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HOUSTON ASTRONAUTICS [redacted]SION

SPACE SHUTTLE ENGINEERING AND OPERATIONS SUPPORT

CR151480

DESIGN NOTE NO. 1.4-4-30

OPTIMIZATION OF THE SPACE SHUTTLE ENTRY GUIDANCE LATERAL DEADBAND, MINIMUM BANK ANGLE LOGIC

MISSION PLANNING, MISSION ANALYSIS, AND SOFTWARE FORMULATION

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Prepared by: P. B. Bump
P. B. Bump
Associate Engineer
488-5660, Ext. 270

Approved by: J. M. Hiott for
H. C. Kyle
Task Manager
488-5660, Ext. 270

Approved by: J. M. Hiott
J. M. Hiott
Integration Manager
Entry through Landing
488-5660, Ext. 270

Approved by: William W. Hinton Jr.
W. W. Hinton, Jr.
Technical Manager
Return and Abort Analysis
488-5660, Ext. 240

Approved by: W. E. Hayes
W. E. Hayes
Project Manager
Mission Planning, Mission Analysis, and Software Formulation
488-5660, Ext. 266

1.0 SUMMARY

This note presents the results of a study of the lateral deadband and minimum bank angle schedule used by the Analytic Drag Control (ADC) entry guidance system. The study investigates the lateral deadband limits and configuration and examines possible changes in the minimum bank angle schedule to improve crossrange control and drag acceleration control for entry. The study recommends a 12.5° lateral deadband to accommodate low L/D dispersions of up to 23%. The study also confirms the effective performance of the current 37°-20° minimum bank angle schedule. In addition, the study establishes the feasibility of decreasing the 37° bank angle limit in conjunction with the use of the 12.5° deadband.

2.0 INTRODUCTION

The lateral deadband and minimum bank angle schedule are designed to enable the orbiter to achieve crossrange control and simultaneously to maintain the nominal drag acceleration reference profile. The limits of the lateral deadband become effective when the difference between the orbiter heading and the heading to the Terminal Area Energy Management Heading Alignment Cylinder (TAEM HAC) exceeds the magnitude of the deadband and the current bank direction is increasing the heading error. In this case, a roll reversal is commanded to nullify the heading error and return the orbiter heading within the deadband. The minimum bank angle schedule is employed when crossranging becomes a priority over drag control. In this situation, the schedule limits the minimum commanded bank angle in order to fly the required crossrange.

3.0 DISCUSSION

To provide positive crossrange control and maintain the orbiter azimuth error within limits, a minimum bank angle command and a lateral deadband are used for entry. The logic implementing these computations is found in the entry guidance subroutine (CONGID-Reference 1) in the Space Vehicle Dynamics Simulation program (SVDS-Reference 2).

A minimum bank angle command is established through the maximum vertical L/D limit, LMN. Initially, LMN is defined as

LMN = ALMN2

DZSGN, the sign of the rate of change in the azimuth error (DELAZ), is then computed by

DZSGN = ABS(DELAZ)-ABS(DZOLD)

where DZOLD is the previous value of DELAZ. If DZSGN is negative, the azimuth error is decreasing; if DZSGN is positive, the azimuth error is increasing. If the azimuth error is increasing and is within YLMIN of the deadband limit (YL), LMN is limited to ALMN1. If the azimuth error is decreasing and is within YLMN2 of the deadband limit, LMN is limited to ALMN1. That is,

if DZSGN > 0. and if YL-YLMIN < ABS(DELAZ),

LMN = ALMN1;

if DZSGN < 0. and if YL-YLMN2 < ABS(DELAZ),

LMN = ALMN1.

Furthermore, if the relative velocity (VE) is greater than VYLMAX LMN is limited to ALMN4; if VE is less than VELMN, LMN is limited to ALMN3.

The maximum vertical L/D command is then computed by

$$LMN = LMN*XLOD$$

where XLOD is the current L/D ratio.

The azimuth error relative to bank direction, DLZRL, is calculated by the equation

$$DLZRL = DELAZ*RK2ROL$$

where RK2ROL is ± 1 and defines the roll direction. If DLZRL is negative, the azimuth error is being nullified; if DLZRL is positive, the azimuth error is not being nullified.

If the vertical L/D (LODV) required to converge and maintain the drag profile is greater than LMN, then crossranging has a higher priority than maintaining the desired drag profile. If the vertical L/D command for the drag profile control is less than the maximum vertical L/D command (LMN) or the roll direction is increasing the crossrange error, the azimuth error (DELAZ) is checked against the deadband limit, YL. In this case, if the heading error is larger than YL, the commanded roll direction is reversed by changing the sign of the roll direction indicator, RK2ROL. If the vertical L/D command for drag profile control is larger than LMN and if the roll direction is nullifying the crossrange error, the vertical L/D command (LODV) is set equal to LMN with the sign of LODV. This logic is implemented in the following manner:

if ABS(LODV) < LMN or DLZRL > 0,

and if DELAZ $\geq$ YL, then RK2ROL = -RK2ROL;

if the test fails, i.e.,

$$ABS(LODV) \geq LMN \text{ and } DLZRL \leq 0,$$

LODV is recalculated by

$$LODV = LMN * SIGN\ (1.0,\ LODV)$$

The current minimum bank angle schedule is shown in Figure 3.0-1.

The lateral deadband is defined by the equation

$$YL = CY0 + CY1 * VE$$

where YL is the deadband value, VE is relative velocity, and CY0 and CY1 are constants determining the deadband ramp configuration. The deadband is then limited so that

$$Y2 < YL < Y1$$

where Y1 and Y2 are the deadband limits. Figure 3.0-2 shows the nominal lateral deadband.

Values for the lateral logic constants are shown in the Appendix.

3.1 LATERAL DEADBAND STUDY

The primary criteria considered in the lateral deadband study were the number of roll reversals experienced during a nominal entry, the miss distance at TAEM interface, and the L/D dispersion capability. An increase in the number of roll reversals during an entry is undesirable because each roll reversal causes a deviation from the reference drag acceleration profile as well as costs additional Reaction Control System (RCS) fuel. The TAEM interface miss distance is considered in order that the vehicle will be in a position to fly a nominal TAEM phase. The L/D dispersion capability of the deadband

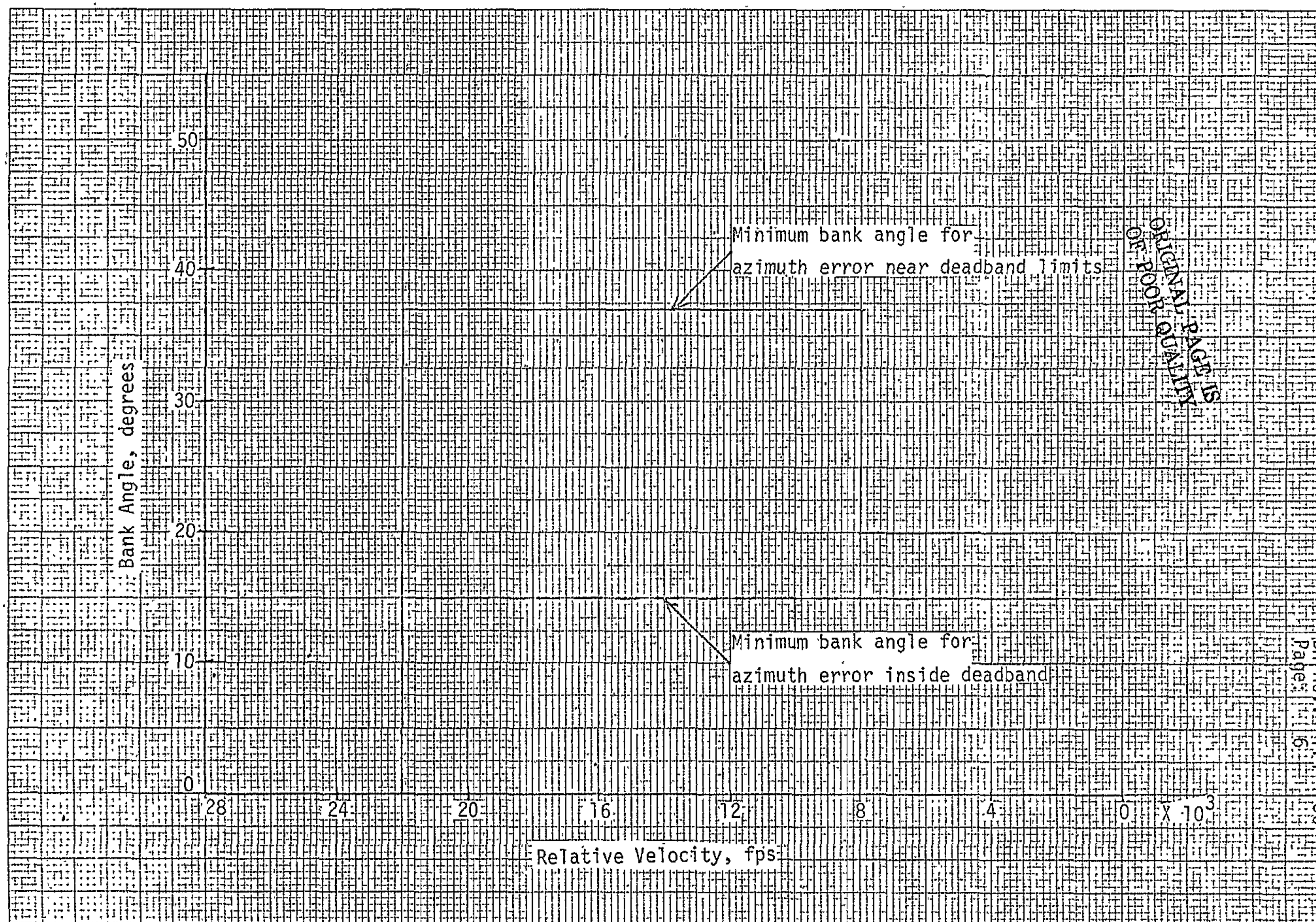

Fig. 3.0-1
Current Minimum Bank Angle Schedule

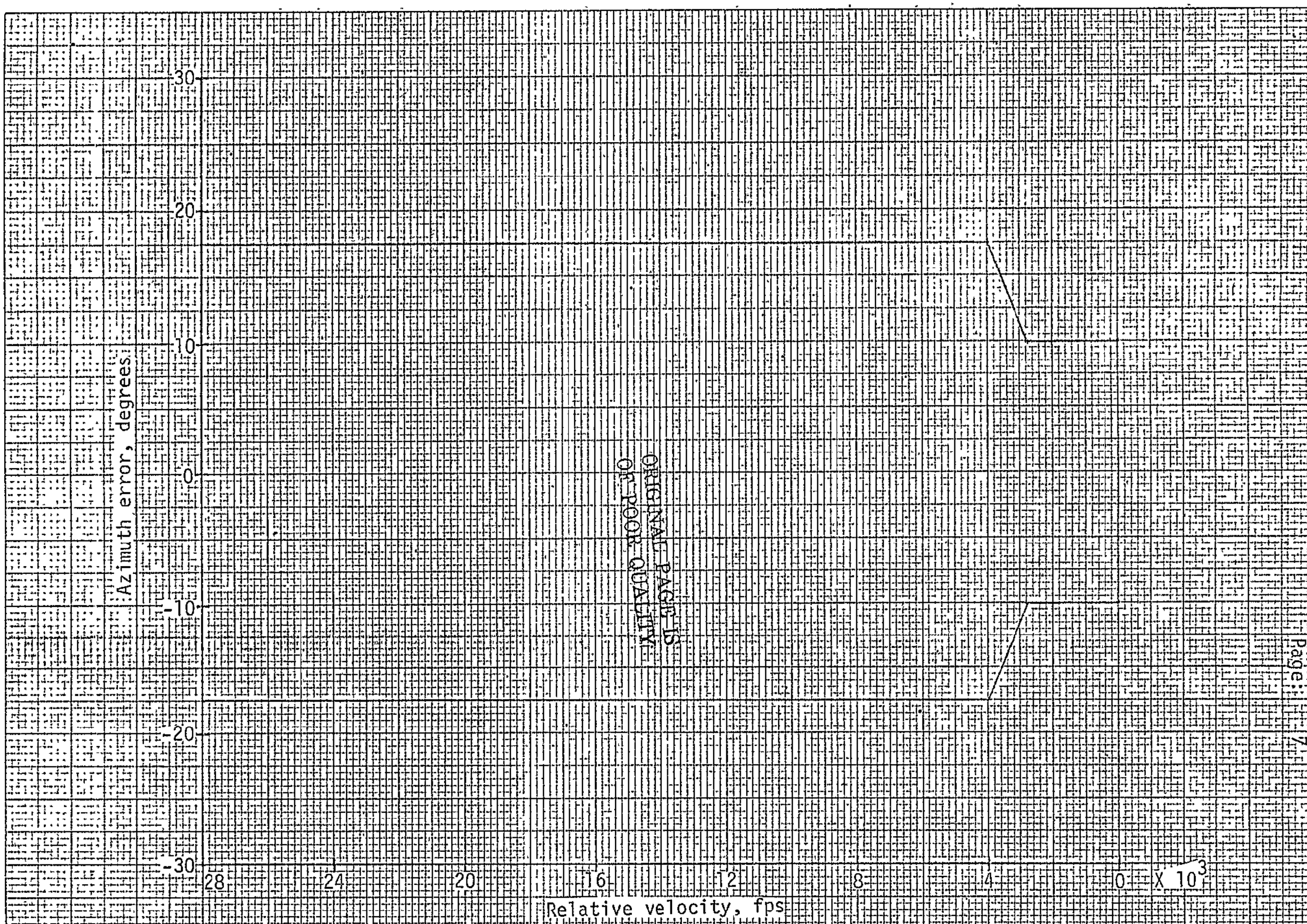

Fig. 3.0-2
Lateral Deadband

is necessary in order that situations involving low L/D may be safely accommodated.

The accompanying charts (Figures 3.1-1 - 3.1-7) show typical deadband variations and subsequent effects on the entry drag acceleration profile. As the deadband decreased in size, the number of roll reversals increased to a maximum of five in the 10° deadband case, as compared to three in the nominal 17.5° deadband case. Decreasing the deadband limits from the current 17.5° to 15° caused an additional roll reversal. As the deadband was increased in size, the TAEM miss distance became the primary factor of concern. The larger deadband limits allowed the orbiter to fly further away from the zero crossrange line than the nominal deadband case. In some of these cases, the orbiter failed to meet the TAEM miss distance criteria (±5 n.m.). Another result of the larger deadband limits was a deviation from the nominal drag acceleration profile. The larger deadband limits introduced a large crossrange component which effectively caused the orbiter to fly a greater total range to the target. The entry guidance lowered the reference drag acceleration profile to compensate for the increased range, resulting in undesirably higher backface temperatures.

The lateral deadband ramp from 17.5° to 10° in the low velocity region near TAEM interface was also examined. The slope and velocity anchor points of the ramp were varied by changing the values of CYO and CY1. The eight study cases considered are shown in Figures 3.1-8 - 3.1-15. The deadband ramp variations produced no significant effects on a nominal entry. There was an increase in the number

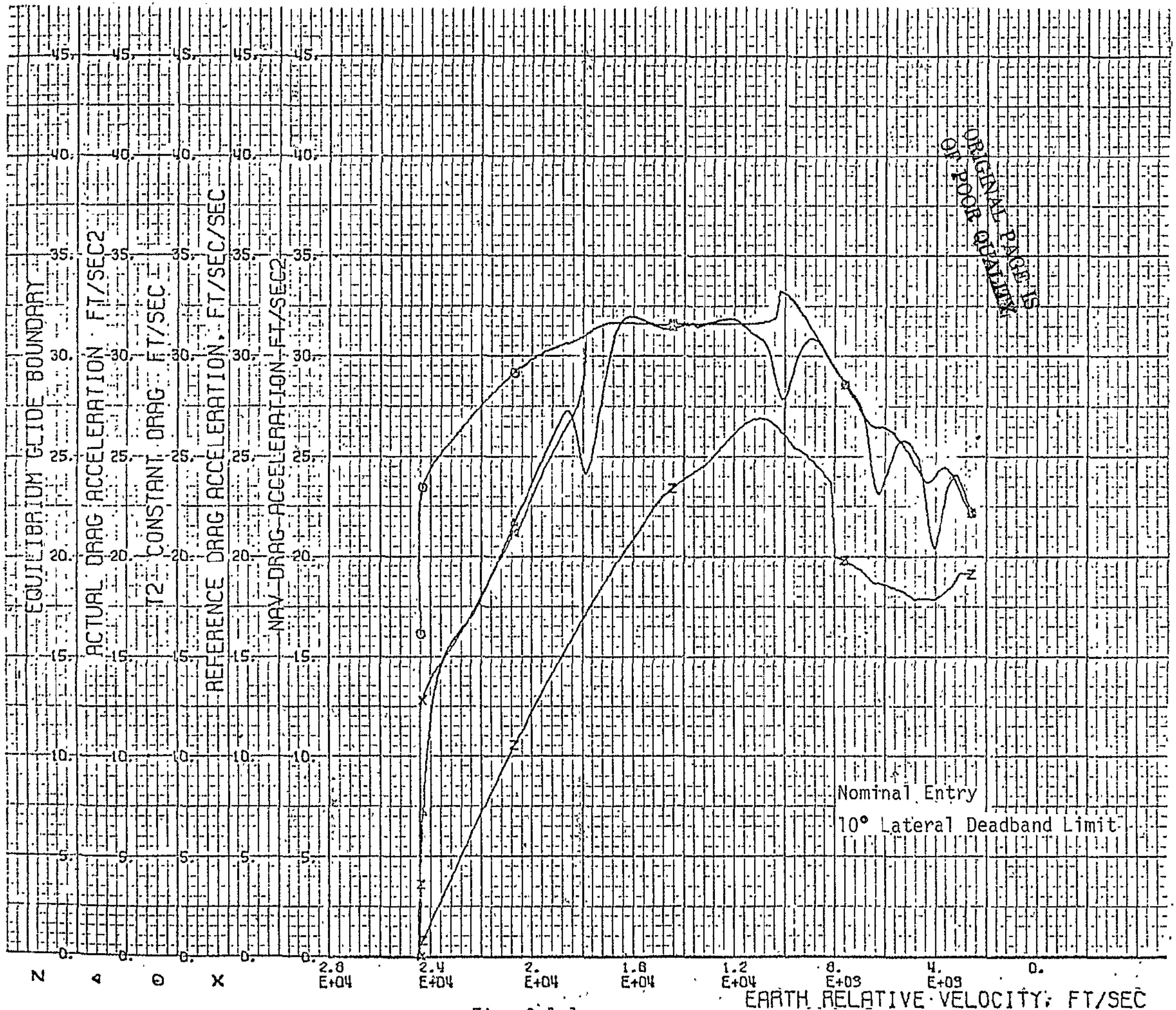

Fig. 3.1-1
Drag Acceleration Profile

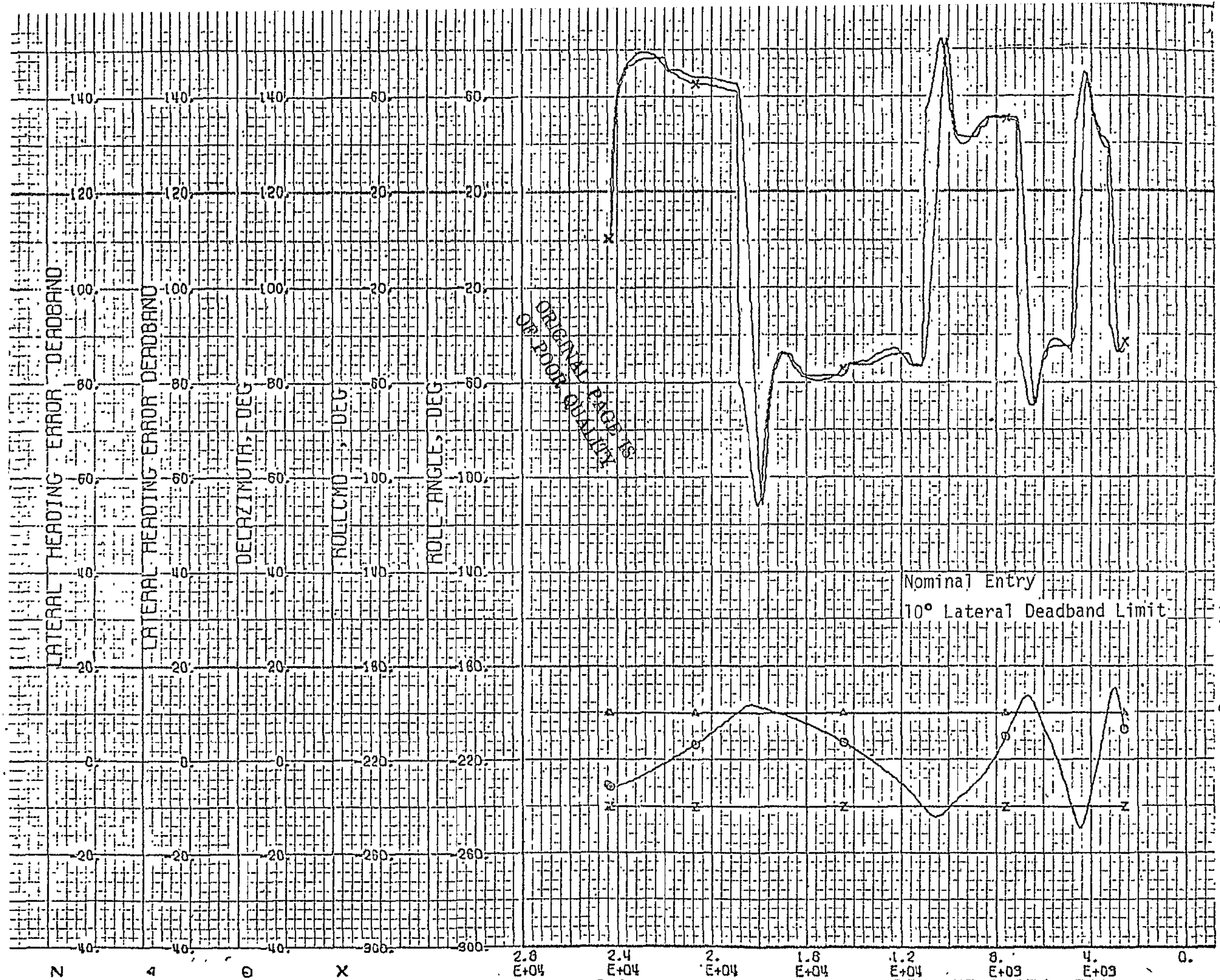

Fig. 3.1-2

Roll Angl... Azimuth Error

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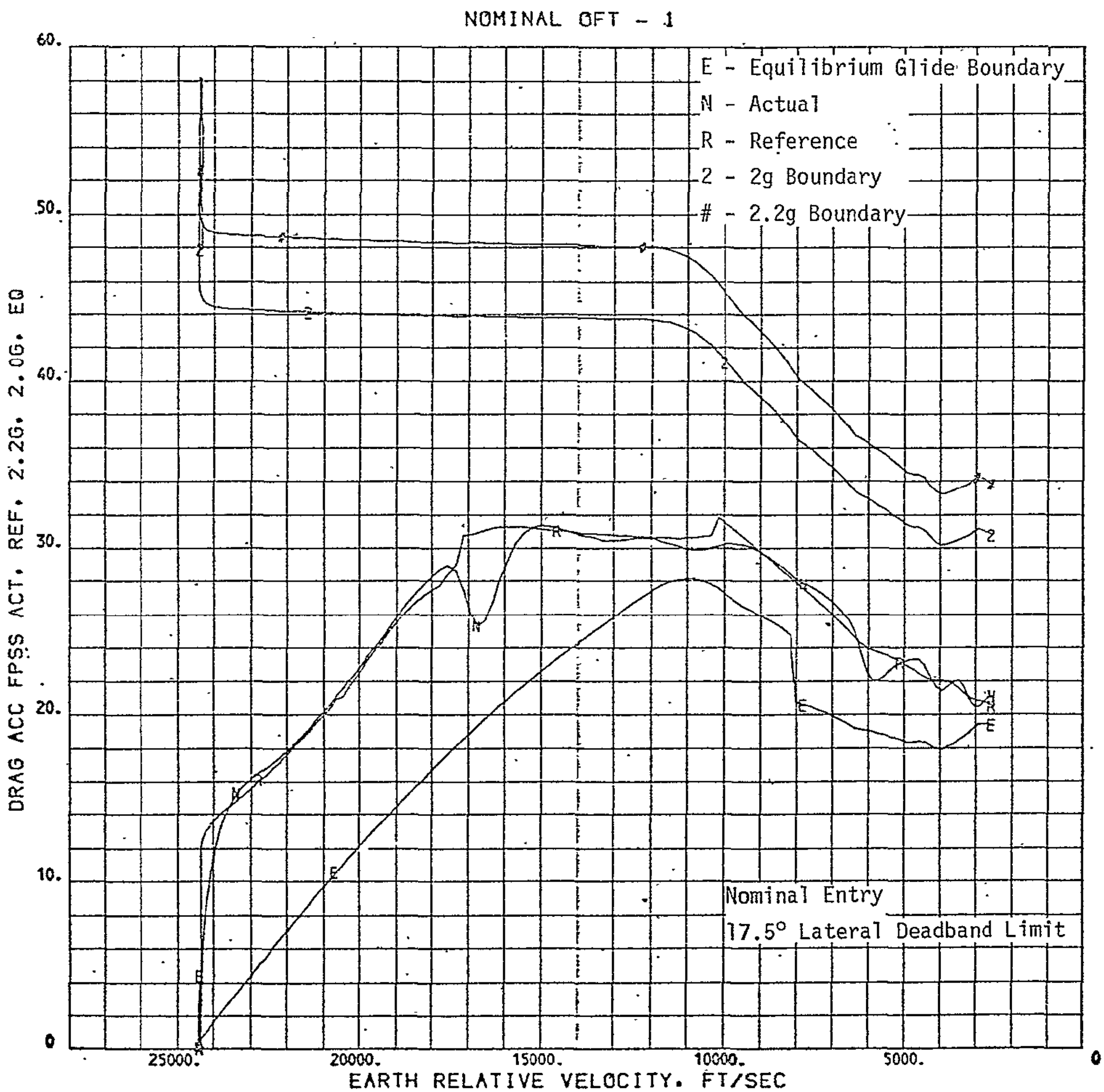

Fig. 3.1-3

Drag Acceleration Profile

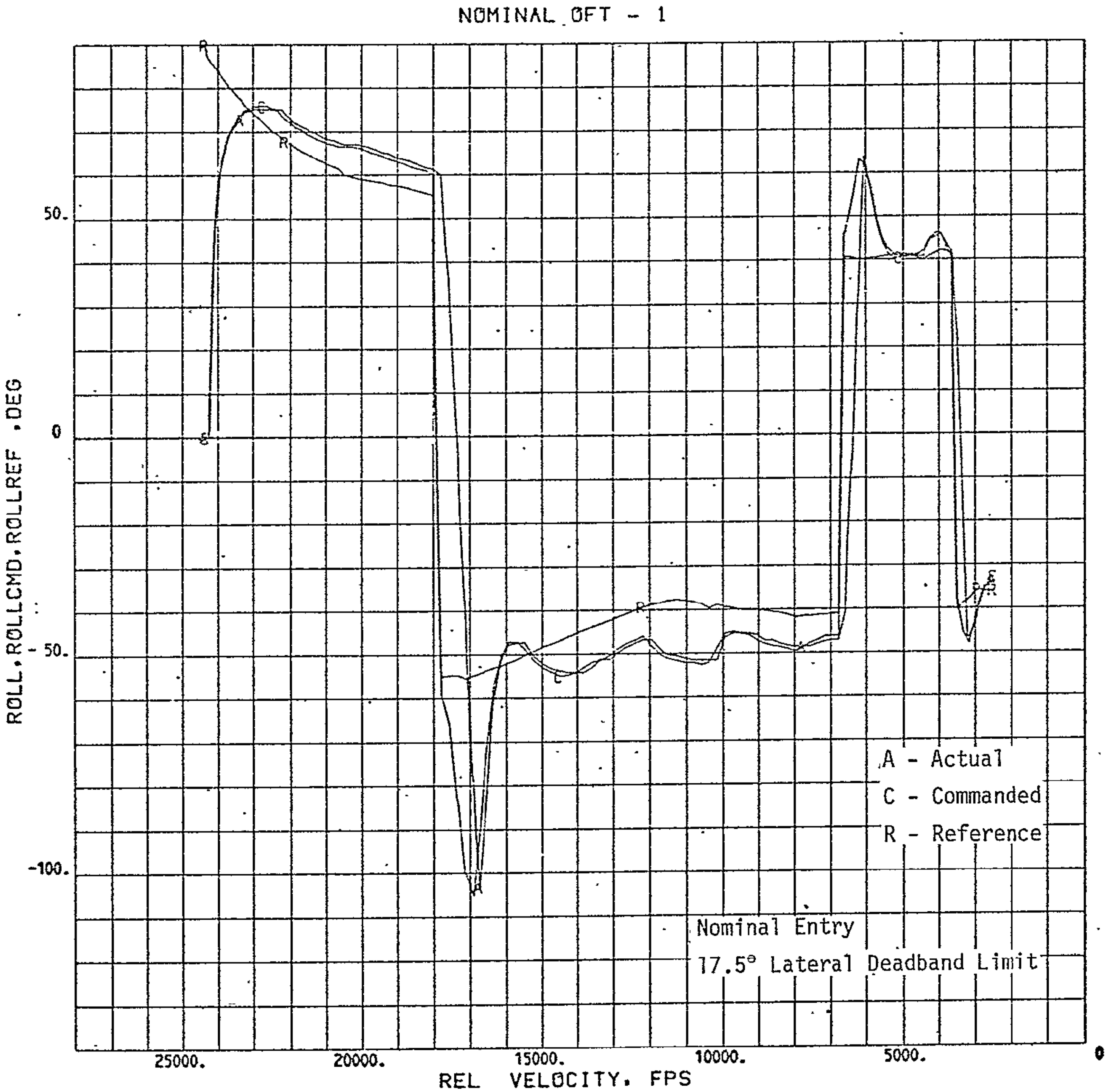

Fig. 3.1-4

Roll Angle

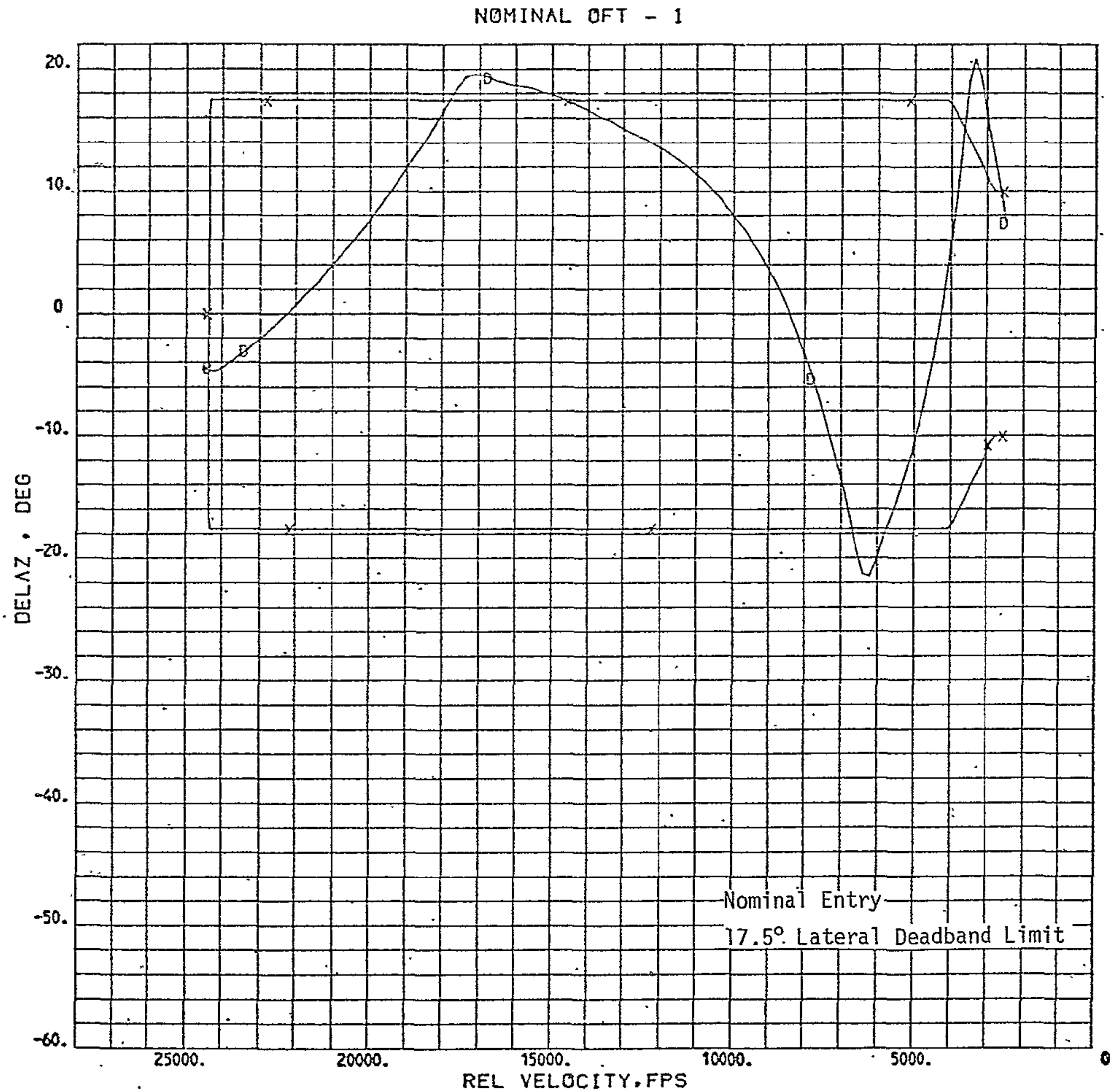

Fig. 3.1-5

Azimuth Error

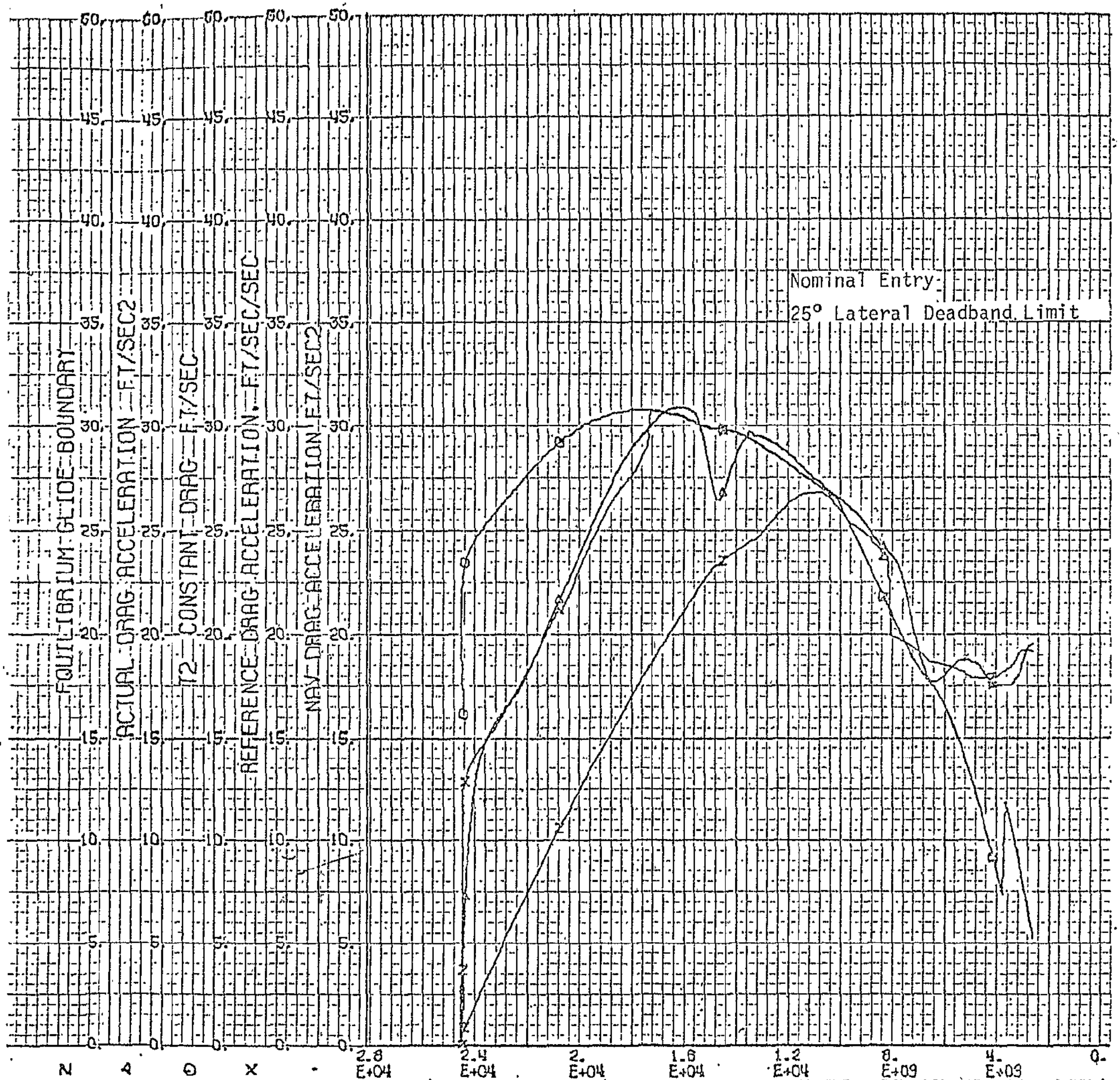

Fig. 3.1-6 Drag Acceleration Profile

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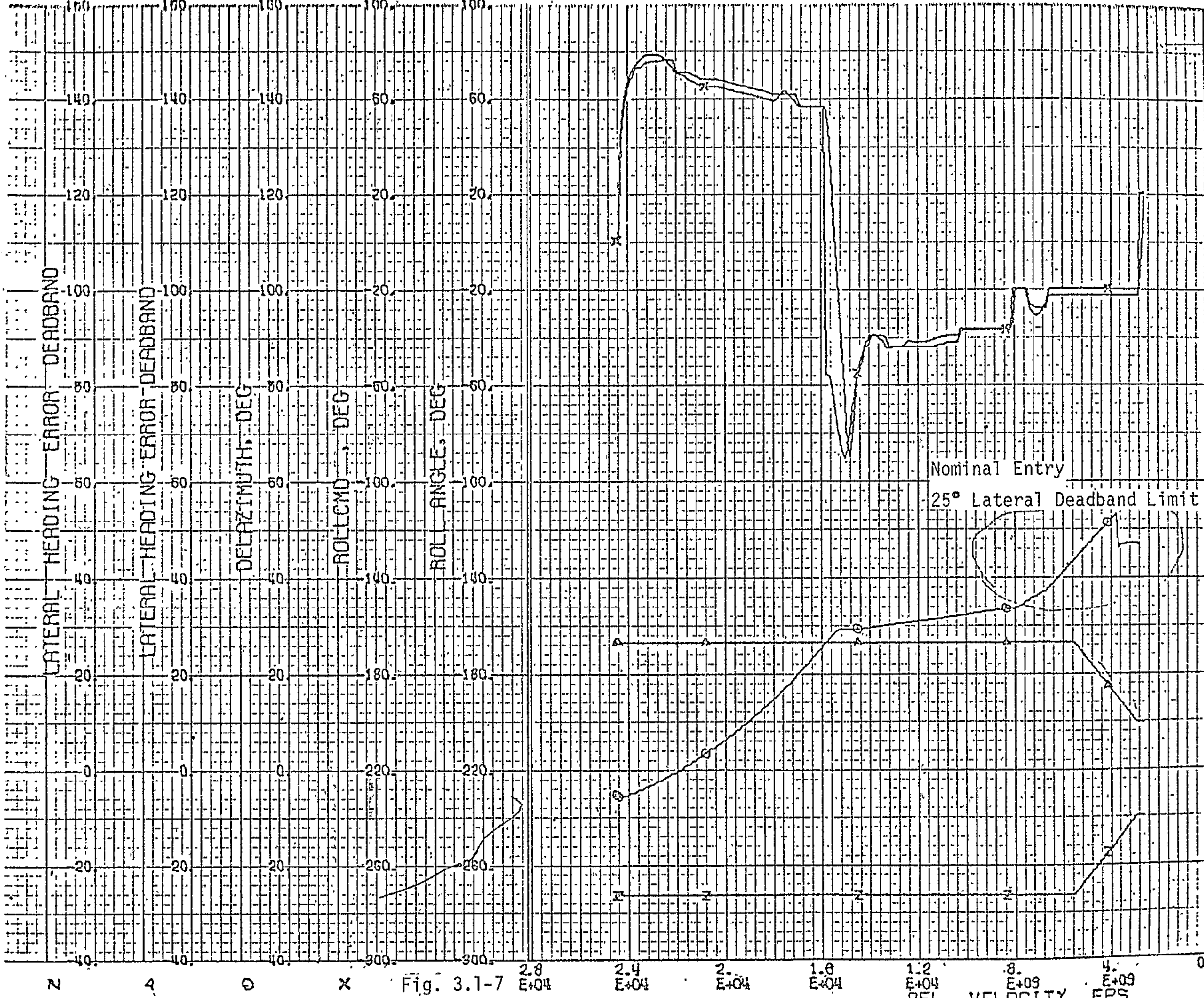


Fig. 3.1-7
Roll Angle and Azimuth Error

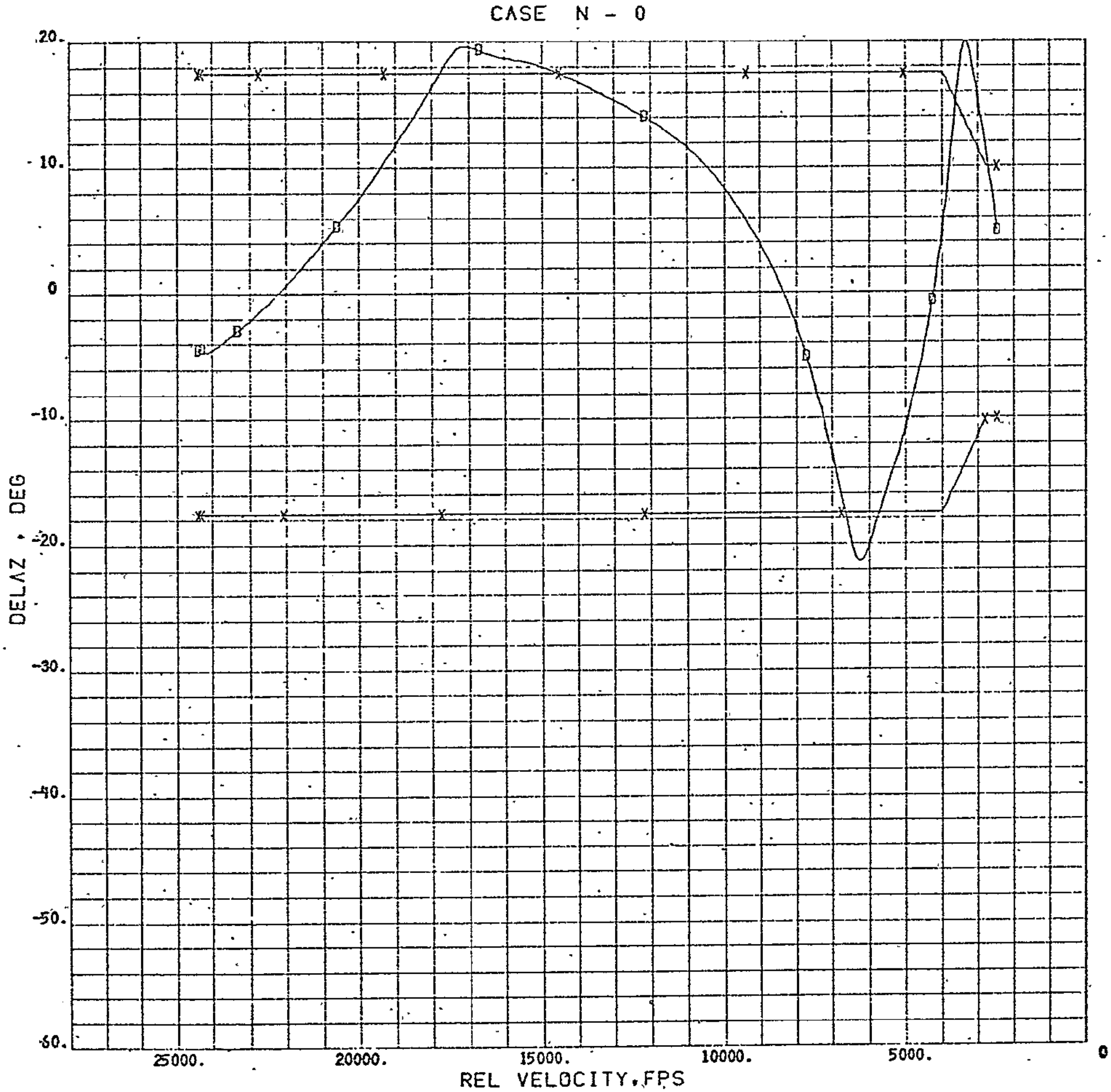
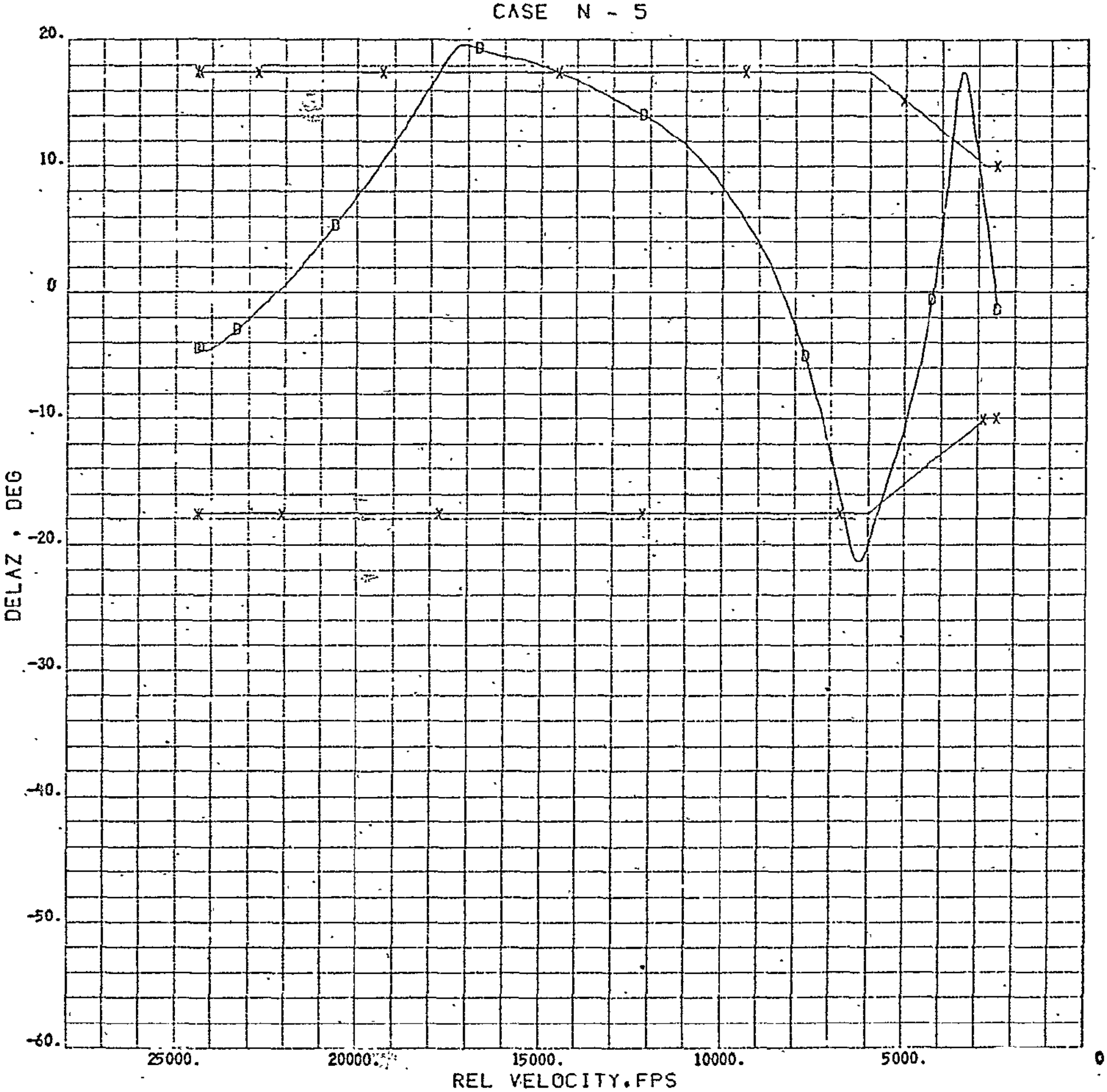


Fig. 3.1-8

Nominal Lateral Deadband Ramp

Azimuth Error



3.1-9

Lateral Deadband Ramp Variations

Azimuth Error

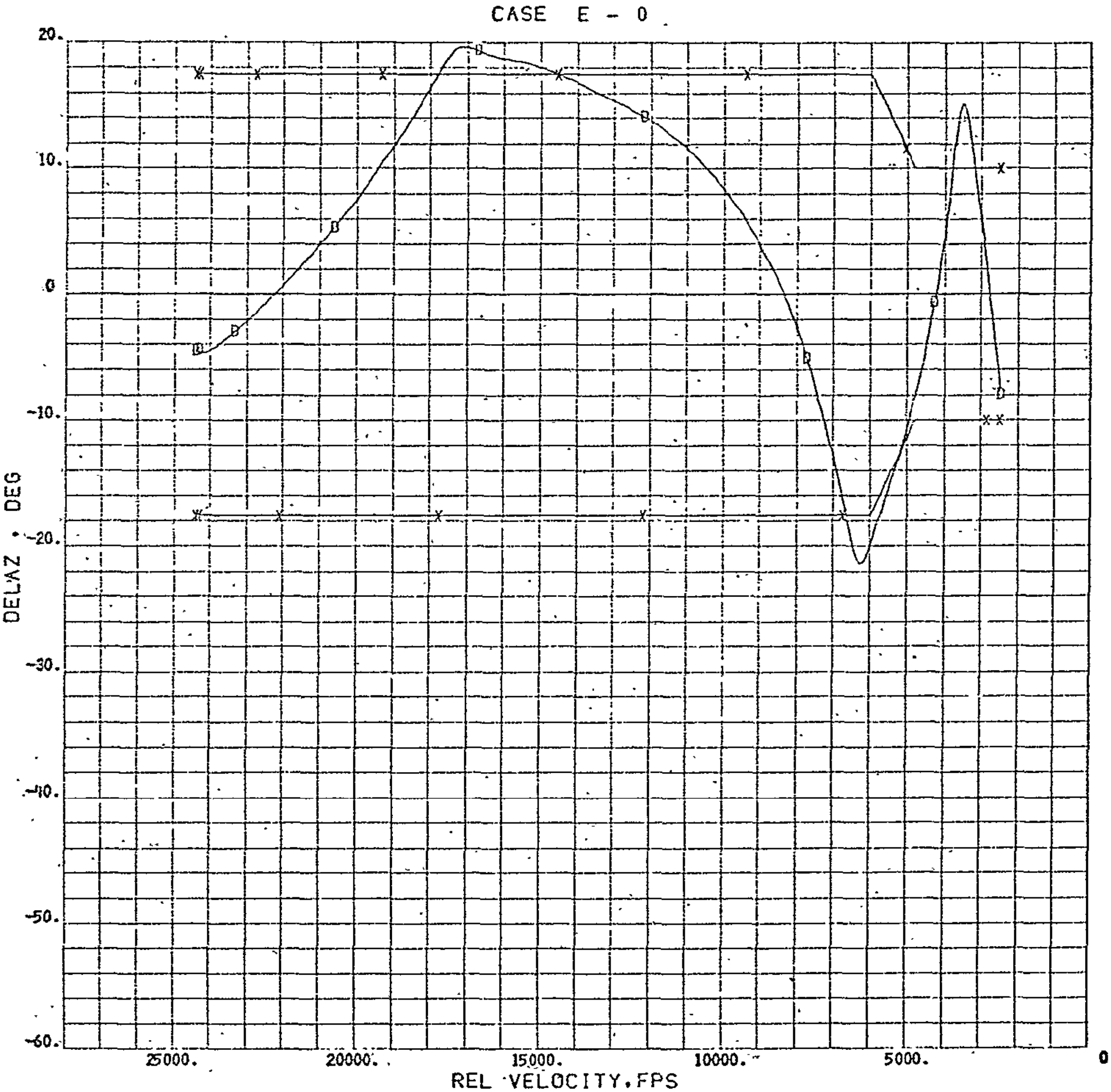


Fig. 3.1-10

Lateral Deadband Ramp Variations

Azimuth Error

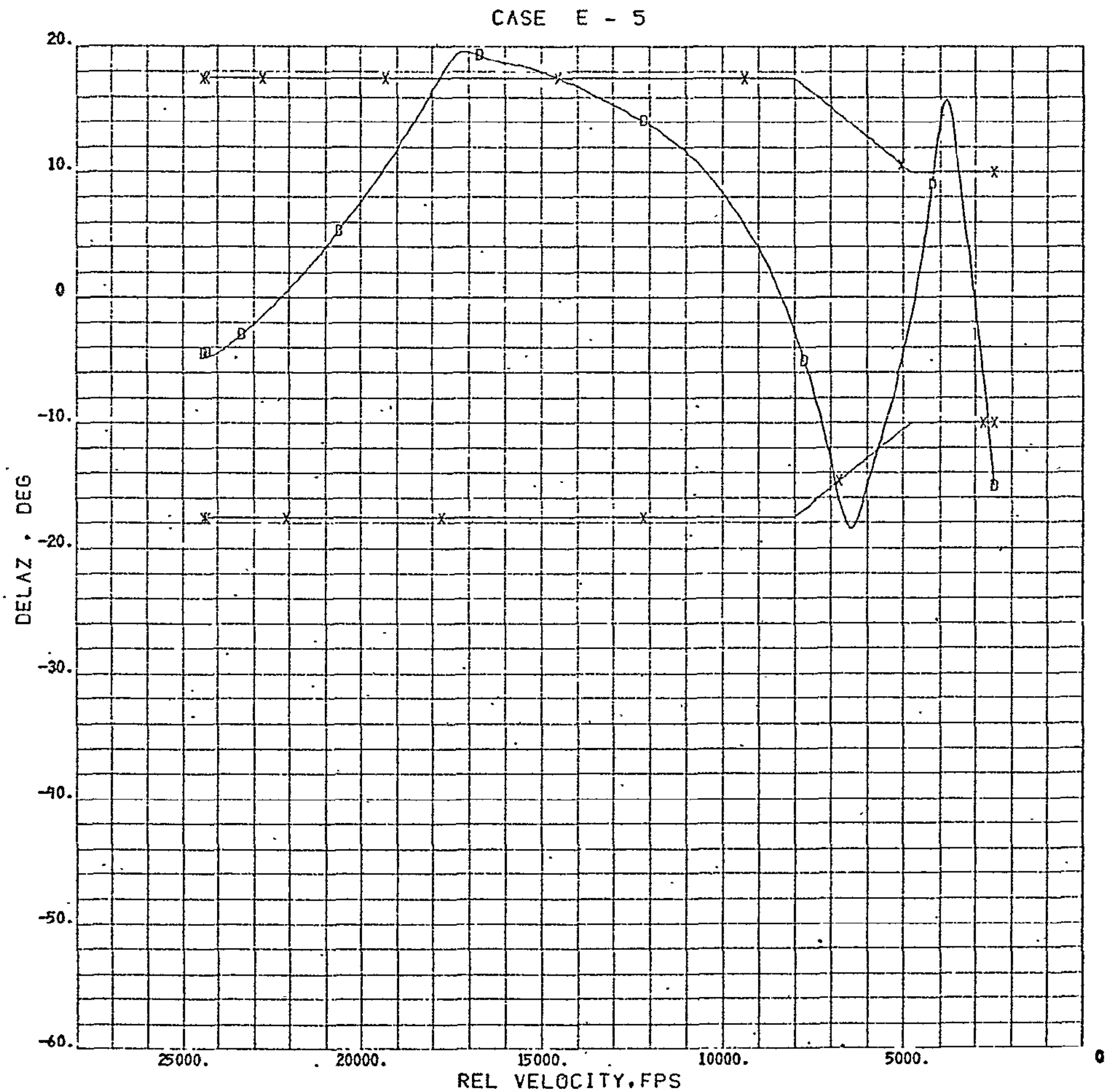


Fig. 3.1-11

Lateral Deadband Ramp Variations

Azimuth Error

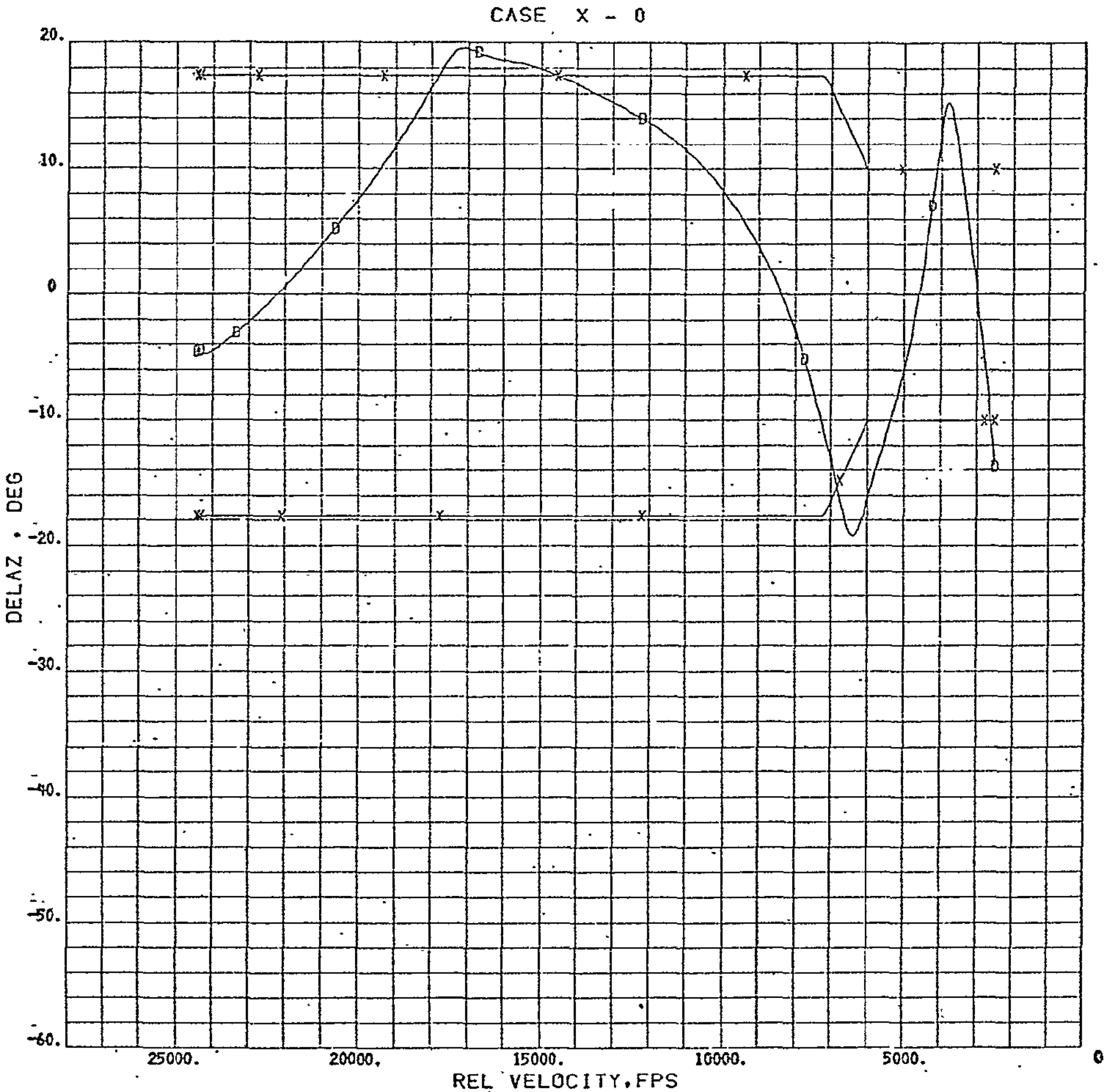


Fig. 3.1-12

Lateral Deadband Ramp Variations

Azimuth Error

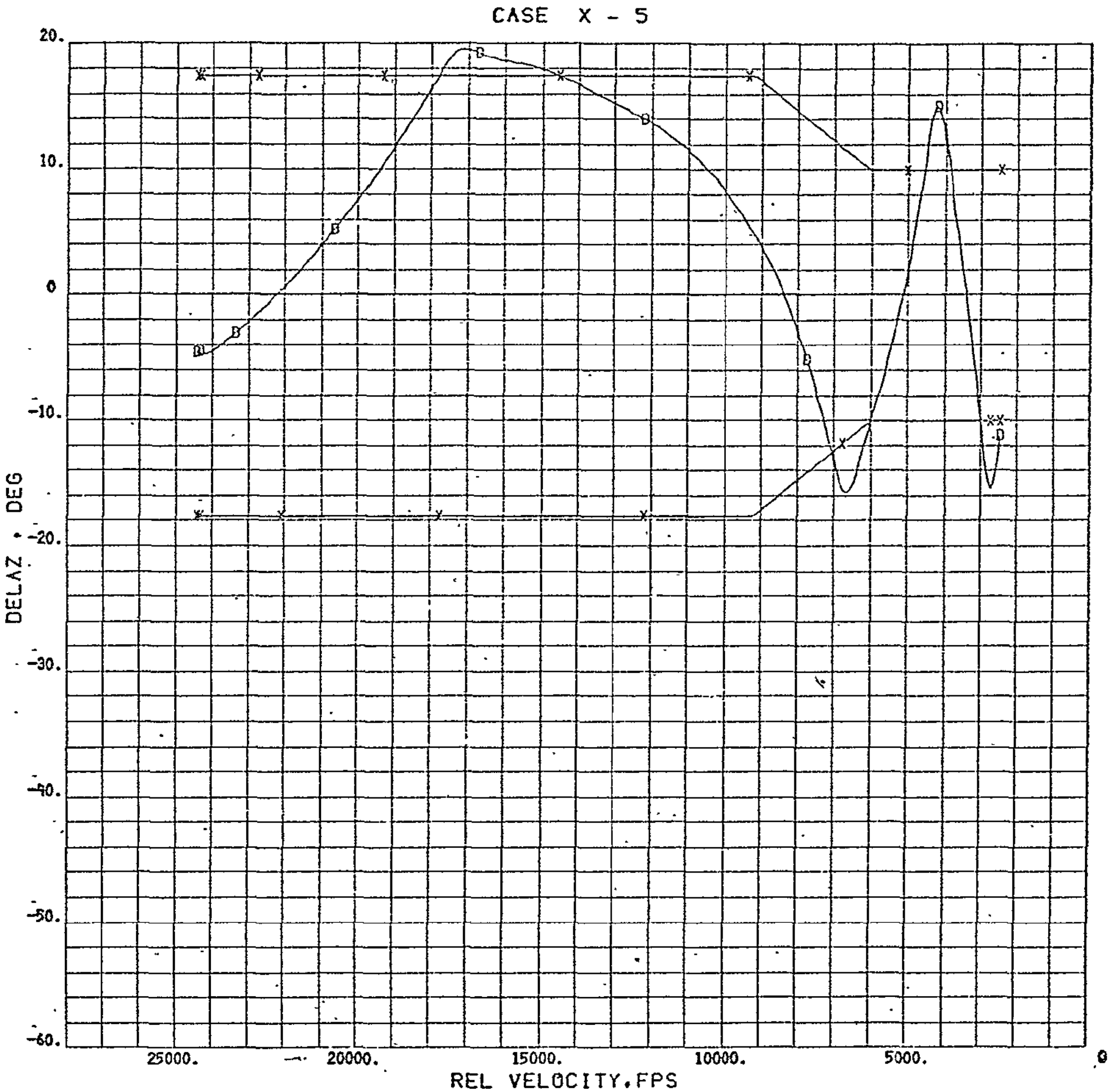


Fig. 3.1-13

Lateral Deadband Ramp Variations

Azimuth Error

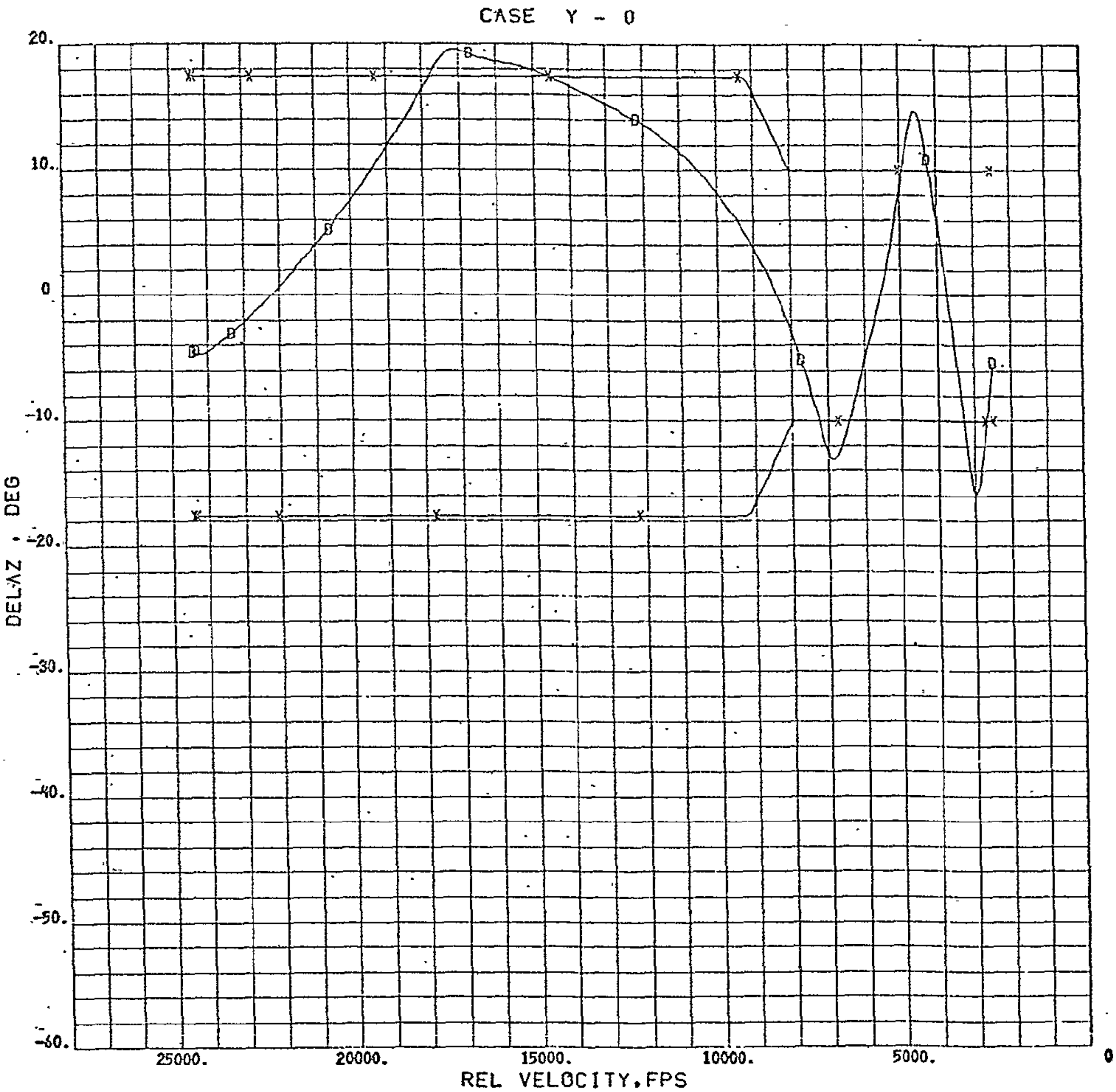


Fig. 3.1-14

Lateral Deadband Ramp Variations

Azimuth Error

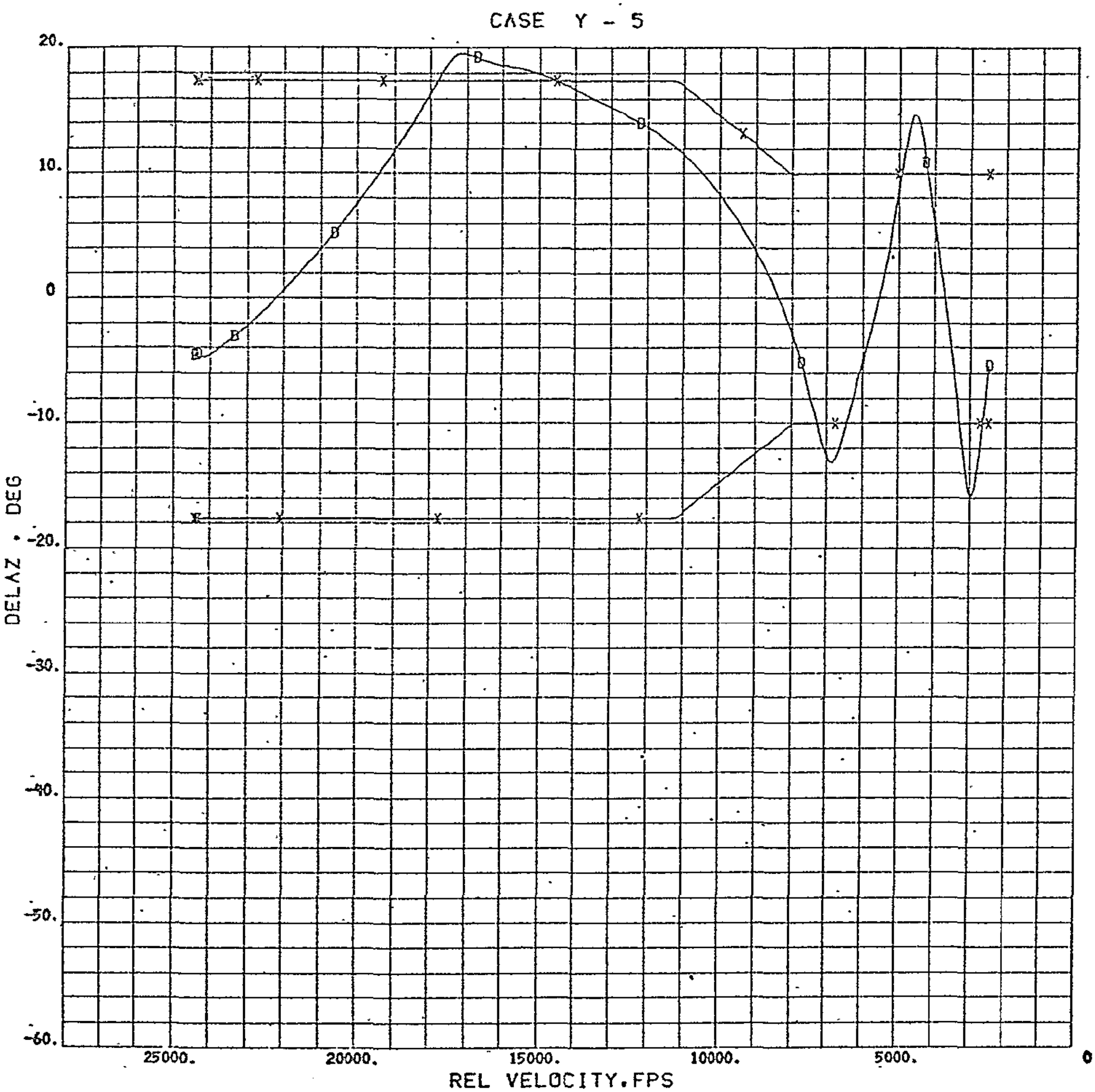


Fig. 3.1-15

Lateral Deadband Ramp Variations

Azimuth Error

of roll reversals in the extreme cases (Cases Y-0 and Y-5), compared to the nominal case (Case N-0), but this is a direct result of moving the ramp anchor points to higher velocities. Moving the anchor points effectively decreased the deadband width and therefore produced the same results - additional roll reversals.

The L/D dispersion capability of the lateral deadband was the final item for study. In these study cases, a constant percentage reduction was applied to the vehicle L/D throughout the entry. Results in Figures 3.1-16 - 3.1-27 show the effect on the orbiter azimuth error and drag acceleration profile of decreasing L/D for the nominal 17.5° deadband. The 20% low L/D cases were selected as the design low L/D situations for the entry guidance, since these cases demonstrated the greatest amount of time required for the azimuth error to return within the deadband following a roll reversal. 18% low L/D cases were then examined for 17°, 16°, 15°, 14°, 12°, and 10° deadbands, with the drag acceleration profiles and azimuth error effects for representative cases shown in Figures 3.1-28 - 3.1-33. In addition, low L/D capability was determined as a function of deadband width for the 17.5°, 15°, and 12.5° deadbands; the low L/D capability of a deadband was defined as the maximum low L/D percentage for which the orbiter could satisfy the TAEM interface miss distance constraints. This function is shown in Figure 3.1-34.

As a result of these study cases, the 12.5° deadband was chosen as the optimal lateral deadband configuration for entry. The 12.5° deadband offered low L/D capability of 23%, compared to 17% for the nominal deadband, while adding only one more roll reversal during

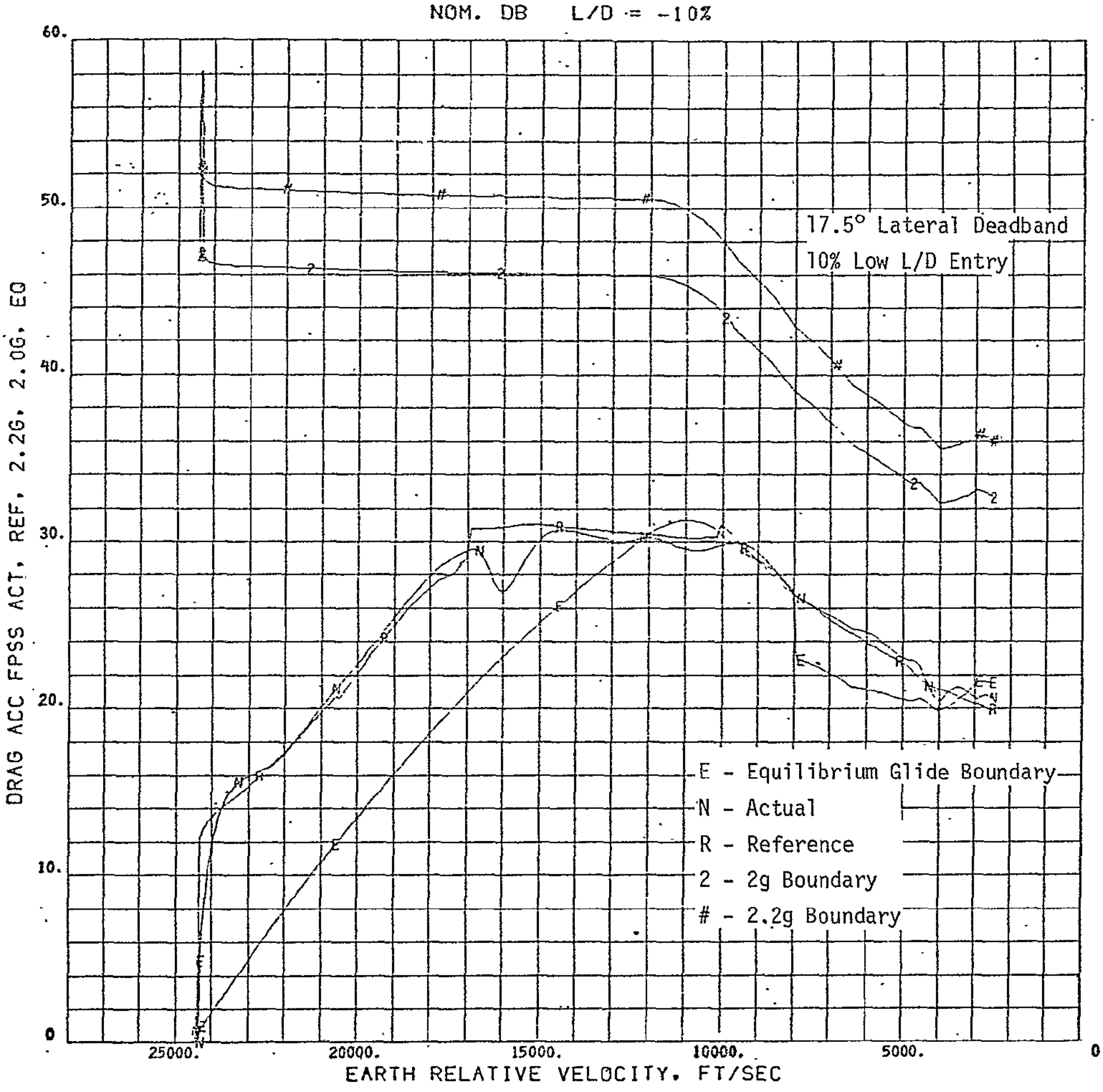


Fig. 3.1-16

Drag Acceleration Profile

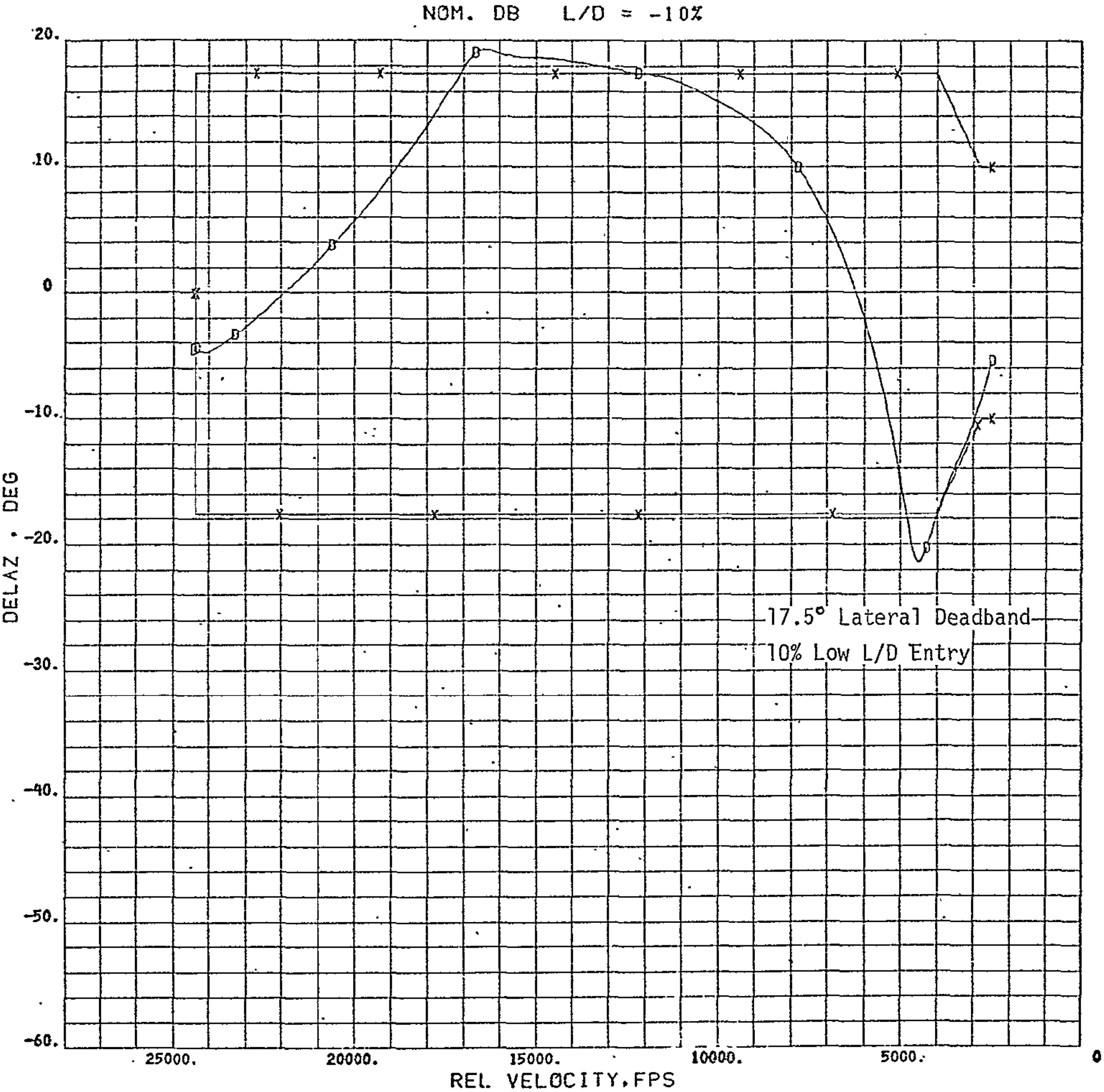


Fig. 3.1-17

Azimuth Error

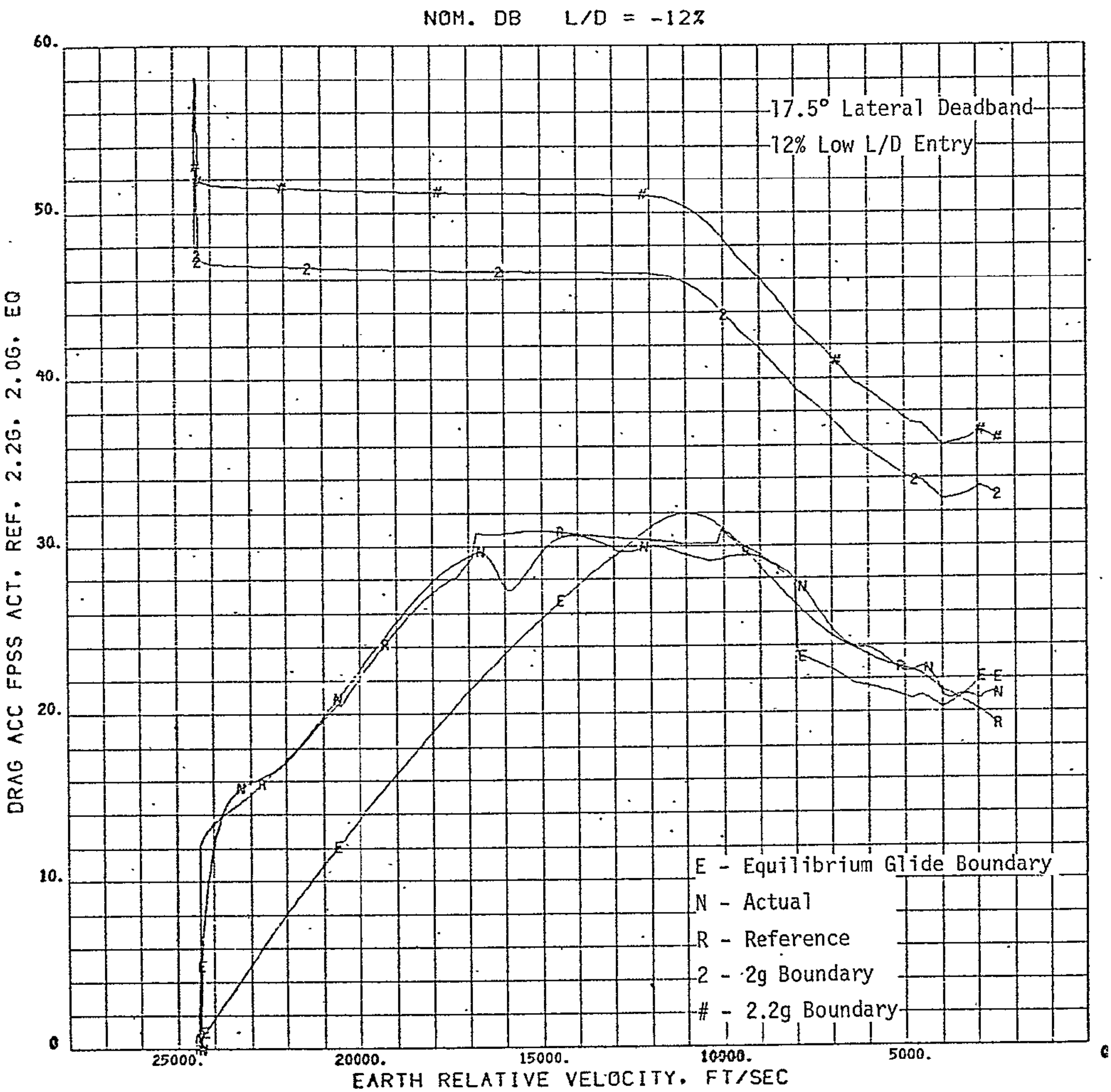


Fig. 3.1-18

Drag Acceleration Profile

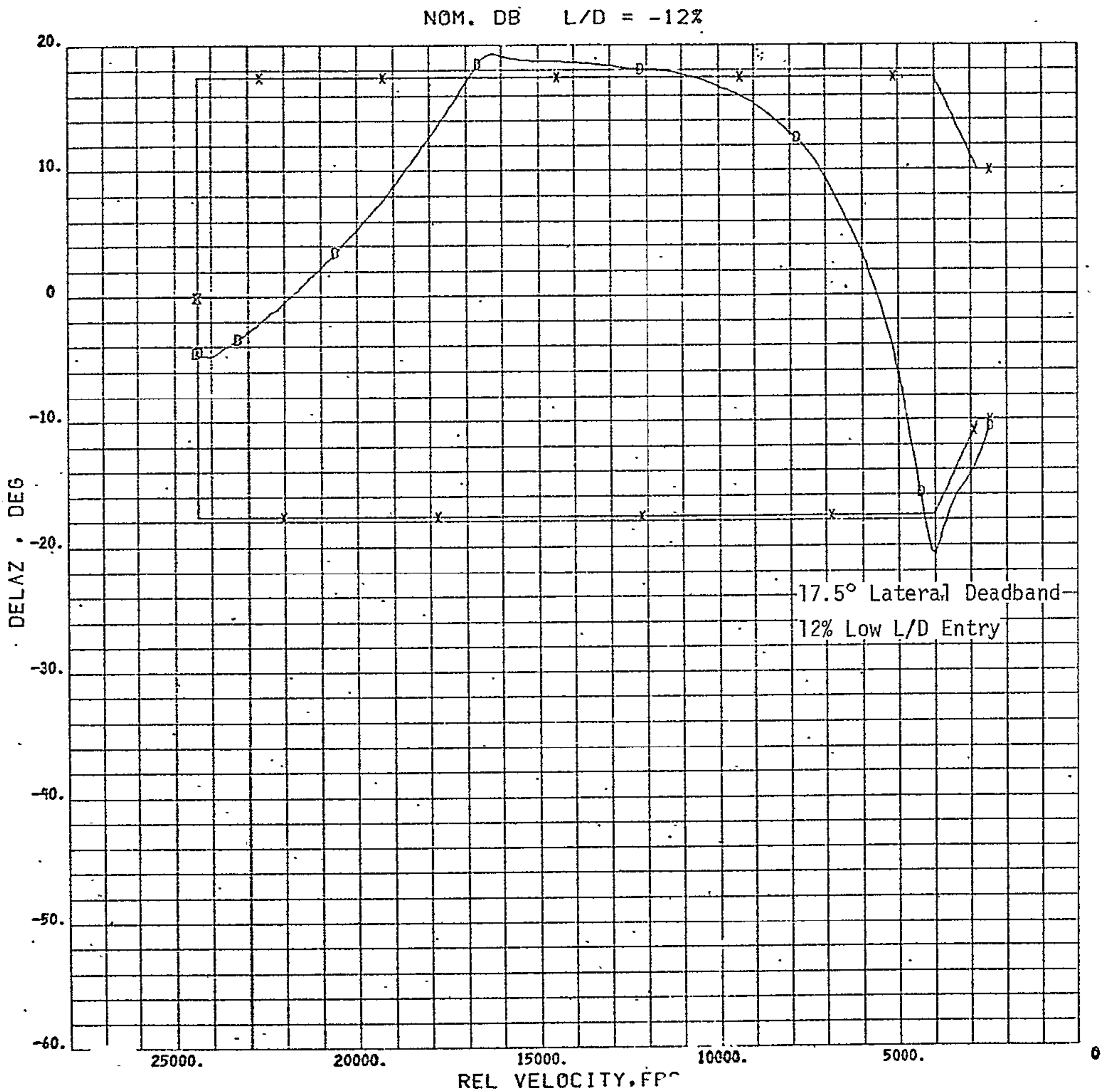


Fig. 3.1-19

Azimuth Erro

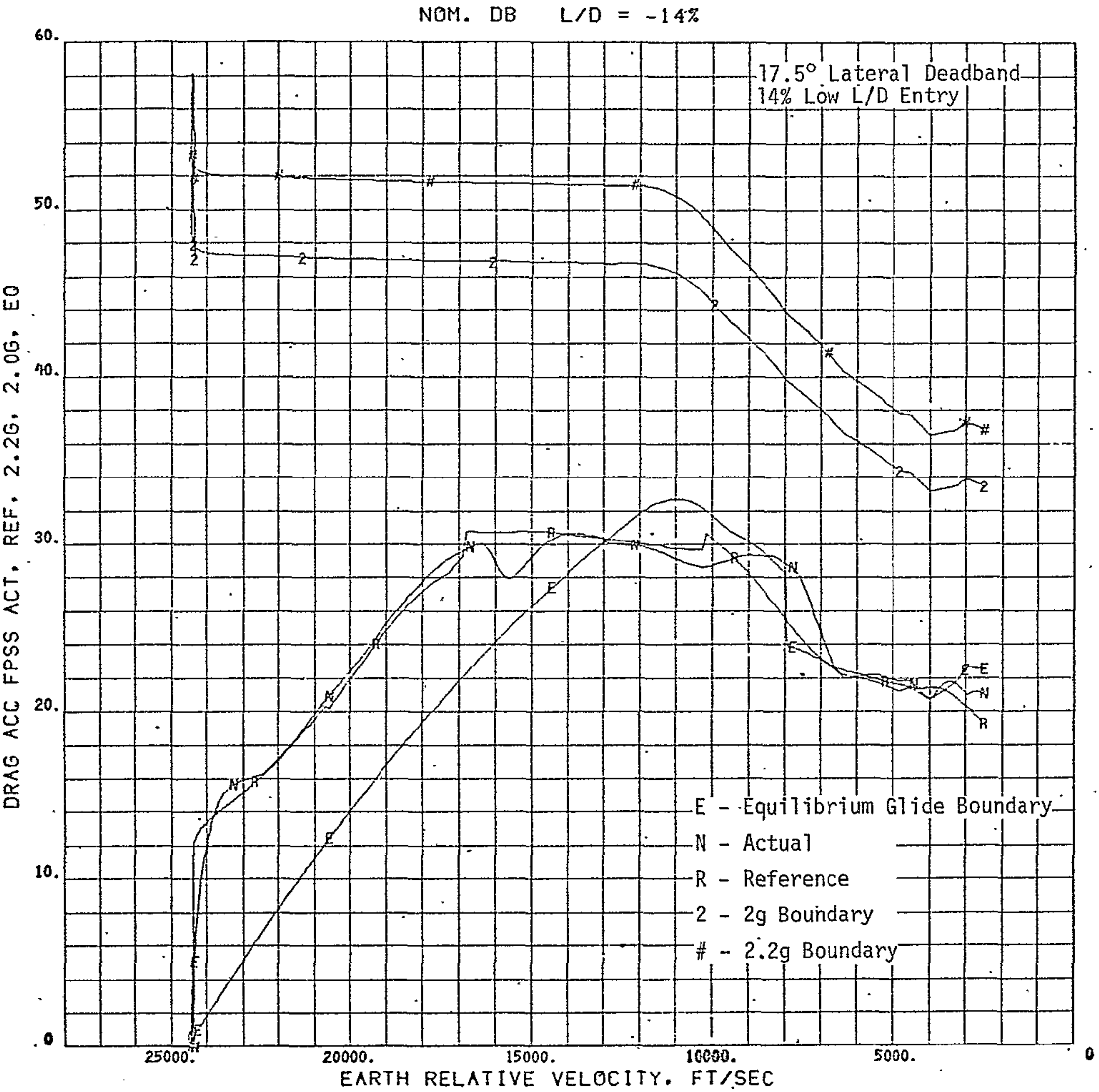


Fig. 3.1-20

Drag Acceleration Profile

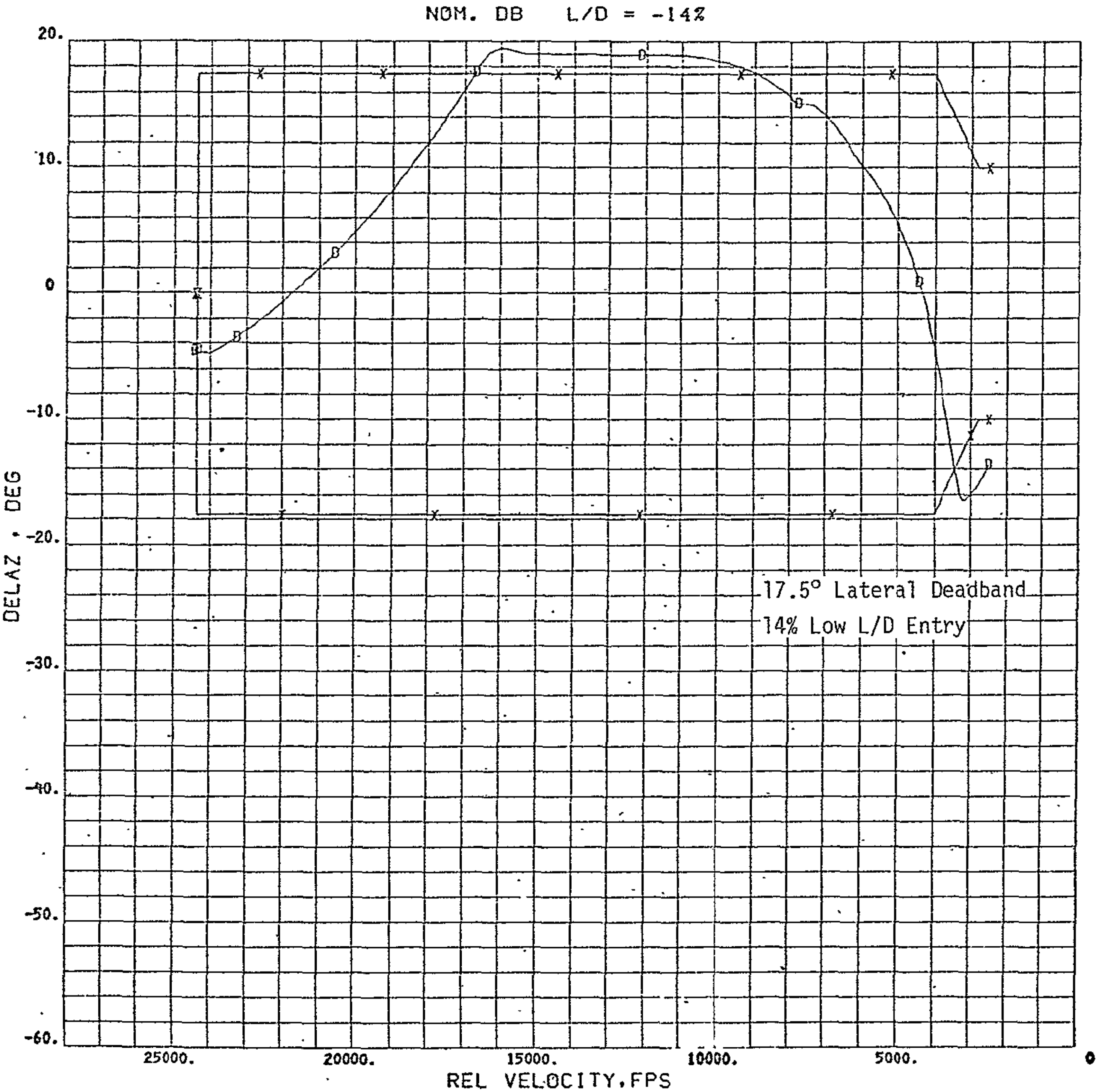


Fig. 3.1-21
Azimuth Error

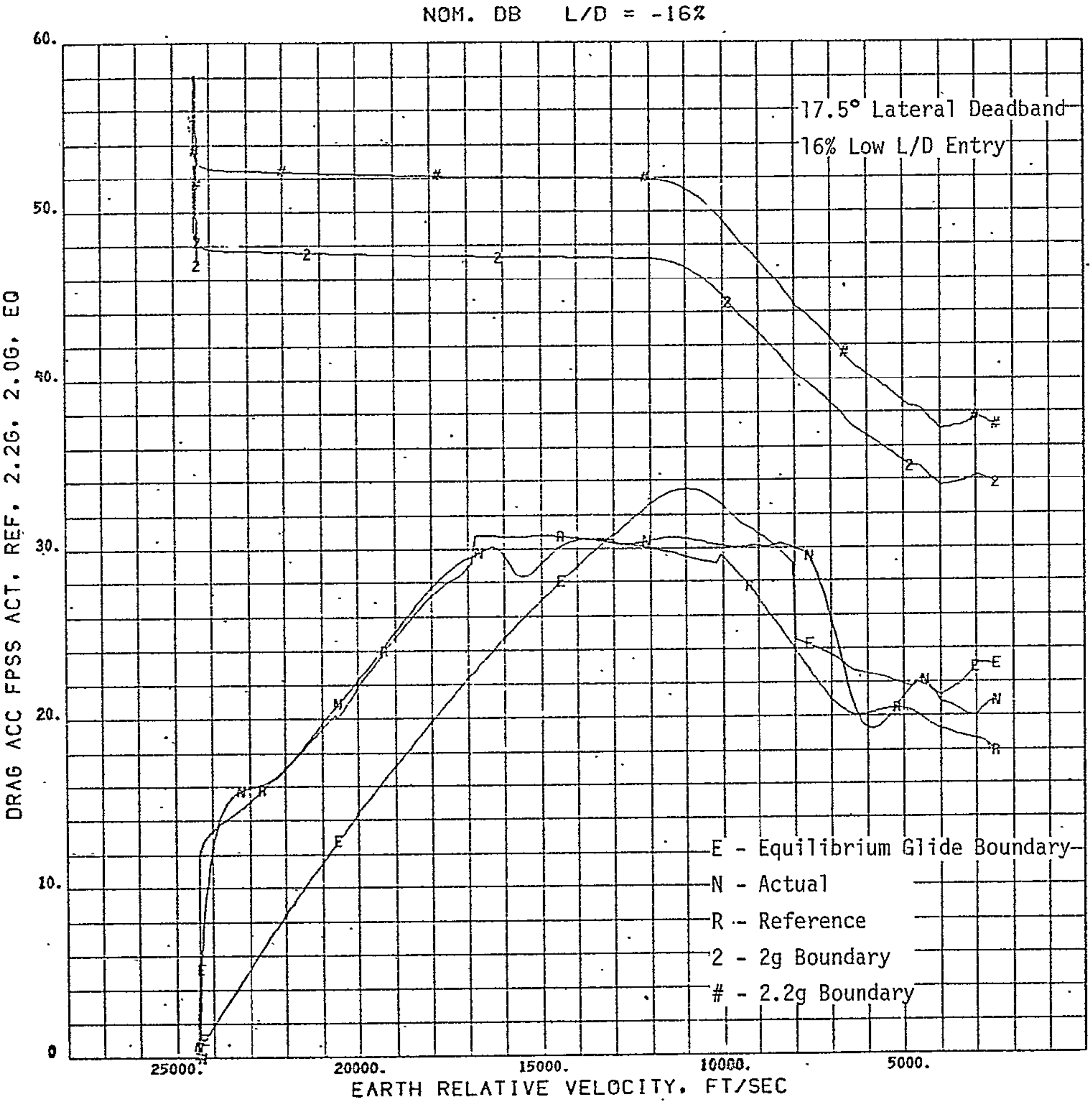


Fig. 3.1-22

Drag Acceleration Profile

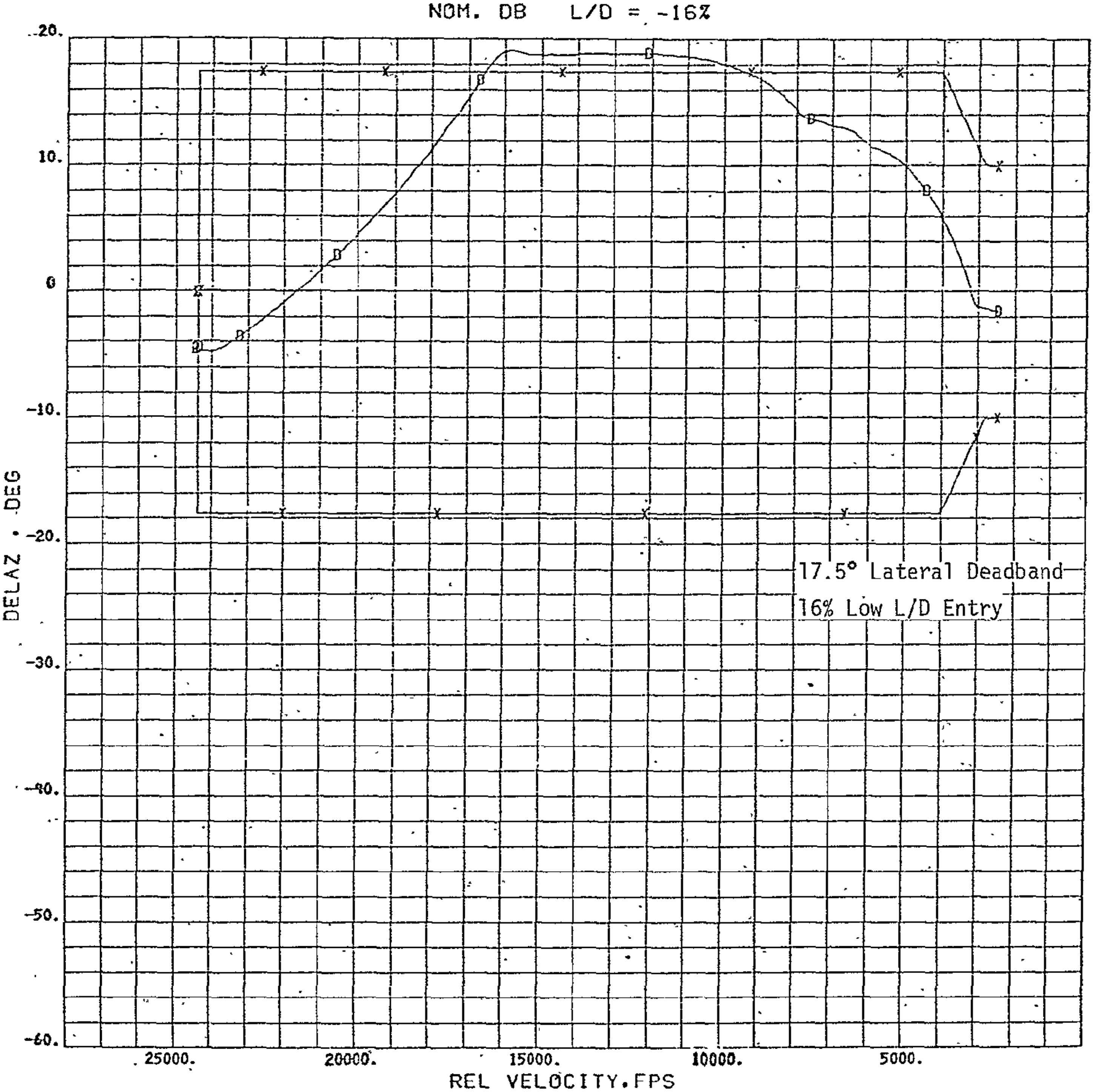


Fig. 3.1-23
Azimuth Error

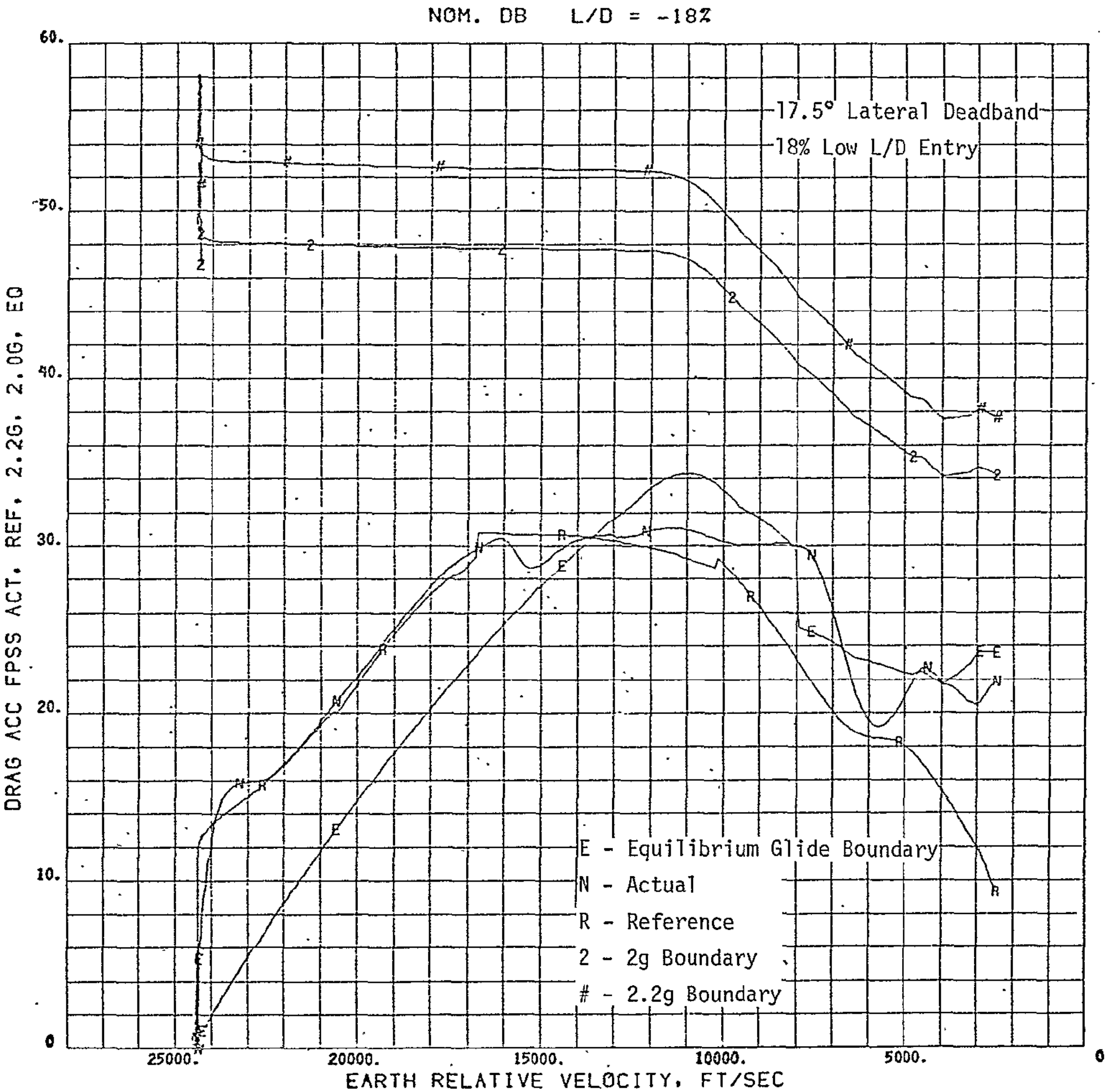


Fig. 3.1-24

Drag Acceleration Profile

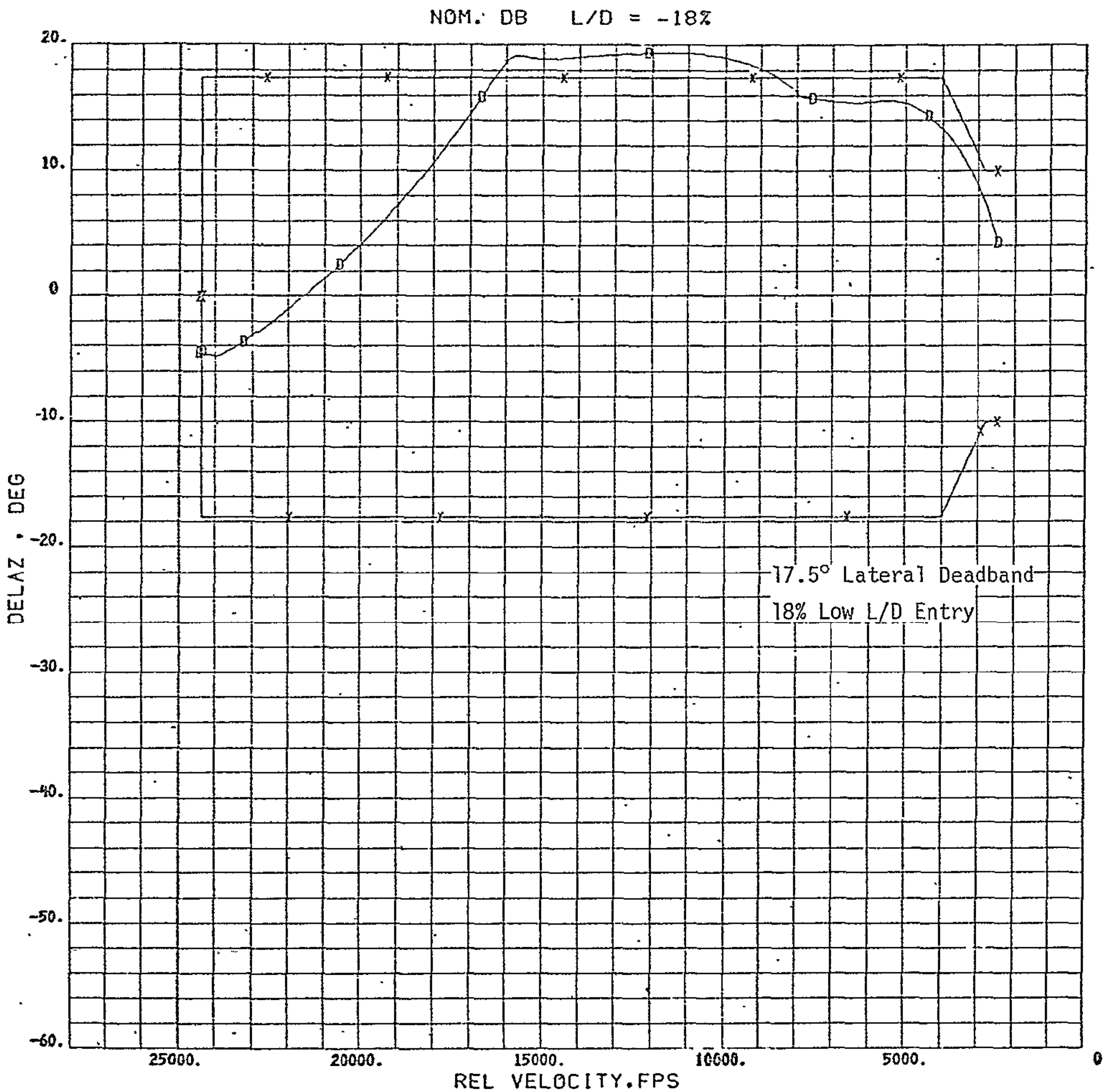


Fig. 3.1-25
Azimuth Error

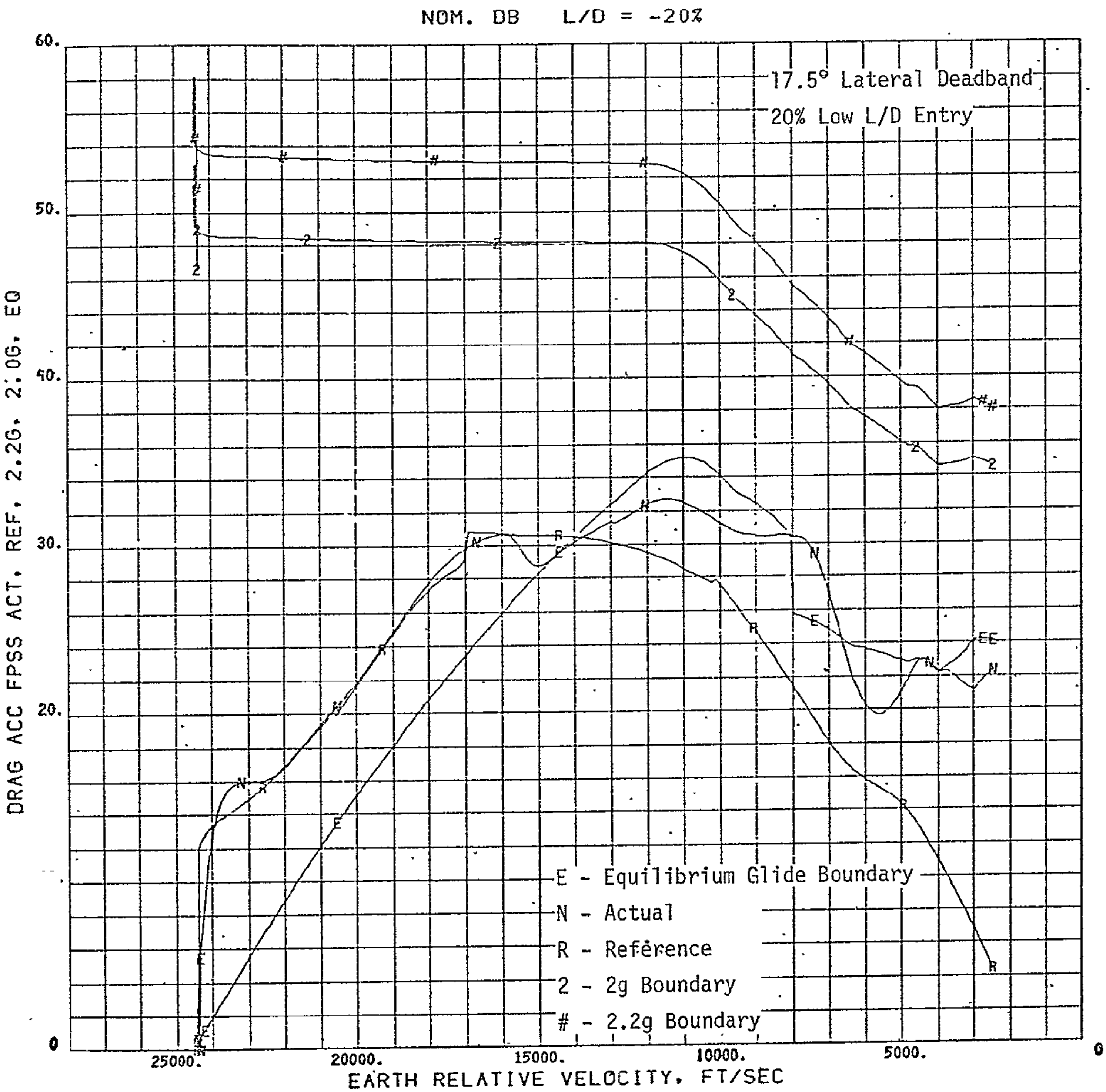


Fig. 3.1-26

Drag Acceleration Profile

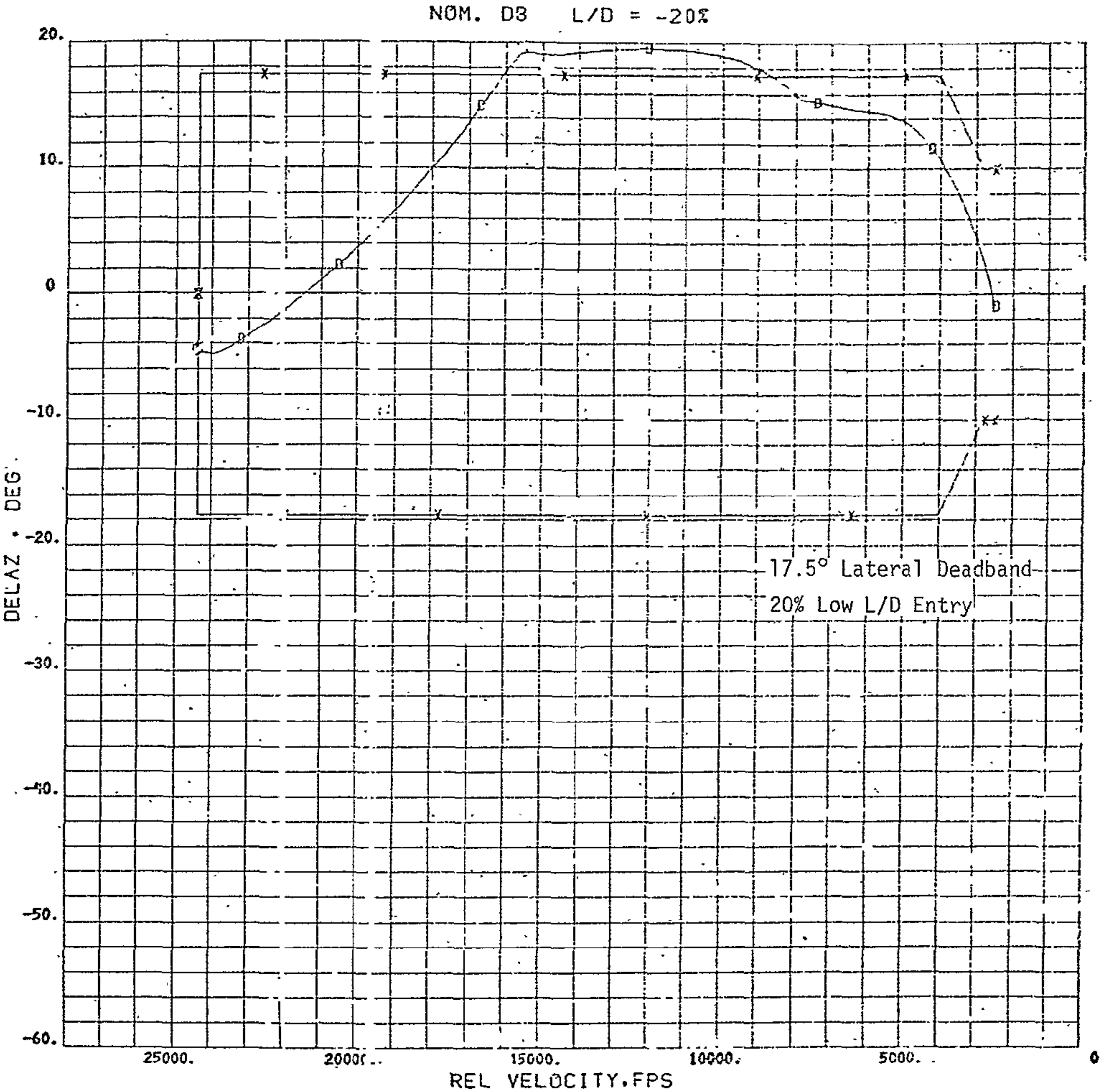


Fig. 3.1-27

Azimuth Error

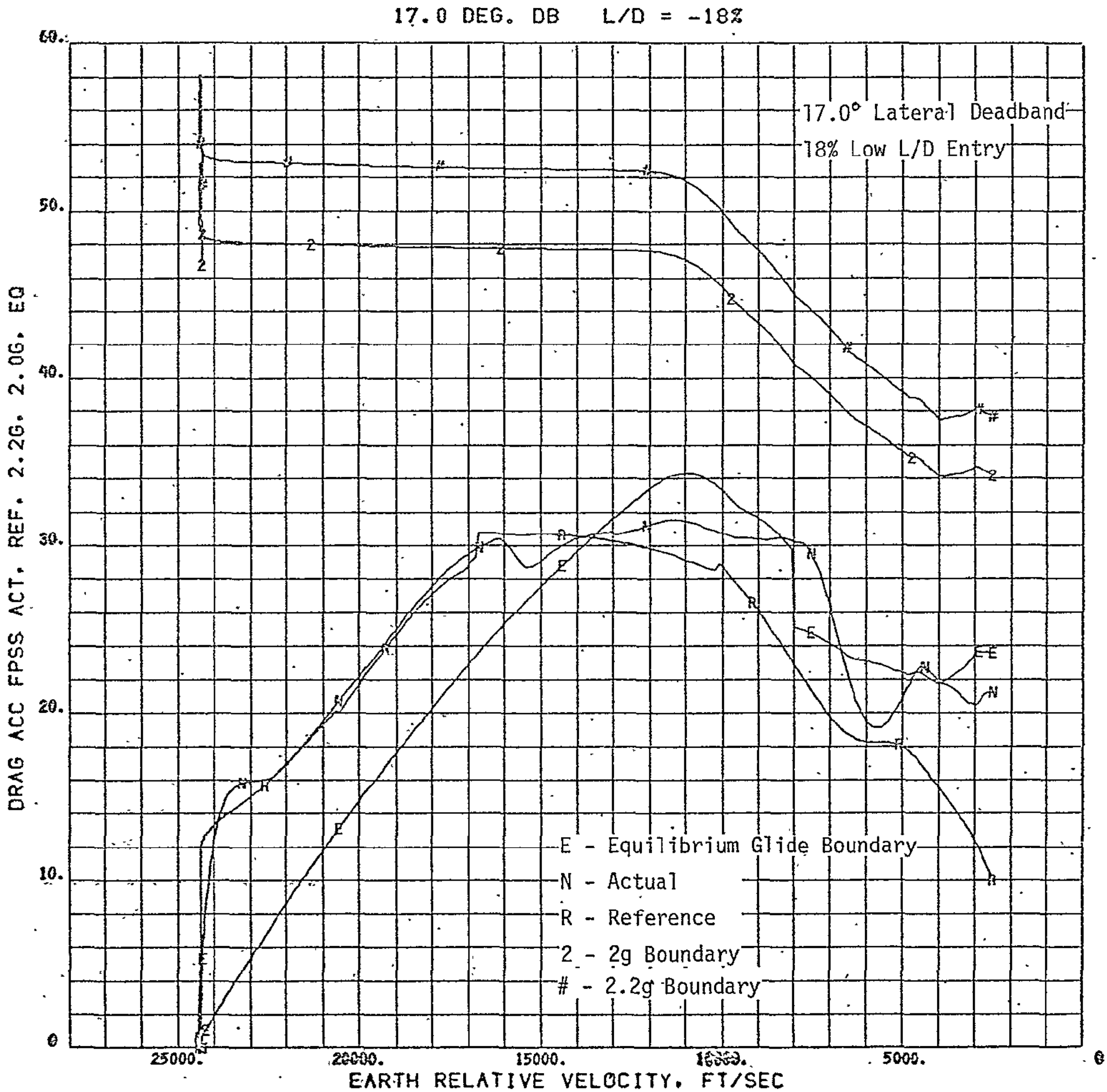


Fig. 3.1-28

Drag Acceleration Profile

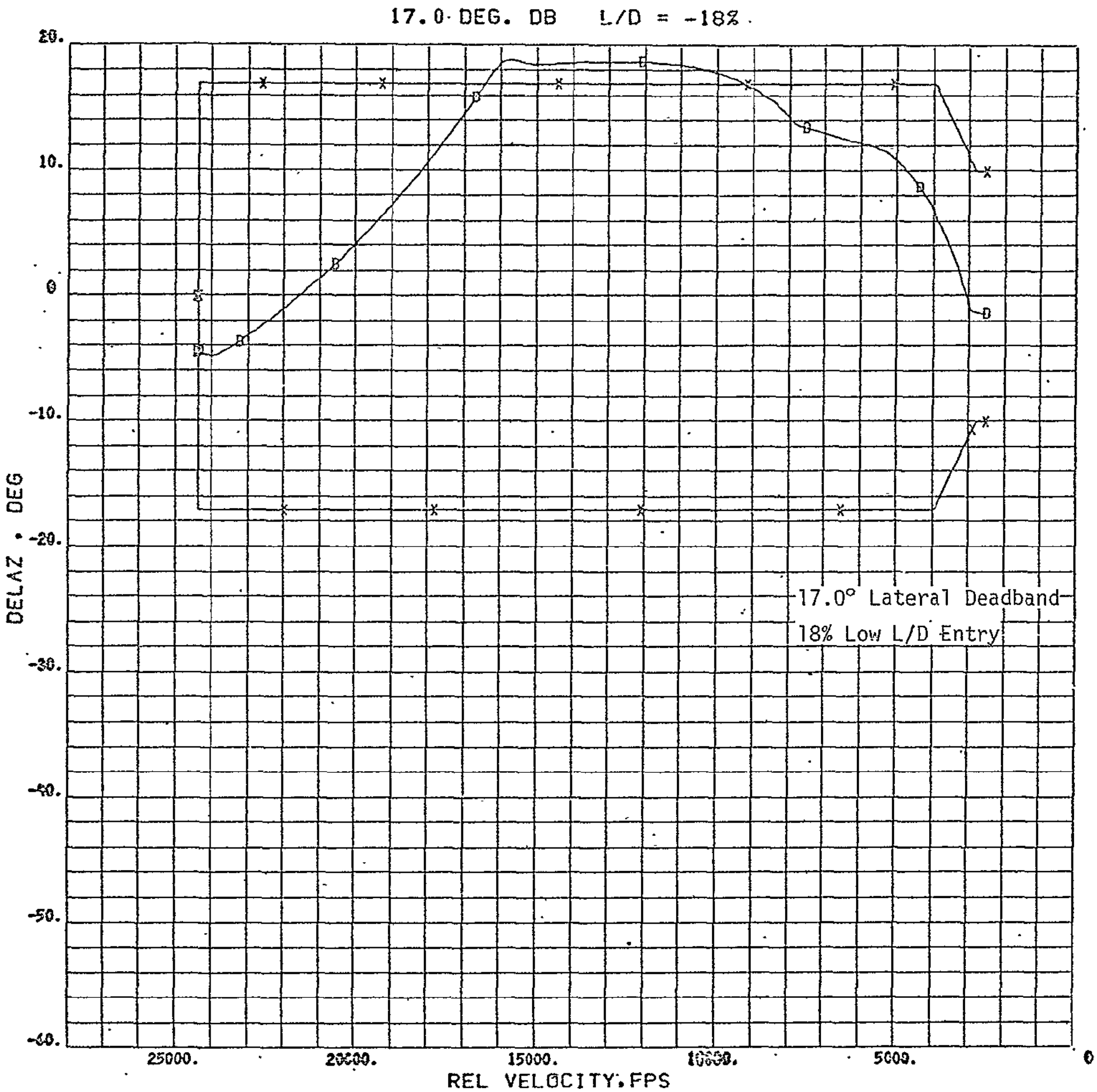


Fig. 3.1-29

Azimuth Error

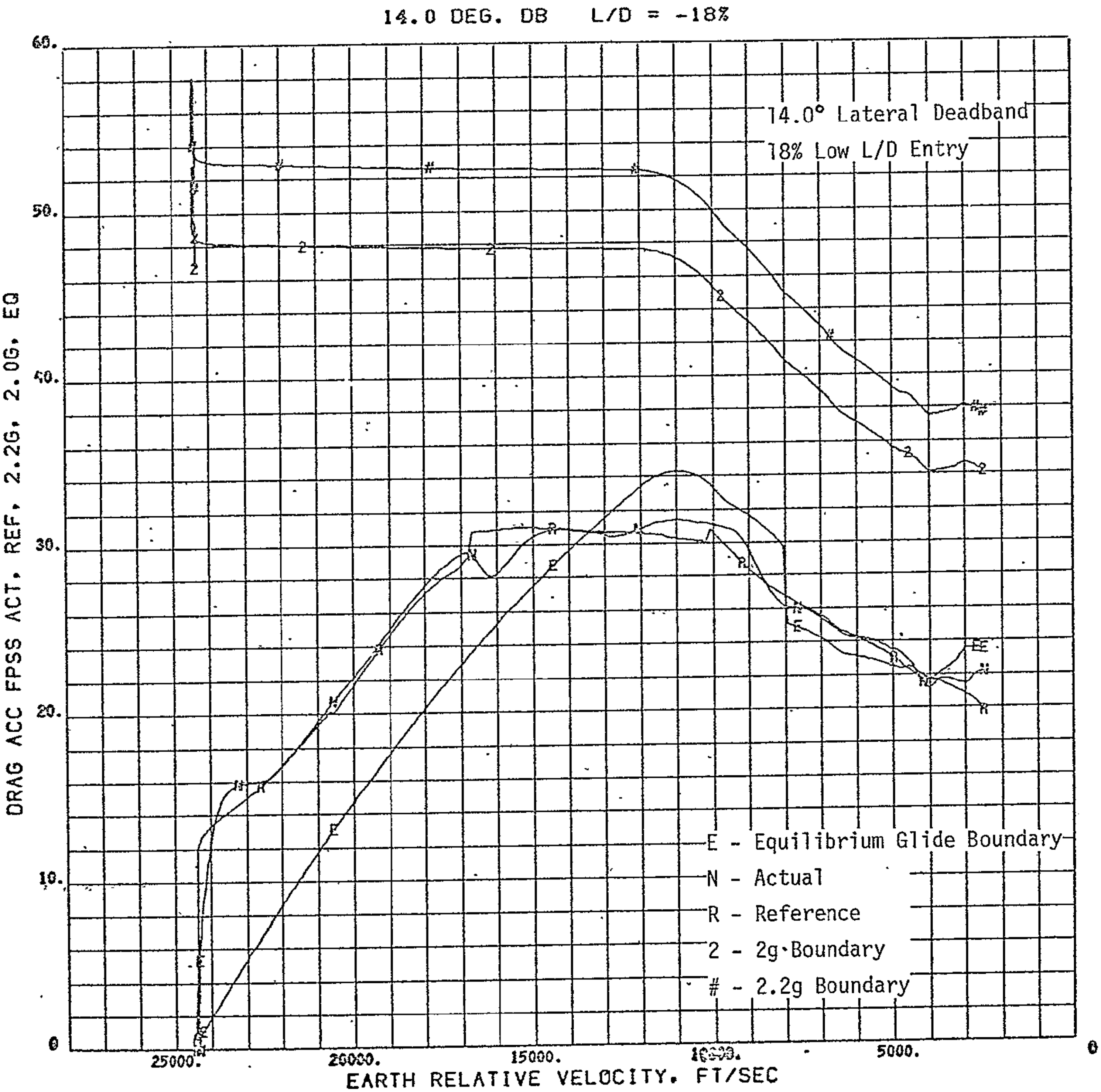


Fig. 3.1-30

Drag Acceleration Profile

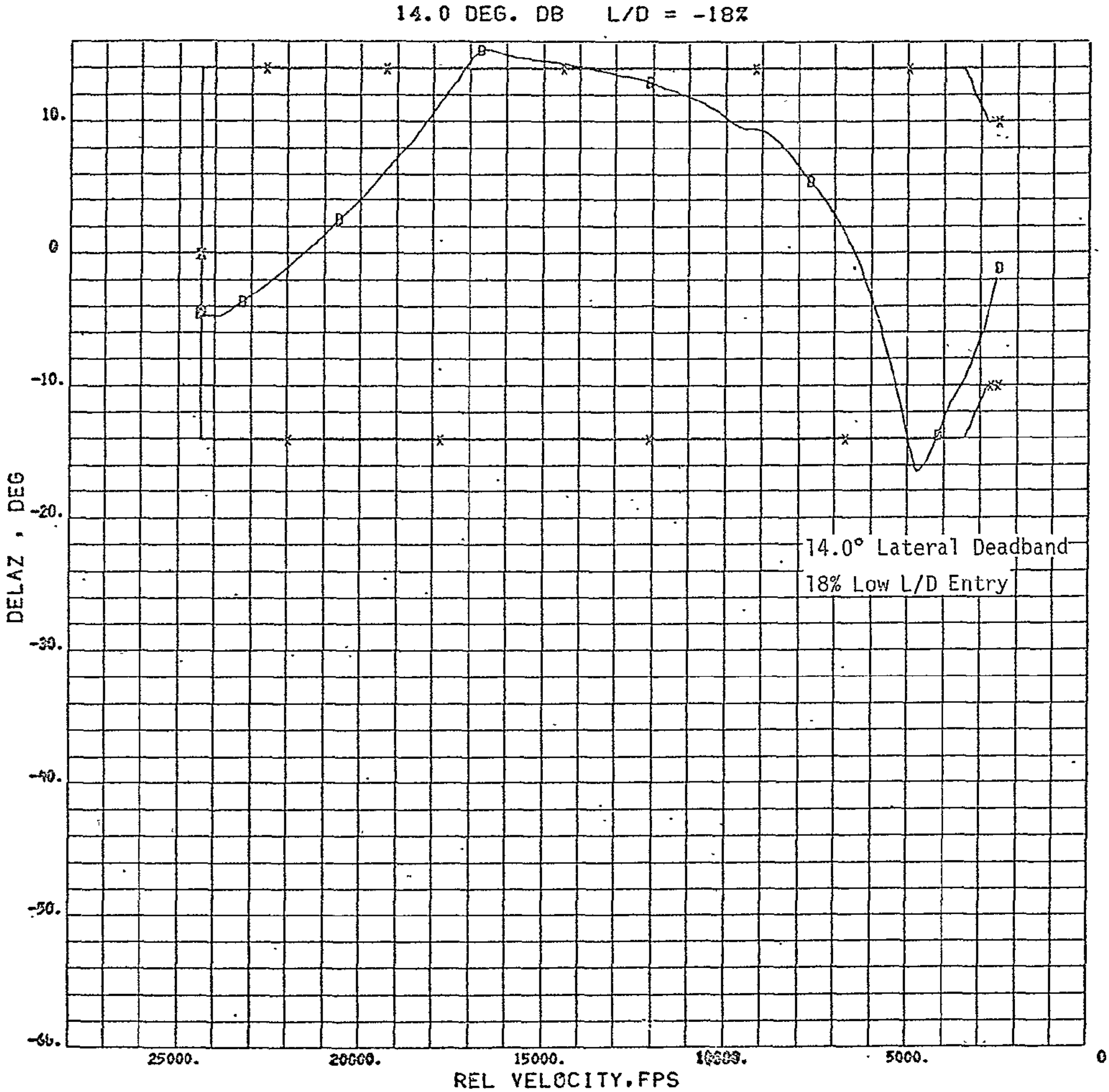


Fig. 3.1-31
Azimuth Error

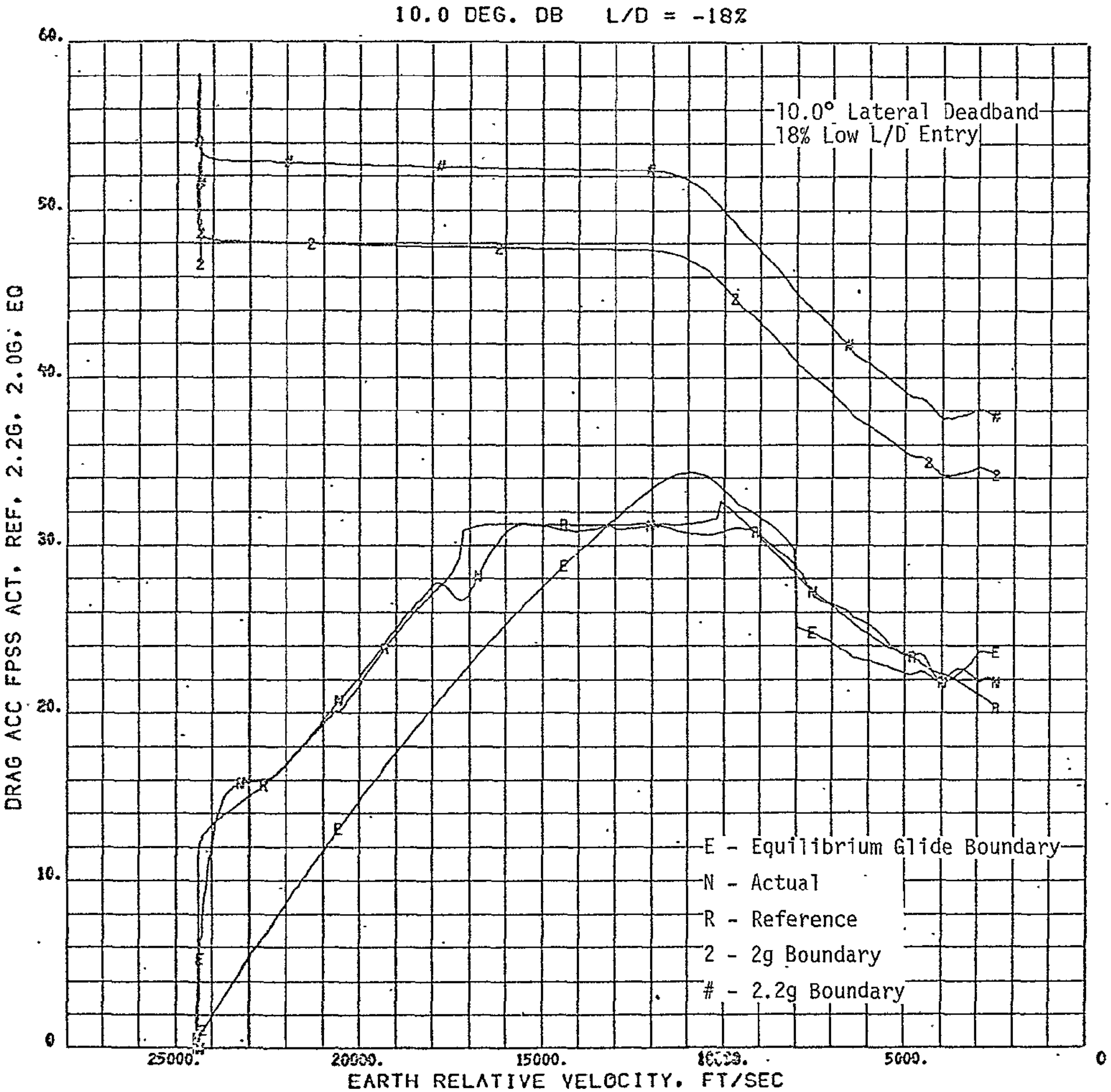


Fig. 3.1-32

Drag Acceleration Profile

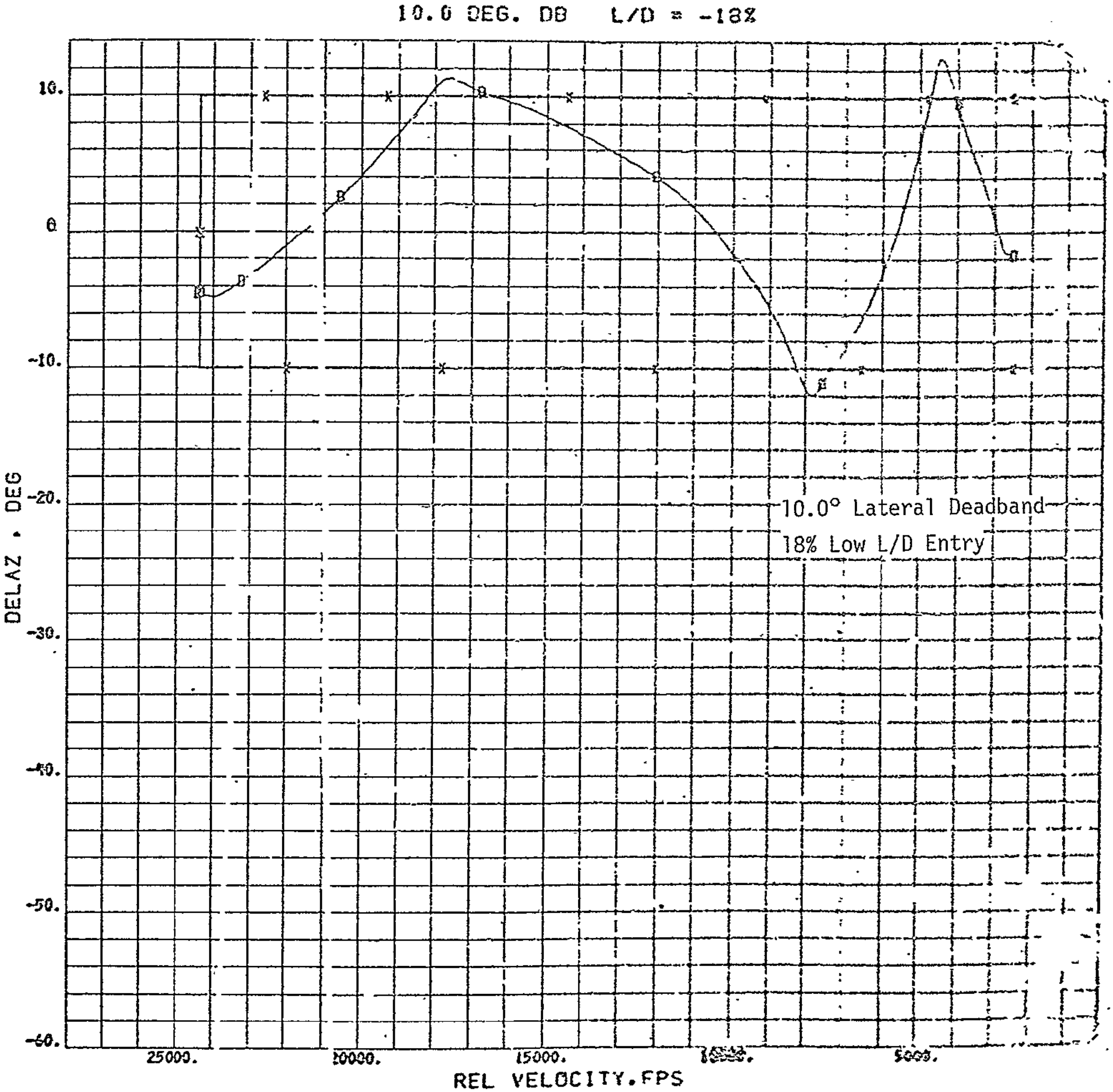


Fig. 3.1-33

Azimuth Error

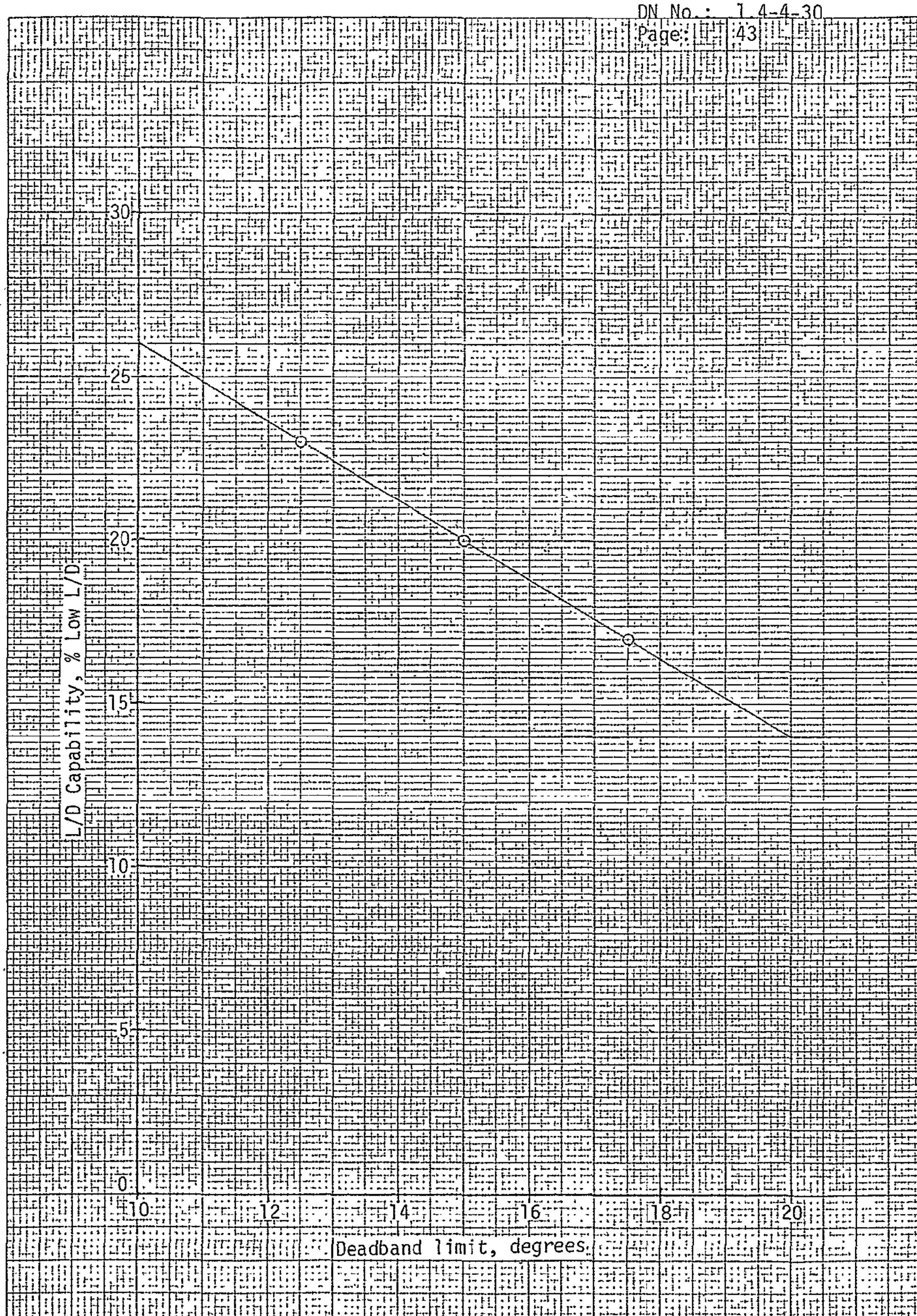


Fig. 3.1-34
L/D Capability vs. Deadband Limits

deadband offered low L/D capability of 23%, compared to 17% for the nominal deadband, while adding only one more roll reversal during entry, even for 20% high L/D cases (Fig. 3.1-35 - Fig. 3.1-40). While the 15° deadband also added only one roll reversal and provided 20% low L/D capability, the 3% extra low L/D capability of the 12.5° deadband may justify its selection, especially since it resulted in no more roll reversals than did the 15° deadband. The 12.5° deadband also exhibited an excellent ability in the 20% low L/D case to return the orbiter azimuth error to within the deadband following a roll reversal. Crossrange test cases under 20% low L/D conditions showed that the 12.5° deadband was superior to the 17.5° deadband for these situations, so no crossrange control has been lost by the narrower deadband. Results are shown in Table 1 and Fig. 3.1-41 - 3.1-52.

3.2 MINIMUM BANK ANGLE SCHEDULE STUDY

The primary concept in the minimum bank angle study was to determine if a minimum bank angle schedule could be established as a function of relative velocity. A procedure was defined to find an optimal minimum bank angle for several particular velocities. The orbiter azimuth error was initialized 2.5° outside the lateral deadband at each of four velocities- 16000 fps, 12000 fps, 8000 fps, and 4000 fps. A constant roll angle was then commanded in order to return the azimuth error within the deadband, and the trajectory was then analyzed to determine the effectiveness of the commanded roll angle. The smallest angle for which the azimuth error immediately decreased was chosen as the optimal minimum bank angle for that velocity. Optimal minimum bank angles were determined for the other velocities

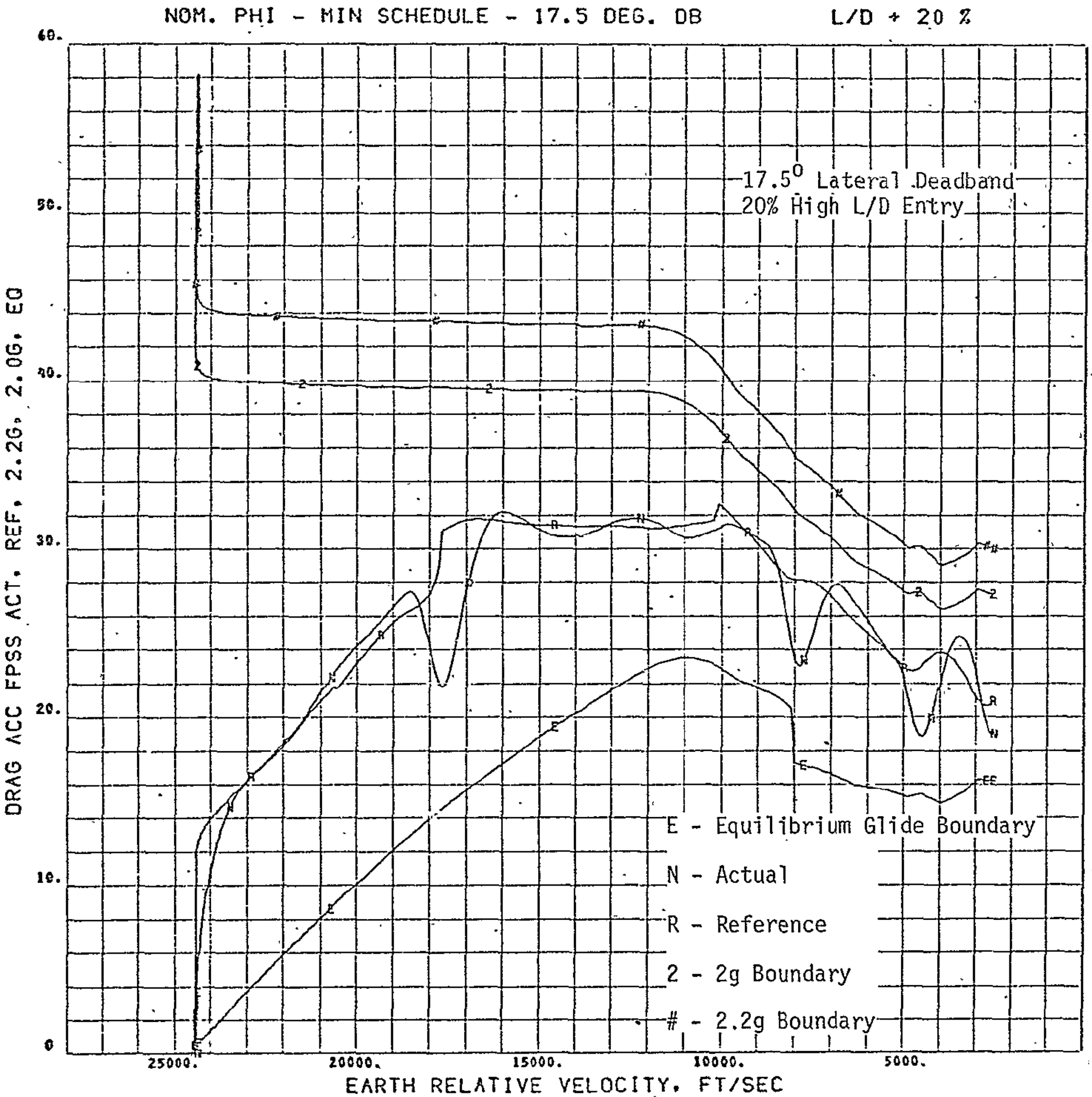


Fig. 3.1-35

Drag Acceleration Profile

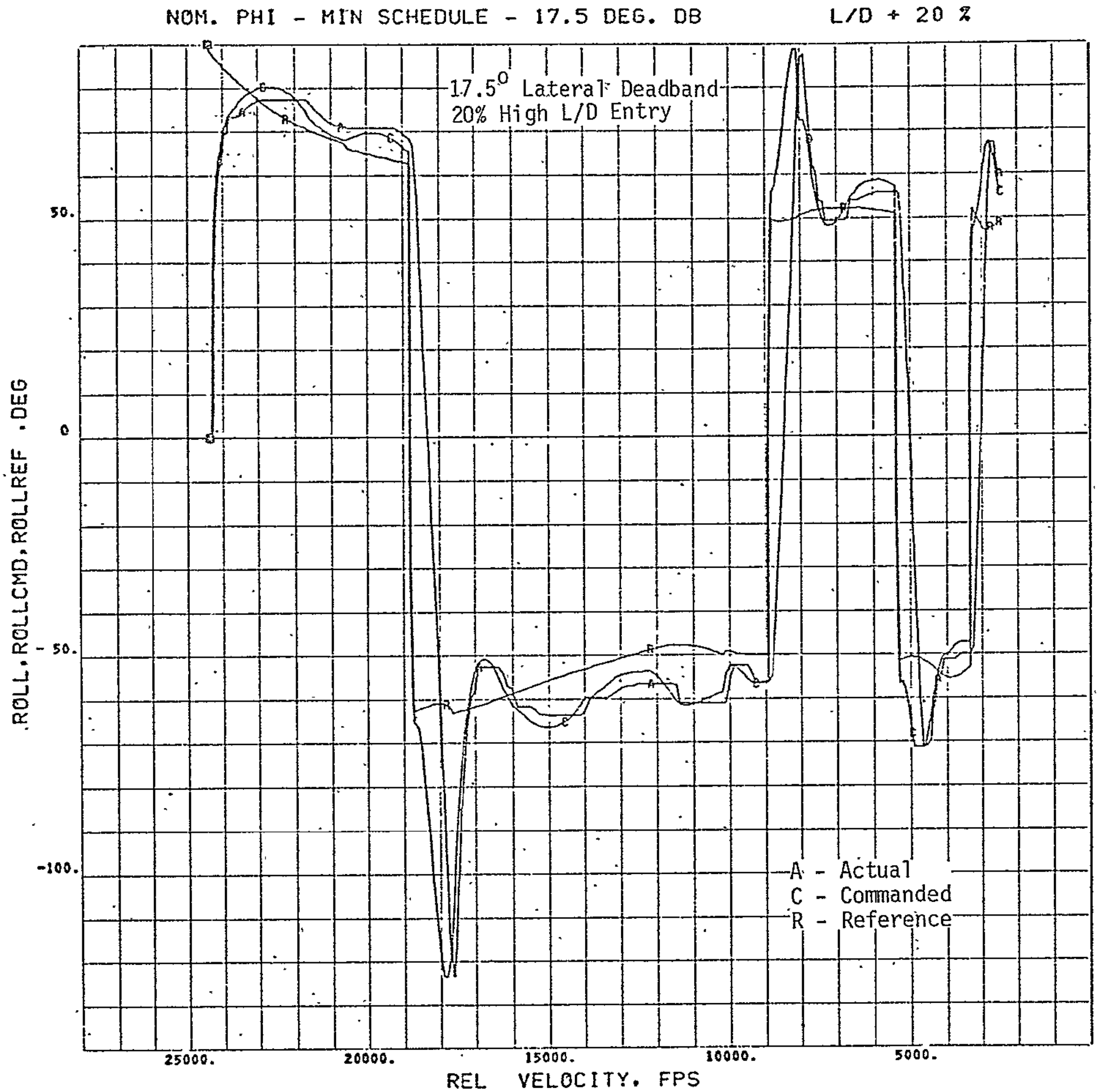


Fig. 3.1-36

Roll Angle

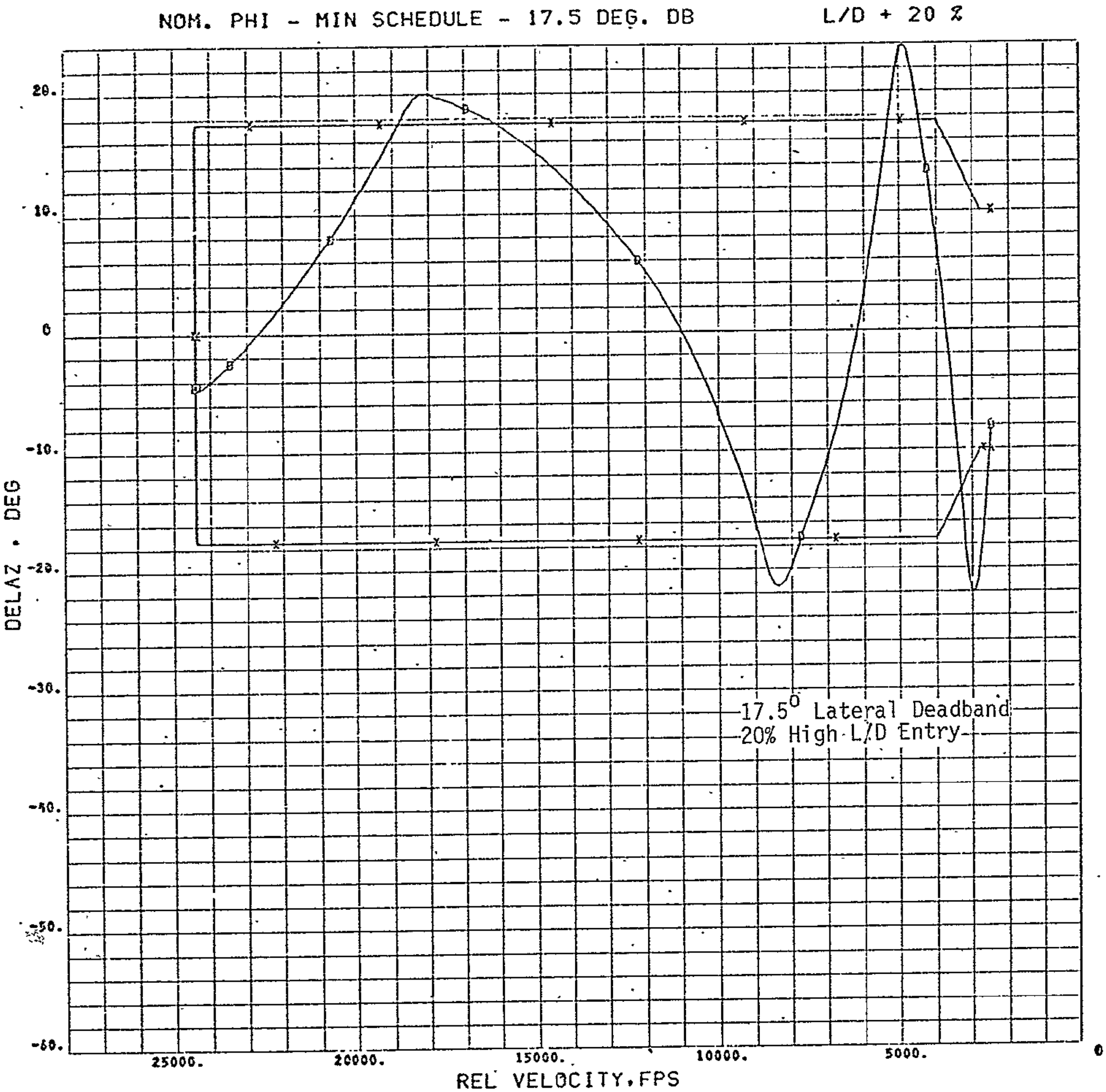


Fig. 3.1-37

Azimuth Error

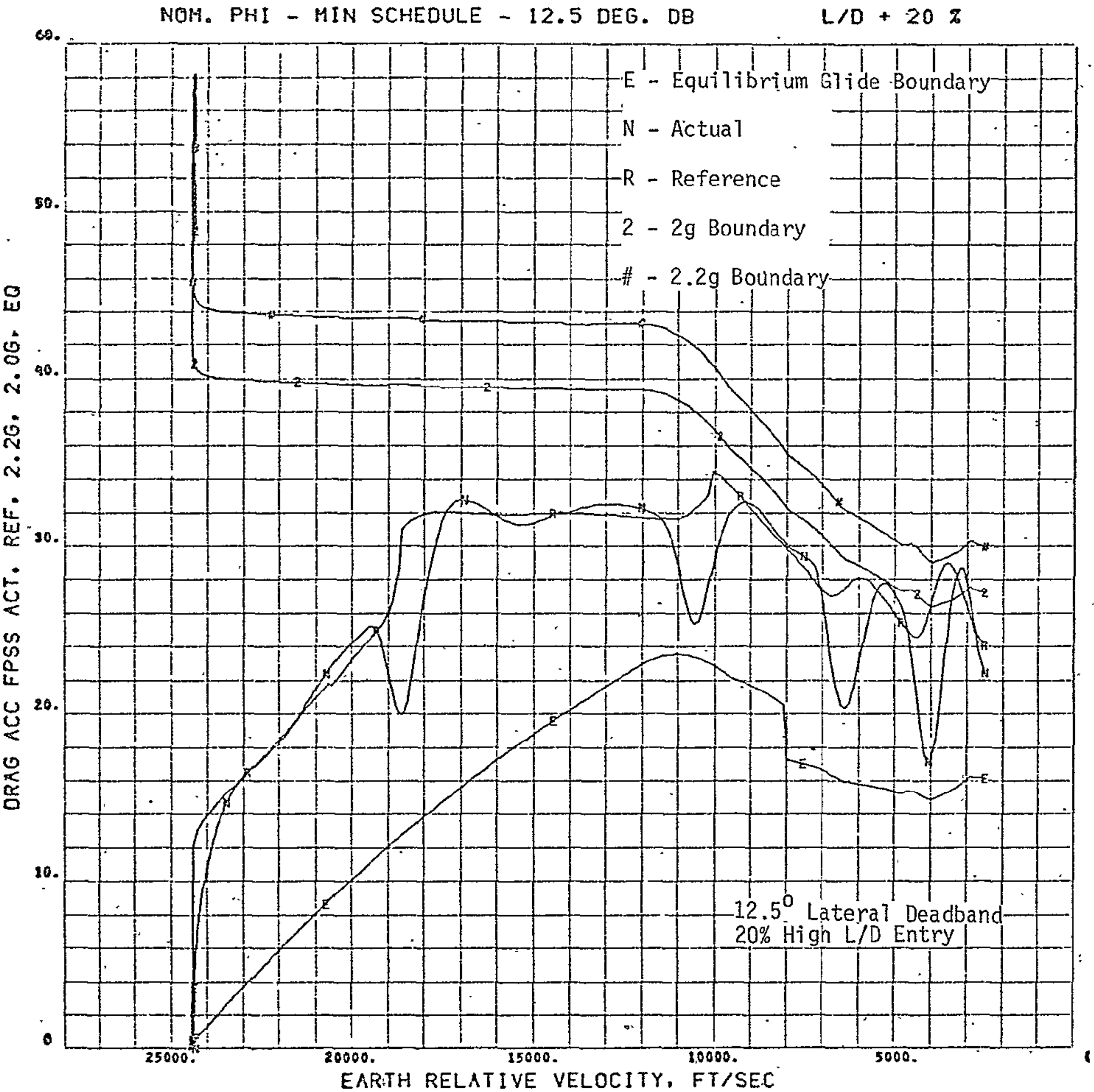


Fig. 3.1-38

Drag Acceleration Profile

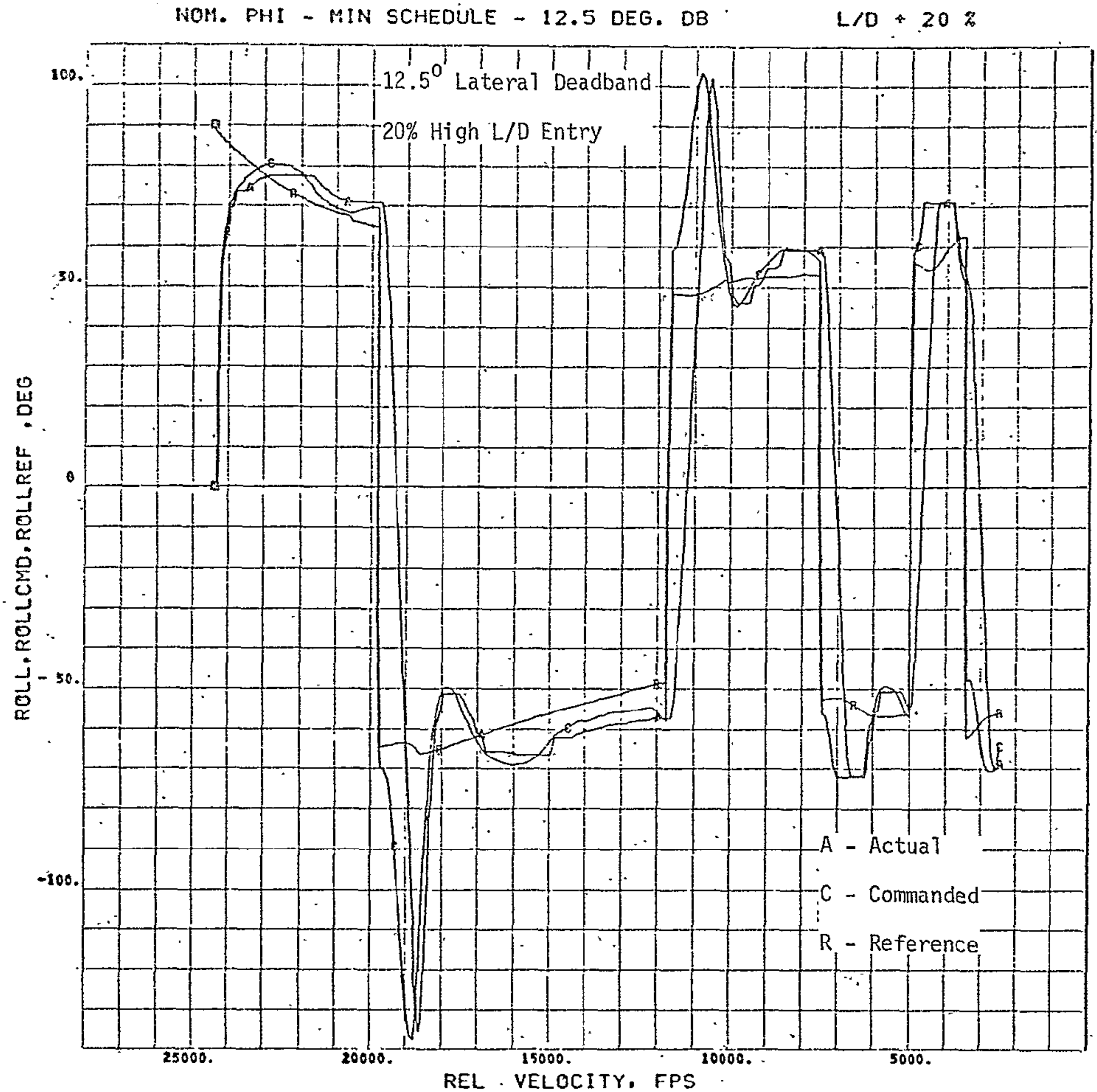


Fig. 3.1-39
Roll Angle

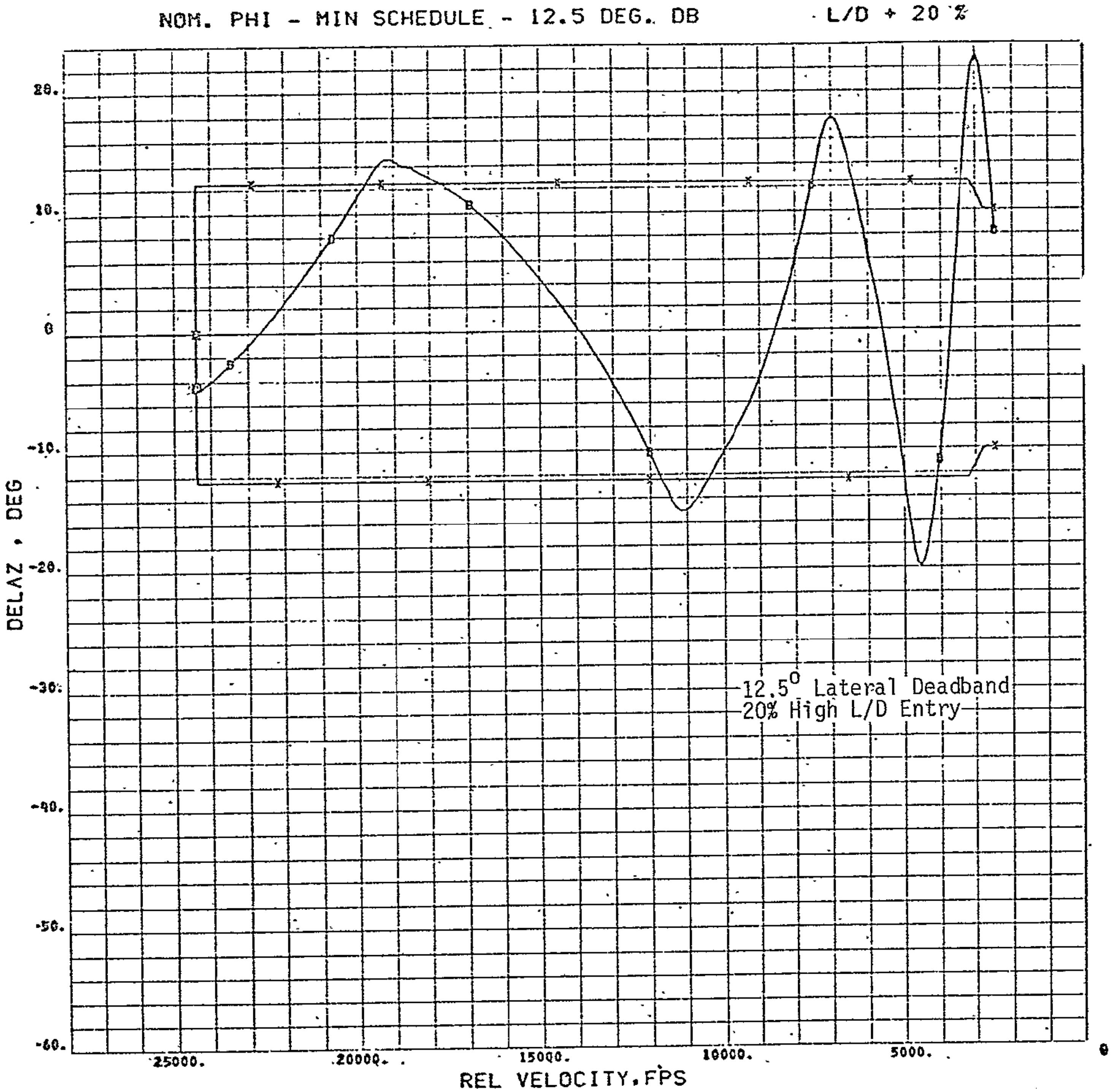


Fig. 3.1-40

Azimuth Error

Crossrange, n.m.	TAEM interface miss distance, n.m.	
	12.5^{o} deadband	17.5^{o} deadband
600	97	97
400	0.65	2.26
200	1.1	21.0

Table 1. Crossrange Capability for 12.5^{o} and 17.5^{o} Lateral Deadbands with 20% low L/D

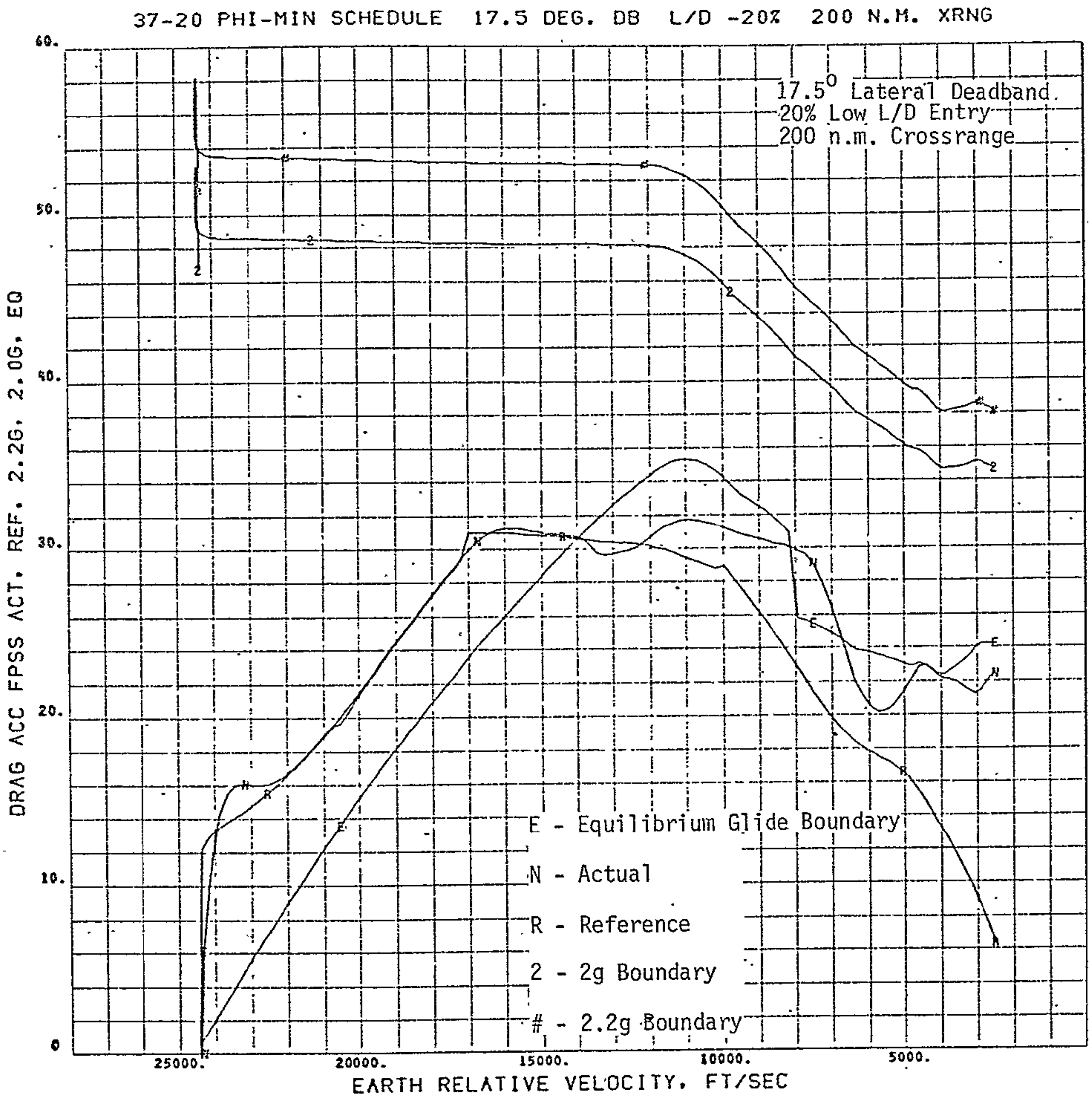


Fig. 3.1-41

Drag Acceleration Profile

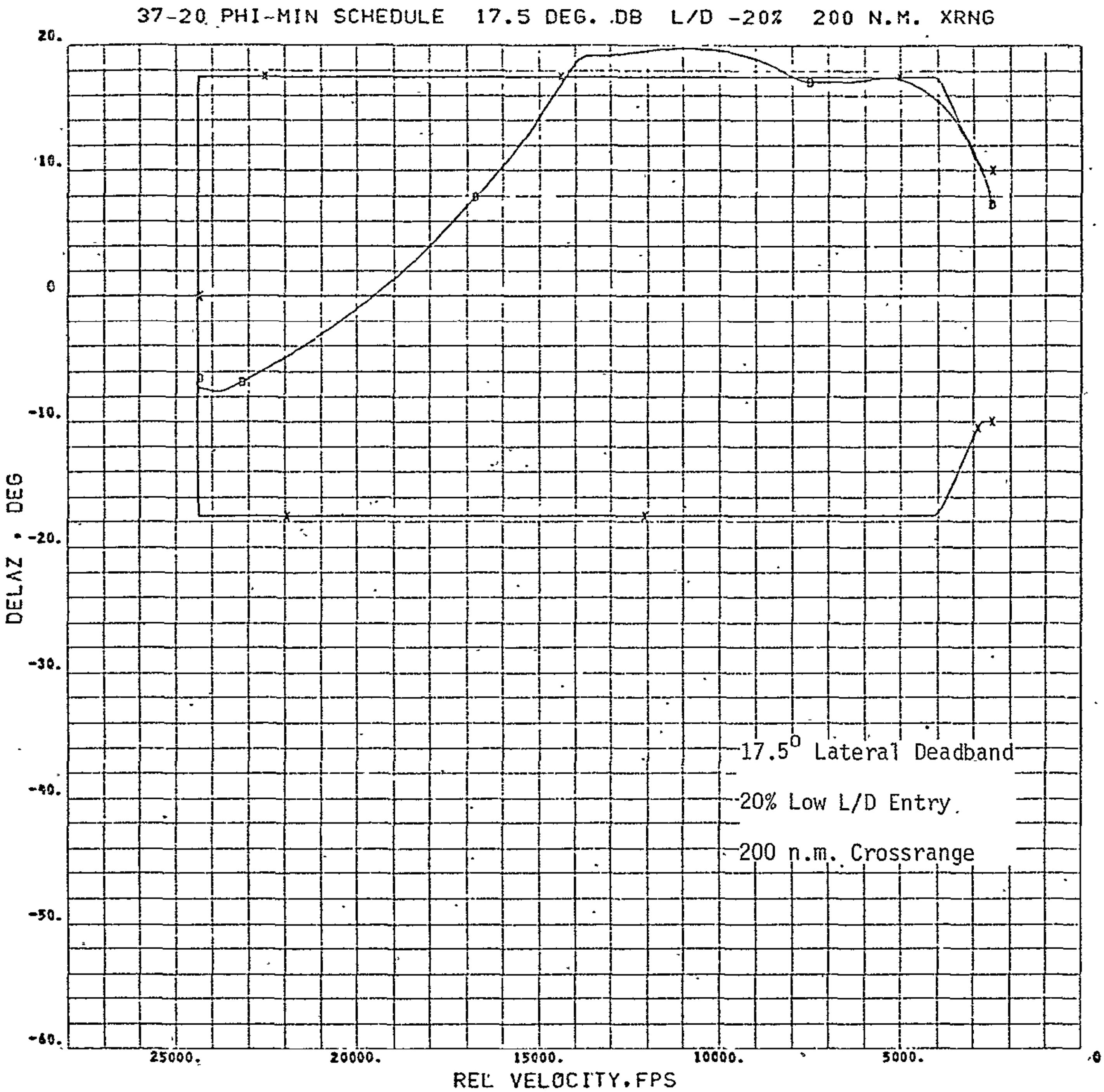


Fig. 3.1-42

Azimuth Error

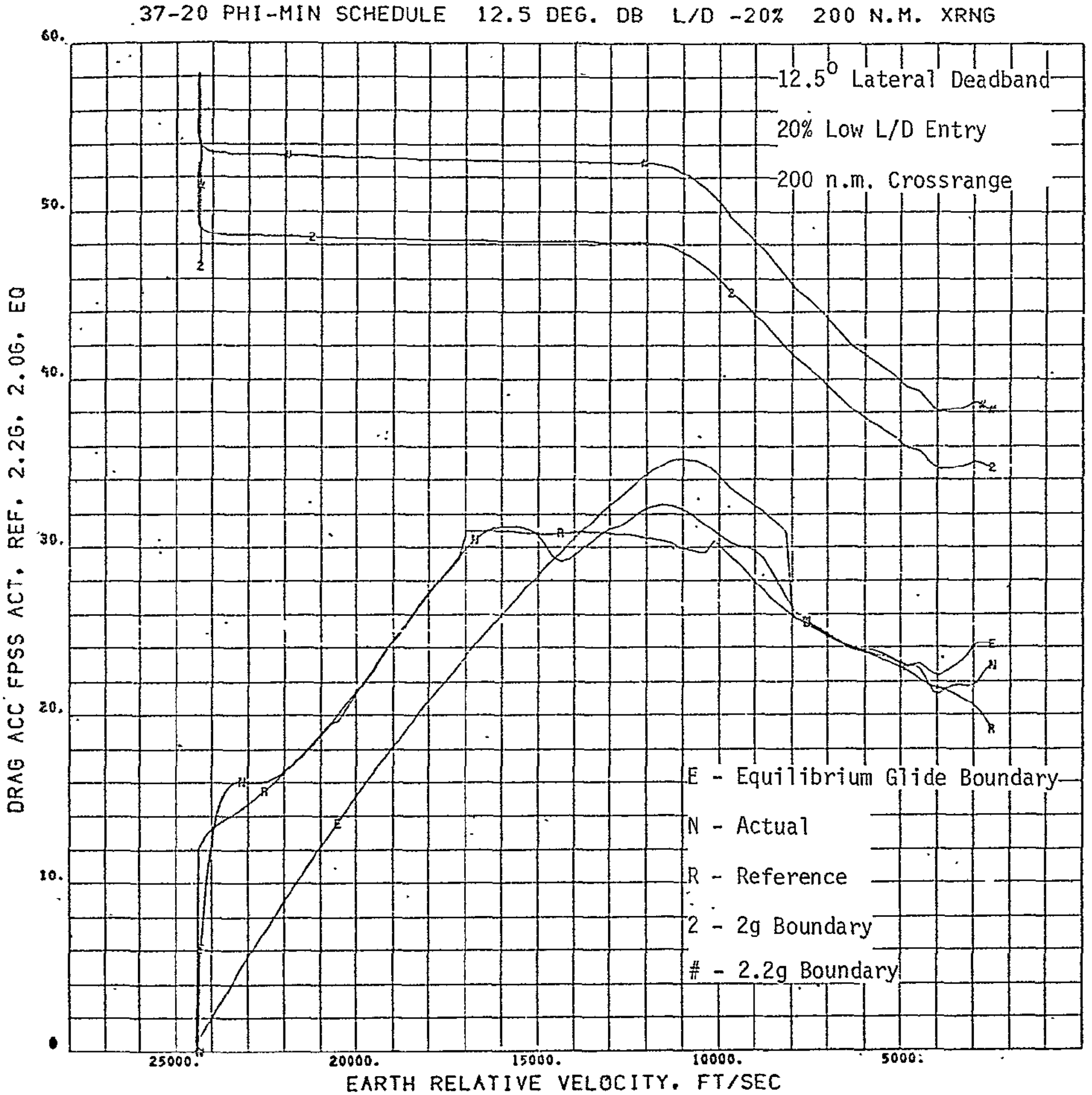


Fig. 3.1-43

Drag Acceleration Profile

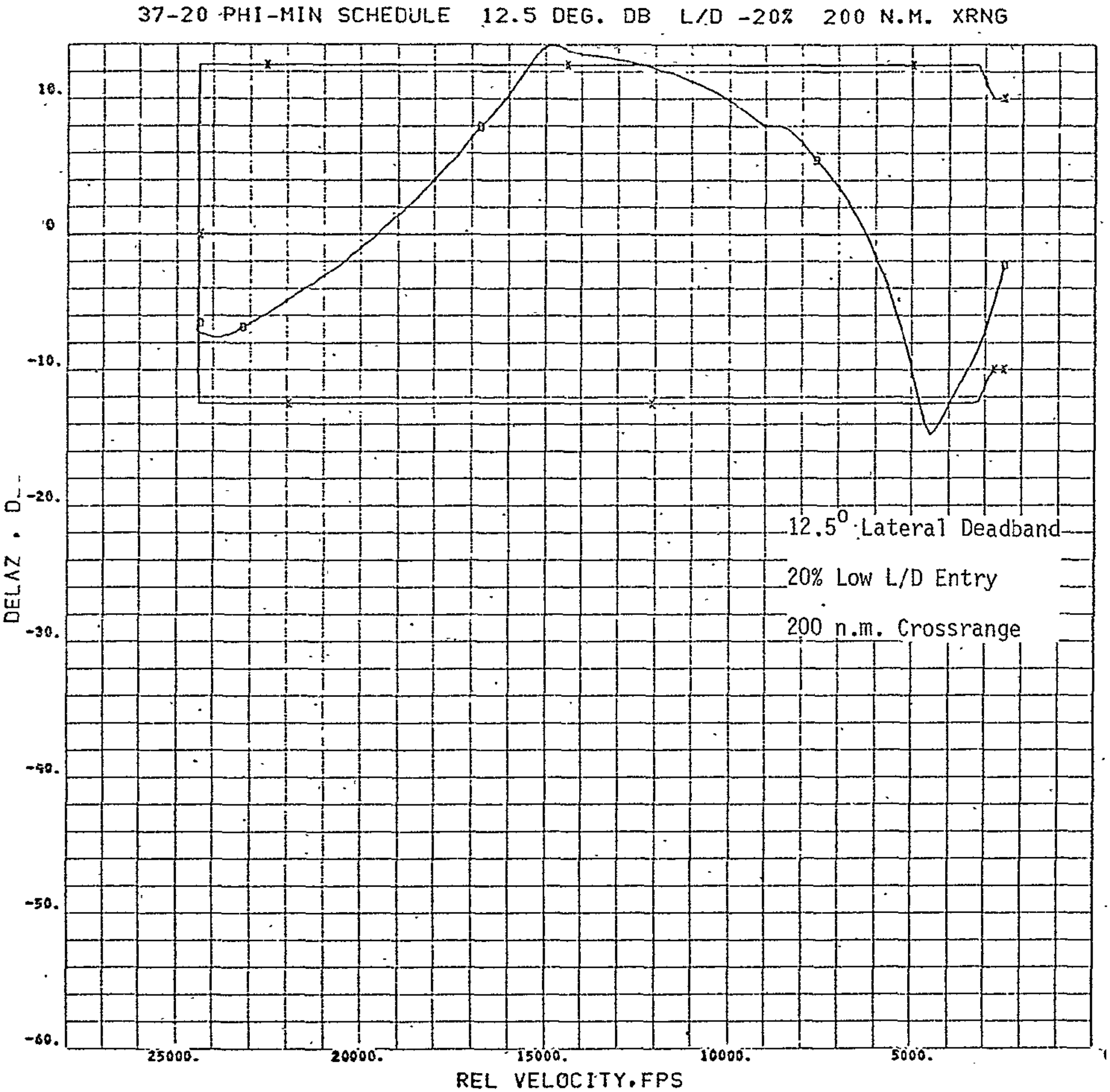


Fig. 3.1-44

Azimuth Error

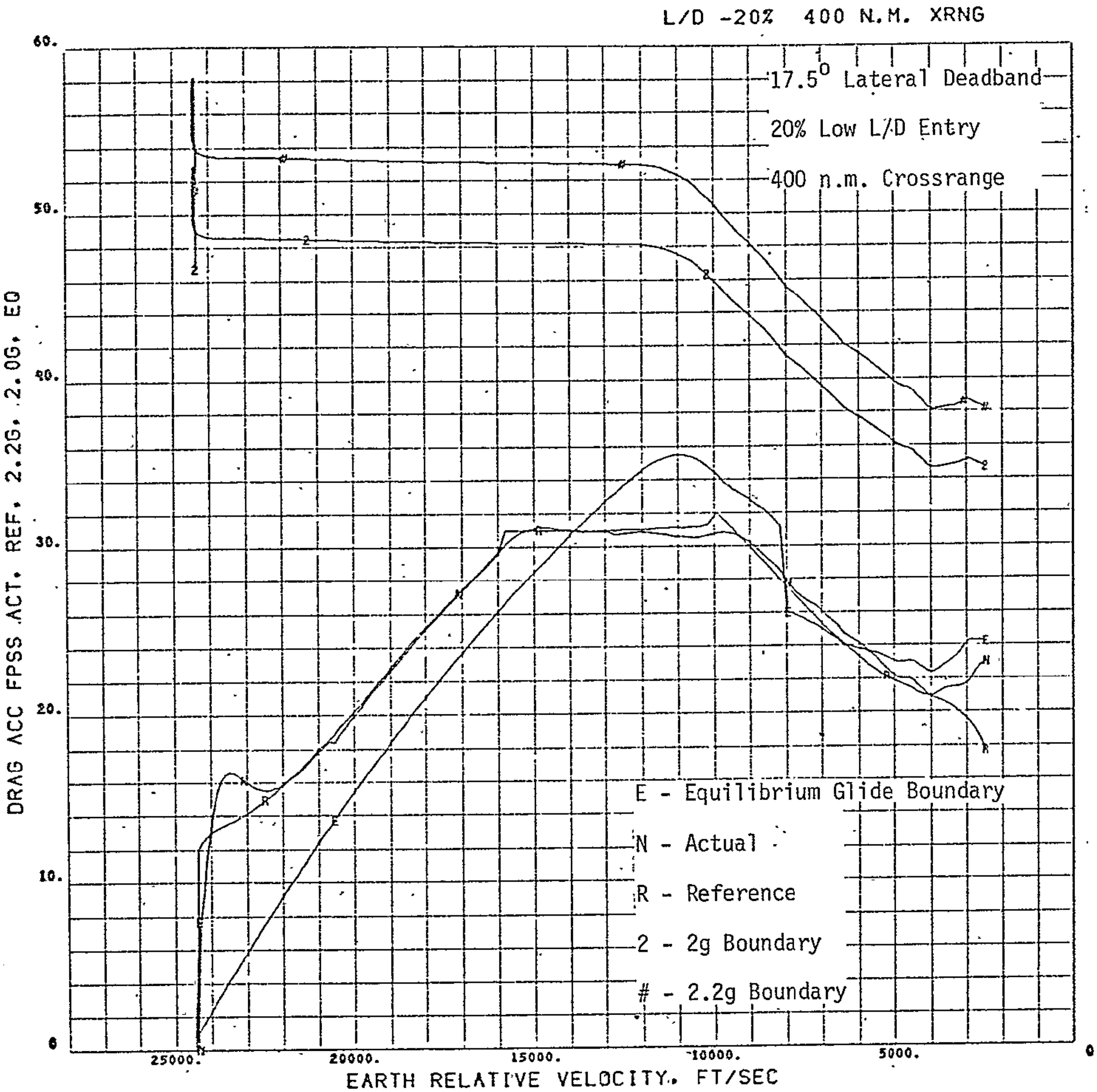


Fig. 3.1-45

Drag Acceleration Profile

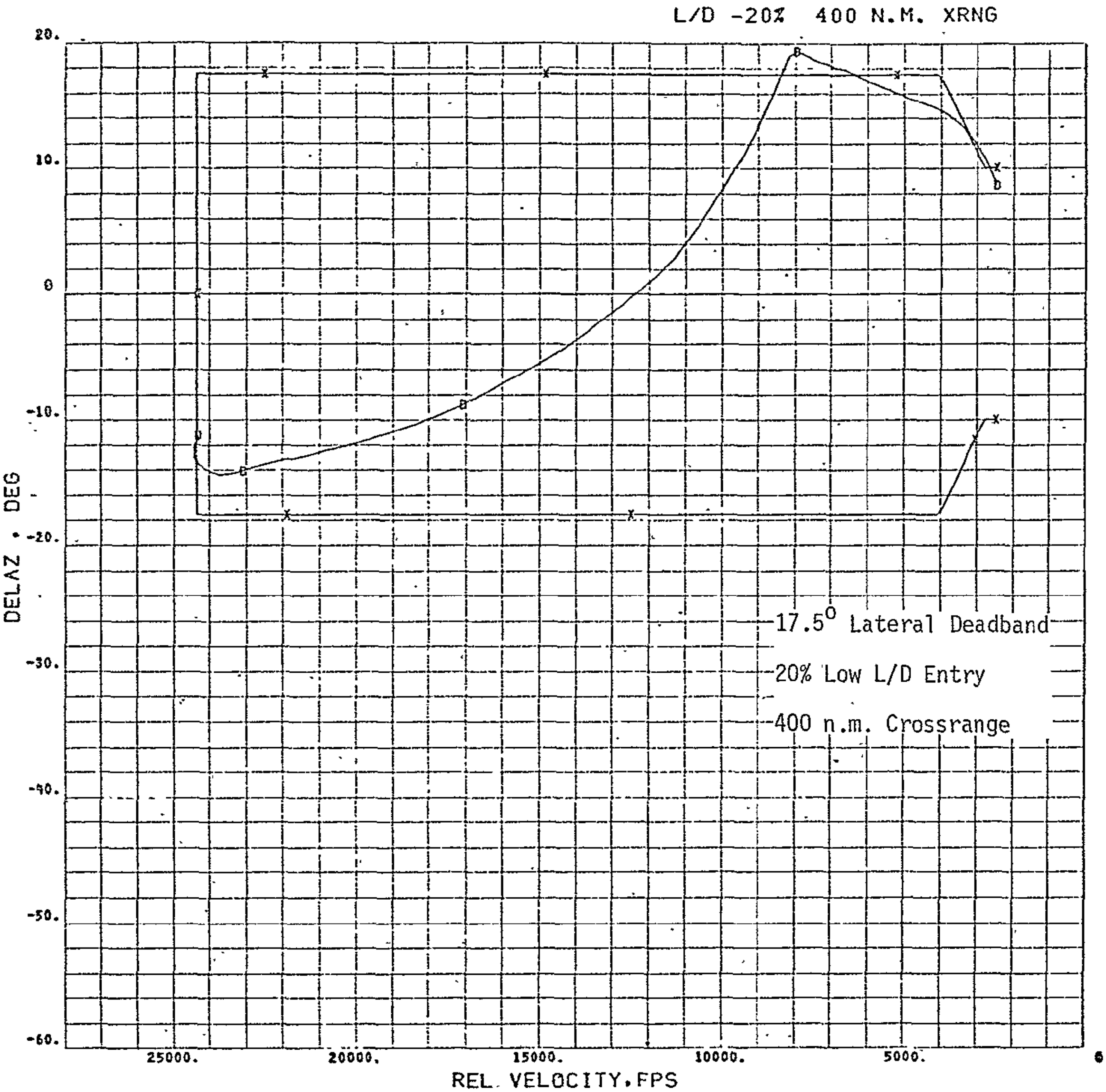


Fig. 3.1-46

Azimuth Error

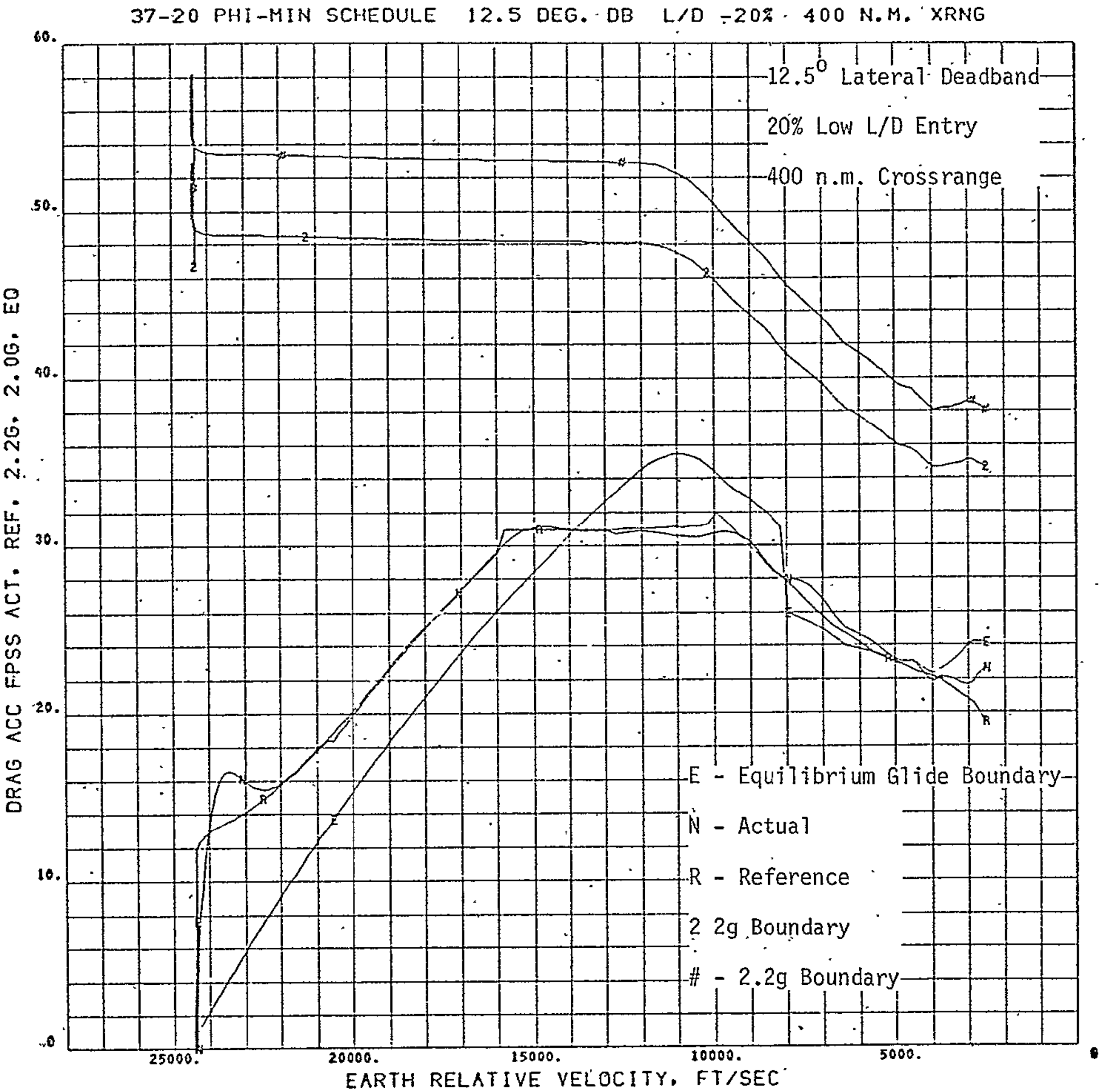


Fig. 3.1-47

Drag Acceleration Profile

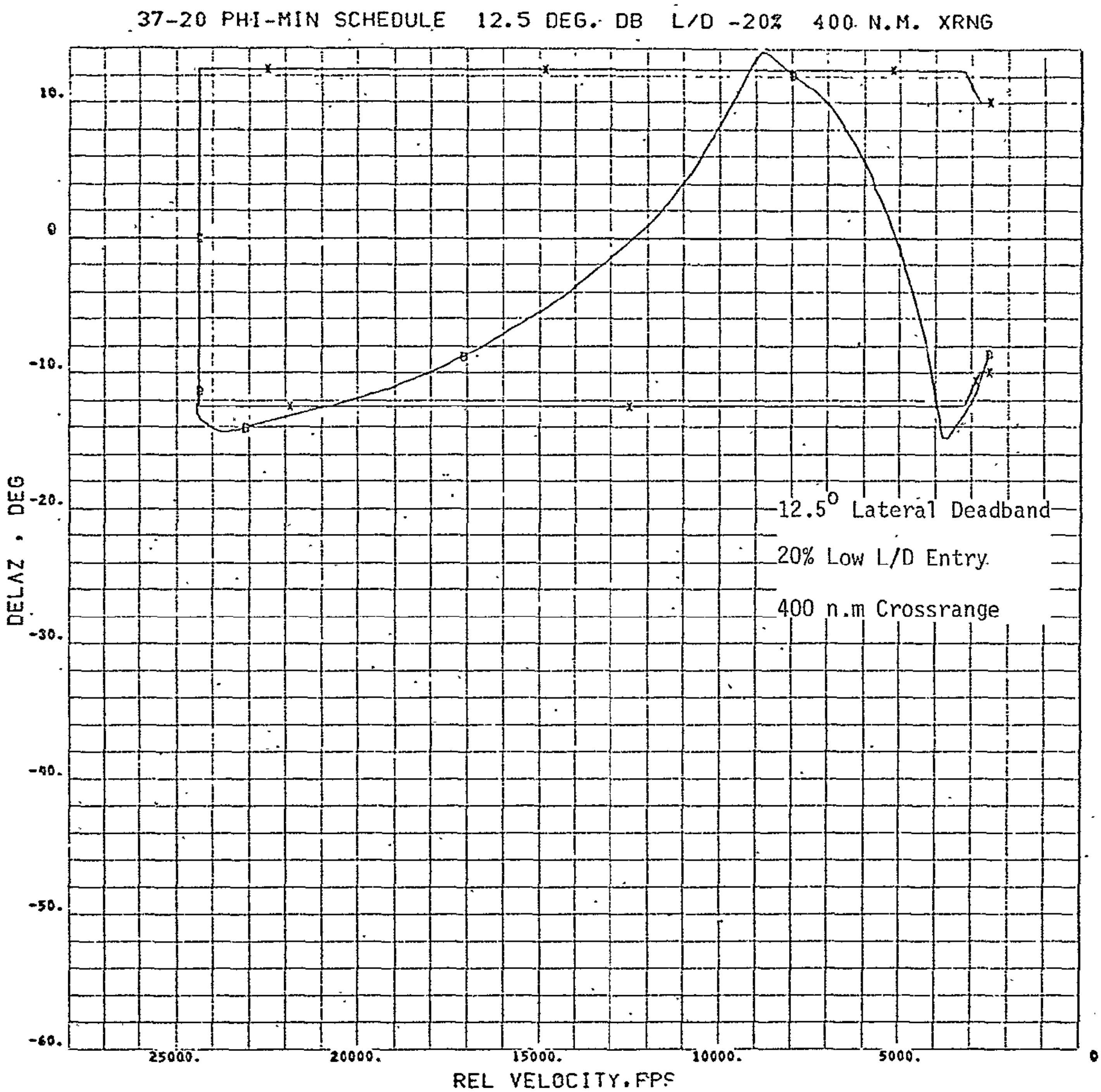


Fig. 3.1-48

Azimuth Error

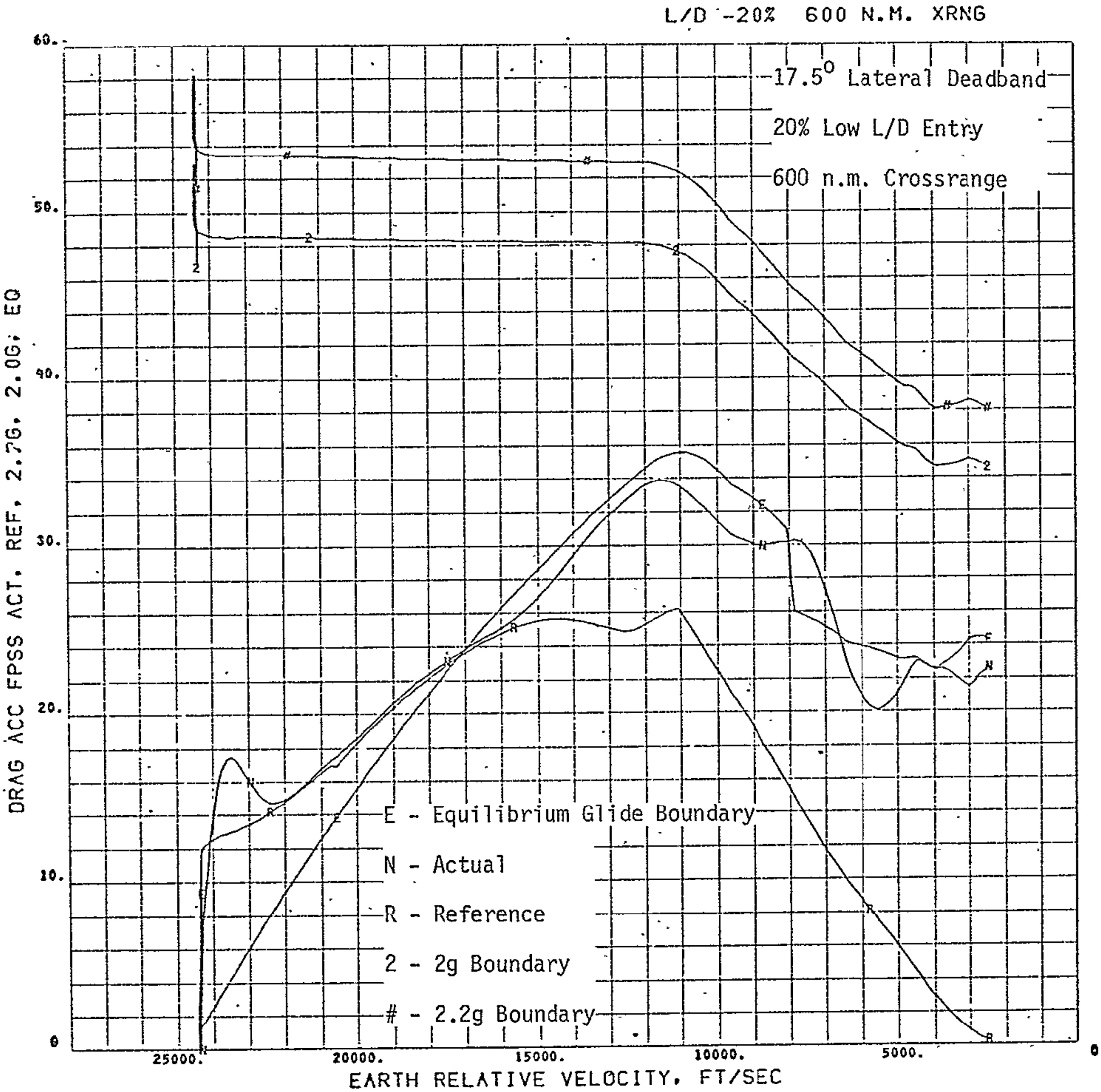


Fig. 3.1-49

Drag Acceleration Profile

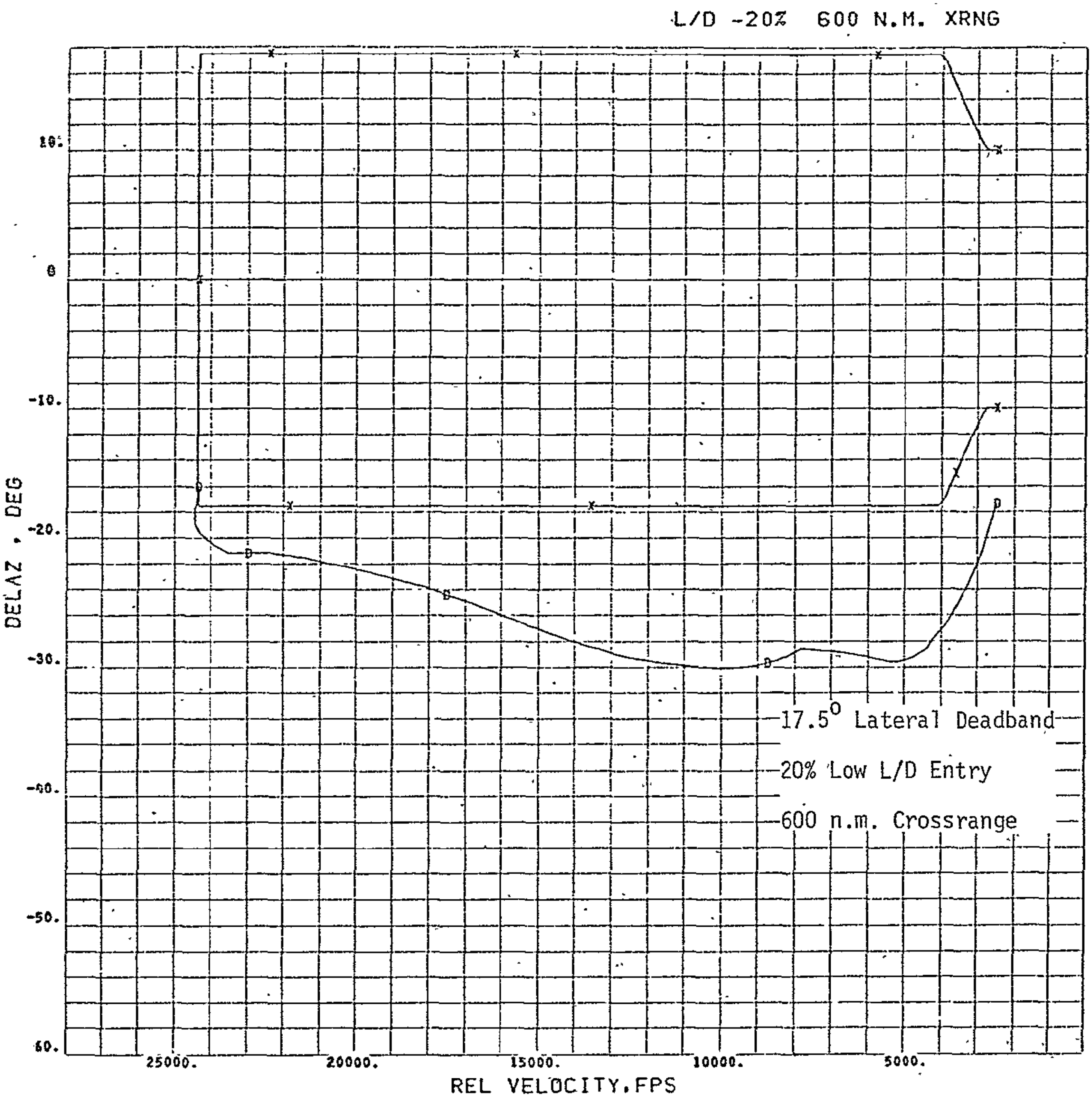


Fig. 3.1-50

Azimuth Error

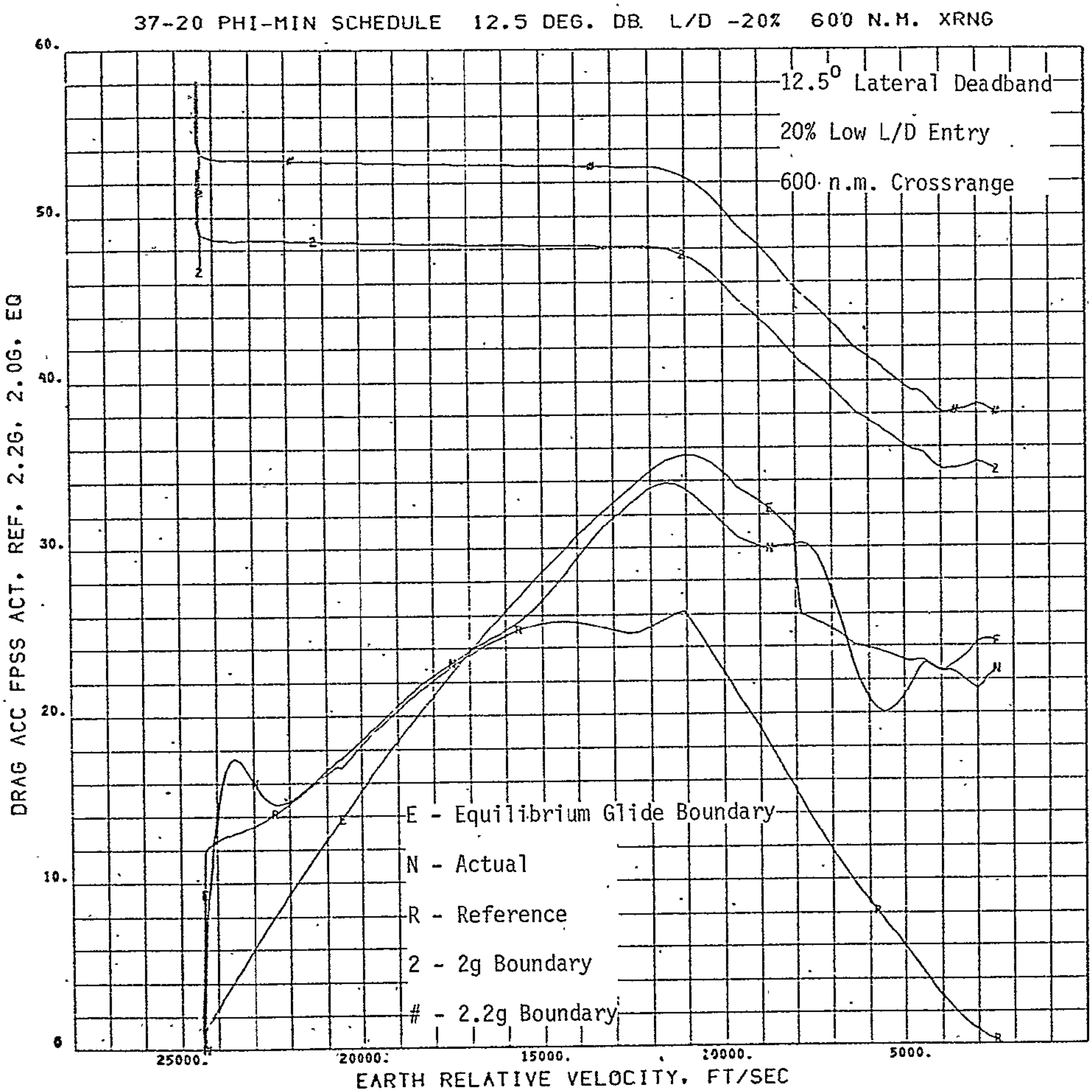


Fig. 3.1-51

Drag Acceleration Profile

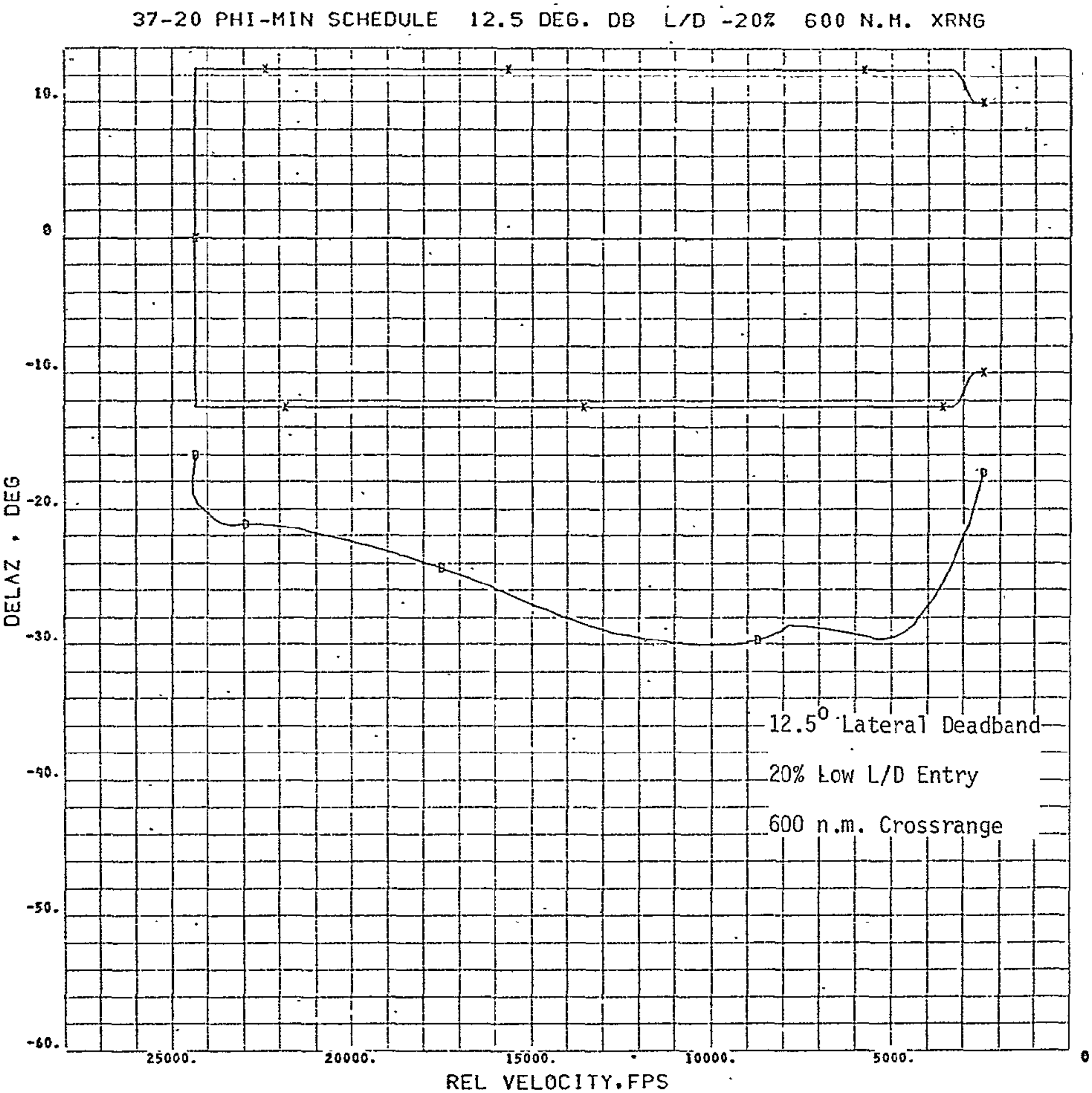


Fig. 3.1-52

Azimuth Error

as well as for cases of 10% low L/D and 20% low L/D. Typical cases are shown in Figures 3.2-1 - 3.2-4. Using this data (Table 2), a quadratic curve fit was then applied for the nominal, 10% low L/D, and 20% low L/D cases.

The 20% low L/D case, as in the lateral deadband study, was selected as the design case in order to accommodate possible low L/D dispersions during entry. The minimum bank angle schedule for this case was limited to between 29^{o} and 60^{o} to eliminate unnecessary portions of the quadratic function in order that the schedule could be used in the entry guidance. This schedule is identified as Schedule #1 in Figure 3.2-5.

Schedule #1 was then incorporated in the entry guidance logic and tested in a nominal entry run. However, the schedule did not allow the guidance to follow the reference drag acceleration profile adequately Figures 3.2-6 - 3.2-8 show that the scheduled minimum bank angle differed by 10^{o} from the reference roll angle, resulting in the actual drag acceleration being 11 fps^{2} higher than the reference profile. The consequence of these deviations was that the roll angle decreased to the 15^{0} limit at a velocity of 13000 fps in order to maintain drag control. Schedule #1 was determined to be too restrictive to be used operationally, since the comparatively steep minimum bank angle schedule resulted in too high a drag level for a nominal entry.

Accordingly, Schedule #1 was continously decreased by 7^{o} to attempt to eliminate this problem. The lowered schedule is identified as Schedule #2 in Figure 3.2-5. Schedule #2 was also limited to between

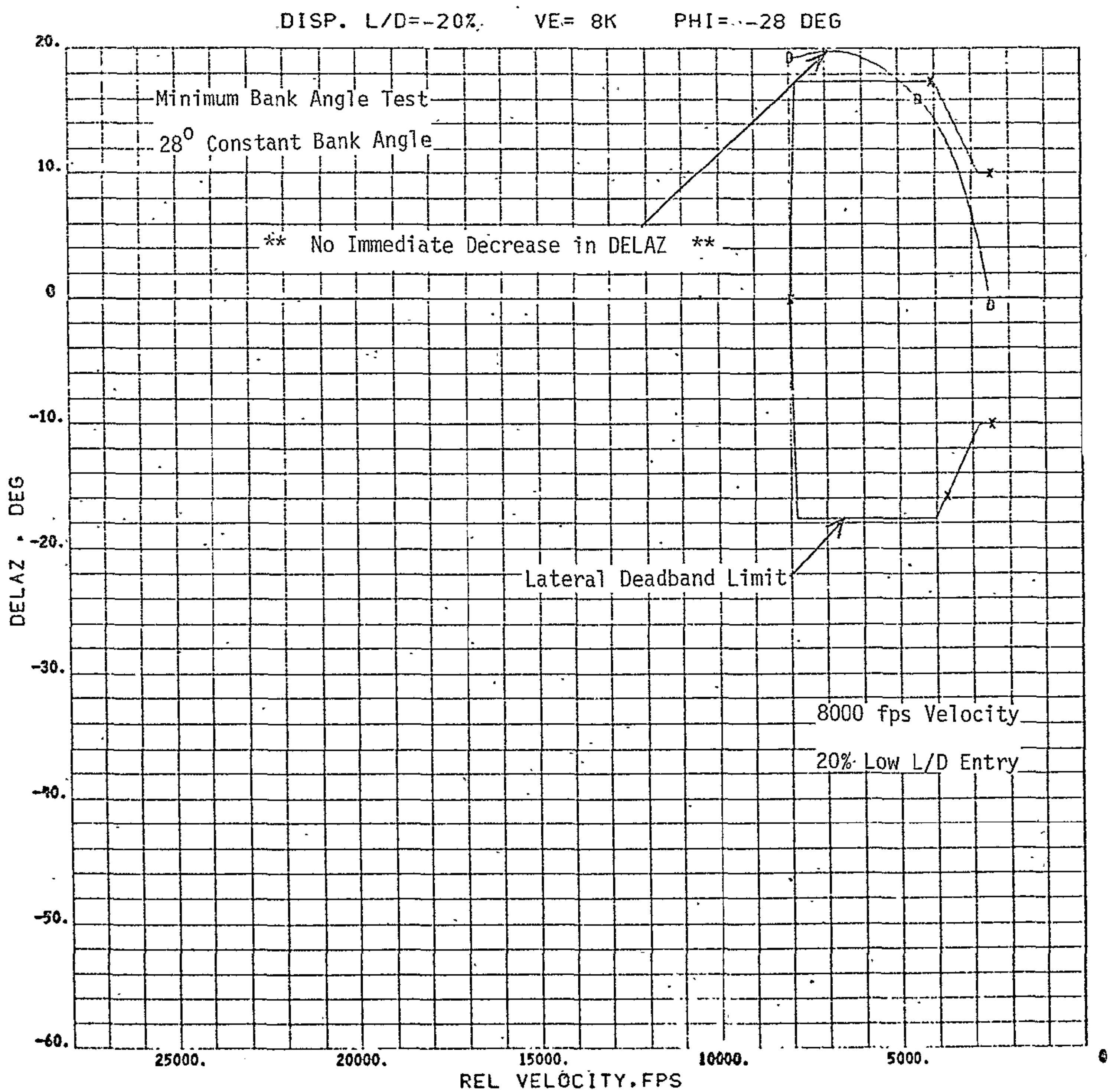


Fig. 3.2-1
Azimuth Error

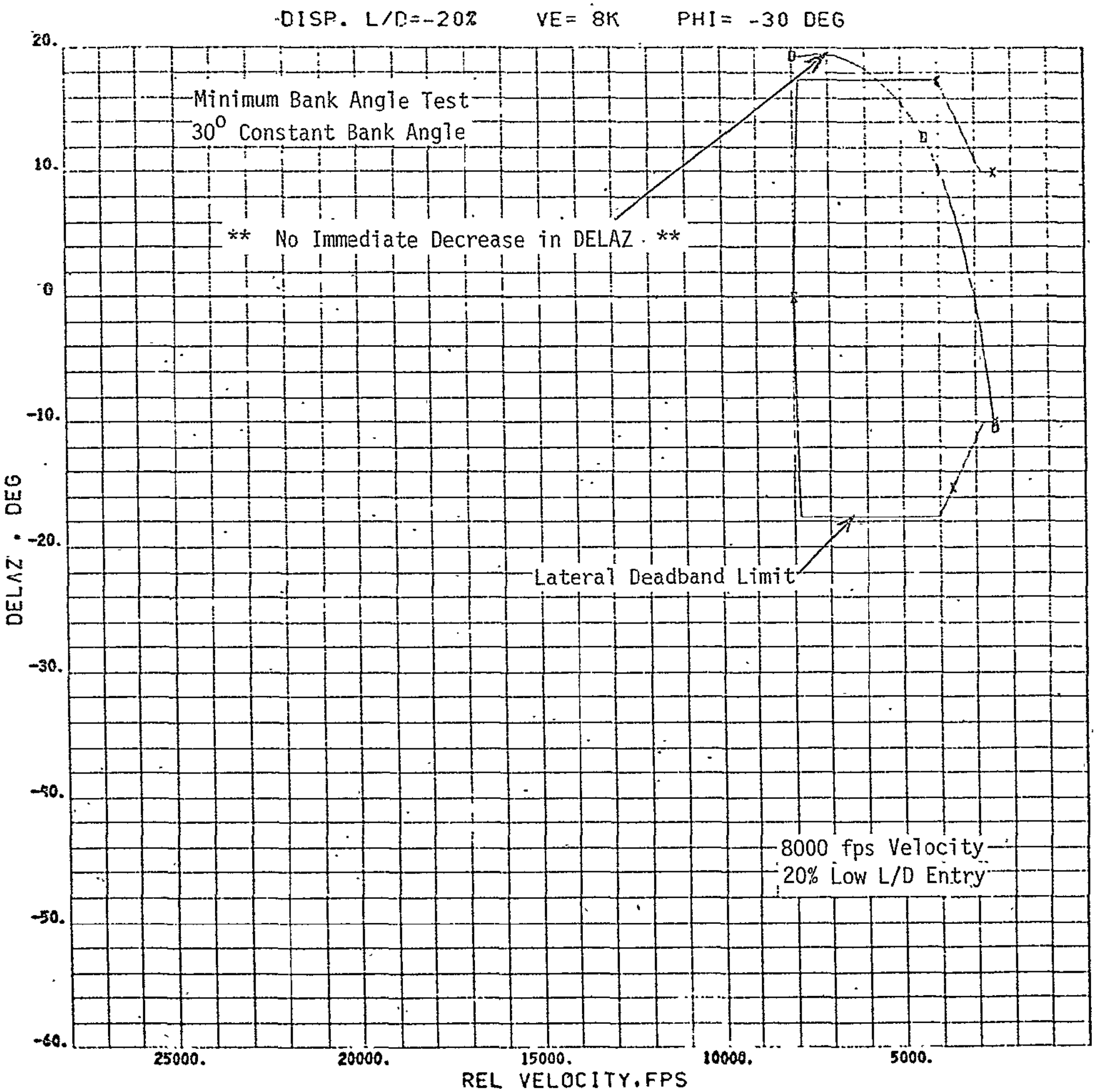


Fig. 3.2-2

Azimuth Error

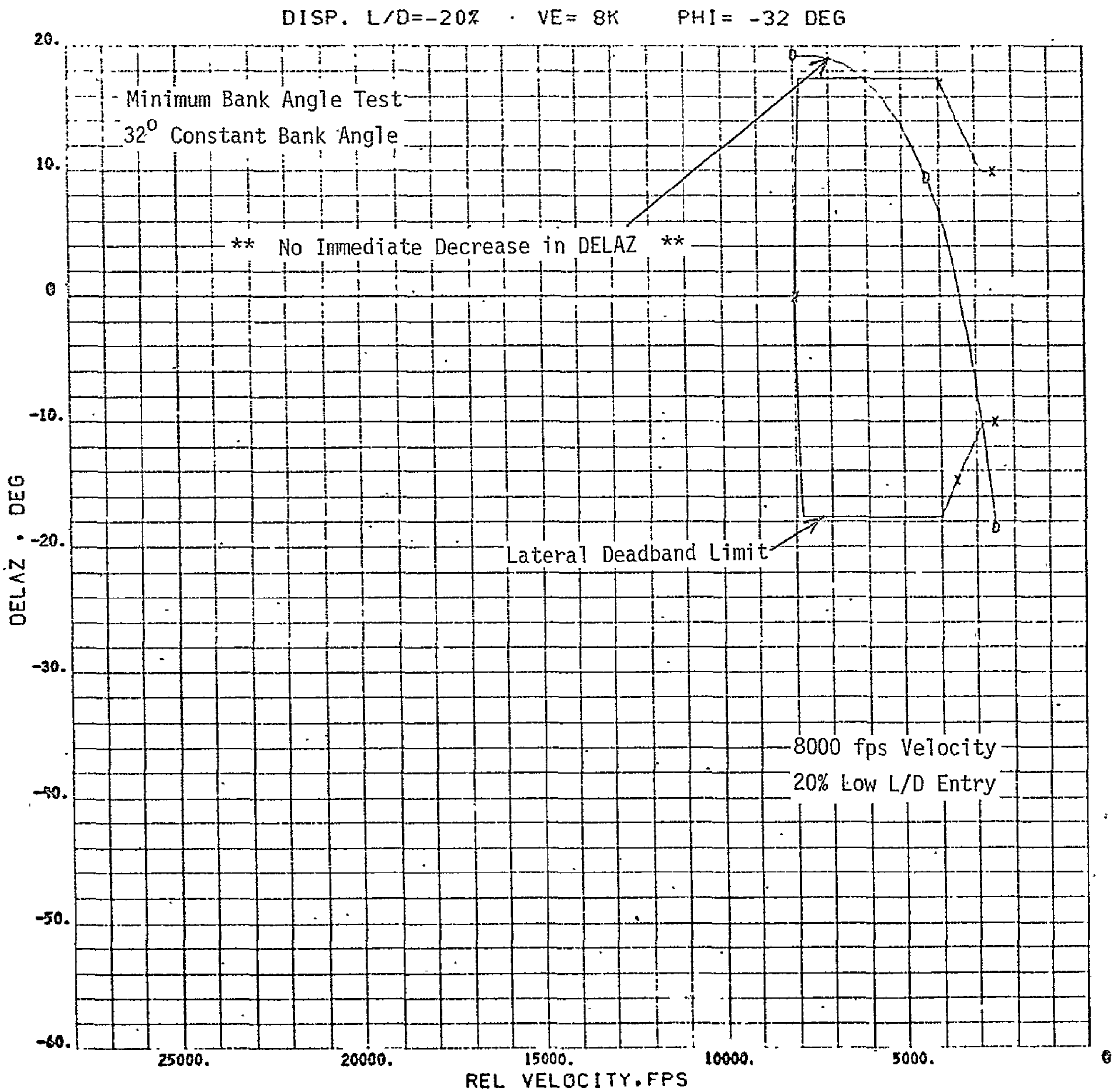


Fig. 3.2-3

Azimuth Error

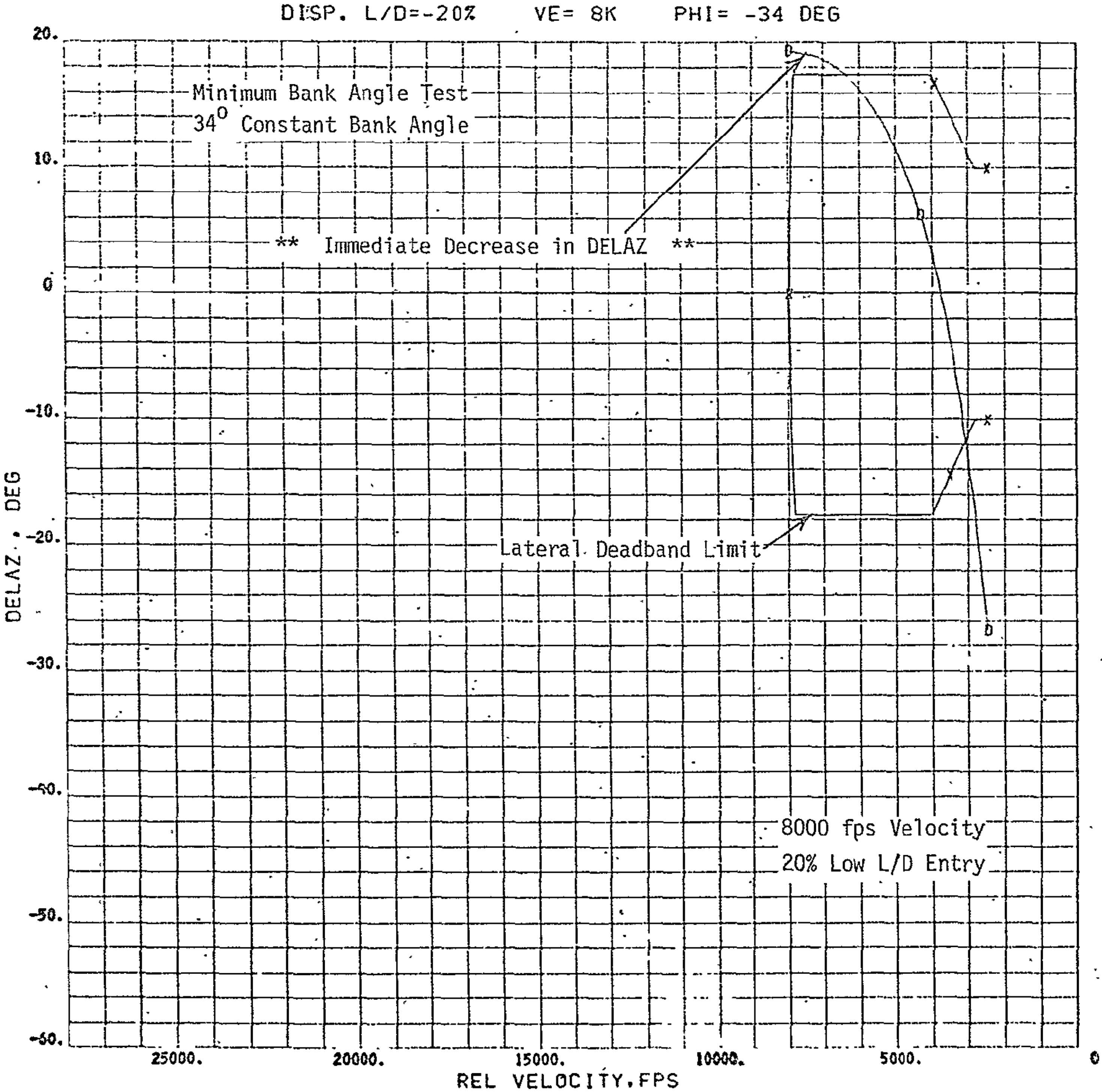


Fig. 3.2-4

Azimuth Error

Relative Velocity, fps	Optimal Minimum Bank Angle, degrees		
	nom. L/D	10% Low L/D	20% Low L/D
16000	62	62	64
12000	40	42	44
8000	30	32	34
4000	27	29	29

Table 2. Optimal Minimum Bank Angles
for Varying L/D Dispersions

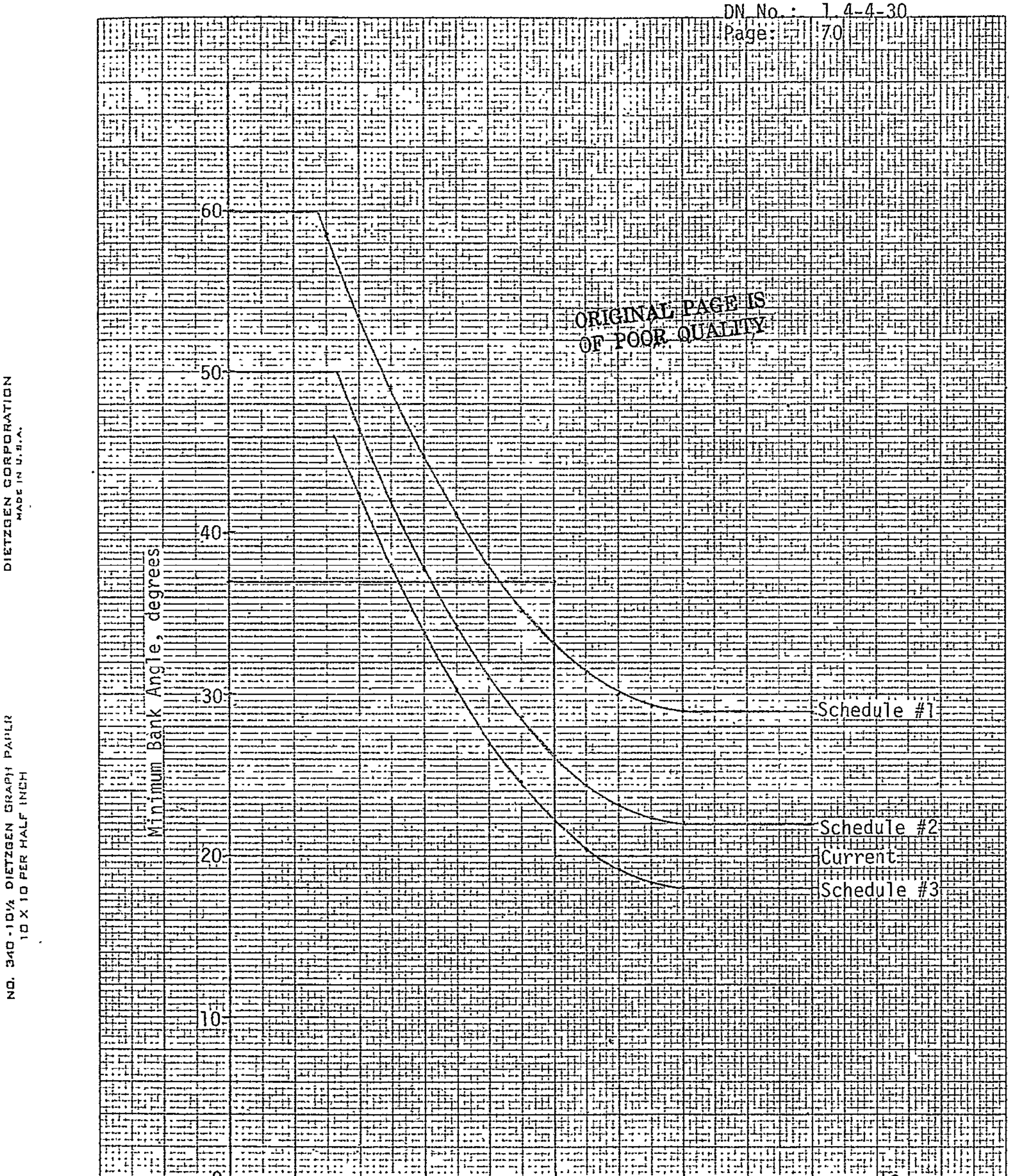


Fig. 3.2-5
Minimum Bank Angle Schedules

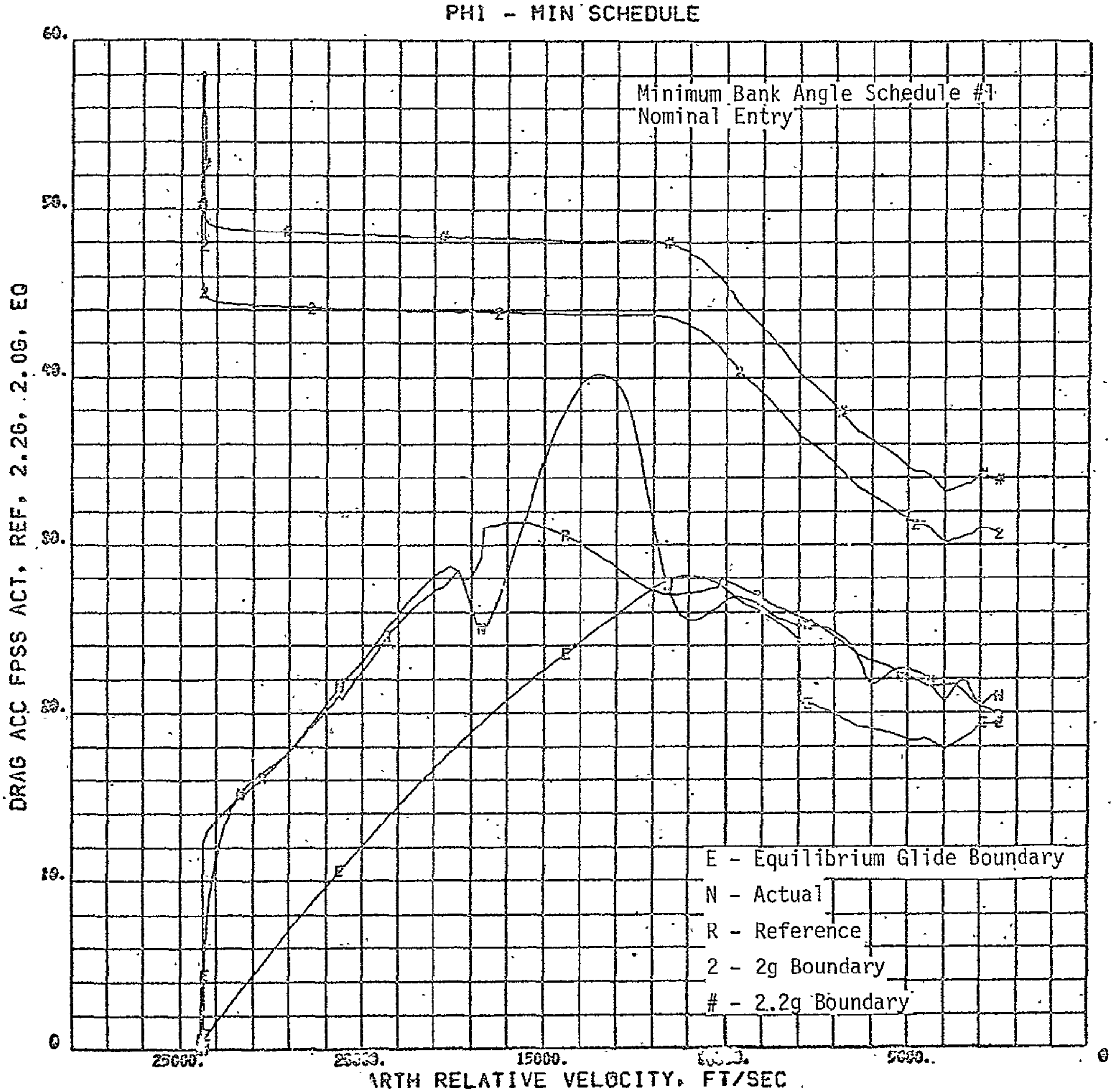


Fig. 3.2-6

Drag Acceleration Profile

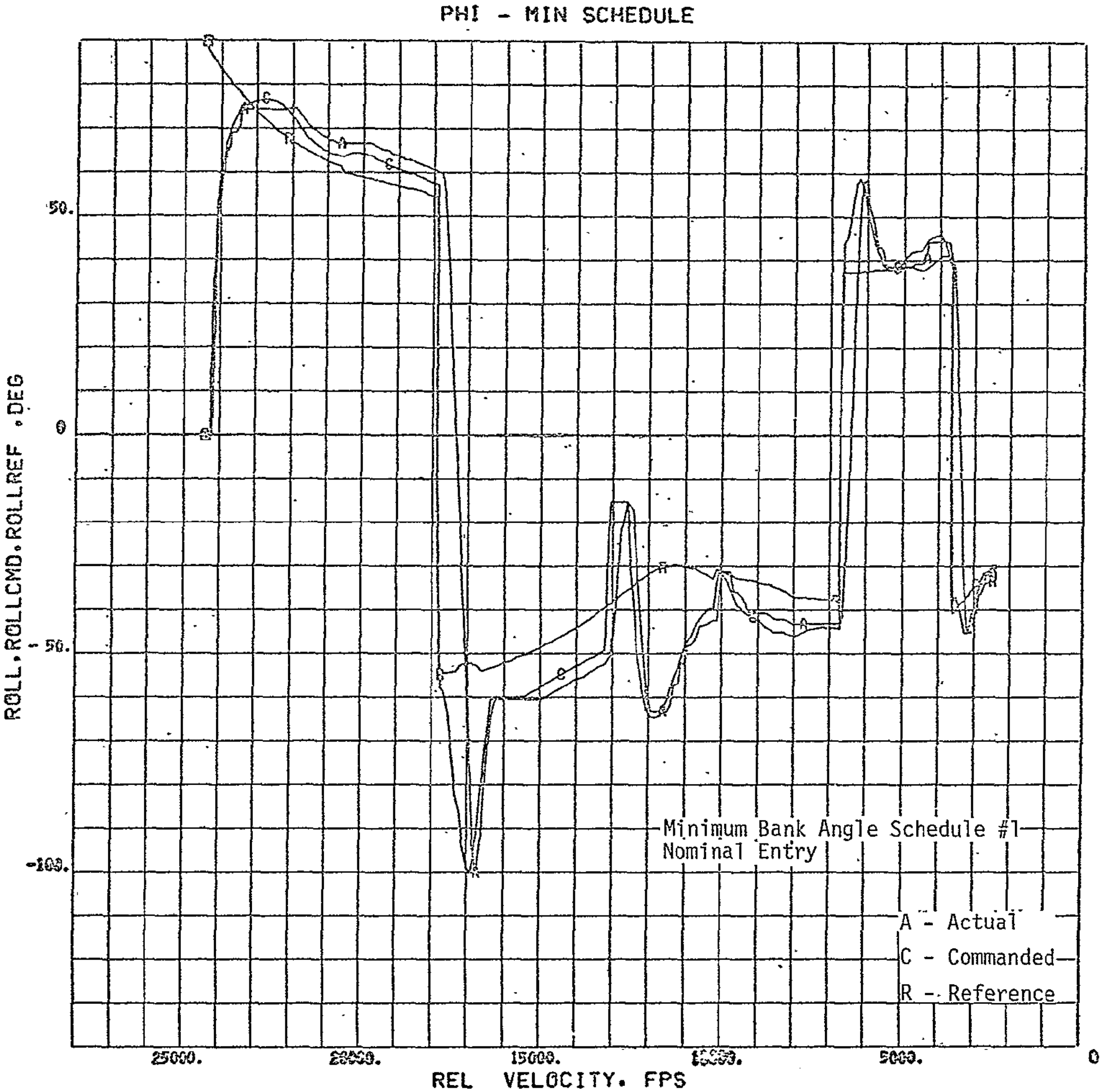


Fig. 3.2-7

Roll Angle

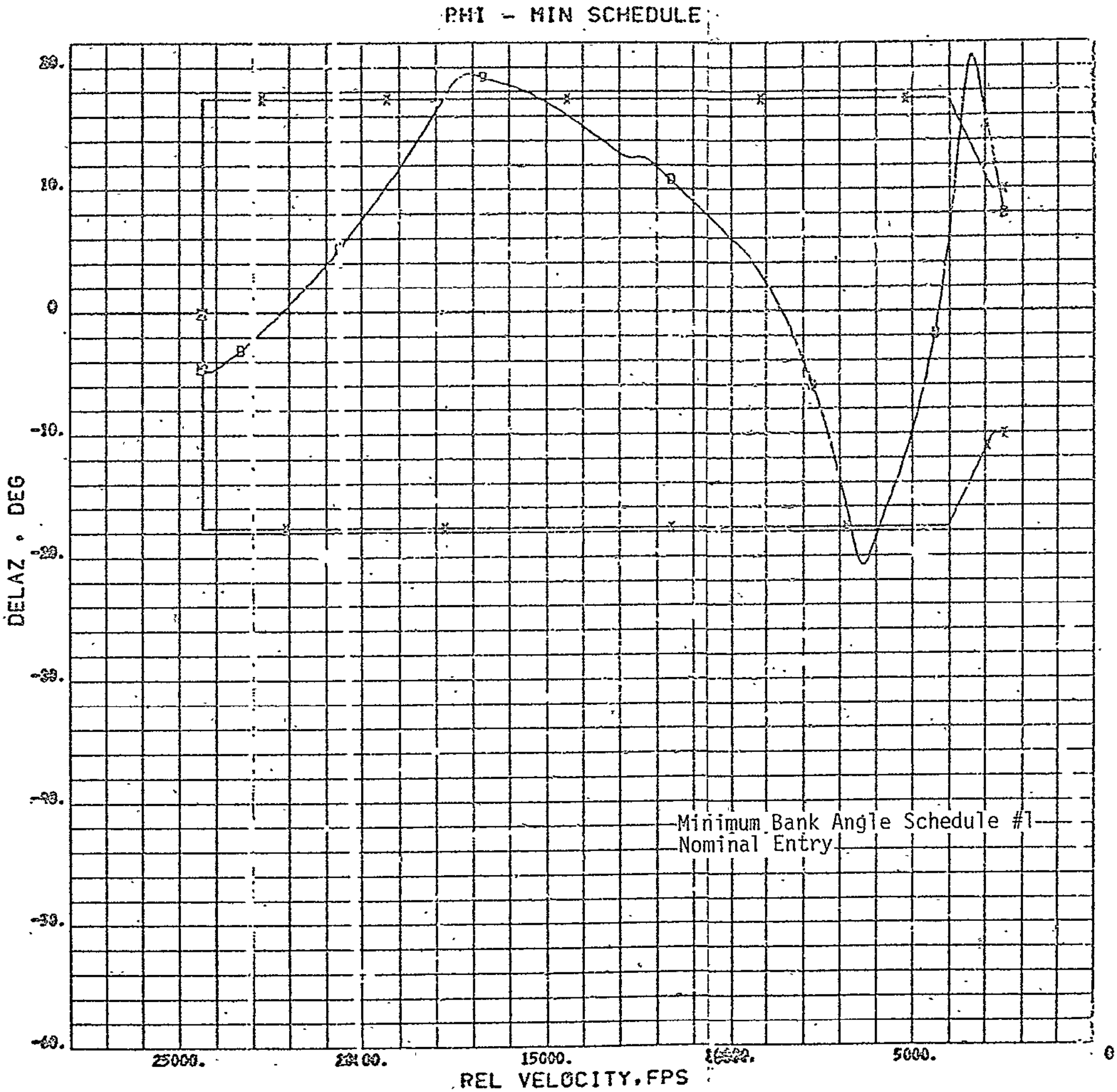


Fig. 3.2-8
Azimuth Error

22° and 50°, similar to Schedule #1. Schedule #2 was much improved over Schedule #1 for nominal entry conditions with the 12.5° lateral deadband; Figures 3.2-9 - 3.2-11 show that the reference drag acceleration profile was maintained without significant deviations. In the 20% low L/D design case (Fig. 3.2-12 - 3.2-14), however, the performance of Schedule #2 was unacceptable; the actual drag acceleration was 9 fps^2 higher than the reference profile, and the roll angle went to the 15° limit at velocities of 12000 fps and 9500 fps. Schedule #2 was still too conservative and too steep to be usable for all entry cases.

In an effort to produce a viable minimum bank angle schedule, it was decided to relax one of the initial constraints. The initialization of the azimuth error 2.5° outside the deadband was considered to be too strict, since the entry guidance lateral logic begins to nullify the azimuth error as soon as it exceeds the deadband limits. It was considered more realistic to initialize the azimuth error exactly at the deadband limit, thereby decreasing the previous initial azimuth error by 2.5°. Tests were then made to determine the effect of decreasing the initial azimuth error by 2.5° for a representative velocity - 12000 fps. Results (Table 3) showed that changing the azimuth error by 2.5° produced a 3.5°-4° change in the optimal minimum bank angle for that velocity.

In accordance with these results, Schedule #3 (Figure 3.2-5) was produced by continuously changing Schedule #2 by 4°. Figures 3.2-15 - 3.2-20 show the effect of Schedule #3 with the 12.5° lateral

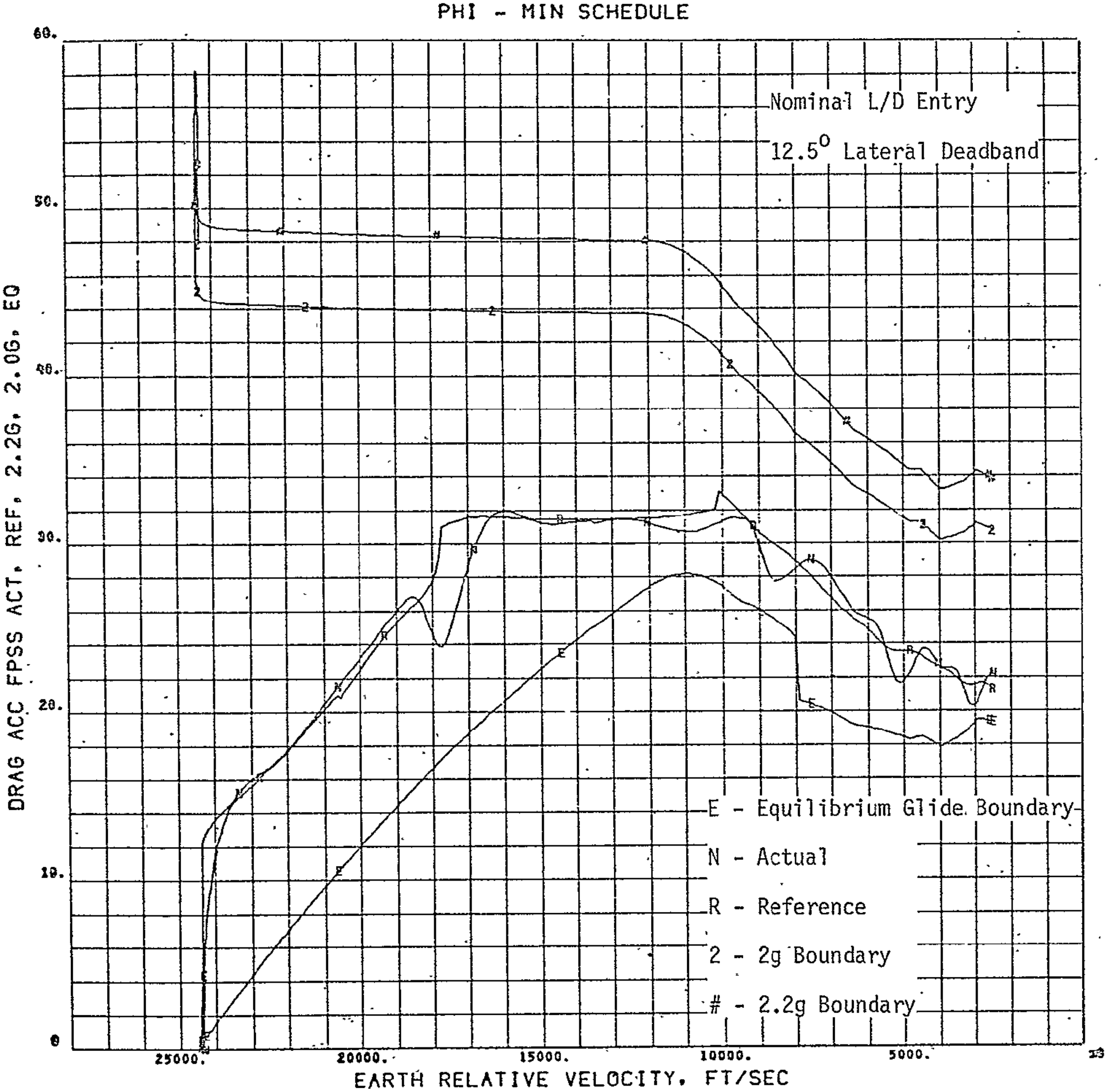


Fig. 3.2-9

Minimum Bank Angle Schedule #2

Drag Acceleration Profile

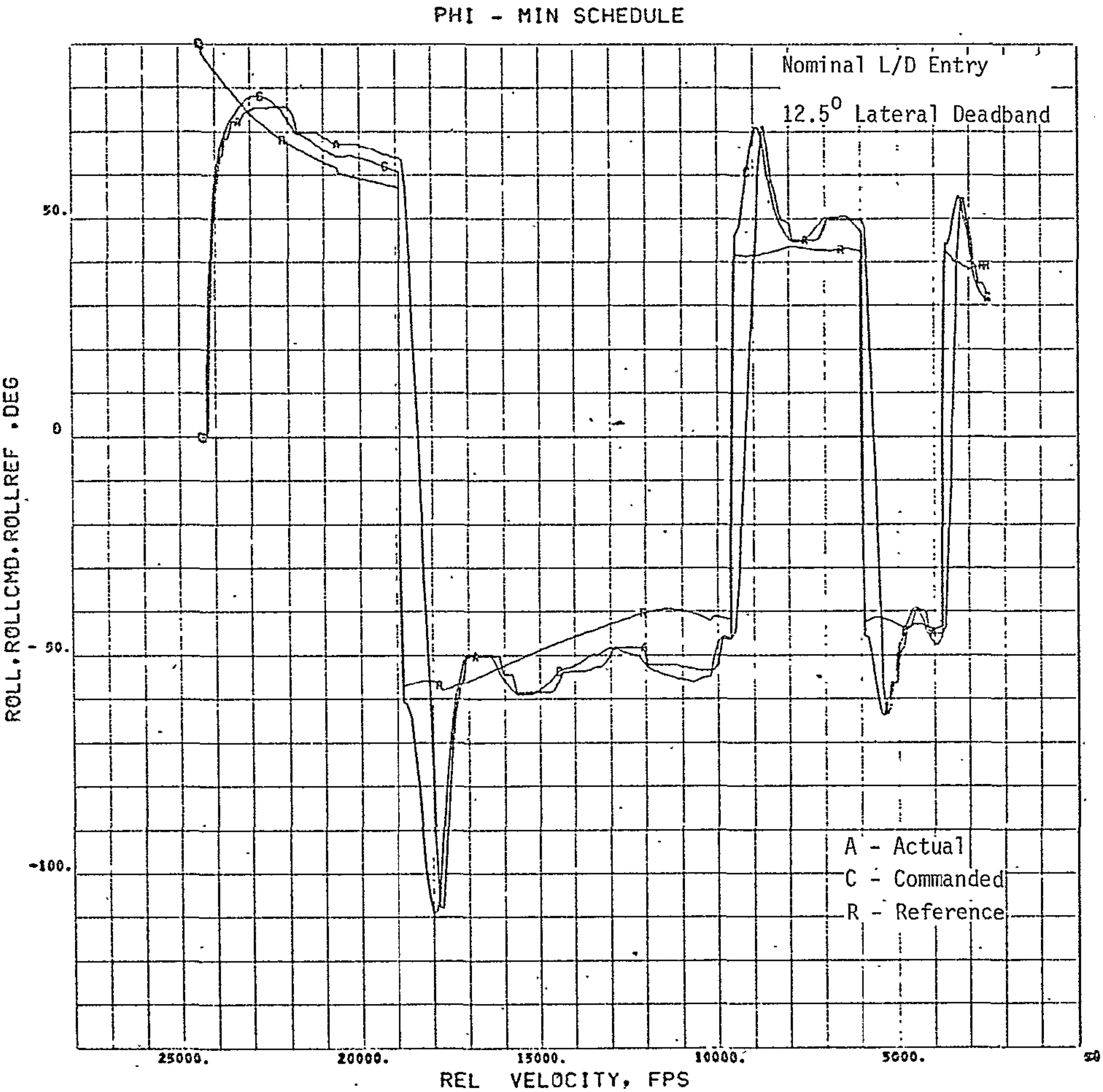


Fig. 3.2-10

Minimum Bank Angle Schedule #2

Roll Angle

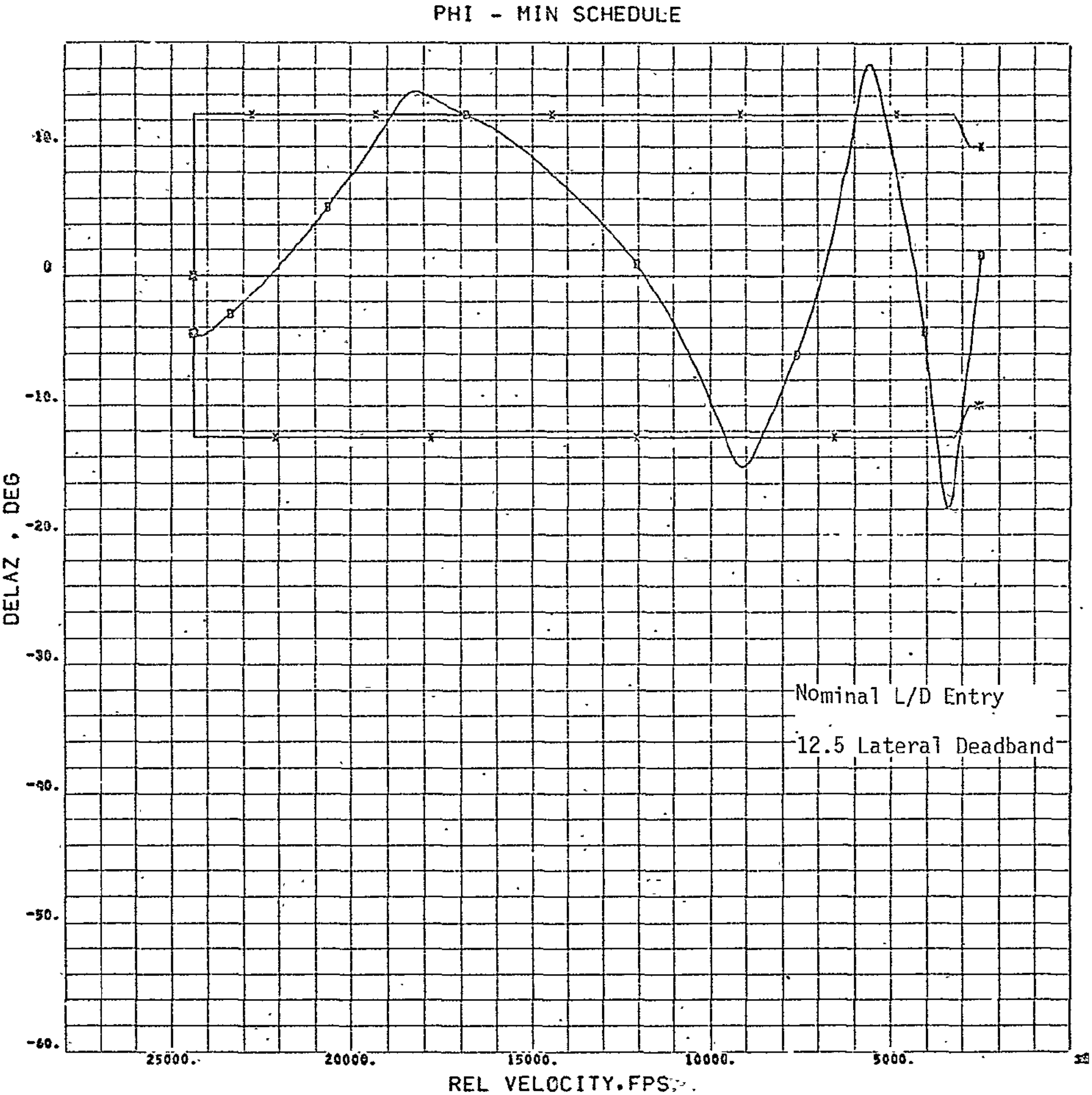


Fig. 3.2-11

Minimum Bank Angle Schedule #2

Azimuth Error

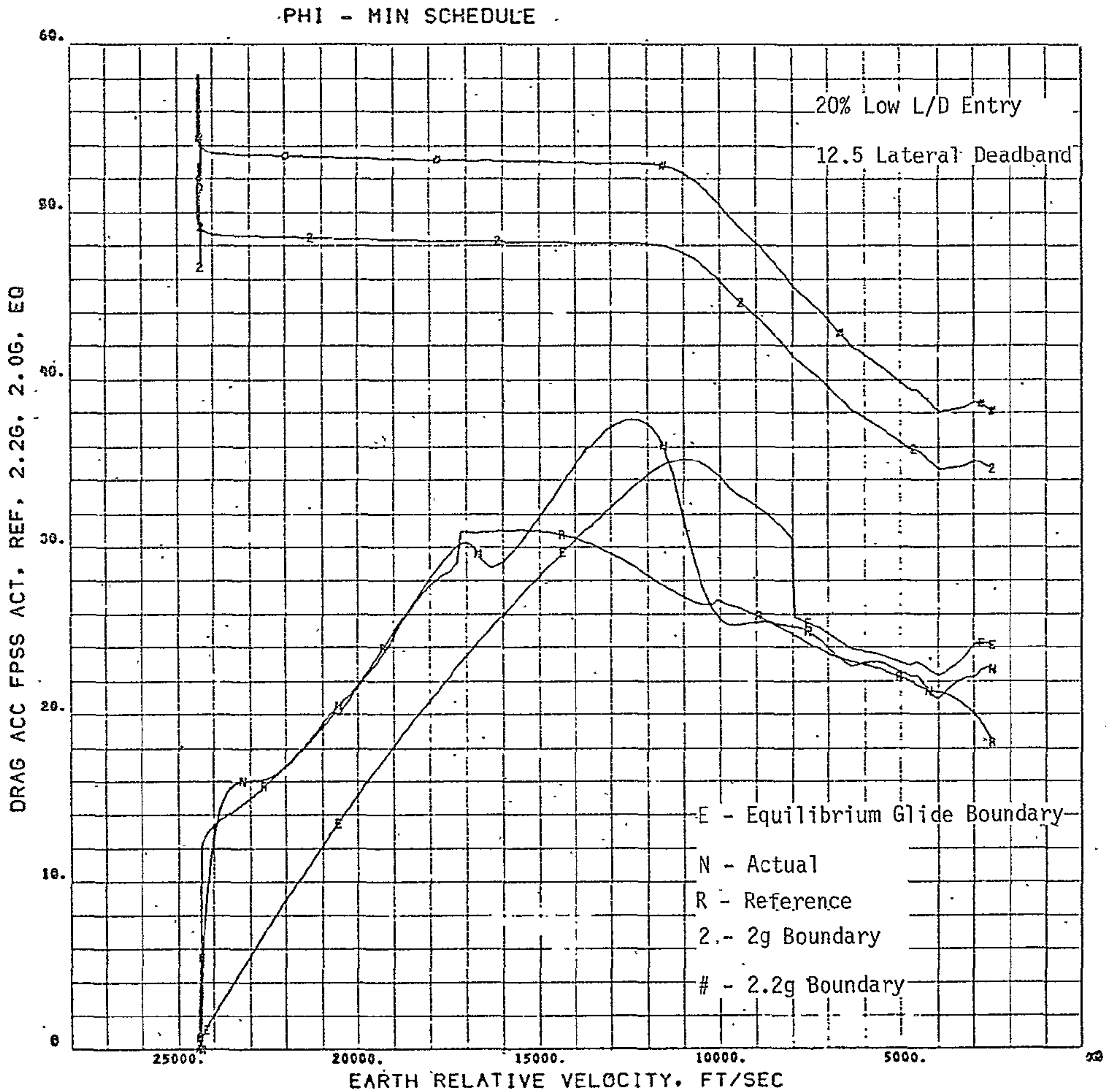


Fig. 3.2-12

Minimum Bank Angle Schedule #2

Drag Acceleration Profile

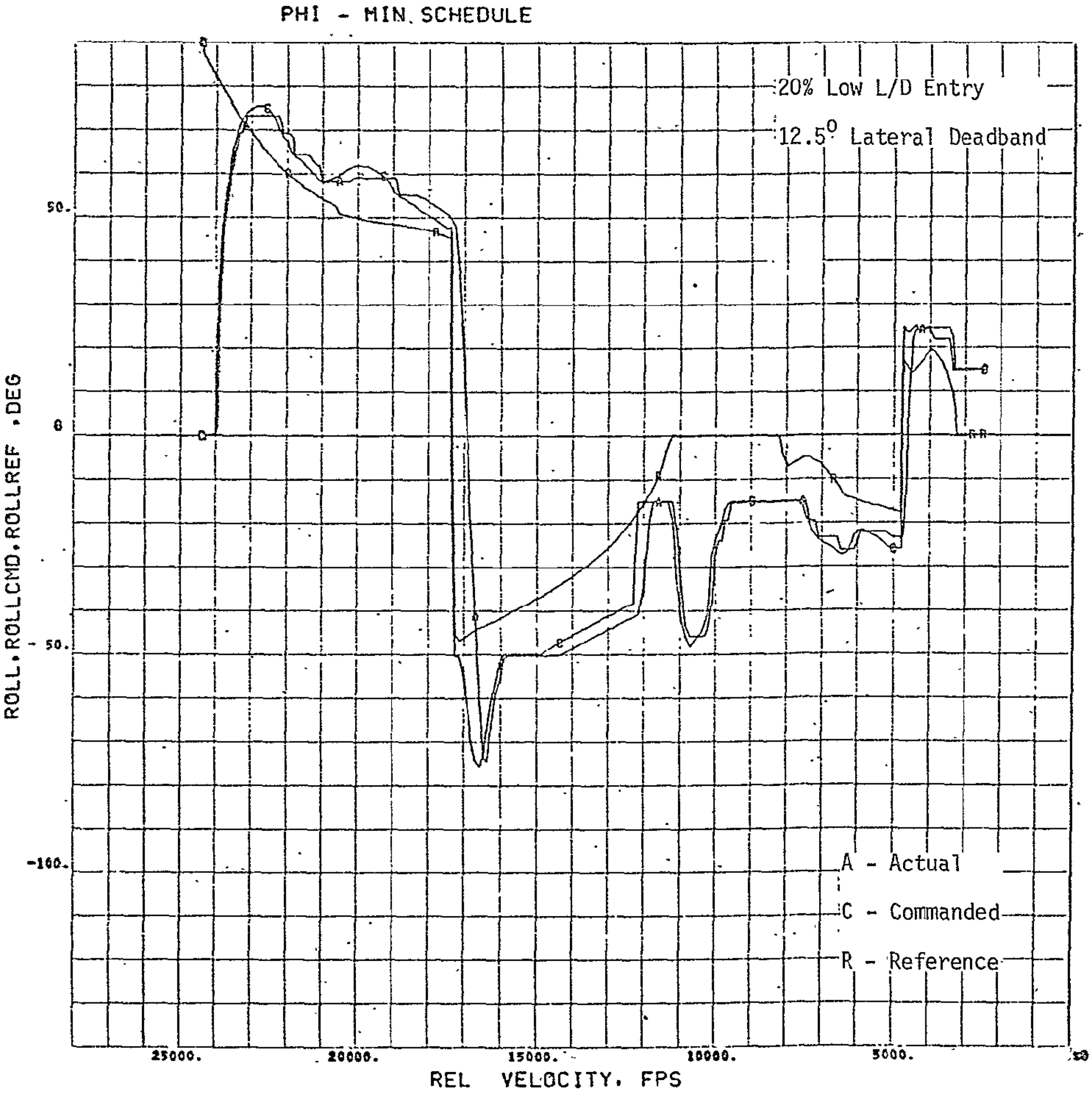


Fig. 3.2-13

Minimum Bank Angle Schedule #2

Roll Angle

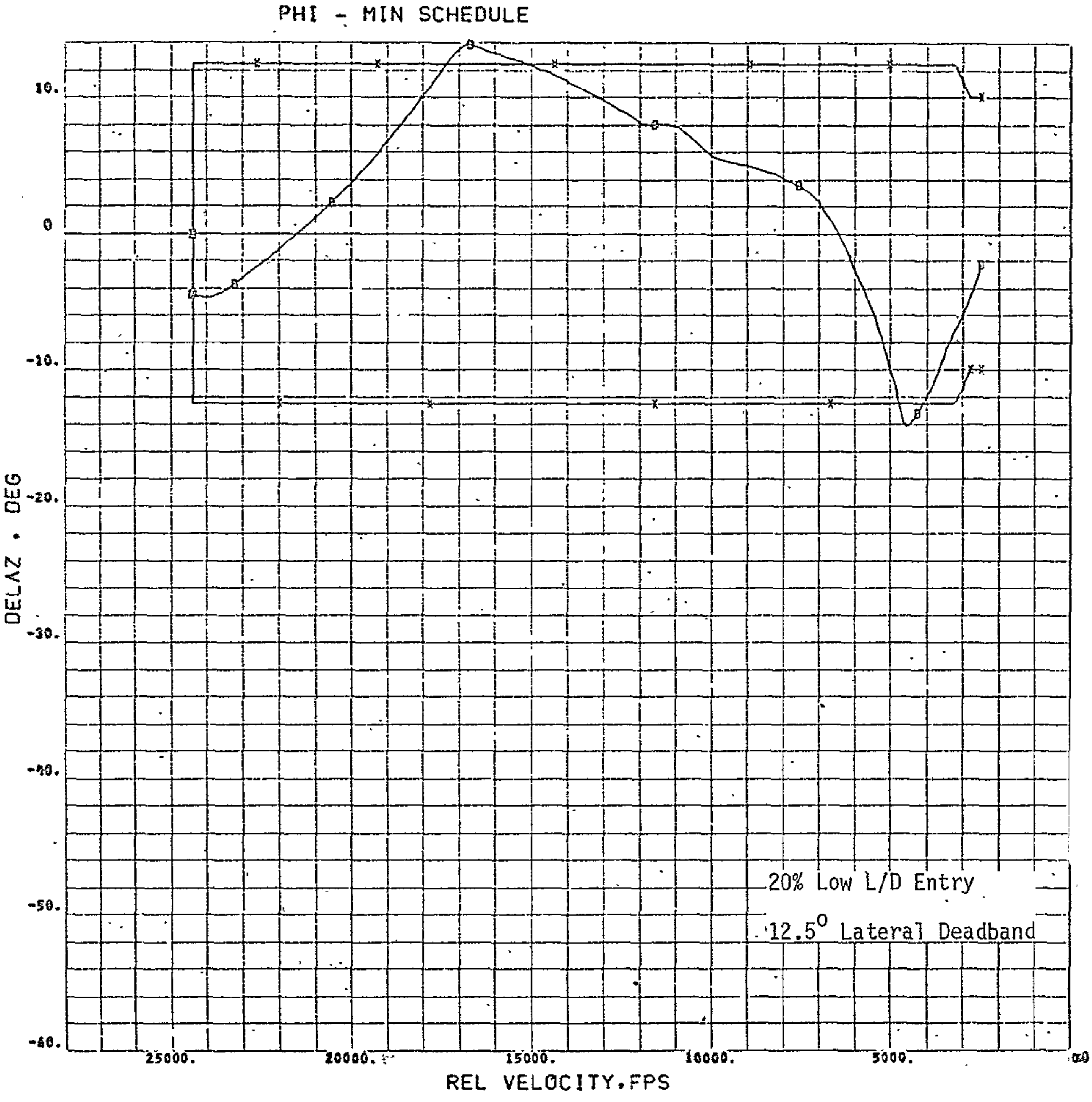


Fig. 3.2-14

Minimum Bank Angle Schedule #2

Azimuth Error

Deadband Limit, degrees	L/D	Minimum Bank Angle, degrees
17.5	nom.	39.89
15.0	nom.	36.18
12.5	nom.	32.38
10.0	nom.	28.25
17.5	20% low	43.27
15.0	20% low	39.52
12.5	20% low	36.00
10.0	20% low	31.17

* Orbiter initialized 2.5° outside deadband
* Constant bank angle commanded to turn orbiter towards deadband immediately

Table 3. Deadband Limit Effects on Minimum Bank Angle for 12000 fps velocity

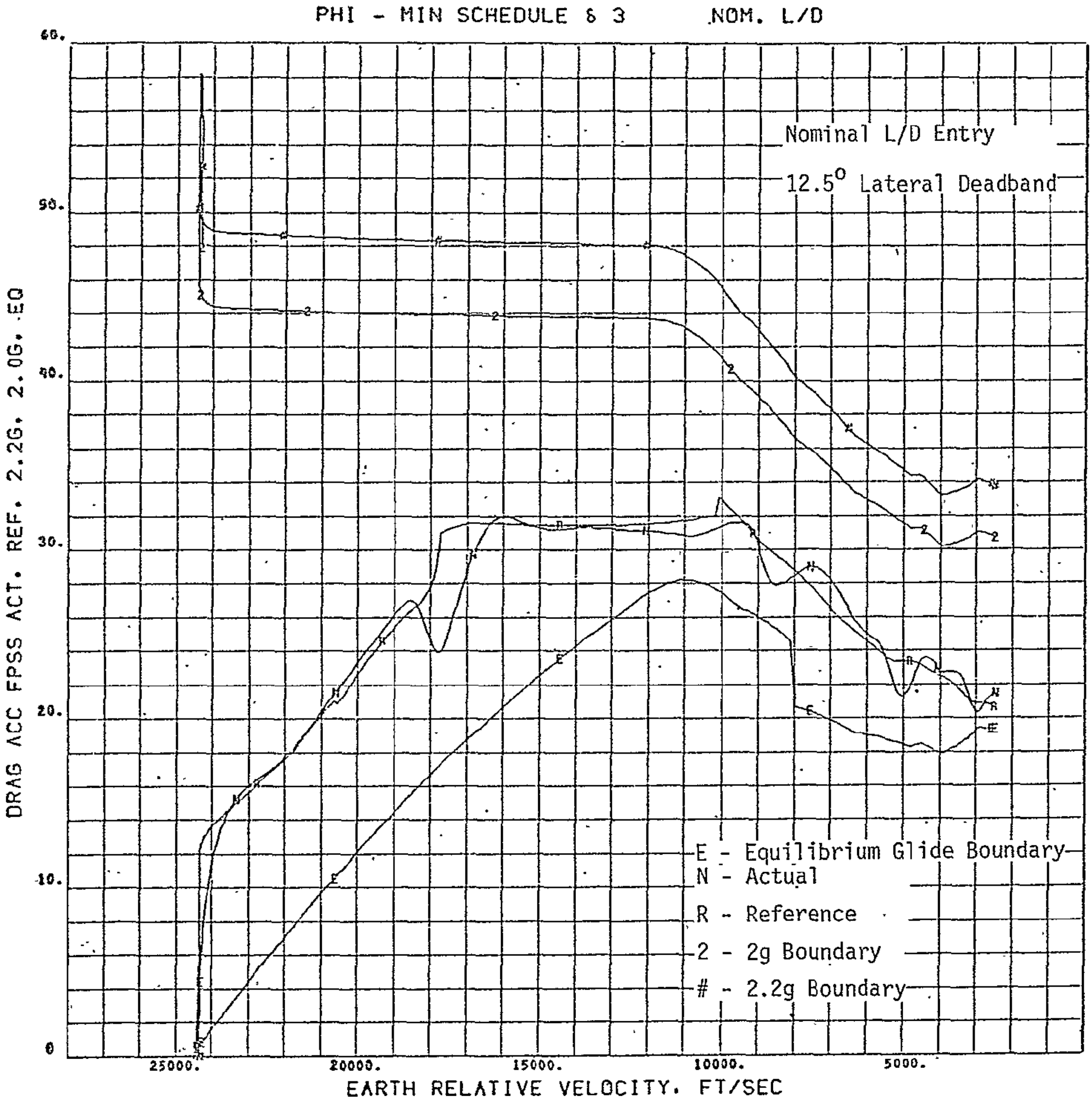


Fig. 3.2-15
Minimum Bank Angle Schedule #3
Drag Acceleration Profile

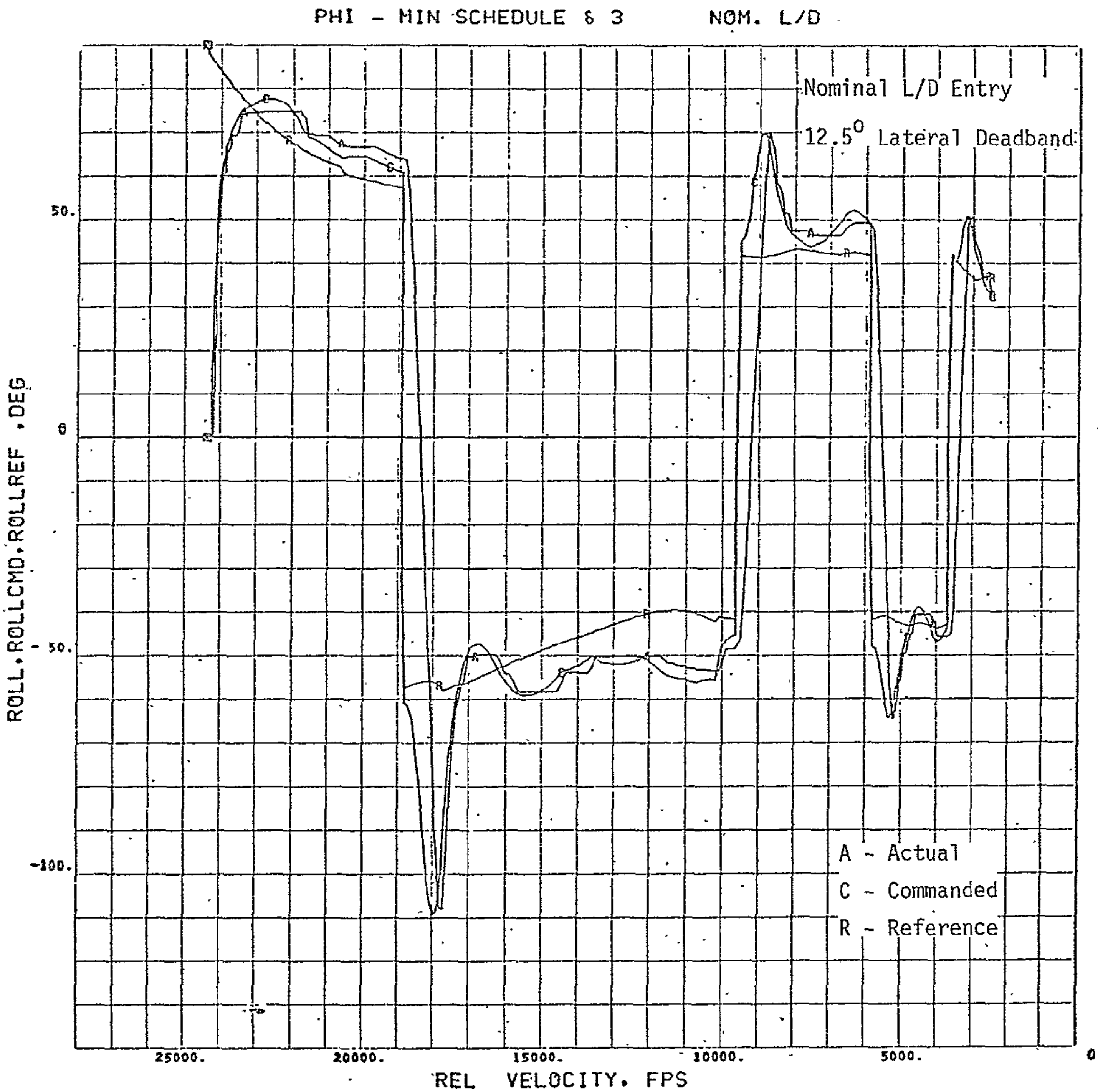


Fig. 3.2-16

Minimum Bank Angle Schedule #3

Roll Angle

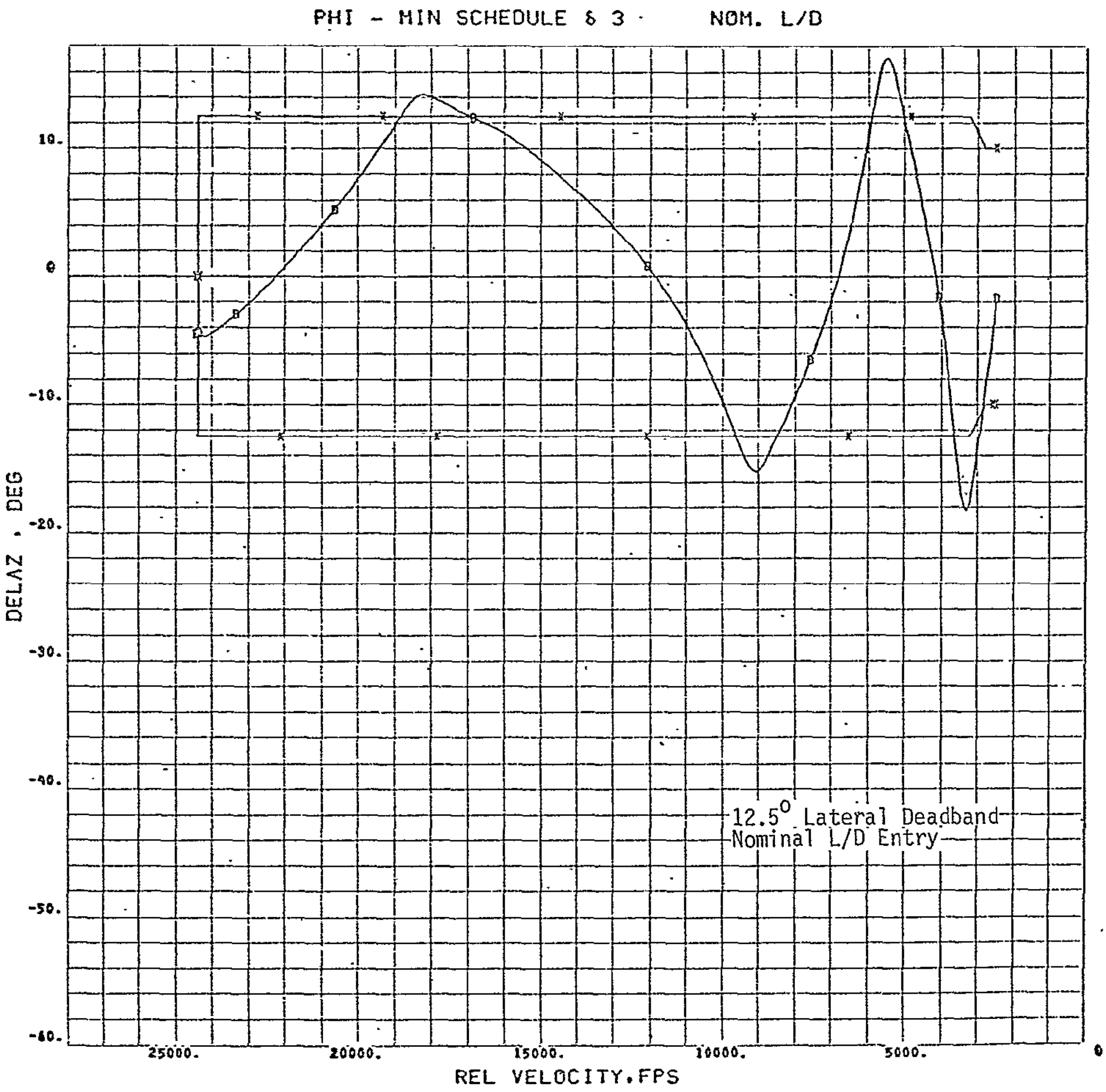


Fig. 3.2-17

Minimum Bank Angle Schedule #3

Azimuth Error

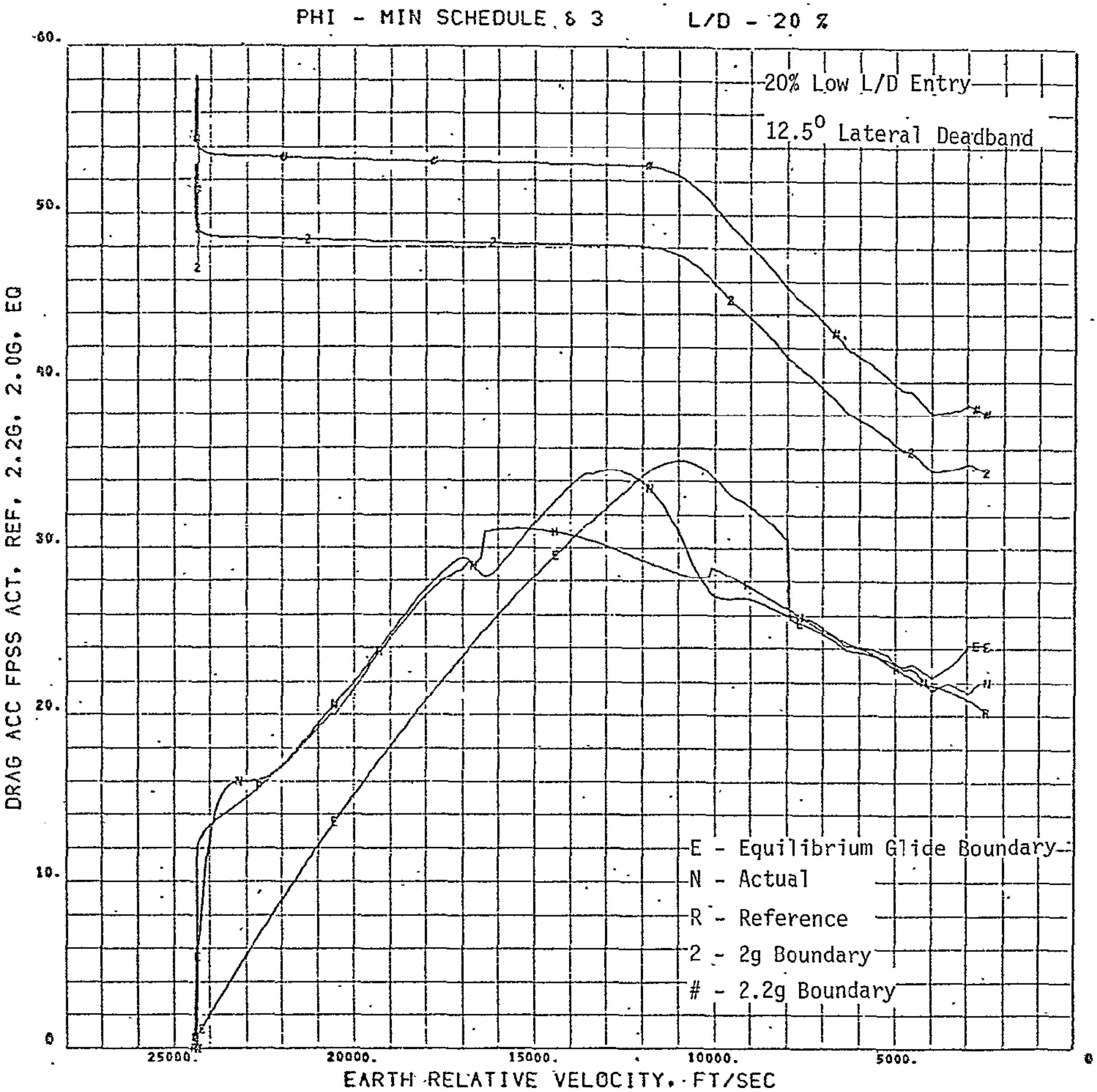


Fig. 3.2-18

Minimum Bank Angle Schedule #3

Drag Acceleration Profile

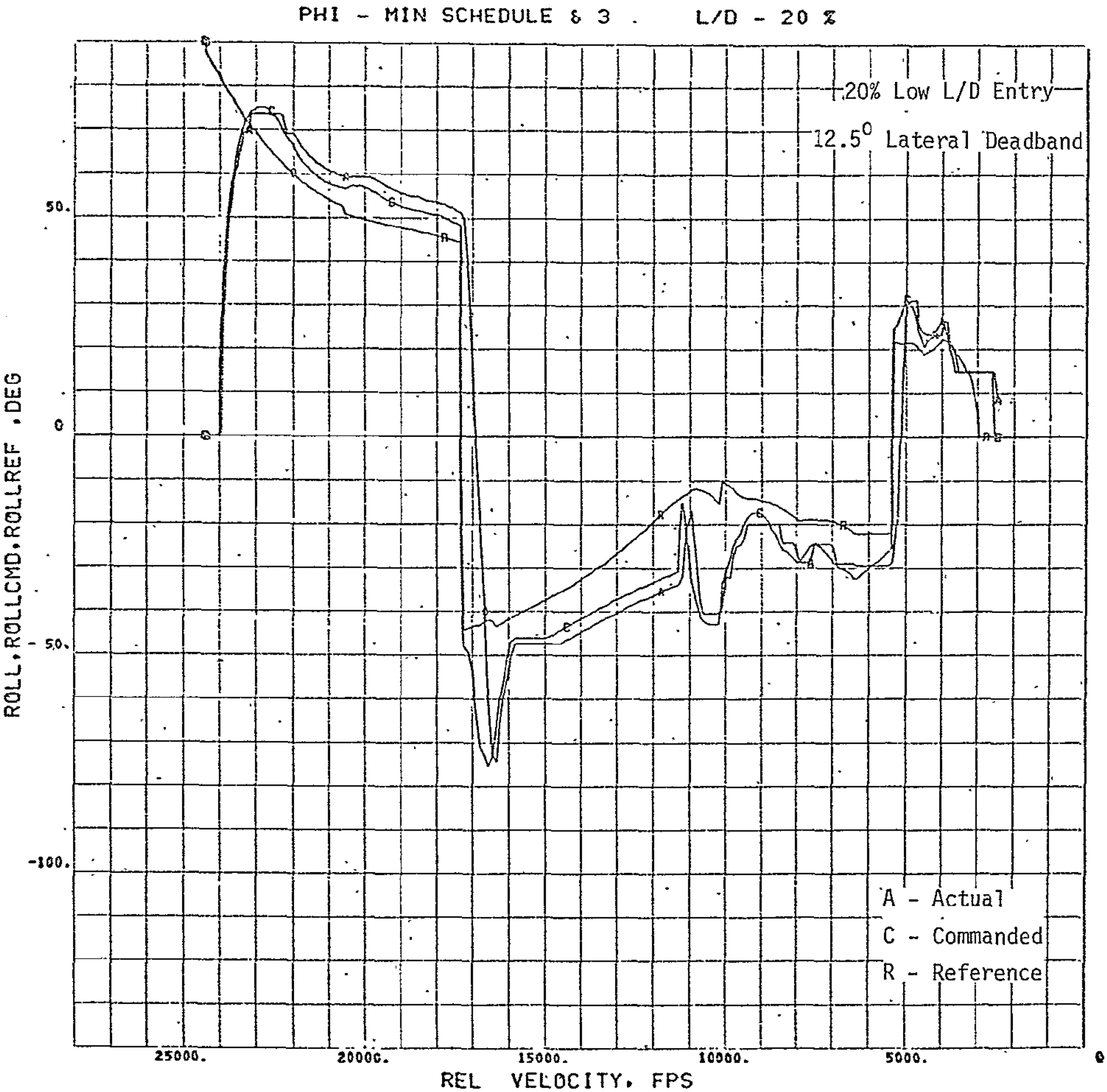


Fig. 3.2-19

Minimum Bank Angle Schedule #3

Roll Angle

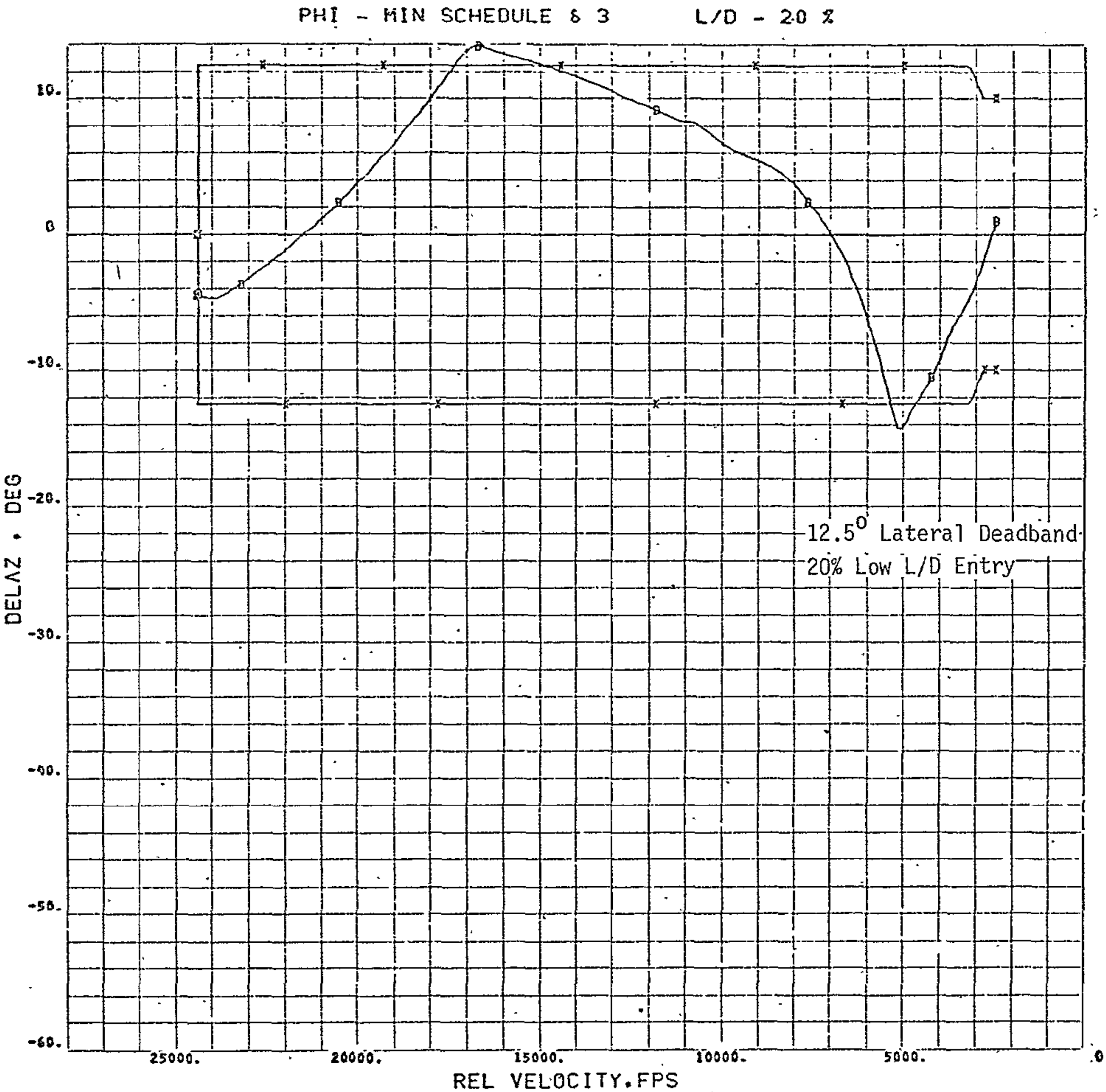


Fig. 3.2-20

Minimum Bank Angle Schedule #3

Azimuth Error

deadband on nominal and low L/D entry test cases. Large deviations from the drag acceleration profile and the reference roll angle were again experienced in the low L/D cases, so Schedule #3 was still too conservative for entry.

No schedule devised by these methods was superior to the performance of the current minimum bank angle schedule. Consequently, no reason to change the nominal schedule was discovered by this portion of the study.

The selection of the 12.5° lateral deadband as the optimal deadband configuration introduced a new element in the minimum bank angle schedule study. The narrower deadband would result in a lower maximum azimuth error than the nominal 17.5° deadband; consequently, it was possible that the 37° roll angle limit could be decreased in order to achieve improved drag control. To test this possibility, 12.5° deadband cases which varied the 37° limit down to 20° were examined for conditions of 20% low L/D and nominal, 0 n.m., and 200 n.m. cross-ranges. The results of extreme case runs are shown in Figures 3.2-21 - 3.2-38 and indicate that the 37° limit could indeed be lowered without apparent unfavorable consequences. The only effect observed was that the lower bank angle limits required more time to return the azimuth error within the deadband following a roll reversal.

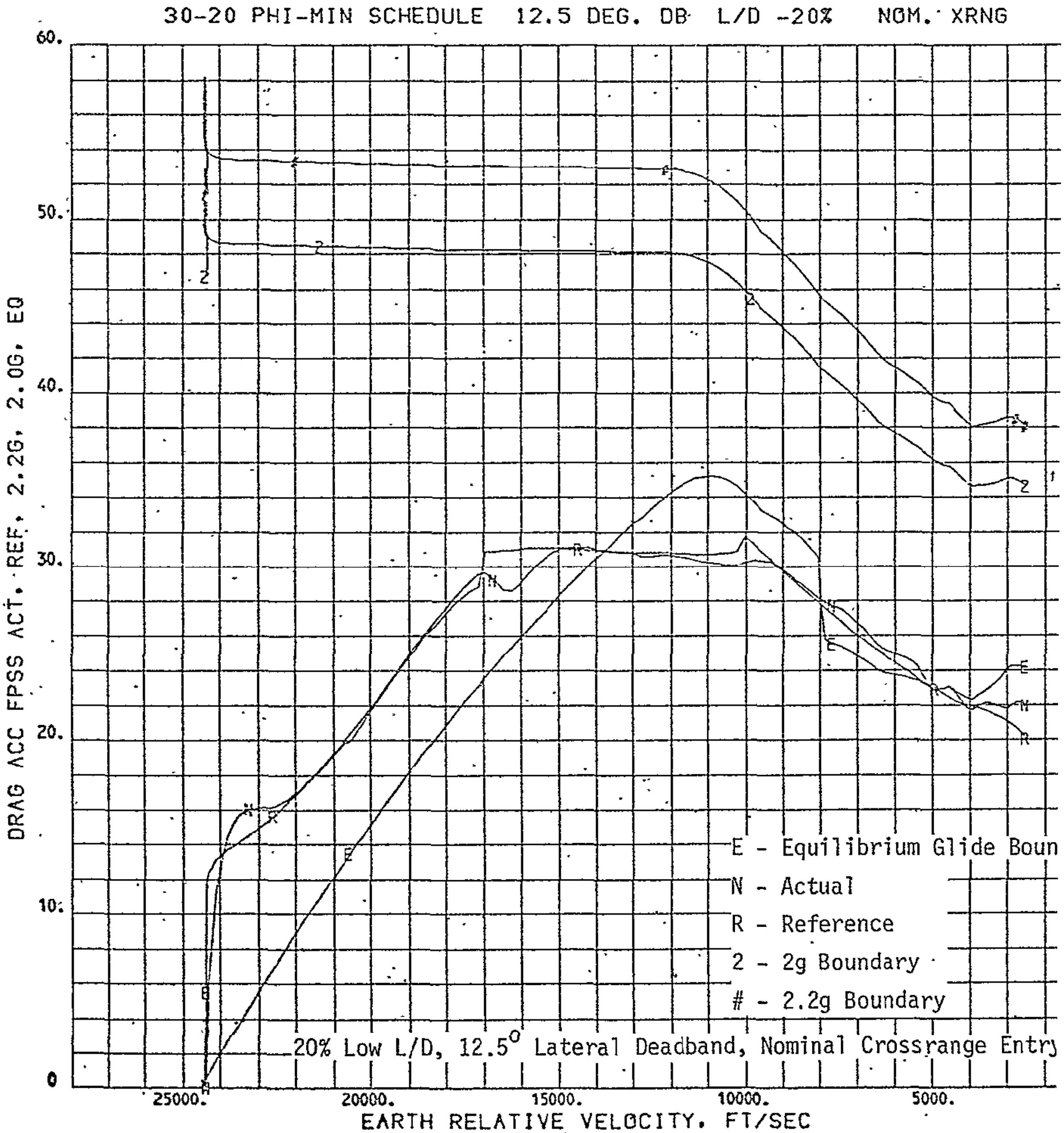


Fig. 3.2-21

30-20 Minimum Bank Angle Schedule

Drag Acceleration Profile

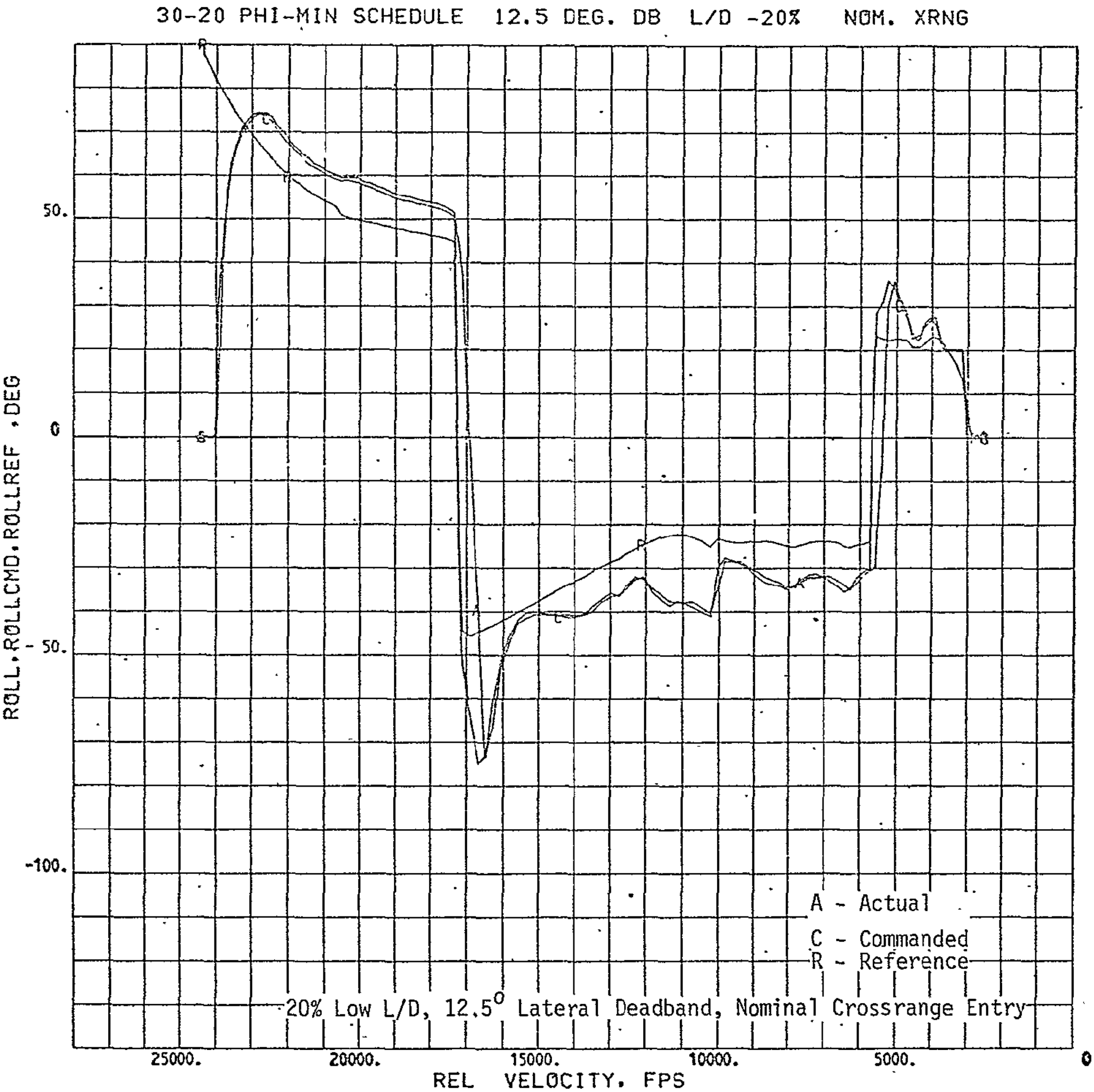


Fig. 3.2-22

30-20 Minimum Bank Angle Schedule

Roll Angle

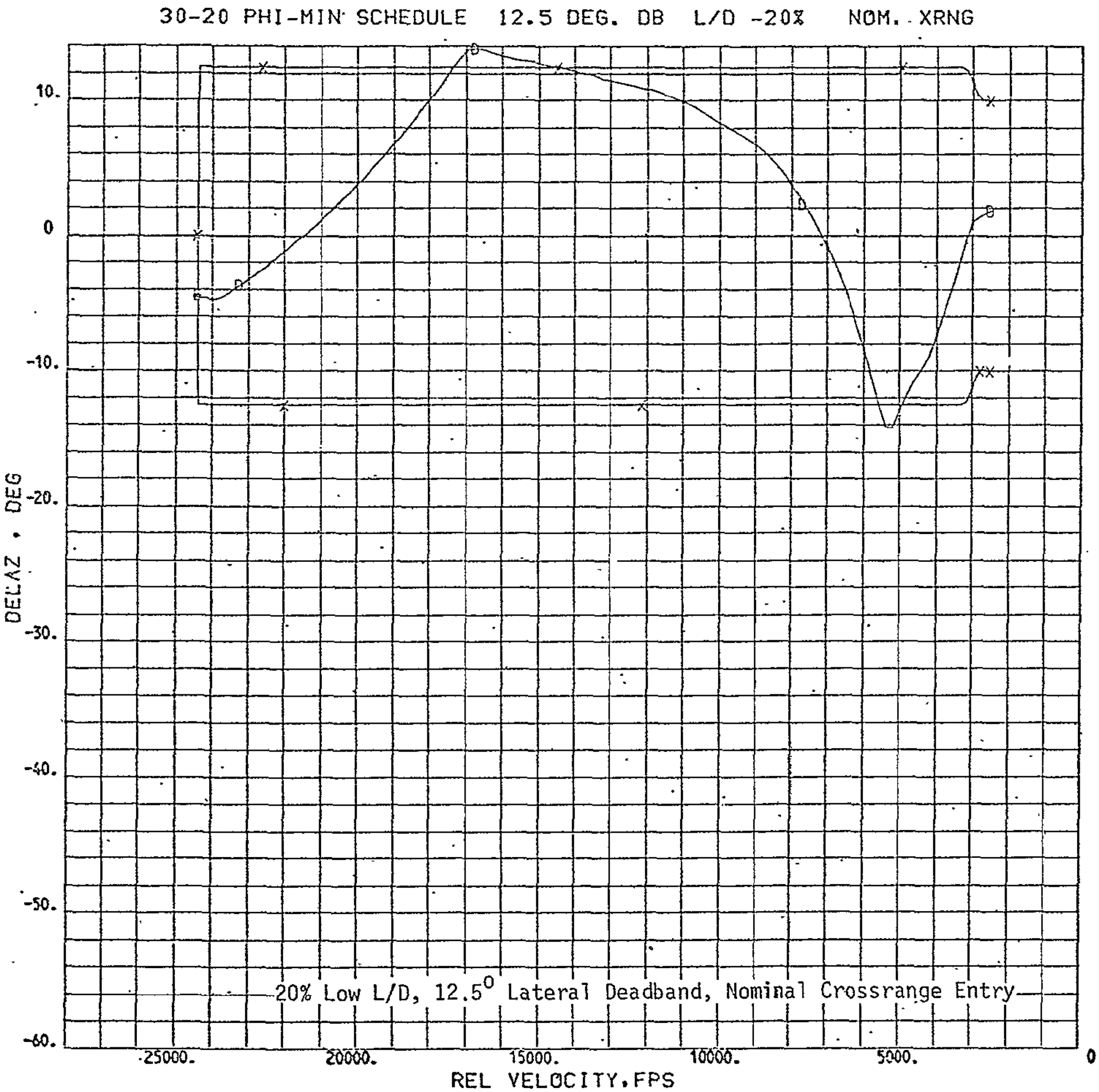


Fig. 3.2-23

30-20 Minimum Bank Angle Schedule

Azimuth Error

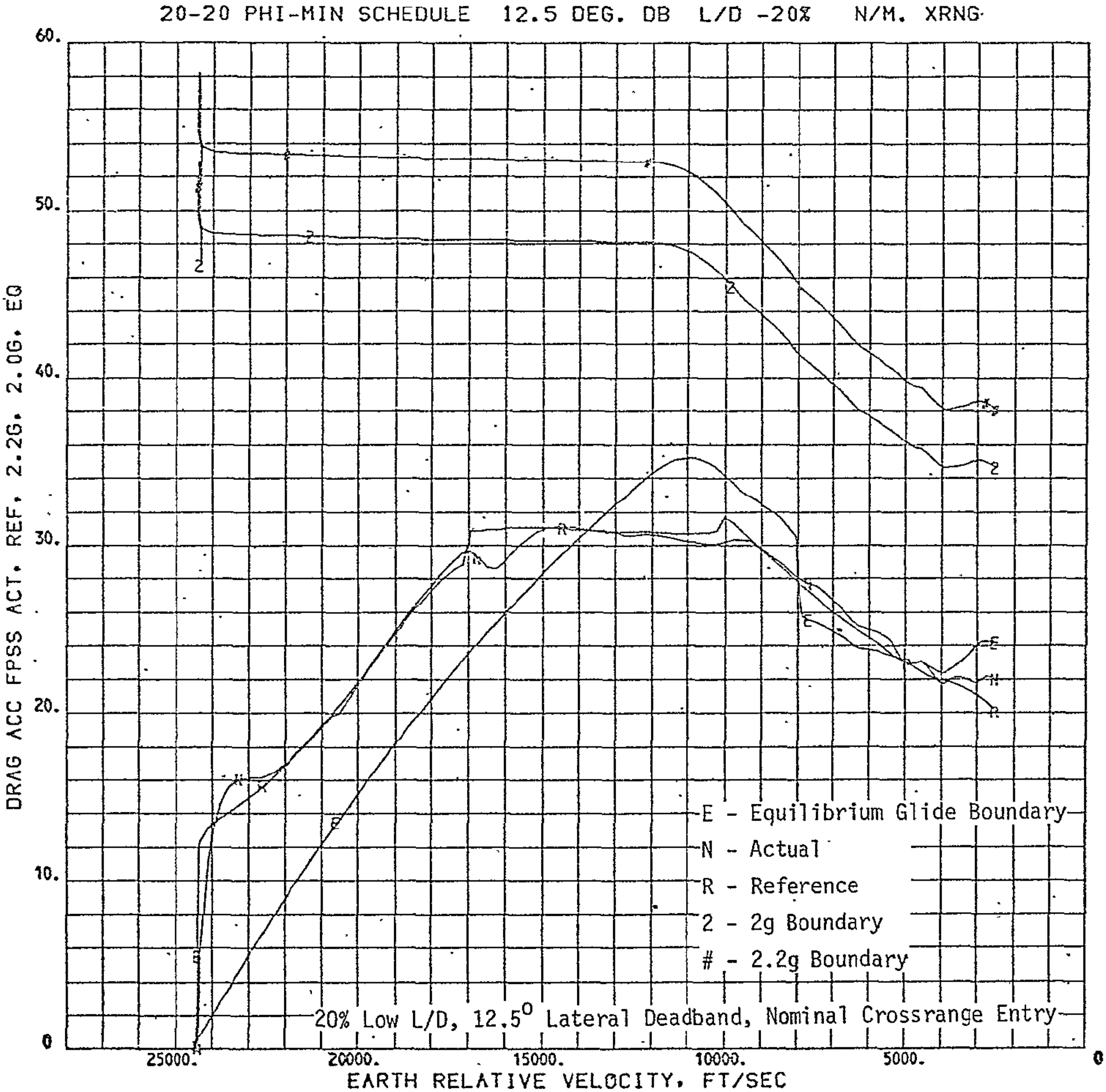


Fig. 3.2-24

20-20 Minimum Bank Angle Schedule

Drag Acceleration Profile

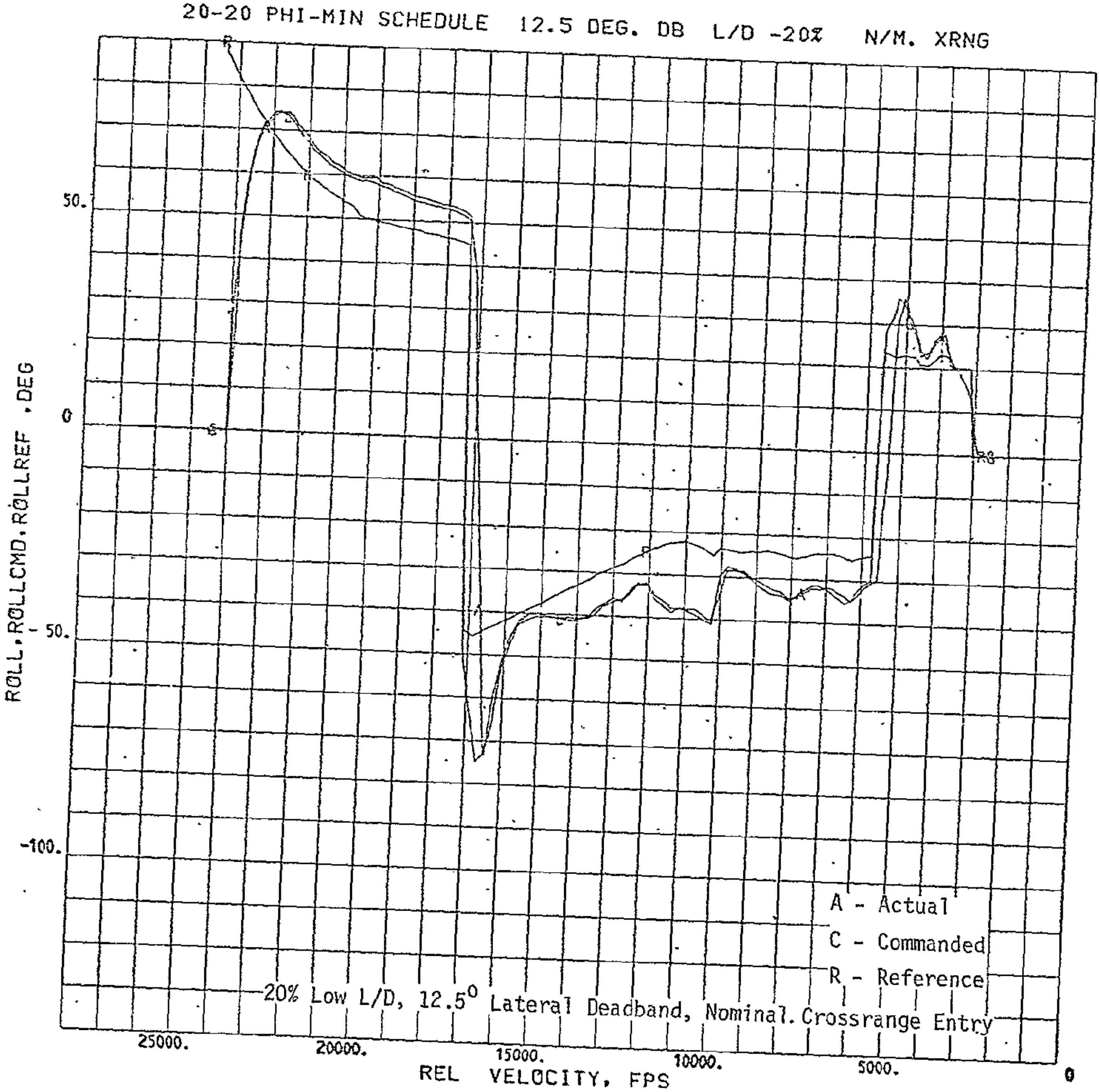


Fig. 3.2-25
20-20 Minimum Bank Angle Schedule
Roll Angle

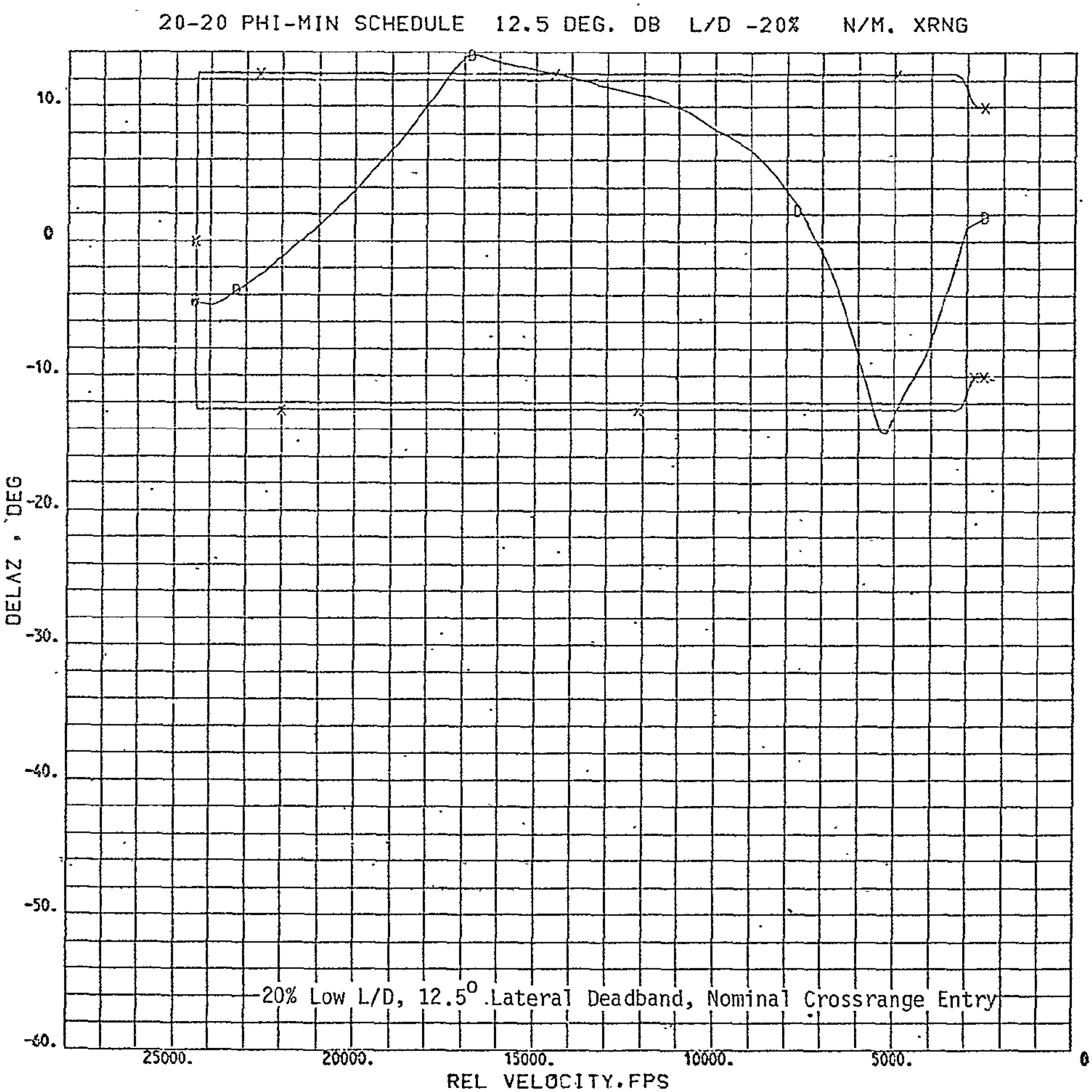


Fig. 3.2-26

20-20 Minimum Bank Angle Schedule

Azimuth Error

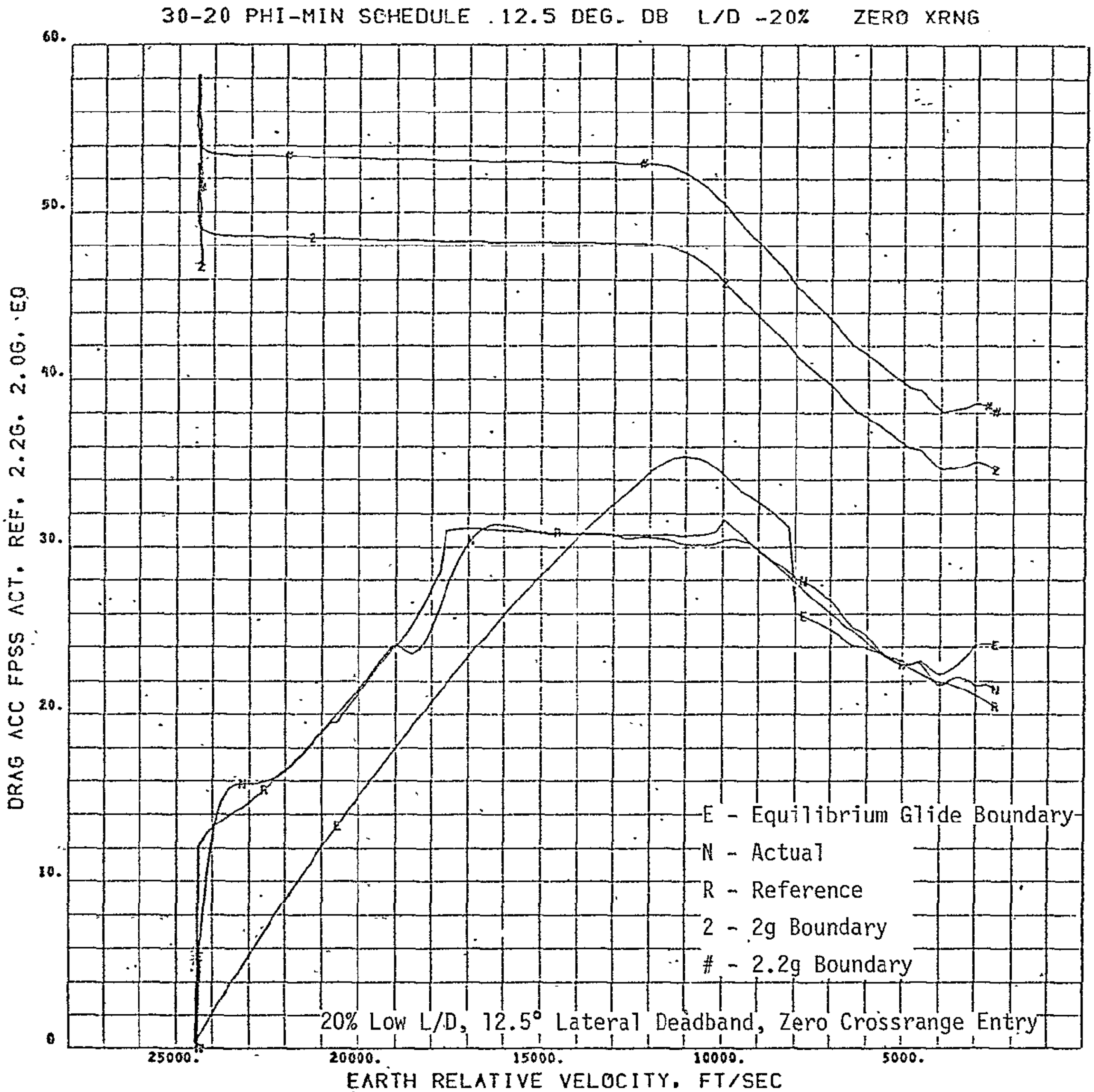


Fig. 3.2-27

30-20 Minimum Bank Angle Schedule

Drag Acceleration Profile

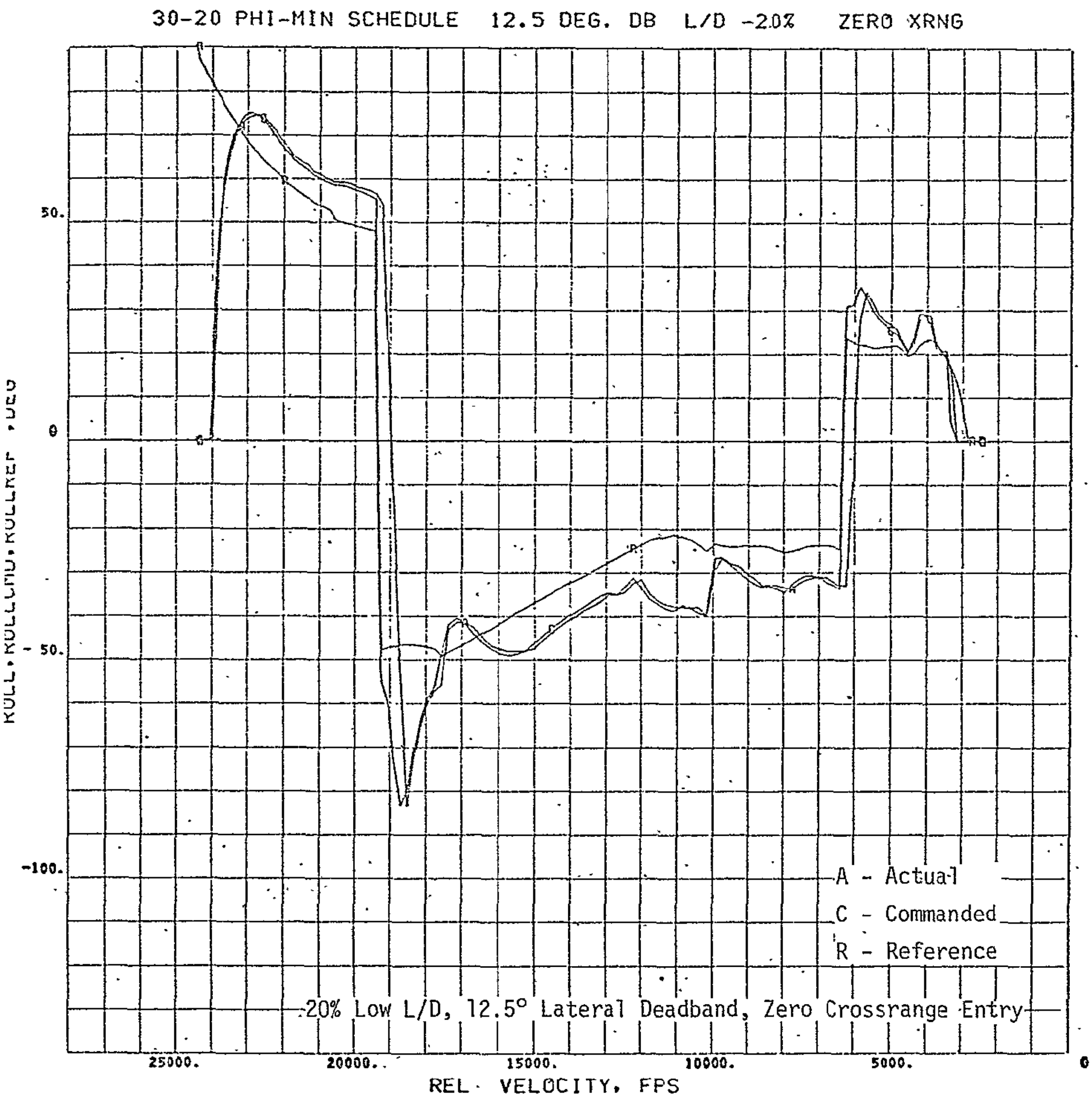


Fig. 3.2-28

30-20 Minimum Bank Angle Schedule

Roll Angle

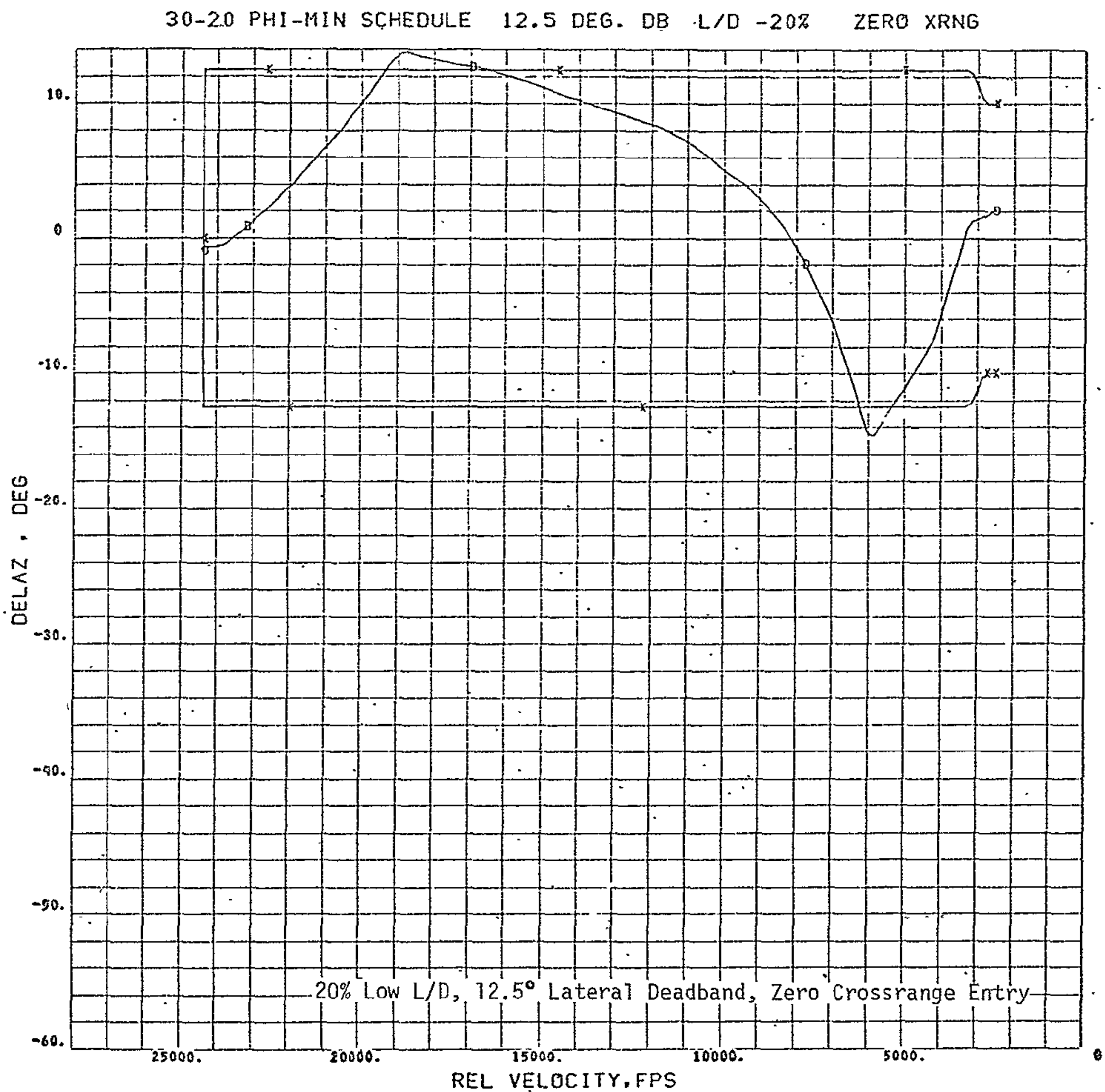


Fig. 3.2-29

30-20 Minimum Bank Angle Schedule

Azimuth Error

C-2

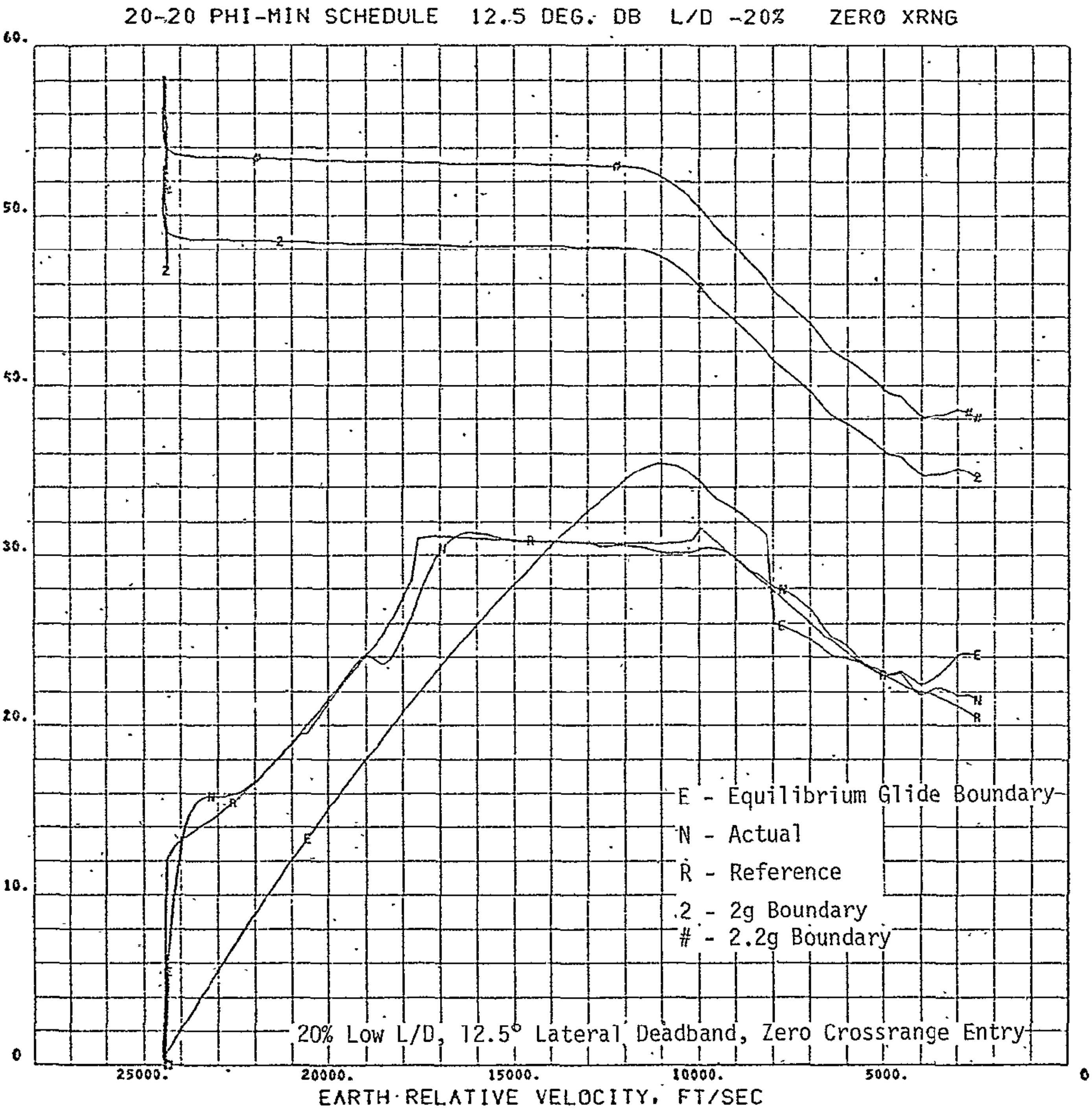


Fig. 3.2-30

20-20 Minimum Bank Angle Schedule

Drag Acceleration Profile

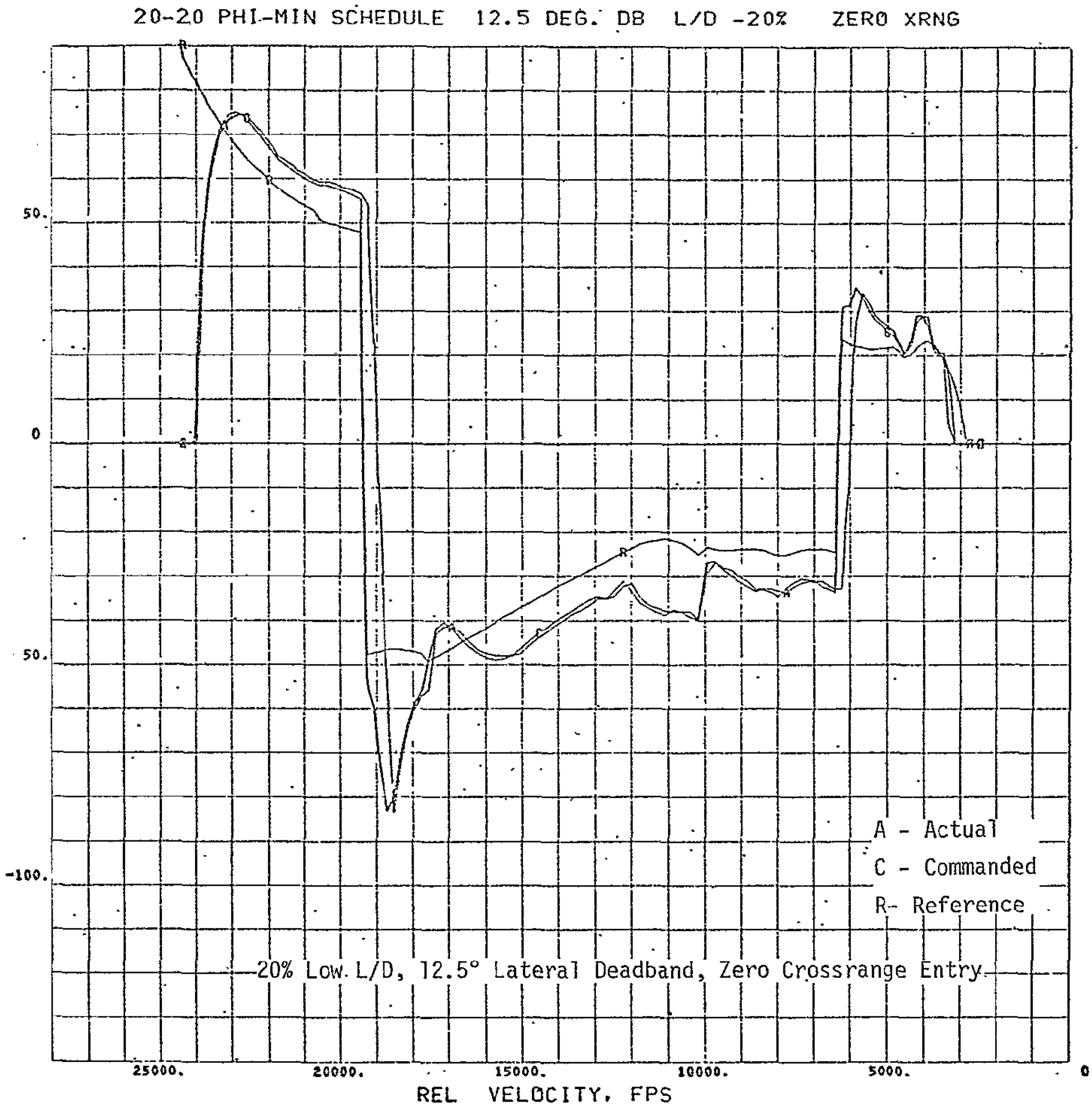


Fig. 3.2-31

20-20 Minimum Bank Angle Schedule

Roll Angle

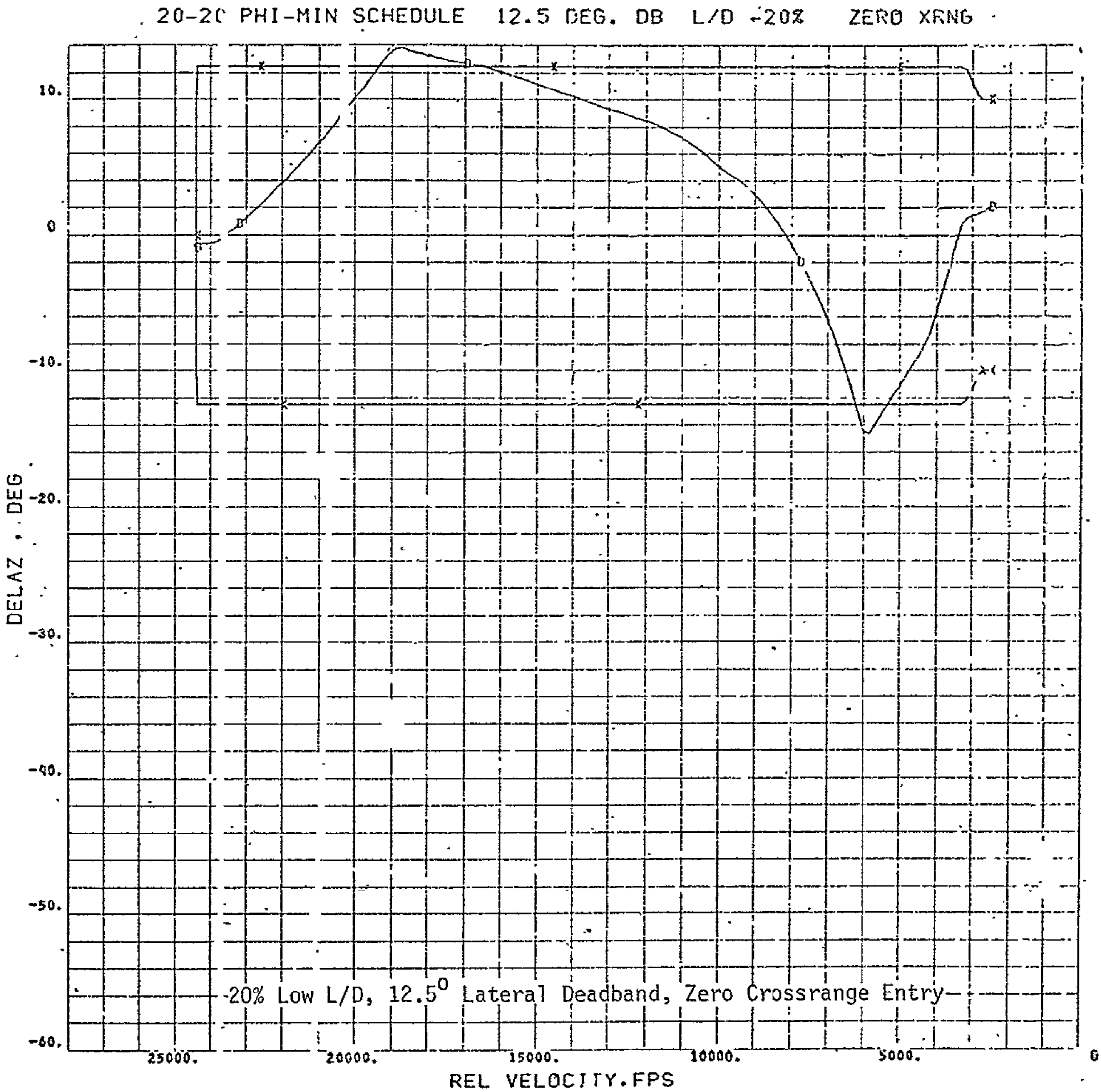


Fig. 3.2-32

20-20 Minimum Bank Angle Schedule

Azimuth Error

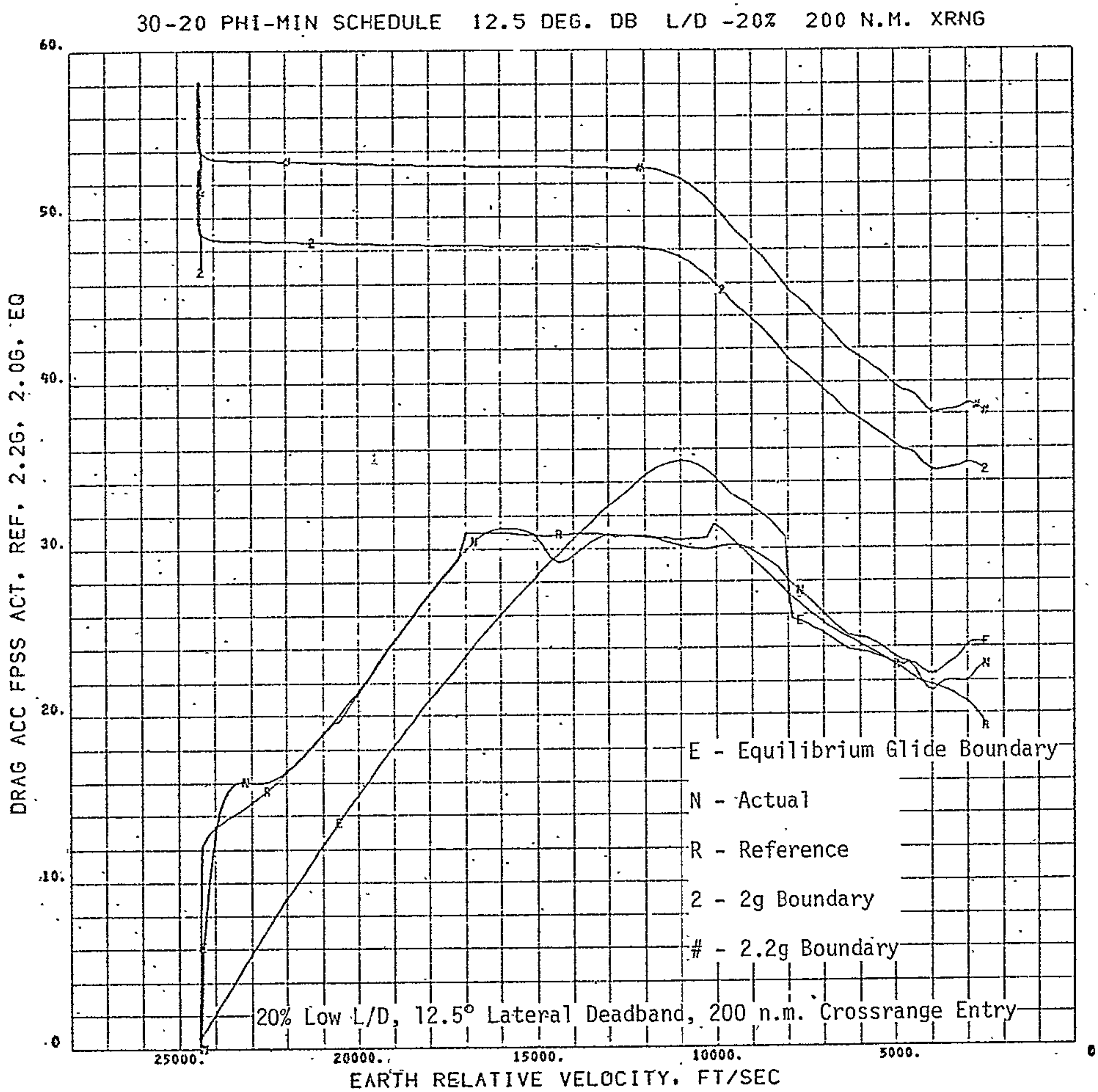


Fig. 3.2-33
30-20 Minimum Bank Angle Schedule
Drag Acceleration Profile

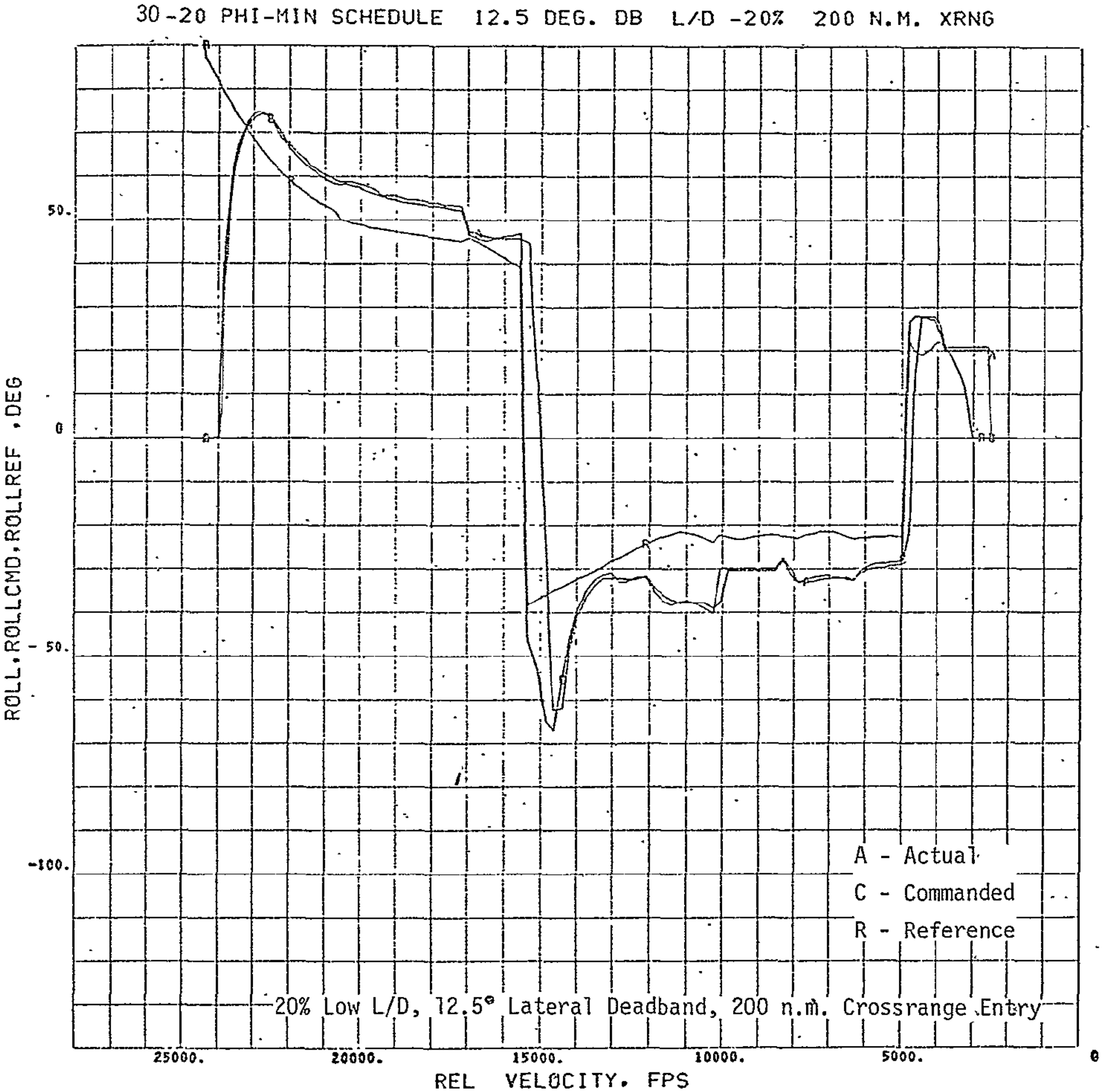


Fig. 3.2-34

30-20 Minimum Bank Angle Schedule

Roll Angle

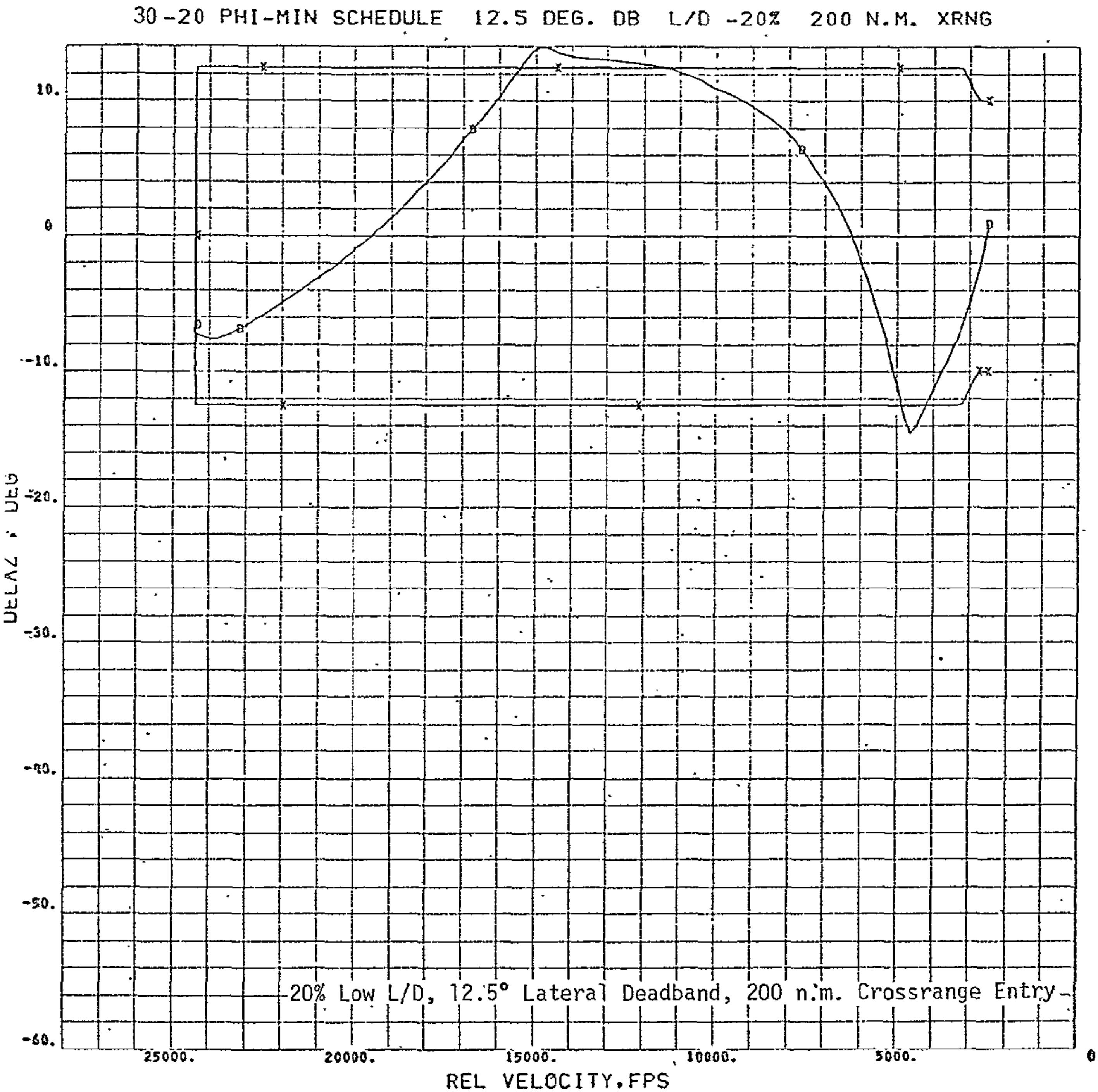


Fig. 3.2-35

30-20 Minimum Bank Angle Schedule

Azimuth Error

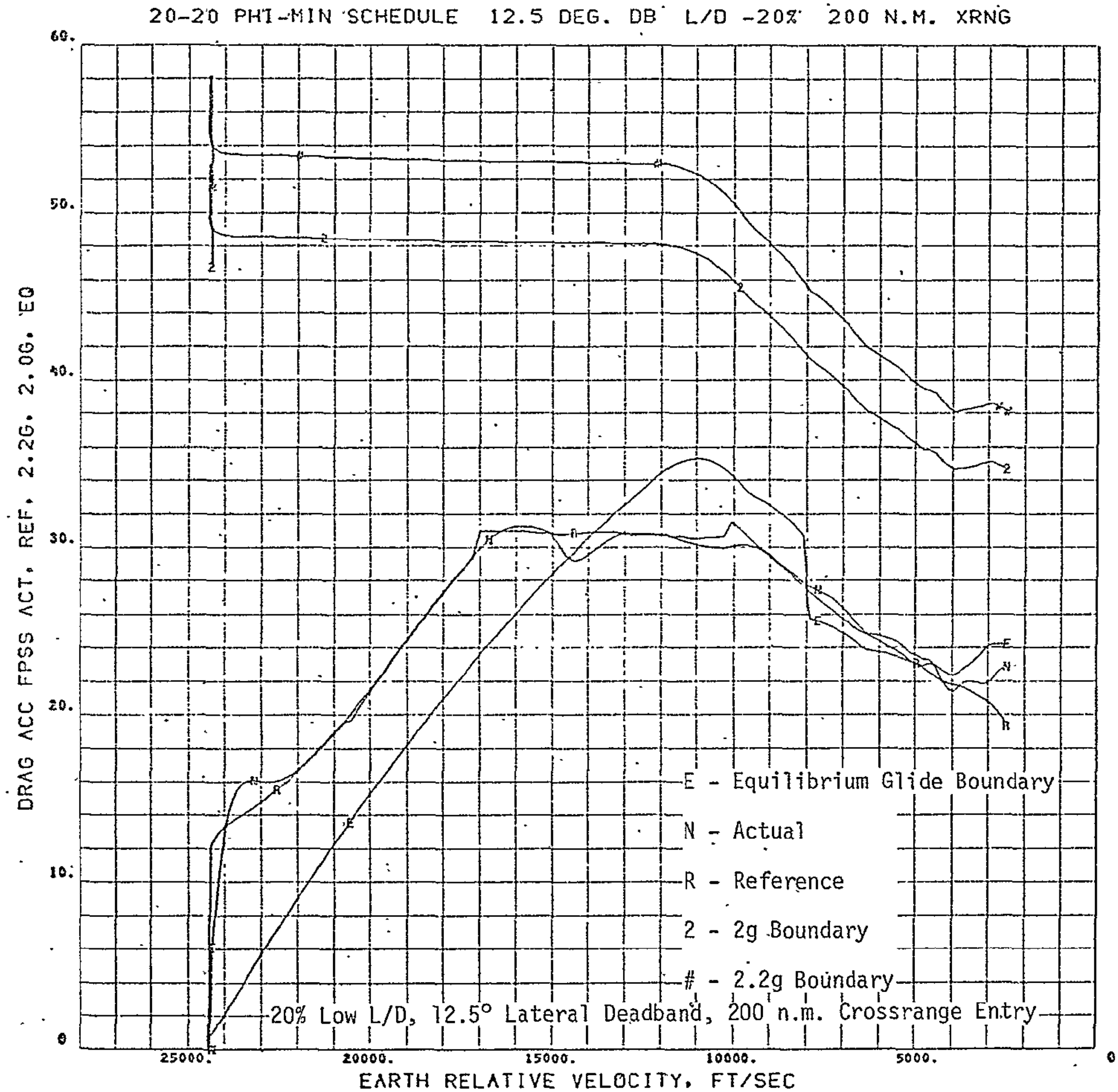


Fig. 3.2-36

20-20 Minimum Bank Angle Schedule

Drag Acceleration Profile

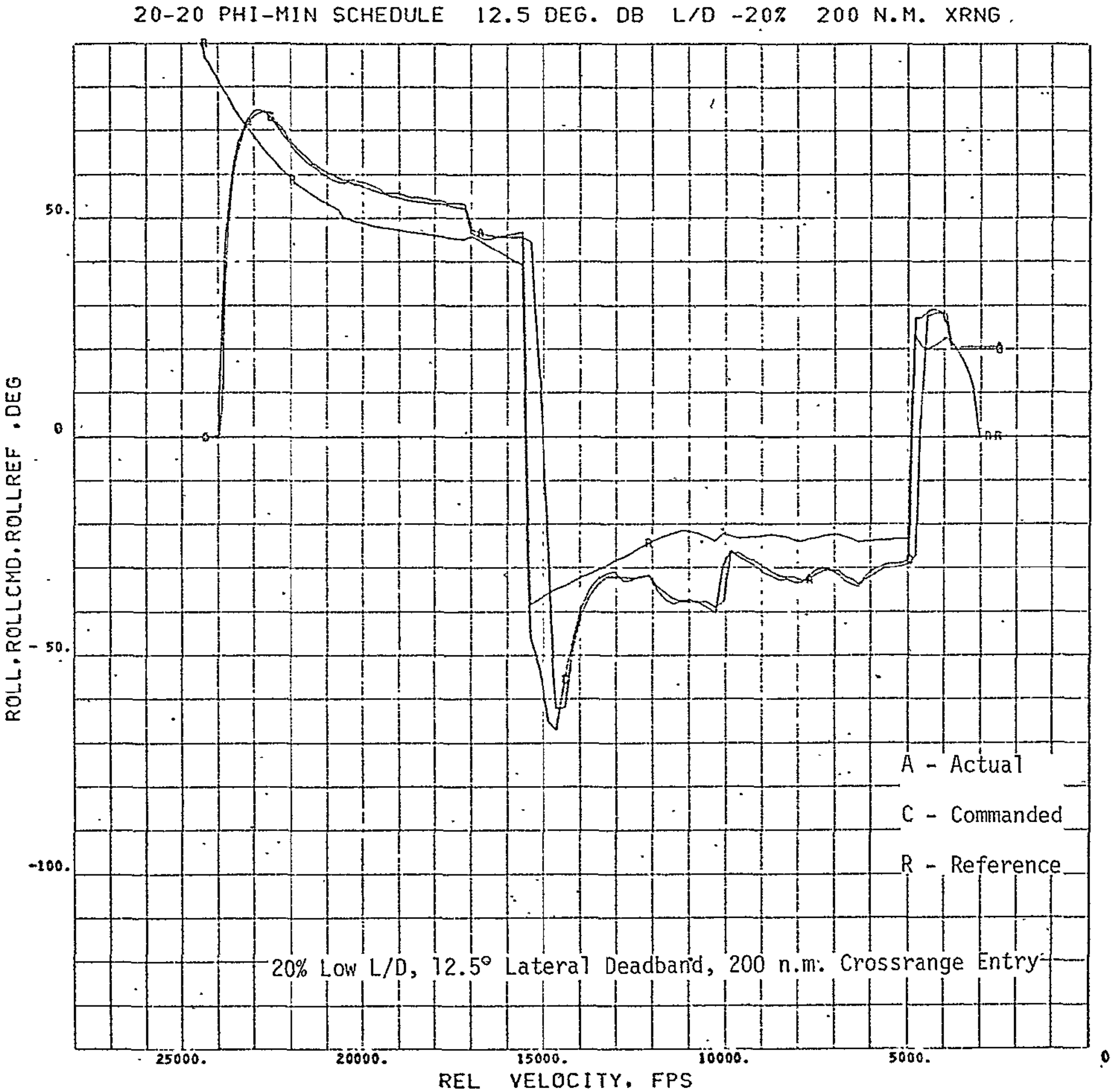


Fig. 3.2-37

20-20 Minimum Bank Angle Schedule

Roll Angle

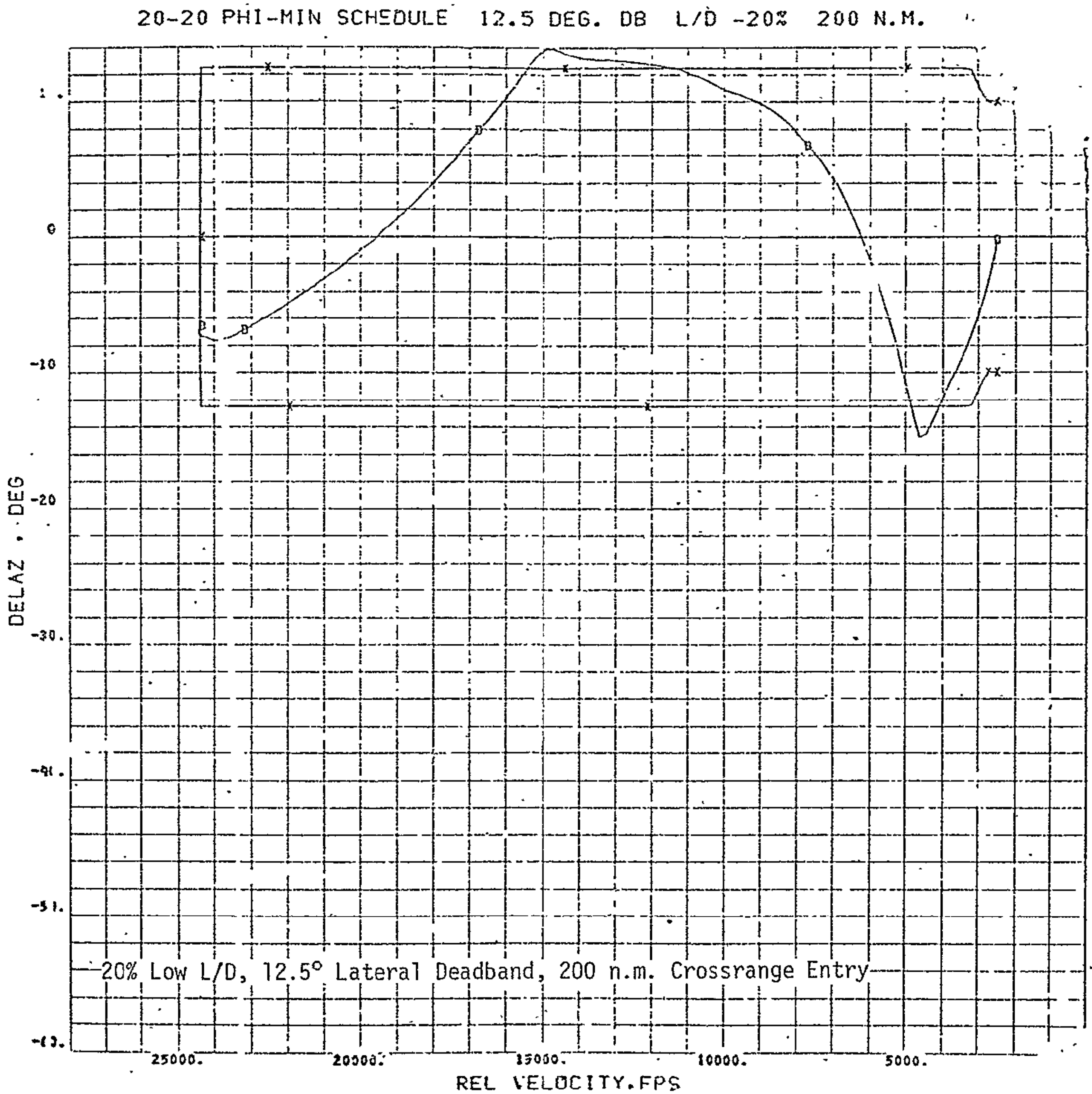


Fig. 3.2-38

20-20 Minimum Bank Angle Schedule

Azimuth Error

4.0 CONCLUSIONS

The 12.5° lateral deadband was shown to be superior to the 17.5° deadband in terms of low L/D capability. The 12.5° deadband also provides equal drag acceleration profile maintenance and improved crossrange control while minimizing the adverse effects of additional roll reversals by adding only a single reversal for all entry cases.

No changes are required for the nominal lateral deadband ramp configuration since it exhibited no undesirable performance characteristics for entry.

The current 37°-20° minimum bank angle schedule was found to be acceptable for all entry conditions.

The use of the 12.5° deadband allowed the current 37° minimum bank angle limit to be lowered in order to increase low L/D capability. Further study will be required to determine precisely a new bank angle limit and to examine its effects under all entry conditions.

5.0 REFERENCES

1. Rockwell International: Space Shuttle Orbital Flight Test, Level C Functional Subsystem Software Requirements Document - Guidance, Navigation and Control - Part A: Guidance. SD 76-SH-0001B, November, 1976.

2. Software Development Branch: Volume II-User's Guide for the Space Vehicle Dynamics Simulation (SVDS) Program. JSC IN 76-FM-26, August, 1976.

Appendix

LATERAL LOGIC CONSTANTS

Lateral Deadband

CY0 = -0.1308996939

CY1 = 0.000109083

Y1 = 0.30543262 (radians)

Y2 = 0.174532925 (radians)

Minimum Bank Angle Schedule

ALMN1 = 0.7986355 (cos 37^o)

ALMN2 = 0.9659258 (cos 15^o)

ALMN3 = 0.93969 (cos 20^o)

ALMN4 = 1.0 (cos 0^o)

VELMN = 8000.0 (fps)

VYLMAX = 23000.0 (fps)

YLMIN = 0.03 (radians)

YLMN2 = 0.07 (radians)