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MCDONNELL DOUGLAS TECHNICAL SERVICES CO.
HOUSTON ASTRONAUTICS DIVISION

SPACE SHUTTLE ENGINEERING AND OPERATIONS SUPPORT

DESIGN NOTE NO. 1.4-4-11

# RTLS ENTRY RANGING ANALYSIS

MISSION PLANNING, MISSION ANALYSIS AND SOFTWARE FORMULATION

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## 1.0 SUMMARY

This note presents the results of a study to define the ranging capability of a Mission 3A Return-to-Launch-Site (RTLS) entry. The study established the limits on downrange and crossrange at the initiation of RTLS entry so that the Terminal Area Energy Management (TAEM) interface conditions were achieved satisfactorily. The downrange and crossrange limits were defined for both nominal RTLS entry conditions and a composite set of dispersed RTLS entry conditions.

The results indicate a wide range of acceptable downrange and crossrange positions are available at RTLS entry initiation for nominal conditions (a 48 nautical mile range of downrange for zero crossrange). This is greatly reduced when dispersions are considered. For dispersed RTLS entry conditions, an 18 nautical mile range of acceptable downranges is available at zero crossrange.

## 2.0 INTRODUCTION

The ranging capability of a Mission 3A RTLS entry was evaluated by defining the downrange and crossrange positions at the initiation of the RTLS entry which allowed TAEM interface conditions to be attained satisfactorily. Downrange/crossrange combinations were investigated by initializing the Space Vehicle Dynamics Simulation (SVDS) to the candidate downrange/crossrange at RTLS entry initiation (defined for this study as the point at which the angle of attack recovery maneuver begins) and executing an Analytic Drag Control (ADC) guided RTLS entry trajectory to the TAEM interface relative velocity of 1500 feet per second. The ADC guidance was modified as documented in Reference 1 to perform the load relief during pullup.

## 3.0 DISCUSSION

The downrange and crossrange position at RTLS entry initiation was varied to define the points where the range at TAEM interface deviated from the nominal range by ±5 nautical miles. TAEM interface was defined by a relative velocity of 1500 feet per second. Downrange and crossrange points within the ±5 nautical mile miss limits were scanned to define the points where the difference between the vehicle azimuth and the target azimuth at TAEM interface exceeded 15 degrees and to identify any points which resulted in undesirable RTLS entry characteristics.

The initial condition for RTLS entry initiation was defined in a plane which passes through a specified Mission 3A RTLS entry initial condition (defined in Table I along with other mission specifications) and the point of tangency on the heading alignment circle. The initial position was varied in this plane and the vehicle heading specified in order to obtain the desired downrange and crossrange. Downrange was defined along the great circle arc in the plane of the relative velocity vector and crossrange was defined along the great circle arc in the plane through the point of tangency on the heading alignment circle perpendicular to the relative velocity vector. For a specified initial downrange and crossrange, a spherical right triangle was defined from which the total range and azimuth of the RTLS entry initial condition were determined. The initial vehicle altitude, velocity magnitude, and

Table I

Mission 3A RTLS Conditions

Nominal Initial Conditions:

| | |
|---|---|
| Geodetic latitude | 30.31°. |
| Longitude | -122.04° |
| Altitude | 232692 FT |
| Inertial velocity | 7019.6 FPS |
| Relative velocity | 6491.6 FPS |
| Inertial flight path angle | -1.60° |
| Relative flight path angle | -1.73° |
| Inertial azimuth | 28.44° |
| Relative azimuth | 18.04° |
| Vehicle weight | 196700 LBS |
| CG | AFT |

Target Conditions:

| | |
|---|---|
| Geodetic latitude | 34.72° |
| Longitude | -120.56° |
| Runway azimuth | -44° |
| Distance from runway to heading alignment circles | 35261 FT |
| Heading alignment circle radius | 20000 FT |

Load Relief Parameters:

| | |
|---|---|
| Recovery angle of attack | 35° |
| Normal load limit | 2.2 g |

Guidance:

Analytic Drag Control (ADC) modified to perform load relief
Roll command magnitude limited to 70°
Roll command maintained at zero through load relief

flight path angle were held constant at the values in Table I to complete definition of the initial condition. Figure 3.0-1 presents the initial downrange/crossrange geometry.

3.1 RTLS Entry Ranging Capability for Nominal Conditions

Figure 3.1-1 presents the initial RTLS entry downrange and crossrange positions which satisfactorily attained the TAEM interface conditions. Identified are the limits on downrange and crossrange so that the range at TAEM interface is within 5 nautical miles of the nominal value and the difference between the vehicle and target azimuth at TAEM interface is less than 15 degrees. Also identified are downrange and crossrange positions which result in violation of the 2.2 g normal load factor limit. For these cases the normal load is maintained adequately at the limit through pullup by the load relief logic, however, later in the trajectory the normal load factor limit is exceeded due to the high reference drag commanded because of the short initial range. Figure 3.1-2 presents the drag and reference drag profiles for one of these cases. Beginning at approximately 3800 feet per second, the reference drag is being limited to prevent excessive loading. The actual drag level, however, overshoots the reference drag resulting in the violation of the normal load factor limit. The normal load factor profile, roll command profile, and altitude profile for this case are presented in Figures 3.1-3 to 3.1-5.

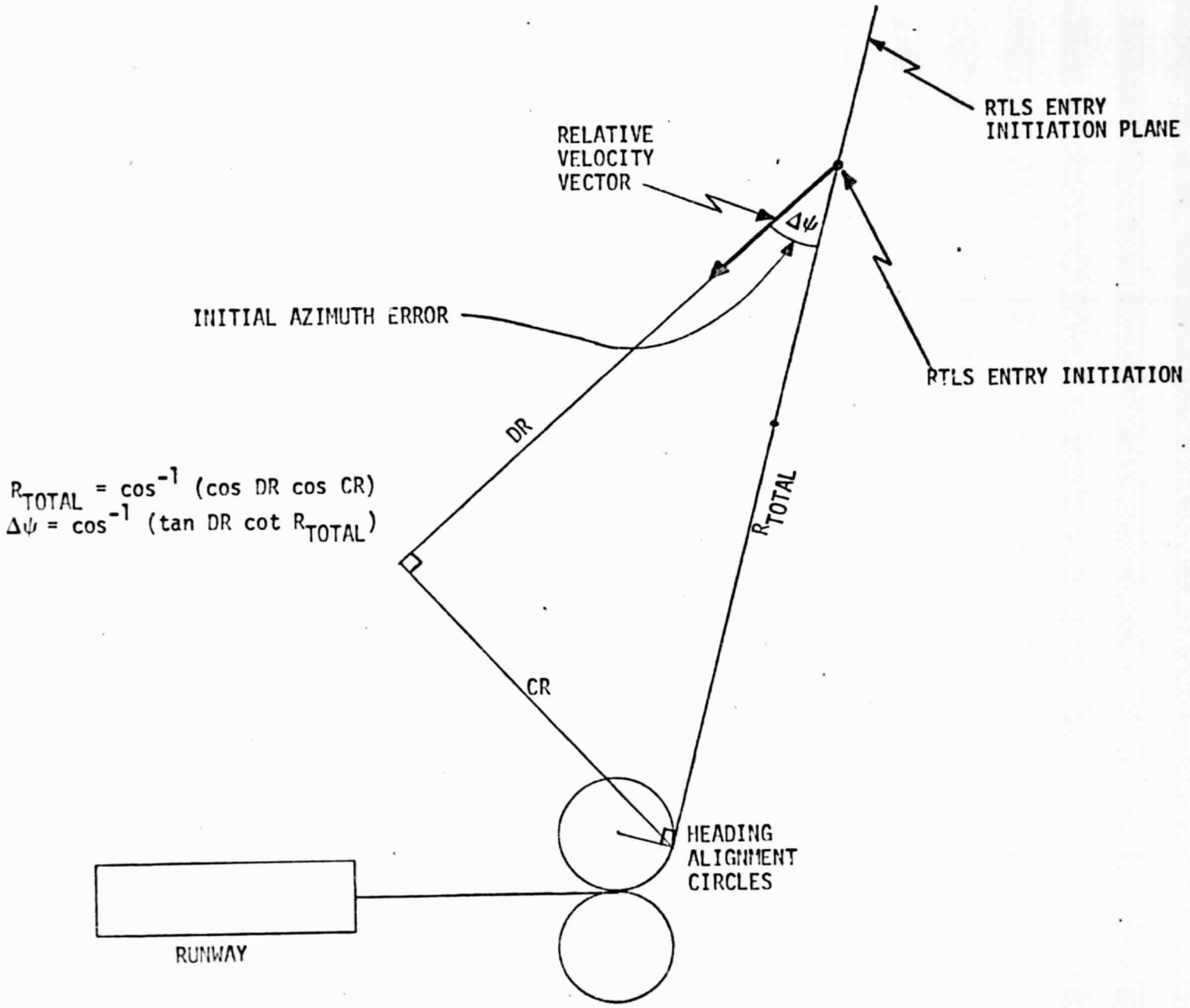


Figure 3.0-1

Initial Downrange/Crossrange Geometry

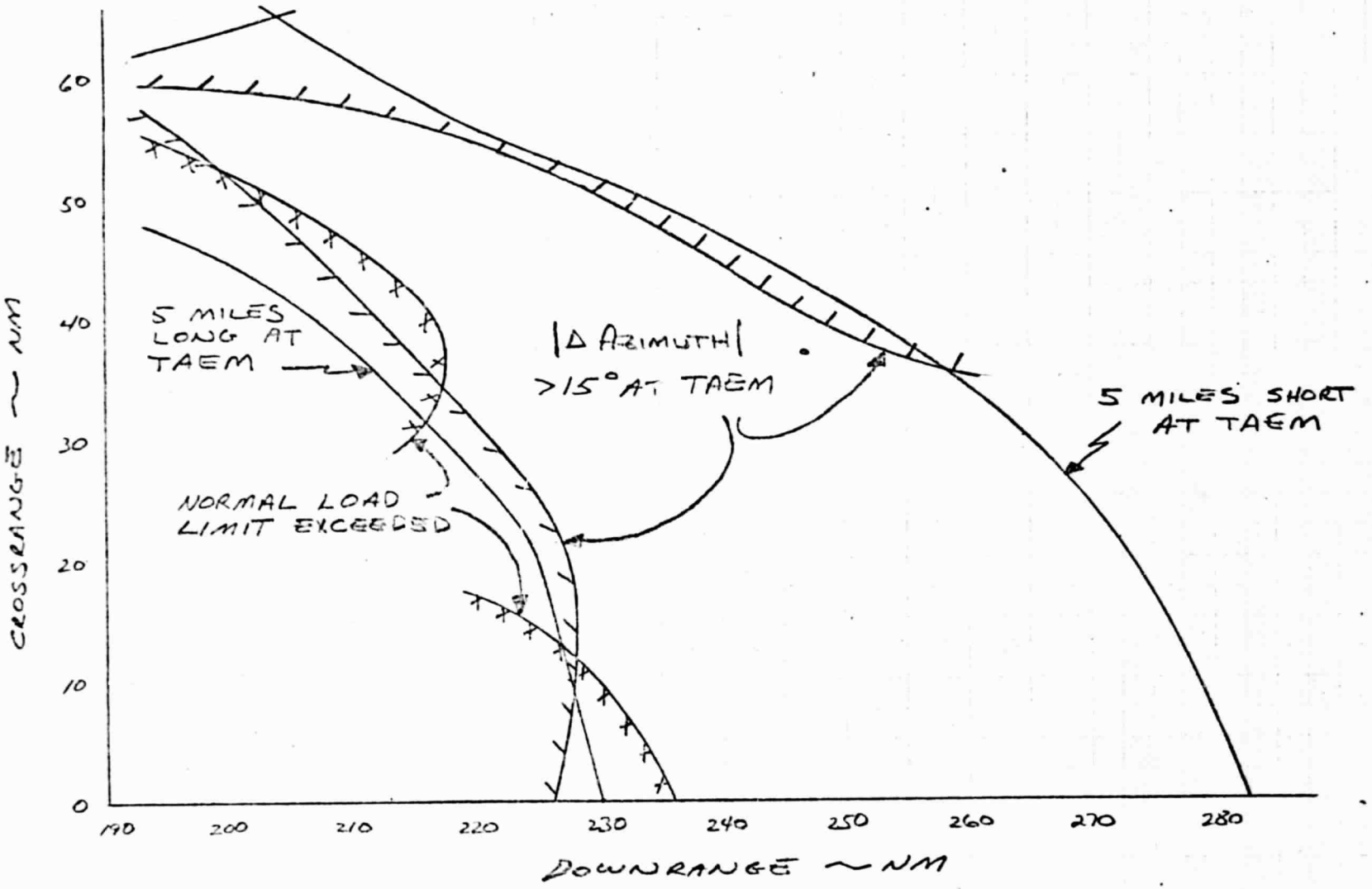


Figure 3.1-1
RTLS Entry Initiation Envelope for Nominal Conditions

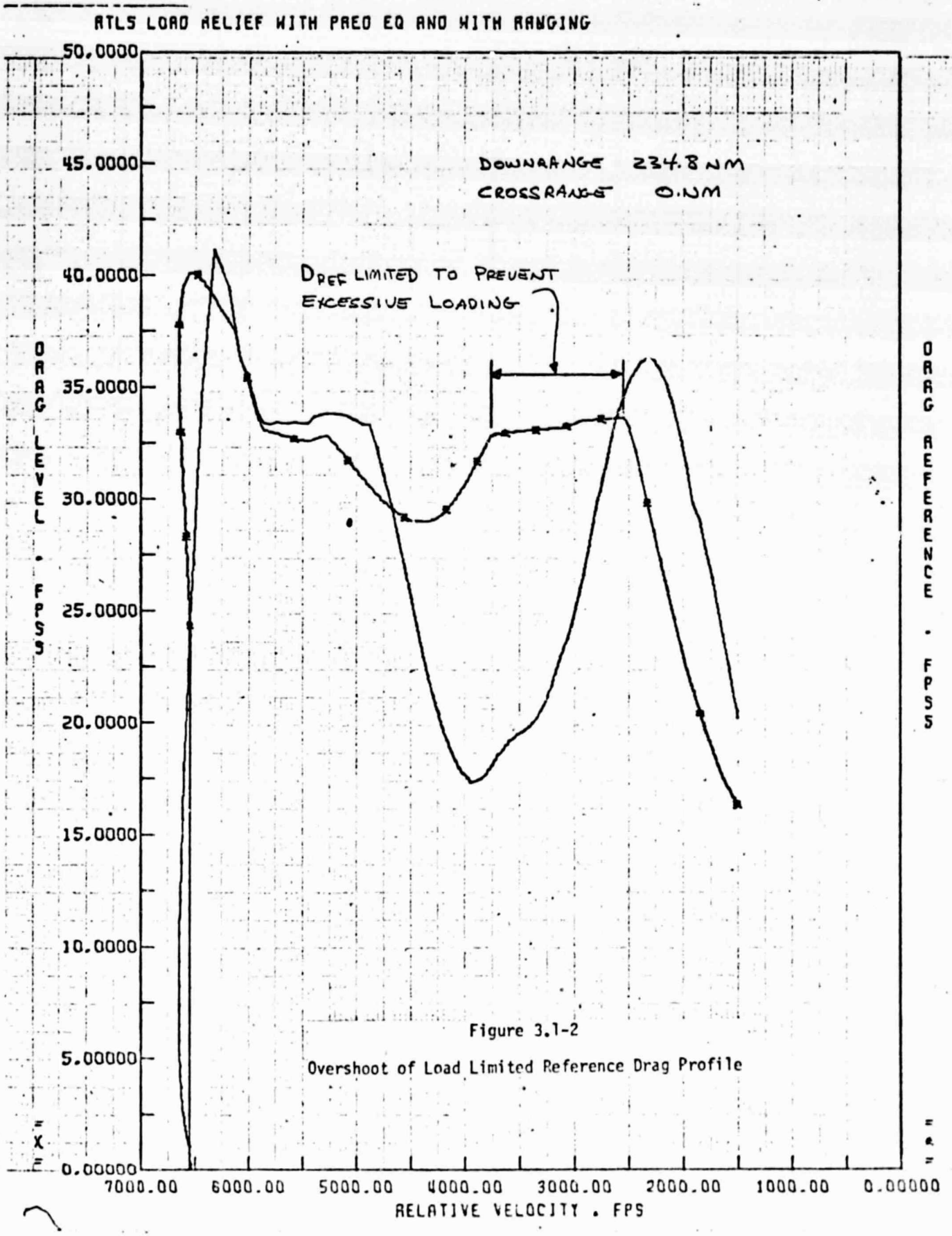


Figure 3.1-2

Overshoot of Load Limited Reference Drag Profile

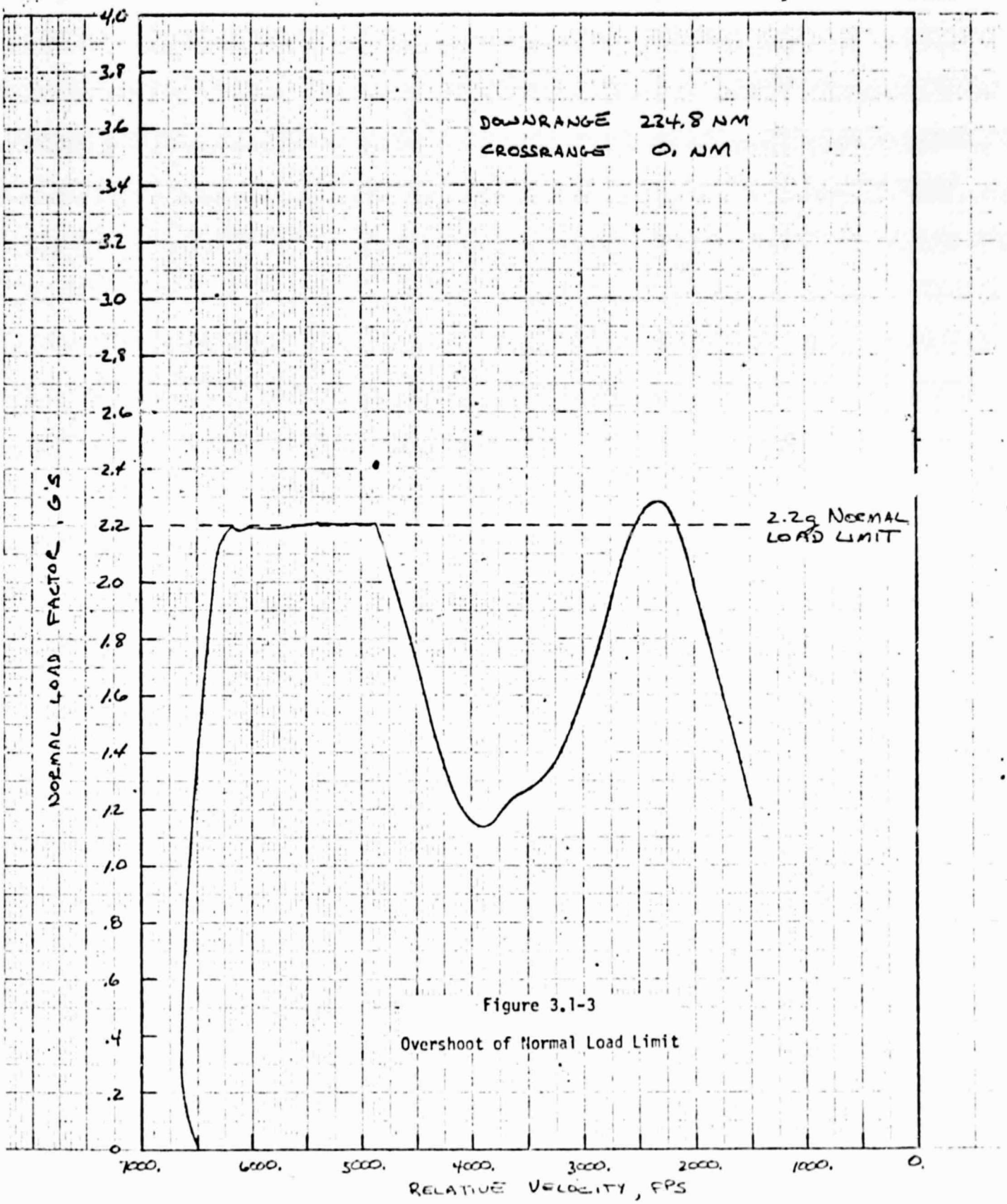


Figure 3.1-3

Overshoot of Normal Load Limit

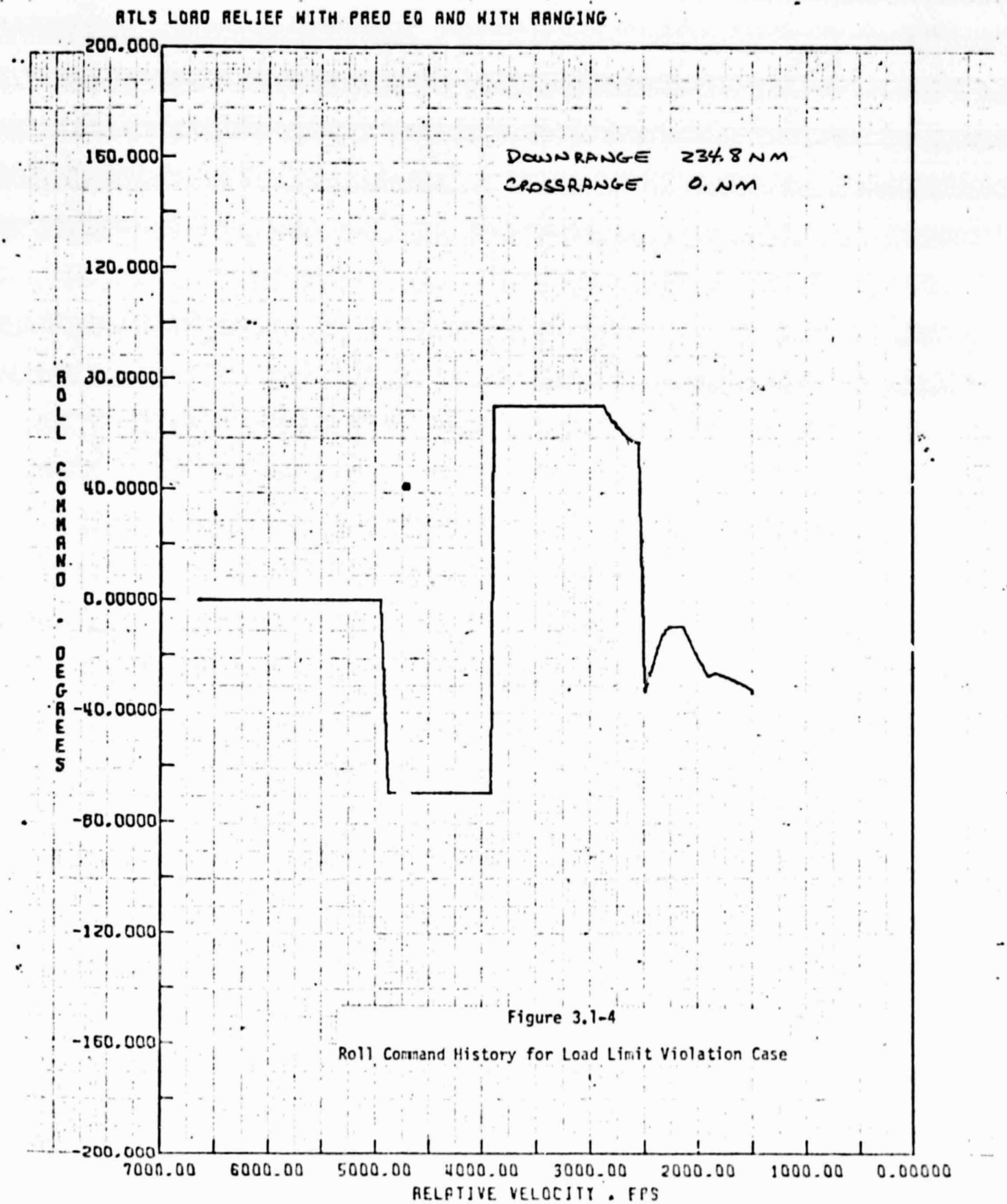


Figure 3.1-4

Roll Command History for Load Limit Violation Case

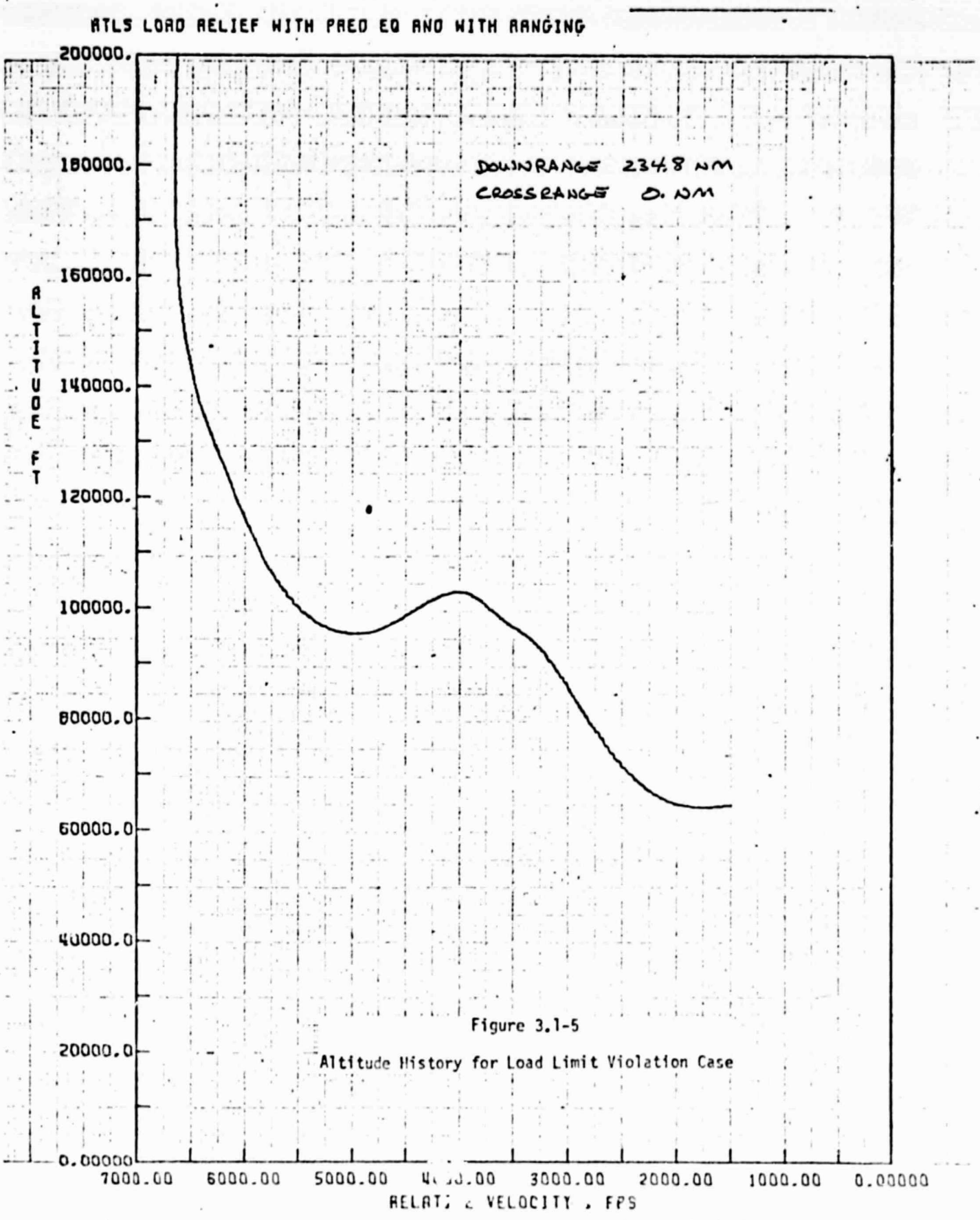


Figure 3.1-5

Altitude History for Load Limit Violation Case

## 3.2 RTLS Entry Ranging Capability for Dispersed Conditions

The effect of various dispersions on the RTLS entry ranging capability was investigated. The dispersions considered and their values are presented in Table II. These dispersions were combined in a manner documented in Reference 2 to produce a composite dispersion set which extended the RTLS entry range capability and a composite dispersion set which reduced the RTLS entry range capability. Using these composite dispersion sets, the downrange/crossrange positions at RTLS entry initiation which satisfactorily attained TAEM interface conditions were defined and are presented in Figure 3.2-1. The criteria of a 5 nautical mile deviation from the nominal TAEM interface range, a 15 degree difference in vehicle and target azimuth at TAEM interface, and a violation of the 2.2 g normal load limit were again used.

Table II

RTLS Entry Dispersions

| ITEM | | 3σ VARIATION |
|---|---|---|
| AERODYNAMICS | | $\pm$10% $C_D$, $\pm$13% $C_L$ ($\pm$6% L/D) |
| SEP. VELOCITY | (NAV) | $\pm$33 FPS |
| ALTITUDE | (NAV) | $\pm$2500 FT |
| GAMMA | (NAV) | $\pm$0.2 DEG |
| RANGE | (NAV) | $\pm$0.4 NM |
| SEP. VELOCITY | (GUID) | $\pm$10 FPS |
| ALTITUDE | (GUID) | $\pm$500 FT |
| GAMMA | (GUID) | $\pm$1.0 DEG |
| RANGE | (GUID) | $\pm$2.0 NM |
| ATMOSPHERIC DENSITY | | VAFB HOT & COLD DAYS |
| WEIGHT | | $\pm$10,000 LBS |
| CENTER OF GRAVITY | | $\pm$1% |

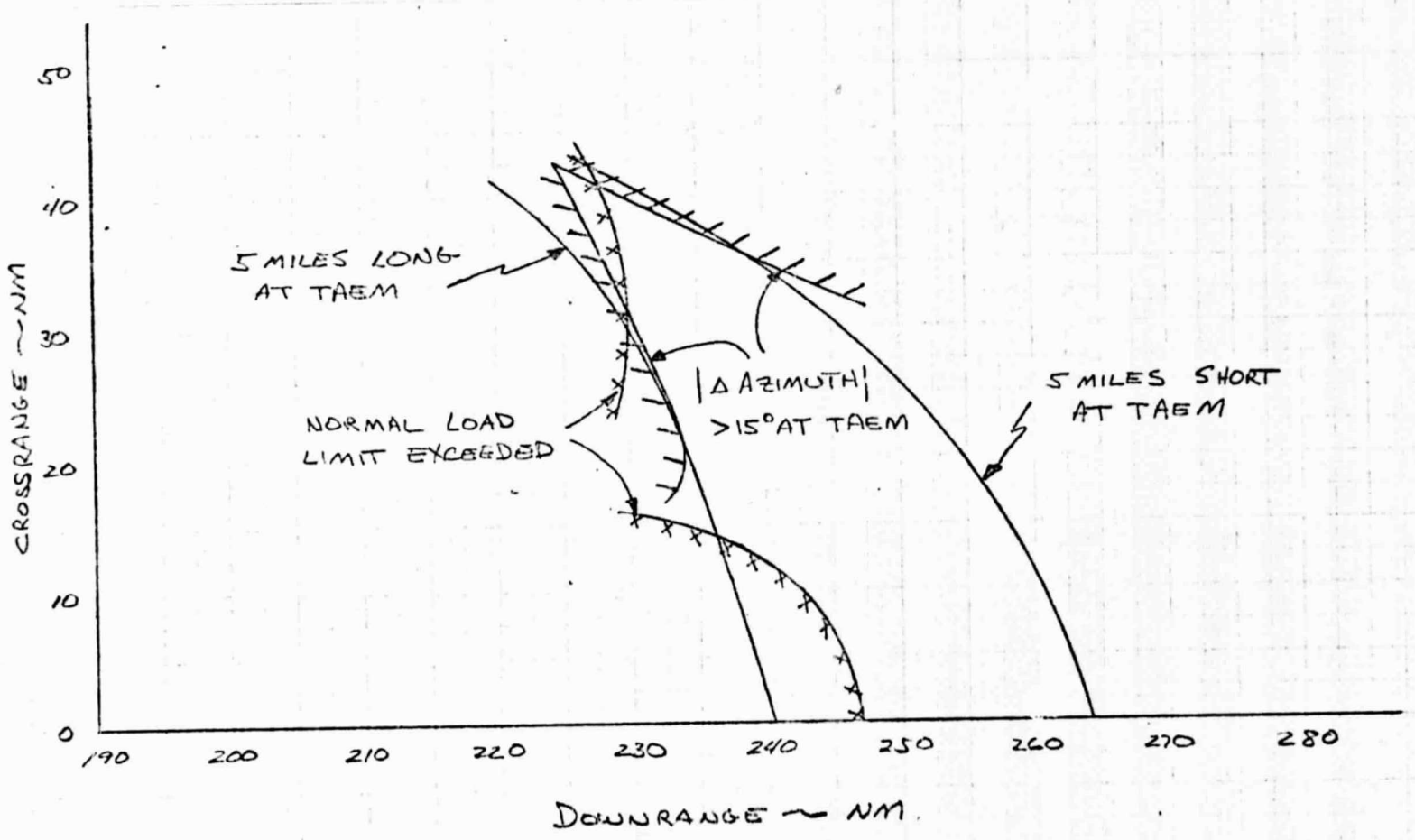


Figure 3.2-1

RTLS Entry Initiation Envelope for Dispersed Conditions

## 4.0 CONCLUSIONS

A wide range of acceptable downrange and crossrange positions is available at RTLS entry initiation for nominal RTLS entry conditions. A 48 nautical mile range of downrange positions is available at a 0. nautical mile crossrange which reduces to 44 nautical miles at a 30 nautical mile crossrange (see Figure 3.1-1). Consideration of dispersions greatly reduces the acceptable downrange and crossrange positions. For the dispersed RTLS entry conditions considered in this study an 18 nautical mile range of downrange positions is available at a 0. nautical mile crossrange which reduces to 15 nautical miles at a 30 nautical mile crossrange (see Figure 3.2-1).

The acceptable downrange and crossrange positions at RTLS entry initiation is not only determined by conditions at TAEM interface, but also load factor considerations during the RTLS entry. For short initial ranges, normal load factor violations may be encountered due to overshoots of the high reference drag profile.

## 5.0 REFERENCES

1. Crull, T. J.: "RTLS Entry Load Relief Parameter Optimization," MDTSCO, SSEOS Design Note No. 1.4-4-9, 28 June 1975.

2. Space Shuttle Flight Performance Data Book, Volume II, Orbiter Entry, SD73-SH-0173-2, January 1974.