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PRELIMINARY LAUNCH ABORT ANALYSIS FOR MANNED APOLLO S-V MISSIONS

By Bobbie D. Weber
Flight Analysis Branch

MISSION PLANNING AND ANALYSIS DIVISION

MANNED SPACECRAFT CENTER
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PROJECT APOLLO

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CONTENTS

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TABLES

FIGURES

Figure		Page

Figure | Page

Figure		Page

PRELIMINARY LAUNCH ABORT ANALYSIS

FOR MANNED APOLLO S-V MISSIONS

By Bobbie D. Weber

SUMMARY

This paper presents a preliminary analysis of aborts during the first powered flight portion of the manned Apollo S-V mission, from lift-off through insertion into earth-parking orbit. The analysis considers primarily the capability of various propulsion systems on the spacecraft to either return the command module (CM) and crew safely to earth immediately following a booster malfunction or to achieve earth orbit from which the CM and crew can deorbit safely or perform an alternate mission. Although recommendations are presented for abort mode definition and duration based on this analysis, this was not the sole purpose of the analysis. The primary purpose of the analysis was to provide sufficient data to show the spacecraft capabilities and limitations, so that, if alternatives to the recommendations are considered, data will be available to weigh the advantages and disadvantages of the alternatives.

INTRODUCTION

It is a well recognized fact that the most critical phase of any manned space flight exists during the launch phase. During the first few minutes of powered flight the situation is very critical with respect to reaction time and dictates a very carefully rehearsed dialogue between the flight controllers and the flight crew. This time-critical phase is characterized by an operational emphasis on crew safety. For the remainder of the boost phase, when reaction time does not have as great an effect on crew safety, the flight crew and ground controllers are more concerned with achieving earth orbit for the purpose of salvaging some mission objectives and/or returning the crew safely to earth. This analysis does not attempt to show what might cause a contingency nor what course the ground controllers and flight crew might follow upon achieving a contingency orbit. The following recommended abort mode definitions and procedures are designed to provide the optimum in operational simplicity and crew safety.

DEFINITIONS OF ABORT MODES

Abort Mode I

Abort Mode I utilized the Apollo launch escape system (LES) to provide a safe separation distance from the booster and automatic entry sequencing to assure safe recovery of the CM and crew in the event booster malfunctions occur from the time the booster is on the pad until about 30 seconds after S-II ignition. A thorough trajectory analysis for abort Mode I has not been conducted for inclusion in this paper due to the high degree of sensitivity of abort trajectories with respect to the LES thrust vector alignment settings which are at this date very preliminary. However, figures 1 and 2 do present the LES configuration and sequences to be used for Block II spacecraft. References 1, 2, and 3 provide sufficient trajectory analysis of this abort mode and can be considered preliminary AS-504 data.

Abort Modes II and III

Abort Mode II does not utilize the spacecraft propulsion systems for range control. For purposes of this analysis, as can be seen in table I, a short duration service propulsion system (SPS) burn was simulated for booster-spacecraft separation. This burn was deleted from the AS-204 separation sequence, and it is not expected that it will be included in the separation sequence for S-V aborts. This analysis was near completion at the time the burn was deleted. Therefore, rather than repeat the analysis to conform to current operational procedures and, thus, delay publication, it was decided to include the burn for abort Modes II, III, and IV. Documentation following the AS-504 preliminary abort studies will not include the simulation of this burn.

Abort Mode II begins at the time of launch escape tower (LET) jettison and continues until the full-lift landing point is 3200 n. mi. downrange from the launch pad. Due to the high entry deceleration loads experienced for aborts during this portion of the launch, the CM will be flown full lift into the Atlantic Continuous Recovery Area (ACRA).

The following sequencing will occur in the event a Mode II abort is initiated for AS-204A. The sequencing for all Modes of S-V aborts will be the same as presented in this paper.

1. The translation hand controller (THC) will be turned counter-clockwise and back to the pre-abort position within 1.7 seconds. This action will cause the booster to cutoff but will inhibit booster/command and service module (CSM) separation; thus allowing sufficient time for the booster thrust to tail off completely prior to booster/CSM separation. Upon receiving the booster cutoff signal, the digital event timer (DET) will be reset to zero.

2. The THC will be turned counter-clockwise at 2.3 seconds after the DET receives the booster cutoff signal.

3. The CSM will separate from the booster 4 seconds following booster cutoff. At this time, the four aft-firing service module (SM) reaction control system (RCS) jets will begin firing to achieve a safe separation distance from the booster.

4. The CSM will begin maneuvering to the CM/SM separation attitude (small-end-forward (SEF) and above the local horizontal) 24 seconds after booster cutoff.

5. The CM will separate from the SM 45 seconds after booster cutoff. At this time it is expected that the CM will be unstable and any exsisting attitude rates will be arrested with the CM RCS.

6. The CM will orient to the entry attitude 55 seconds after booster cutoff.

7. The CM should be oriented to the entry attitude (big-end-forward) 100 seconds after booster cutoff.

Abort Mode III will employ SPS retrograde burns to avoid land landings. Abort Mode III will begin when the full-lift landing point is 3200 n. mi. downrange from the launch pad. During this portion of the launch, entry deceleration loads resulting from aborts are not as critical as during the Mode II portion. Therefore, range control to avoid African impacts using lift-vector orientation can be employed. All entries, following a Mode III abort, will normally be half lift with the lift vector rolled left of the full-lift position. Therefore, the first Mode III landing point will be uprange of the discrete recovery area (DRA) (intersection of the pre-abort orbit plane and 3200 n. mi. range) and south of the pre-abort orbital groundtrack. When the half-lift landing point is downrange from the DRA and in Africa, the SPS will be fired retrograde until the half-lift landing point is 3200 n. mi.

downrange from the launch pad. This burn will be of any magnitude greater than 2 seconds. (Current operational procedures dictate that no burns less than 2 seconds will be performed.) For aborts from the nominal trajectory the burn could be as long as 160 seconds. Figure 3 shows the spacecraft attitude to be employed for both retrograde and posigrade burns in launch abort situations requiring SPS burns. After the half-lift landing point is safely across Africa, near recovery area 1B, Mode III aborts will result in landings in the Indian Ocean. For the nominal 72° launch azimuth the Indian Ocean landing area will be located at 8200 n. mi. downrange from the launch pad. Finally, abort Mode III would be performed only in the event an immediate return to earth is desired or in the event very dispersed conditions exist from which the spacecraft is incapable of achieving orbit.

The following will be used for Mode III aborts:

1. Same as for Mode II.

2. Same as for Mode II.

3. Same as for Mode II.

4. Twenty-four seconds after booster cutoff the CSM will begin maneuvering to the SPS retrograde attitude (see fig. 3).

5. At booster cutoff plus 125 seconds the Mode III SPS burn will be performed via the SCS ΔV mode which will maintain the CSM inertial attitude corresponding to the relative attitude at SPS burn initiation throughout the burn.

6. The sequencing following the SPS burn will be the same as 4 through 7 for Mode II except the time will be referenced to SPS cutoff rather than booster cutoff.

Abort Mode IV

Abort Mode IV will utilize the SPS to achieve a minimum perigee orbit. Mode IV aborts will be performed when the SPS has the capability of achieving a 75.0-n. mi. perigee assuming the spacecraft has not descended below 75.0-n. mi. altitude between the time of abort (booster cutoff) and SPS cutoff upon achieving the 75.0-n. mi. perigee. Also, the Mode IV SPS burn is to be initiated at cutoff plus 125 seconds.

Finally, a sub-mode exists for abort Mode IV. When sufficient time exists for the ground controllers to compute and relay to the crew an apogee kick maneuver (posigrade maneuver applied at apogee of the pre-abort orbit) designed to raise perigee above 75.0 n. mi., this maneuver will be employed in lieu of the SPS Mode IV burn at booster cutoff plus 125 seconds.

The following will be used for Mode IV aborts:

1. Same as Mode II.

2. Same as Mode II.

3. Same as Mode II.

4. The CSM will begin maneuvering to the SPS posigrade attitude (fig. 3) 24 seconds after booster cutoff.

5. At booster cutoff plus 125 seconds the Mode IV burn will be initiated and will be performed using the SCS ΔV mode. The SPS will burn until the CSM has achieved a 75.0-n. mi. perigee.

DISCUSSION AND RESULTS

Simulation Constants

The enclosed data are the results of three-degrees-of-freedom digital computer simulations. The spacecraft propulsion system characteristics that were used can be found in reference 4. Reference 5 contains the CM aerodynamic configuration used. The launch vehicle reference trajectory used was that for the nominal 72° launch azimuth found in reference 6. The sequence of events for this trajectory is presented in table II. The J-2 engine tailoff characteristics given in reference 7 were used in simulating both the S-II and S-IVB tailoff as indicated in table I.

Nominal Launch Trajectory Parameters

Figures 4 through 8 present various nominal launch vehicle trajectory parameters as given in reference 6. Figures 4 and 5 present the nominal range versus altitude and the nominal altitude versus inertial velocity, respectively. These figures, when compared to figures for AS-204 (ref. 1), are characterized by the absence of the high loft necessary for maximum payload in the S-IB trajectories. This is also apparent when figure 7 (inertial velocity versus inertial flight-path angle) is compared to a similar figure for AS-204 (ref. 1) in that the flight-path angles for AS-504 are not nearly as negative as those for the AS-204 trajectory. Whenever possible, the launch abort data has been presented as functions of inertial velocity at abort (booster cutoff) with time of abort presented as a secondary scale. If a more accurate reading of time of abort is desired, this can be obtained from figures 6(a) and 6(b) which present inertial velocity, inertial flight-path angle, range, and altitude as functions of ground elapsed time (g.e.t.) from lift-off. Figure 8 presents the groundtrack for the 72° azimuth launch trajectory.

Abort Modes II and III

Figure 9 presents the groundtracks for various launch azimuths from the pad to the Indian Ocean. On this figure it can be seen that all the groundtracks intersect at 180° inertial central angle from the pad. At one time this intersection point was considered for the only Mode III launch abort recovery area and was therefore designated as the IORA (Indian Ocean Recovery Area). However, the advantage in the simplicity of having only one Mode III recovery area, the earth-fixed coordinates (longitude, λ, and latitude, ϕ) of which would be independent of launch azimuth, was out-weighed by its disadvantages. Some of the disadvantages are:

1. When performing maneuvers required to land at the IORA, the post-abort perigee was near or greater than the Apollo Guidance Computer's (AGC) reference altitude. This meant that in the event the crew lost ground-voice contact the AGC might be unable to aid them in performing a Mode III abort maneuver.

2. The abort maneuver, if not performed exactly as computed, resulted in very large landing dispersions.

3. If it were required to perform a posigrade burn to the IORA, the horizon would not be in daylight for late evening launches. Since a lit horizon is necessary for initial thrust vector orientation, the crew would either be unable to align the thrust vector or a misalignment would result in large landing range dispersions.

Range of landing is presented as a function of longitude of landing for aborts from the 72° azimuth launch trajectory in figure 10.

The geodetic latitude and the longitude of full-lift landing points resulting from Mode II aborts are presented in figure 11.

The effect of CM aerodynamics on range is shown in figures 12 and 13. Figure 12 shows the landing distances from the launch pad for free-fall aborts from the nominal trajectory for full-, half-, and zero-lift entries as functions of inertial velocity at abort. Figure 13 presents the footprint length and distance from the half-lift landing point to the footprint toe as functions of inertial velocity at abort.

During the S-II stage of flight, a booster malfunction resulting in a slow trajectory divergence from the nominal might place the crew in very unsafe regions of flight. Those regions defined by very low velocities and very high flight-path angles are characterized by the high deceleration loads that are experienced if an abort is performed. The regions defined by very low velocities and very low flight-path angles are characterized by the lack of sufficient time to properly orient the CM to the correct entry attitude following abort initiation and service module (SM) separation. For these reasons limitations have been placed on these regions of flight. First, a slow trajectory divergence will be allowed provided sufficient time from abort initiation (booster cutoff) to entry interface (300 000-ft altitude) is available for aborts from the trajectory. This limit is that 100 seconds of free fall be available above 300 000 ft. Second, the divergence will be allowed if aborts from the trajectory will result in no greater than 16 g during entry.

Figure 14, which presents the time of free fall above 300 000 ft as a function of inertial velocity at abort, indicates that the limit of 100 seconds is never violated for aborts from the nominal trajectory.

Maximum entry load factor is presented as a function of inertial velocity at abort for full-lift, zero-lift and half-lift entries in figure 15. It can be seen that aborts from the nominal trajectory never exceed the 16-g limit for full-lift entries.

Although it has been established that the maximum entry load level shall be limited to 16 g, the time spent above a lower g level should be considered. Figure 16(a) presents the time above various g levels during entry for Mode II aborts from the nominal trajectory. Figure 16(b) (taken from ref. 8) presents the maximum time that can be allowed above a given g level before crew safety is affected. When comparing the two figures, note that for no time of abort from the nominal trajectory is the crew safety limit (effect of transverse g) violated.

Figure 17 presents the 100-second time of free fall (T_{FF}) limit and the 16-g limit as functions of inertial velocity and inertial flight-path angle. Also, the half-lift 16-g limit and times of free fall of 150 and 200 seconds are presented.

Figure 18 indicates the effect of CM aerodynamics on range by presenting landing range as a function of inertial velocity and inertial flight-path angle at abort for full-lift entries (fig. 18(a)), half-lift entries (fig. 18(b)), and zero-lift entries (fig. 18(c).

As mentioned previously, at one time it was considered to have the single Mode III launch abort recovery area in the Indian Ocean. One of the reasons for selecting this area was that very preliminary data indicated that if retrograde burns were performed to land at the DRA there would not have been sufficient T_{FF} to orient the CM prior to entry. However, this is presently not a problem for aborts from the nominal trajectory as indicated by figure 19 which presents SPS burn time (retrograde) required to land at the DRA and the T_{FF} remaining after the required retrograde burn as functions of inertial velocity at abort.

Figure 19 was derived from figures 20 and 21 which present CM landing range and T_{FF} remaining above 300 000 ft for various SPS range control burns as functions of inertial velocity at abort.

It has been considered to use the SM Reaction Control System (RCS) to avoid African impacts in the event the SPS fails. Figure 22 shows the RCS posigrade range control capability by presenting the landing range following a 540-second RCS burn at 100 percent effective thrust (four thrusters firing full time) as a function of inertial velocity at abort. Retrograde burns were not considered due to the lack of sufficient T_{FF} in that portion of the trajectory where the retrograde burn would need to be employed. Various delay times were considered for initiation of the RCS burn but the results were negligible when compared to the nominal minimum delay time (125 seconds from booster cutoff).

Abort Mode IV

Figure 23 presents the SPS burn time and SPS ΔV required to achieve a 75.0-n. mi. perigee as functions of inertial velocity at abort for aborts from the nominal trajectory. An abort from the velocity where Mode IV SPS ΔV is zero requires only that the separation sequence presented in table I be performed to achieve a 75.0-n. mi. perigee. This figure also shows the first time of abort to be at a velocity of 22 753 fps. This corresponds to a ground elapsed time of 536.0 seconds.

Figures 24 through 27 show comparisons of various trajectory parameters for the Mode IV SPS burns for times of abort (t_a) at 536.0 seconds g.e.t. (first time of abort the Mode IV SPS burn achieves a 75.0-n. mi. perigee) and at 535.9 seconds g.e.t. Figure 24 (range versus altitude) indicates that the burn at 535.9 seconds descends slightly below 75.0-n. mi. altitude during the SPS burn. The minimum altitude during the SPS burn (for t_a = 535.9 seconds) was approximately 74.6 n. mi. occurring about 2200 n. mi. downrange from the launch pad. It was at this point the burn came near to achieving the 75.0-n. mi. perigee. However, at this point the spacecraft was at a perigee and the subsequent burn only rotated the line of apsides lowering the perigee, as more ΔV was applied, and raising the apogee. This effect can be seen in figure 25 which presents perigee altitude and apogee altitude as functions of inertial velocity for the two Mode IV SPS burns (at t_a = 536.0 seconds and t_a = 535.9 seconds). Inertial flight-path angle and time of free fall as functions of inertial velocity for the two Mode IV SPS burns are presented in figures 26 and 27, respectively.

As indicated by figure 3, the initial thrust vector alignment for posigrade and retrograde burns will be 31.7° between the line of sight to the horizon and the X-body axis at SPS initiation. Also, the SPS abort burns will be performed using the stabilization and control subsystem (SCS) ΔV mode which will hold the inertial attitude corresponding to the initial thrust vector alignment attitude. The effect of holding the inertial attitude is shown in figure 28 which presents the pitch above the local horizontal as a function of inertial velocity for the Mode IV SPS burn at t_a = 535.9 seconds.

The apogee altitudes and true anomalies following the Mode IV SPS burn required to achieve a 75.0-n. mi. perigee are presented as functions of the inertial velocity at abort in figure 29.

One of the most critical operational procedures that might occur following an abort initiation are those required for orbit determination, maneuver calculation, and relaying information to the crew prior to loss of ground-to-air voice contact. The most reliable voice link between the ground controllers and the crew would be via a ground based site. Figure 30, which presents downrange distance from the pad at abort, at Mode IV SPS burn initiation, and SPS burn termination as functions of inertial velocity at abort, indicates the amount of time available to perform the required operational tasks prior to Bermuda loss of signal.

The Mode IV data generated in this study assumed a 125-second delay from booster cutoff to SPS ignition and that the initial thrust vector alignment would be 31.7° between the X-body axis and the line of sight to the horizon. Both assumptions were based on the operational procedure to be used for the AS-204 mission. However, there was some doubt as to whether the same procedures would be optimum for AS-504. After examining various delay times and initial thrust vector orientation angles, it was found that both assumptions were optimum for AS-504. Figure 31 presents the SPS burn time required to achieve a 75.0-n. mi. vacuum perigee as a function of delay time from booster cutoff for various times of abort. Figure 32 presents the SPS burn time required to achieve a 75.0-n. mi. perigee as a function of the angle between the X-body axis and the line of sight to the horizon for various abort times. It has been suggested on AS-204 that the Mode IV SPS burn should be performed as soon as possible, even prior to the minimum delay time of 125 seconds. Note that upon examining various delay times for Mode IV aborts during the late S-II phase of flight and the early S-IVB phase, SPS burns following delay times less than 125 seconds could not achieve a 75.0-n. mi. perigee; whereas, the SPS burns following the 125-second delay did achieve a 75.0-n. mi. perigee. For these cases the SPS burns following delay times less than 125 seconds were initiated either prior to apogee or at apogee.

Figure 33 presents the apogee altitudes resulting from Mode IV SPS burns which were initiated with various initial thrust vector alignments.

All Mode IV data mentioned previously were generated assuming the abort was initiated from the nominal AS-504 launch trajectory. Figure 34 presents the SPS Mode IV ΔV required to achieve a 75.0-n. mi. perigee as a function of inertial velocity and inertial flight-path angle at booster cutoff. The data generated for this figure assumed various flight-path angle dispersions at the nominal velocity and altitude.

Figure 35 shows the Mode IV SPS ΔV required to achieve a 75.0-n. mi. perigee and the apogee kick ΔV required to achieve a 75.0-n. mi. perigee as functions of inertial velocity and inertial flight-path angle at abort. The line through the intersection of the Mode IV and apogee kick ΔV lines represents a performance tradeoff; i.e., in the region above this line it would be less expensive to perform a contingency orbit insertion at apogee of the pre-abort orbit rather than at 125 seconds after booster cutoff. Also, for any V_i, γ_i along this line the time to apogee is 125 seconds. As mentioned previously, it was found that SPS Mode IV burns following an abort during the early S-IVB phase performed prior to apogee or at apogee could not achieve a 75.0-n. mi. perigee. It can also be seen by figure 35 that apogee kicks which are initiated less than 125 seconds after booster cutoff require more ΔV to achieve a 75.0-n. mi. perigee than the Mode IV SPS burns initiated 125 seconds after booster cutoff. This would indicate that an optimum true anomaly exists for performing the Mode IV SPS burn and that this optimum true anomaly is greater than 180°.

Although a performance tradeoff for performing apogee kicks as opposed to Mode IV burns at booster cutoff plus 125 seconds does exist, there also exists operational time limits which would disallow the tradeoff line shown on figure 35 to be used as a cue for performing one type of contingency orbit insertion as opposed to the other. Presently, the flight controllers have estimated that it would require approximately 3 minutes to switch the real-time computer from launch phase (the computer mode in which the Mode IV SPS ΔV is computed) to orbit phase (the computer mode in which apogee kicks are computed), compute the required apogee kick maneuver, and relay the information to the crew. Figure 36 presents various times to apogee from booster cutoff as functions of inertial velocity and inertial flight-path angle at booster cutoff. One of these lines will be used as a cue for switching from one contingency orbit insertion mode to another (i.e., above the line apogee kicks will be performed; below the line Mode IV SPS burns will be performed at cutoff plus 125 seconds). With the insertion ship in the Atlantic located such that the ship's acquisition occurs before loss of contact with Bermuda, the ship should have contact with the spacecraft approximately 3 to 4 minutes after loss of contact with Bermuda. Therefore, it does appear feasible that the ground controllers could compute an apogee kick maneuver and relay the information to the crew via the insertion ship.

Figure 37 presents time to S-IVB cutoff as a function of inertial velocity for the nominal AS-504 launch trajectory.

Figure 38 presents a portion of scale 2 and scale 3 of plotboard Ia and offers several limit lines and information lines as candidates for plotboard Ia.

CONCLUSIONS

This analysis has been conducted to provide recommendations for launch abort procedures and definitions of the abort modes for S-V missions. Unless otherwise notified these recommendations will be incorporated in volume II (abort studies) of the preliminary abort and alternate mission document for AS-504 to be published in the near future.

As previously indicated the primary launch abort modes, following LET jettison, are Modes II and IV. Abort Mode III should be considered a backup abort mode available for immediate return to earth in the event the spacecraft is not allowed to either achieve or continue to an earth-parking orbit.

Sufficient data have been presented to compare alternate abort procedures and abort mode definitions with those presented.

TABLE I.- SEPARATION SEQUENCE USED TO SIMULATE

ABORT MODES II, III, AND IV

Event	Time from abort initiation, sec
Booster cutoff, begin J-2 tailoff[1]	0.00
End J-2 tailoff, begin RCS + X	1.84
End RCS + X, begin SPS separation	6.00
End SPS separation, begin CSM coast	8.00
Begin SPS abort maneuver if required	125.00

[1]Thrust decay for each J-2 engine of the S-II stage was assumed to be the same as the single J-2 engine in the S-IVB stage. The thrust decay for the engines was assumed to have occurred simultaneously.

TABLE II.- SEQUENCE OF EVENTS FOR THE LAUNCH PHASE OF AS-504

(First Launch Opportunity)

Event	Time from liftoff, min:sec	Geodetic latitude, longitude, deg	Altitude, n. mi.
Lift-off	00:00	28.608 - 80.604	0
S-IC cutoff	02:38.561	28.845 - 79.763	33
S-II ignition	02:42.106	28.866 - 79.686	35
LET jettison	03:13.874	29.060 - 78.966	49
S-II cutoff	08:49.305	31.834 - 64.668	103
S-IVB first ignition	09:03.393	31.868 - 64.394	103
S-IVB first cutoff (insertion to earth parking orbit)	11:13.850	32.634 - 55.053	103

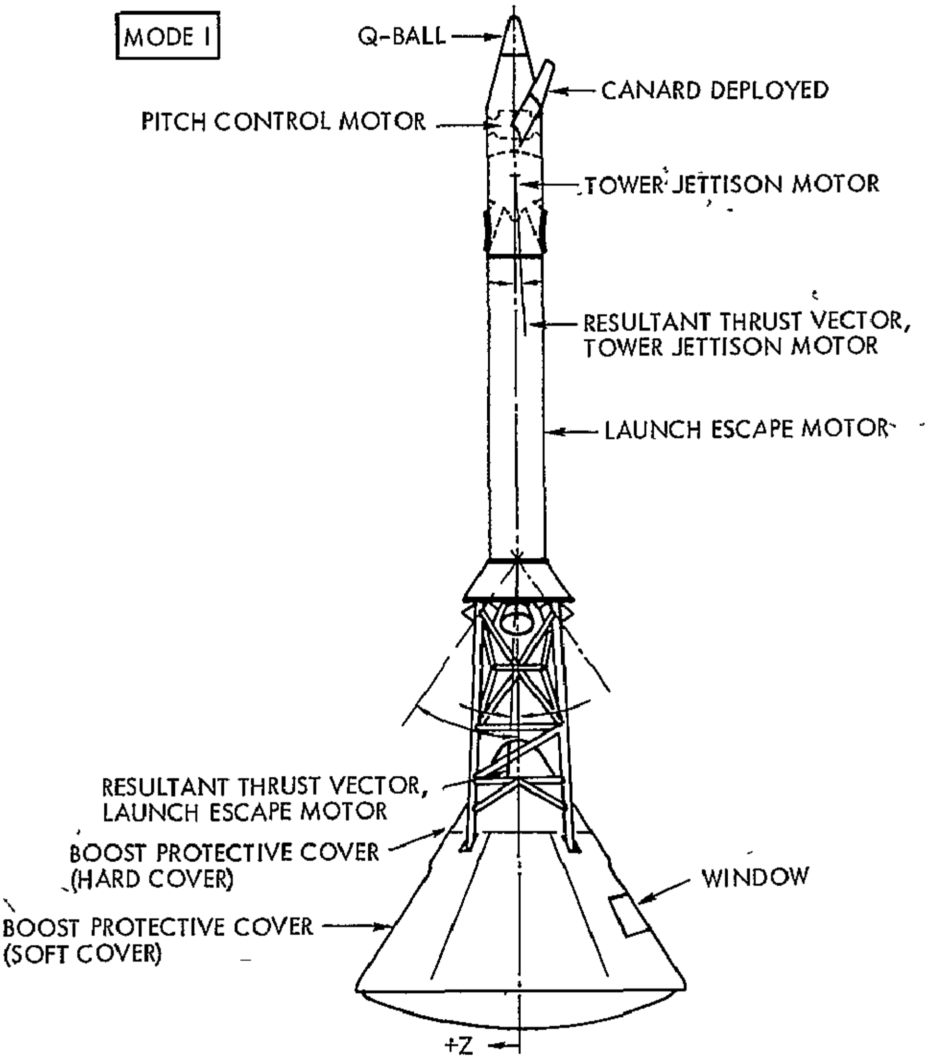
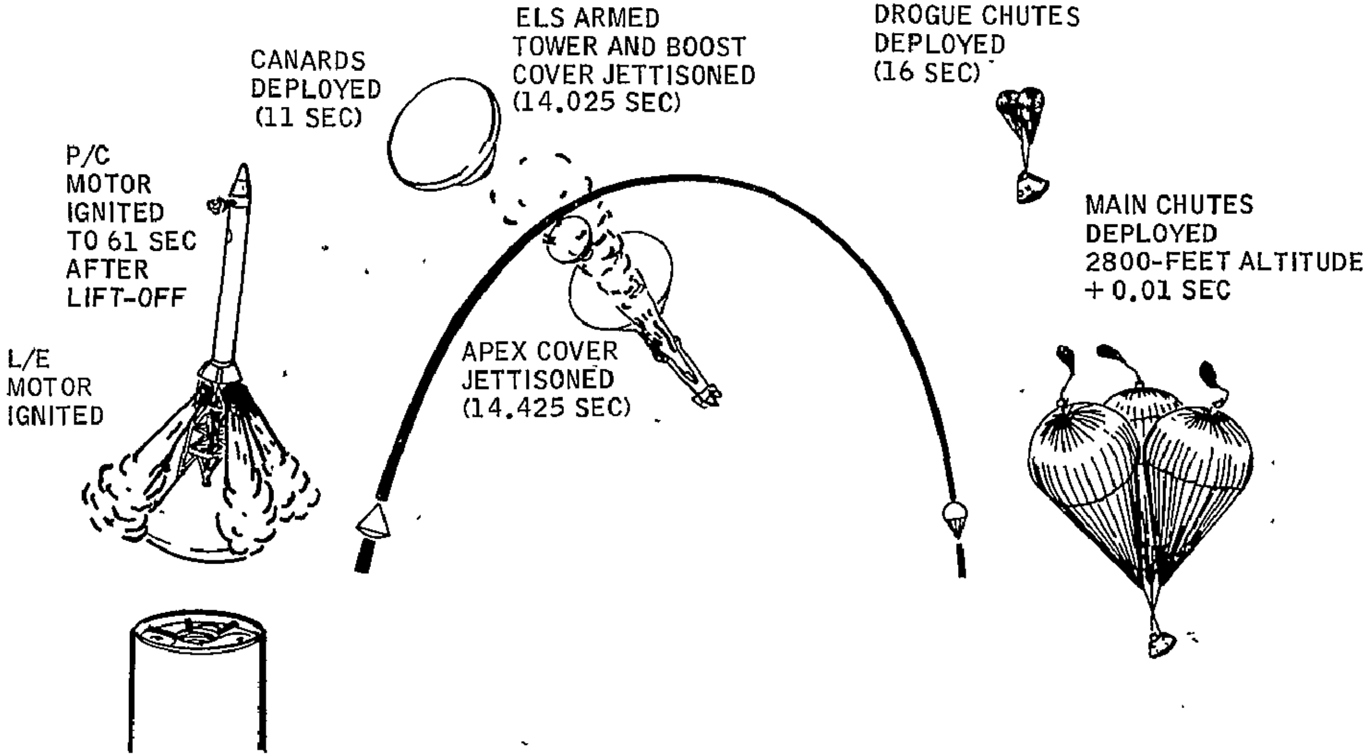
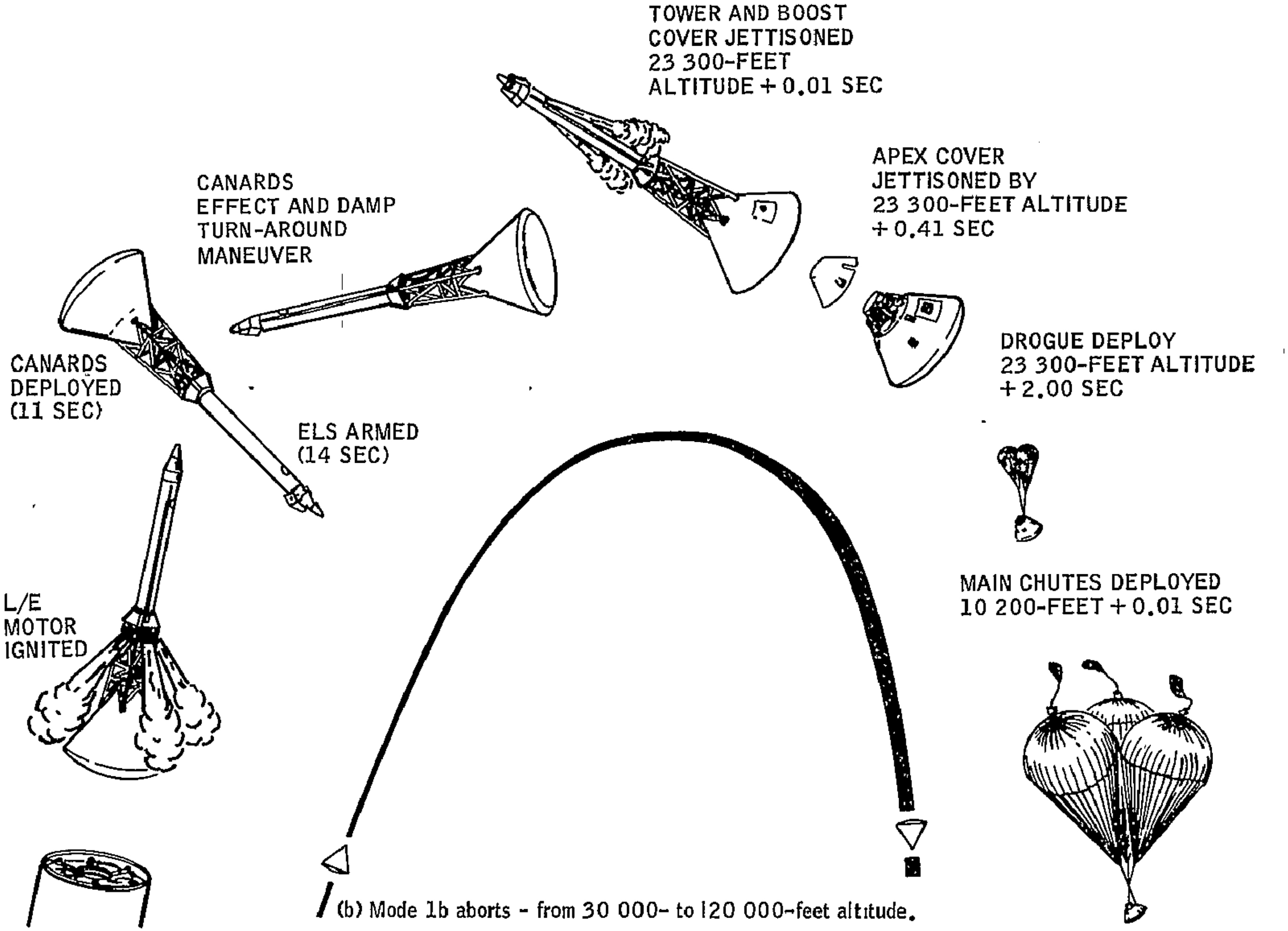


Figure 1.- Launch escape vehicle configuration.



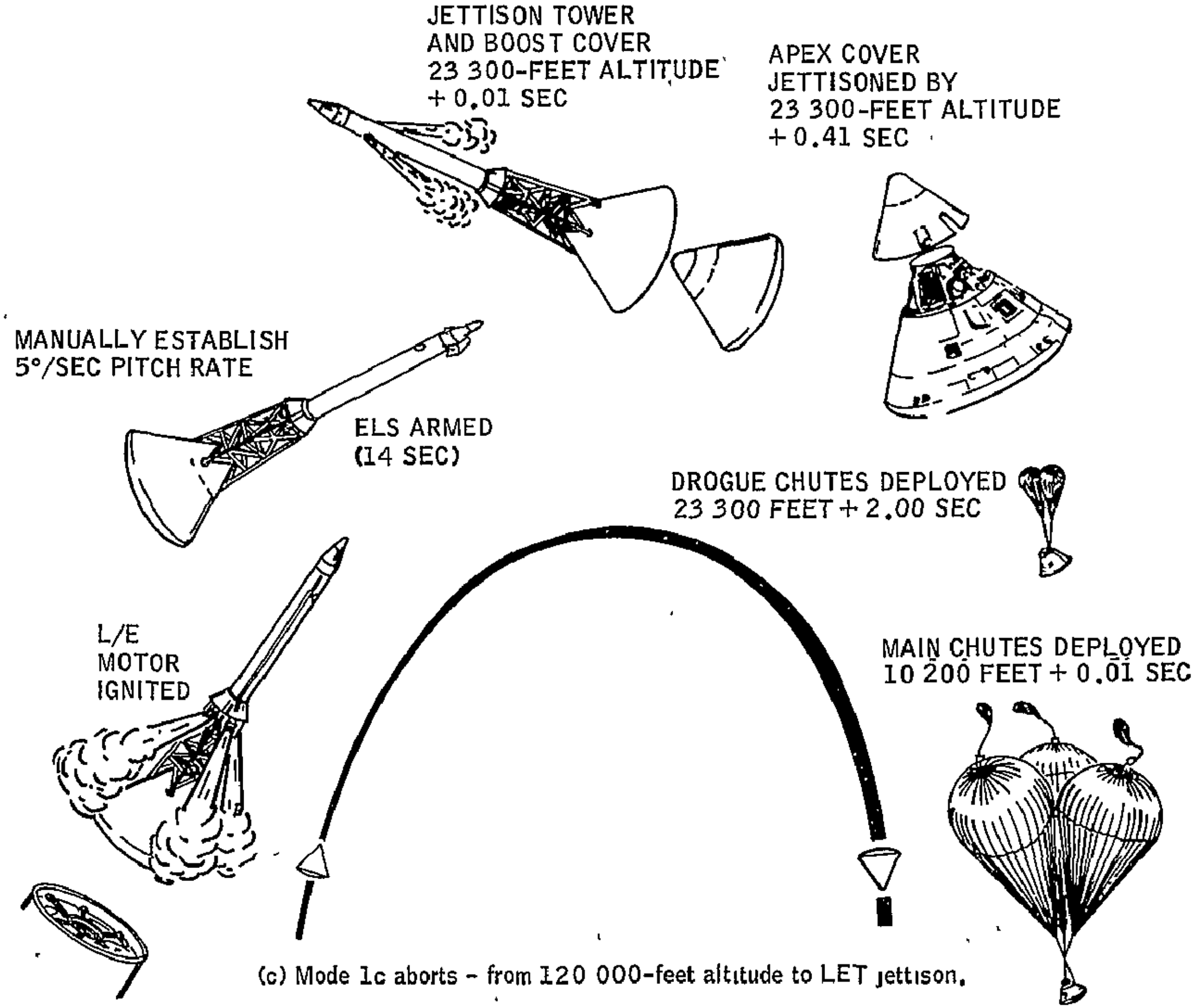
(a) Mode Ia aborts - from the pad to 30 000-feet altitude.

Figure 2.- AS-504 LES abort sequences for different altitude regions.



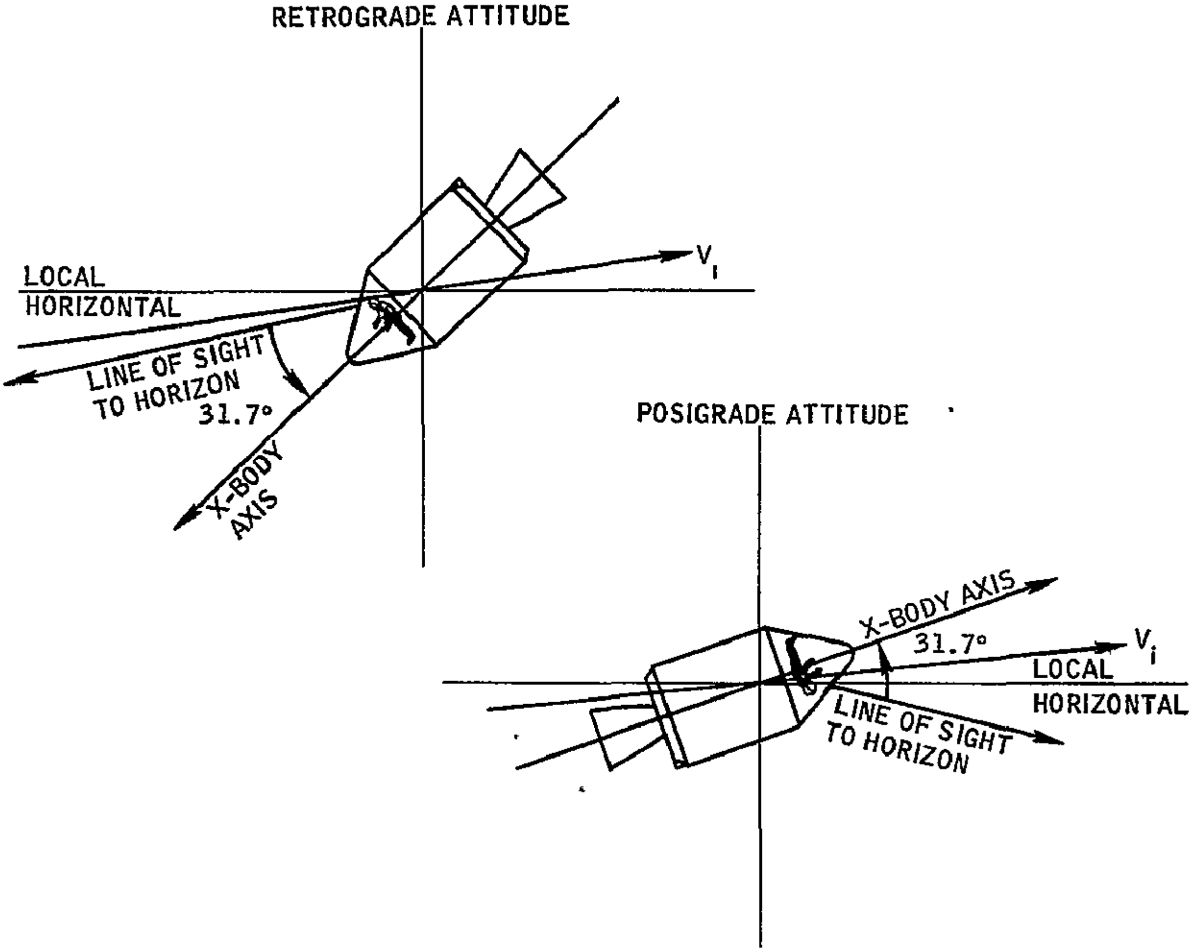
(b) Mode 1b aborts - from 30 000- to 120 000-feet altitude.

Figure 2.- Continued.



(c) Mode 1c aborts - from 120 000-feet altitude to LET jettison.

Figure 2.- Concluded.



NOTE: SPS RETROGRADE AND POSIGRADE MANEUVERS WILL NORMALLY BE INITIATED AT BOOSTER CUTOFF PLUS 125 SECONDS FOR ALL LAUNCH ABORTS REQUIRING SPS MANEUVERS. THE ATTITUDES PRESENTED ABOVE ARE THE REQUIRED SPACECRAFT ORIENTATIONS AT SPS IGNITION. THE SUBSEQUENT ABORT MANEUVER WILL BE CONTROLLED VIA THE SCS; WHEREBY, THE SCS SHALL MAINTAIN THE INERTIAL ATTITUDE WHICH CORRESPONDS TO THE RELATIVE ATTITUDE AT SPS IGNITION.

Figure 3.- Spacecraft altitude required at SPS ignition for launch abort maneuvers.

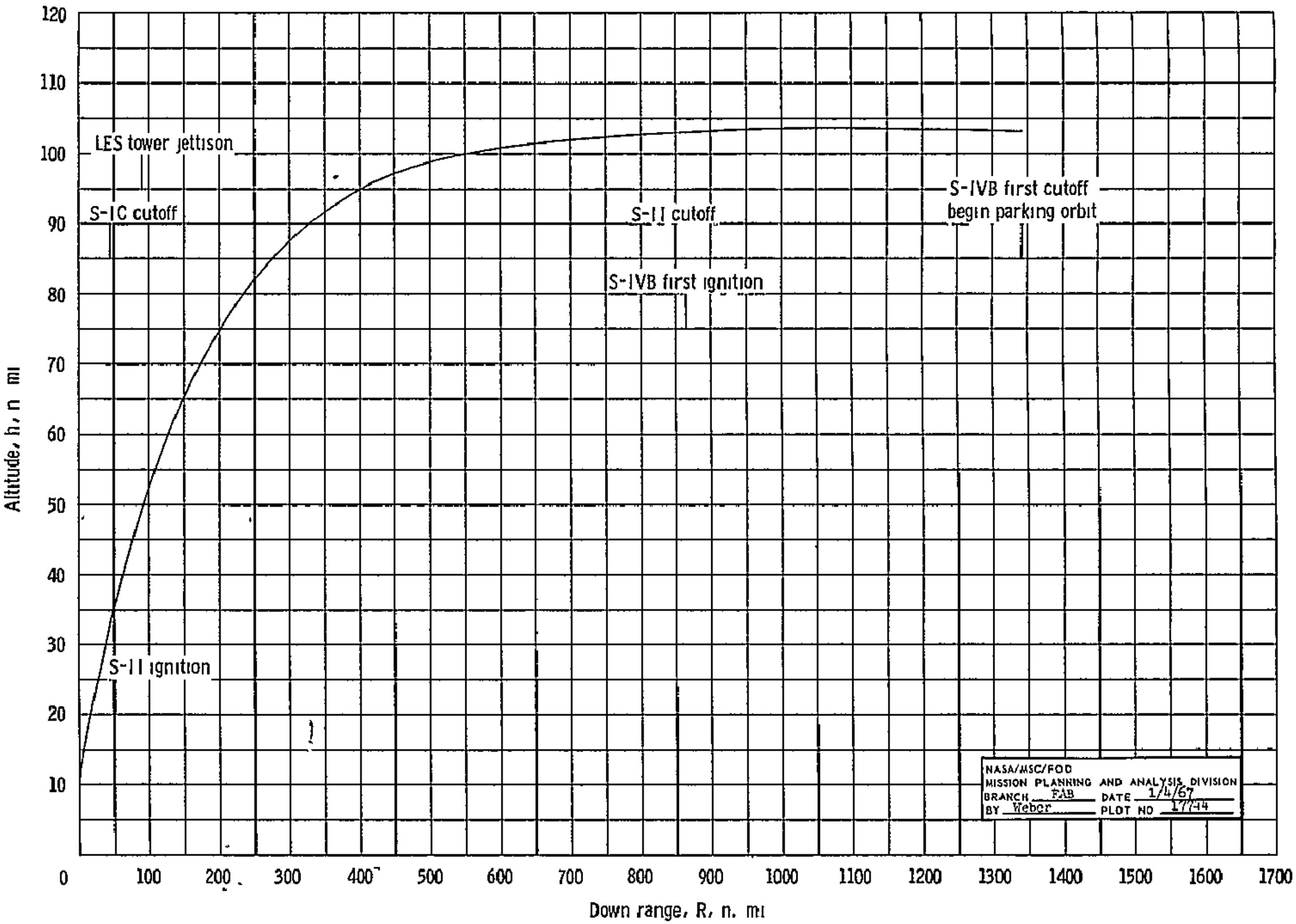


Figure 4. - Nominal range and altitude profile for AS-504.

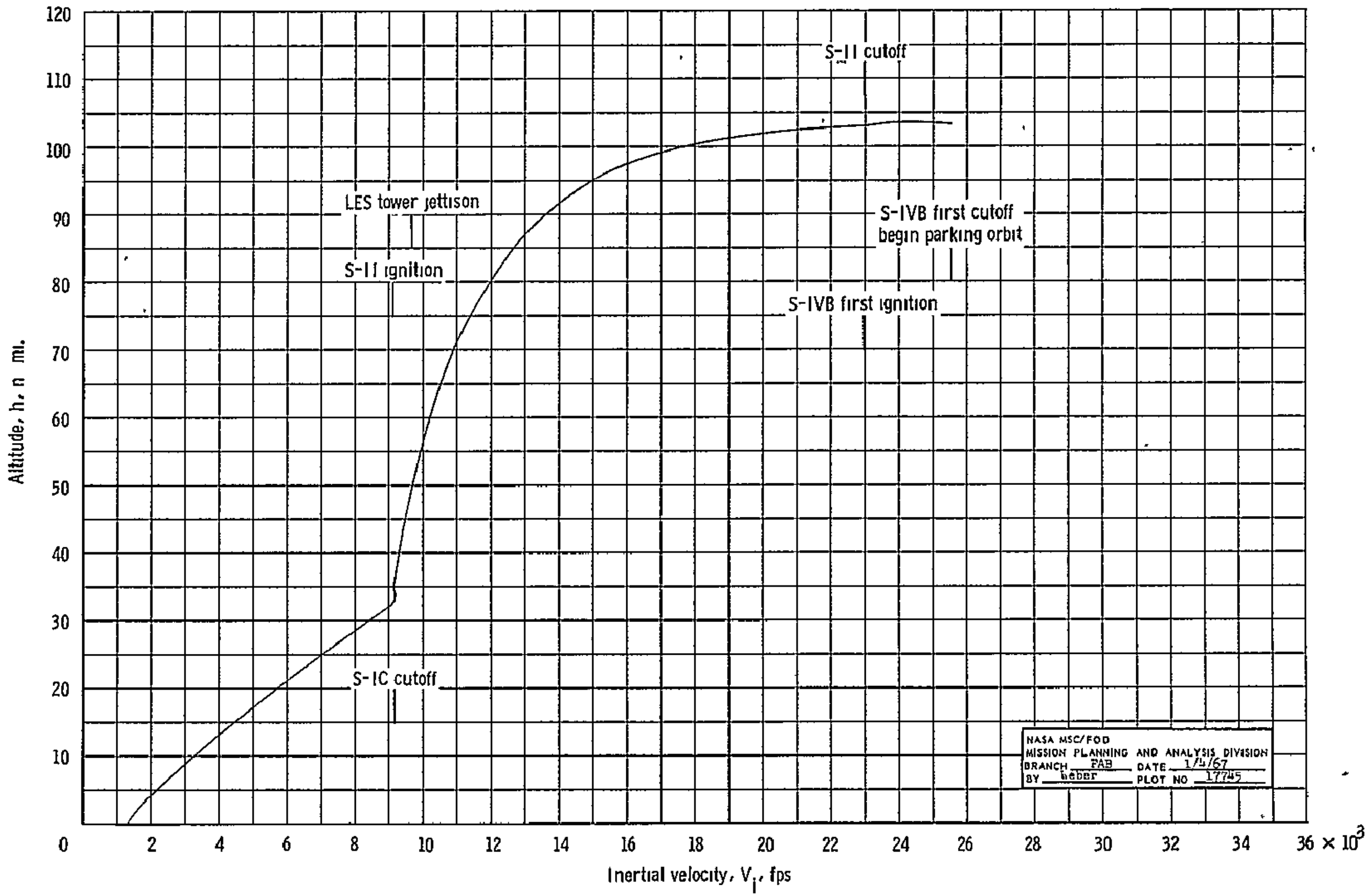
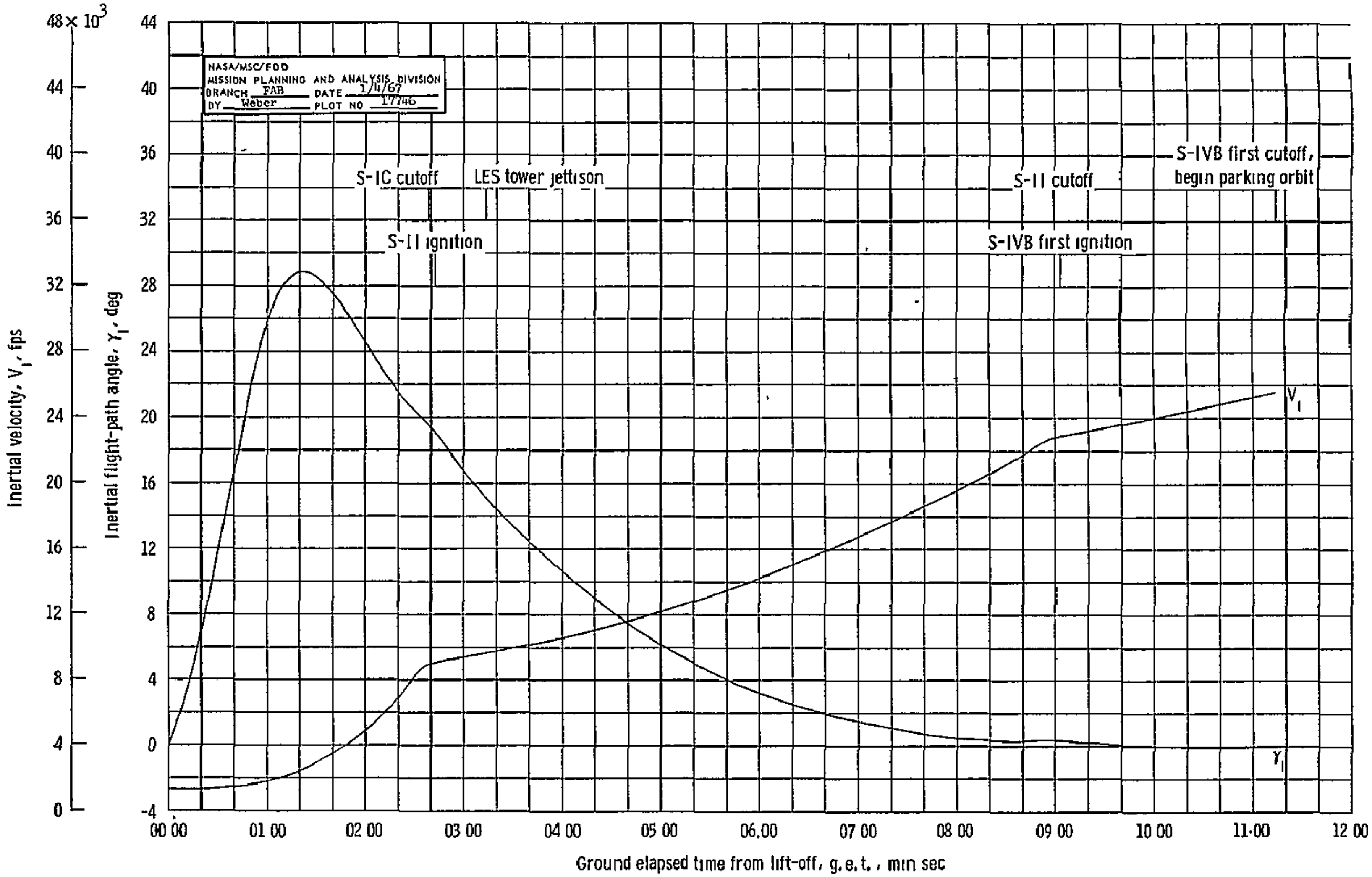
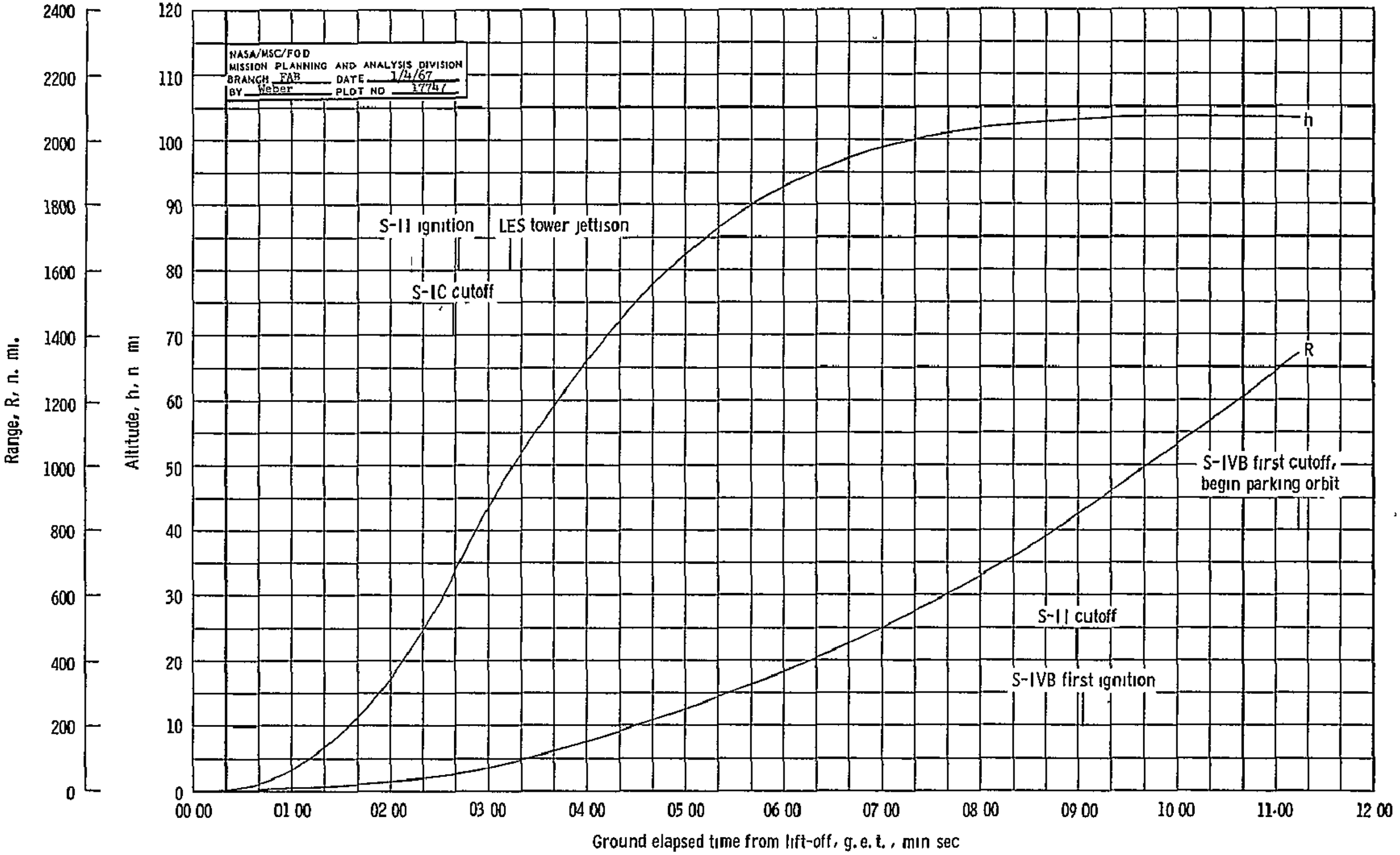


Figure 5. - Altitude as a function of velocity for the nominal AS-504 launch.



(a) Inertial velocity and flight-path angle

Figure 6. - Nominal trajectory parameters as functions of ground elapsed time from lift-off.



(b) Range and altitude

Figure 6.- Concluded

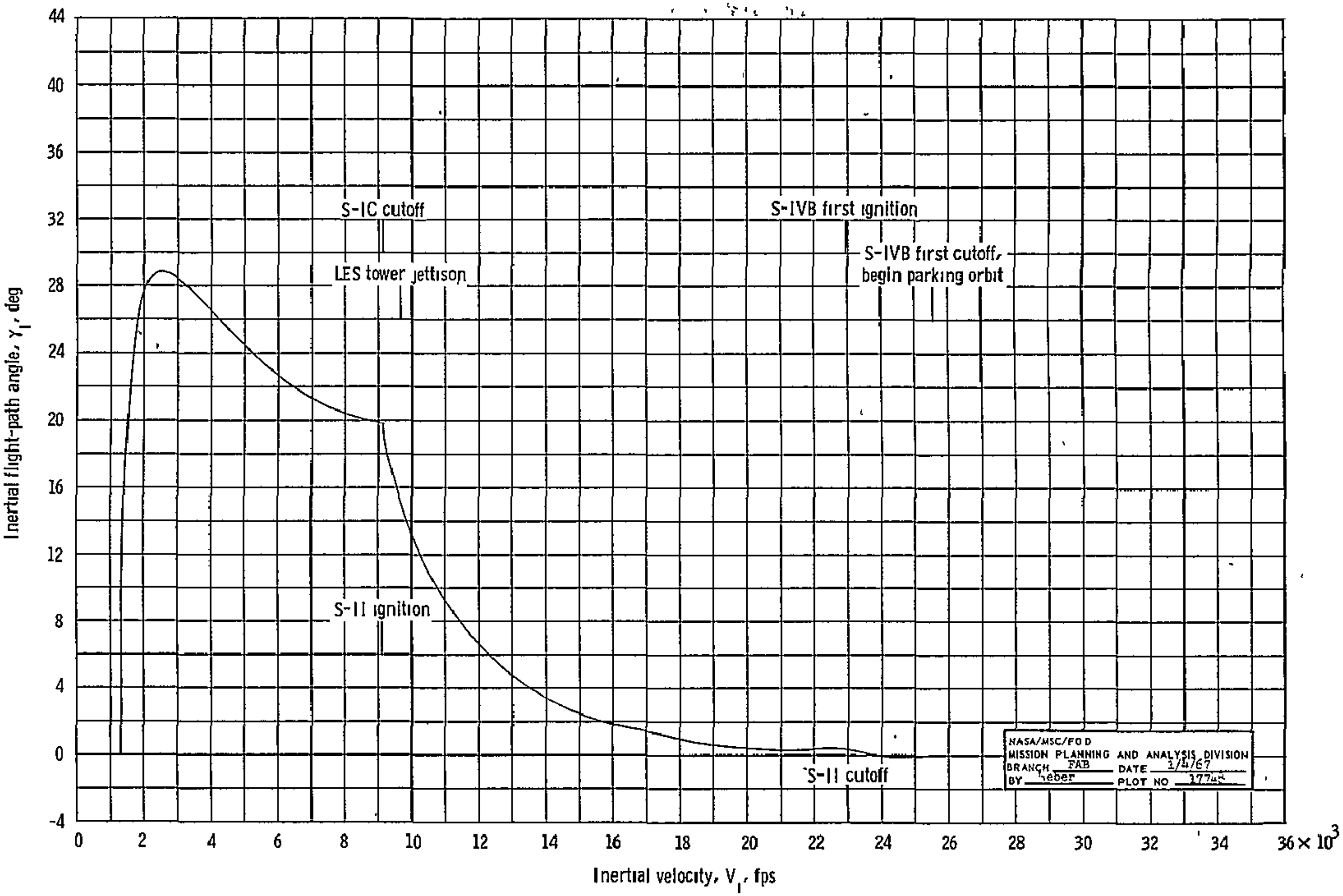


Figure 7 - Nominal inertial velocity and flight-path angle profile for AS-504.

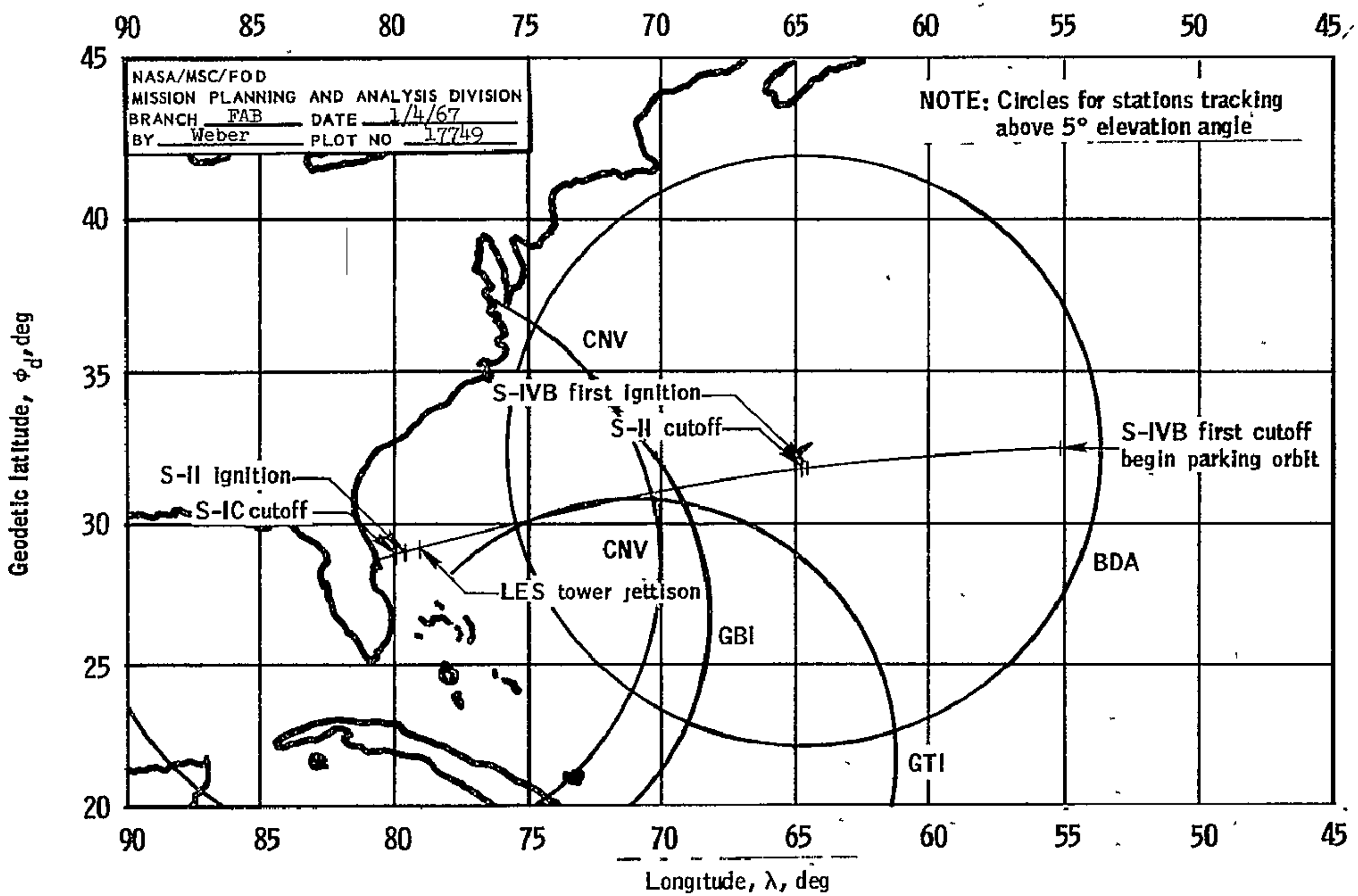


Figure 8.- Groundtrack for the launch phase of AS-504.

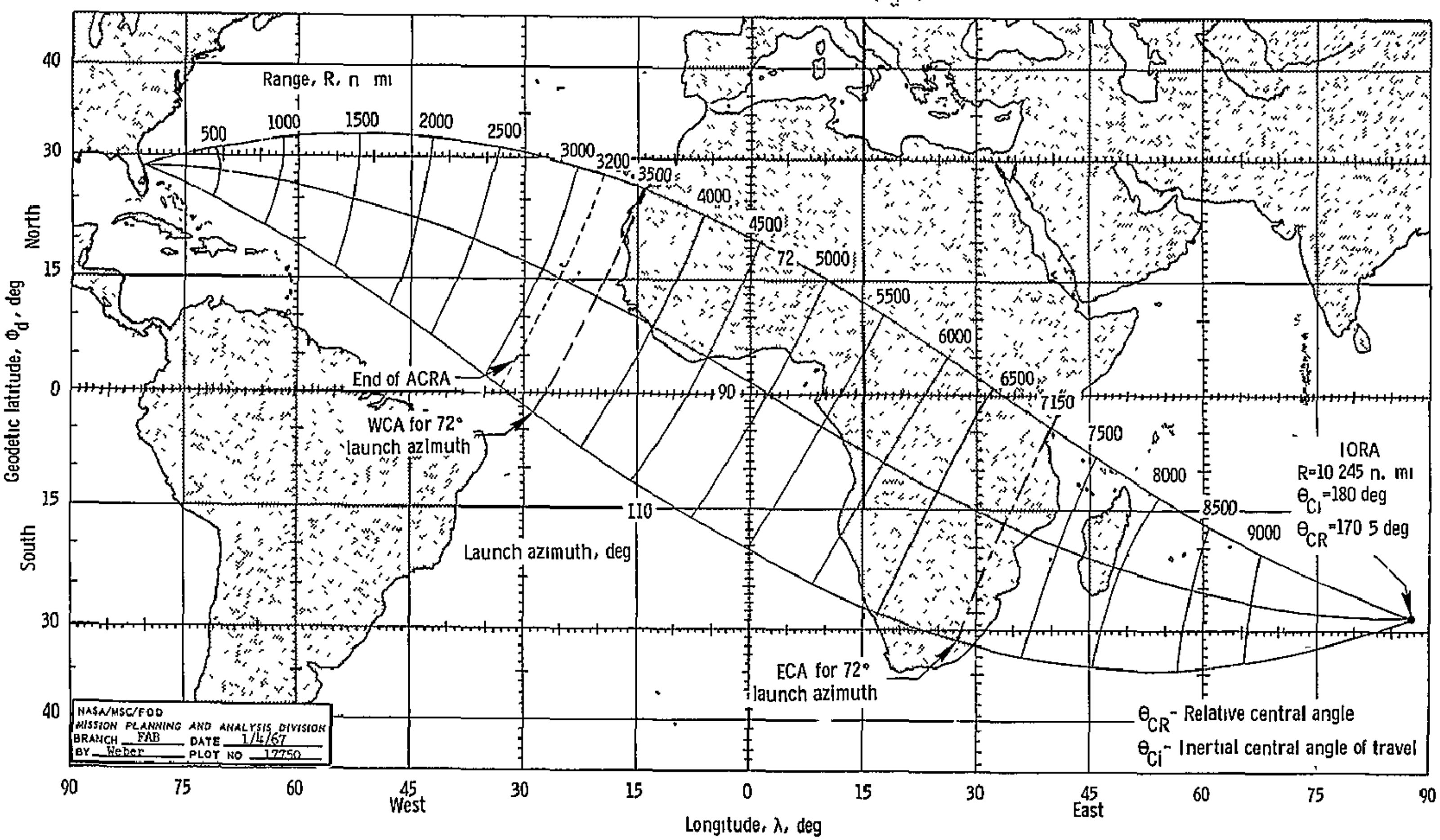


Figure 9. - Groundtracks from the pad to the Indian Ocean Recovery Area (IO RA) for trajectories having 72°, 90°, and 110° launch azimuths

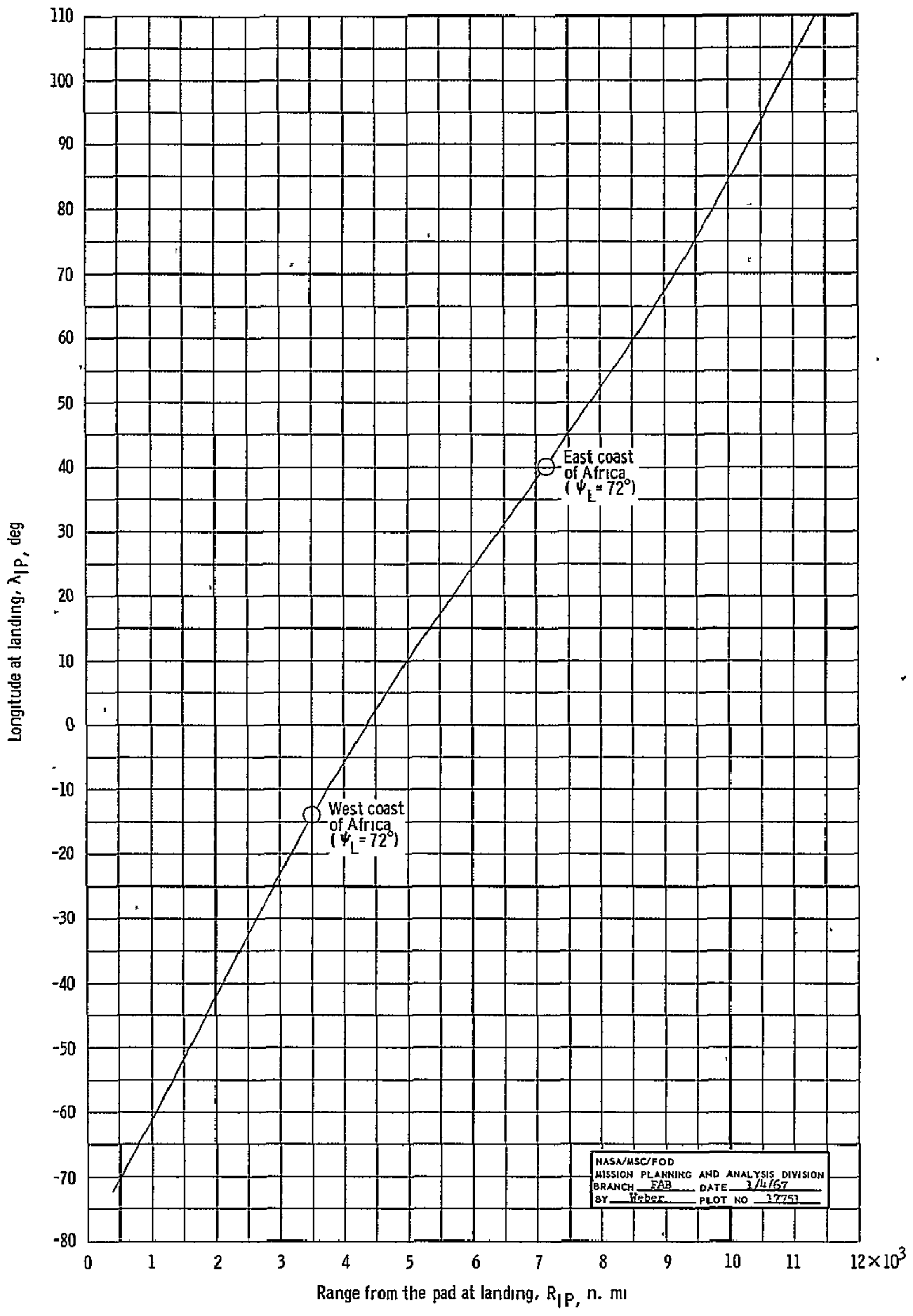


Figure 10. - Longitude at landing versus range from the pad for Mode II aborts from the nominal trajectory.

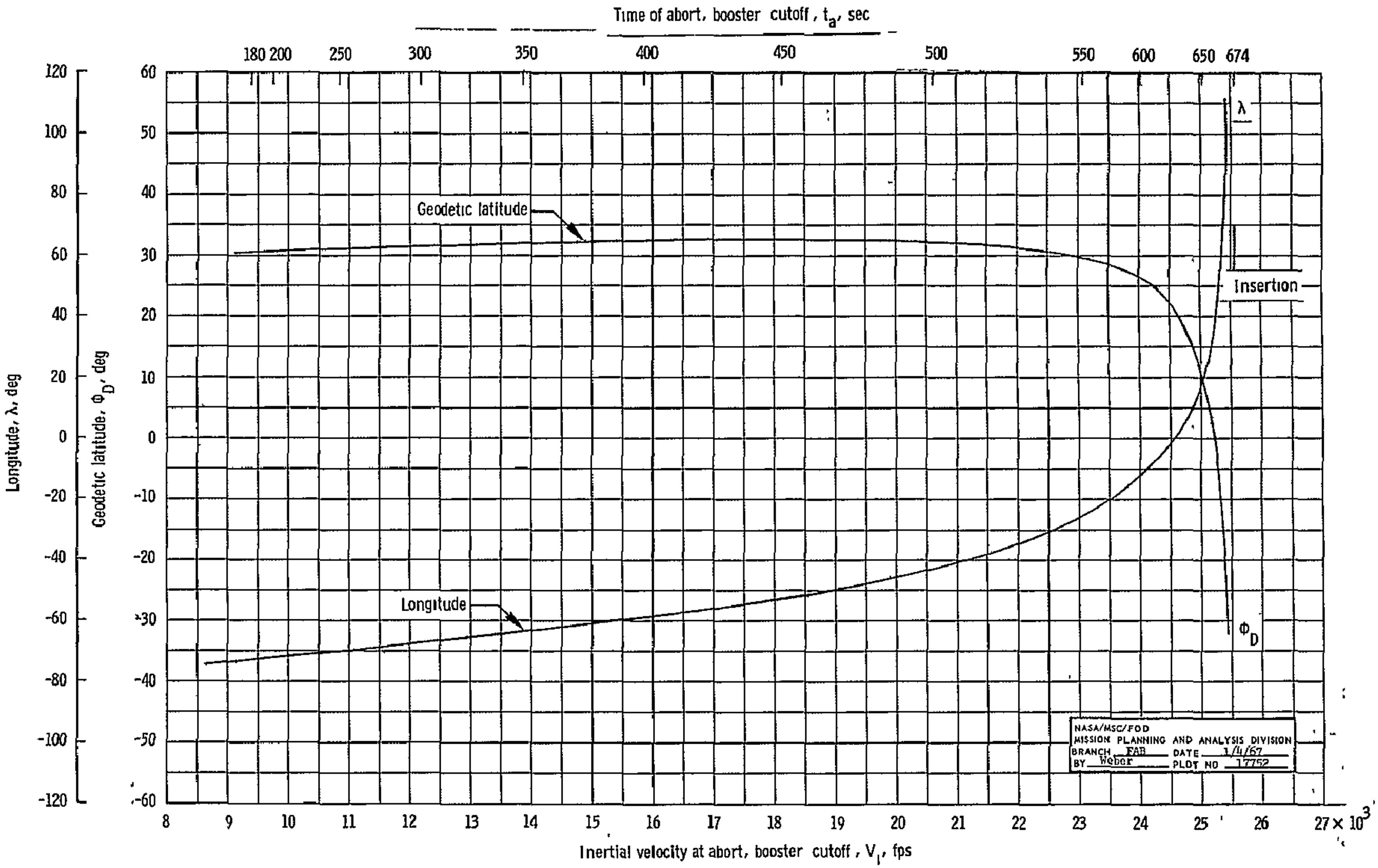


Figure 11. -Geodetic latitude and longitude of full-lift landing points as functions of inertial velocity at abort.

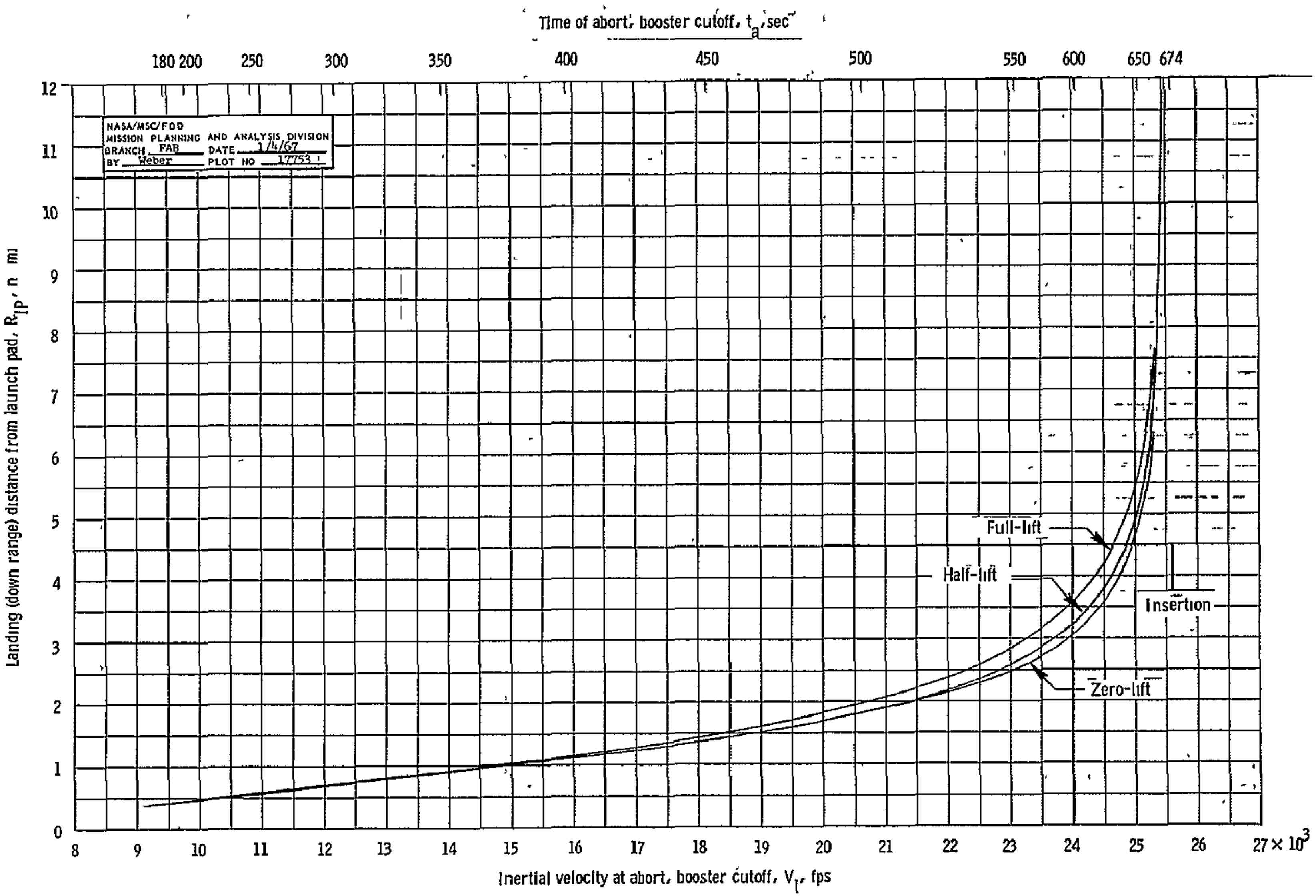


Figure 12. - CM down range landing distance from the launch pad as a function of inertial velocity at abort.

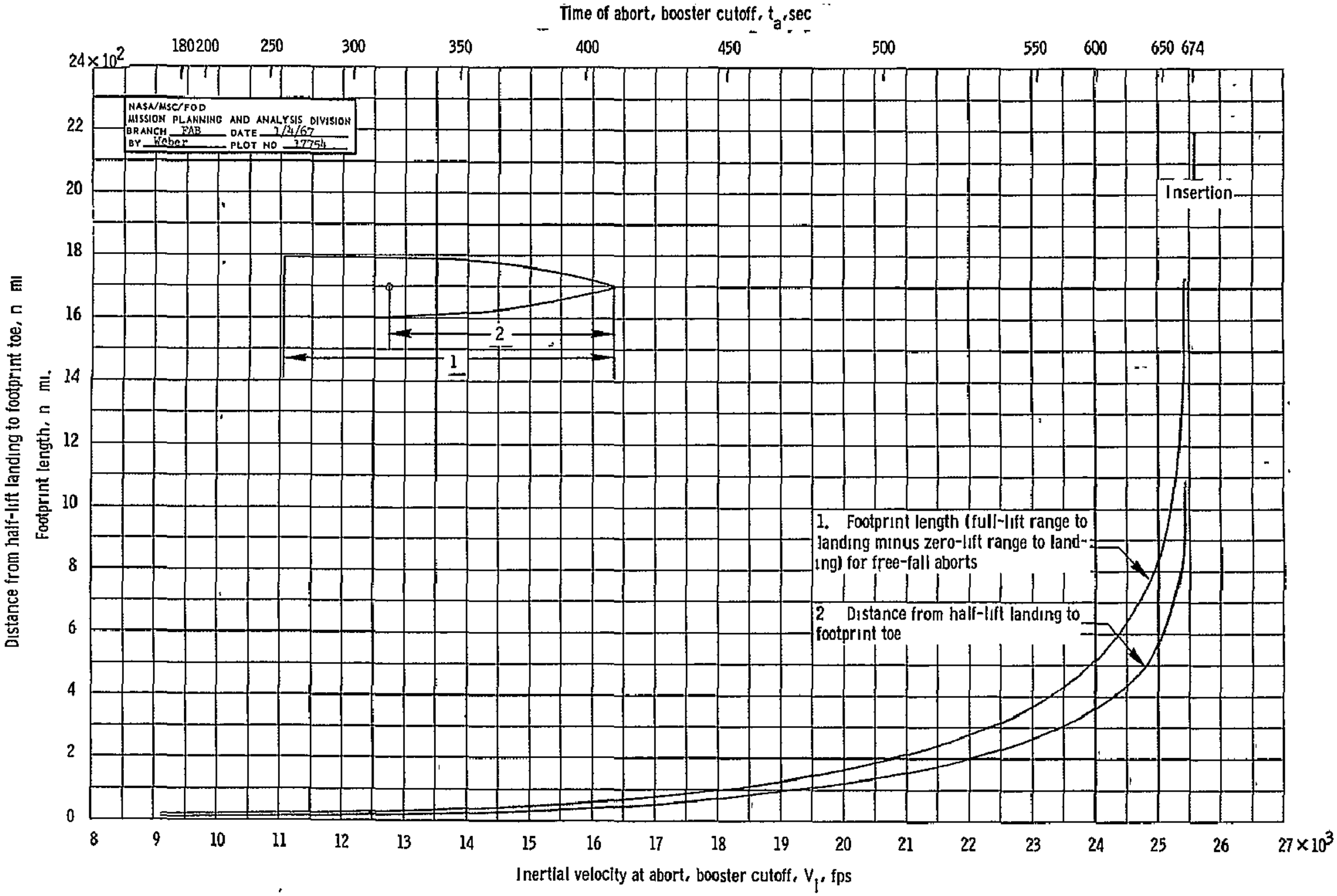


Figure 13.- Footprint length and distance from half-lift landing point to footprint toe for free-fall aborts as functions of inertial velocity at abort.

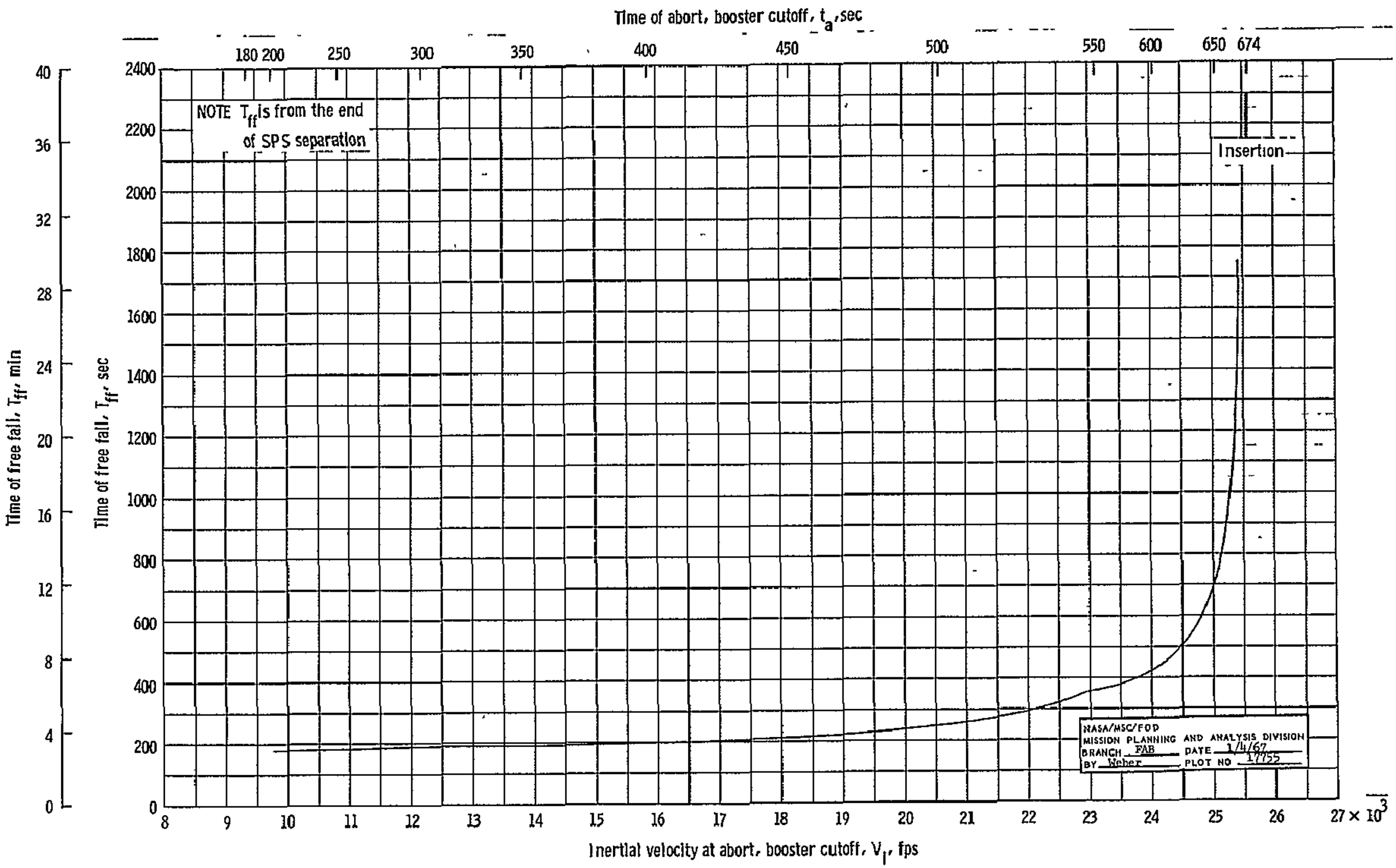


Figure 14.- Time of free fall above 300 000 feet as a function of inertial velocity abort for Mode II aborts from the nominal trajectory.

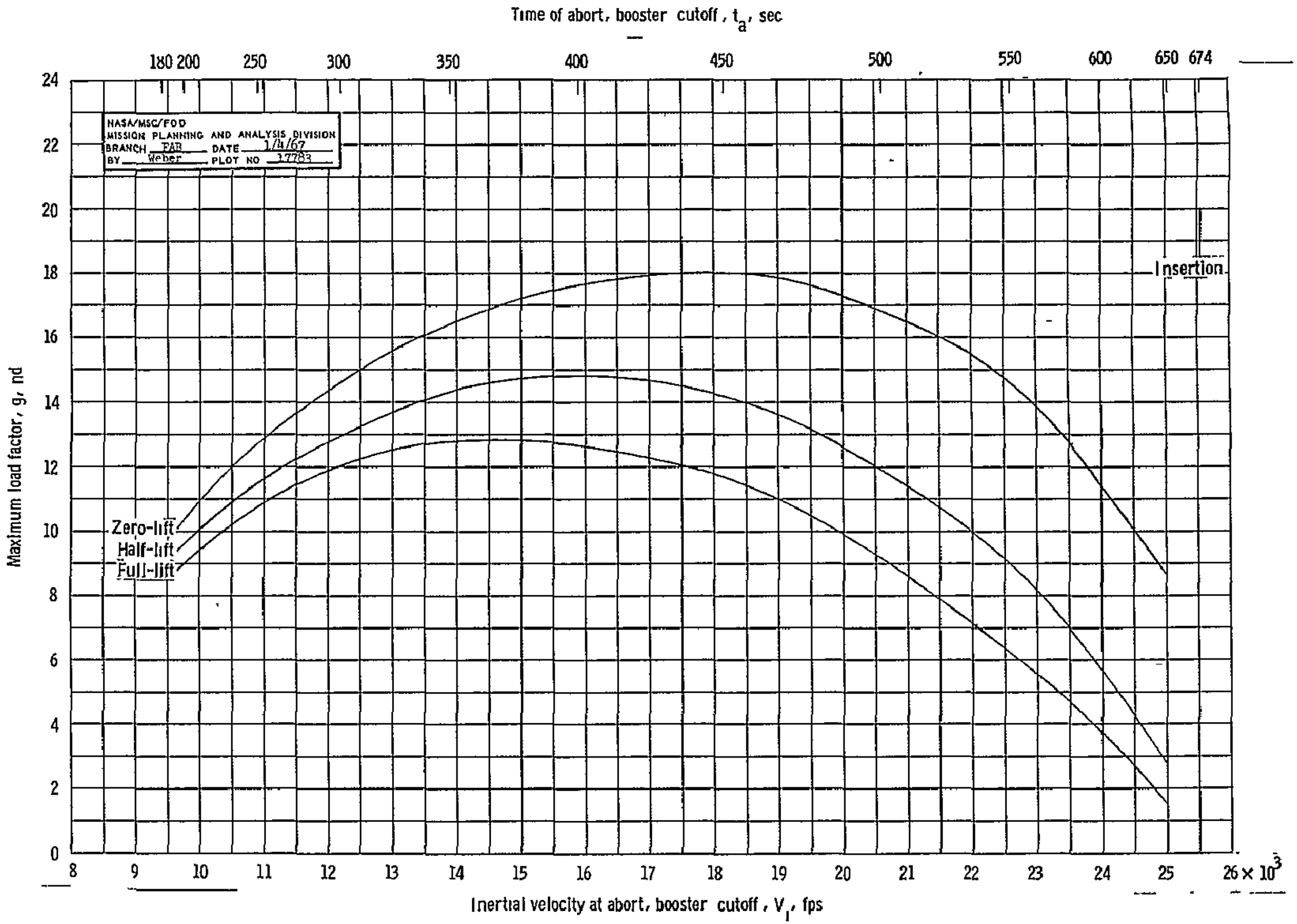
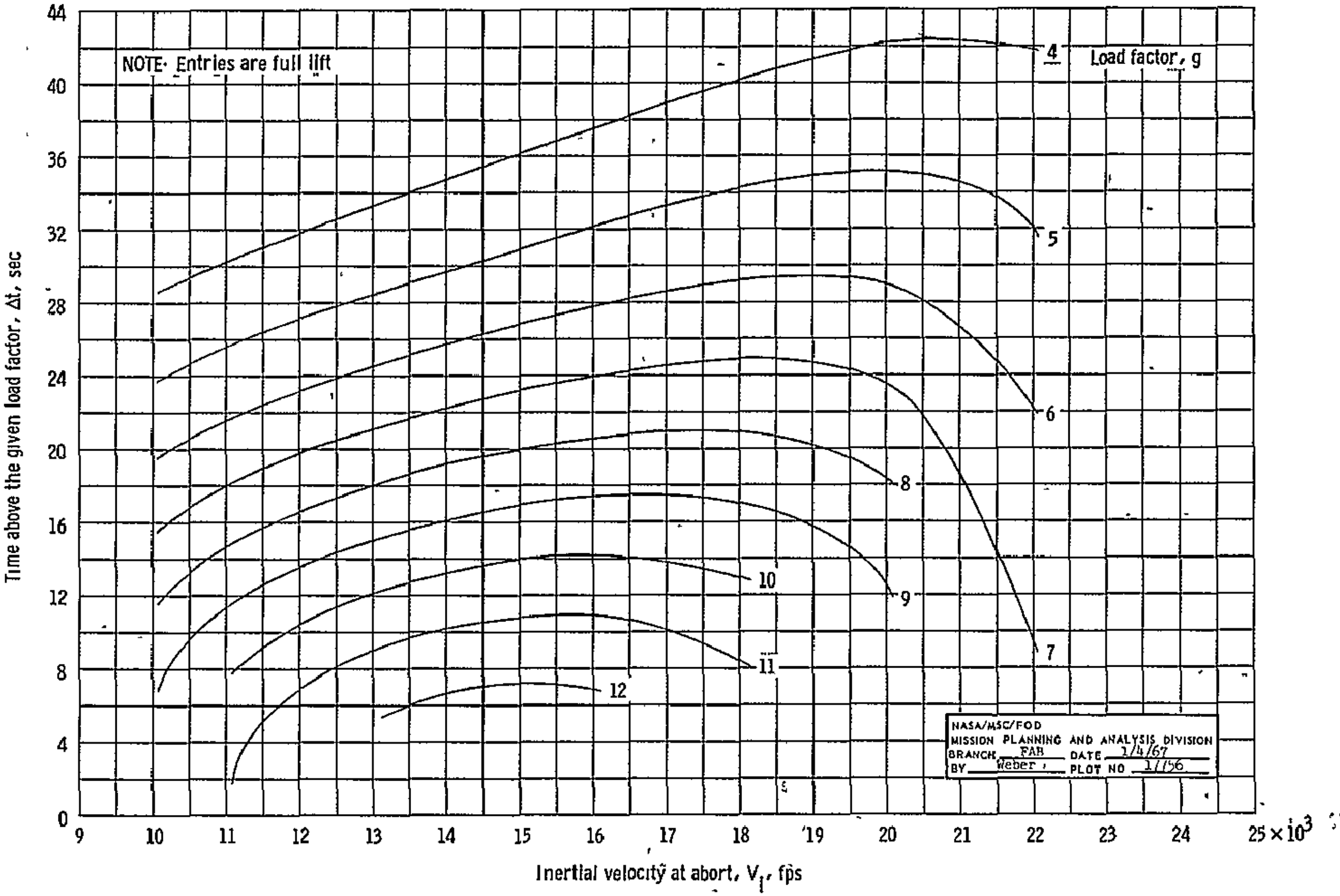
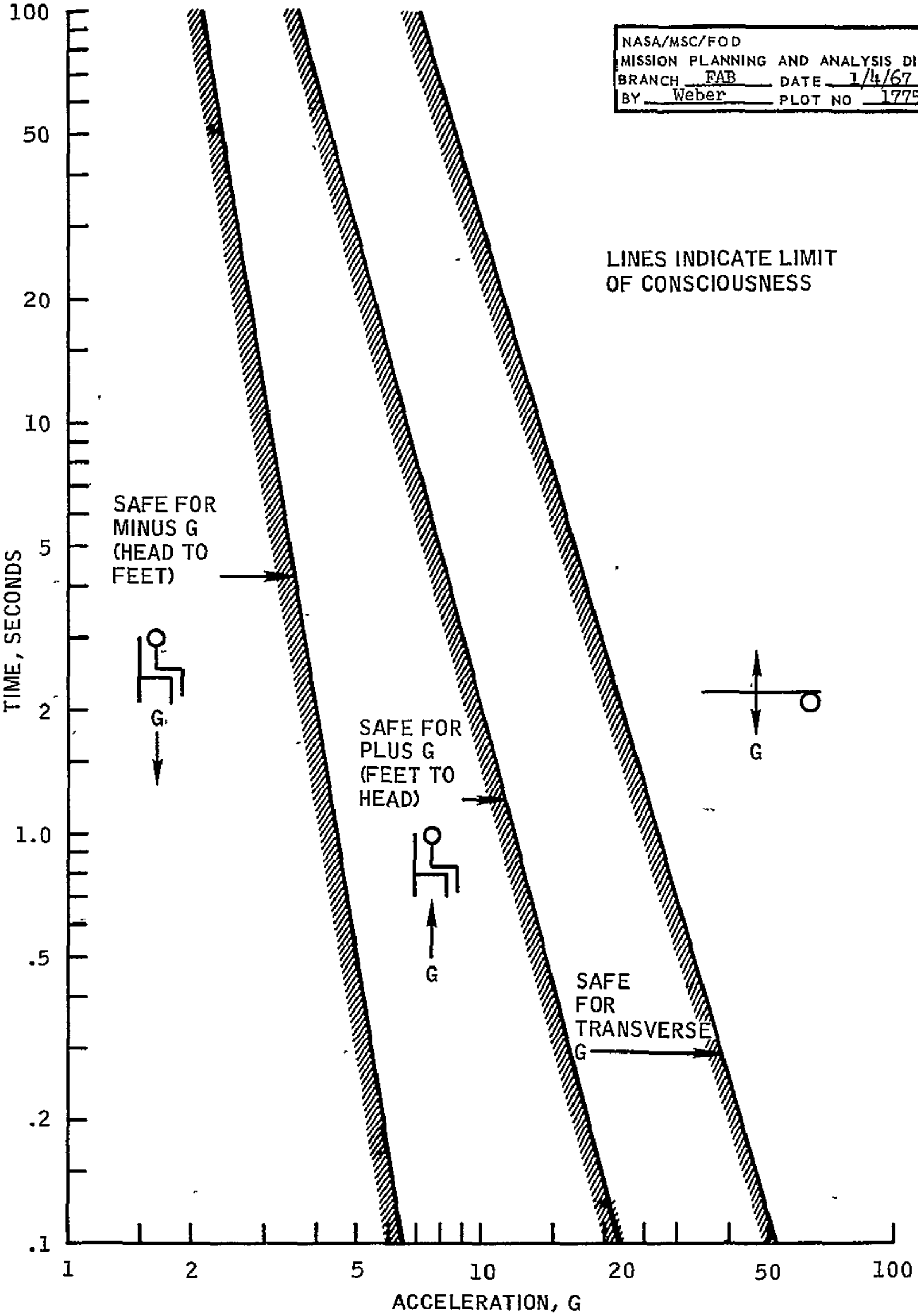


Figure 15. - Maximum entry load factor for aborts from the nominal trajectory.



(a) Time spent above various entry load factors as a function of inertial velocity at abort.

Figure 16.- Mode II entry loads (g) and their effects.



(b) Tolerance of man to g for a given period of time.

Figure 16.- Concluded.

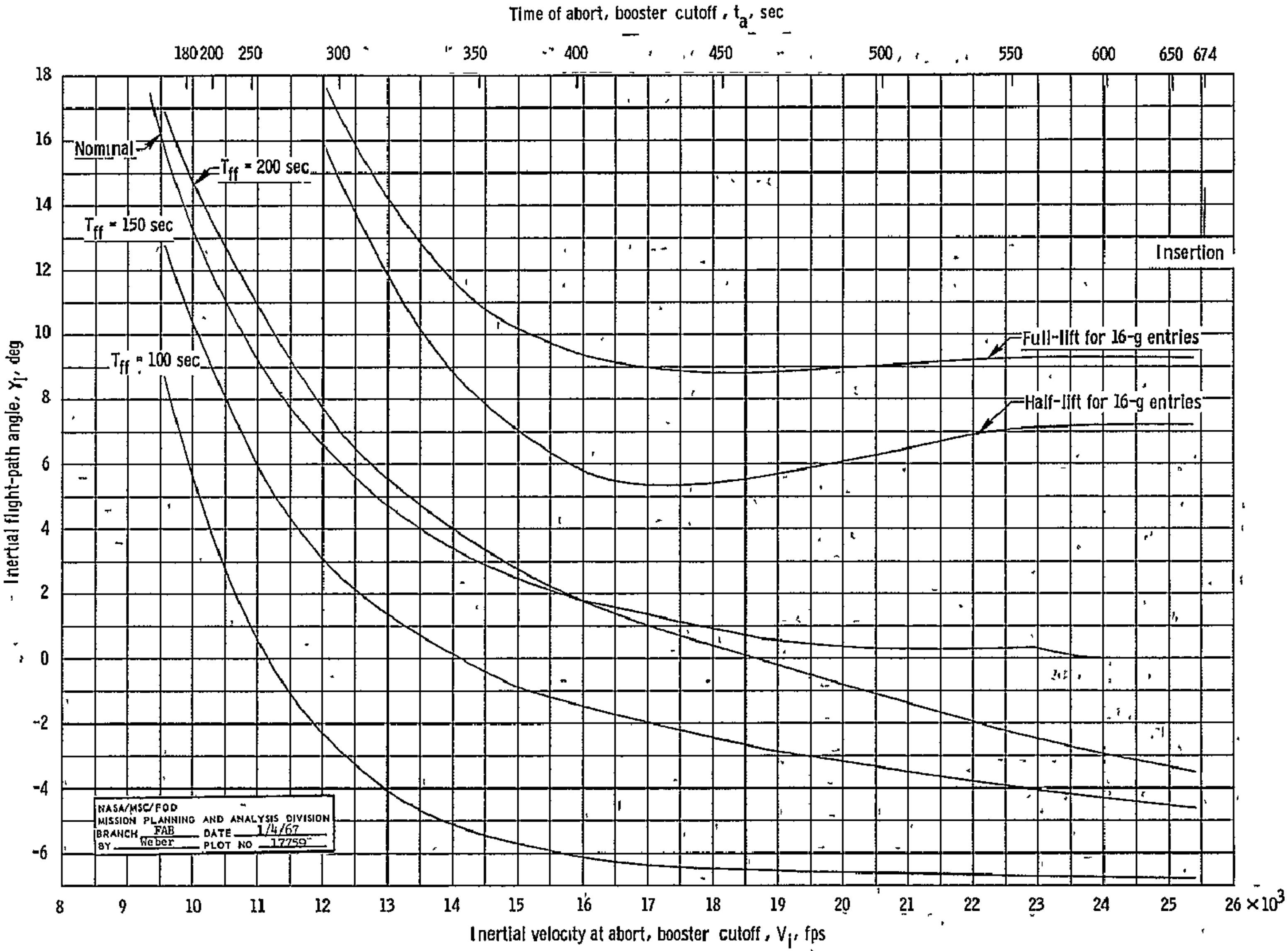
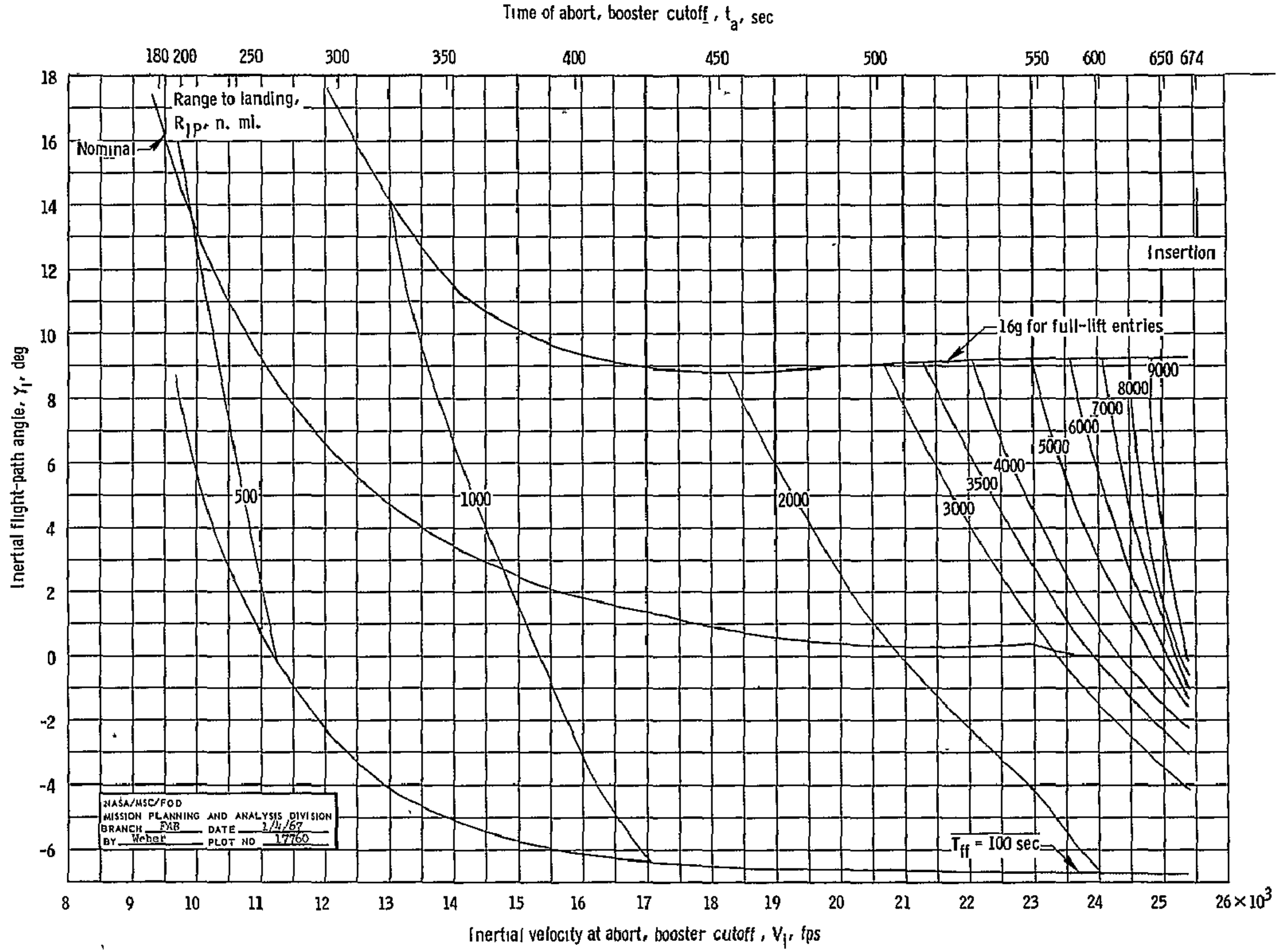
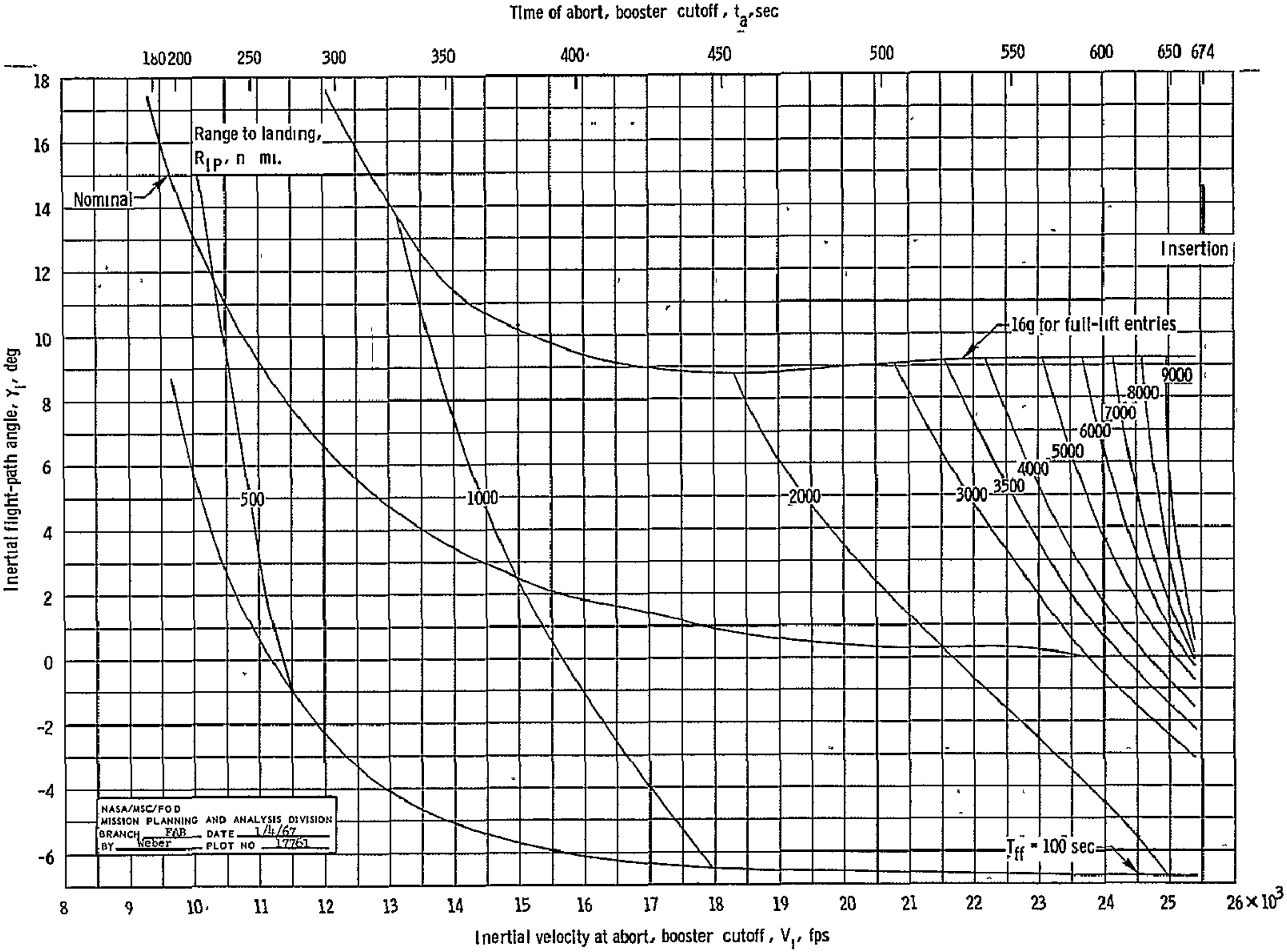


Figure 17.- Time of free fall remaining above 300 000 feet after a 2-second SPS burn, and 16-g for full-lift entries as functions of inertial velocity and inertial flight-path angle.



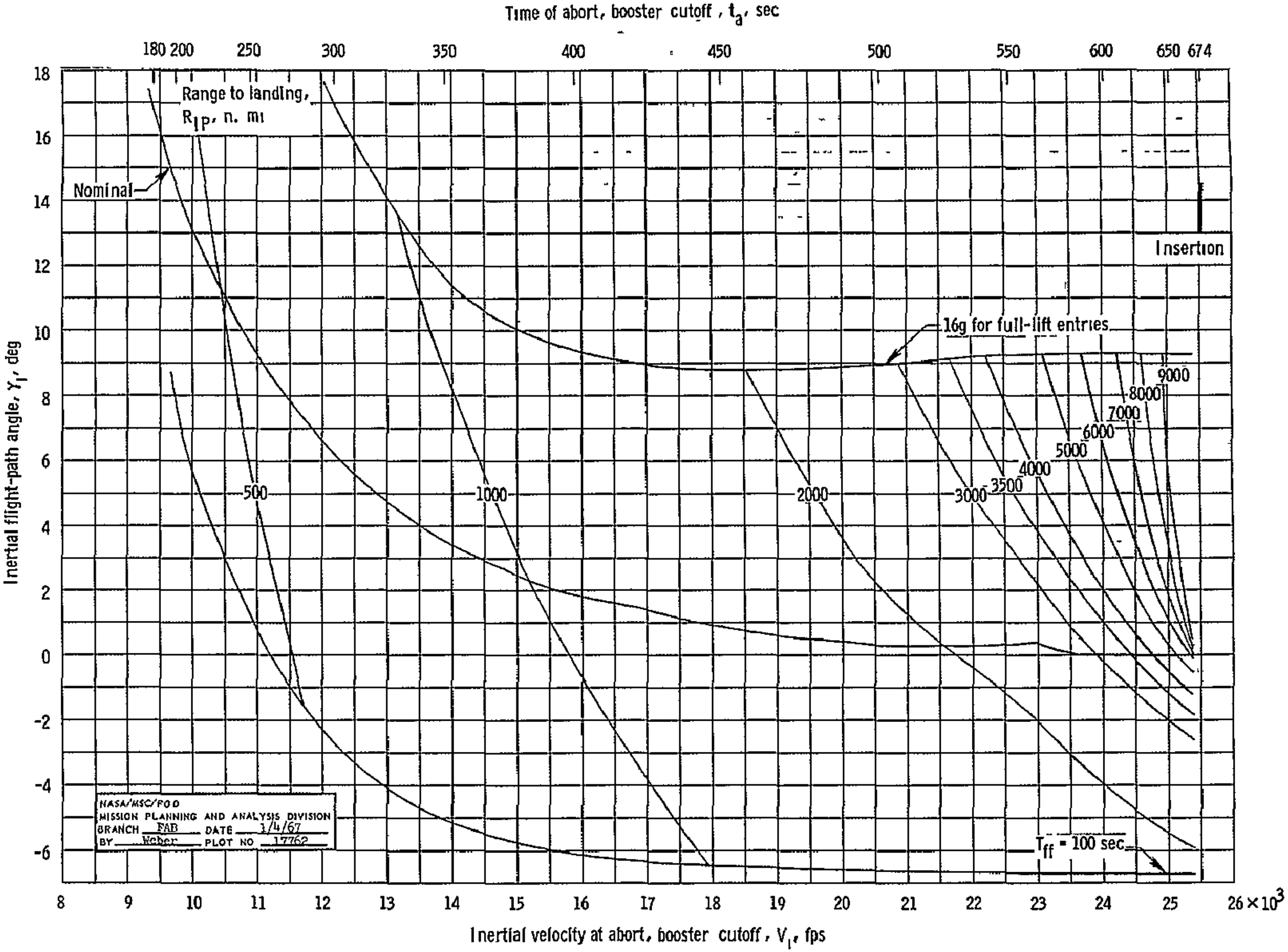
(a) Full-lift entries.

Figure 18.- Range at landing as a function of inertial velocity and inertial flight-path angle.



(b) Half-lift entries.

Figure 18.- Continued.



(c) Zero-lift entries.

Figure 18. - Concluded.

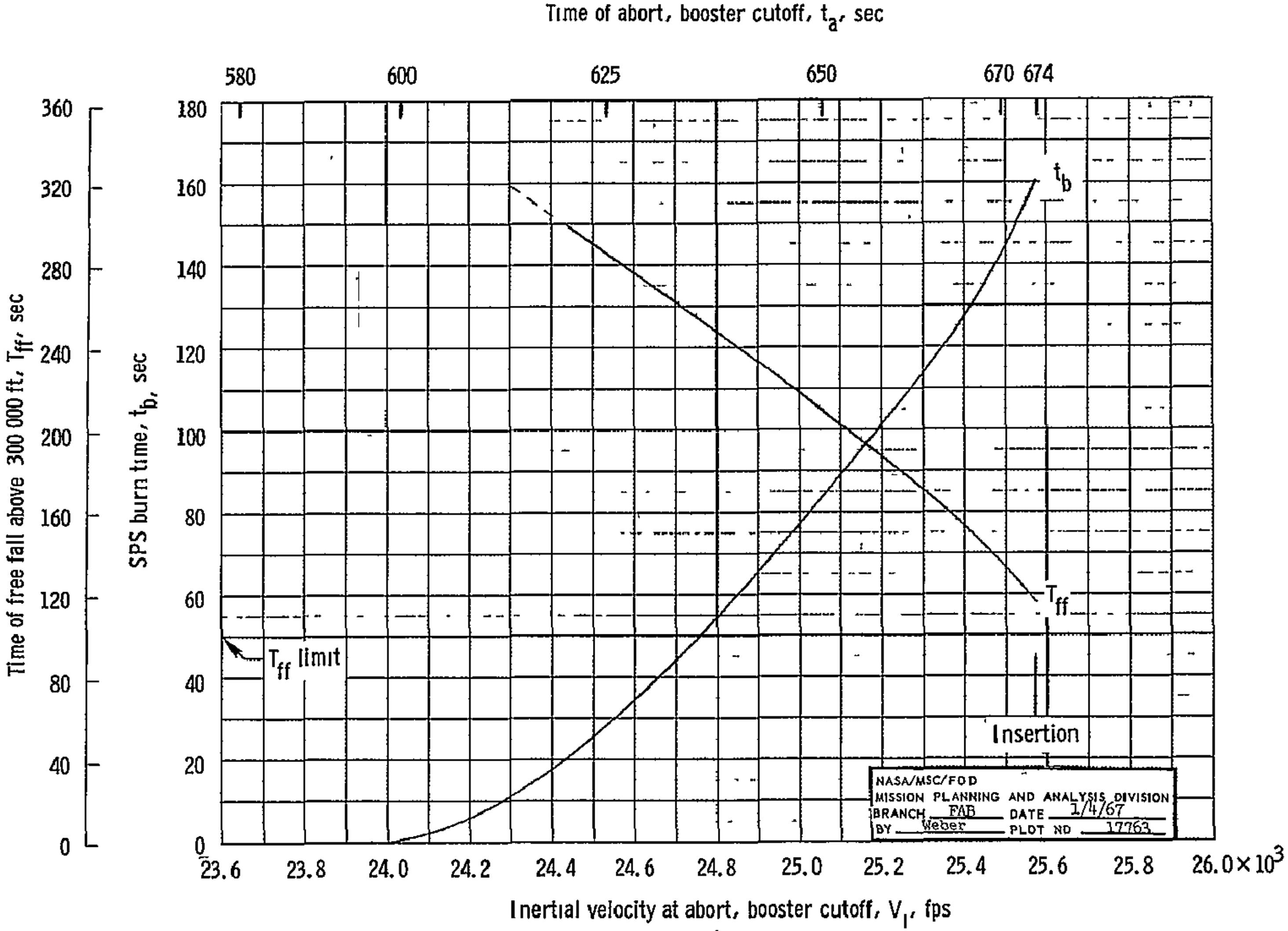


Figure 19. - SPS burn time (retrograde) required to land at the west coast of Africa (range = 3200 n. mi.) and time of free fall remaining after the SPS burn as functions of inertial velocity at abort.

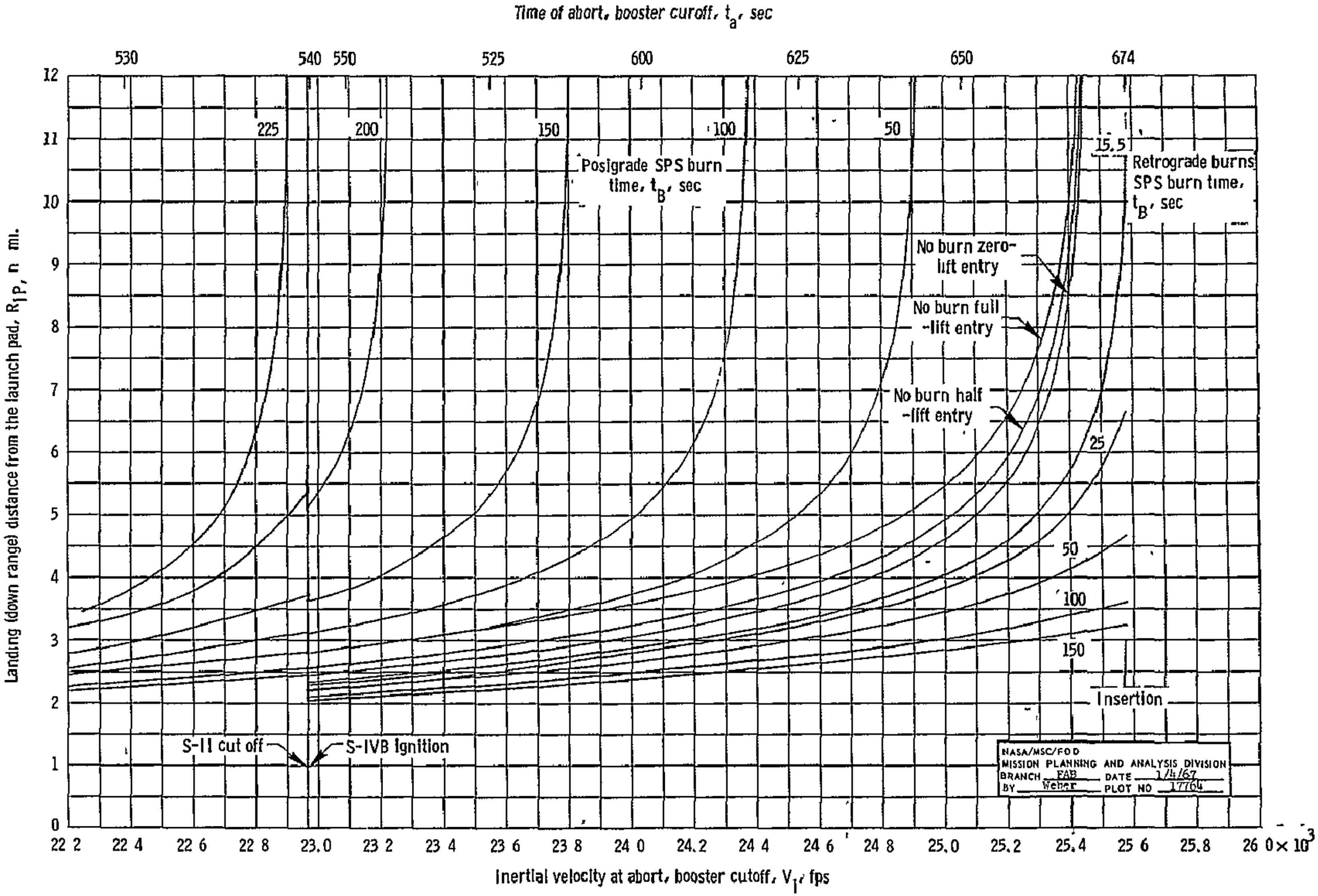


Figure 20. - CM down range landing distance from the launch pads as a function of inertial velocity at abort for various SPS range-control burns

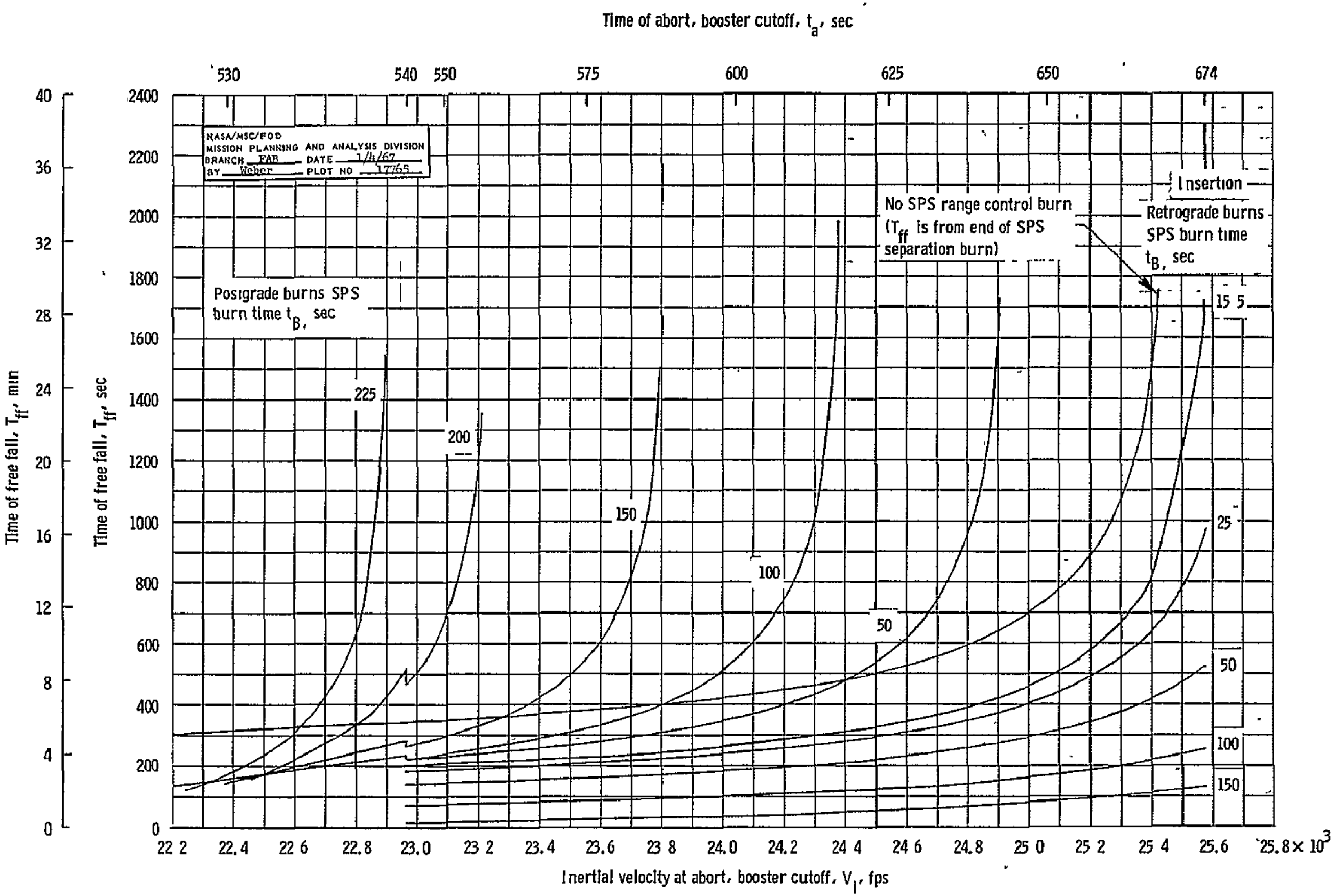


Figure 21. - Time of free fall above 300 000 feet as a function of inertial velocity at abort. (T_{ff} is referenced to the end of the SPS burn).

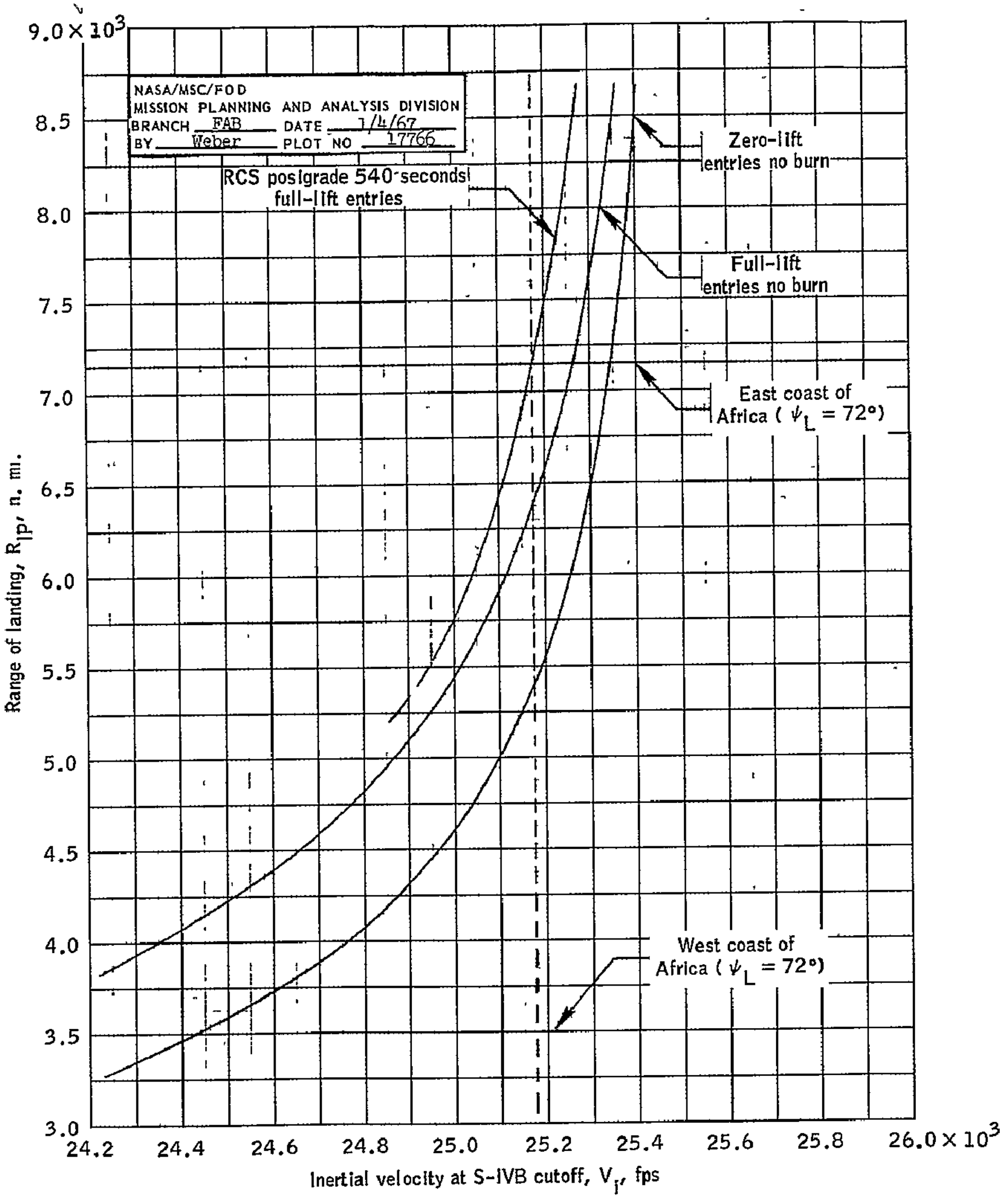


Figure 22.- RCS posigrade range-control capability.

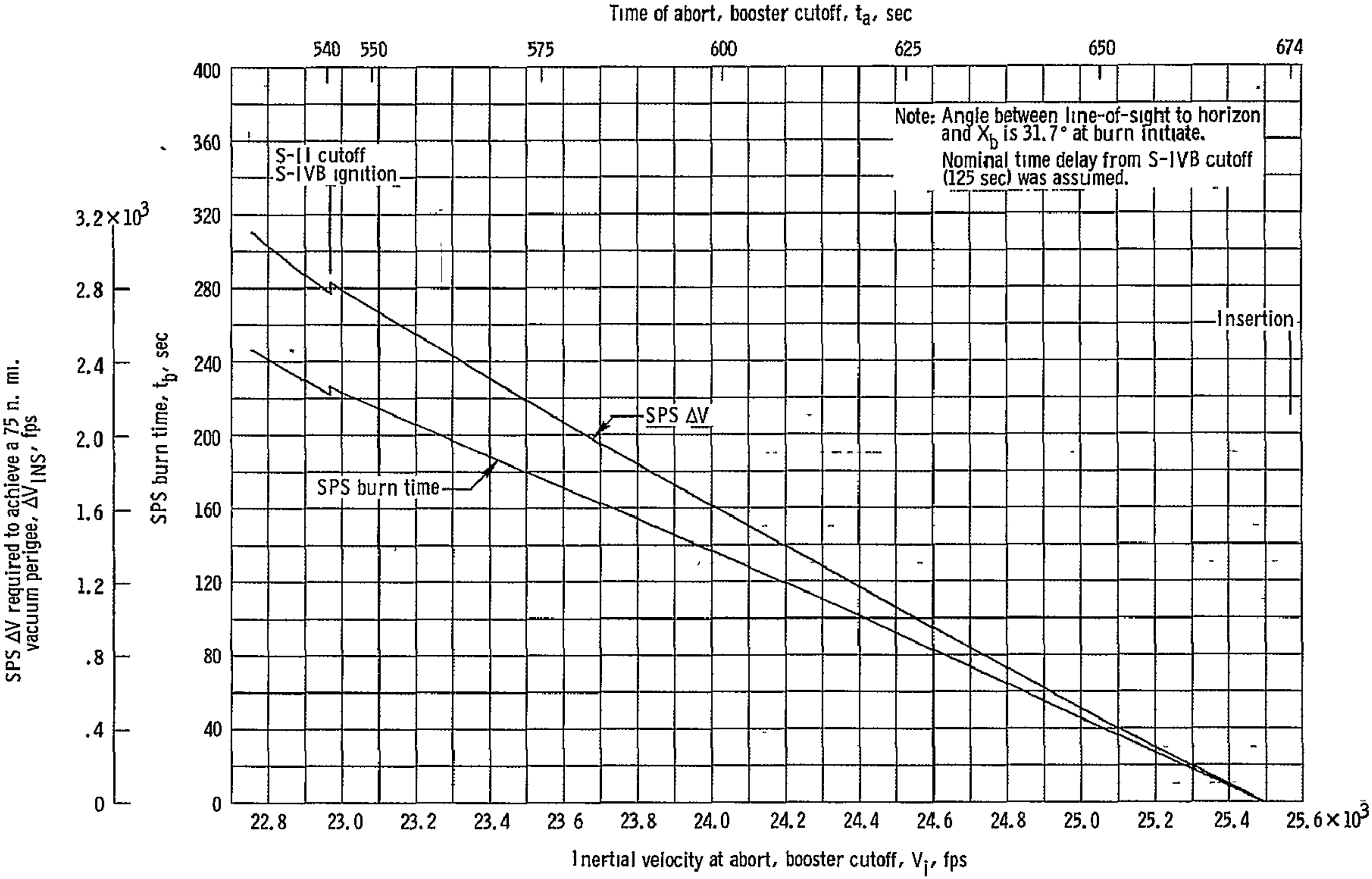


Figure 23. - SPS burn time and ΔV required to achieve a 75-nautical mile vacuum perigee as functions of inertial velocity at abort.

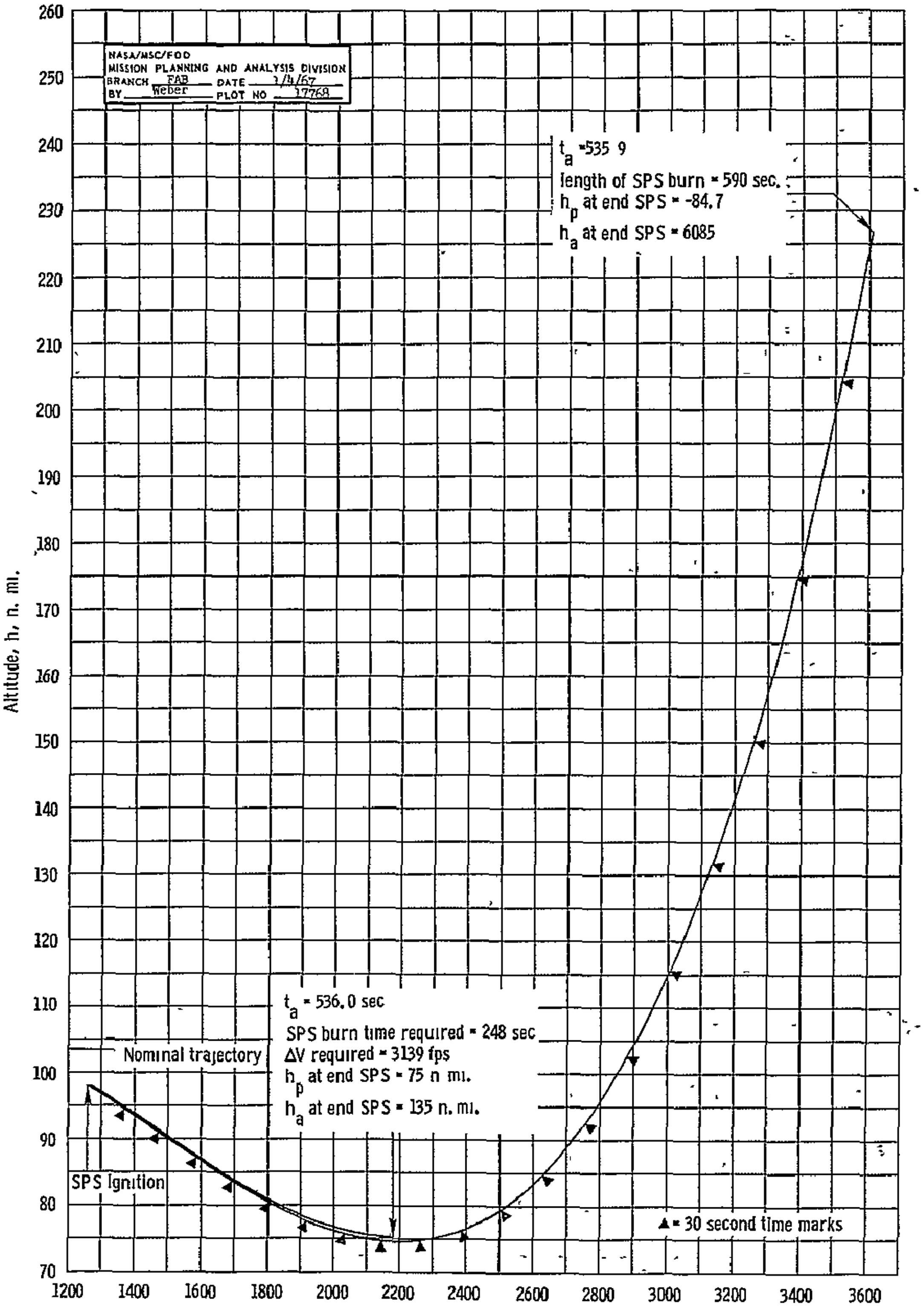


Figure 24. - Altitude versus range for SPS Mode IV burns at t_a = 536.0 seconds (first time of abort the SPS Mode IV burn achieves a 75.0 nautical mile perigee) and at t_a = 535.9 seconds.

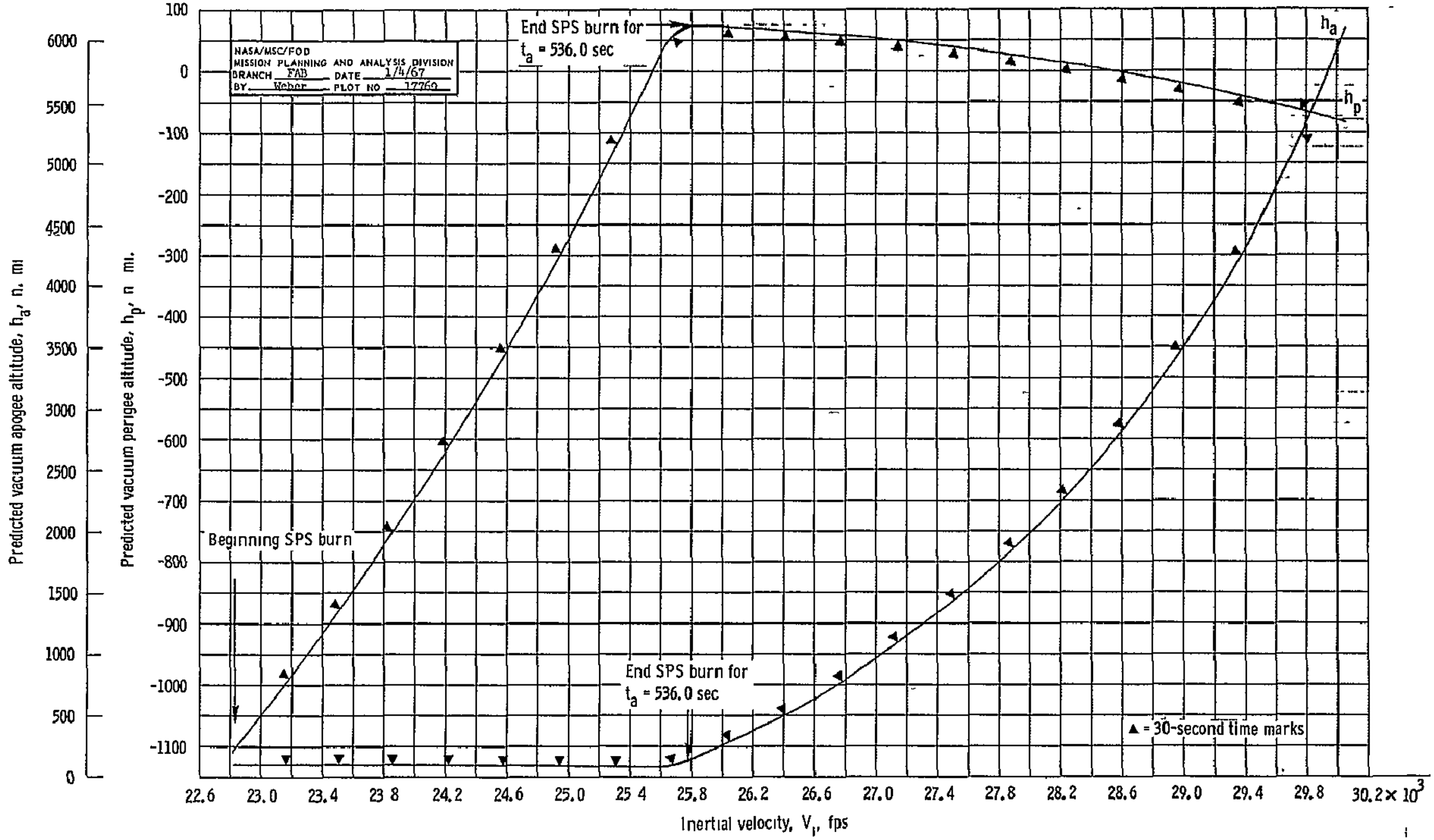


Figure 25.- Perigee altitude and apogee altitude versus inertial velocity for SPS Mode IV burns at t_a = 536.0 seconds (first time of abort the SPS Mode IV burn achieves a 75.0-nautical mile perigee) and at t_a = 535.9 seconds.

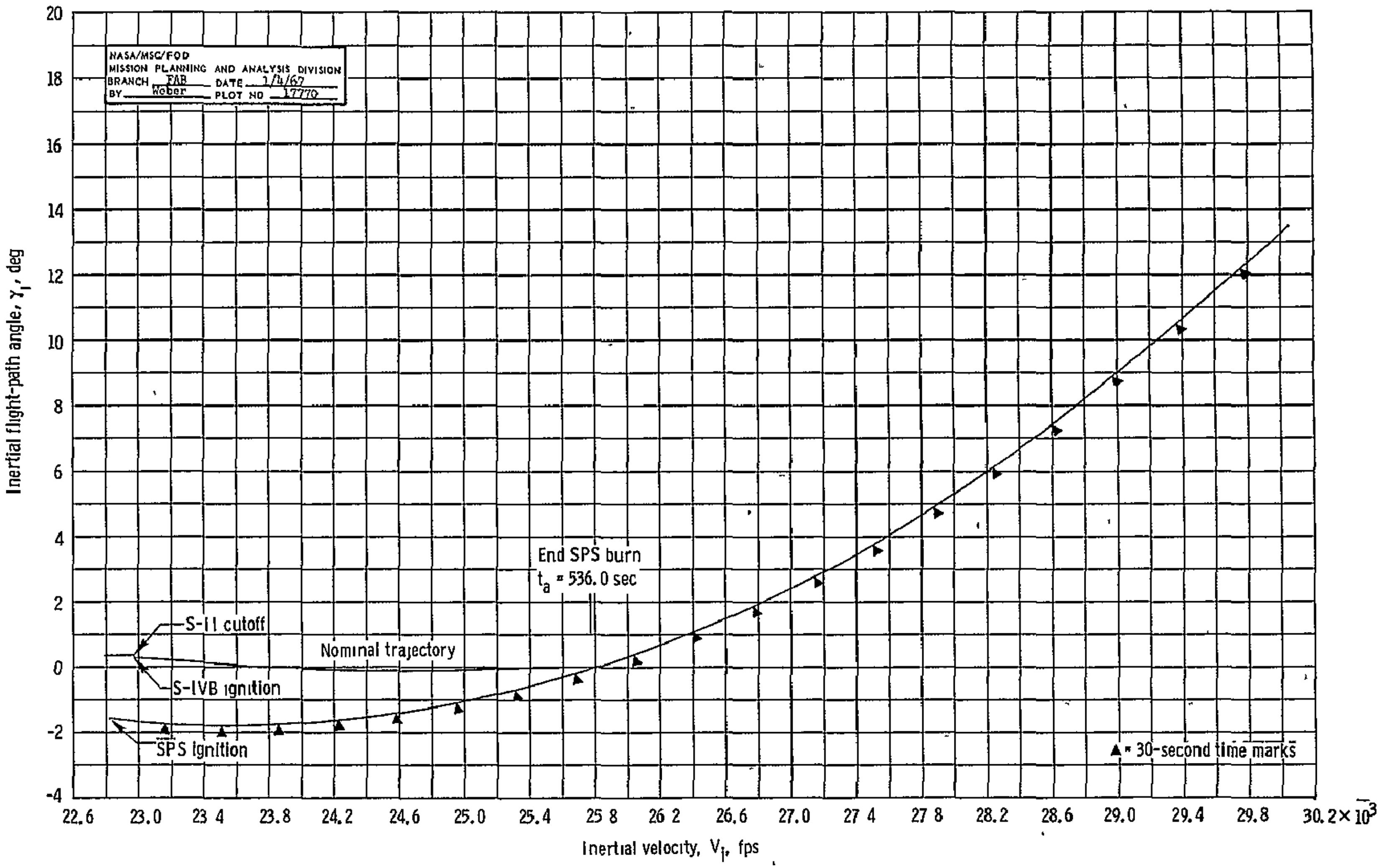


Figure 26. - Inertial velocity versus inertial flight-path angle for SPS Mode IV burns at t_a = 536.0 seconds (first time of abort the SPS Mode IV burn achieves a 75.0-nautical mile perigee) and at t_a = 535.9 seconds.

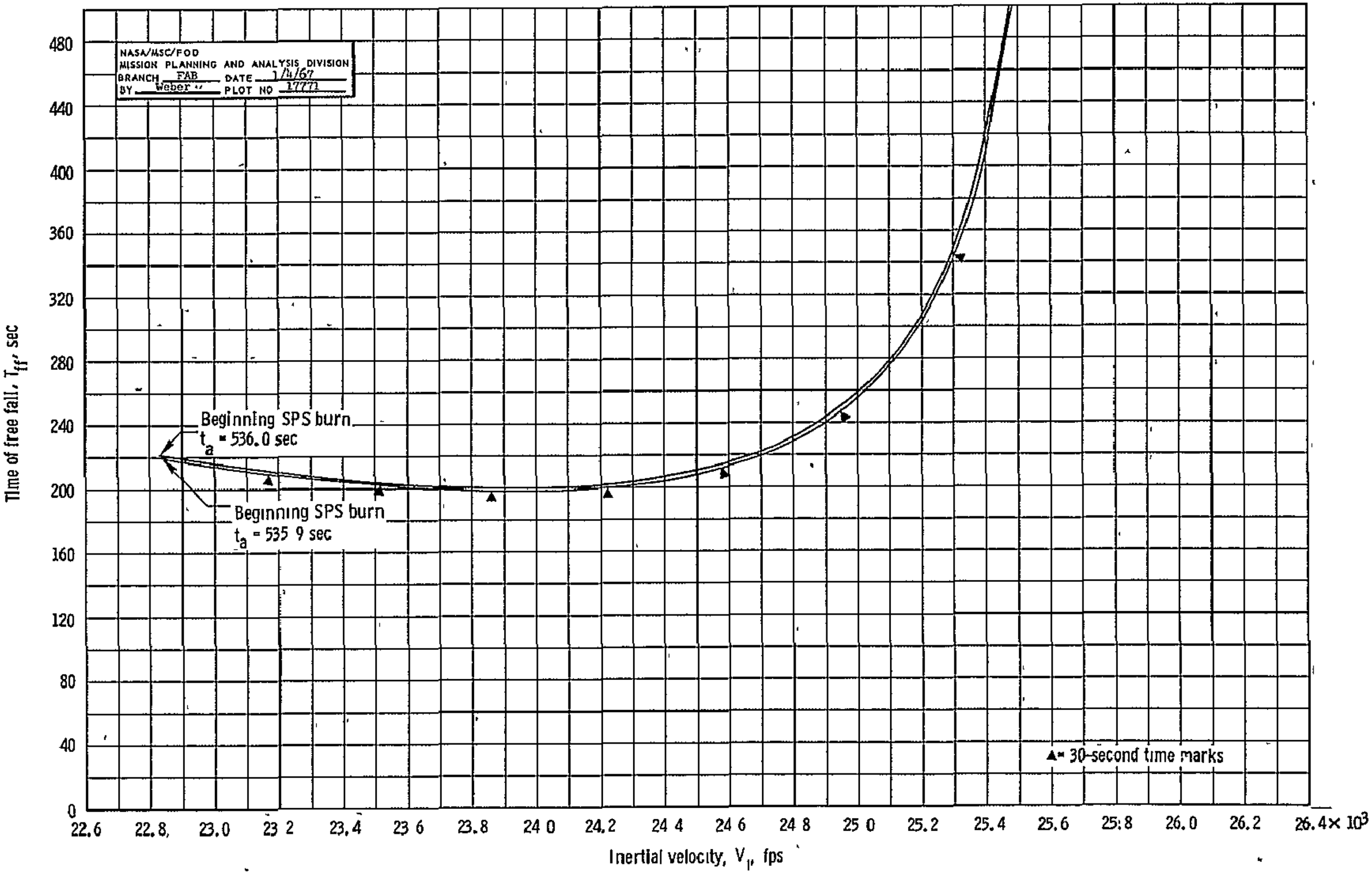


Figure 27. Time of free fall versus inertial velocity for the SPS Mode IV burns at 536.0 seconds (first time of abort the SPS Mode IV burn achieves a 75.0 nautical mile perigee) and at t_a = 535.9 seconds.

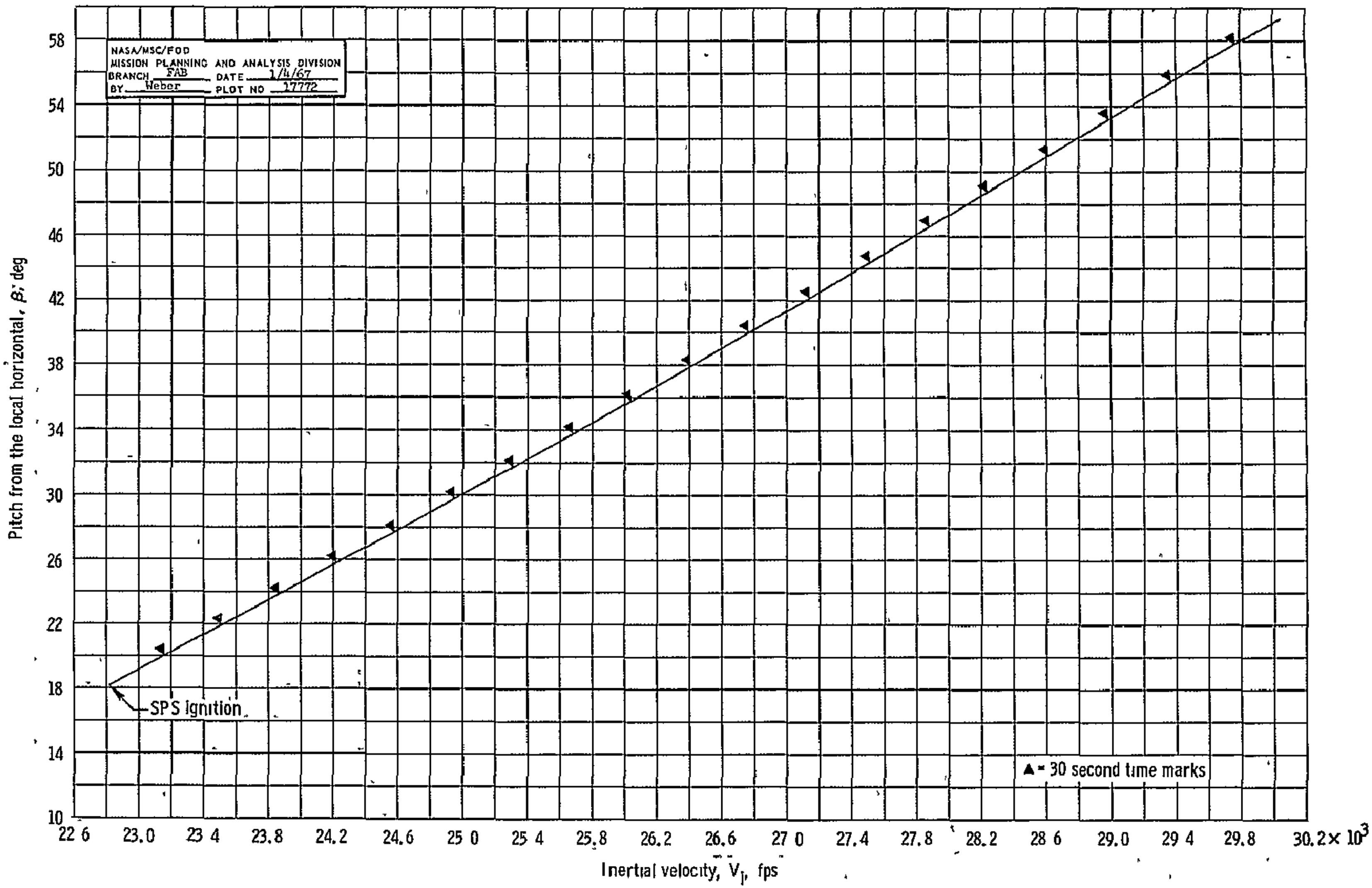


Figure 28.- Perigee altitude and apogee altitude versus inertial velocity for SPS Mode IV burns at t_a = 536.0 seconds (first time to abort the SPS Mode IV burn achieves a 75.0 nautical mile perigee) and at t_a = 535.9 seconds.

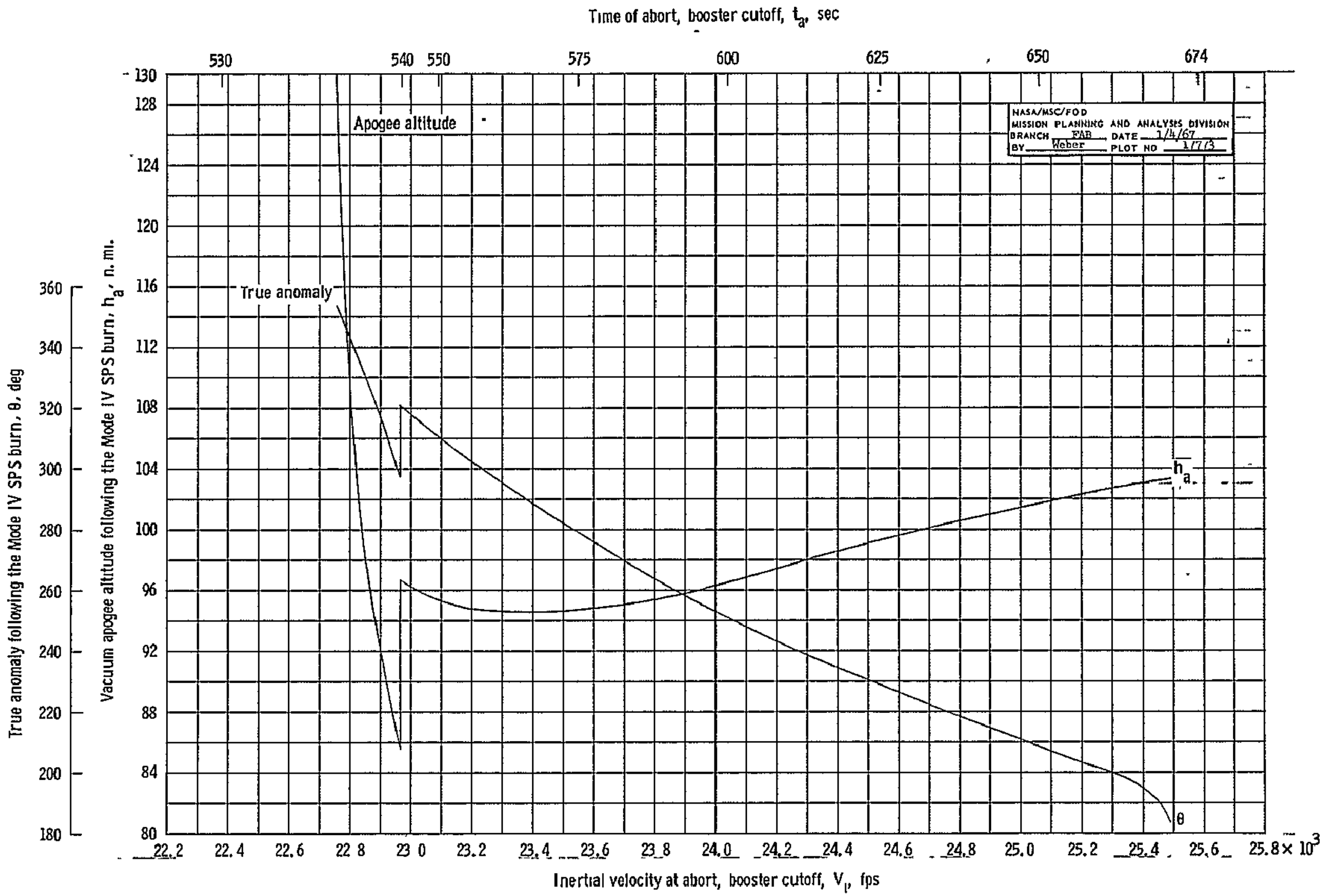


Figure 29 - Apogee altitude and true anomaly following the required Mode IV SPS burn as functions of inertial velocity at abort for Mode IV aborts from the nominal trajectory.

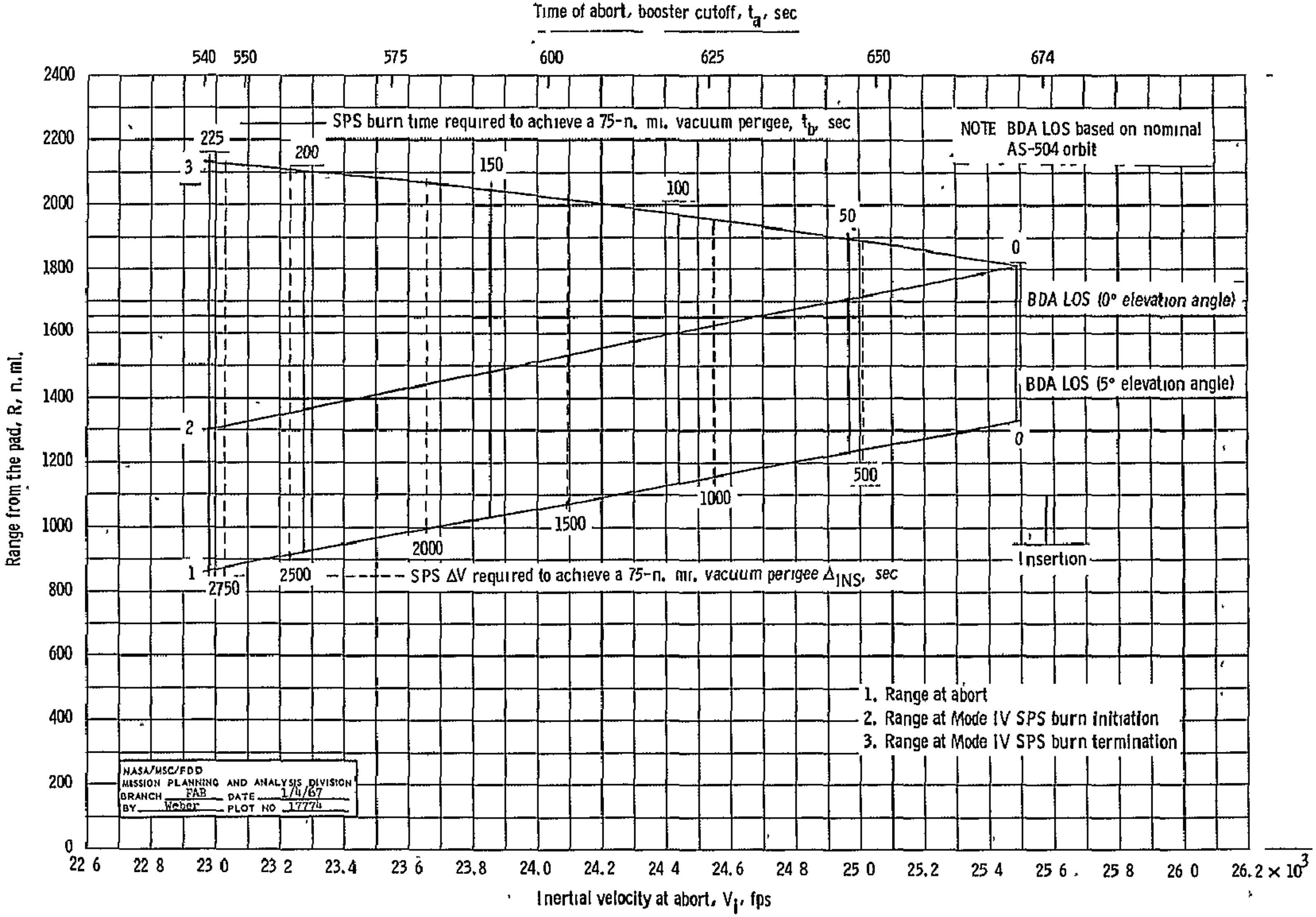


Figure 30. - Down range distance from the pad at abort, Mode IV SPS burn initiation, and Mode IV SPS burn termination as functions of inertial velocity at abort for Mode IV aborts from the nominal trajectory

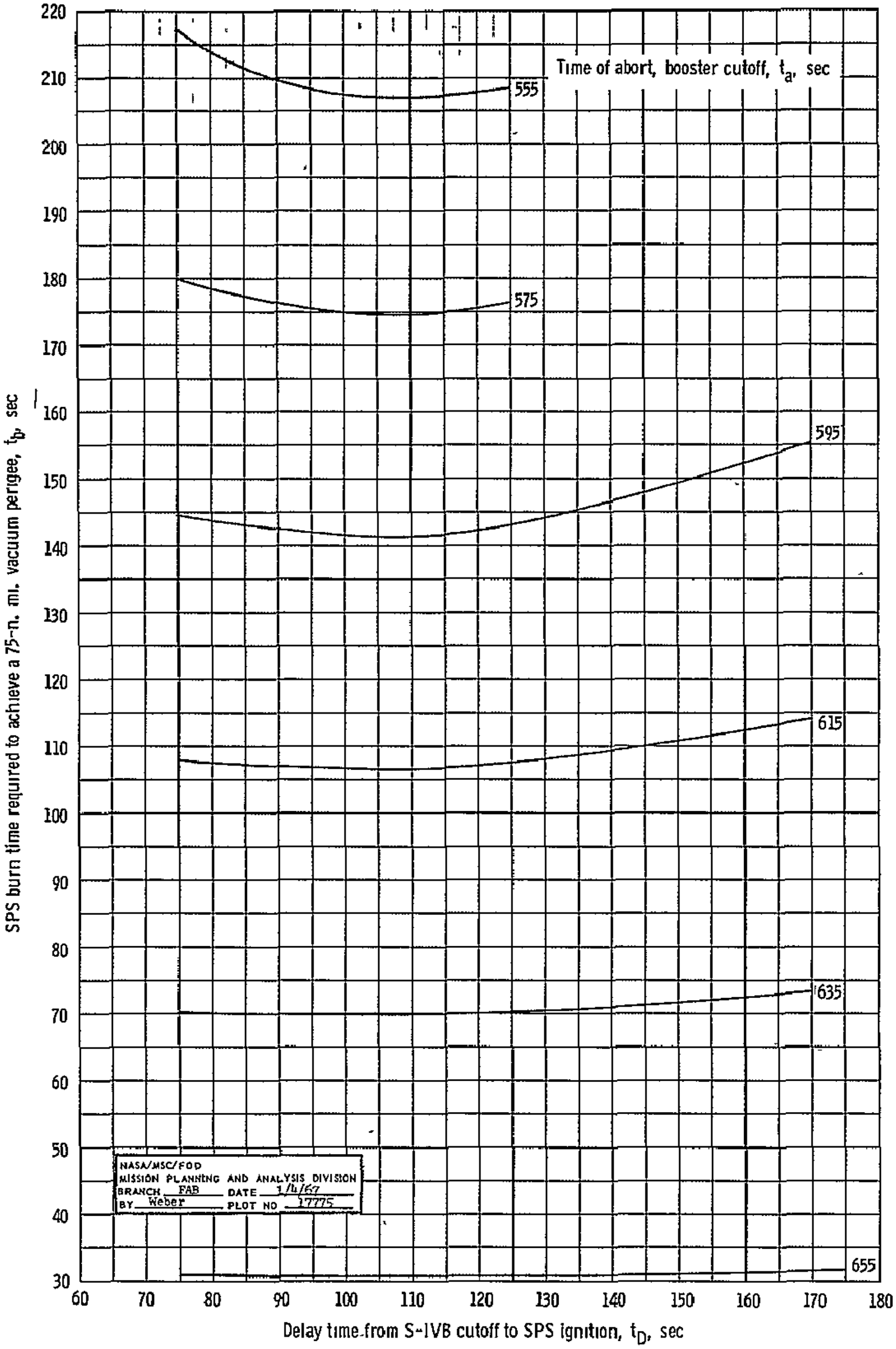


Figure 31. - SPS burn time required to achieve a 75-n mi. vacuum perigee as a function of delay time from S-IVB cutoff to SPS ignition for various times of abort.

2

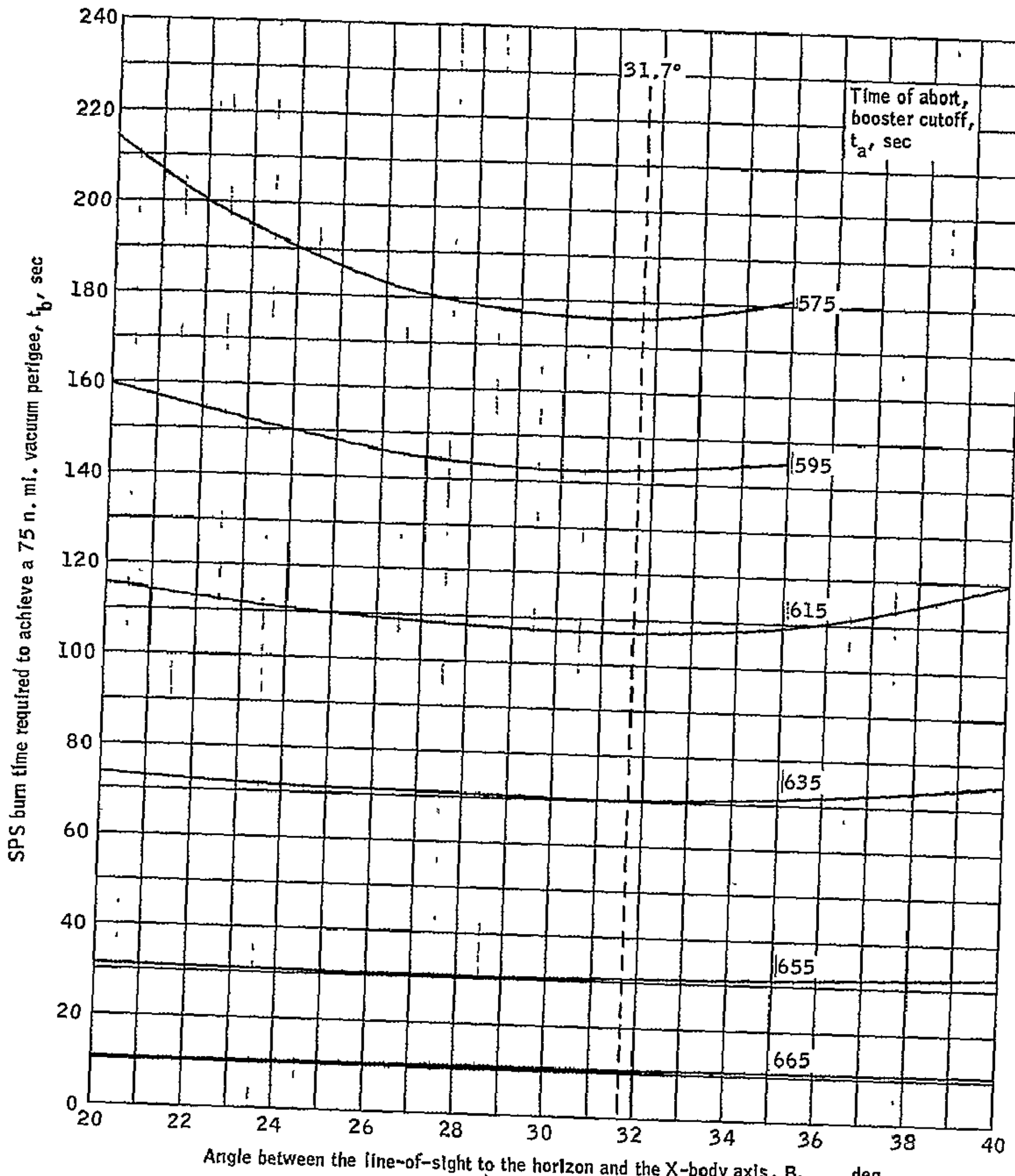


Figure 32.- SPS burn time required to achieve a 75 nautical miles vacuum perigee as a function of the angle between the line-of-sight to the horizon and the X-body axis at SPS burn initiation for various times of abort.

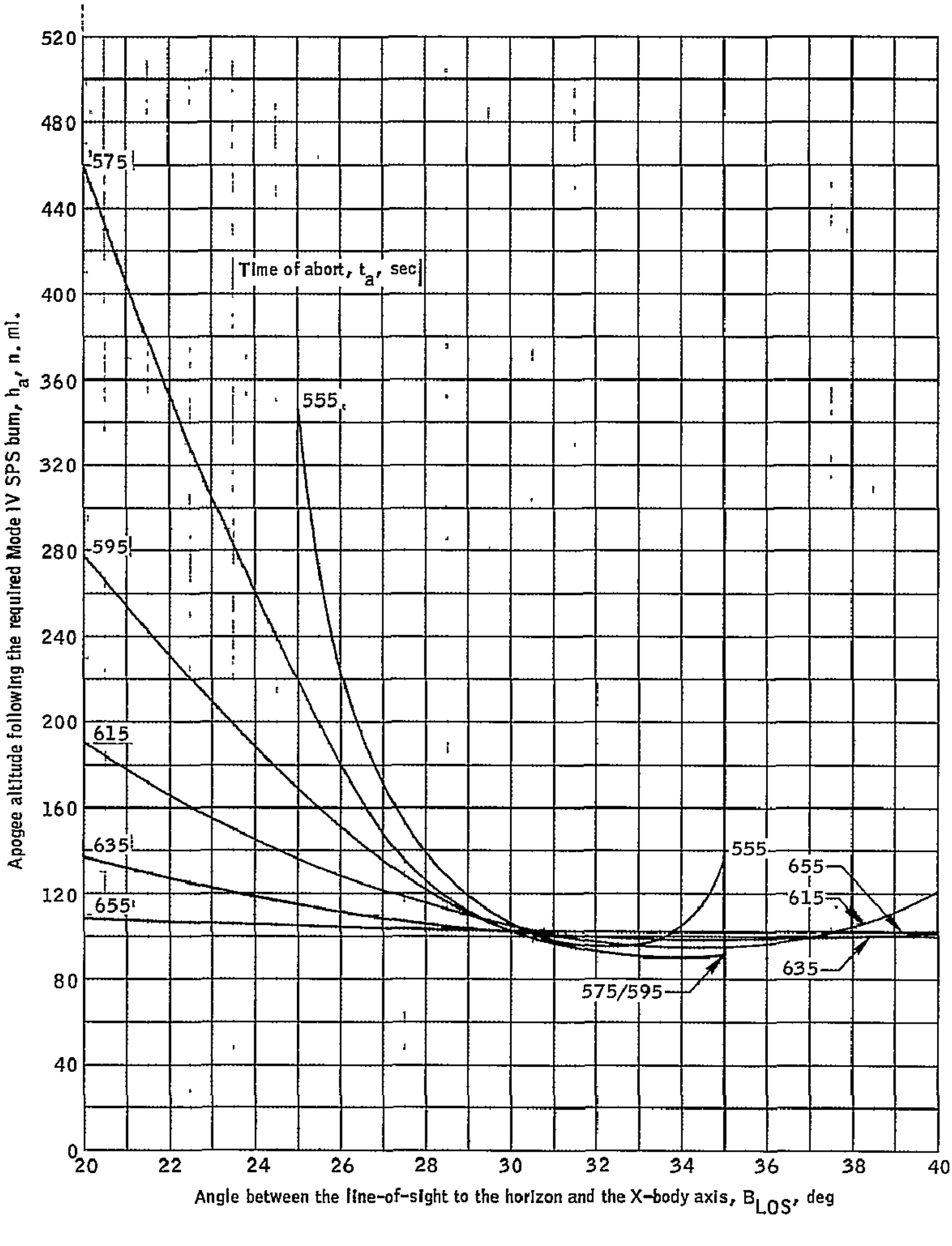


Figure 33.- Apogee altitude following the Mode IV SPS burn required to achieve a 75 nautical mile perigee as a function of the angle between the X-body axis and the line-of-sight to the horizon at SPS burn initiation for various times of abort.

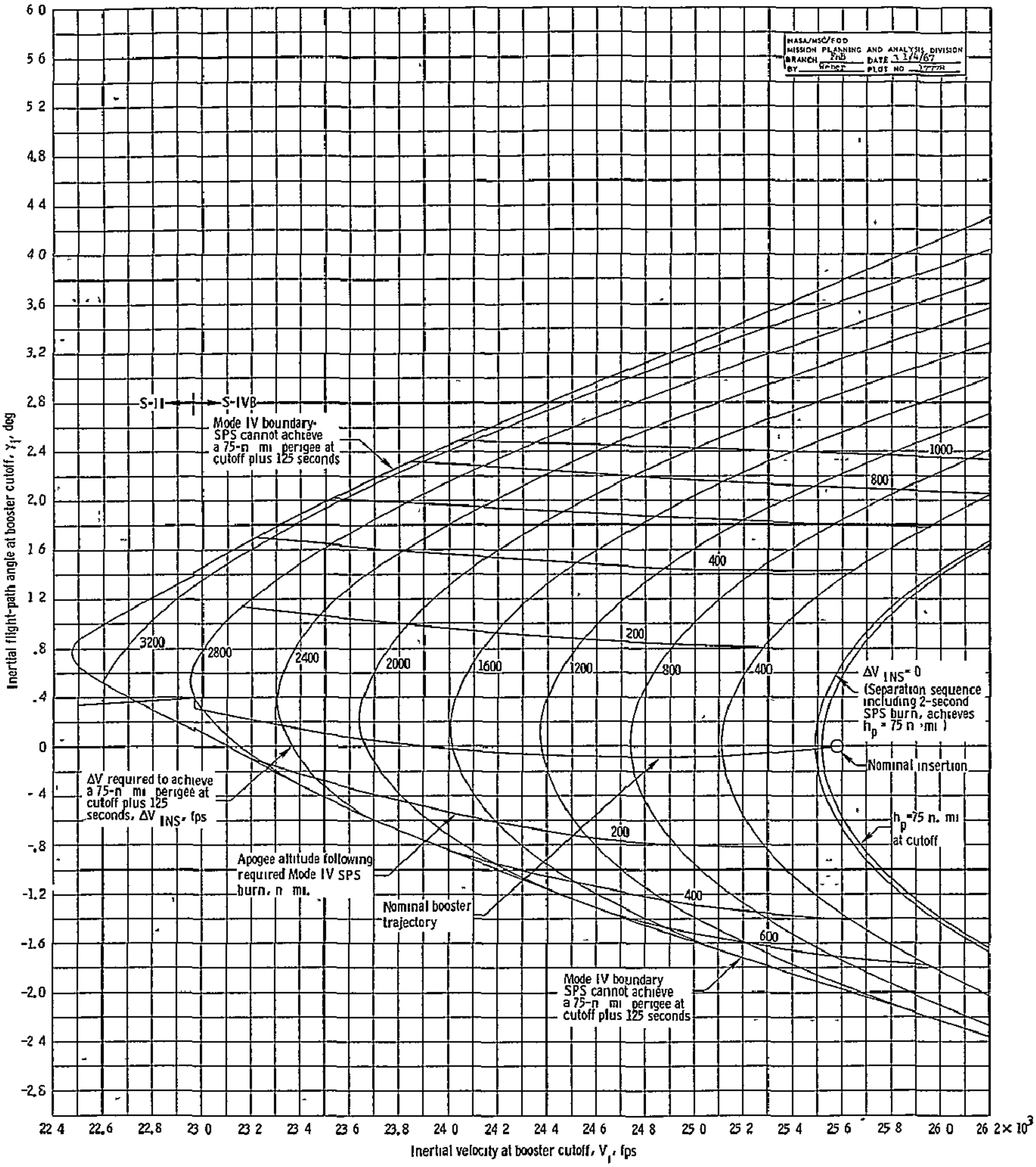


Figure 34 - ΔV required to achieve a 75-nautical mile perigee at booster cutoff plus 125 seconds as a function of inertial velocity and inertial flight-path angle at booster cutoff

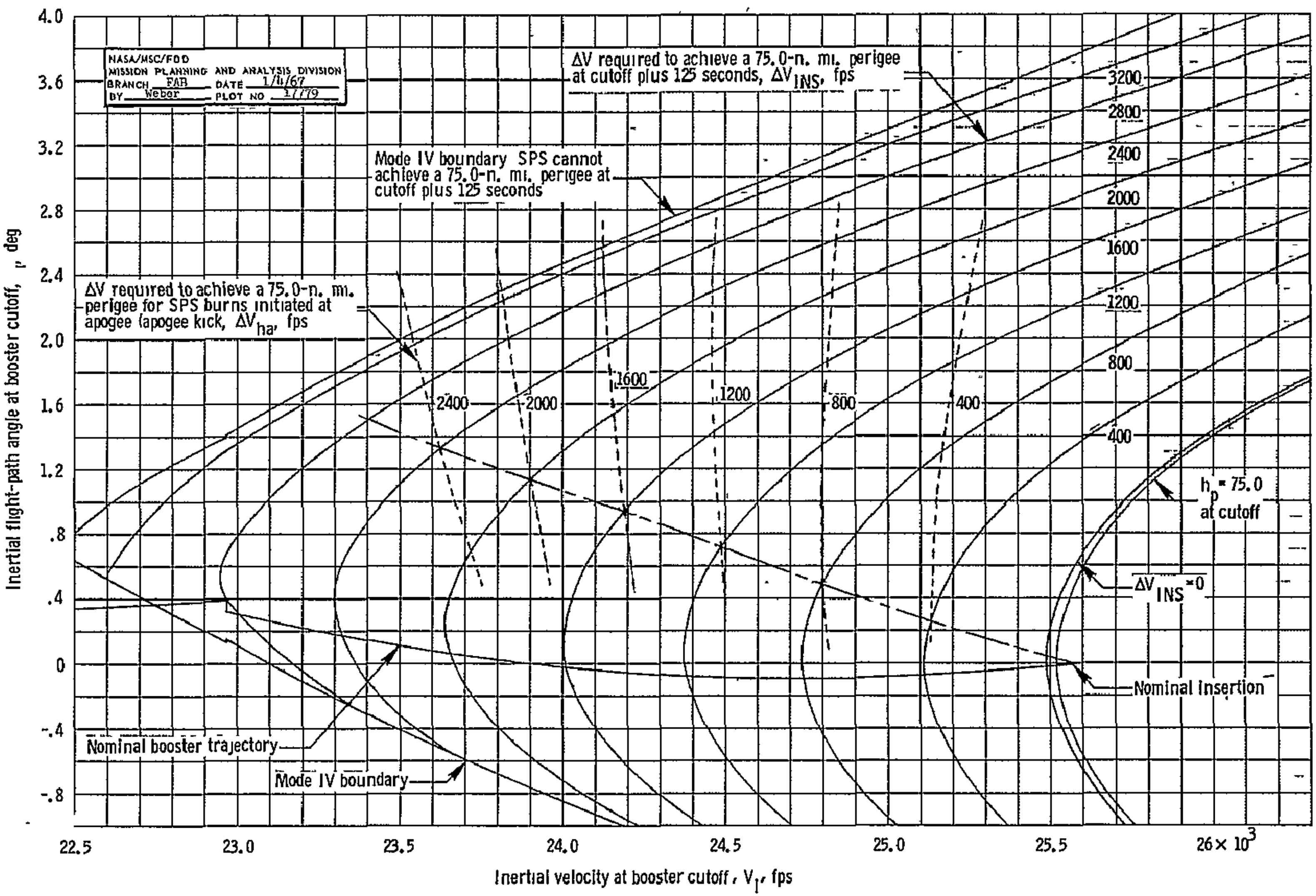


Figure 35. - Mode IV ΔV and apogee kick ΔV required to achieve a 75.0-nautical mile perigee as functions of inertial velocity and inertial flight-path angle at booster cutoff.

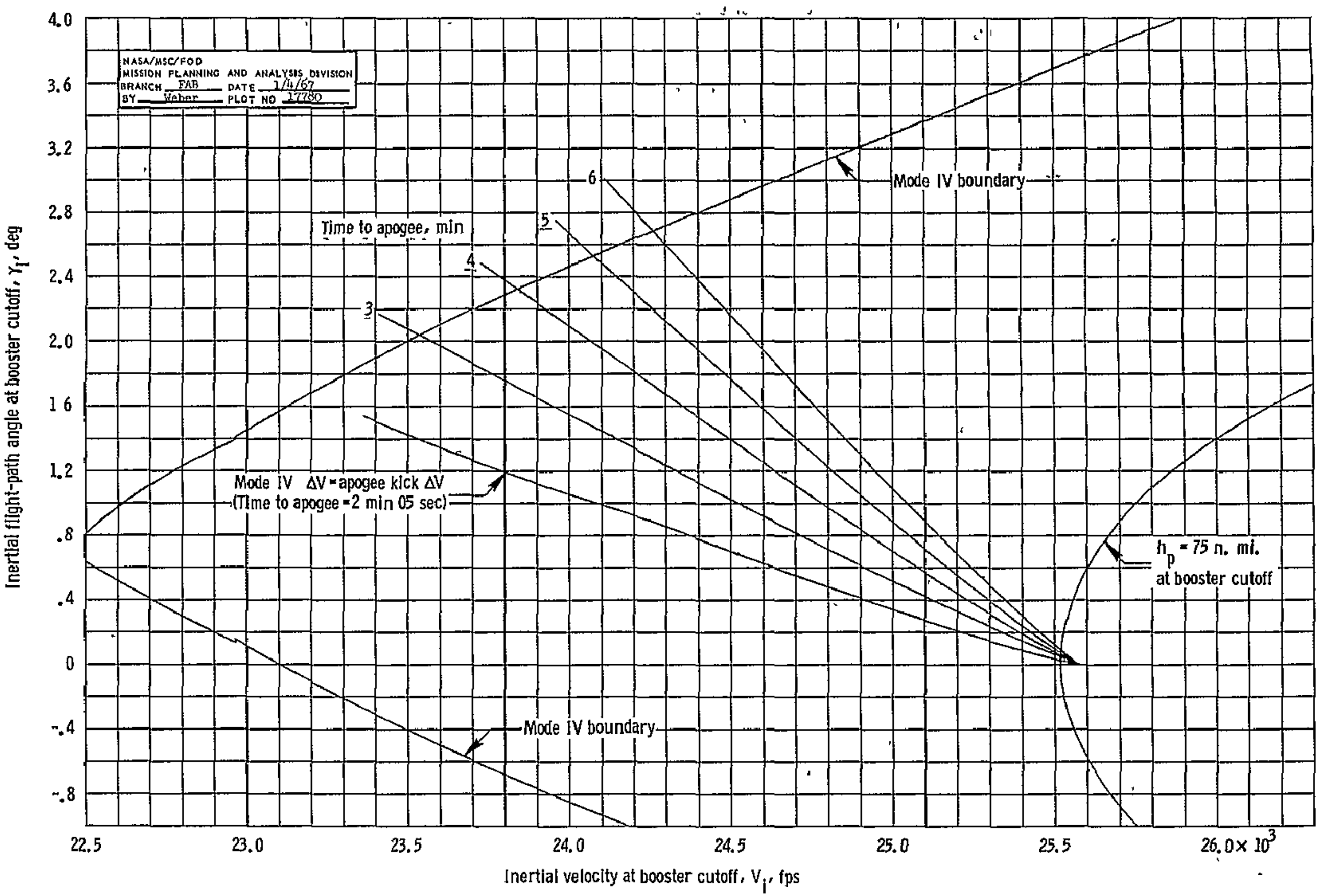


Figure 36. - Time to apogee from booster-cutoff as a function of inertial velocity and inertial flight-path angle at booster cutoff.

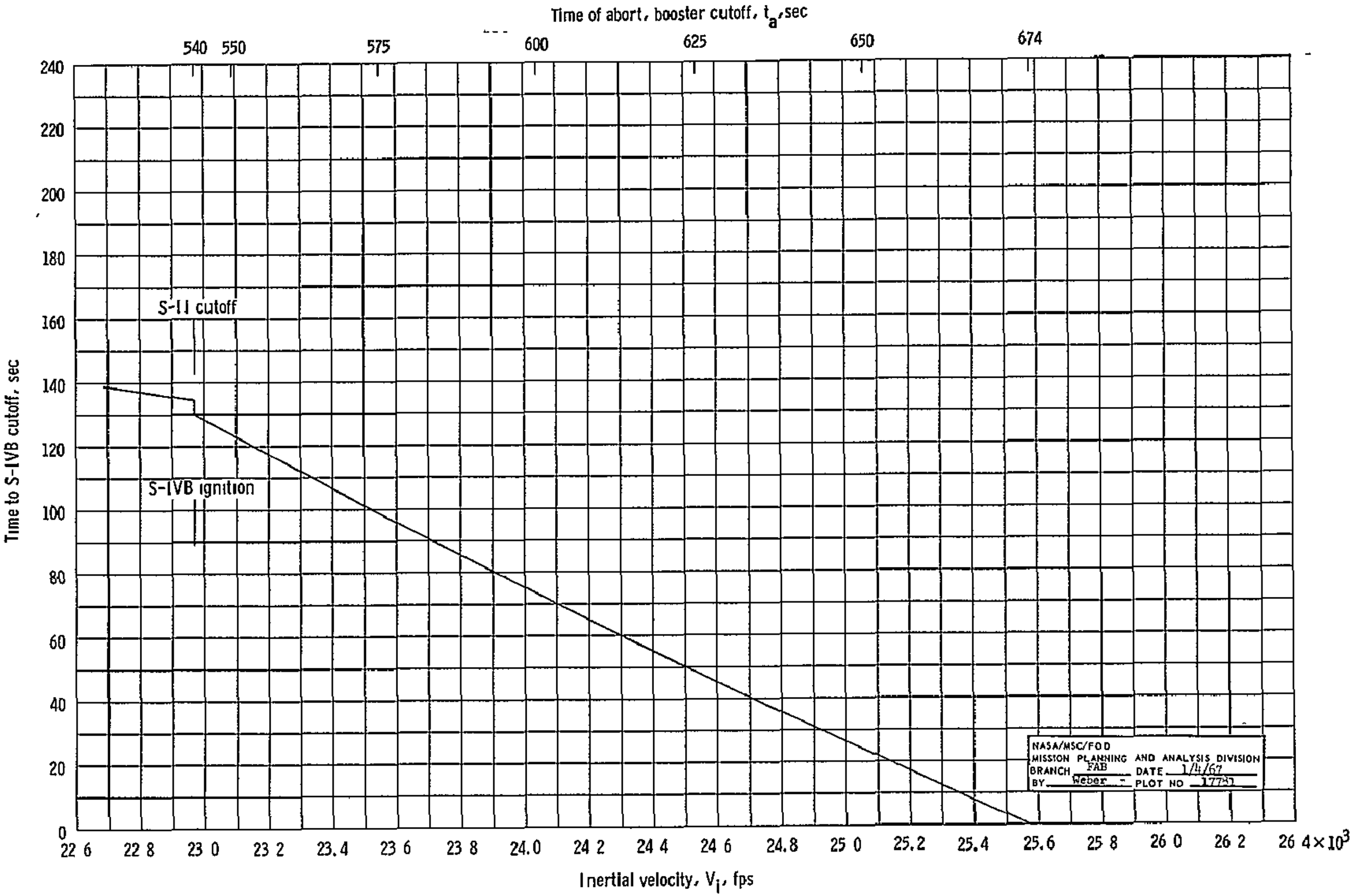


Figure 37 - Time to S-IVB cutoff as a function of inertial velocity for the nominal AS-504 launch trajectory

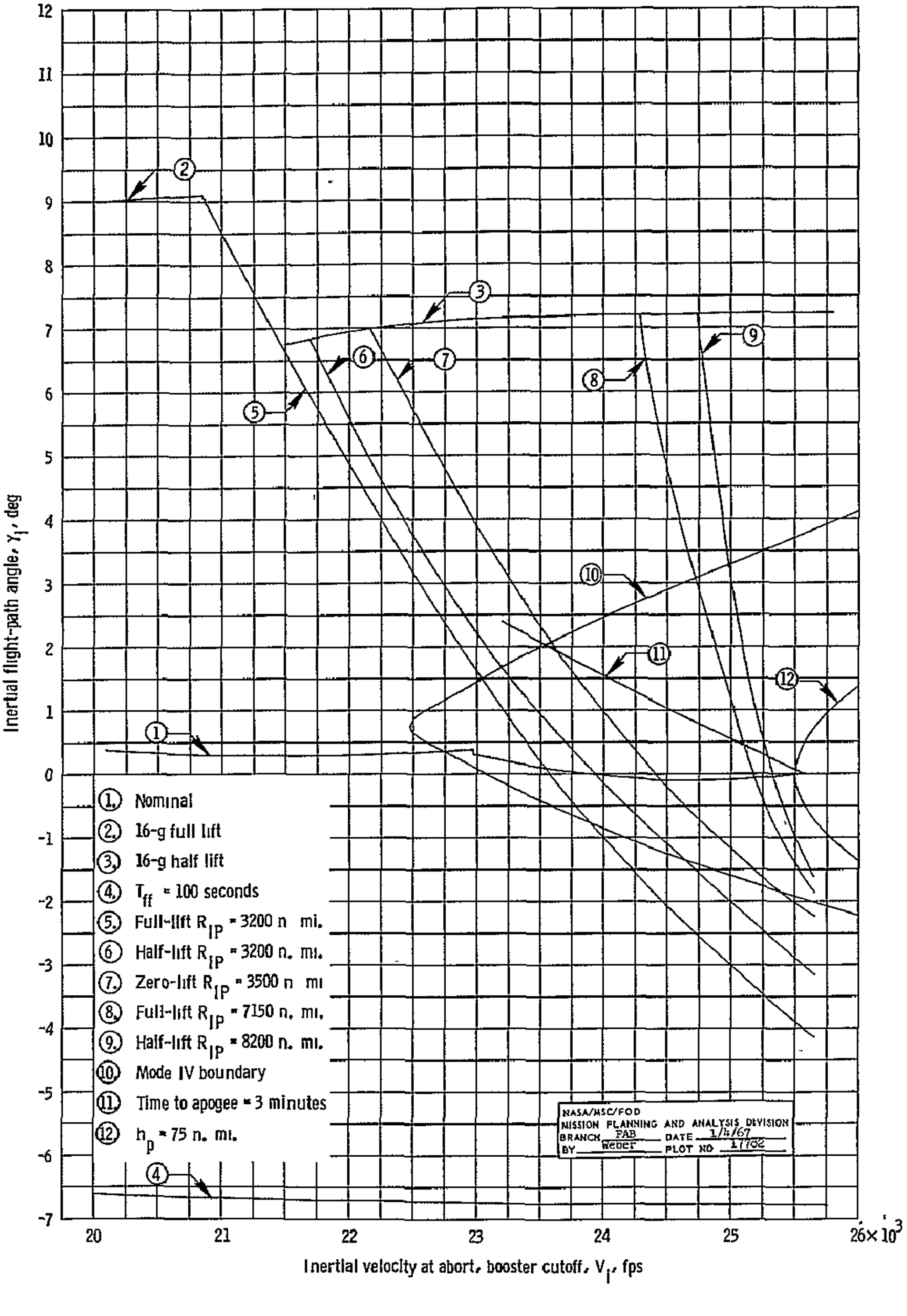


Figure 38. - Plotboard 1a limit line and information line candidates for AS-504.

REFERENCES

1. Henderson, Edward M.; Lunde, Alfred N.; and Newman, Samuel R.: Spacecraft Operational Abort and Alternate Mission Studies for AS-204A, Volume I - Abort Studies. MSC Internal Note No. 66-FM-113, October 28, 1966.

2. Apollo Mission Planning Task Force: Abort Trajectory Performance Studies, October 15, 1964.

3. Defife, John E.: Abort Trajectory Analysis of the Apollo Launch Escape Vehicle with Canards. MSC Internal Note No. 64-ET-39, July 2, 1964.

4. TRW Report No. 2131-H002-T8-000: Apollo Mission Data Specification B, Apollo Saturn 504 and Subsequent Missions (U), Confidential, March 1, 1966.

5. Mission Analysis Branch: AS-504A Preliminary Spacecraft Reference Trajectory, Volume I (U), Confidential. July 1, 1966.

6. Boeing Company, The: AS-504 Preliminary Launch Vehicle Reference Trajectory, Volumes I and II (U), Confidential. Document No. D5-15481, July 13, 1966.

7. Saturn IB J-2 Engine Characteristics. MSFC Memorandum R-P & VE-PPE-66-M-90, May 11, 1966.

8. Flight Research Division, Langley Aeronautical Laboratory: Notes on Space Technology. February-May, 1958.