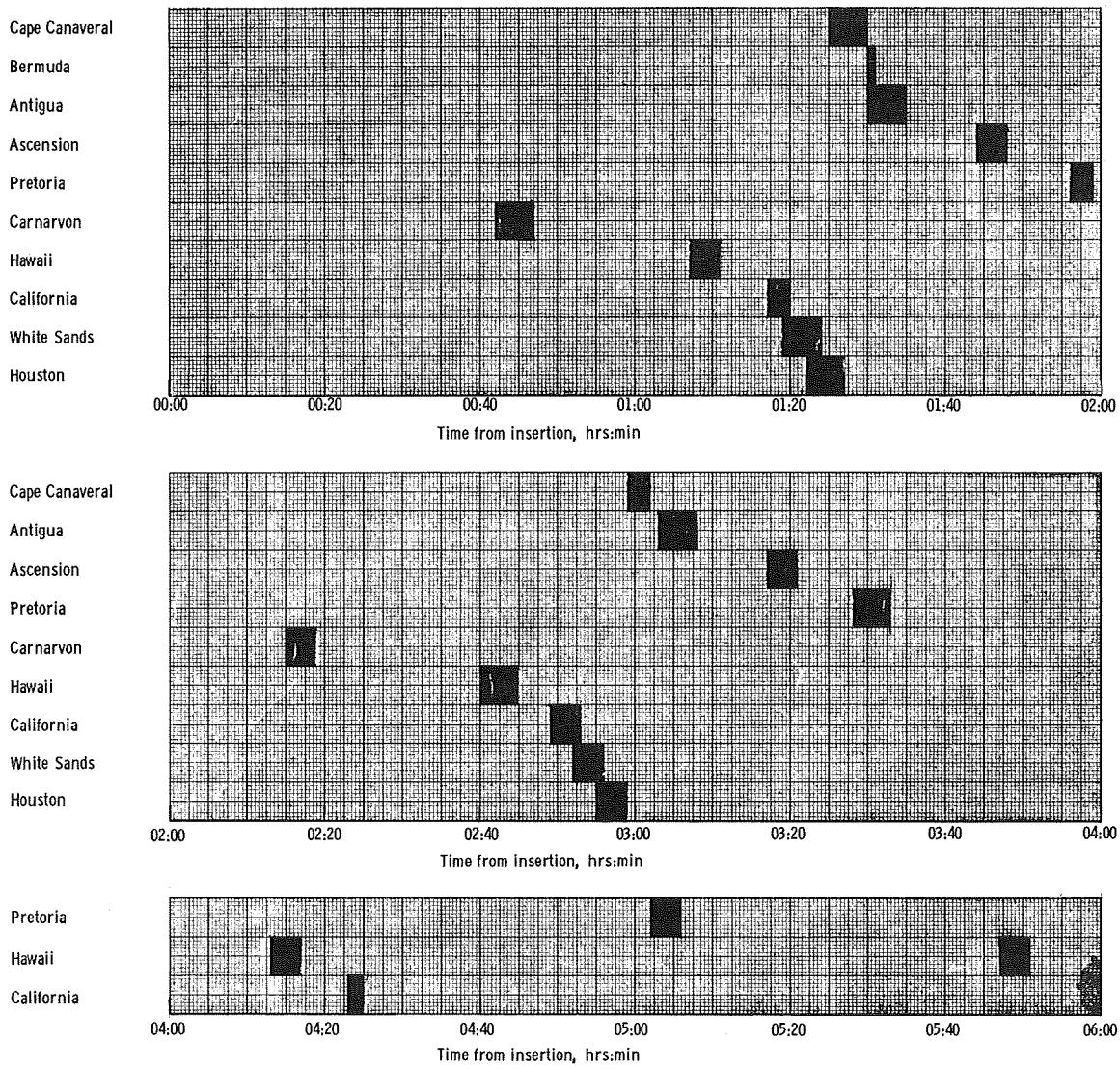
(a) Inclination 33°, launch azimuth 72.6°

Figure 4. - Radar contact time with vehicle for earth parking orbits.



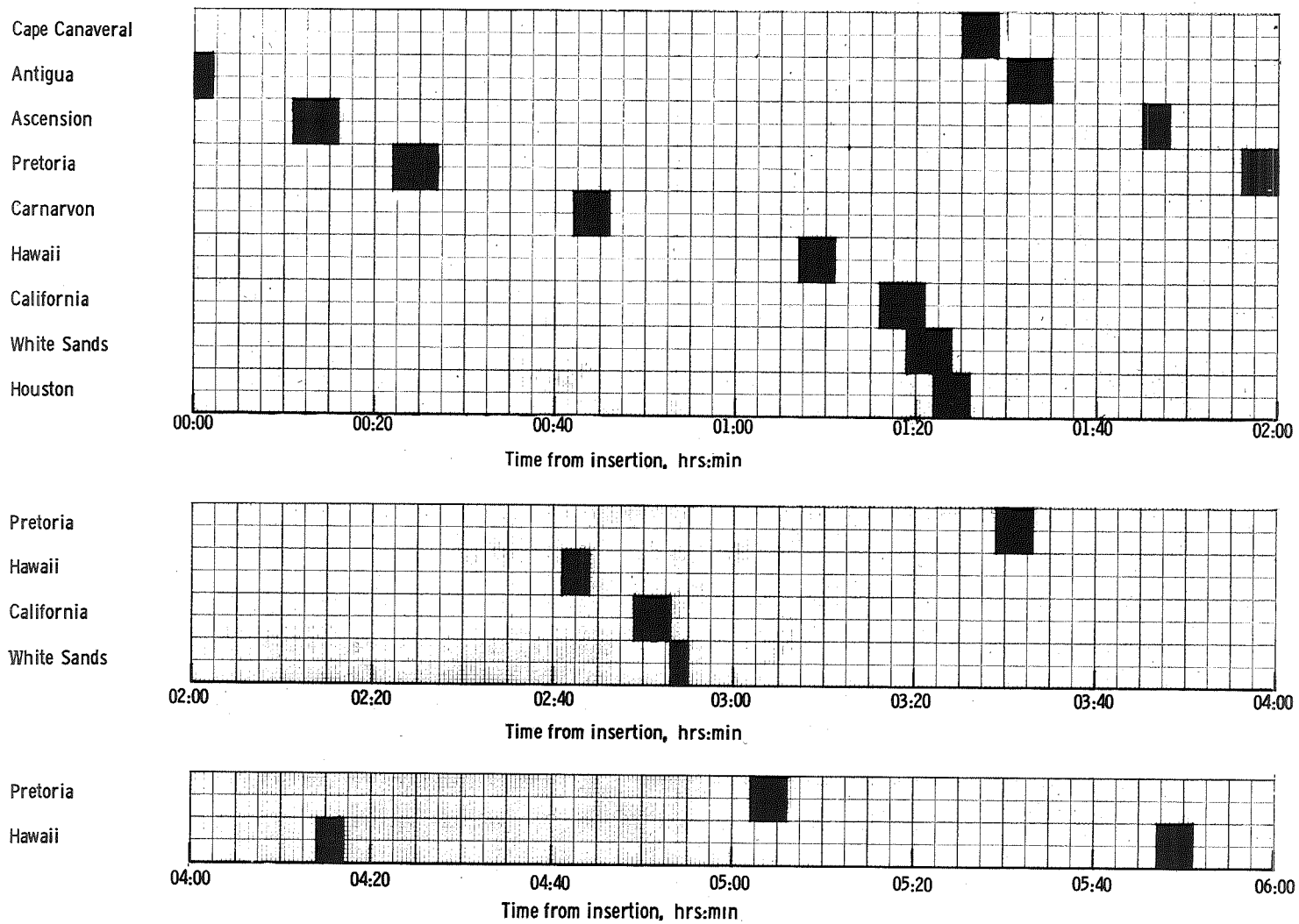
(b) Inclination 32°, launch azimuth 74.8°.

Figure 4. - Continued.



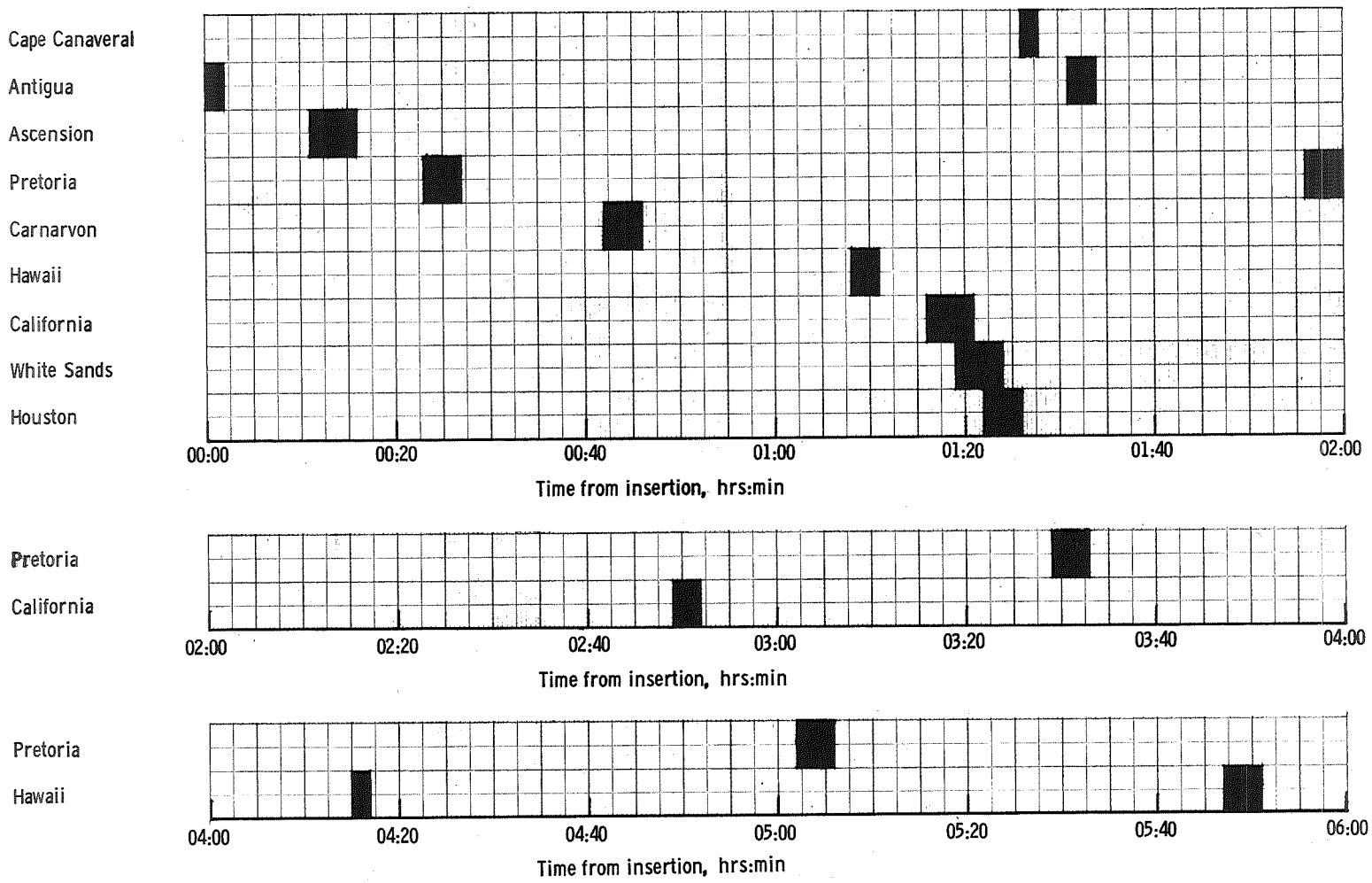
(c) Inclination 28.5°, launch azimuth 90°.

Figure 4. - Continued.



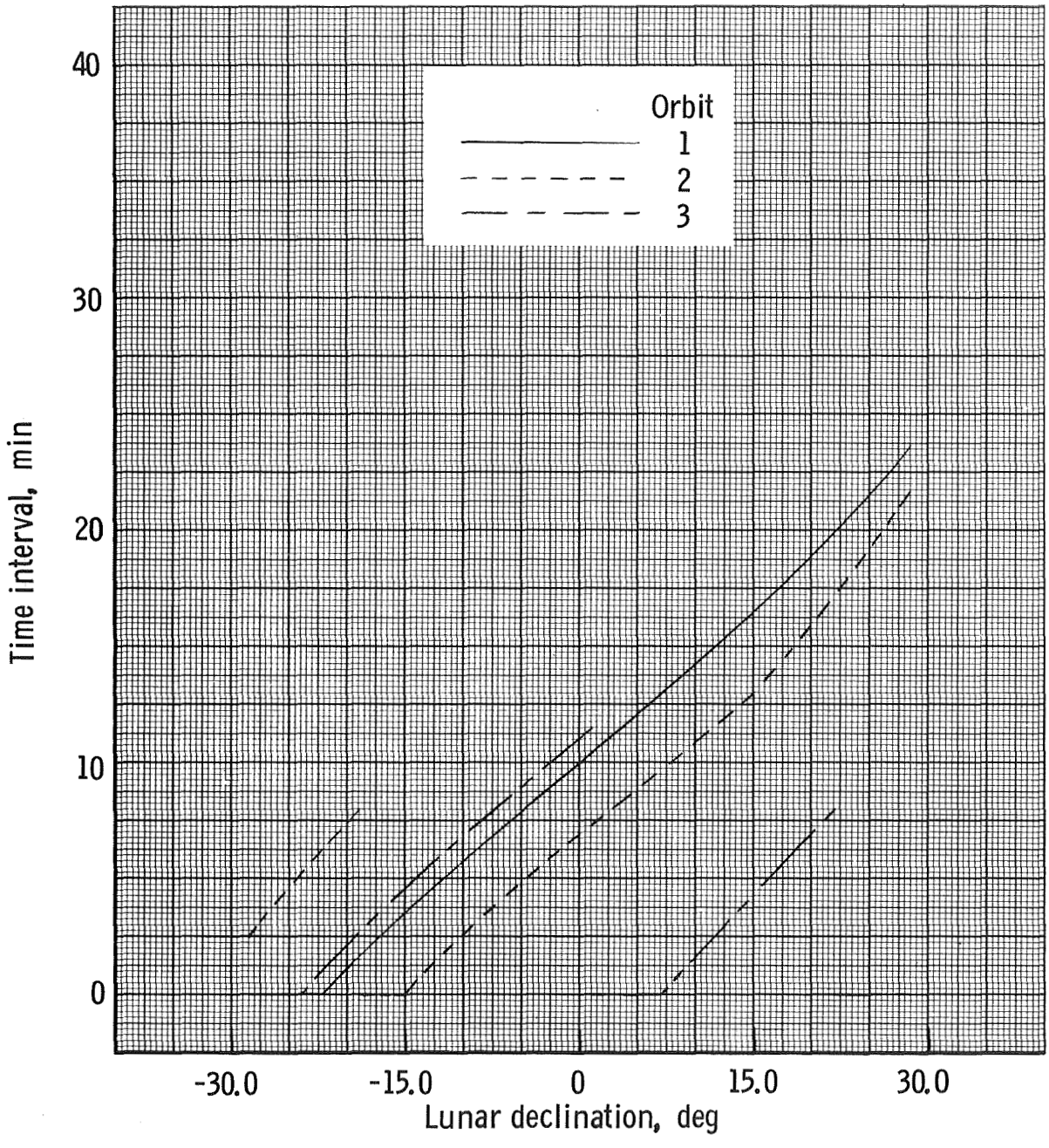
(d) Inclination 31°, launch azimuth 102.7°.

Figure 4. - Continued.



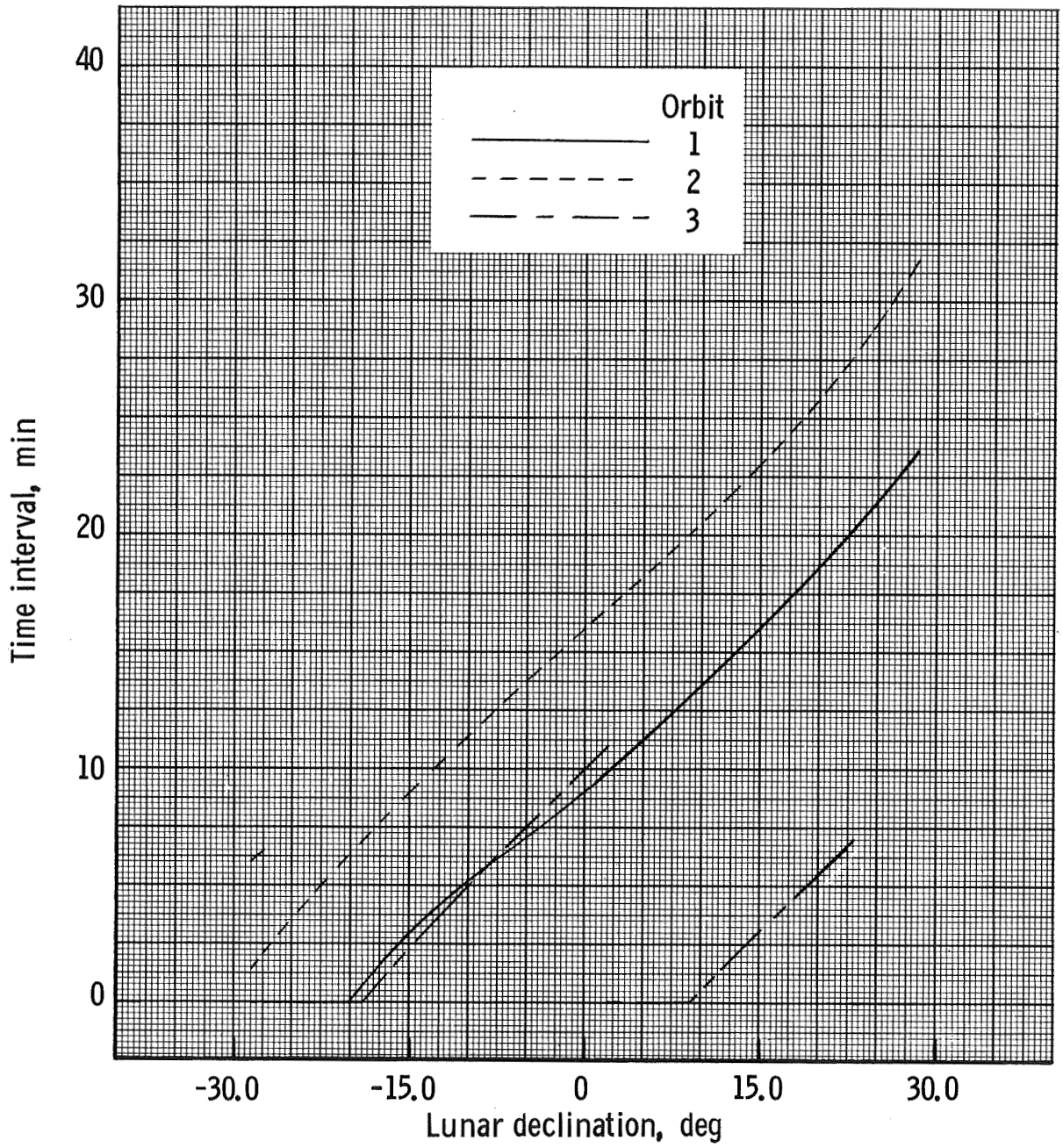
(e) Inclination 33°, launch azimuth 107.4°.

Figure 4. - Concluded.



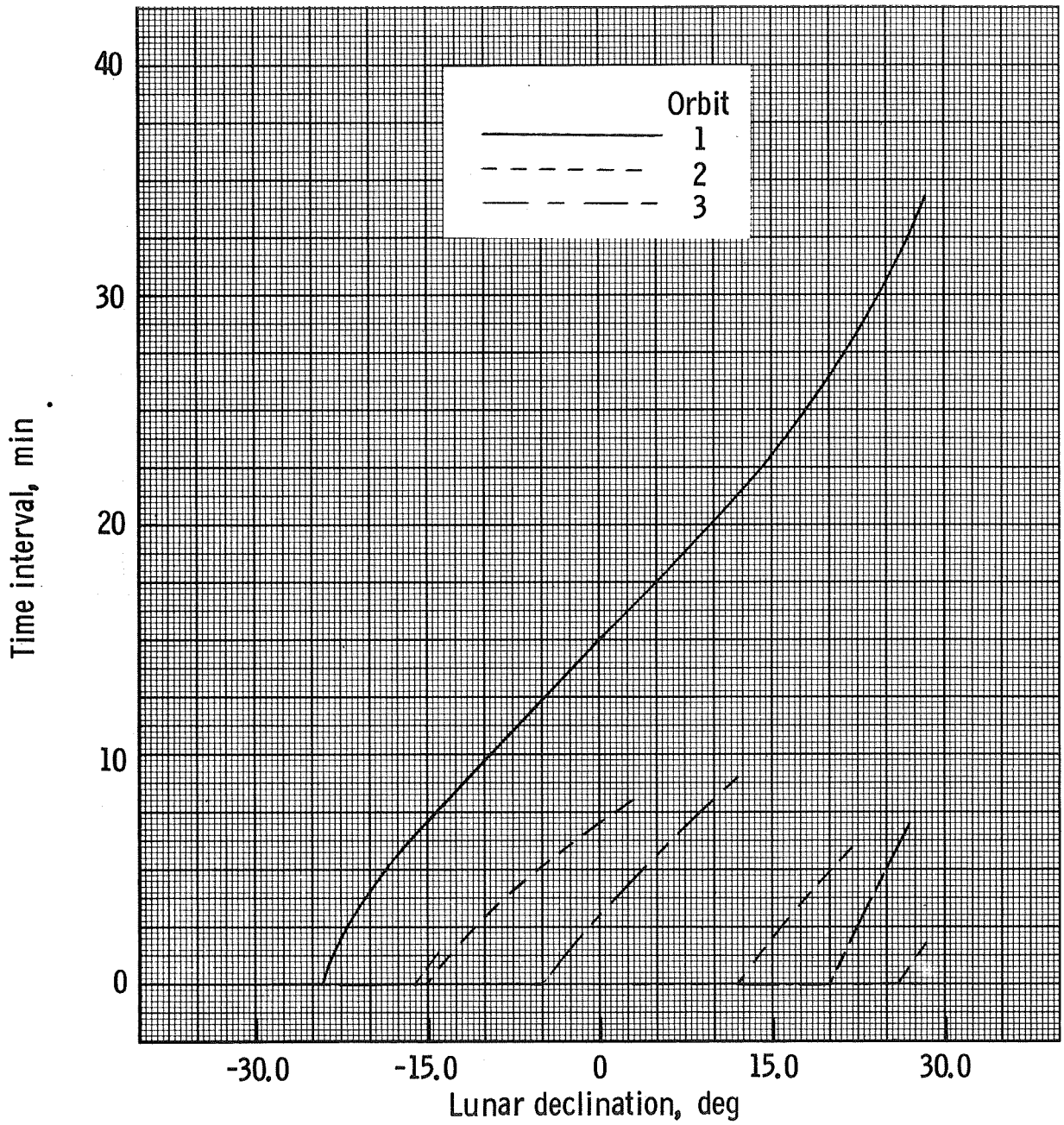
(a) Inclination 33.0°, launch azimuth 72.6°, Atlantic injection area.

Figure 5. - Time interval from final radar contact in an earth parking orbit to initiation of translunar injection thrusting.



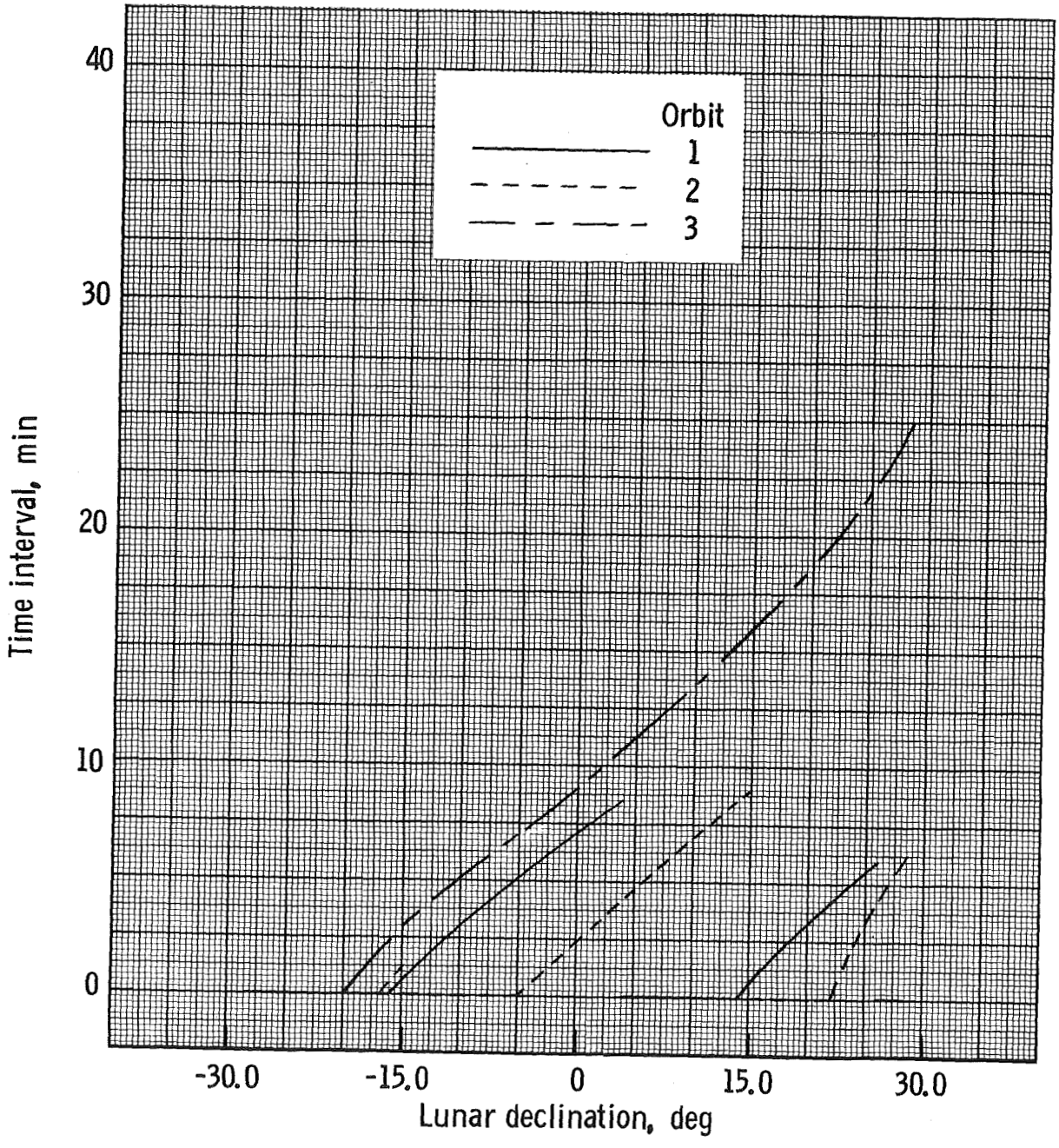
(b) Inclination 32.0°, launch azimuth 74.8°, Atlantic injection area.

Figure 5. - Continued.



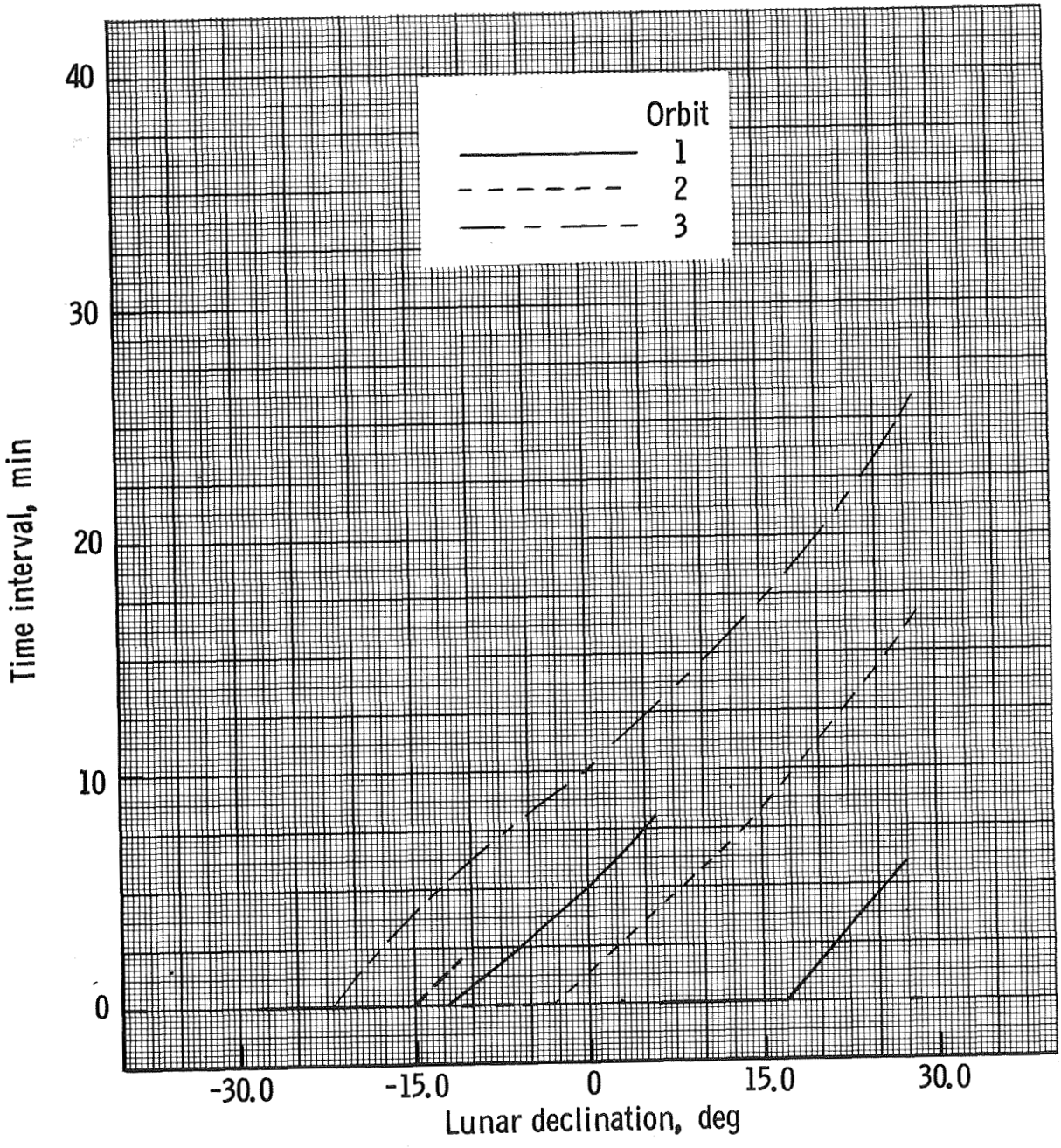
(c) Inclination 28.5°, launch azimuth 90.0°, Atlantic injection area.

Figure 5. - Continued.



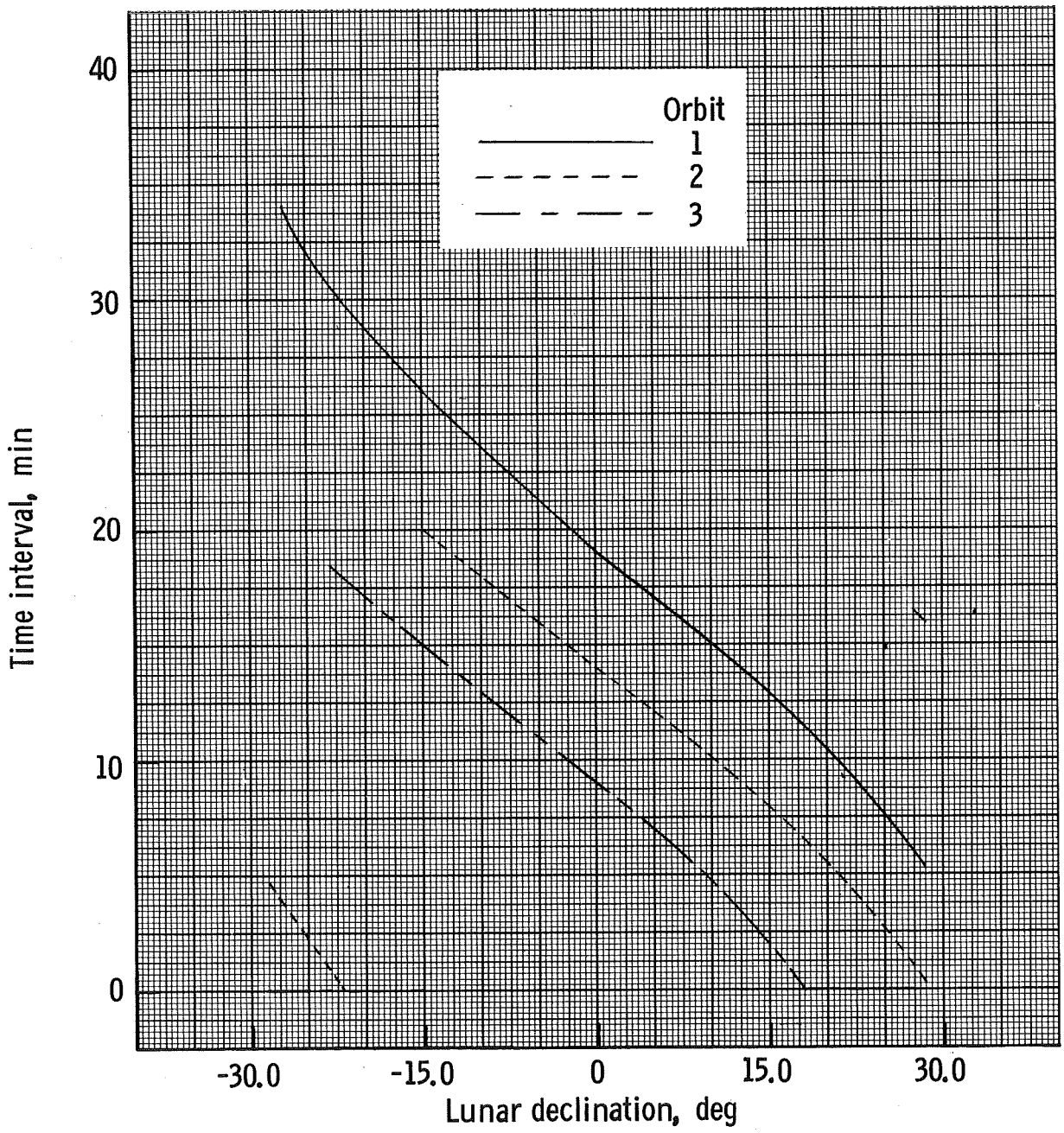
(d) Inclination 31.0°, launch azimuth 102.7°, Atlantic injection area.

Figure 5. - Continued.



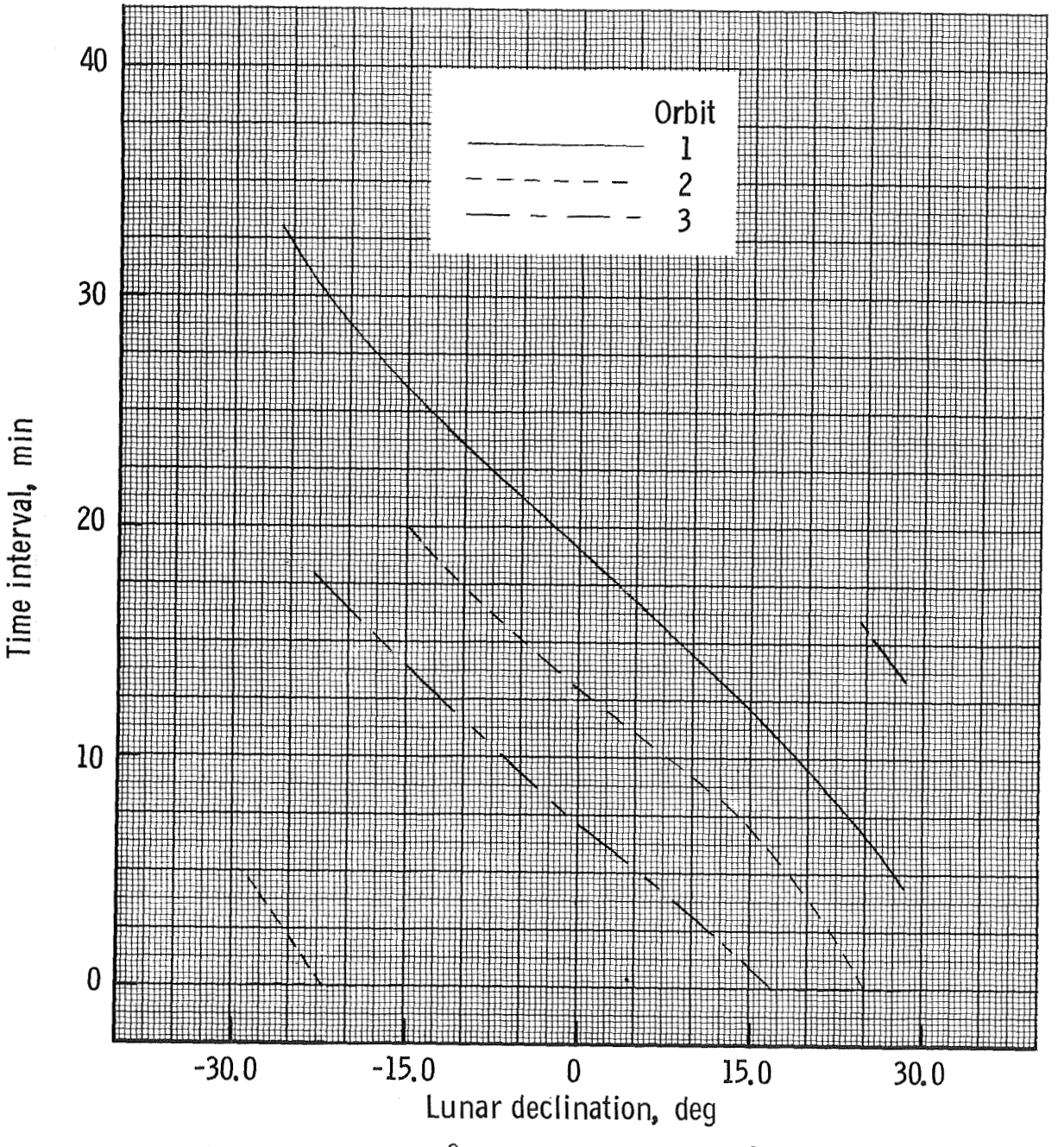
(e) Inclination 33.0°, launch azimuth 107.4°, Atlantic injection area.

Figure 5. - Continued.



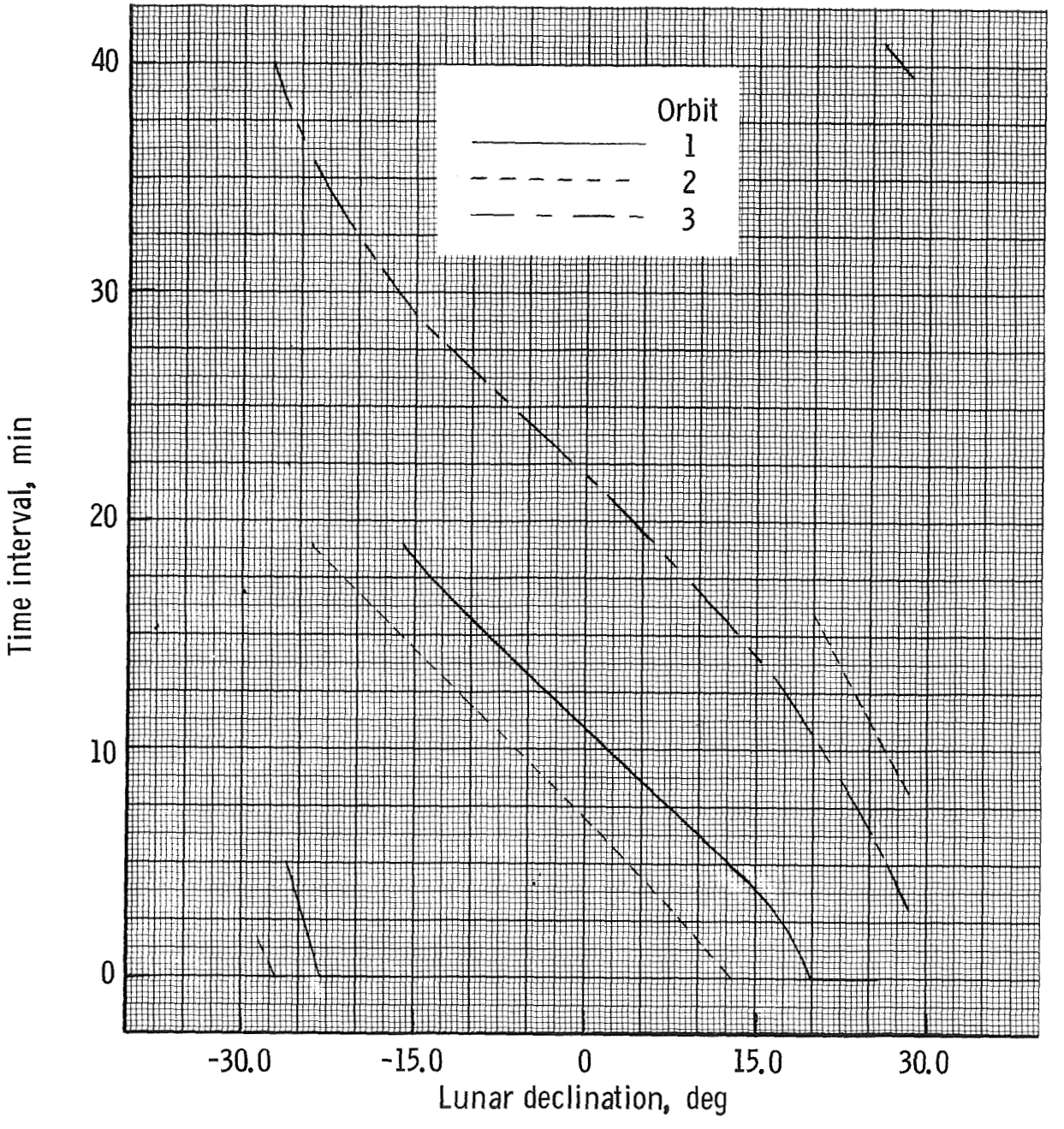
(f) Inclination 33.0°, launch azimuth 72.6°, Pacific injection area.

Figure 5. - Continued.



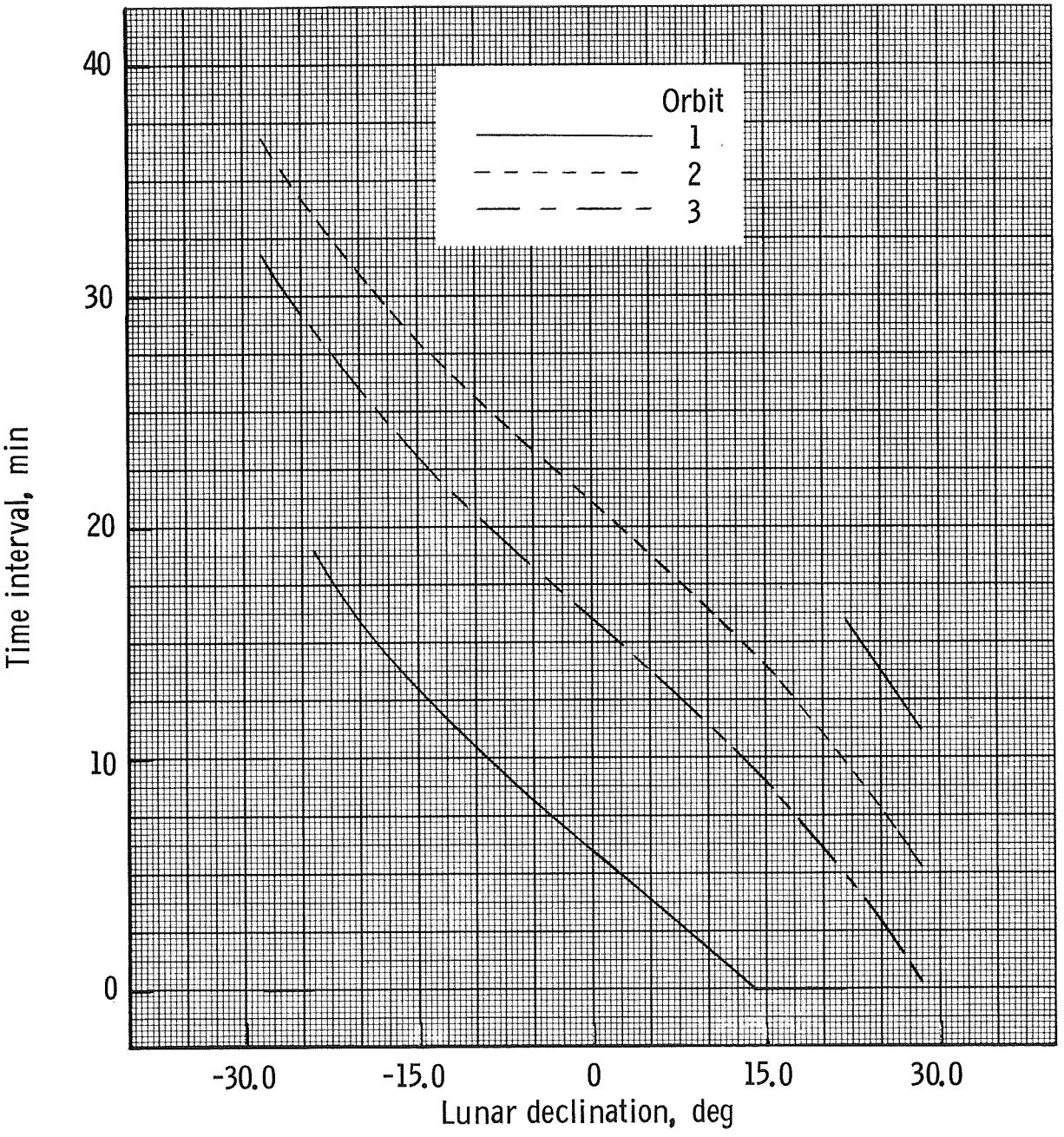
(g) Inclination 32.0°, launch azimuth 74.8°, Pacific injection area.

Figure 5. - Continued.



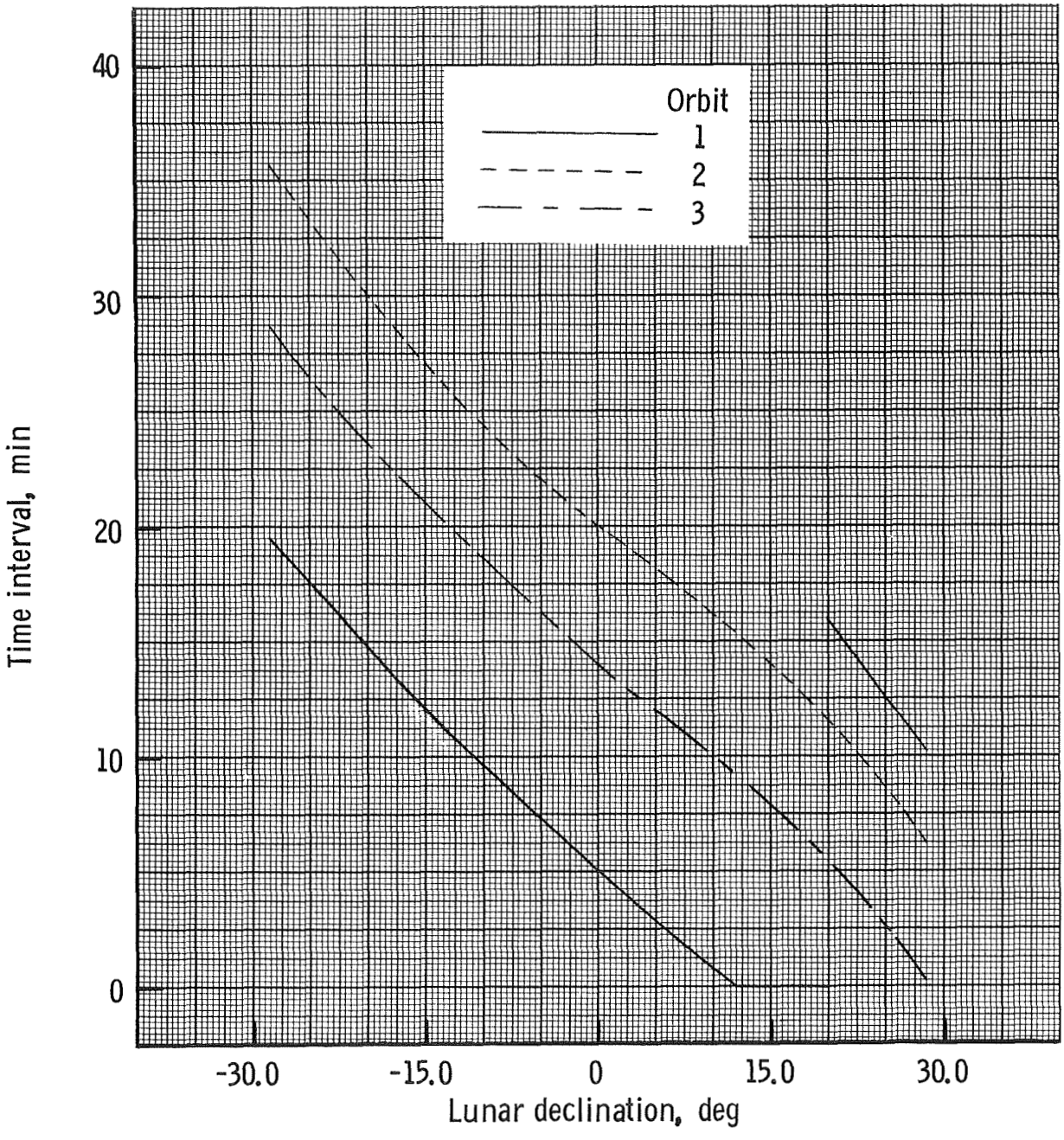
(h) Inclination 28.5°, launch azimuth 90.0°, Pacific injection area.

Figure 5. - Continued.



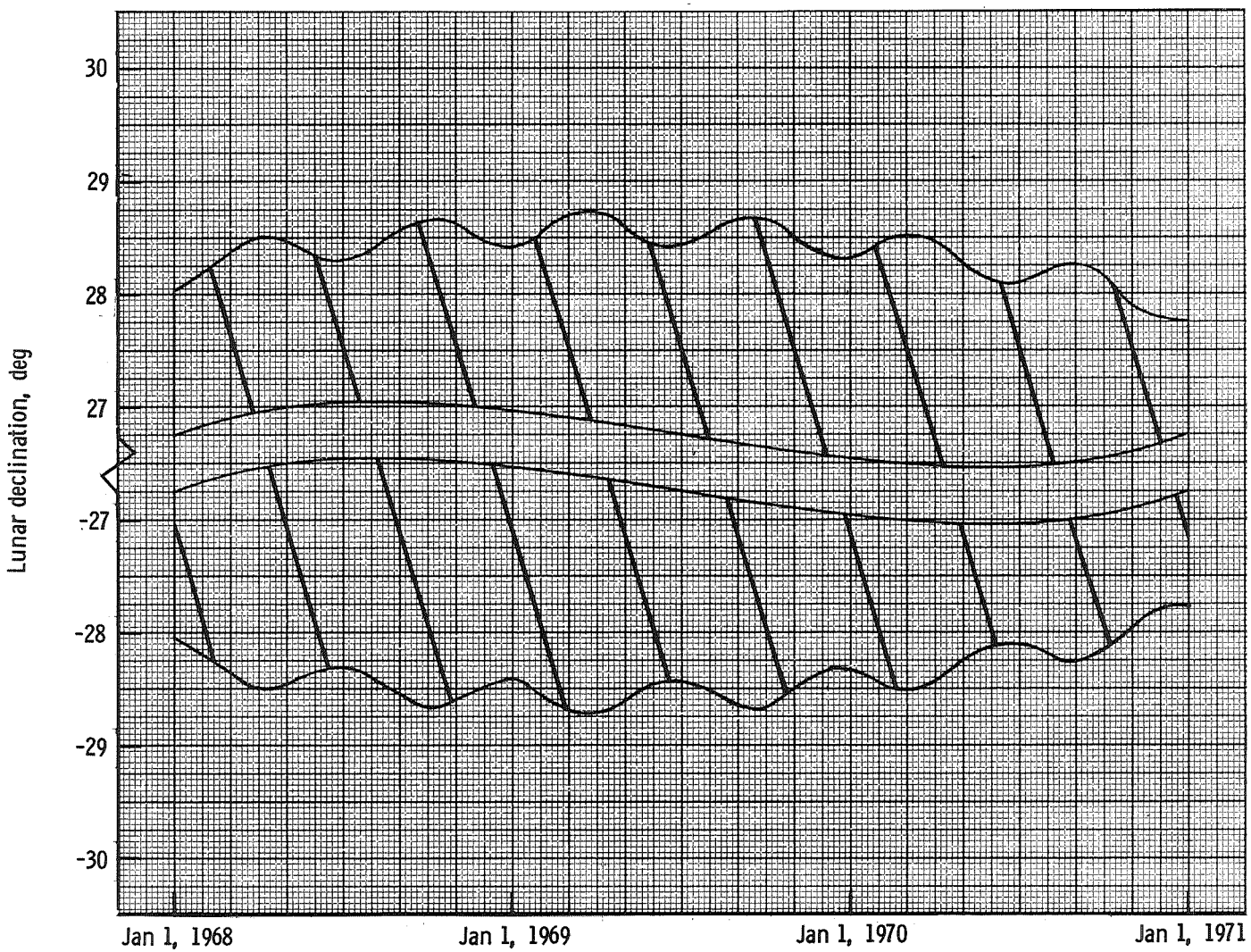
(i) Inclination 31.0°, launch azimuth 102.7°, Pacific injection area.

Figure 5. - Continued.



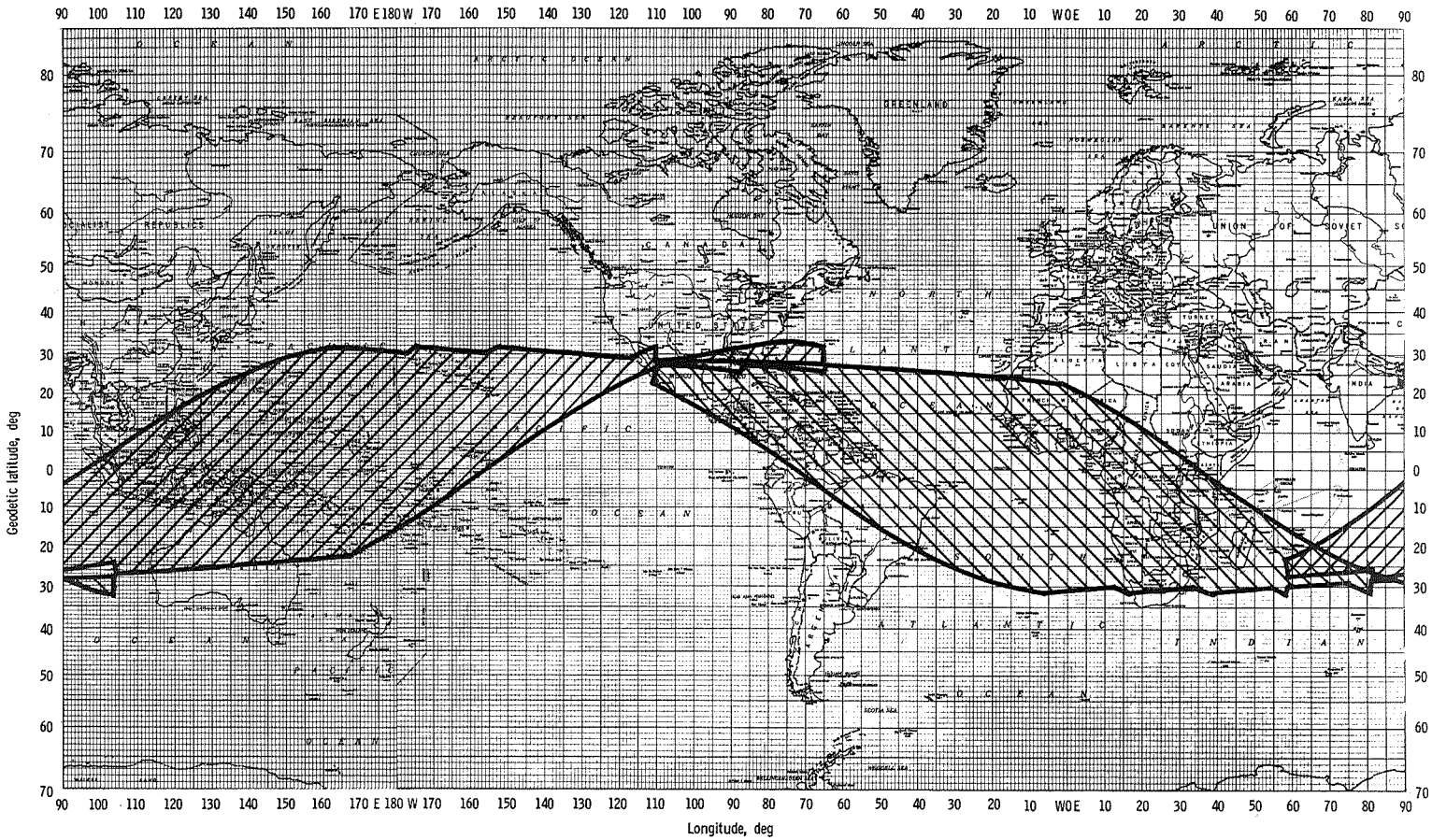
(j) Inclination 33.0°, launch azimuth 107.4°, Pacific injection area.

Figure 5. - Concluded.



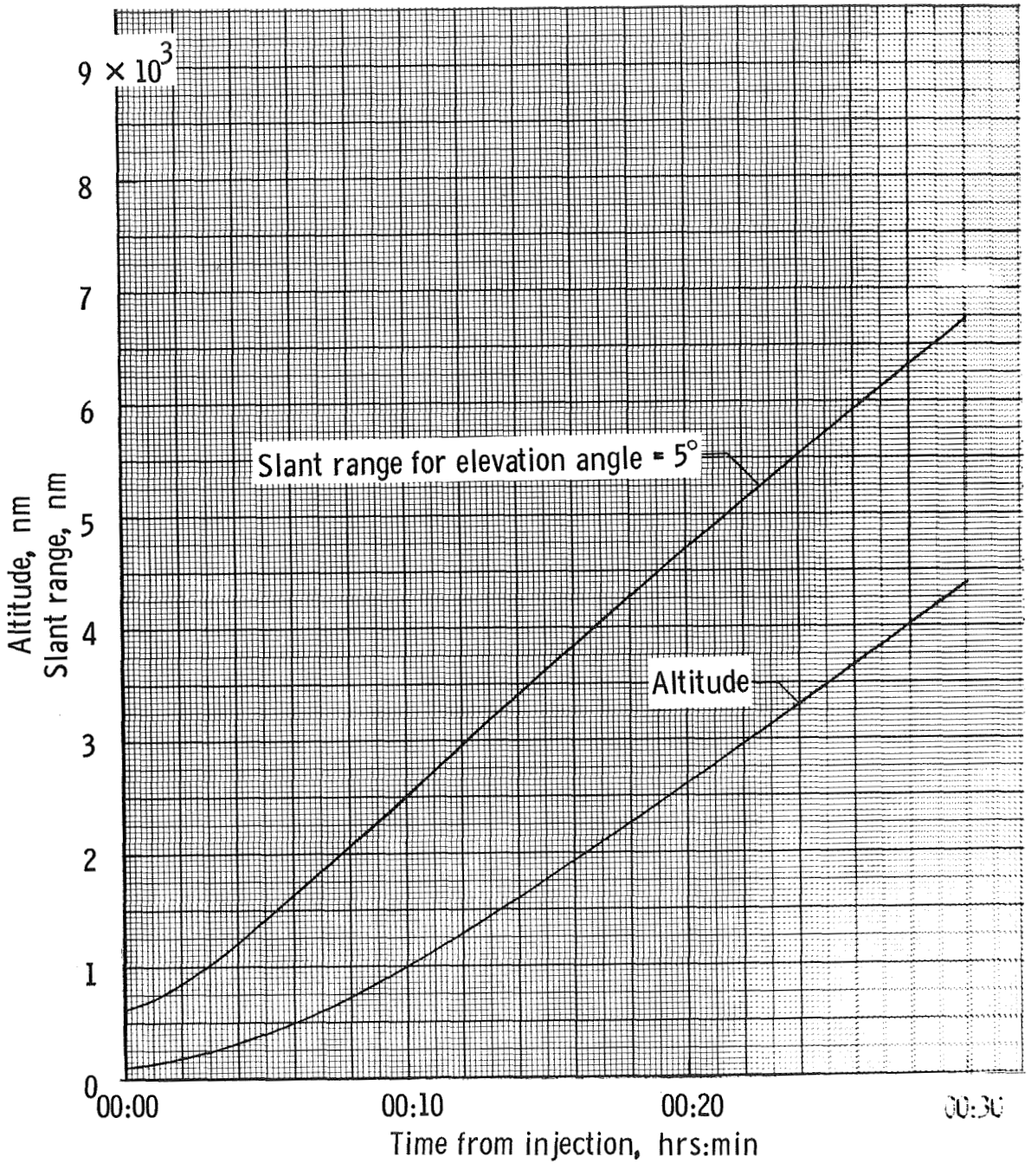
(a) Maximum range of lunar declination.

Figure 6. - Maximum range of lunar declination for 1968, 1969, and 1970 and its influence on the total injection area in 1970.



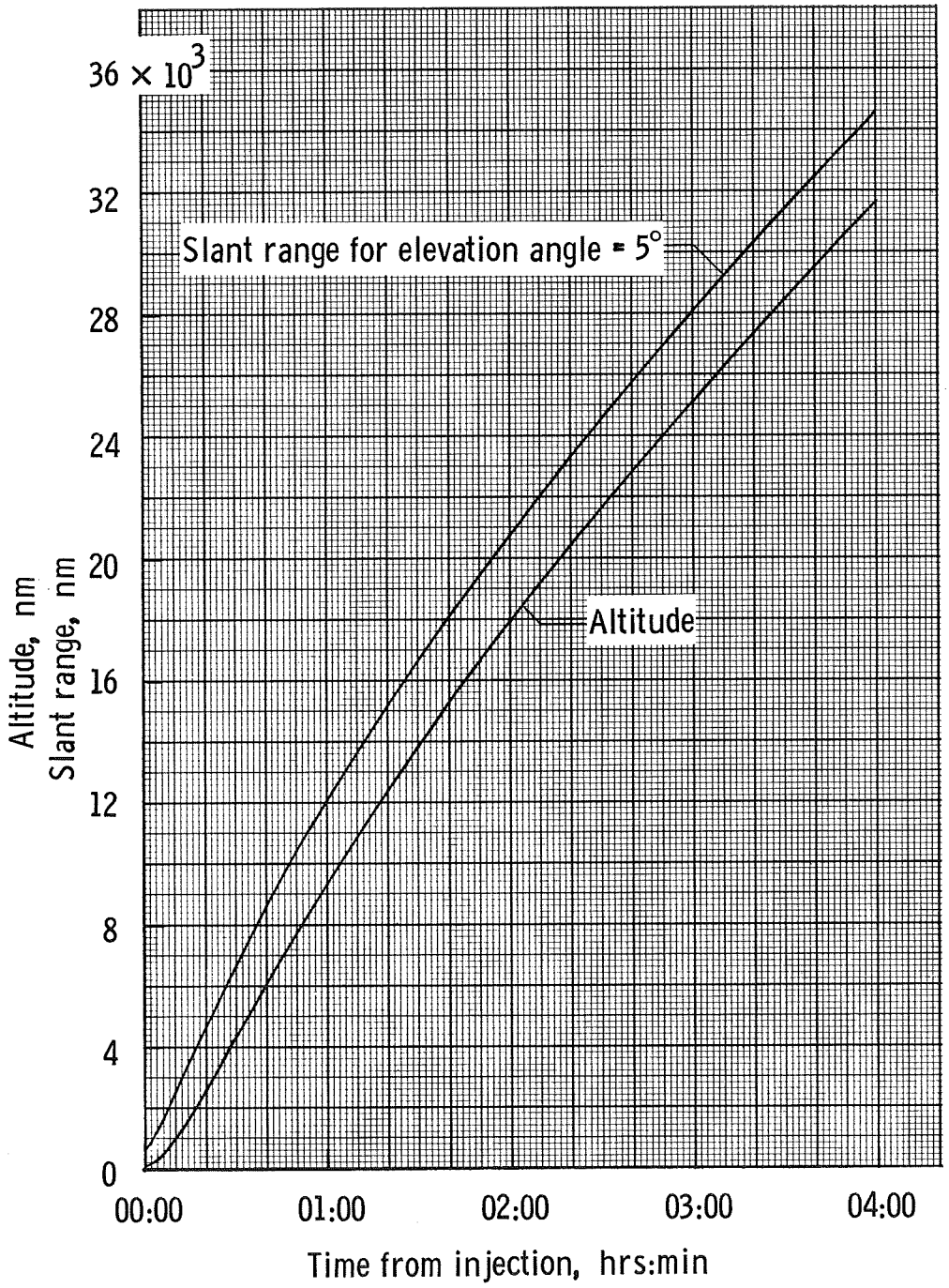
(b) Atlantic and Pacific injection areas for -28.5° to 28.5° lunar declinations for the first three earth parking orbits from launch azimuths of 72° to 108°.

Figure 6. - Concluded.



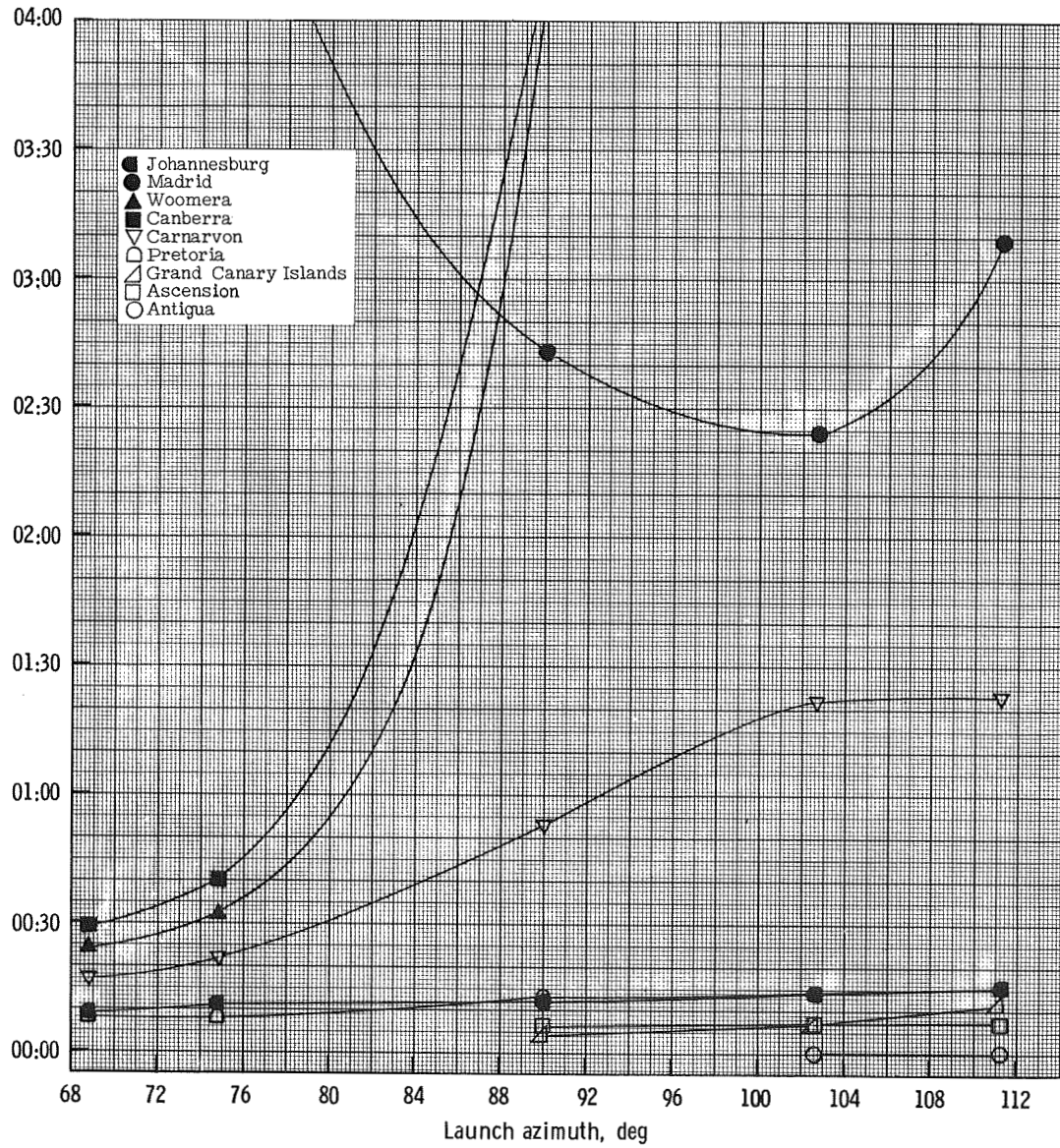
(a) From injection to 30 minutes.

Figure 7. - Altitude and radar slant range of spacecraft versus time from injection.



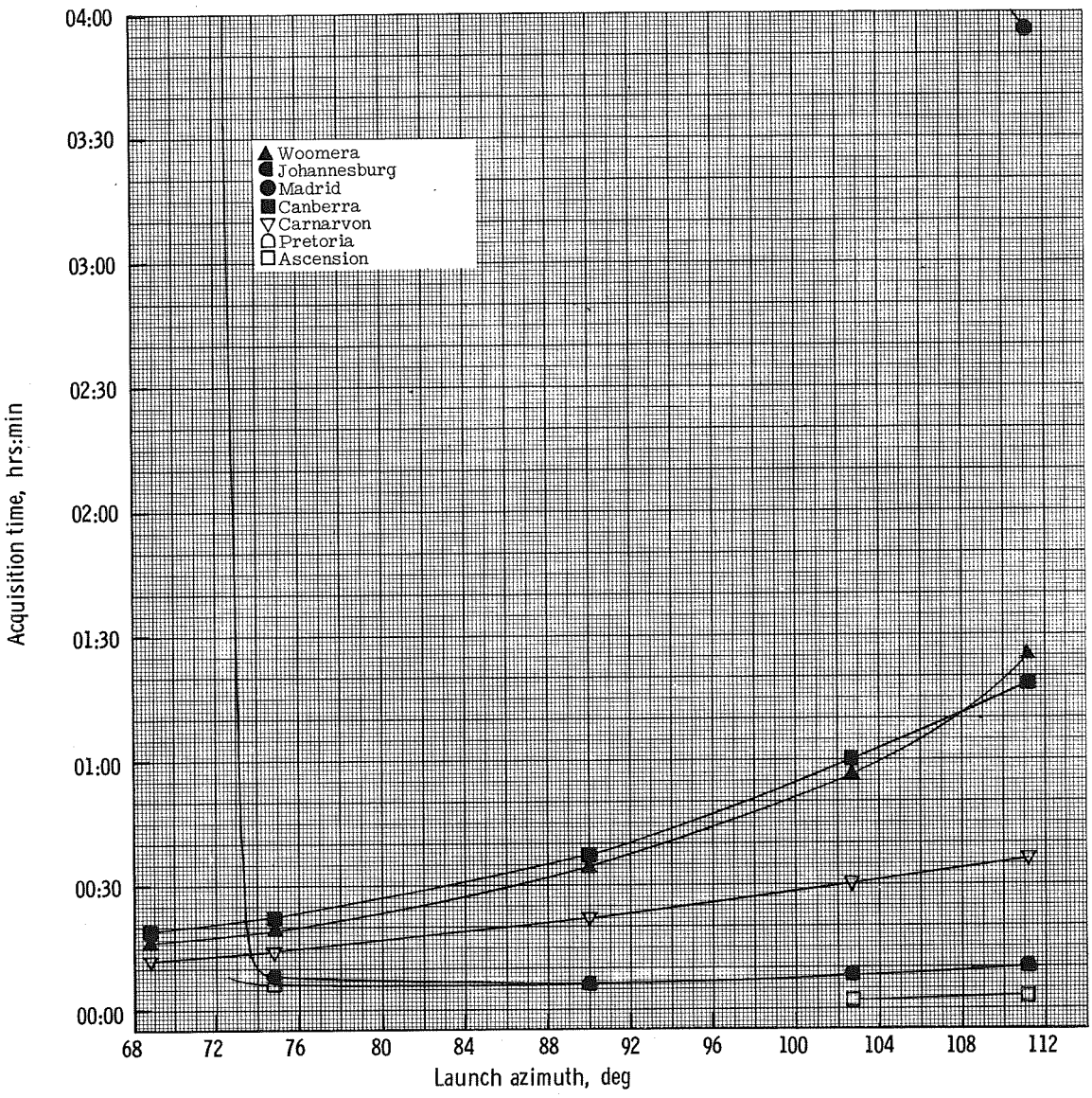
(b) From injection to 4 hours.

Figure 7. - Concluded.



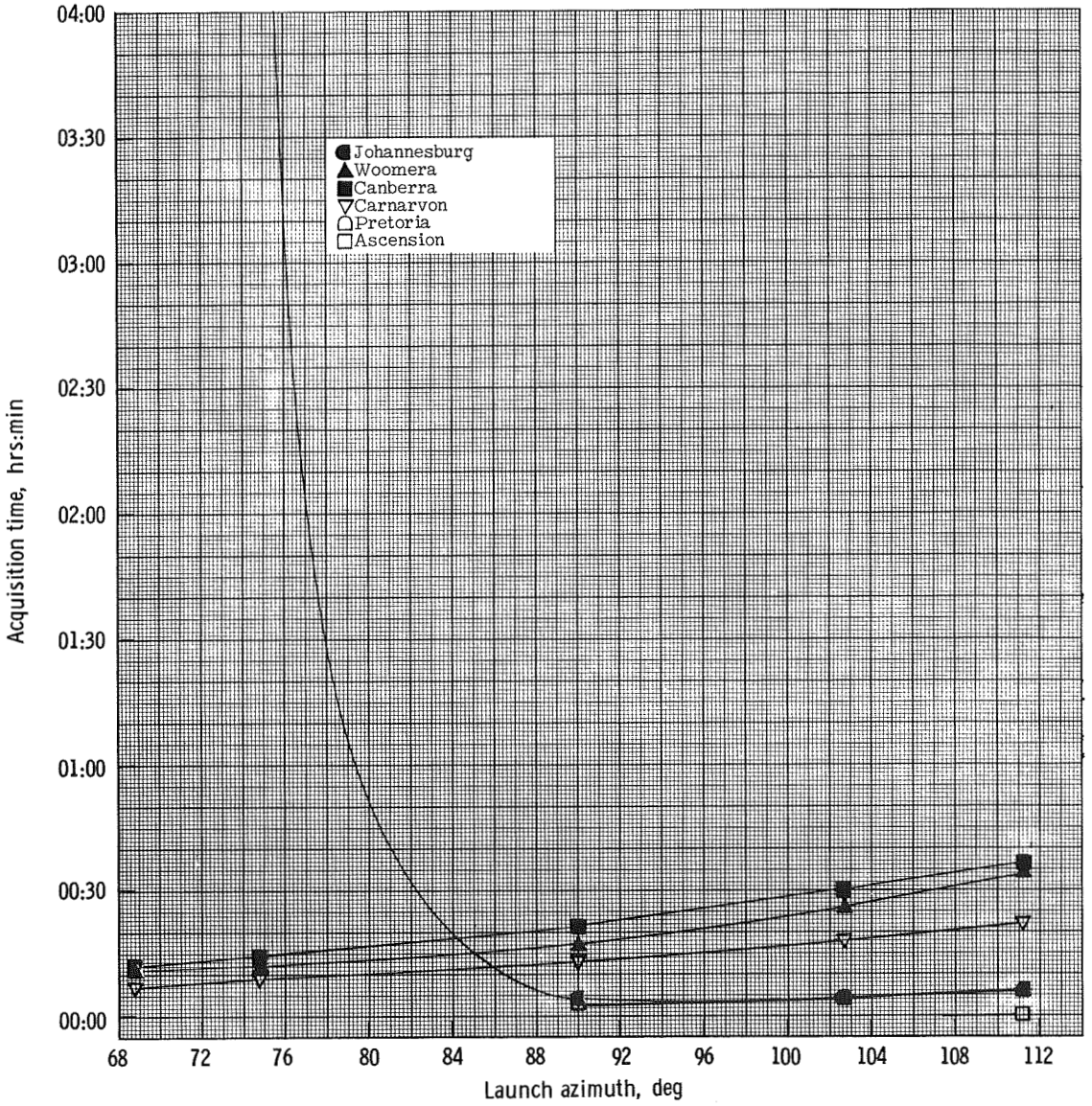
(a) Atlantic injection from first orbit (injection azimuth> 90°), -27.5° lunar declination.

Figure 8. - Apollo post injection acquisition times for Atlantic and Pacific injections.



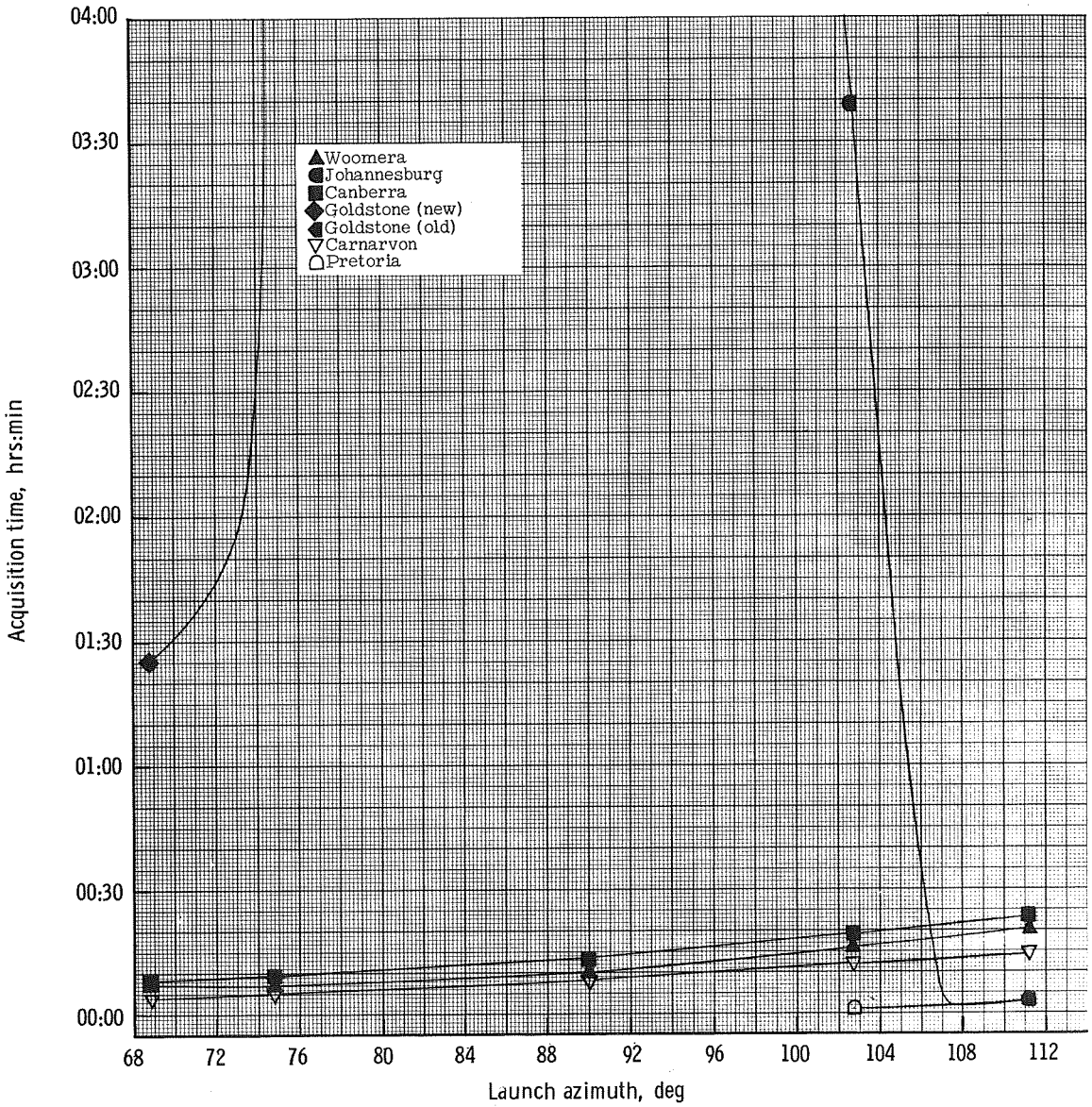
(b) Atlantic injection from first orbit (injection azimuth > 90°), -15° lunar declination.

Figure 8. - Continued.



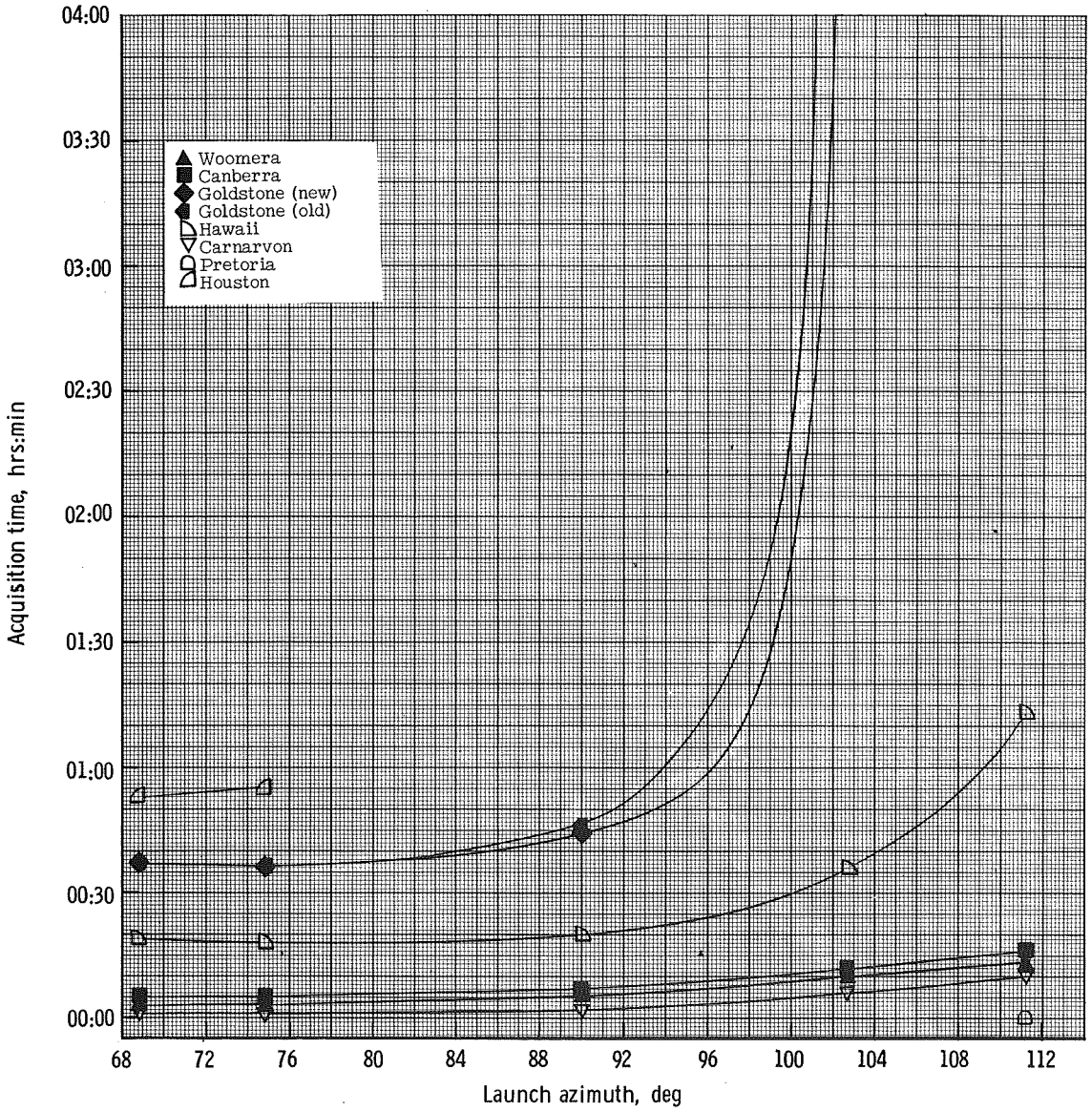
(c) Atlantic injection from first orbit (injection azimuth > 90°), 0° lunar declination.

Figure 8. - Continued.



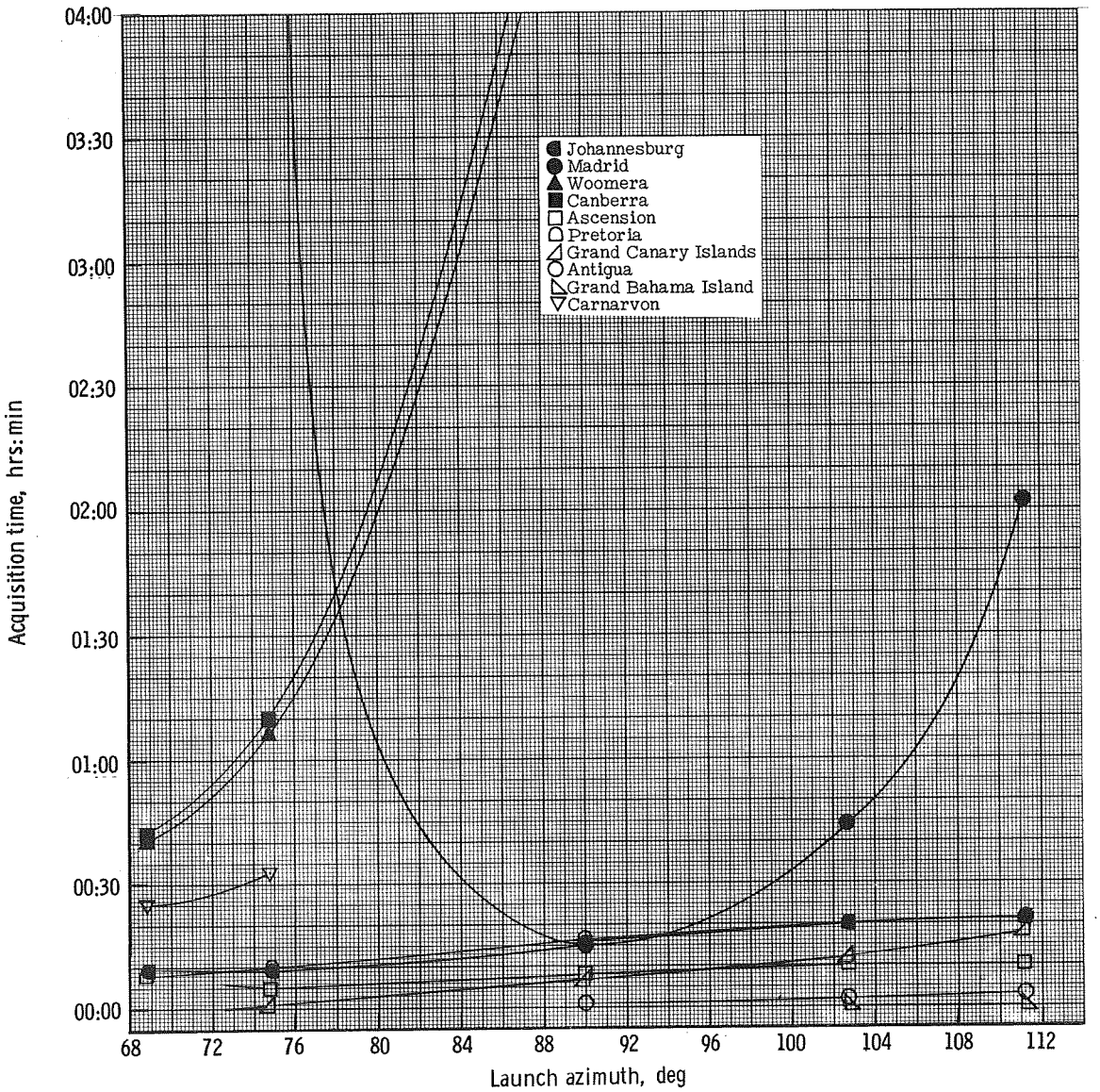
(d) Atlantic injection from first orbit (injection azimuth > 90°), 15° lunar declination.

Figure 8. - Continued.



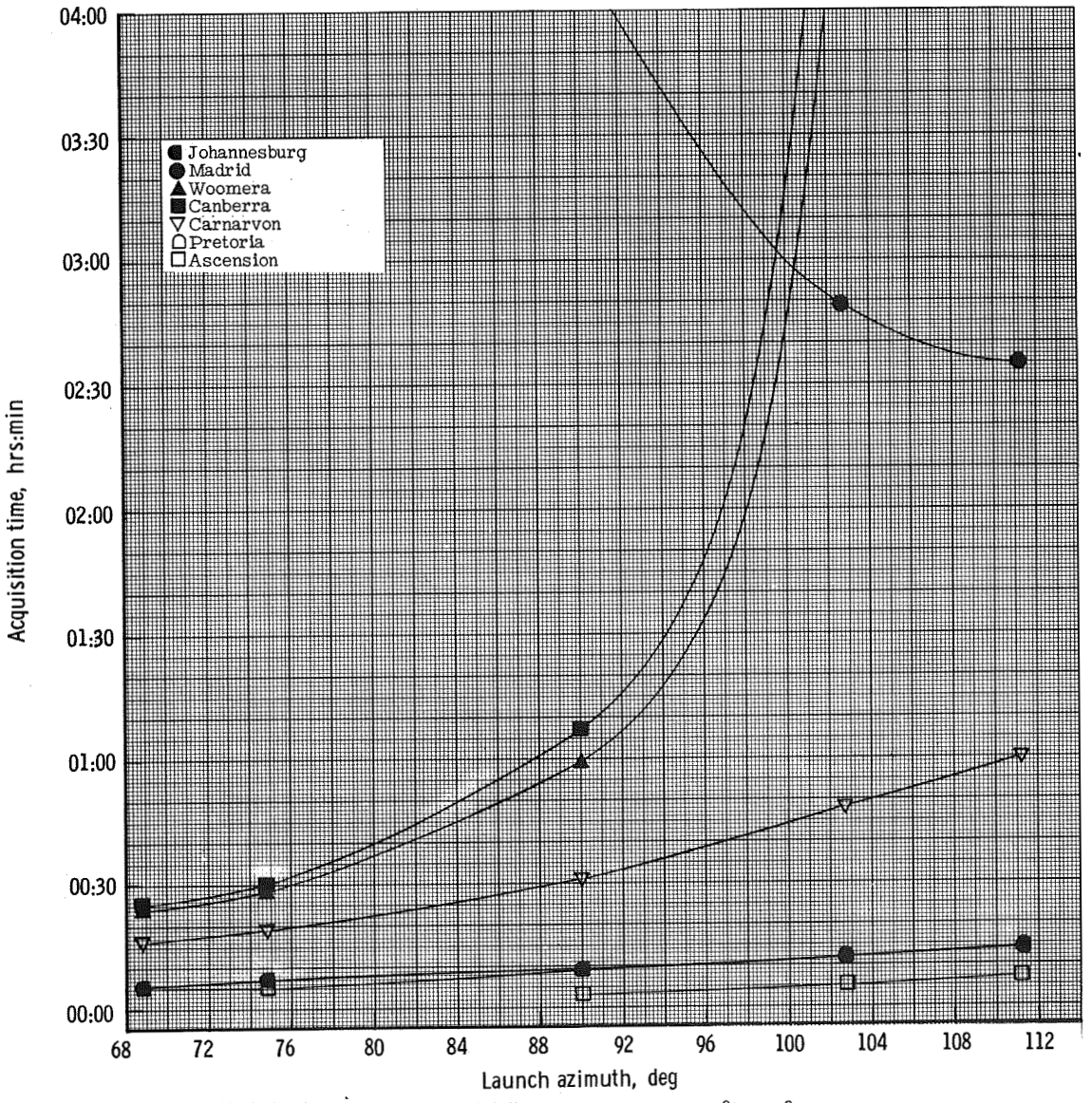
(e) Atlantic injection from first orbit (injection azimuth > 90°), 27.5° lunar declination.

Figure 8. - Continued.



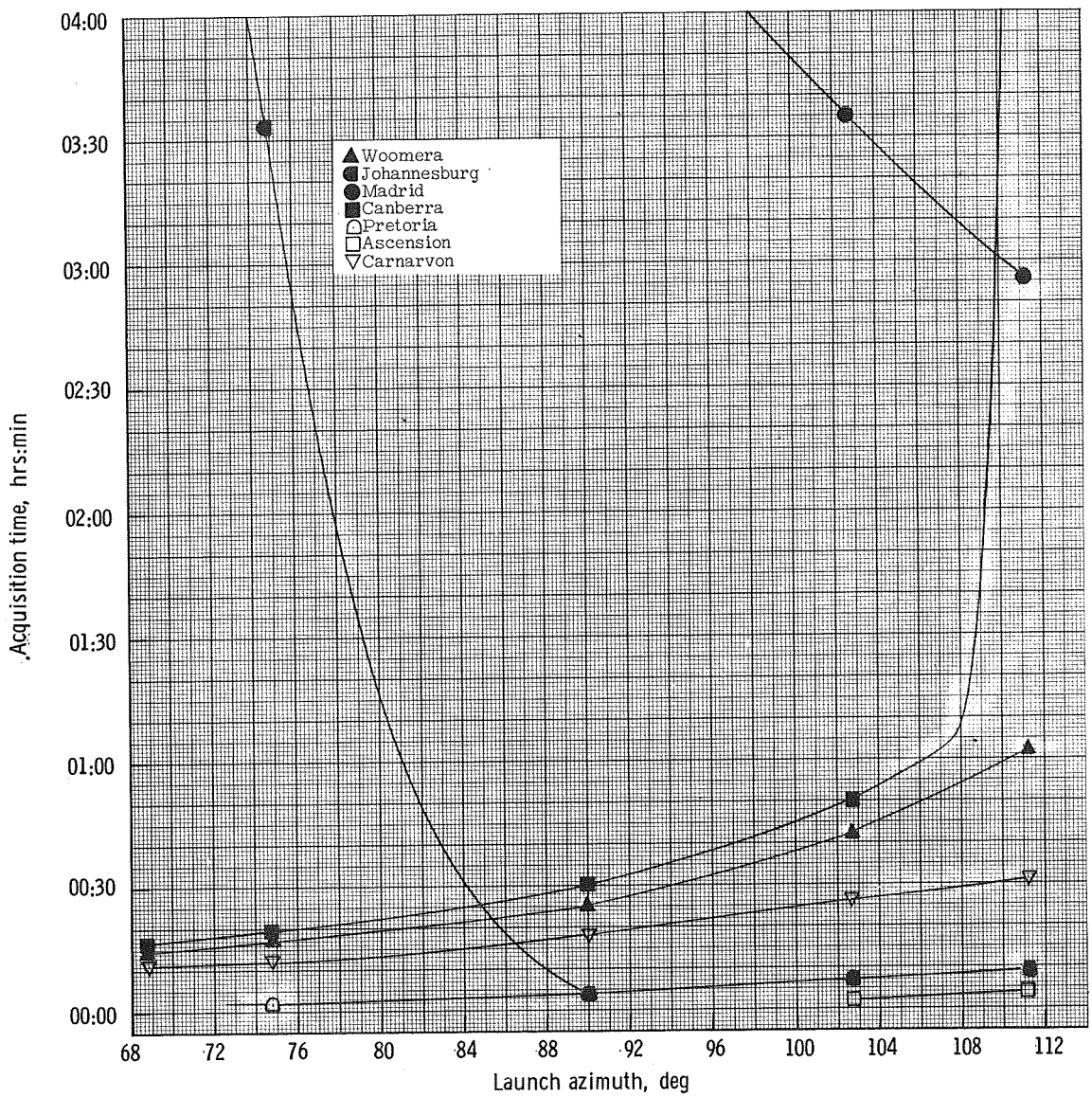
(f) Atlantic injection from second orbit (injection azimuth > 90°), -27.5° lunar declination.

Figure 8. - Continued.



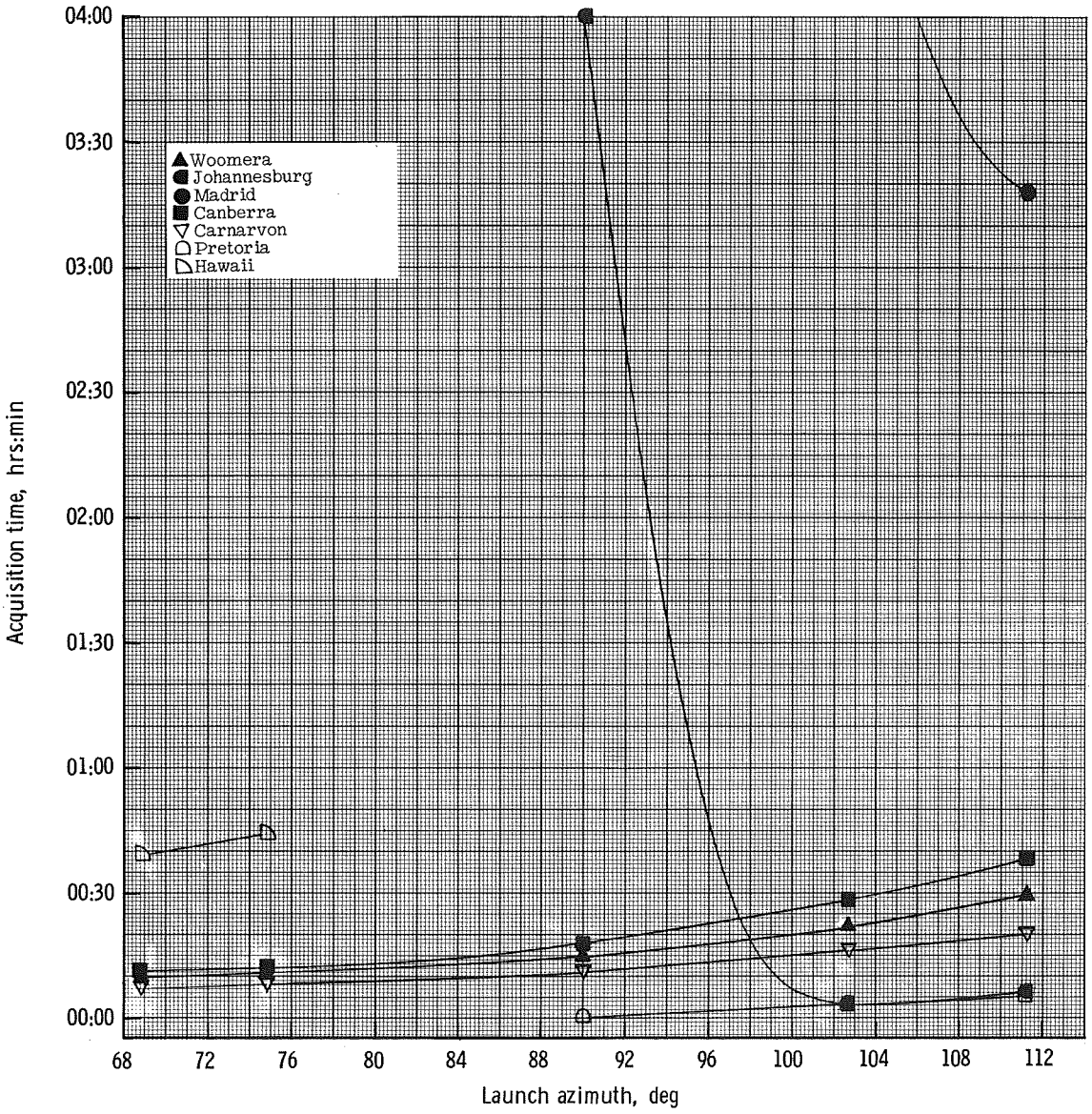
(g) Atlantic injection from second orbit (injection azimuth > 90°), -15° lunar declination.

Figure 8. - Continued.



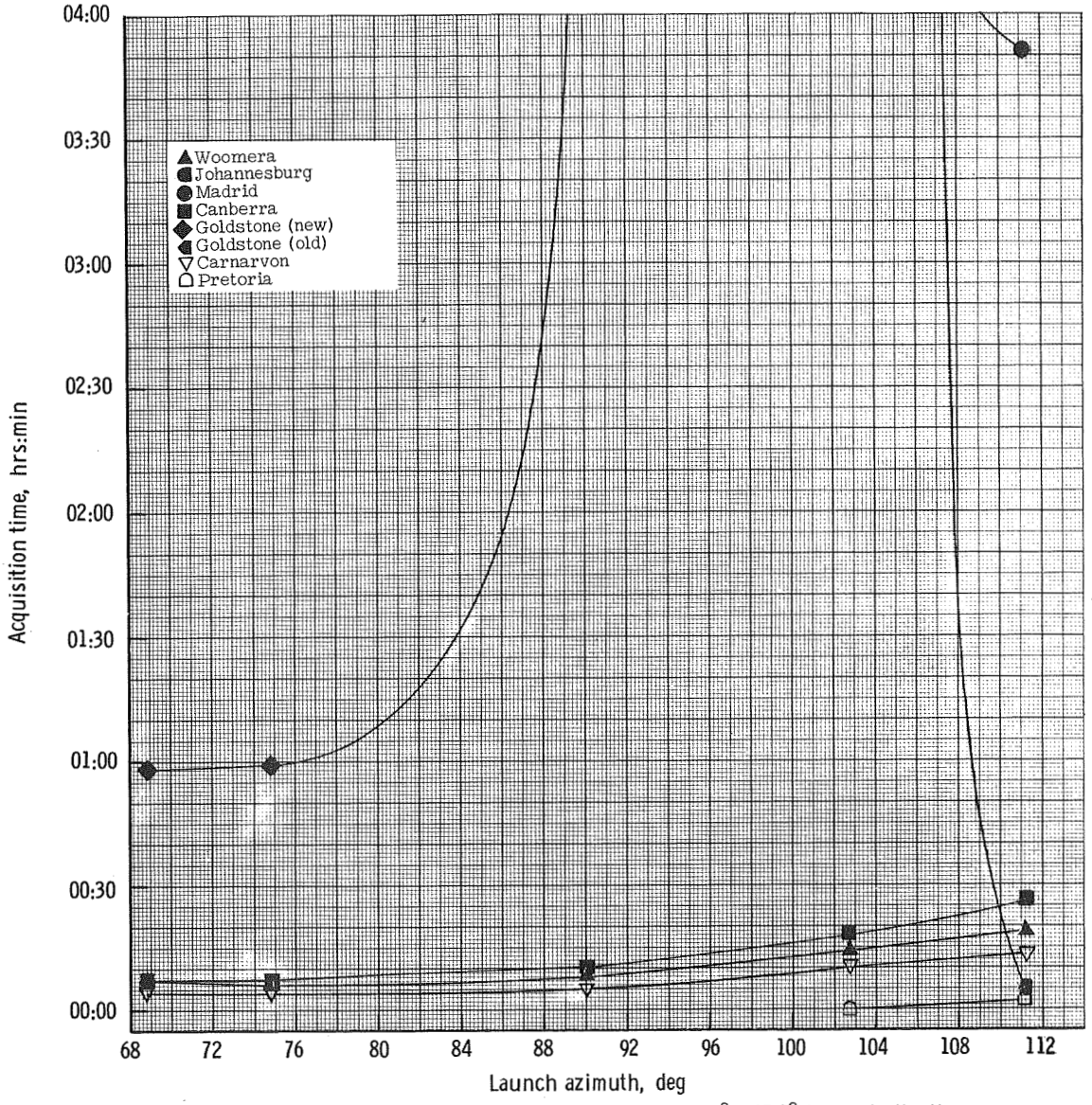
(h) Atlantic injection from second orbit (injection azimuth > 90°), 0° lunar declination.

Figure 8. - Continued.



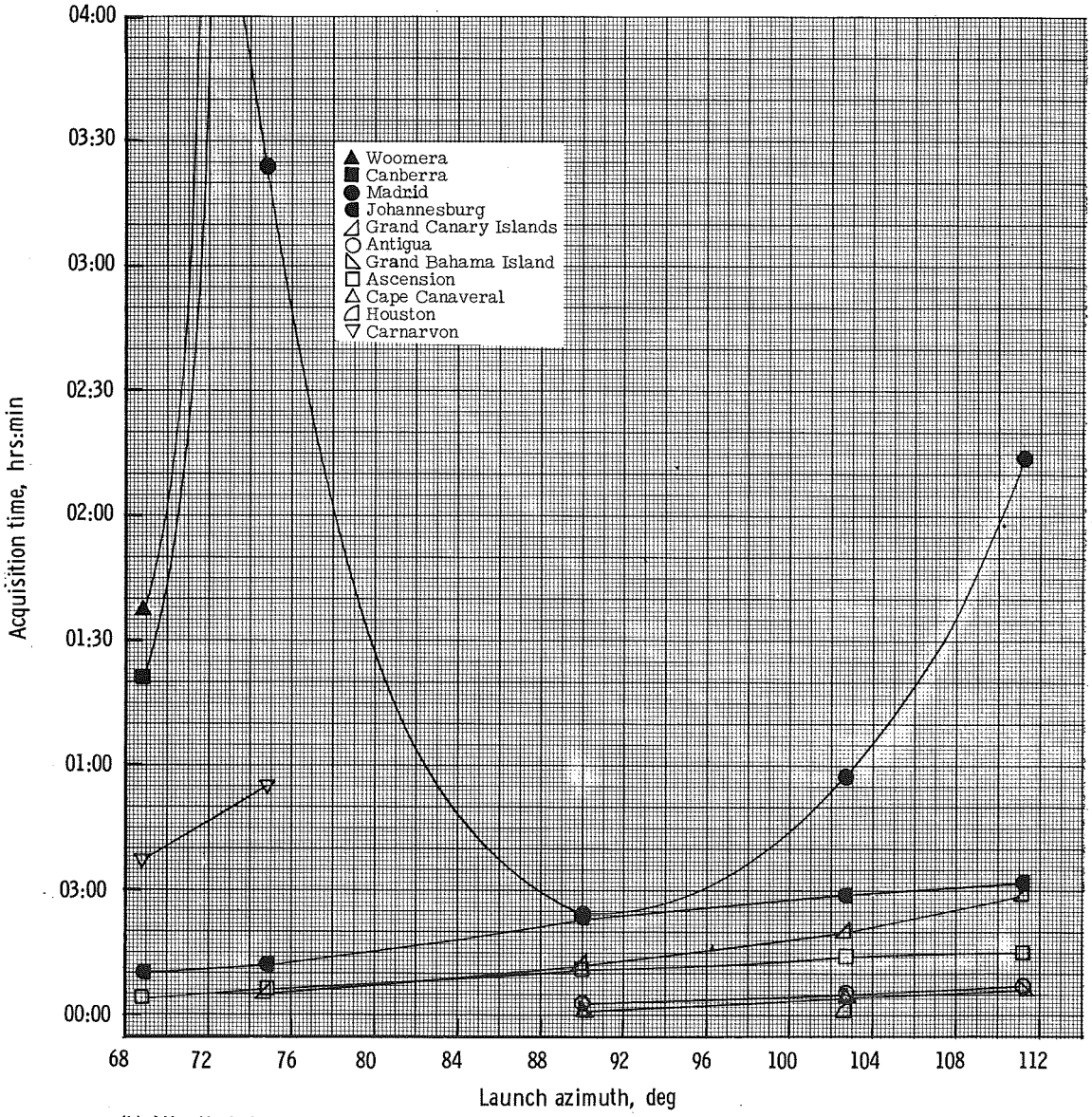
(i) Atlantic injection from second orbit (injection azimuth > 90°), 15° lunar declination.

Figure 8. - Continued.



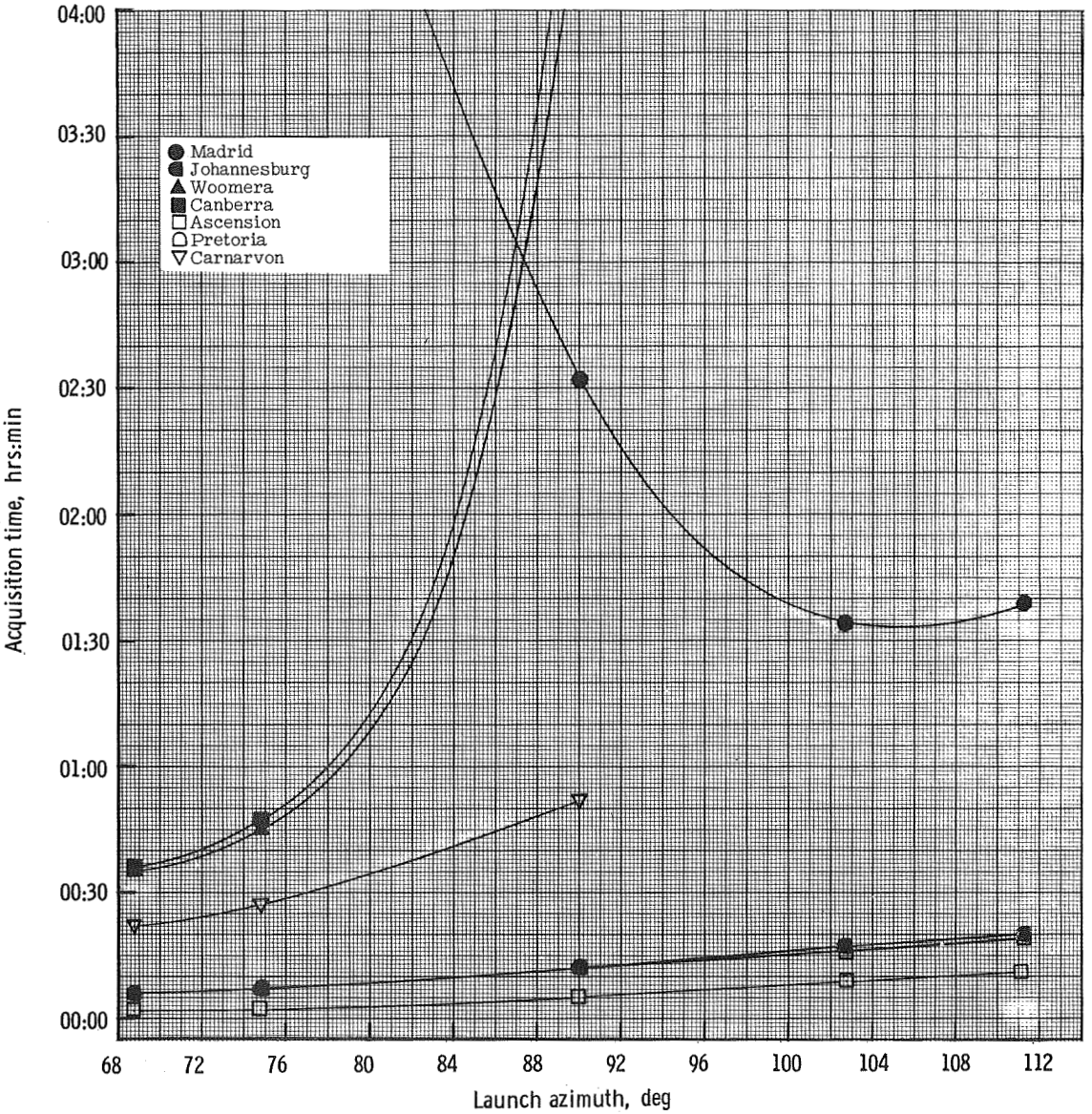
(j) Atlantic injection from second orbit (injection azimuth > 90°), 27.5° lunar declination.

Figure 8. - Continued.



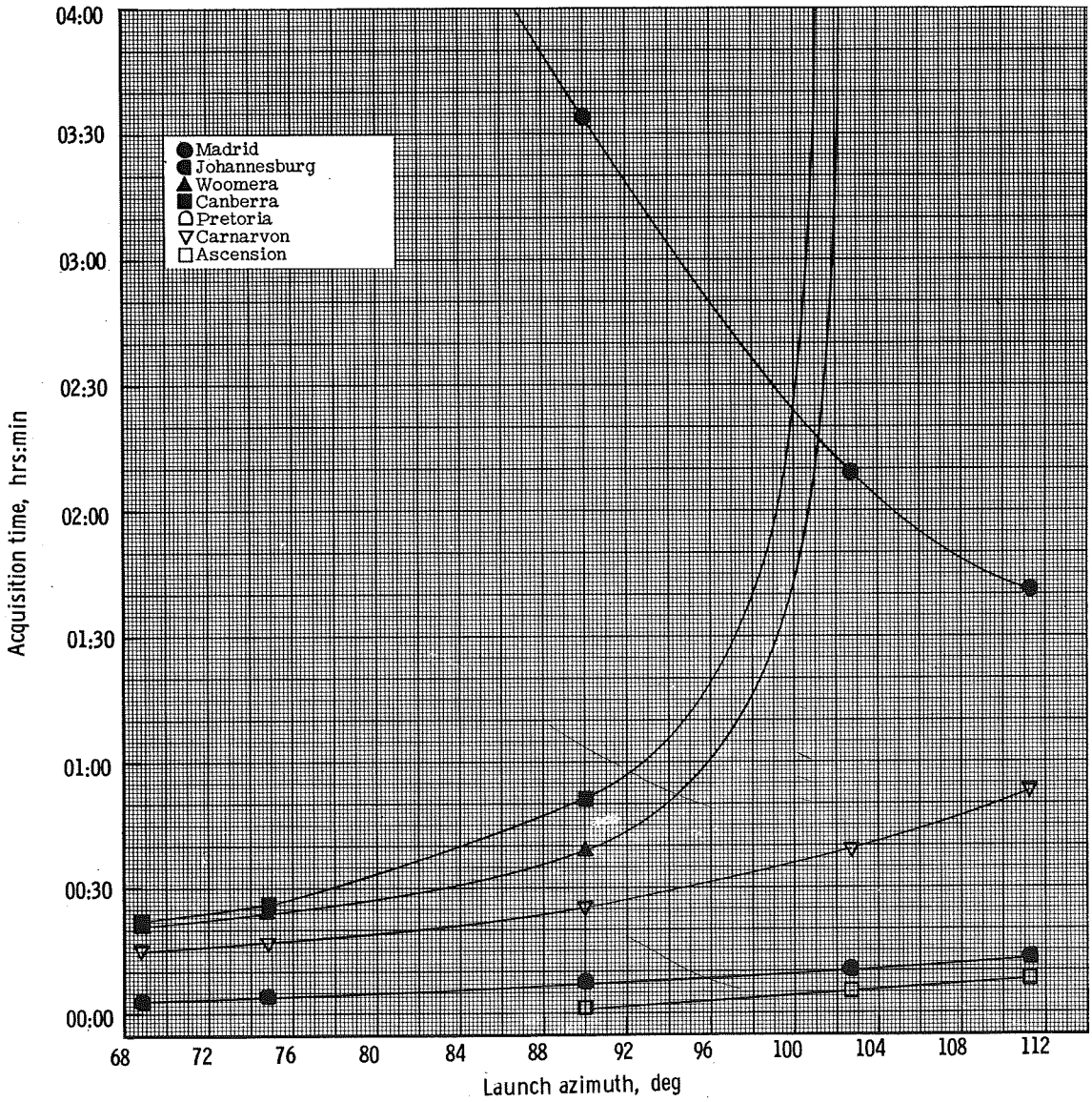
(k) Atlantic injection from third orbit (injection azimuth > 90°), -27.5° lunar declination.

Figure 8. - Continued.



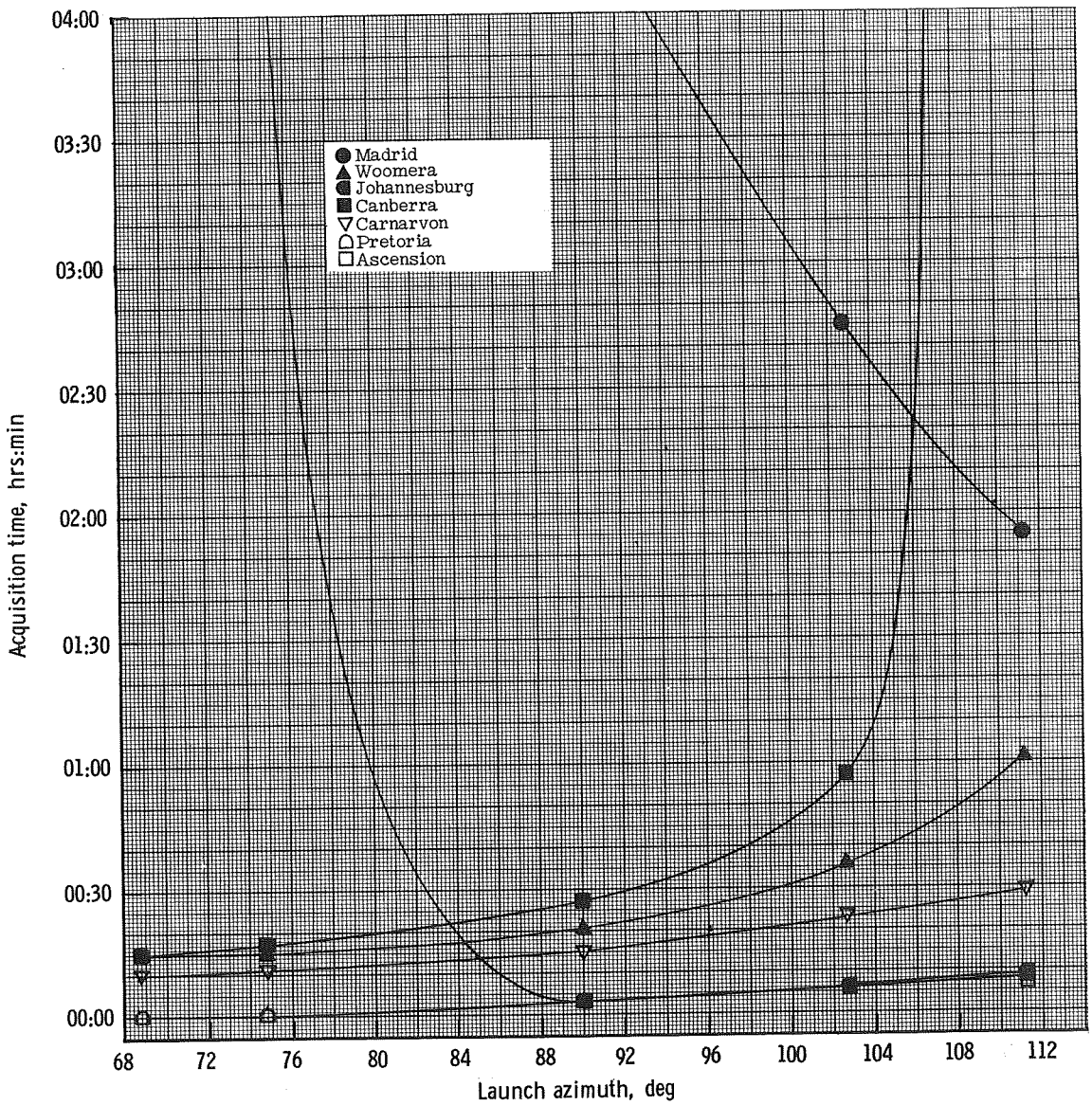
(l) Atlantic injection from third orbit (injection azimuth > 90°), -15° lunar declination.

Figure 8. - Continued.



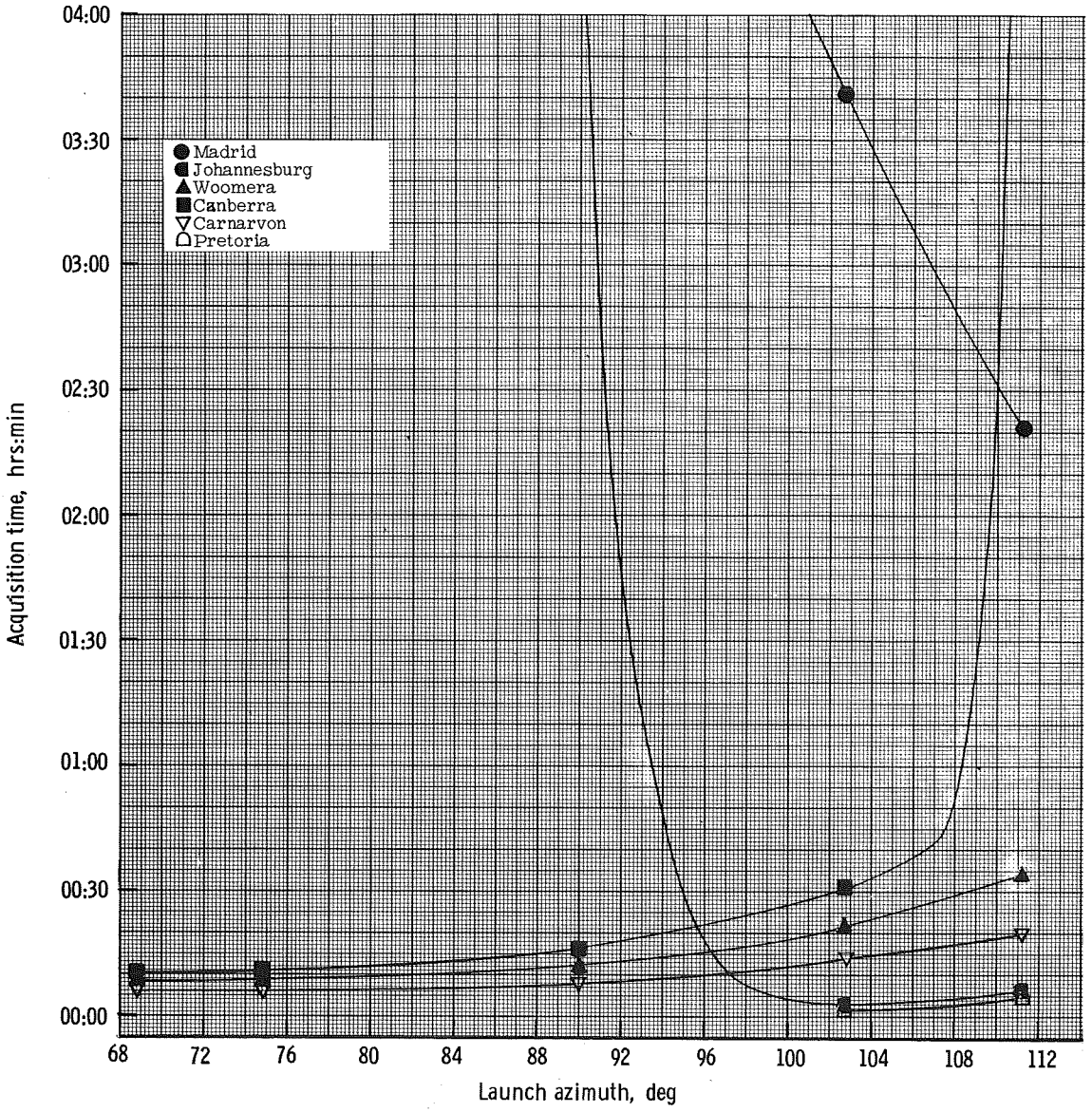
(m) Atlantic injection from third orbit (injection azimuth > 90°), 0° lunar declination.

Figure 8. - Continued.



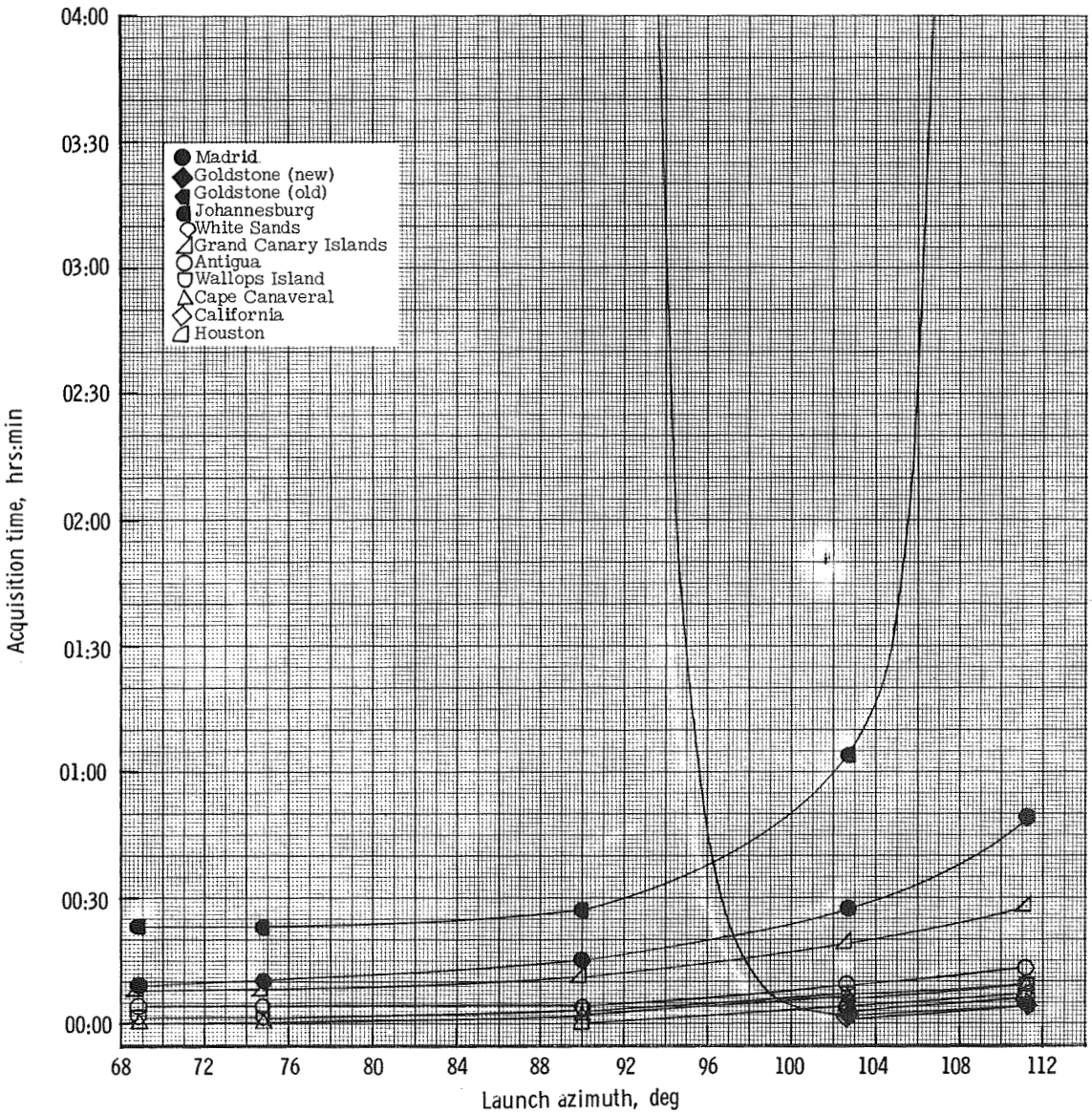
(n) Atlantic injection from third orbit (injection azimuth > 90°), 15° lunar declination.

Figure 8. - Continued.



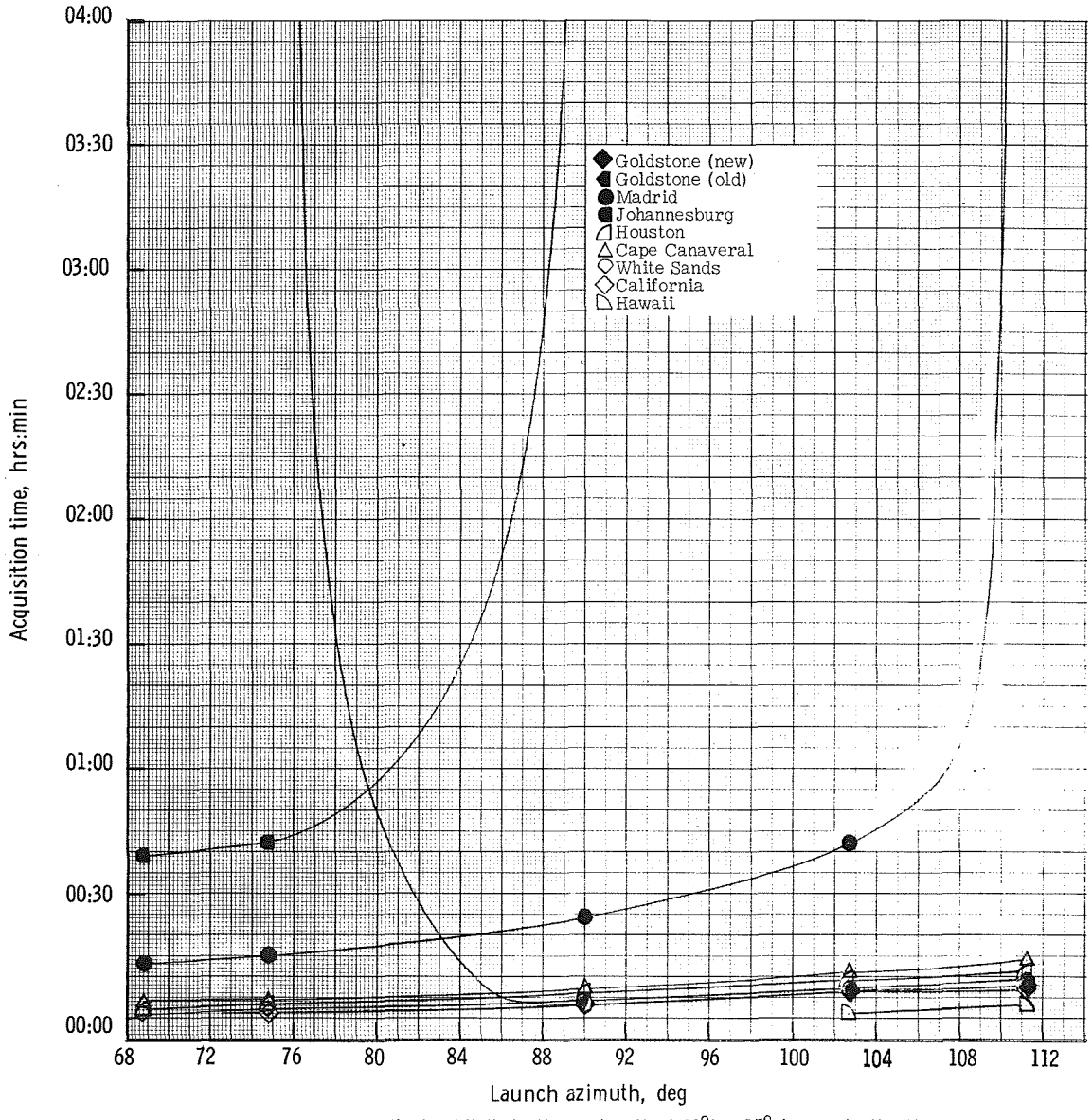
(o) Atlantic injection from third orbit (injection azimuth > 90°), 27.5° lunar declination.

Figure 8. - Continued.



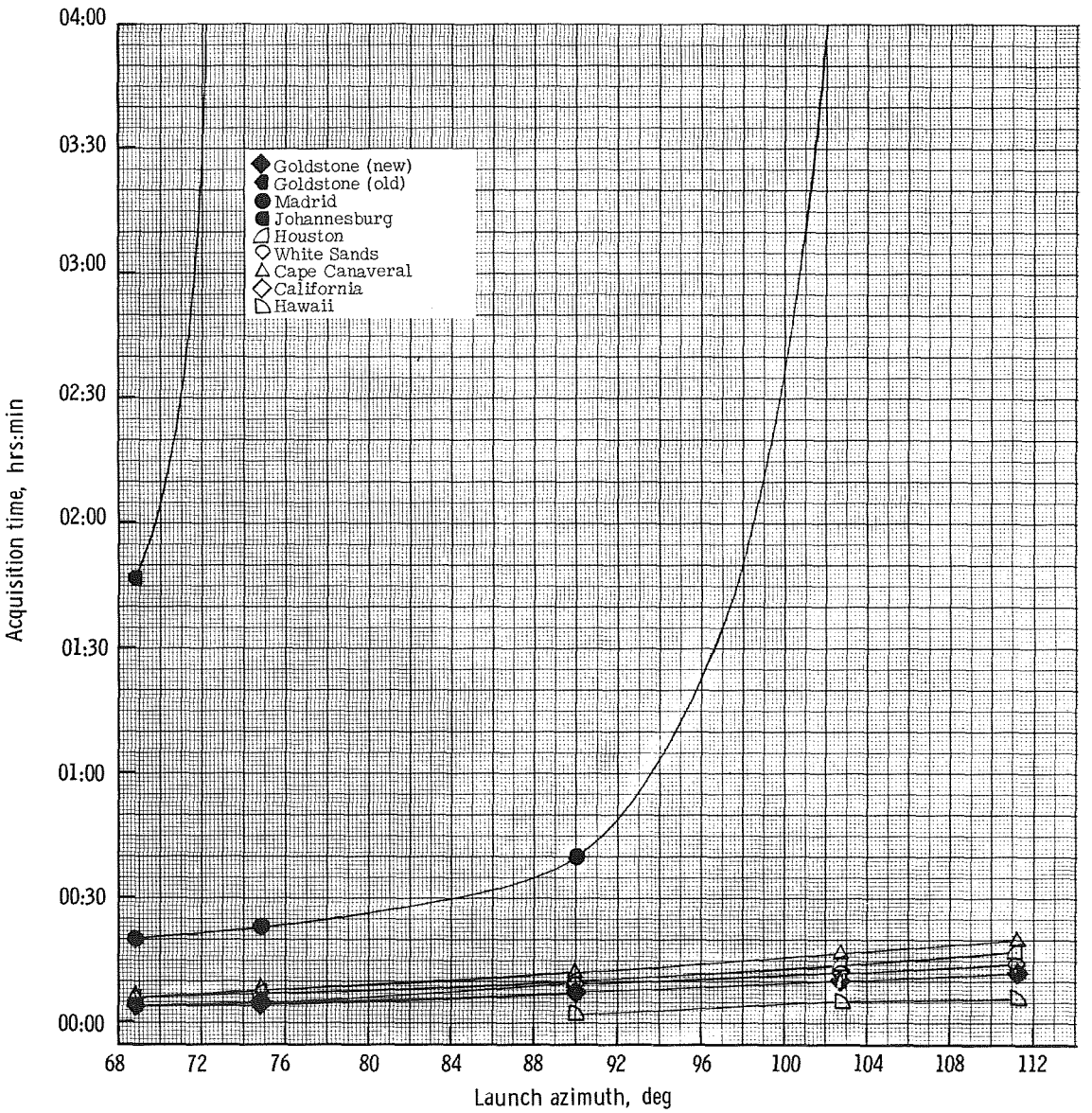
(p) Pacific injection from first orbit (injection azimuth < 90°), -27.5° lunar declination.

Figure 8. - Continued.



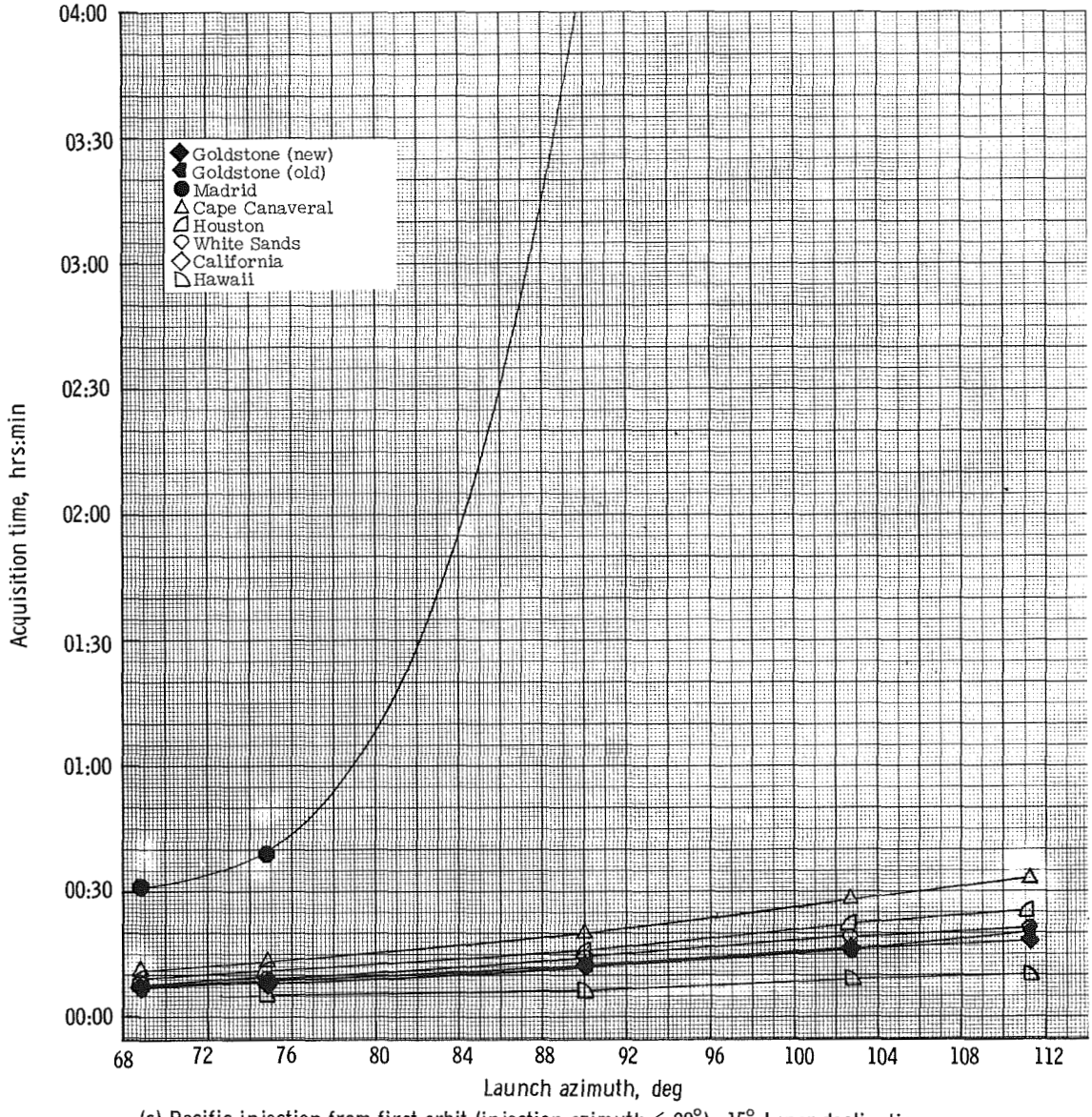
(q) Pacific injection from first orbit (injection azimuth < 90°), -15° lunar declination.

Figure 8. - Continued.



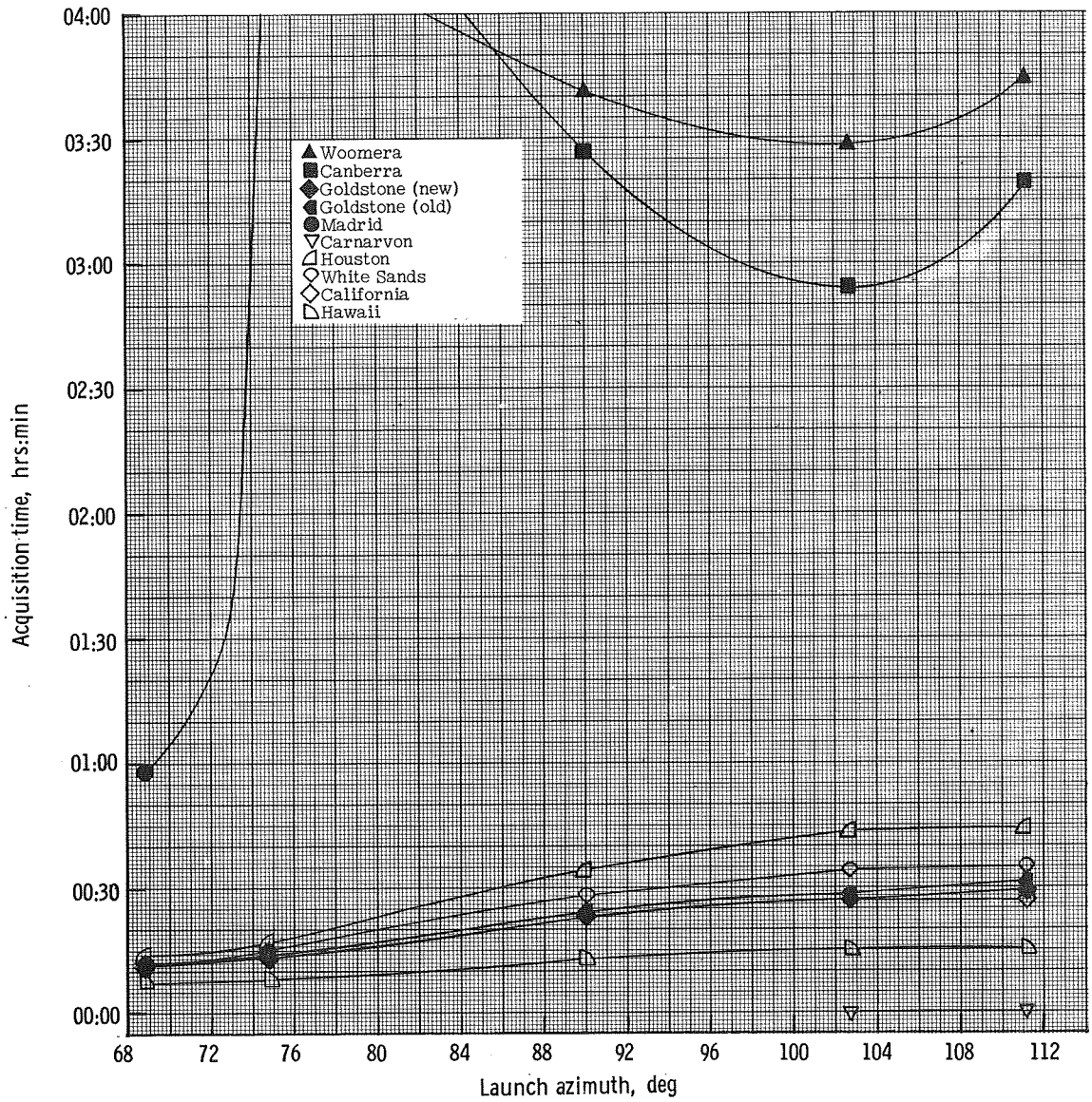
(r) Pacific injection from first orbit (injection azimuth < 90°), 0° lunar declination.

Figure 8. - Continued.



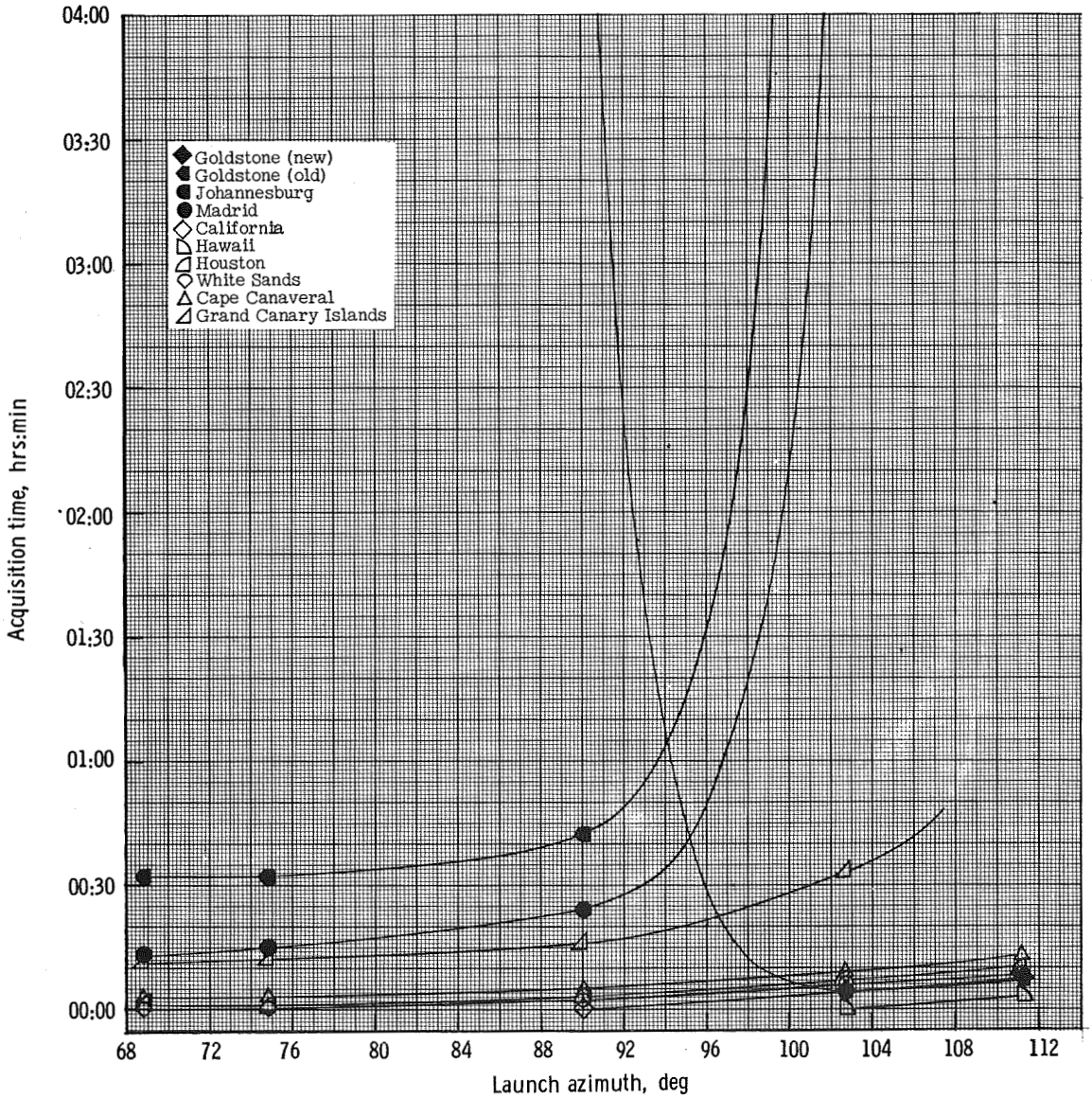
(s) Pacific injection from first orbit (injection azimuth < 90°), 15° lunar declination.

Figure 8. - Continued.



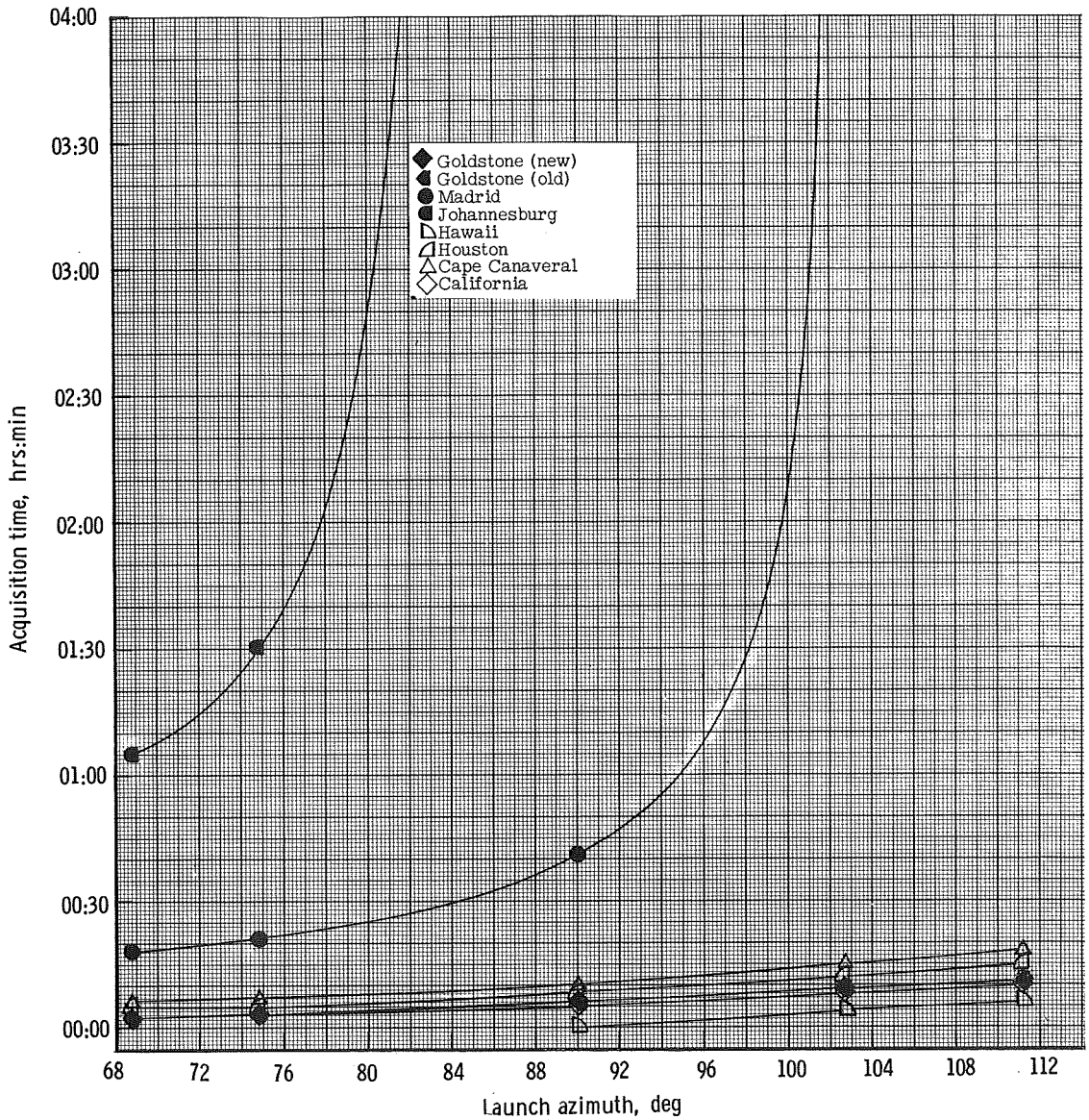
(t) Pacific injection from first orbit (injection azimuth < 90°), 27.5° lunar declination.

Figure 8. - Continued.



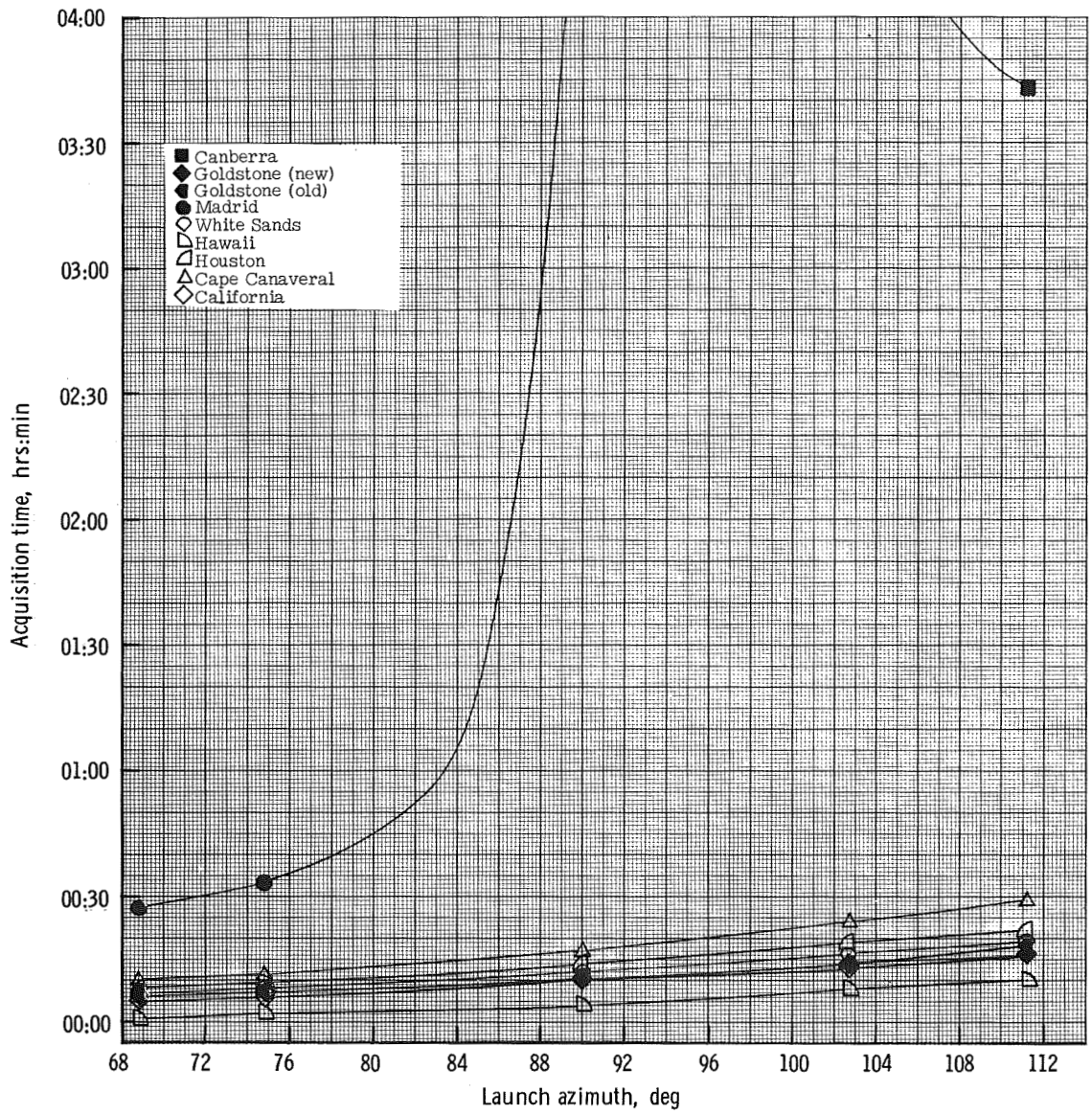
(u) Pacific injection from second orbit (injection azimuth < 90°), -27.5° lunar declination.

Figure 8. - Continued.



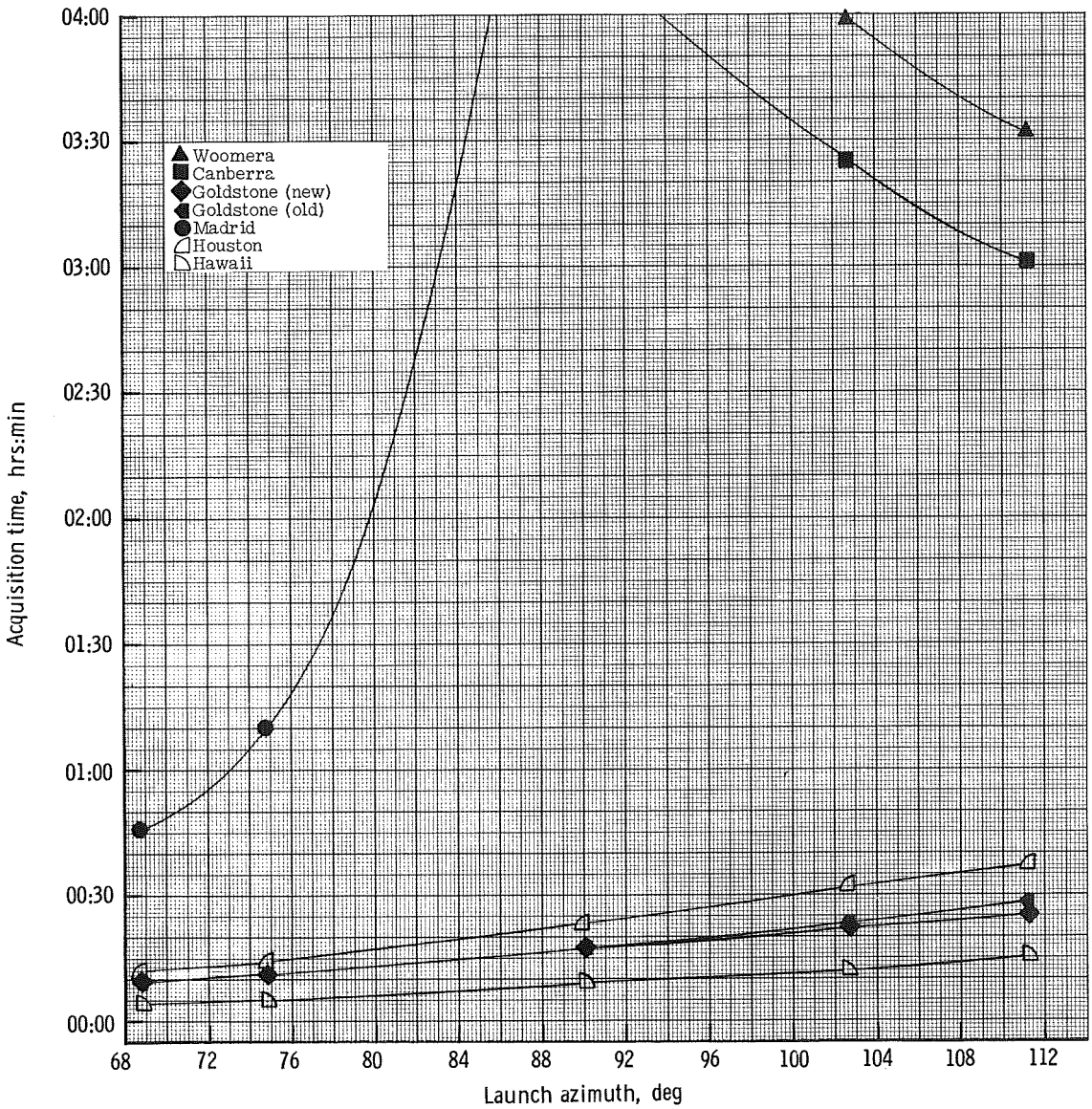
(v) Pacific injection from second orbit (injection azimuth < 90°), -15° lunar declination.

Figure 8. - Continued.



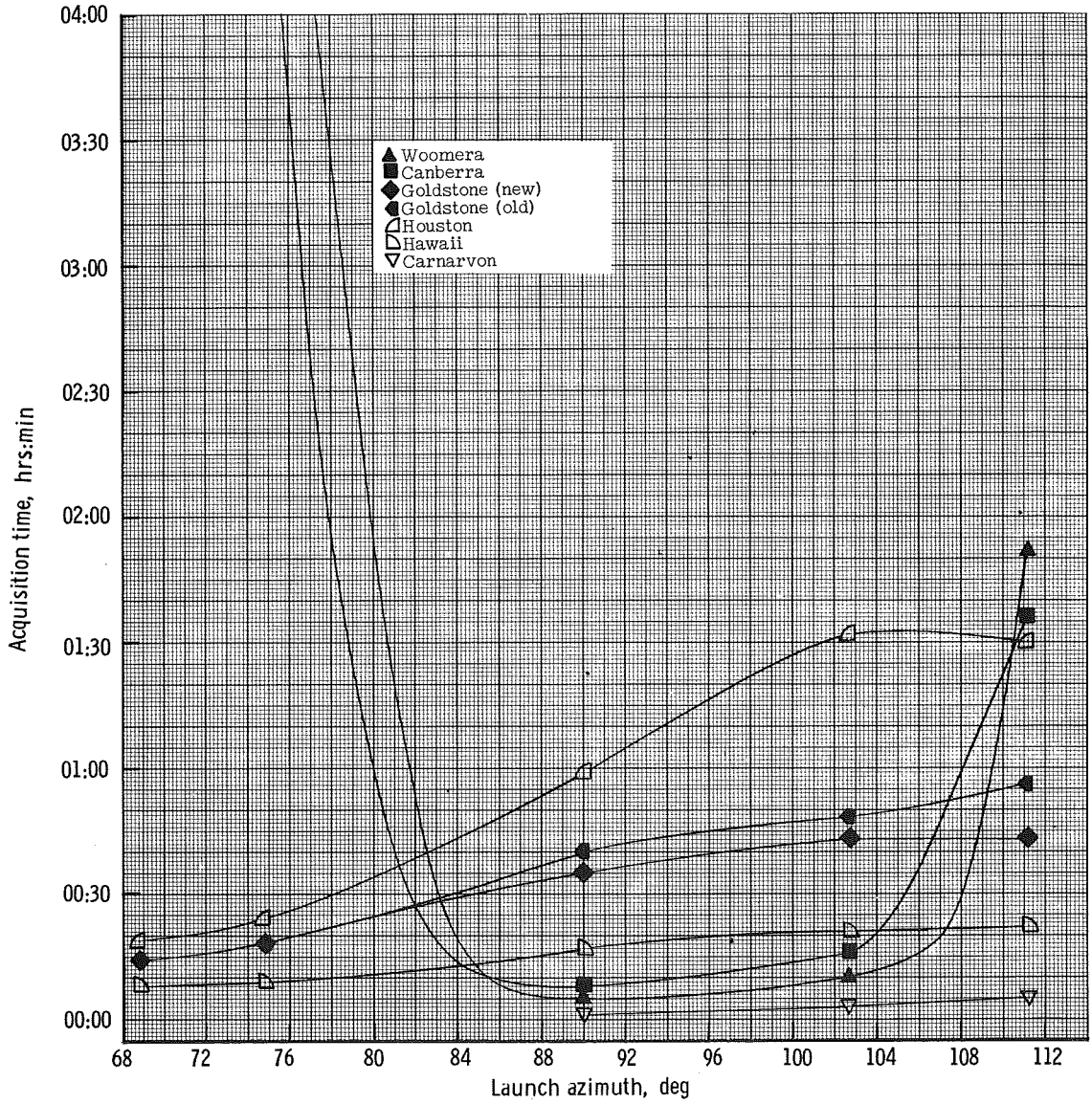
(w) Pacific injection from second orbit (injection azimuth < 90°), 0° lunar declination.

Figure 8. - Continued.



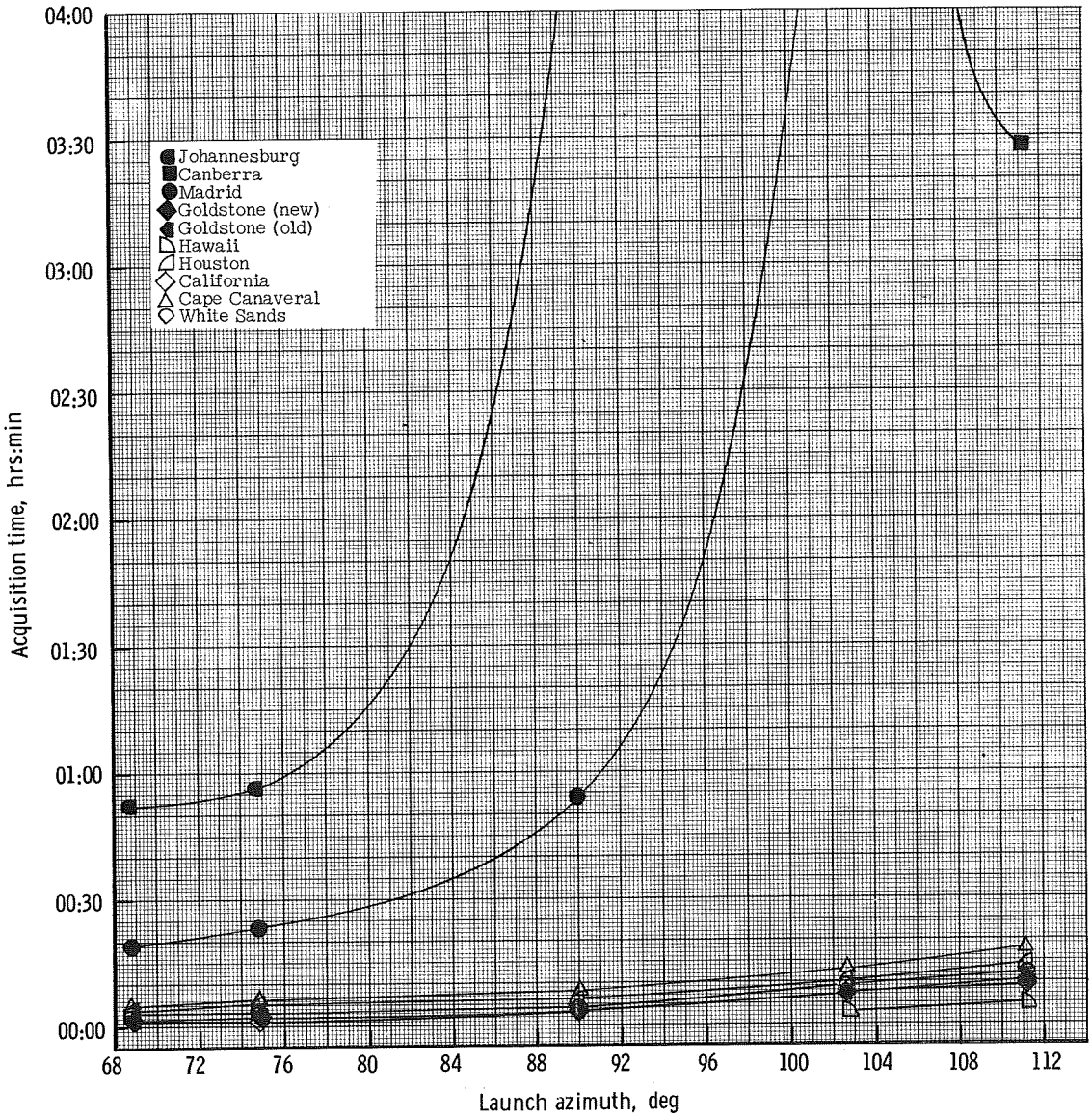
(x) Pacific injection from second orbit (injection azimuth < 90°), 15° lunar declination.

Figure 8. - Continued.



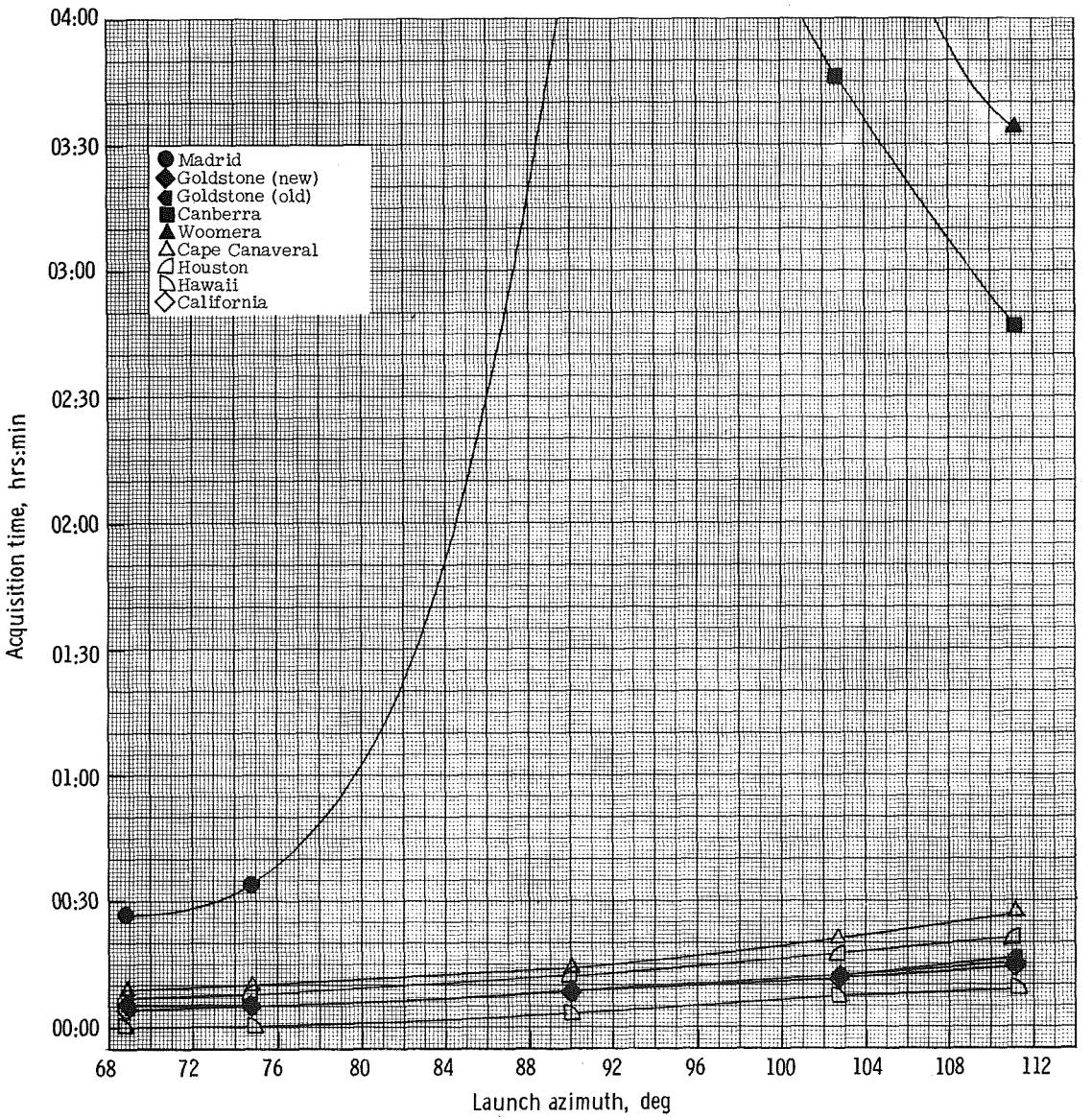
(y) Pacific injection fromsecond orbit (injection azimuth < 90°), 27.5° lunar declination.

Figure 8. - Continued.



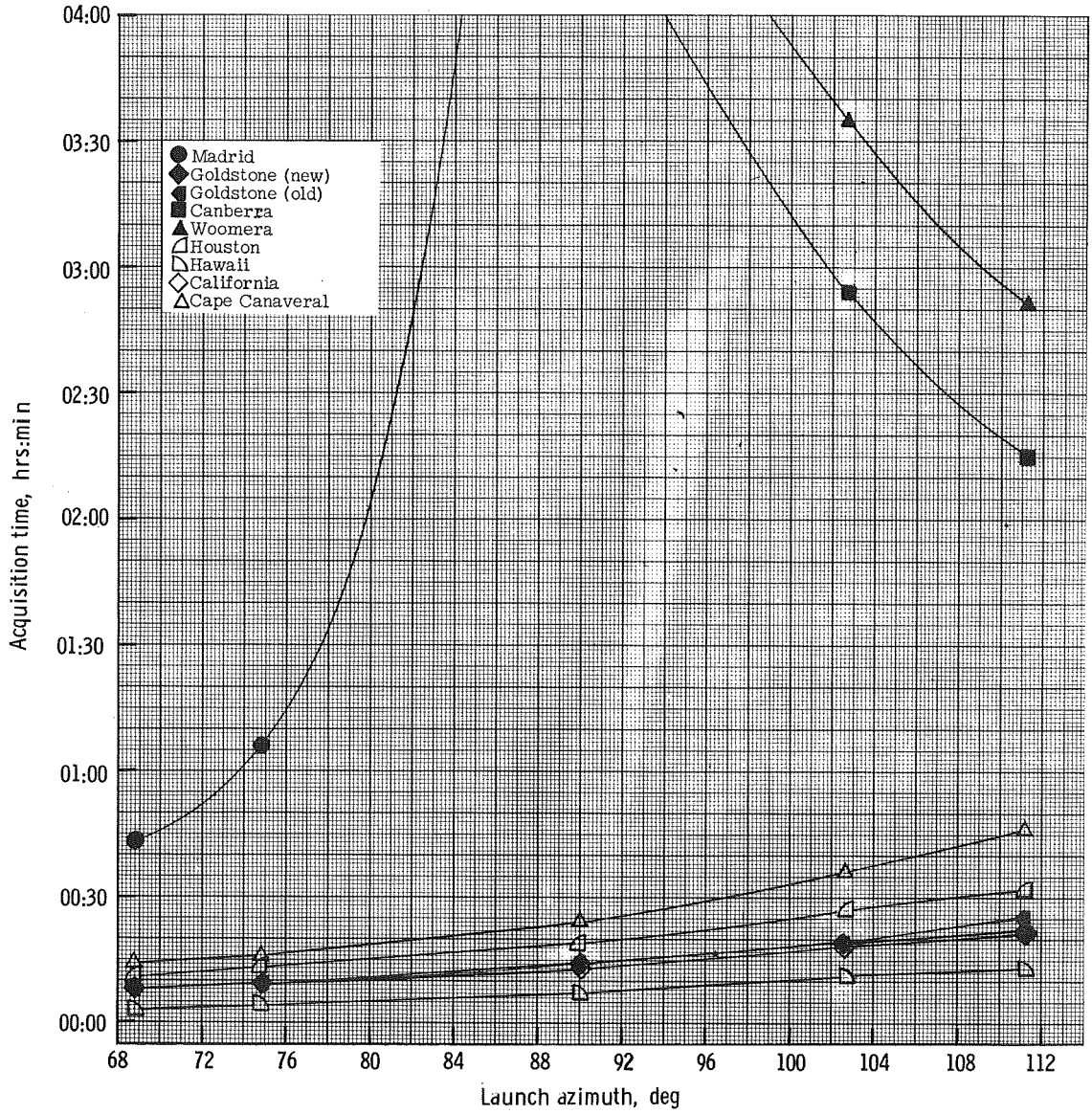
(z) Pacific injection from third orbit (injection azimuth < 90°), -27.5° lunar declination.

Figure 8. - Continued.



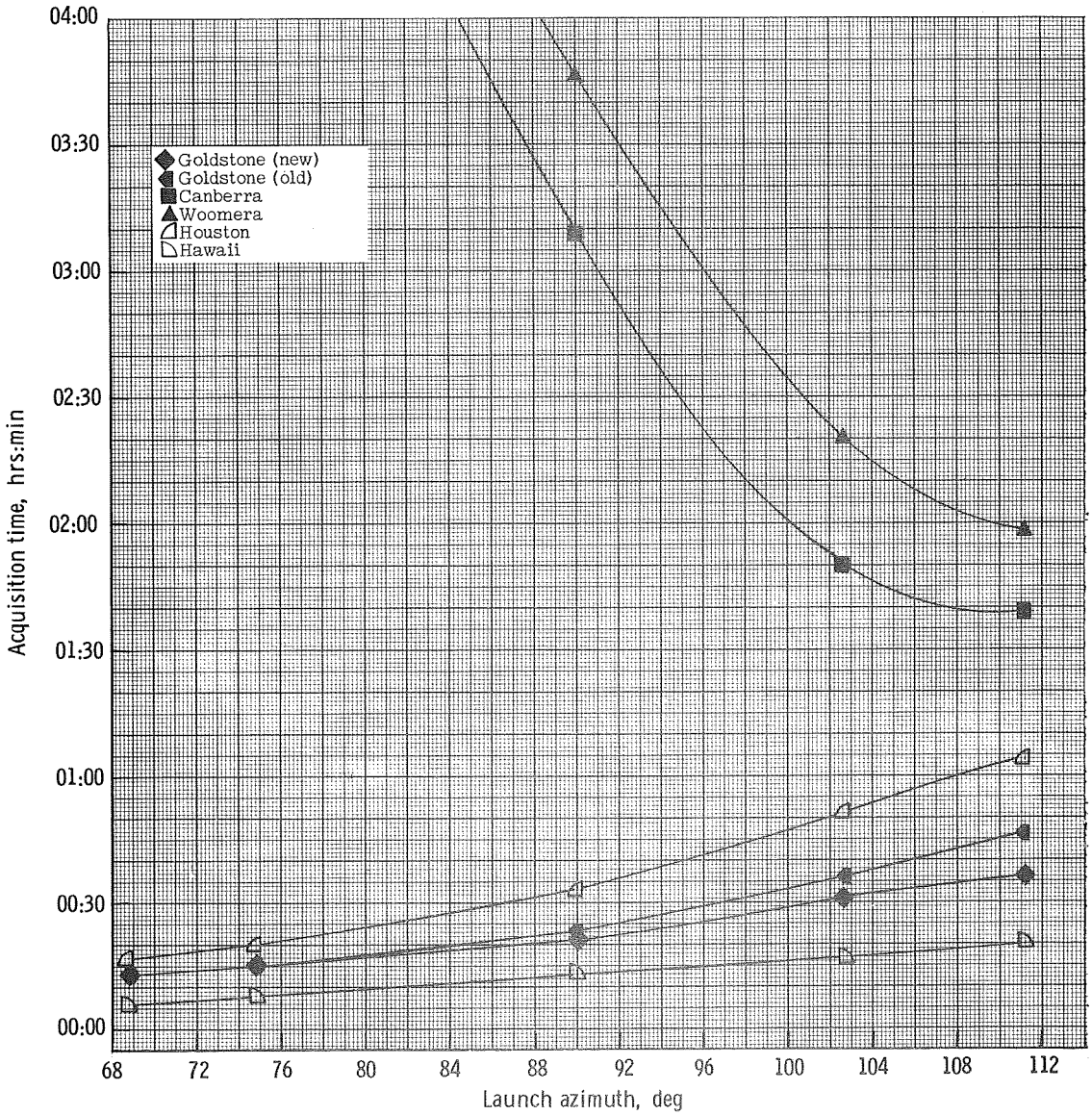
(aa) Pacific injection from third orbit (injection azimuth < 90°), -15° lunar declination.

Figure 8. - Continued.



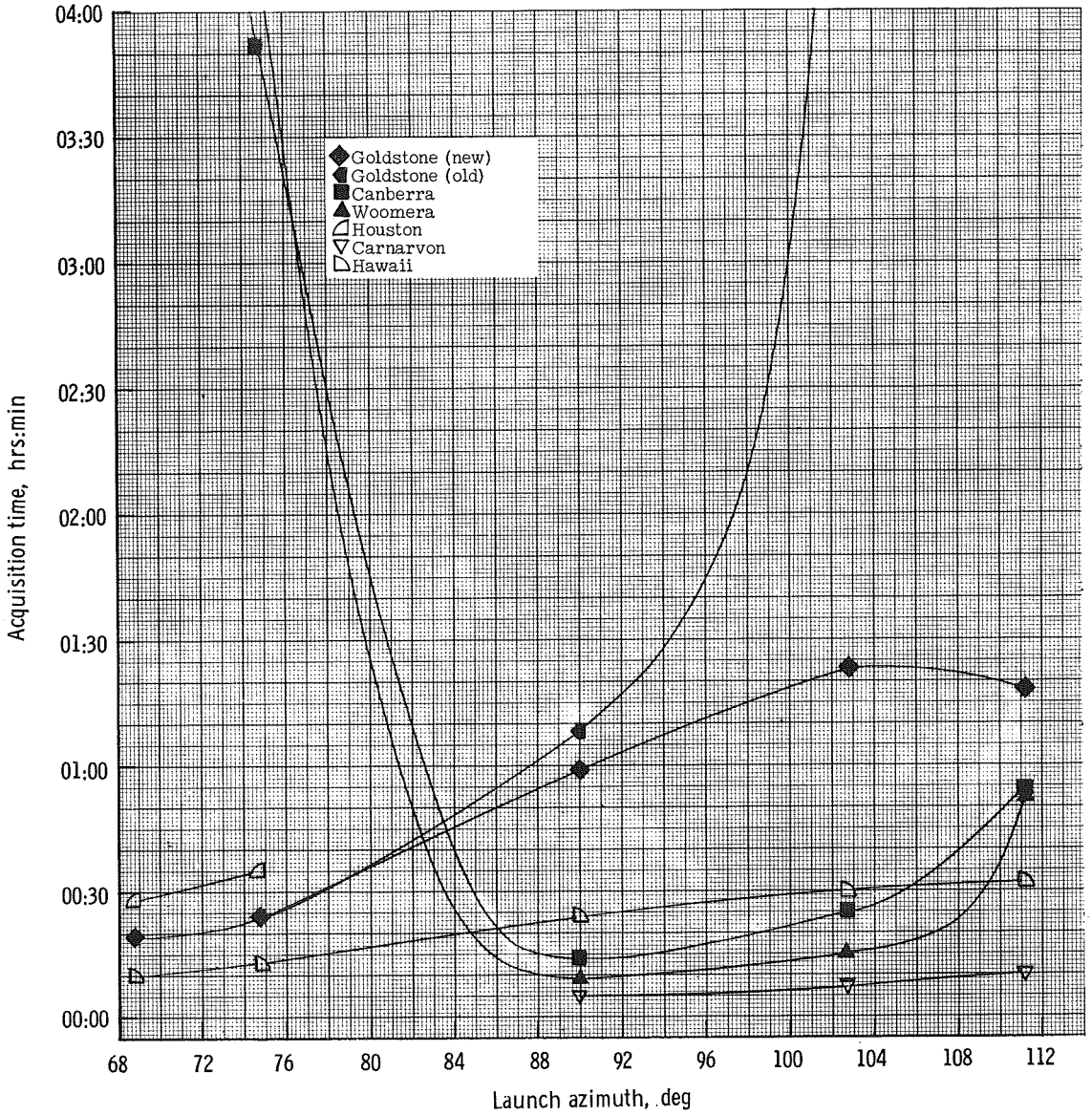
(bb) Pacific injection from third orbit (injection azimuth < 90°), 0° lunar declination.

Figure 8. - Continued.



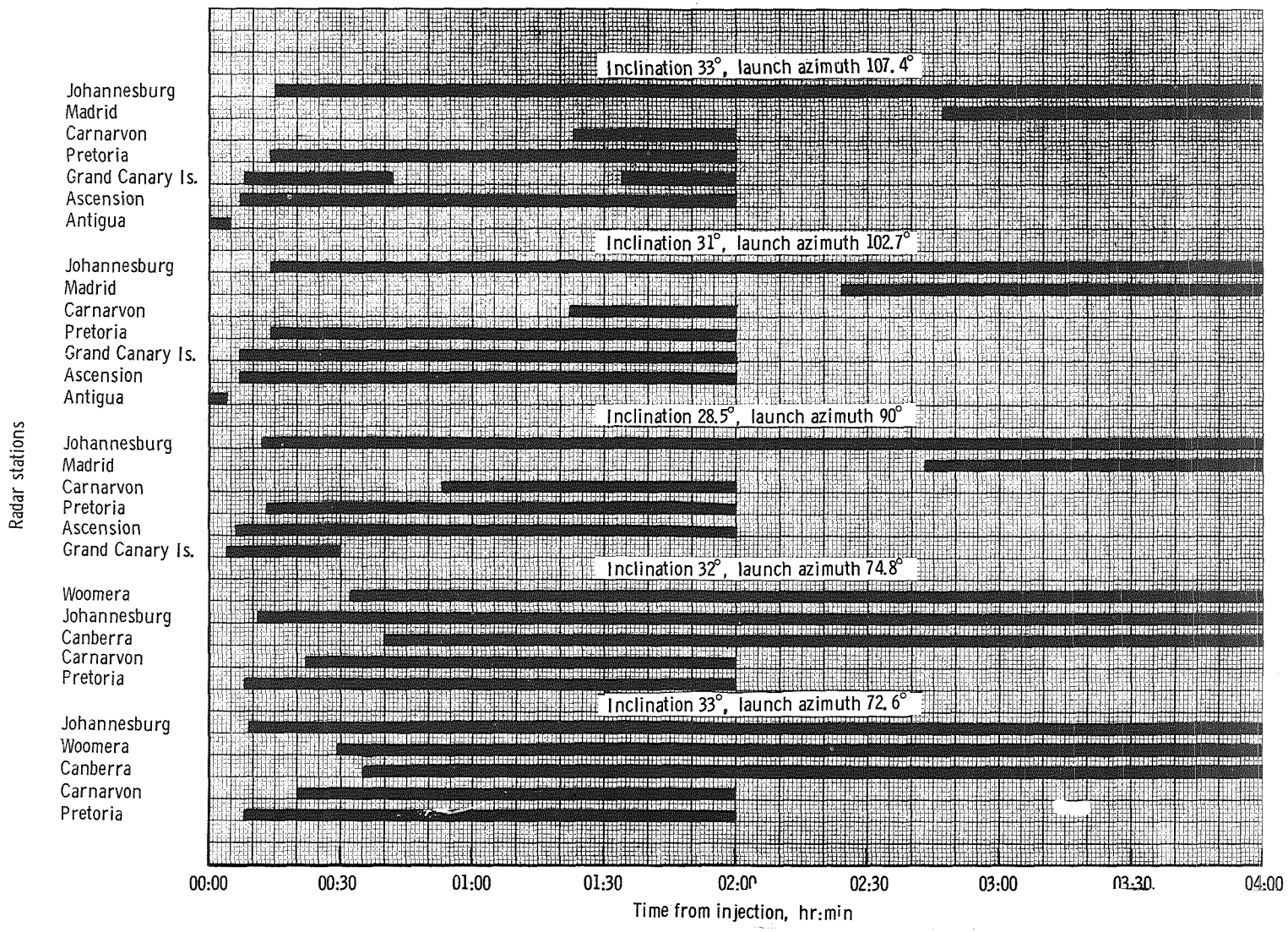
(cc) Pacific injection from third orbit (injection azimuth < 90°), 15° lunar declination.

Figure 8. - Continued.



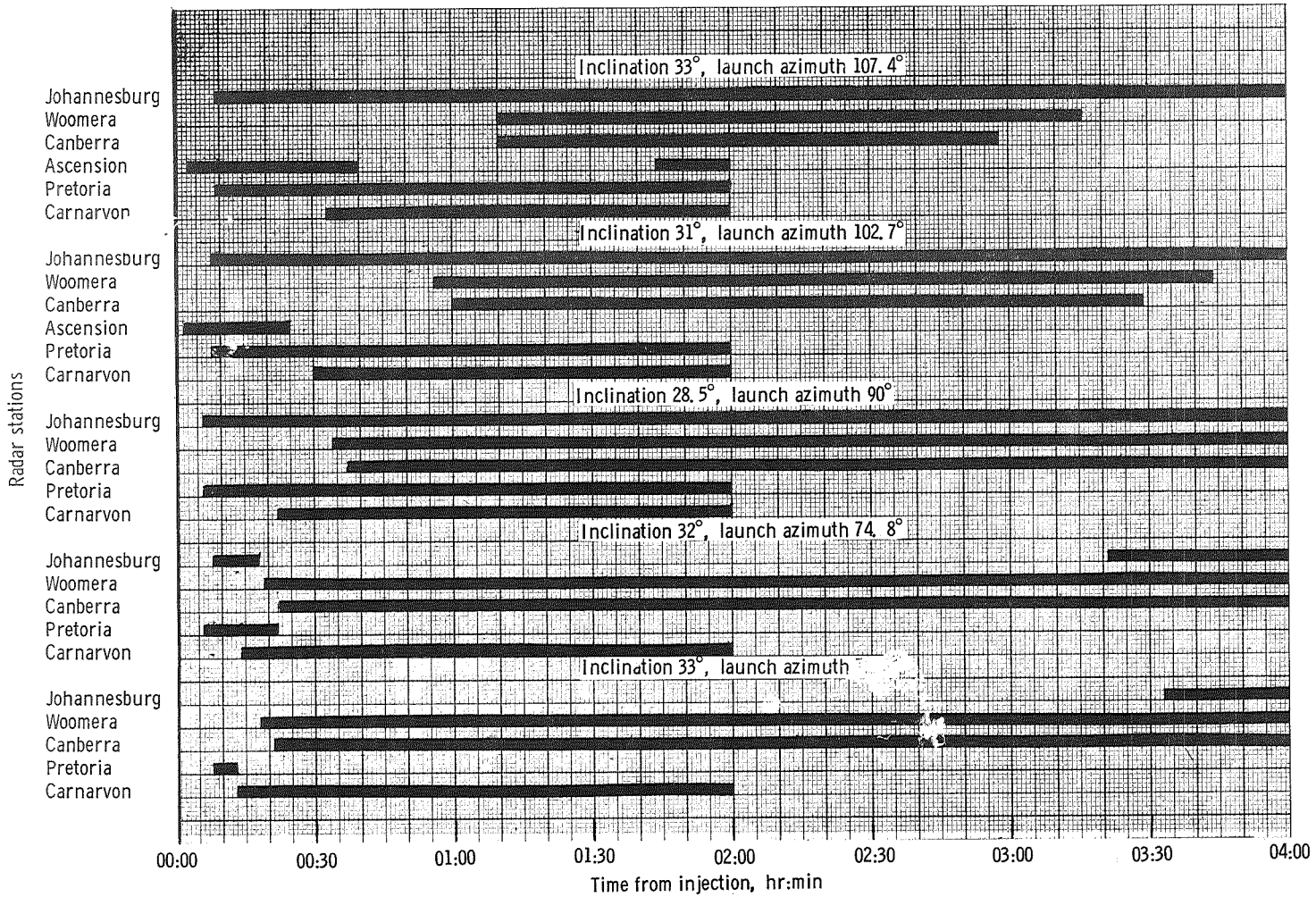
(dd) Pacific injection from third orbit (injection azimuth < 90°), 27.5° lunar declination.

Figure 8. - Concluded.



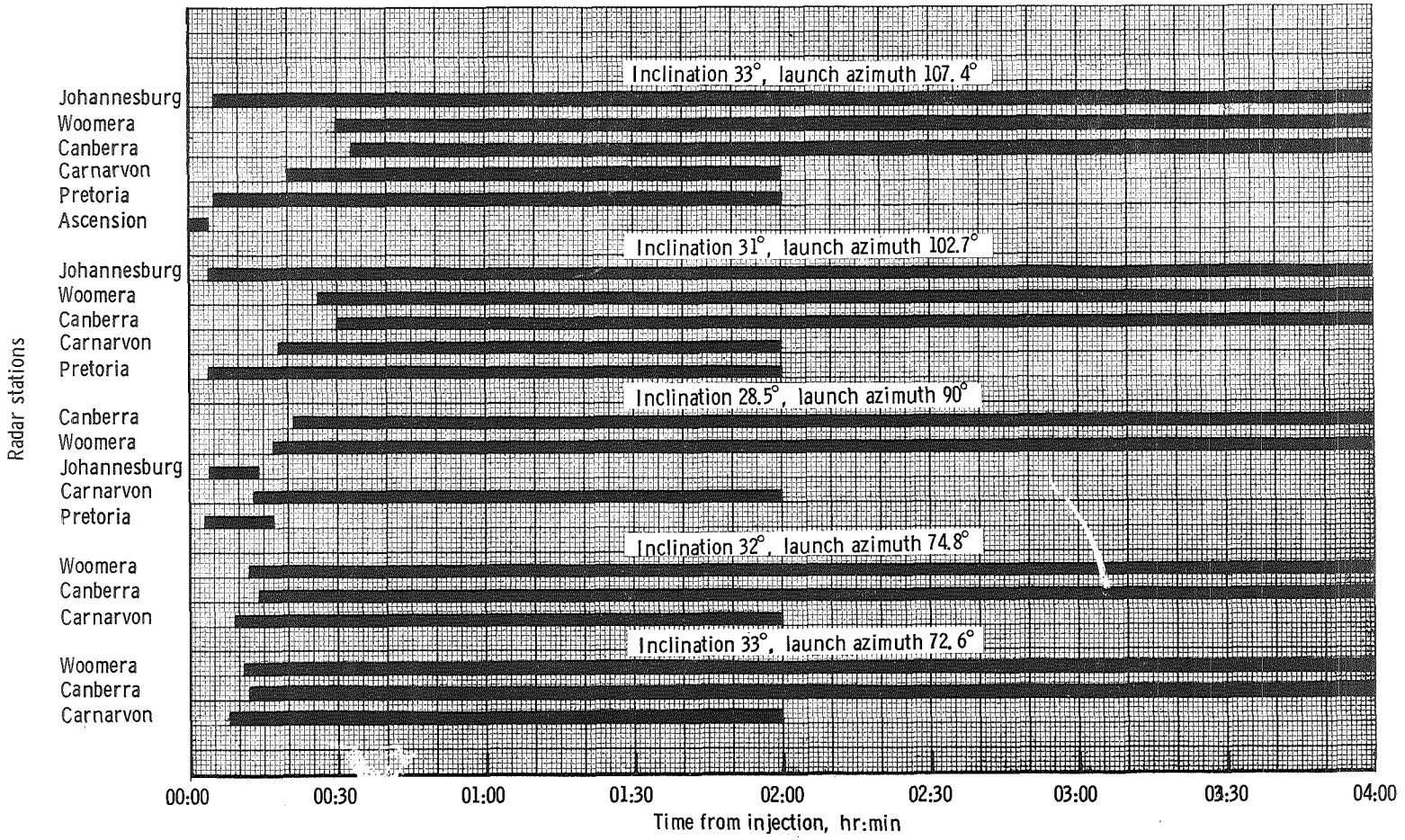
(a) Atlantic injection from first orbit (injection azimuth > 90°), -27.5° lunar declination.

Figure 9. - Radar contact time with spacecraft after injection.



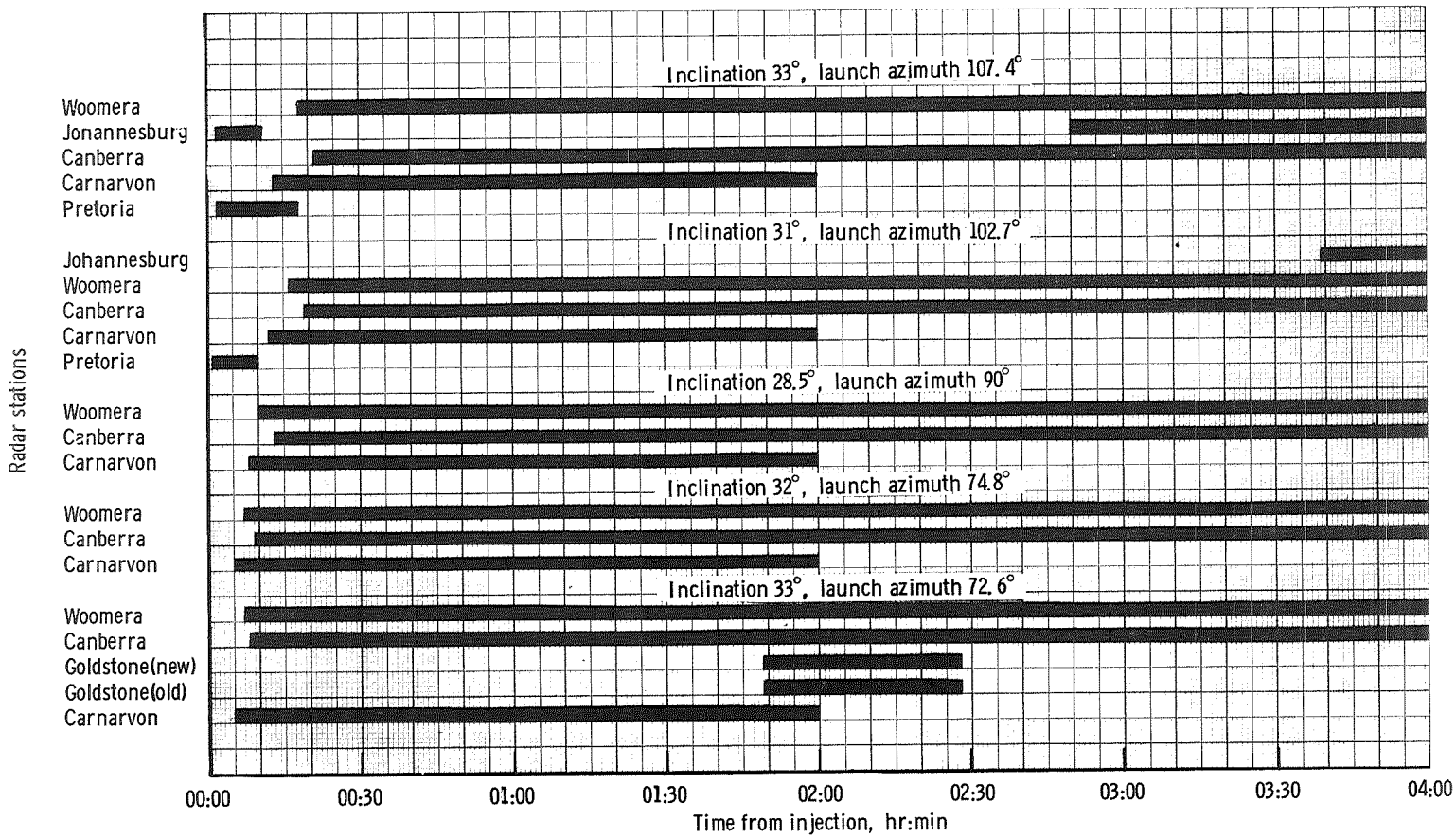
(b) Atlantic injection from first orbit (injection azimuth > 90°), -15° lunar declination.

Figure 9. - Continued.



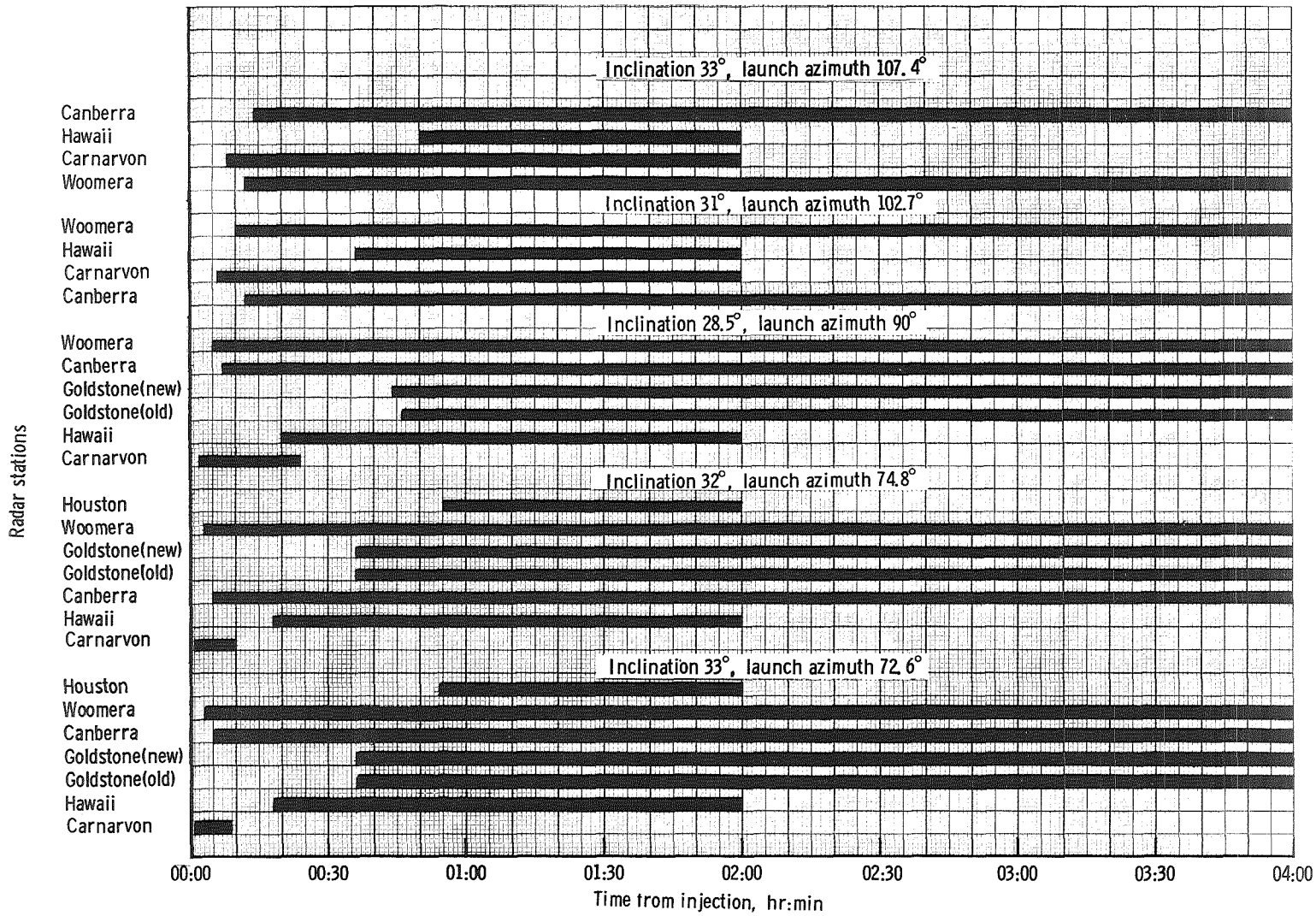
(c) Atlantic injection from first orbit (injection azimuth > 90°), 0° lunar declination.

Figure 9. - Continued.



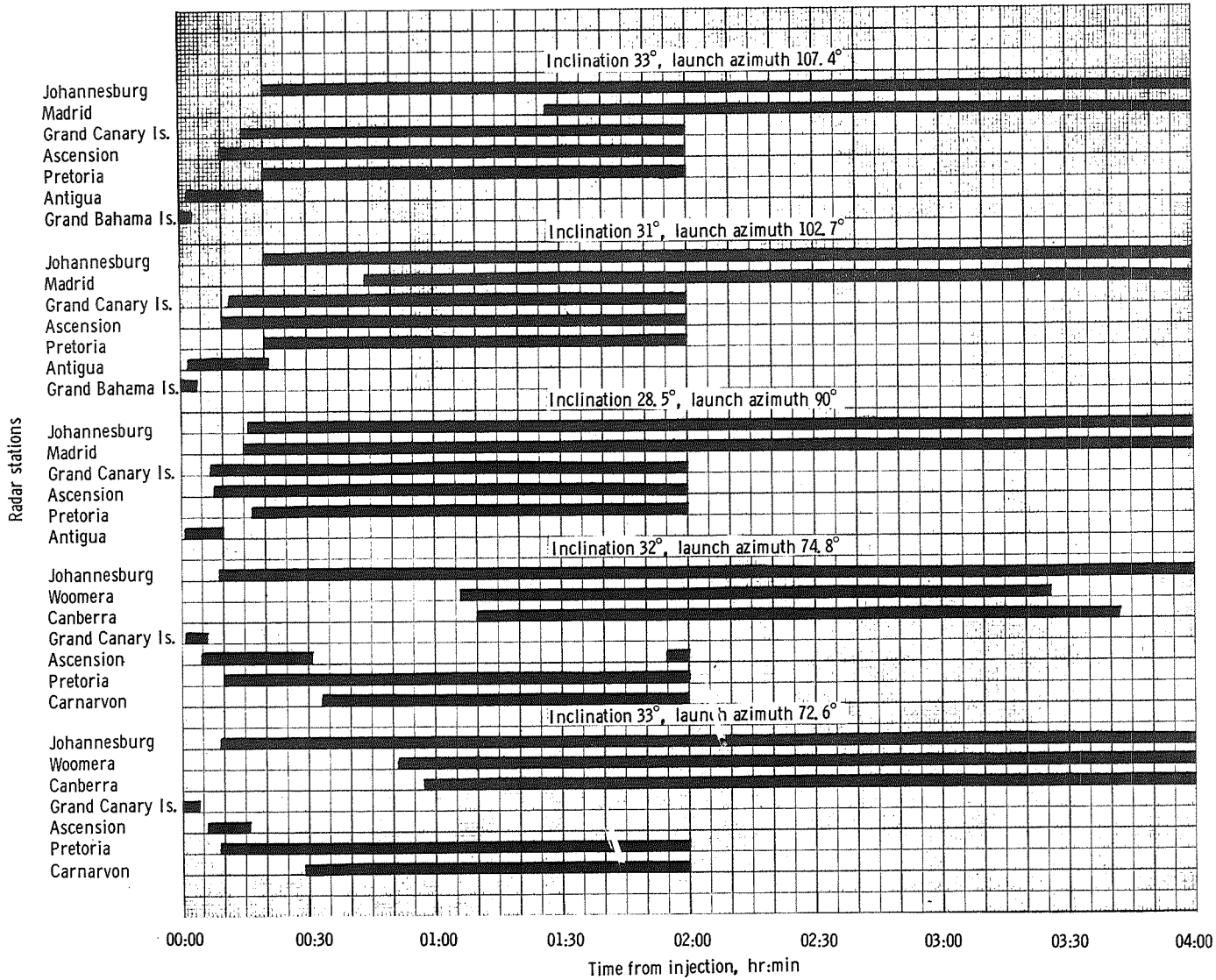
(d) Atlantic injection from first orbit (injection azimuth > 90°), 15° lunar declination.

Figure 9. - Continued.



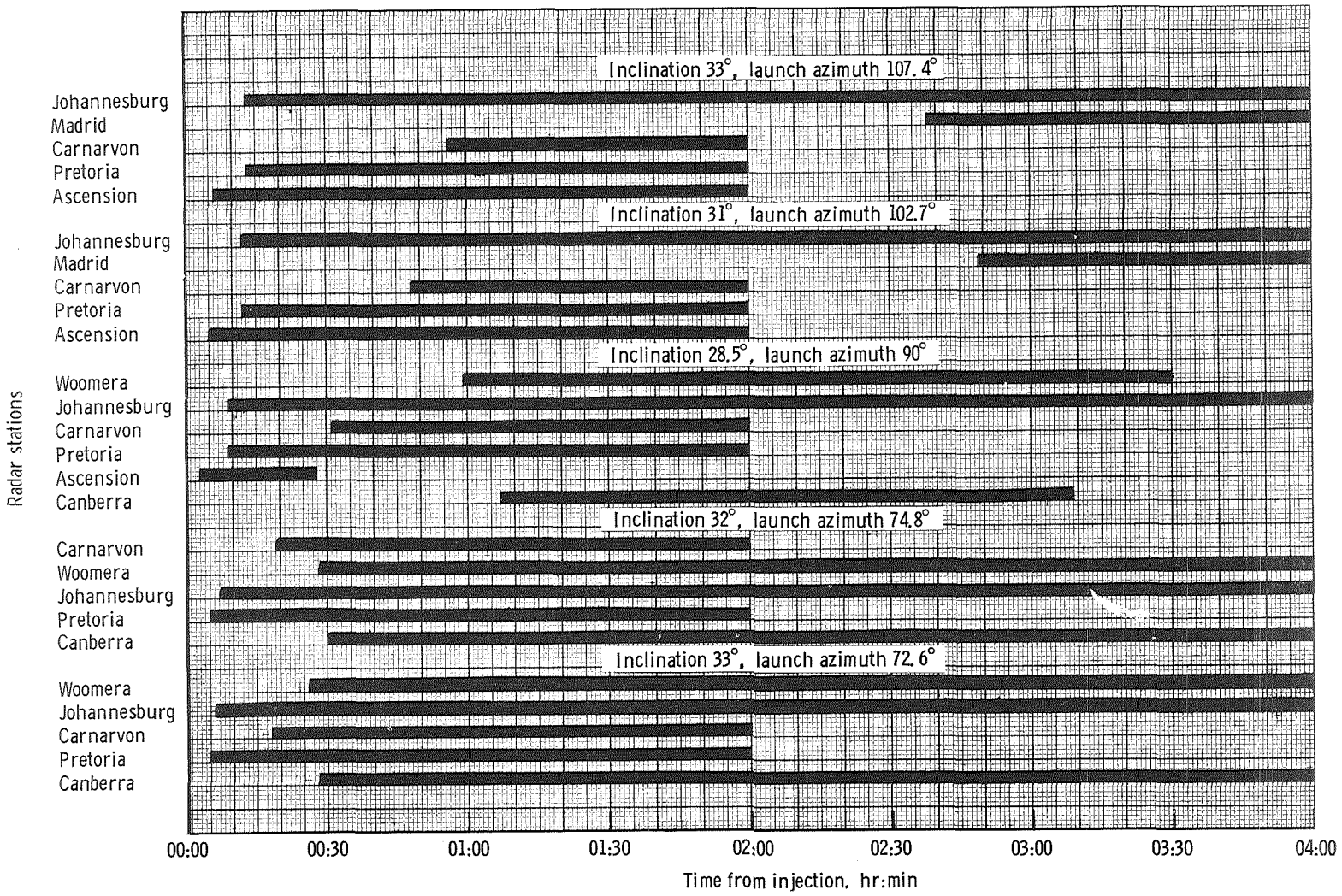
(e) Atlantic injection from first orbit (injection azimuth > 90°), 27.5° lunar declination.

Figure 9. - Continued.



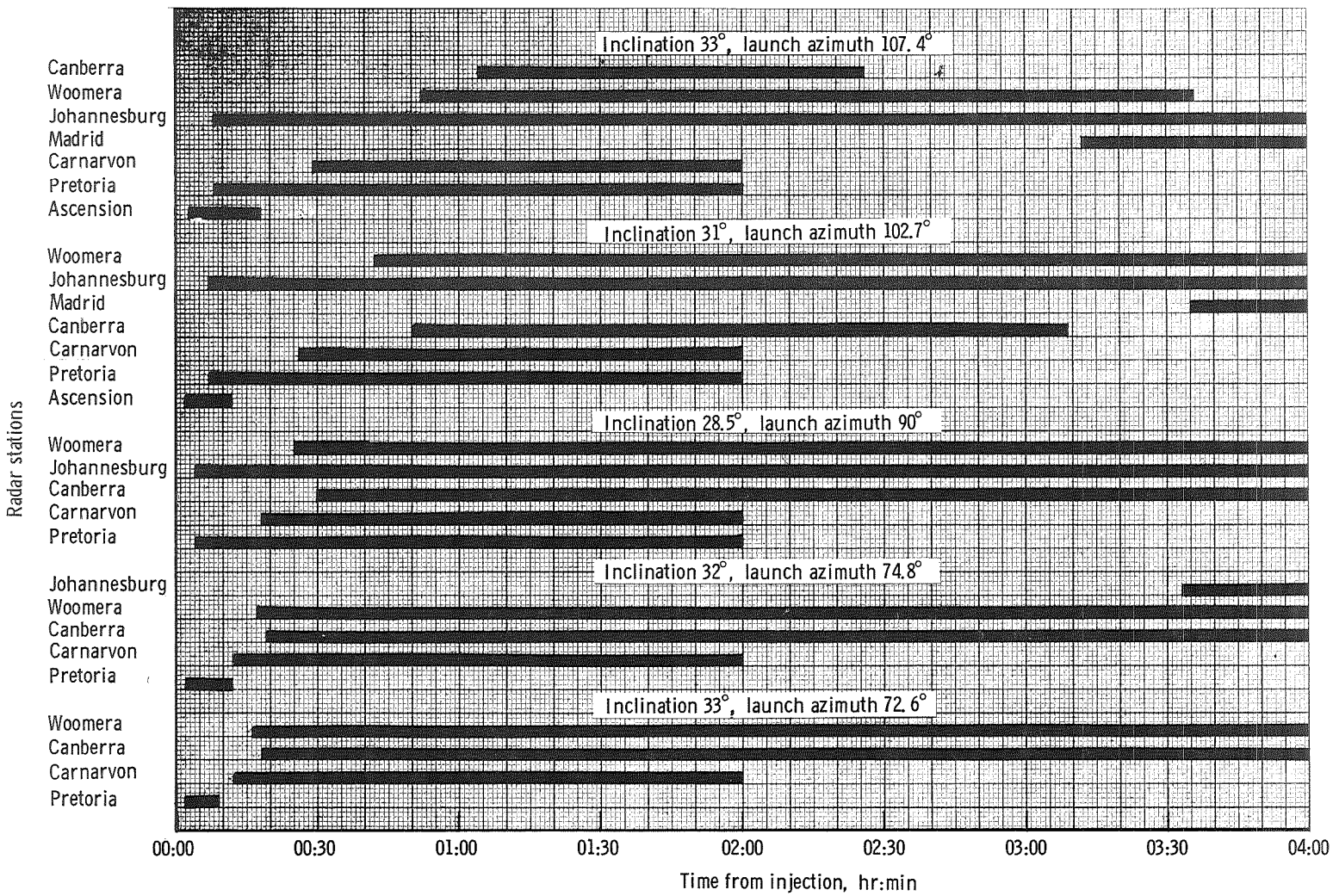
(f) Atlantic injection from second orbit (injection azimuth > 90°), -27.5° lunar declination.

Figure 9. - Continued.



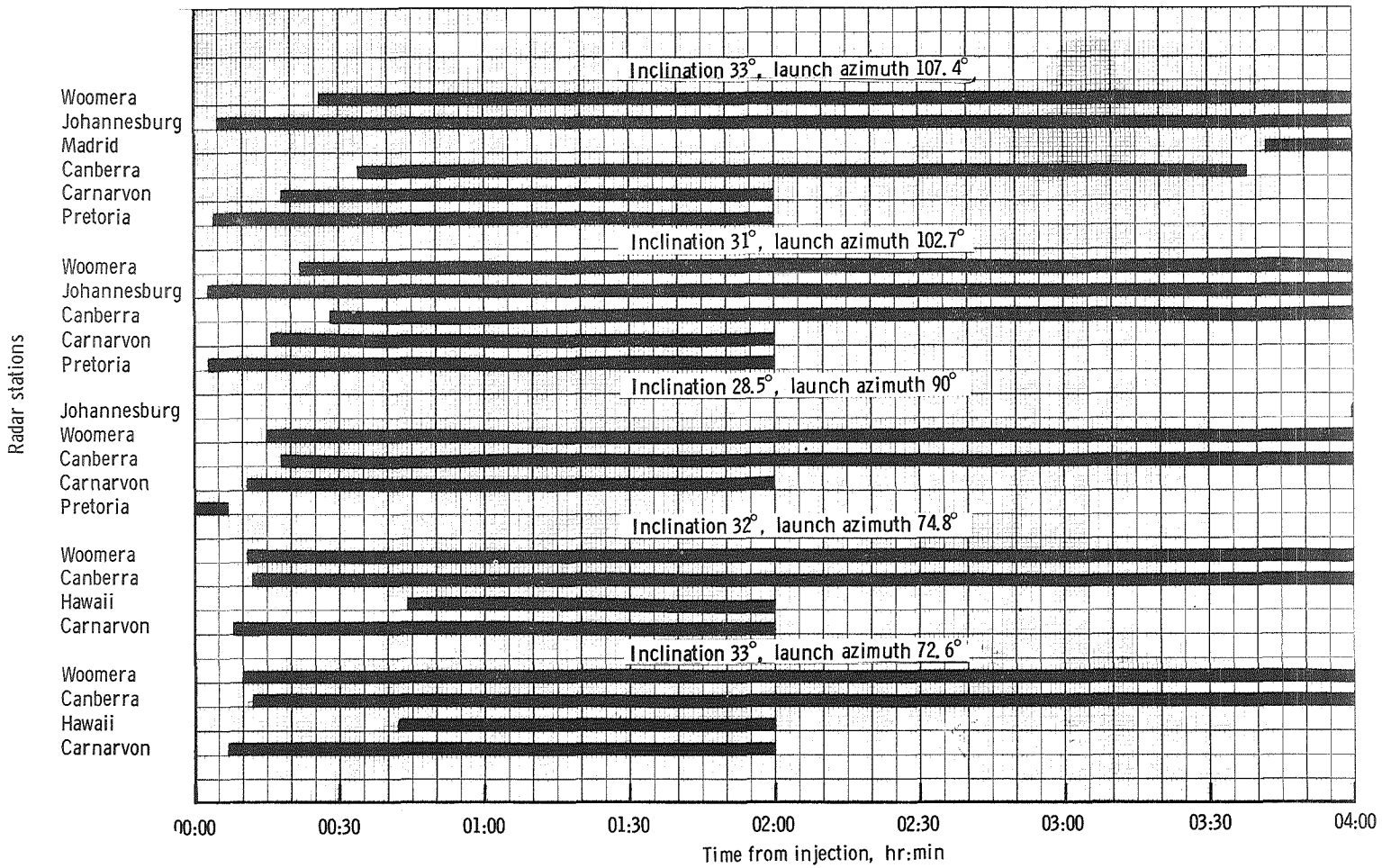
(g) Atlantic injection from second orbit (injection azimuth > 90°), -15° lunar declination.

Figure 9. - Continued.



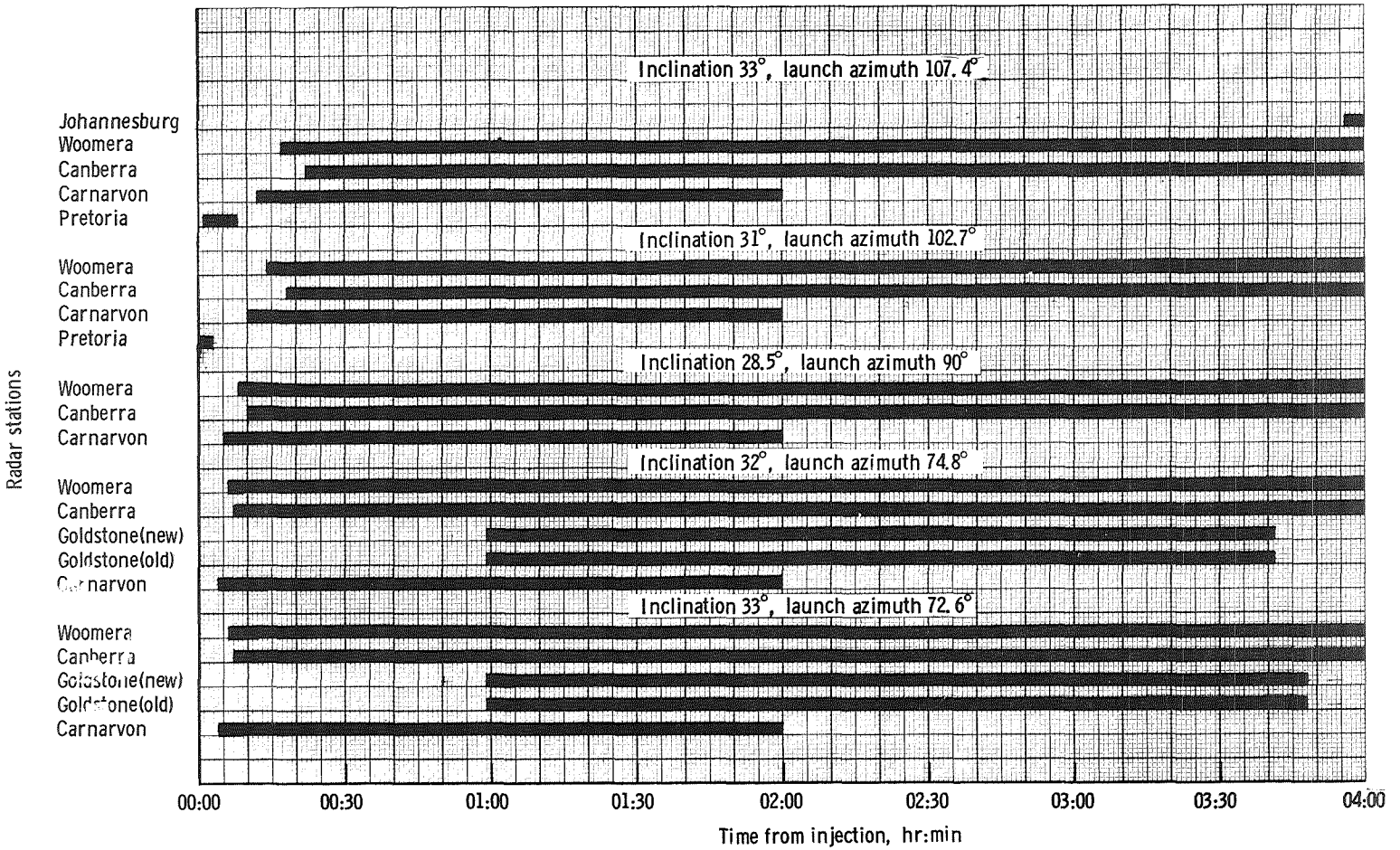
(h) Atlantic injection from second orbit (injection azimuth > 90°), 0° lunar declination.

Figure 9. - Continued.



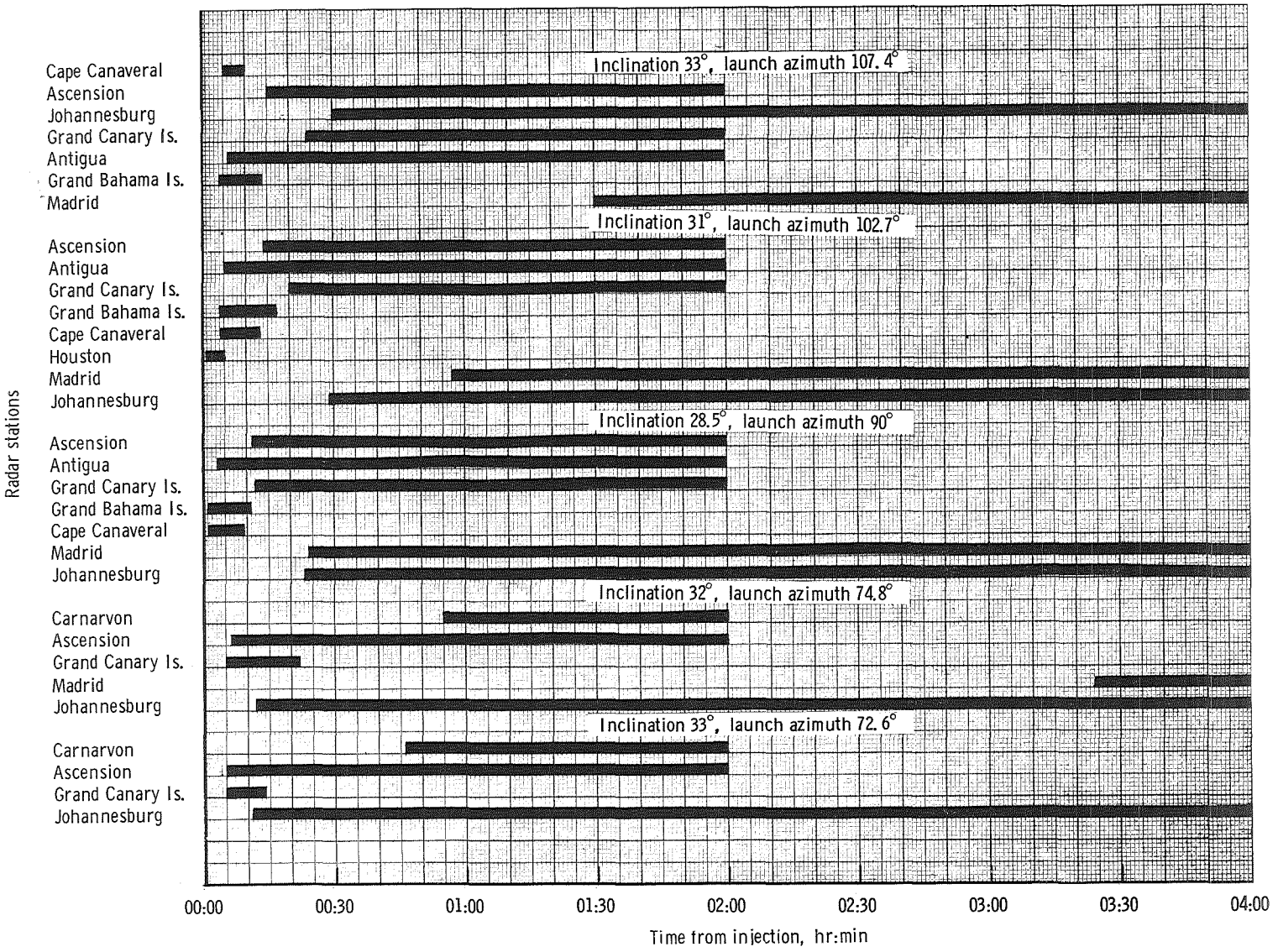
(i) Atlantic injection from second orbit (injection azimuth > 90°), 15° lunar declination.

Figure 9. - Continued.



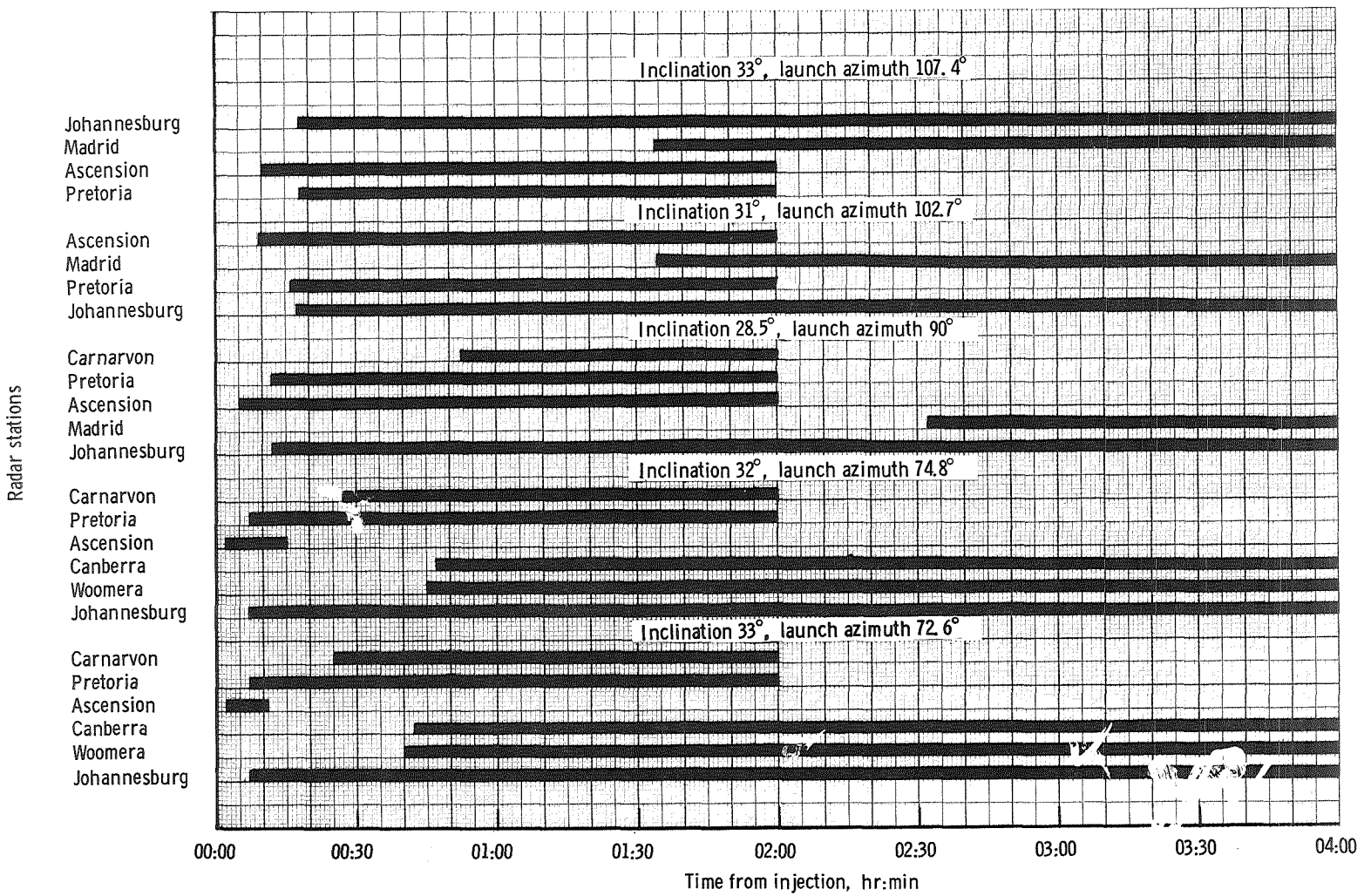
(j) Atlantic injection from second orbit (injection azimuth > 90°), 27.5° lunar declination.

Figure 9. - Continued.



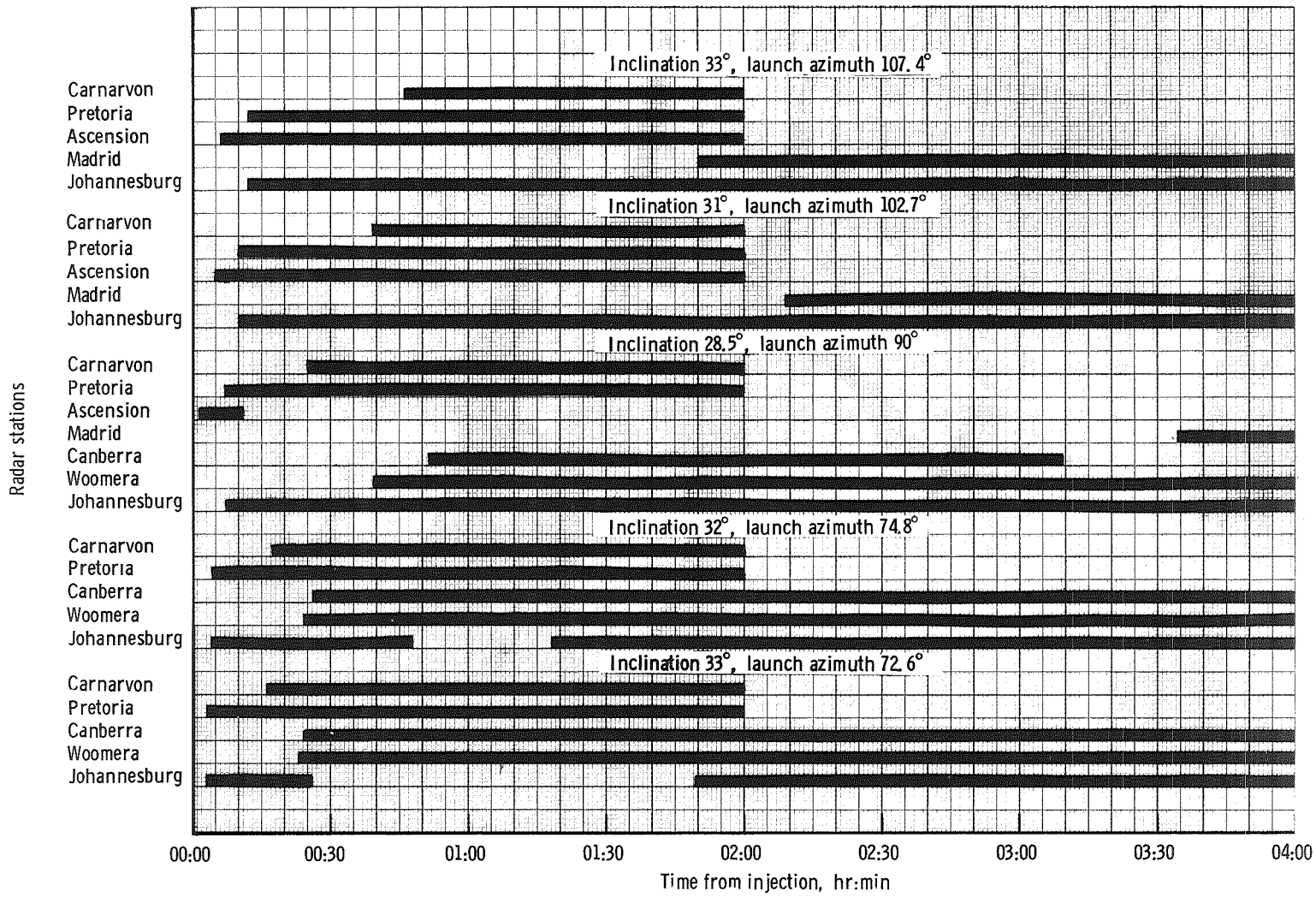
(k) Atlantic injection from third orbit (injection azimuth > 90°), -27.5° lunar declination.

Figure 9. - Continued.



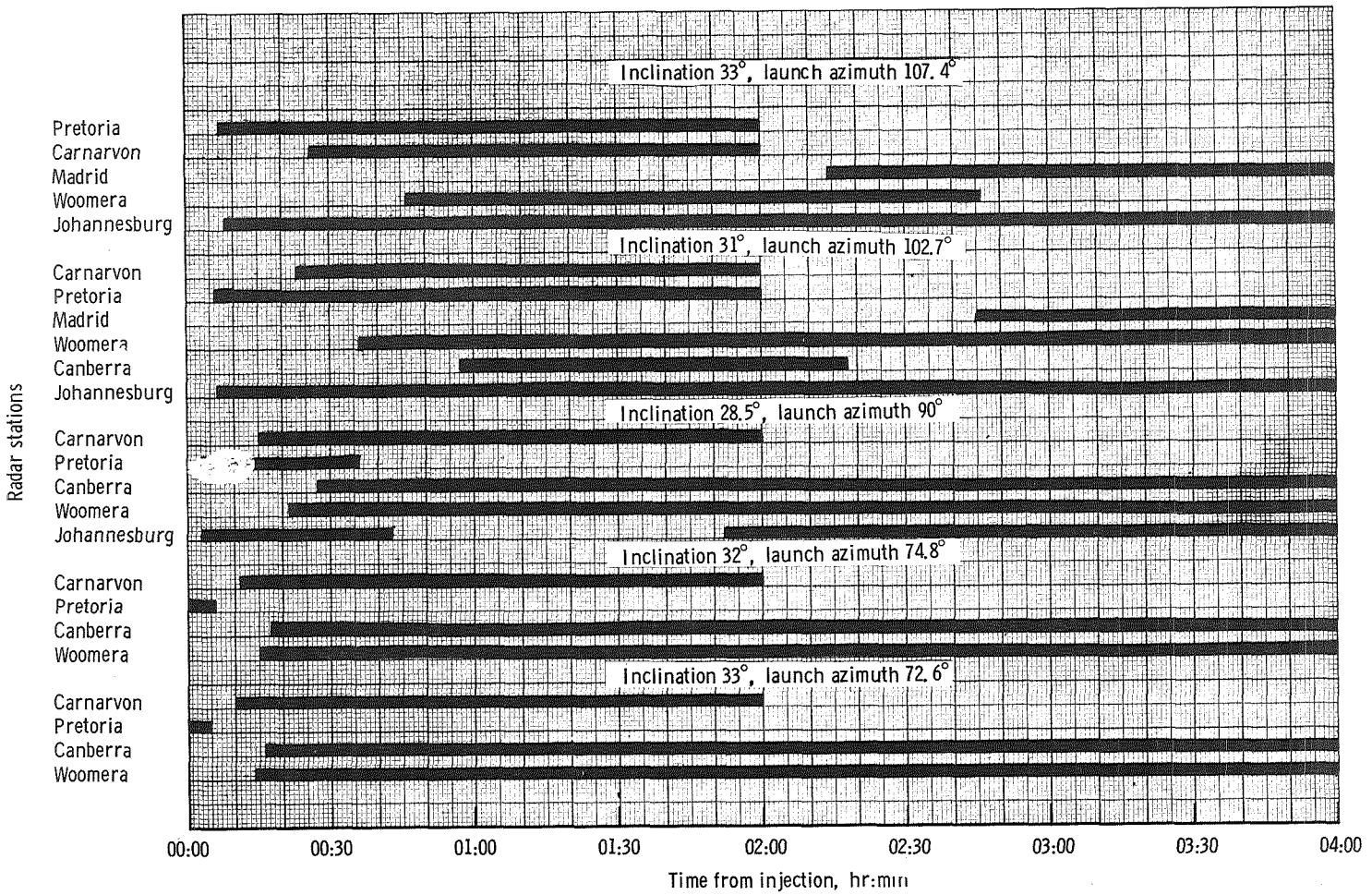
(l) Atlantic injection from third orbit (injection azimuth > 90°), -15° lunar declination.

Figure 9. - Continued.



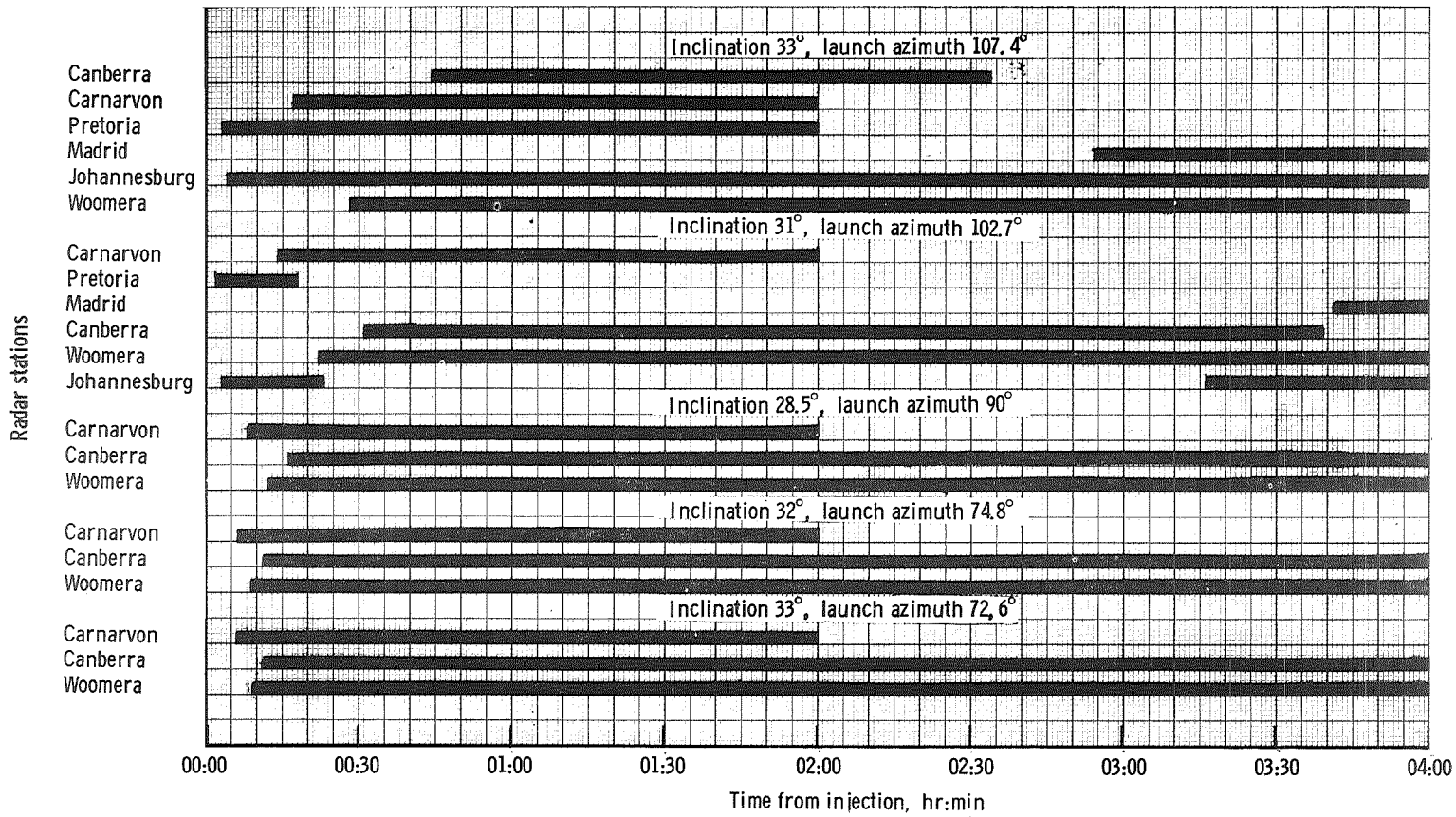
(m) Atlantic injection from third orbit (injection azimuth > 90°), 0° lunar declination.

Figure 9. - Continued.



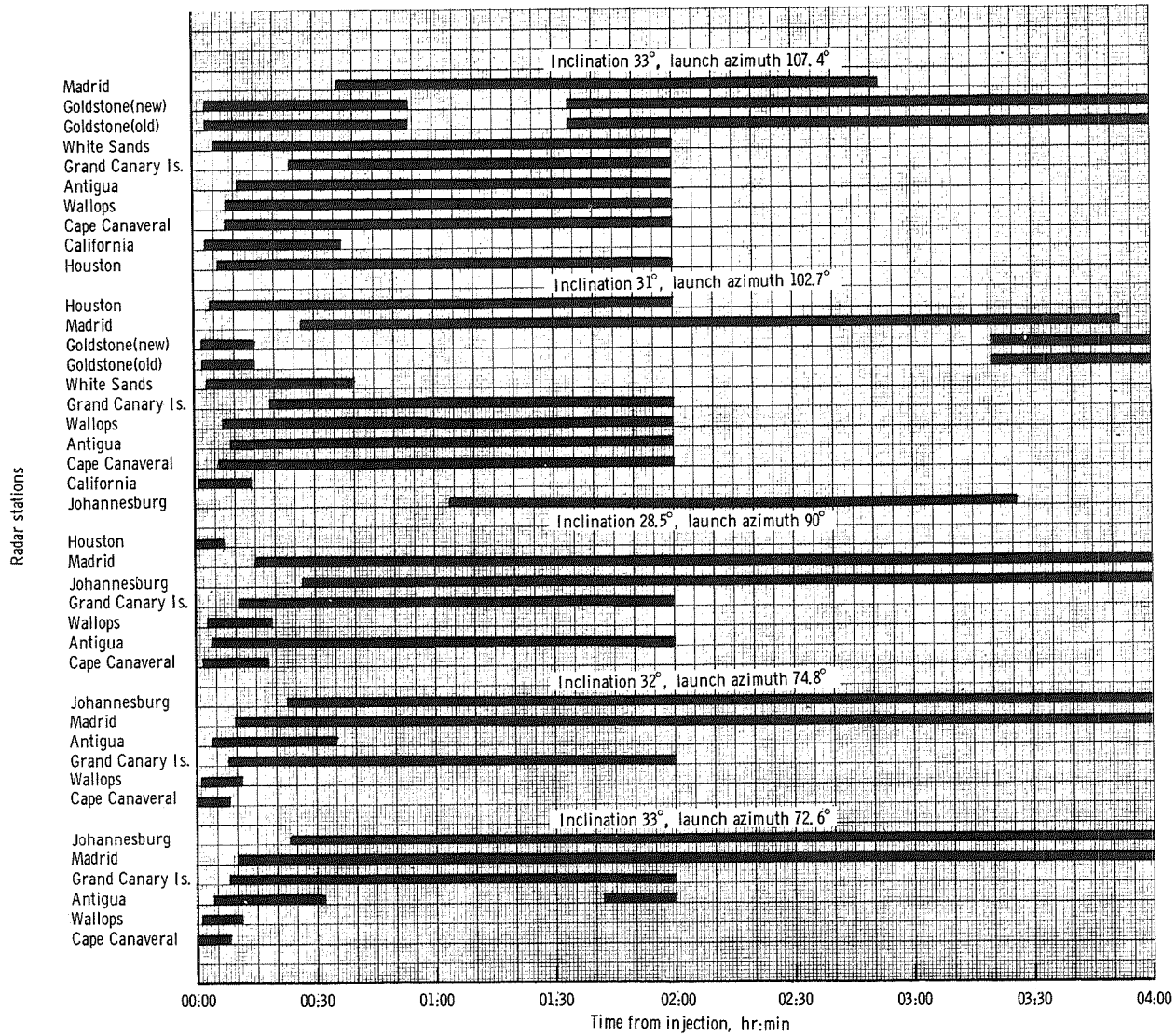
(n) Atlantic injection from third orbit (injection azimuth > 90°), 15° lunar declination.

Figure 9. - Continued.



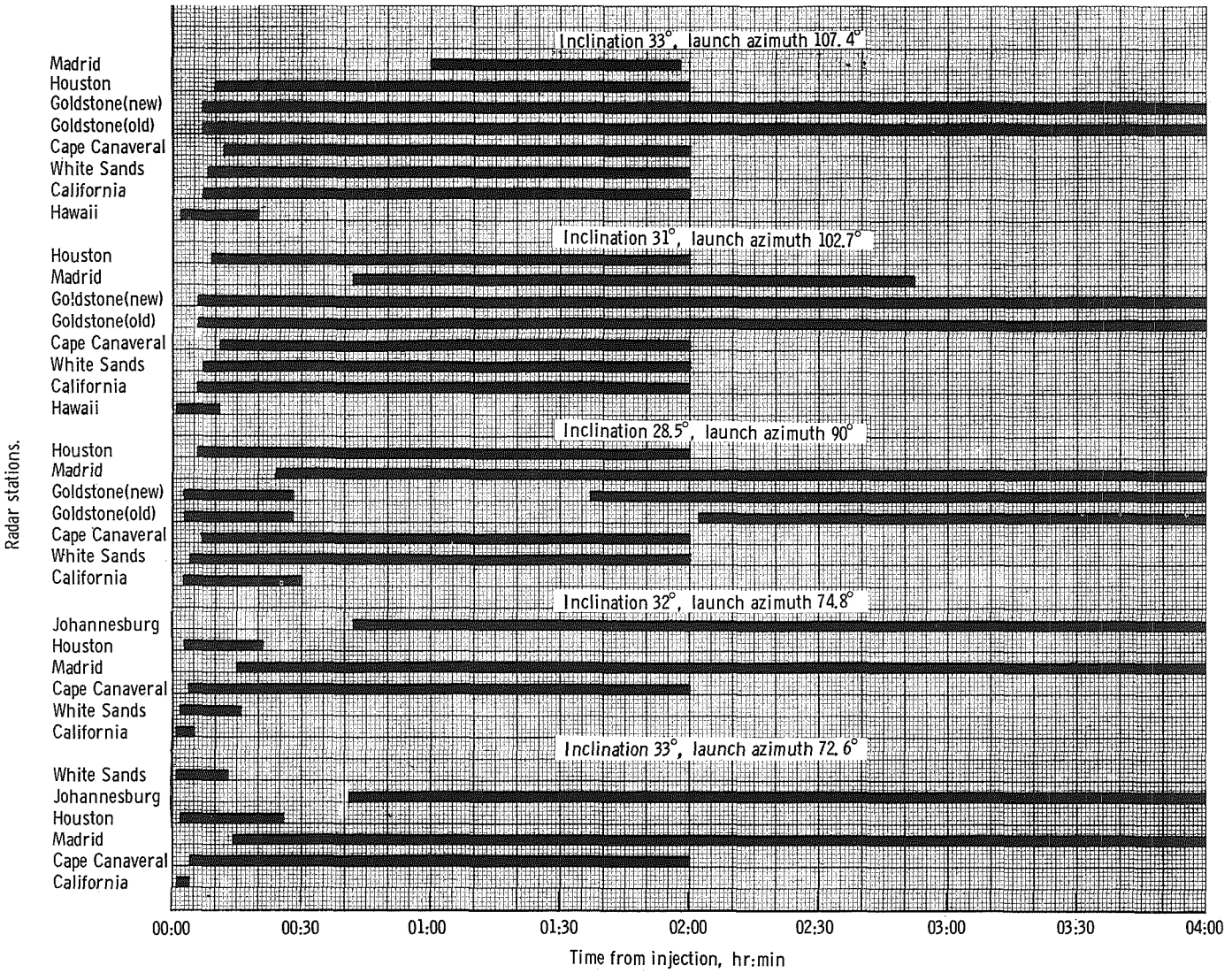
(o) Atlantic injection from third orbit (injection azimuth > 90°), 27.5° lunar declination.

Figure 9. - Continued.



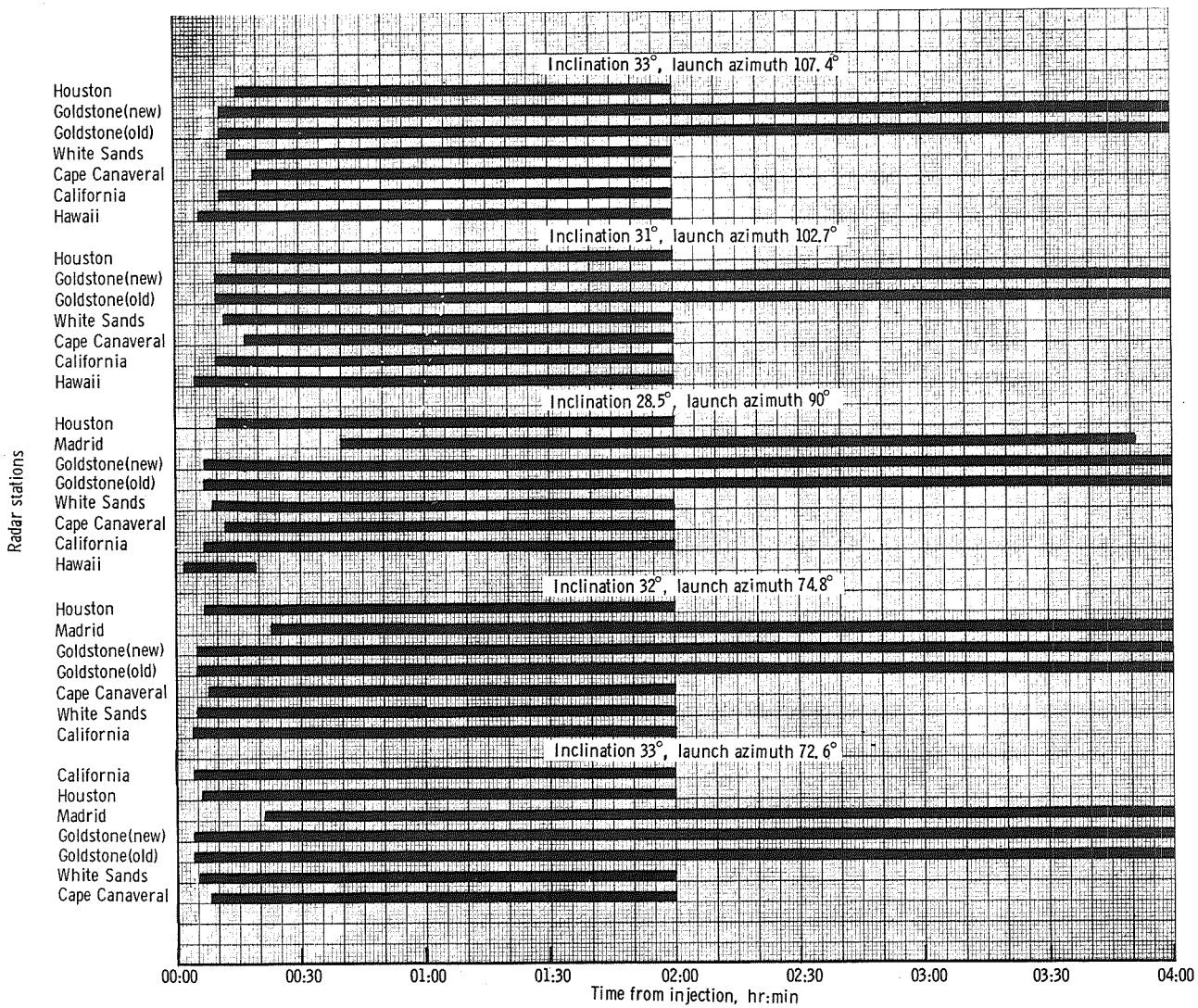
(p) Pacific injection from first orbit (injection azimuth < 90°), -27.5° lunar declination.

Figure 9. - Continued.



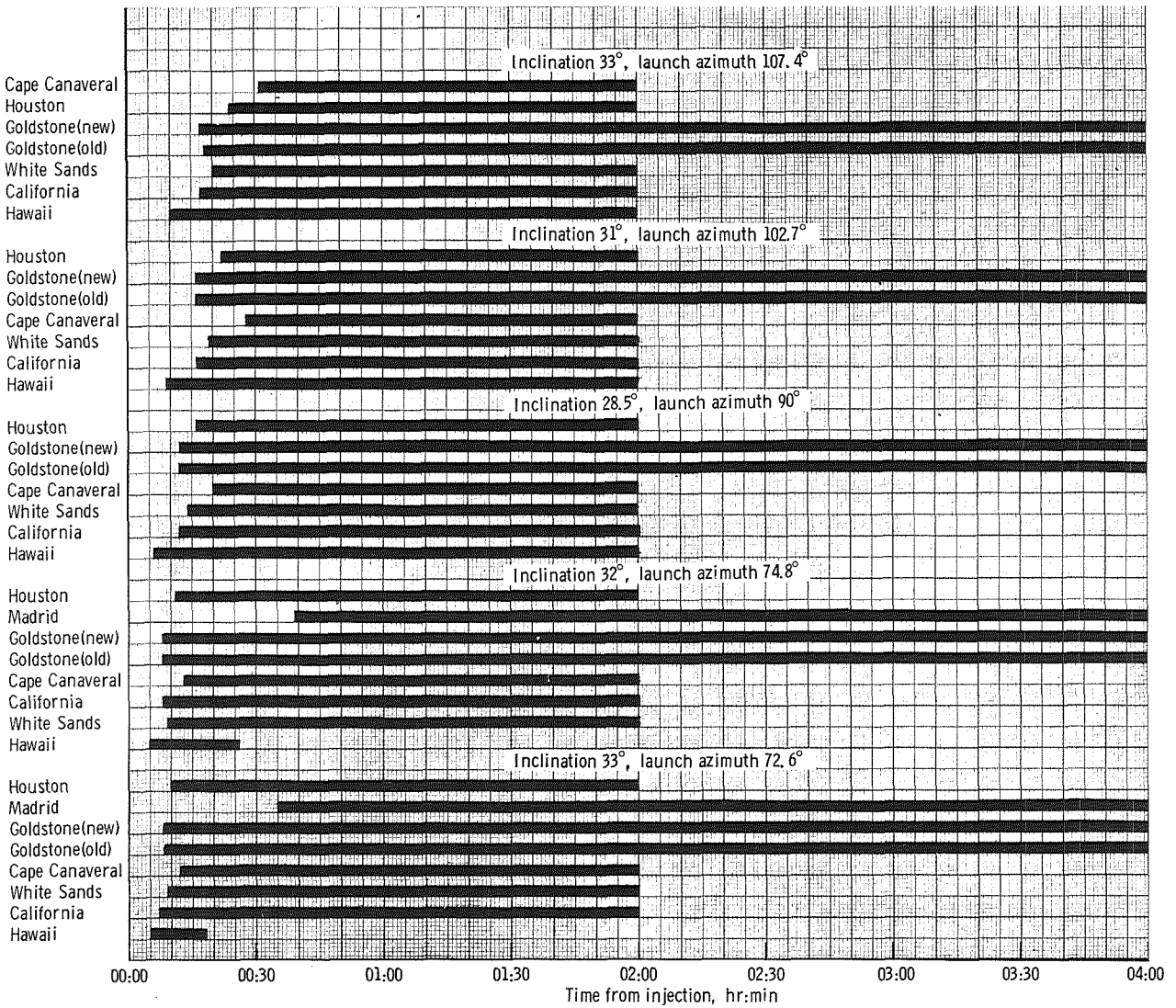
(q) Pacific injection from first orbit (injection azimuth < 90°), -15° lunar declination.

Figure 9. - Continued.



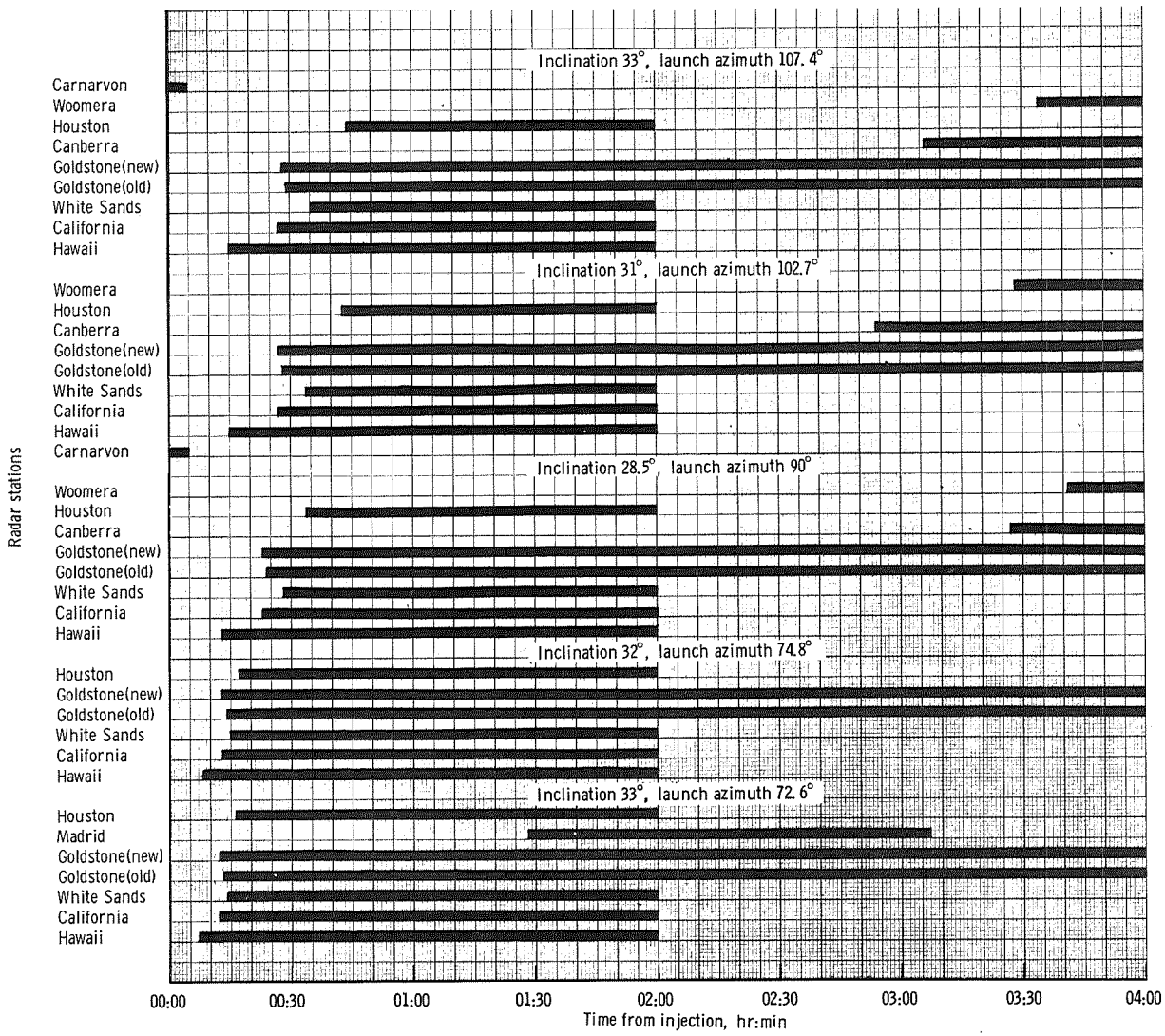
(r) Pacific injection from first orbit (injection azimuth < 90°), 0° lunar declination.

Figure 9. - Continued.



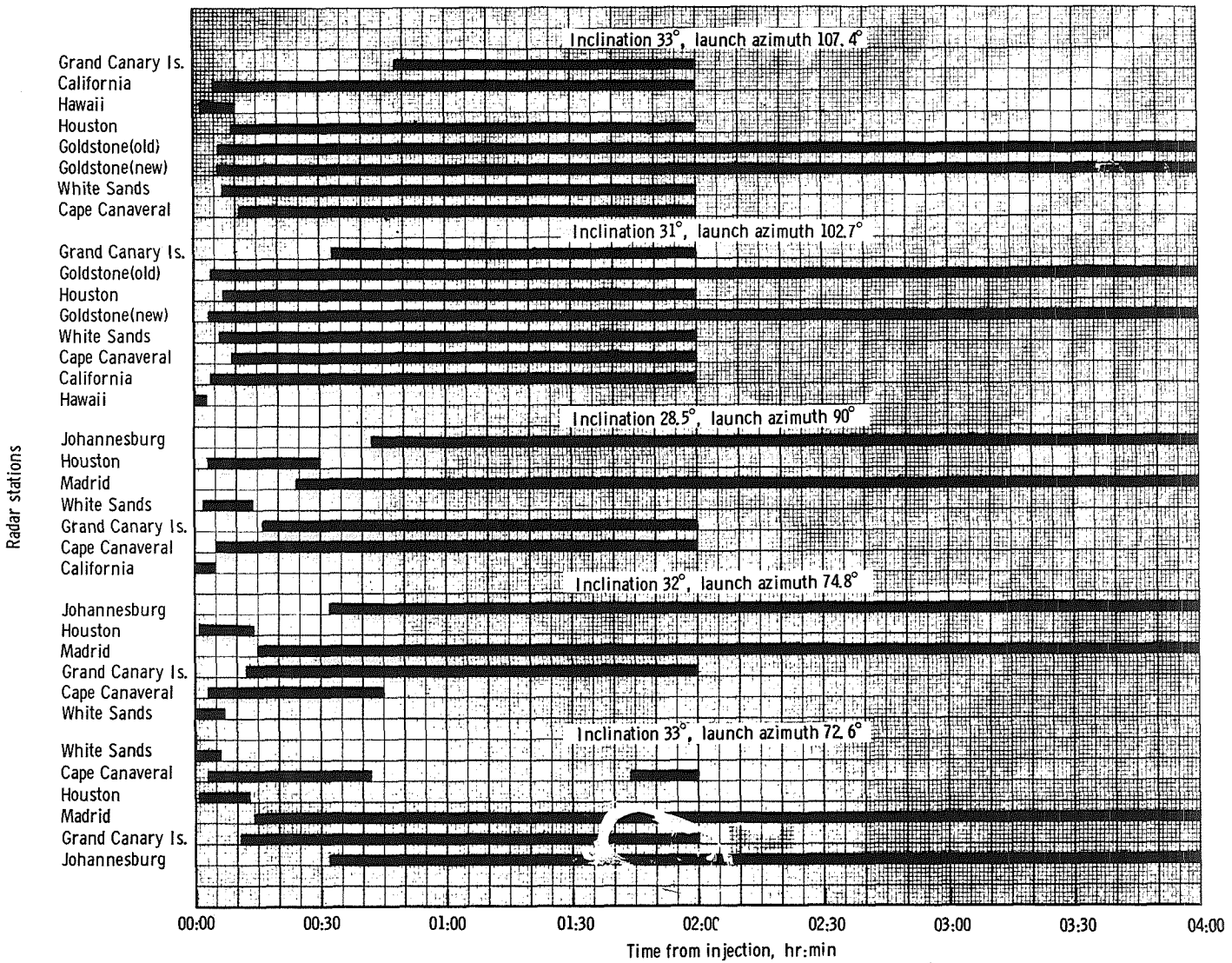
(s) Pacific injection from first orbit (injection azimuth < 90°), 15° lunar declination.

Figure 9. - Continued.



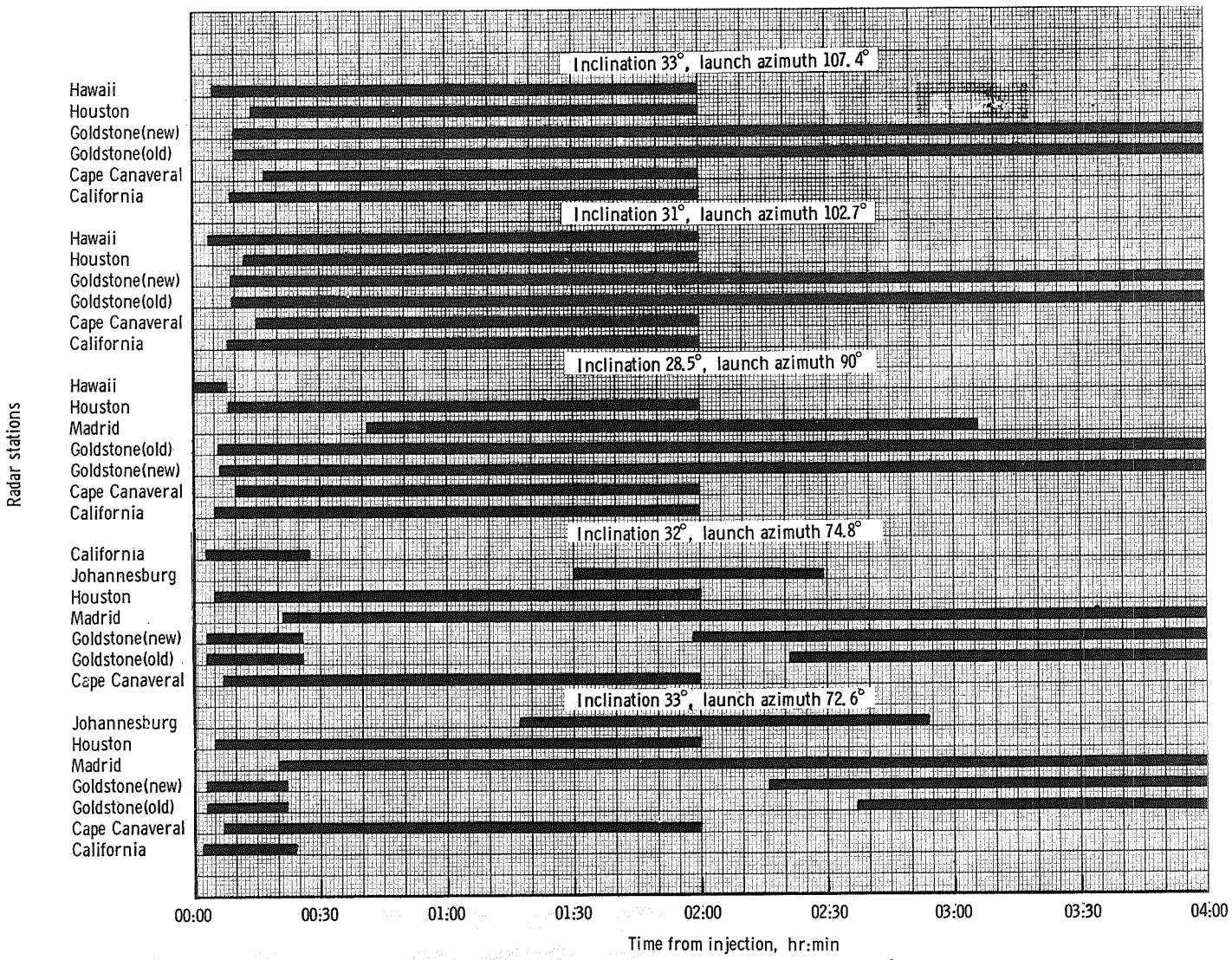
(t) Pacific injection from first orbit (injection azimuth < 90°), 27.5° lunar declination.

Figure 9. - Continued.



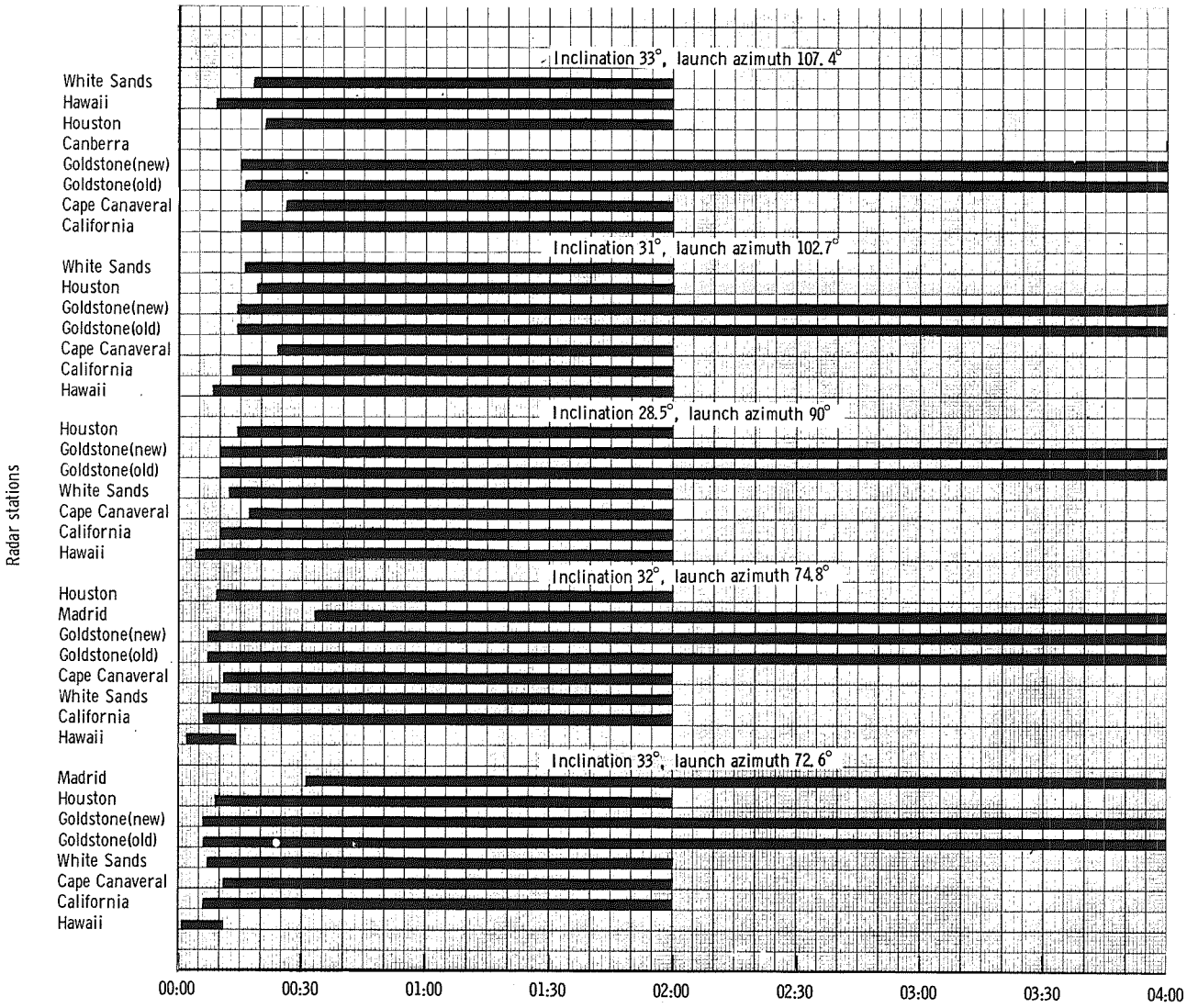
(u) Pacific injection from second orbit (injection azimuth < 90°), -27.5° lunar declination.

Figure 9. - Continued.



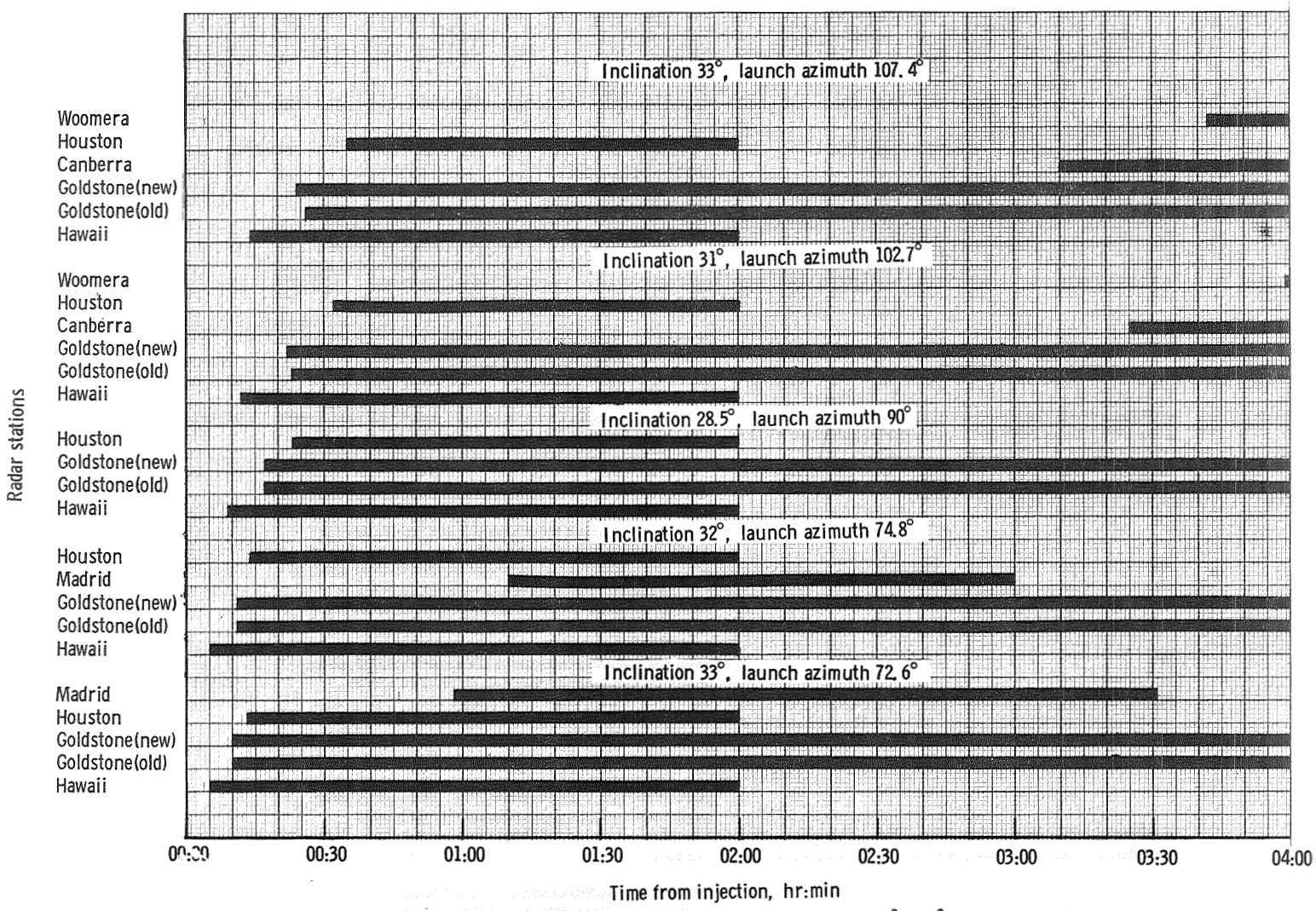
(v) Pacific injection from second orbit (injection azimuth < 90°), -15° lunar declination.

Figure 9. - Continued.



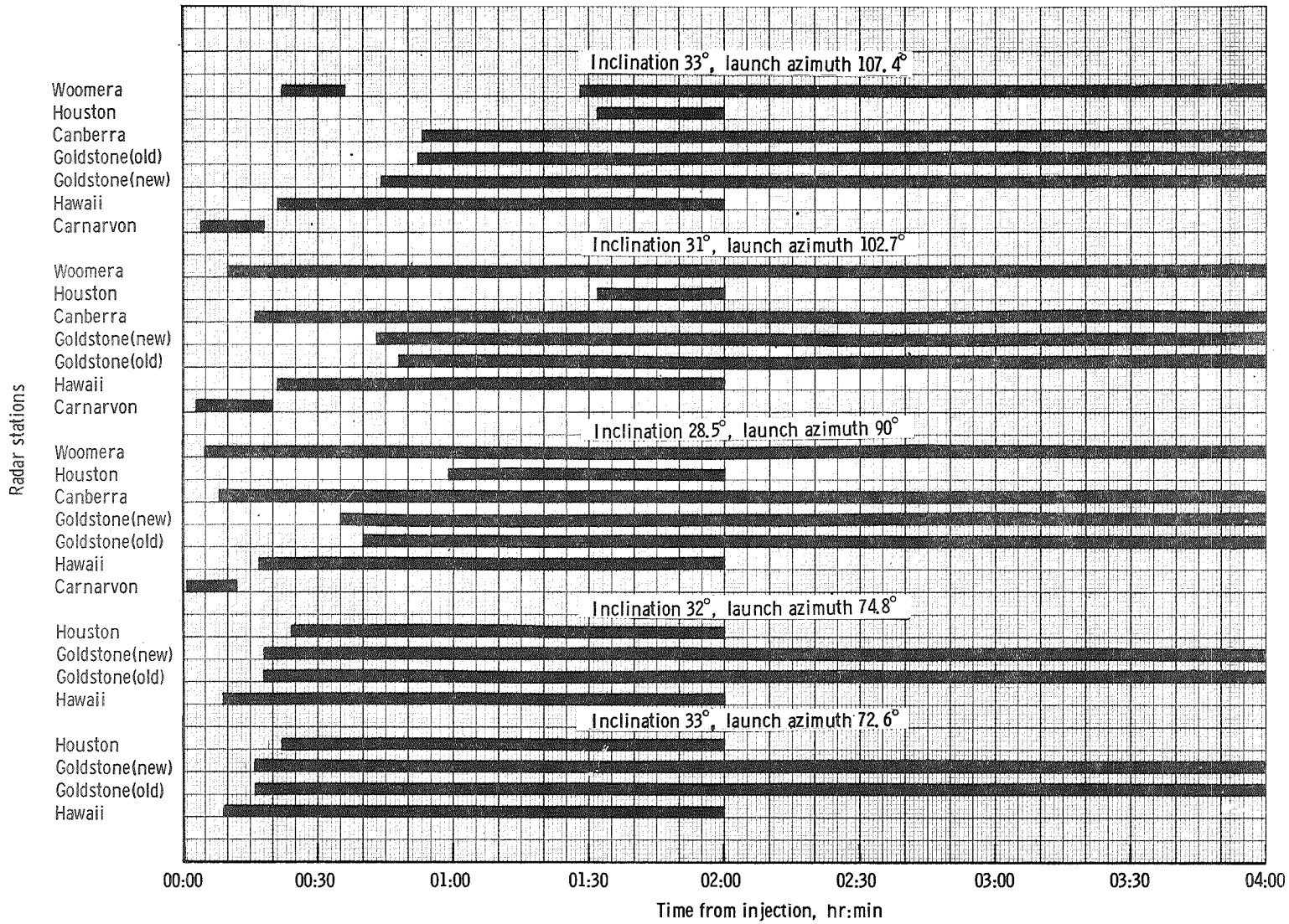
(w) Pacific injection from second orbit (injection azimuth < 90°), 0° lunar declination.

Figure 9. - Continued.



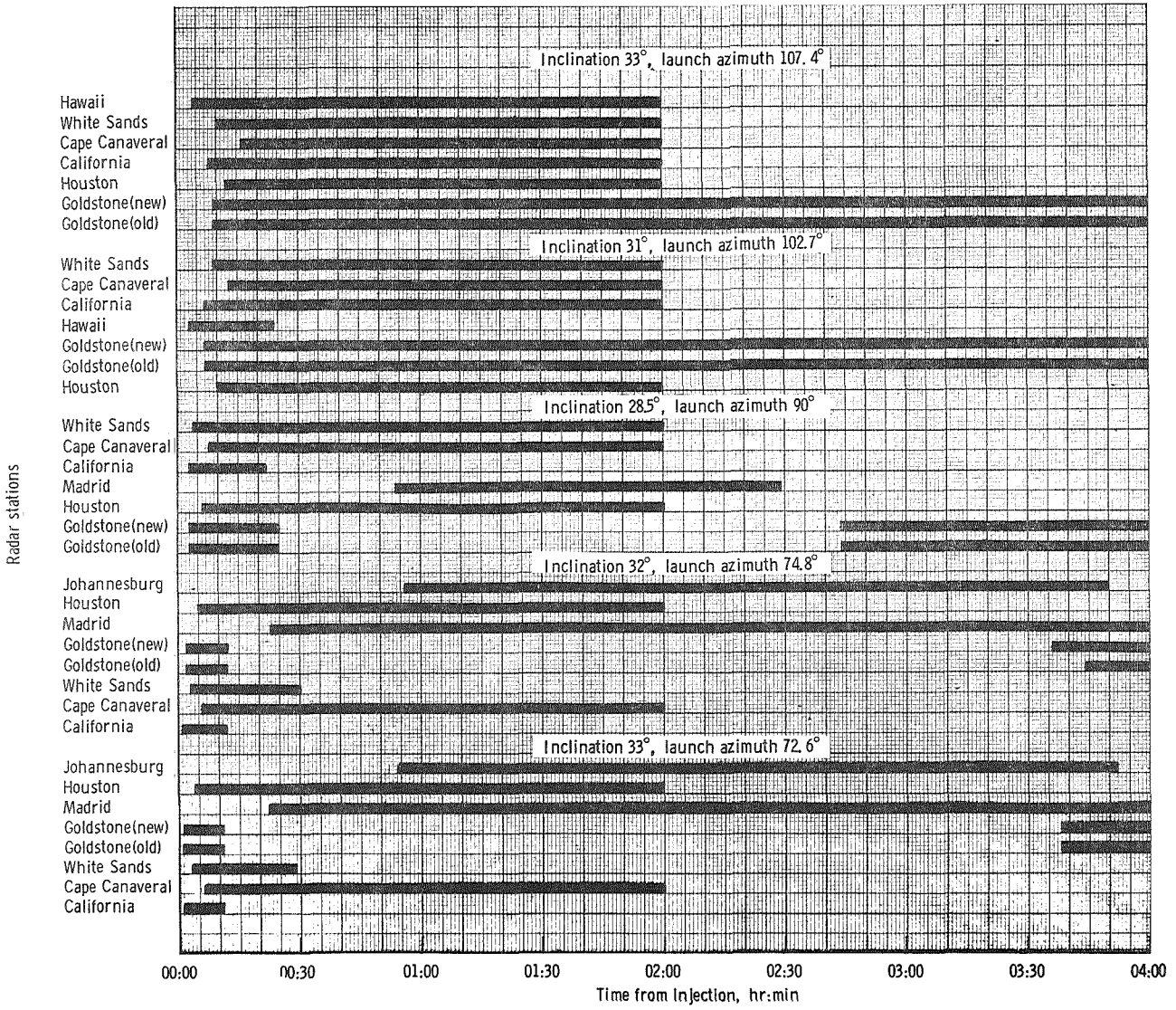
(x) Pacific injection from second orbit (injection azimuth < 90°), 15° lunar declination.

Figure 9. - Continued.



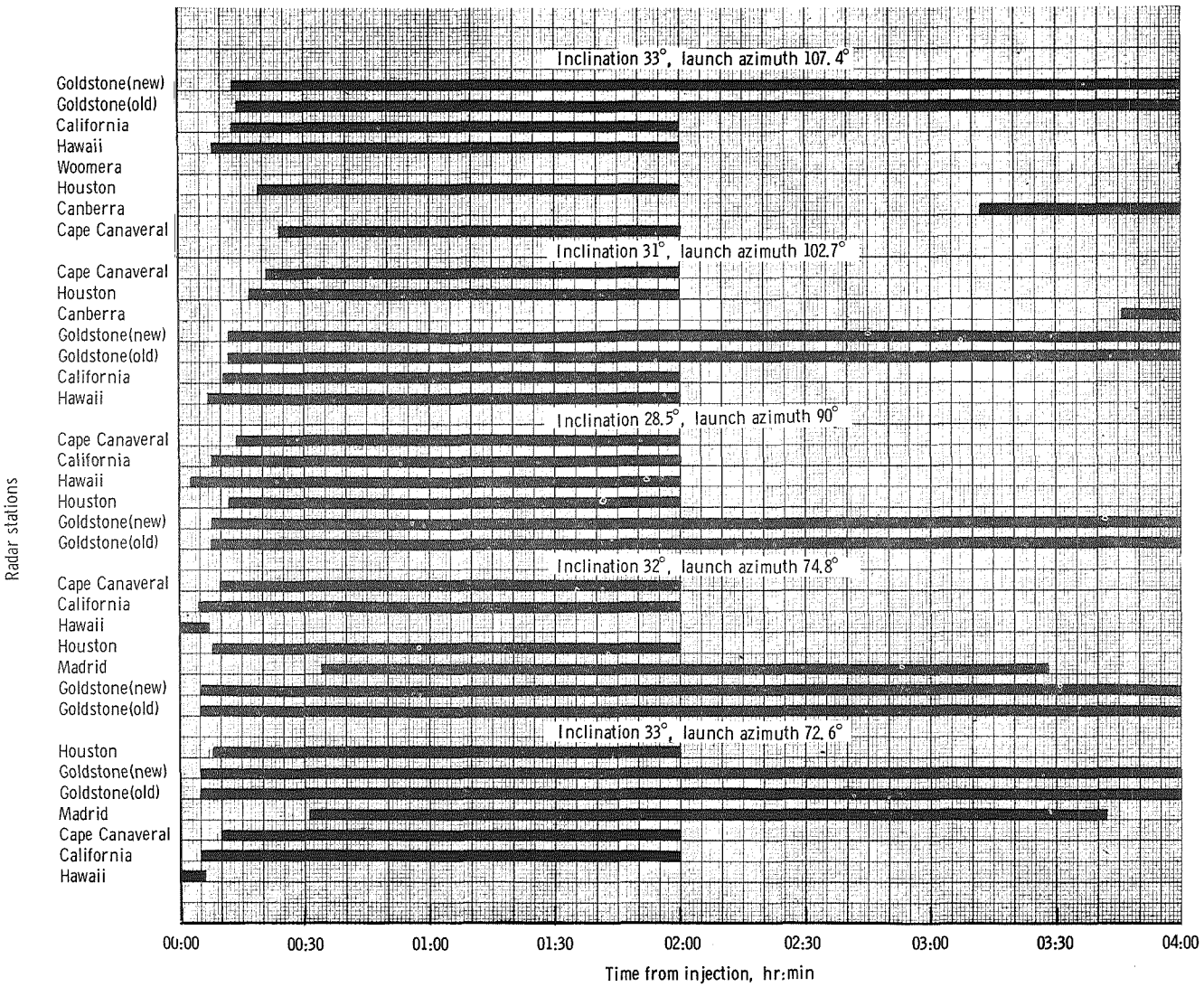
(y) Pacific injection from second orbit (injection azimuth < 90°), 27.5° lunar declination.

Figure 9. - Continued.



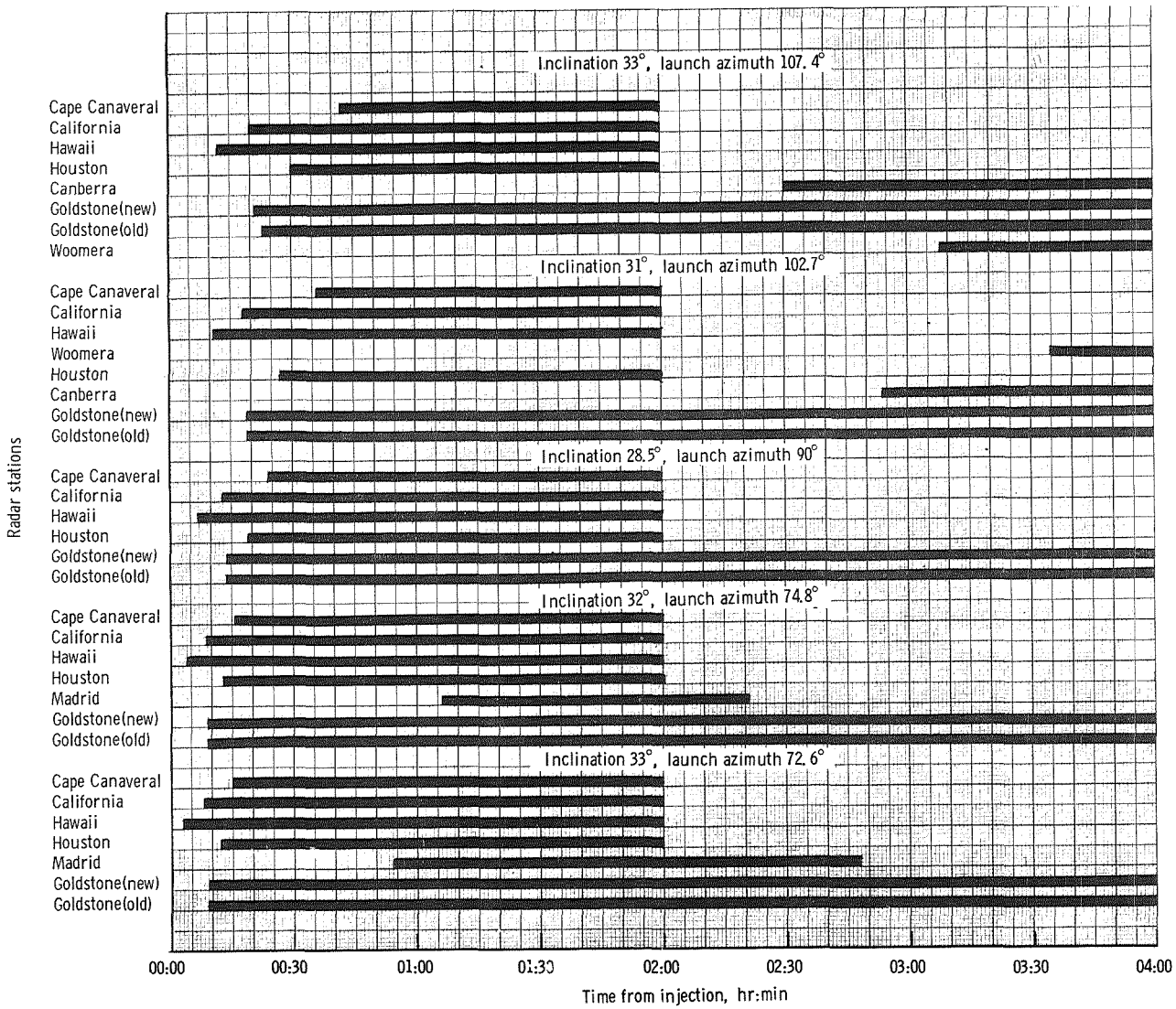
(z) Pacific injection from third orbit (injection azimuth < 90°), -27.5° lunar declination.

Figure 9. - Continued.



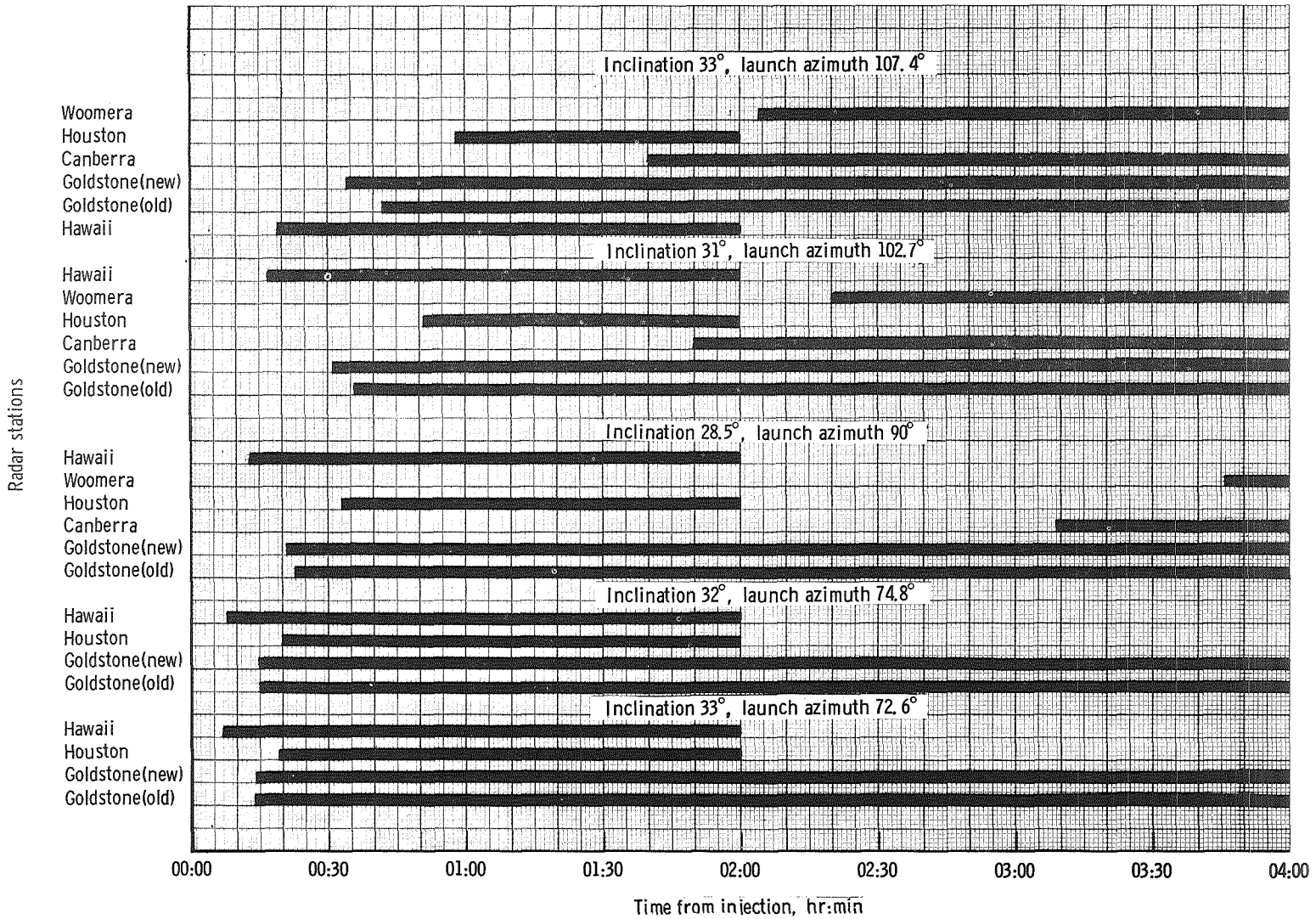
(aa) Pacific injection from third orbit (injection azimuth < 90°), -15° lunar declination.

Figure 9. - Continued.



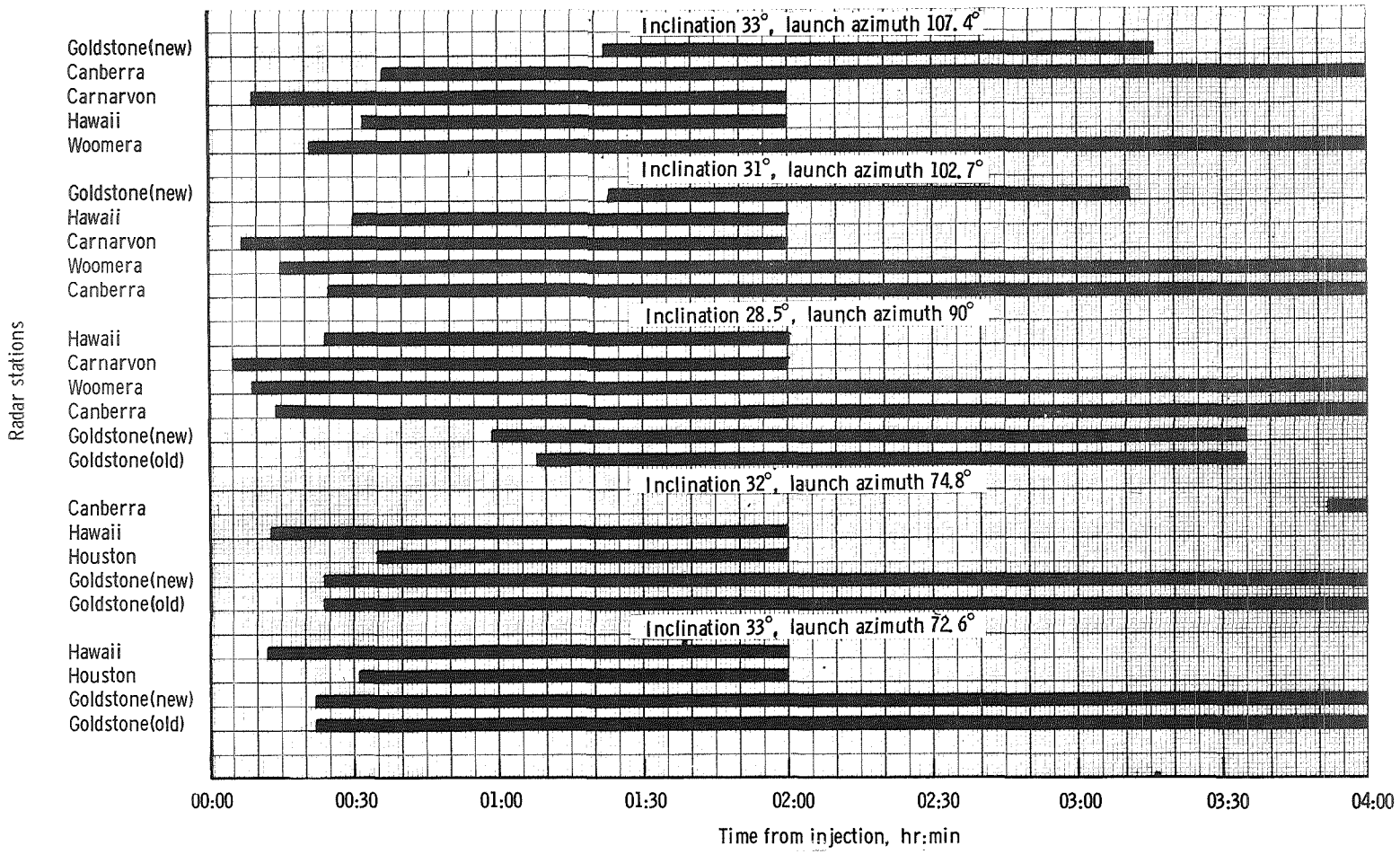
(bb) Pacific injection from third orbit (injection azimuth < 90°), 0° lunar declination.

Figure 9. - Continued.



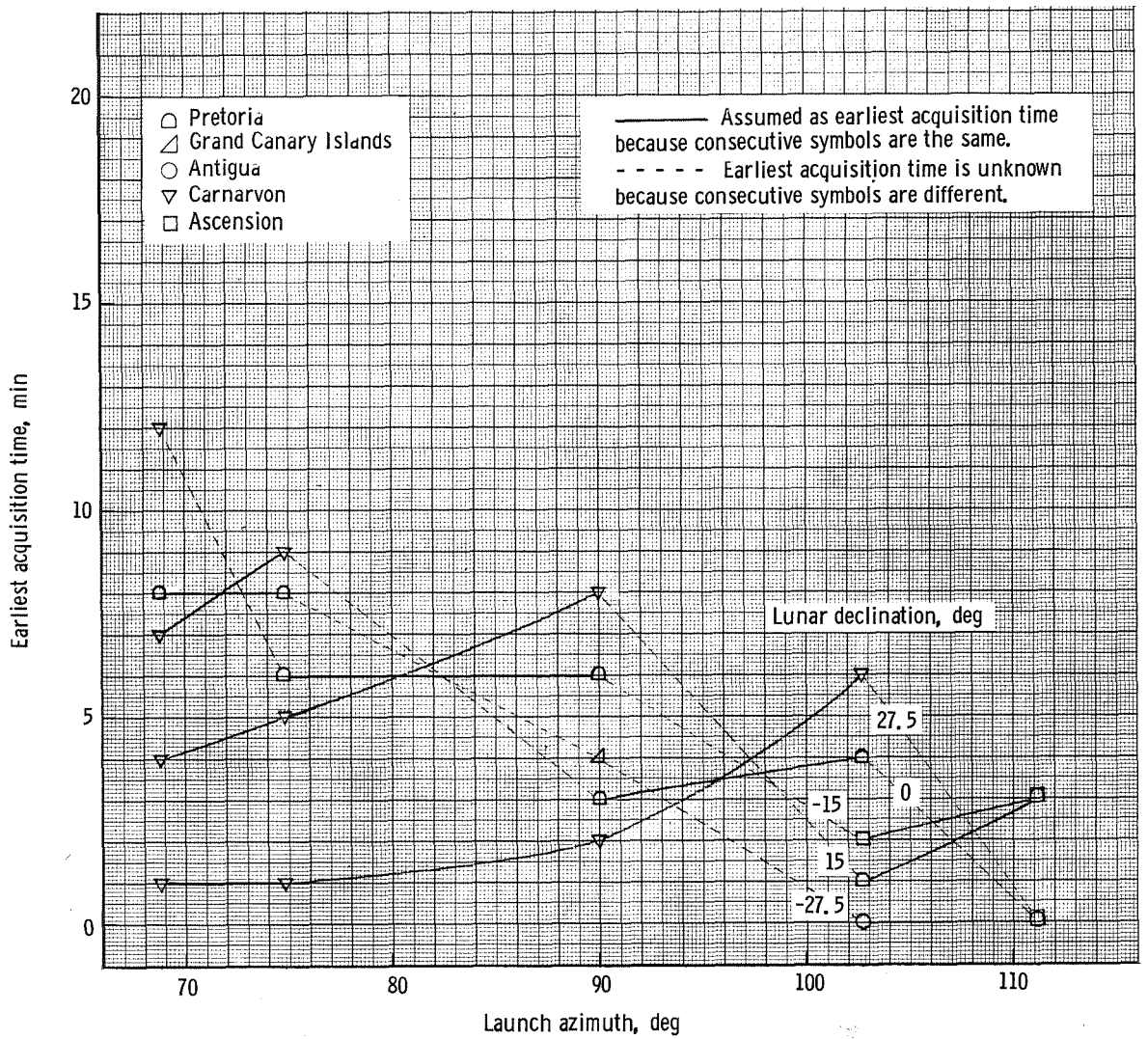
(cc) Pacific injection from third orbit (injection azimuth < 90°), 15° lunar declination.

Figure 9. - Continued.



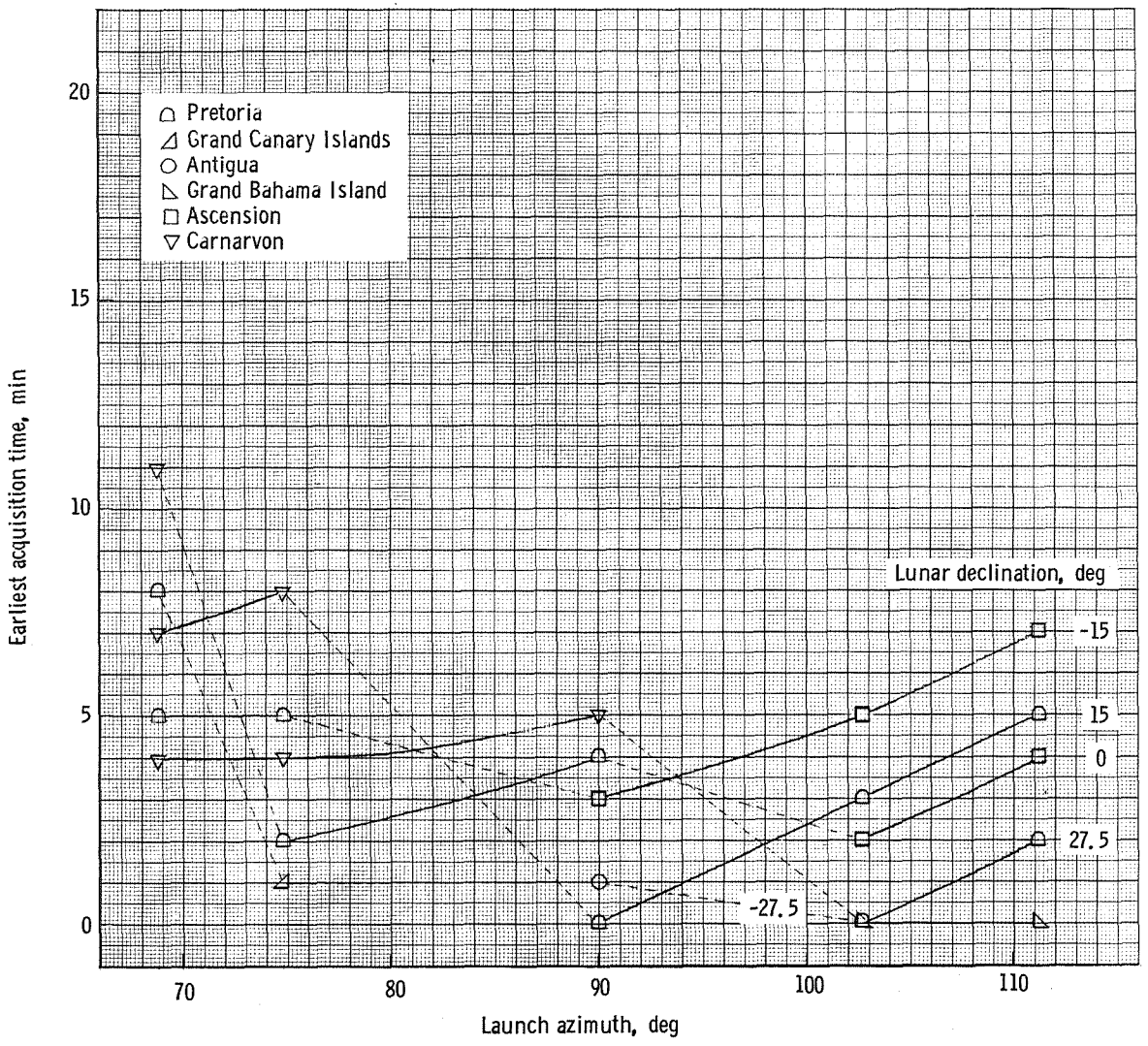
(dd) Pacific injection from third orbit (injection azimuth < 90°), 27.5° lunar declination.

Figure 9. - Concluded.



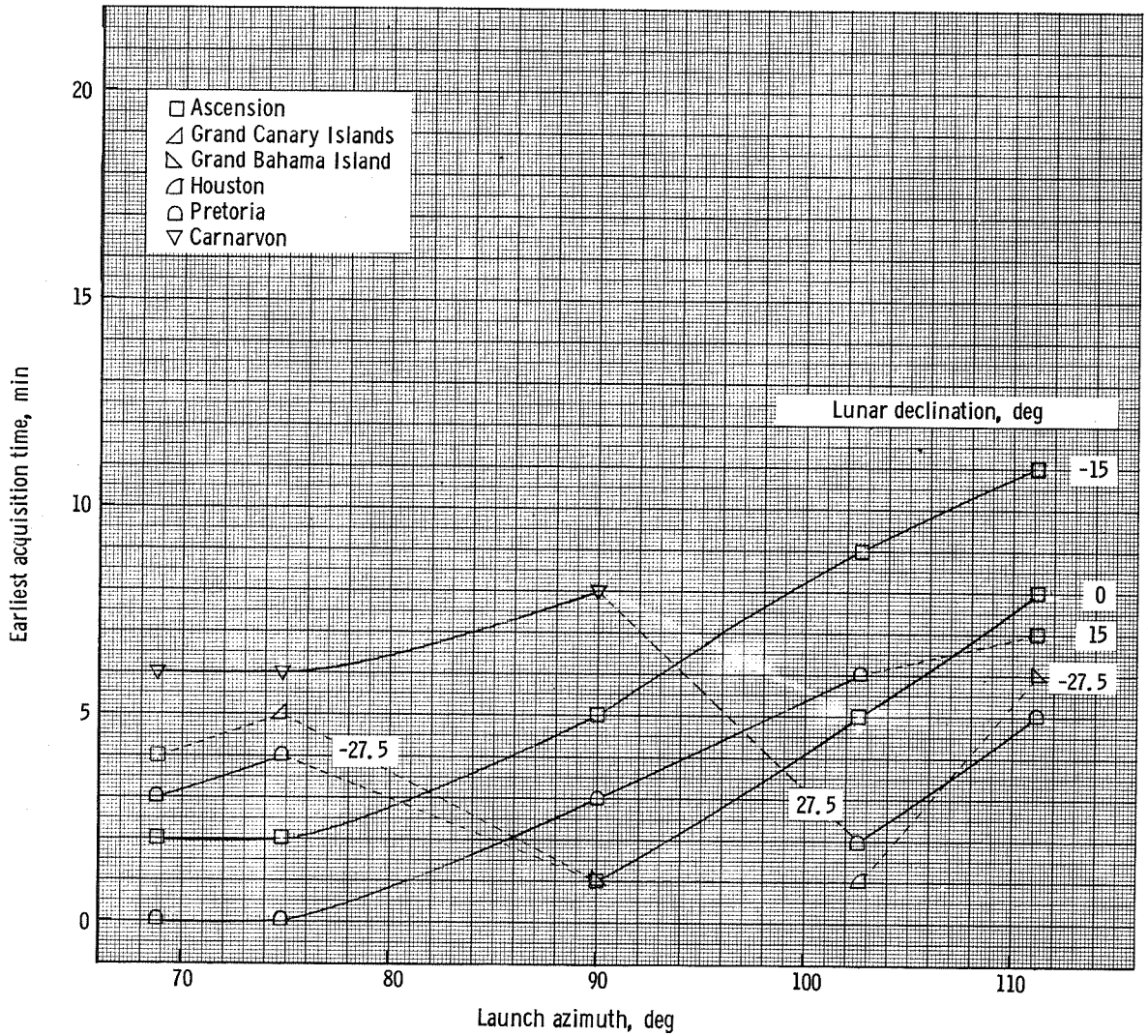
(a) Atlantic injections from first parking orbit.

Figure 10. - Time of earliest acquisition following translunar injection.



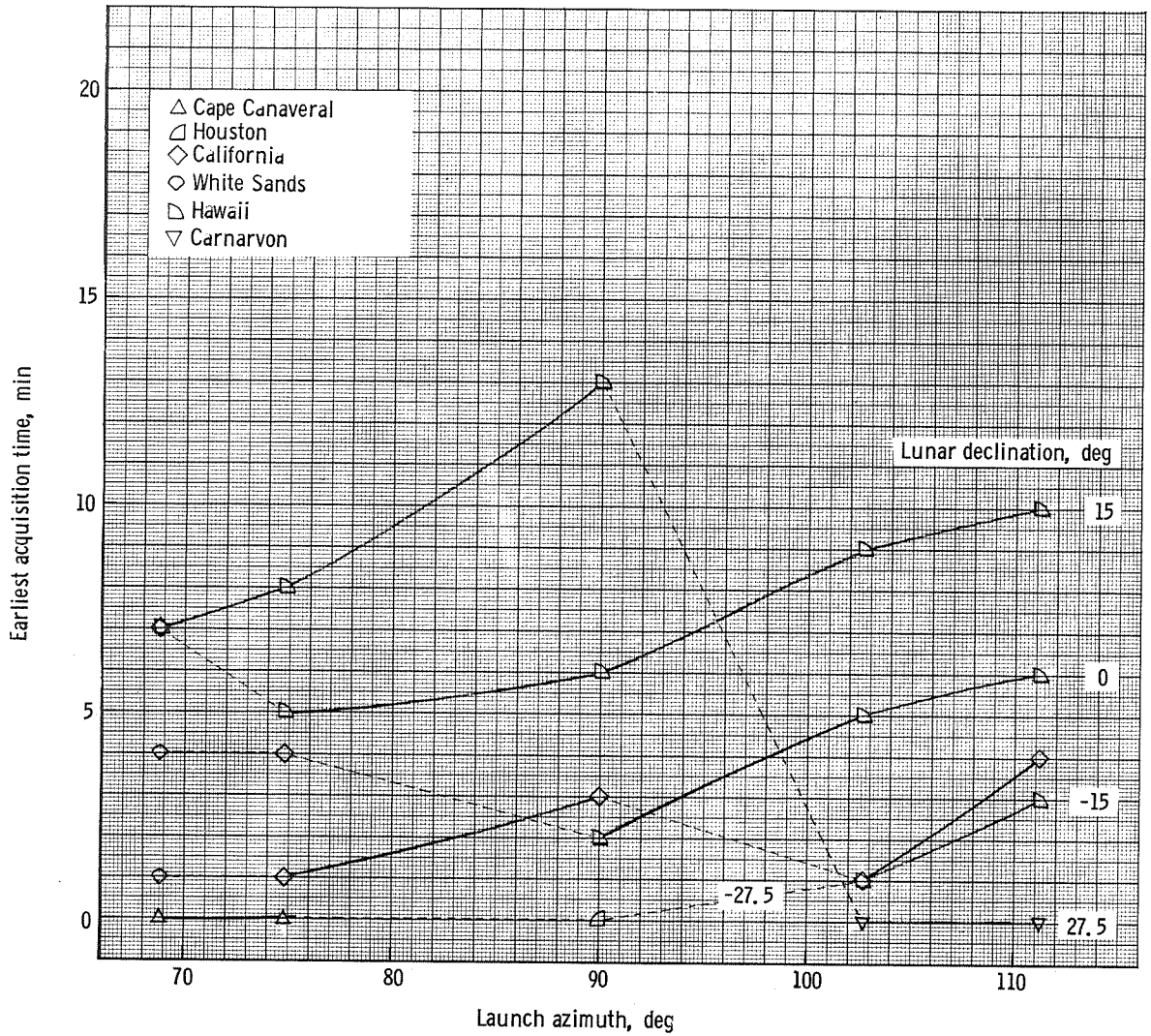
(b) Atlantic injections from second parking orbit.

Figure 10. - Continued.



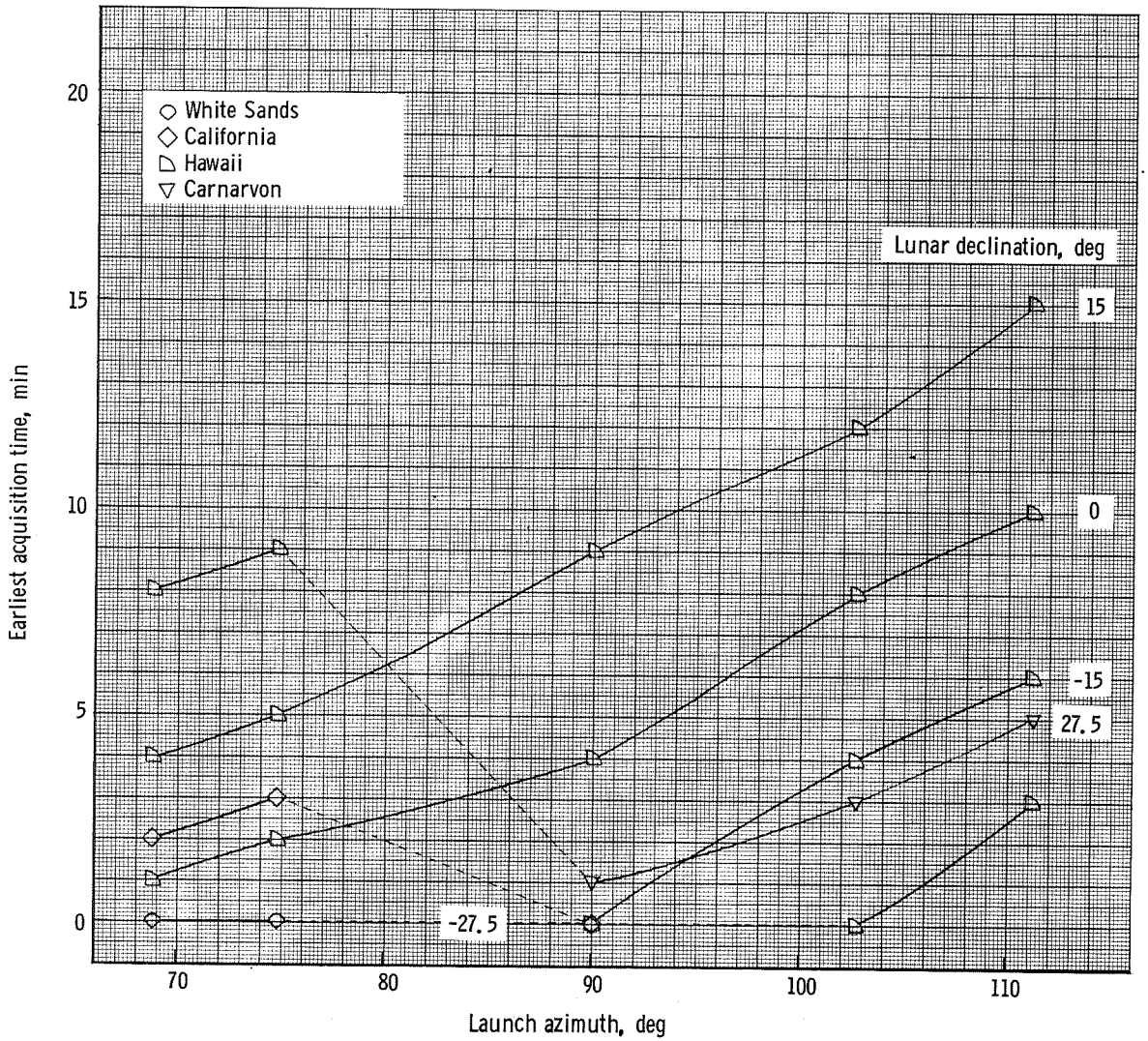
(c) Atlantic injections from third parking orbit.

Figure 10. - Continued.



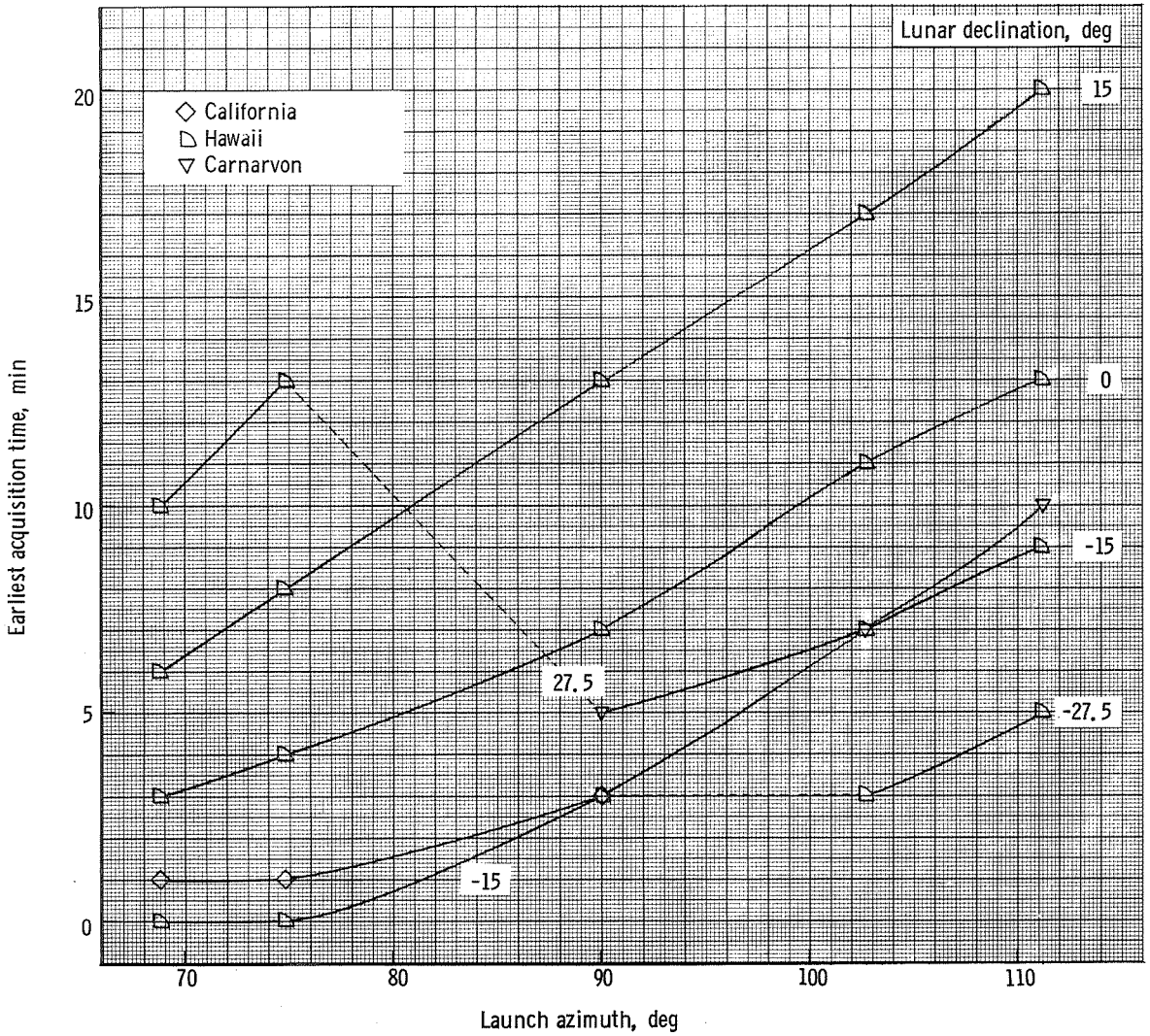
(d) Pacific injections from first parking orbit.

Figure 10. - Continued.



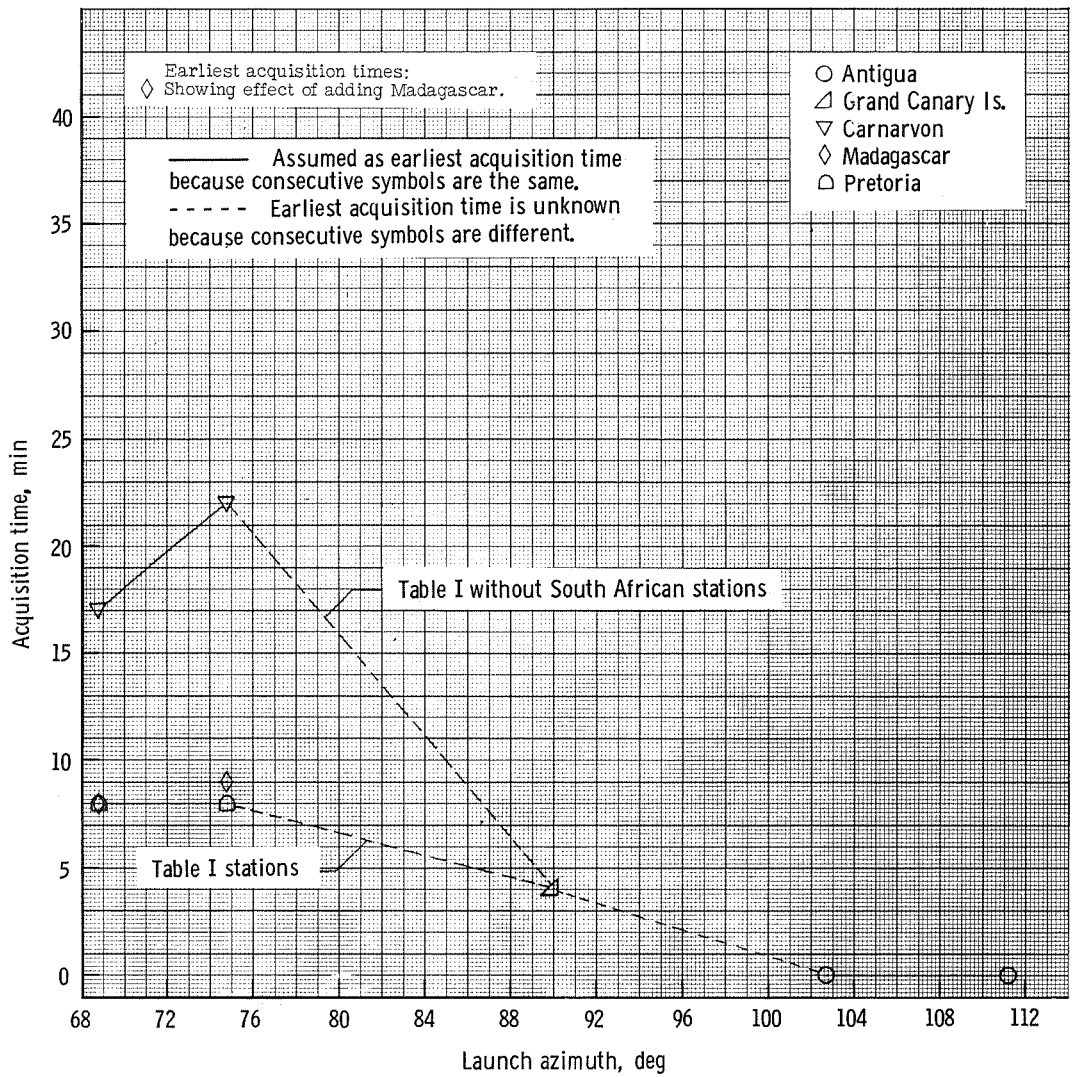
(e) Pacific injections from second parking orbit.

Figure 10. - Continued.



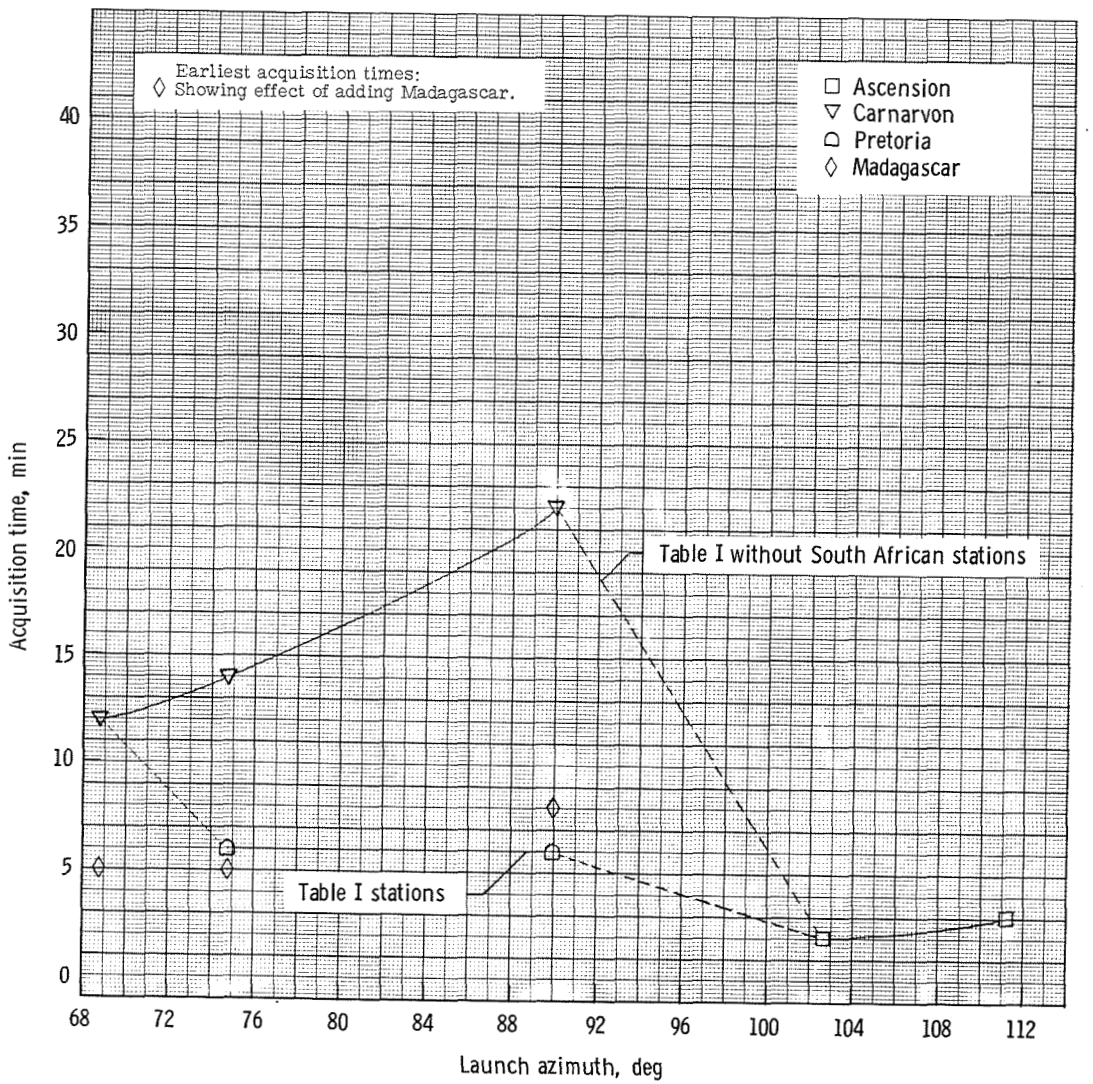
(f) Pacific injections from third parking orbit.

Figure 10. - Concluded.



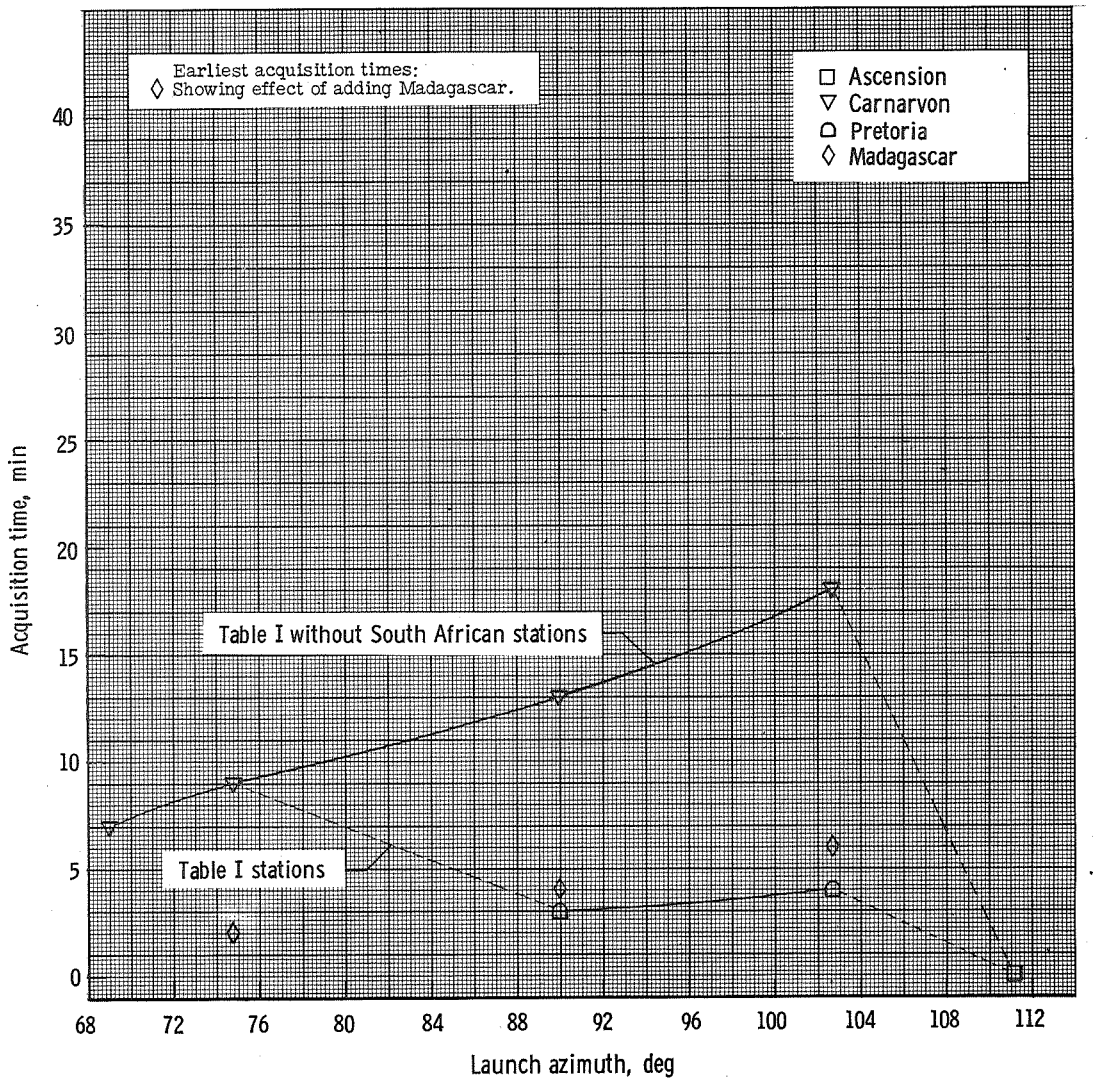
(a) Atlantic injection from first orbit, lunar declination -27.5°.

Figure 11. - Earliest acquisition times reflecting the effect of South African stations, Madagascar, and Guam.



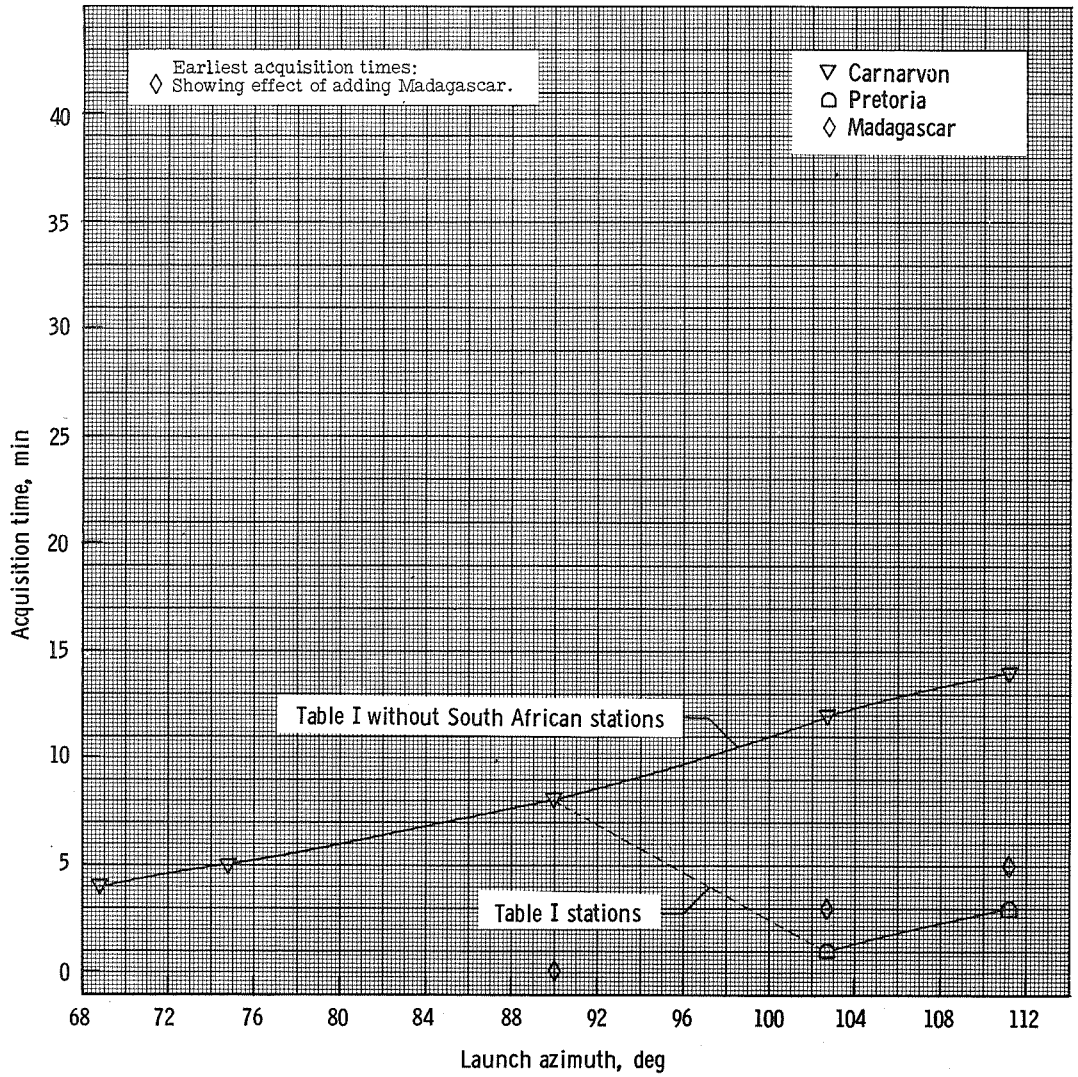
(b) Atlantic injection from first orbit, lunar declination -15°.

Figure 11. - Continued.



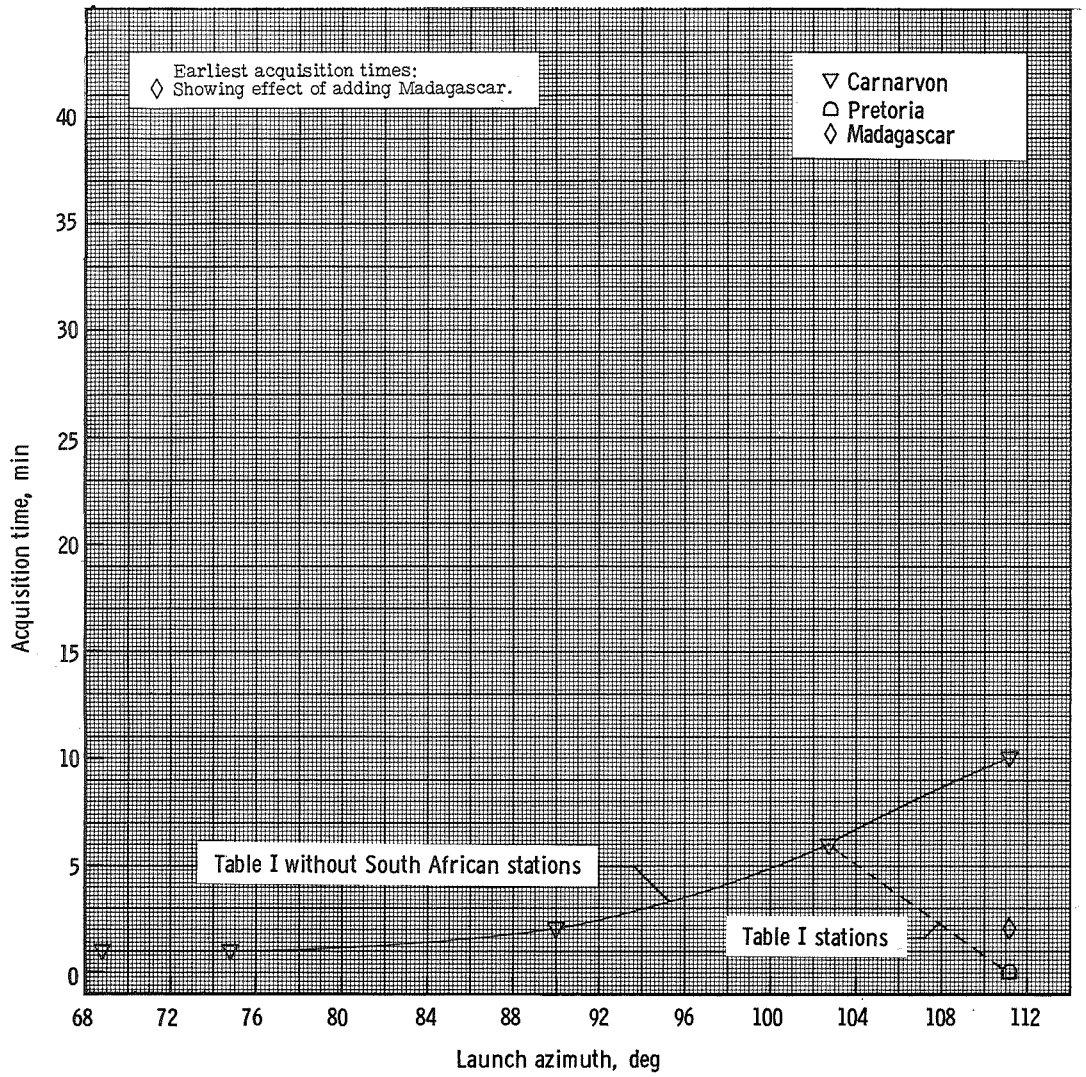
(c) Atlantic injection from first orbit, lunar declination 0°.

Figure 11. - Continued.

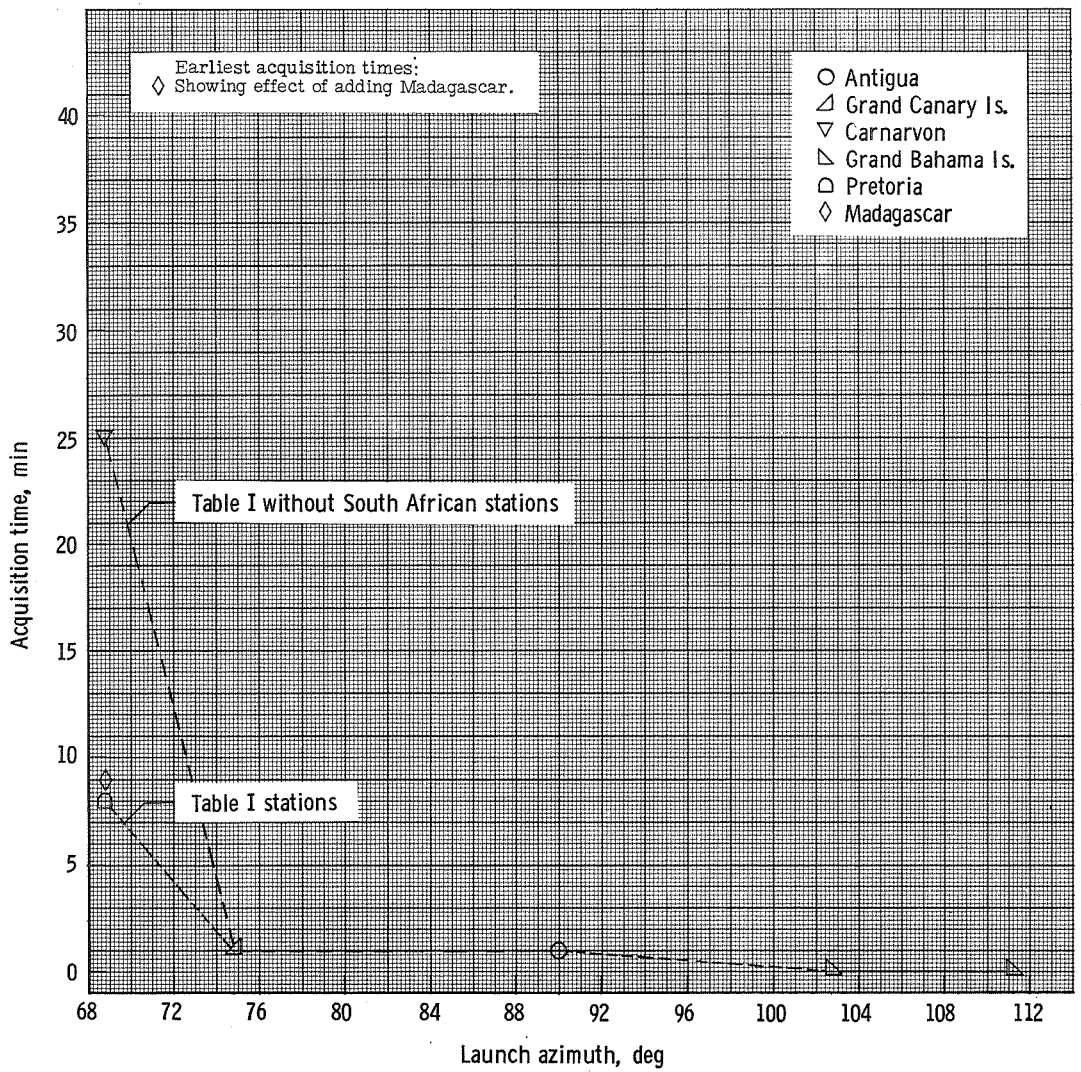


(d) Atlantic injection from first orbit, lunar declination 15°.

Figure 11. - Continued.

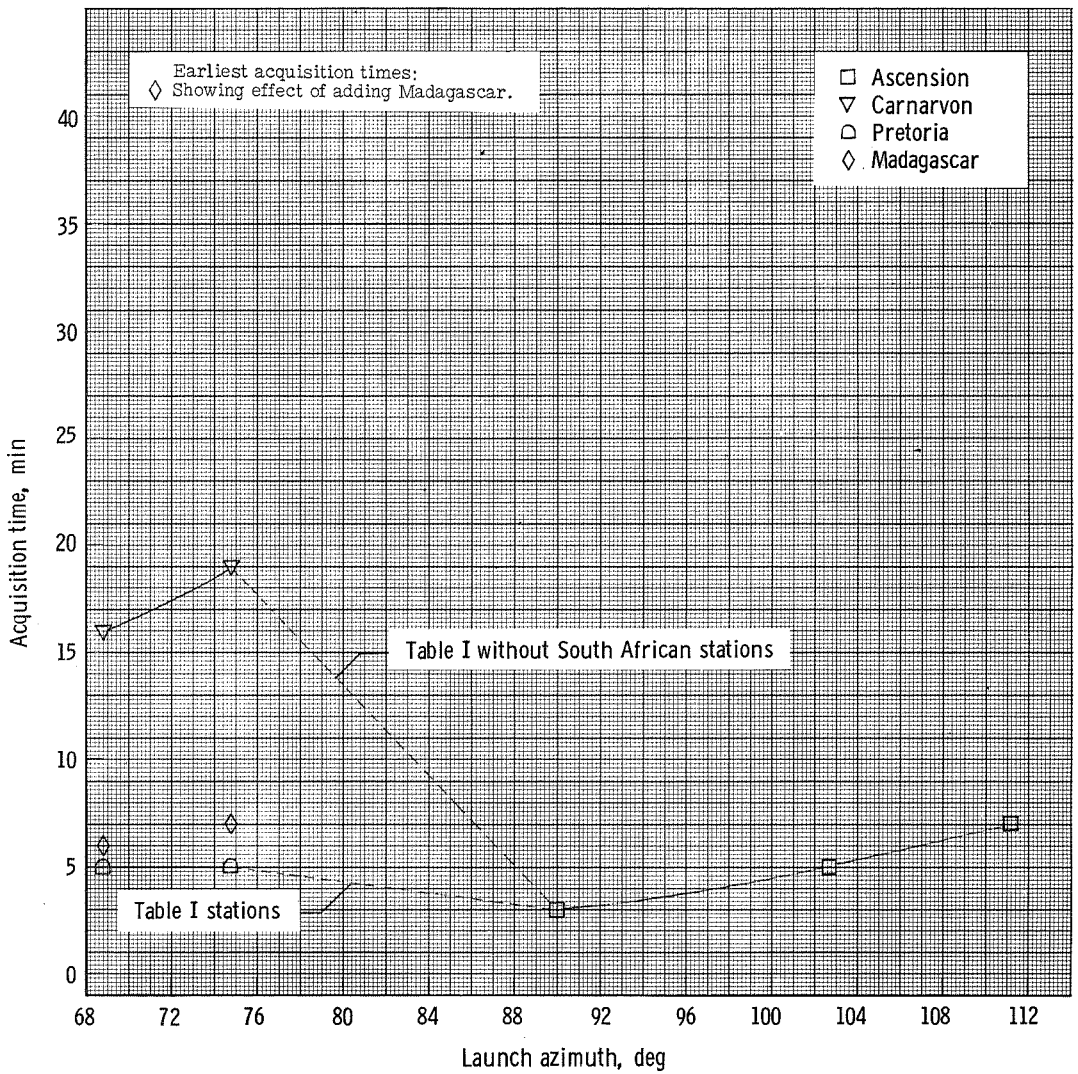


(e) Atlantic injection from first orbit, lunar declination 27.5°.
Figure 11. - Continued.



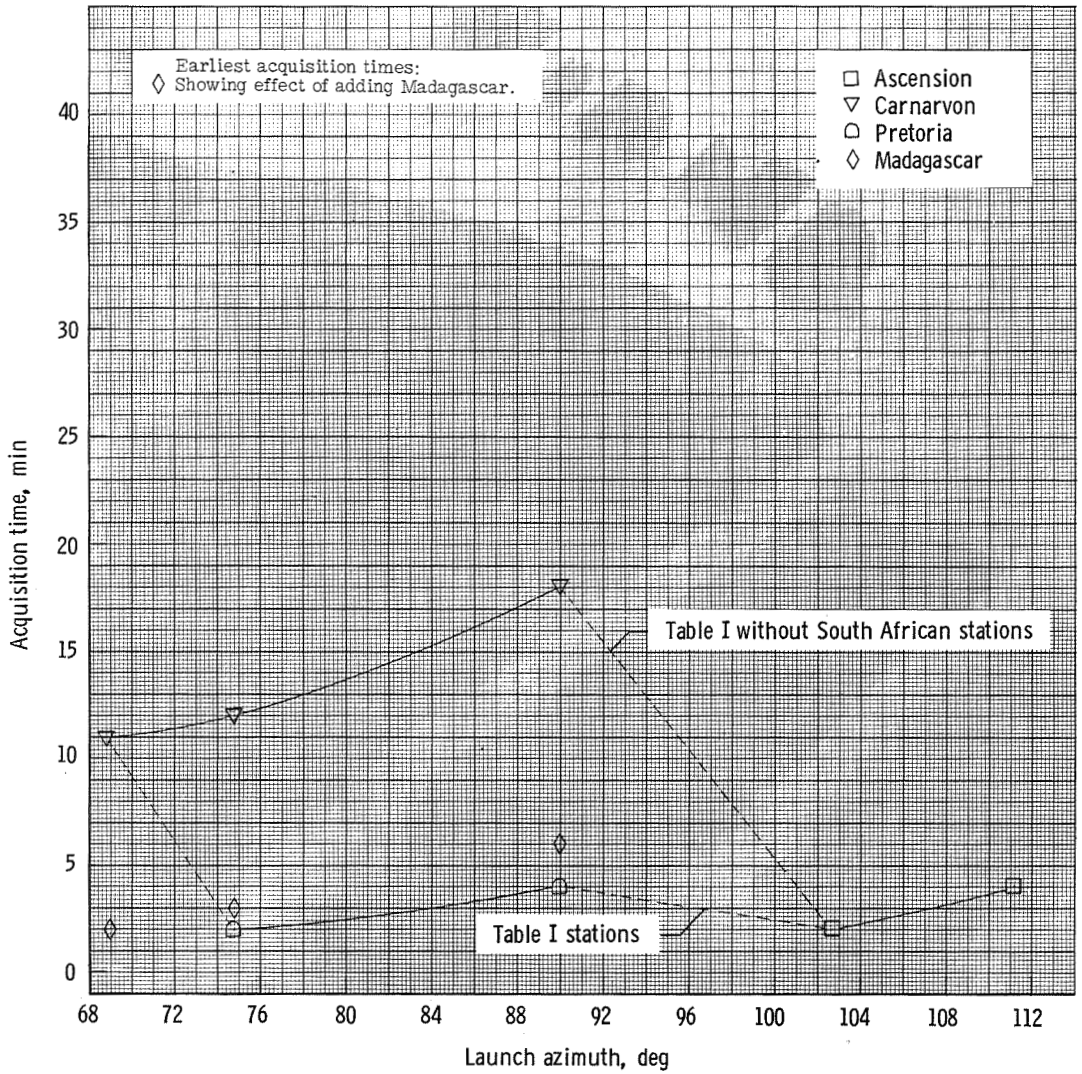
(f) Atlantic injection from second orbit, lunar declination -27.5°.

Figure 11. - Continued.



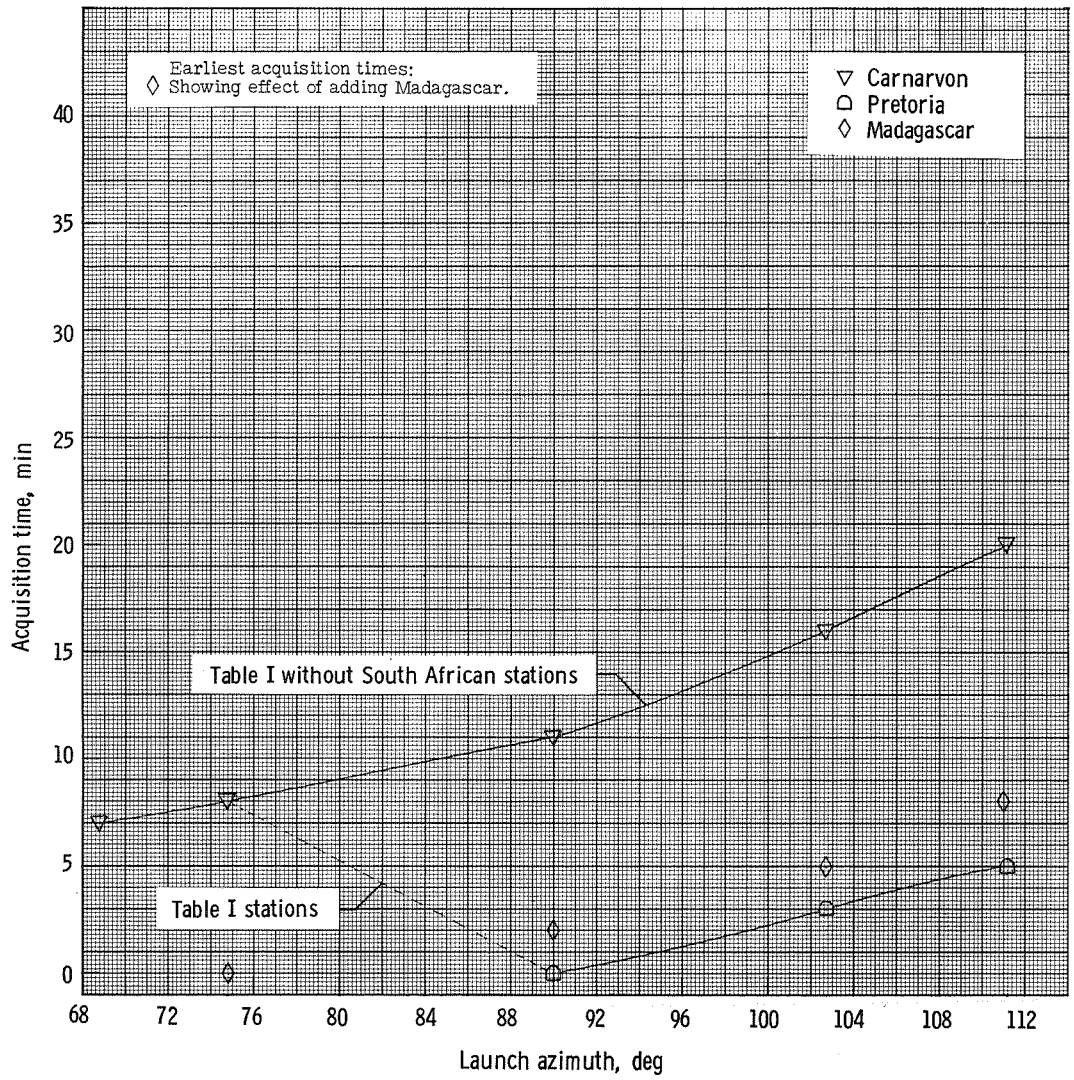
(g) Atlantic injection from second orbit, lunar declination -15°.

Figure 11. - Continued.



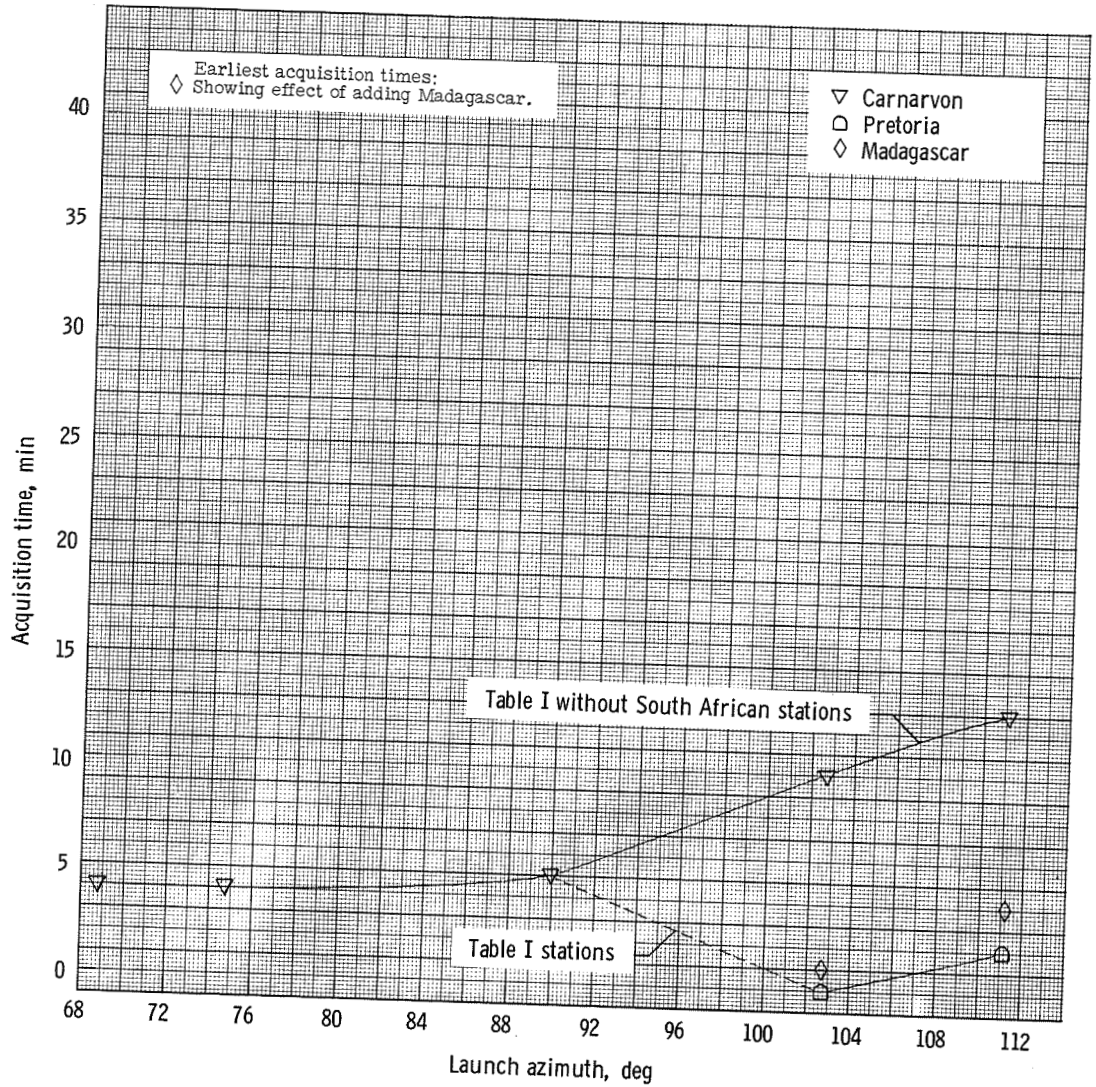
(h) Atlantic injection from second orbit, lunar declination 0°.

Figure 11. - Continued.



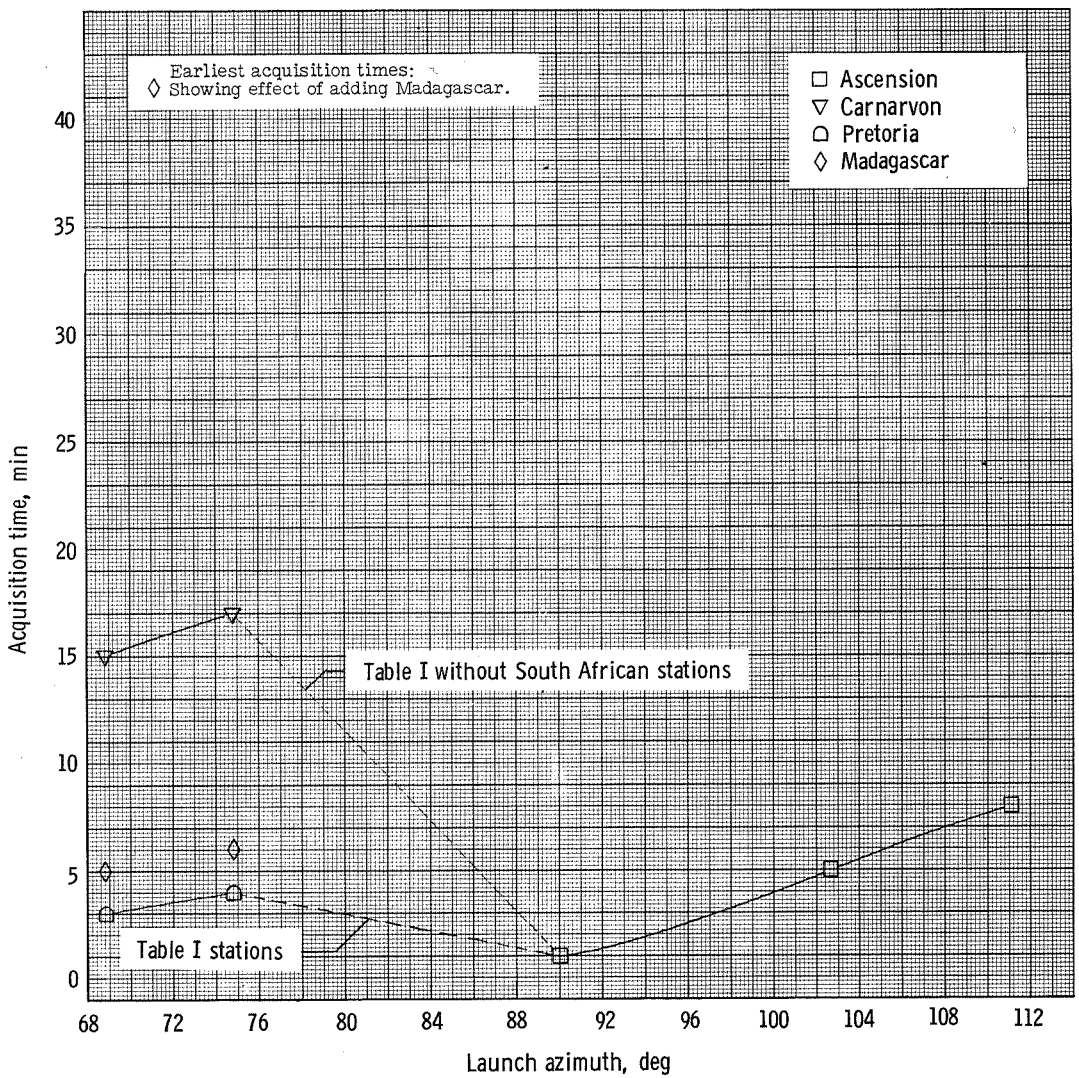
(i) Atlantic injection from second orbit, lunar declination 15°.

Figure 11. - Continued.



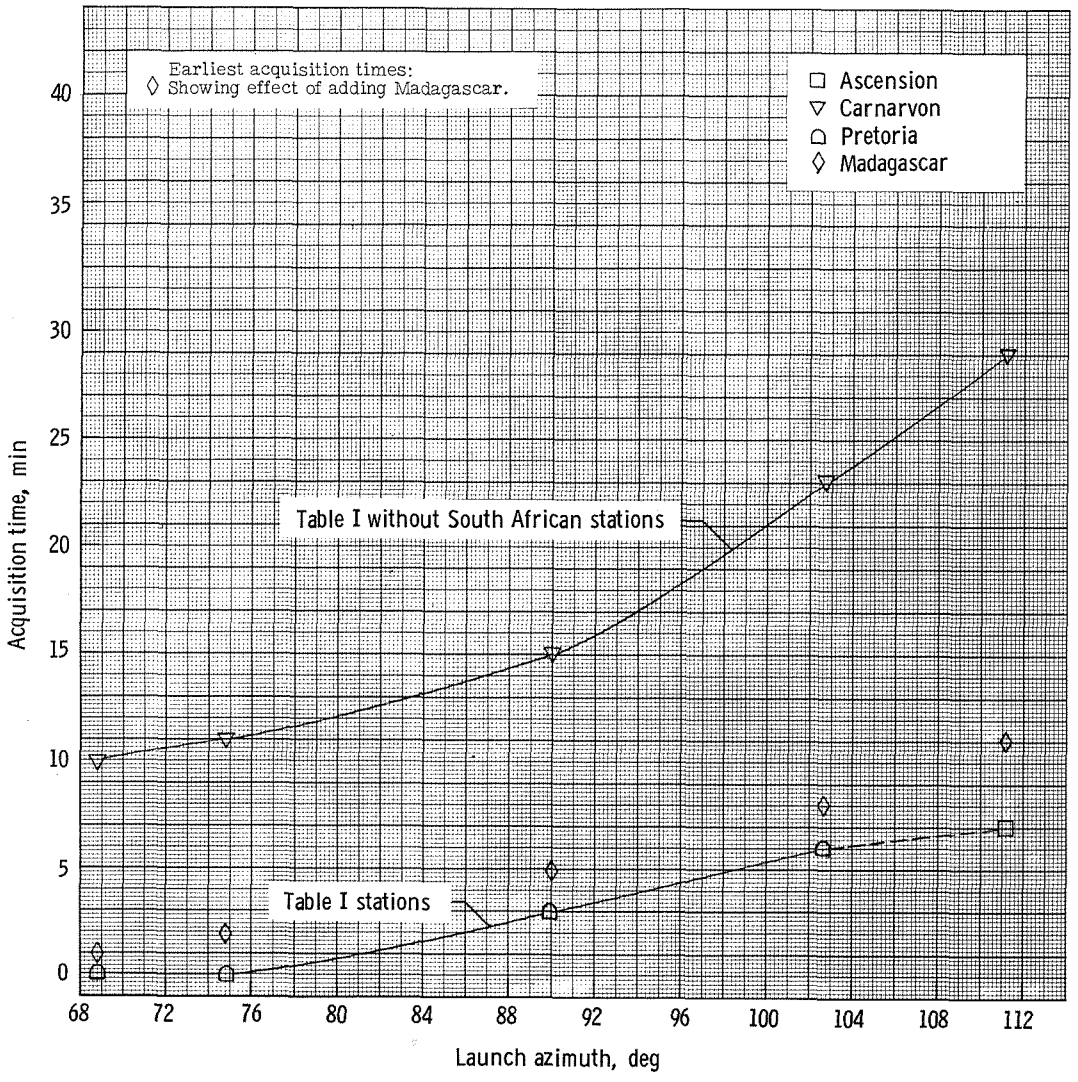
(j) Atlantic injection from second orbit, lunar declination 27.5°.

Figure 11. - Continued.



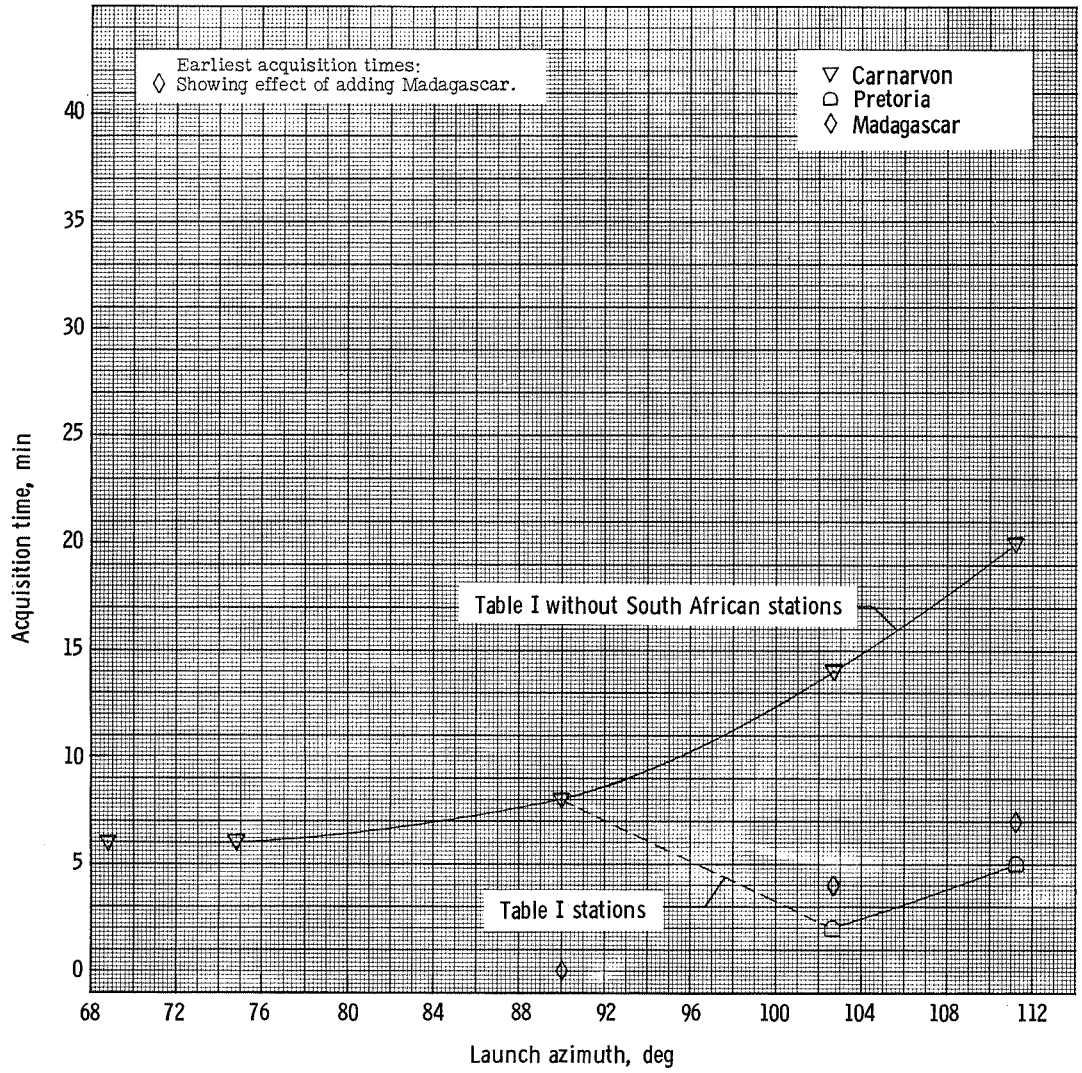
(k) Atlantic injection from third orbit, lunar declination 0°.

Figure 11. - Continued.



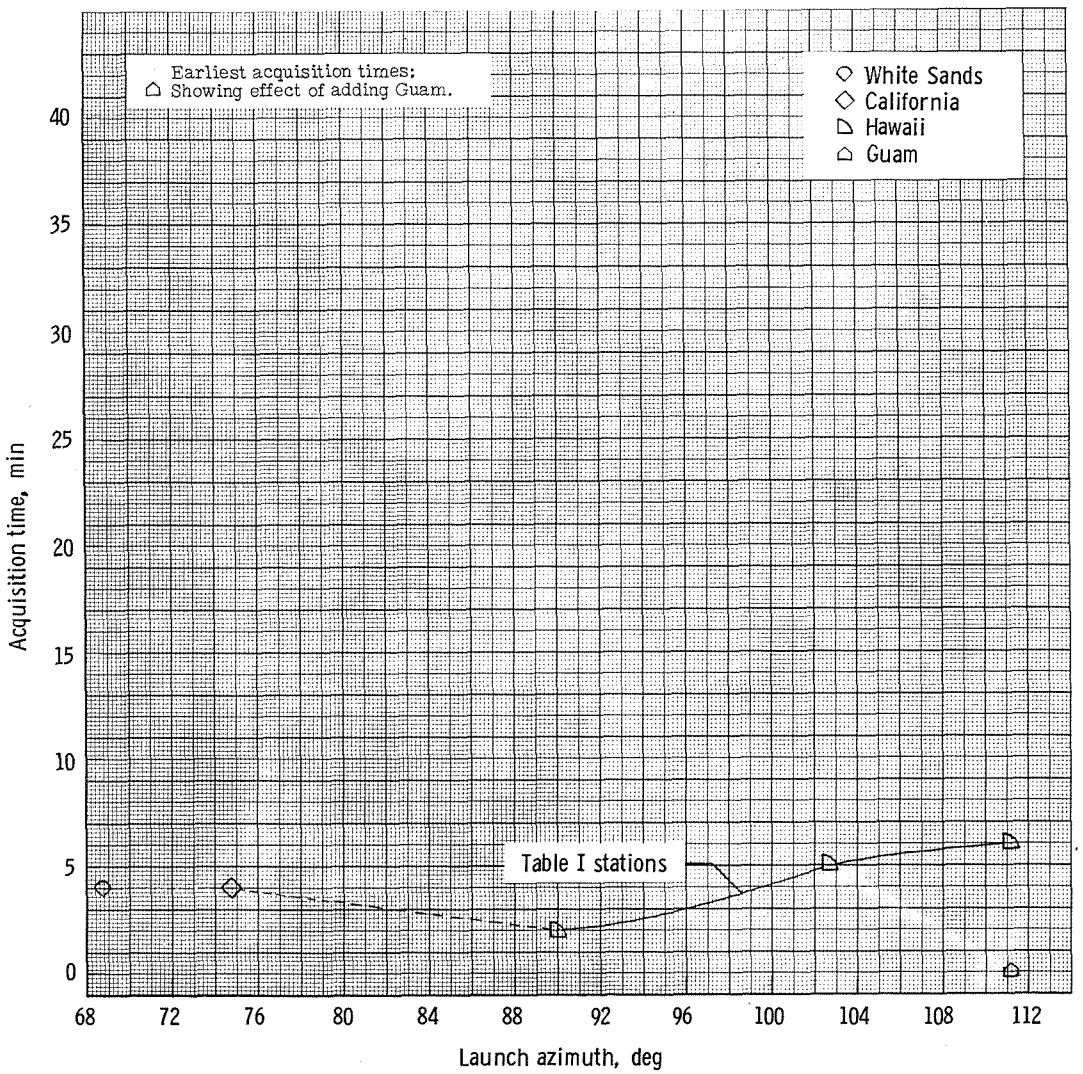
(l) Atlantic injection from third orbit, lunar declination 15°.

Figure 11. - Continued.



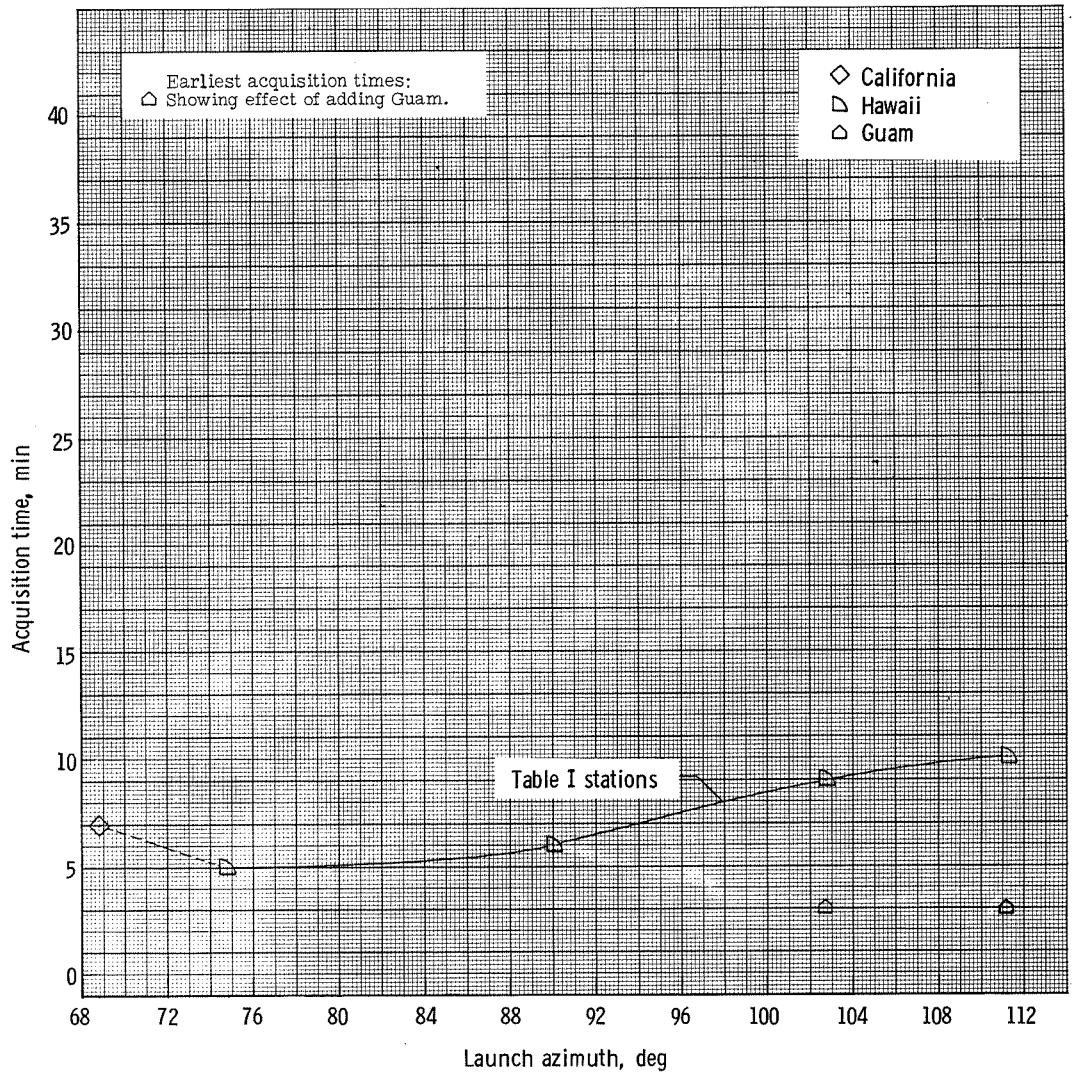
(m) Atlantic injection from third orbit, lunar declination 27.5°.

Figure 11. - Continued.



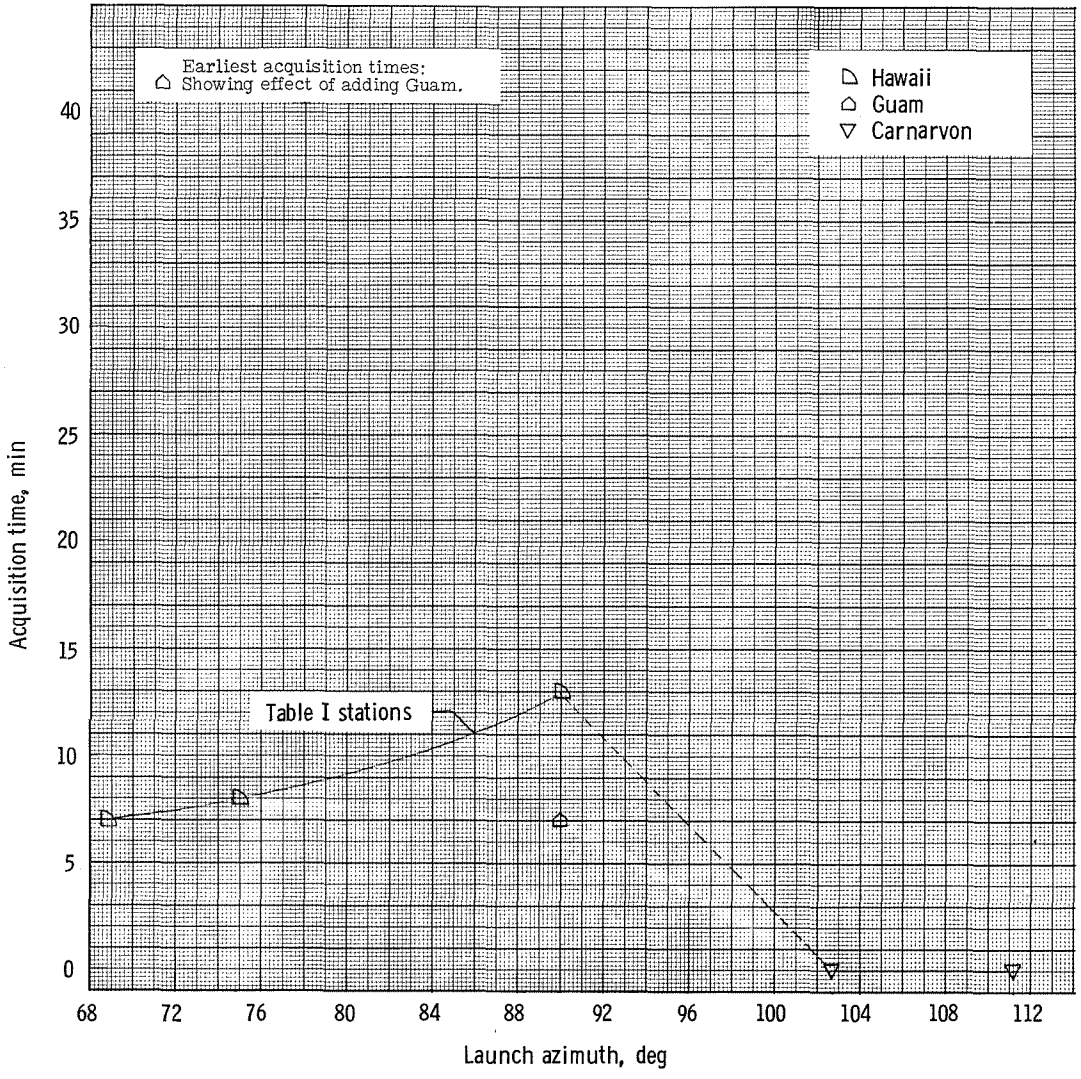
(n) Pacific injection from first orbit, lunar declination 0°.

Figure 11. - Continued.



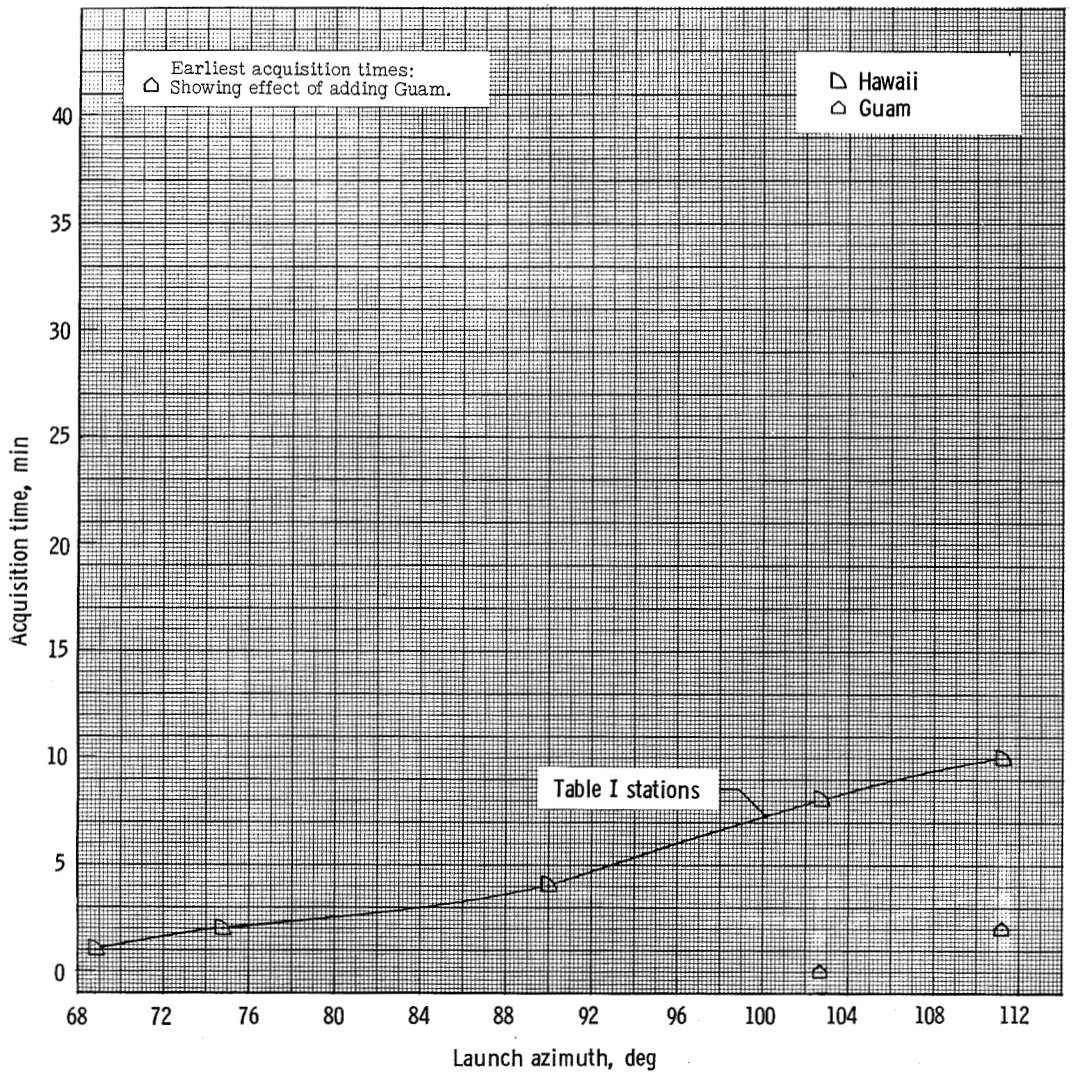
(o) Pacific injection from first orbit, lunar declination 15°.

Figure 11. - Continued.



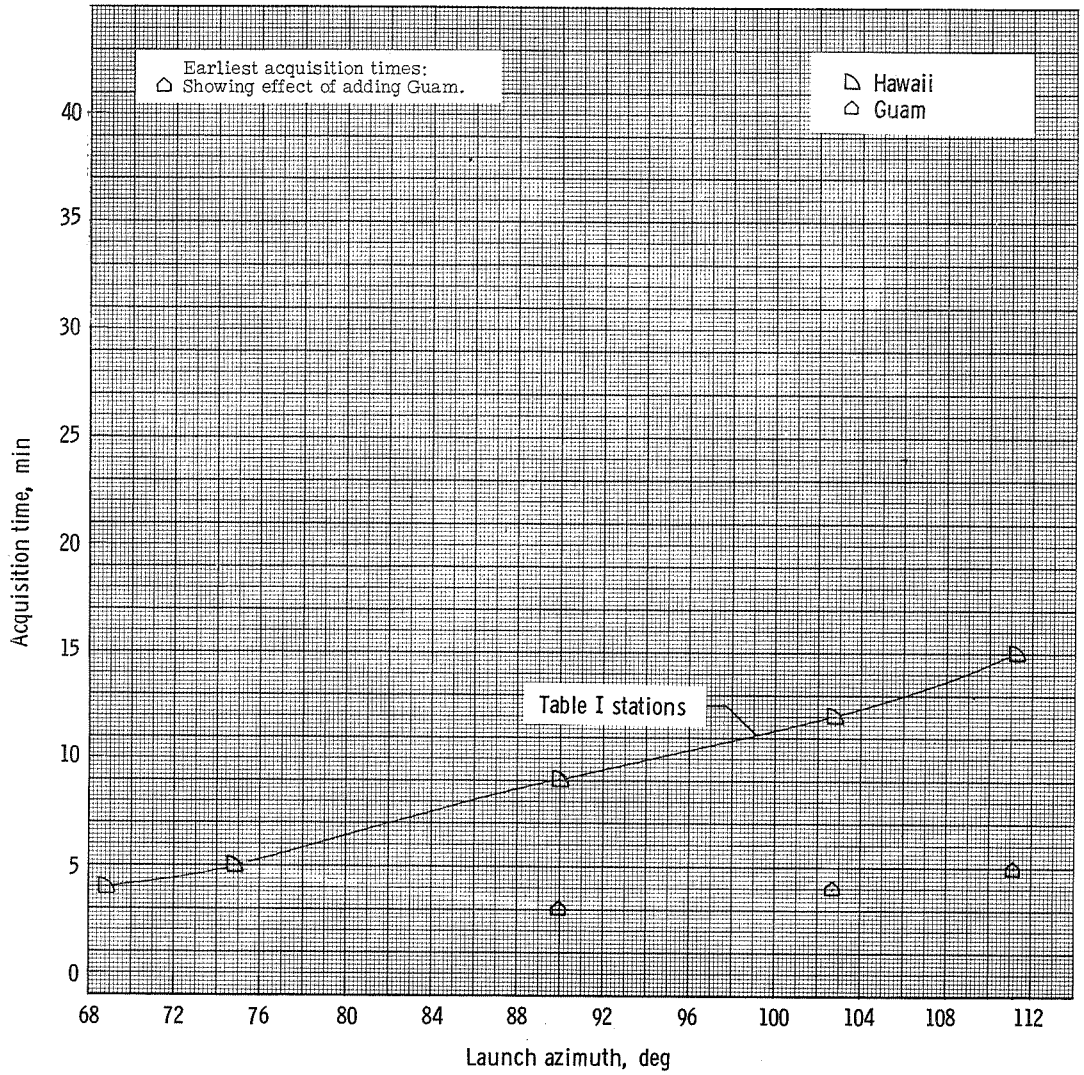
(p) Pacific injection from first orbit, lunar declination 27.5°.

Figure 11. - Continued.



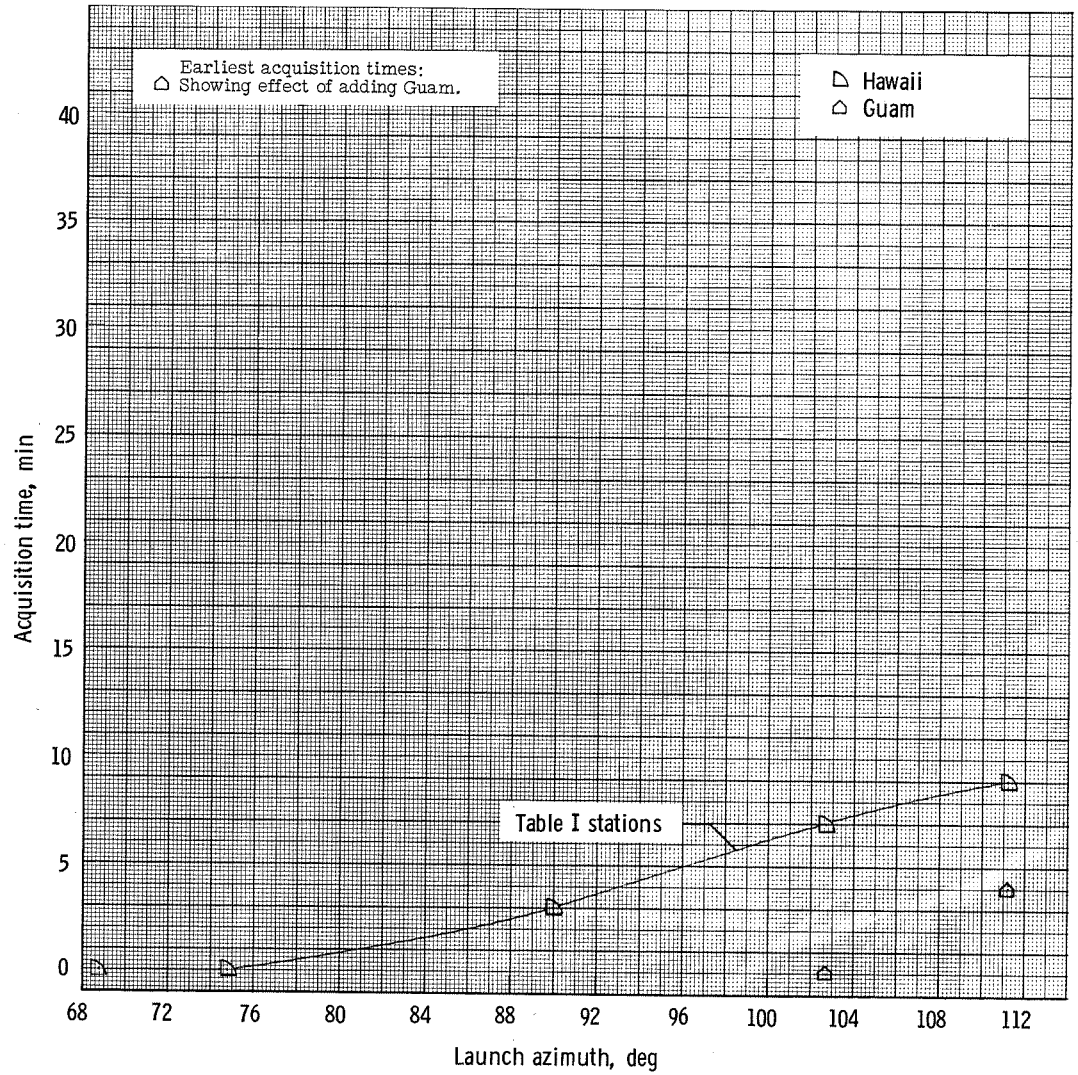
(q) Pacific injection from second orbit, lunar declination 0°.

Figure 11. - Continued.



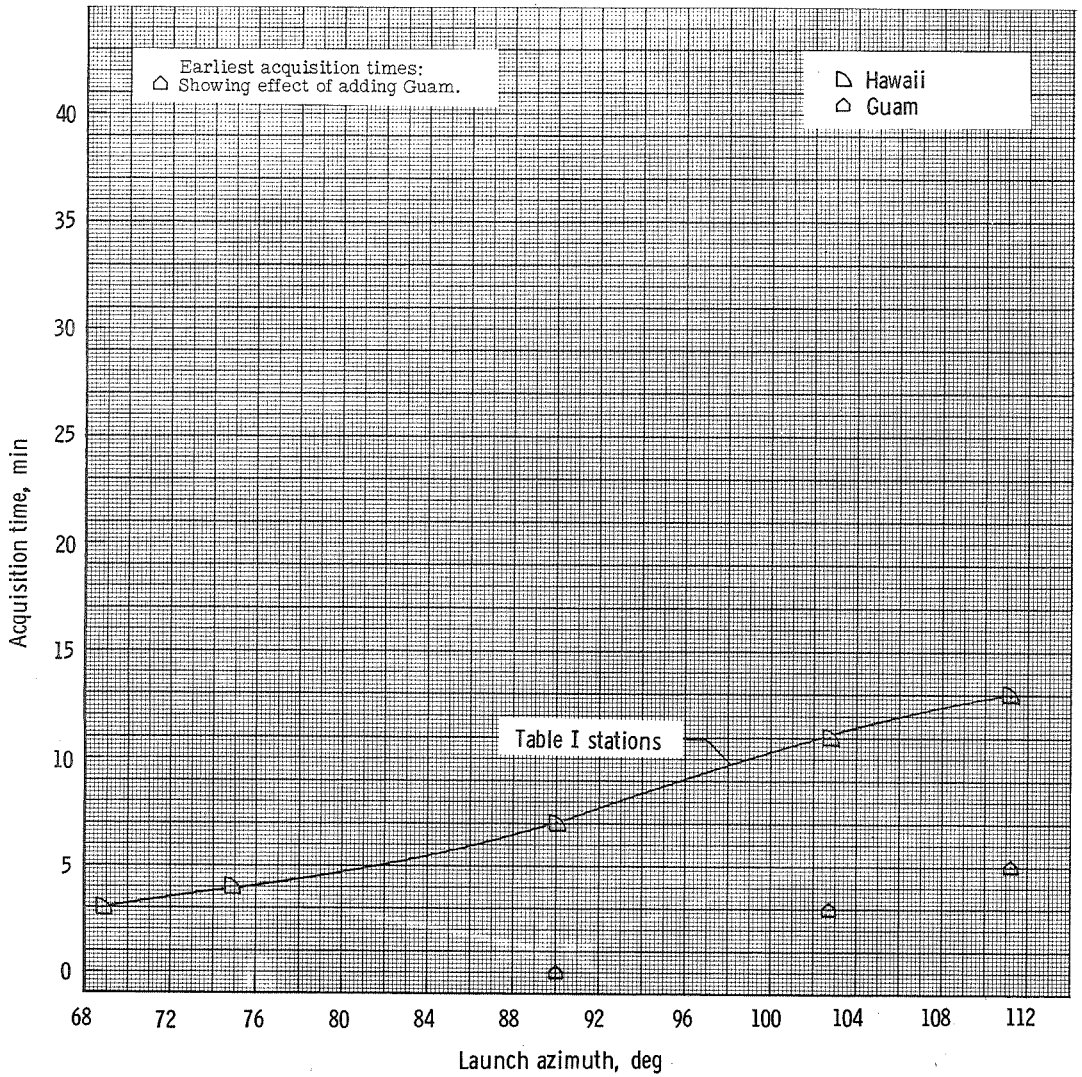
(r) Pacific injection from second orbit, lunar declination 15°.

Figure 11. - Continued.



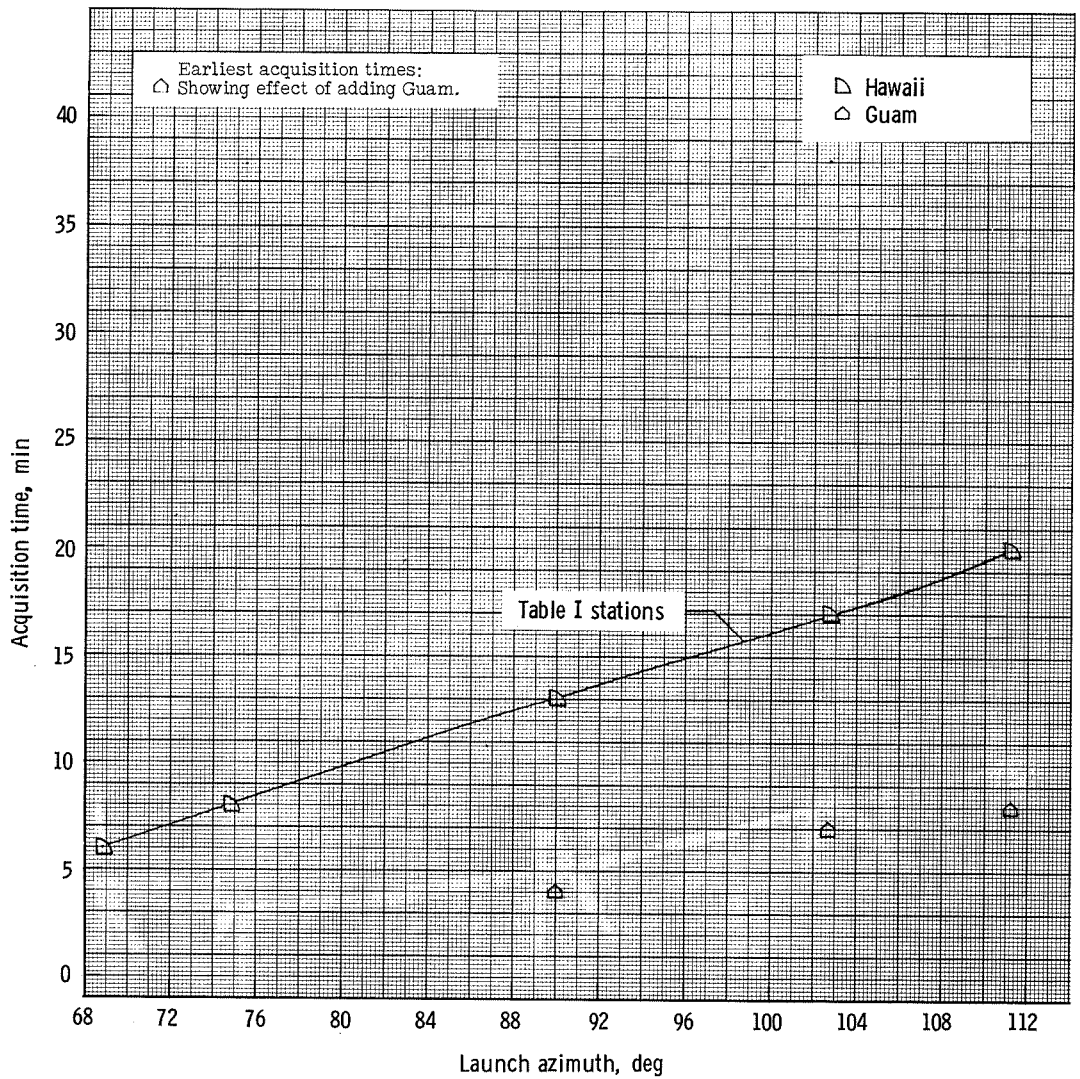
(s) Pacific injection from third orbit, lunar declination -15°.

Figure 11. - Continued.



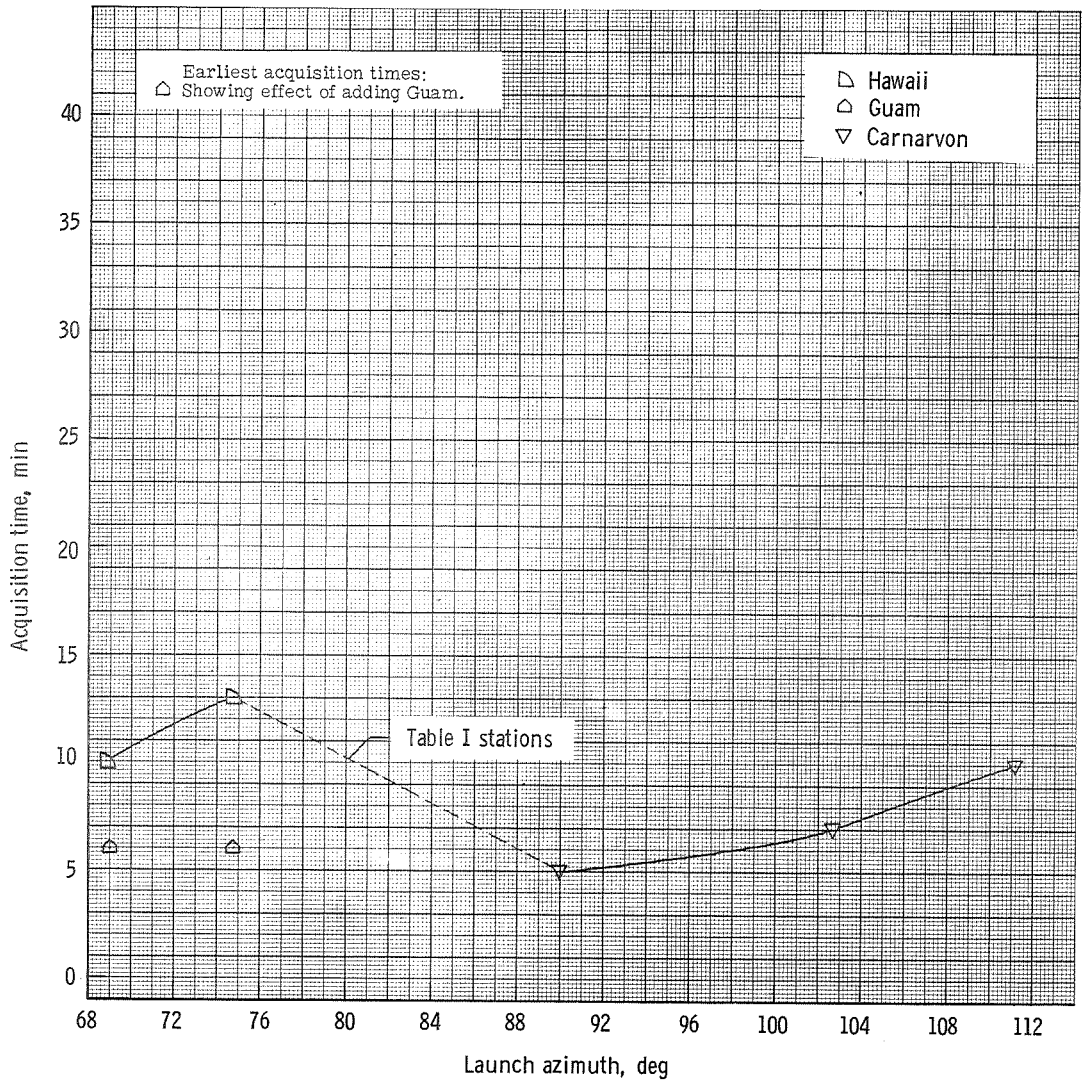
(t) Pacific injection from third orbit, lunar declination 0°.

Figure 11. - Continued.



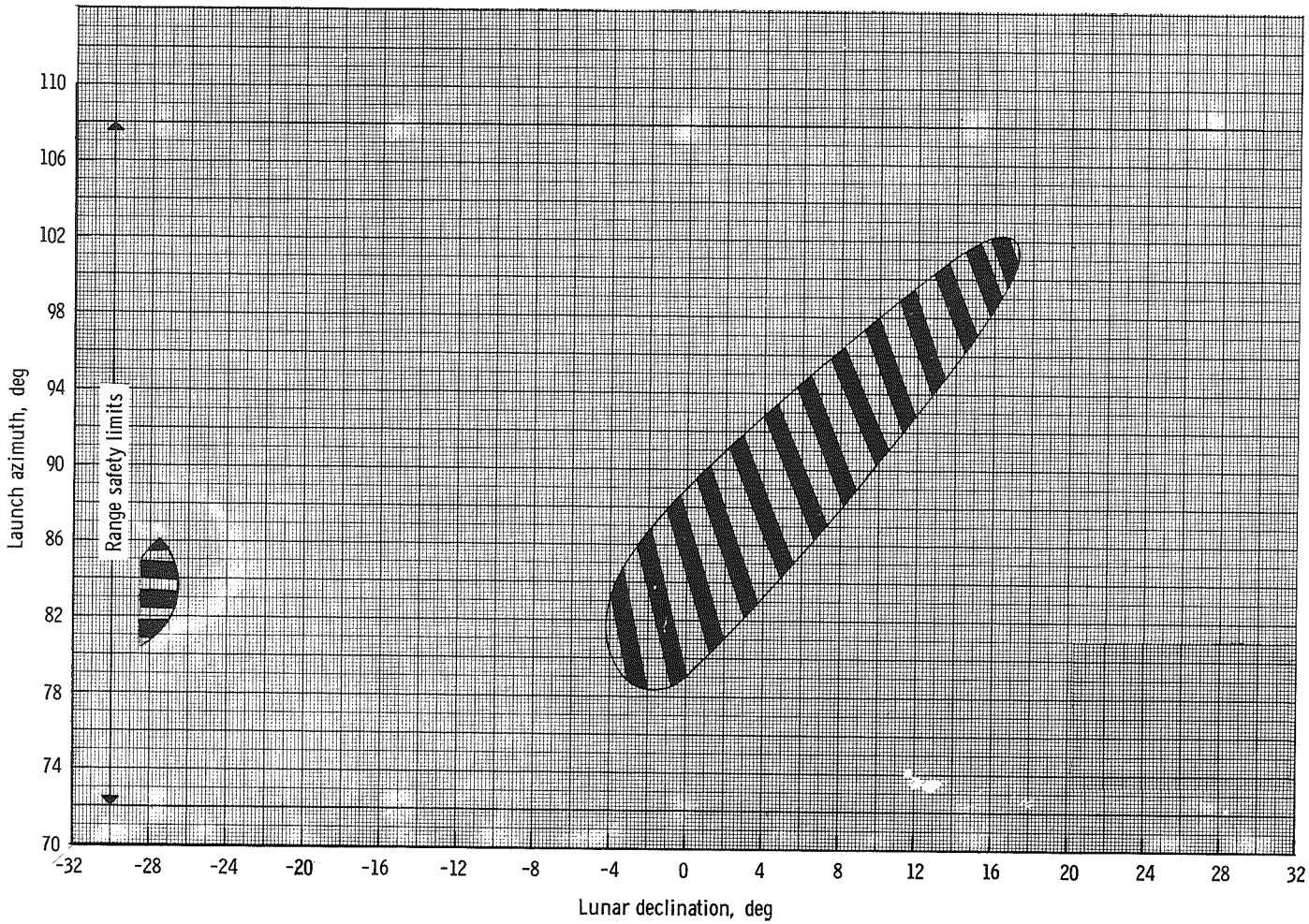
(u) Pacific injection from third orbit, lunar declination 15°.

Figure 11. - Continued.



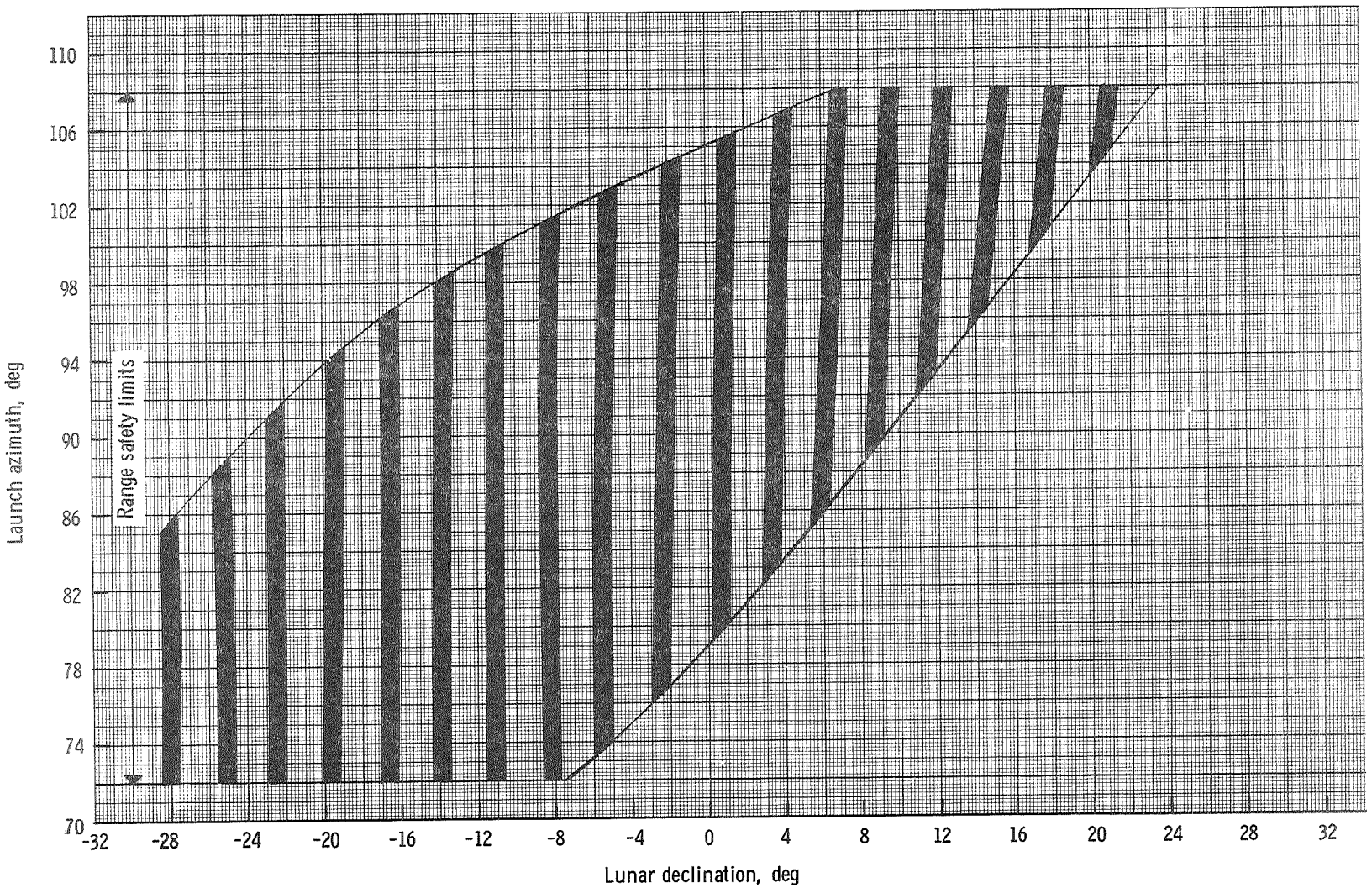
(v) Pacific injection from third orbit, lunar declination 27.5°.

Figure 11. - Concluded.



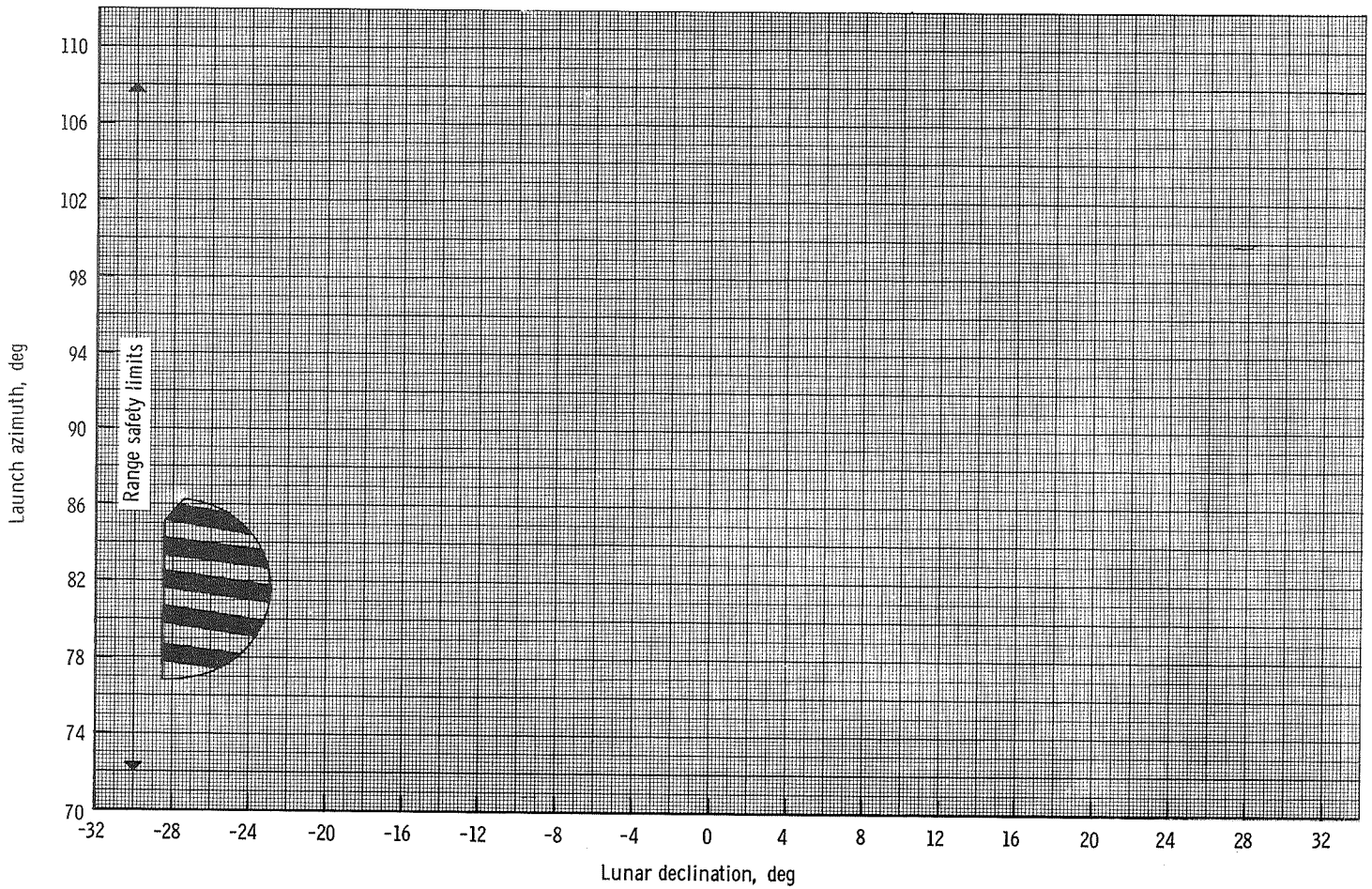
(a) Atlantic injection from first orbit, Table I stations.

Figure 12. - Loss of launch window considering Table I stations, Madagascar and Guam with a 10-minute post injection acquisition requirement.



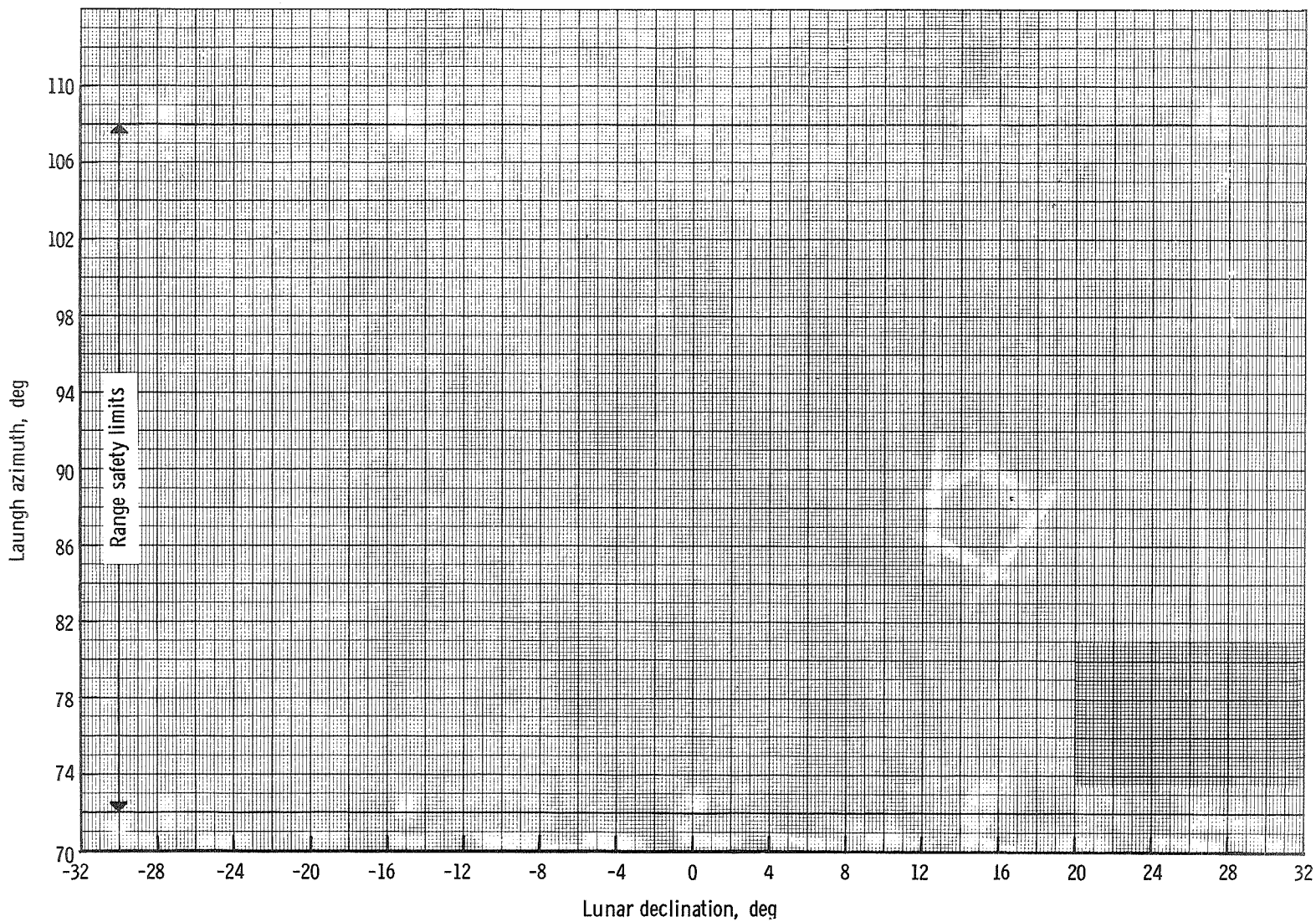
(b) Atlantic injection from first orbit, Table I stations without South African stations.

Figure 12. - Continued.



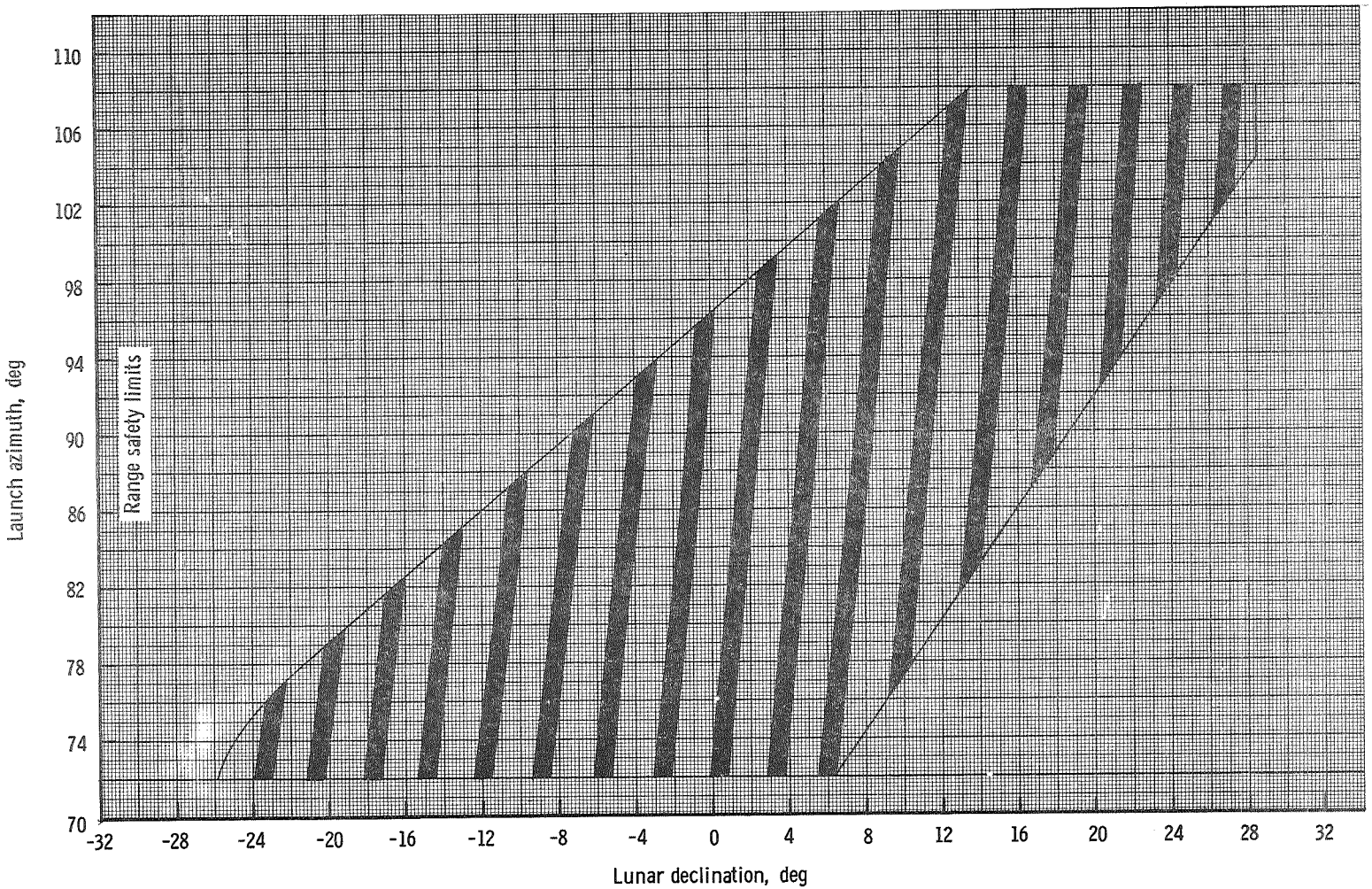
(c) Atlantic injection from first orbit, Table I stations without South African stations and with Madagascar.

Figure 12. - Continued.



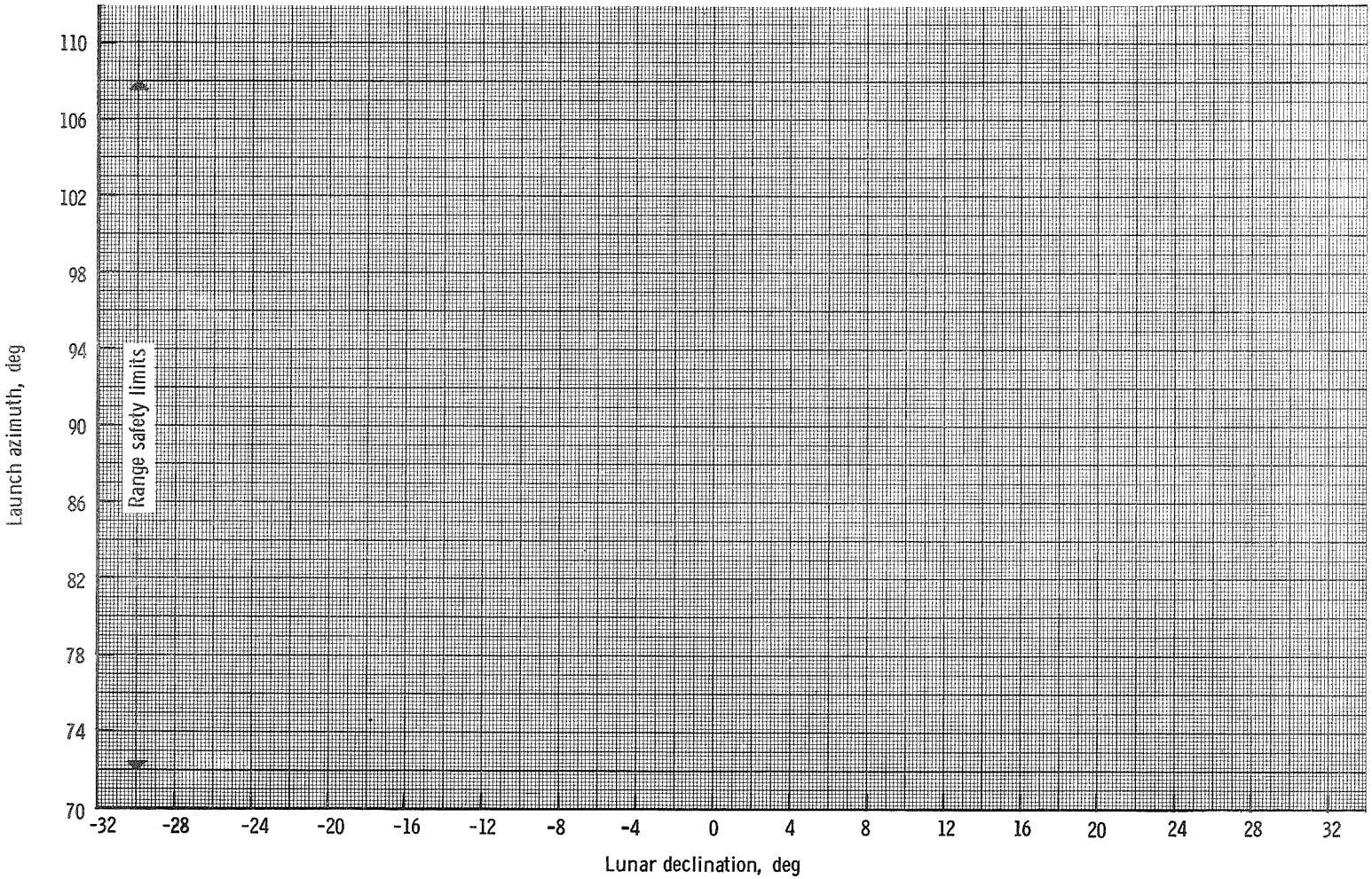
(d) Atlantic injection from second orbit, Table I stations.

Figure 12. - Continued.



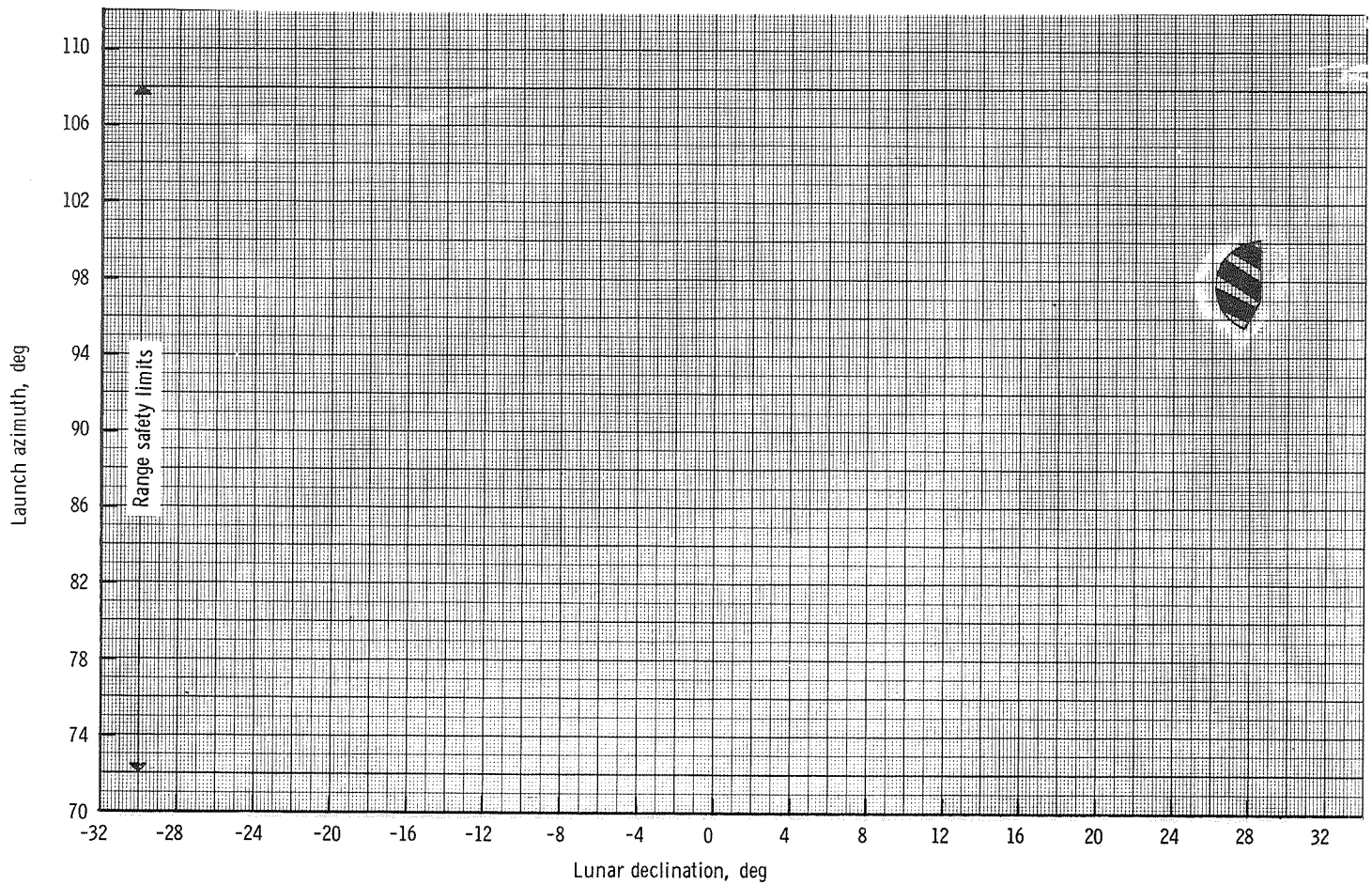
(e) Atlantic injection from second orbit, Table I stations without South African stations.

Figure 12. - Continued.



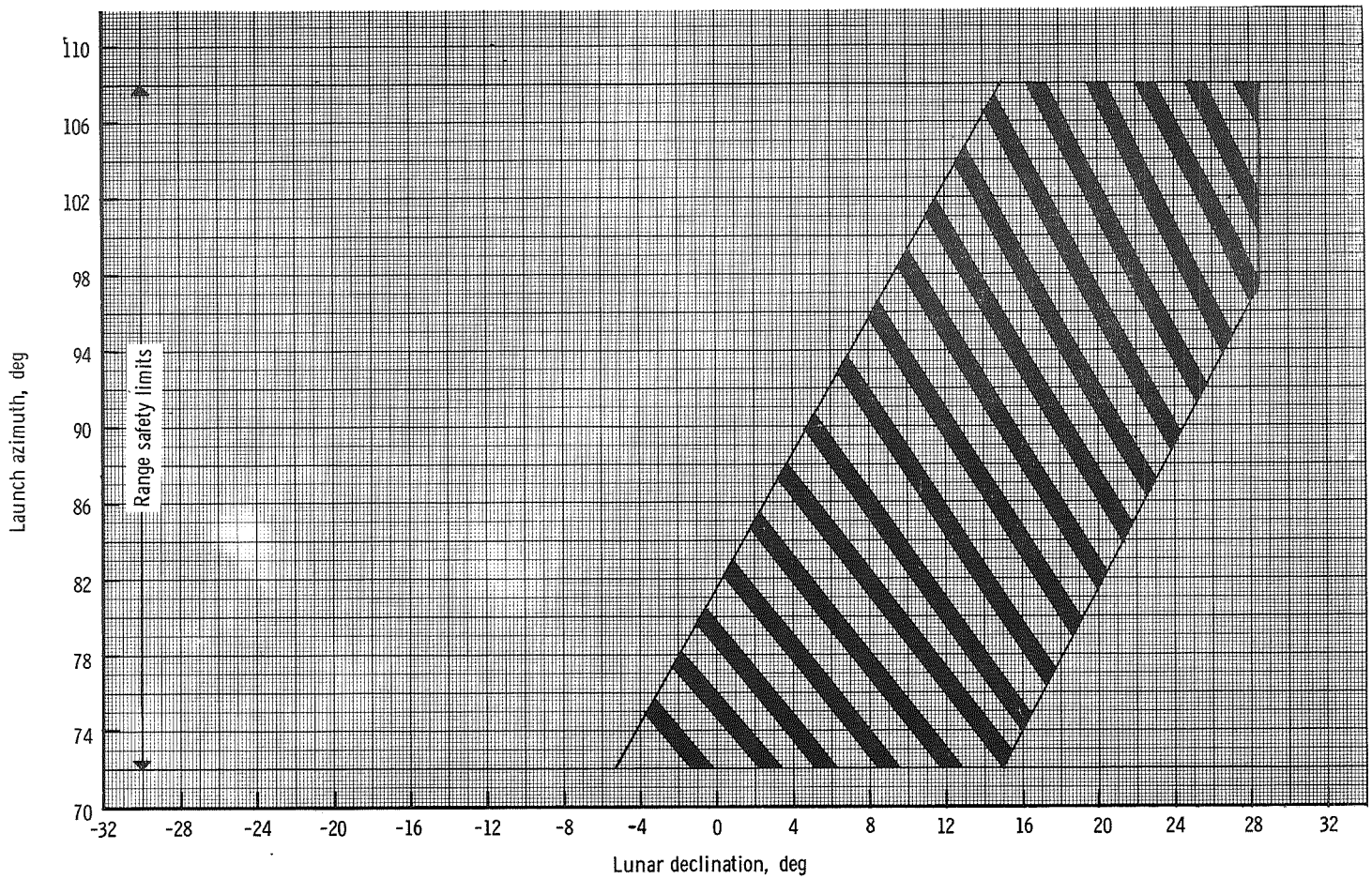
(f) Atlantic injection from second orbit, Table I stations without South African stations and with Madagascar.

Figure 12. - Continued.



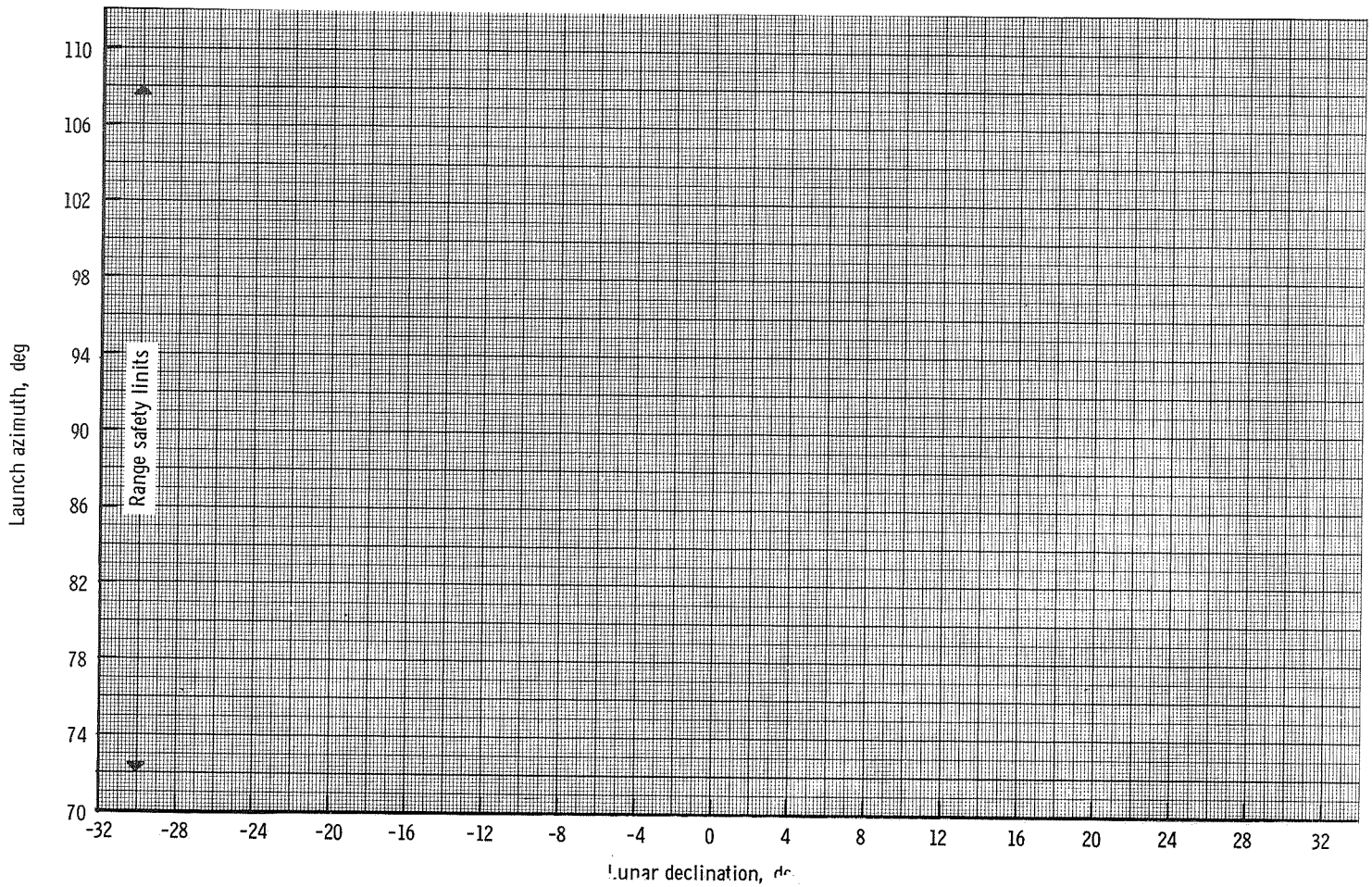
(g) Atlantic injection from third orbit, Table I stations.

Figure 12. - Continued.



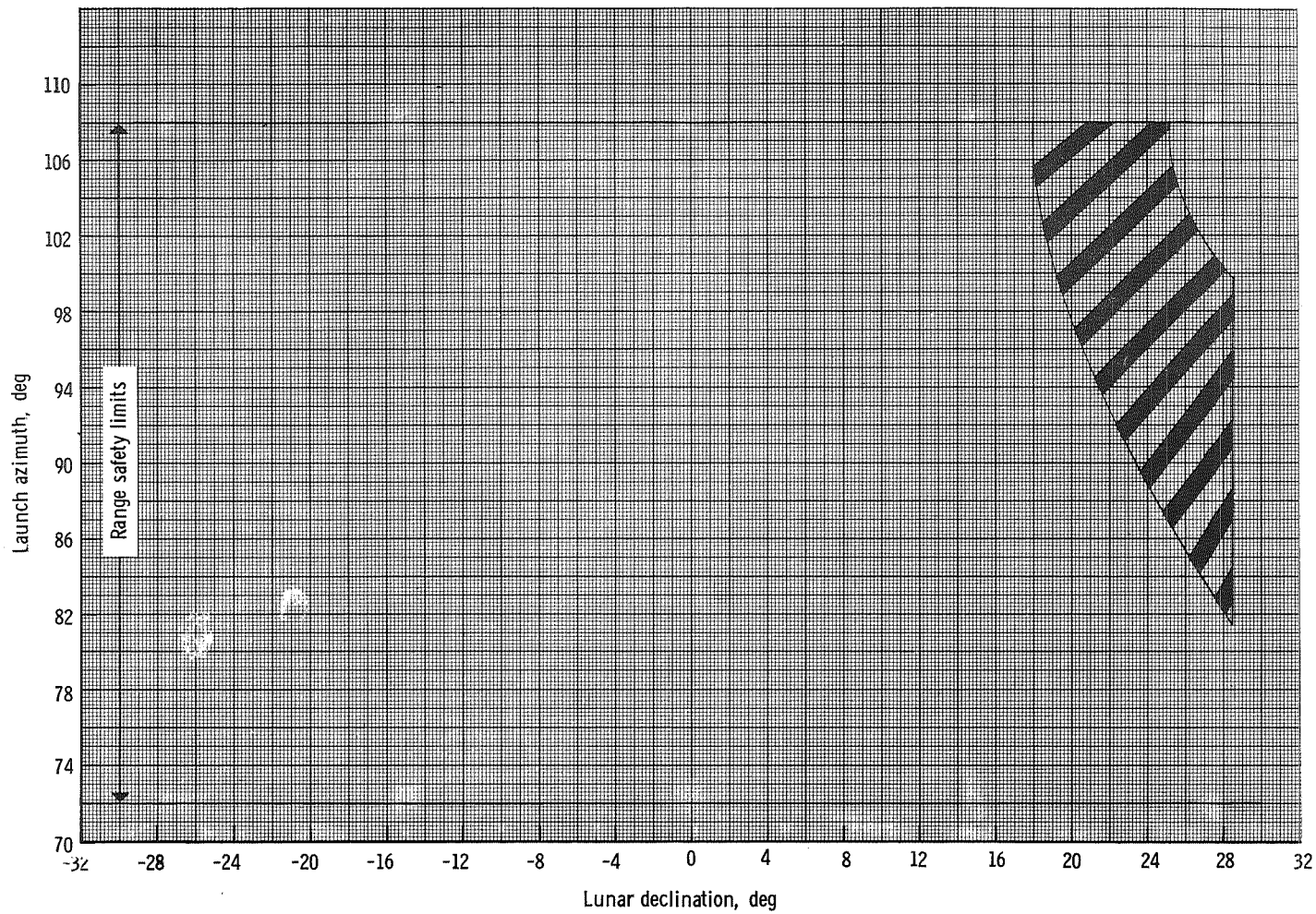
(h) Atlantic injection from third orbit, Table I stations without South African stations.

Figure 12. - Continued.



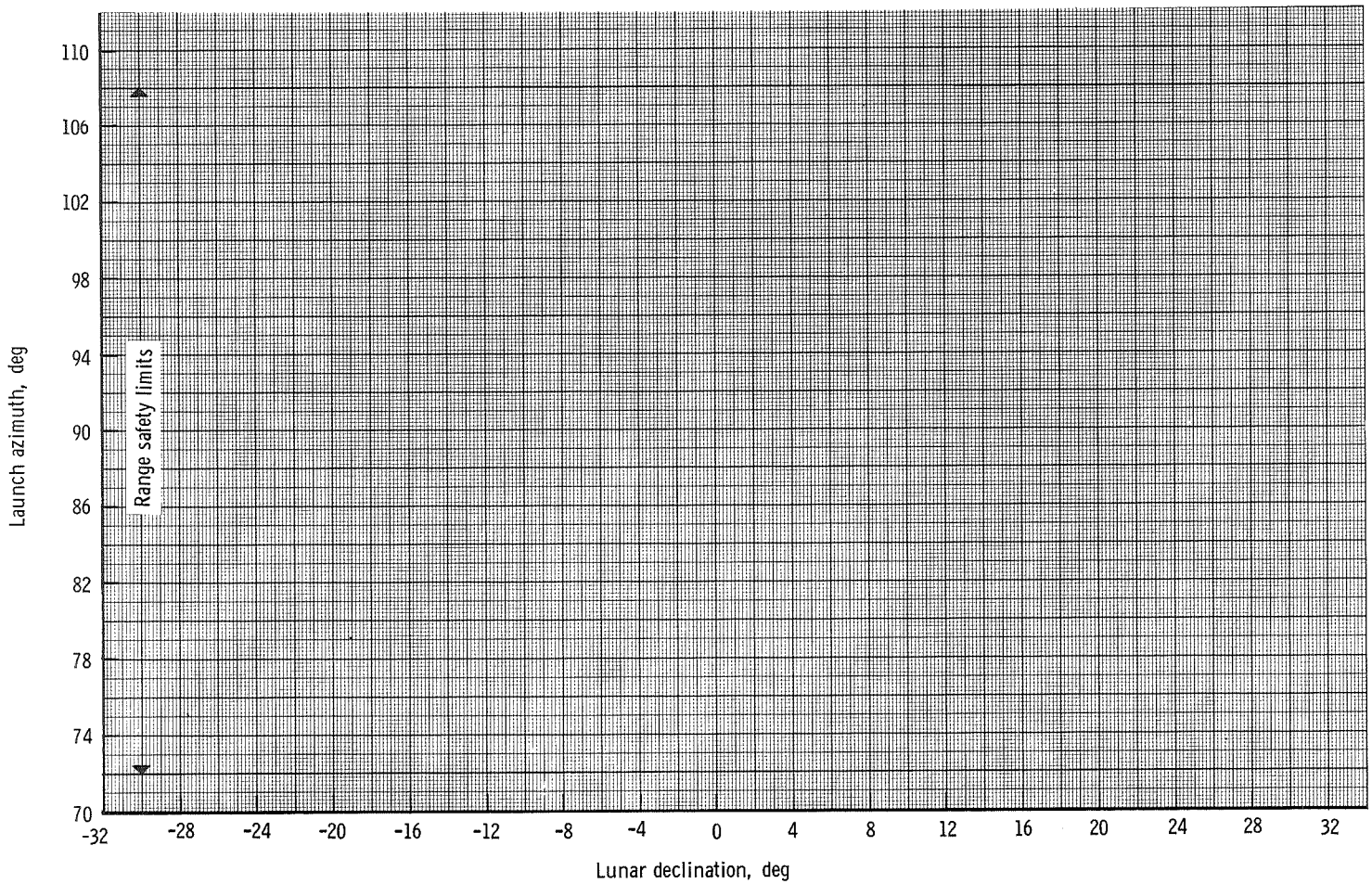
(i) Atlantic injection from third orbit, Table I stations without South African stations and with Madagascar.

Figure 12. - Continued.



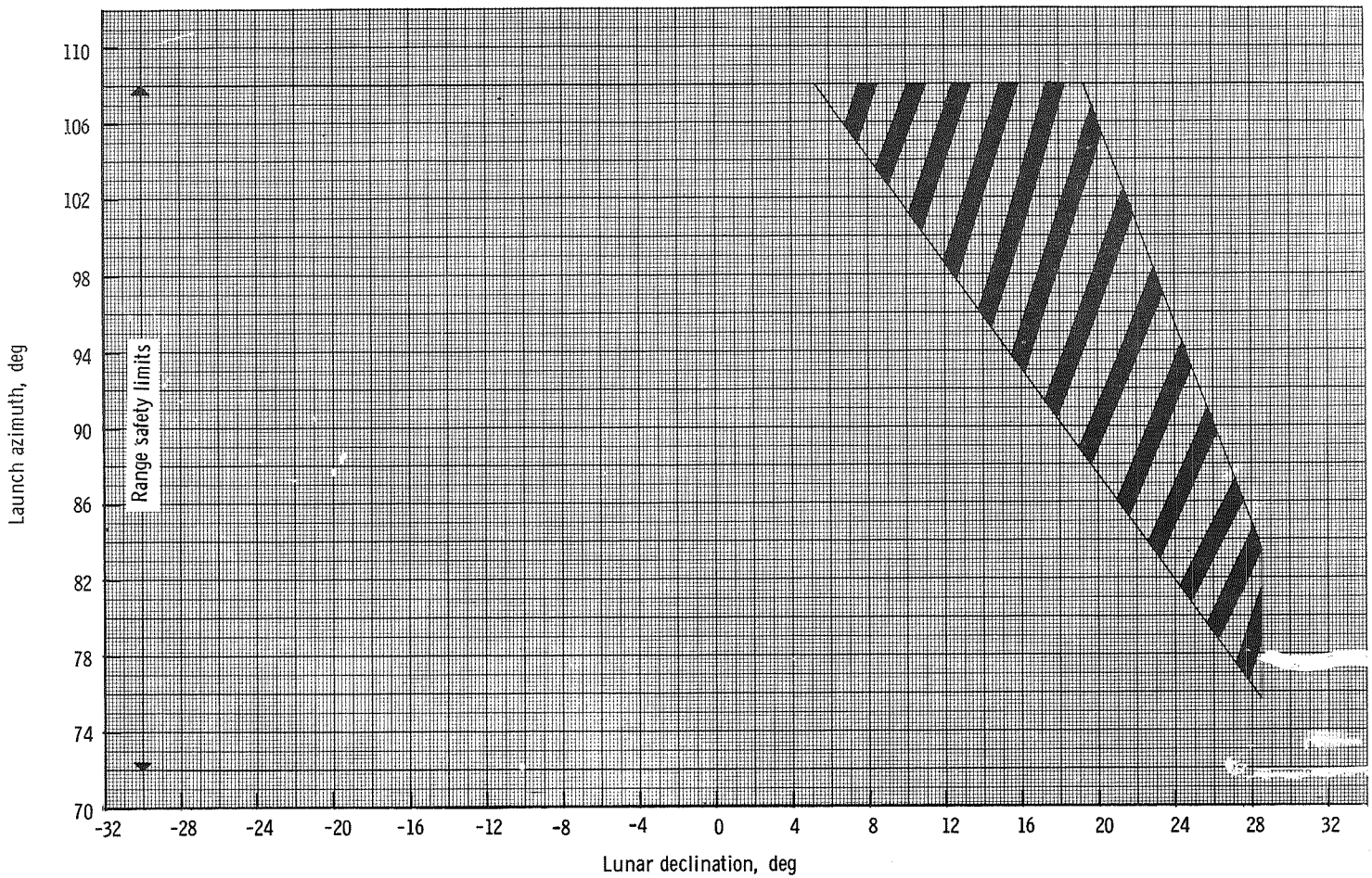
(j) Pacific injection from first orbit, Table I stations.

Figure 12. - Continued.



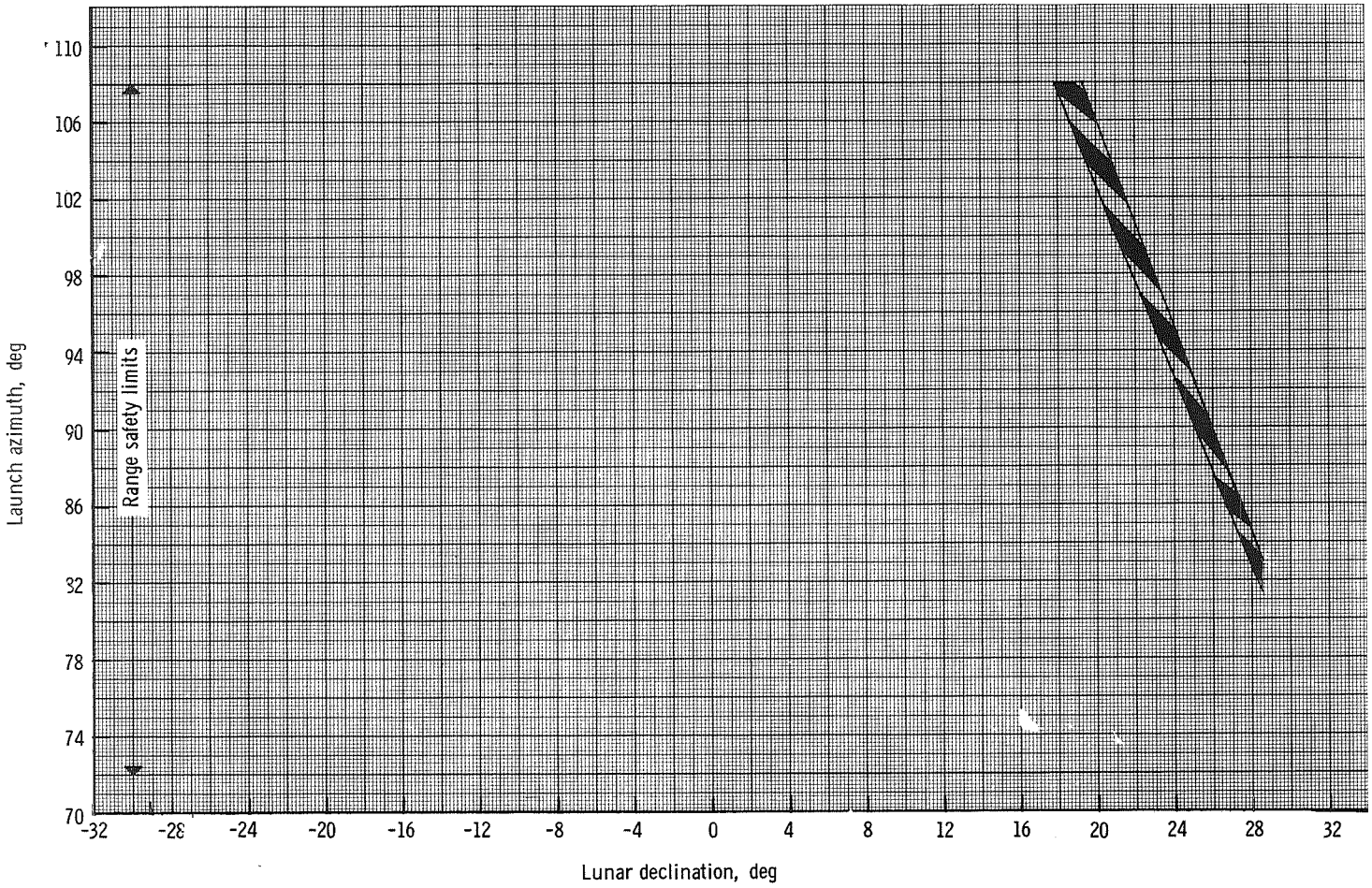
(k) Pacific injection from first orbit, Table I stations and Guam.

Figure 12. - Continued.



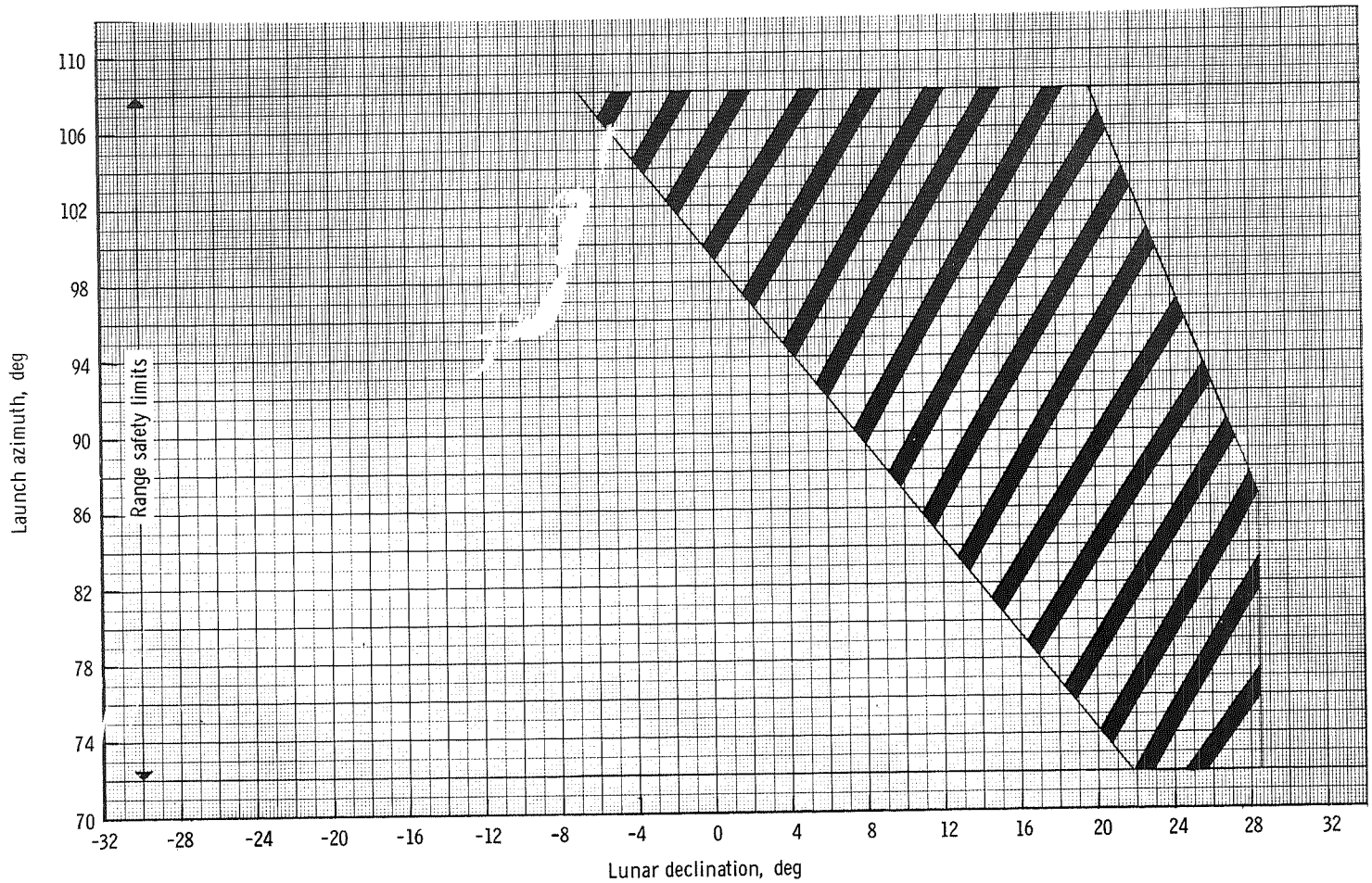
(l) Pacific injection from second orbit, Table I stations.

Figure 12. - Continued.



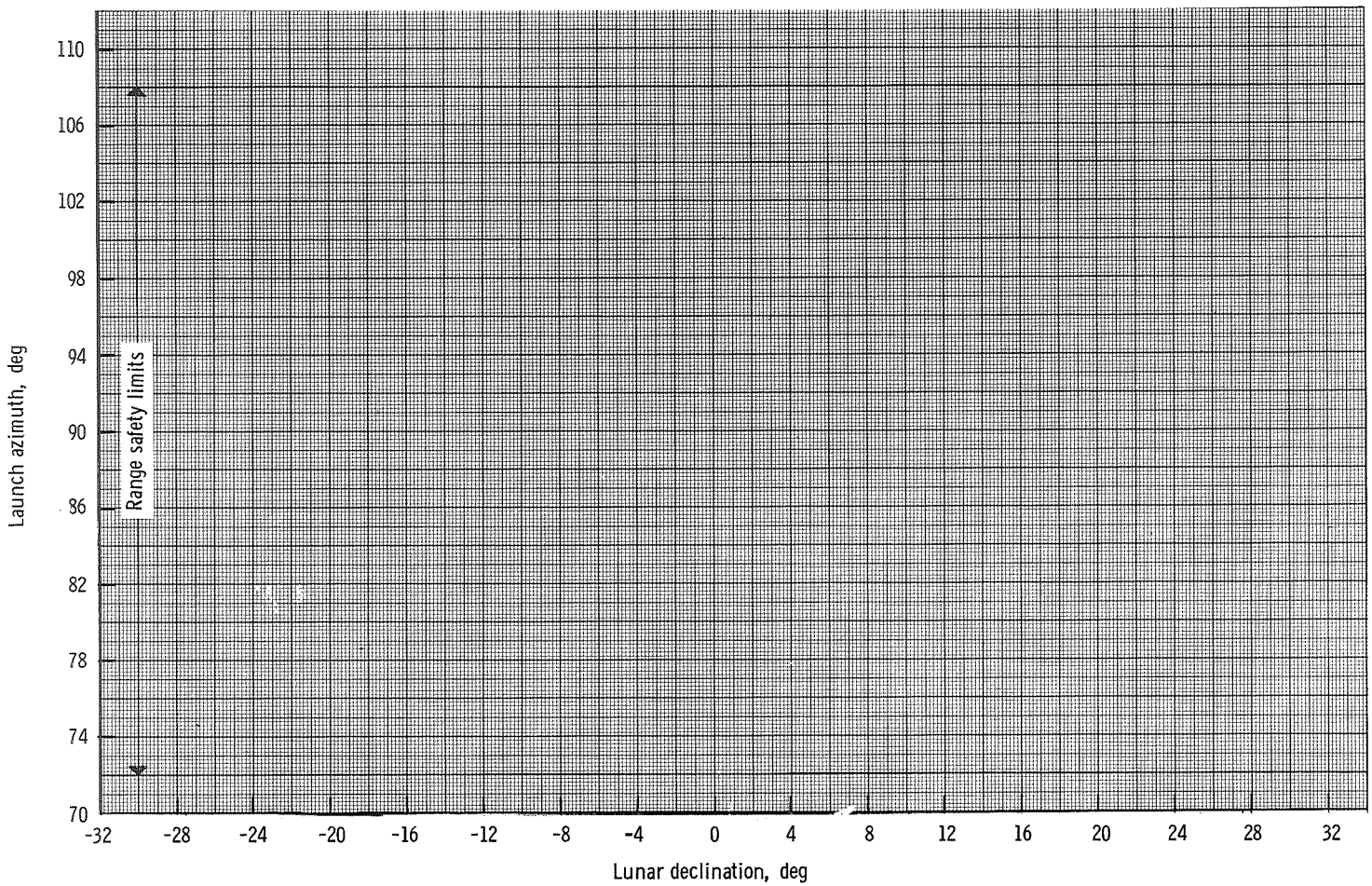
(m) Pacific injection from second orbit, Table I stations and Guam.

Figure 12. - Continued.



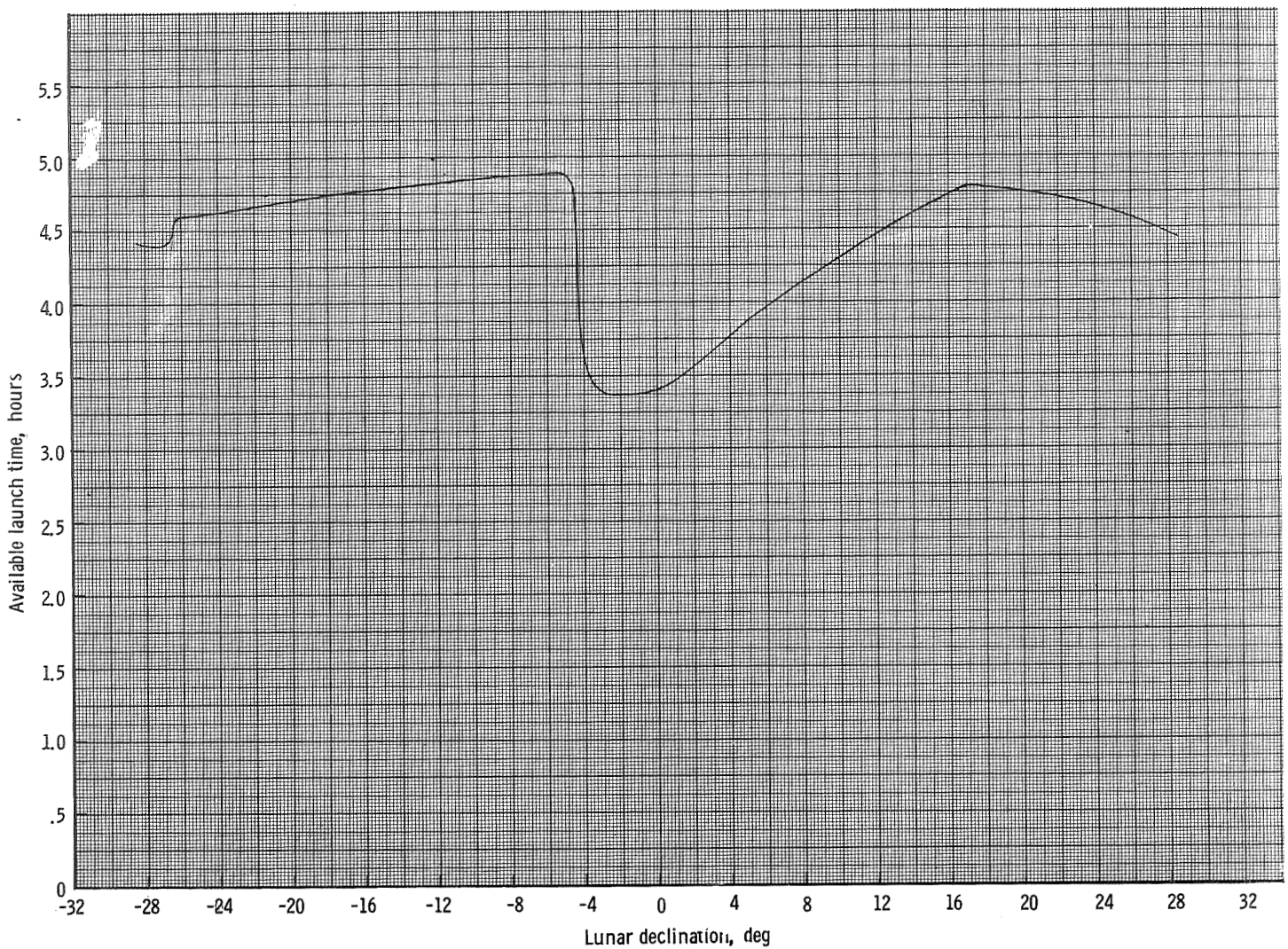
(n) Pacific injection from third orbit, Table I stations.

Figure 12. - Continued.



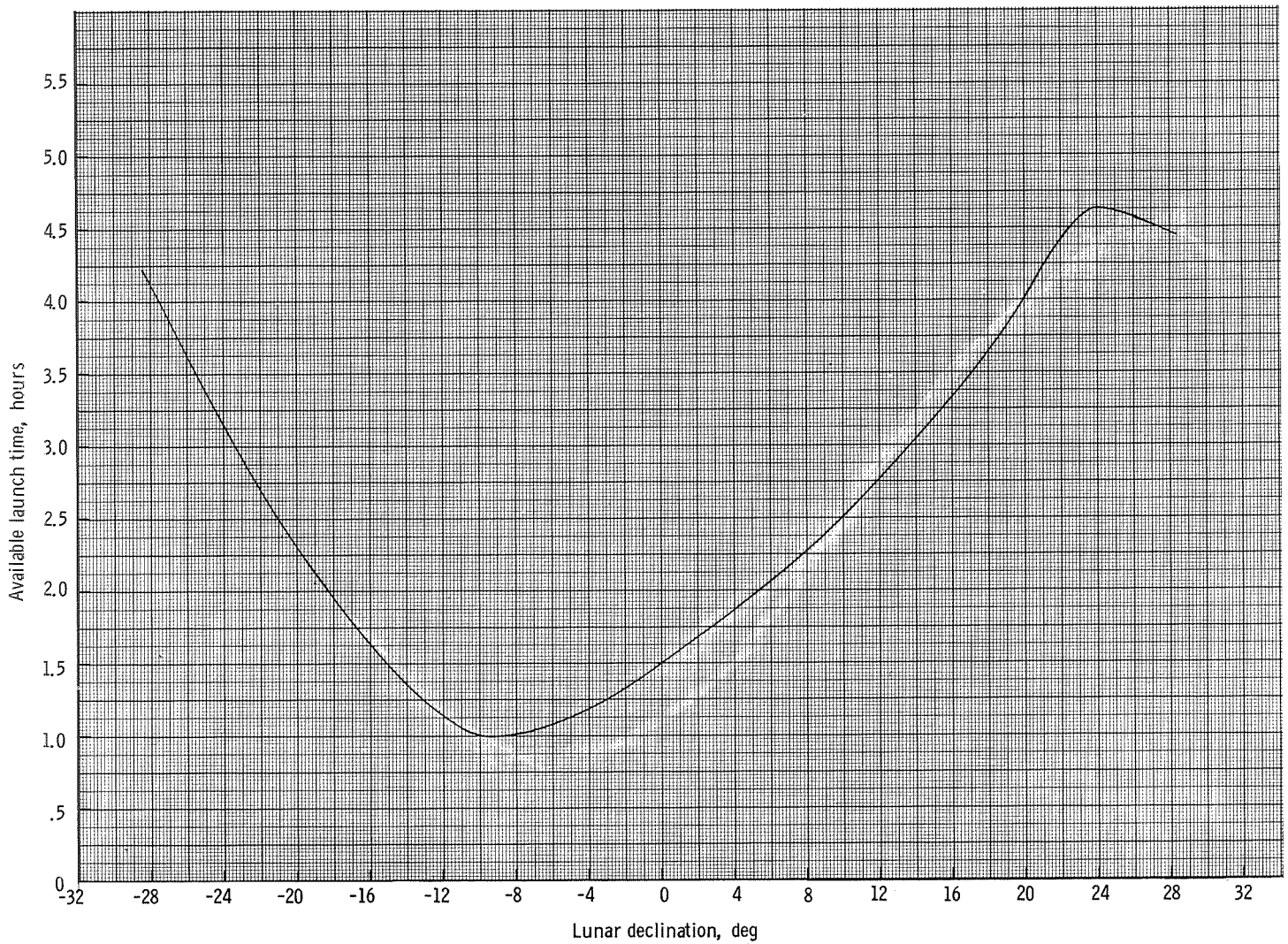
(o) Pacific injection from third orbit, Table I stations and Guam.

Figure 12. - Concluded.



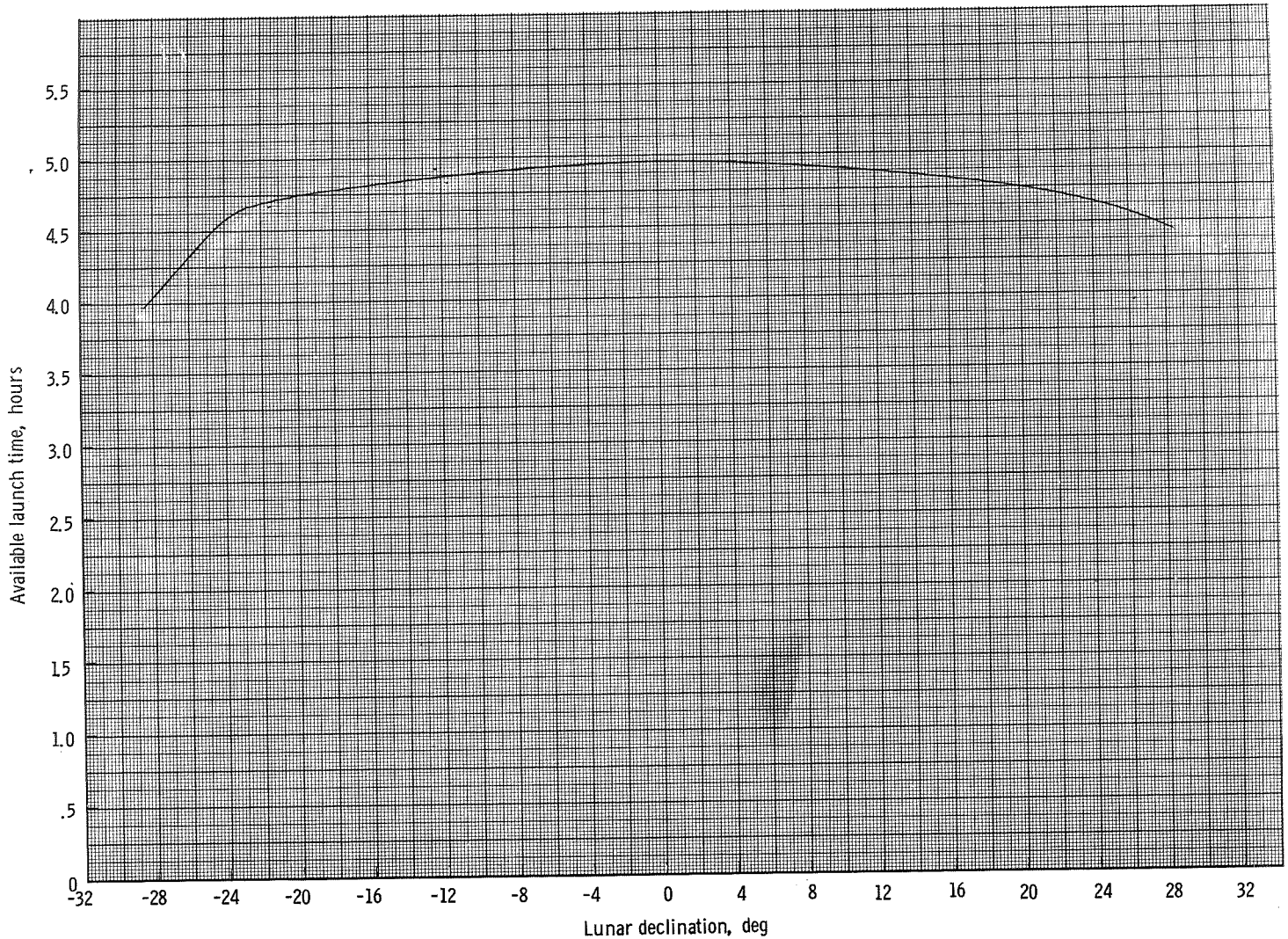
(a) Atlantic injection from first orbit, Table I stations.

Figure 13. - Available launch time considering Table I stations, Madagascar and Guam with a 10-minute post injection acquisition requirement.



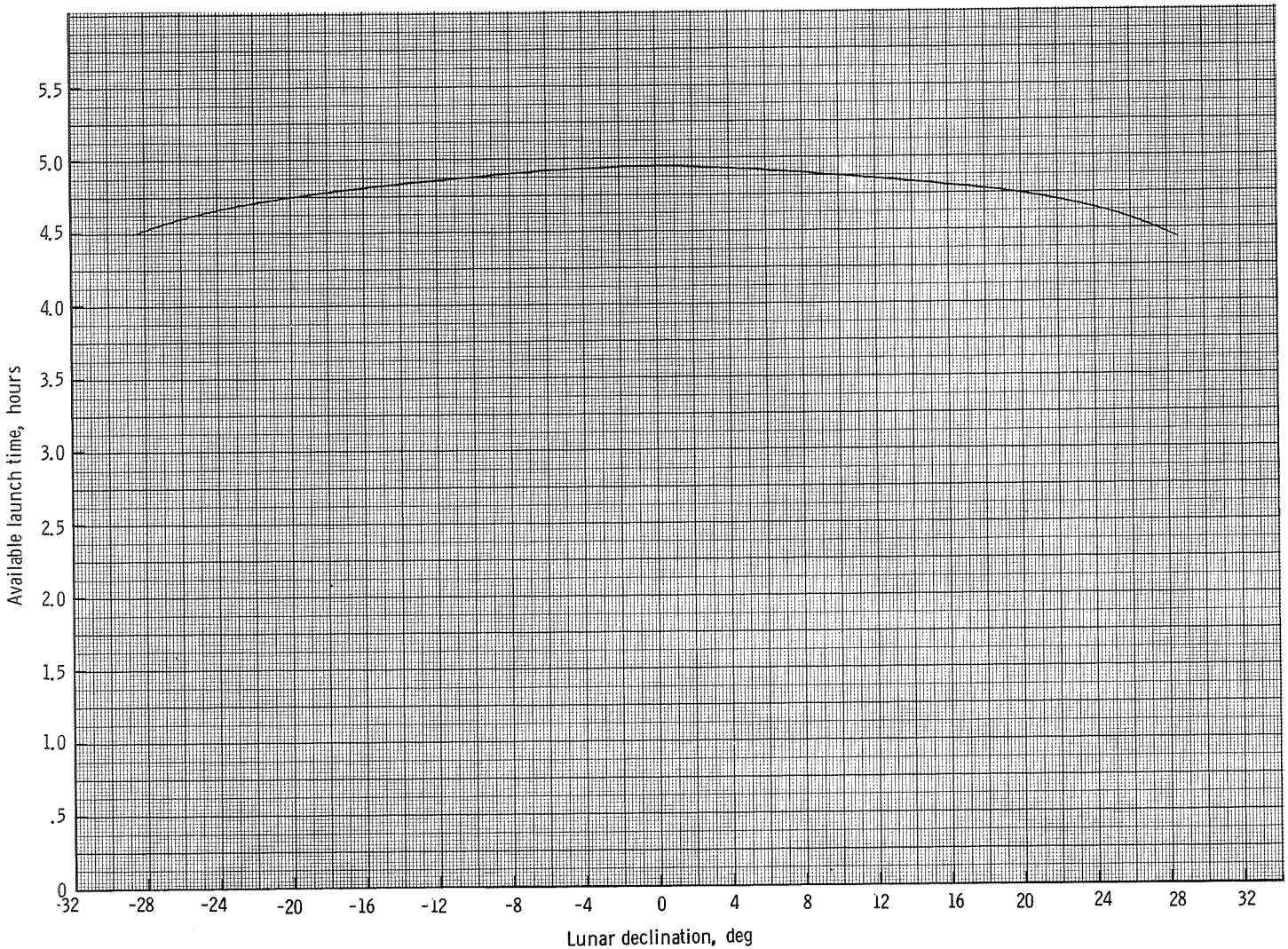
(b) Atlantic injection from first orbit, Table I stations without South African stations.

Figure 13. - Continued.



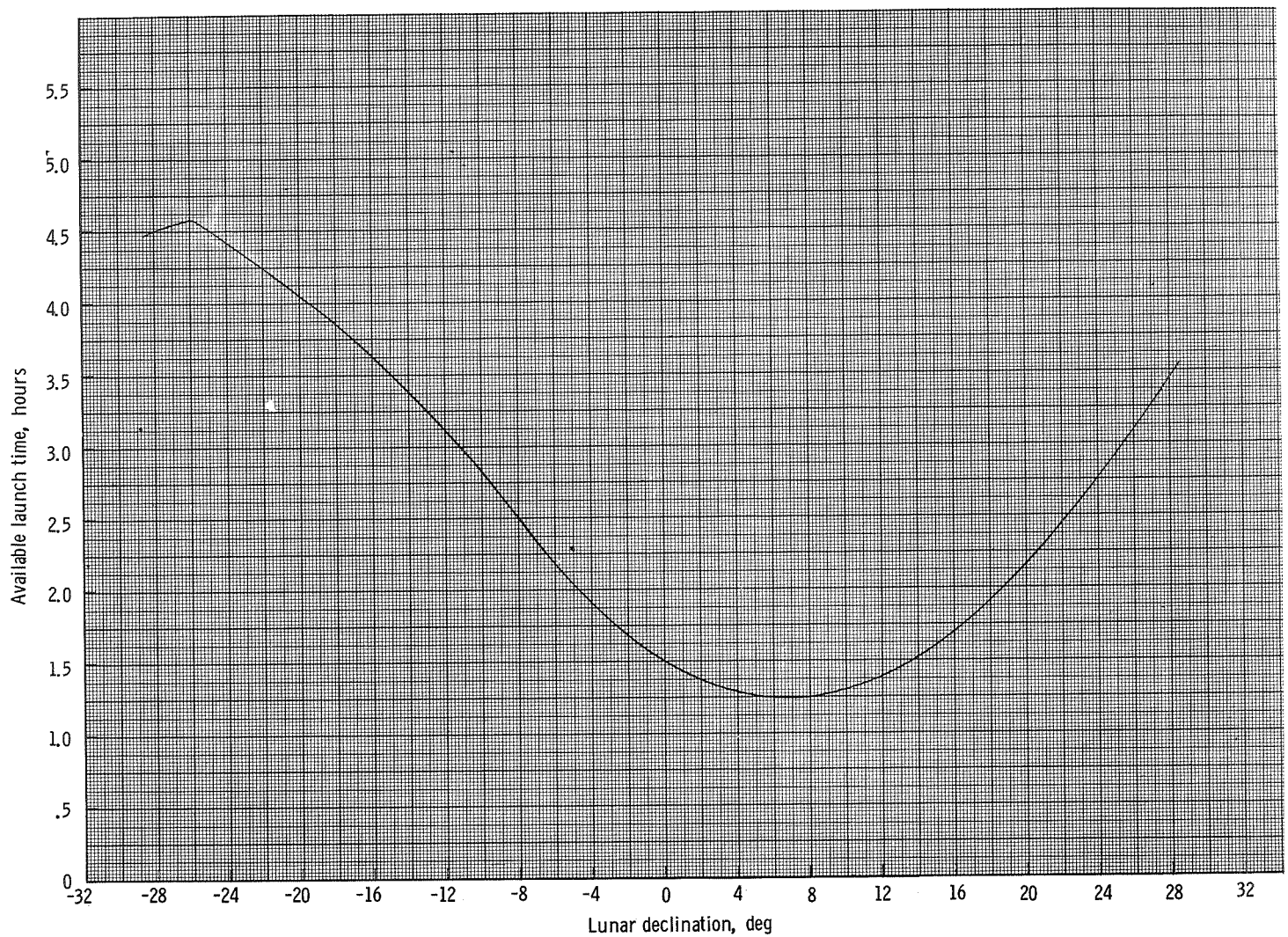
(c) Atlantic injection from first orbit, Table I stations without South African stations and with Madagascar.

Figure 13. - Continued.



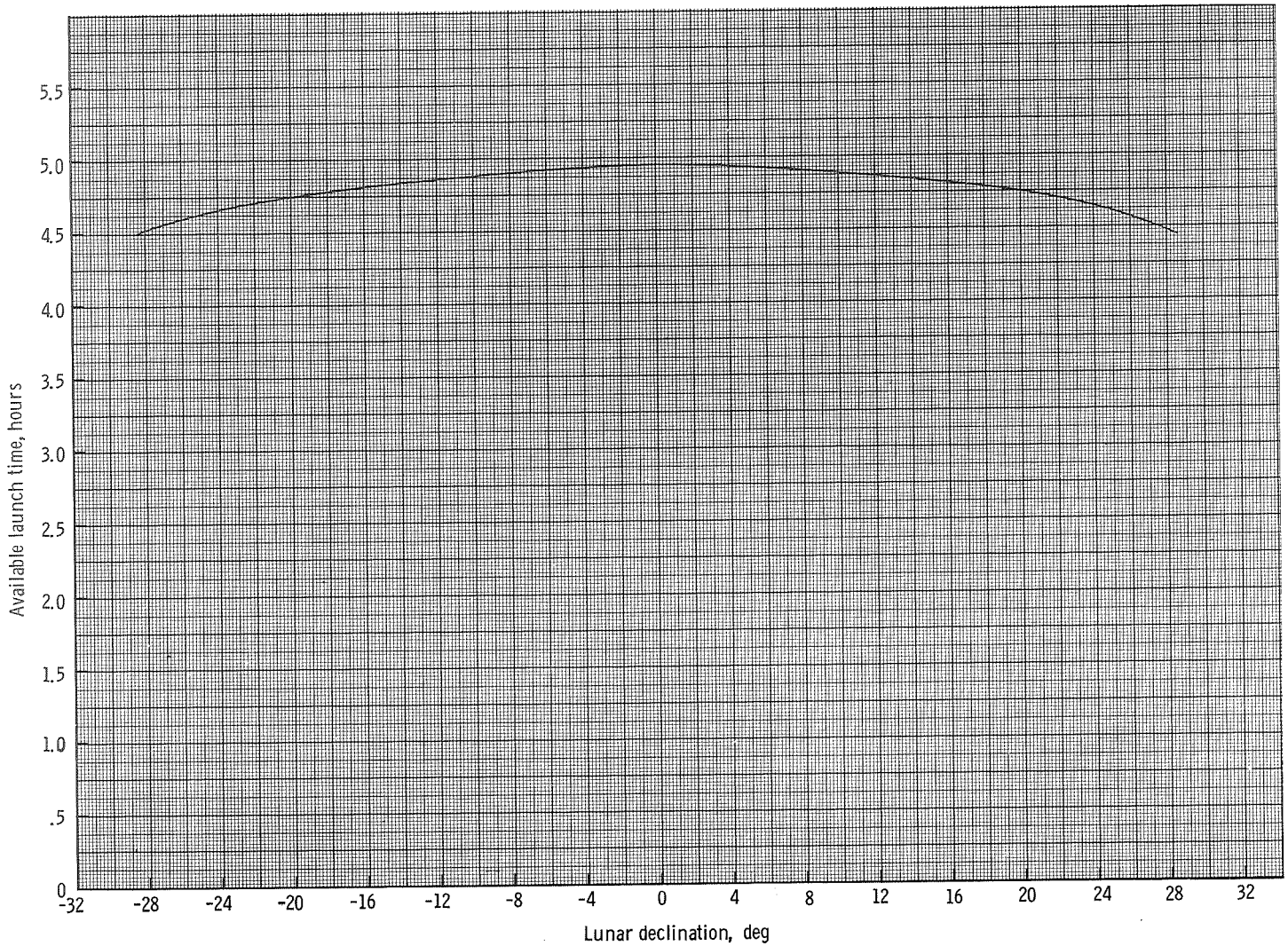
(d) Atlantic injection from second orbit, Table I stations.

Figure 13. - Continued.



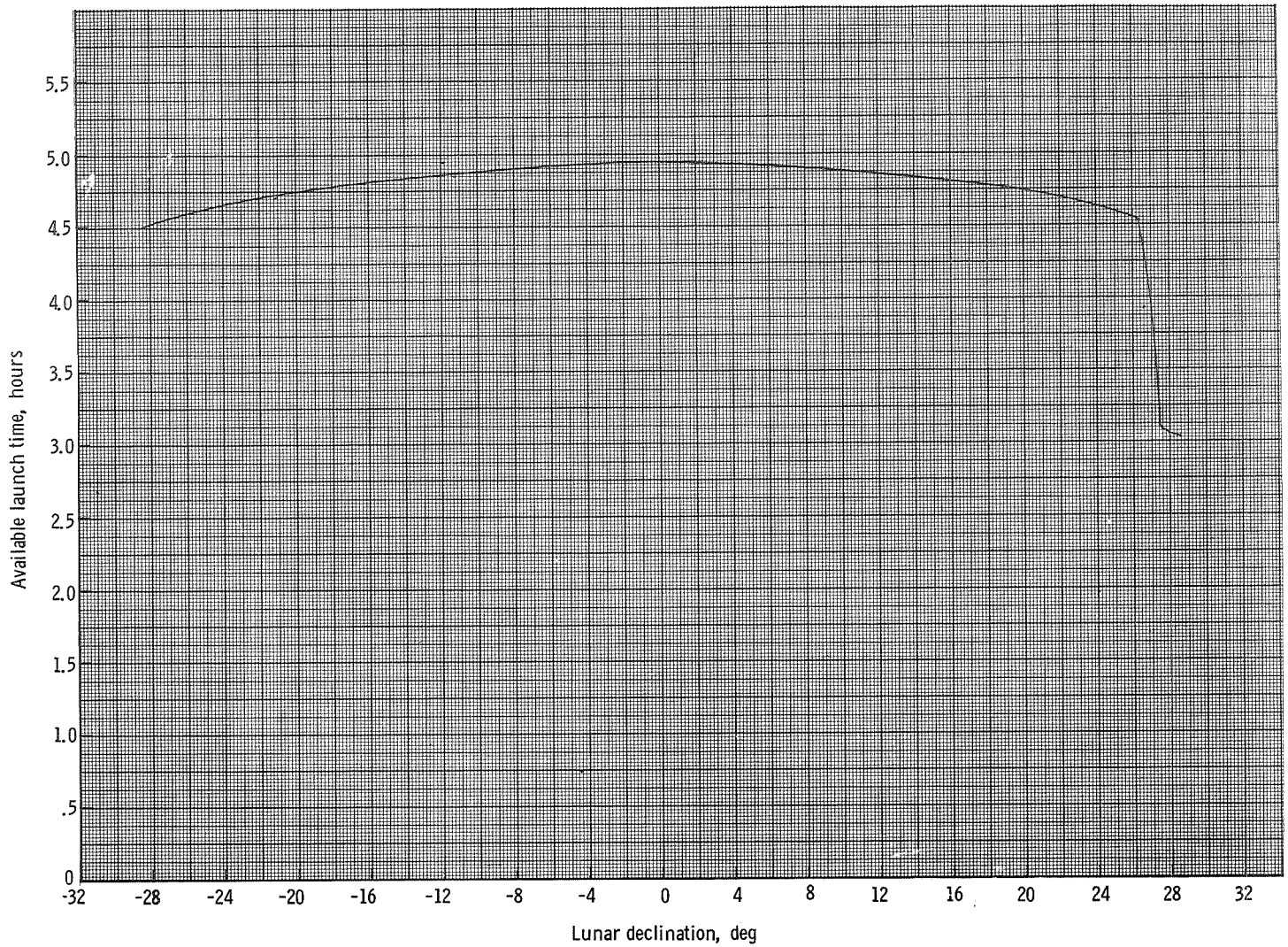
(e) Atlantic injection from second orbit, Table I stations without South African stations.

Figure 13. - Continued.



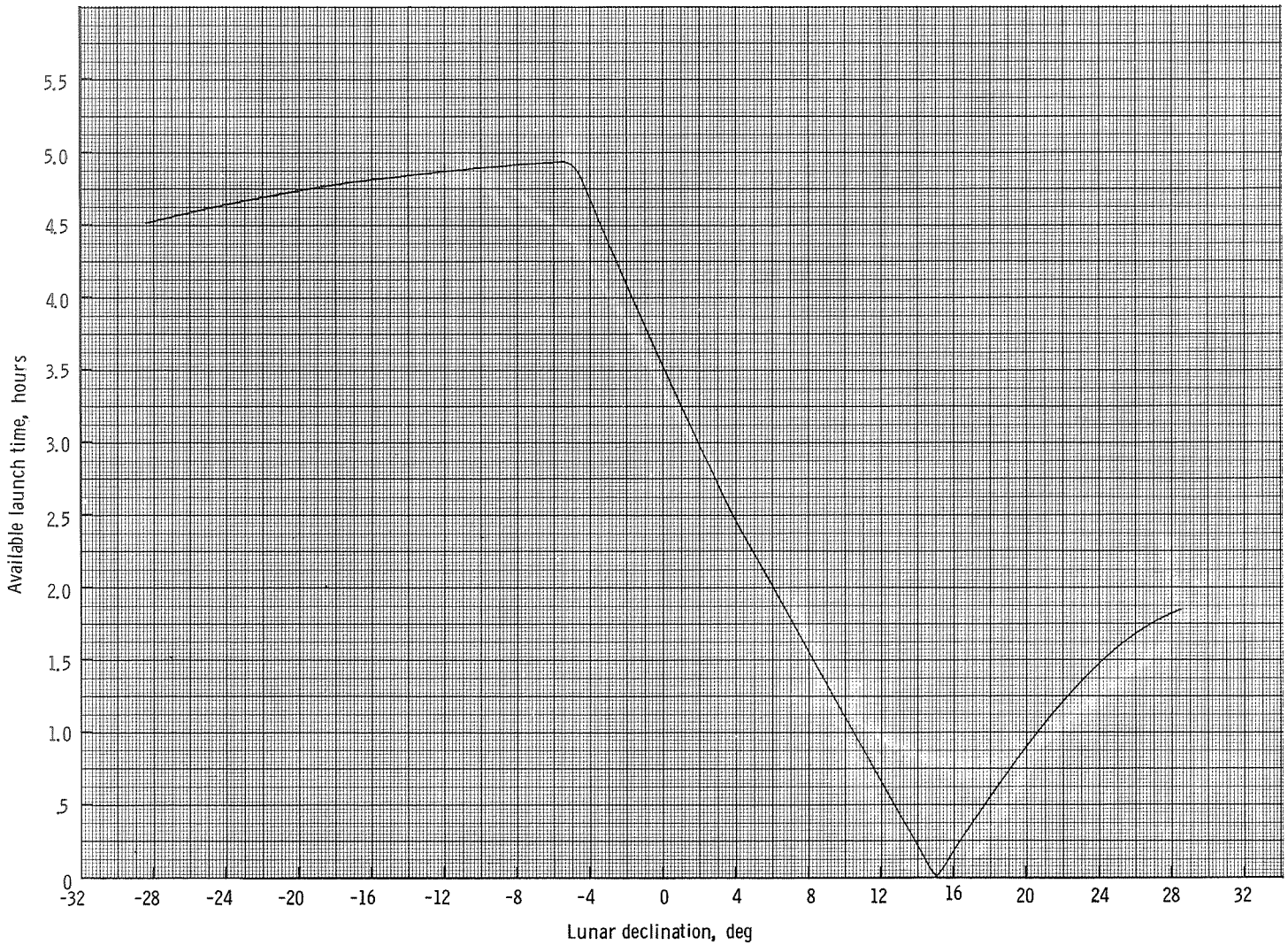
(f) Atlantic injection from second orbit, Table I stations without South African stations and with Madagascar.

Figure 13. - Continued.



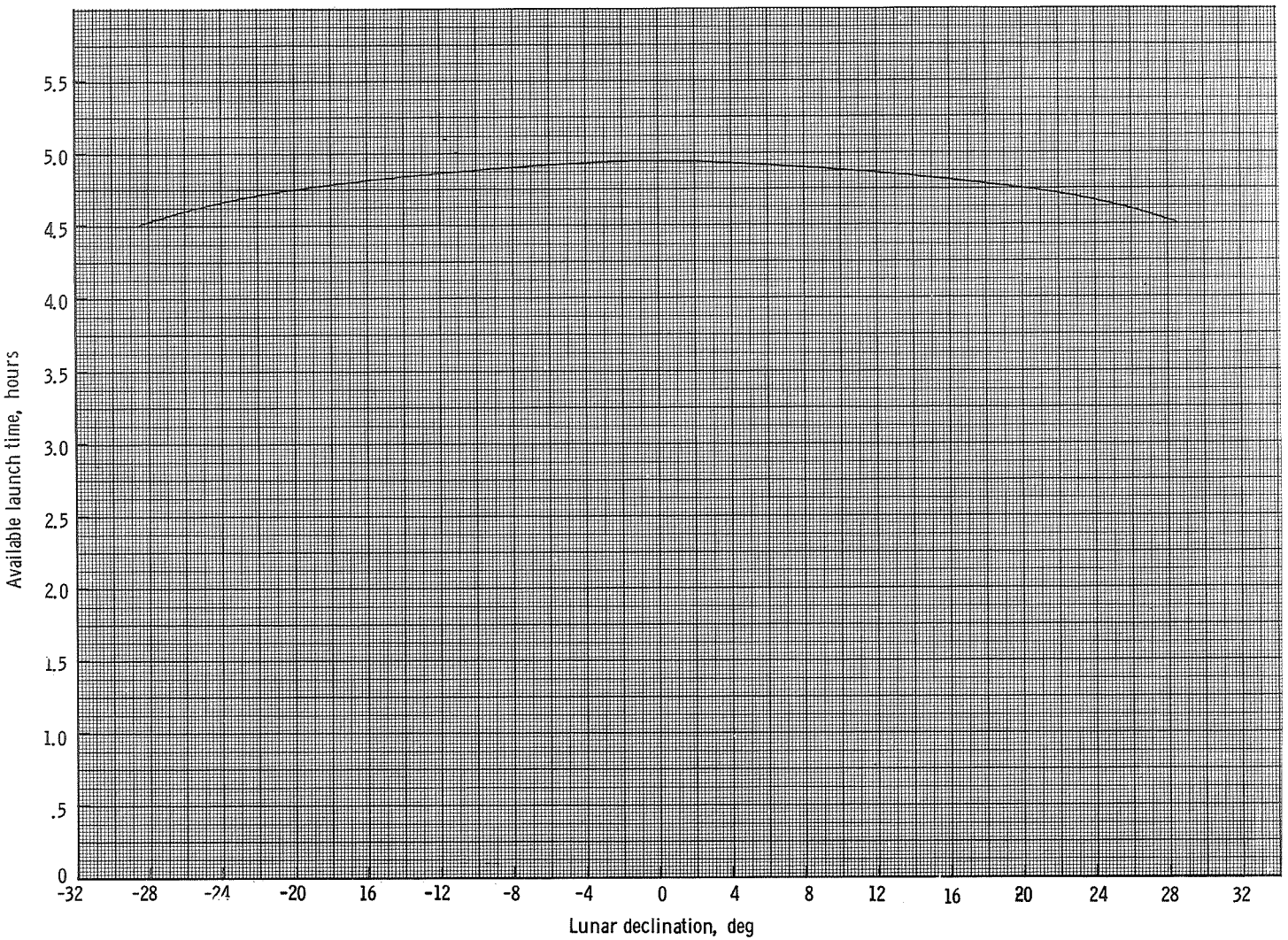
(g) Atlantic injection from third orbit, Table I stations.

Figure 13. - Continued.



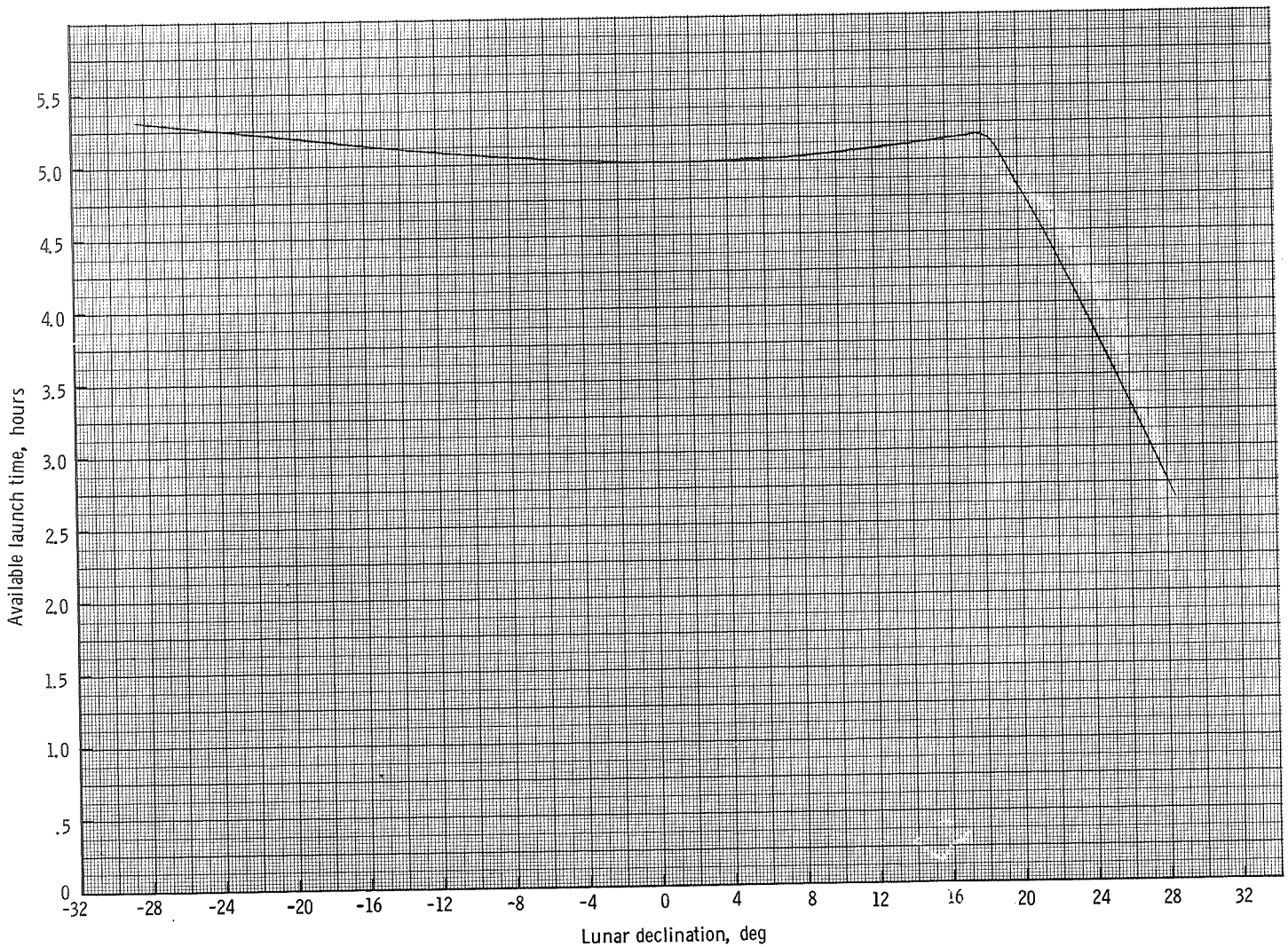
(h) Atlantic injection from third orbit, Table I stations without South African stations.

Figure 13. - Continued.



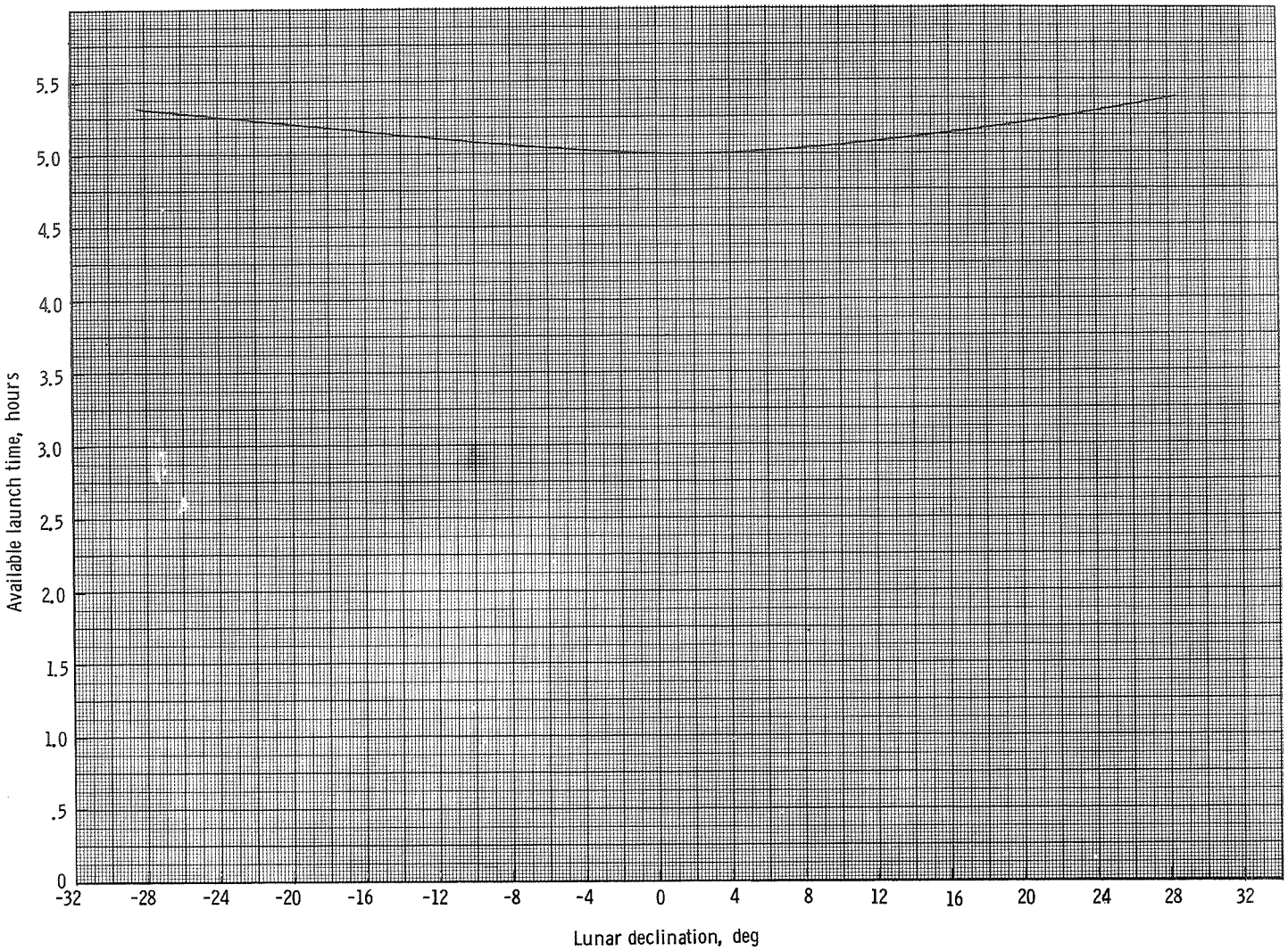
(i) Atlantic injection from third orbit, Table I stations without South African stations and with Madagascar.

Figure 13. - Continued.



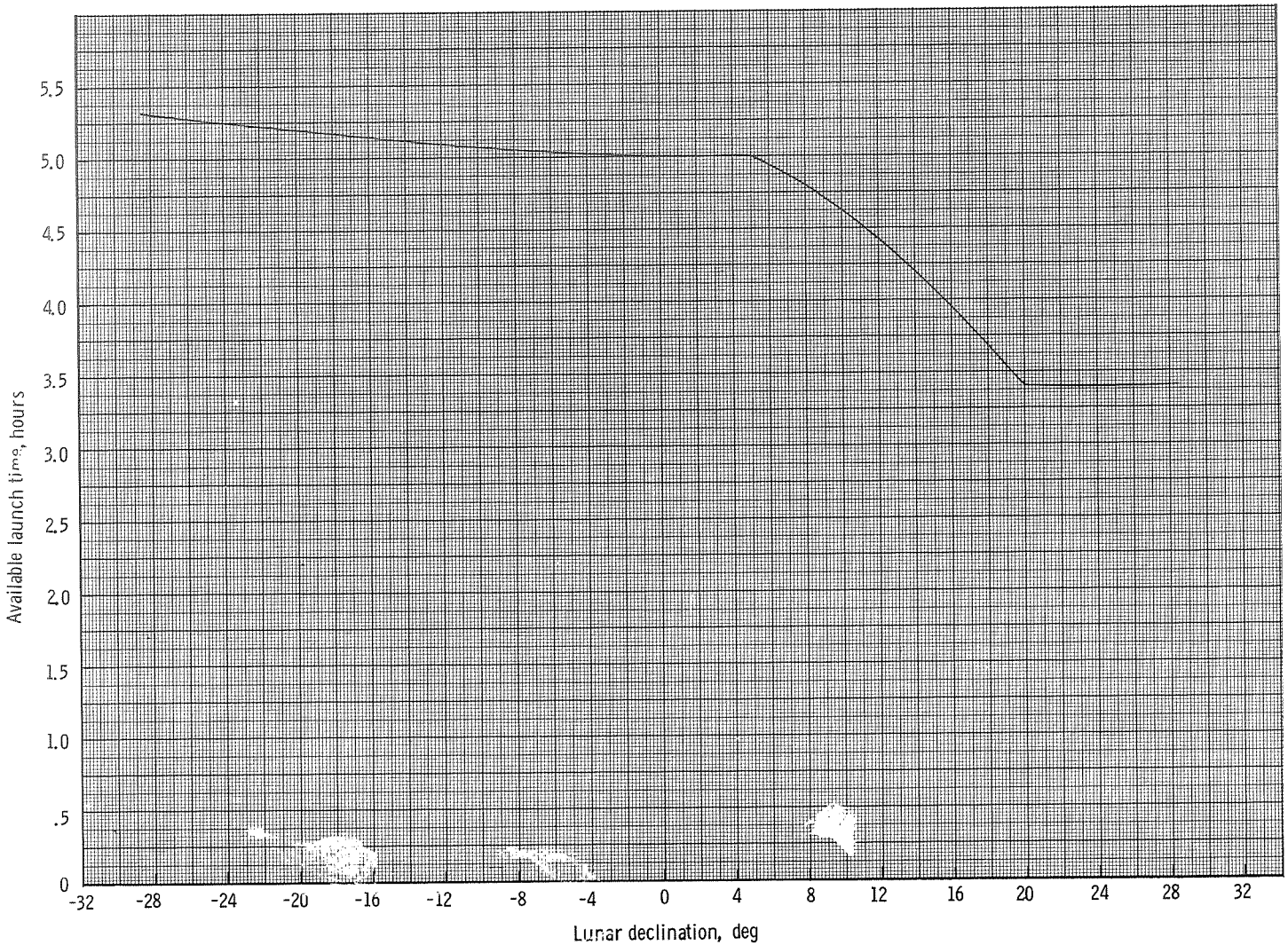
(j) Pacific injection from first orbit, Table I stations.

Figure 13. - Continued.



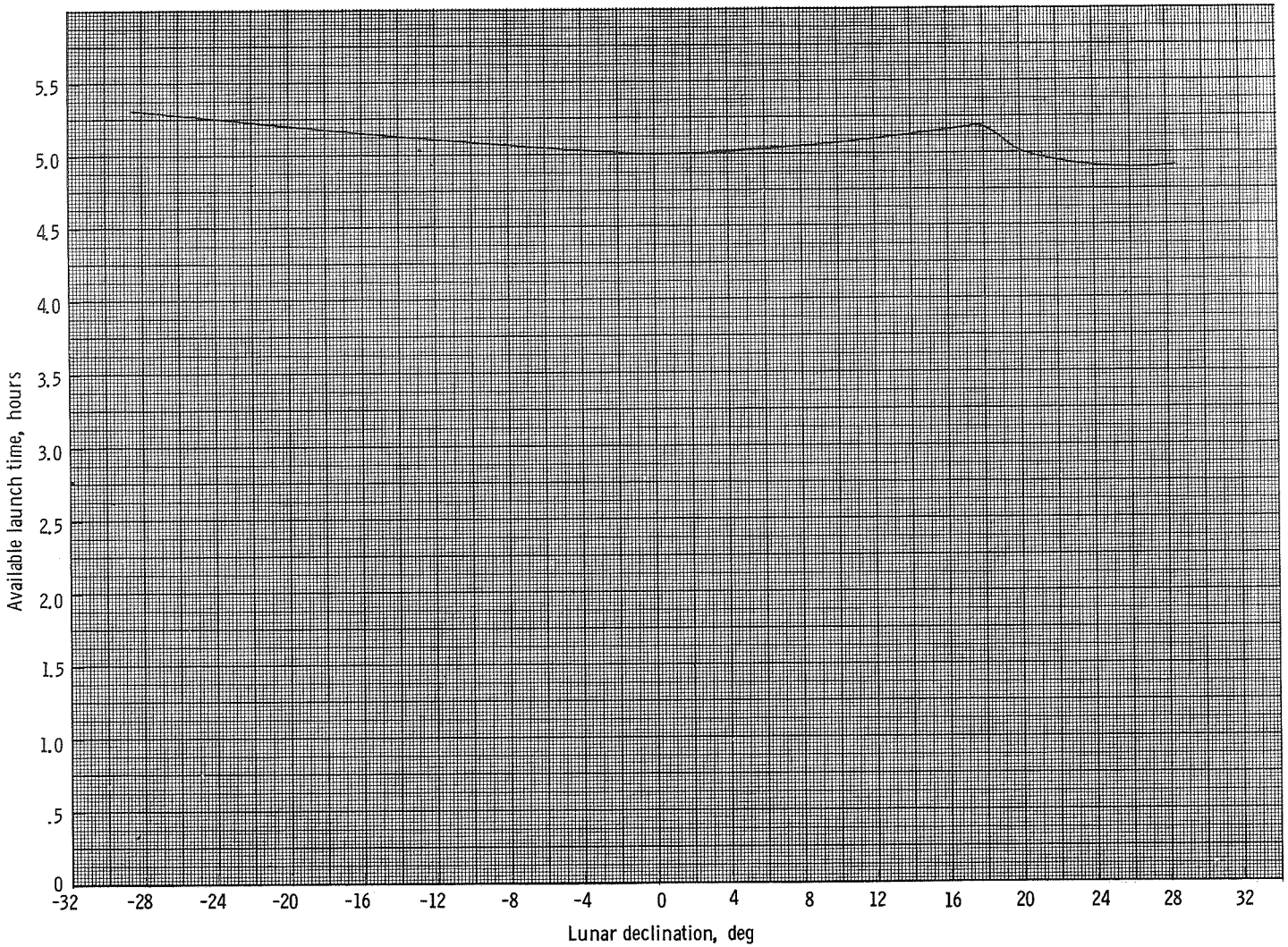
(k) Pacific injection from first orbit, Table I stations and Guam.

Figure 13. - Continued.



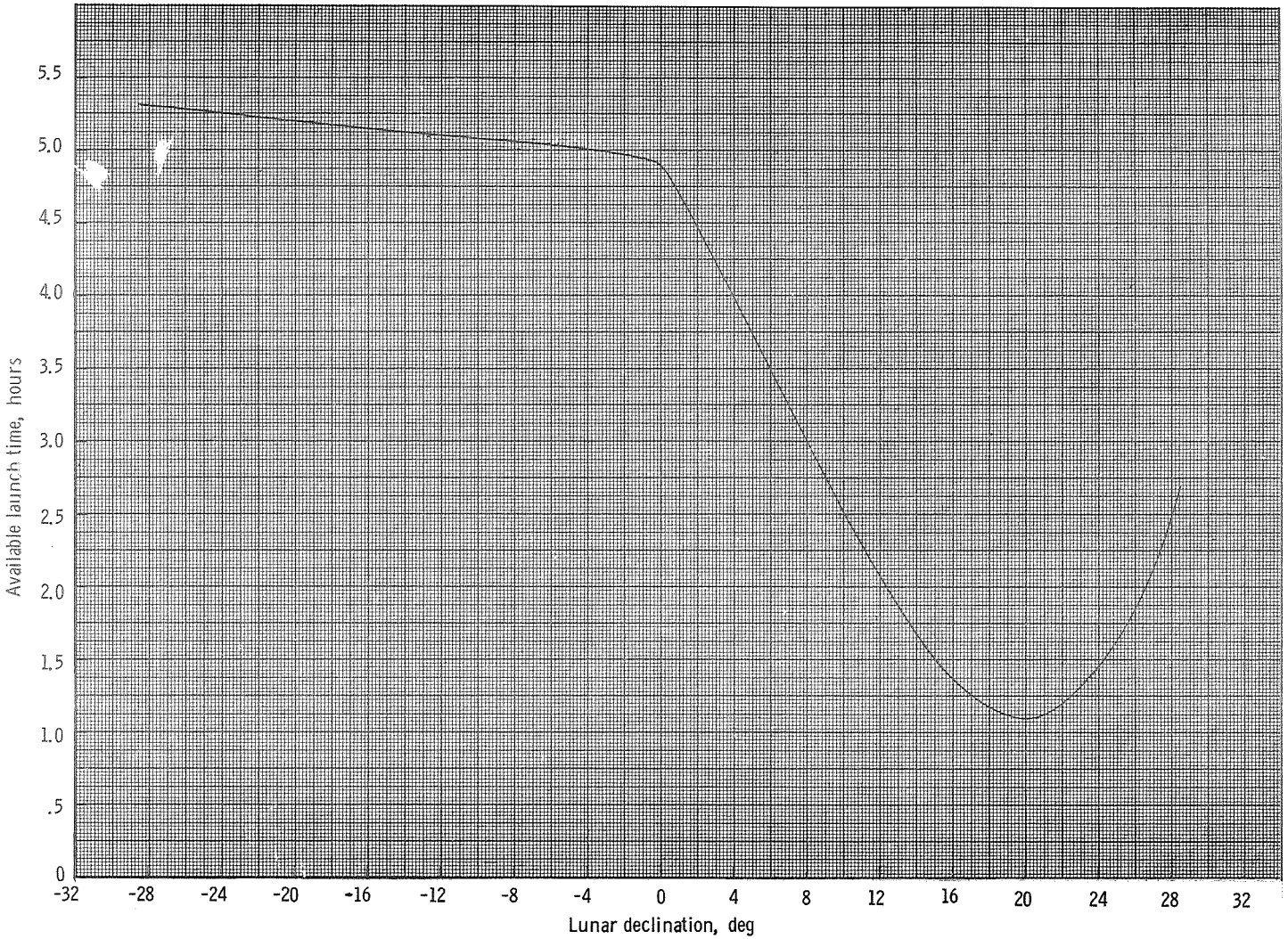
(l) Pacific injection from second orbit, Table I stations.

Figure 13. - Continued.



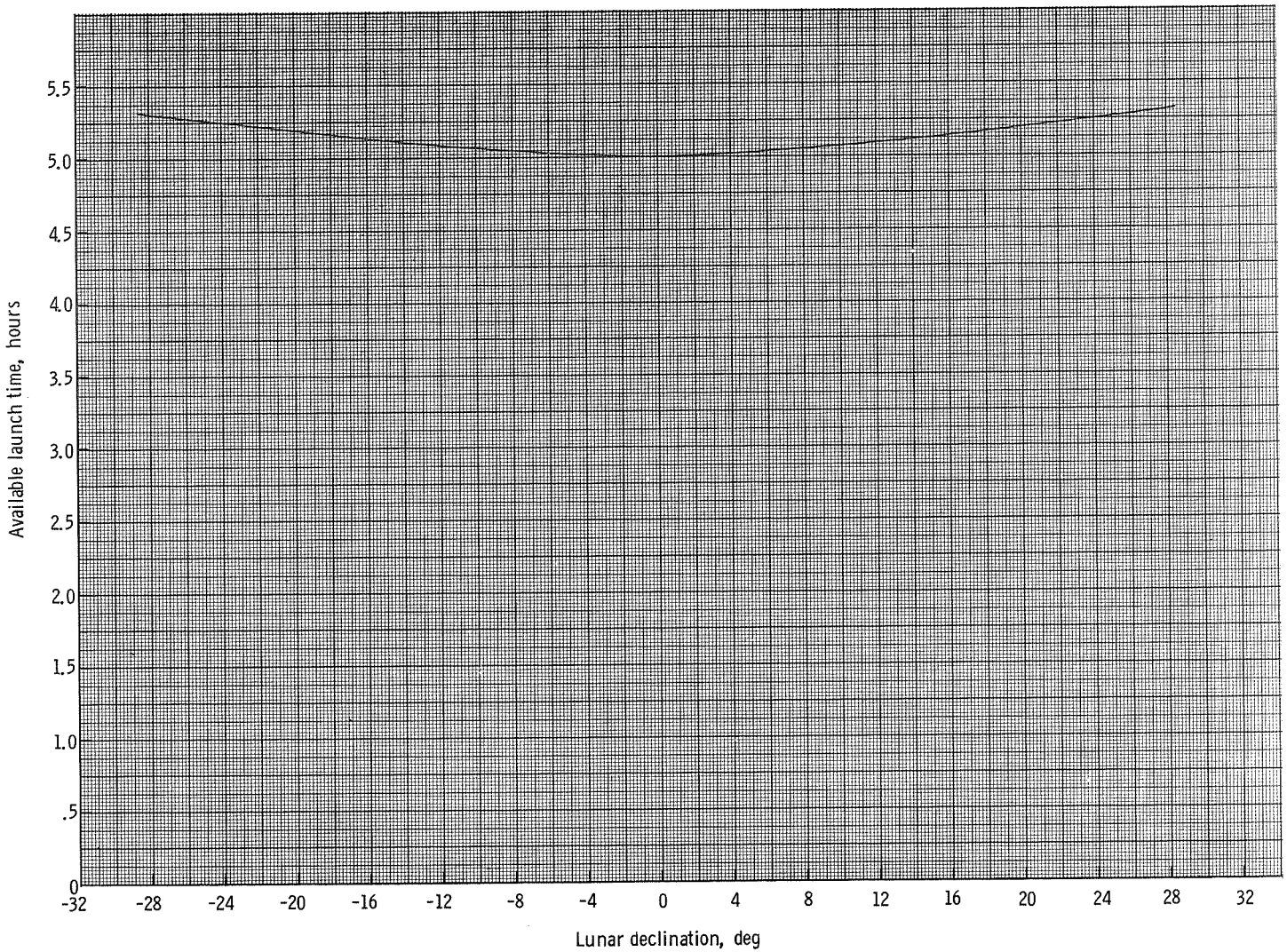
(m) Pacific injection from second orbit, Table I stations and Guam.

Figure 13. - Continued.



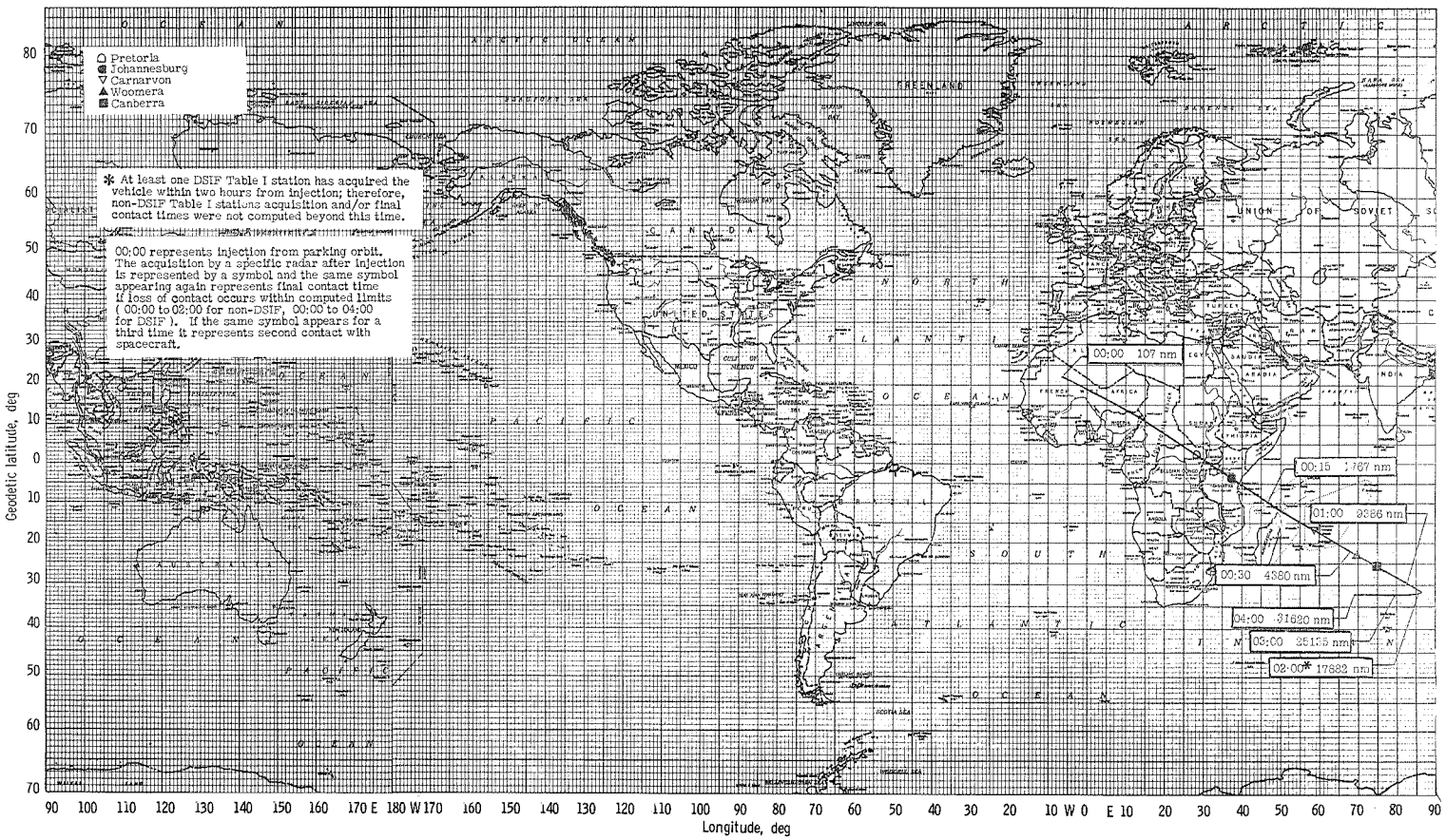
(n) Pacific injection from third orbit, Table I stations.

Figure 13. - Continued.



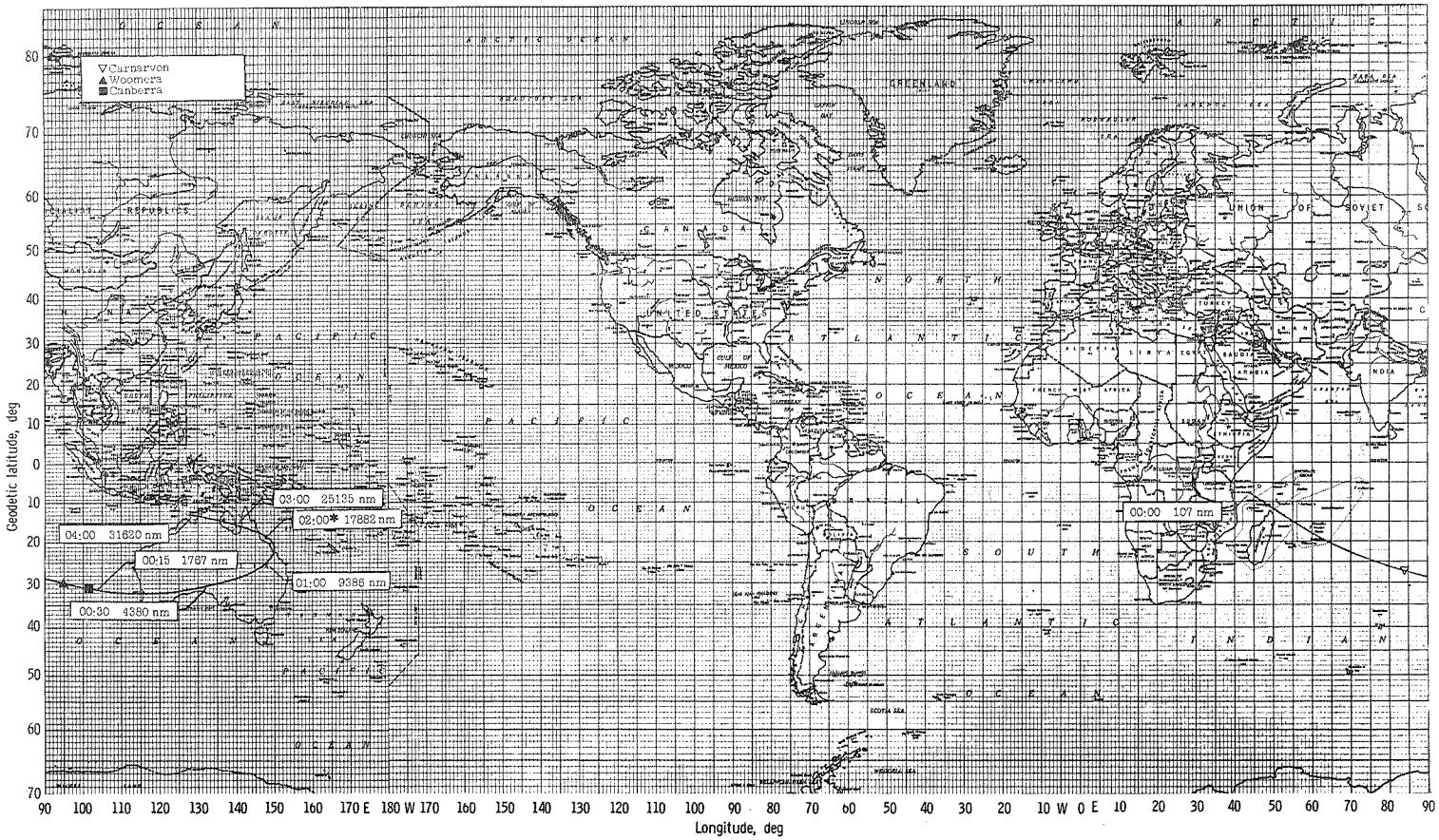
(o) Pacific injection from third orbit, Table I stations and Guam.

Figure 13. - Concluded.



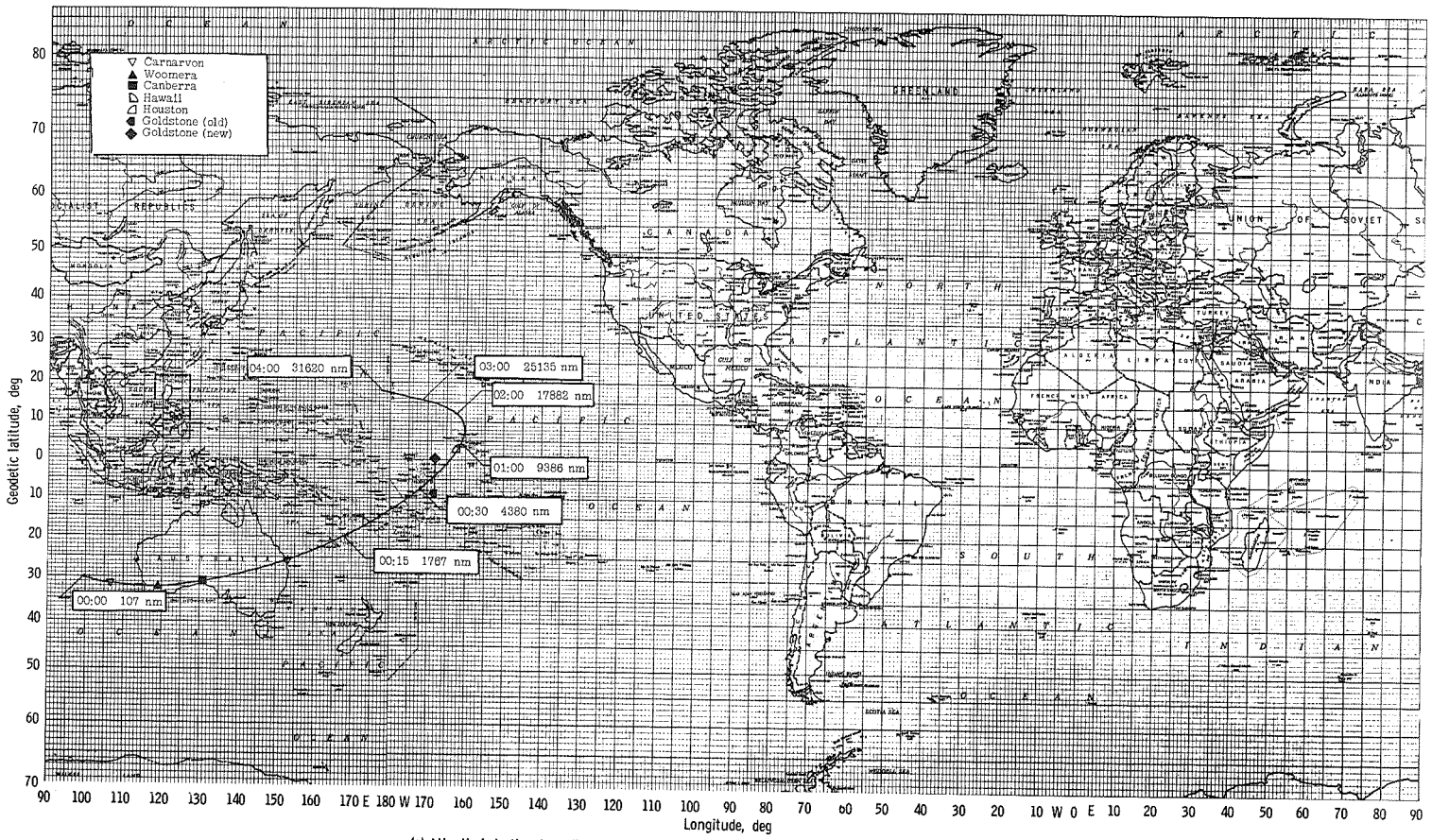
(a) Atlantic injection from first orbit, inclination angle 32°, launch azimuth 74.8°, lunar declination -27.5°.

Figure 14. - Translunar trajectory ground track after injection showing radar coverage.



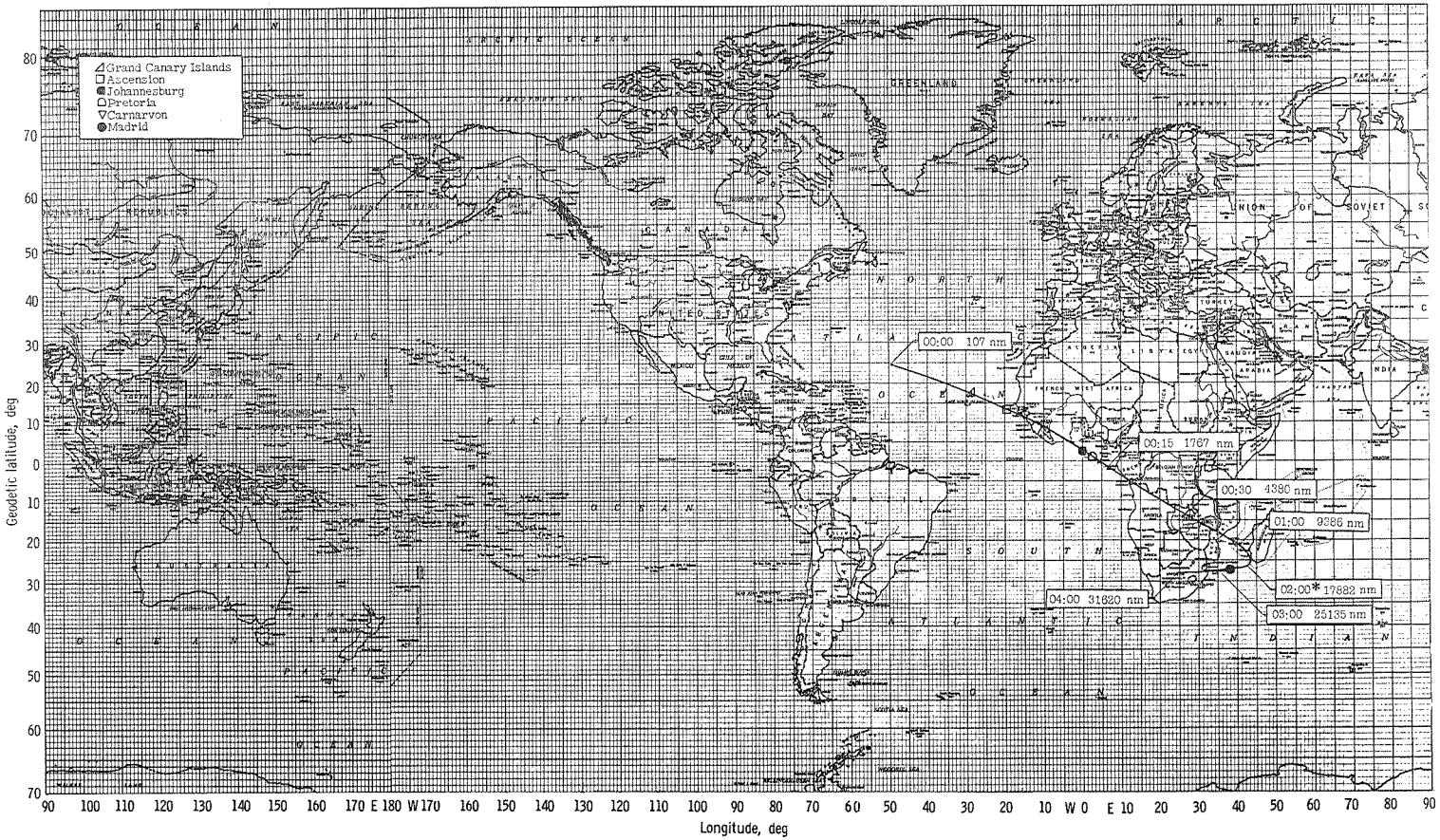
(b) Atlantic injection from first orbit, inclination angle 32°, launch azimuth 74.8°, lunar declination 0°.

Figure 14. - Continued.



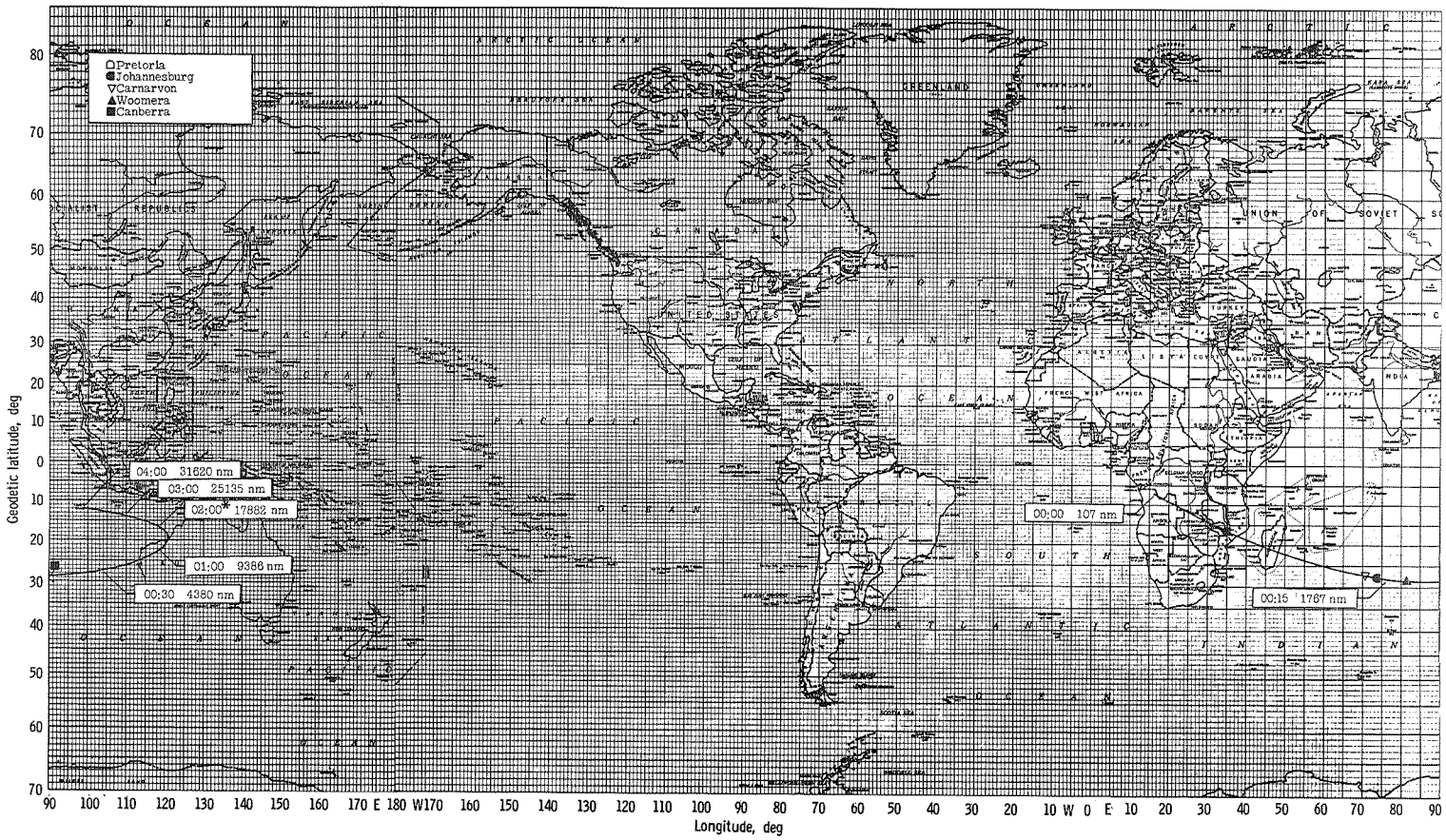
(c) Atlantic injection from first orbit, inclination angle 32°, launch azimuth 74.8°, lunar declination 27.5°.

Figure 14. - Continued.



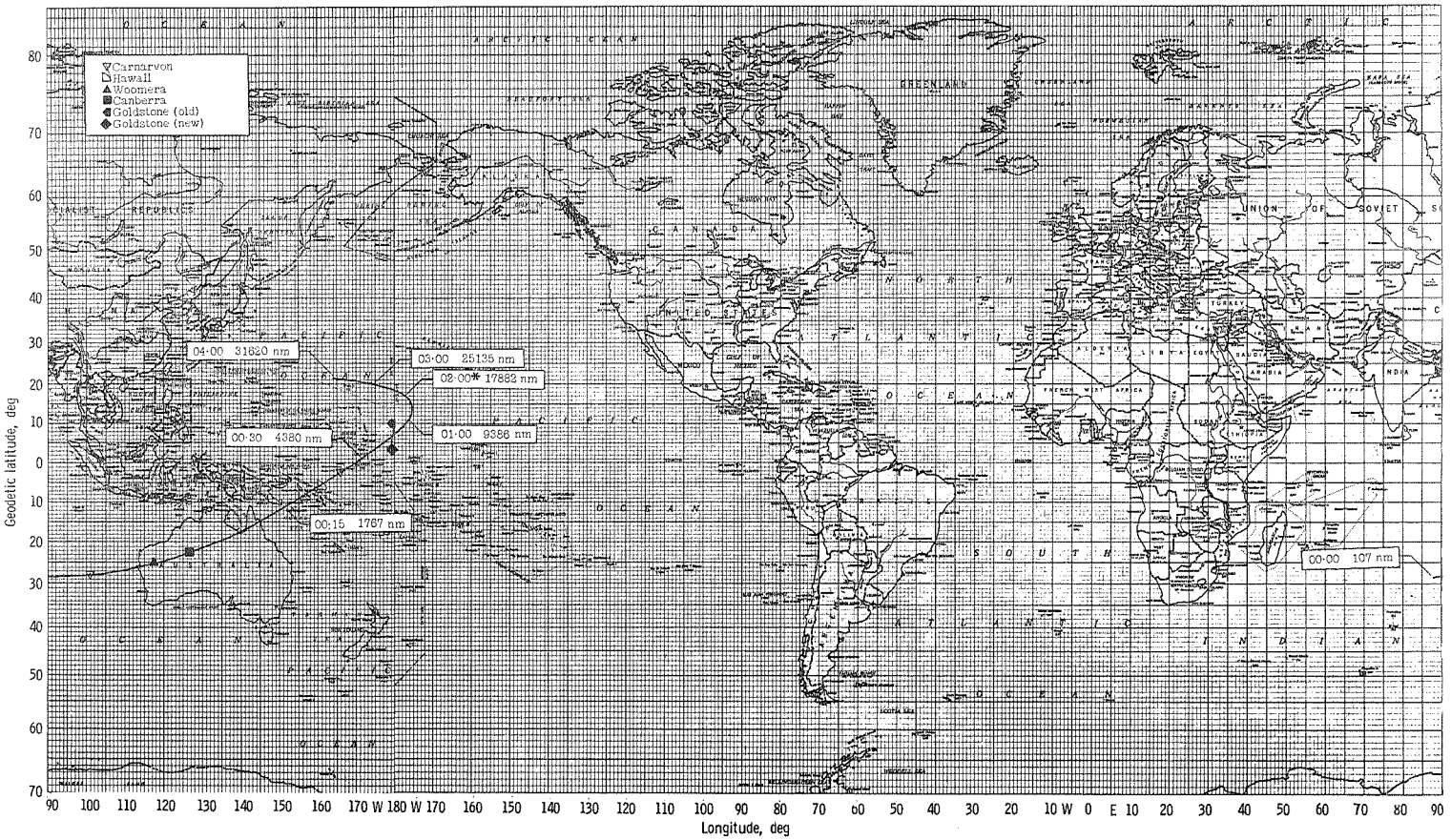
(d) Atlantic injection from first orbit, inclination angle 28.5°, launch azimuth 90°, lunar declination -27.5°.

Figure 14. - Continued.



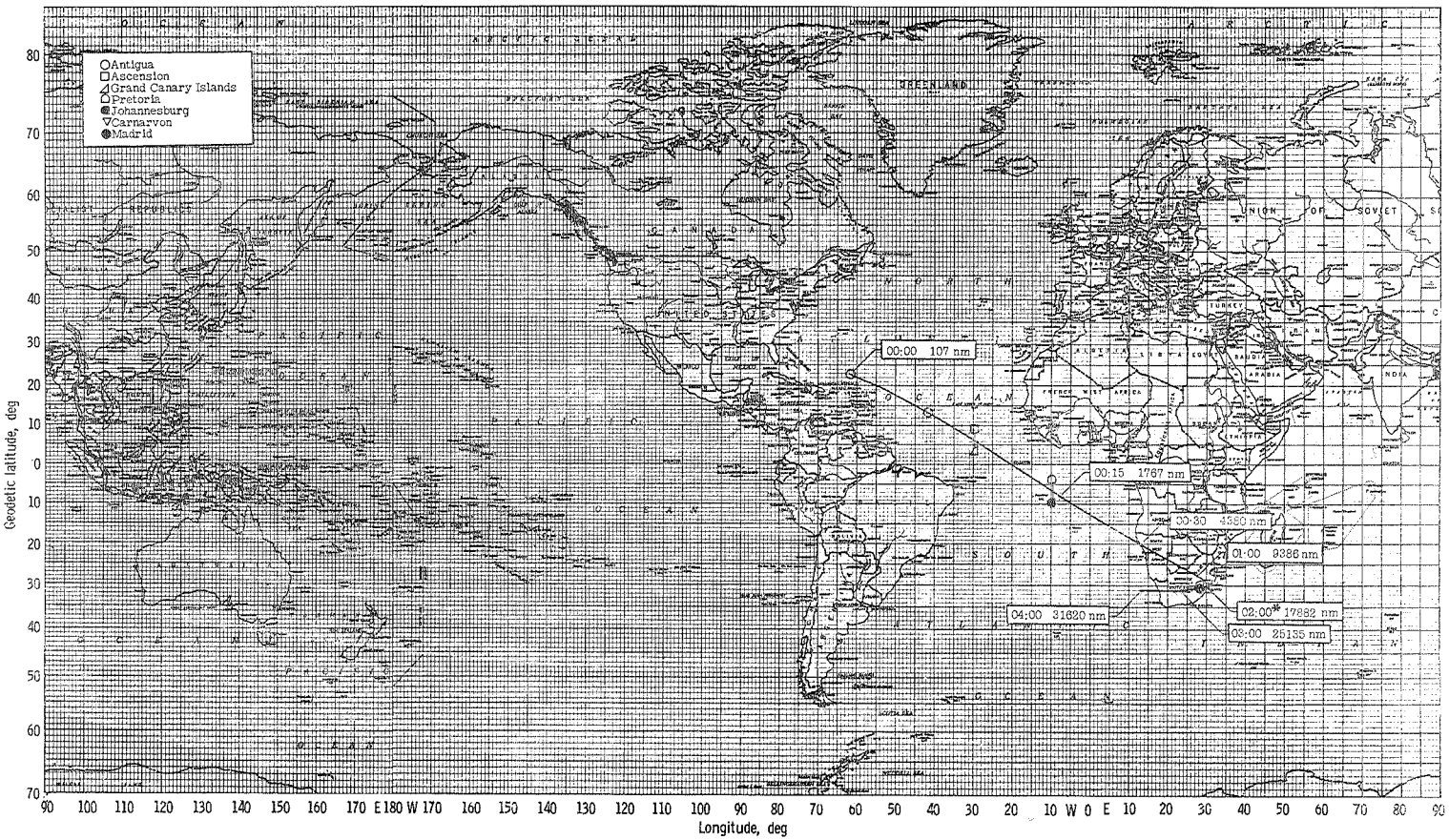
(e) Atlantic injection from first orbit, inclination angle 28.5°, launch azimuth 90°, lunar declination 0°.

Figure 14. - Continued.



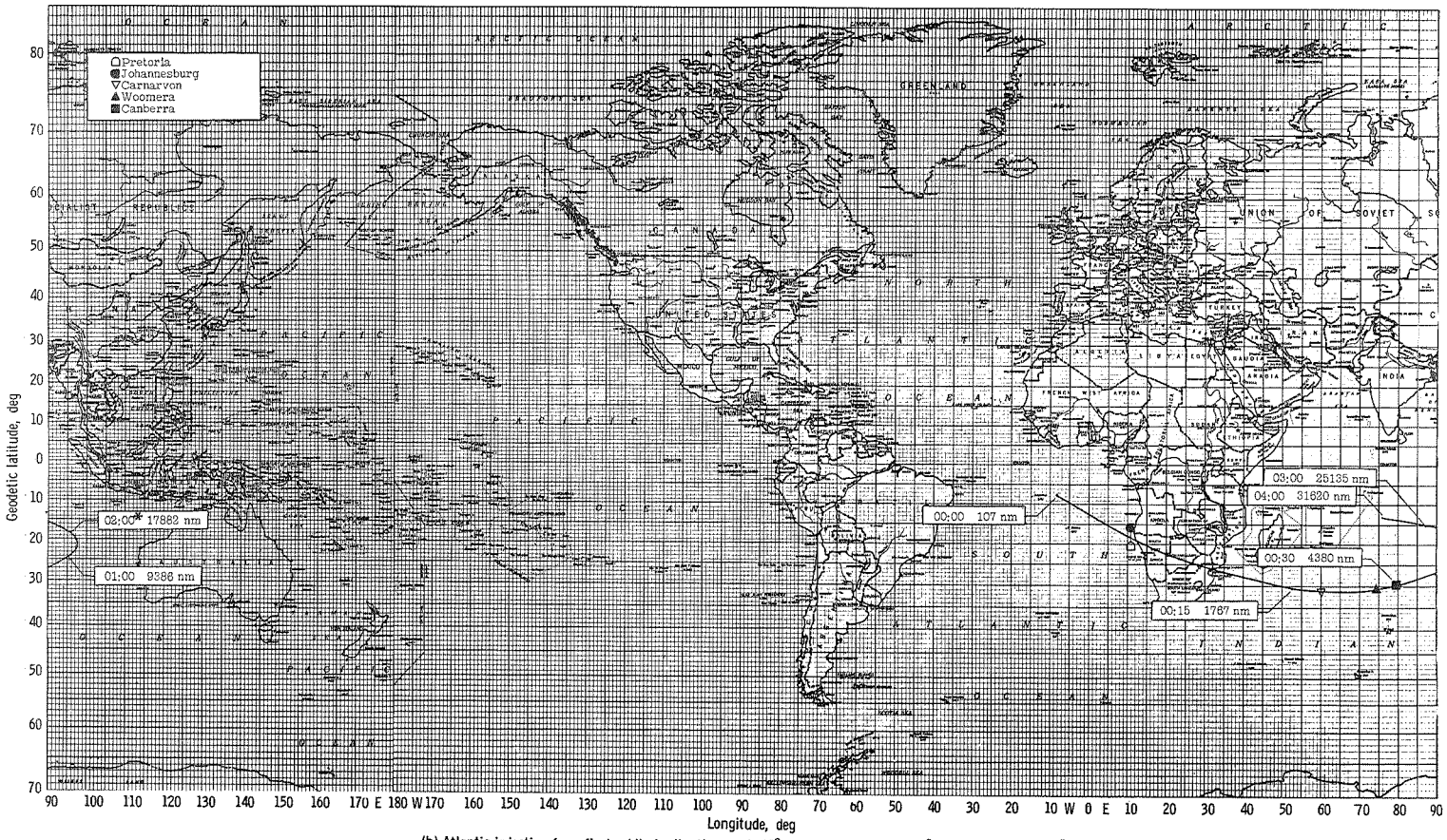
(f) Atlantic injection from first orbit, inclination angle 28.5°, launch azimuth 90°, lunar declination 27.5°.

Figure 14. - Continued.



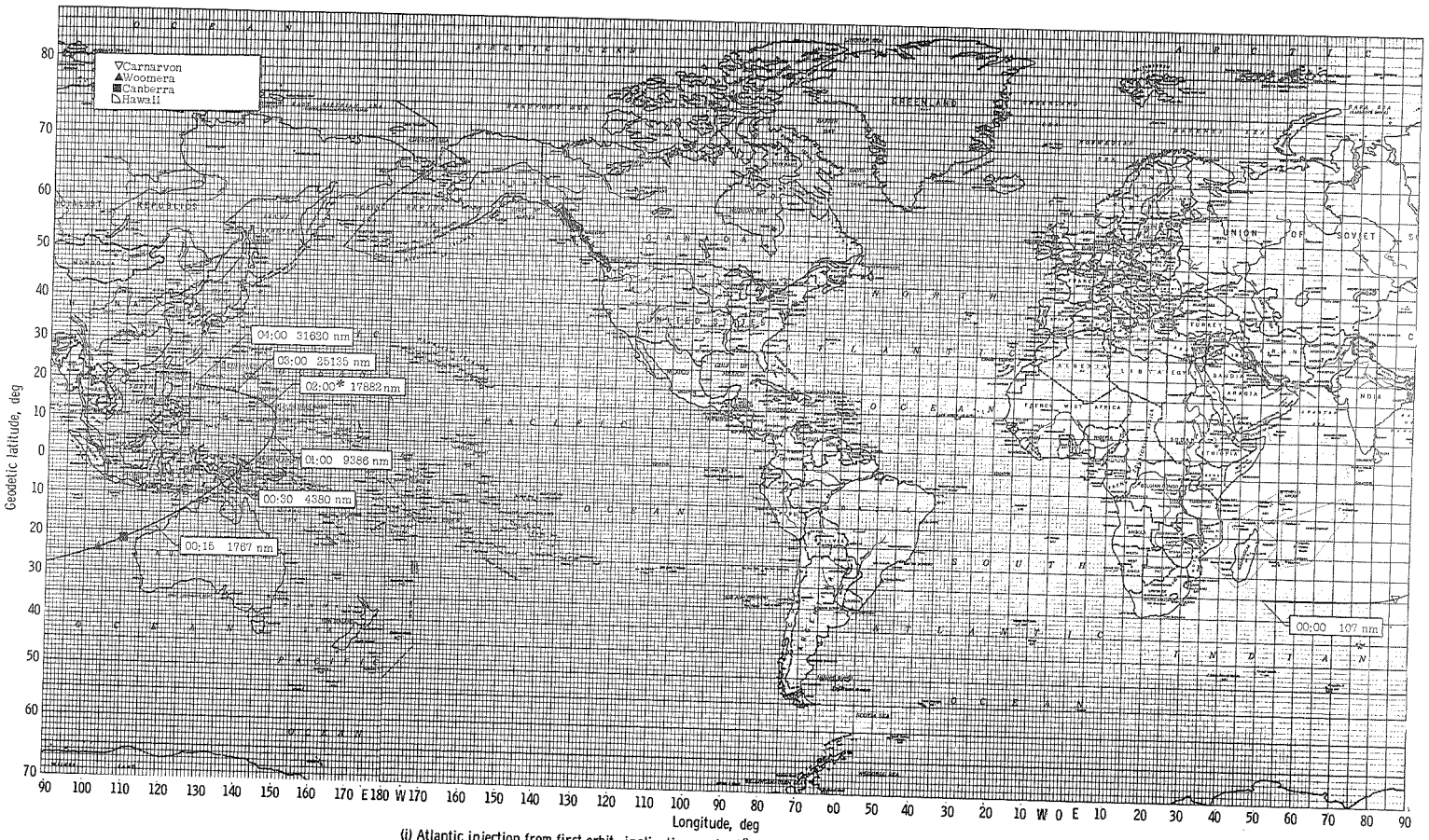
(g) Atlantic injection from first orbit, inclination angle 31°, launch azimuth 102.7°, lunar declination -27.5°.

Figure 14. - Continued.



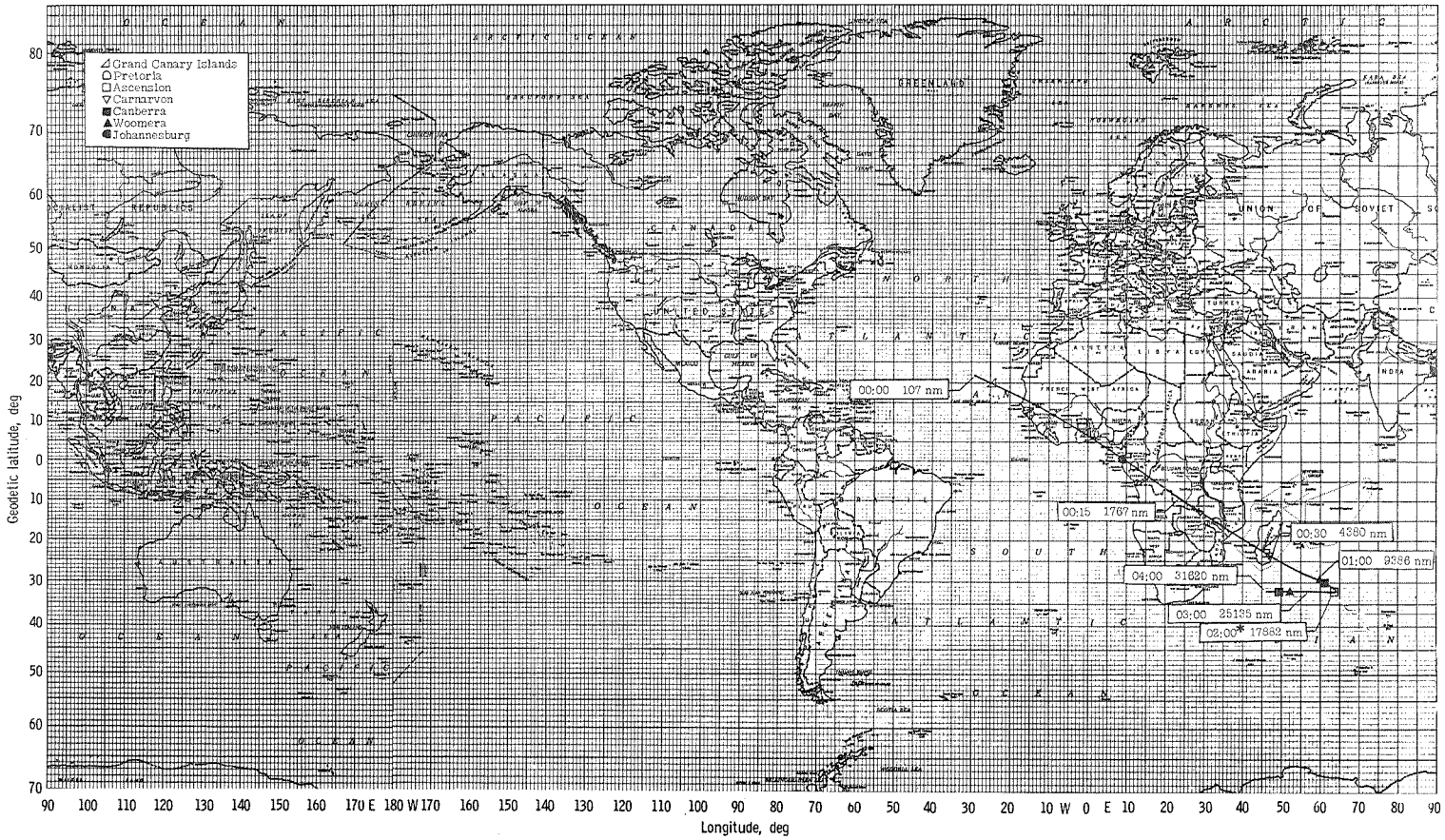
(h) Atlantic injection from first orbit, inclination angle 31°, launch azimuth 102.7°, lunar declination 0°.

Figure 14. - Continued.



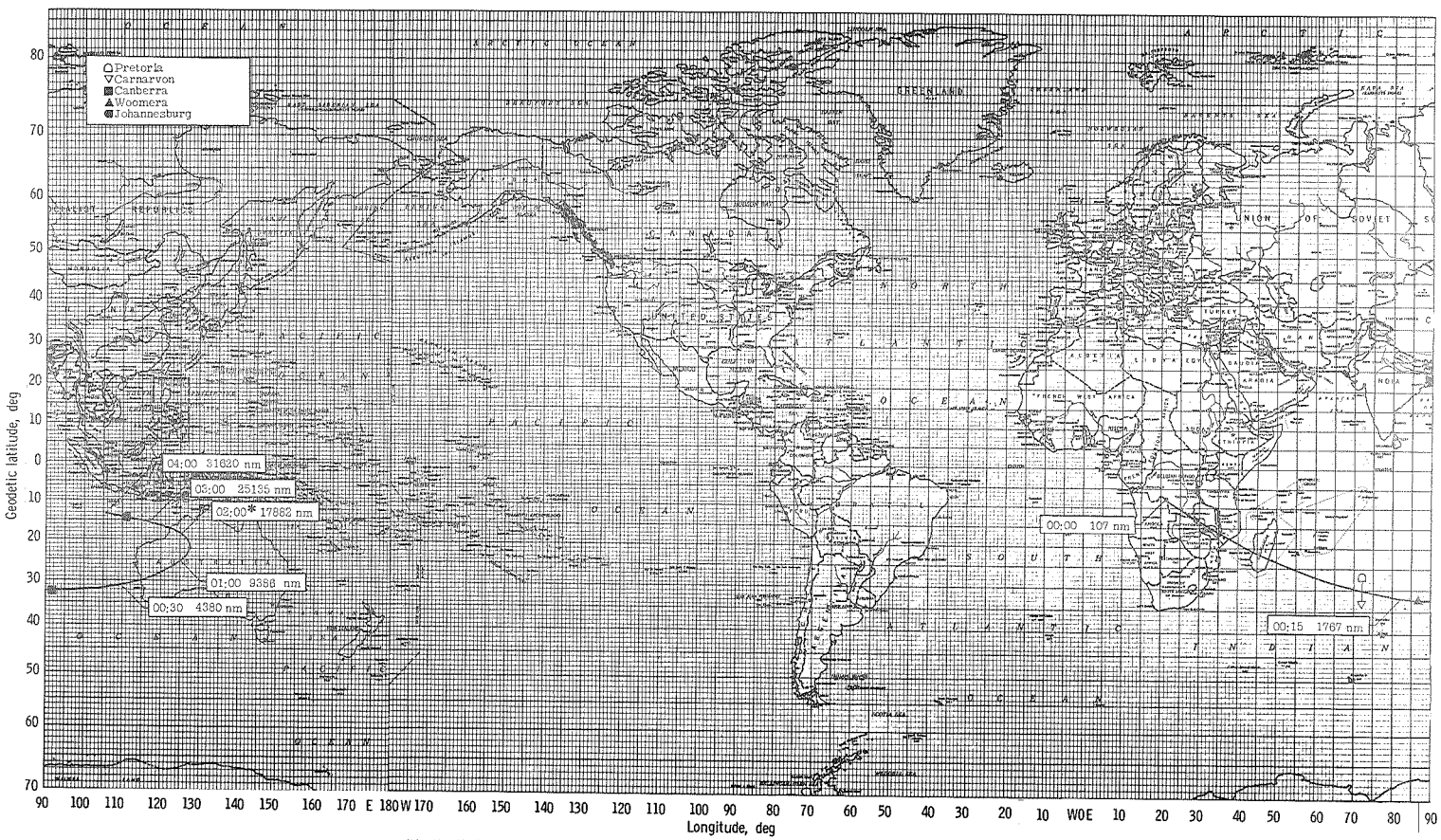
(i) Atlantic injection from first orbit, inclination angle 31°, launch azimuth 102.7°, lunar declination 27.5°.

Figure 14. - Continued.



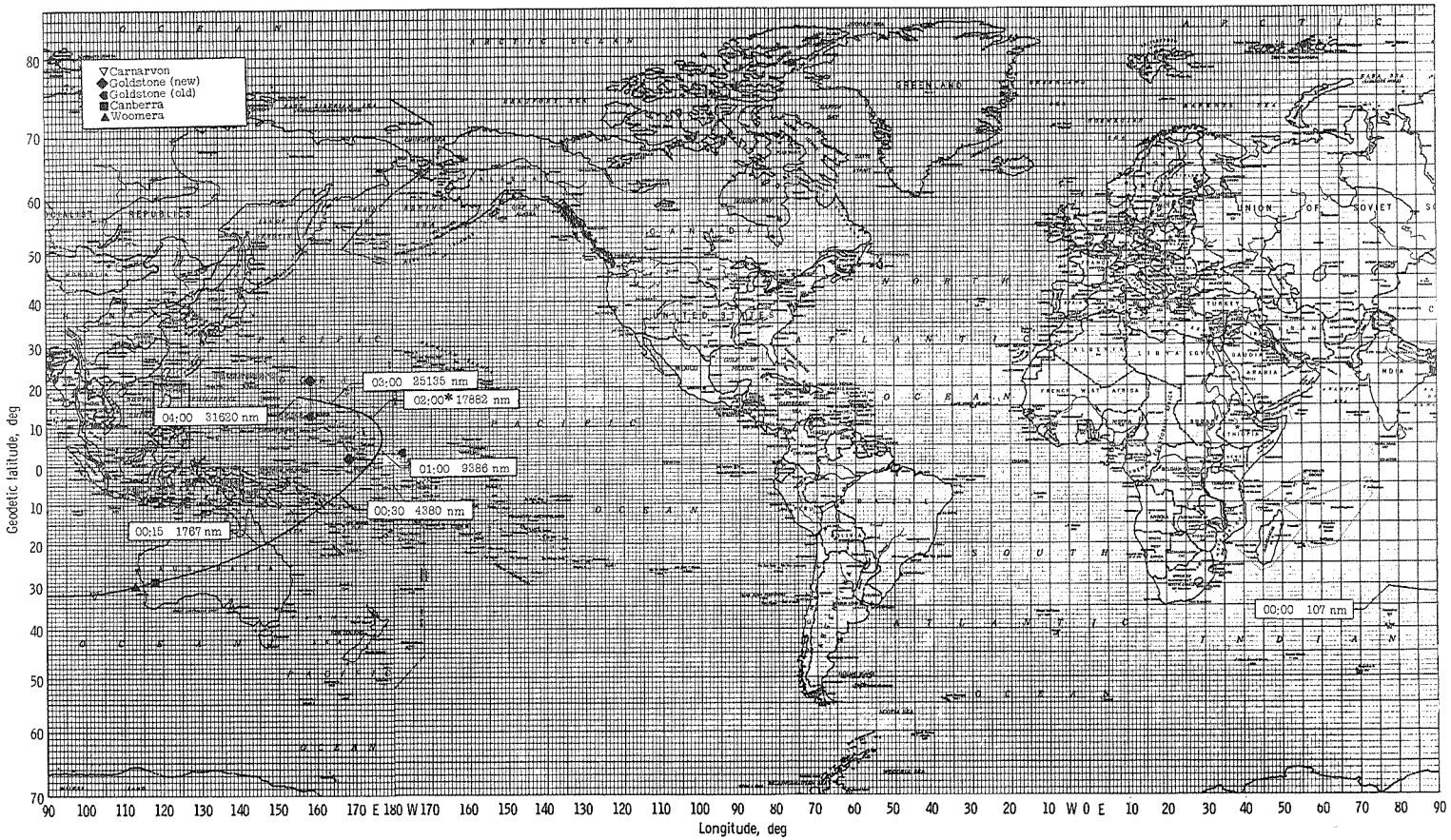
(j) Atlantic injection from second orbit, inclination angle 32°, launch azimuth 74.8°, lunar declination -27.5°.

Figure 14. - Continued.



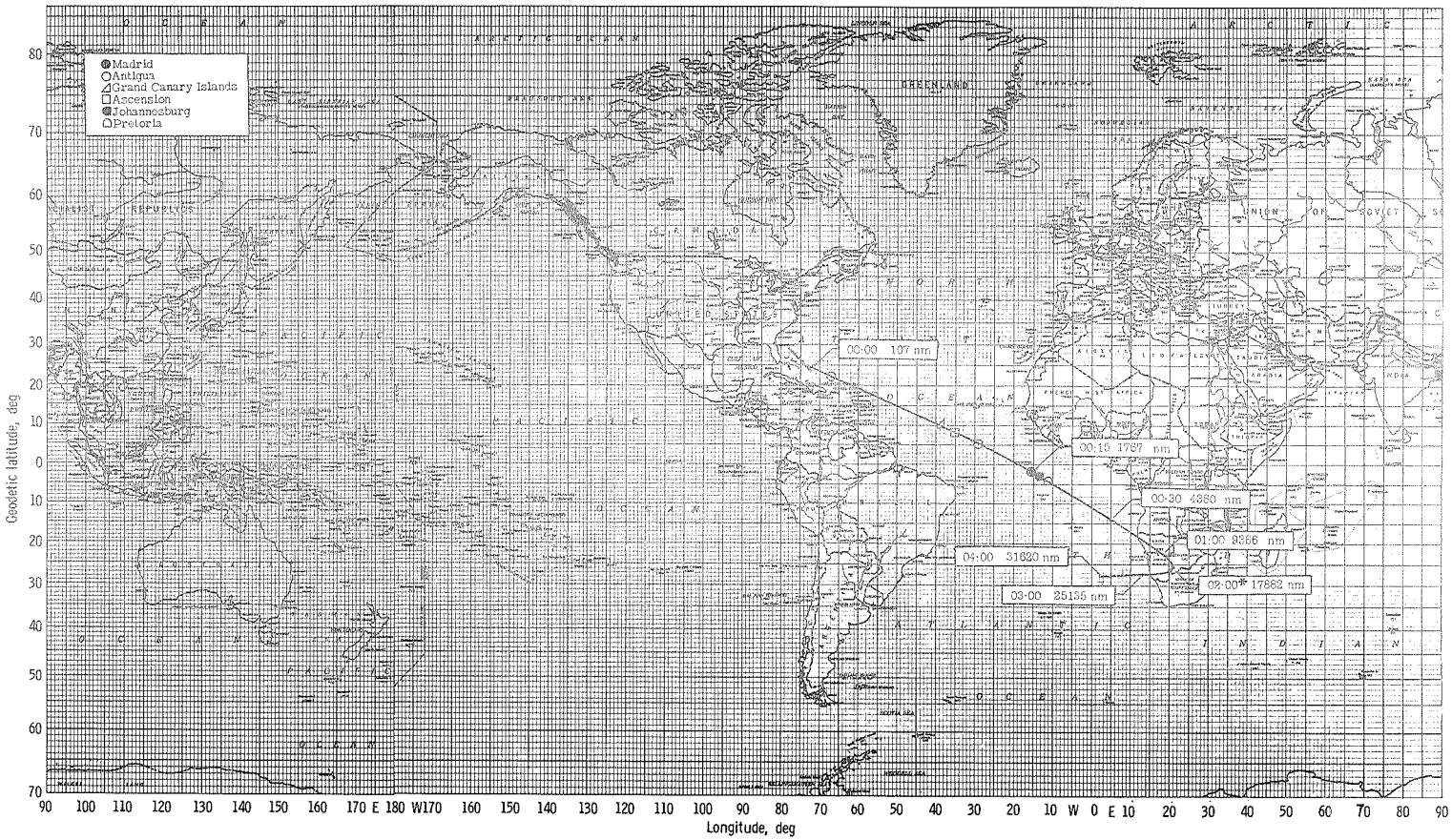
(k) Atlantic injection from second orbit, inclination angle 32°, launch azimuth 74.8°, lunar declination 0°.

Figure 14. - Continued.



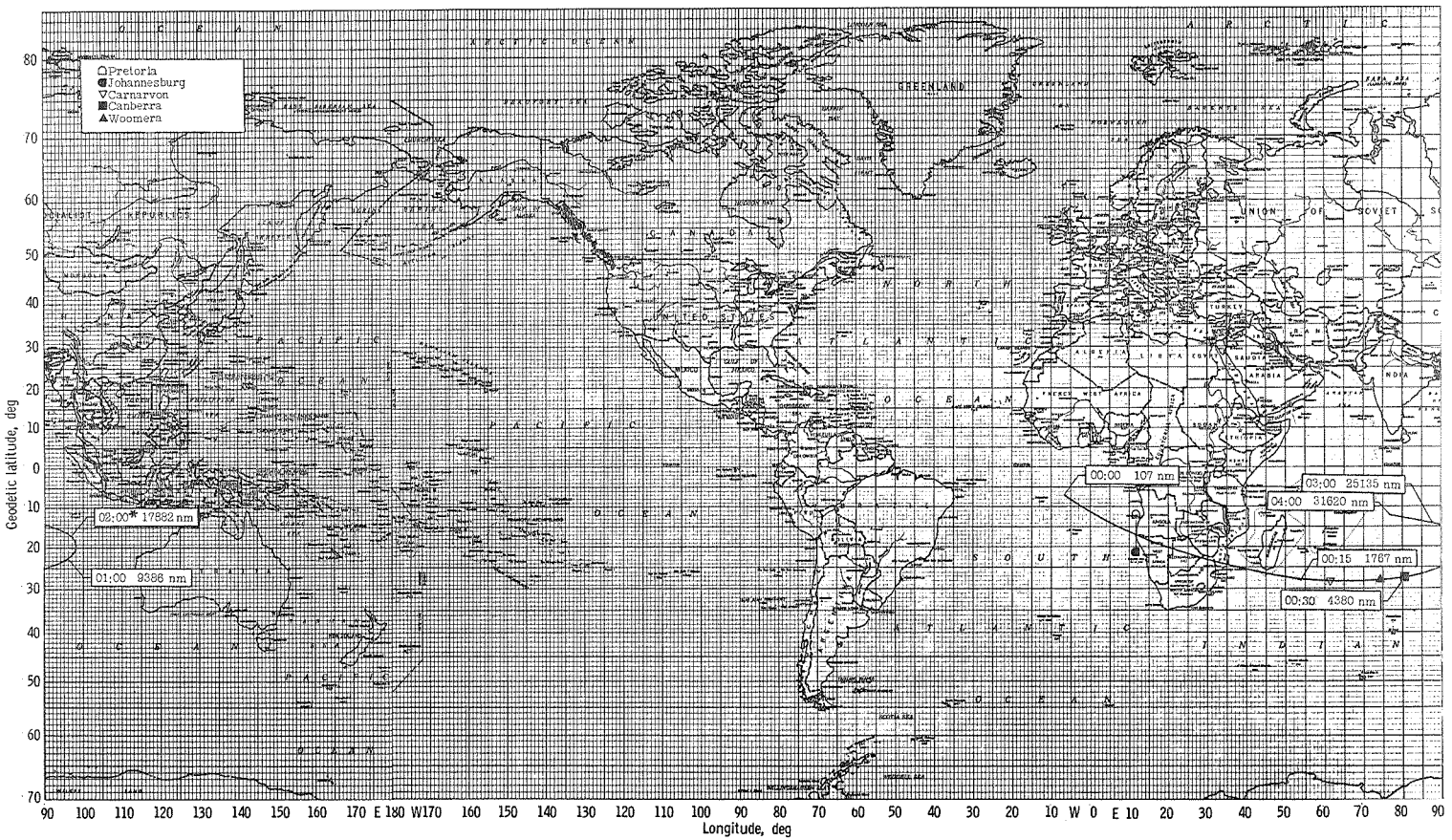
(l) Atlantic injection from second orbit, inclination angle 32°, launch azimuth 74.8°, lunar declination 27.5°.

Figure 14. - Continued.



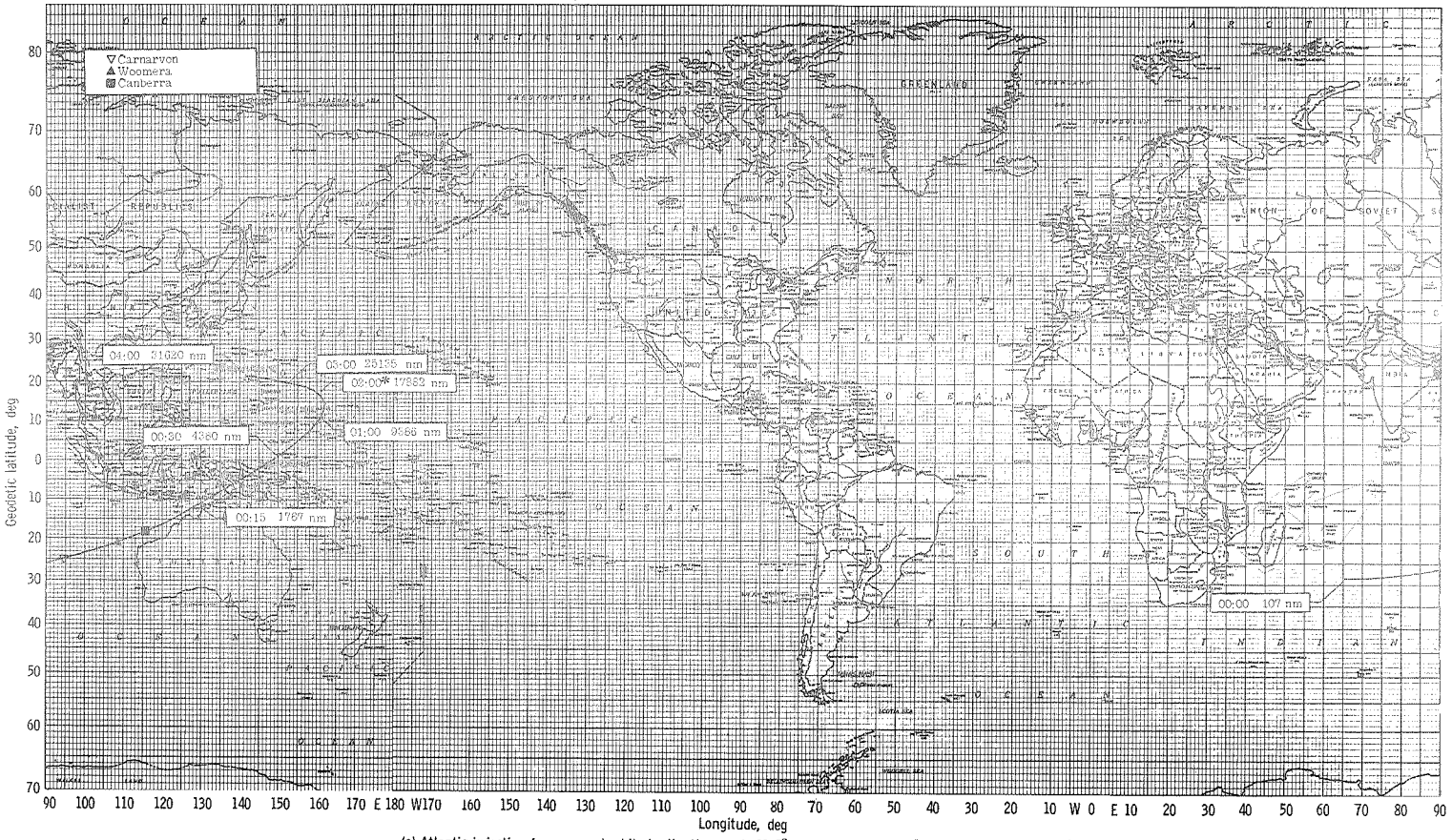
(m) Atlantic injection from second orbit, inclination angle 28.5°, launch azimuth 90°, lunar declination -27.5°.

Figure 14. - Continued.



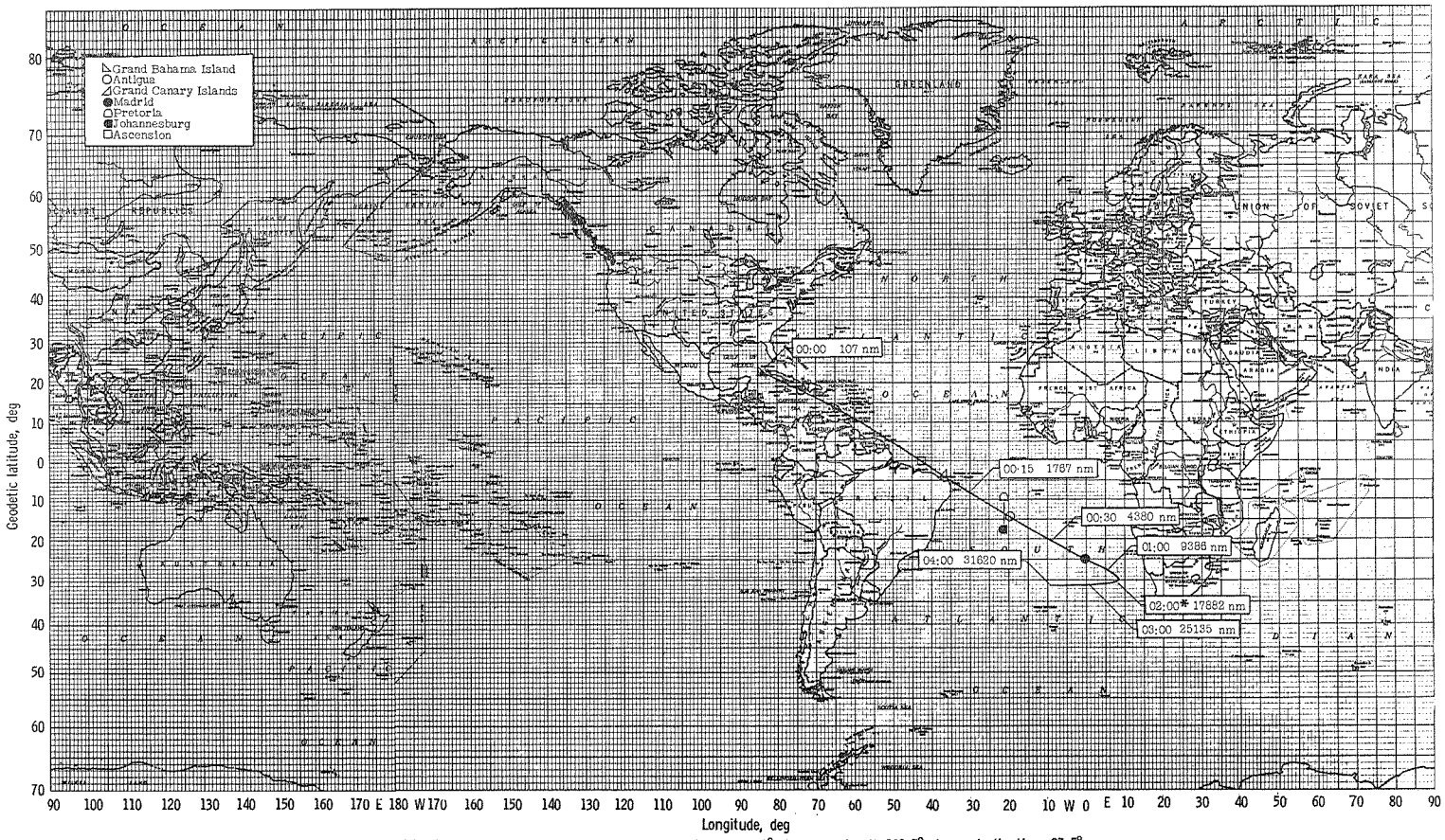
(n) Atlantic injection from second orbit, inclination angle 28.5°, launch azimuth 90°, lunar declination 0°.

Figure 14. - Continued.



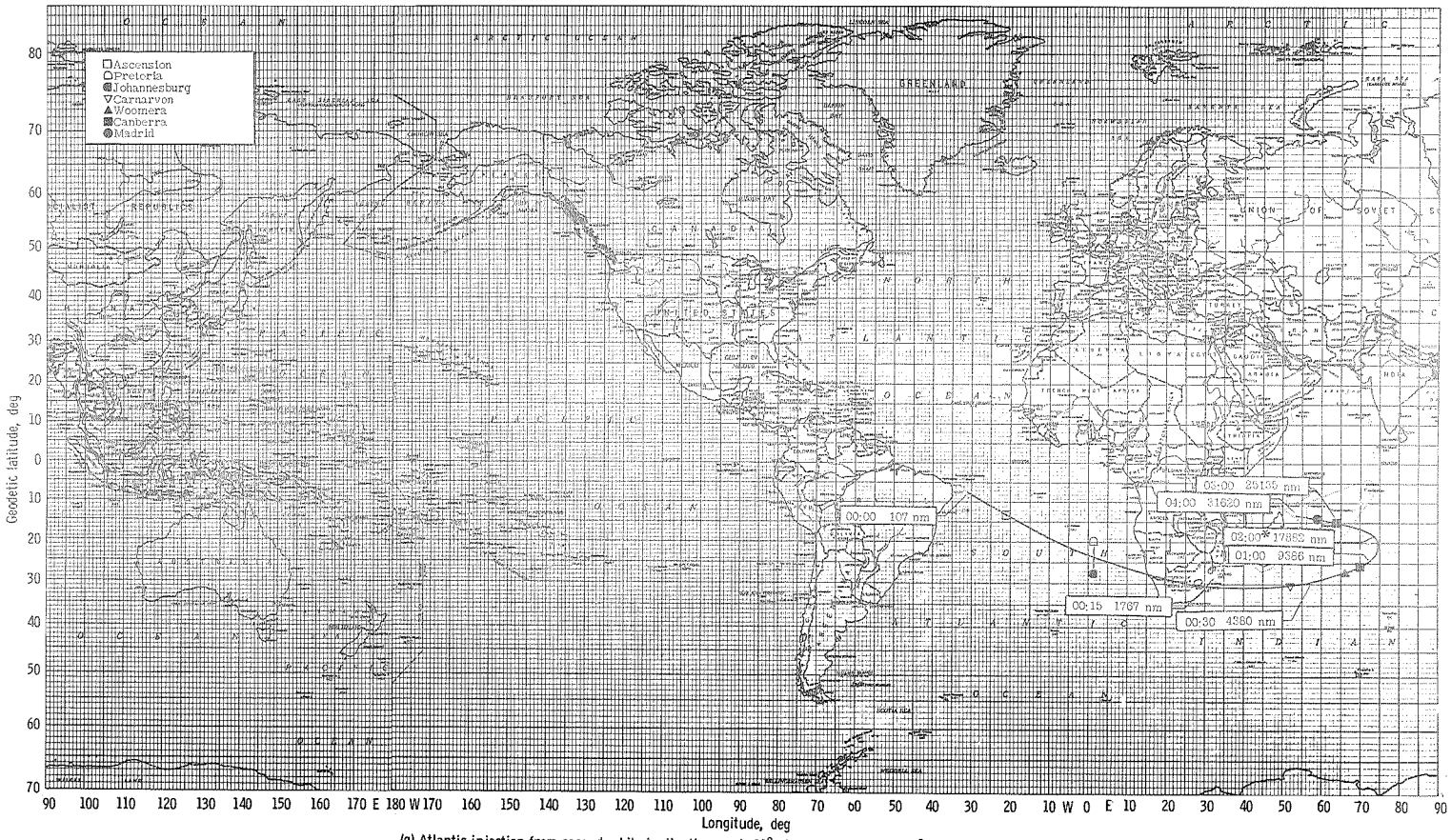
(o) Atlantic injection from second orbit, inclination angle 28.5°, launch azimuth 90°, lunar declination 27.5°.

Figure 14. - Continued.



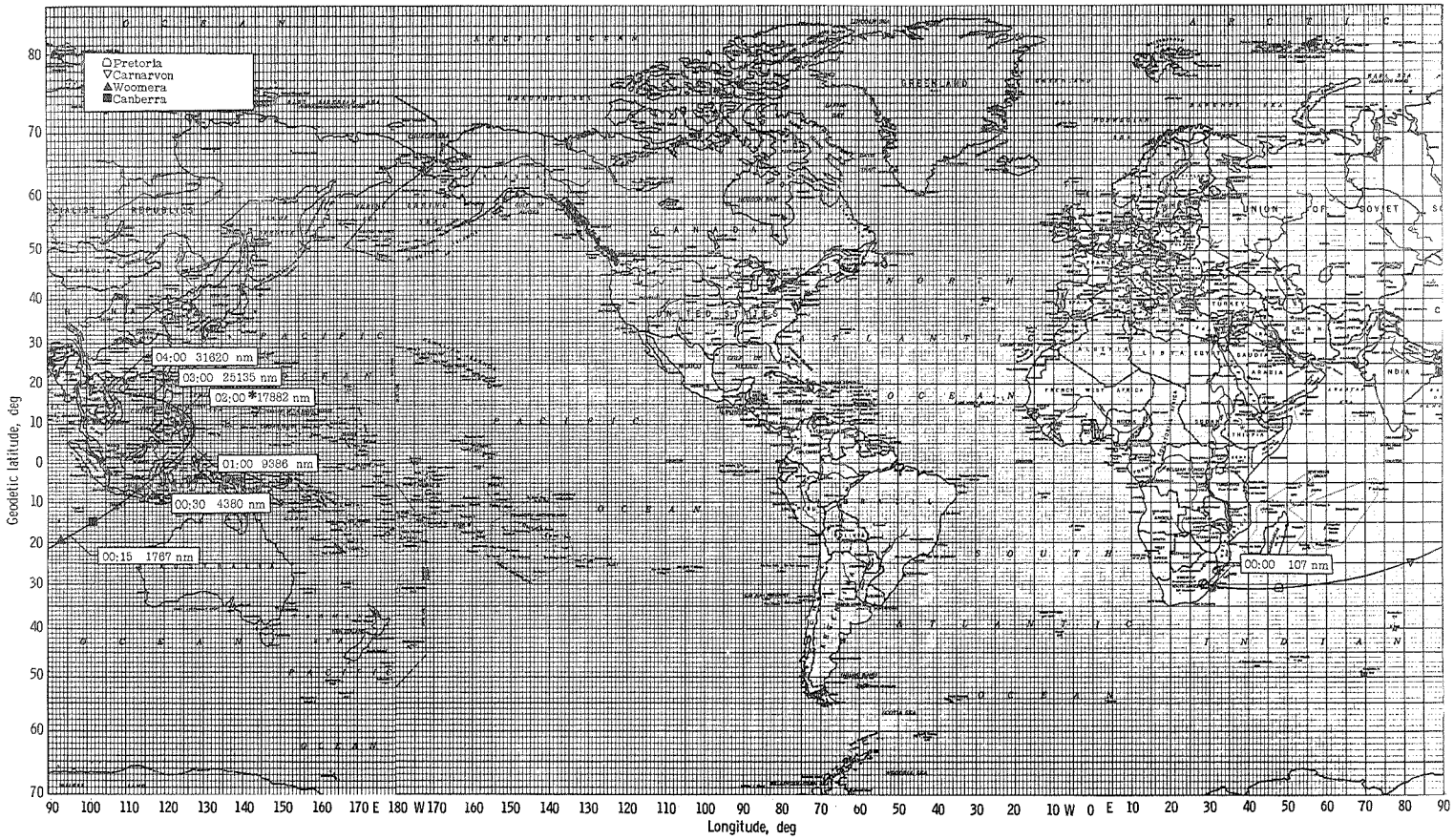
(p) Atlantic injection from second orbit, inclination angle 31°, launch azimuth 102.7°, lunar declination -27.5°.

Figure 14. - Continued.



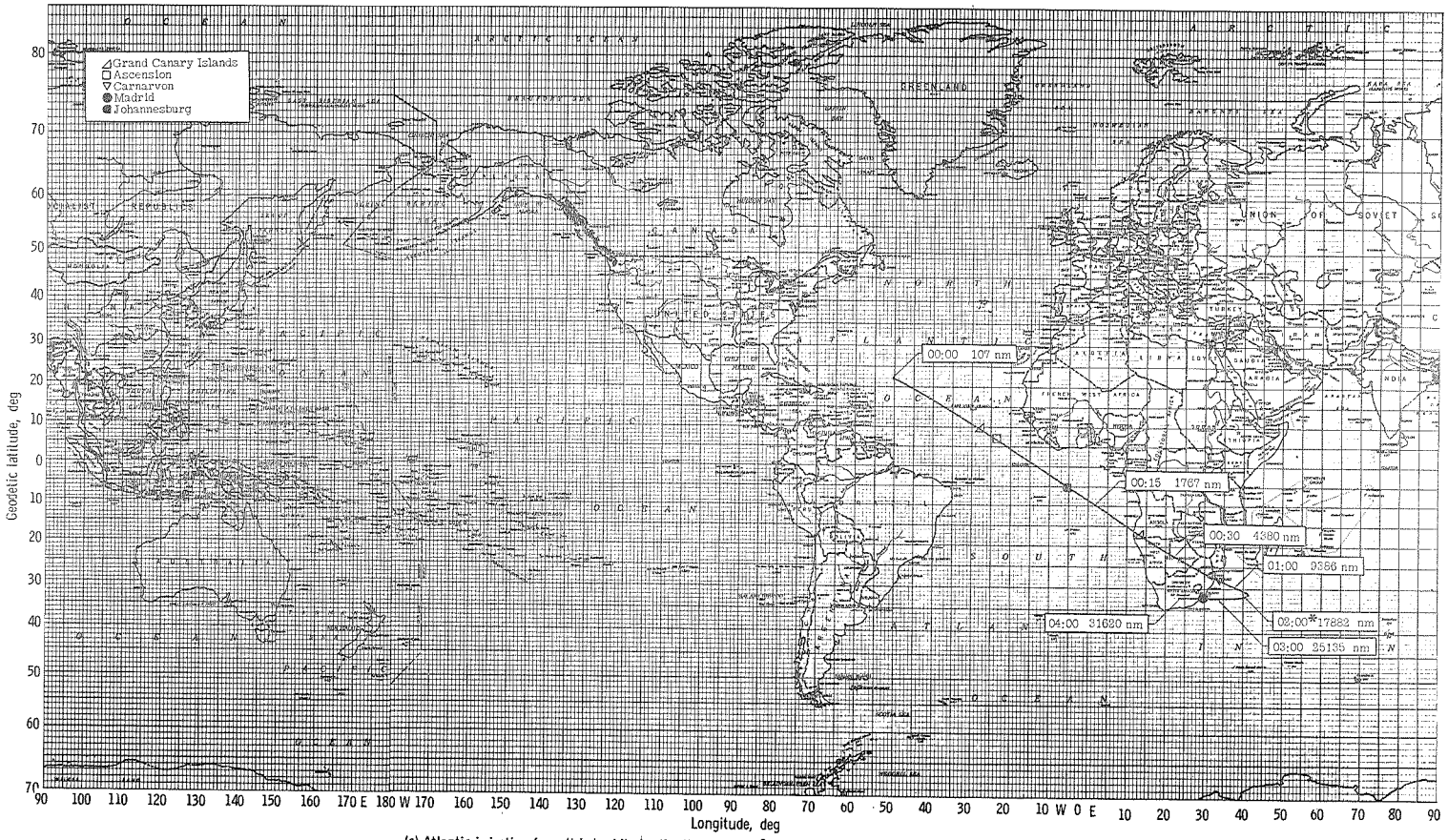
(q) Atlantic injection from second orbit, inclination angle 31°, launch azimuth 102.7°, lunar declination 0°.

Figure 14. - Continued.



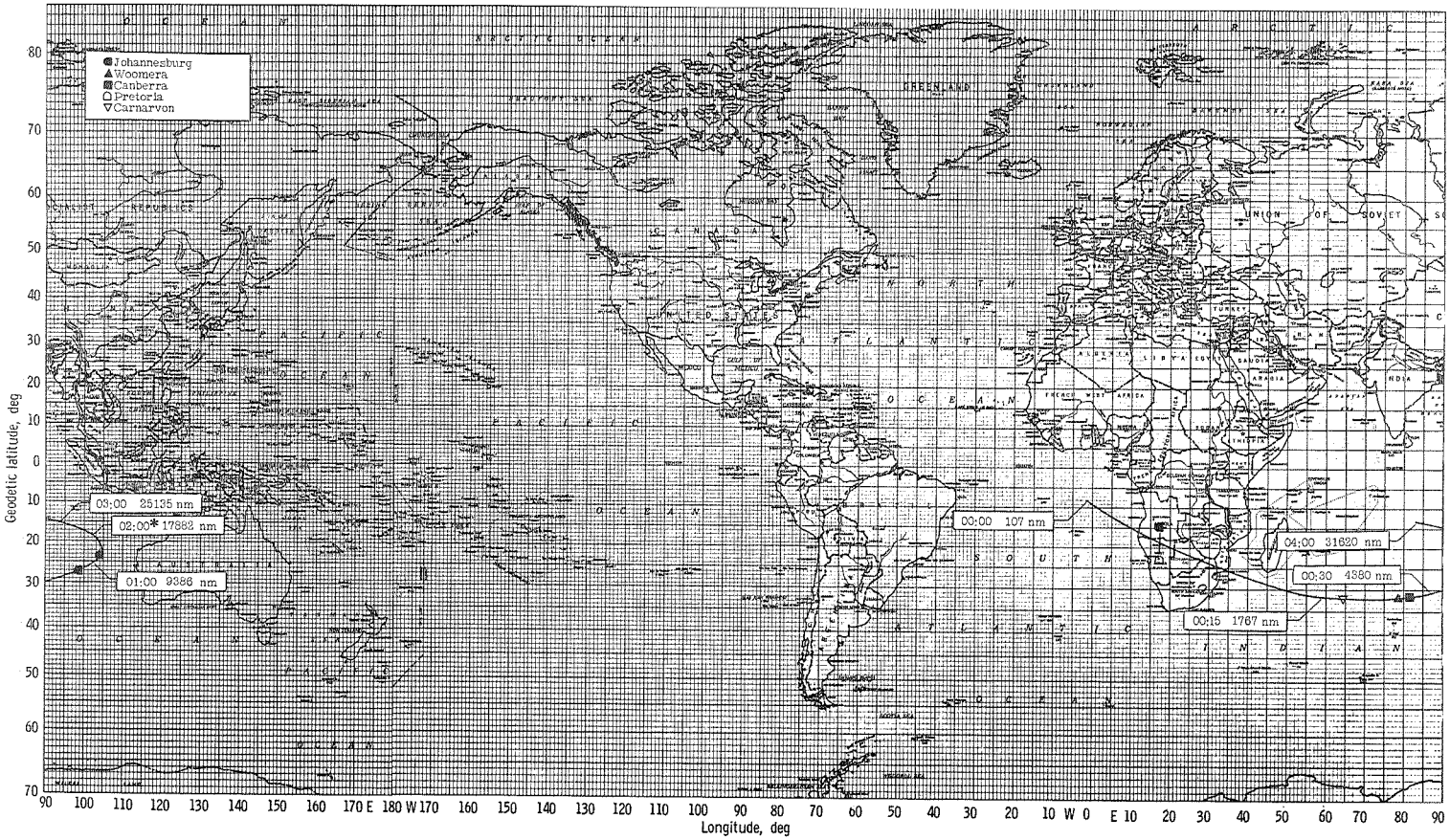
(r) Atlantic injection from second orbit, inclination angle 31°, launch azimuth 102.7°, lunar declination 27.5°.

Figure 14. - Continued.



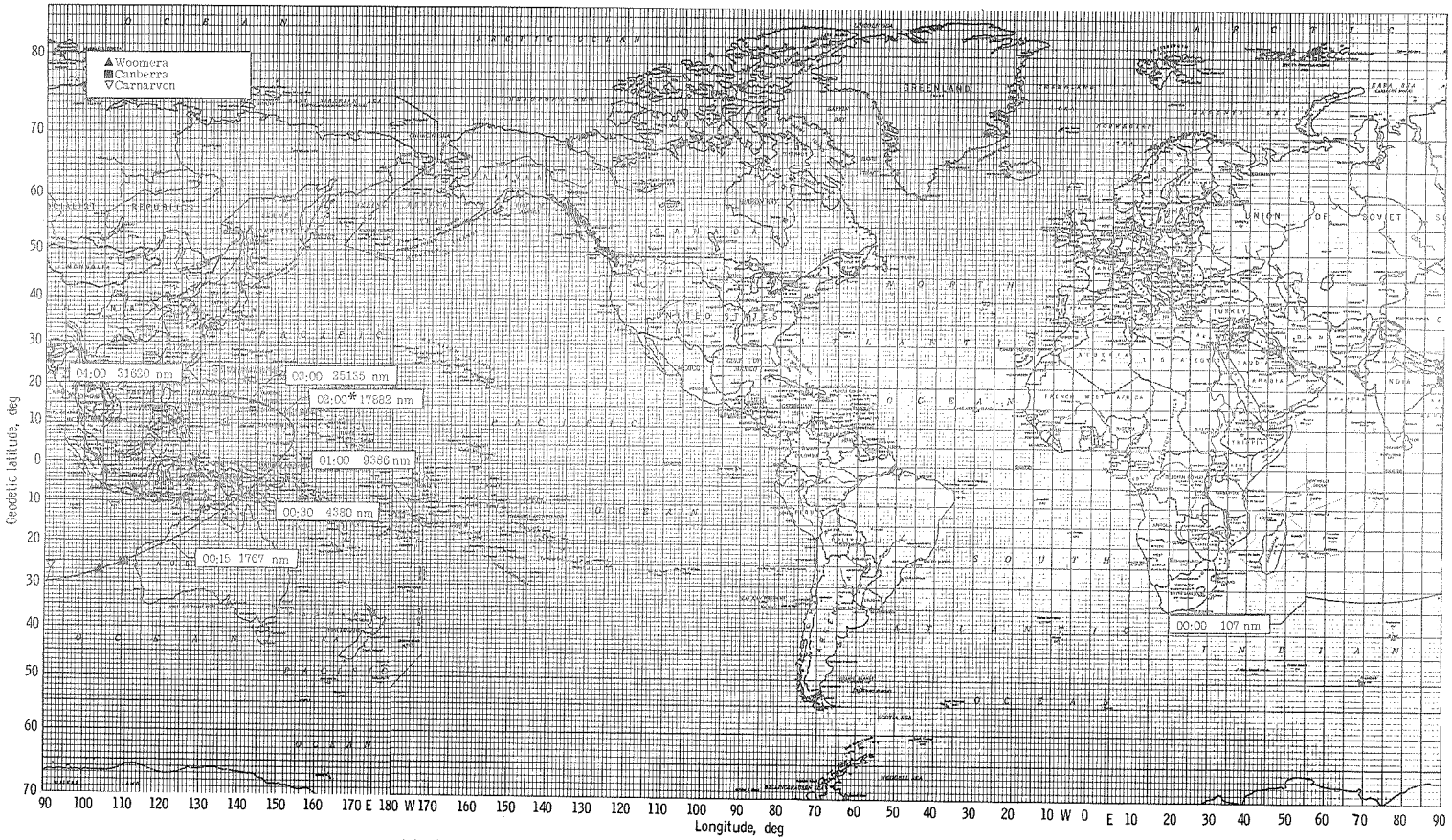
(s) Atlantic injection from third orbit, inclination angle 32°, launch azimuth 74.8°, lunar declination -27.5°.

Figure 14. - Continued.



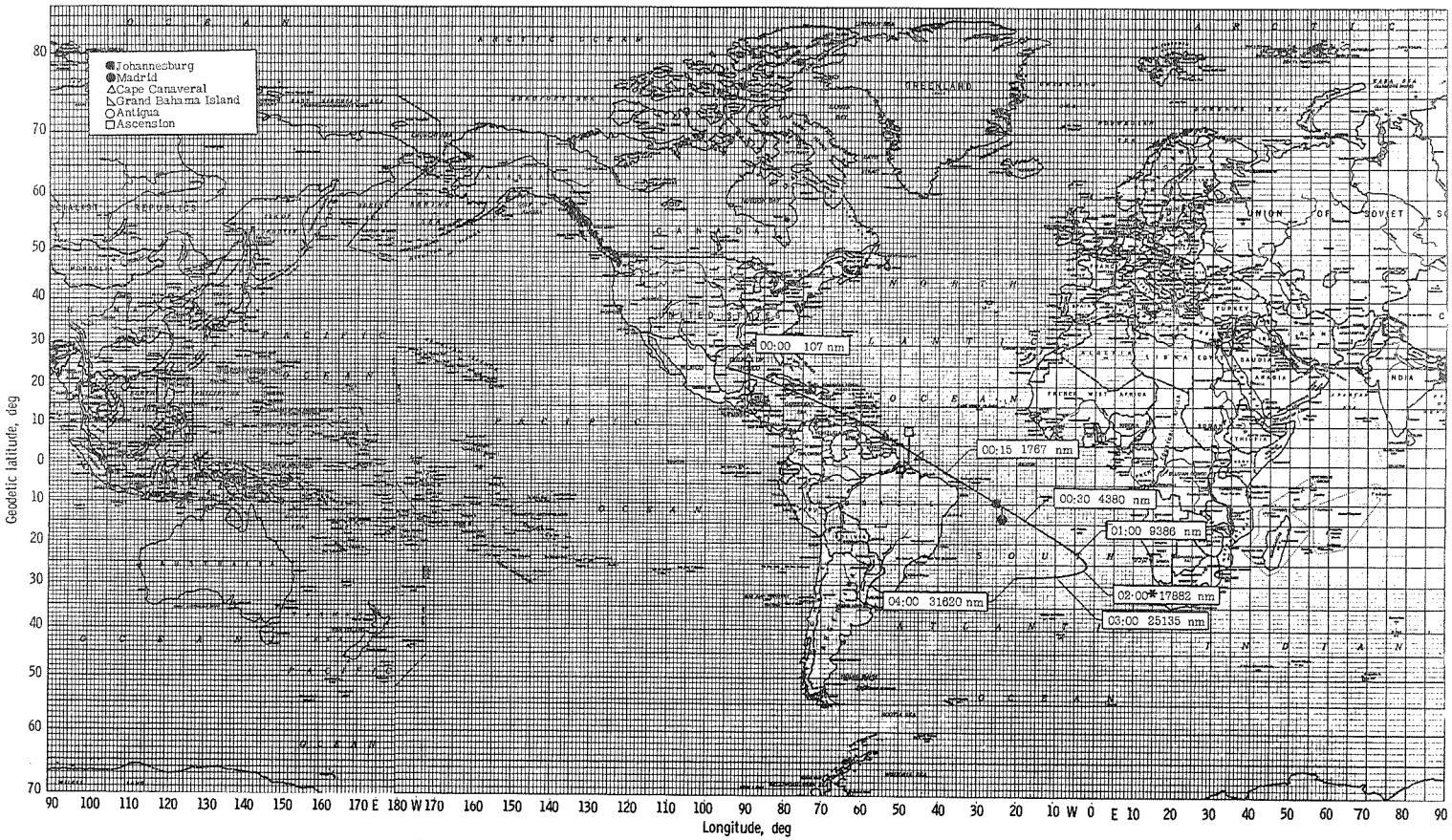
(t) Atlantic injection from third orbit, inclination angle 32°, launch azimuth 74.8°, lunar declination 0°.

Figure 14. - Continued.



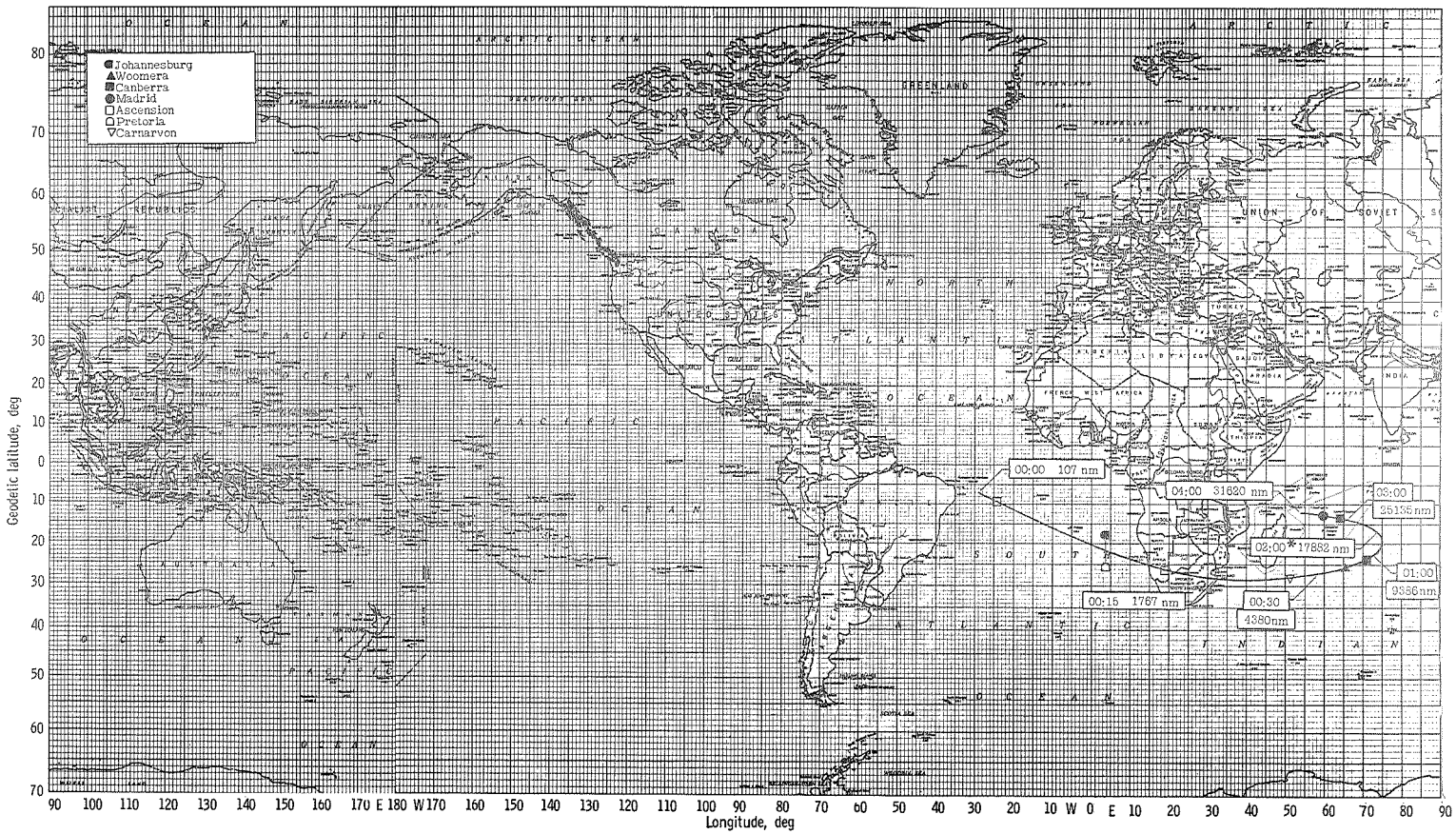
(u) Atlantic injection from third orbit, inclination angle 32°, launch azimuth 74.8°, lunar declination 27.5°.

Figure 14. - Continued.



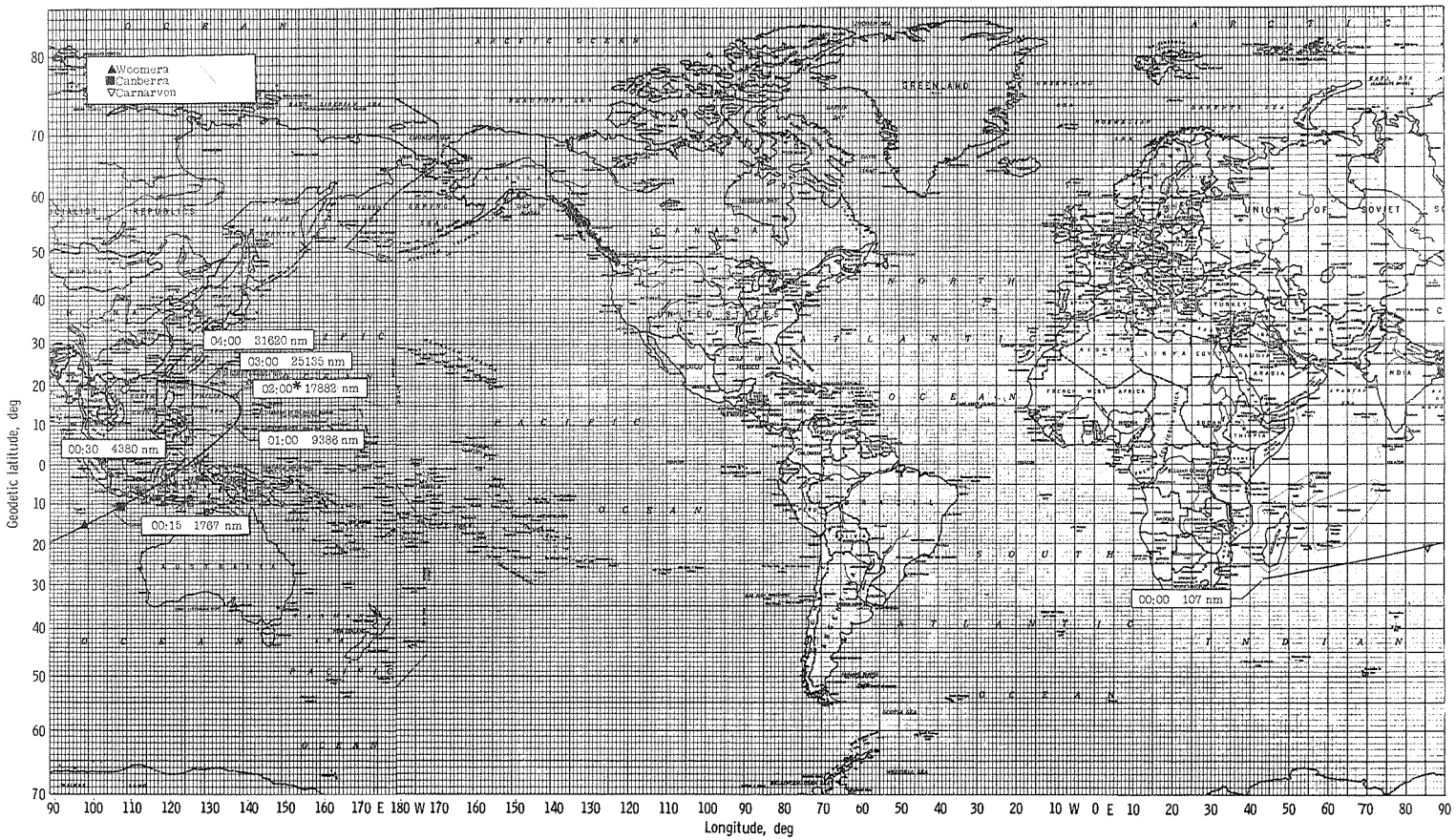
(v) Atlantic injection from third orbit, inclination angle 28.5°, launch azimuth 90°, lunar declination -27.5°.

Figure 14. - Continued.



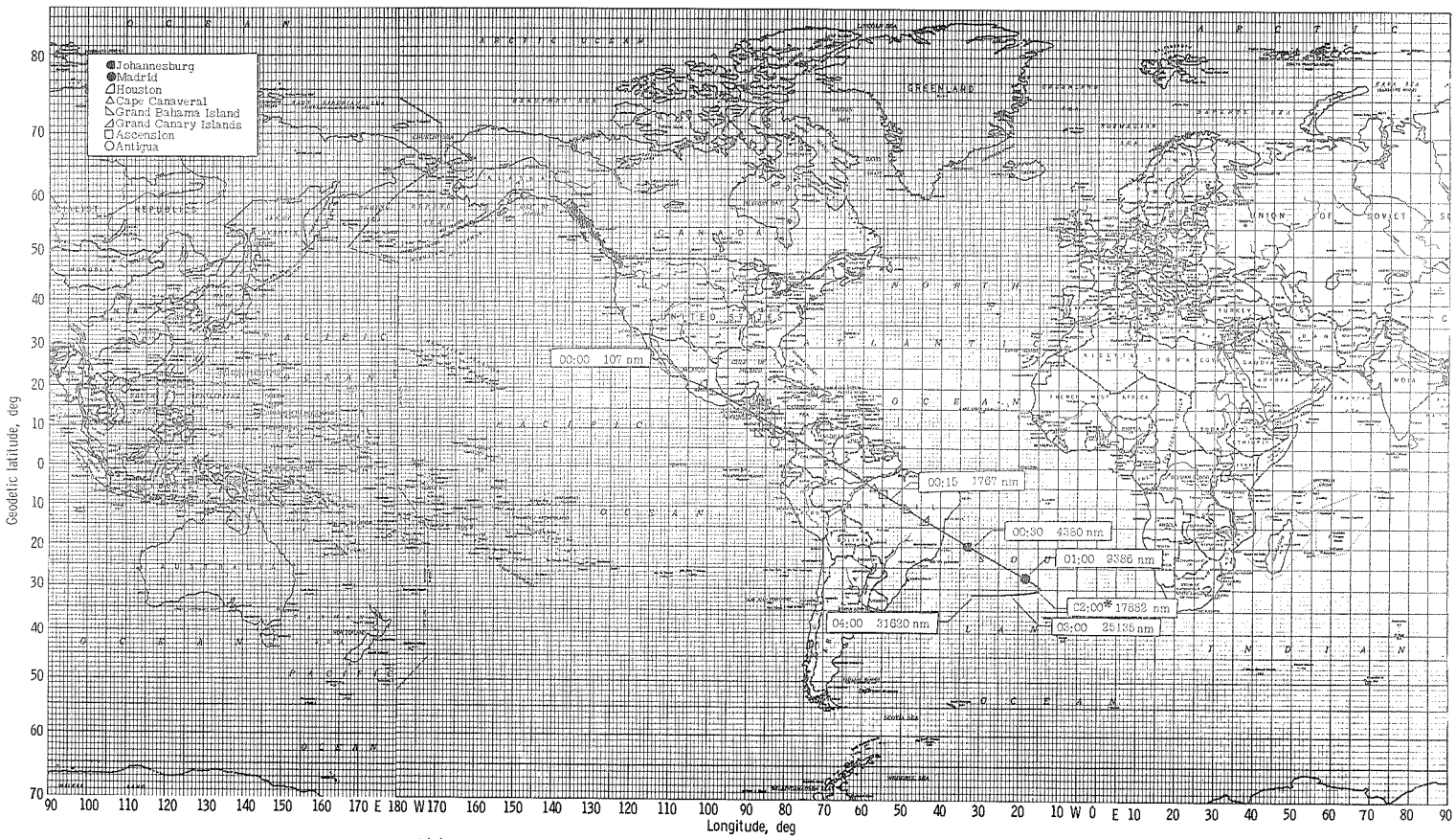
(w) Atlantic injection from third orbit, inclination angle 28.5°, launch azimuth 90°, lunar declination 0°.

Figure 14. - Continued.



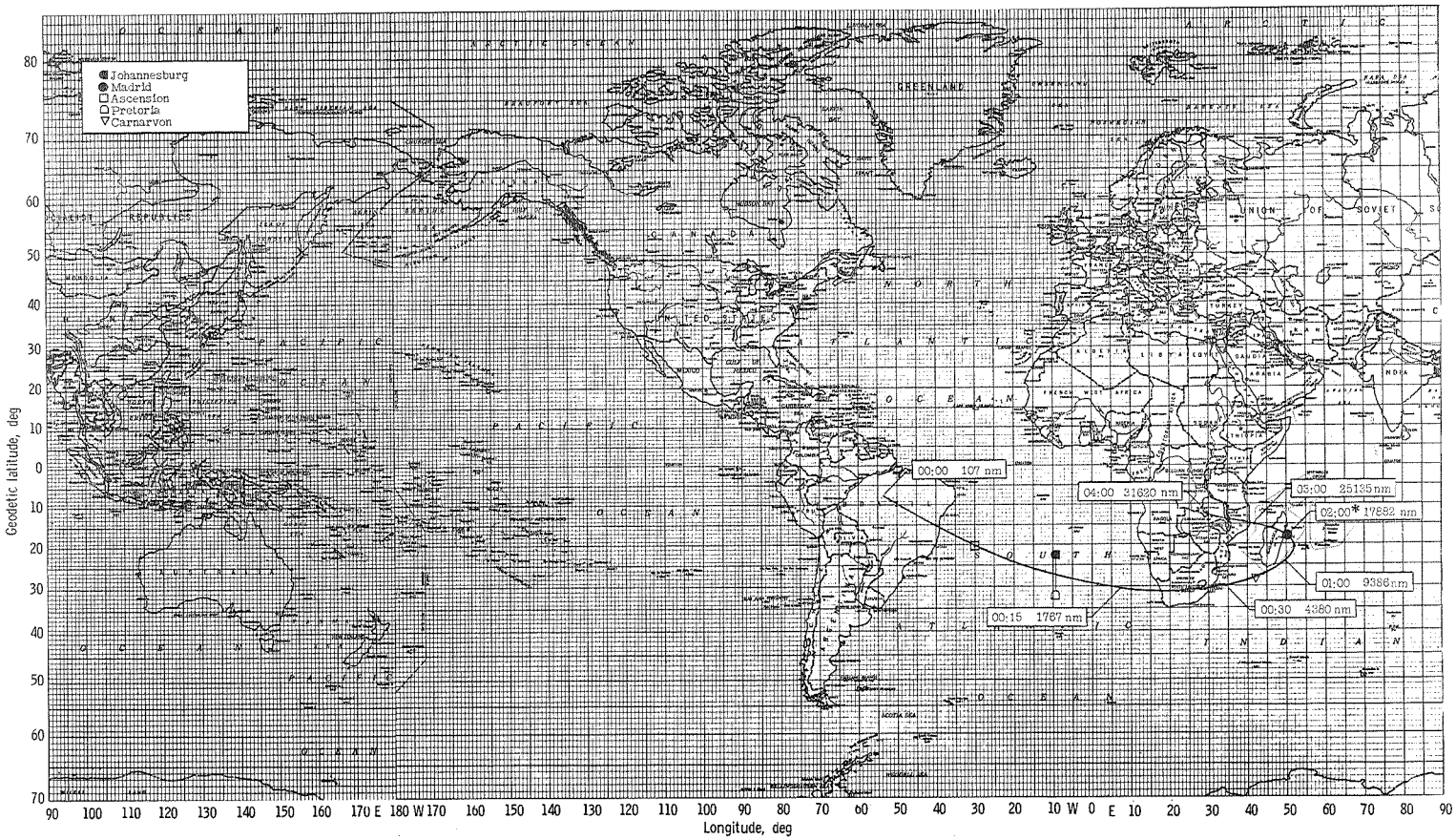
(x) Atlantic injection from third orbit, inclination angle 28.5°, launch azimuth 90°, lunar declination 27.5°.

Figure 14. - Continued.



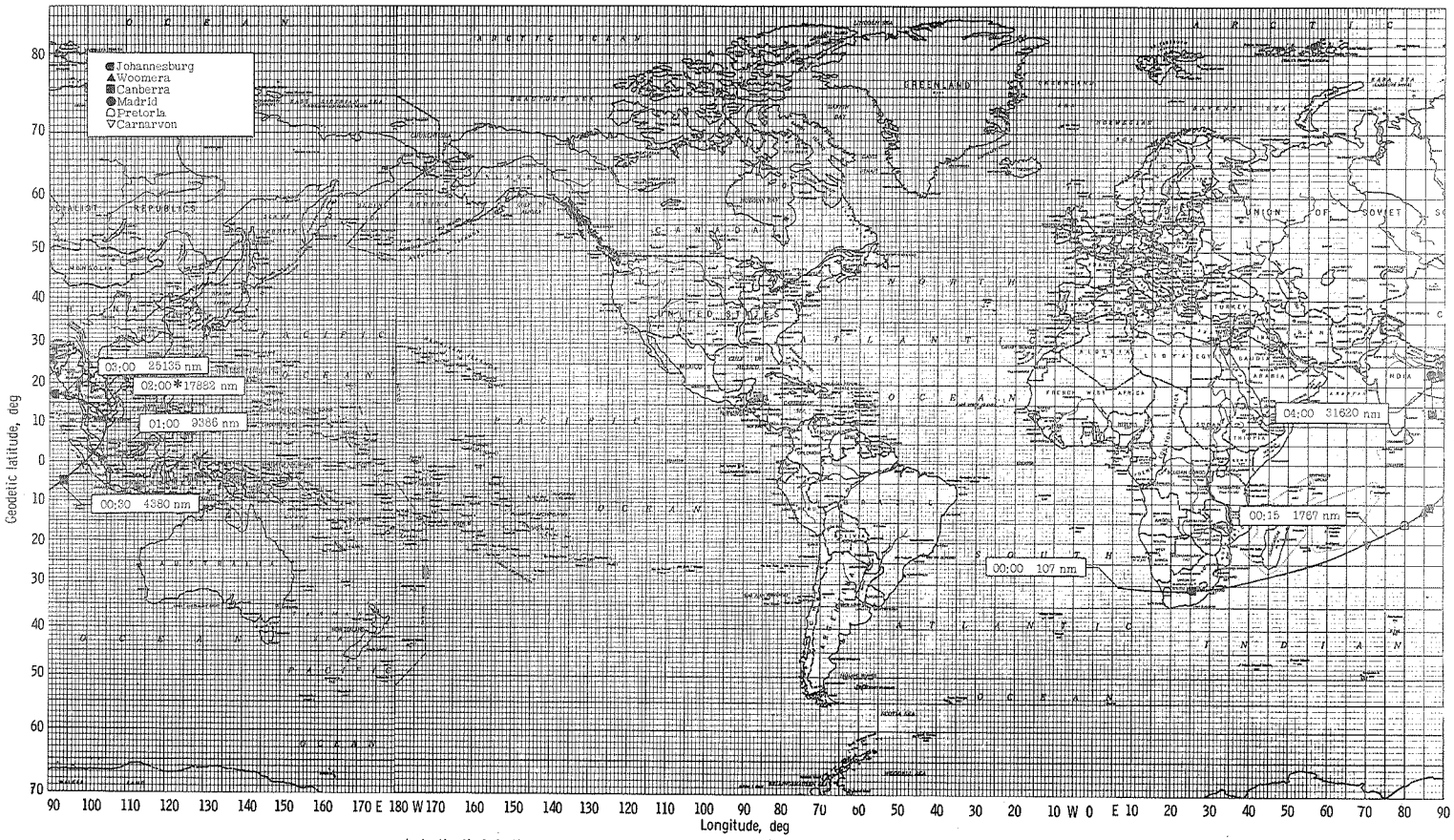
(y) Atlantic injection from third orbit, inclination angle 31°, launch azimuth 102.7°, lunar declination -27.5°.

Figure 14. - Continued.



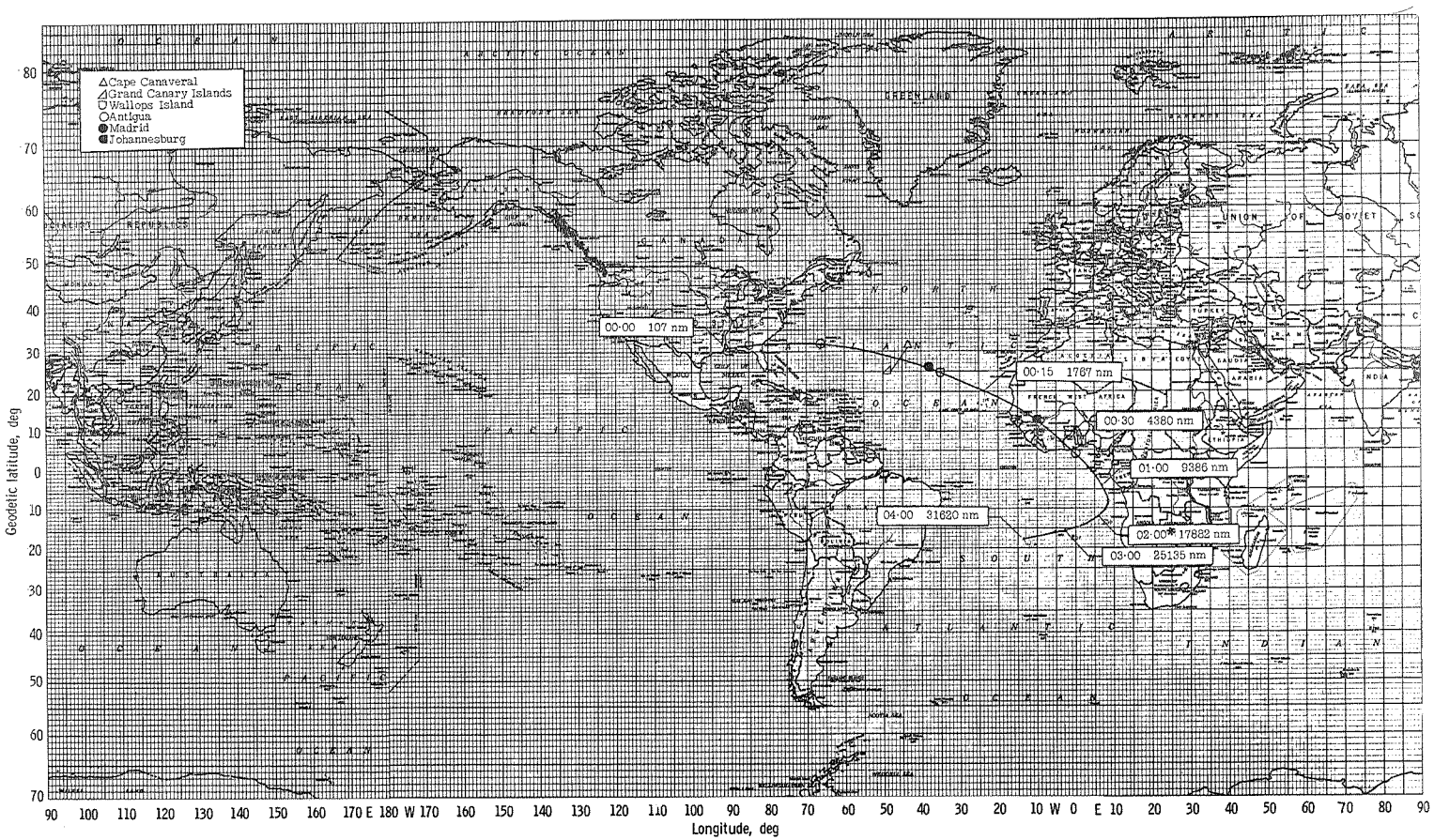
(z) Atlantic injection from third orbit, inclination angle 31°, launch azimuth 102.7°, lunar declination 0°.

Figure 14. - Continued.



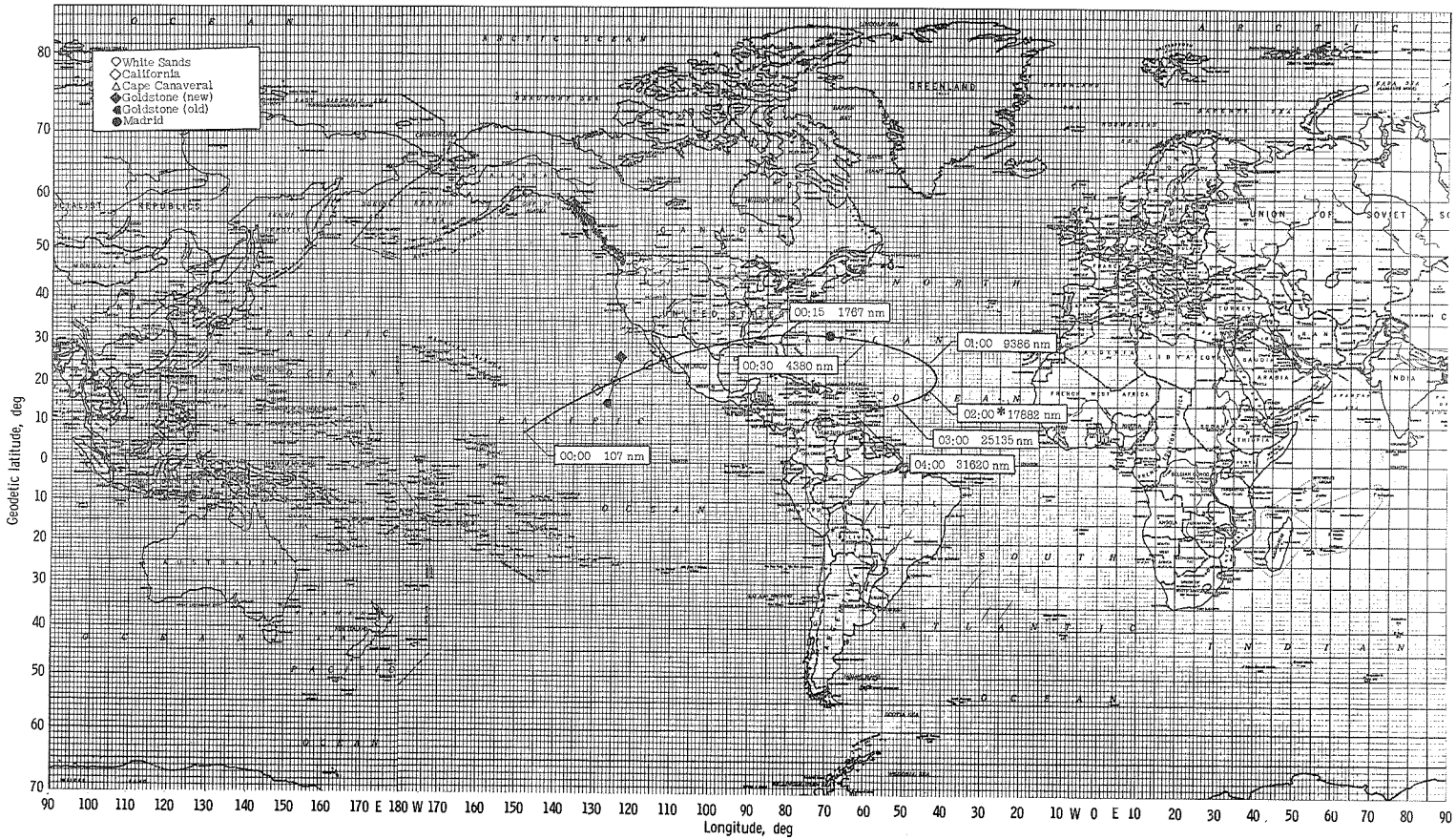
(aa) Atlantic injection from third orbit, inclination angle 31°, launch azimuth 102.7°, lunar declination 27.5°.

Figure 14. - Continued.



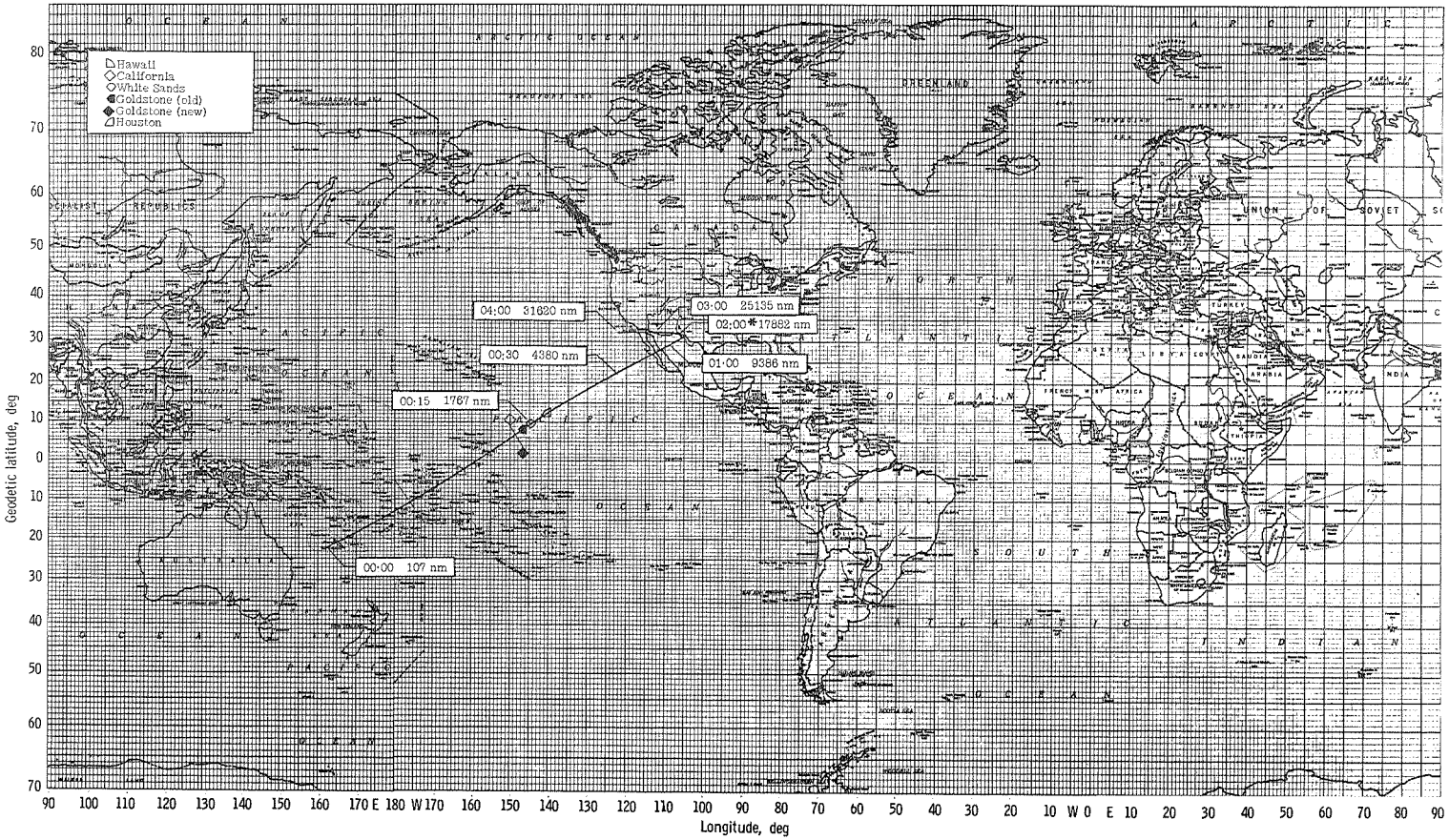
(bb) Pacific injection from first orbit, inclination angle 32°, launch azimuth 74.8°, lunar declination -27.5°.

Figure 14. - Continued.



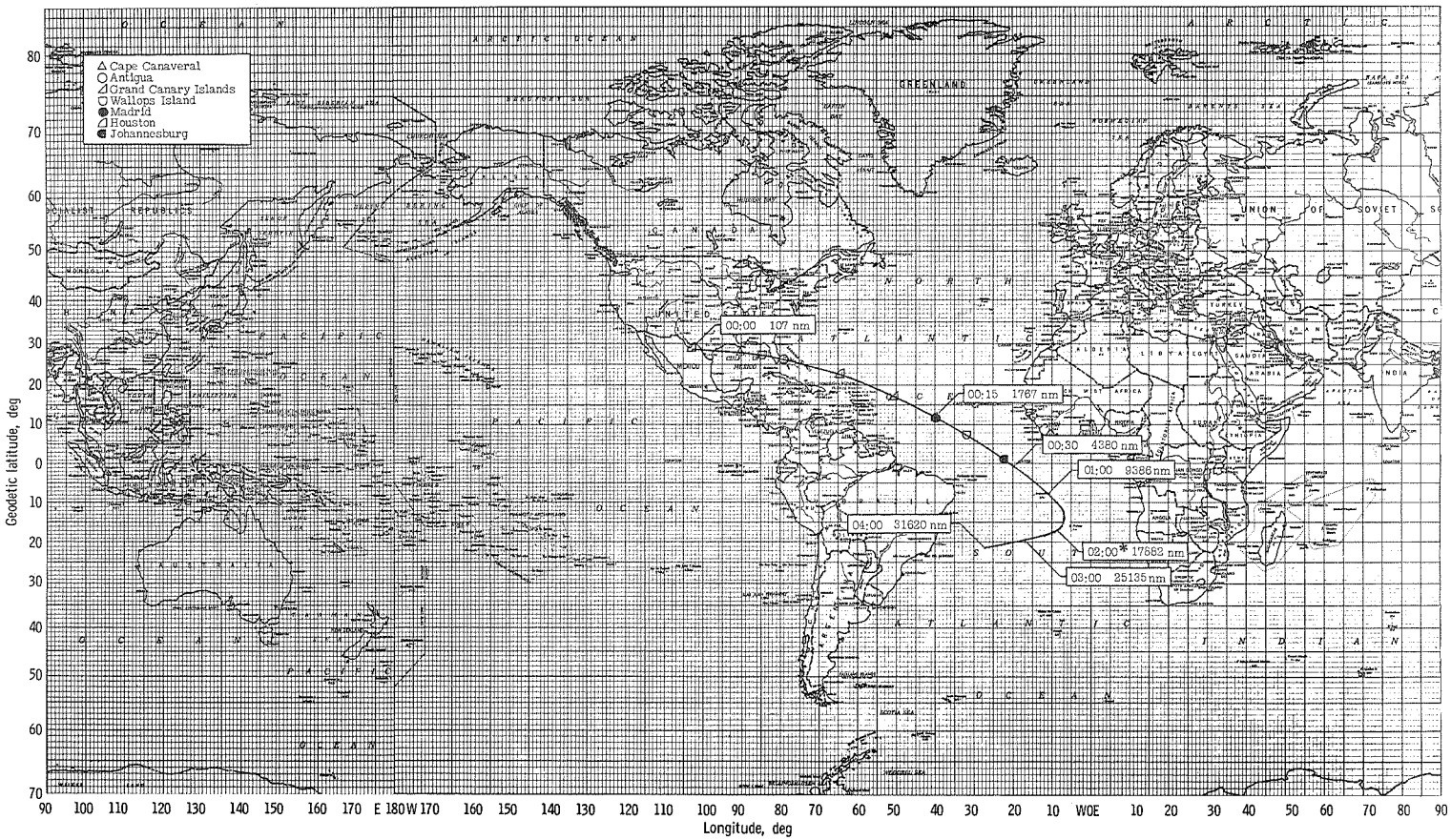
(cc) Pacific injection from first orbit, inclination angle 32°, launch azimuth 74.8°, lunar declination 0°

Figure 14. - Continued.



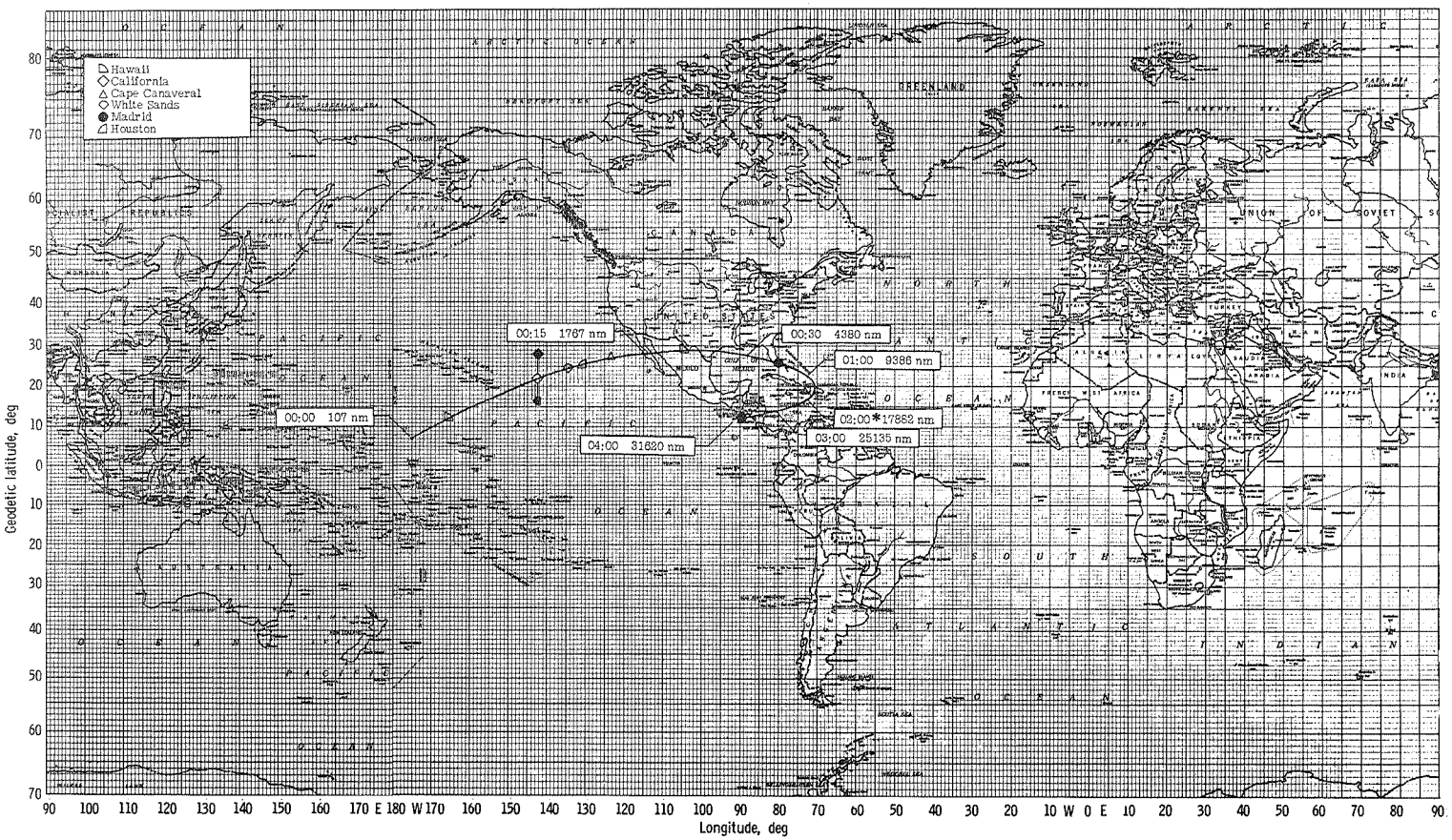
(dd) Pacific injection from first orbit, inclination angle 32°, launch azimuth 74.8°, lunar declination 27.5°.

Figure 14. - Continued.



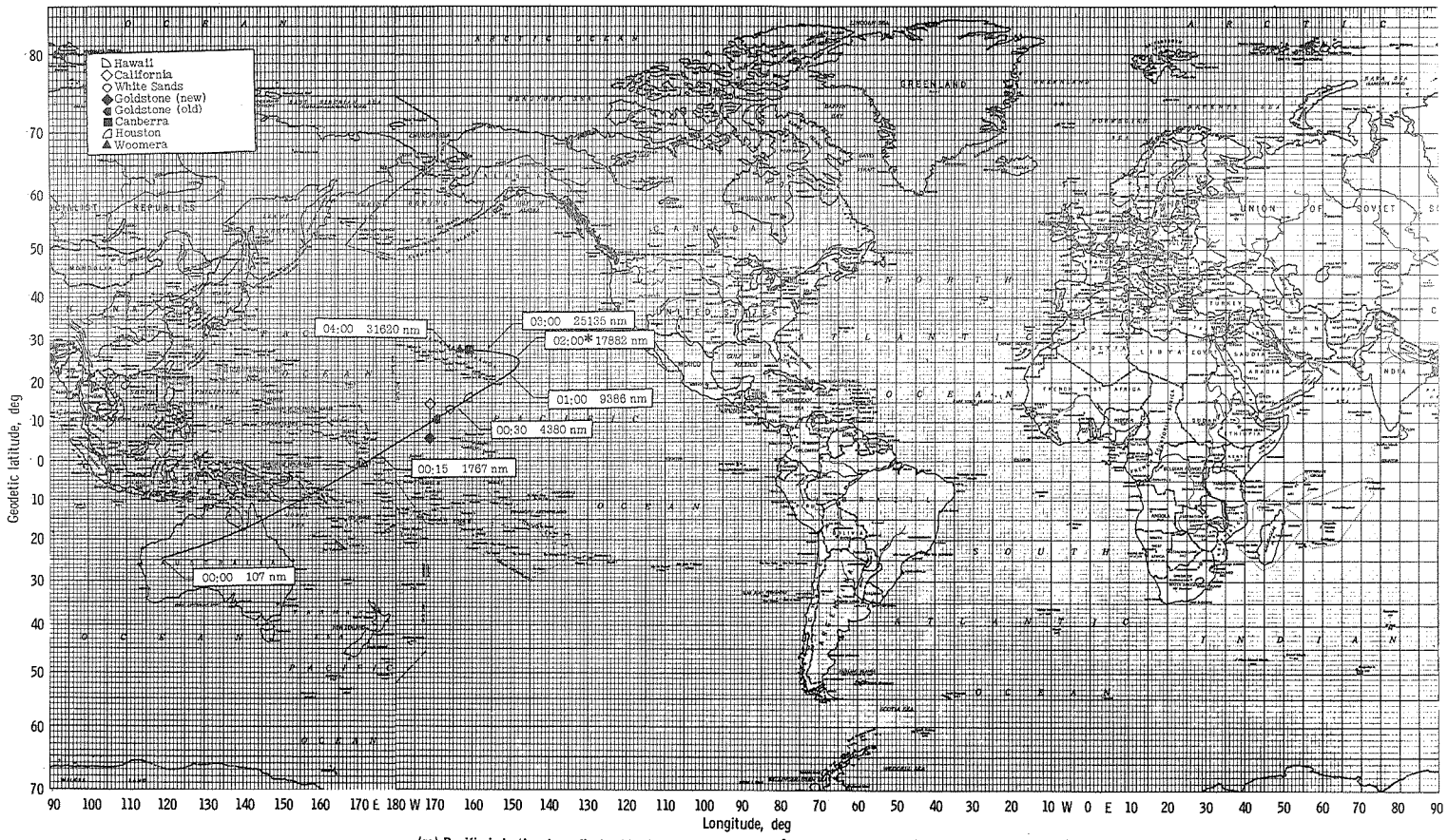
(ee) Pacific injection from first orbit, inclination angle 28.5°, launch azimuth 90°, lunar declination -27.5°.

Figure 14. - Continued.



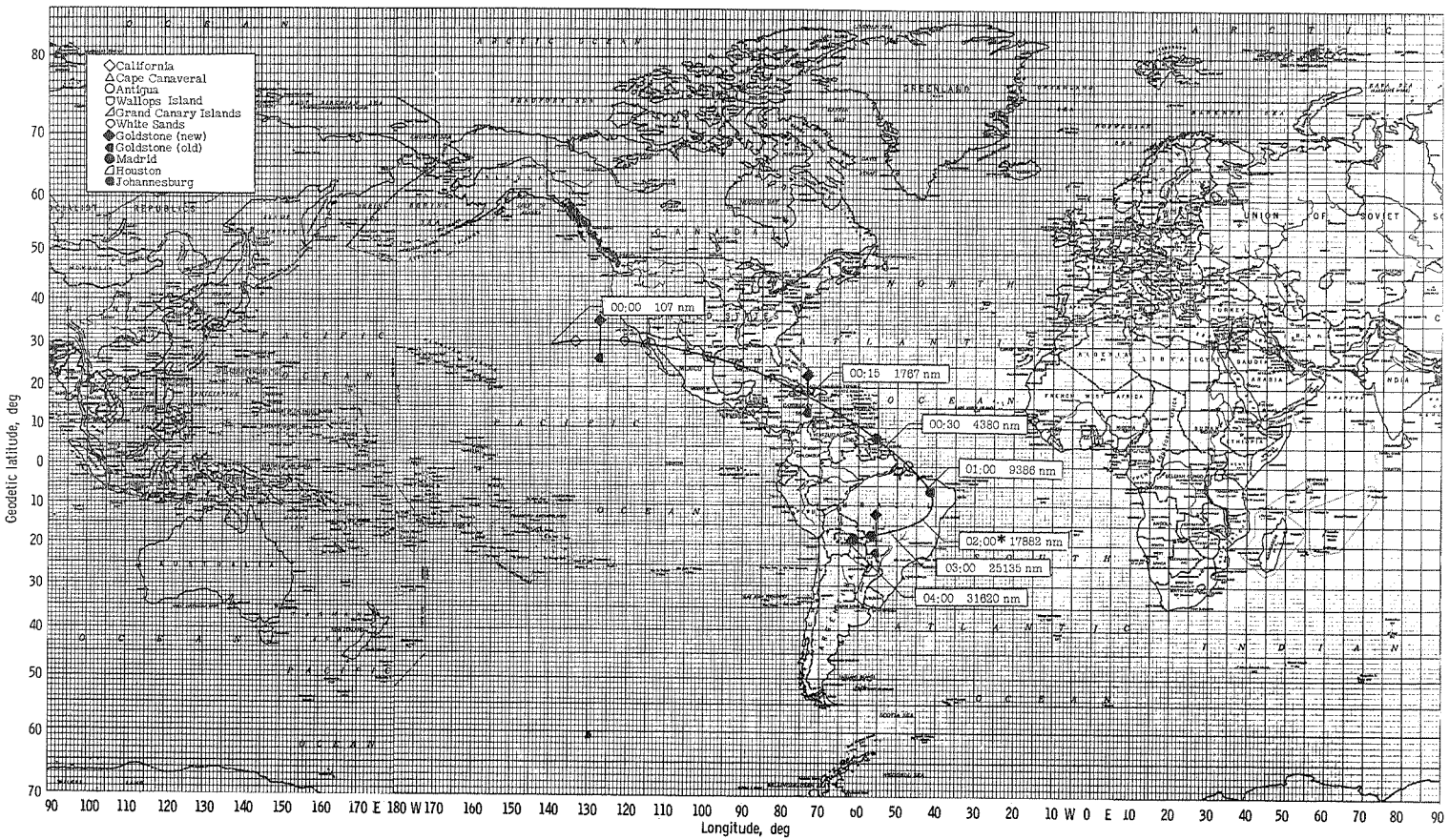
(ff) Pacific injection from first orbit, inclination angle 28.5°, launch azimuth 90°, lunar declination 0°.

Figure 14. - Continued.



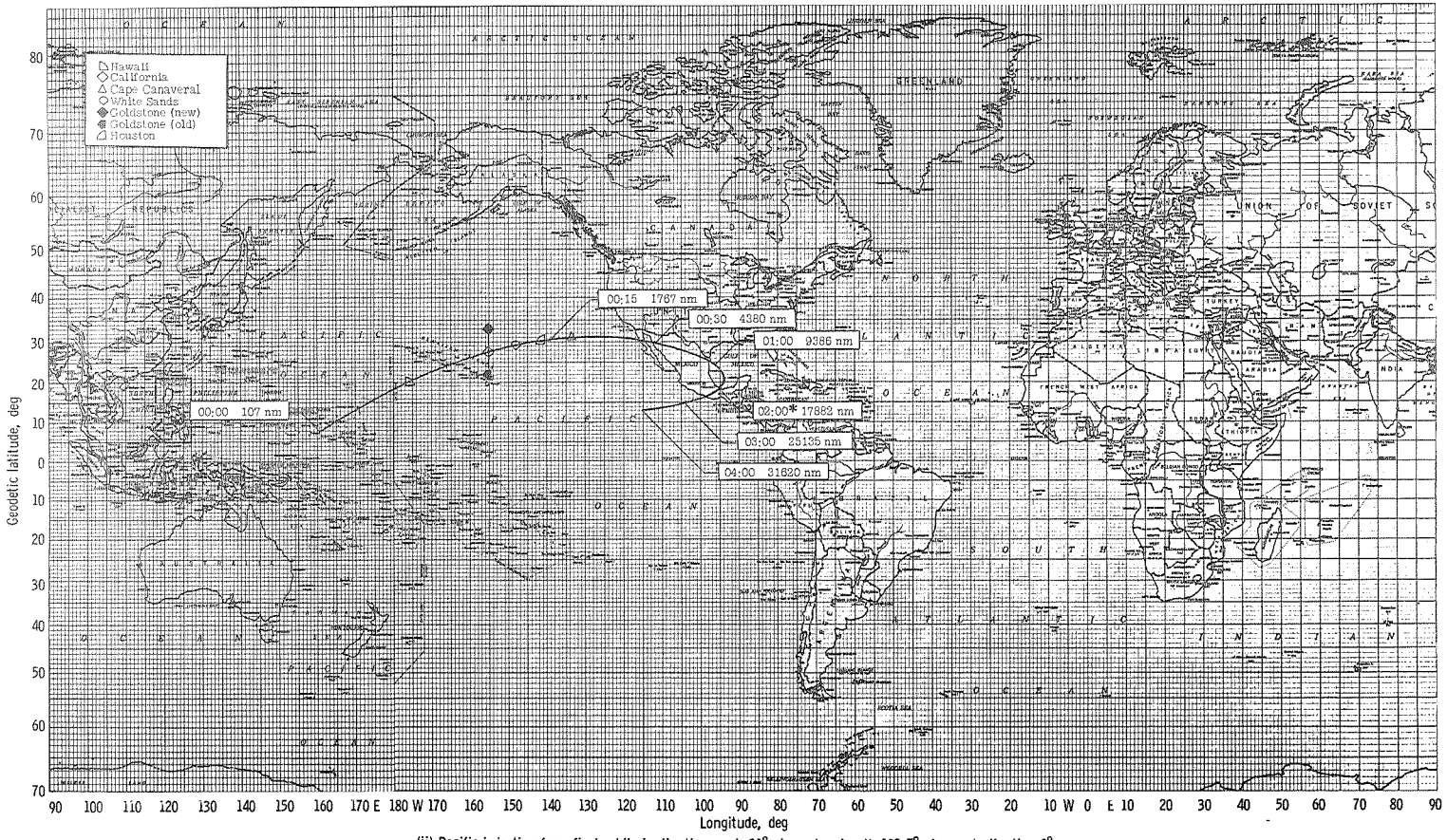
(gg) Pacific injection from first orbit, inclination angle 28.5°, launch azimuth 90°, lunar declination 27.5°.

Figure 14. - Continued.



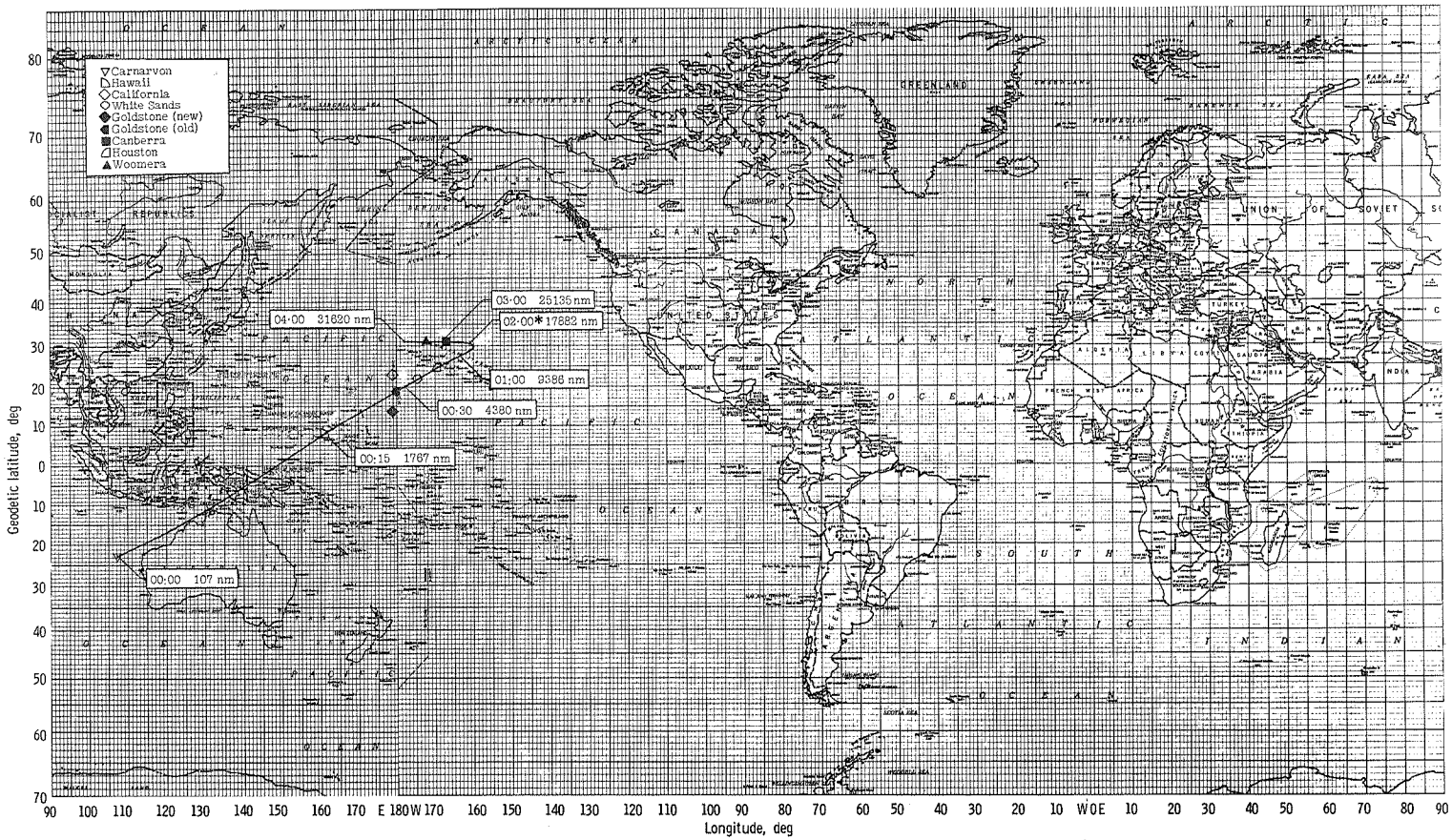
(hh) Pacific injection from first orbit, inclination angle 31°, launch azimuth 102.7°, lunar declination -27.5°.

Figure 14. - Continued.



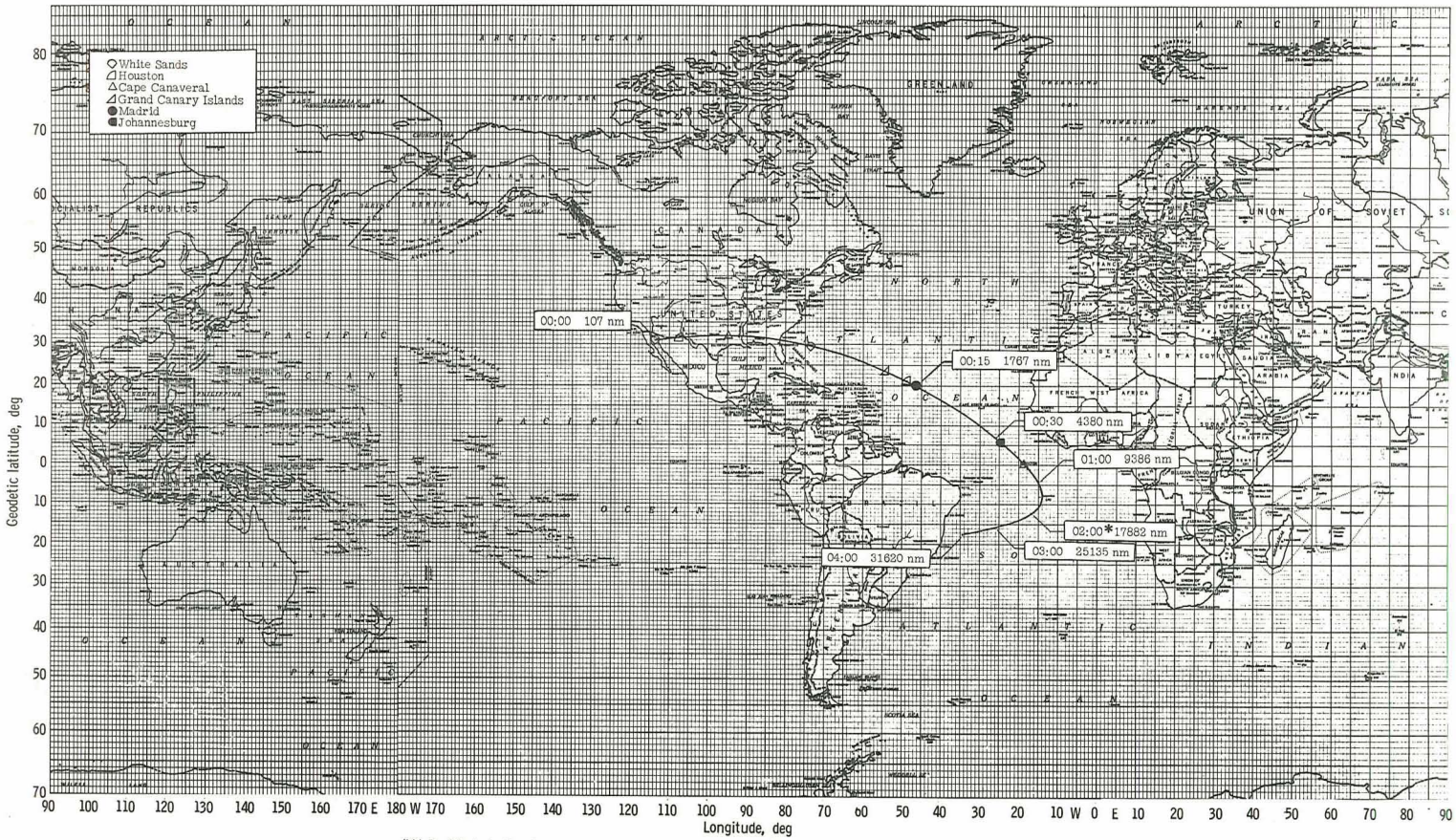
(ii) Pacific injection from first orbit, inclination angle 31°, launch azimuth 102.7°, lunar declination 0°.

Figure 14 - Continued.



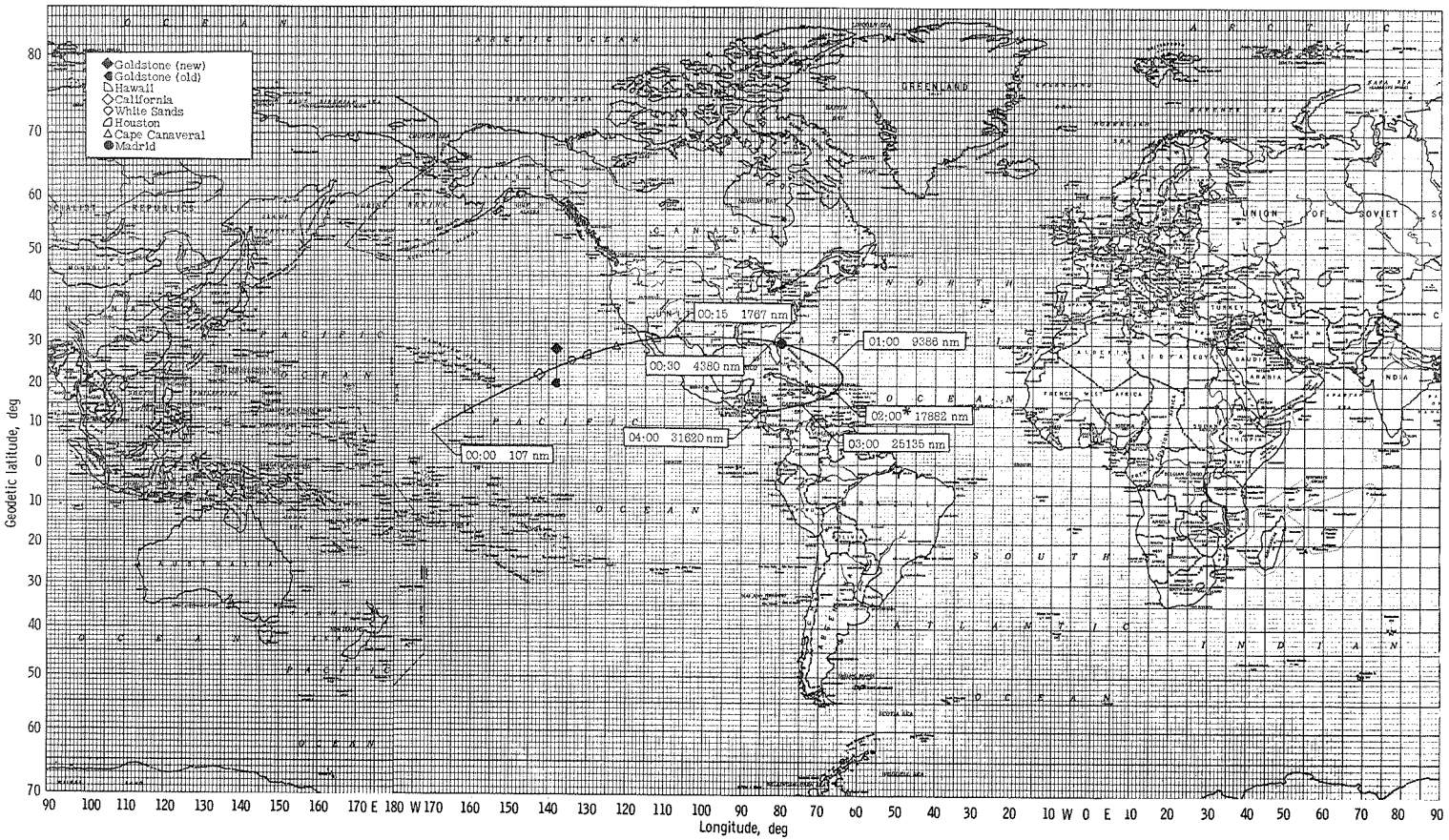
(jj) Pacific injection from first orbit, inclination angle 31°, launch azimuth 102.7°, lunar declination 27.5°.

Figure 14. - Continued.



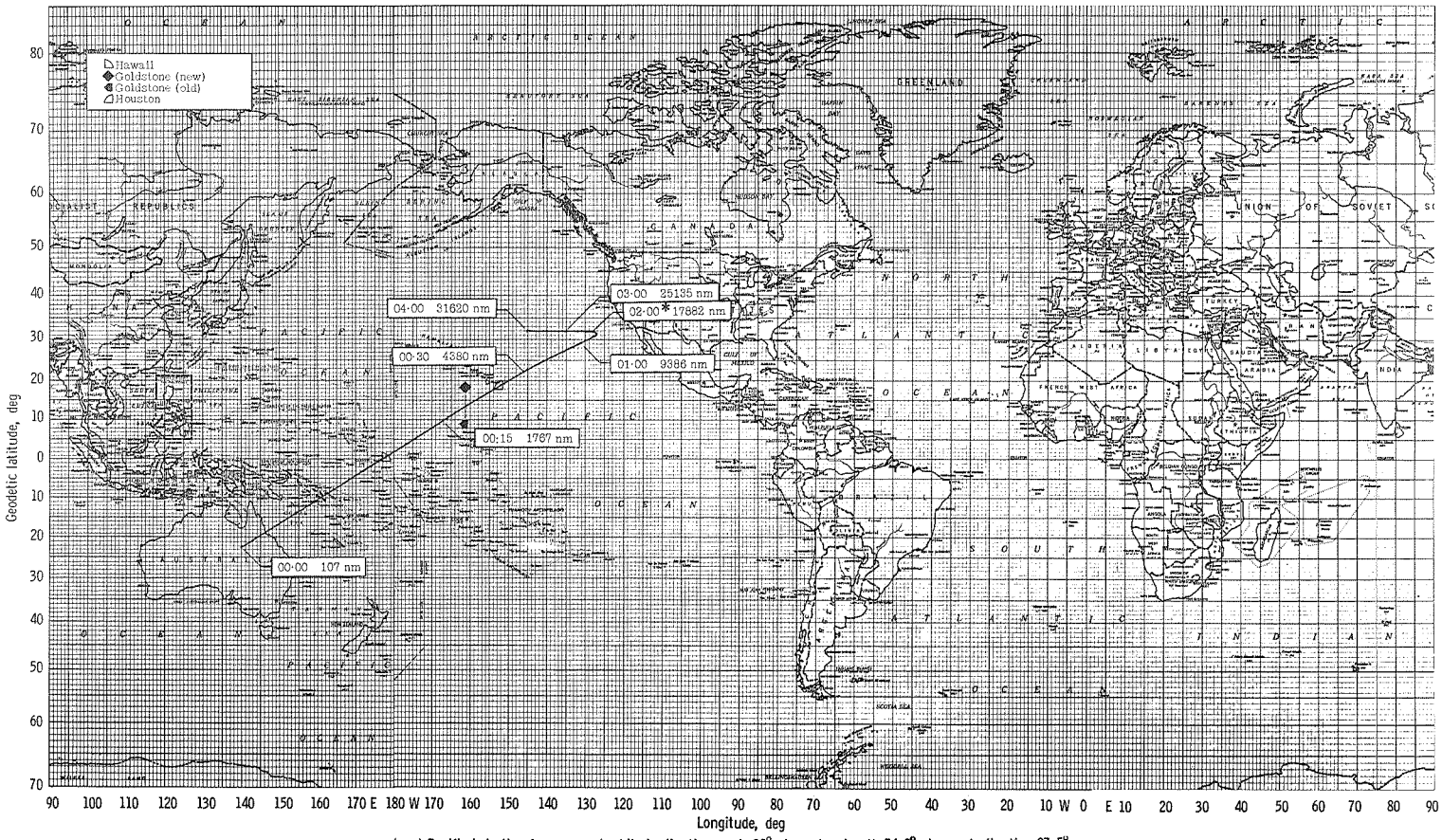
(kk) Pacific injection from second orbit, inclination angle 32°, launch azimuth 74.8°, lunar declination -27.5°.

Figure 14. - Continued.



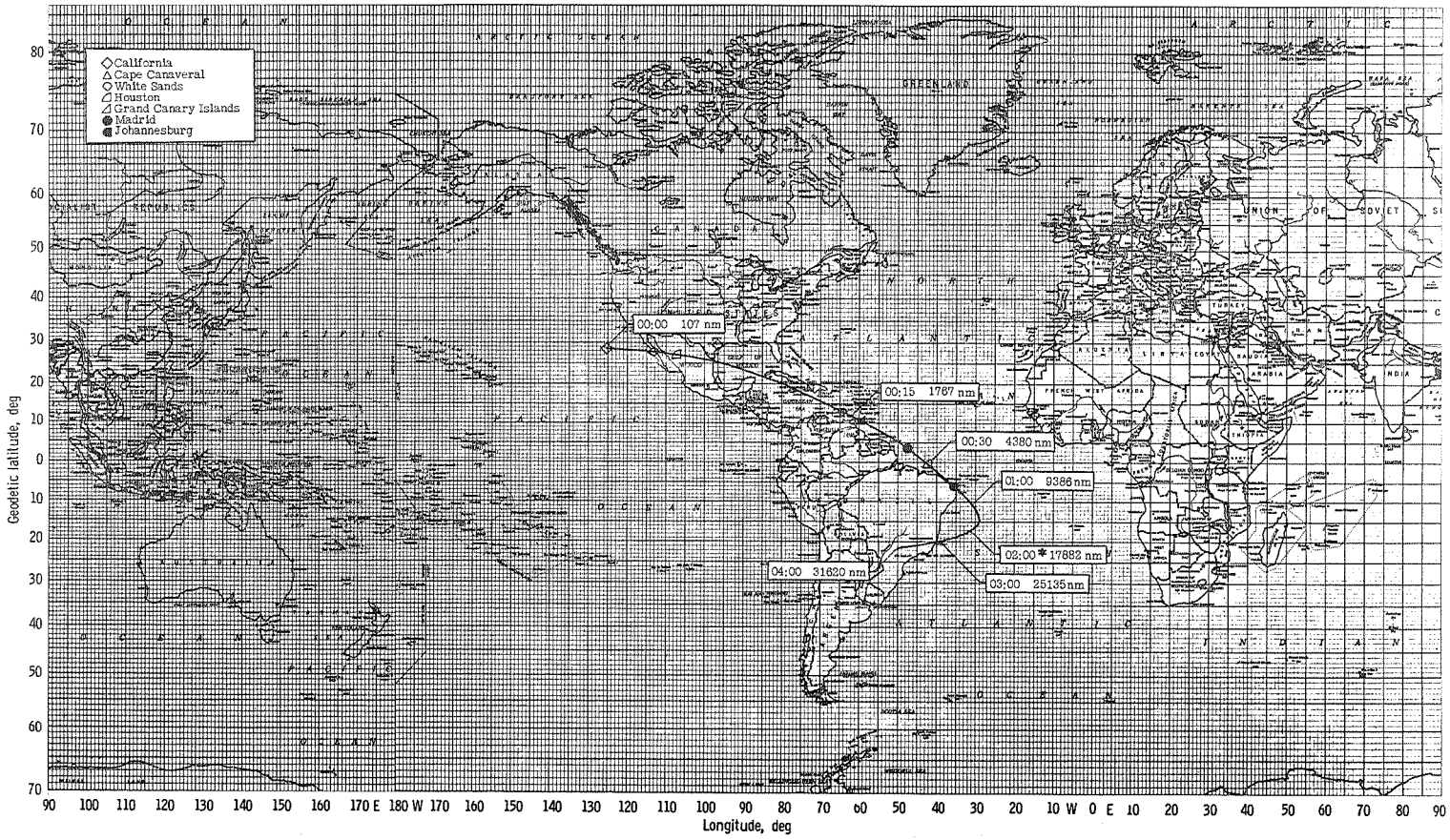
(II) Pacific injection from second orbit, inclination angle 32°, launch azimuth 74.8°, lunar declination 0°.

Figure 14. - Continued.



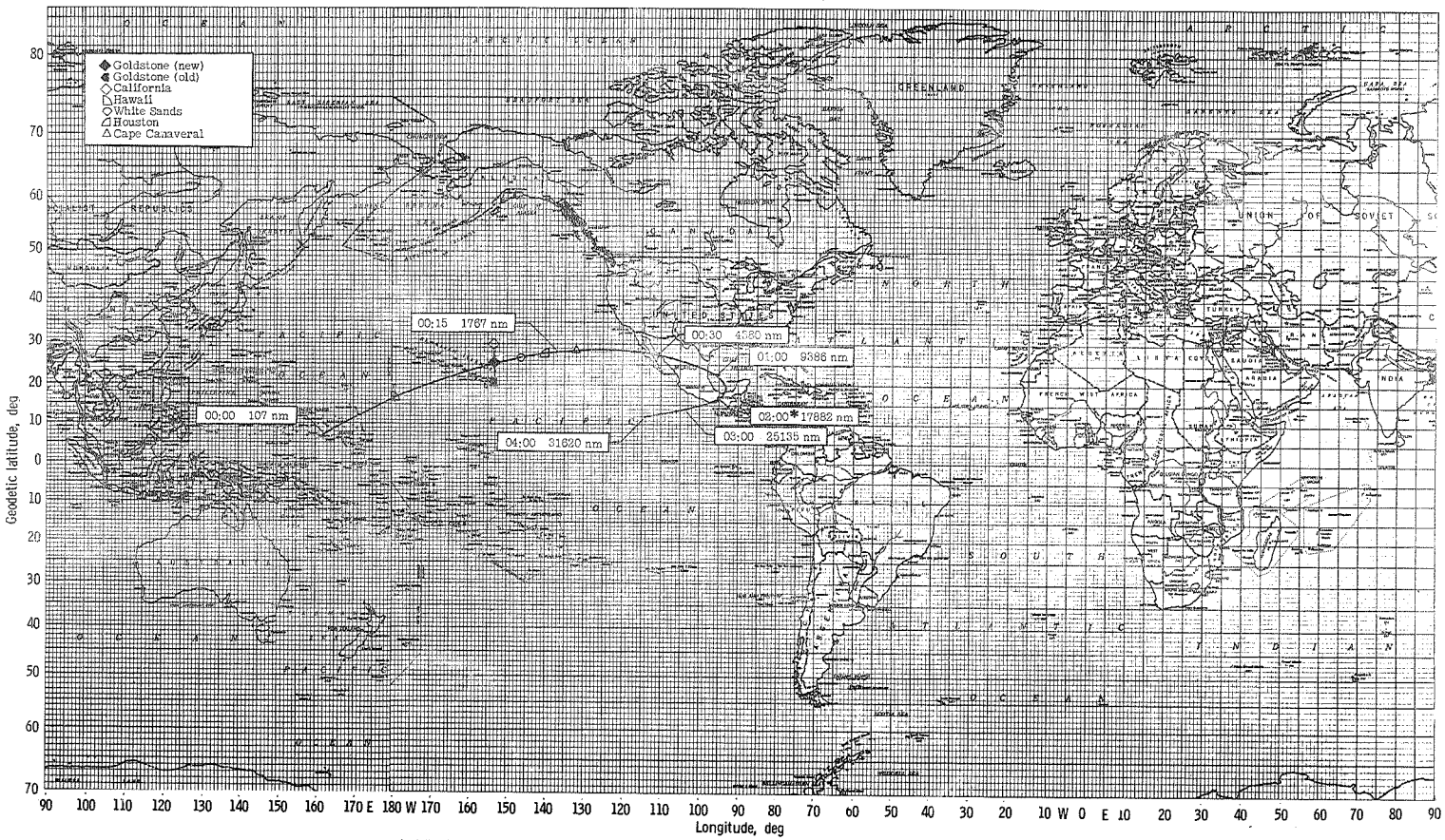
(mm) Pacific injection from second orbit, inclination angle 32°, launch azimuth 74.8°, lunar declination 27.5°.

Figure 14 - Continued.



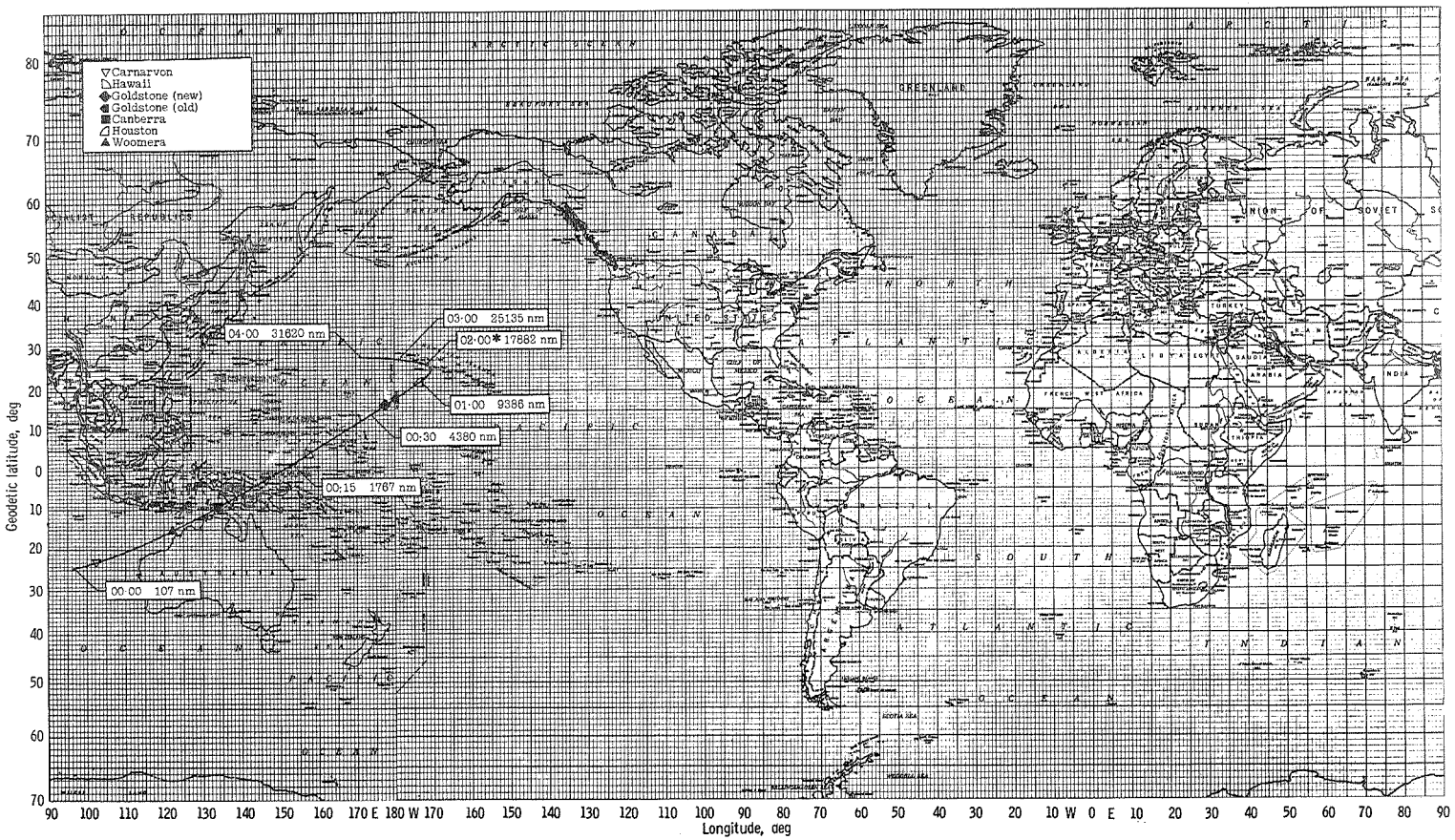
(nn) Pacific injection from second orbit, inclination angle 28.5°, launch azimuth 90°, lunar declination -27.5°.

Figure 14. - Continued.



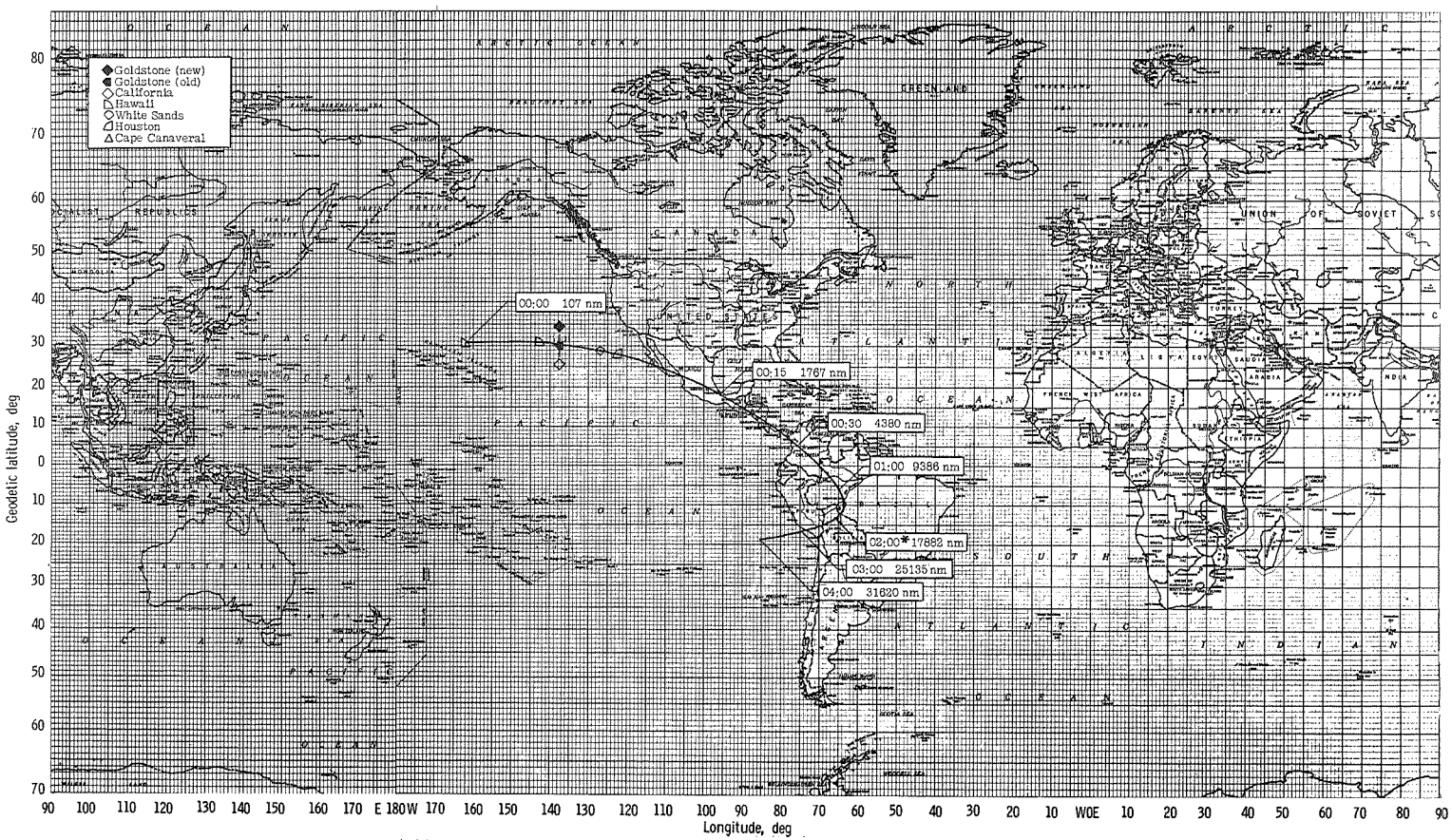
(oo) Pacific injection from second orbit, inclination angle 28.5°, launch azimuth 90°, lunar declination 0°.

Figure 14. - Continued.



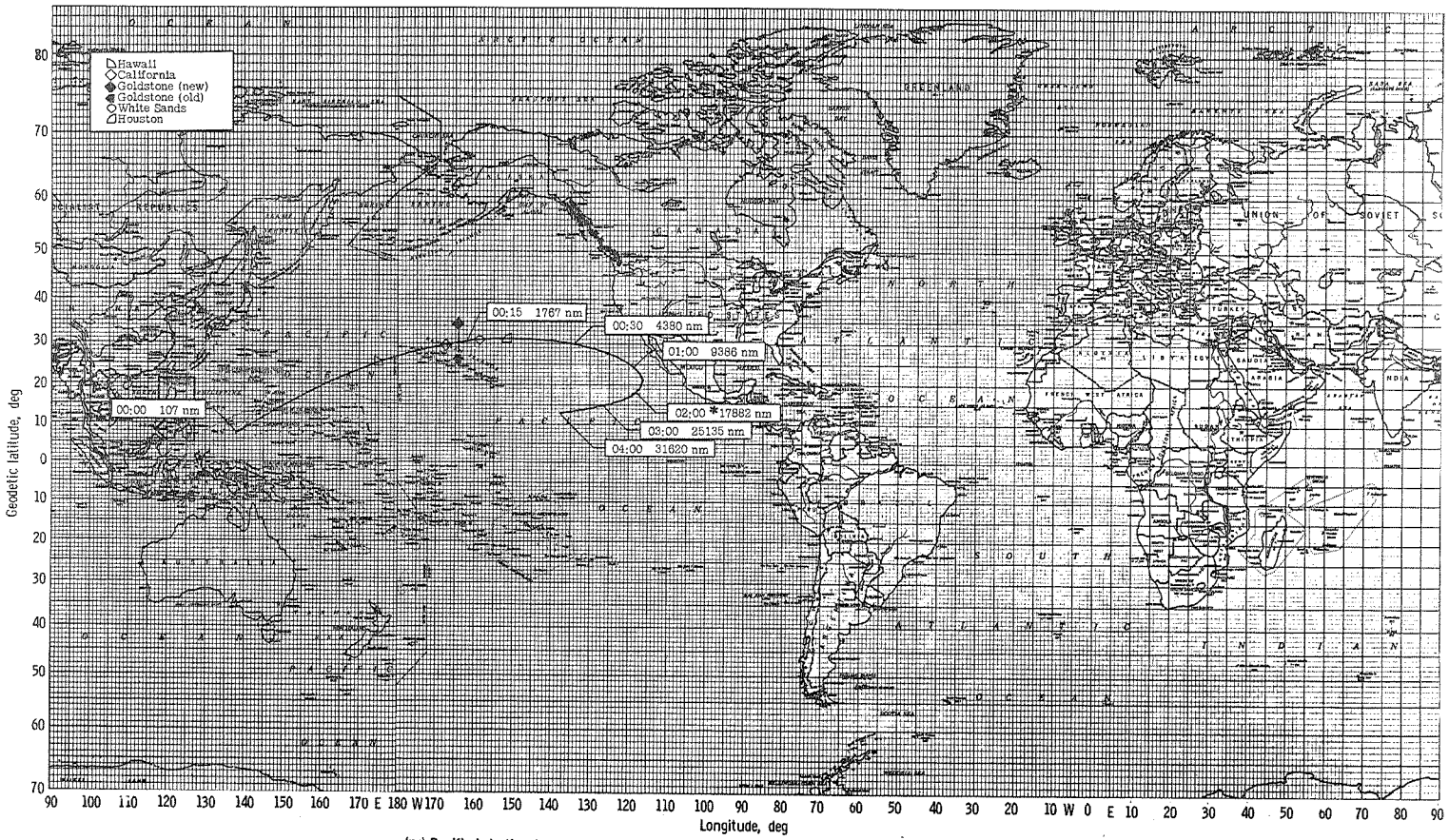
(pp) Pacific injection from second orbit, inclination angle 28.5°, launch azimuth 90°, lunar declination 27.5°.

Figure 14. - Continued.



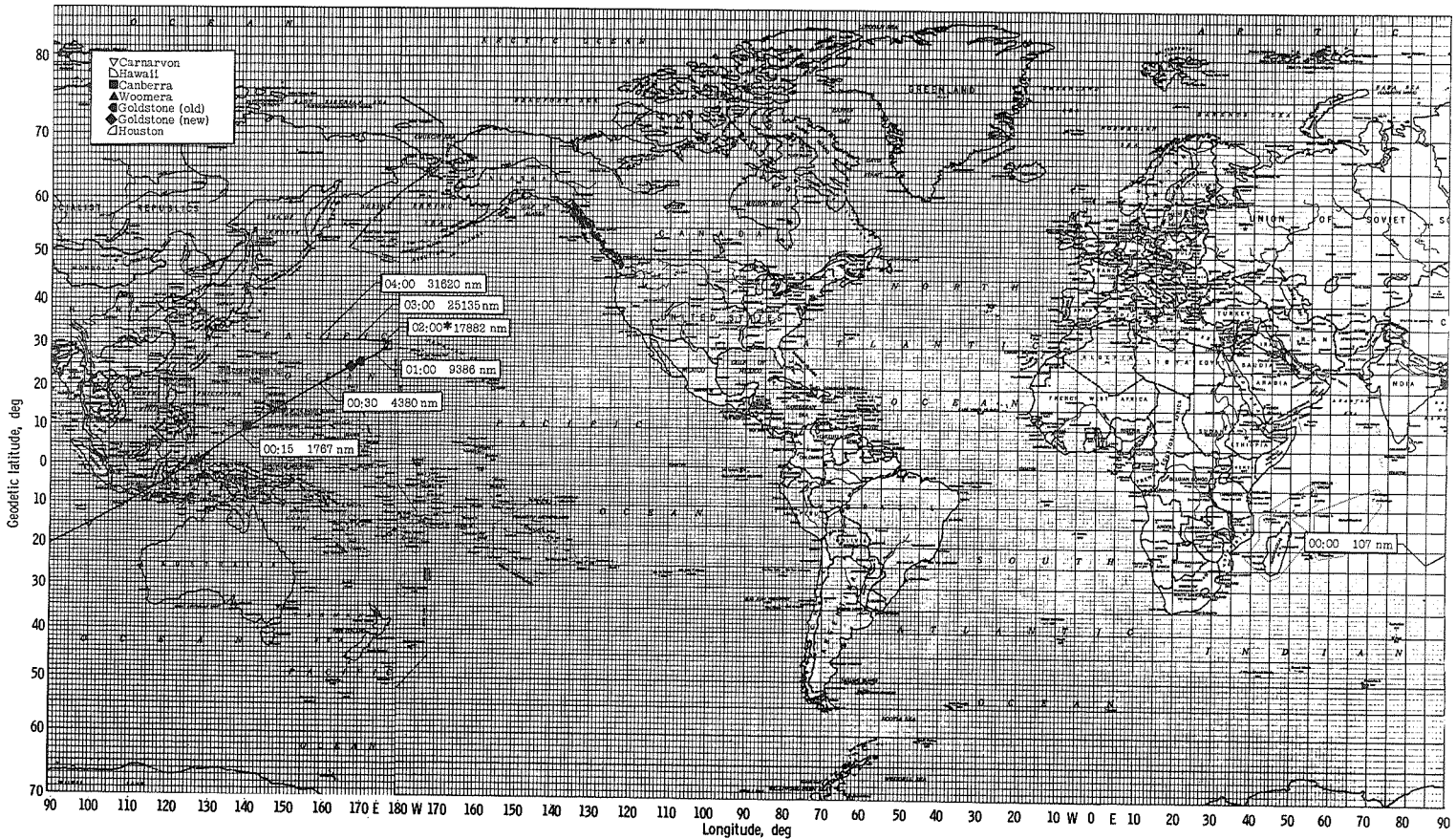
(qq) Pacific injection from second orbit, inclination angle 31°, launch azimuth 102.7°, lunar declination -27.5°.

Figure 14. - Continued.



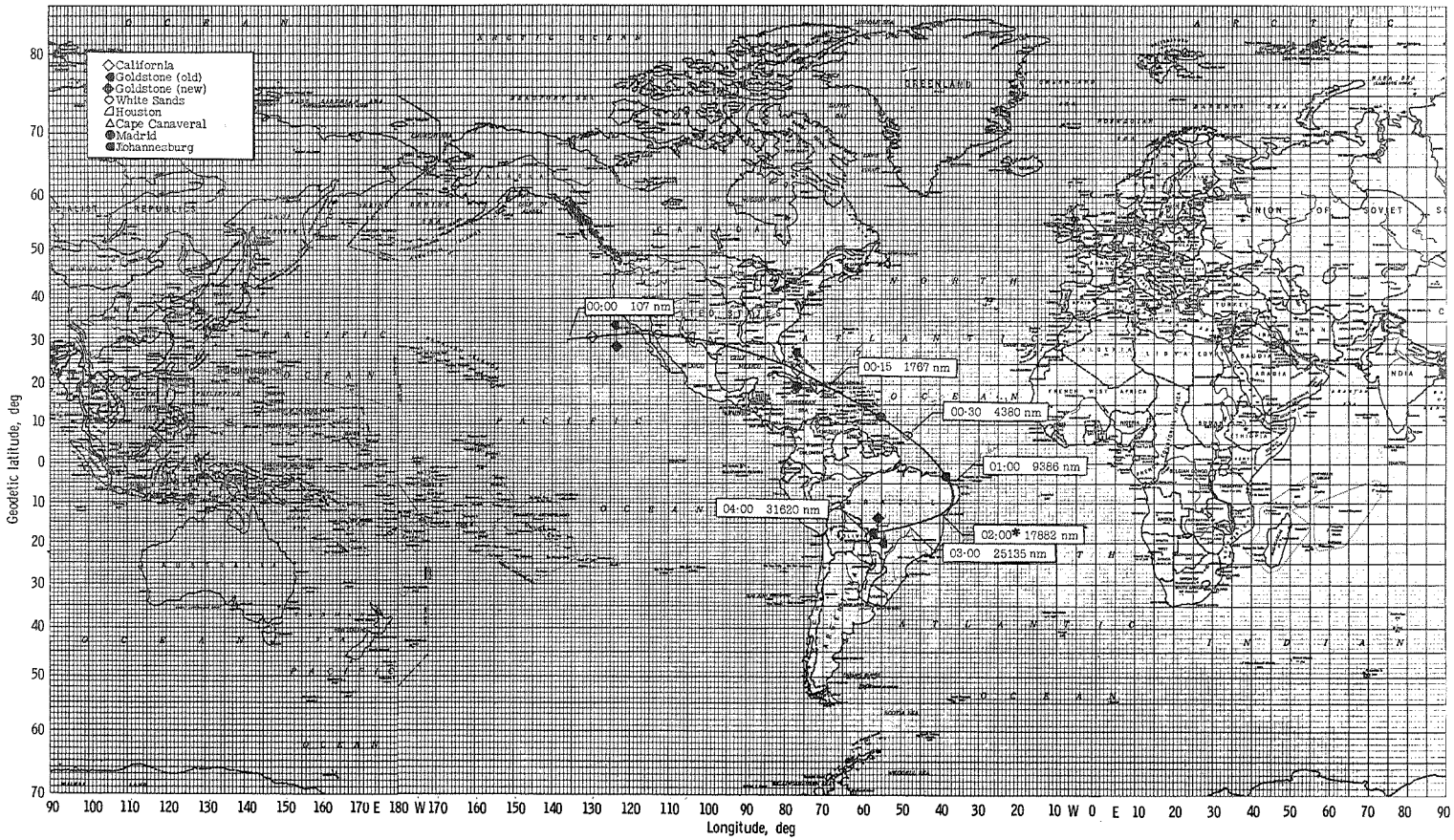
(rr) Pacific injection from second orbit, inclination angle 31°, launch azimuth 102.7°, lunar declination 0°.

Figure 14 - Continued.



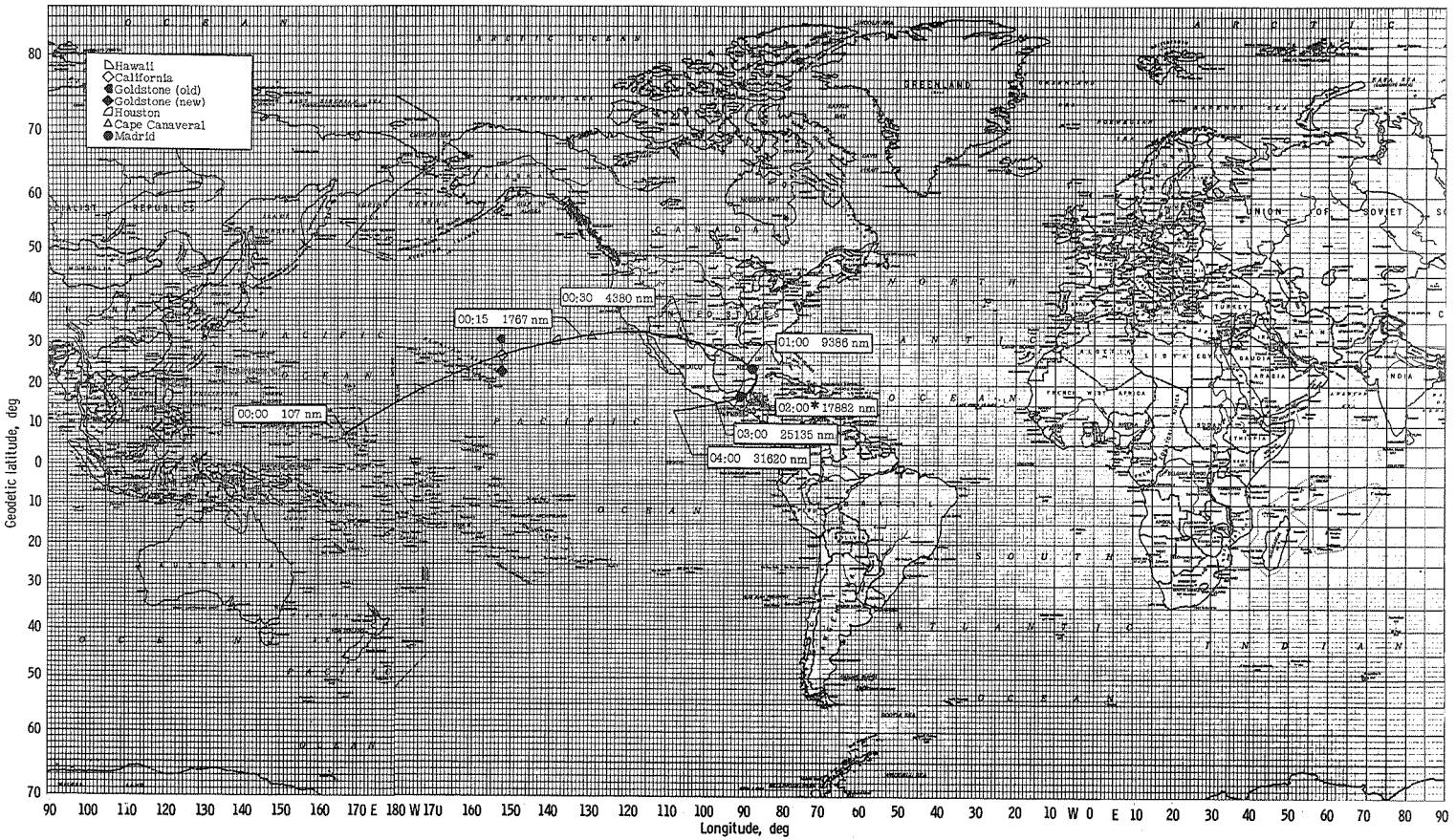
(ss) Pacific injection from second orbit, inclination angle 31°, launch azimuth 102.7°, lunar declination 27.5°.

Figure 14. - Continued.



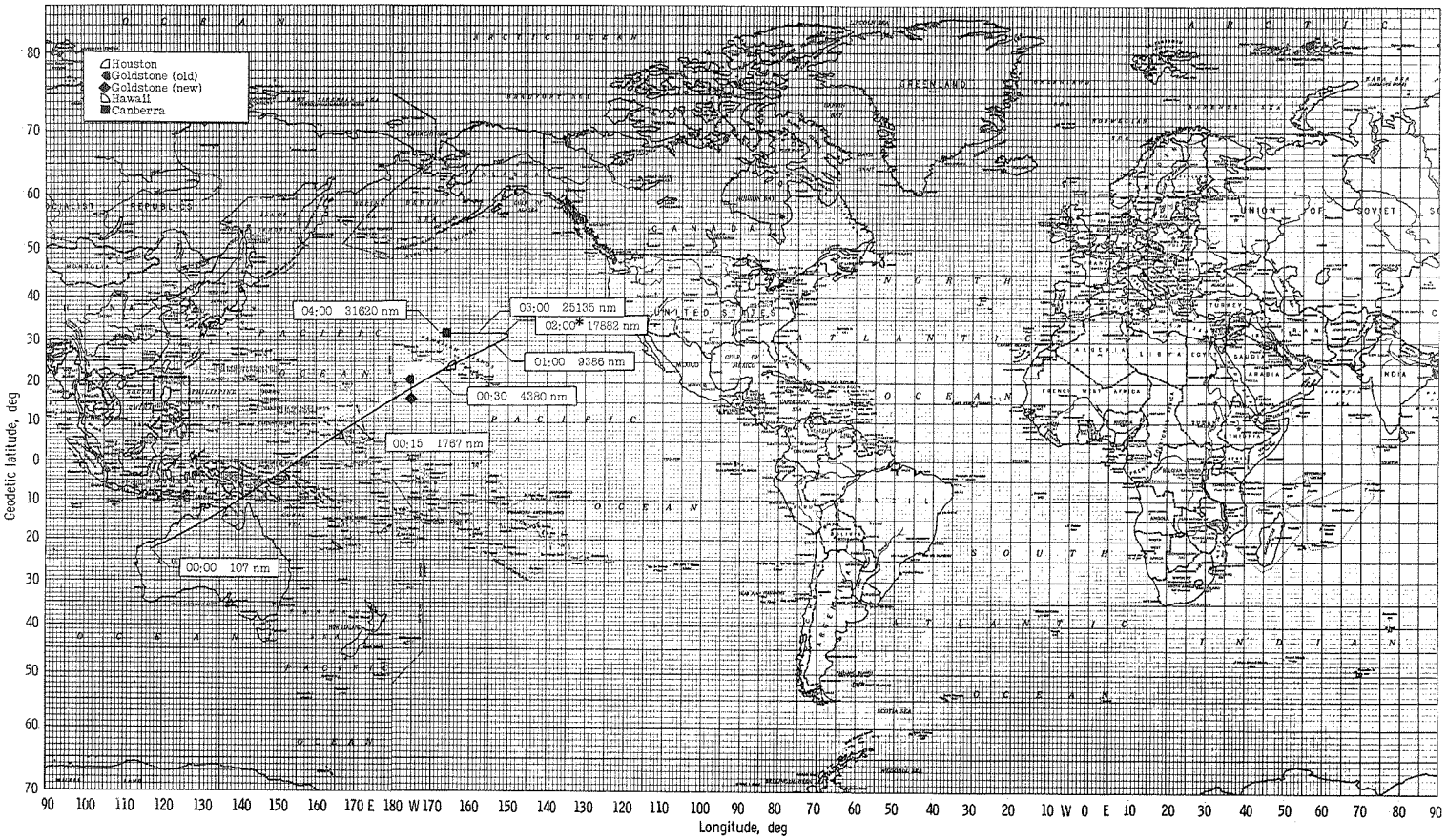
(tt) Pacific injection from third orbit, inclination angle 32°, launch azimuth 74.8°, lunar declination -27.5°.

Figure 14. - Continued.



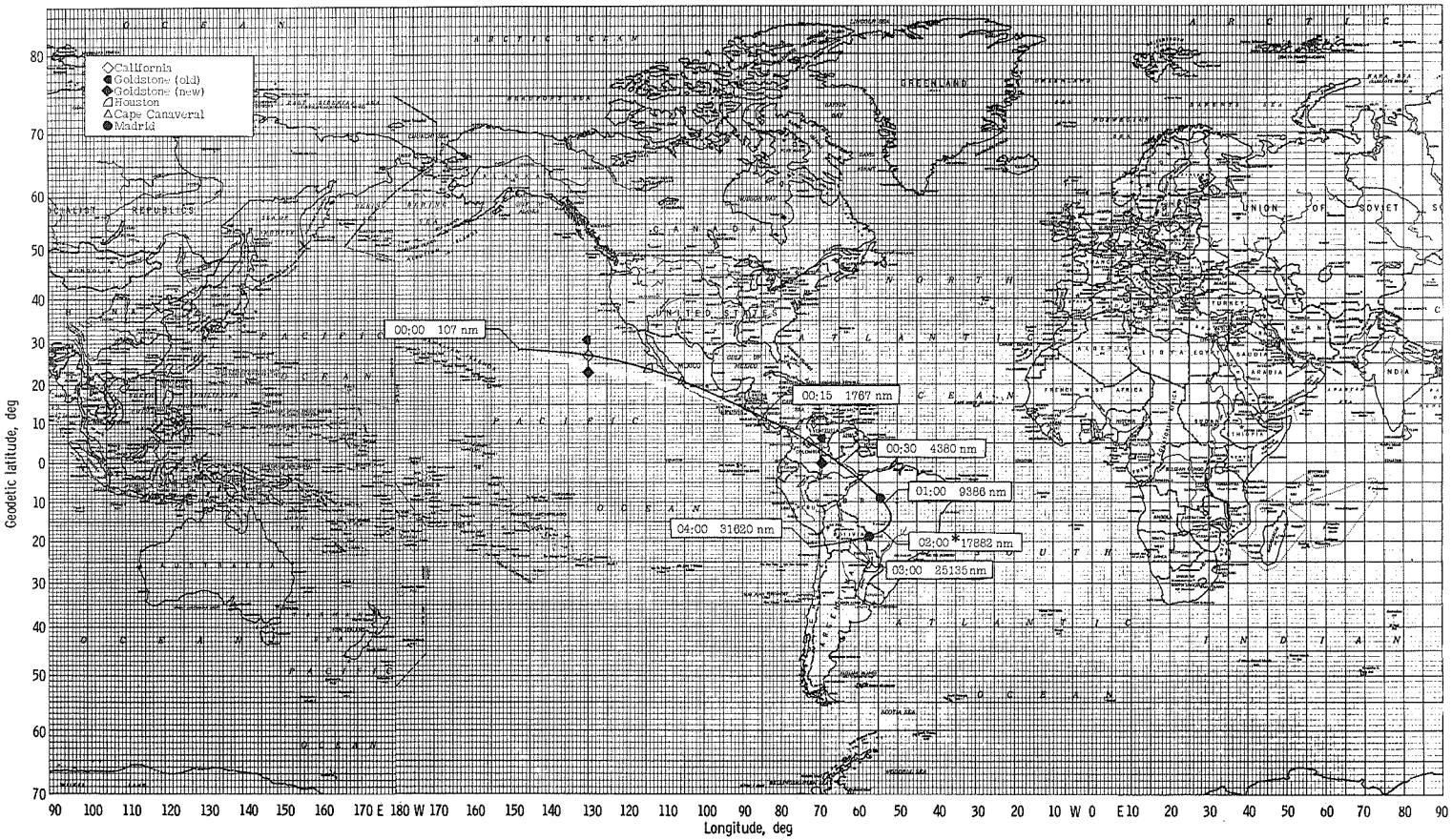
(uu) Pacific injection from third orbit, inclination angle 32°, launch azimuth 74.8°, lunar declination 0°.

Figure 14. - Continued.



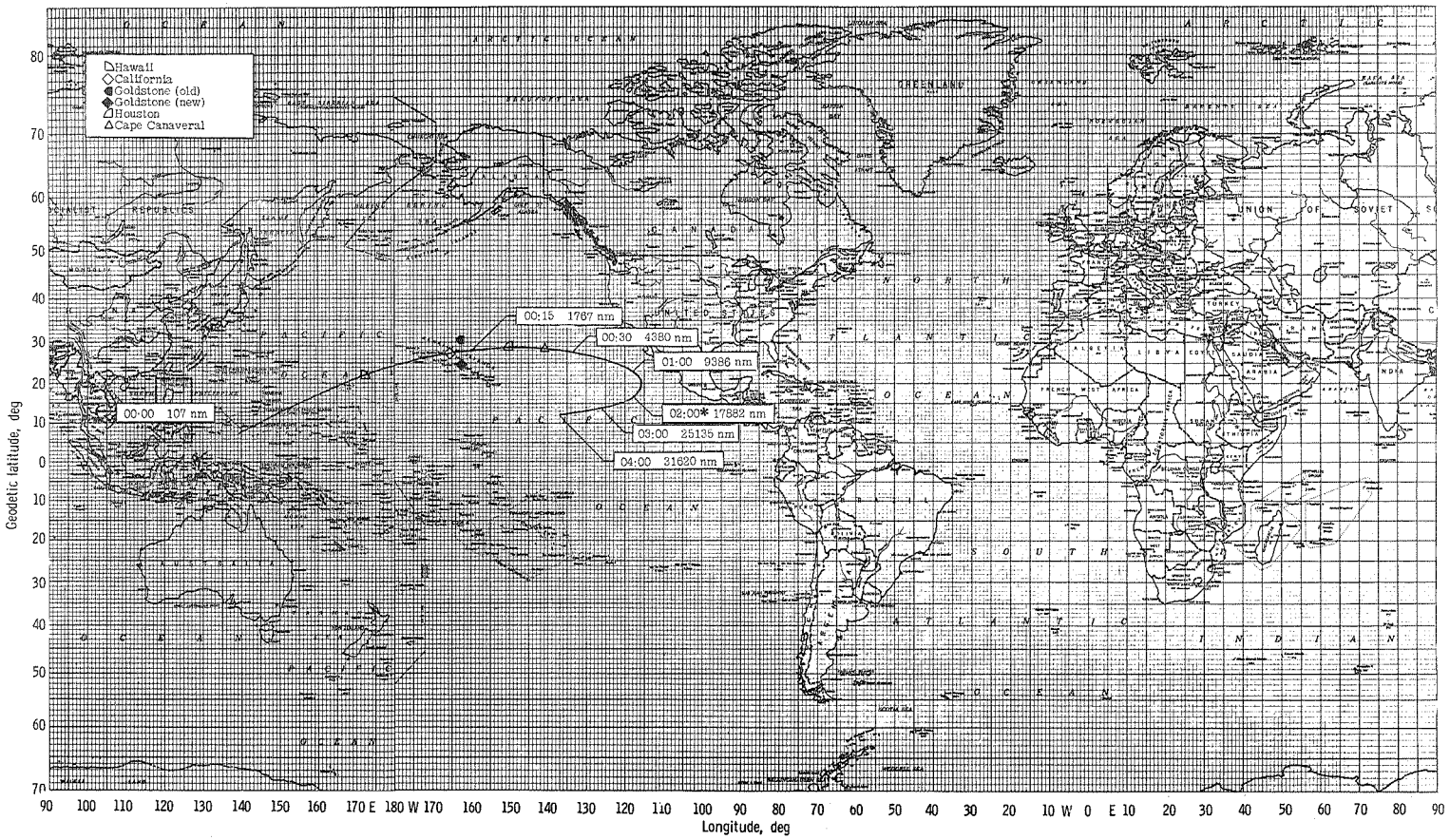
(vv) Pacific injection from third orbit, inclination angle 32°, launch azimuth 74.8°, lunar declination 27.5°.

Figure 14. - Continued.



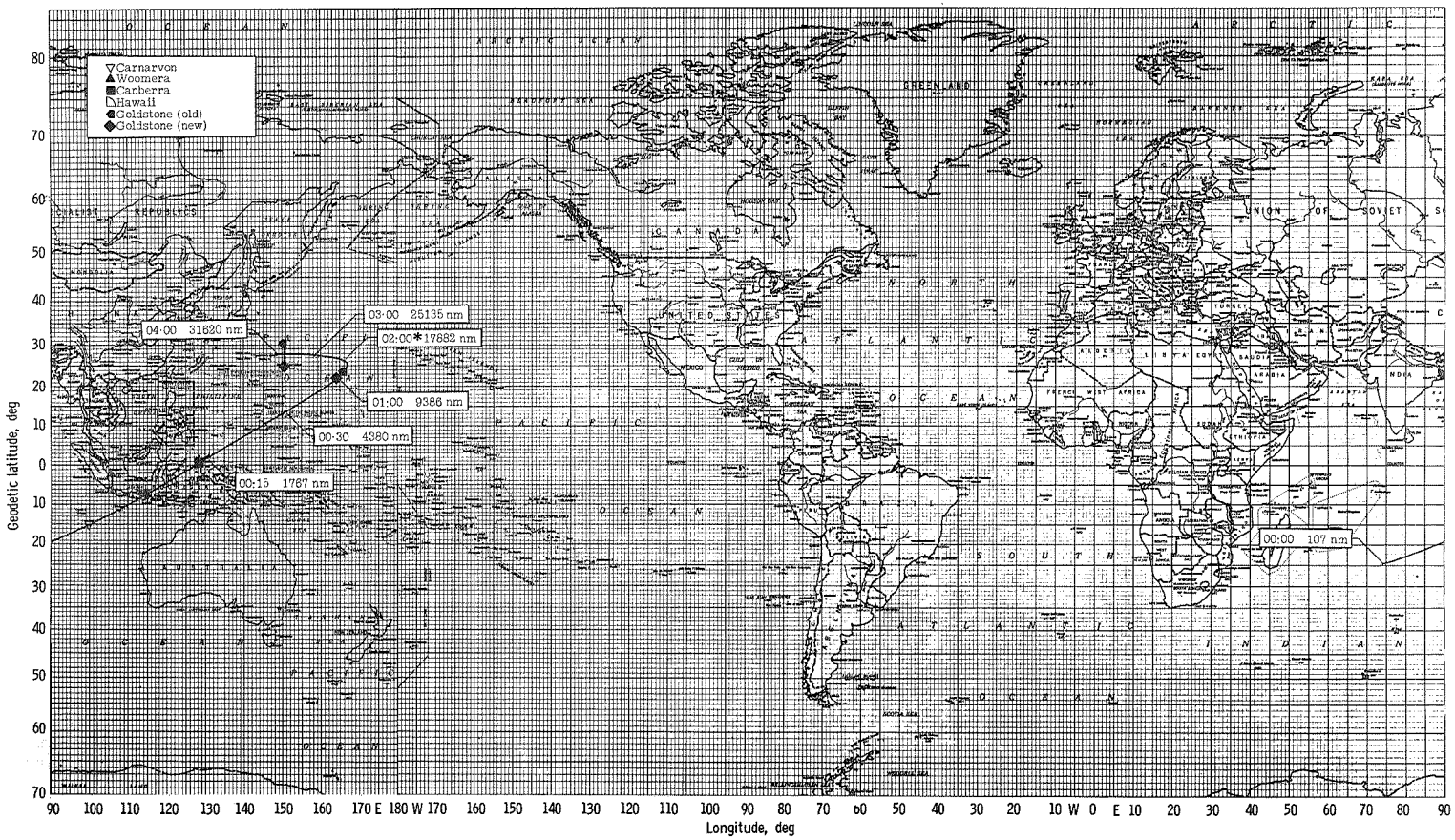
(ww) Pacific injection from third orbit, inclination angle 28.5°, launch azimuth 90°, lunar declination -27.5°.

Figure 14. - Continued.



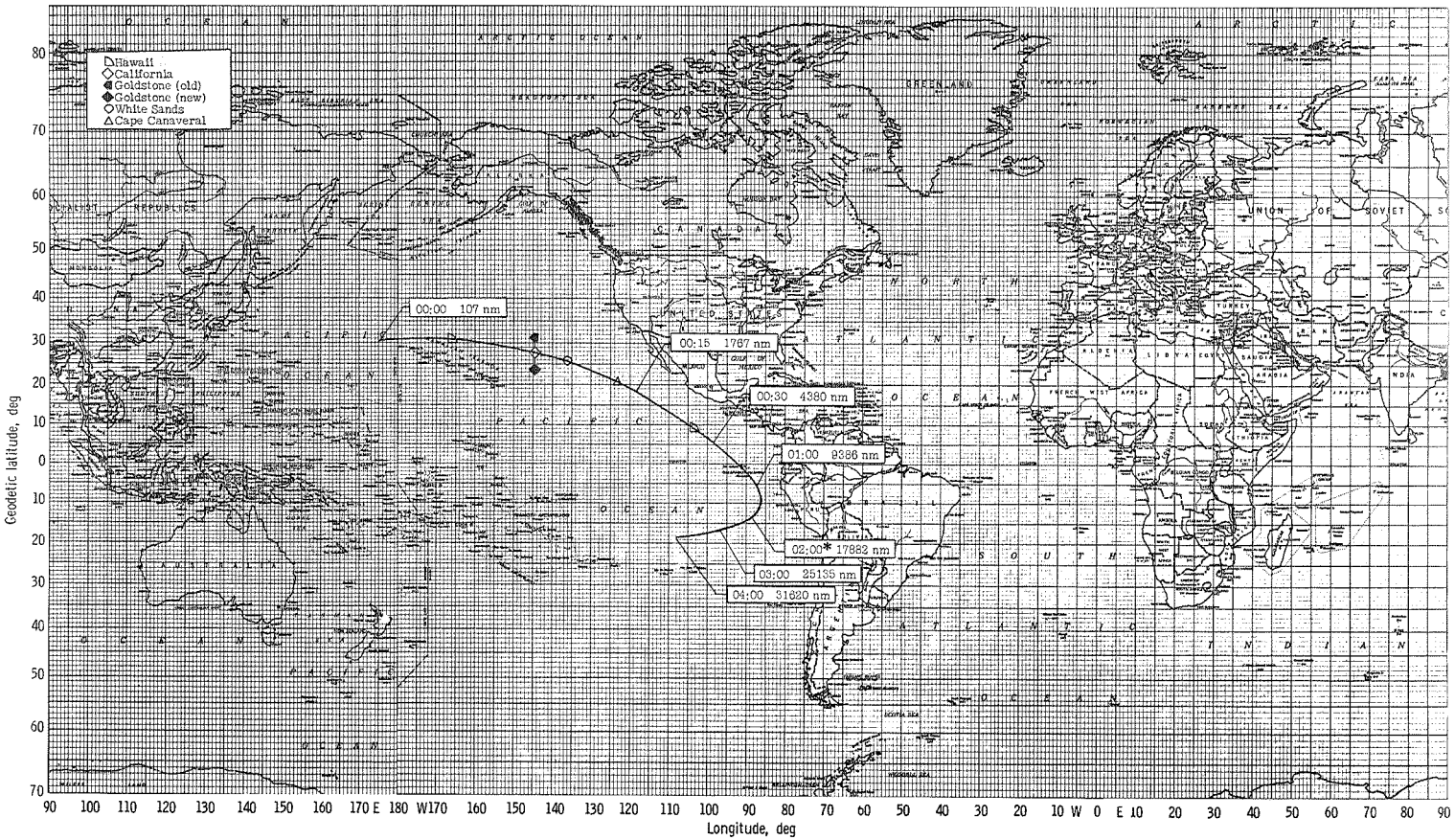
(xx) Pacific injection from third orbit, inclination angle 28.5°, launch azimuth 90°, lunar declination 0°.

Figure 14. - Continued.



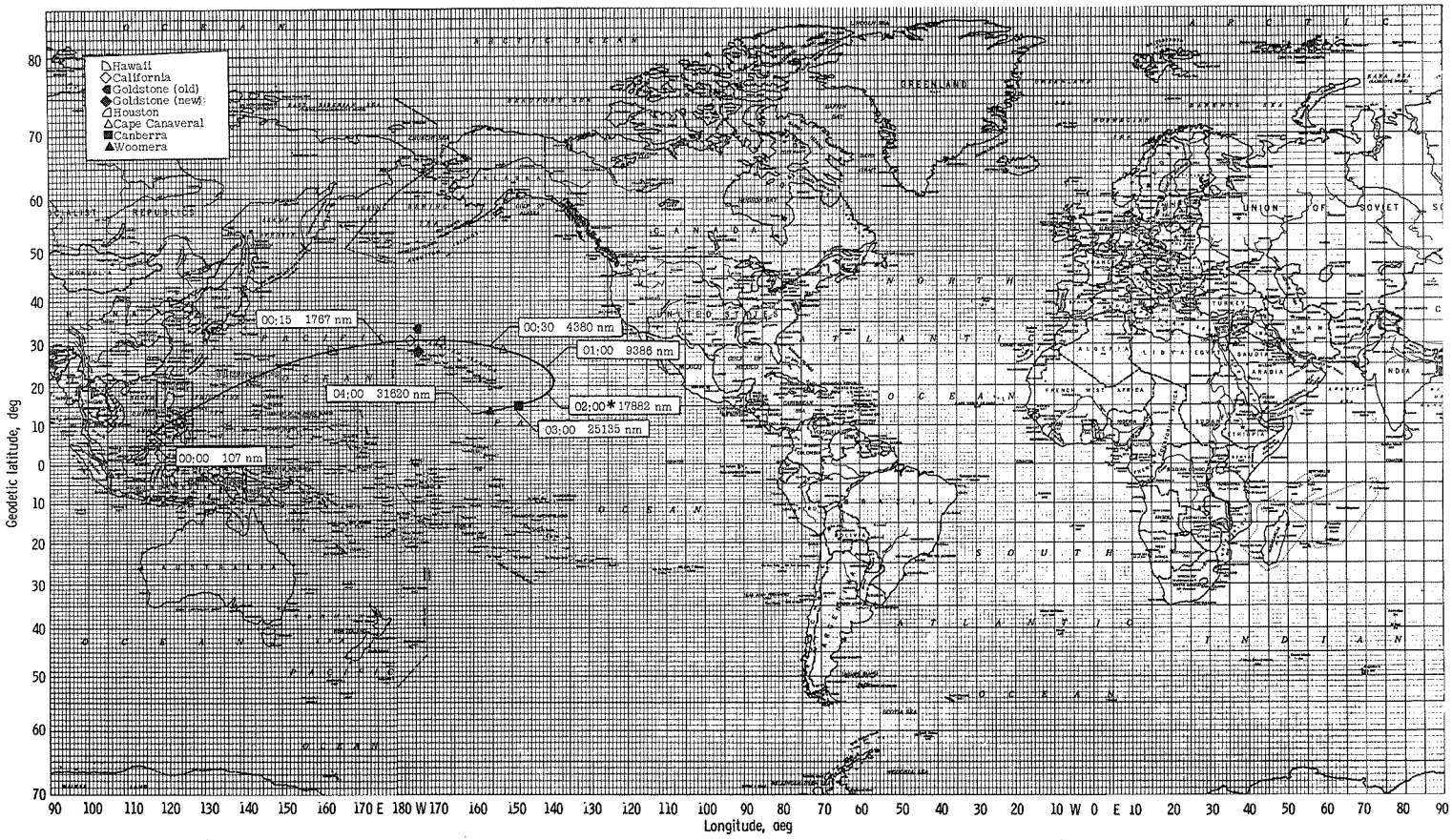
(yy) Pacific injection from third orbit, inclination angle 28.5°, launch azimuth 90°, lunar declination 27.5°.

Figure 14. - Continued.



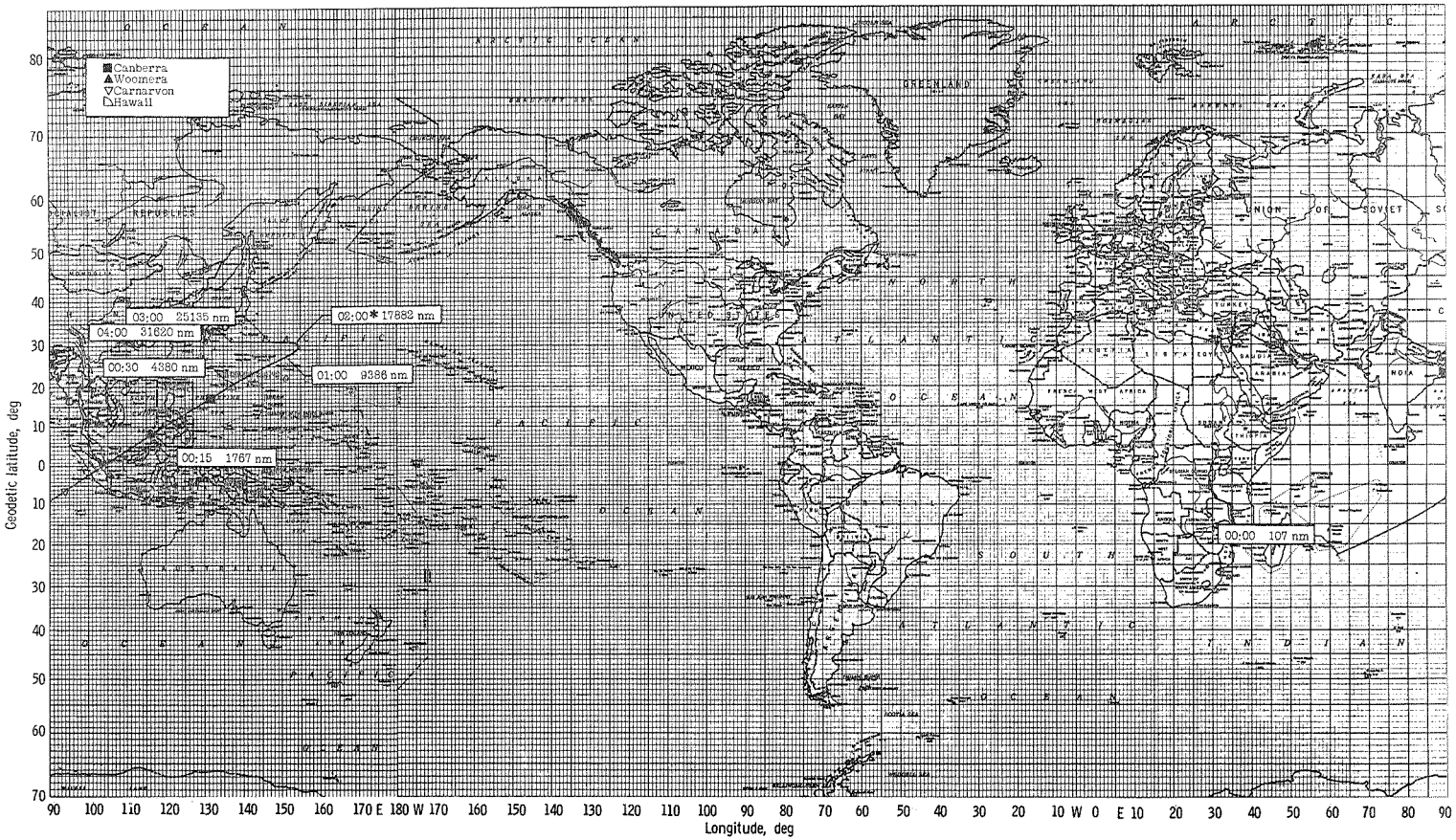
(zz) Pacific injection from third orbit, inclination angle 31°, launch azimuth 102.7°, lunar declination -27.5°.

Figure 14. - Continued.



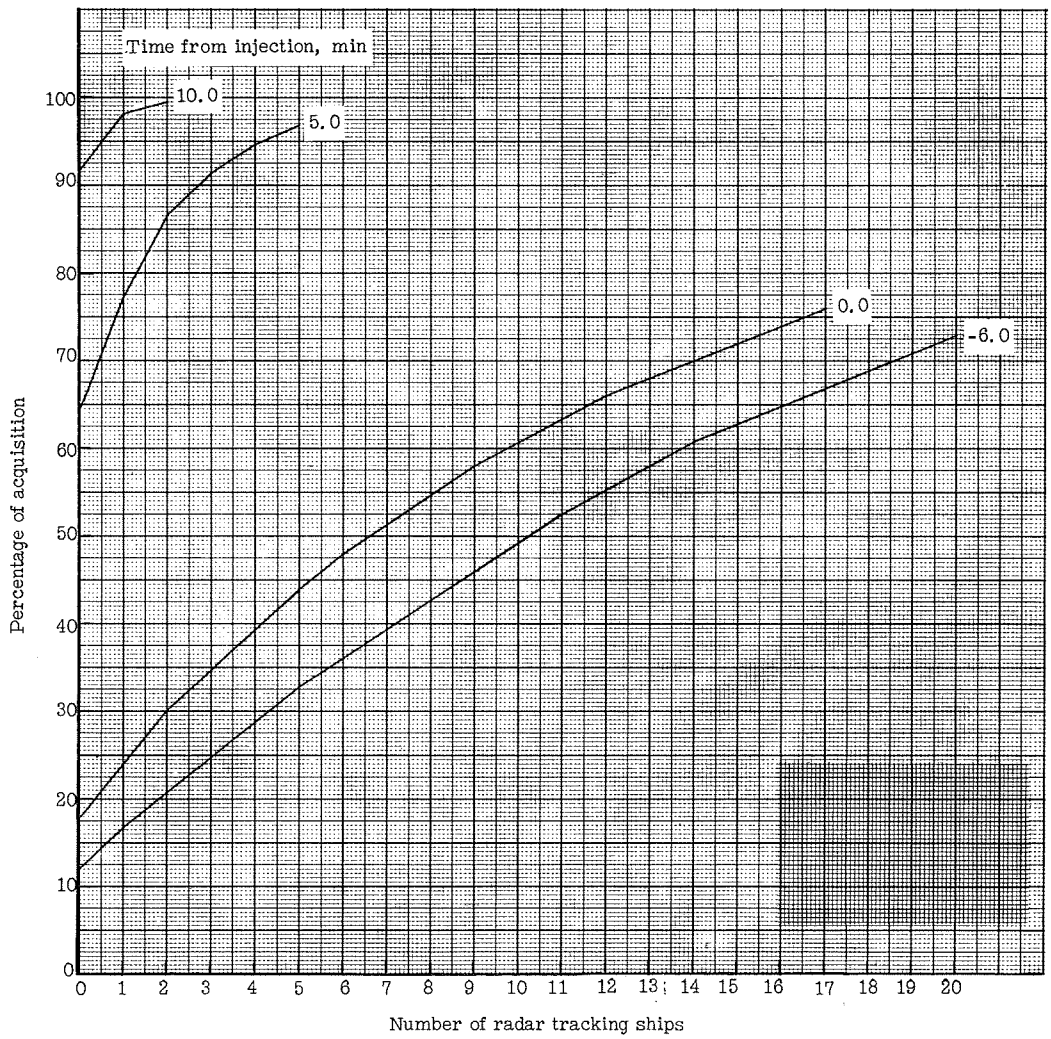
(aaa) Pacific injection from third orbit, inclination angle 31°, launch azimuth 102.7°, lunar declination 0°.

Figure 14. - Continued.



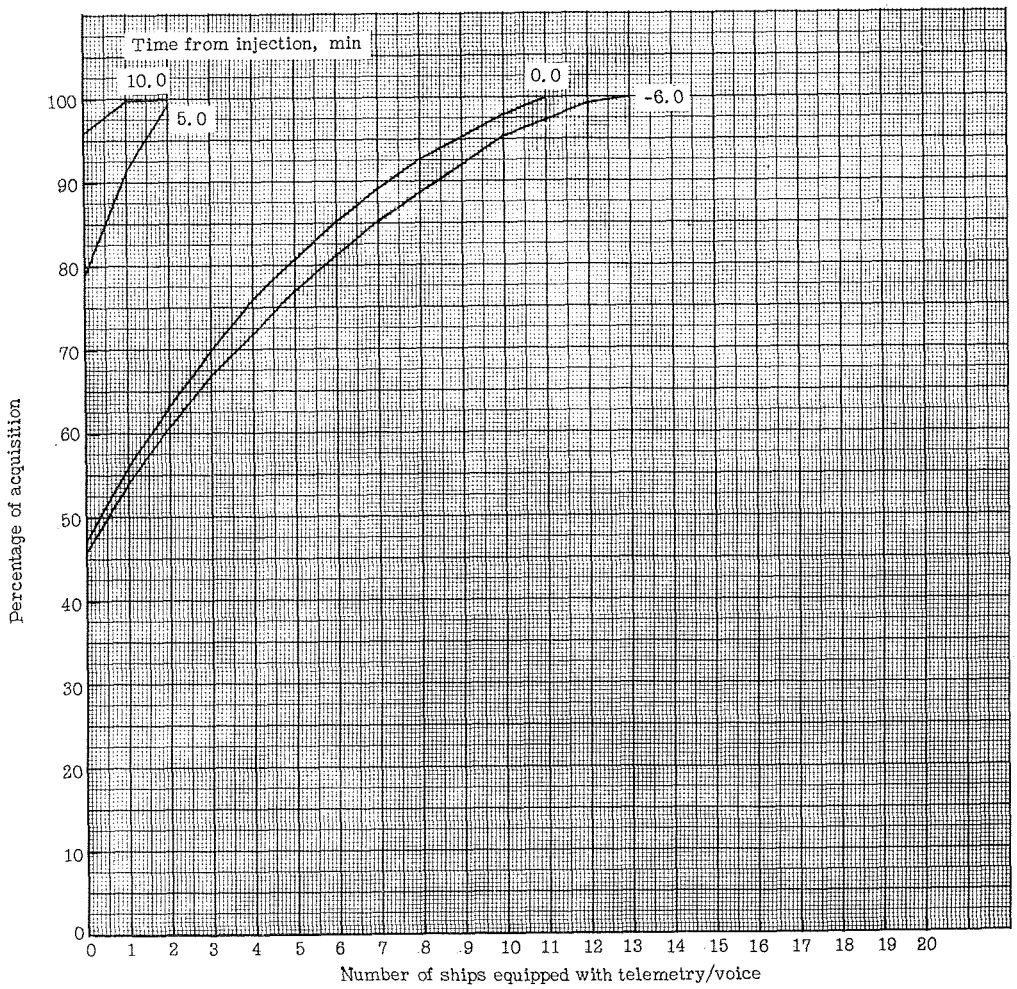
(bbb) Pacific injection from third orbit, inclination angle 31°, launch azimuth 102.7°, lunar declination 27.5°.

Figure 14. - Concluded.



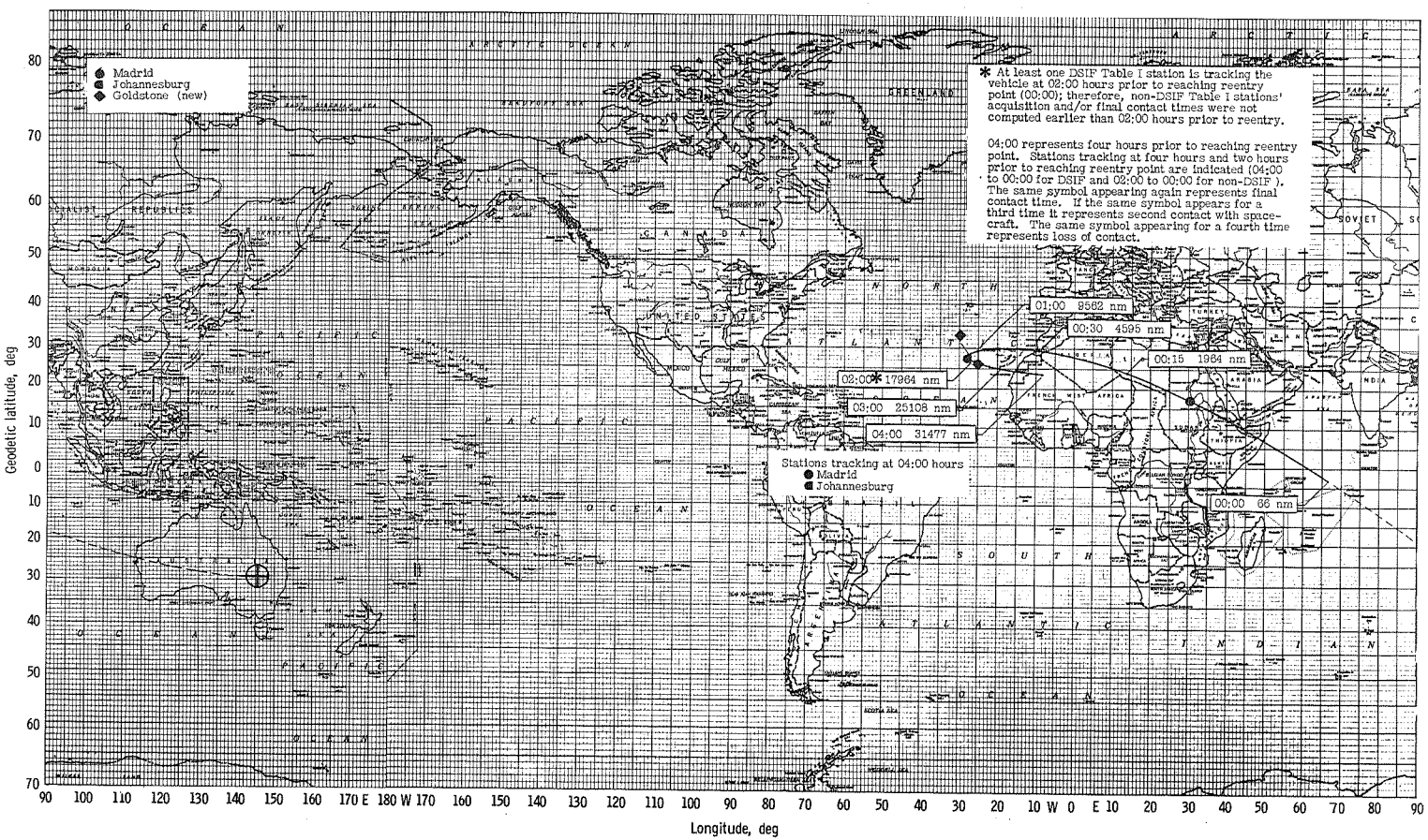
(a) Ships necessary (in addition to Table I stations) to obtain a given percentage of radar acquisition and tracking for injections from first, second, and third earth parking orbits.

Figure 15. - Number of tracking ships versus percentage of acquisition.



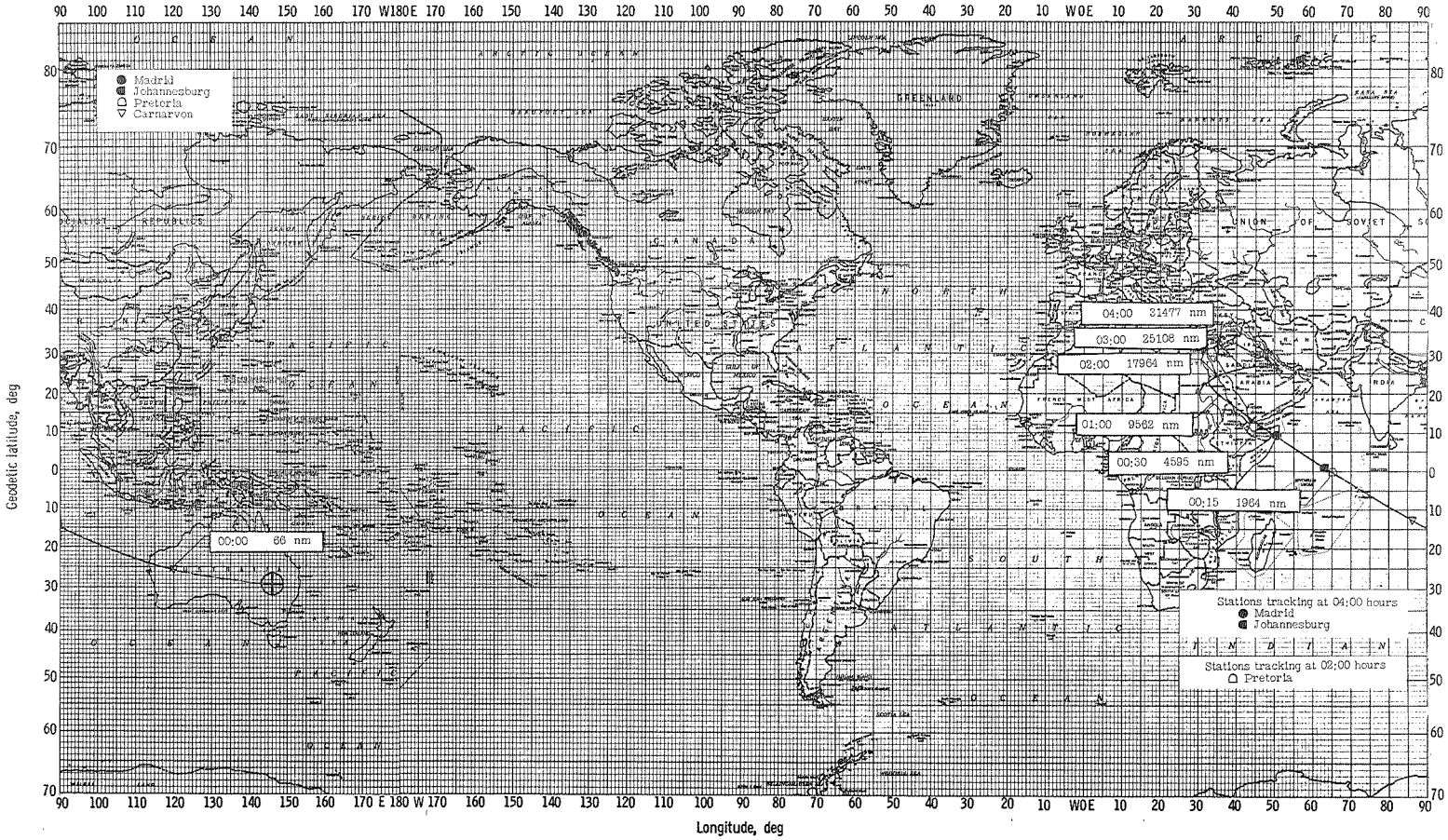
(b) Ships necessary (in addition to Table I stations; Kano, Nigeria; Zanzibar, Tanganyika; Guaymas, Mexico; and Canton Island) to obtain a given percentage of telemetry/voice acquisition for injections from first, second, and third earth parking orbits.

Figure 15. - Concluded.



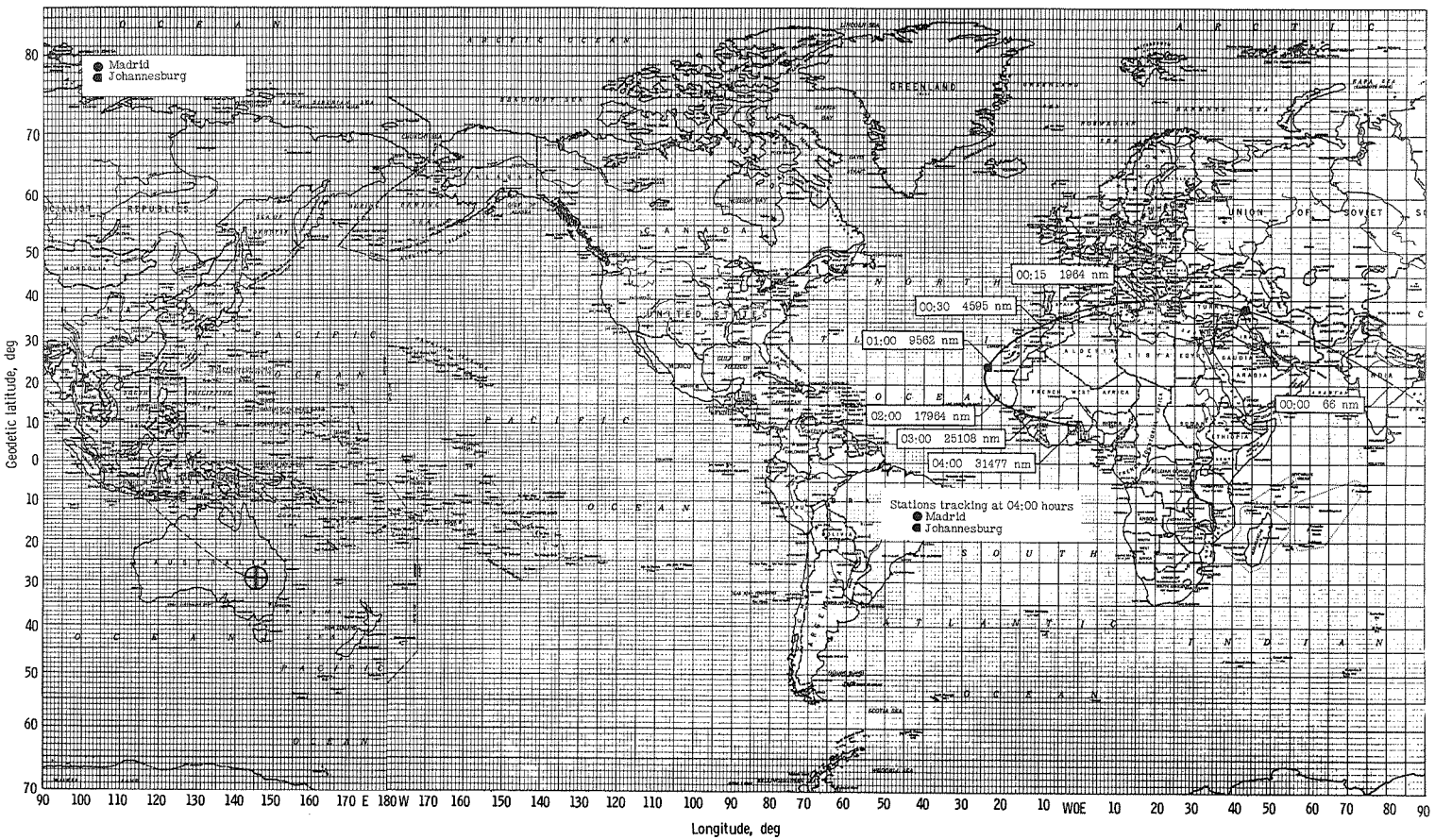
(a) 5000 nm reentry range for Australian landing, inclination = 29°.

Figure 16. - Transearth return trajectory showing radar coverage.



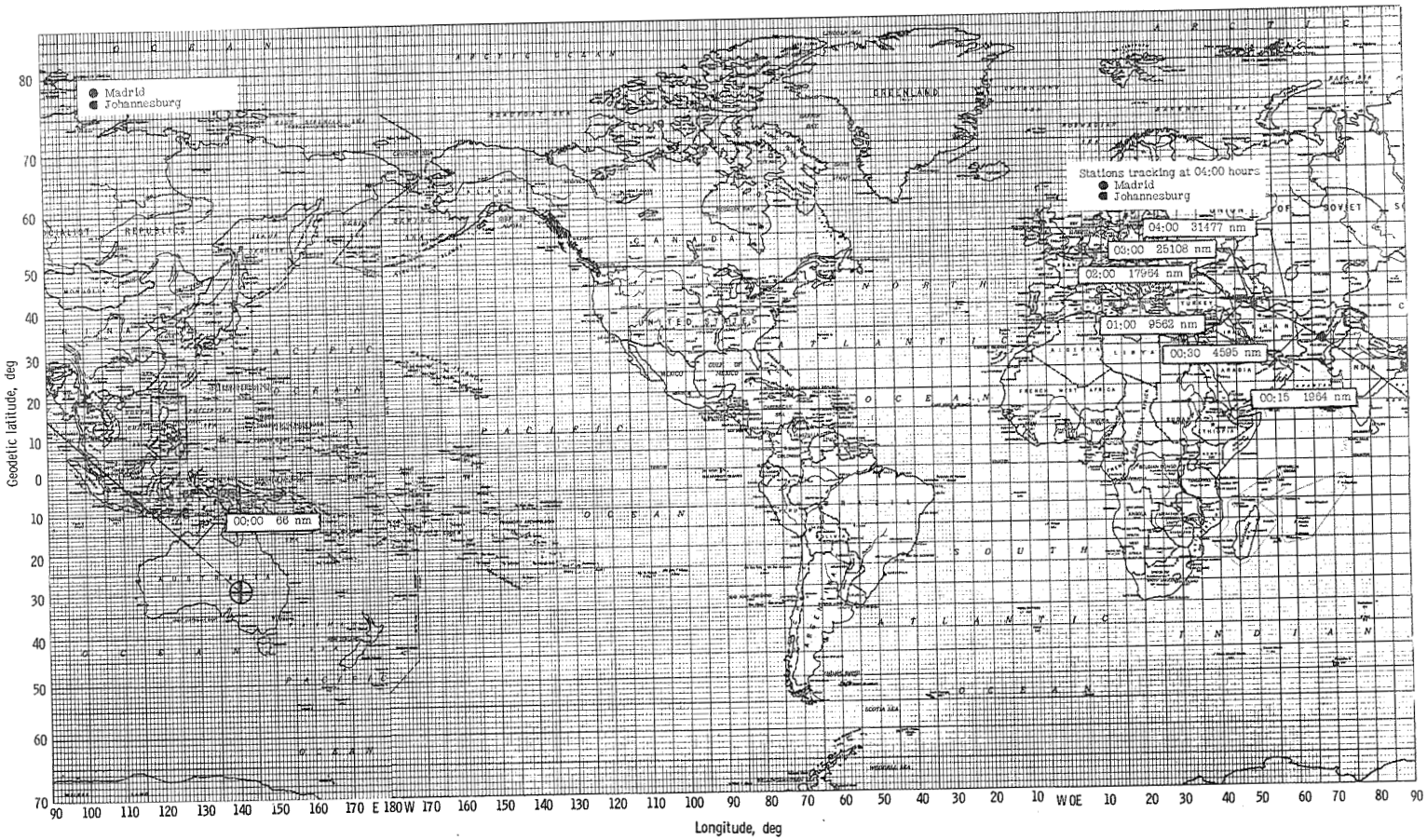
(b) 1650 nm minimum reentry range for Australian landing, inclination = 29°.

Figure 16.- Continued.



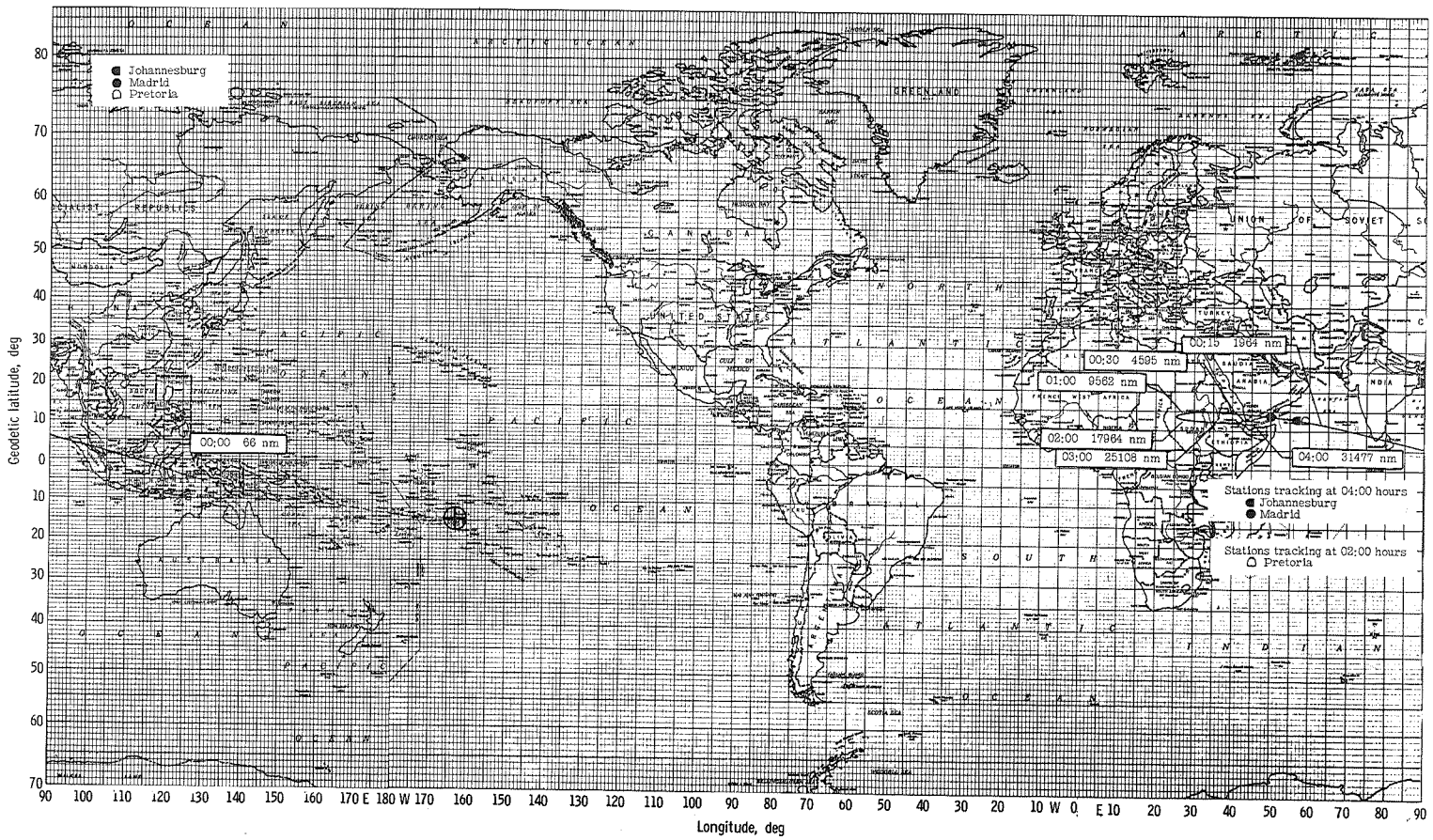
(c) 5000 nm reentry range for Australian landing, inclination = 40°.

Figure 16. - Continued.



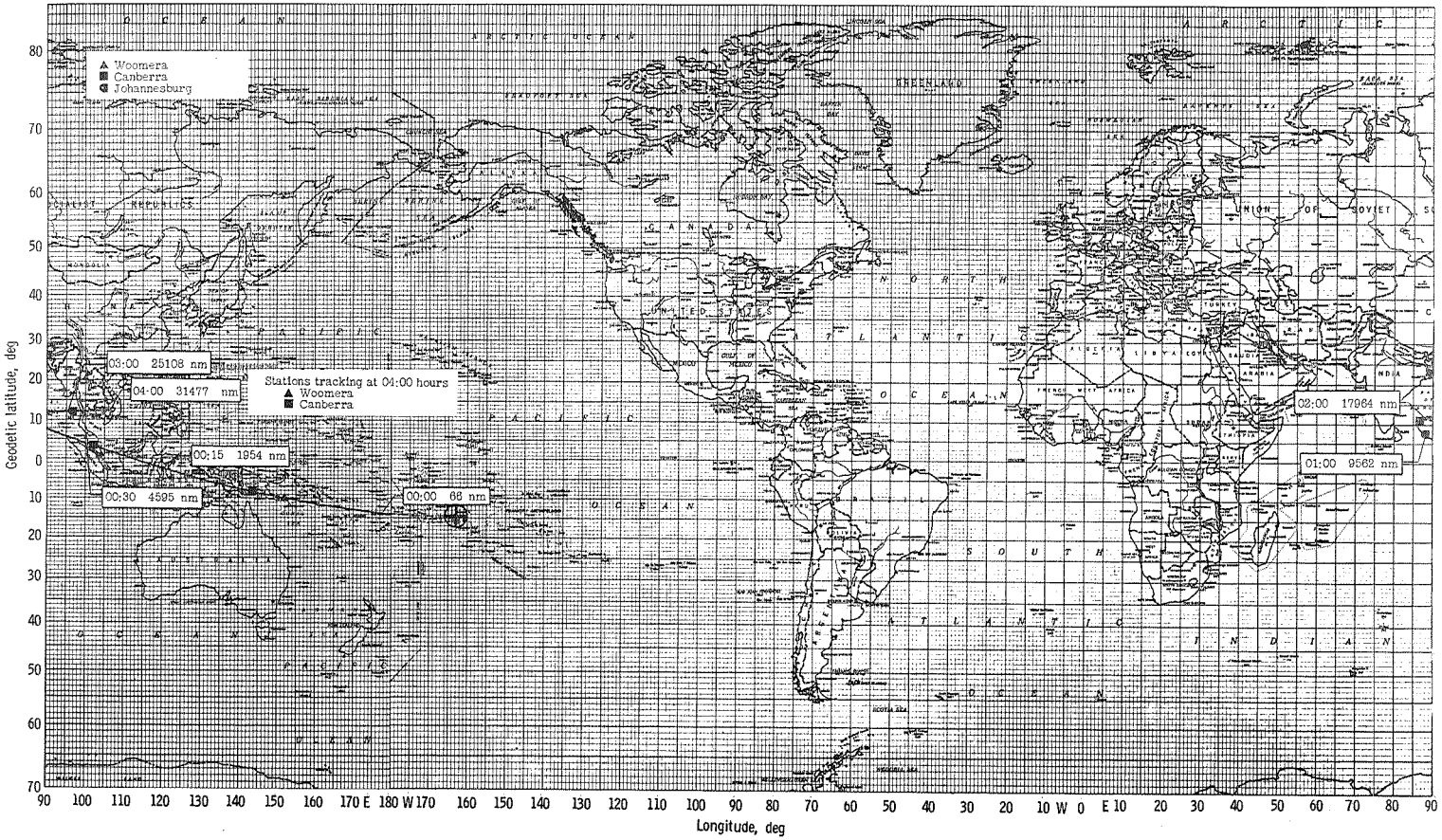
(d) 1200 nm reentry range for Australian landing, inclination = 40°.

Figure 16. - Continued.



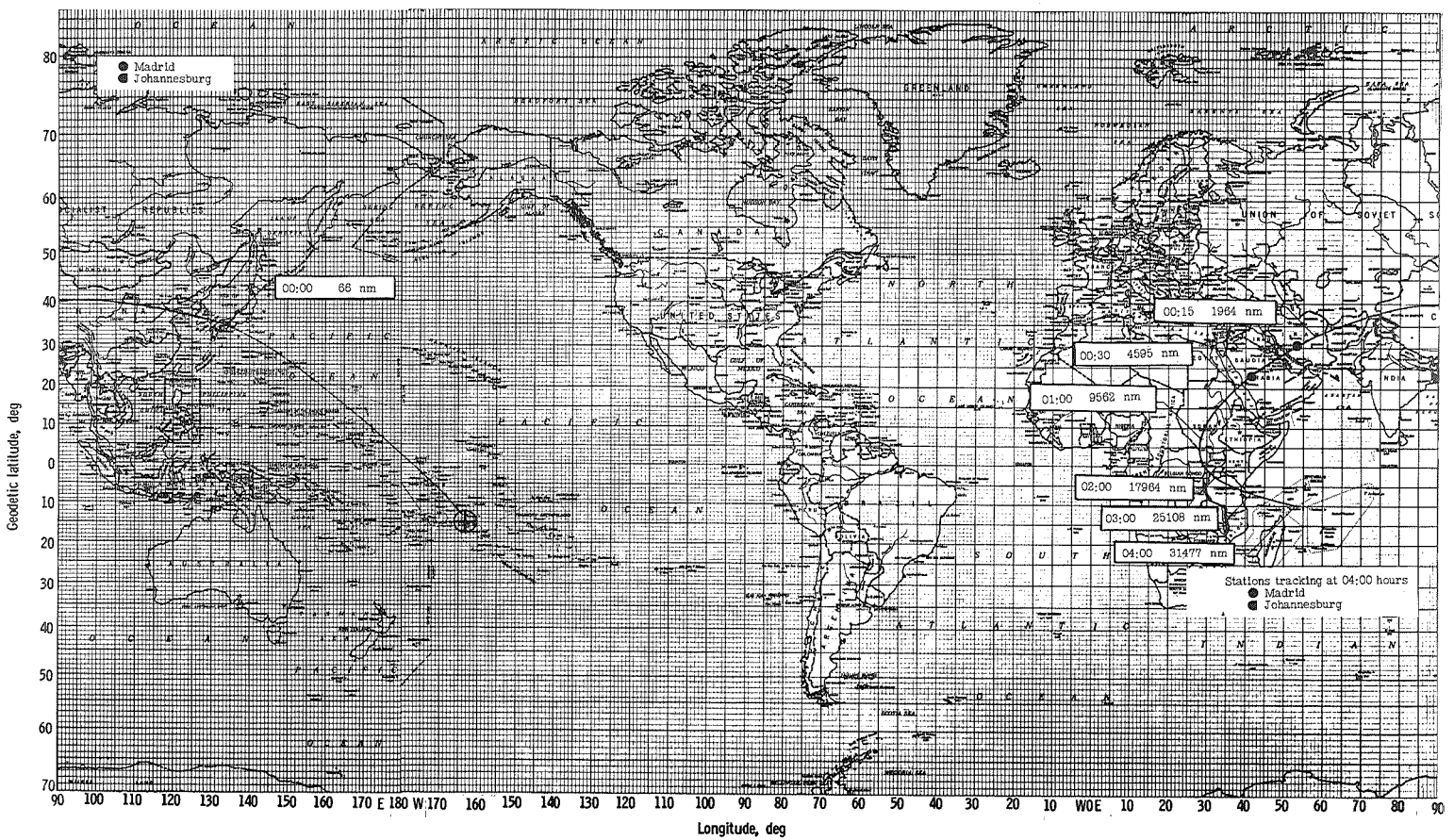
(e) 5000 nm reentry range for Samoa Island landing, inclination = 14.5°.

Figure 16. - Continued.



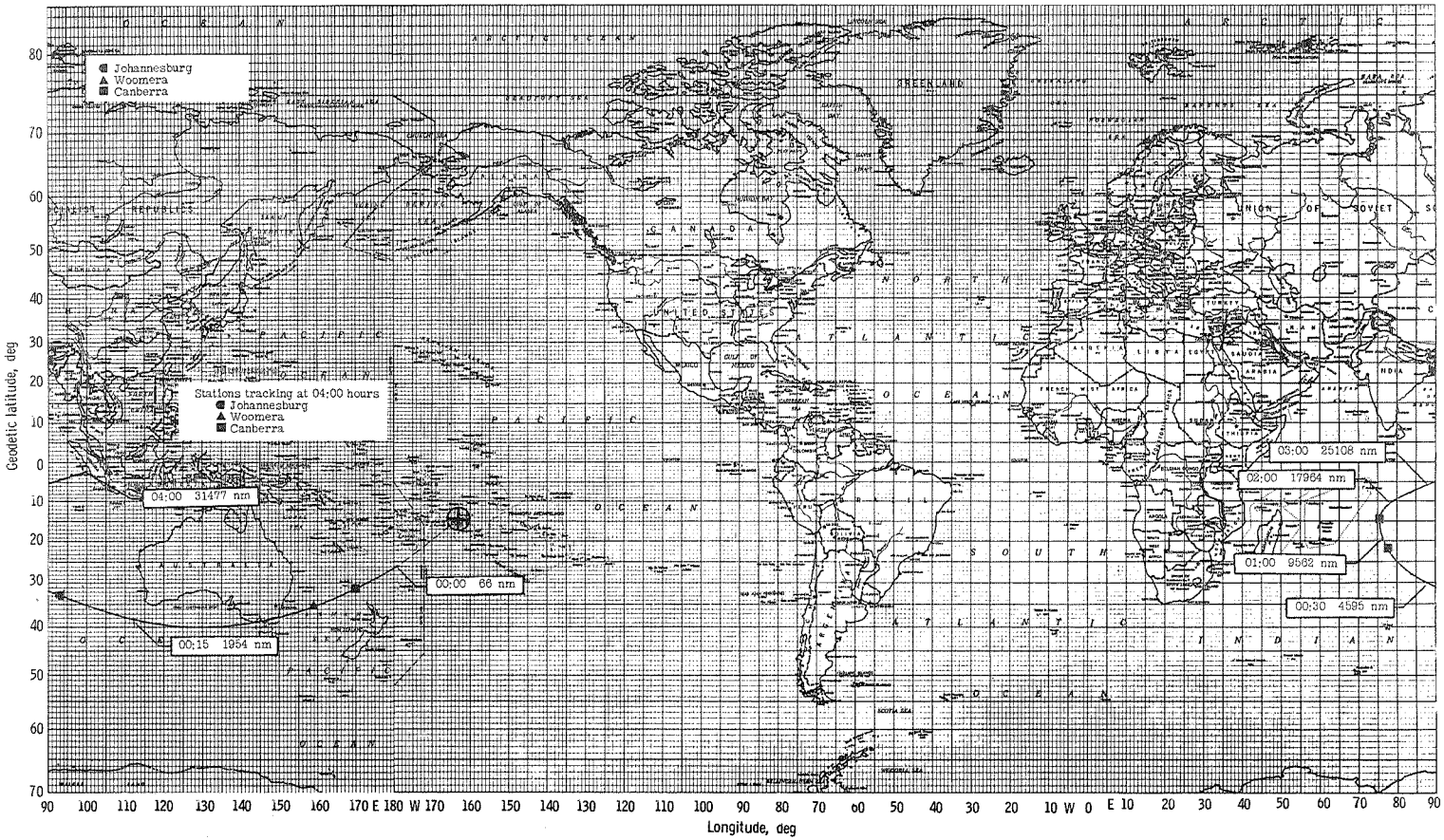
(f) 1200 nm reentry range for Samoa Island landing, inclination = 14.5°.

Figure 16. - Continued.



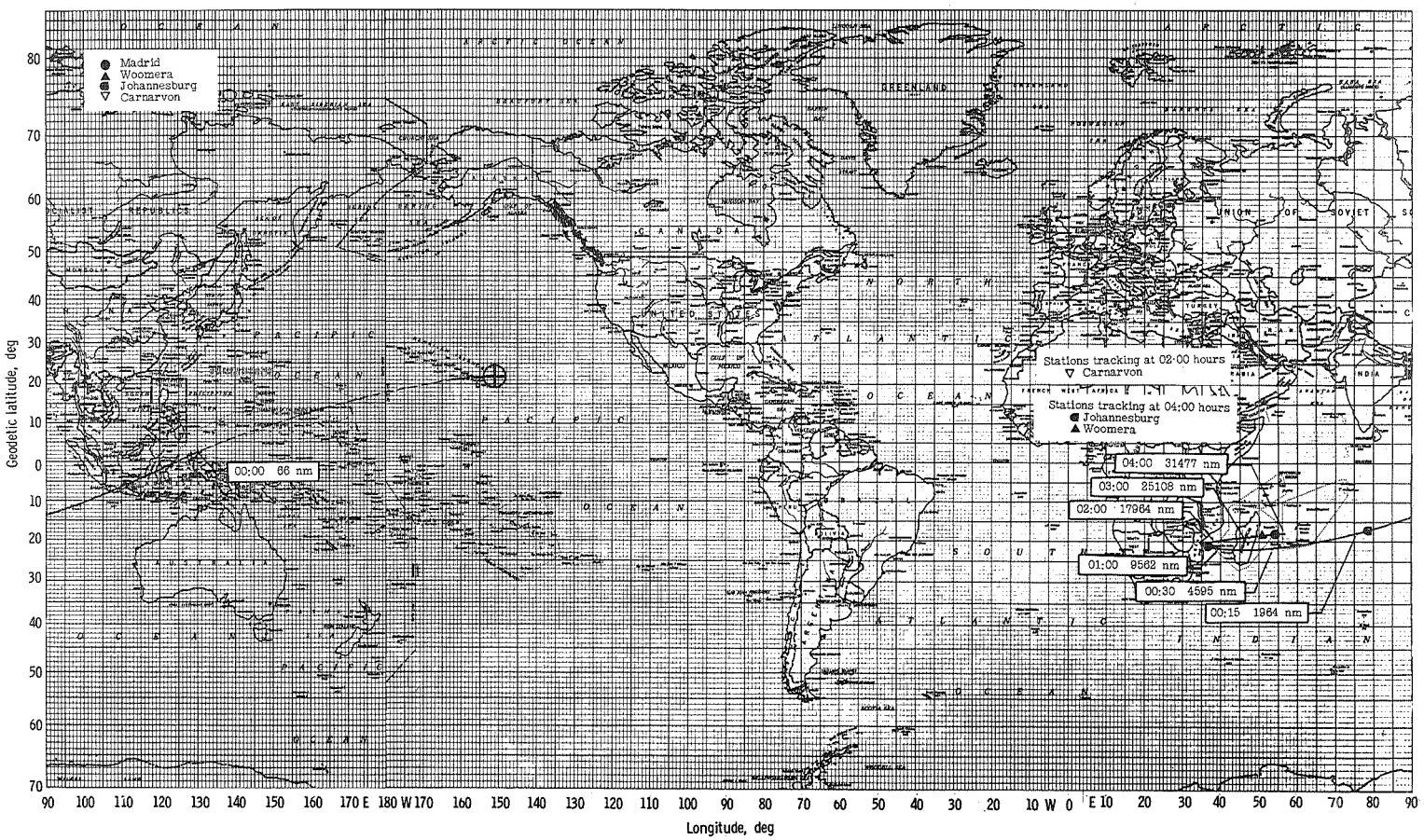
(g) 5000 nm reentry range for Samoa Island landing, inclination = 40°.

Figure 16. - Continued



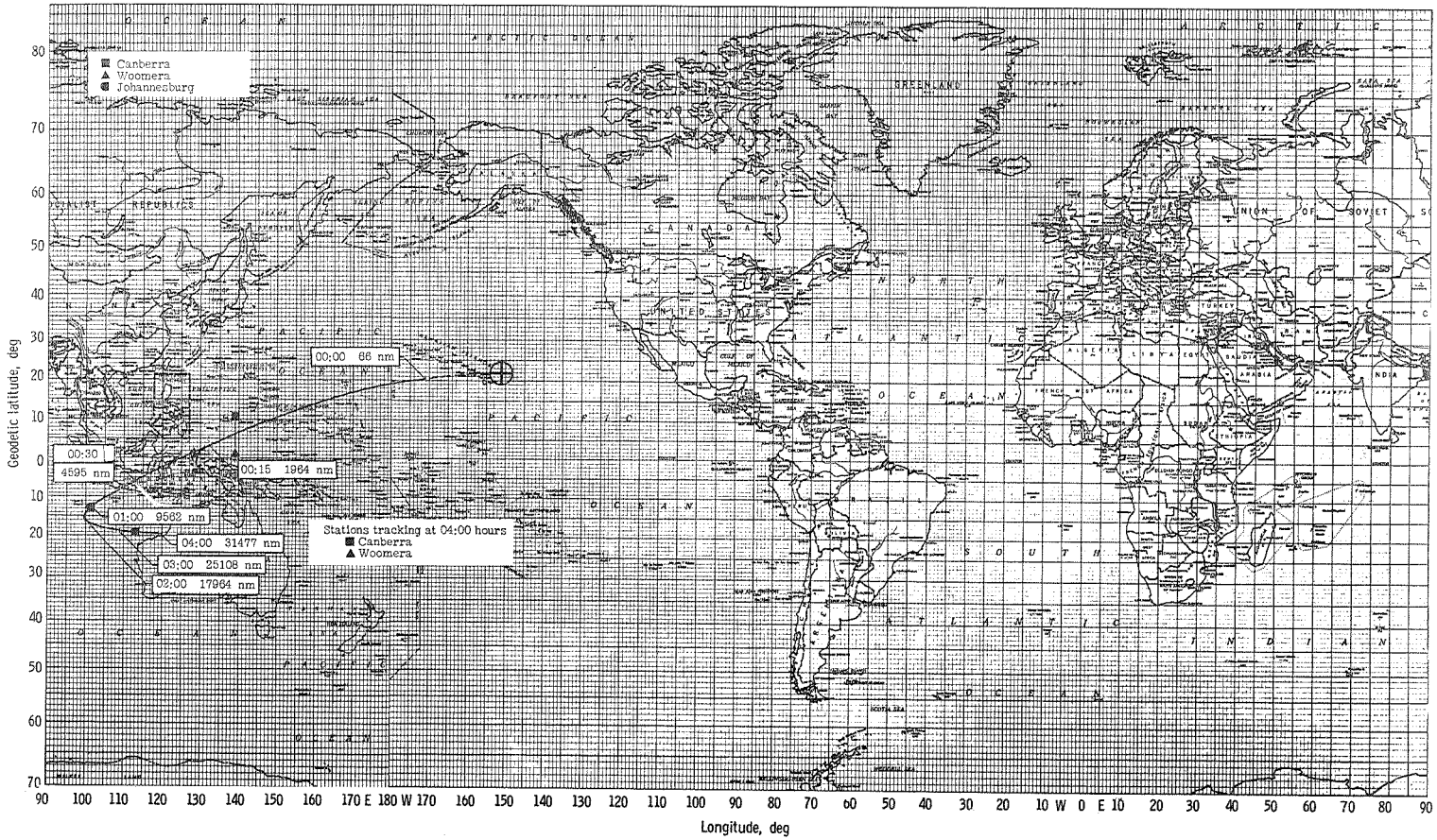
(h) 1200 nm reentry range for Samoa Island landing, inclination = 40°.

Figure 16. - Continued.



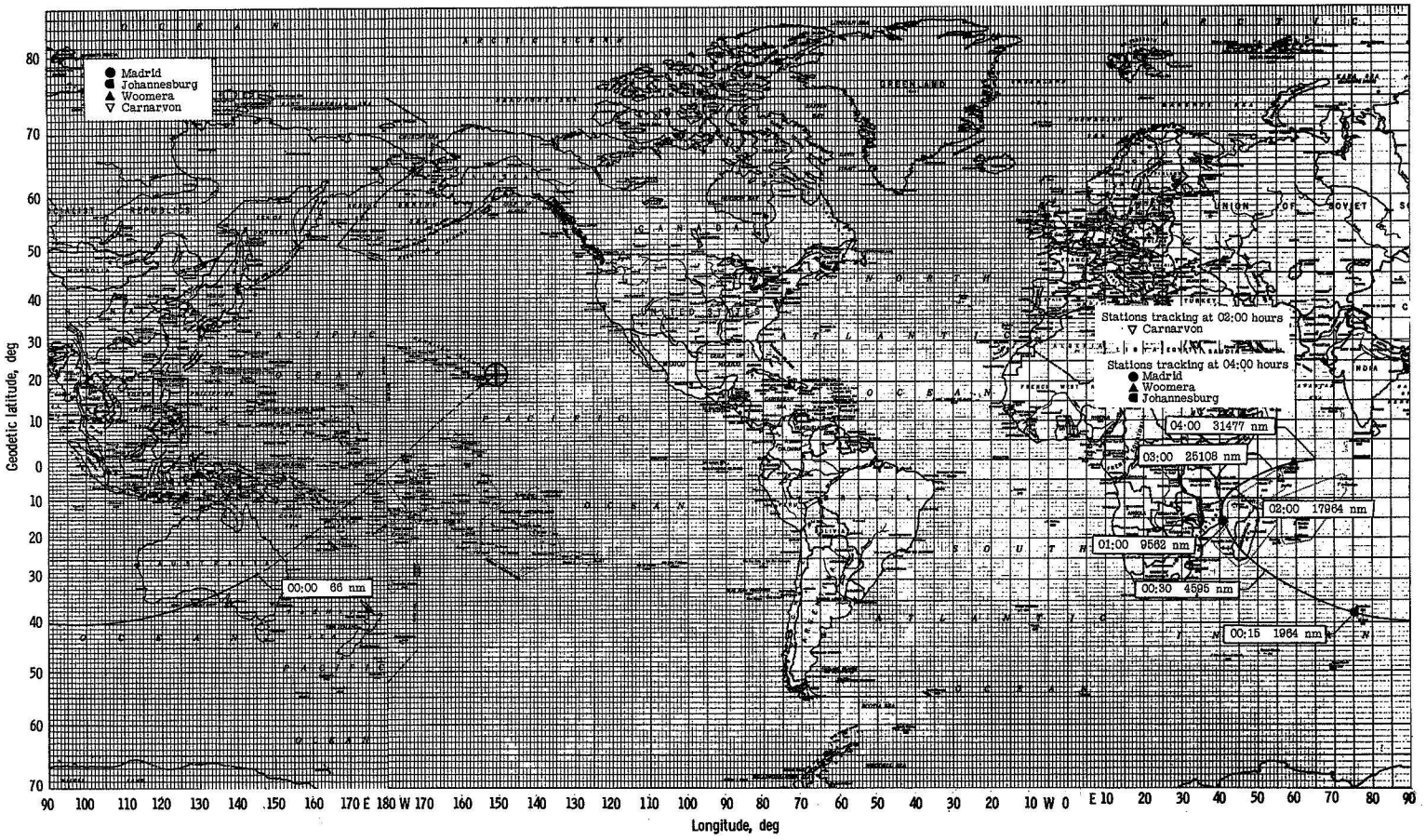
(i) 5000 nm reentry range for Hawaiian landing, inclination = 22°.

Figure 16. - Continued.



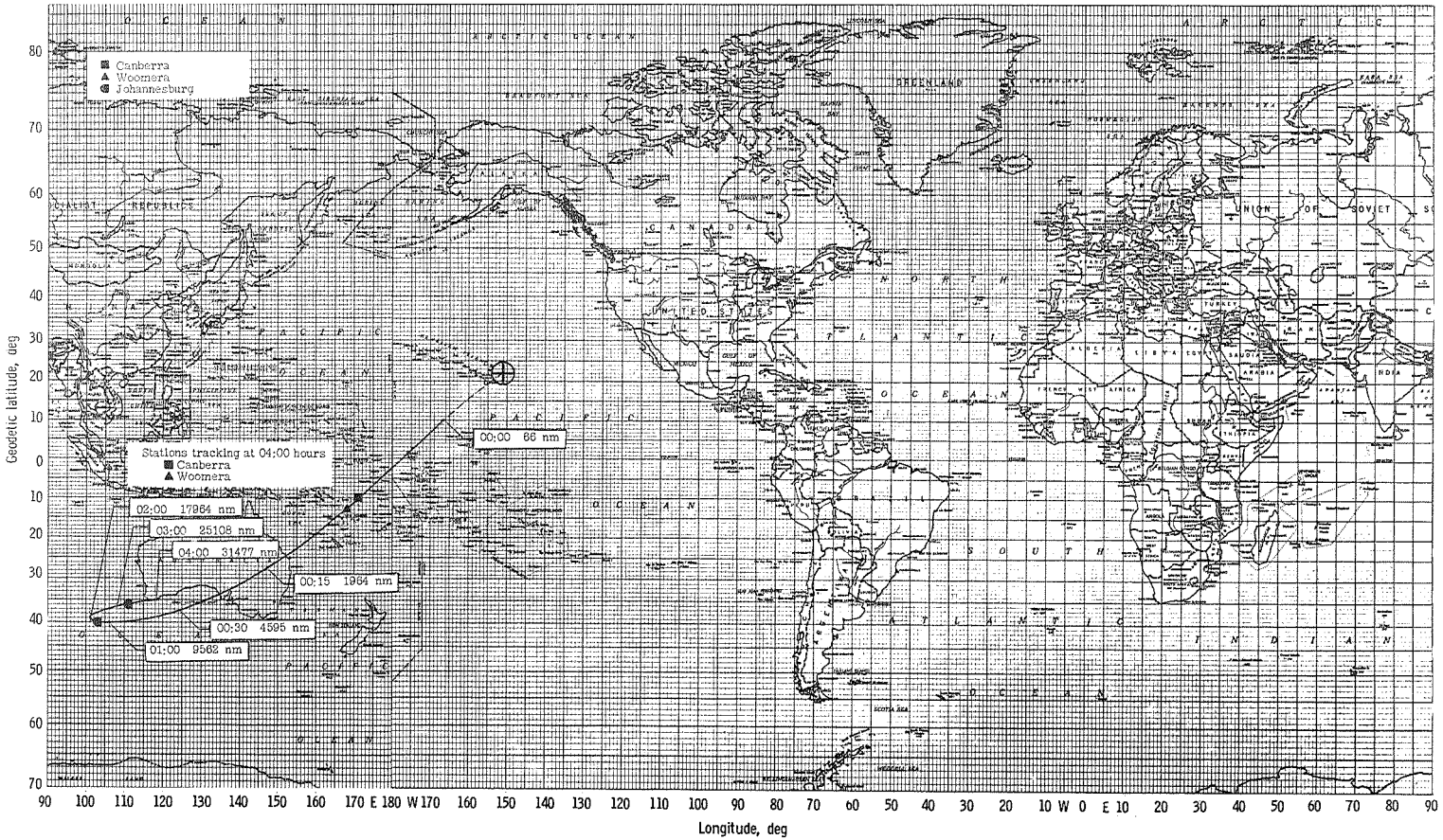
(j) 1200 nm reentry range for Hawaiian landing, inclination = 22°.

Figure 16. - Continued.



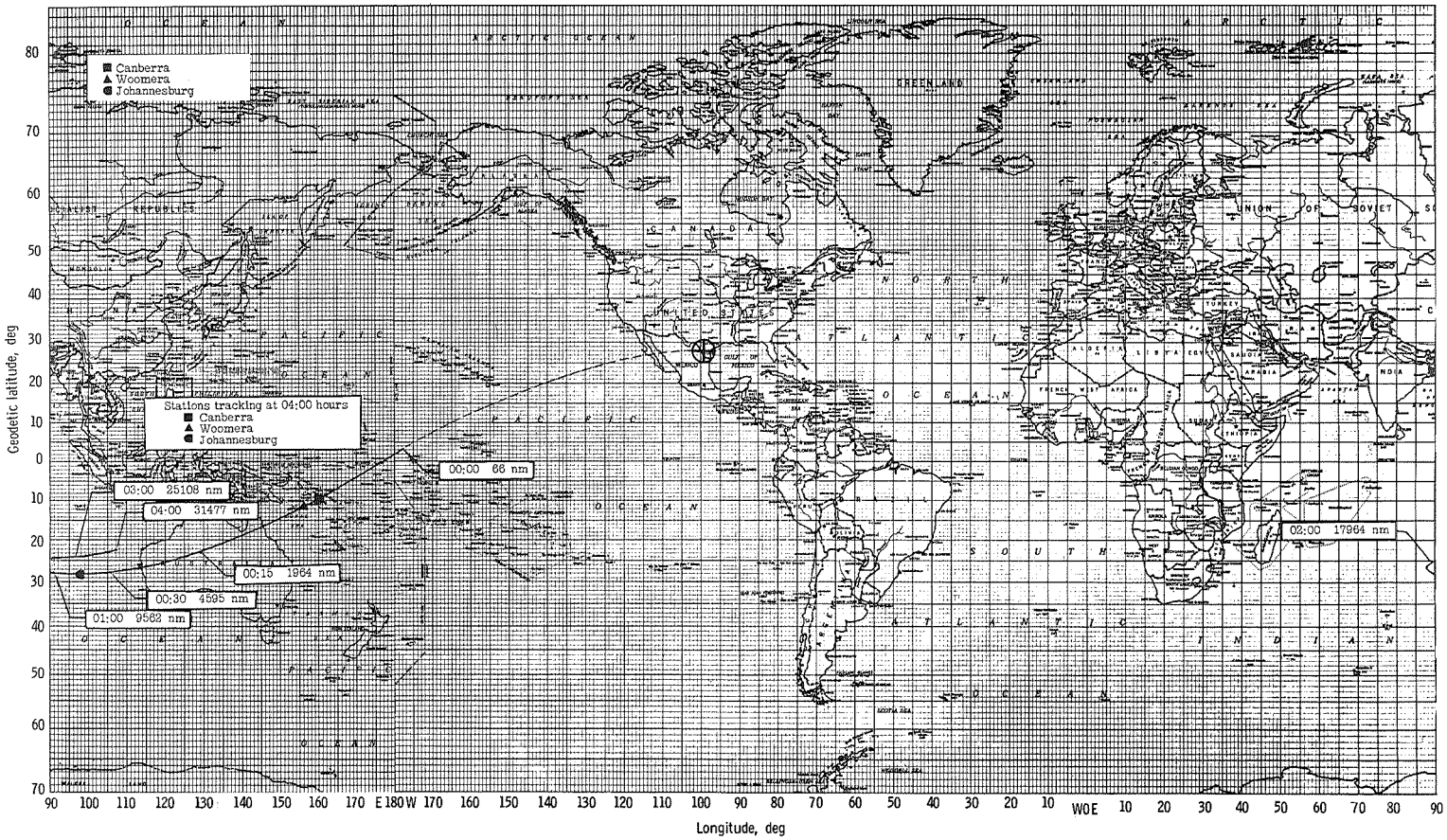
(k) 5000 nm reentry range for Hawaiian landing, inclination = 40°.

Figure 16. - Continued.



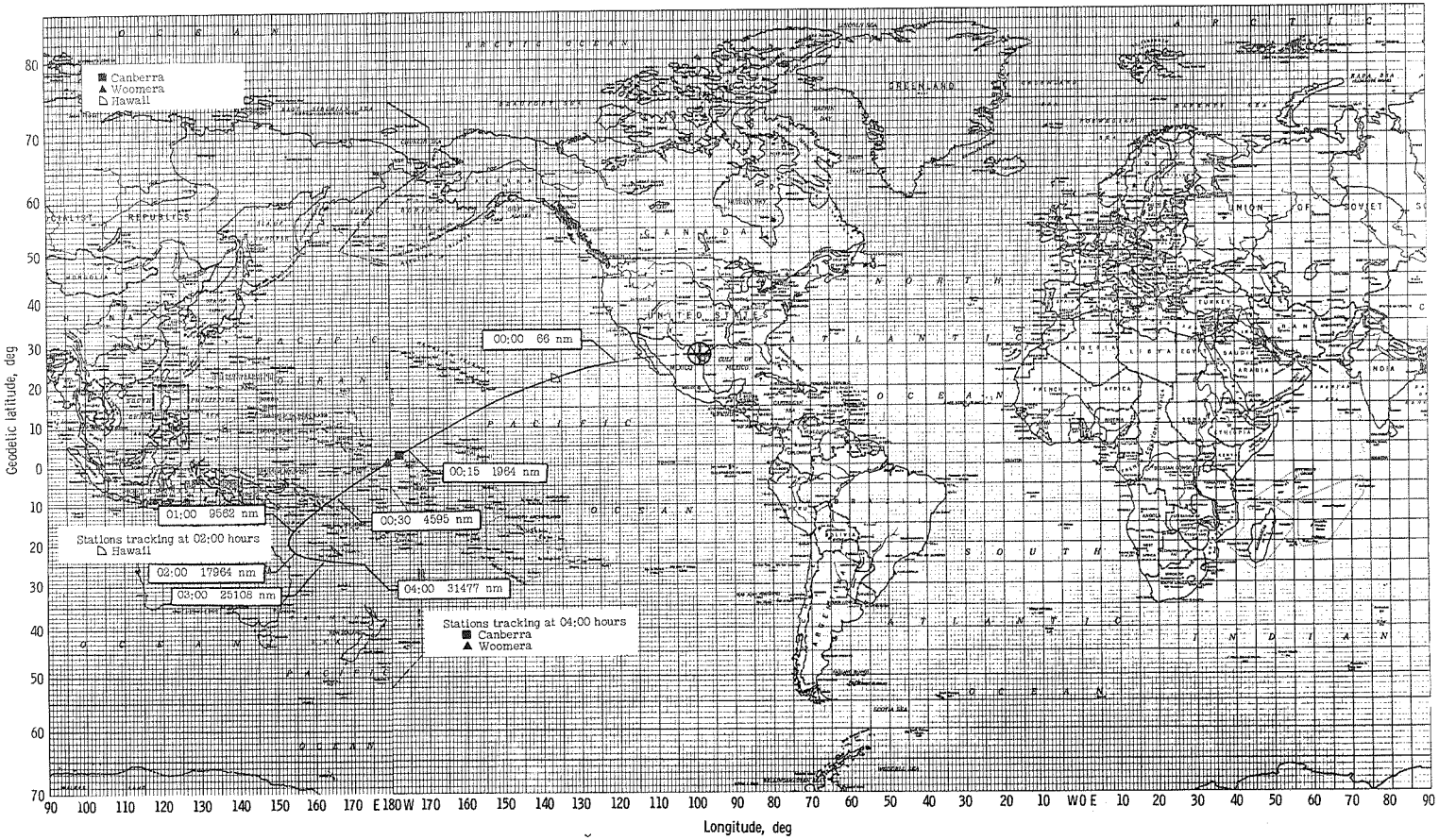
(l) 1200 nm reentry range for Hawaiian landing, inclination = 40°.

Figure 16. - Continued.



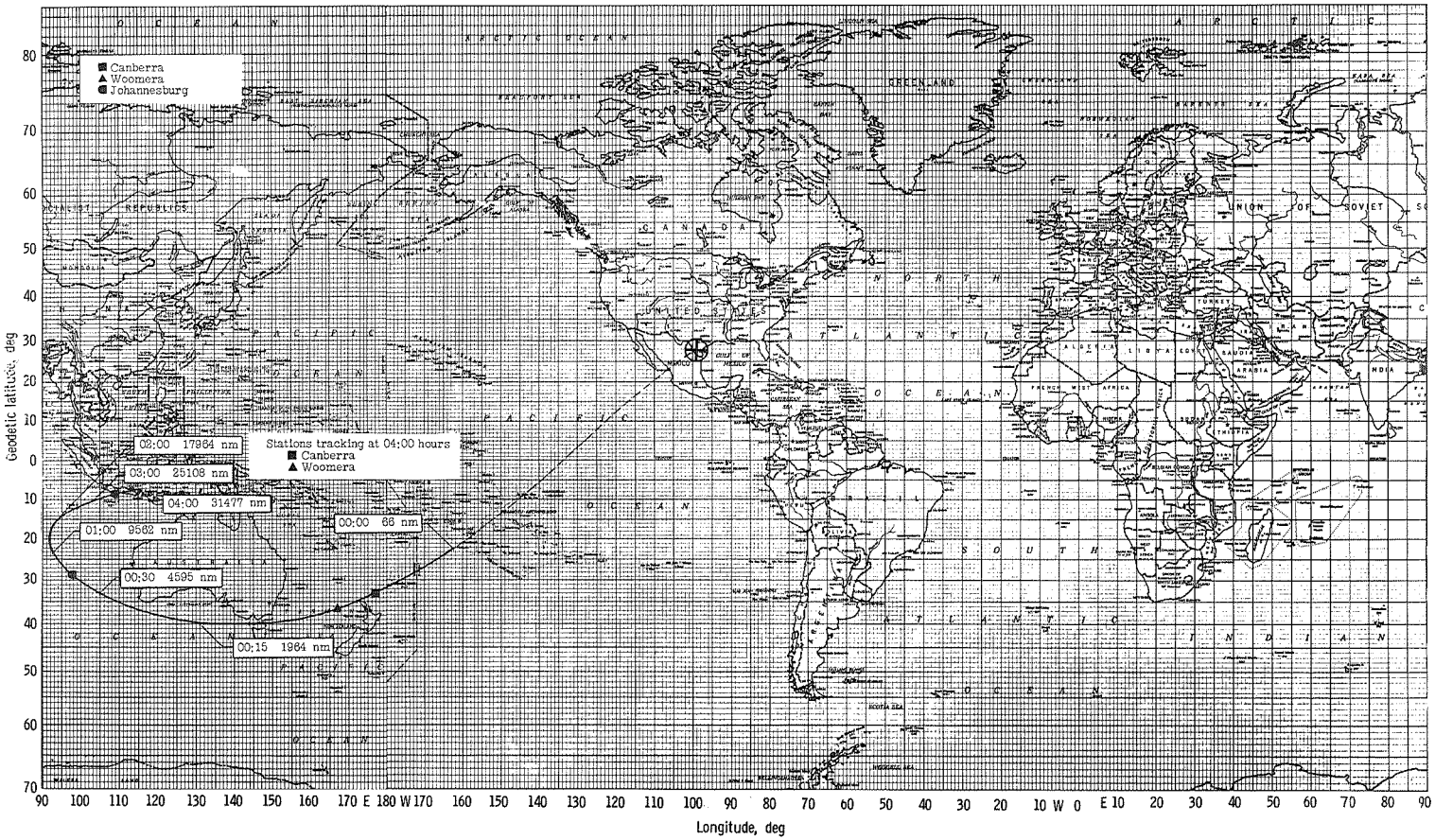
(m) 5000 nm reentry range for Southern United States landing, inclination = 28°.

Figure 16. - Continued.



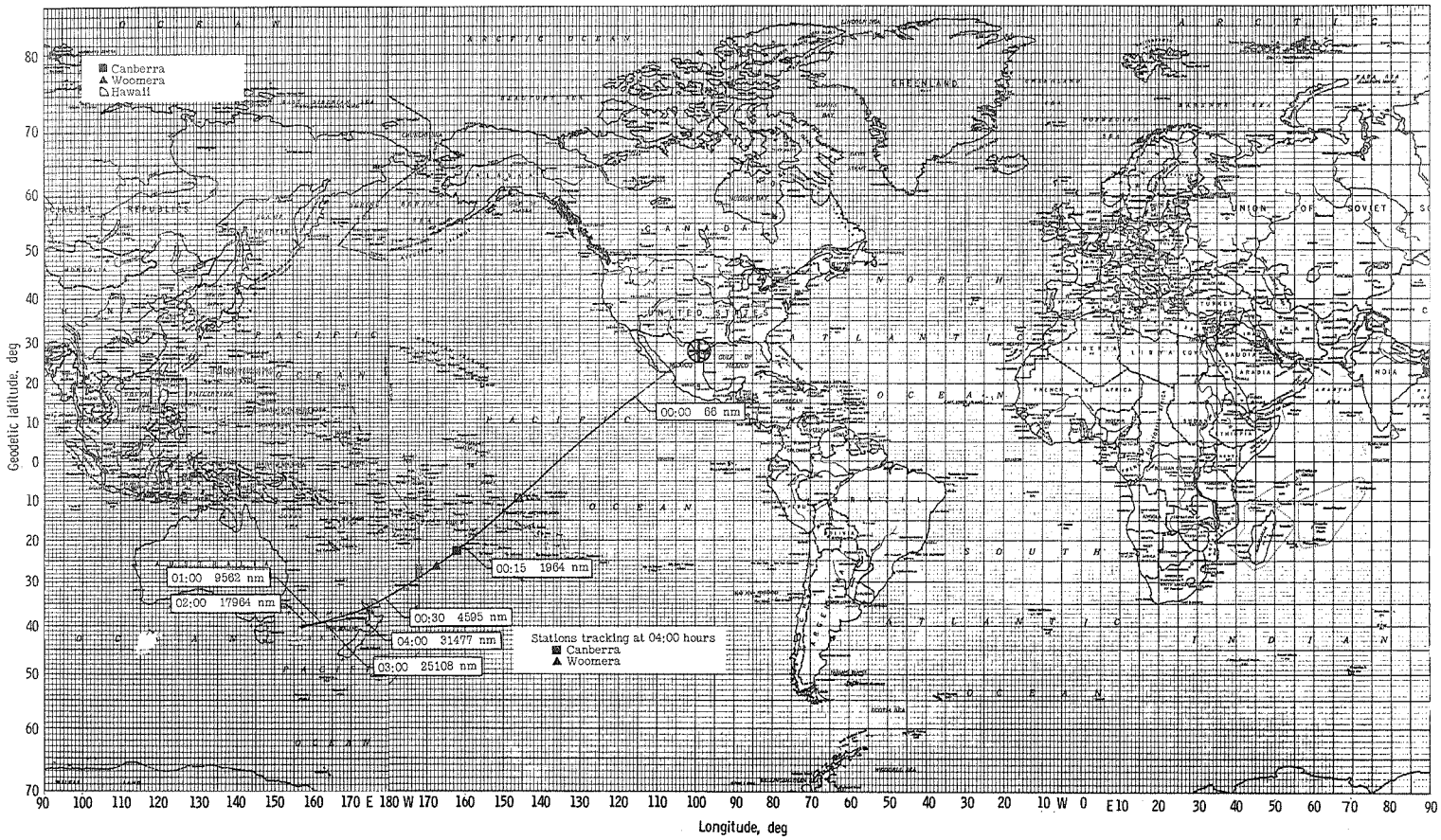
(n) 1200 nm reentry range for Southern United States landing, inclination = 28°.

Figure 16. - Continued.



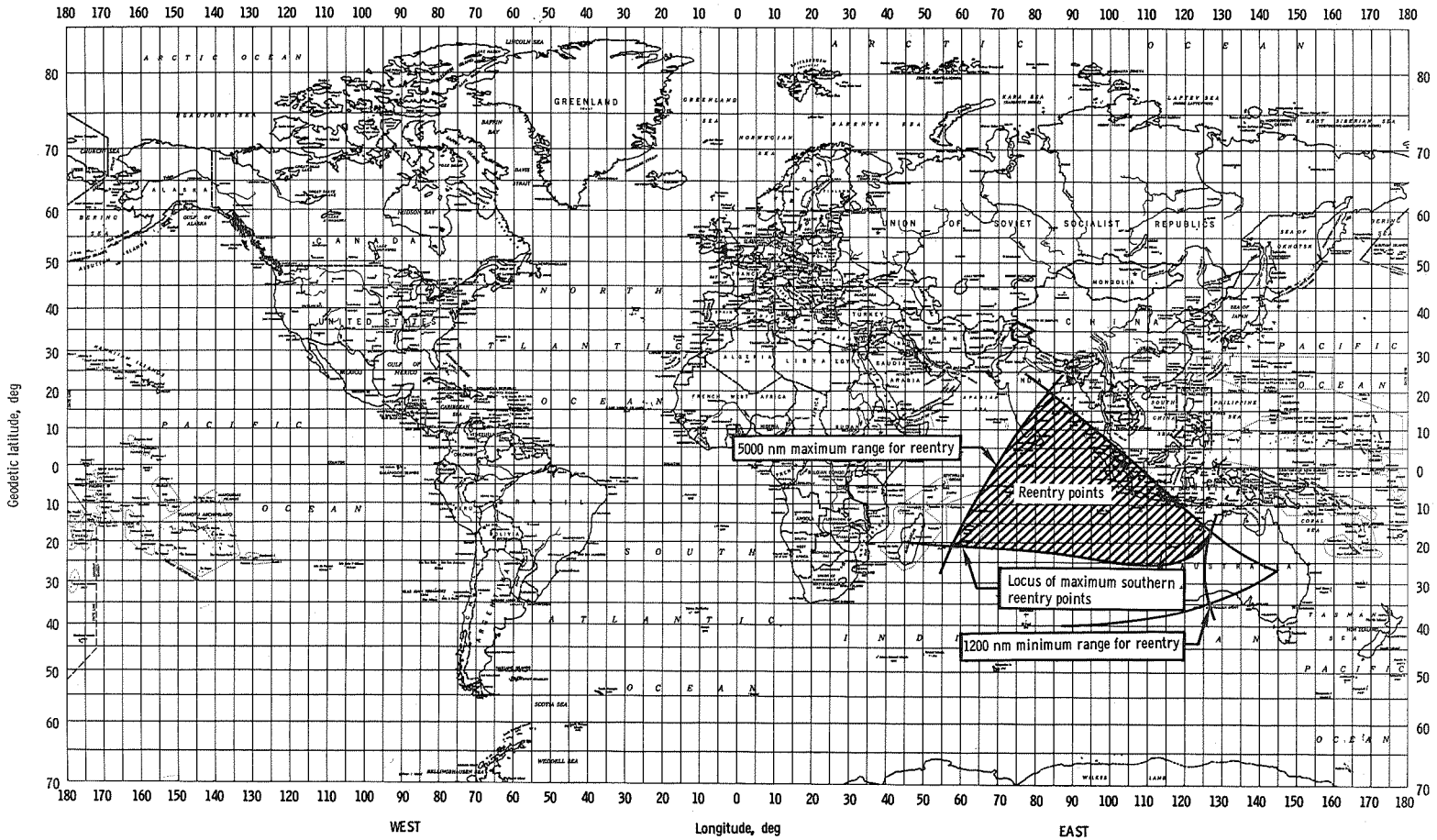
(o) 5000 nm reentry range for Southern United States landing, inclination = 40°.

Figure 16. - Continued.



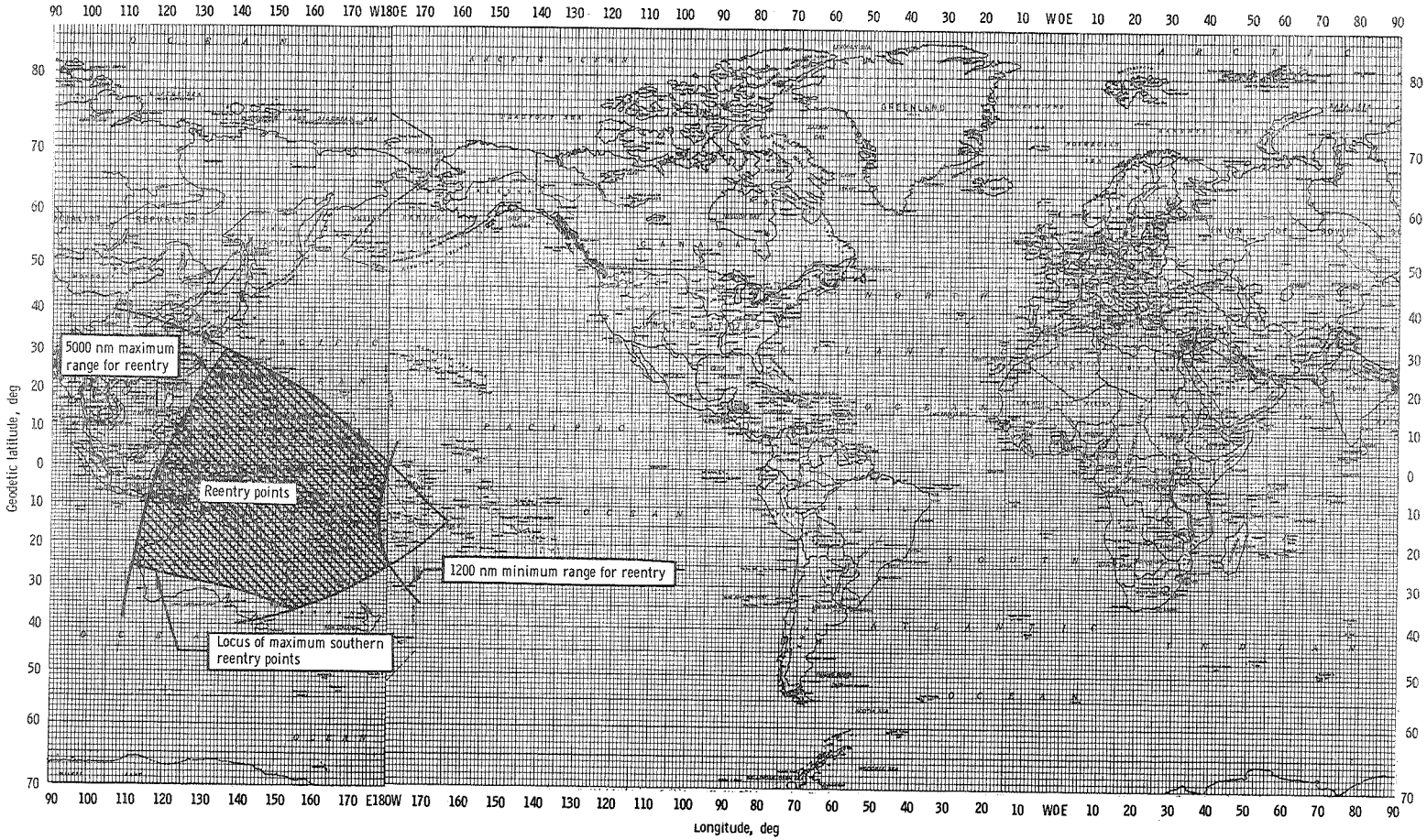
(p) 1200 nm reentry range for Southern United States landing, inclination = 40°.

Figure 16. - Concluded.

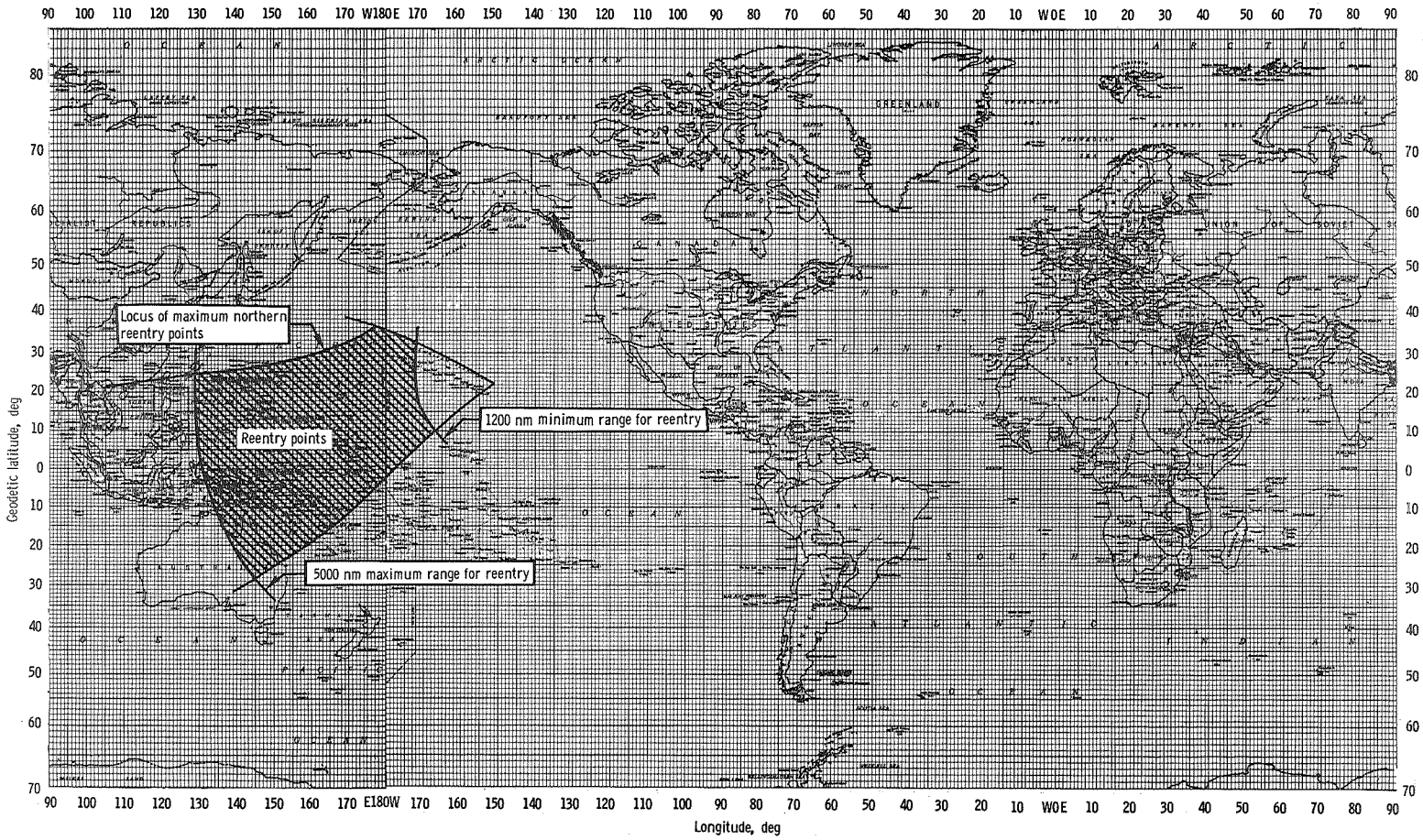


(a) Australian landing

Figure 17. - Ground track envelopes and reentry points for the prime landing sites.

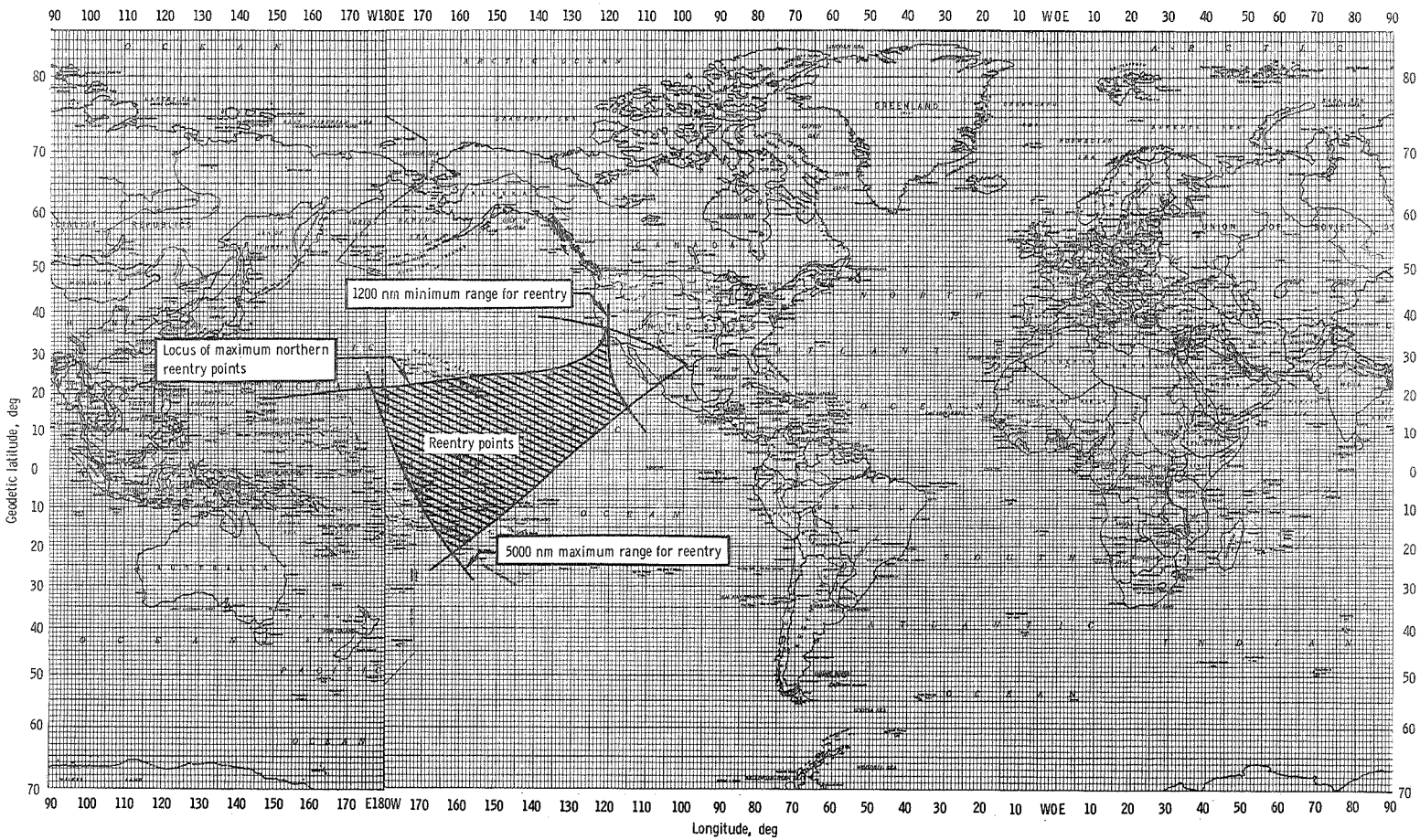


(b) Samoa Island landing
Figure 17. - Continued.



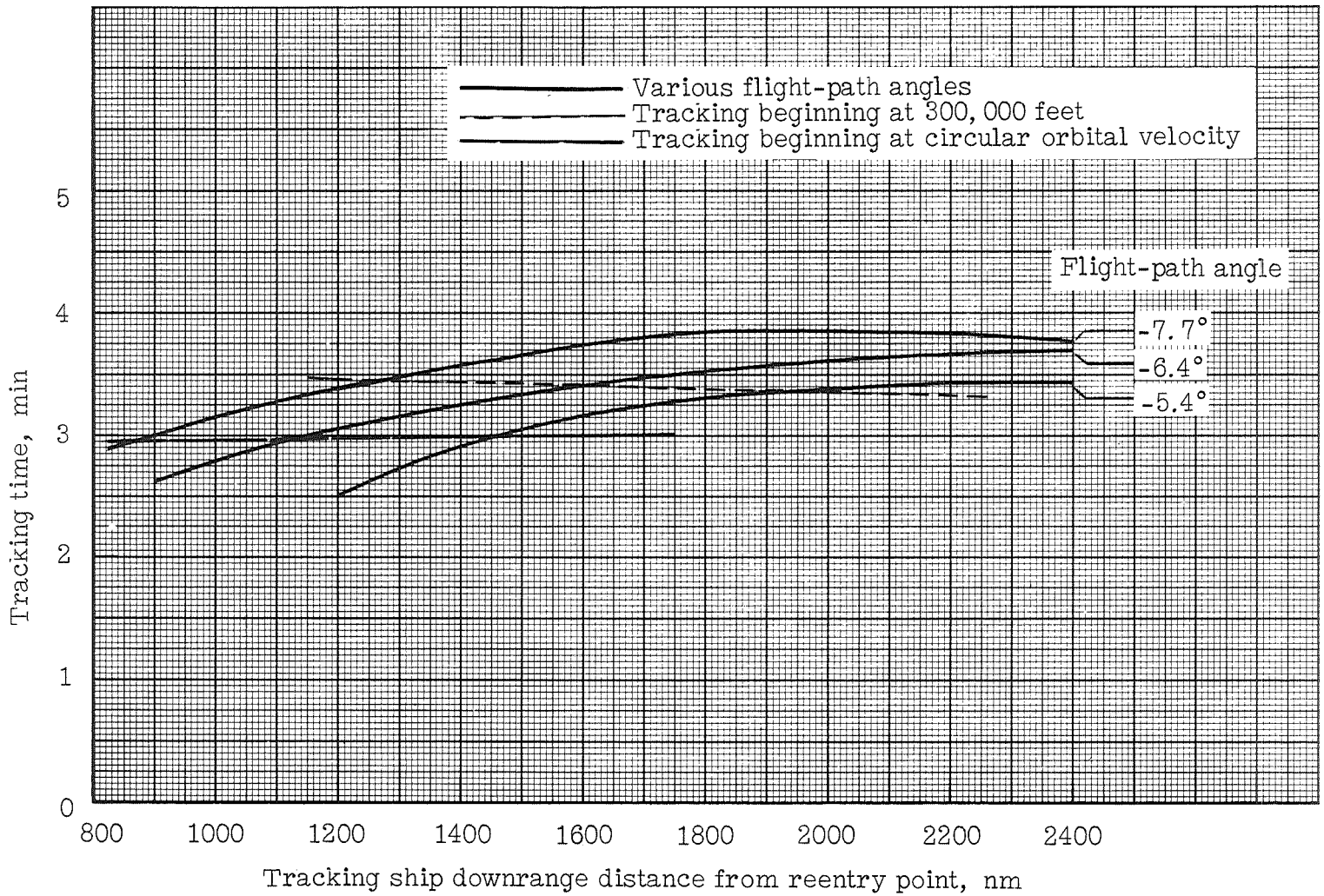
(c) Hawaiian landing

Figure 17. - Continued.



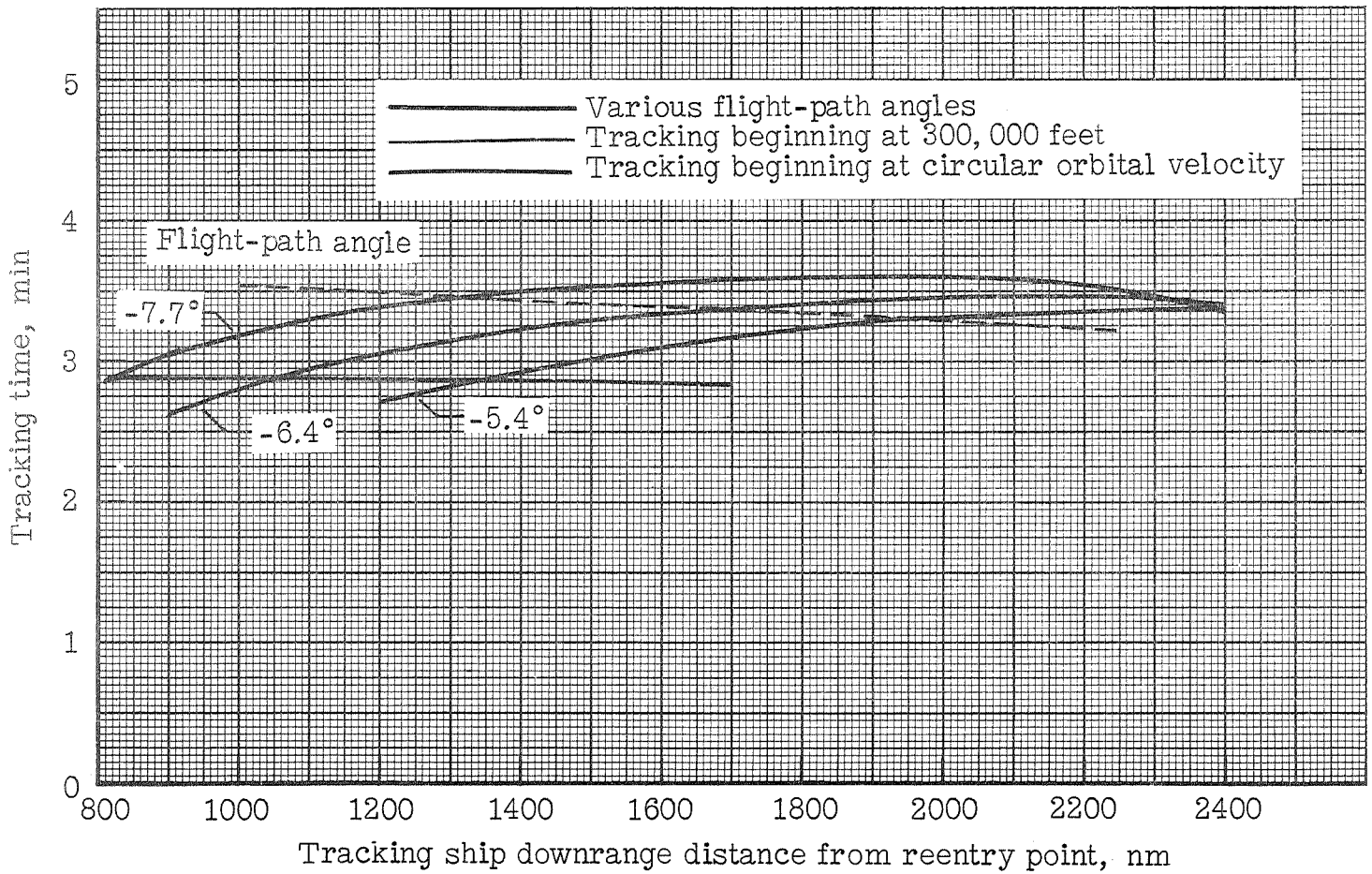
(d) Southern United States landing

Figure 17. - Concluded.



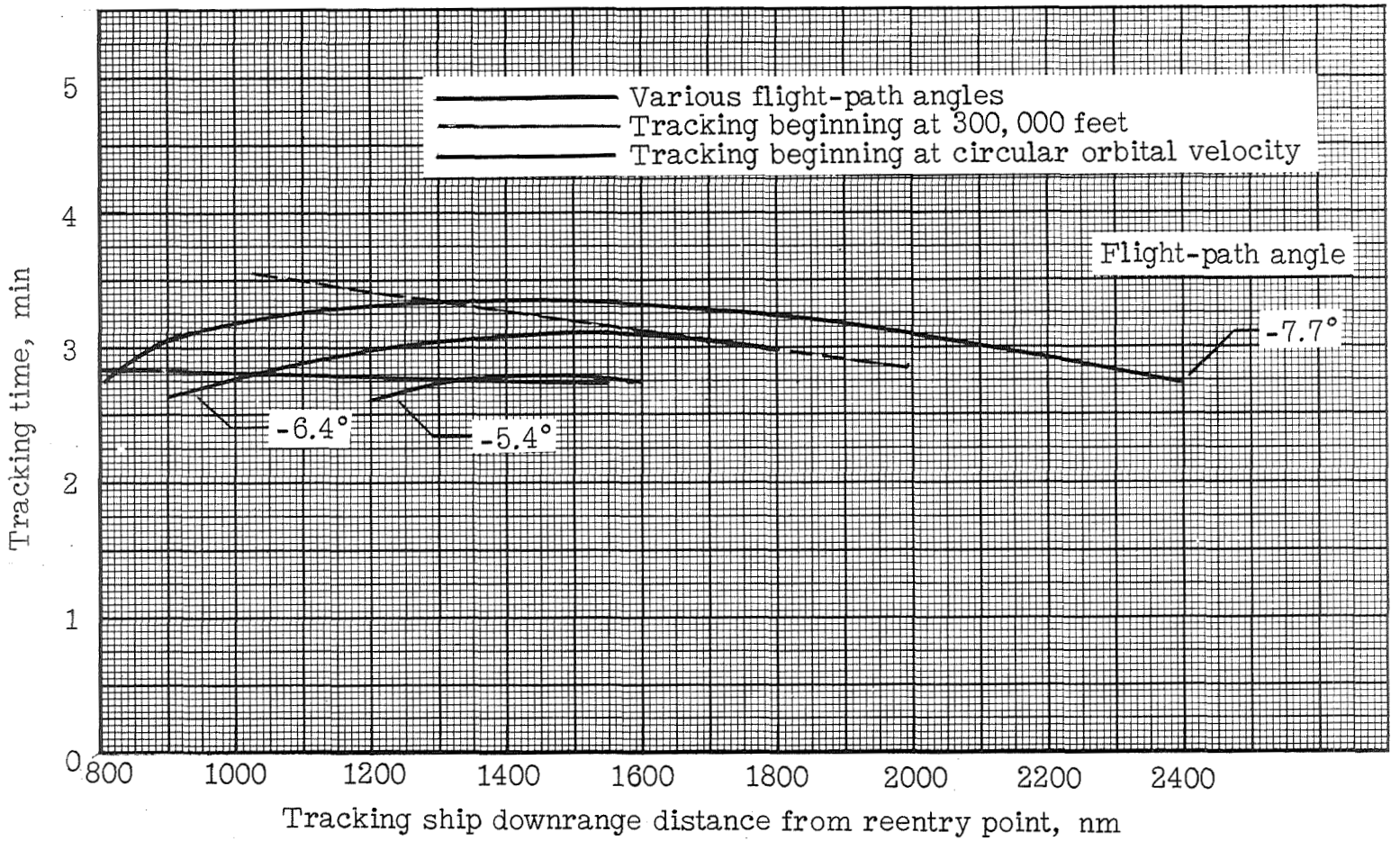
(a) Reentry range equals 5, 000 nm.

Figure 18. - Tracking time versus tracking ship downrange distance from reentry point for tracking initiated at circular orbital velocity and at 300, 000 feet.



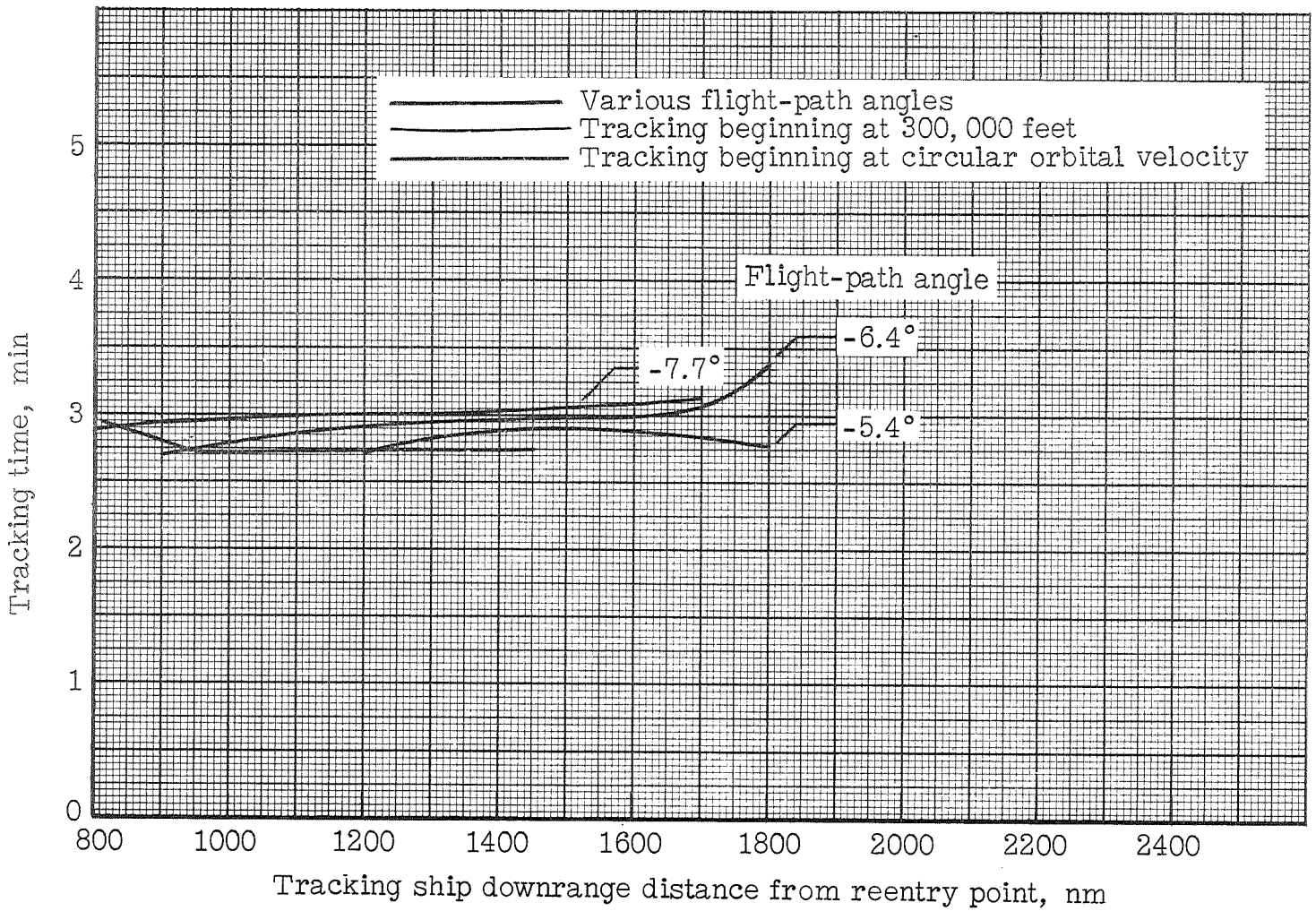
(b) Reentry range equals 4, 000 nm.

Figure 18. - Continued.



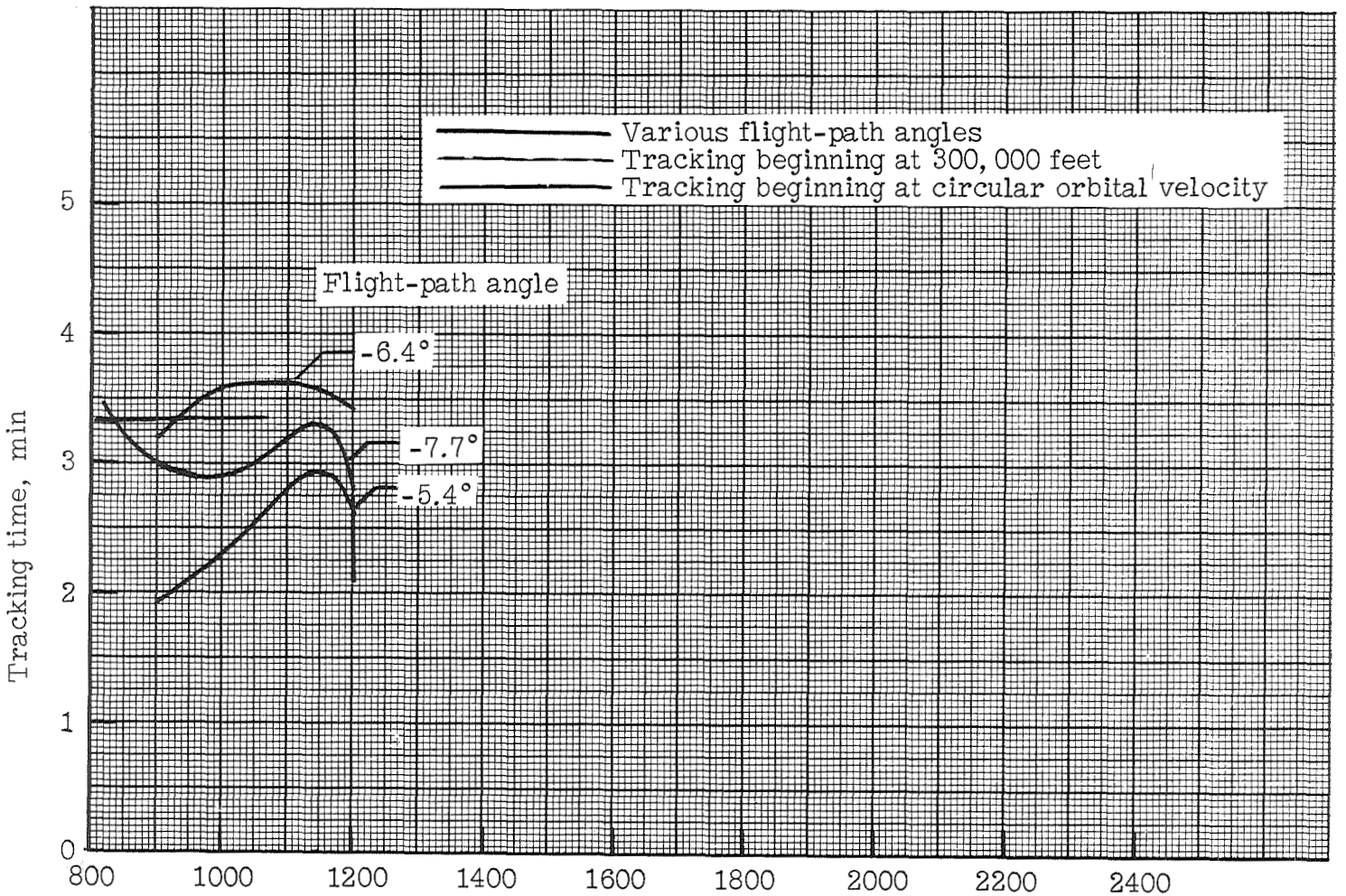
(c) Reentry range equals 3, 000 nm.

Figure 18. - Continued.



(d) Reentry range equals 2, 000 nm.

Figure 18. - Continued.



(e) Reentry range equals 1, 000 nm.

Figure 18. - Concluded.

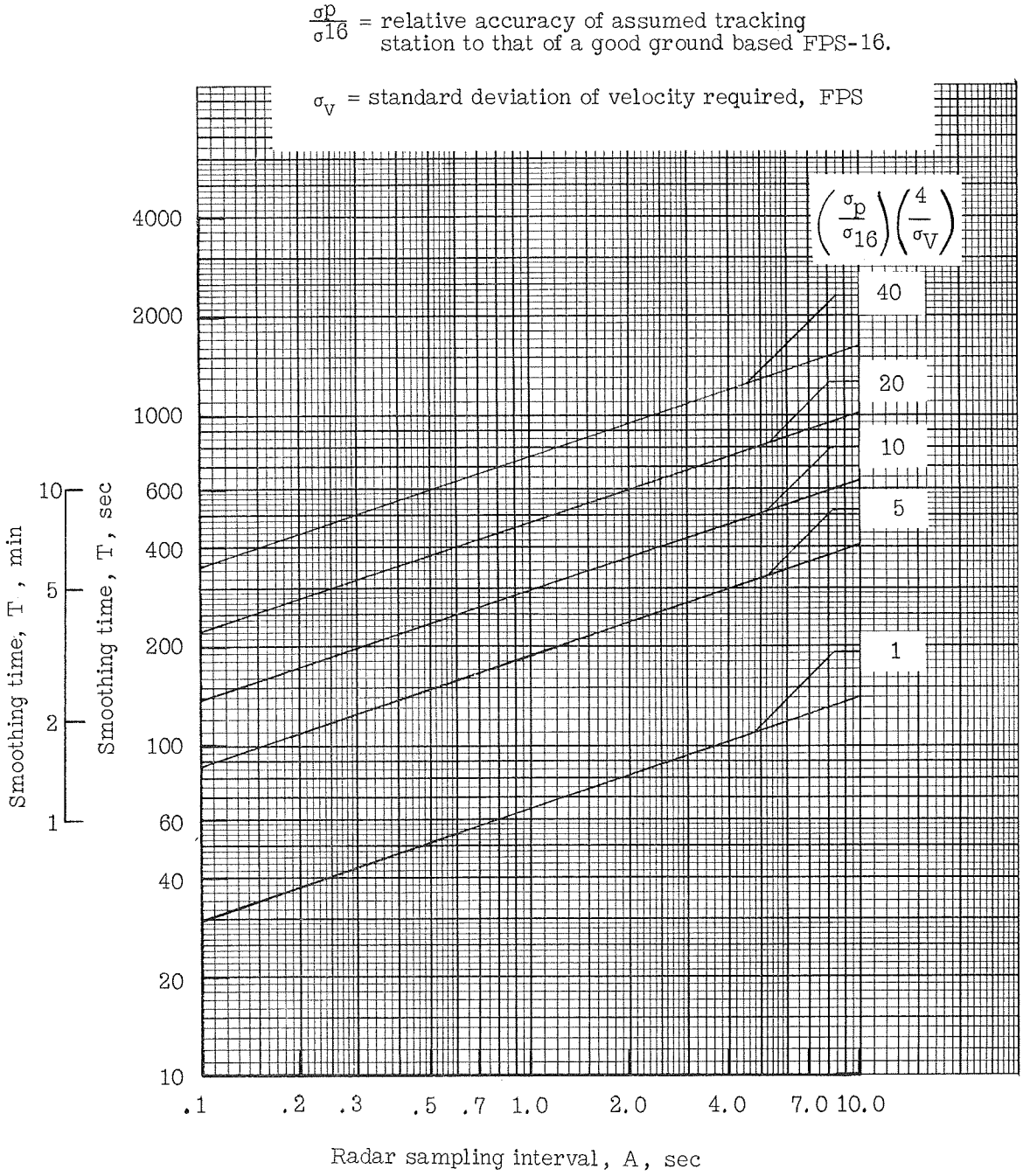
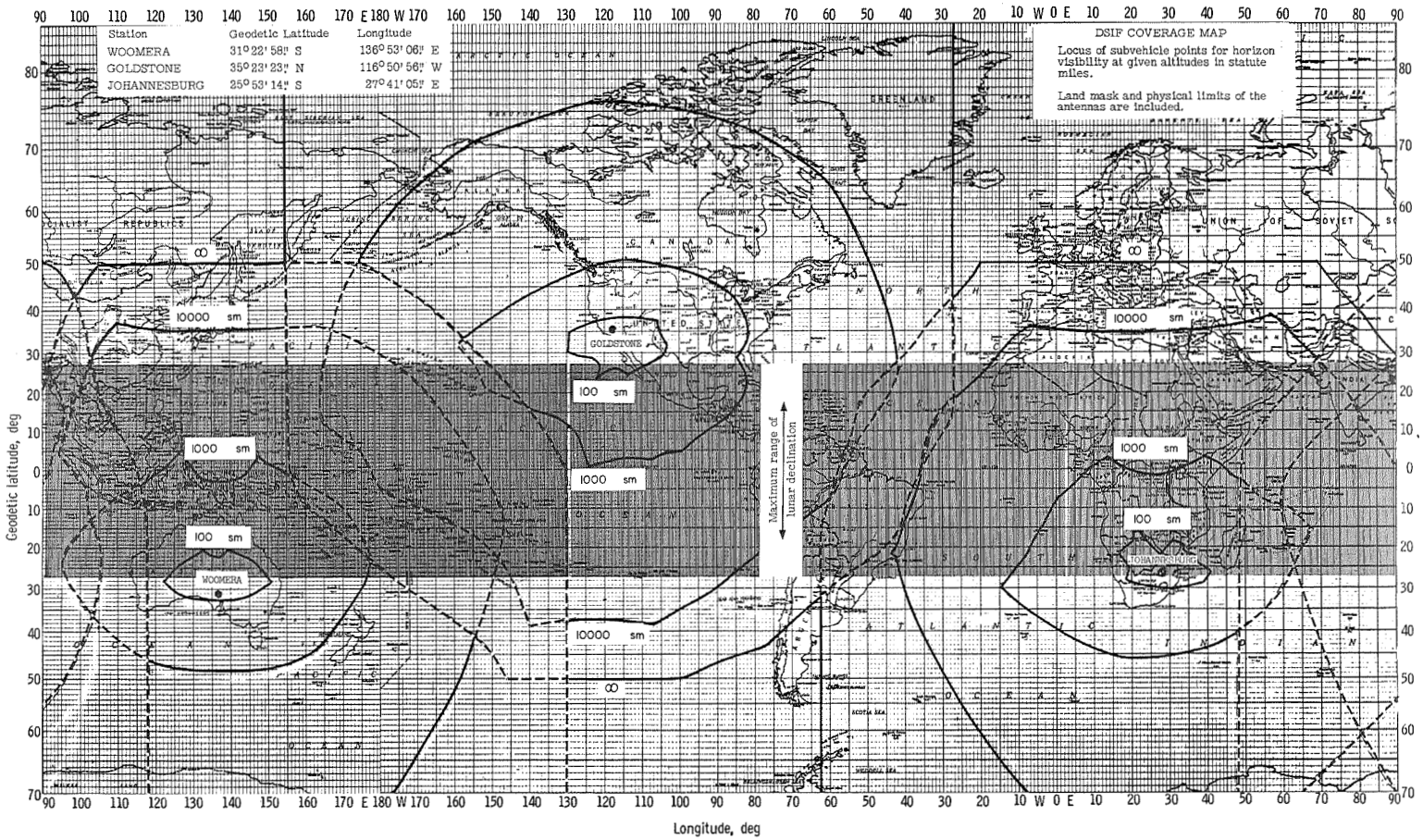
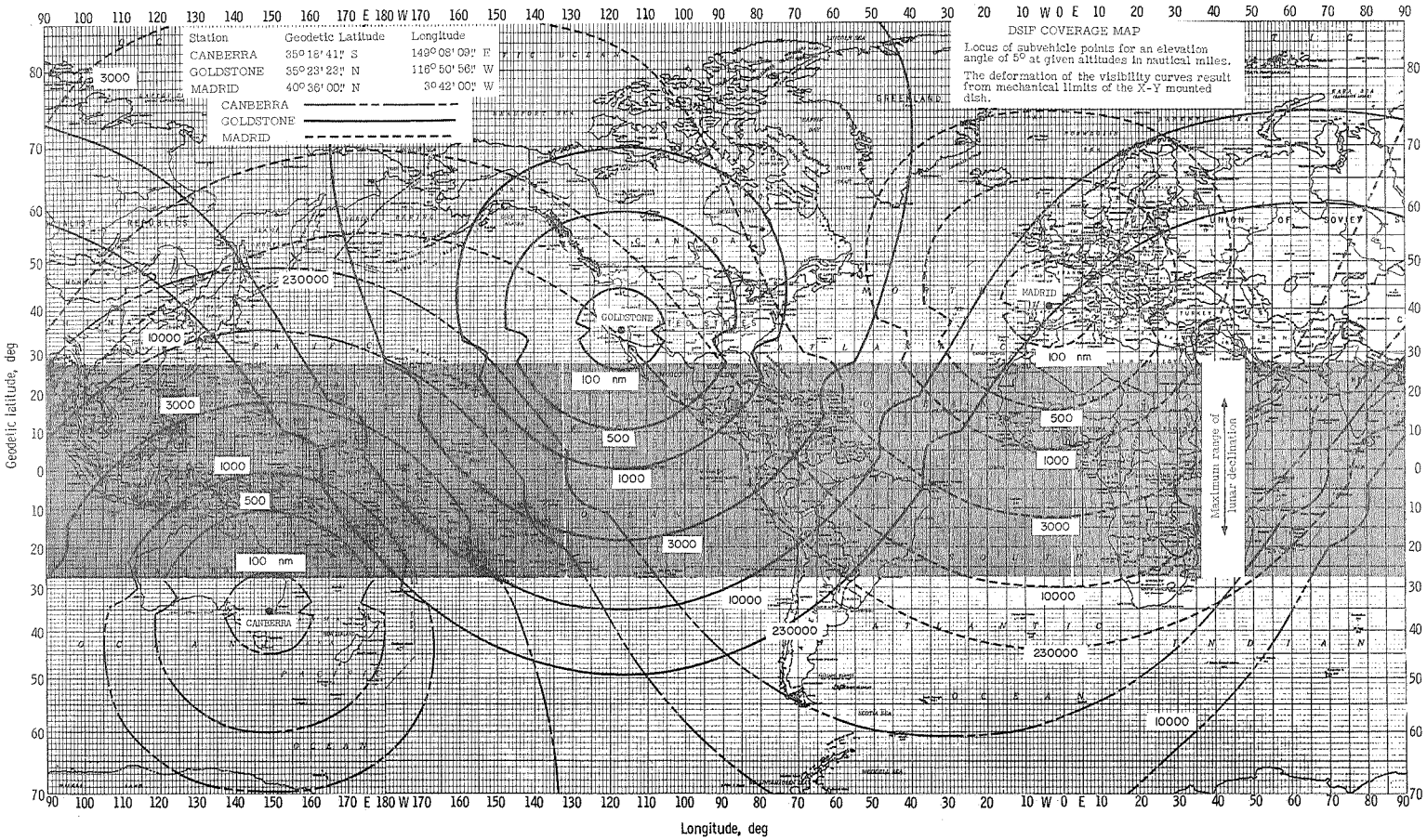


Figure 19.- Smoothing time versus radar sampling interval.



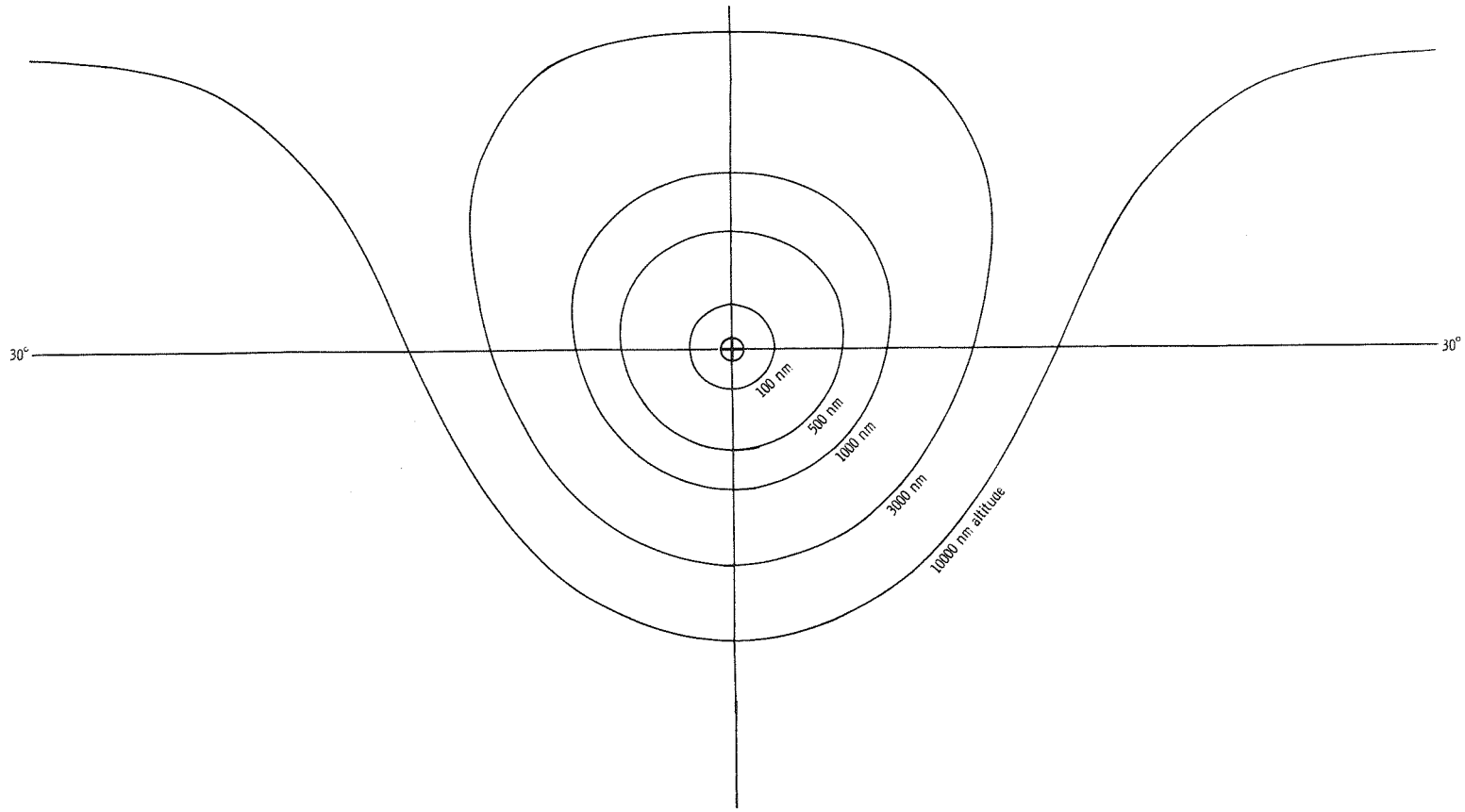
(a) Present 85 foot polar mount DSIF antennas.

Figure 20. - Radar coverage contours.



(b) Proposed 200-250 foot X-Y mount DSIF antennas.

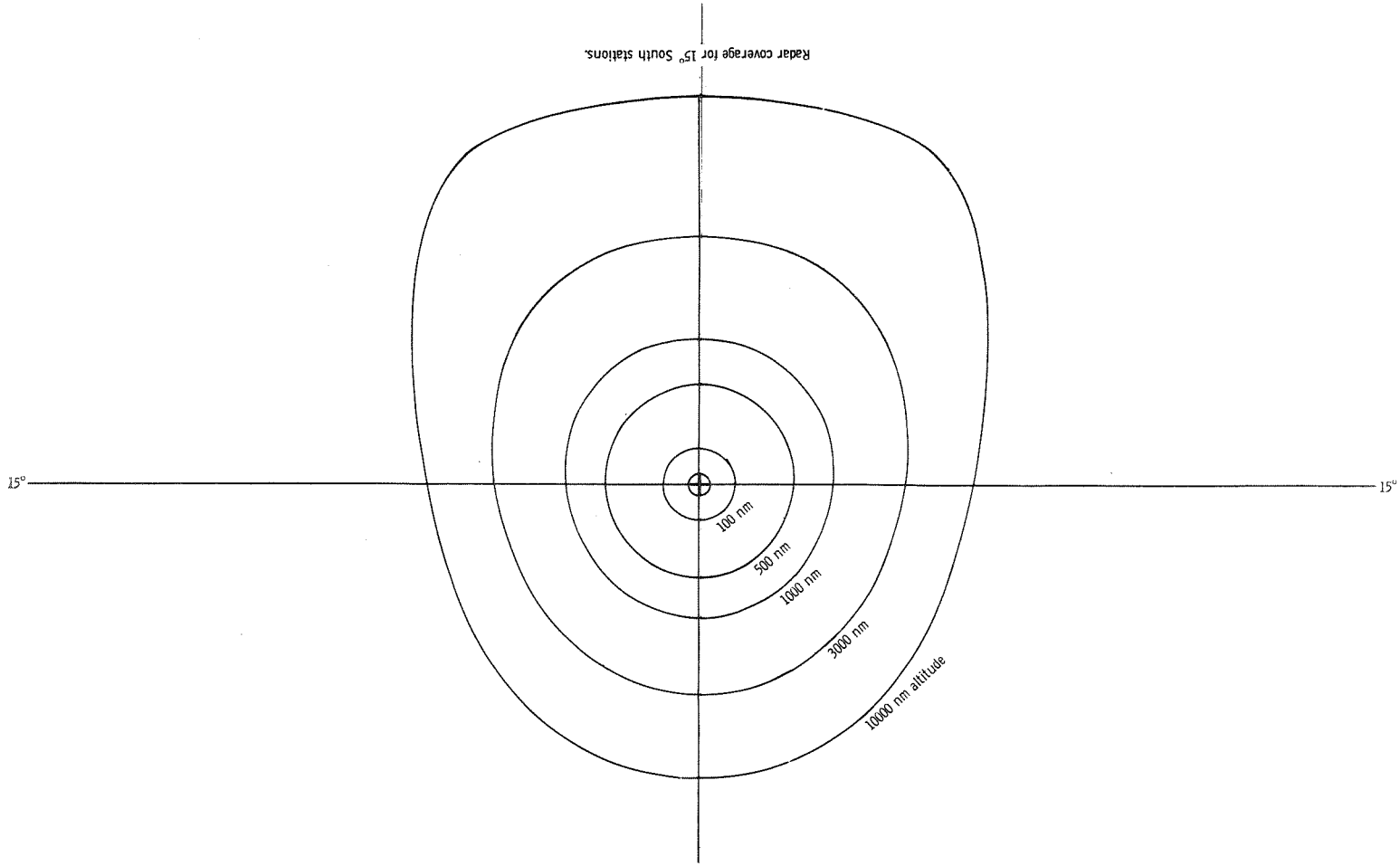
Figure 20. - Continued.



Radar coverage for 30° North stations.

(c) Overlay for 30° North or South radar stations.

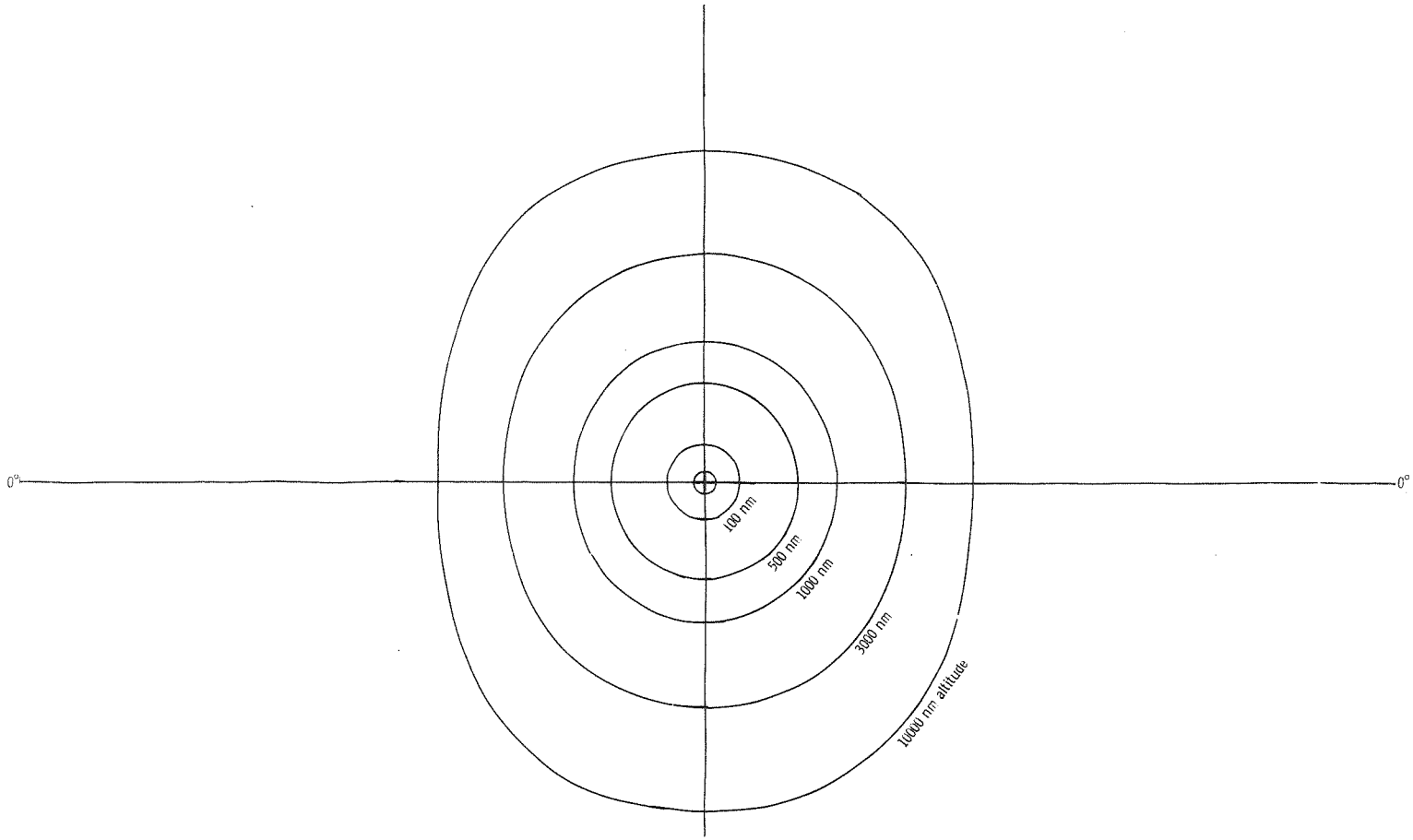
Figure 20. - Continued.



Radar coverage for 15° North stations.

(d) Overlay for 15° North or South radar stations.

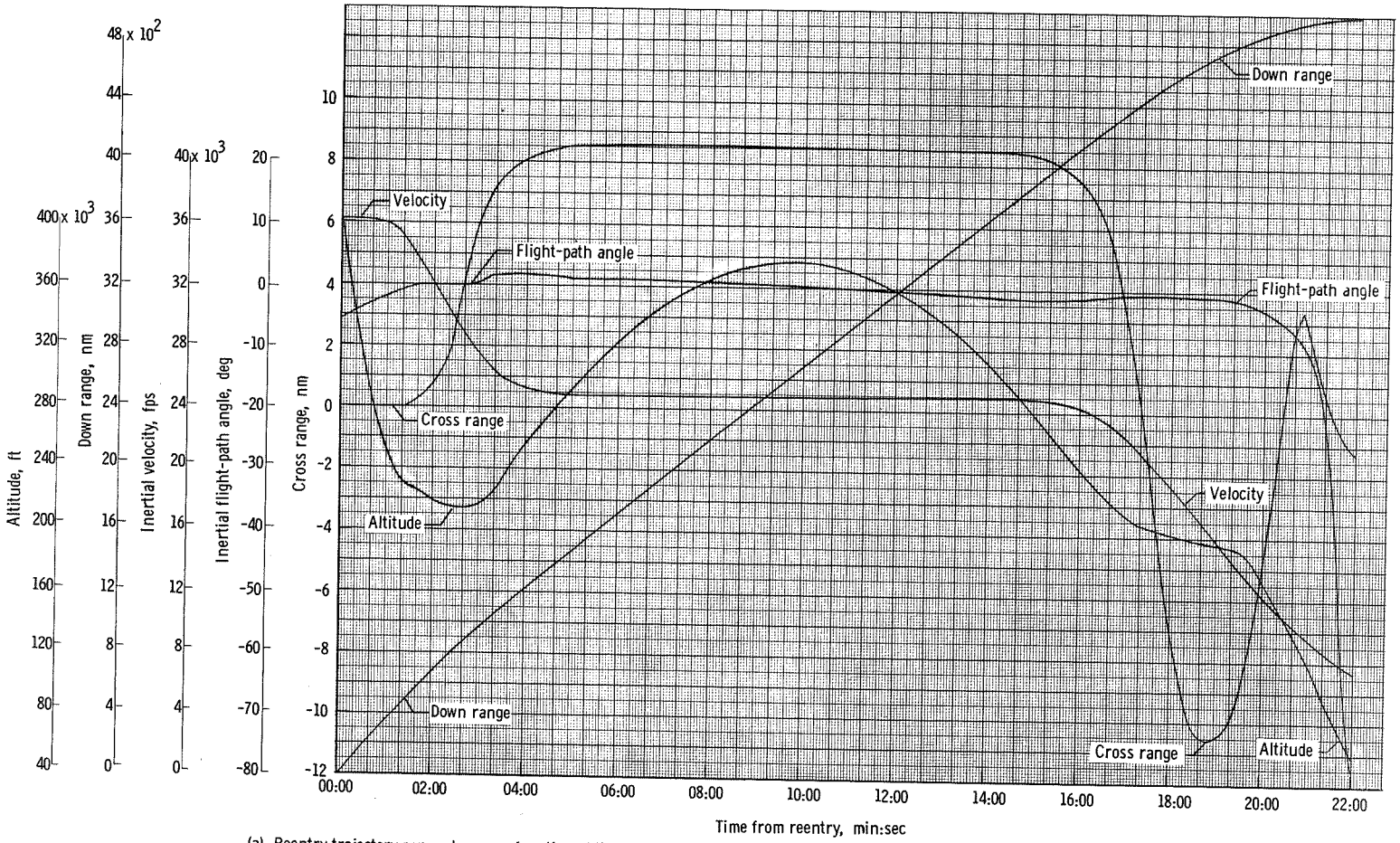
Figure 20. - Continued.



Radar coverage for equitorial stations.

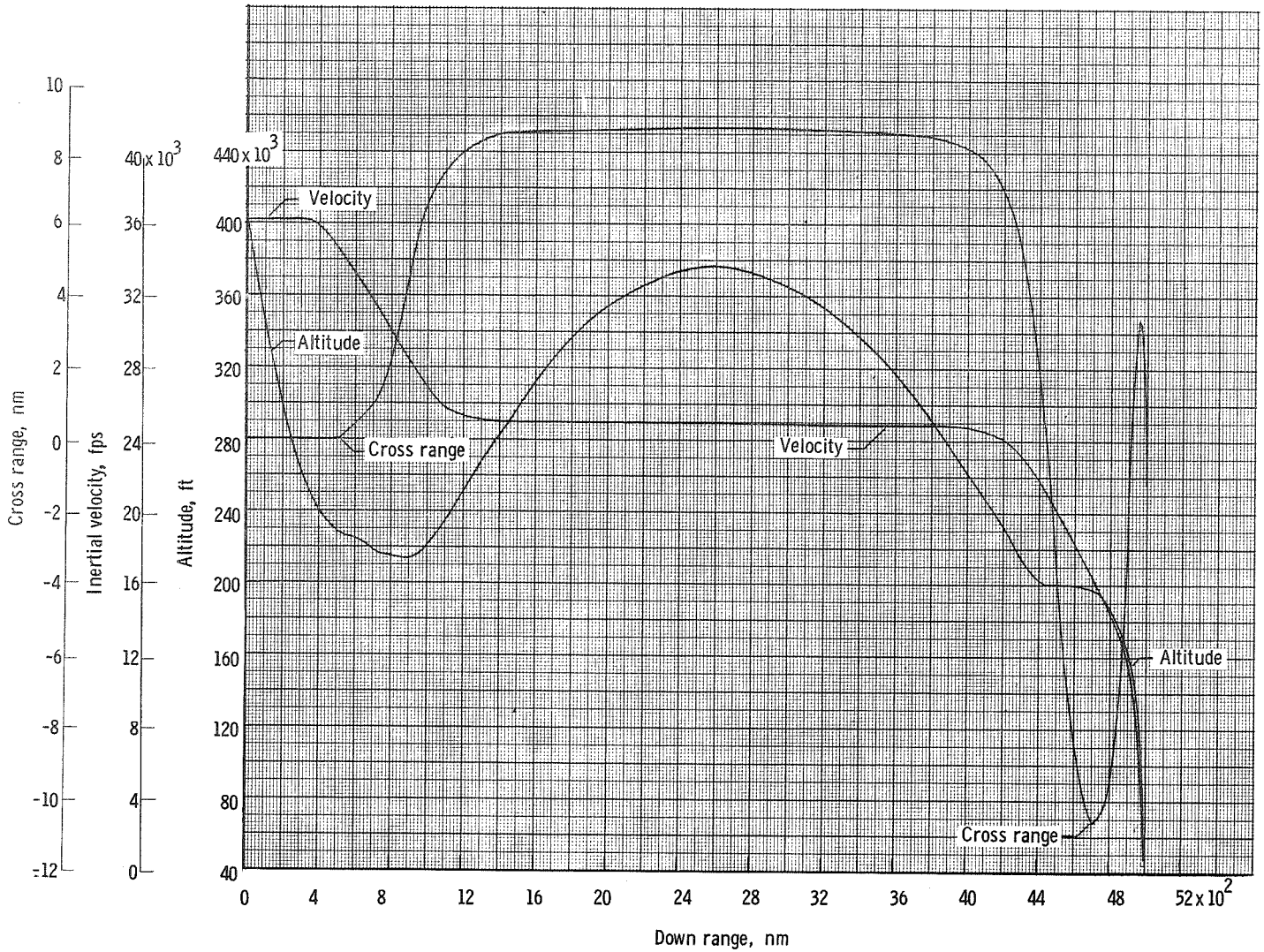
(e) Overlay for equatorial radar stations.

Figure 20. - Concluded.



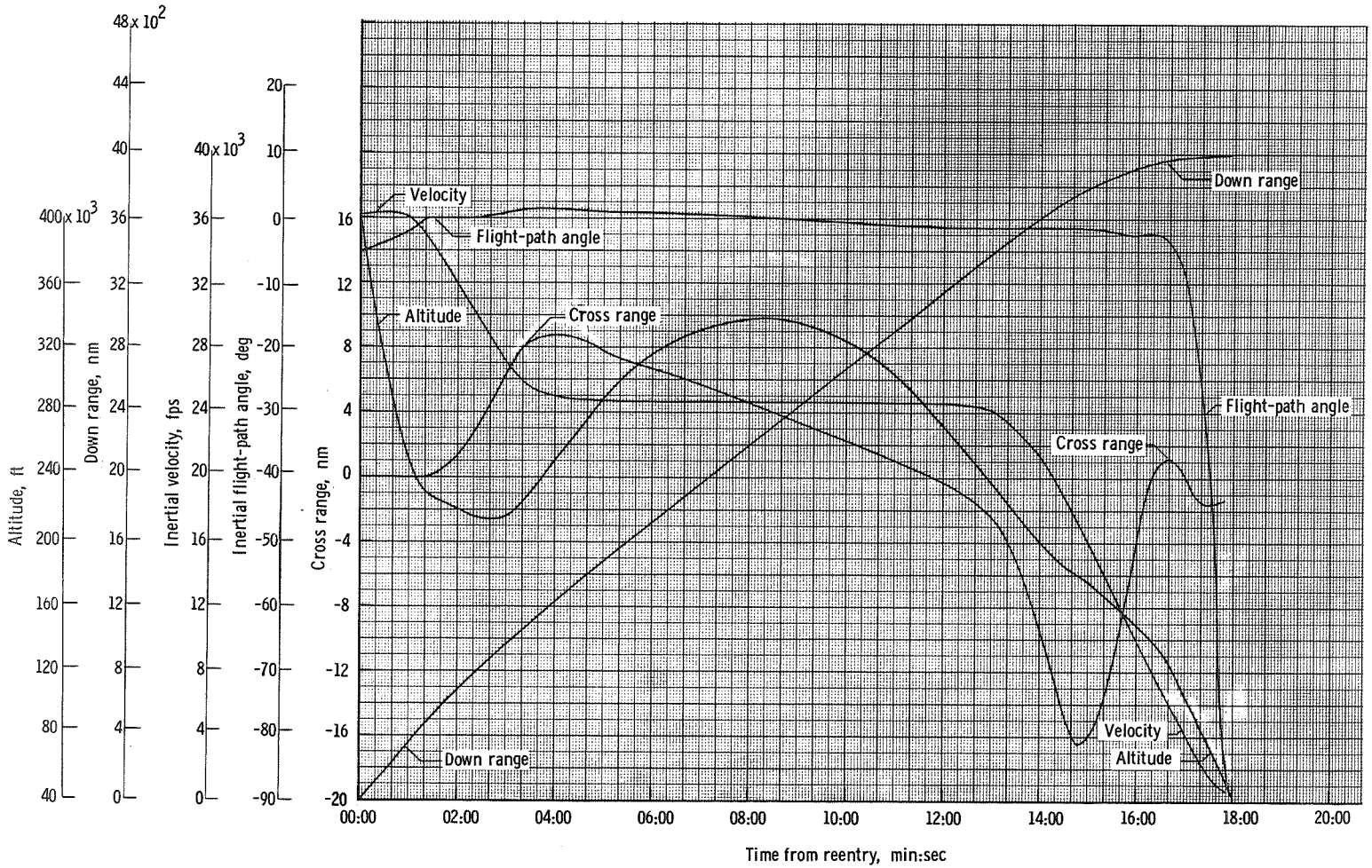
(a) Reentry trajectory parameters as a function of time for an initial flight-path angle = -5.4° and a reentry range = 5000 nm.

Figure 21.- Guided reentry trajectory.



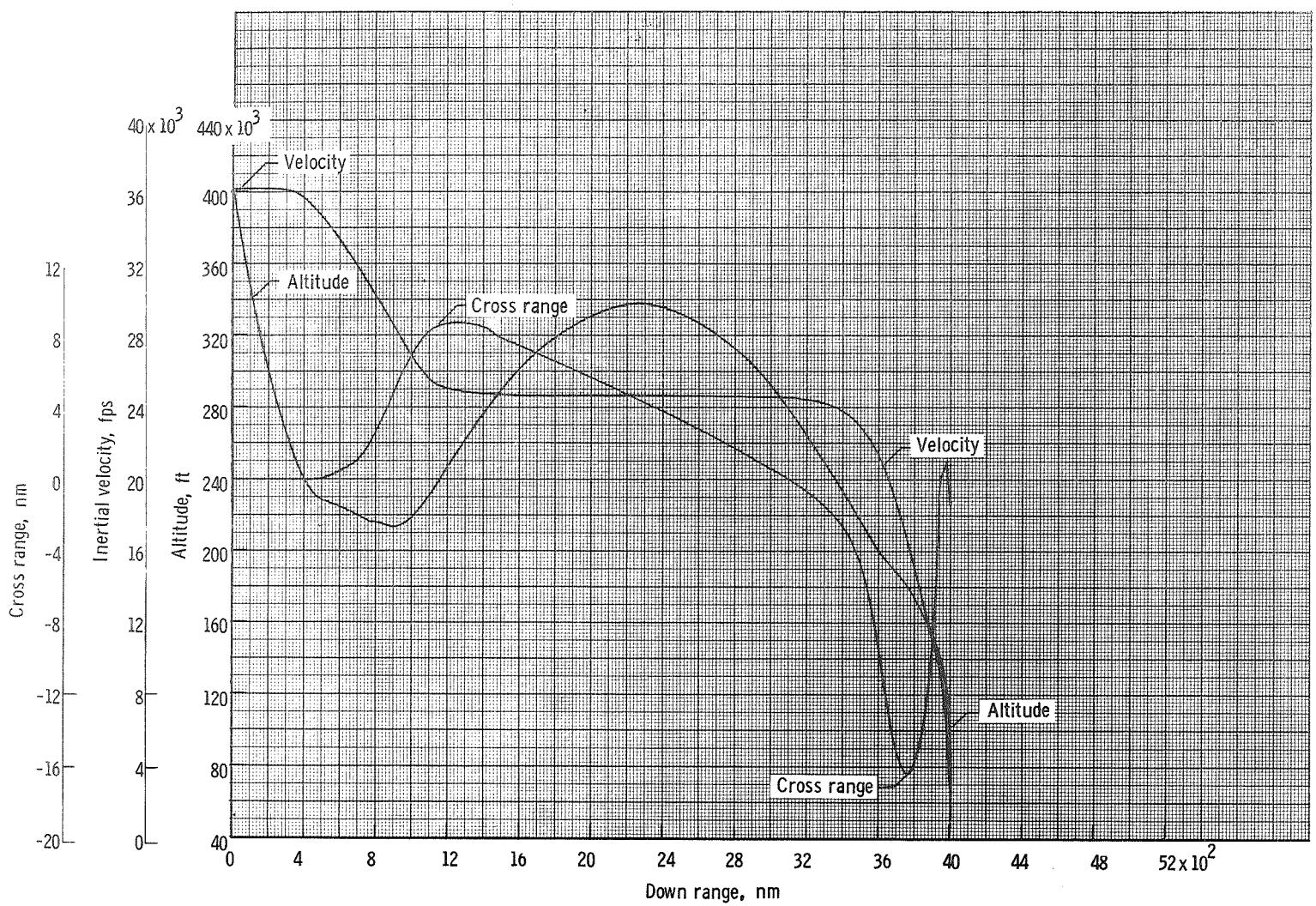
(b) Reentry trajectory parameters as a function of range for an initial flight-path angle = -5.4° and a reentry range = 5000 nm.

Figure 21. - Continued.



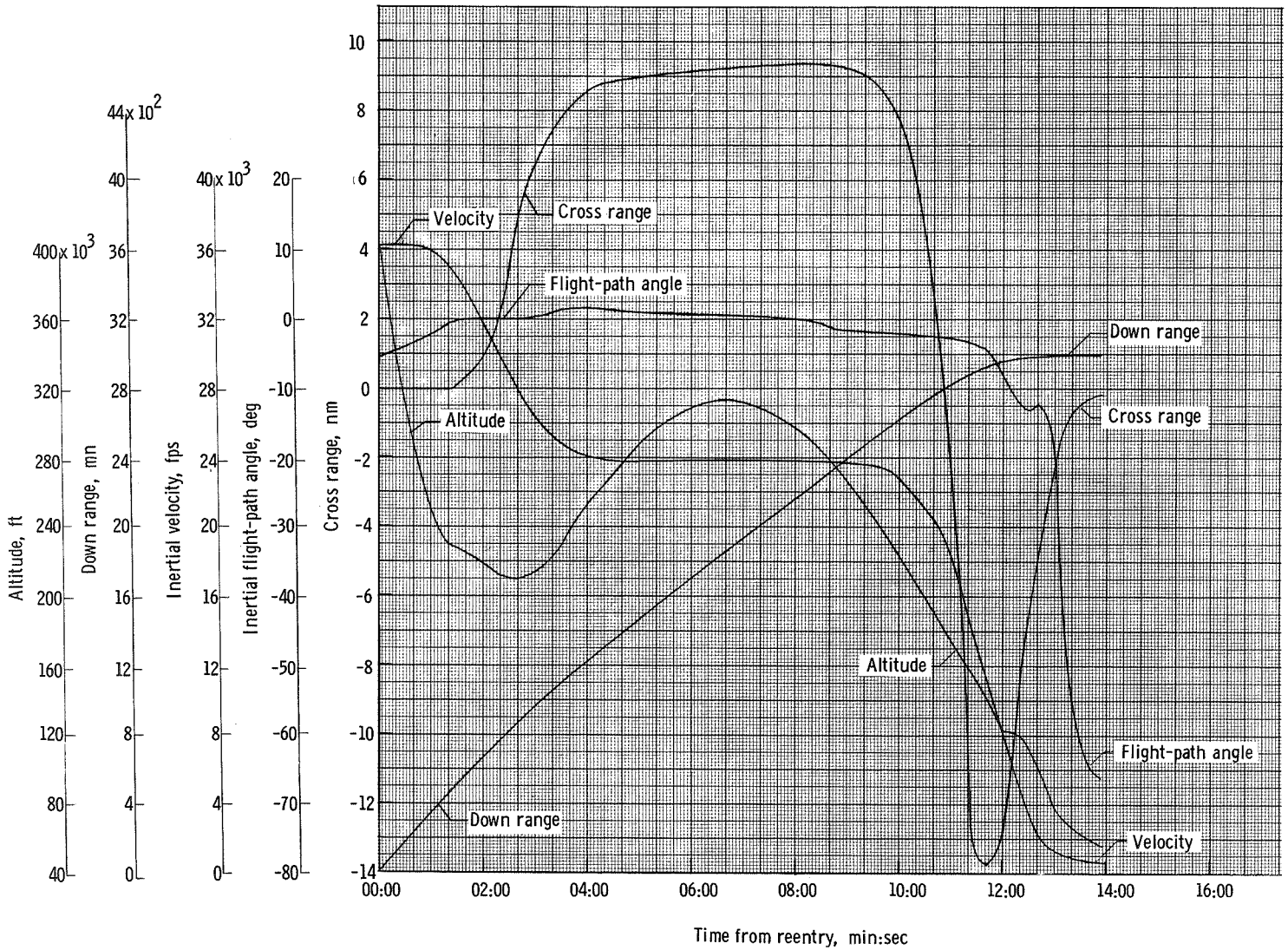
(c) Reentry trajectory parameters as a function of time for an initial flight-path angle = -5.4° and a reentry range = 4000 nm.

Figure 21. - Continued.



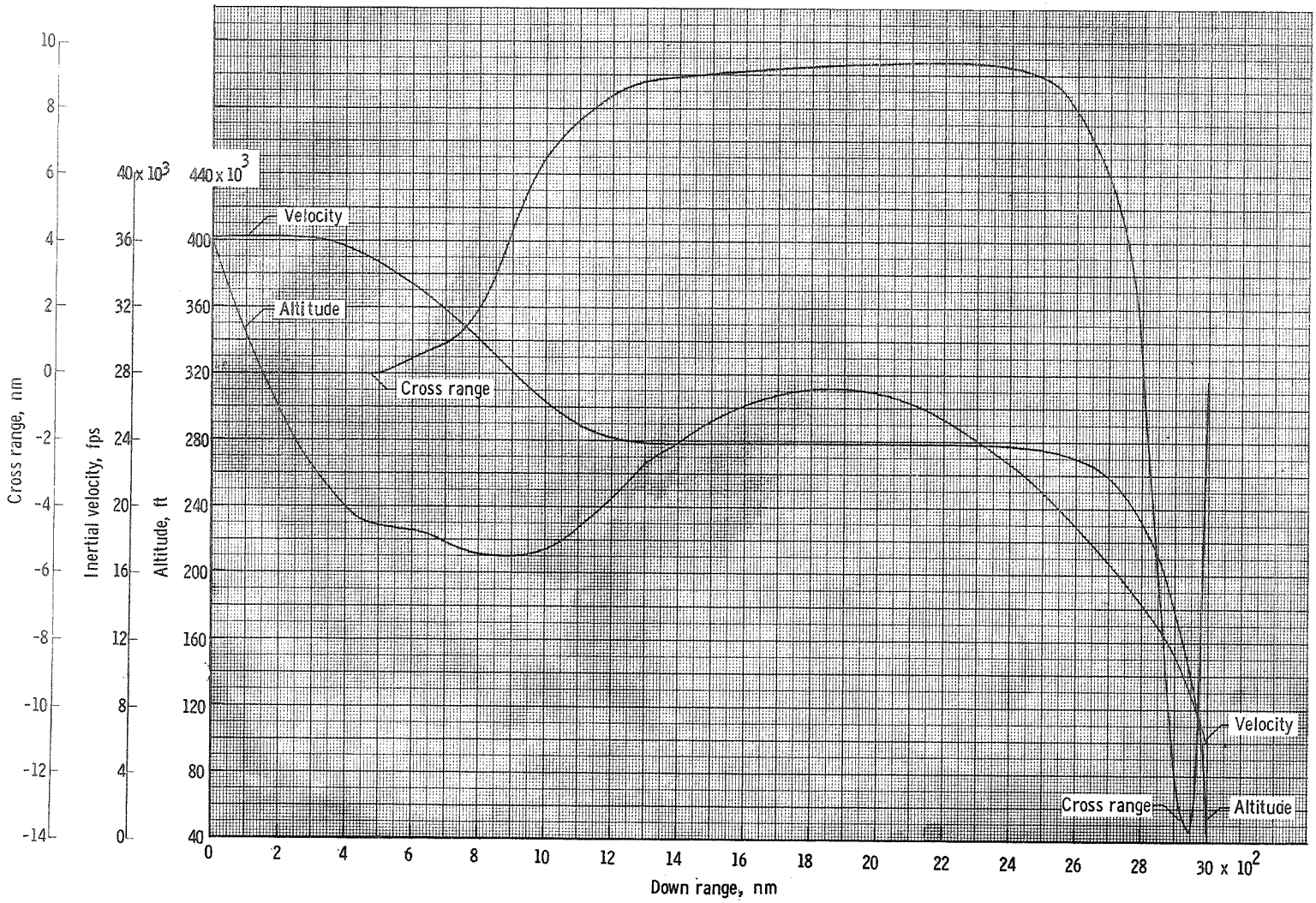
(d) Reentry trajectory parameters as a function of range for an initial flight-path angle = -5.4° and a reentry range = 4000 nm.

Figure 21. - Continued.



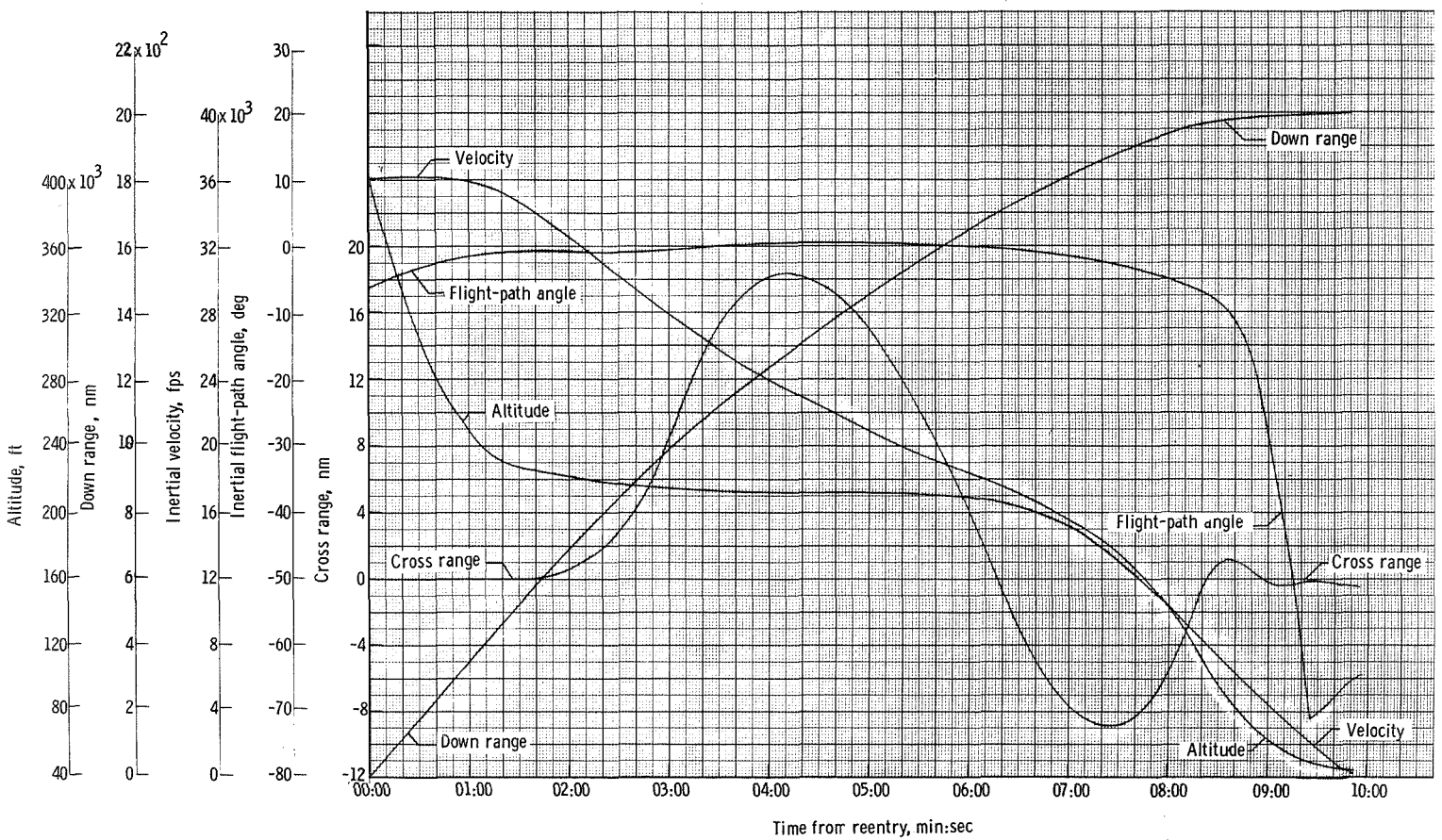
(e) Reentry trajectory parameters as a function of time for an initial flight-path angle = -5.4° and a reentry range = 3000 nm.

Figure 21.- Continued.



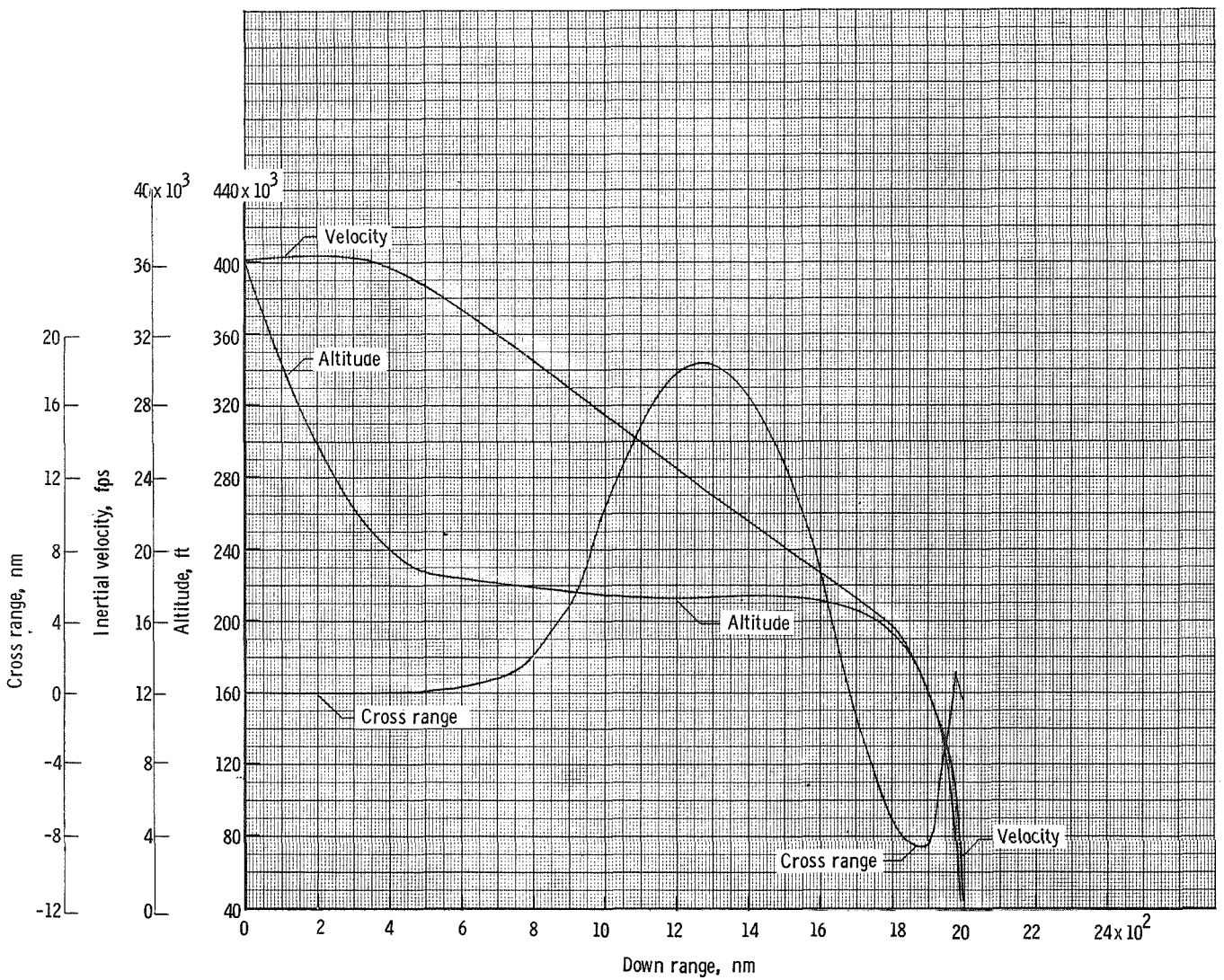
(f) Reentry trajectory parameters as a function of range for an initial flight-path angle = -5. 4° and a reentry range = 3000 nm.

Figure 21. - Continued.



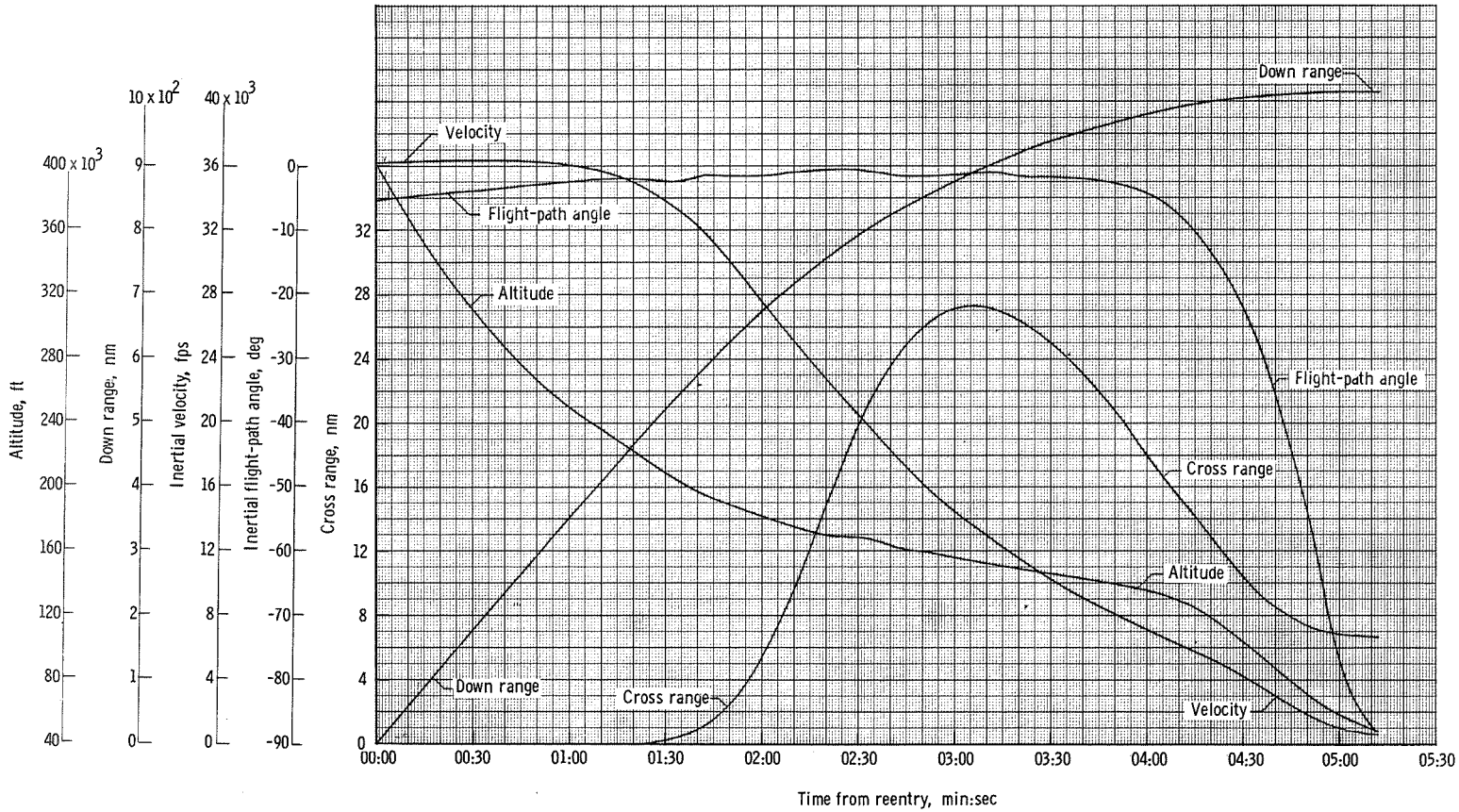
(g) Reentry trajectory parameters as a function of time for an initial flight-path angle = -5.4° and a reentry range = 2000 nm.

Figure 21. - Continued.



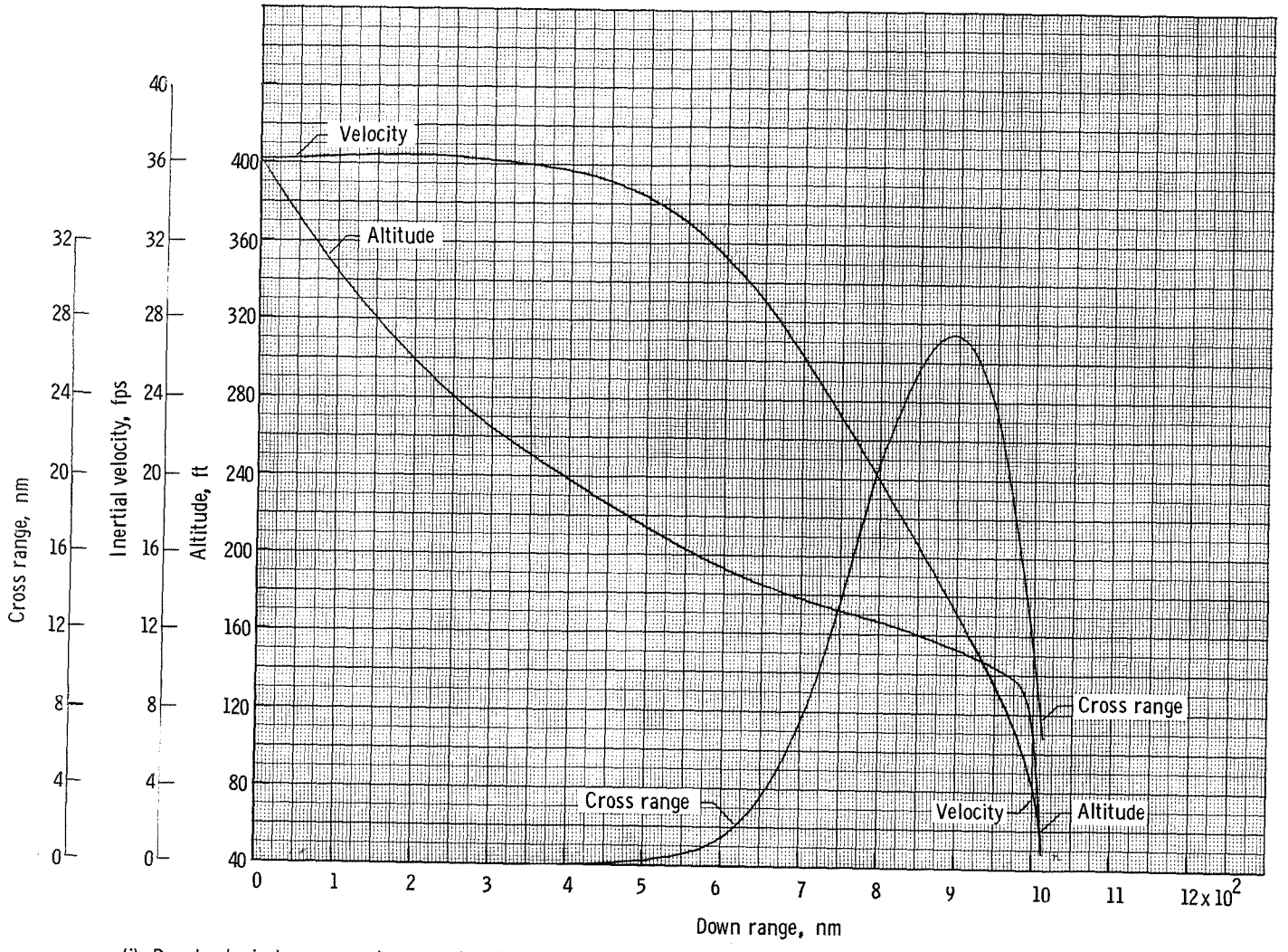
(h) Reentry trajectory parameters as a function of range for an initial flight-path angle = -5.4° and a reentry range = 2000 nm.

Figure 21.- Continued.



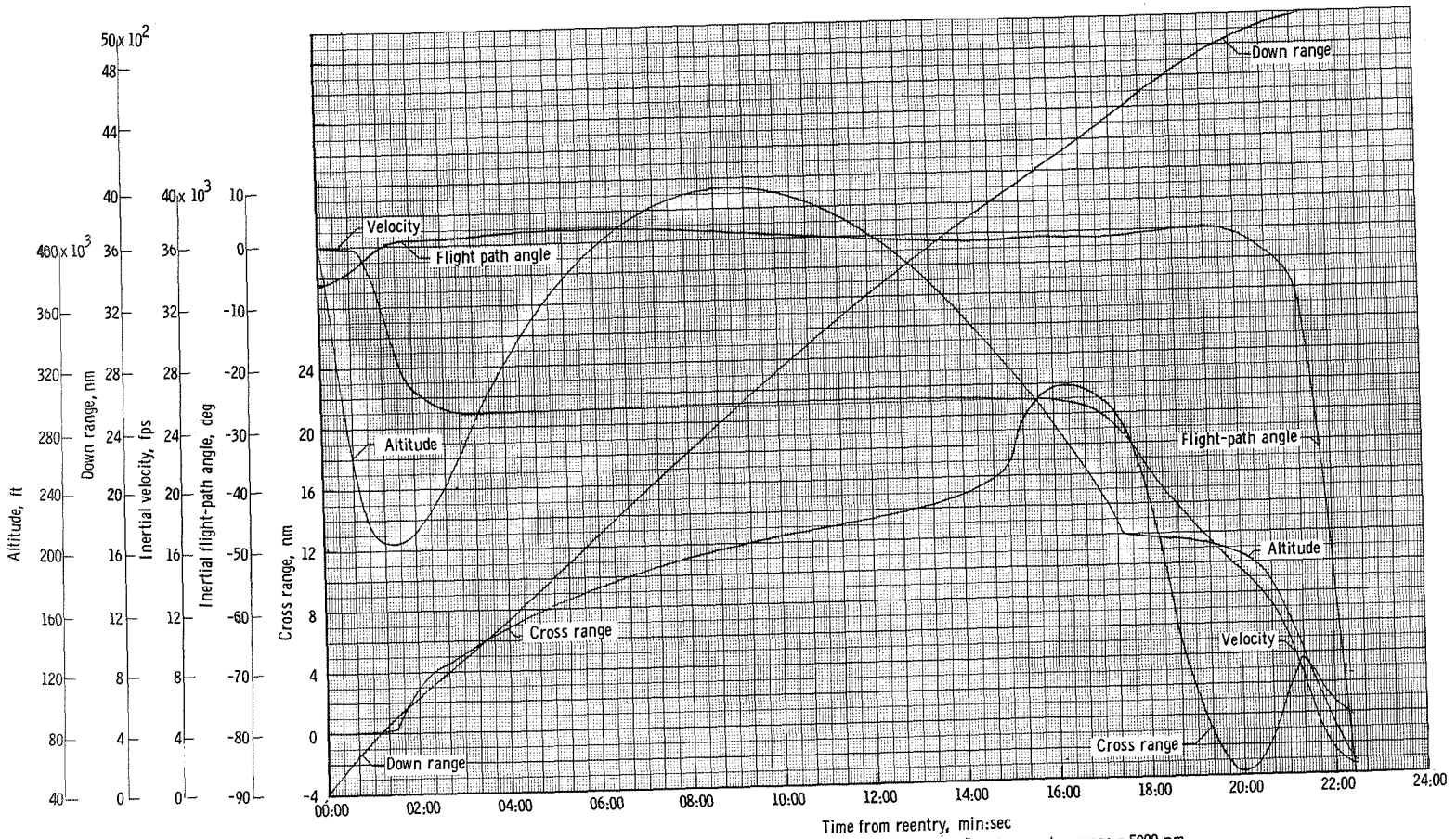
(i) Reentry trajectory parameters as a function of time for an initial flight-path angle = -5.4° and a reentry range = 1000 nm.

Figure 21. - Continued.



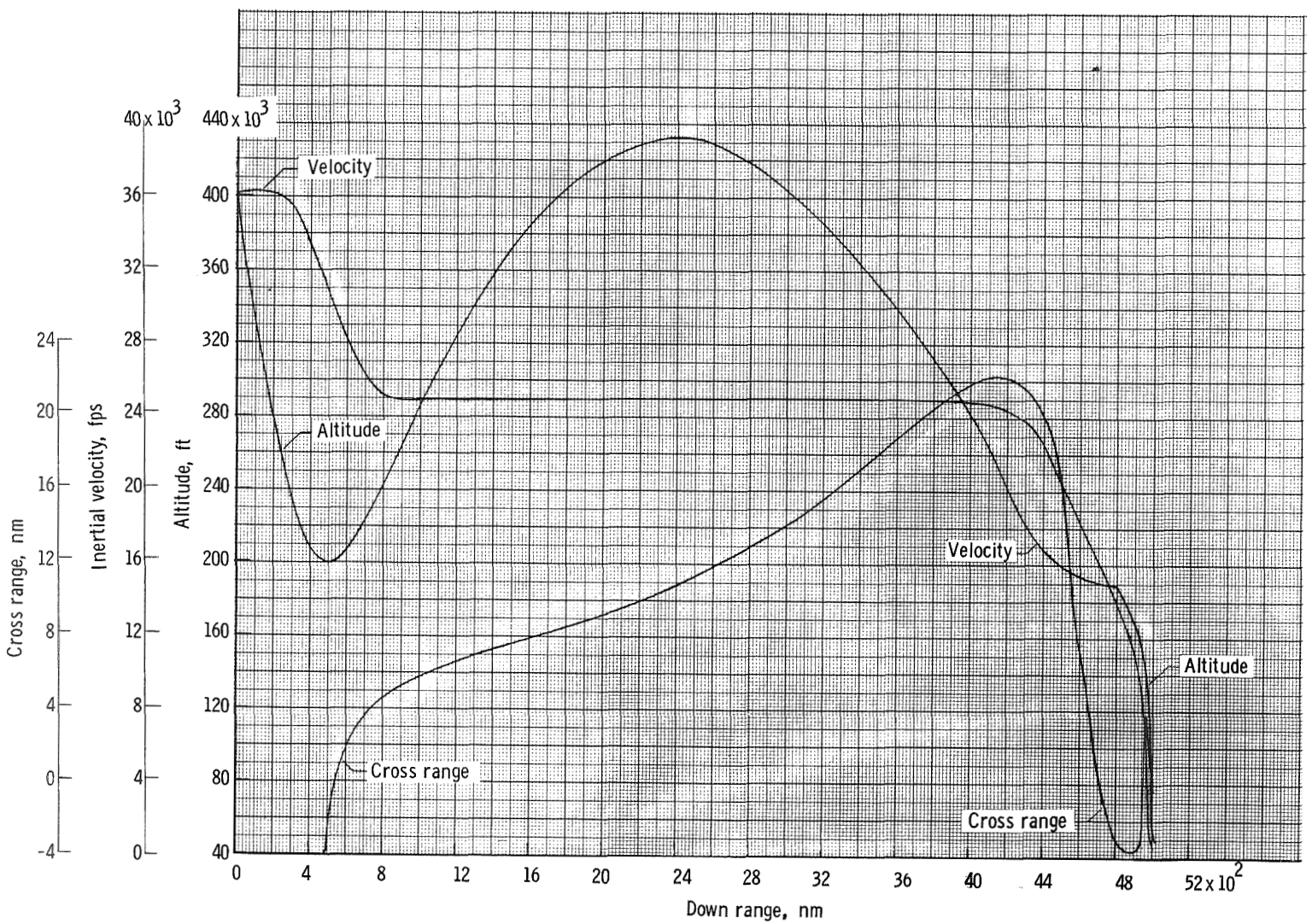
(j) Reentry trajectory parameters as a function of range for an initial flight-path angle = -5.4° and a reentry range = 1000 nm.

Figure 21.- Continued.



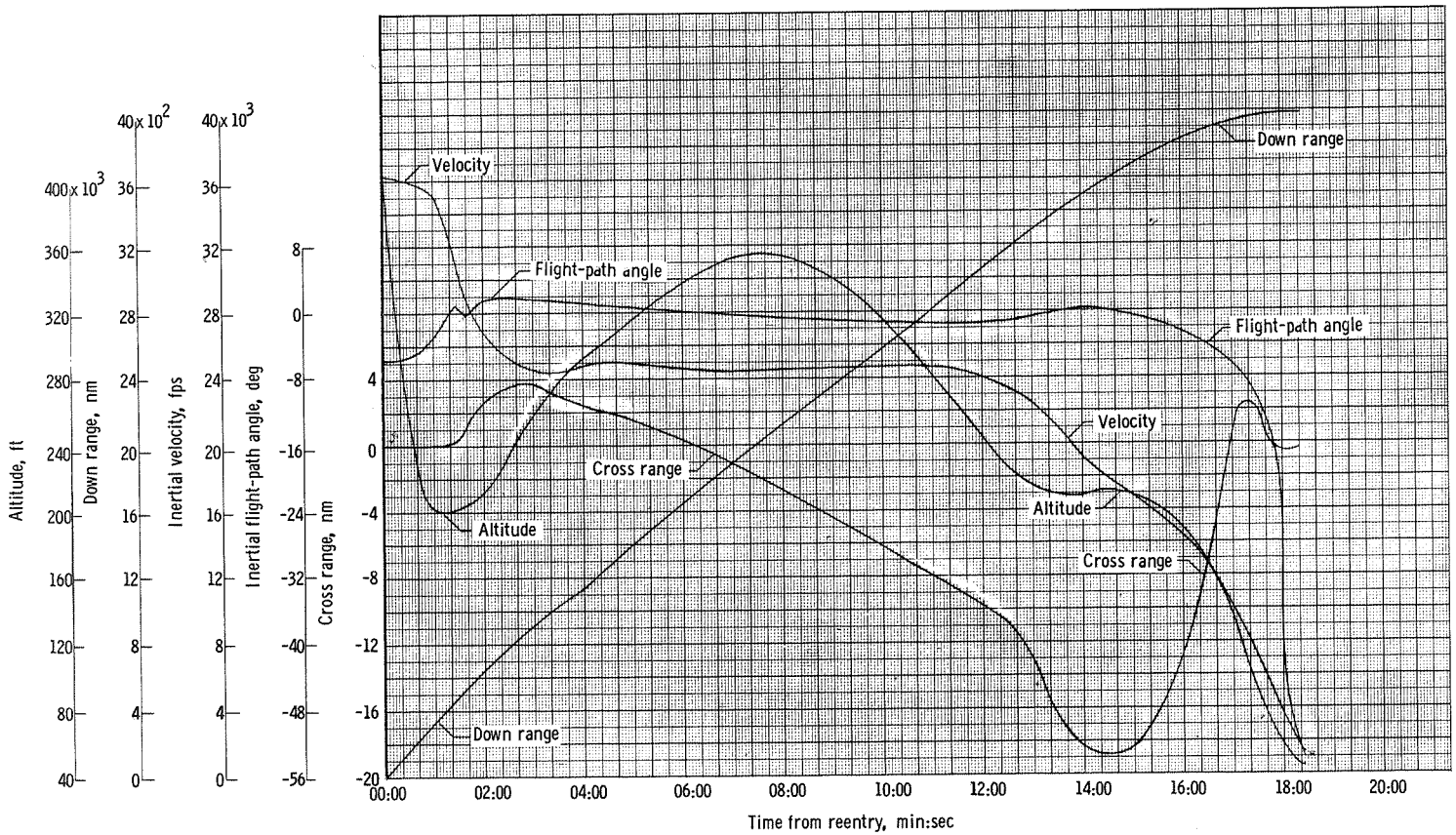
(k) Reentry trajectory parameters as a function of time for an initial flight-path angle = -6.4° and a reentry range = 5000 nm.

Figure 21. - Continued.



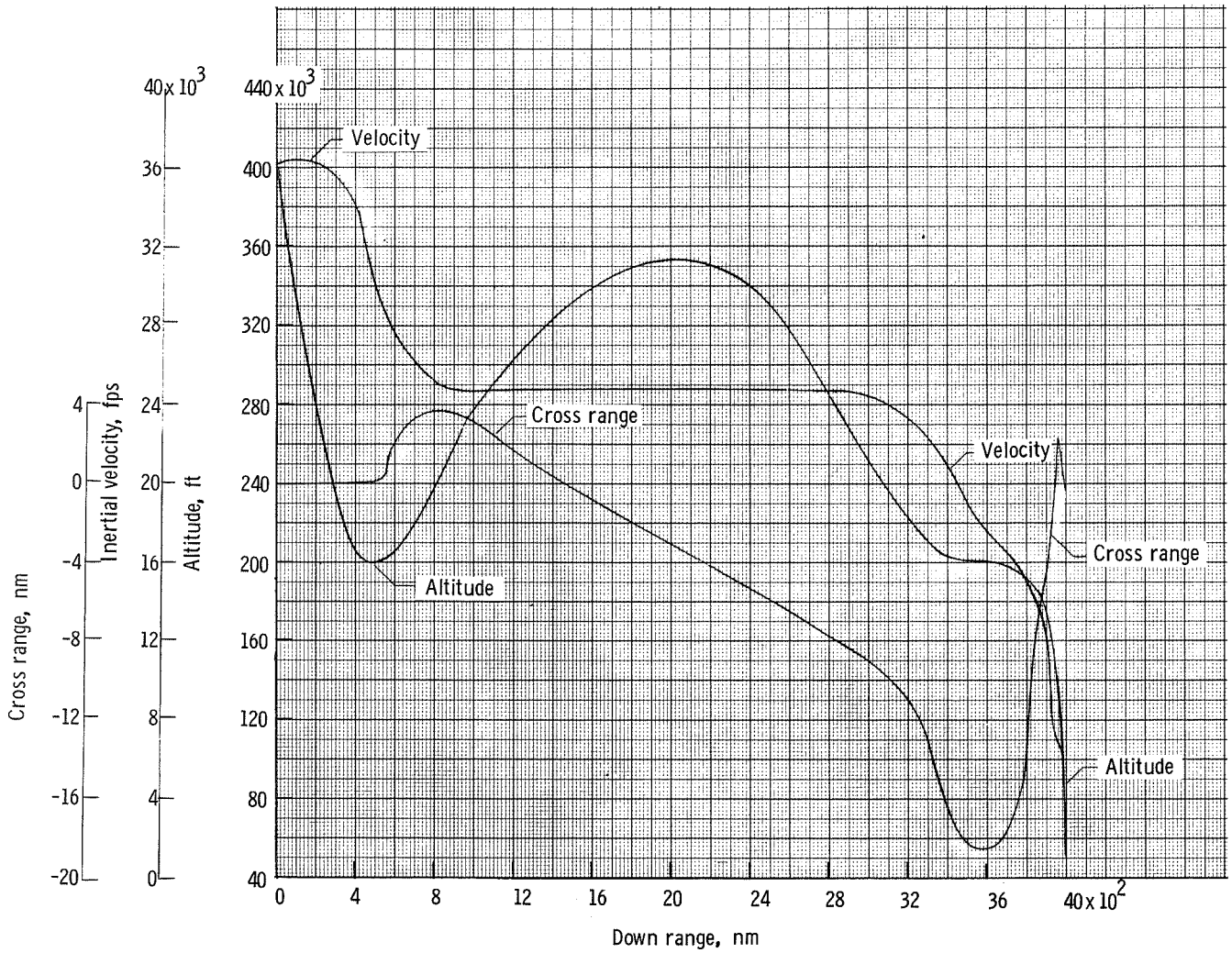
(l) Reentry trajectory parameters as a function of range for an initial flight-path angle = -6.4° and a reentry range = 5000 nm.

Figure 21. - Continued.



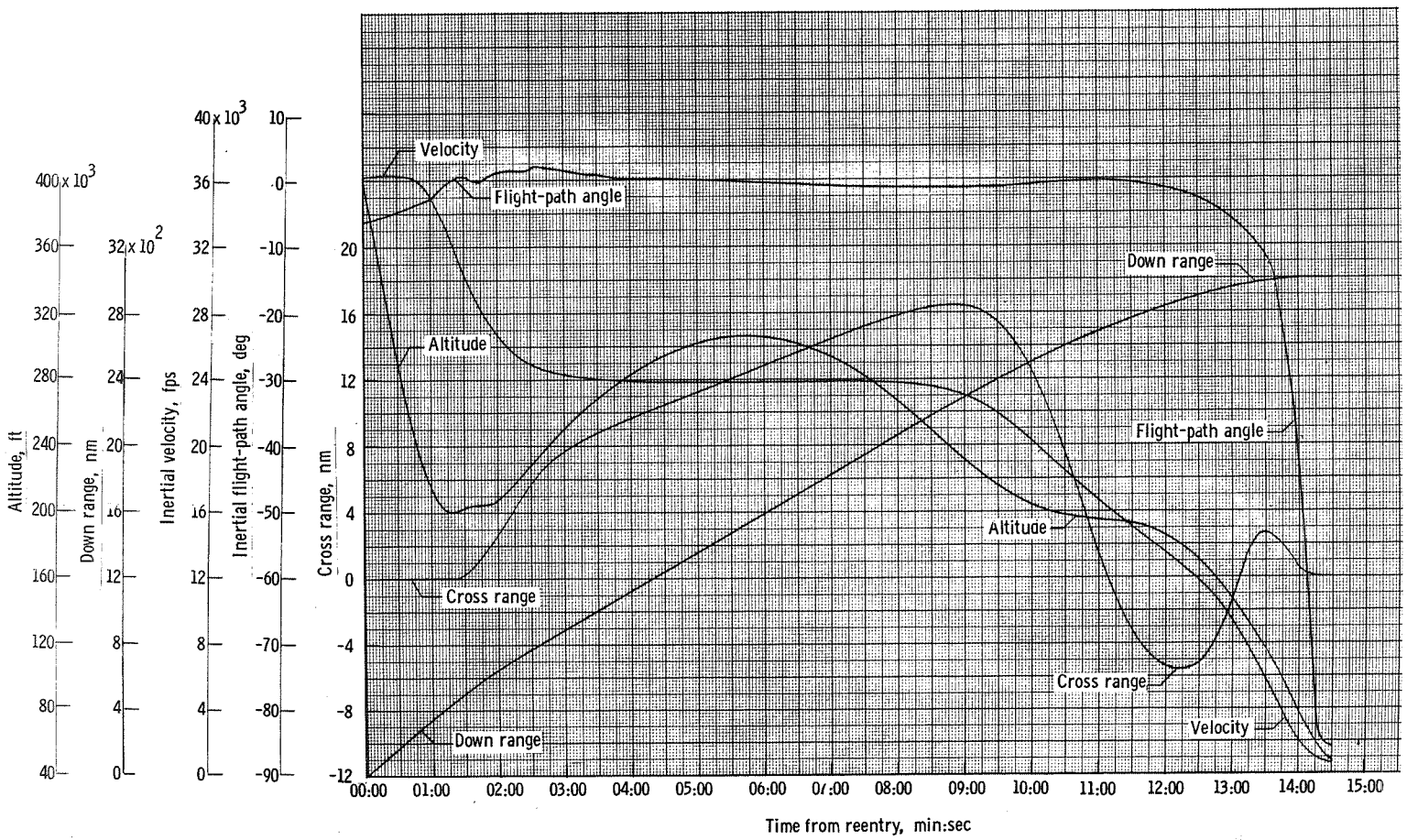
(m) Reentry trajectory parameters as a function of time for an initial flight-path angle = -6.4° and a reentry range = 4000 nm.

Figure 21. - Continued.



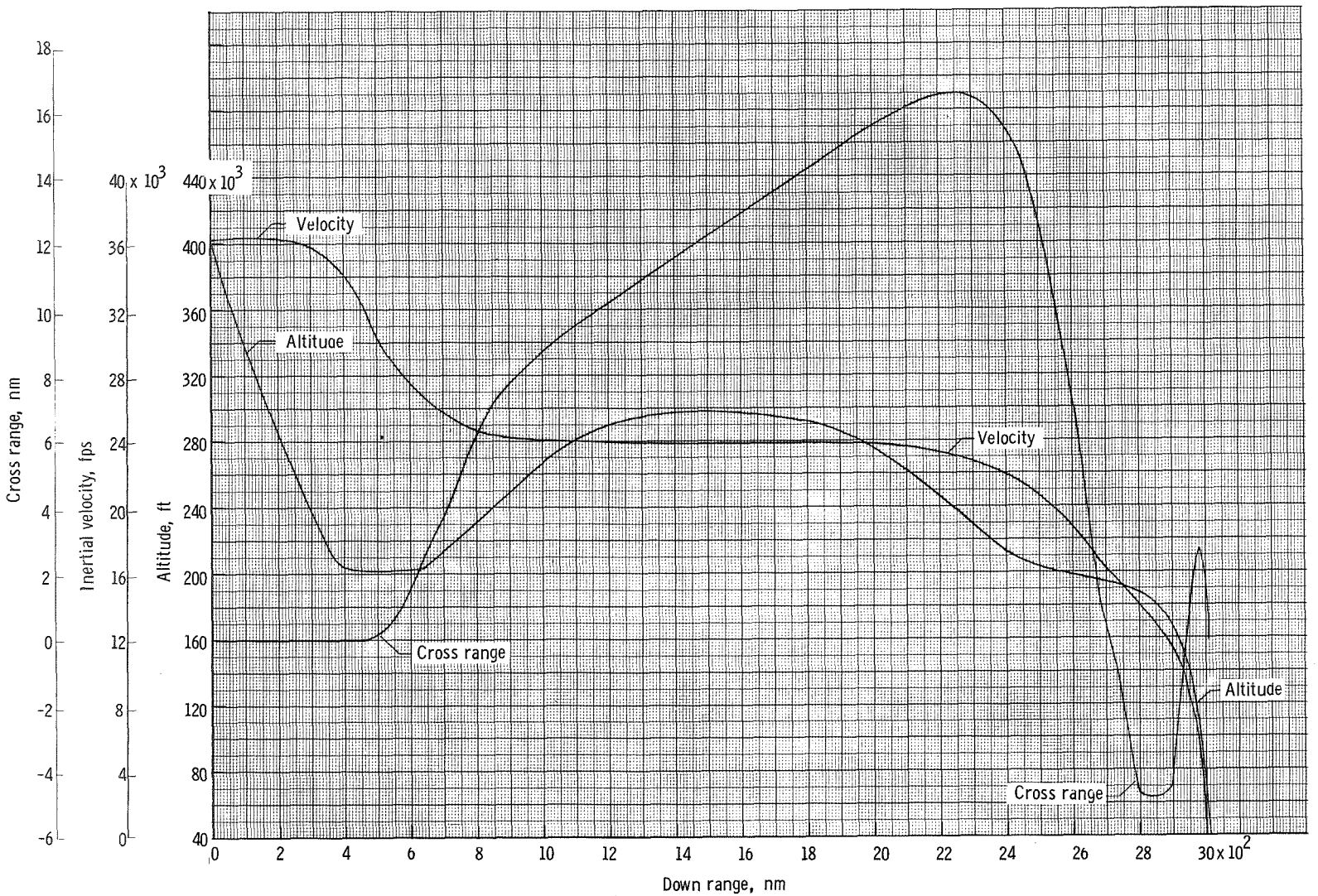
(n) Reentry trajectory parameters as a function of range for an initial flight-path angle = -6.4° and a reentry range = 4000 nm.

Figure 21.- Continued.



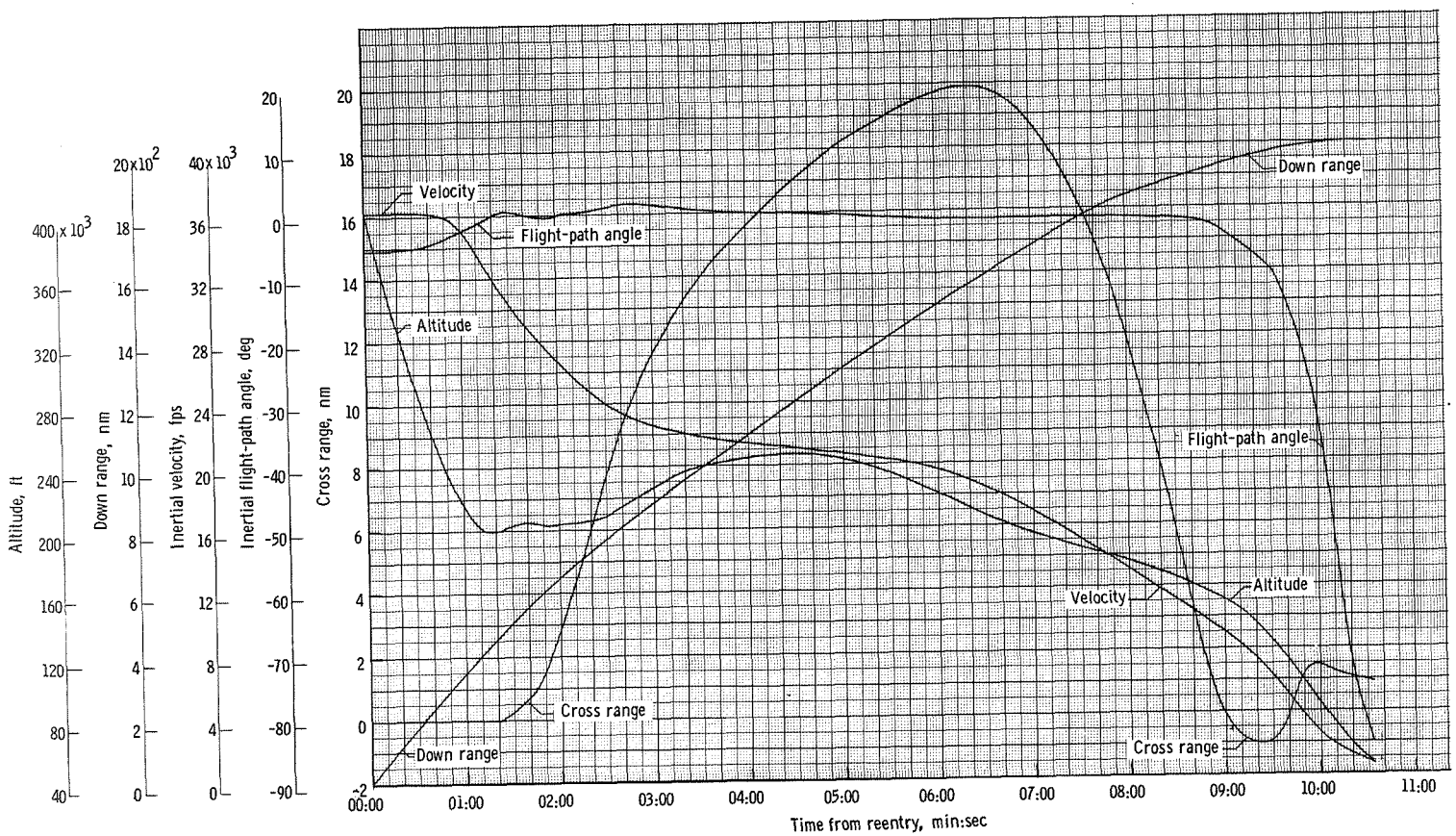
(o) Reentry trajectory parameters as a function of time for an initial flight-path angle = -6.4° and a reentry range = 3000 nm.

Figure 21.- Continued.



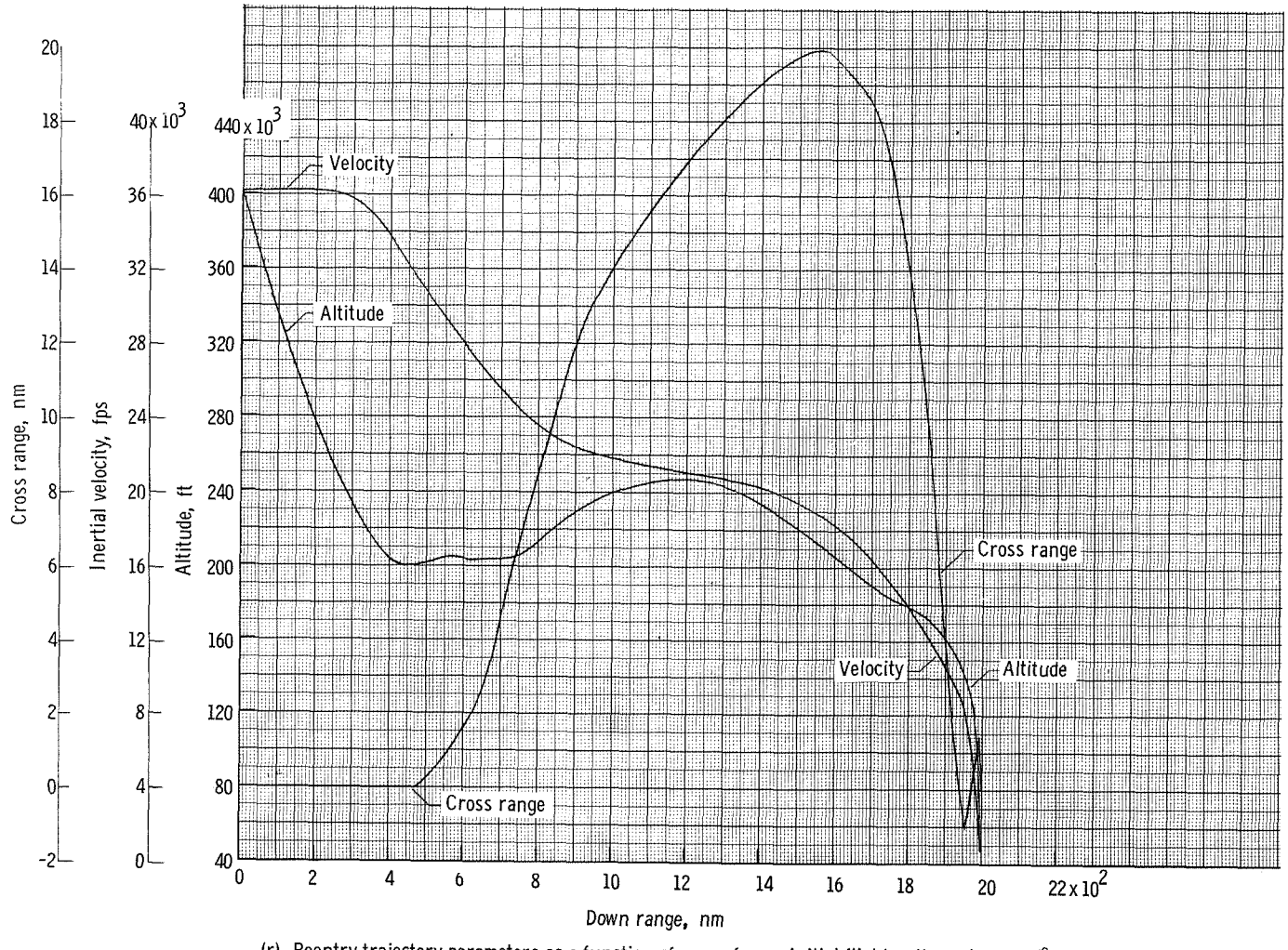
(p) Reentry trajectory parameters as a function of range for an initial flight-path angle = -6.4° and a reentry range = 3000 nm.

Figure 21.- Continued.



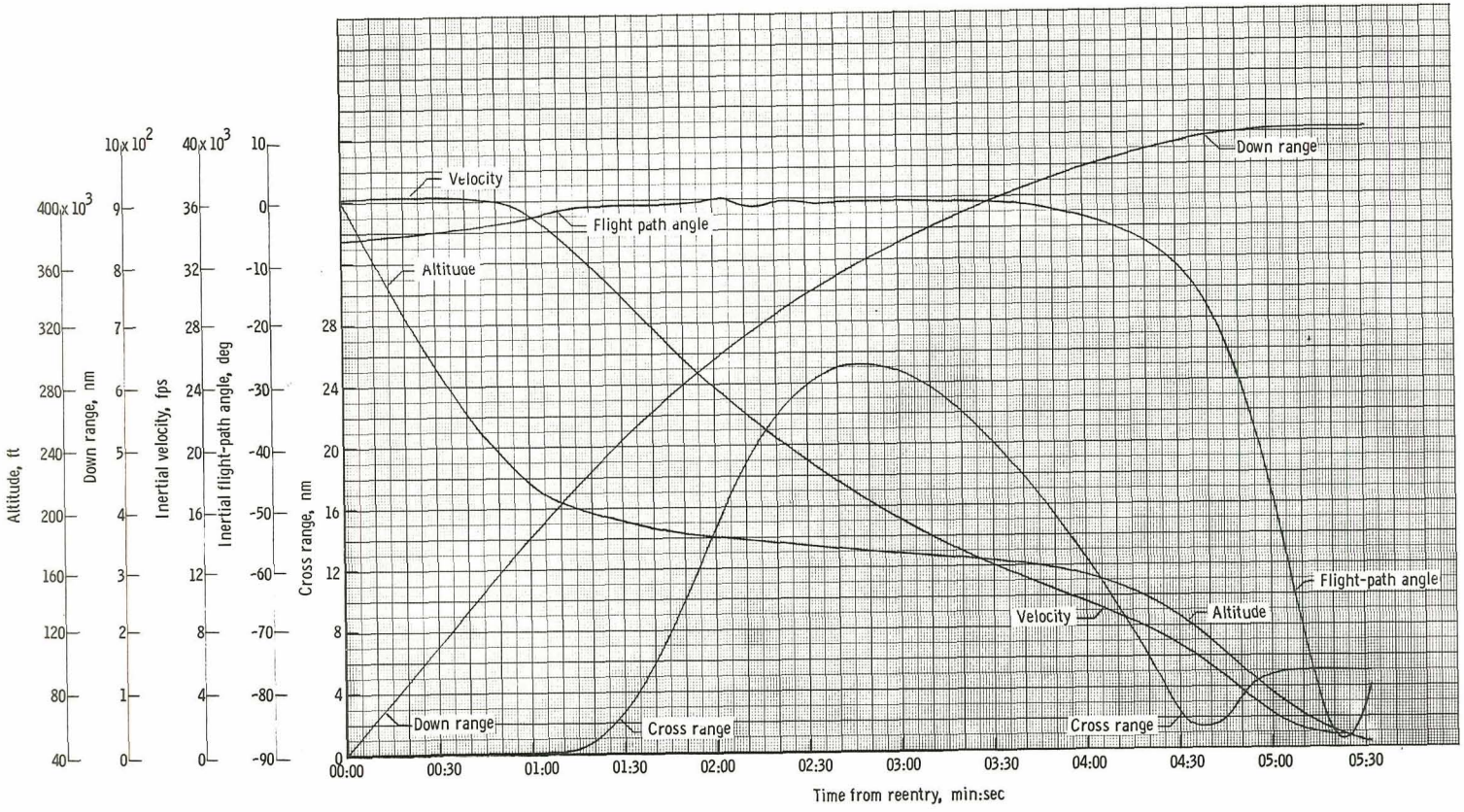
(q) Reentry trajectory parameters as a function of time for an initial flight-path angle = -6.4° and a reentry range = 2000 nm.

Figure 21.- Continued.



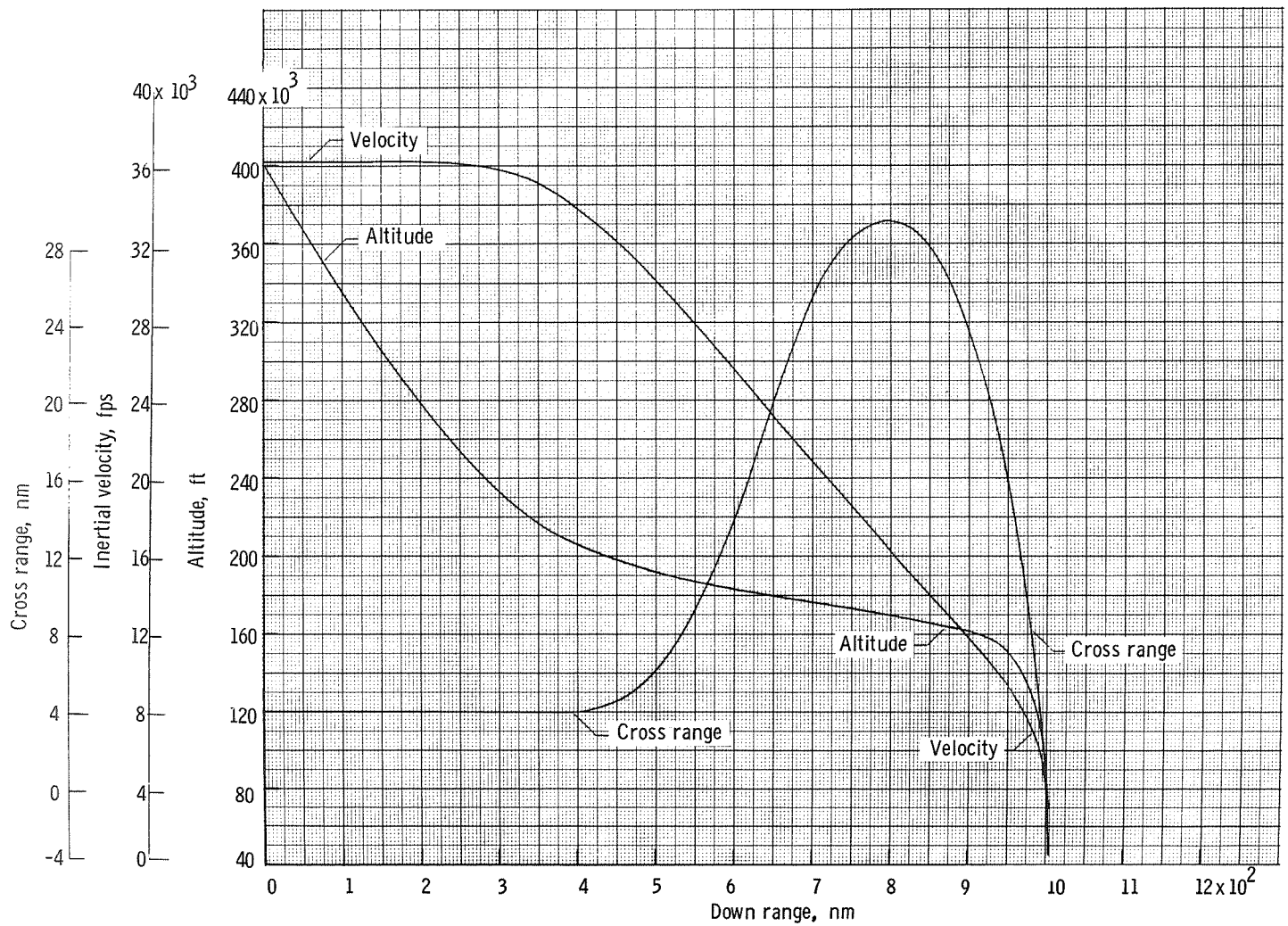
(r) Reentry trajectory parameters as a function of range for an initial flight-path angle = -6.4° and a reentry range = 2000 nm.

Figure 21. - Continued.



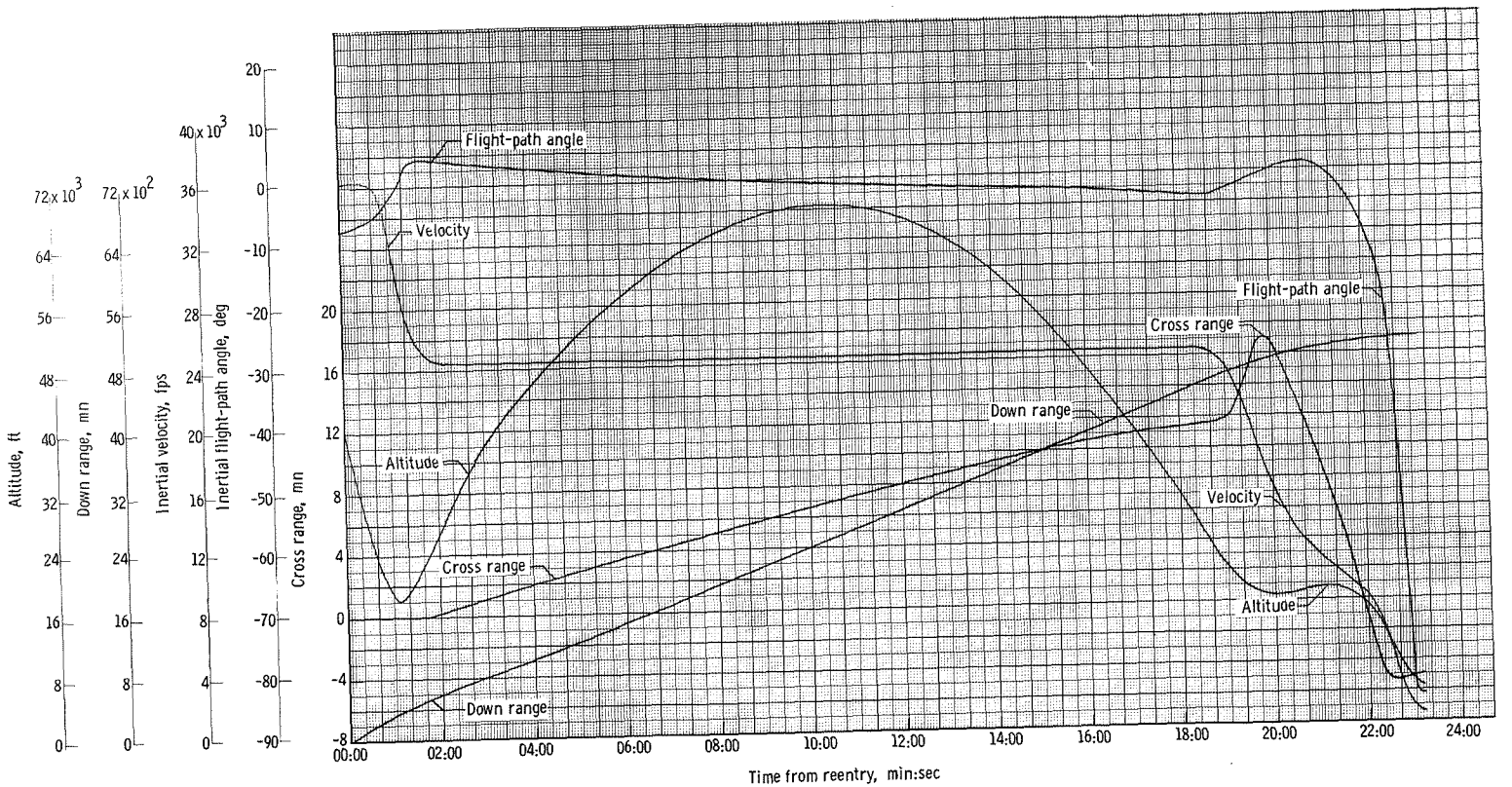
(s) Reentry trajectory parameters as a function of time for an initial flight-path angle = -6.4° and a reentry range = 1000 nm.

Figure 21. - Continued.



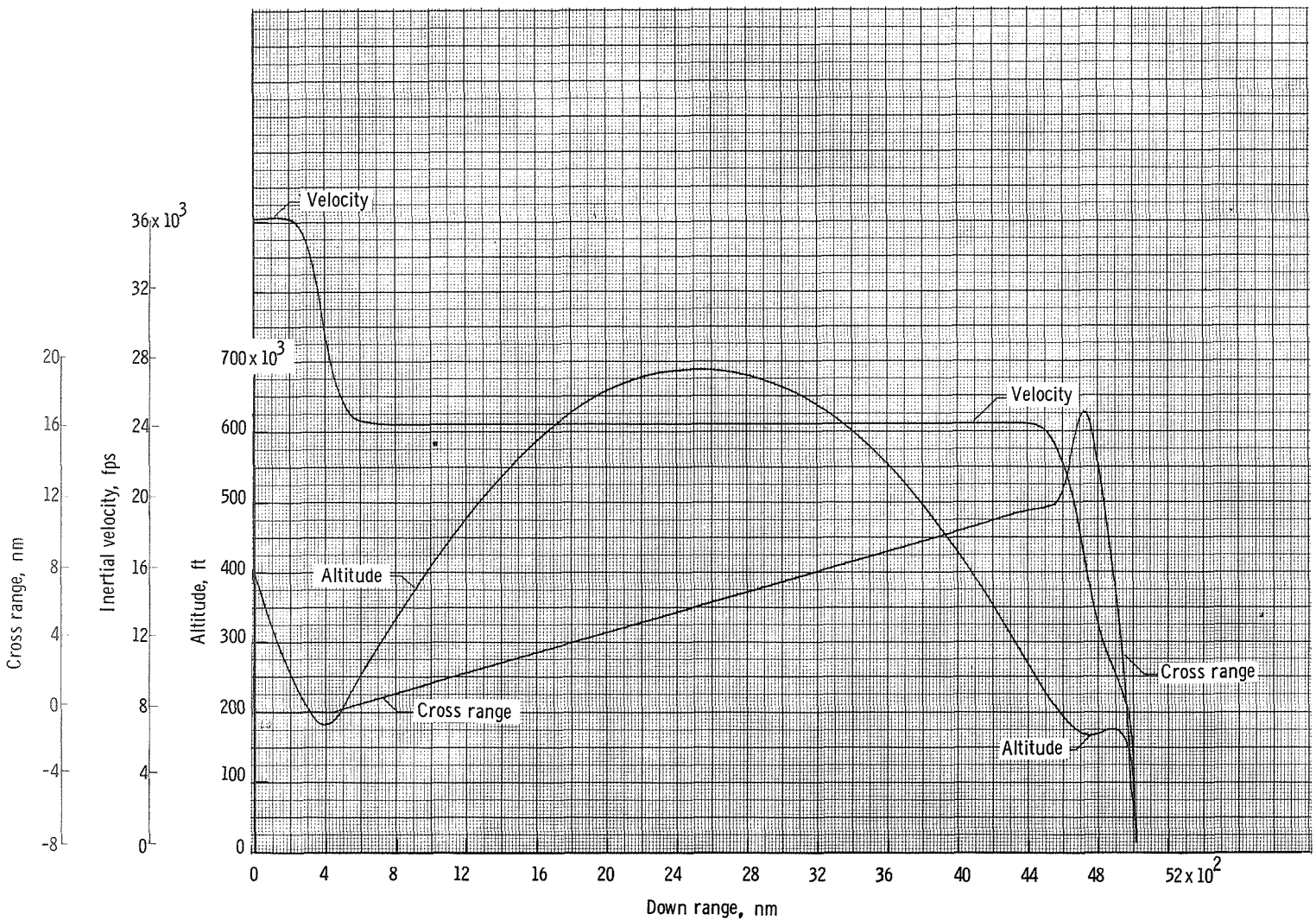
(t) Reentry trajectory parameters as a function of range for an initial flight-path angle = -6.4° and a reentry range = 1000 nm.

Figure 21. - Continued.



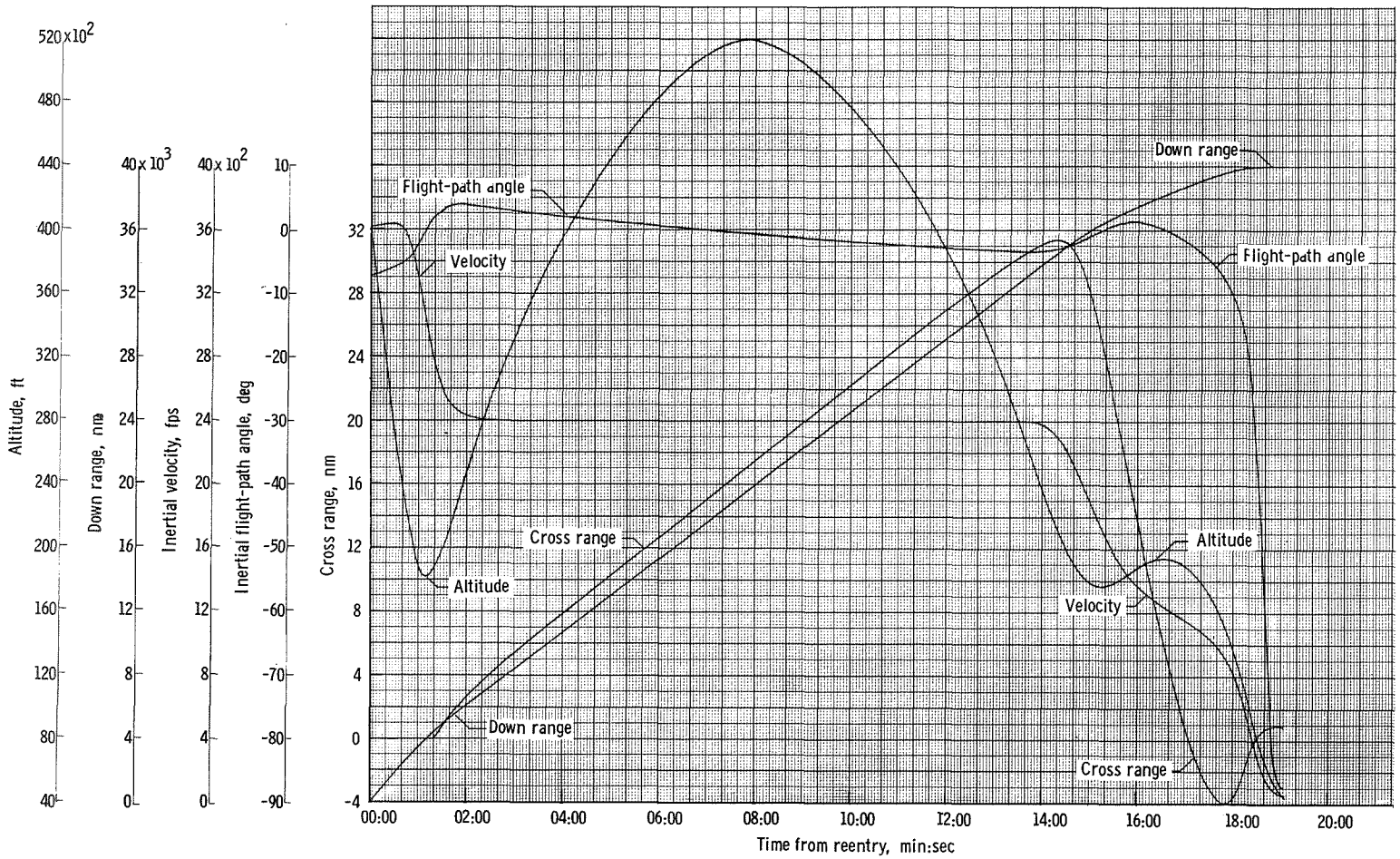
(u) Reentry trajectory parameters as a function of time for an initial flight-path angle = -7.4° and a reentry range = 5000 nm.

Figure 21. - Continued.



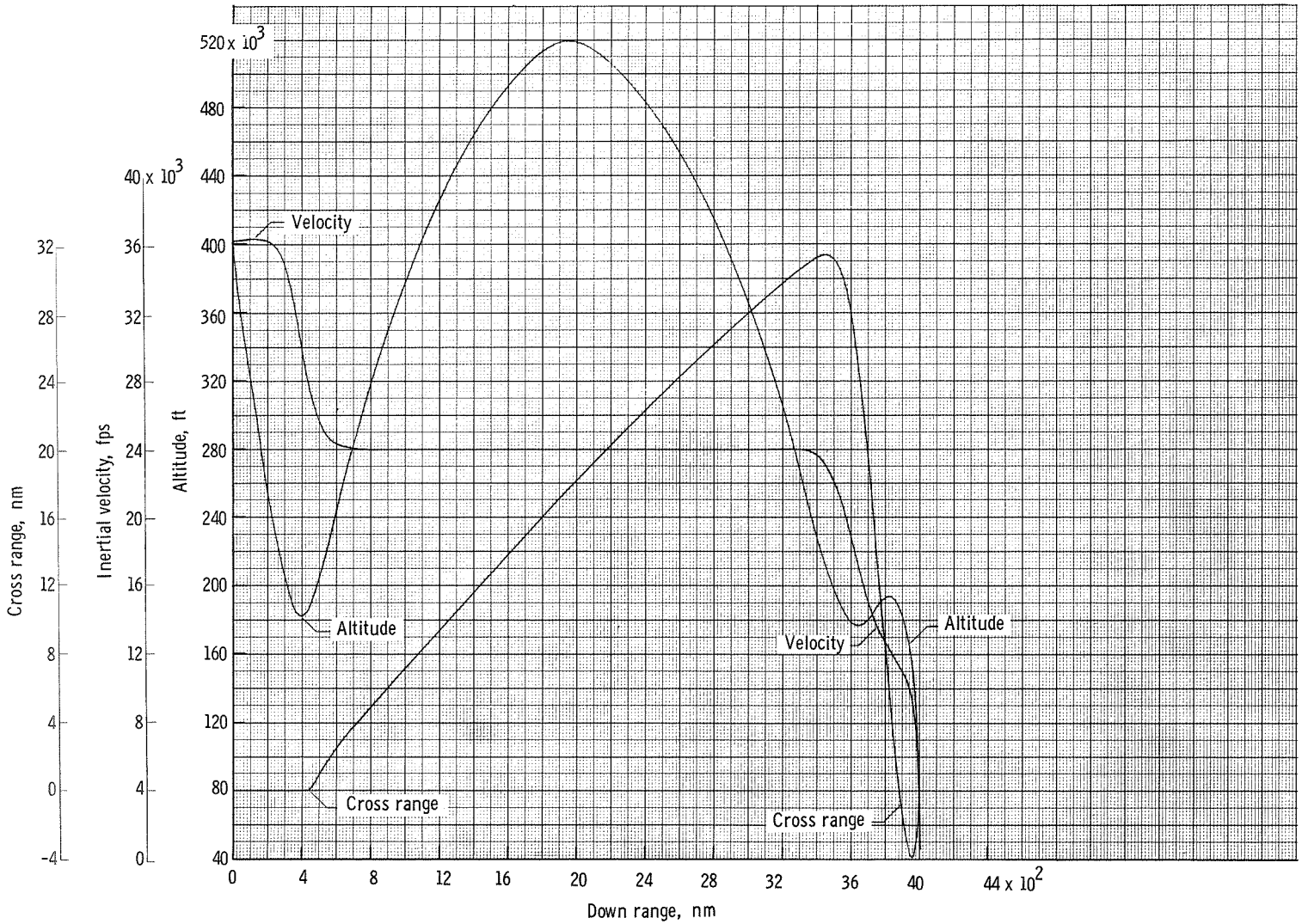
(v) Reentry trajectory parameters as a function of range for an initial flight-path angle = -7.4° and a reentry range = 5000 nm.

Figure 21. - Continued.



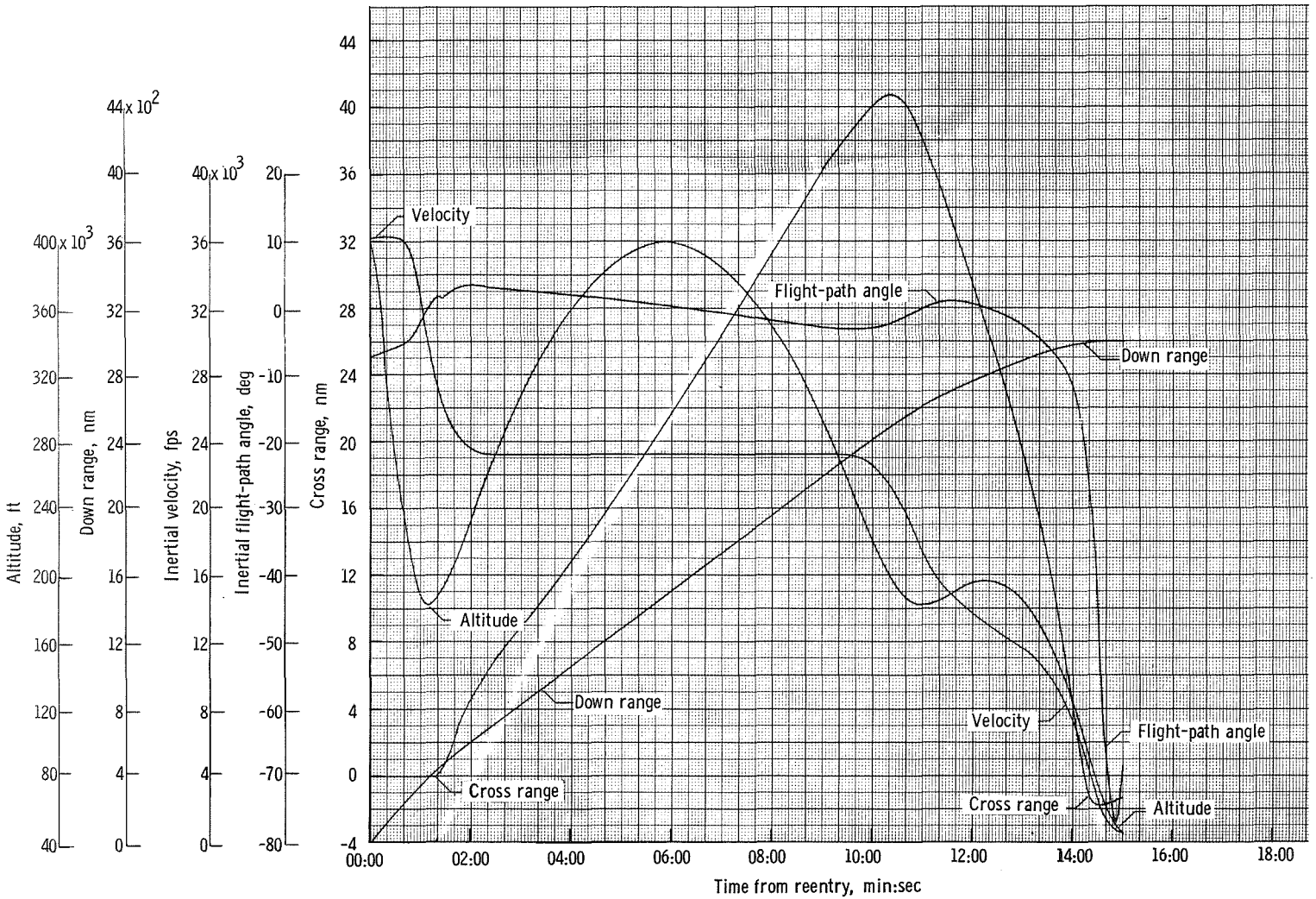
(w) Reentry trajectory parameters as a function of time for an initial flight-path angle = -7.4° and a reentry range = 4000 nm.

Figure 21.- Continued.



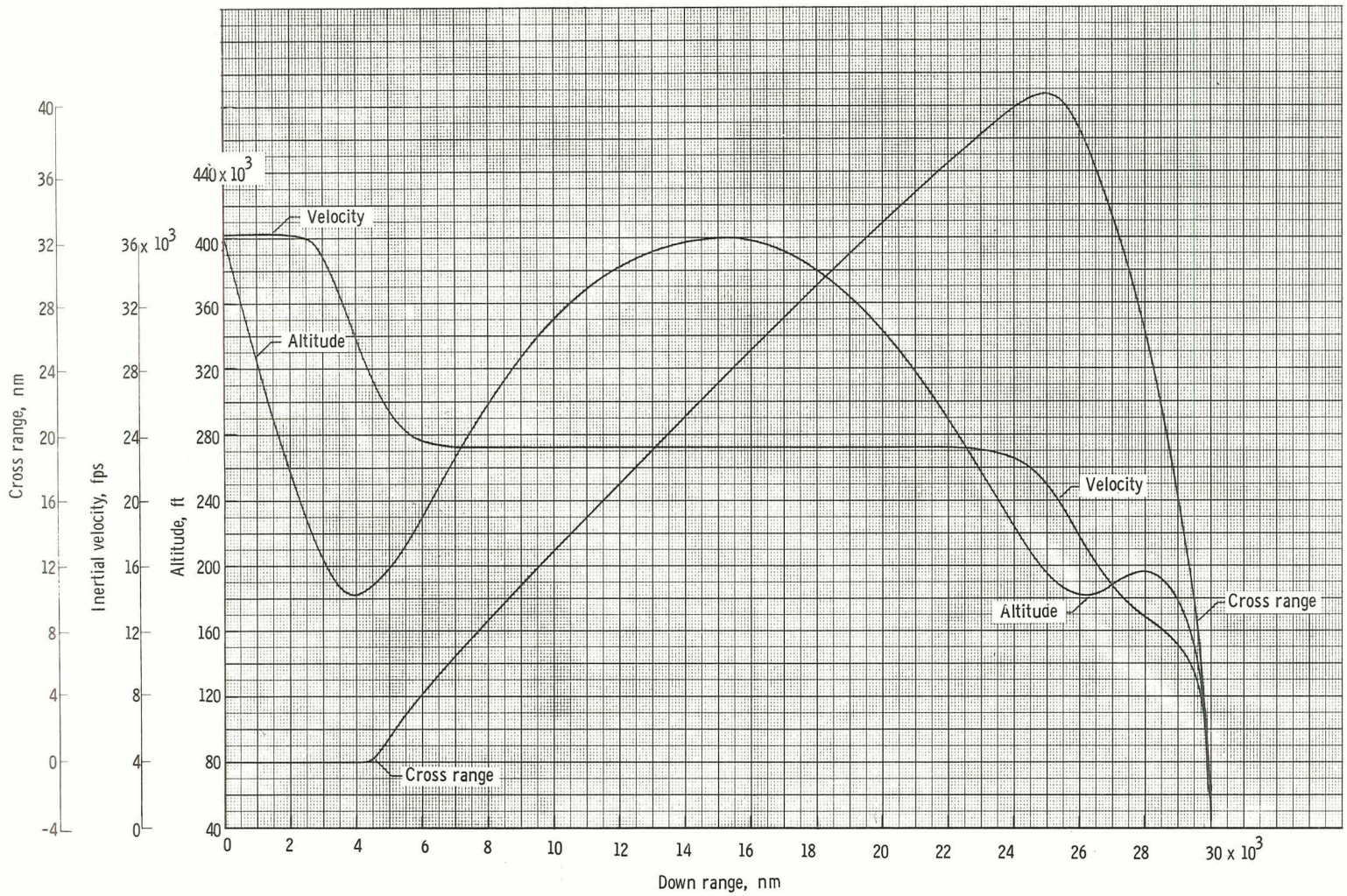
(x) Reentry trajectory parameters as a function of range for an initial flight-path angle = -7.4° and a reentry range = 4000 nm.

Figure 21. - Continued.



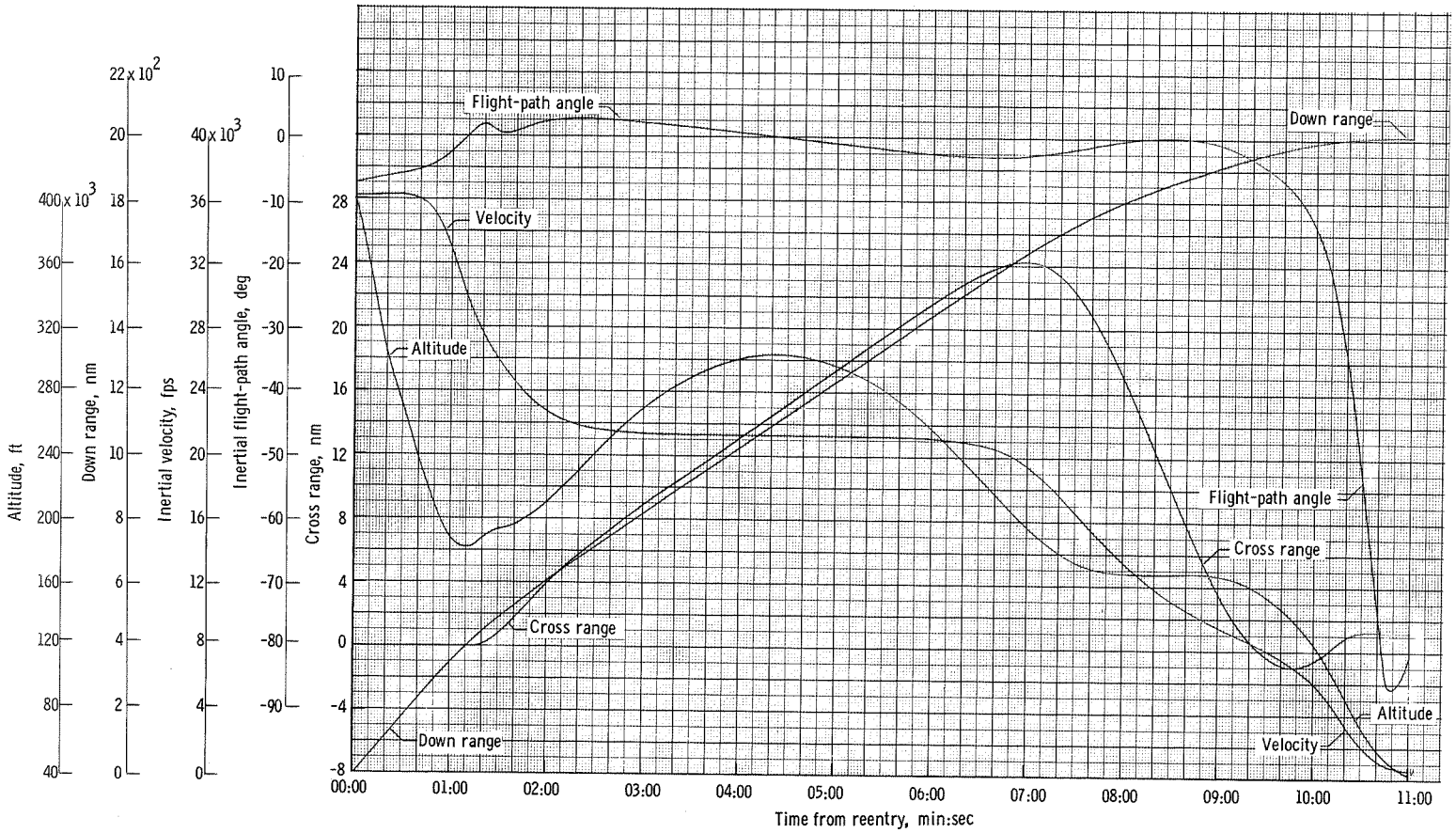
(y) Reentry trajectory parameters as a function of time for an initial flight-path angle = -7.4° and a reentry range = 3000 nm.

Figure 21.- Continued.



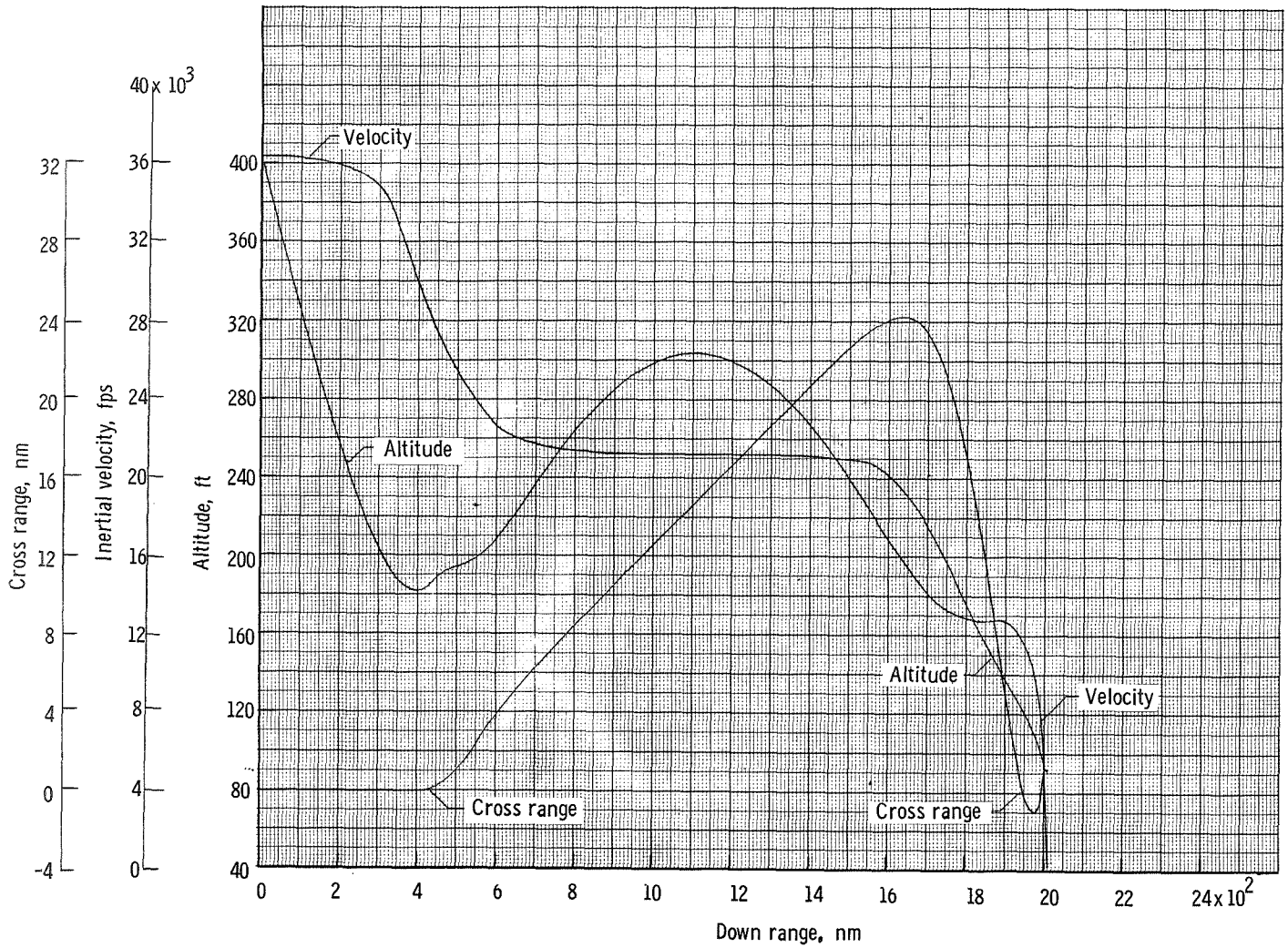
(z) Reentry trajectory parameters as a function of range for an initial flight-path angle = -7.4° and a reentry range = 3000 nm.

Figure 21. - Continued.



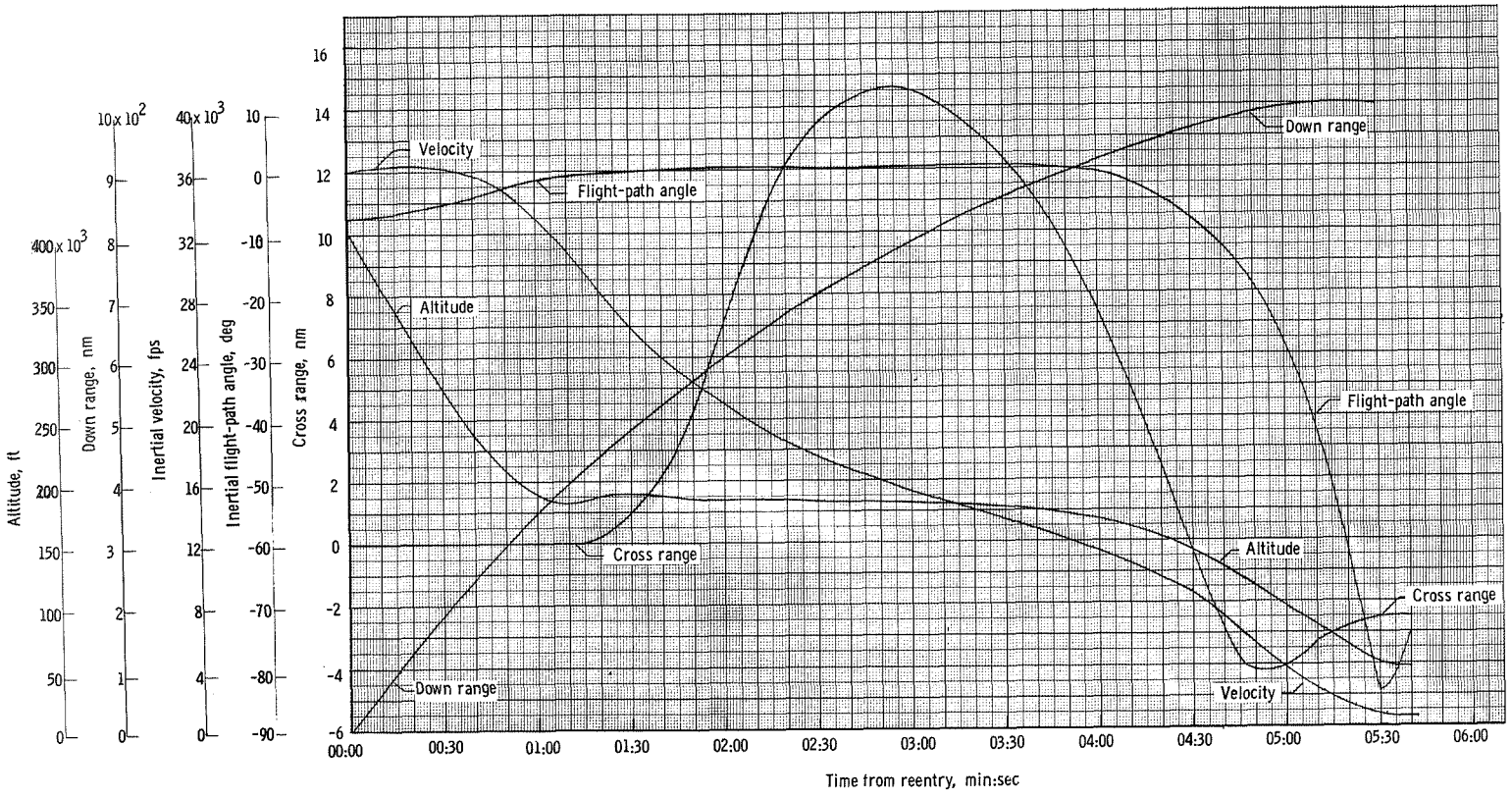
(aa) Reentry trajectory parameters as a function of time for an initial flight-path angle = -7.4° and a reentry range = 2000 nm.

Figure 21. - Continued.



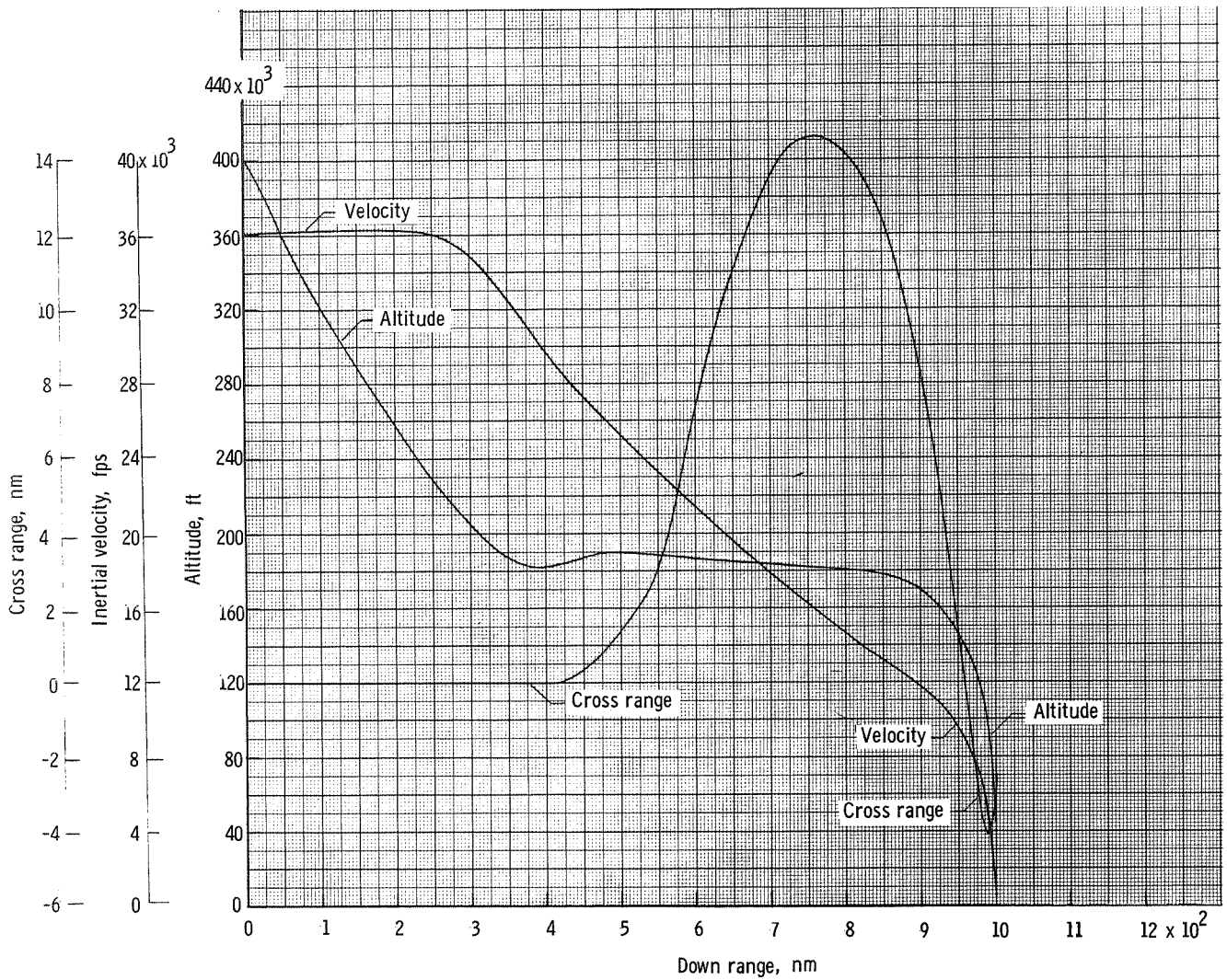
(bb) Reentry trajectory parameters as a function of range for an initial flight-path angle = -7.4° and a reentry range = 2000 nm.

Figure 21. - Continued.



(cc) Reentry trajectory parameters as a function of time for an initial flight-path angle = -7.4° and a reentry range = 1000 nm.

Figure 21. - Continued.



(dd) Reentry trajectory parameters as a function of range for an initial flight-path angle = -7.4° and a reentry range = 1000 nm.

Figure 21. - Concluded.

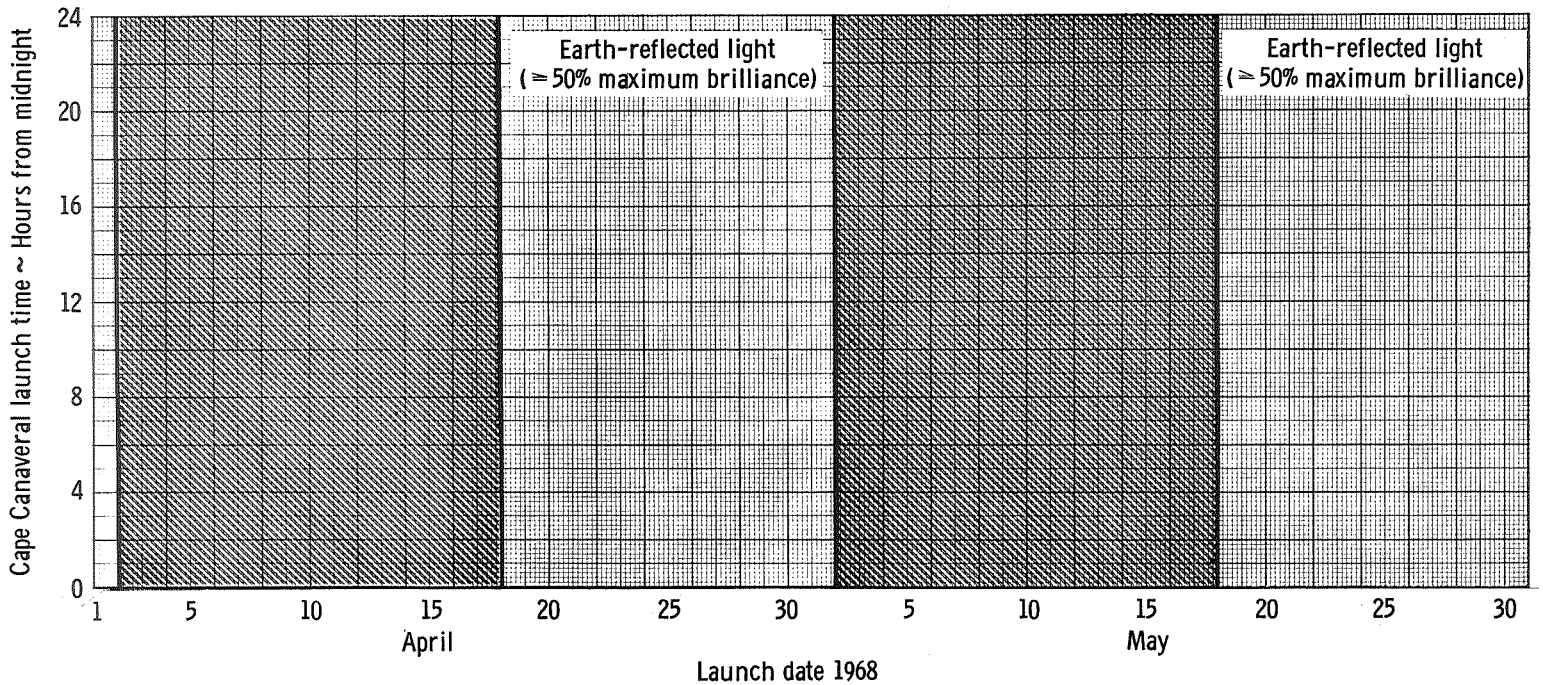


Figure 22. - Favorable lunar lighting periods.

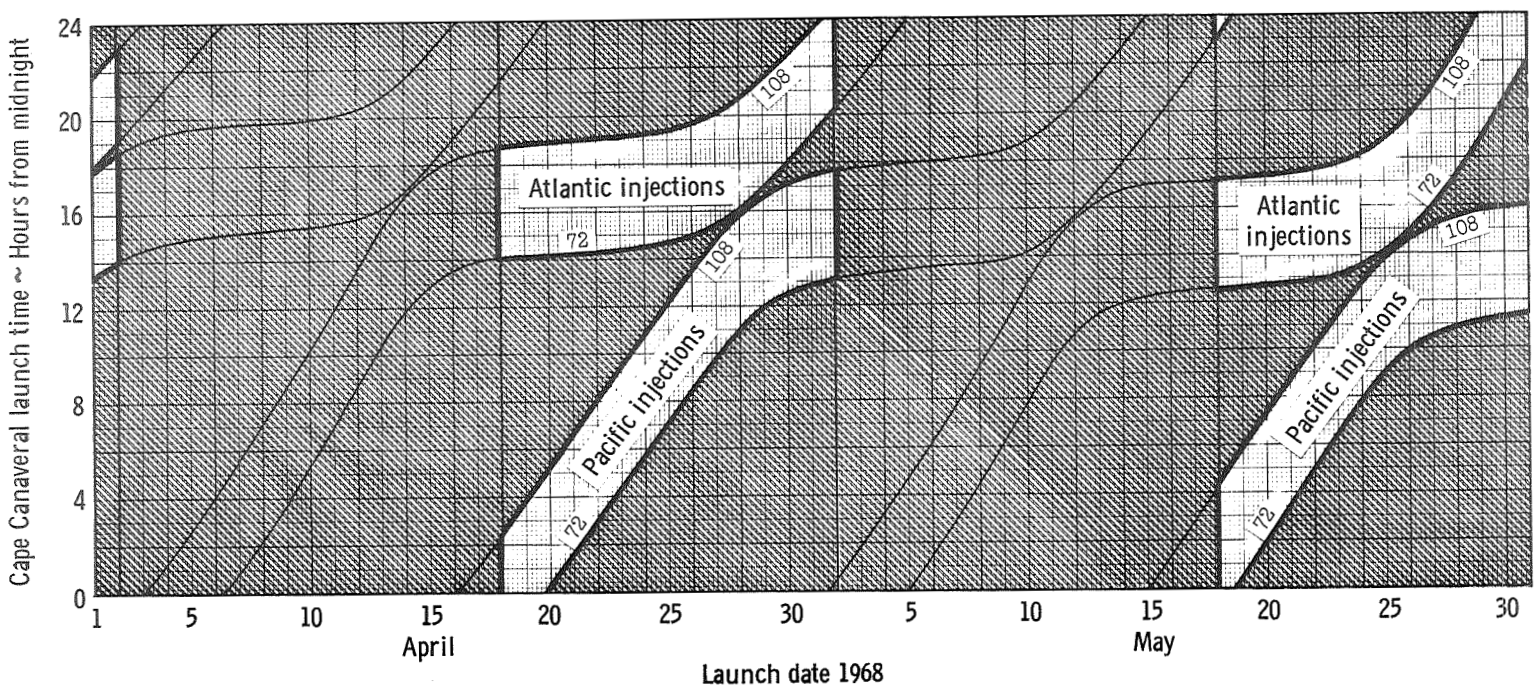


Figure 23.- Application of range-safety launch azimuth limits.

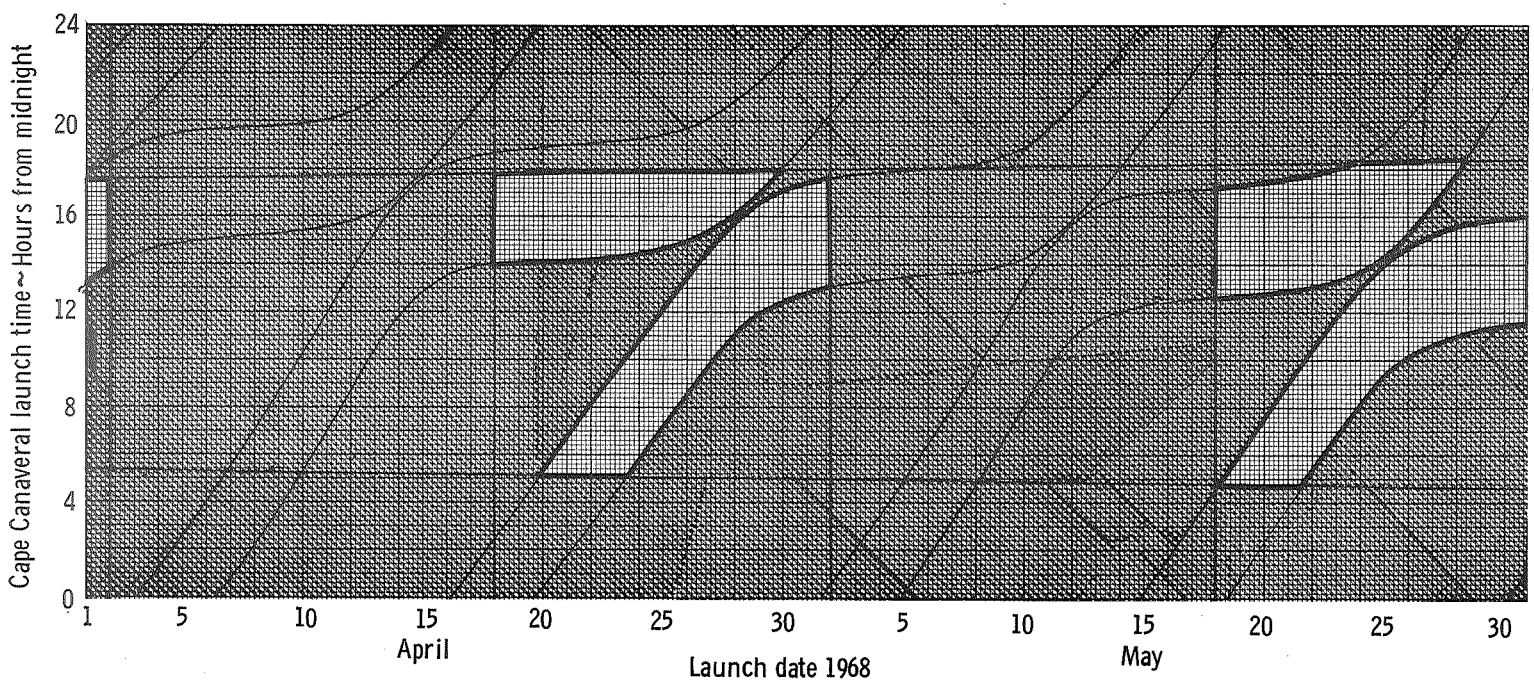


Figure 24. - Application of launch lighting restrictions.

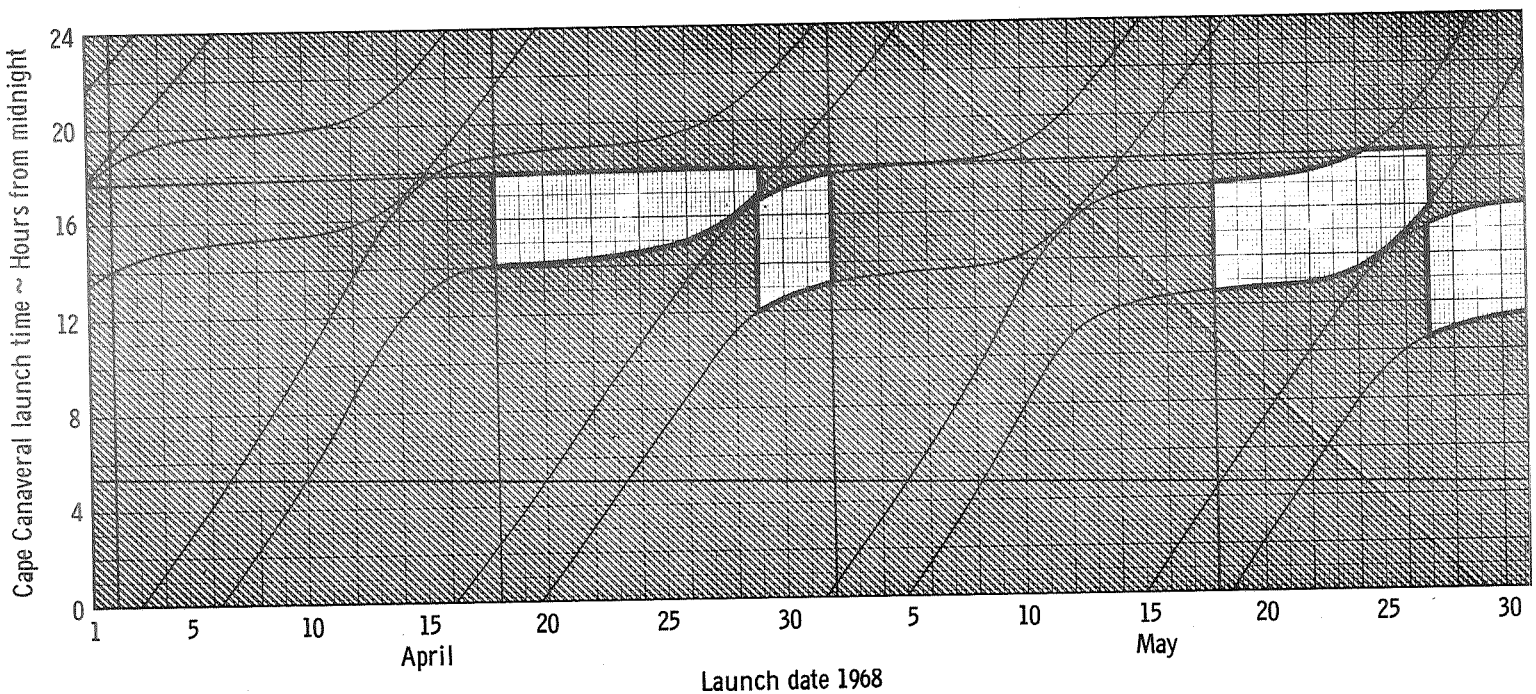


Figure 25.- Application of maximum inclination restrictions.

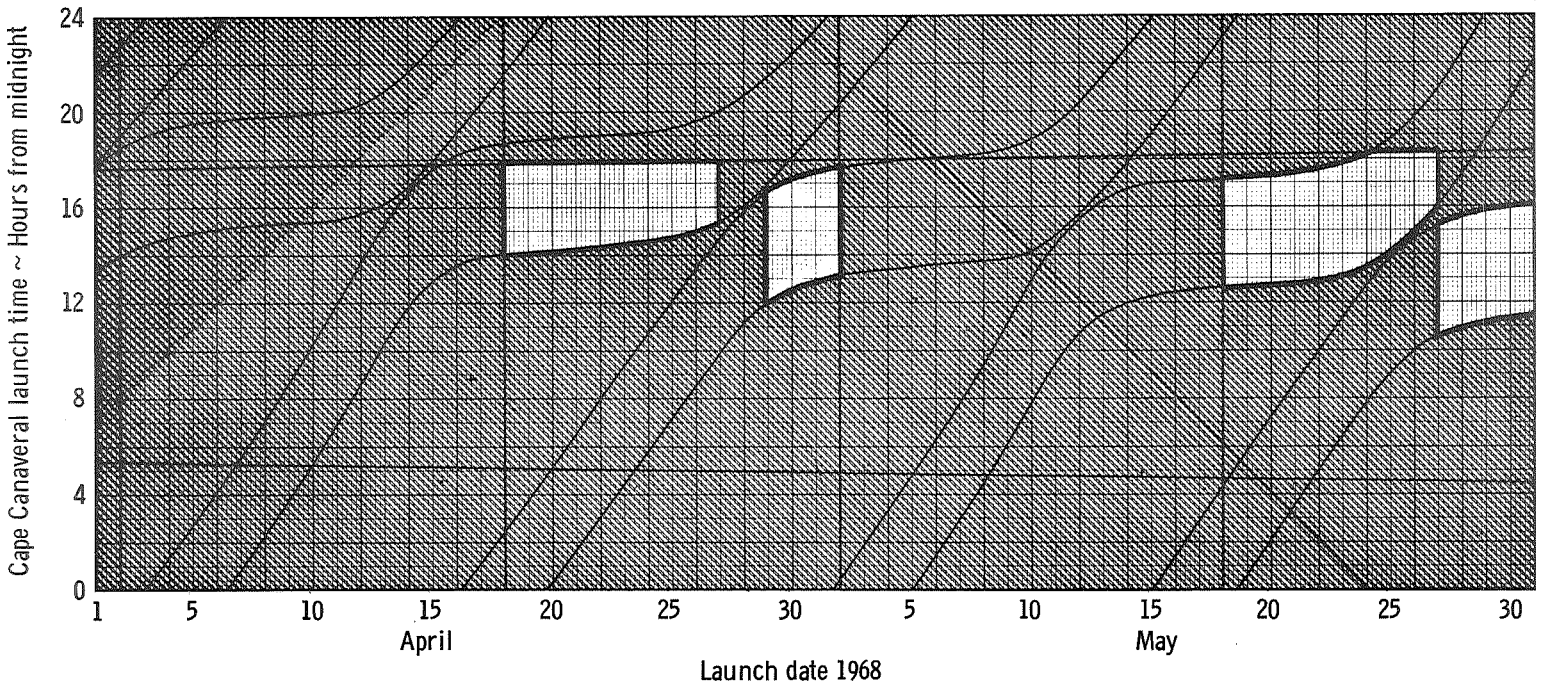


Figure 26.- Application of minimum daily window constraint.

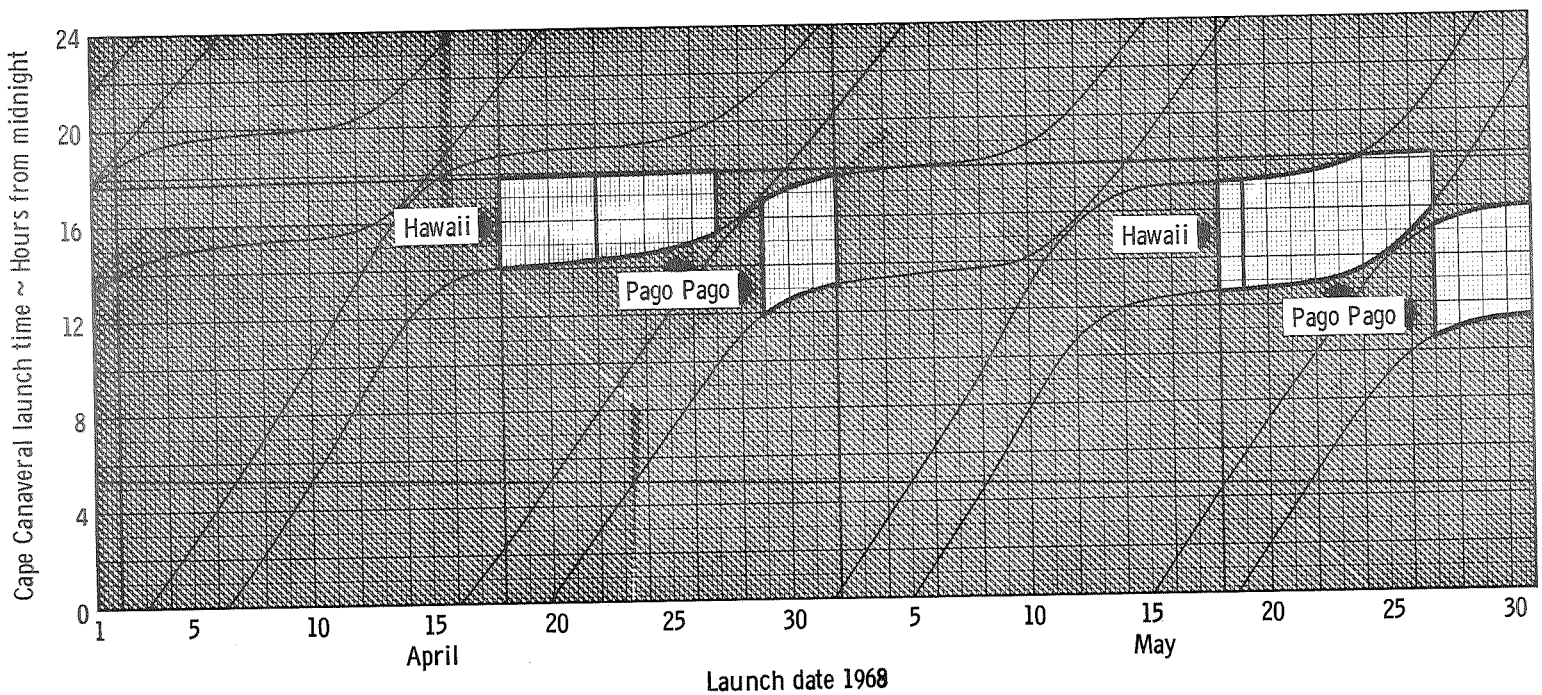


Figure 27.- Final launch windows with return sites shown.

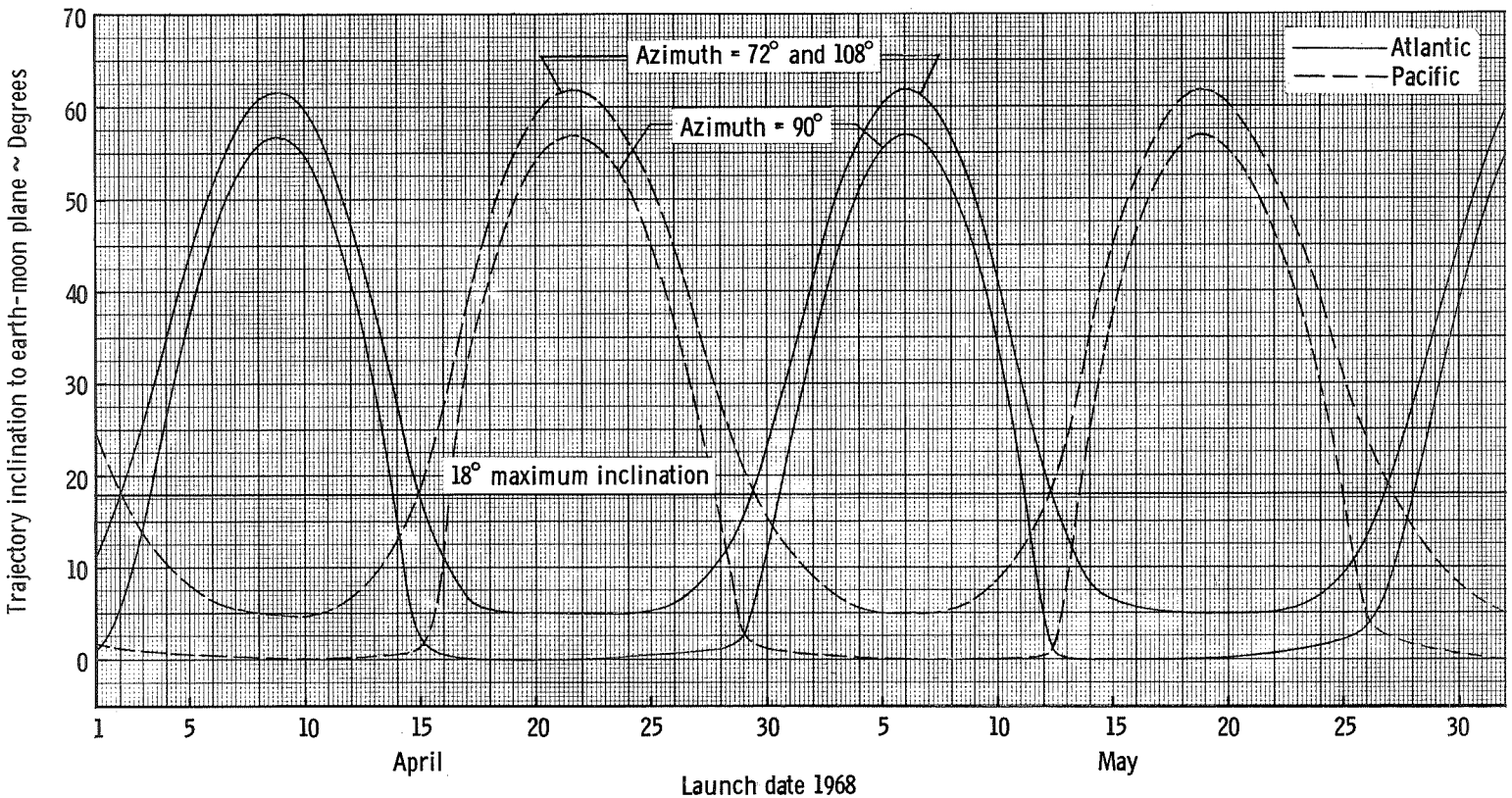
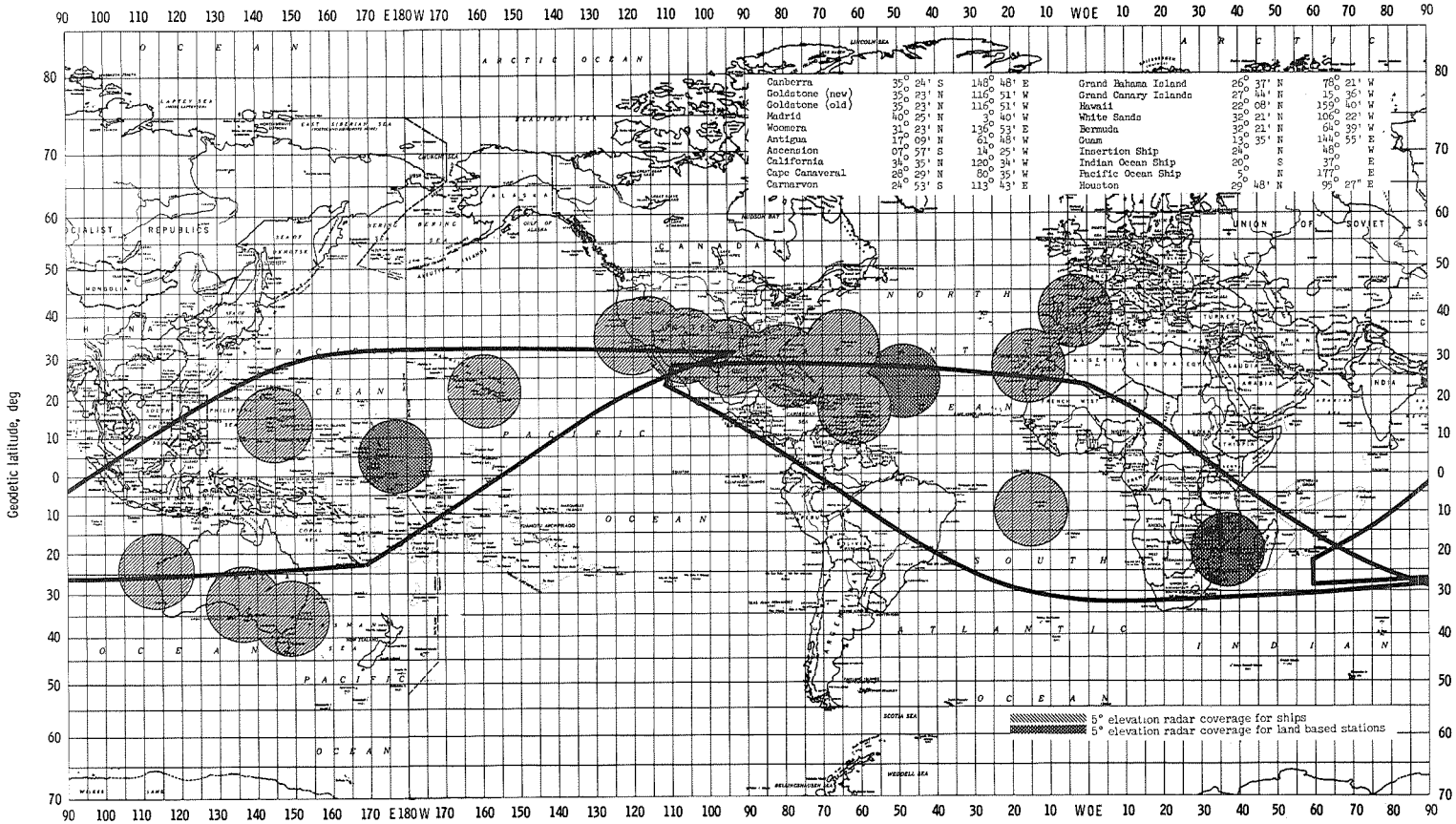
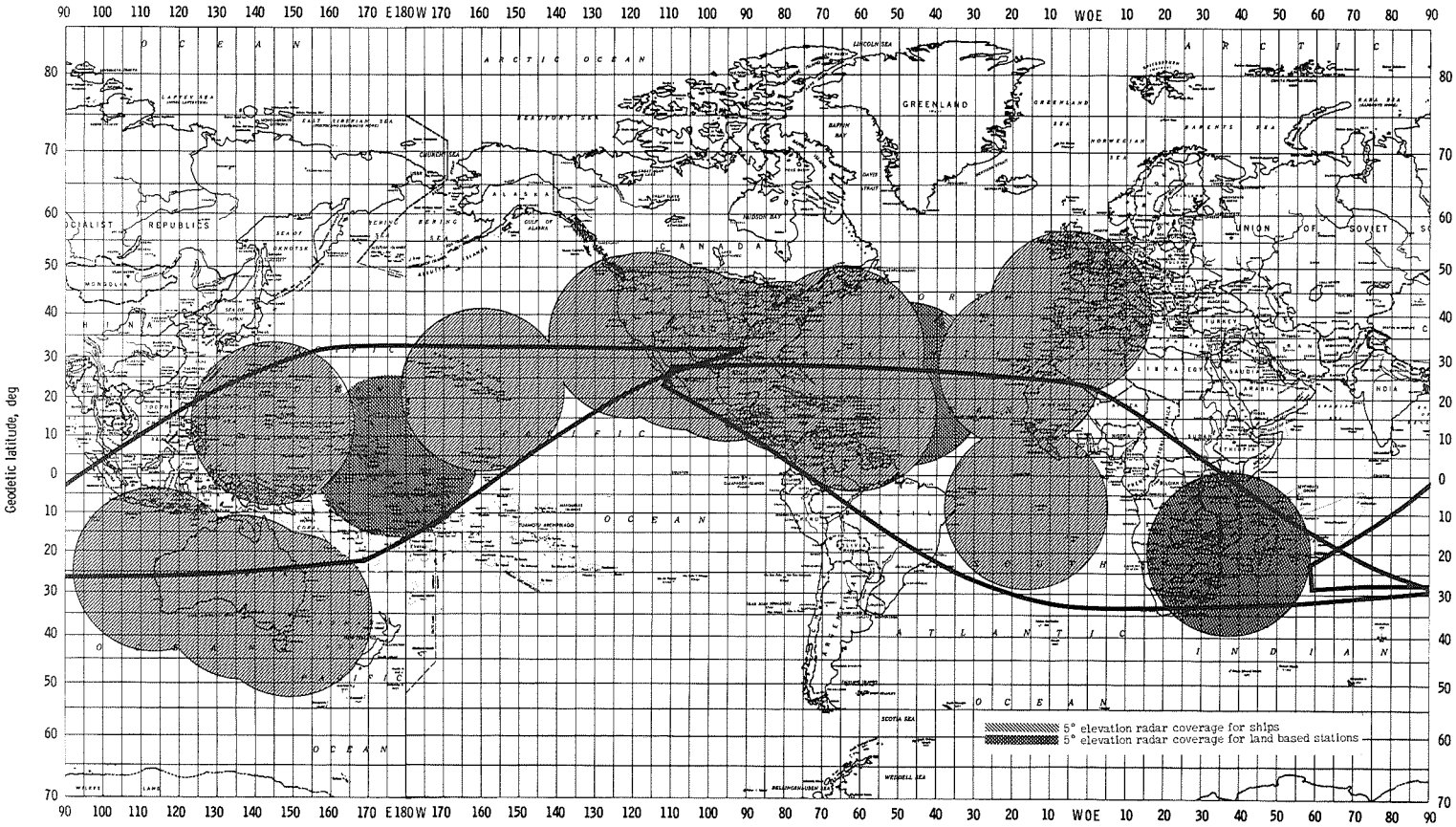


Figure 28.- Earth-moon plane trajectory inclination requirements for Atlantic and Pacific injections.



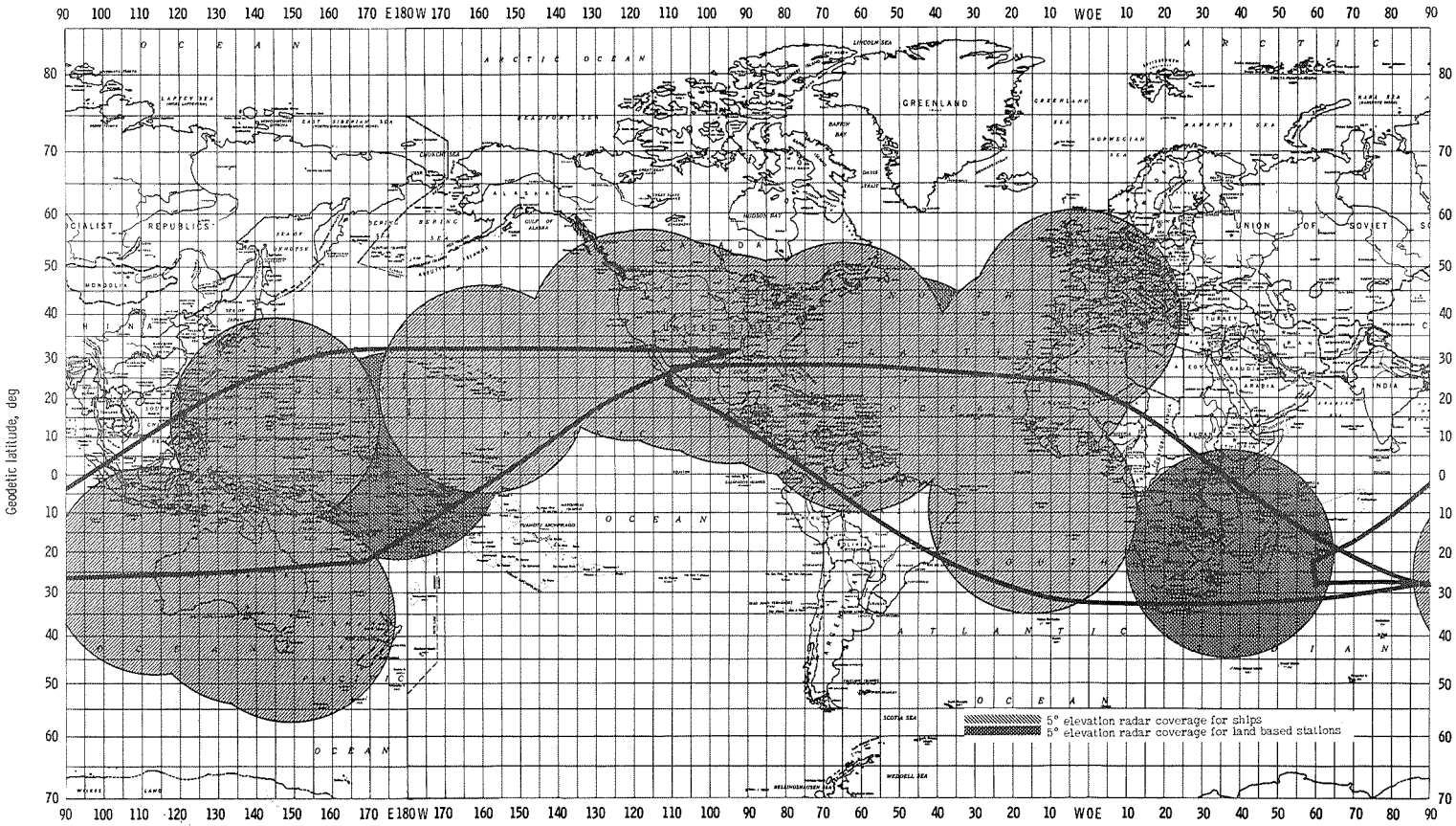
(a) Translunar injection, 107 nautical miles altitude.

Figure 29. - Radar coverage of Atlantic and Pacific translunar injection areas by land based stations and ships.



(b) Five minutes after translunar injection, 392 nautical miles altitude.

Figure 29. - Continued.



(c) Seven minutes after translunar injection, 603 nautical miles altitude.

Figure 29. - Concluded.