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EXCESSIVE ENTRY LOADS FOR ABORT TRAJECTORIES FROM THE NOMINAL AS-205/101 LAUNCH PROFILE

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PROJECT APOLLO

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FIGURES

Figure		Page
1	Maximum entry load factors versus abort time for different launch profiles	6
2	Maximum entry load factors versus abort velocity for different launch profiles	7
3	Comparison of launch altitude versus range profiles	8
4	Comparison of launch altitude versus velocity profiles	9
5	Comparison of velocity and flight-path angle versus altitude profiles	10
6	Comparison of flight-path angle versus velocity profiles with associated abort limits	11
7	Comparison of flight-path angle versus velocity at entry interface profiles with current abort limit	12
8	Entry load factor variation with lift-to-drag ratio at entry interface	13
9	Desired limit for launch trajectory design at entry interface	14
10	Desired limit for launch trajectory design for different altitudes	15
11	Comparison of sustained accelerations for aborts from different launch profiles with human limits	16
12	Load factor variation during entry with different L/D's	17
13	Comparison of sustained accelerations for aborts of different L/D's with human limits	18
14	Different entry load factor limits at entry interface for reduced L/D	19
15	Different entry load factor limits for reduced L/D	20

16 Effects of SPS burn attitude on maximum entry load factor and free-fall time. 21

17 Effects of SPS burn-time on maximum entry load factor and free-fall time. 22

18 Abort limit with maximum launch vehicle dispersions. . . 23

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SUMMARY AND INTRODUCTION

Current abort trajectory studies for the nominal AS-205/101 launch trajectory have produced entry load factors (g's) exceeding the established 16-g limitation for aborts initiated from the nominal launch profile. This condition is caused by the steep profile dictated by the 120-n. mi. insertion altitude necessary to achieve the 120/150-n. mi. (perigee altitude to apogee altitude) orbit. The higher altitudes along the launch trajectory tend to pull the g boundary down such that the nominal ascent trace violates the current 16-g limitation. This violation occurs for the current lift-to-drag ratio (L/D) of 0.33. Lowering the L/D increases the g's accordingly but does not cause the violation. As it now stands, current operational procedures would inhibit such a launch.

Four methods are now being investigated in an attempt to alleviate this situation:

1. Reshape the launch profile.

2. Raise the 16-g abort limit to 18 g.

3. Use the spacecraft propulsion to improve entry conditions.

4. Use the maximum launch vehicle dispersion envelope as the abort guide and fly through the high g region.

The simplest solution (method 2) would be to raise the g limit to a higher value of human tolerance; however, there is insufficient biodynamics data available to make this decision. The most practical solution (method 4) would be to use the maximum dispersion envelope of the launch vehicle that makes it possible to obtain orbit (hp > 75 n. mi.) as the guide for flying through the high g region.

DISCUSSION OF METHODS

As can be seen from figures 1 and 2, g's for aborts from the 120/150-n. mi. orbit launch profile are much more severe than those for the other Apollo missions investigated. Note that the L/D used for these aborts is based on current data specification (L/D = 0.33) and not the speculated lower value (L/D $\approx$ 0.25).

Figures 3 through 7 show trajectories from which the various launch configurations can be compared. The higher altitude profile is obvious in figures 3 and 4. A composite of the trajectory parameters is plotted on figure 5. Figure 6 shows each launch trajectory with its associated 16-g abort boundary. (Note: The 120/150-n. mi. orbit profile violates its abort boundary.) The reason for the shifts in the g boundaries is contributed primarily to the changes in altitude of each trajectory (though it is not obvious from this plot). A valid comparison of each launch trajectory can be made at entry interface (h = 300 000 ft), figure 7. This display enables an analysis of velocity and flight-path angle based on constant altitude, and each trace can be compared to a given g boundary. Figure 8 shows the effects of L/D variation on a 14-g and 16-g boundary with the nominal 120/150-n. mi. trace at entry interface.

Reshape the Launch Profile

A possible solution could be to reshape the launch trajectory to allow satisfactory clearance of the 16-g abort boundary. For lack of sufficient data, it was arbitrarily decided that a 15-g boundary (L/D = 0.242) would provide the necessary pad below the 16-g limit. Therefore, if Marshall Space Flight Center (MSFC) can design a launch profile not to violate this 15-g limit, it would be operationally feasible to fly that trajectory. Figure 9 depicts this limit (15 g) at entry interface with the current launch profile. Based on the conditions at entry interface this limit was analytically calculated for constant altitudes and shown on figure 10 with the nominal trace. These plots have been made available to MSFC for launch trajectory redesign considerations. However, it is highly dubious that MSFC can help the situation. The current design is performance critical for the 205 launch into a 120/150-n. mi. orbit, and any reshaping would definitely degrade performance.

Raise the Abort Limit

Another solution could be to raise the current 16-g limit to a higher value, thus widening the corridor above the current trajectory, that is, if the limit could be raised and not jeopardize the safety of the crew. Present limits are based on peak g's; however, the controlling factor is the time the crew is exposed to given g values (load factor duration). An emergency limit and performance limit were obtained from references 1 and 2. The g-time histories for critical abort times from the basic launch profiles are compared with these limits on figure 11. Figure 12 shows the effects of reduced L/D on a high g abort from the 120/150-n. mi. orbit profile and can be compared to these limits on figure 13. As can be seen, none of these loadings violate the emergency limit. How valid is this emergency limit? A phone conversation with Dr. William R. Carpentier, Program Support Branch of the Medical Operations Office, indicated that no work was being done in this area at MSC. Dr. L. L. Hammangren was working in this area but has since left the Center, and no one presently is specializing in bio-dynamics. The Flight Operations Directorate has already made a request (ref. 3) for an investigation of this area but no response has been given. Another phone conversation with Dr. Shropshire at Wright-Patterson AFB indicated that he had researched this area thoroughly and is forwarding some of his results.

It appears from the current emergency limits (fig. 11, 12, and 13) that the peak g value could be raised to 18 g's. This increase would allow more trajectory freedom even with reduced L/D, as indicated on figures 14 and 15. However, the medical and crew personnel would have to concur on this limit. Also, consideration should be given the spacecraft's structural limit (presently defined as 20 g's).

Use Spacecraft Propulsion System to Improve Entry Conditions

Another proposal to aid the current high g area of the 120/150-n. mi. orbit launch was devoted to spacecraft performance. This procedure would be to use the service propulsion system (SPS) to burn out of the high g region if the booster failed in this region. It would be an additional launch abort mode - fixed ignition time (delay from S-IVB cutoff) and fixed SPS burn duration and attitude. This would be an additional procedure to learn and train for but would be much less costly than reshaping the launch trajectory.

Preliminary studies have indicated that entry g's could be reduced by 1 or 2 g's by optimizing delay time, burn time, and burn attitude. A burn attitude survey in the vicinity of a high g abort was investigated and is shown on figure 16. This study showed that an optimum burn attitude of pitching along the radius vector would reduce g's and increase free fall the most. Note that the scribe on the window (31.7° between the line of sight to the horizon and the spacecraft's X-body axis) is a less desirable attitude. Also, the attitudes using the horizon in the spacecraft's window are not optimum. Unfortunately, the villain in this type procedure was the current constraint of a 125-second delay time from booster cutoff to SPS burn ignition. As can be seen from figure 17, the free-fall limit (t_{ff} = 100 seconds to 300 000-ft altitude) is violated for a 27-second burn and g's were reduced from 16.1 to 15.1. Also shown are other delay times and it can be seen that the delay time corresponding to the time when free fall is no longer violated appears to be the optimum delay time to reduce g's for this case. Therefore, a shorter sequence (t_d < 100 seconds) would enable a longer burn, thus reducing g's more. Also, less delay would allow more flexibility in burn attitude.

Reducing the L/D would result in longer spacecraft burns and further optimization to decrease entry g's. A precision maneuver could be helpful to reduce g's a small amount. However, a booster failure in the high g regime would result in a mandatory SPS burn and any failure in performing this burn would result in excessive g's. Therefore, due to the mandatory requirement to use the SPS, it is not a recommended operational procedure for the first manned mission but could be employed for future missions.

Use the Maximum LV Dispersion Envelope and Fly the High g Region

The final proposal is to use the maximum launch vehicle dispersion envelope as an abort guide to fly through the high g region ($g > 16$). This procedure would require MSFC to construct a dispersion envelope which stipulates launch vehicle capability to achieve an orbit with at least a 75-n. mi. perigee altitude. The envelope (fig. 18) would be used to assess the launch vehicle trajectory and an evaluation of the launch vehicle systems would be made before making a commitment to fly through the high g region (similar to GO/NO GO). If launch vehicle trajectory or systems are noncommittal, the mission would be aborted at a convenient time prior to exceeding 16 g. Once the commitment has been made, no abort action should be initiated in the high g region unless an inadvertent cutoff or an extremely deviated trajectory occurs within this region. For all other failures or deviations, abort action should be delayed until g's are reduced below 16. For the very remote cases of cutoffs inside the high g region, an emergency spacecraft procedure could be devised to reduce g's as shown above.

CONCLUSIONS

It has been shown that the current launch trajectory (120/150) is operationally unacceptable because excessive g's are inherent for some of the aborts. Four methods to eliminate this problem are being investigated:

1. Reshaping the launch profile around the high g region.

2. Raising the g limit to avoid the violation.

3. Using the spacecraft's SPS to burn out of the high g region should a failure occur.

4. Using the maximum launch vehicle dispersion envelope as the abort guide and fly through the high g region.

It is very optimistic that MSFC can reshape the launch trajectory to avoid the high g's and still maintain adequate performance to insert the CSM/S-IVB configuration into a 120/150-n. mi. orbit. Increasing the g limit from 16 to 18 would be the simplest method to relieve the problem, but it would subject the crew and spacecraft to higher entry loads. Further study needs to be done to justify the increase. Adding a new abort mode to reduce g's is advantageous because it is cheaper than sacrificing performance to reshape the boost trajectory. This procedure would be mandatory, which would be operationally undesirable, if the LV failed in a high g region. Using the maximum launch vehicle dispersion envelope to commit to flying through the high g region is the most practical solution. This method requires MSFC participation in generating the envelope, and a flight control procedural change in allowing flight in the regime where entry g's could exceed the abort limitation.

As indicated, the higher g's for this launch are contributed to the steeper launch profile and not decreasing L/D. The ever decreasing L/D tends to aggravate the problem and g's increase correspondingly. Unless one of the methods mentioned is acceptable, the current 120/150-n. mi. insertion orbit cannot be achieved under current operational control procedures.

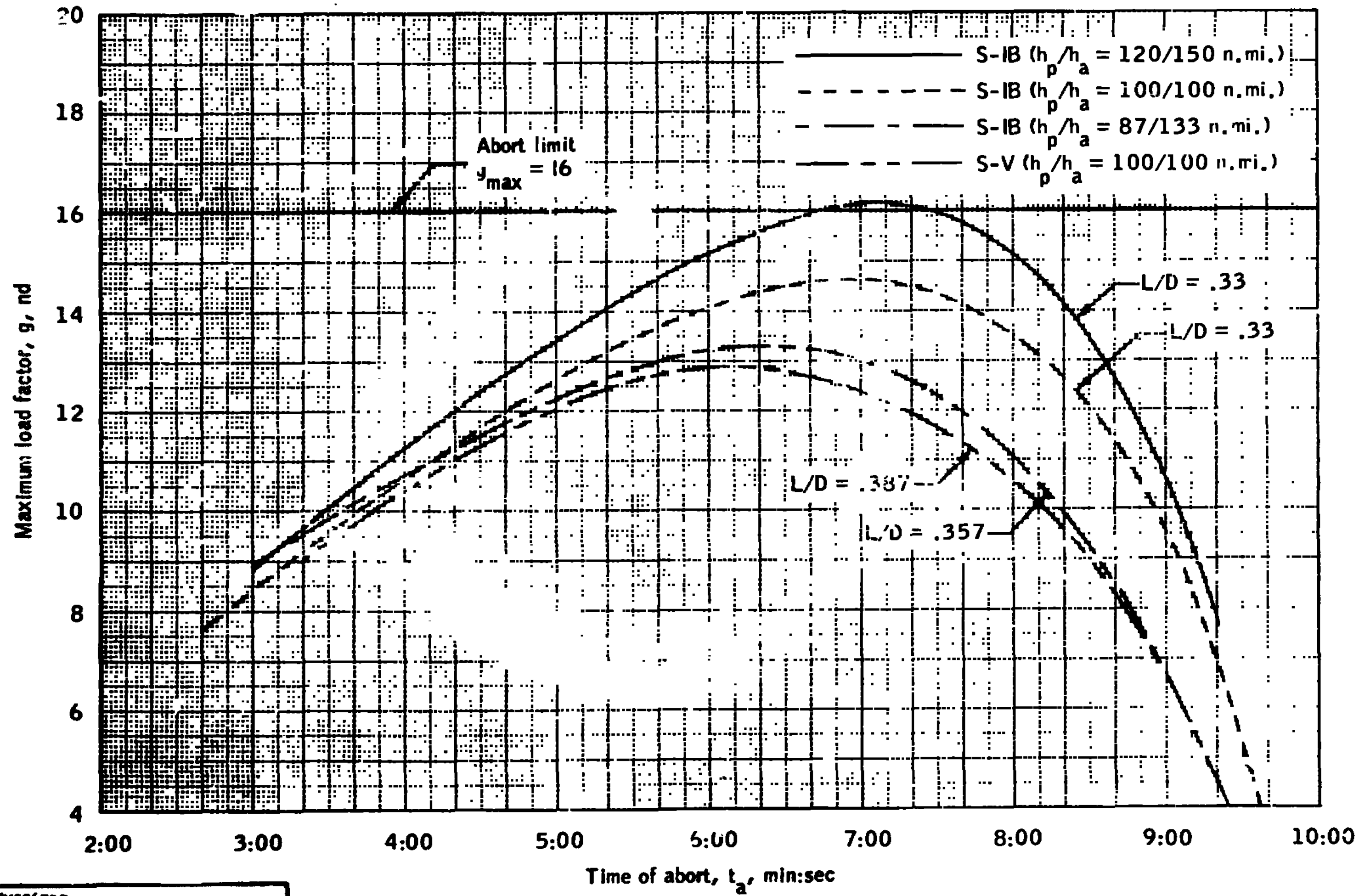

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Figure 1.- Maximum entry load factors versus abort time for different launch profiles.

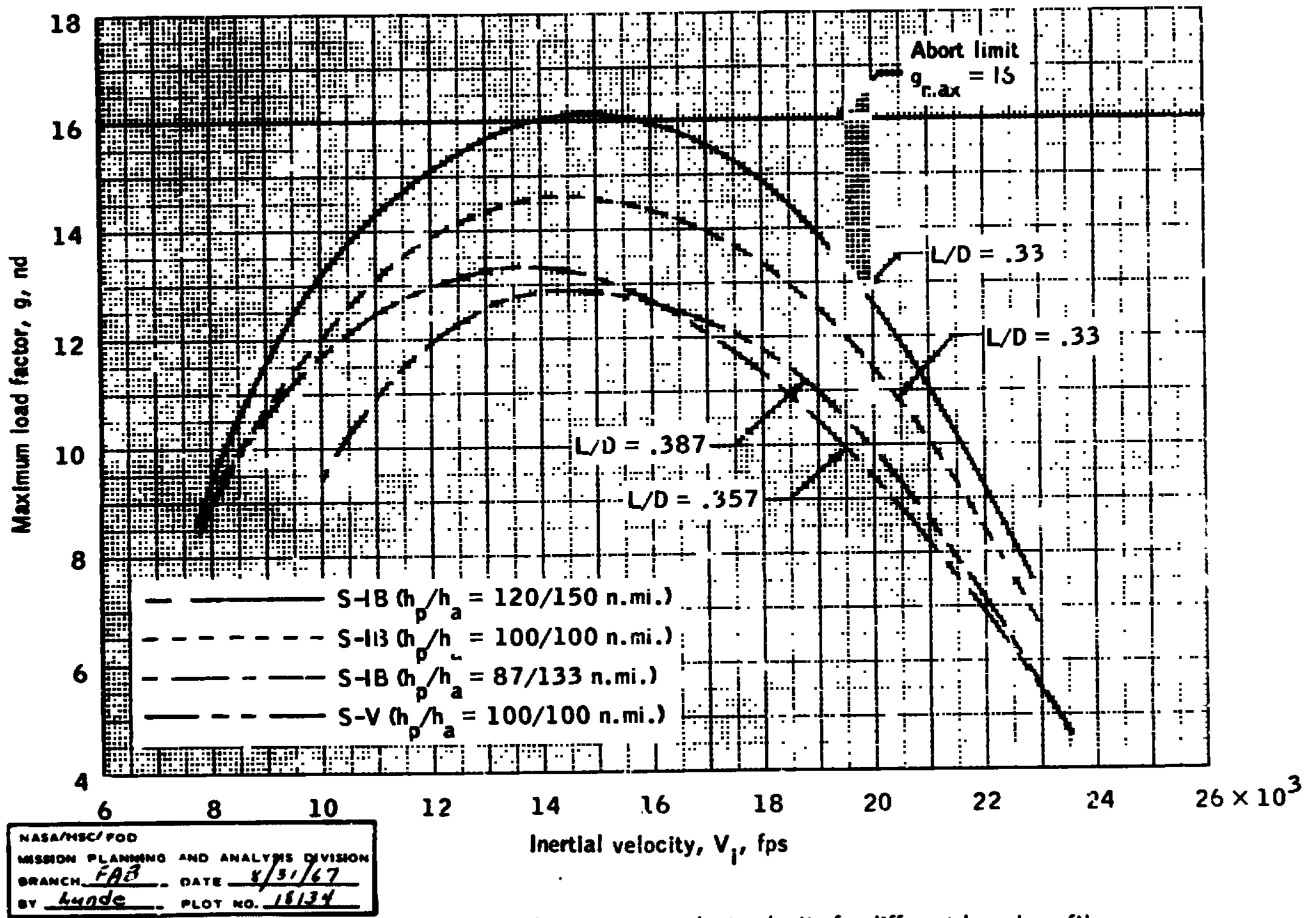

Figure 2.- Maximum entry load factors versus abort velocity for different launch profiles.

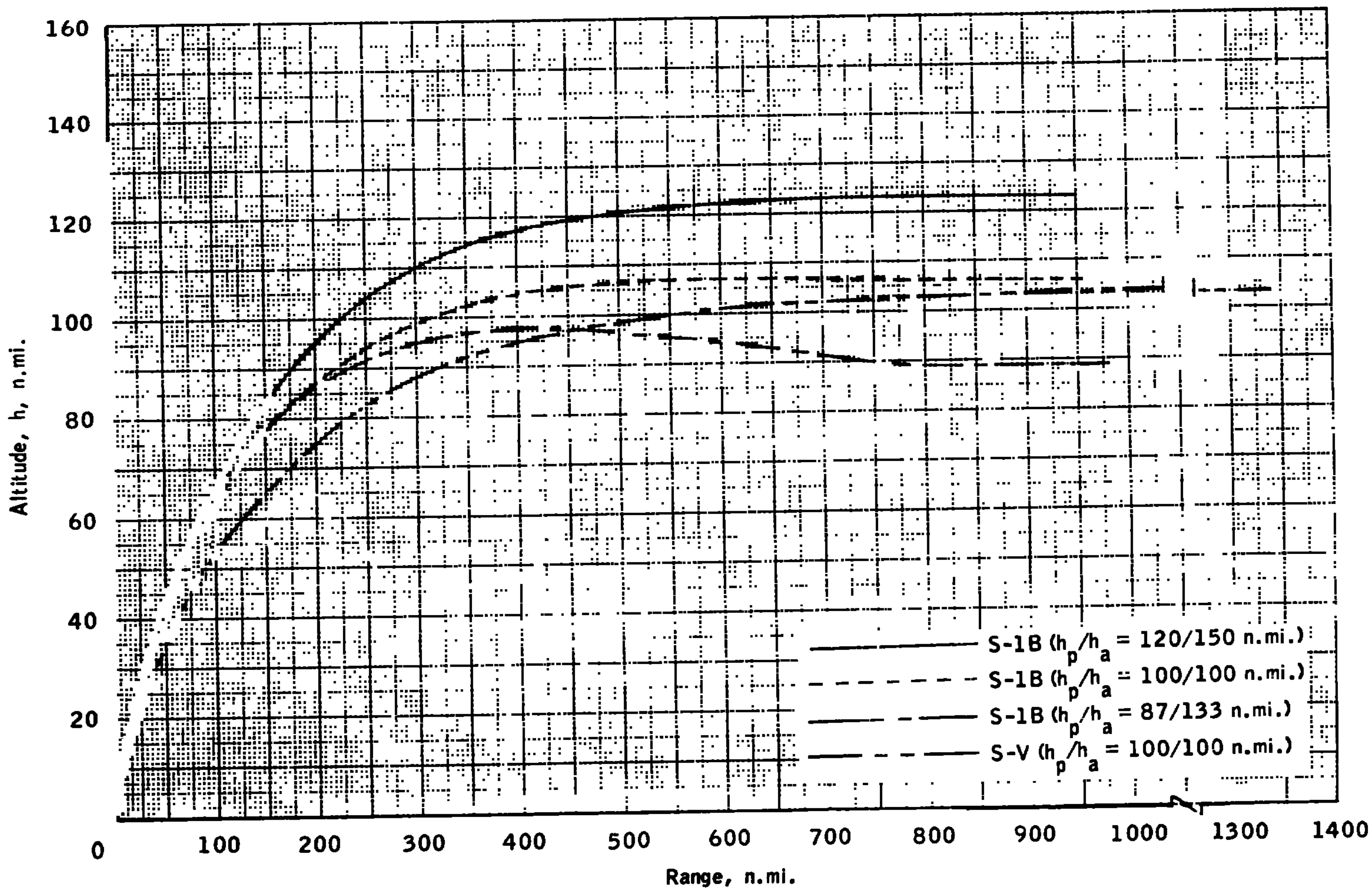

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Figure 3.- Comparison of launch altitude versus range profiles.

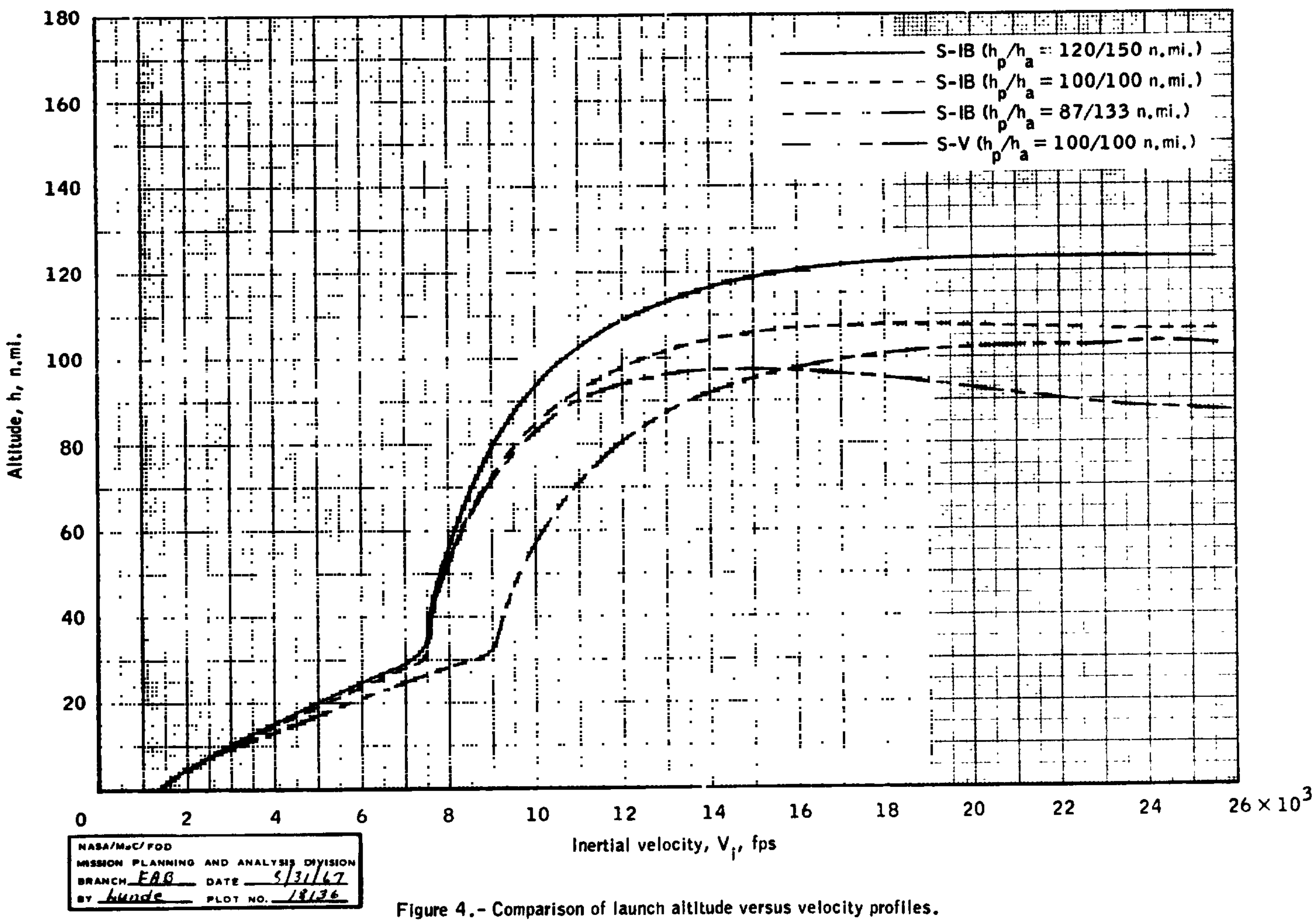

Figure 4.- Comparison of launch altitude versus velocity profiles.

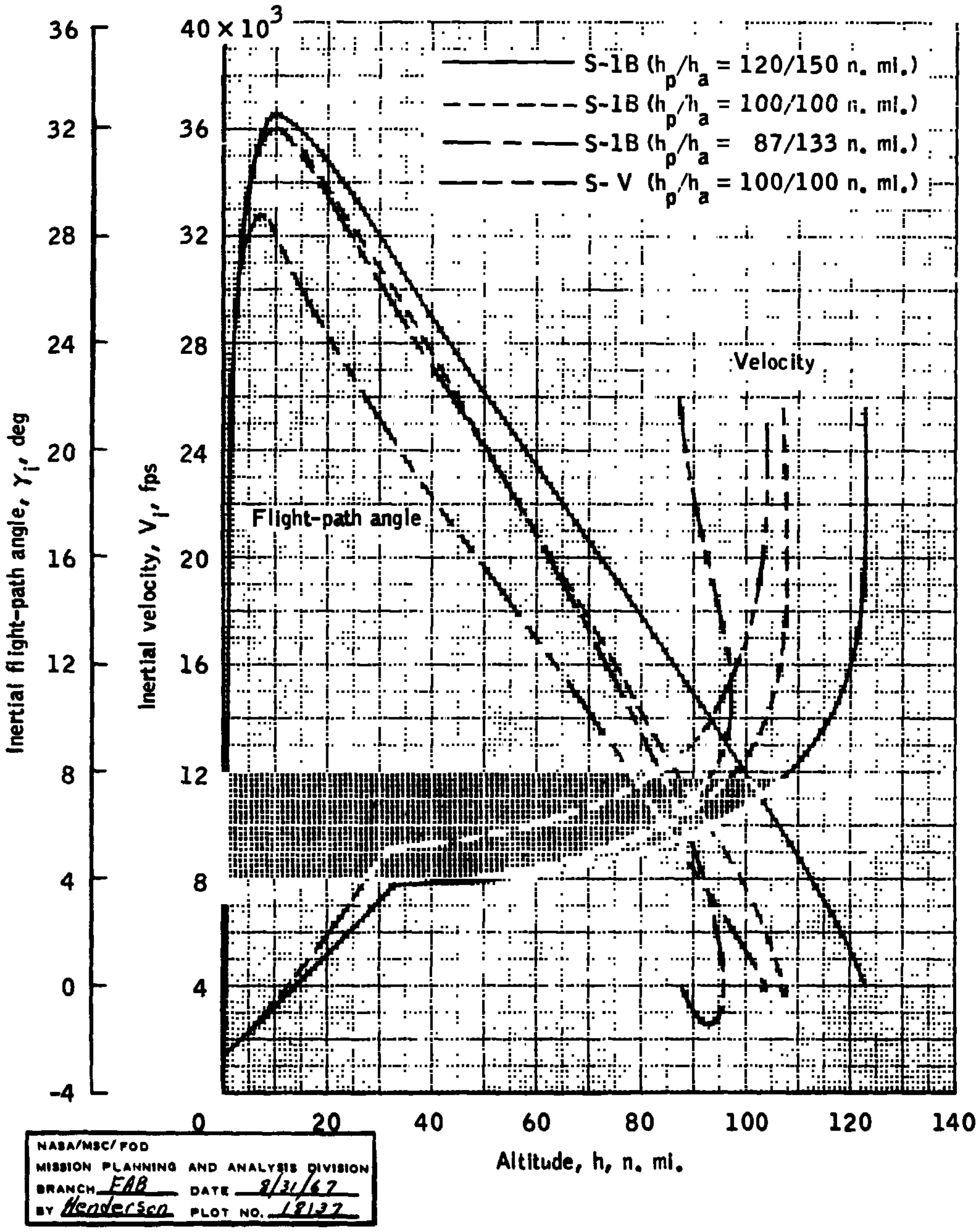

Figure 5.- Comparison of velocity and flight-path angle versus altitude profiles.

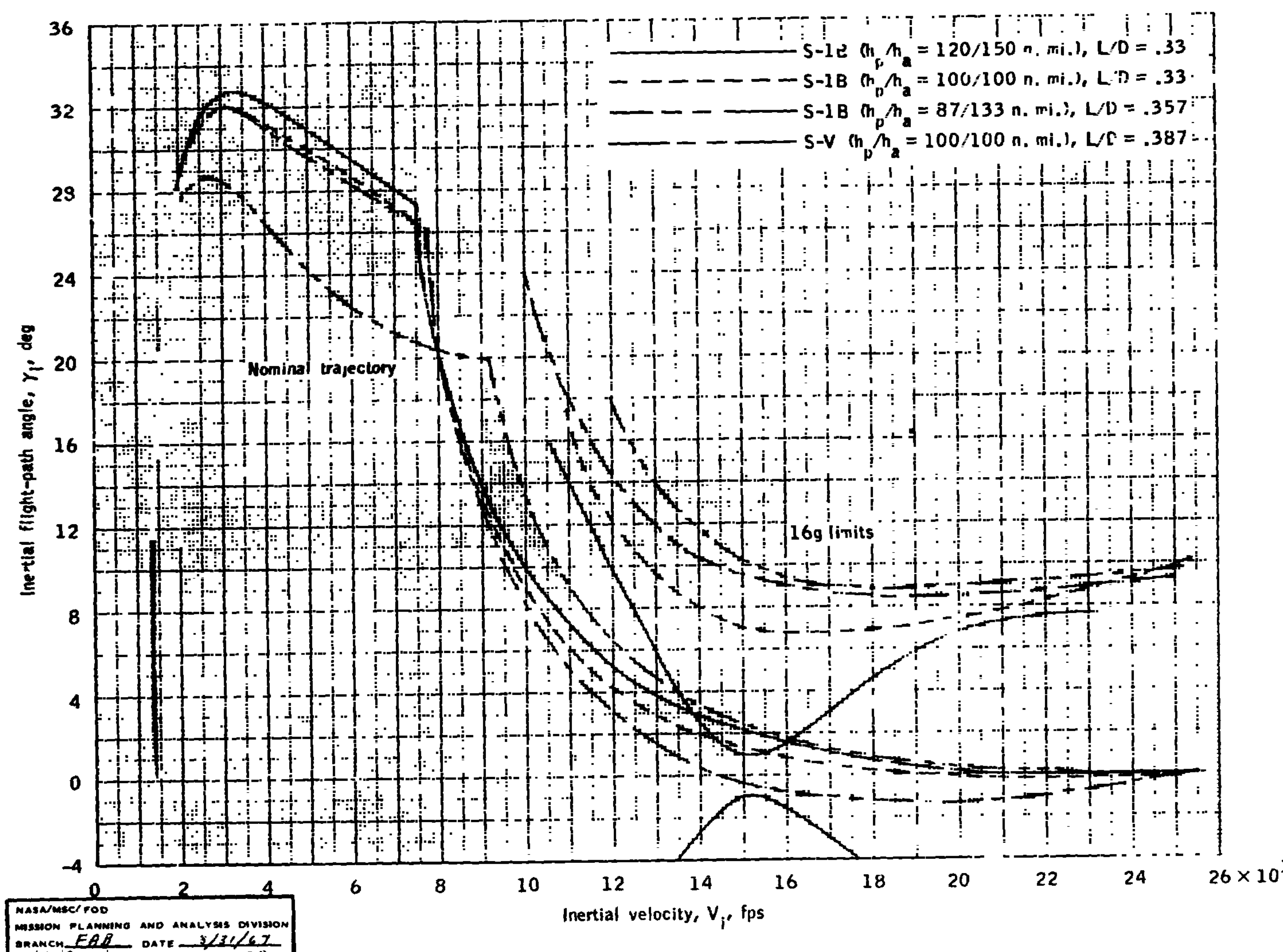

Figure 6.- Comparison of flight-path angle versus velocity profiles with associated abort limits.

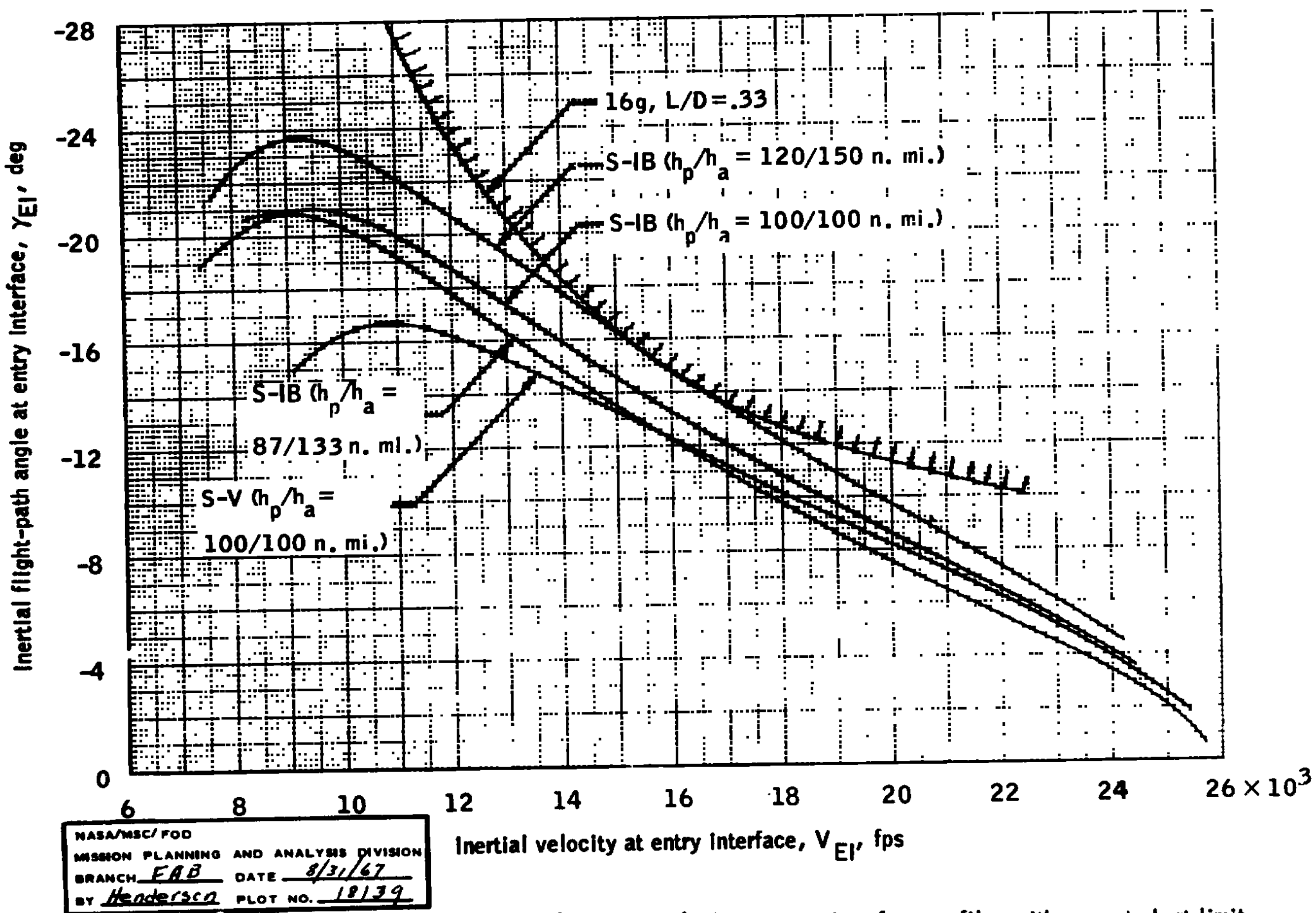

Figure 7.- Comparison of flight-path angle versus velocity at entry interface profiles with current abort limit.

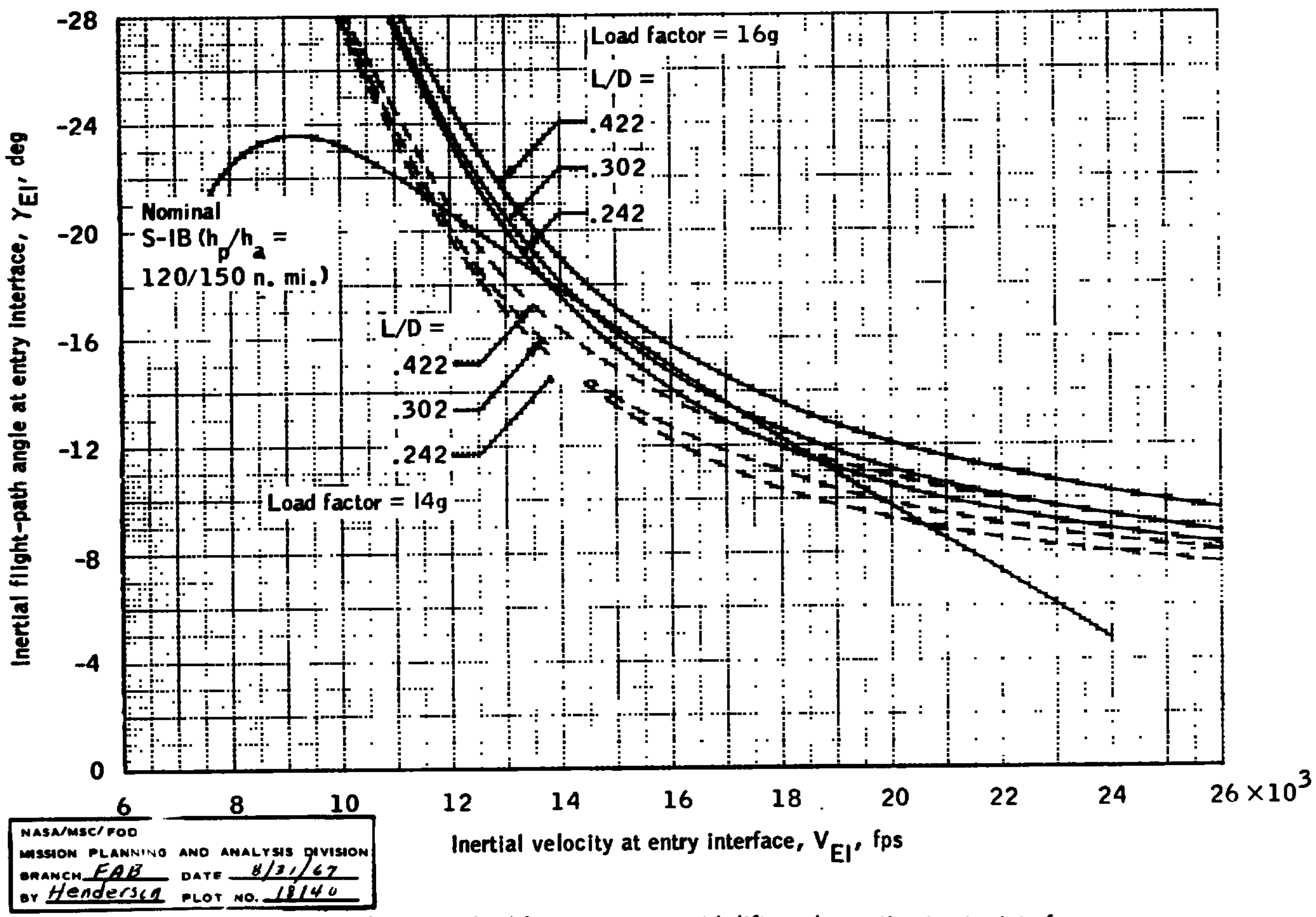

Figure 8.- Entry load factor variation with lift-to-drag ratio at entry interface.

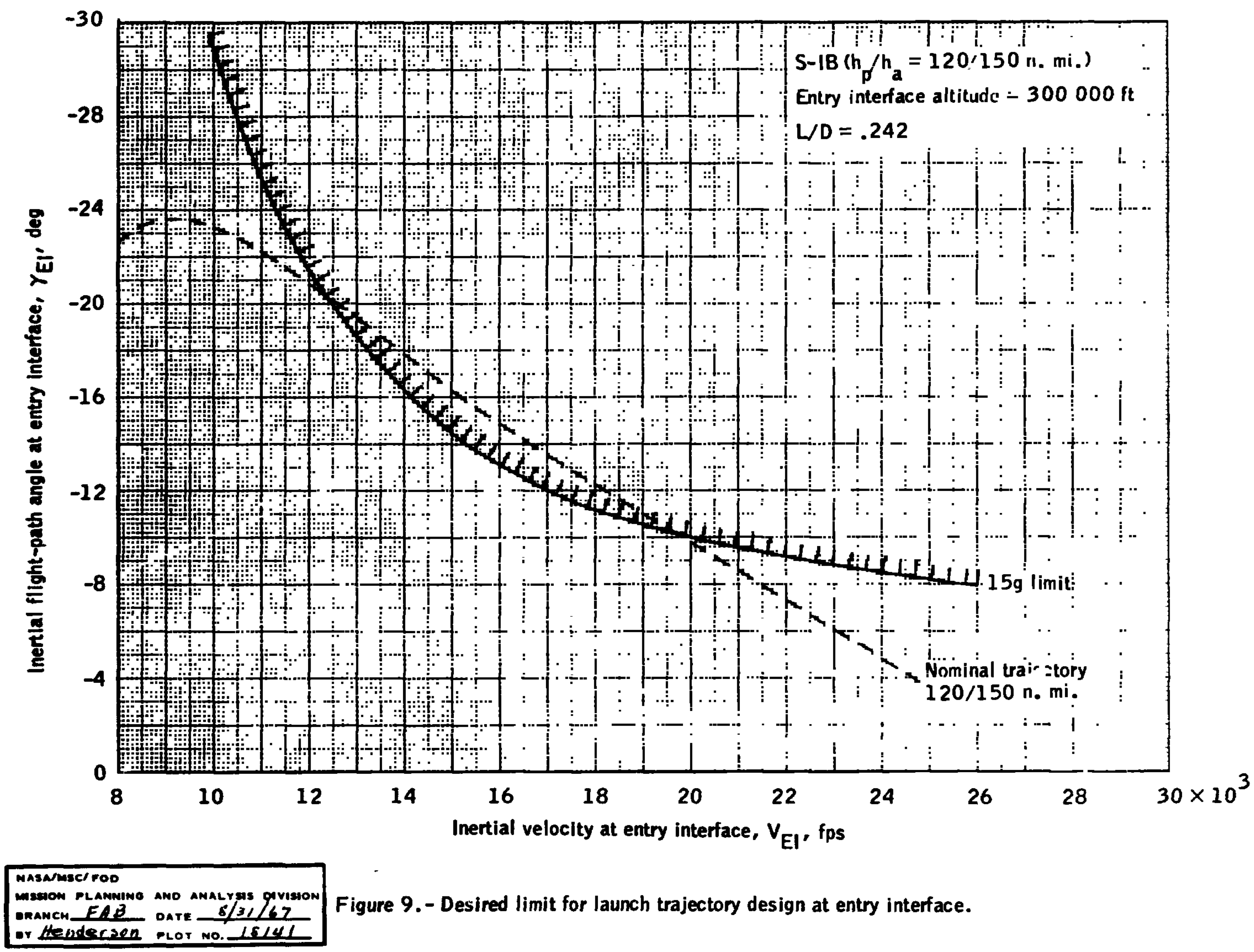

Figure 9.- Desired limit for launch trajectory design at entry interface.

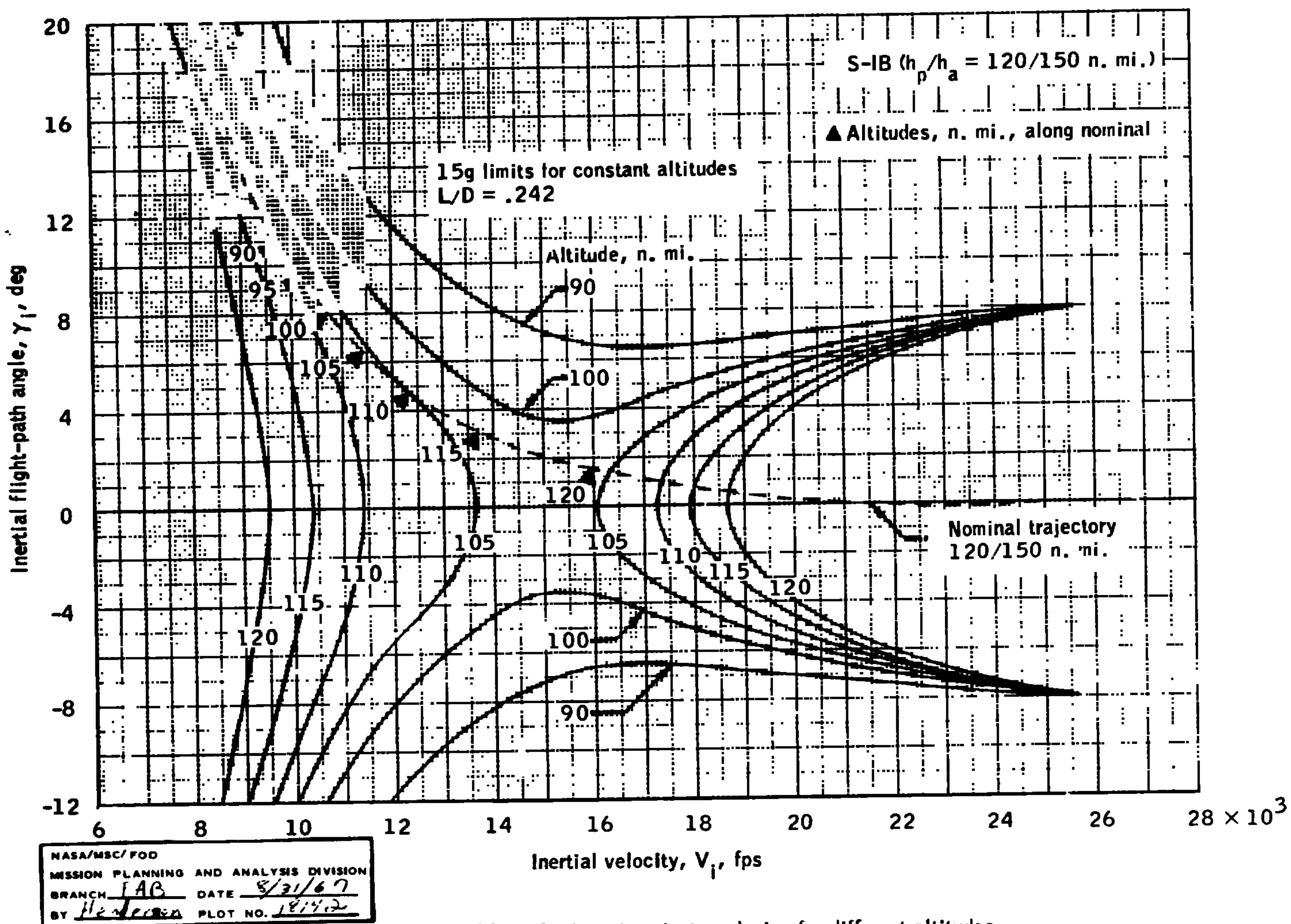

Figure 10.- Desired limit for launch trajectory design for different altitudes.

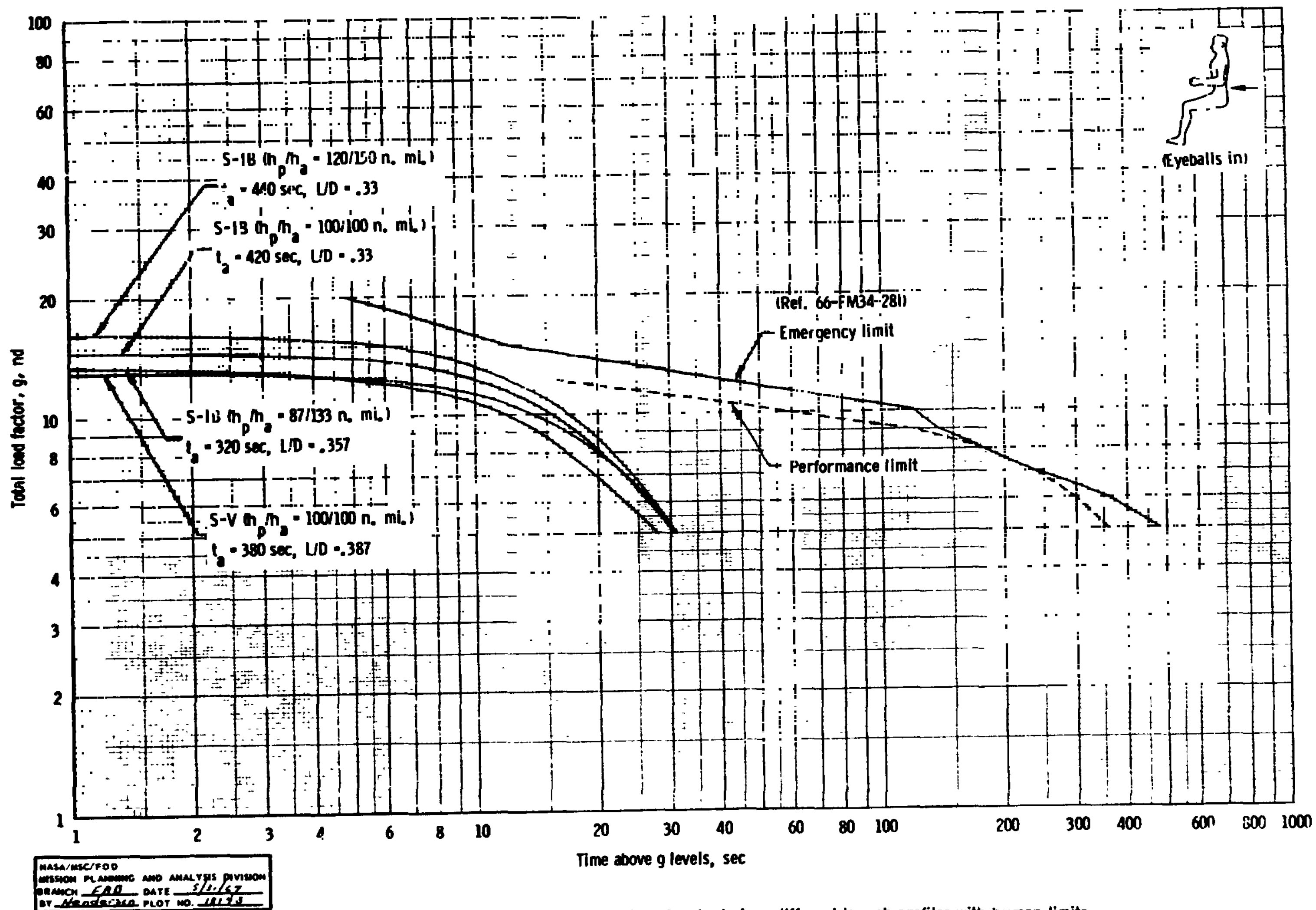

Figure 11. - Comparison of sustained accelerations for aborts from different launch profiles with human limits.

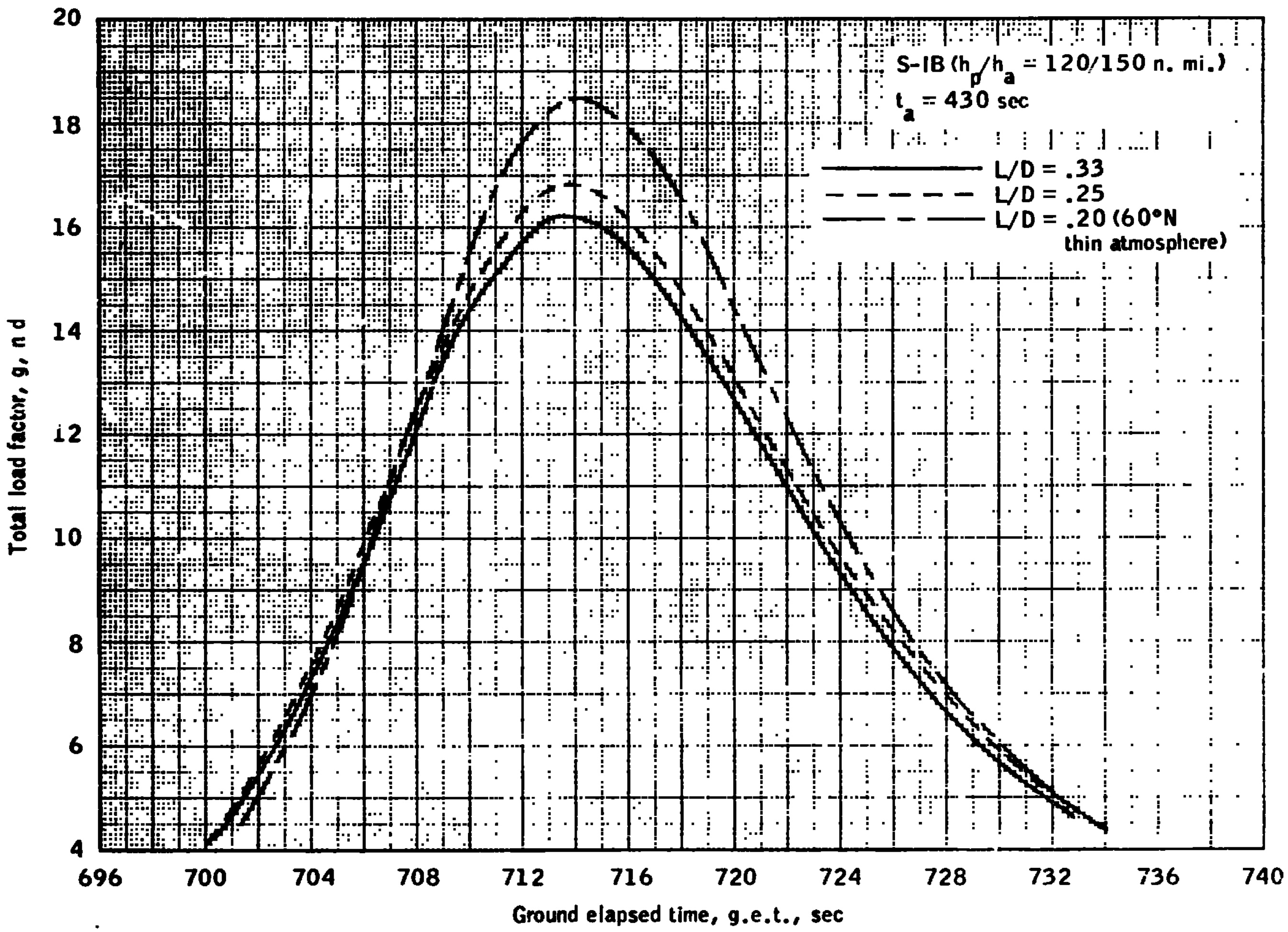

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Figure 12.- Load factor variation during entry with different L/D's.

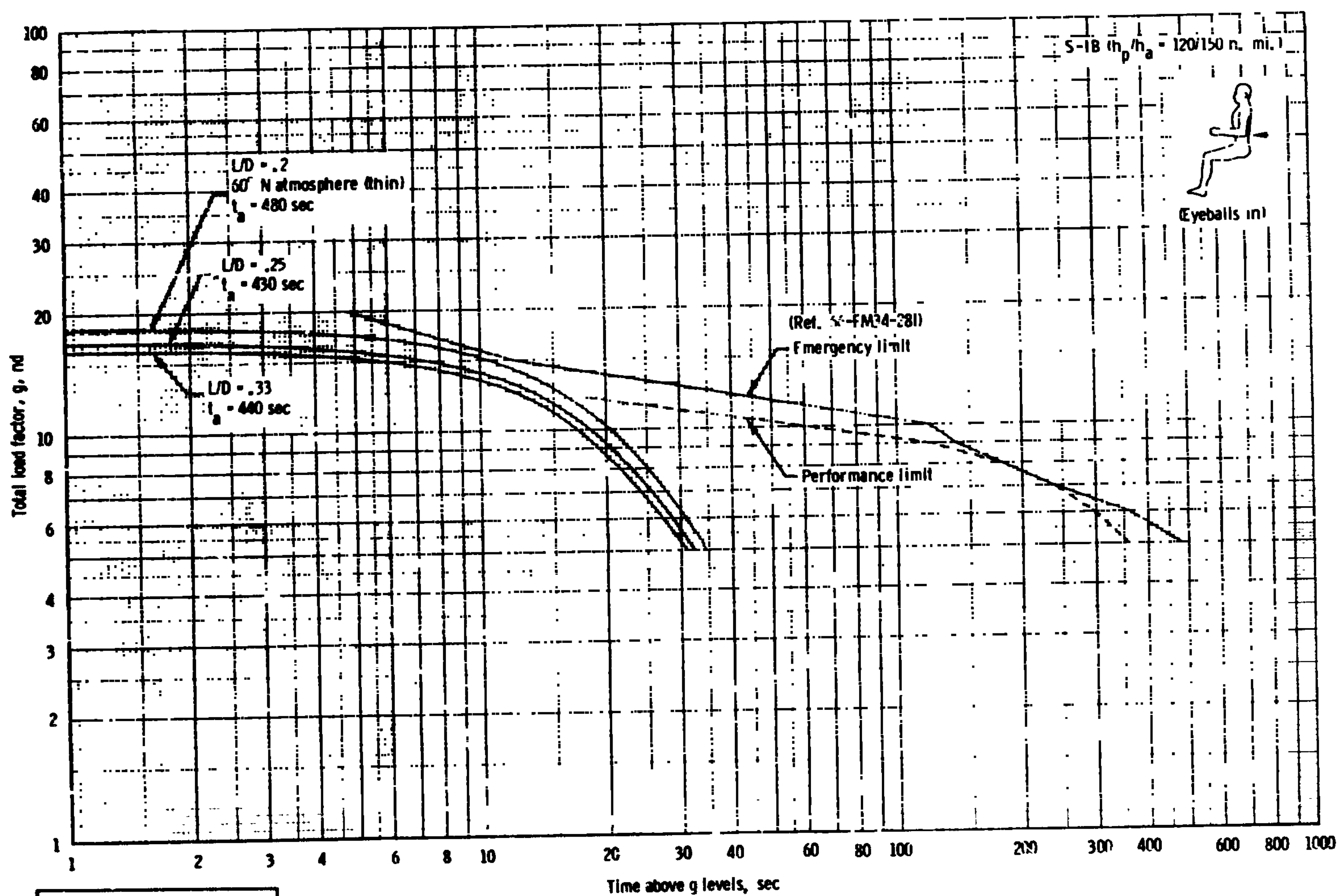

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Figure 13. - Comparison of sustained accelerations for aborts of different L/D's with human limits.

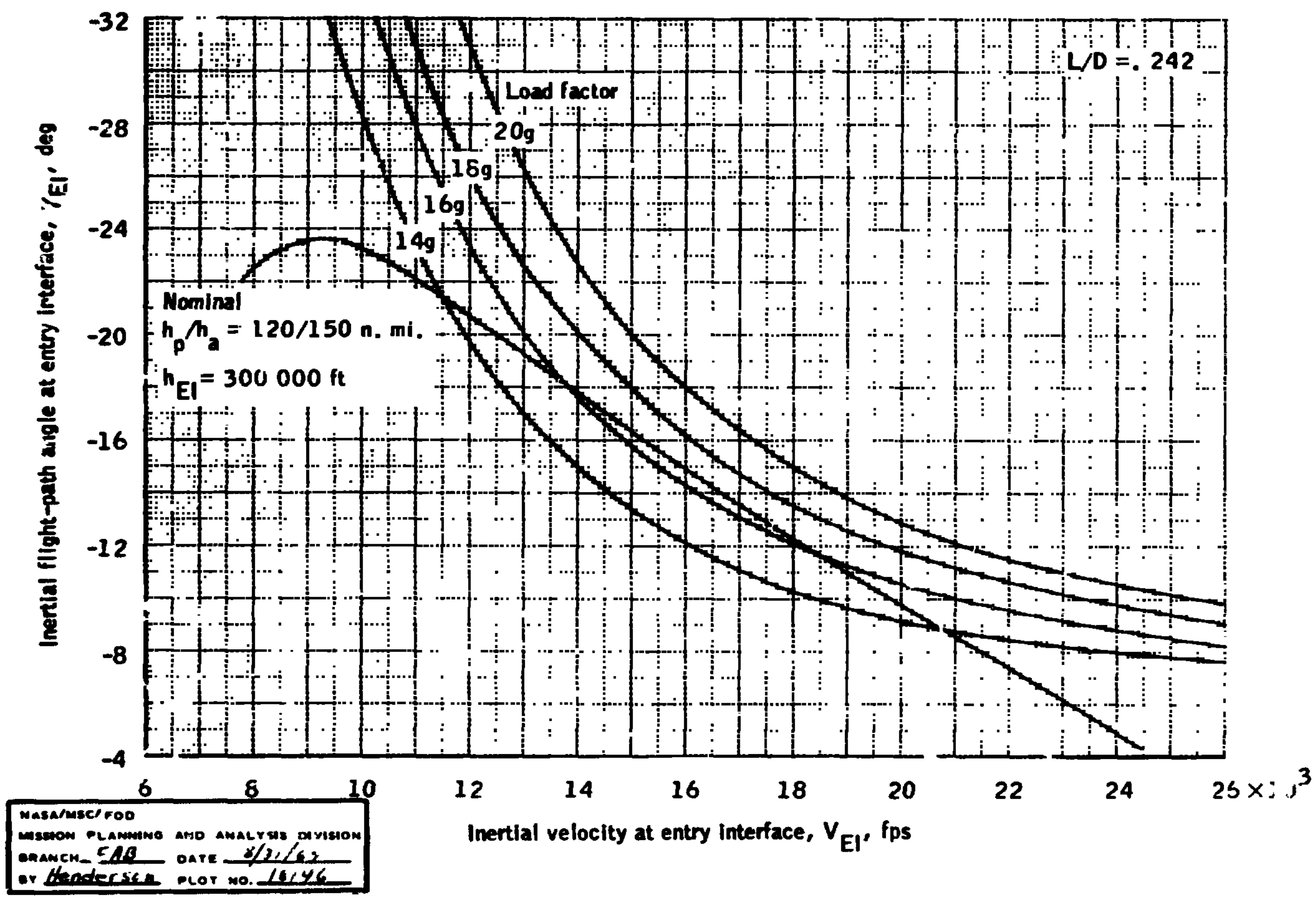

Figure 14.- Different entry load factor limits at entry interface for reduced L/D.

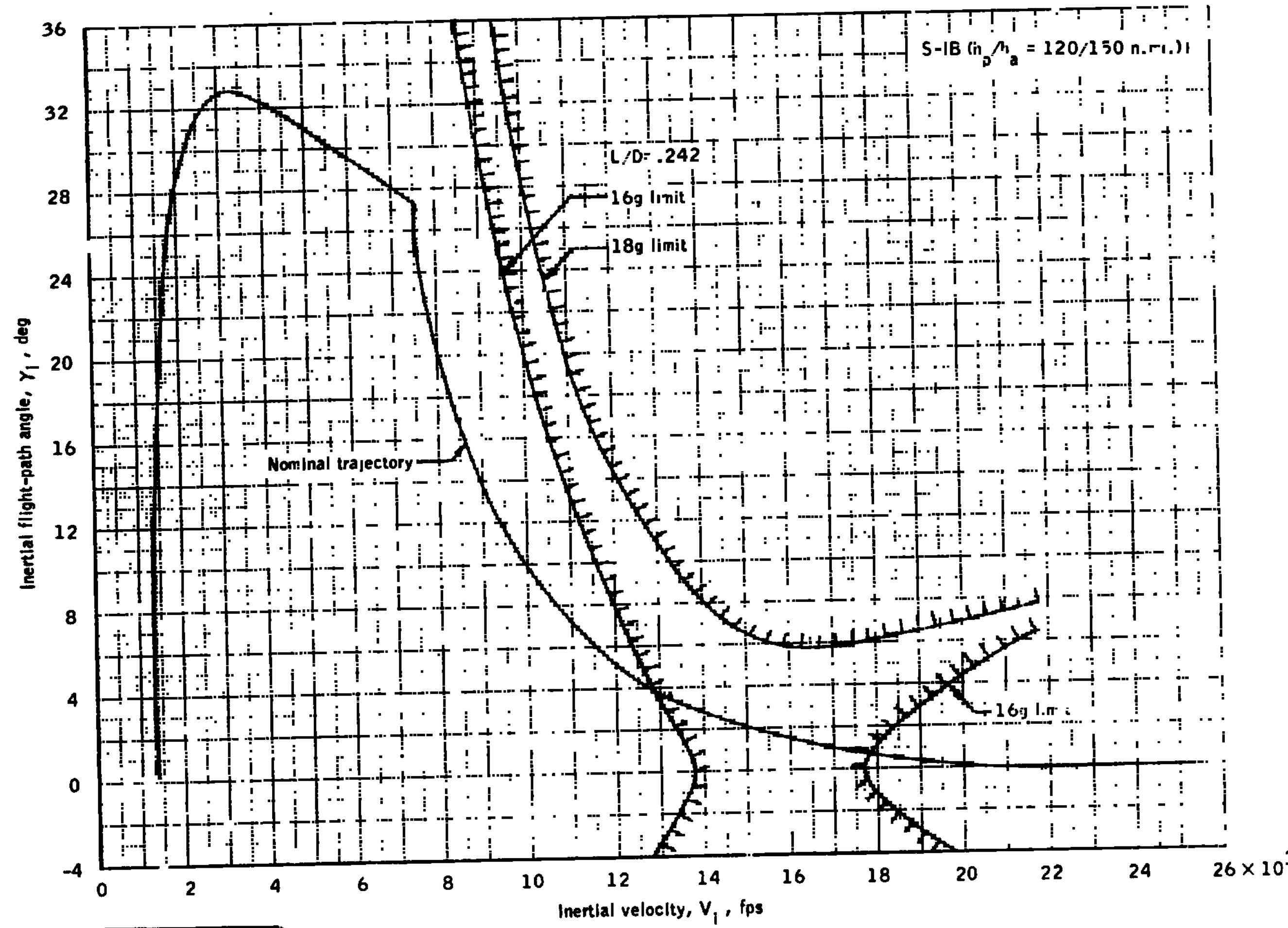

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Figure 15.- Different entry load factor limits for reduced L/D.

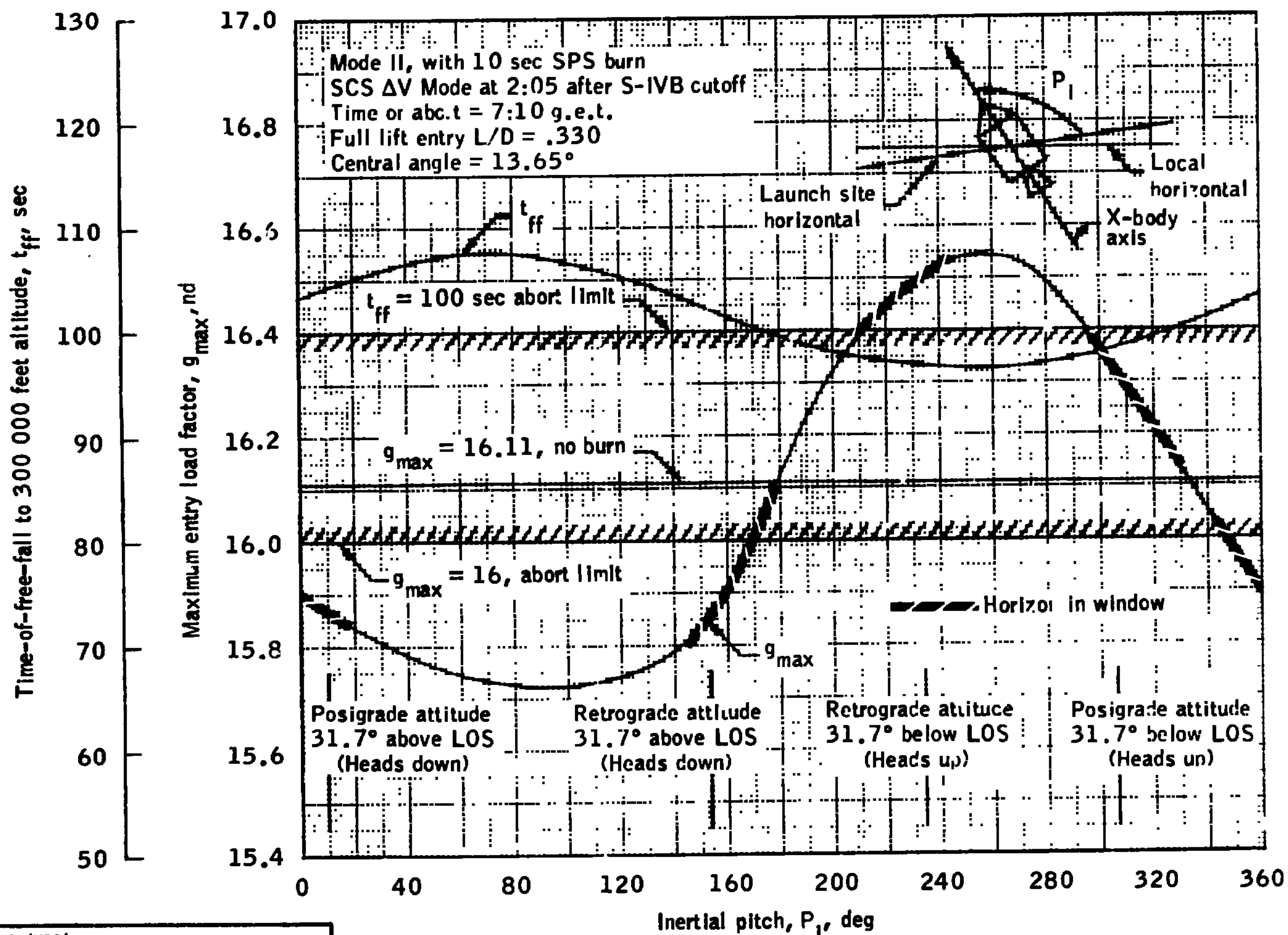

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Figure 16.- Effects of SPS burn attitude on maximum entry load factor and free-fall time.

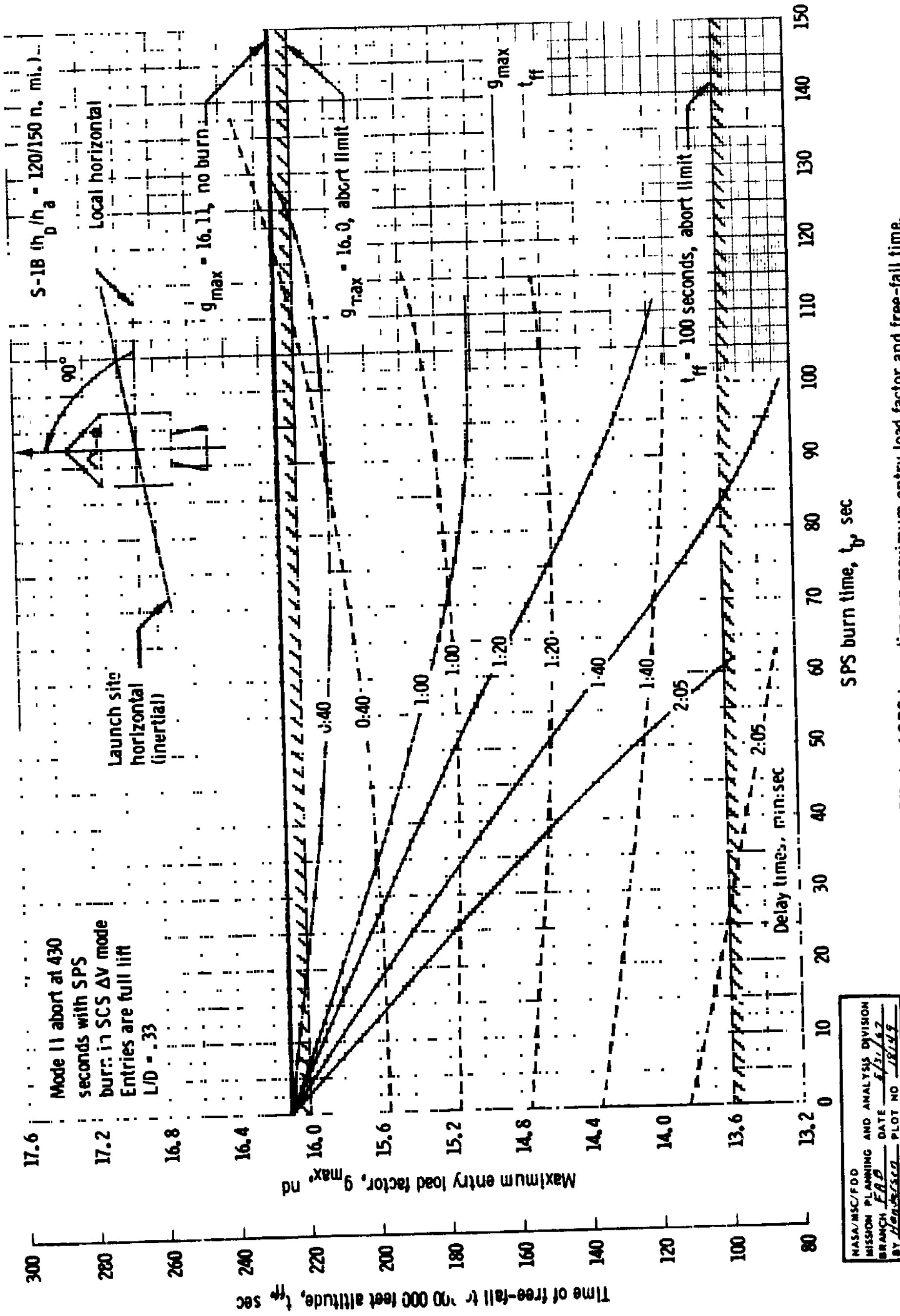

Figure 17. Effects of SPS burn time on maximum entry load factor and free-fall time.

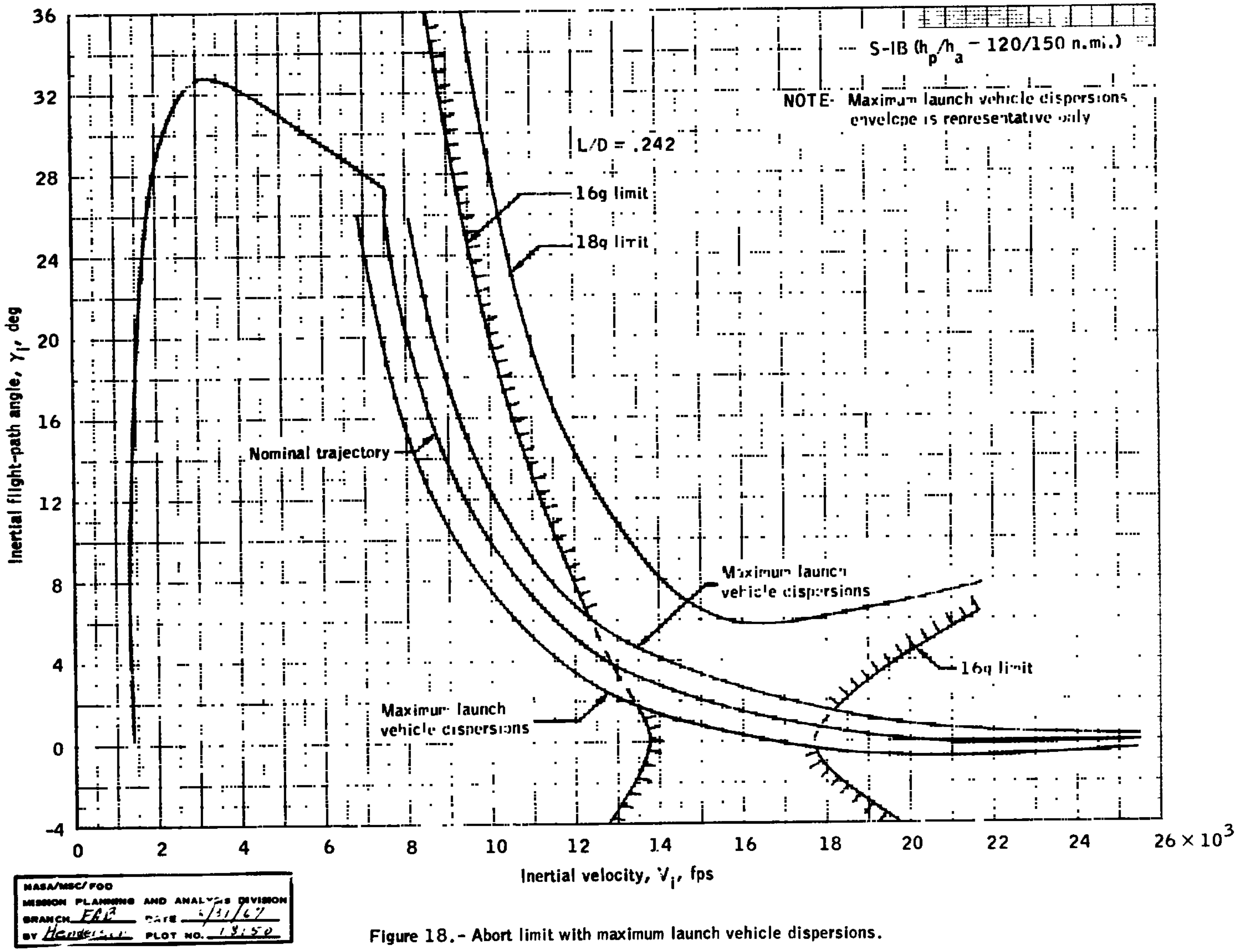

Figure 18.- Abort limit with maximum launch vehicle dispersions.

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2. North American Reports SID 64-1237 and SID 64-1345.

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