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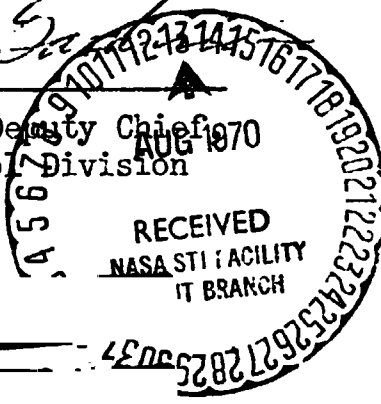
APOLLO PROGRAM

MAXIMUM ALLOWABLE LATERAL VELOCITY ERRORS
DURING LM POWERED DESCENT

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SUMMARY

A study has been conducted using a LM Digital Powered Descent Simulation Program to determine the magnitude of lateral velocity error which can be tolerated by the LM descent guidance system. The large lateral velocity errors studied are not velocities which are anticipated but rather are velocities which, if encountered, may affect the functioning of the landing radar updating of the guidance and navigation process. The study showed that a satisfactory descent was obtained for a lateral velocity error of 200 ft/sec even though radar data dropped out for 12 seconds after the second update because of the resulting pilot roll angle of nearly 50° . For a 150 ft/sec error, no radar dropout occurred. The study also revealed that landing site visibility for lateral velocity errors as large as 100 ft/sec closely approximated the nominal descent visibility.

INTRODUCTION

The LM landing radar (LR) uses four beams to measure altitude and velocity of the LM with respect to the lunar surface (fig 1). If the LR is functioning properly, a data good discrete is sent to the LGC. Upon receipt of this discrete the LGC accepts radar data, performs the tests listed in Table I, and weights this data into the LGC state vector.

The data good condition of the radar depends mainly on the incidence angles (angle from local vertical) of the four beams and the velocity magnitude along each beam. A lateral velocity error, when velocity updating starts near or after the higate aim point in the descent, could produce a spacecraft roll angle large enough to make the velocity beam incidence angles exceed the data good boundary thereby causing loss of radar data for a period of time. This, in turn, could cause the guidance to miss the logate aim conditions. The objectives of this study were to (1) determine the magnitude of lateral velocity errors that would produce a radar data loss condition, and (2) determine the ability of the guidance systems to correct lateral velocity errors.

DESCRIPTION OF SIMULATION

A detailed description of the digital program used in this study is contained in the reference. Only the most significant radar updating characteristics of the program have been presented in this report.

State Vector Update

To simulate the radar updating process, two state vectors (SV) are used in the descent program: (1) the LGC SV corresponds to the SV which the LGC would calculate if it received data from the PIPA's only, and (2) the actual SV (subscript a) which differs from the LGC computed SV because of accelerometer scale factor and bias errors, IMU misalignment, radar antenna misalignment, and/or initial condition errors at ignition. When radar updating begins, the LGC SV is gradually updated to the actual SV. Before updating occurs a data good test is performed. In this test the incidence angle of each beam is compared with a maximum incidence angle for the current altitude (figures 1 & 2). The zero doppler angle (angle between a vector perpendicular to LM velocity vector and the radar beam) is compared with a minimum zero doppler angle of 10° . Beams one, two, and four must pass this test for altitude updates and beams one, two, and three must pass for velocity updates. If the data good test is failed, the updates are discontinued until 6 sec after the test is passed again. Although the maximum allowable incidence angles are functions of both altitude and velocity, the maximum allowable incidence angles used in this program were assumed to be dependent on altitude only.

TEST PROGRAM

The initial conditions and the guidance aim point targeting used in this study are shown in Table II. Runs 1, 2, and 3 were initialized at higate with the LGC lateral velocity zero ($\dot{Y}_0 = 0$) and with the actual lateral velocity (\dot{Y}_{a0}) being detected by the LR at the start of data read. The fourth run was initialized at pericyynthion with the LGC and actual state vectors identical but with an accelerometer bias error in the lateral direction which produced an LGC lateral velocity error of 100 ft/sec at higate. Velocity updating started 16 seconds after the higate aim point for all four runs.

DISCUSSION OF RESULTS

The study results are contained in plots of pilot roll angle, visibility angle, incidence angle, and velocity recovery as functions of time from higate. Also, a table showing the delta V penalty incurred by the guidance in correcting the velocity errors is included.

Velocity Recovery

The guidance system was able to make a successful landing for the range of velocity errors considered in this study. Radar dropout occurred for the 200 ft/sec error case because of the large roll angle (fig 3) which caused the allowable incidence angle to be exceeded (fig 4). Reacquisition of velocity, however, occurred about 12 seconds later and a successful landing was achieved. The velocity recovery time history of the actual and LGC velocities for the radar dropout case is shown in figure 5. Landing site visibility actually increased for the error cases considered as can be seen in figure 6. It is interesting to note that there is only about a 4 degree maximum difference between the nominal visibility and the visibility resulting from recovery of a velocity error of 100 ft/sec. Finally, the recovery from the more realistic case of a 100 ft/sec error at higate caused by y-axis accelerometer bias of 0.214 ft/sec^2 is not significantly different than that resulting from the artificially induced 100 ft/sec initial condition error.

Limitations of Radar Model

The simplified radar model used in this study is shown in figure 2. The principal limitation of this radar model is the assumption that the maximum allowable incidence angle is a function of altitude only. Actually this angle is also at least a function of the beam velocity (the vehicle velocity projected along the radar beam). To determine the effect of this limitation, radar dropouts were calculated for runs 2 and 3 using preliminary data (maximum allowable incidence angle as a function of velocity and altitude) obtained from a detailed radar math model. The radar dropouts obtained in runs 2 and 3 were compared with those obtained using the EG23 data. This comparison showed that the no-dropout condition of run 2 would have occurred. However, in run 3 the dropout which occurred would have been caused by the incidence angle of beam 2, not beam 3, exceeding the maximum allowable incidence angle for beam 2. Also, beam 2 came within 2° of exceeding the maximum incidence angle at several other points in the trajectory.

CONCLUDING REMARKS

The results of this study indicate that the LM guidance system can operate sufficiently well in the presence of large initial lateral velocity errors (up to 200 ft/sec) at higate and remove these errors before the hover aim point is reached. Velocity errors greater than 25 ft/sec are not anticipated in a normal descent and, in the event lateral velocity errors of the magnitude used in this study did occur, the astronaut would be required to override the alarm triggered by the LGC data reasonableness test (Table I) to obtain updating of the LGC.

REFERENCE

EG27/Control Requirements Branch: General purpose digital program for LM powered descent - Presimulation report. EG27-61-67 dated April 17, 1967.

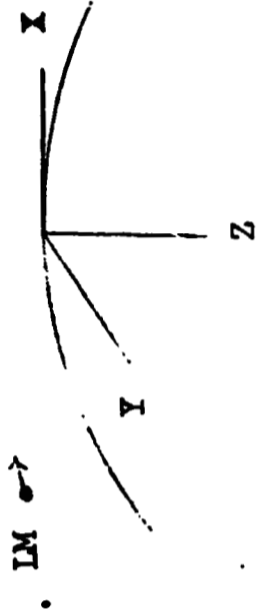
TABLE I. - TESTS PERFORMED BY LGC PRIOR TO
ACCEPTANCE OF RADAR UPDATES

Test	Function of Test
Phase	If LM is in either transition phase 1 or 3 no radar updates are allowed.
Altitude	If $15000 < h \leq 25000$ ft altitude updates are allowed. If $h \leq 15,000$ ft altitude & velocity updates are allowed.
Data Reasonable	If $ \Delta h $, radar altitude update, > 50 ft + $(.175)(\text{LGC measured altitude})$ alarm is turned on & no radar altitude updates allowed. If $ \Delta V $, radar update of a velocity component, > 25 ft/sec + $(.155)(\text{LGC measured velocity})$ an alarm is turned on and no radar updates accepted unless astronaut overrides alarm.
Data Good	The LR data good discrete signifies that the radar tracking loops are locked-on and tracking satisfactory. If this discrete is present, the LGC accepts radar data from the LR.

TABLE II. - MIT TRAJECTORY NO. 472285
AIM POINT CONDITIONS

Aim Points	Desired Aim Point Conditions							
	X_D	Z_D	\dot{X}_D	\dot{Z}_D	\ddot{X}_D	\ddot{Z}_D	\dddot{X}_D	\dddot{Z}_D
(1) False	-159,005	-16,376	1497	-49.9	-14.3	-1.345	-.0147	
(2) High Gate	-34,193	-9389	596.6	158.4	-8.18	1.51	-.00914	
(3) Hover	-3.3	-115	2.5	1.4	-1.25	-0.7	.96547	

Landing Site Coordinates



Initial Conditions at High Gate

$$\begin{aligned}
 X_0 &= -34,193 & Y_0 &= 0 & Z_0 &= -9389 \\
 \dot{X}_0 &= 596.6 & \dot{Y}_0 &= 0 & \dot{Z}_0 &= 158.4
 \end{aligned}$$

Initial Conditions at Periapsis

$$\begin{aligned}
 X_0 &= 1,416,980 & Y_0 &= 0 & Z_0 &= 126,866 \\
 \dot{X}_0 &= 5395.4 & \dot{Y}_0 &= 0 & \dot{Z}_0 &= -1360
 \end{aligned}$$

TABLE III. - RUN CONDITIONS AND RESULTS

Run	Initial Error	ΔV Penalty	Max. Pilot Roll
1	$\dot{Y}_{a0} = 100 \text{ ft/sec}$	18 ft/sec	36. Deg
2	$\dot{Y}_{a0} = 150 \text{ ft/sec}$	48 "	45. "
3	$\dot{Y}_{a0} = -200 \text{ ft/sec}$	99 "	48.8 "
4	$Y_{BIAS} = .214 \text{ ft/sec}^2$	32 "	37. "

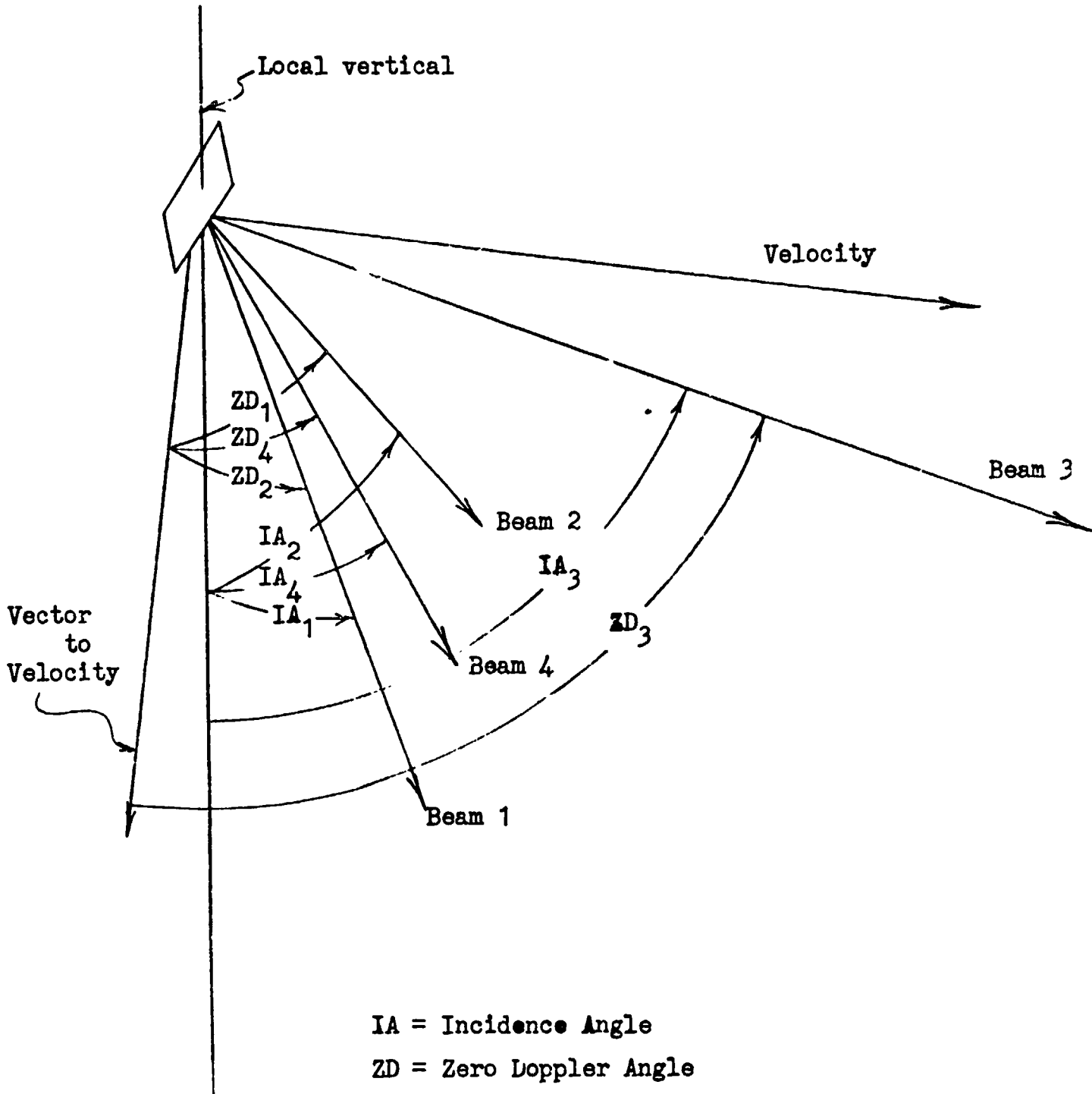
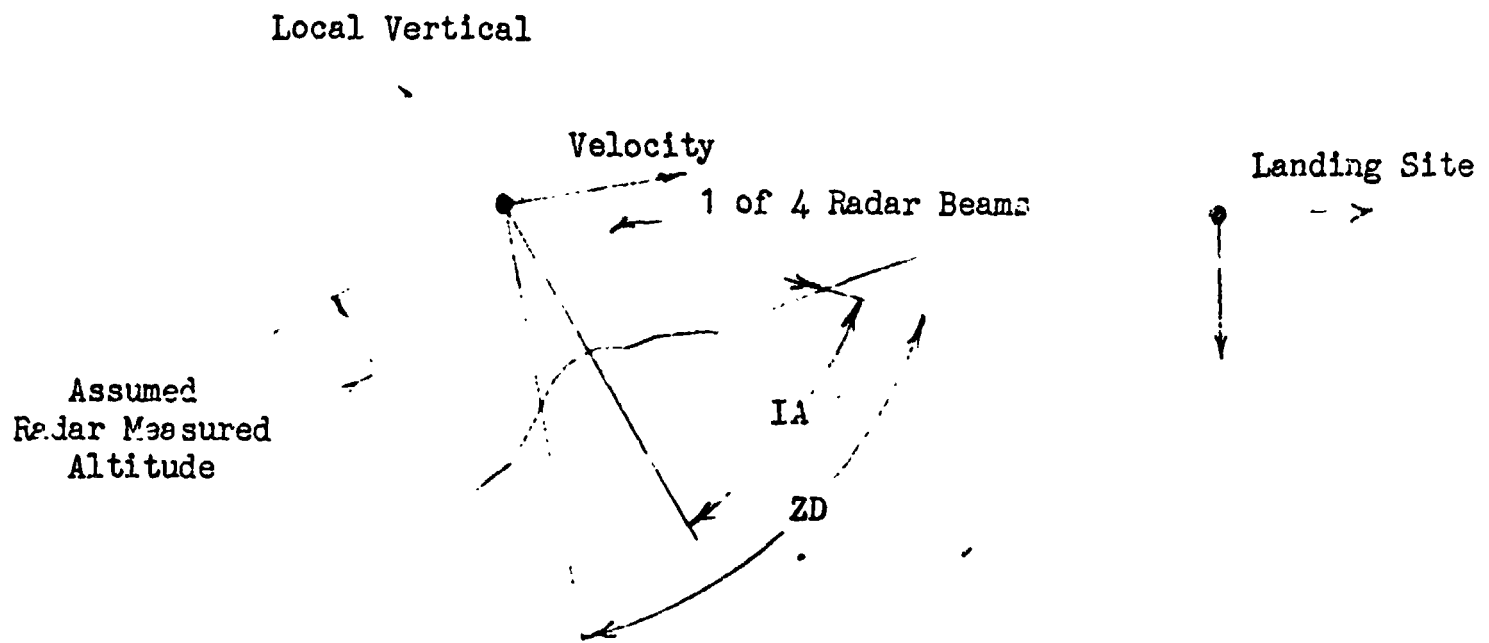
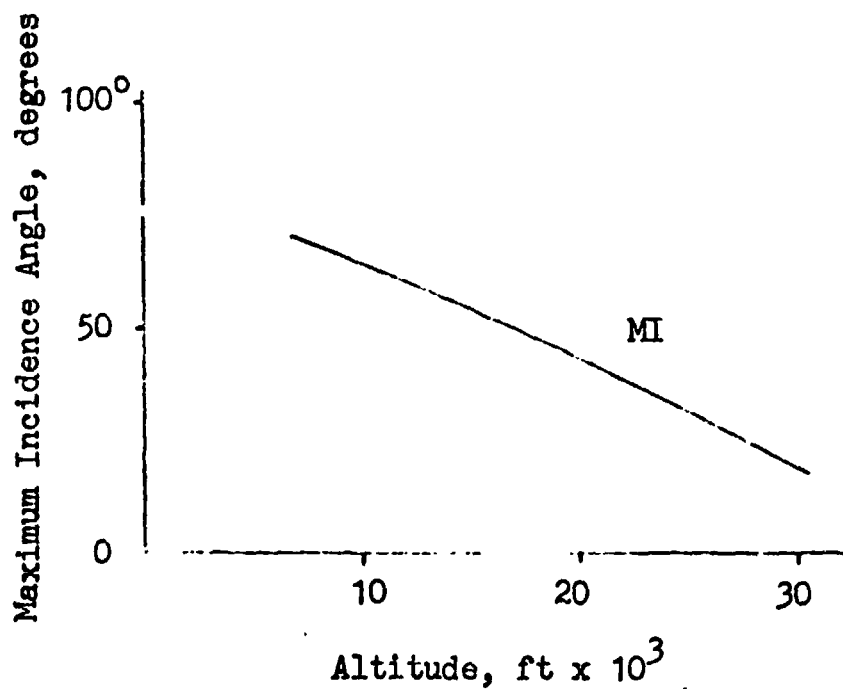


Figure 1. - Zero Doppler and Incidence Angles



Geometry of Critical Radar Angles



Radar Data Good Criteria

1. Each radar velocity beam must have $IA < MI$.
2. Each radar velocity beam must have $ZD > 10^\circ$.
3. The altimeter beam must have $IA < MI$ & velocity beams one & two must be good.

Limit Criteria of Radar Angles

Figure 2. - Simulated radar model

Run 1 Lateral velocity error = 100 ft/sec
 Run 2 Lateral velocity error = 150 ft/sec
 Run 3 Lateral velocity error = -200 ft/sec
 Run 4 Lateral acceleration error = .214 ft/sec²

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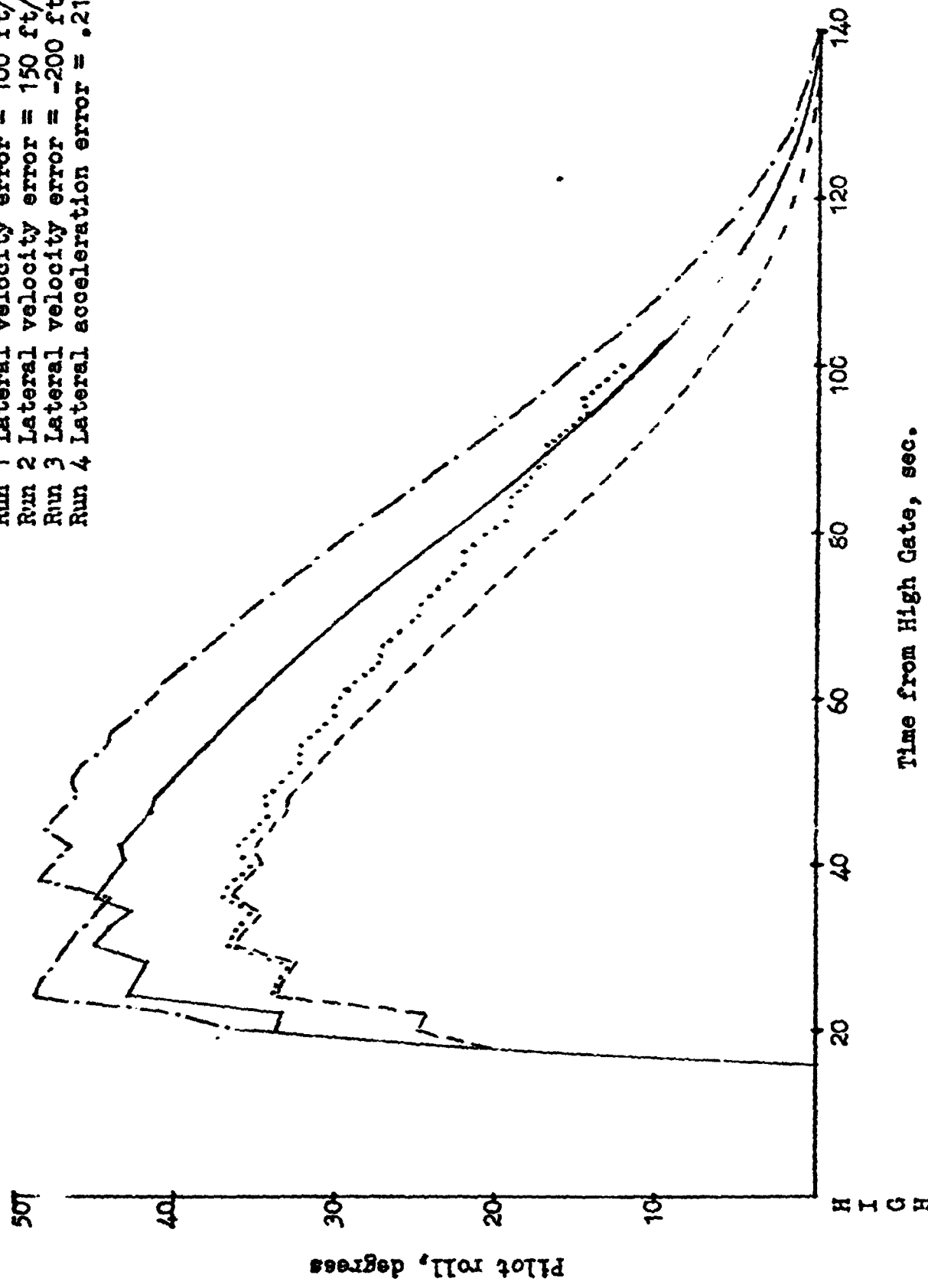


Figure 3. - Pilot roll for runs 1, 2, 3, & 4 (Note: Run #3 - Roll angle is negative)

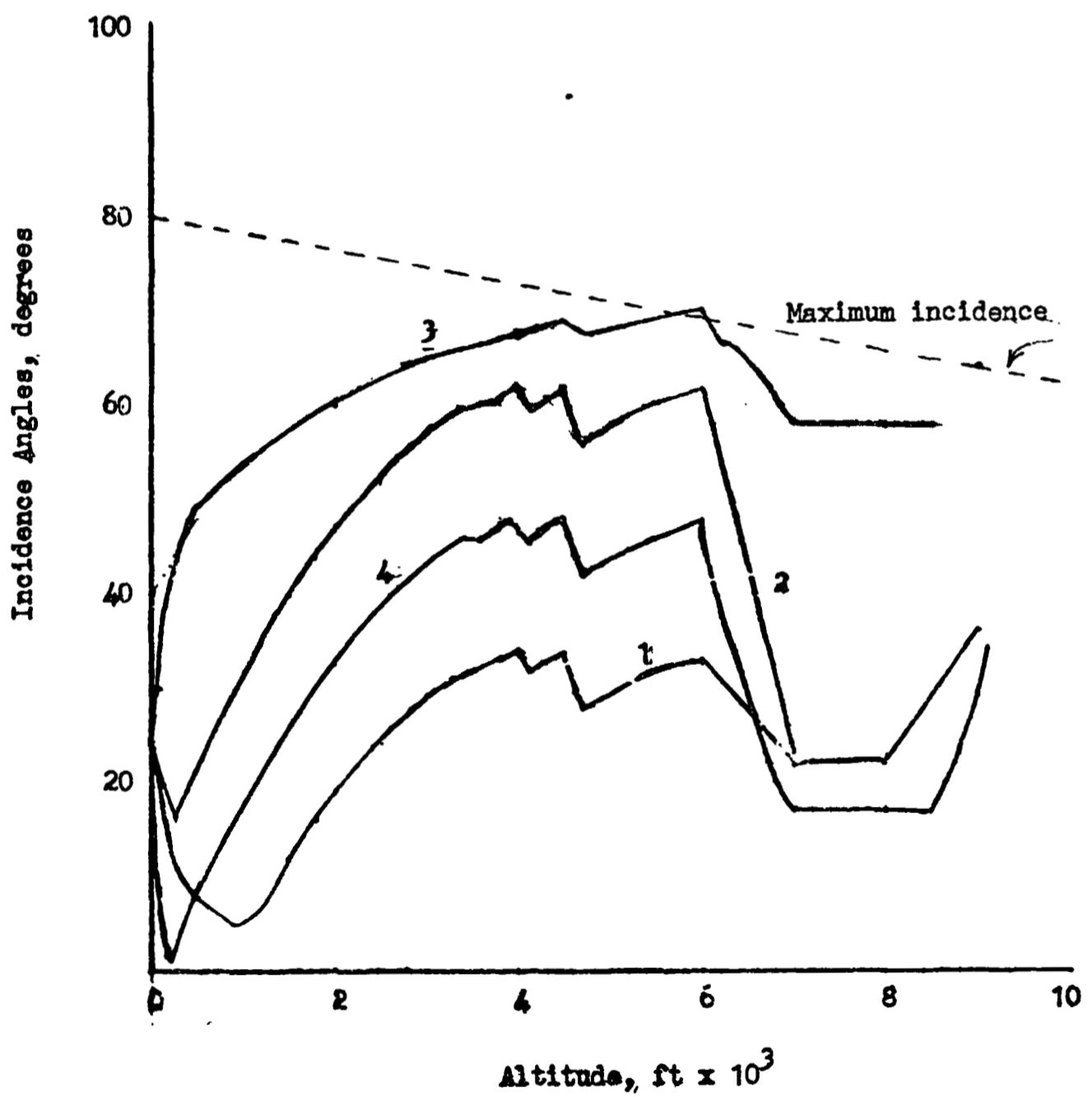


Figure 4. - Incidence angles of radar beams 1, 2, 3, & 4 for run 3. (with lateral velocity = -200 ft/sec)

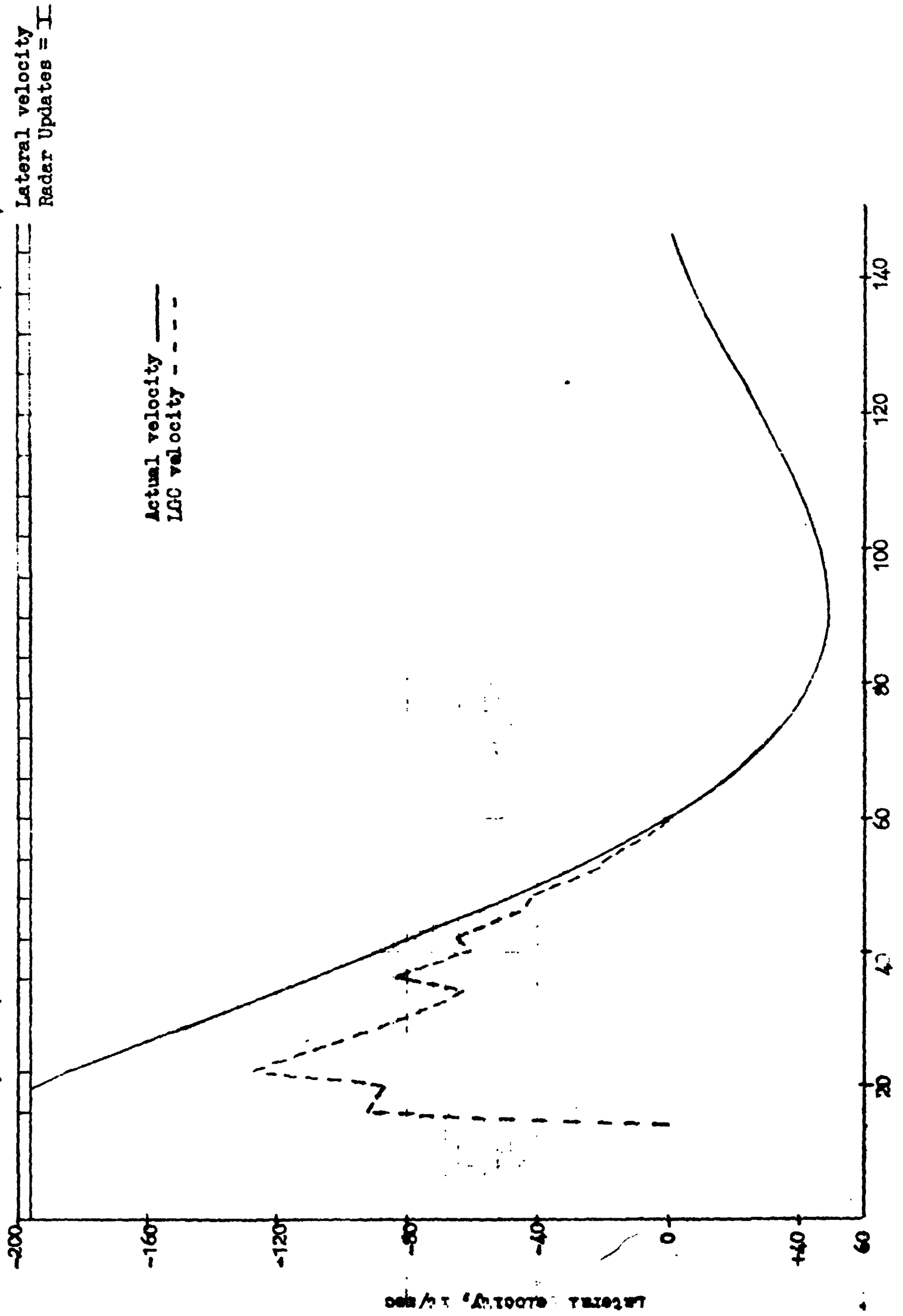


Figure 3. - Actual lateral velocity & LGC measured velocity for run 3.

MIT Nominal - - - - -
 Lateral Velocity error of 100 ft/sec - - - - -
 Lateral Velocity error of 150 ft/sec - - - - -
 Lateral Velocity error of 200 ft/sec - - - - -
 Lateral Acceleration BIHS of .214 ft/sec²

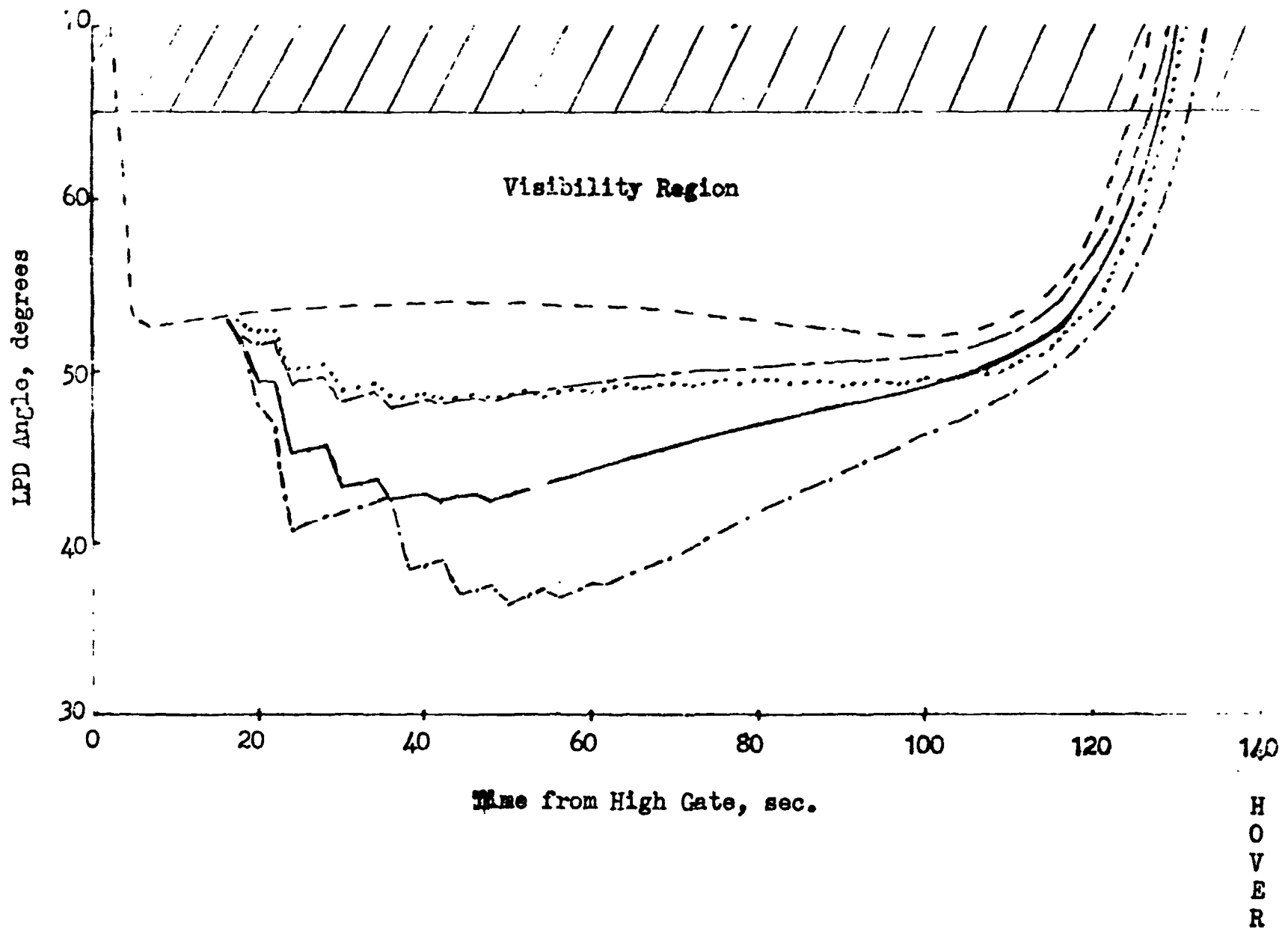


Figure 6. - LPD Angle during final approach phase