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FALSE HIGH GATE TARGETING FOR LM POWERED DESCENT

MANNED SPACECRAFT CENTER
HOUSTON, TEXAS
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PROJECT APOLLO

FALSE HIGH GATE TARGETING FOR LM POWERED DESCENT

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SUMMARY

This report presents false high gate targeting (FHGT), a technique to reduce the sensitivity of the LM descent guidance system to radar altitude updates. Guidance sensitivity is reduced by using a false target which adds a bias time of 60 seconds to the time-to-go (Tgo) to the high gate aim point ($Tgo \geq 60$). FHGT allows the LM state vector to be updated with landing radar using the presently established radar weighting functions but reduces the reaction of the guidance system to large updates. Thus, navigation errors are removed without pérmitting the guidance system to closely follow fluctuations in terrain.

The aim points of the FHGT can be chosen to provide a nominal trajectory identical to that of the present high gate targeting. For off-nominal conditions, though, a variation of the real high gate conditions can be expected for FHGT. The results of this study show that for the three-sigma navigation errors considered, there is little difference in the trajectory conditions (visibility profile and altitude at 2000 ft range from landing site) after high gate. But with a terrain slope uncertainty of $\pm 1^{\circ}$ considered, there are large differences in trajectory conditions after high gate between the present system and FHGT. These differences can be eliminated with either an automatic or manual landing site redesignation (2000 ft max) based on the known altitude miss at high gate ($h_{LGC} - h_{DESIRED}$). Even with this redesignation, FHGT will provide at least a 30 ft/sec characteristic velocity saving. This saving is based only on navigation error and terrain slope effects--the saving can be much larger with respect to terrain deviation effects.

A technique proposed by Bellcomm for desensitizing the final approach visibility profile to radar updates by updating range in proportion to altitude updates was also considered in this study. This technique when incorporated with FHGT resulted in trajectory dispersions after high gate that were less than the present system, i.e., at 2000 ft range from the landing site, h = 450-880 for present system (terrain slope but not deviation considered), h = 400-860 for FHGT with redesignation at high gate, h = 520-730 for FHGT with redesignation and with Bellcomm technique. A 60 ft/sec ΔV penalty is associated with the Bellcomm technique, though.

The possible changes to the present LM descent software needed to implement FHGT are: (1) redefining the high gate targeting parameters (to the false target), (2) shifting by 60 seconds any event that occurs as a function of Tgo, e.g., aim point change, and (3a) the possible addition of an automatic L.S. redesignation at high gate based upon altitude miss (the astronaut could manually make this redesignation), or (3b) the adoption of Bellcomm's technique for range updating after high gate, or (3c) both 3a and 3b.

INTRODUCTION

During a LM descent to the lunar surface, a radar will be used to measure altitude and will update the LGC computed state vector. The altitude deviation of the lunar terrain from the elevation of the landing site (to which the state vector is referenced) can cause two types of problems. A navigation error can be introduced into the LGC, and second, because of increased guidance sensitivity to an altitude update as an aim point (such as high gate) is approached, the guidance system may overreact with a resulting miss of the aim point, an excessive use of ΔV, or possible loss of radar track due to a large attitude maneuver.

If the LM descent system can be desensitized to terrain deviation, then the probability of successful initial lunar landings can be enhanced and/or the landing site selection for future missions can be broadened. There are two avenues of attack to desensitize the system--operate on the guidance system or on the navigation system. Studies have been and are being conducted (report pending) on the navigation system, such as filtering the radar data and/or radar weighting function readjustments. This report presents a slight modification to the guidance system which will desensitize the approach to high gate to altitude updates.

False High Gate Targeting (FHGT)

The guidance sensitivity can be shown mathematically to be inversely proportional to the Tgo to its aim point. FHGT reduces this sensitivity by aiming for a target which is 60 seconds beyond the real high gate, which essentially adds a bias of 60 seconds to Tgo. With this target, a nominal trajectory is established which intersects the high gate aim point at Tgo = 60 seconds. An aim point change occurs at Tgo = 60 seconds.

To evaluate the false high gate targeting technique (FHGT), a digital simulation was conducted. Guidance performance obtained with FHGT was compared to performance obtained without it for LM descents over rough terrain with navigation errors, thrust errors, and terrain slope uncertainty.

DESCRIPTION OF SIMULATION

The program iteration time was two seconds. A time delay of one second existed between the time the guidance commands were computed and the execution of the commands. A control system delay was approximated by assuming the thrust vector maneuvers to be the commanded position at a constant rate of 5 deg/sec. The program was initialized at the start of full thrust (FTP) near pericynthion with the I.C.'s and targeting parameters as indicated in table I. A detailed description of the digital program is presented in reference 1.

Radar Model

For each of the four radar beams (three velocity and one altitude), the incidence angle, the angle between the beam and the local vertical, and the magnitude of the velocity along the beam were computed. Radar altitude updates began at an altitude of approximately 24,000 ft (Tgo = 160 sec to high gate) and radar velocity updates began at $h_{LGC} \leq 10{,}000$ ft.

No radar dropouts were allowed after radar acquisition. By using radar data obtained from reference 2, points were established where radar dropout would have occurred.

Terrain Model

A single terrain elevation versus range could be specified in the program. The terrain profile could also be rotated about the landing site to simulate the uncertainty in terrain slope.

Navigation Error Model

An actual state vector and a LGC state vector were computed. These state vectors differed in initial conditions at ignition and thereafter because of acceleration differences resulting from IMU misalignment and accelerometer bias. Two (worst case) combinations of errors and initial conditions were used to produce an error in altitude of approximately ±3,000 ft at radar altitude acquisition and an error in rate of descent (ROD) of ±20 ft/sec at radar velocity acquisition. (These navigation errors will be referred to as three-sigma errors.) The two worst case combinations of navigation errors were combined with high and low thrust profiles to form the four worst case conditions: thrust high-vehicle high (THVH), thrust high-velicle low (THVL), thrust low-vehicle high (TLVH), and thrust low-vehicle low (TLVL). Actual initial errors and resulting altitude and ROD errors at radar acquisition are shown in table II.

Limitation of Simulation

Results of this study may be affected by the following items:

a. A perfect radar was used in which no radar dropouts were allowed after radar acquisition except for a programed dropout at high gate for the antenna rotation period.

b. The terrain deviation measured by the radar was assumed to be directly beneath the vehicle, not at the point where the radar beam would have intersected the lunar surface.

c. Terrain slope was not included in the calculation of radar beam incidence angles.

d. The uncertainty in the measurement of terrain slope was assumed to be no greater than $\pm 1^{\circ}$.

TEST PROGRAM

The run conditions are given in Table III. Runs were made to determine which conditions (including $\pm 1^{\circ}$ terrain slope) produced the worst effects with false and fixed high gate targeting. Runs were then made to compare false targeting with fixed targeting using the worst case conditions for descents to the Censorinus landing sites. The terrain profiles for the Censorinus and Copernicus landing sites used in this study are shown in figure 1.

DISCUSSION OF RESULTS

Effects of Terrain on Fixed and False High Gate Targeting

During a LM descent over rough terrain, large variations in vehicle attitude will occur as the radar system senses prominent terrain features. With the present targeting (a fixed target at high gate), the guidance system over-reacts to the radar altitude updates it receives and tends to follow the terrain. If the radar system measures altitude to the bottom of a crater, the guidance system directs the LM to pitch toward the horizontal to correct for what appears to the LGC as a vehicle high condition. When the radar system measures the altitude to the higher surface past the crater, the guidance system directs the LM to pitch toward the vertical to correct for what now appears to the LGC as a vehicle low condition. As the LM approaches the high gate aim point and Tgo approaches zero, the reaction of the guidance system to terrain deviations increases.

With the present guidance equations, the commanded acceleration is computed as a quadratic function of Tgo. Mathematically, pitch sensitivity ($\frac{\partial \theta}{\partial h}$) to altitude updates can be shown to be a function of $1/Tgo^2$ (reference 3). FHGT adds a bias time of 60 seconds to Tgo which effectively reduces the pitch (and thrust) sensitivity to terrain deviations. Figure 2 shows pitch and thrust sensitivities as a function of Tgo for fixed and false high gate targeting. As the high gate aim point is approached, the pitch and thrust sensitivity approach infinity with fixed targeting. The present solution to this problem is a linear guidance routine which is entered at Tgo = 20 seconds. FHGT pitch and thrust sensitivity approach the finite values of .005 deg/ft and .25 lb/ft, respectively, at high gate, and therefore, a linear guidance routine is not required with FHGT. The performance of false and fixed high gate targeting is compared for LM descents to the Censorinus science site and the Copernicus crater in the next two sections.

Censorinus.- To illustrate the advantages of FHGT for LM descents over rough terrain, descents were made to the Censorinus science landing site with fixed and false high gate targeting. Three worst case combinations of I.C. conditions and slope (TLVL-1°, THVH+1°, and THVL+1°) were used.

The worst case combinations produced the largest pitch deviation from nominal (TLVL-1°), the largest ΔV penalty (THVH+1°), and the worst landing site visibility (THVL+1°) in TRW's Approach Terrain Evaluation Study (reference 4). Descents were also made with FHGT using VH-1° and VL+1° conditions, which produced the largest high gate miss (for FHGT) and caused the altitude and ROD constraints at manual takeover to be violated. Figure 3 shows pitch and altitude profiles with fixed and false high gate targeting. Table IV shows the visibility time, change in ΔV from nominal, and pertinent high gate conditions for FHGT and fixed high gate targeting.

Figure 3 and table IV illustrate that for the simulated descents to Censorinus, FHGT (a) reduces pitch deviations prior to high gate by a factor of about five, and therefore reduces the probability of a loss of track by radar system, (b) provides a more near-nominal visibility time after high gate, (c) requires less ΔV-max penalty of 18 ft/sec compared with 41 ft/sec for fixed targeting, (d) prevents the crash conditions of some cases.

A comparison of the radar data (beam incidence angle and beam velocity) with radar dropout data from reference 2 indicates that loss of radar lock would not have occurred in the descents to Censorinus with FHGT. With fixed targeting, however, loss of radar lock would have occurred. The results listed in table IV for fixed targeting would probably have been worse if radar dropouts had been allowed.

Copernicus.- A LM descent to the crater Copernicus was made with false and fixed high gate. No off-nominal conditions were used. A more complete study of Copernicus landings with fixed targeting is given in reference 5. Figure 4 shows that radar dropouts would have occurred with fixed targeting but would not have occurred with FHGT. Had radar dropouts been allowed, the descent with fixed targeting would probably have resulted in a crash. A comparison of ΔV penalties indicated on figures 4(a) and 4(b) show the FHGT saves at least 60 ft/sec.

Maximum Allowable Terrain Criteria for FHGT

Using a model crater in which crater width is a function of crater depth (W = 6d), a maximum allowable terrain criteria was developed for FHGT. A crater with its center a constant range from the L.S. was increased in magnitude until one of the following occurred during LM descent: (1) pitch deviated more than 12° from nominal, (2) total ΔV increased or decreased more than 50 fps, (3) visibility time was reduced to less than 140 seconds, or (4) ROD at high gate increased or decreased more than 25 ft/sec. Three points were obtained in this manner at ranges of 41,000, 72,000, and 95,000 ft to the landing site. Figure 5 gives a plot of maximum allowable crater depth for FHGT as a function of range to the landing site. Also shown is a similar plot for fixed high gate obtained from reference 6. With FHGT, a landing site may be chosen with craters which are two times (at radar acquisition) to five times (near high gate) larger than the craters over which the LM can safely fly with fixed high gate targeting.

Effects of Thrust and Navigation Errors on FHGT

Simulated LM descents using FHGT were made with off-nominal thrust profiles and three-sigma navigation errors. Table V (for 0° slope uncertainty) shows the pertinent high gate conditions, landing site vixibility time, the altitude at a range 2000 ft, and the change in ΔV from the nominal. The altitude at high gate ranged between 9466-9888 ft for fixed targeting and between 8095-11228 ft for FHGT. However, at a range of 2000 ft, the spread in altitude was 520-760 ft for fixed targeting and 490-800 for FHGT (see figure 6 for 0° slope uncertainty). There was little variation in landing site visibility time between FHGT and fixed targeting.

With FHGT off-nominal conditions produced a variation in the real high gate conditions, however, this variation only slightly affected the post high gate trajectory. For the worst condition with respect to characteristic velocity, FHGT produced a ΔV saving of 43 ft/sec when compared to fixed targeting (penalty of 20 ft/sec compared to nominal).

Effect of a Terrain Slope Uncertainty of $\pm 1^{\circ}$ and Navigation Errors on Fixed Targeting and FHGT

A $\pm 1^{\circ}$ terrain slope may have a severe effect on both false and fixed targeting. Because fixed targeting follows terrain slope closely, moderate (15° or less) pitch deviations may occur. These pitch deviations may not cause the radar to lose track (unless a 4-6 db reduction in power return occurs), but they do enhance the possibility of a radar loss occurring when local terrain deviations are sensed. Figure 7 shows a comparison of the pitch and altitude profiles for both false and fixed targeting. The pitch deviations are less with FHGT because it does not follow terrain slope as closely. However, because FHGT does not follow terrain slope closely, it produces a large variation in altitude at high gate.

Violation of Manual Takeover Constraints with FHGT.- Because the guidance sensitivity to terrain is reduced with FHGT, the ability of the guidance to follow terrain slope is also reduced. An off-nominal vehicle high condition which would normally cause the altitude to be 1636 ft too high at high gate (when combined with a -1° slope) caused the high gate altitude to be 2914 ft too high. Similarly, a vehicle low condition, which would normally cause the altitude to be 1497 ft too low at high gate, caused the altitude to be 2552 ft too low when combined with a $+1^{\circ}$ terrain slope. A high or low altitude at high gate causes the final approach to be too steep (for VH) or too shallow. The manual takeover constraints on h and $\dot{h}$ are violated when the final approach is too steep and visibility of the landing site may be impaired when the final approach is too shallow. Figure 6 shows the altitude for a range from 0-2000 ft to the landing site. The altitude at 2000 ft range varies from 340 ft with TLVL$+1^{\circ}$ to 1125 ft with THVH-1° for FHGT and from 450 ft (THVL$+1^{\circ}$) to 879 ft with THVH-1° for fixed targeting. The next two sections present two methods to improve the poor final approach trajectory caused by FHGT.

Landing Site Redesignations to Correct Steep or Shallow Final Approaches

A steep or shallow approach to the landing site can be corrected by a landing site redesignation at high gate. This redesignation should be proportional to the difference between the LGC altitude and the nominal altitude at high gate ($h_r = h_{lgc} - h_n$). For a VH condition, a positive redesignation makes the final approach shallower; for a VL condition, a negative redesignation makes the final approach steeper.

The cases which caused the worst final approach (VH-1° and VH$+1^{\circ}$) with false high gate targeting were rerun with a landing site redesignation equal to h_r ($h_r \leq 2000$ ft). The results, shown in figures 8 and 9, indicate that the final approach can be improved such that it compares favorably with that obtained with fixed high gate targeting. Table VI gives the ΔV and visibility time for false (with L.S. redesignation) and fixed high gate targeting with VH-1° and VL+1° conditions. Although a positive redesignation produces a ΔV penalty with respect to the FHGT without a redesignation, FHGT still results in a ΔV saving of 30 ft/sec compared to fixed high gate targeting. A redesignation of the landing site at high gate does not cause any additional violation of the manual-takeover-constraints. The redesignation could be made automatically by the LGC at high gate or it could be made manually by the astronaut based on a plot of LPD inputs as a function of h_r.

Range Updates After High Gate

A technique devised by Bellcomm to reduce LPD sensitivity to radar updates (reference 7) was also studied as a possible method to correct the steep (or shallow) final approaches produced by FHGT. With this technique, range to the landing site is updated in proportion to the altitude updates received after high gate.

The worst cases (VH-1° and VL+1°) were repeated using the Bellcomm technique and a combination of the Bellcomm technique and a landing site redesignation at high gate. Figures 8 and 9 show the resulting improvement in final approach. The combination of a landing site redesignation with the Bellcomm technique provided the greatest improvement in final approach, however, it also produced the largest ΔV penalty (for VH). A LM descent to Censorinus (THVH+1°) was repeated with this technique. LPD angle and altitude during final approach are shown in figure 10. This technique not only improves the final approach but also improves landing site visibility and reduces the apparent movement of the landing site caused by radar altitude update. Adoption of the Bellcomm range updating technique would probably eliminate the need to make a landing site redesignation at high gate.

CONCLUSION

FHGT is a relatively simple technique (requiring few changes to the present software system) which will permit a LM descent over rougher (by a factor of 5 near high gate) terrain than is possible with the present guidance system and will provide a ΔV saving of at least 30 ft/sec.

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TABLE I. - DESCRIPTION OF TRAJECTORY CONDITIONS

Initial Conditions at Pericynthion

X_o = -130800 $\quad$ Y_o = 0 $\quad$ Z_o = -1,432,337

$\dot{X}_o$ = 1387.6 $\quad$ $\dot{Y}_o$ = 0 $\quad$ $\dot{Z}_o$ = 5396.8

		Desired Aim Point Conditions					
Aim Point	X_D	Z_D	$\dot{X}_D$	$\dot{Z}_D$	$\ddot{X}_D$	$\ddot{Z}_D$	$\dddot{Z}_D$
False high gate	-3550	-14,440	-295	50	-3.25	-8.75	-.00640
Fixed high gate	+9592	-33,088	-159.2	561	-2.174	-8.20	-.00918
Hover	+77	-1.73	-3.1	1.3	0	- .65	.03430

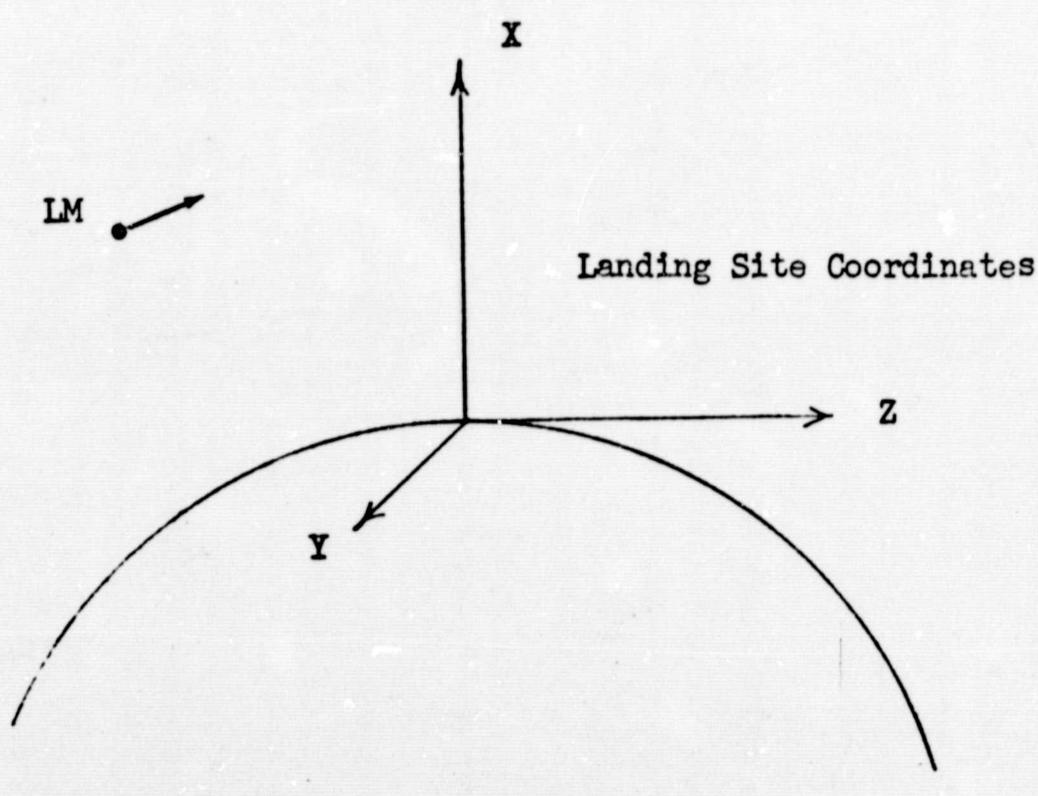

TABLE II. - WORST CASE COMBINATIONS OF ERRORS

	Initial Position Error ft			IMU Misalignment deg			Acceleration Bias ft/sec^2			Resultant Errors at Radar Acquisition	
	XO	YO	ZO	$\Delta\theta$	$\Delta\phi$	$\Delta\psi$	X_{BIAS}	Y_{BIAS}	Z_{BIAS}	h (ft)	ROD (ft/sec)
THVH	1108	0	0	-.18	.18	-.18	.00492	.00492	-.00492	3199	20
THVL	-1108	0	0	.18	.18	-.18	-.00492	.00492	.00492	-3209	-19.3
TLVH	1108	0	0	-.18	.18	-.18	.00492	.00492	-.00492	2899	19.6
TLVL	-1108	0	0	.18	.18	-.18	-.00492	.00492	.00492	-2907	-19.0

Definition of terms

Th = Thrust high
TL = Thrust low
VH = Vehicle high
VL = Vehicle low

TH = (9805 + .54t) lb
TL = (9488 + .438t) lb

TABLE III. - RUN CONDITIONS

Figure No.	Terrain	Terrain slope deg	Type of Errors	Targeting
4a	Copernicus	0	0	False
4b	"	0	0	Fixed
3b	Cen - A	+1	THVH	False
3c	"	+1	THVL	"
3a	"	-1	TLVL	"
3b	"	+1	THVH	Fixed
3c	"	+1	THVL	"
3a	"	-1	TLVL	"
3e	Cen - B	+1	THVH	False
3f	"	+1	THVL	"
3d	"	-1	TLVL	"
3e	"	+1	THVH	Fixed
3f	"	+1	THVL	"
3d	"	-1	TLVL	"
3h	Cen - C	+1	THVH	False
3i	"	+1	THVL	"
3g	"	-1	TLVL	"
3h	"	+1	THVH	Fixed
3i	"	+1	THVL	"
3g	"	-1	TLVL	"

Figure No.	Terrain	Terrain slope deg	Type of Errors	Targeting
6b	Flat	0	THVH	False
6b	"	0	THVL	"
6b	"	0	TLVH	"
6b	"	0	TLVL	"
6a	"	0	THVH	Fixed
6a	"	0	THVL	"
6a	"	0	TLVH	"
6a	"	0	TLVL	"
7e	"	-1	THVH	False
7f	"	-1	THVL	"
7g	"	-1	TLVH	"
7h	"	-1	TLVL	"
7e	"	-1	THVH	Fixed
7f	"	-1	THVL	"
7g	"	-1	TLVH	"
7h	"	-1	TLVL	"
7a	"	+1	THVH	False
7b	"	+1	THVL	"
7c	"	+1	TLVH	"
7d	"	+1	TLVL	"

Figure No.	Terrain	Terrain slope deg	Type of Errors	Targeting
7a	Flat	+1	THVH	Fixed
7b	"	+1	THVL	"
7c	"	+1	TLVH	"
7d	"	+1	TLVL	"
8	"	-1	THVH	False/red
8	"	-1	TLVH	"
8	"	+1	THVL	"
8	"	+1	TLVL	"
8	"	-1	THVH	False/Z-up
8	"	-1	TLVH	"
8	"	+1	THVL	"
8	"	+1	TLVL	"
8	"	-1	THVH	False/Comp
8	"	-1	TLVH	"
8	"	+1	THVL	"
8	"	+1	TLVL	"
10	Cen-C	+1	THVH	False/Z-up
--	Cen-A	-1	THVH	False
--	"	+1	TLVL	"
--	Cen-B	-1	THVH	"
--	"	+1	TLVL	"

TABLE IV. - RESULTS FROM LM DESCENTS TO THE SCIENCE SITE CENSORINUS WITH FIXED AND FALSE HIGH GATE TARGETING

Targeting	Approach Profile	Worst Case Conditions	Visibility time sec (140 nom)	Change in ΔV from nom	Attitude at higate ft	ROD @ higate ft/sec
FALSE	A	TLVL-1°	82	-39	11351	-125.2
FALSE	A	THVH+1°	90	-2	11822	-162.3
FALSE	A	THVL+1°	128	+9	9051	-87.8
FALSE	B	TLVL-1°	100	-39	10843	-132.0
FALSE	B	THVH+1°	120	0	11449	-164.3
FALSE	B	THVL+1°	140	+4	8491	-92.6
FALSE	C	TLVL-1°	128	-38	10565	-122.9
FALSE	C	THVH+1°	102	+18	11253	-163.4
FALSE	C	THVL+1°	110	+8	8405	-83.1
FIXED	A	TLVL-1°	72	+20	13771	-65.5
FIXED	A	THVH+1°	62	+4	12106	-94.9
FIXED	A	THVL+1°	76	+19	12202	-52.2
FIXED	B	TLVL-1°	CRASH	CRASH	12591	-217.7
FIXED	B	THVH+1°	72	15	11448	-140.0
FIXED	B	THVH+1°	CRASH	CRASH	10654	-218.9
FIXED	C	TLVL-1°	88	-8	12368	-134.6
FIXED	C	THVH+1°	72	-6	11190	-118.5
FIXED	C	THVL+1°	86	+41	11302	-62.5
FALSE	A	*TLVL+1°	90	-47	9011	-87
FALSE	A	*THVH-1°	76	+21	14229	-184
FALSE	B	*TLVL+1°	116	-54	8435	-89.3
FALSE	B	*THVH-1°	84	_17	13699	-184.8

* Worst case conditions for FHGT

TABLE Va. - RESULTS FROM LM DESCENTS WITH NAV. AND THRUST ERROR AND $\pm 1^{\circ}$ TERRAIN SLOPE UNCERTAINTIES W/FALSE TARGETING

Conditions	Visibility time, sec	* $\delta\Delta V$ ft/sec	h @ higate ft	ROD @ higate ft/sec	h @ 2000' range, ft
THVH	141	+20	11228	-193	750
THVL	141	+11	8264	-133	490
TLVH	140	-31	10787	-172	800
TLVL	142	-40	8095	-129	525
THVH+1°	146	+22	10401	-191	565
THVL+1°	145	+ 4	7051	-111	350
TLVH+1°	140	-38	9578	-158	580
TLVL+1°	140	-41	7040	-108	340
THVH-1°	143	+54 **	12504	-203	1125
THVL-1°	143	+21	9608	-155	630
TLVH-1°	140	-22	11918	-188	1020
TLVL-1°	146	-33	9302	-150	610

* Nom ΔV = 6624

** Thrust pulse

TABLE Vb. - RESULTS FROM LM DESCENTS WITH NAV. AND THRUST ERRORS AND $\pm 1^{\circ}$ TERRAIN SLOPE UNCERTAINTIES W/FIXED TARGETING

Conditions	Visibility time, sec	* $\delta\Delta V$ ($\Delta V - \Delta V_{nom}$) ft/sec	h @ higate ft	ROD @ higate ft/sec	h @ 2000' range, ft
THVH	146	+63 **	9618	-189.7	730
THVL	138	+21	9562	-142.6	540
TLVH	147	+ 9	9888	-183.5	760
TLVL	138	-33	9466	-144.7	520
THVH+1°	146	+11	9092	-157.7	520
THVL+1°	136	+27	8969	-113.5	450
TLVH+1°	146	-38	9317	-150.9	560
TLVL+1°	137	-60	9083	-112.2	475
THVH-1°	147	+78 **	10280	-223.0	870
THVL-1°	143	+33	10201	-171.7	615
TLVH-1°	146	+34 **	10412	-217.3	880
TLVL-1°	144	- 7	10003	-174.8	580

* Nom ΔV = 6632

** Thrust pulse

TABLE VI. - ΔV COMPARISONS

ΔV @ 10'

Conditions	X-update only (FHGT)	Redesignation @ h.g. (FHGT)	Combination (FHGT)	FHGT	Present Fixed h.g. Targeting
THVH-1	6761	6670	6763	6678	6710
THVH-1	6686	6625	6705	6602	6666
THVH+1	6568	6603	6544	6628	6659
TLVL+1	6516	6556	6492	6583	6572

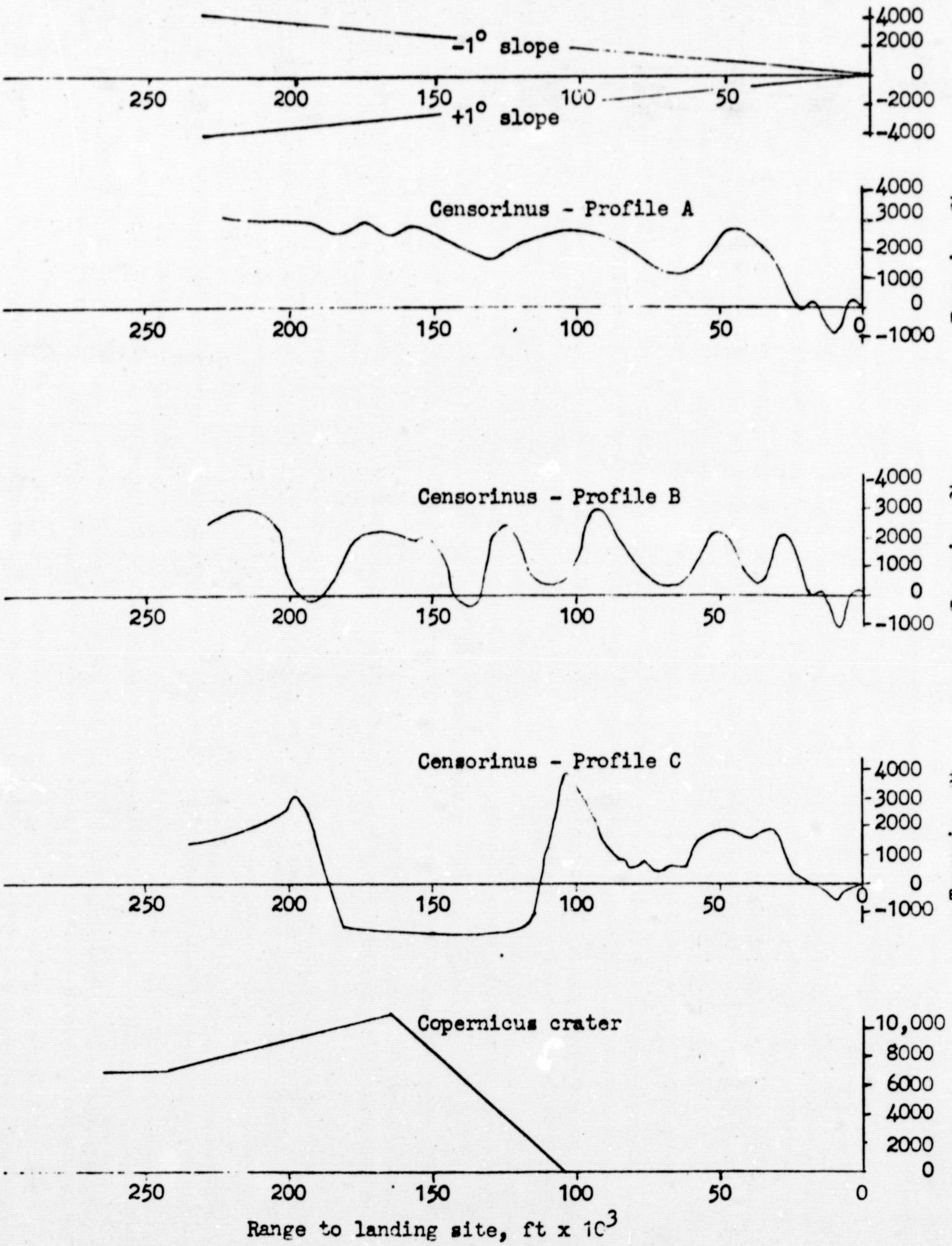

Figure 1. - Terrain profiles

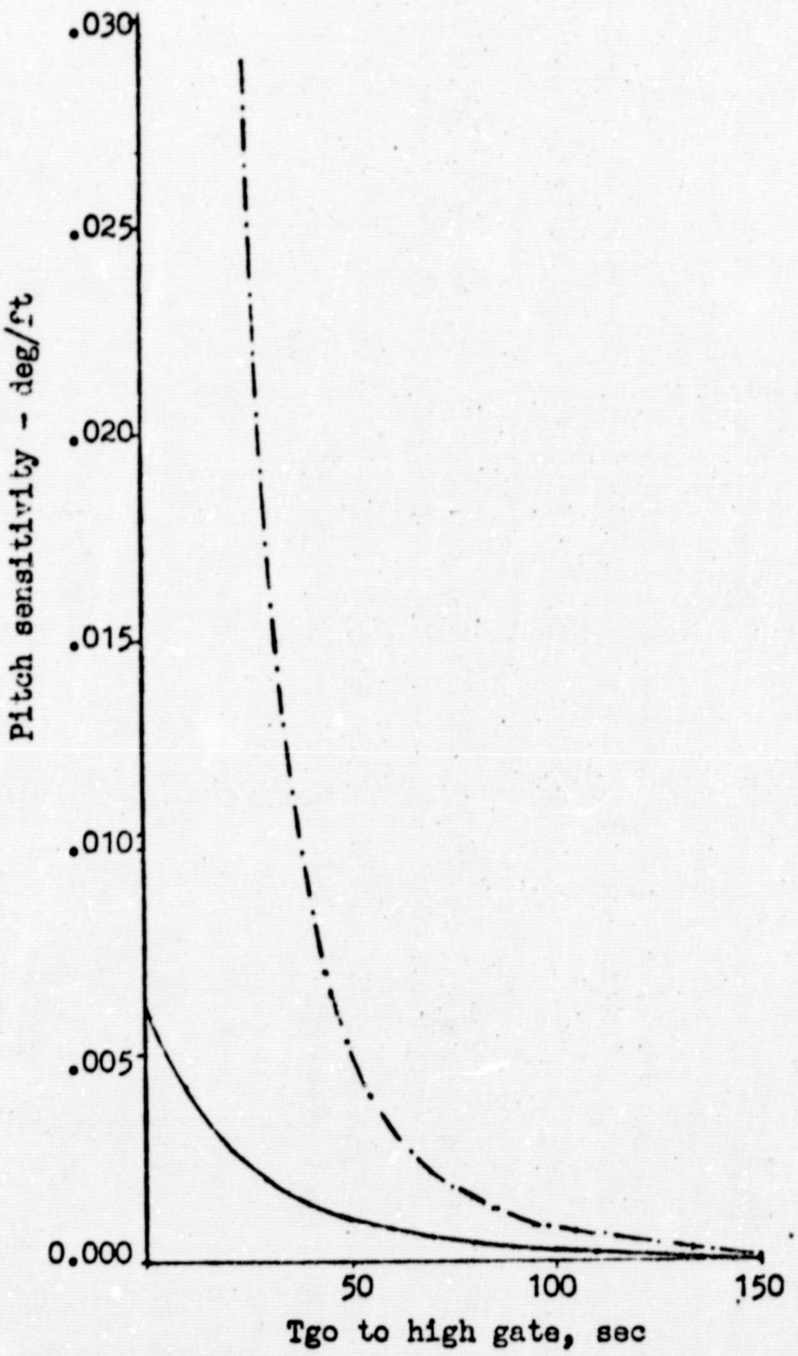

Figure 2a. - Pitch sensitivity to altitude updates as a function of Tgo

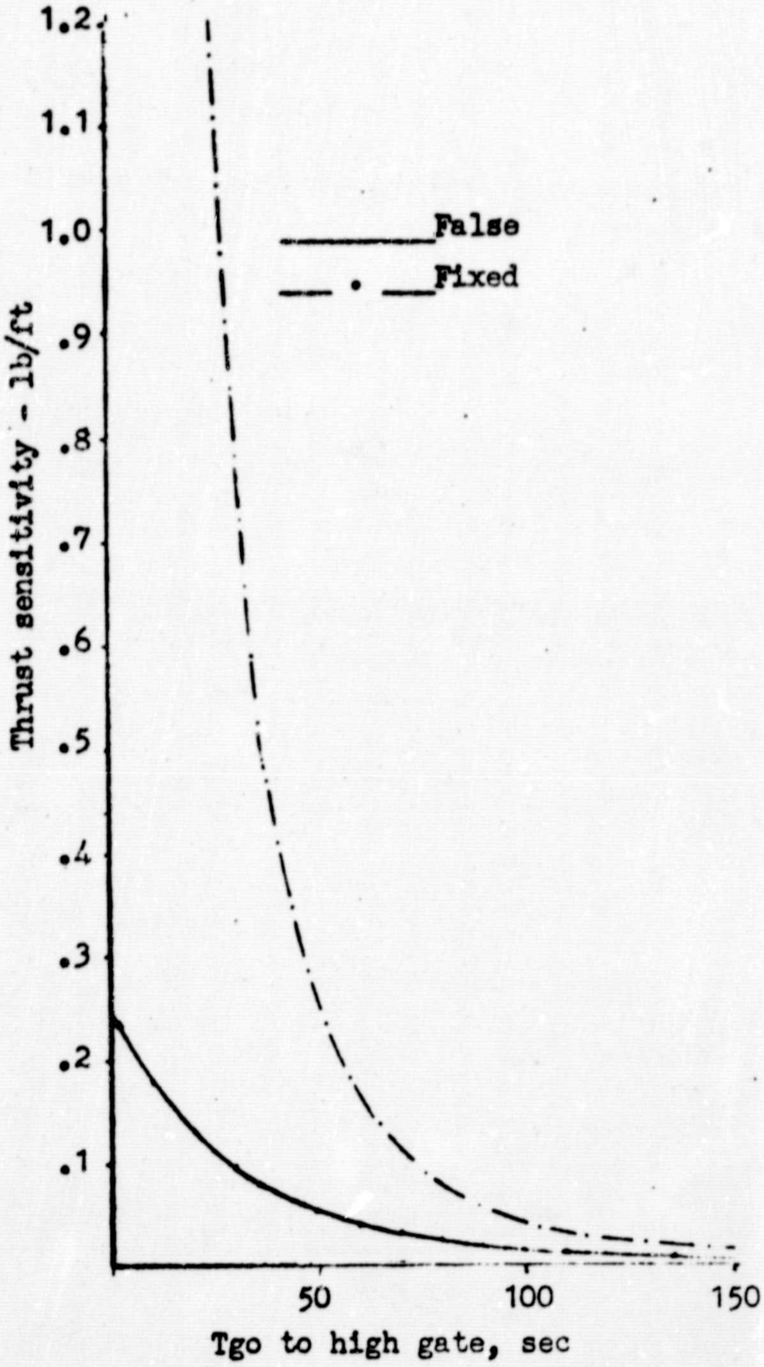

Figure 2b. - Thrust sensitivity to altitude updates as a function of Tgo

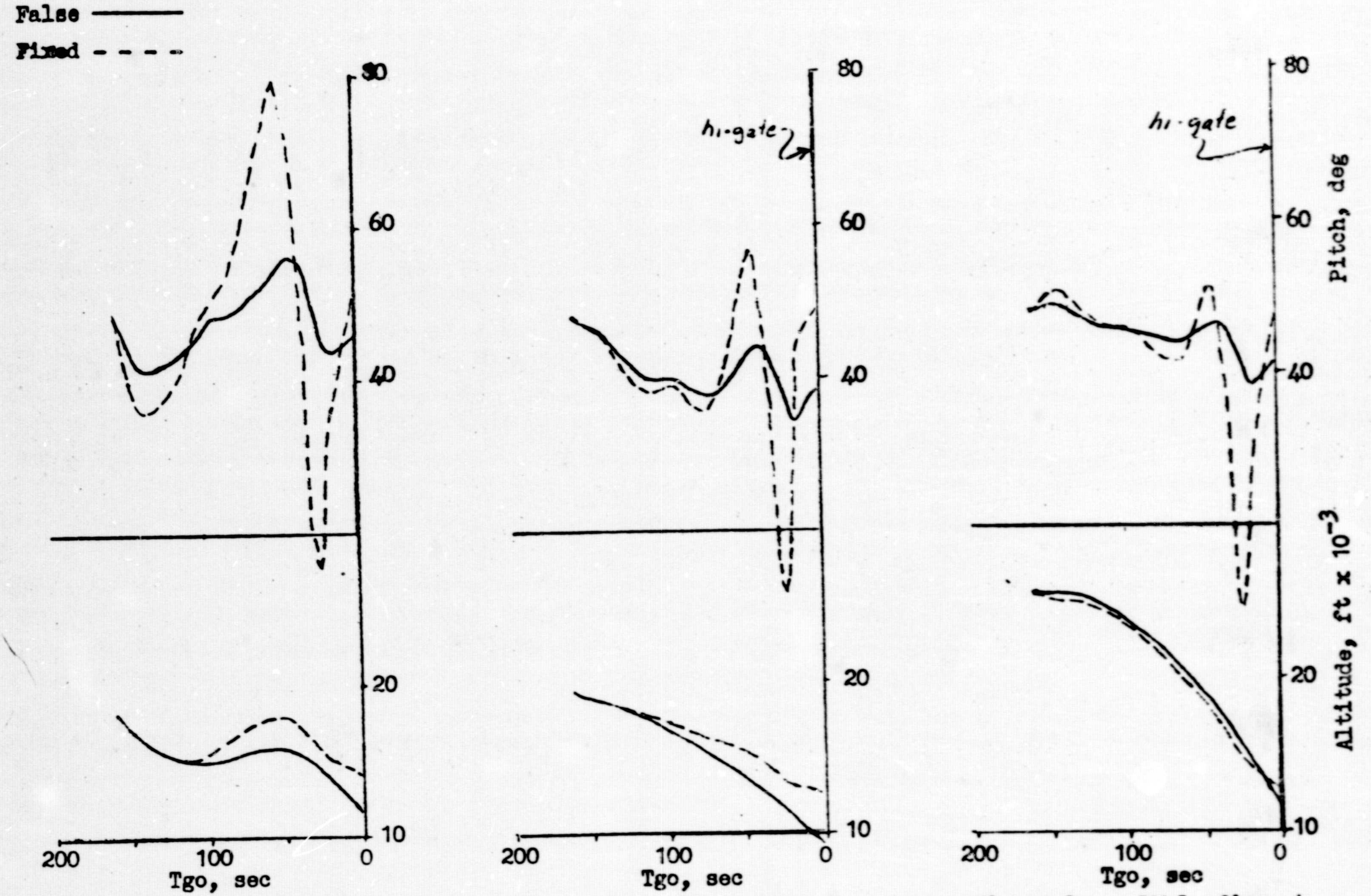

Figure 3a. - LM landing at Censorinus -A w/TLVL-1°

Figure 3b. - LM landing at Censorinus -A w/THVL+1°

Figure 3c. - LM landing at Censorinus -A w/THVH+1°

Figure 3. - Pitch and altitude profiles during braking phase (after radar acquisition) for a LM descent to the Censorinus landing site with worst case conditions

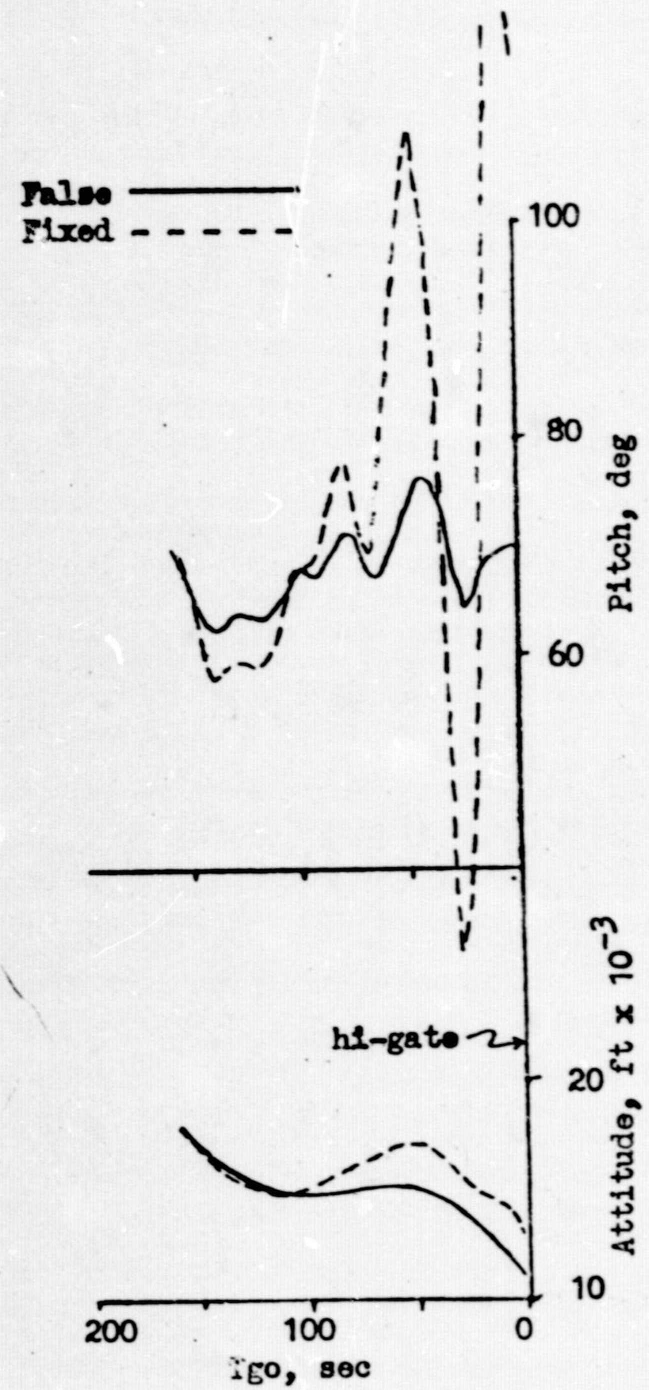

Figure 3d. - Cen B
TLVL-1° (Crash
with fixed)

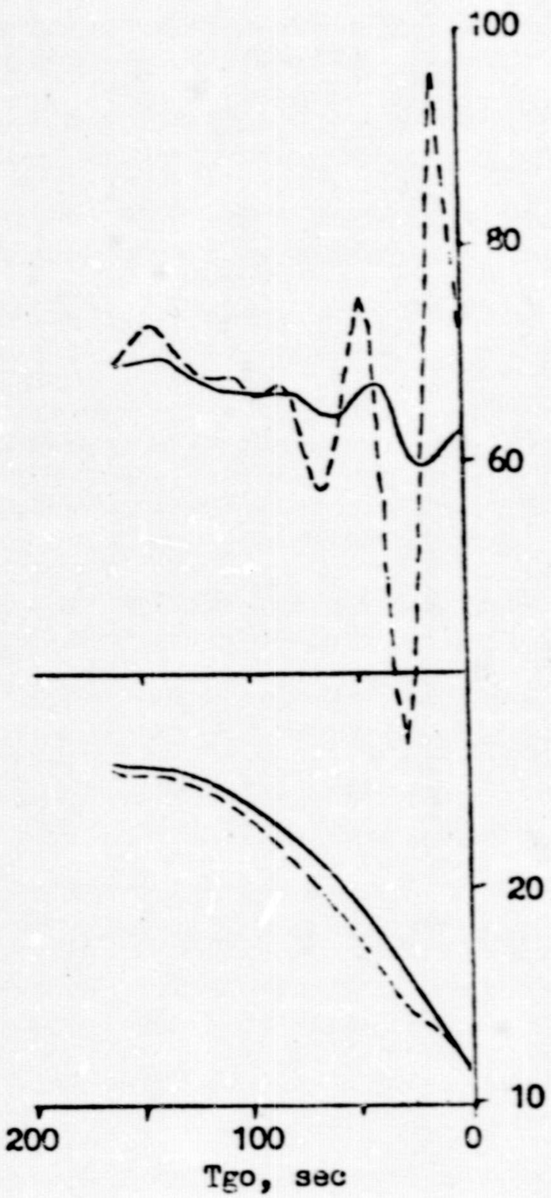

Figure 3e. - Cen B
THVH+1

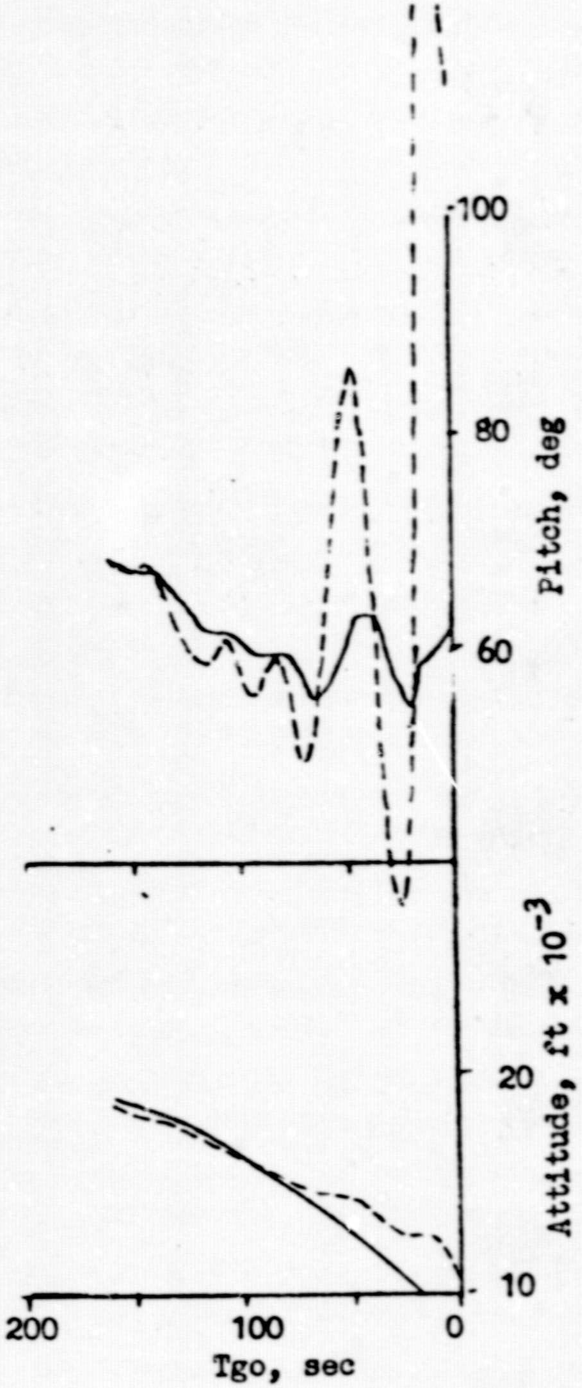

Figure 3f. - Cen B
THVL+1 (Crash with
fixed)

Figure 3. - Continued

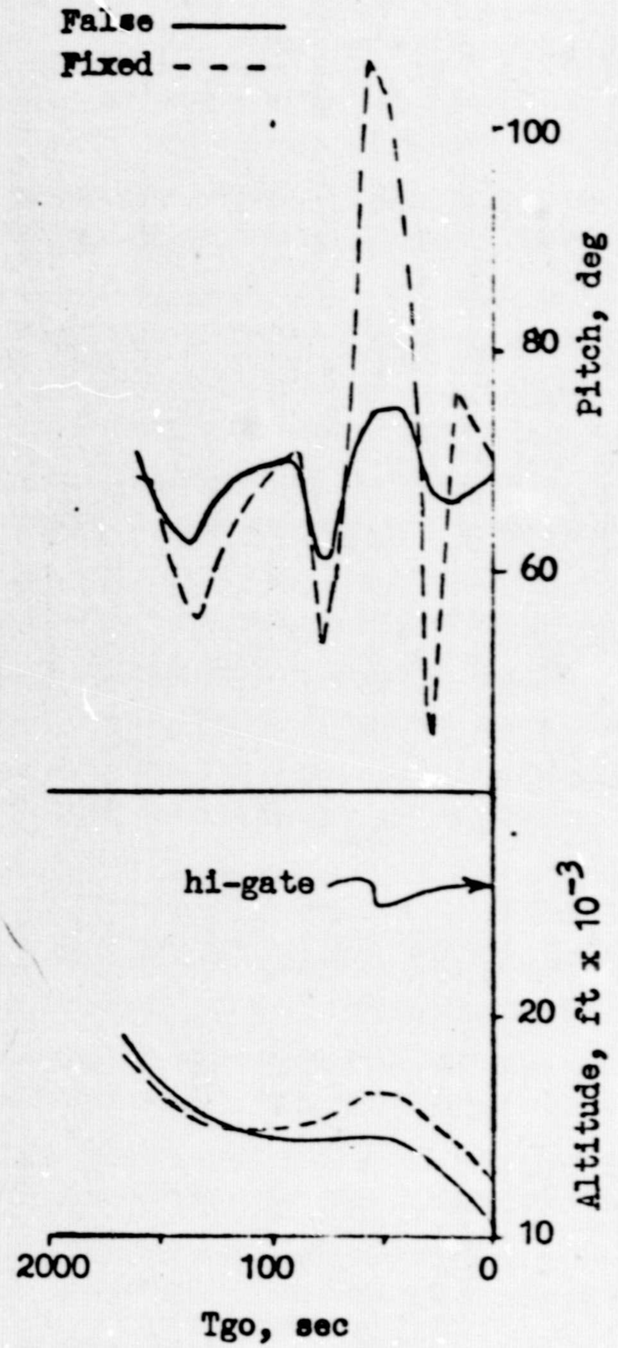

Figure 3g. - Cen C
TLVL-1°

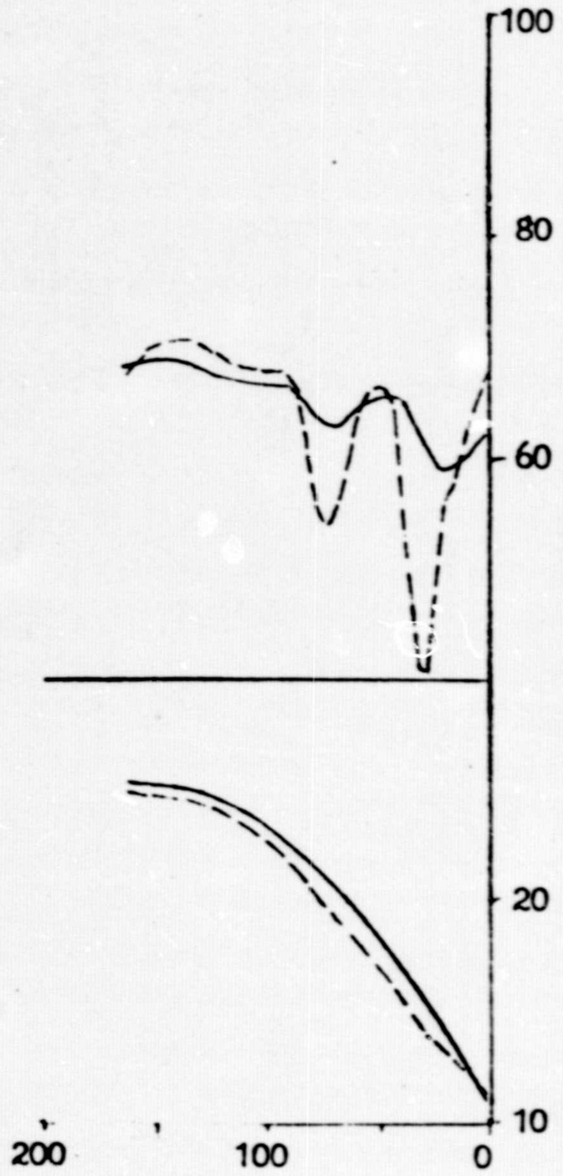

Figure 3h. - Cen C
THVH+1°

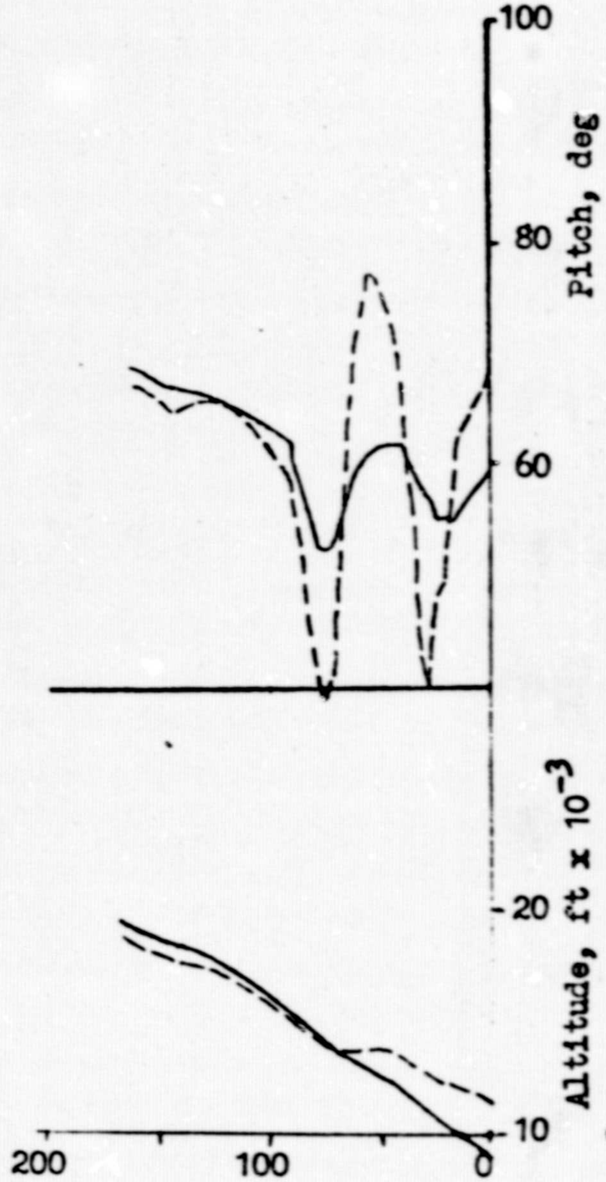

Figure 3i. - Cen C
THVL+1°

Figure 3. - Continued

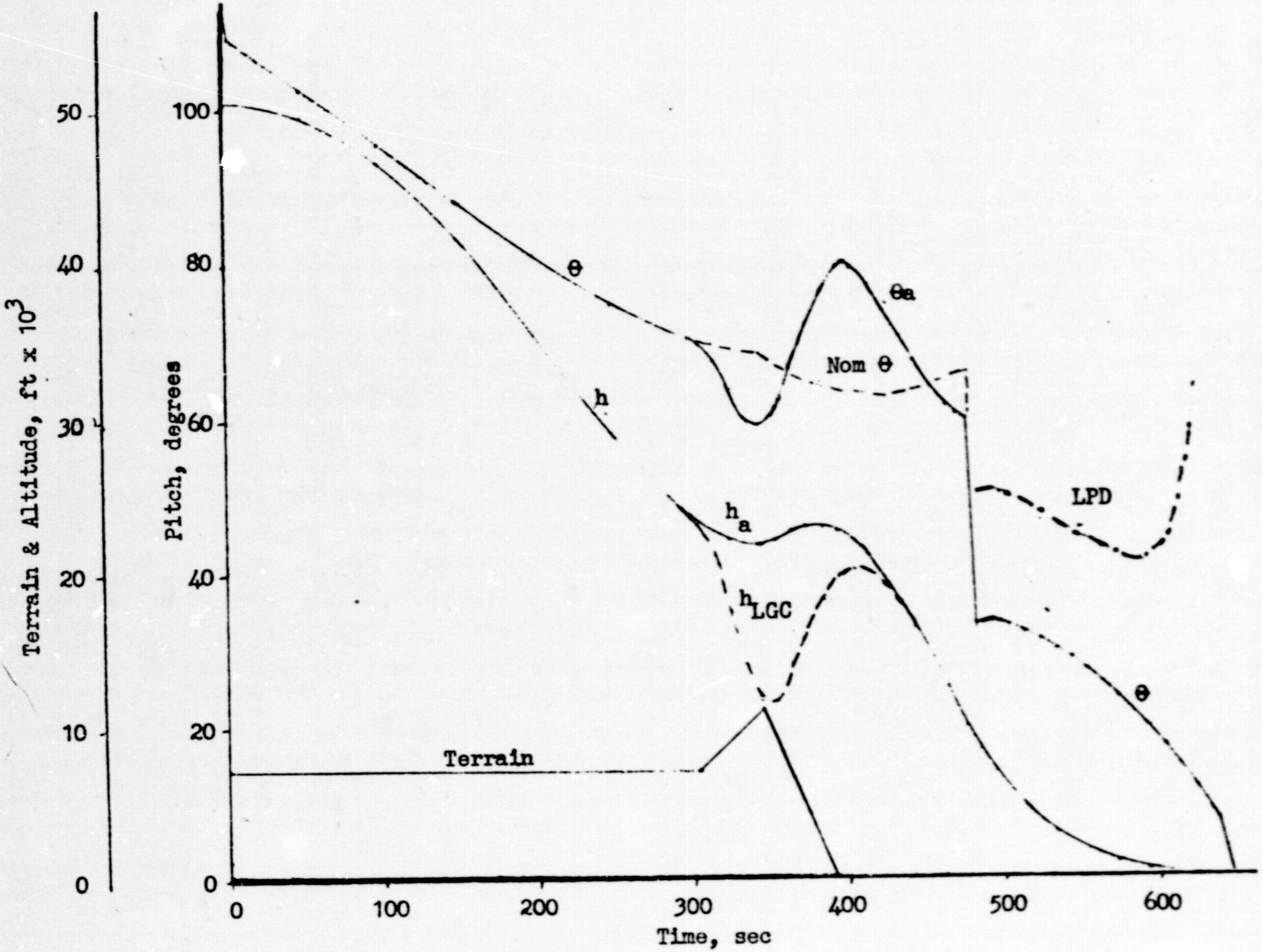

Figure 4a. - Copernicus landing w/false high gate and perfect radar n&v
V penalty = 62 ft/sec

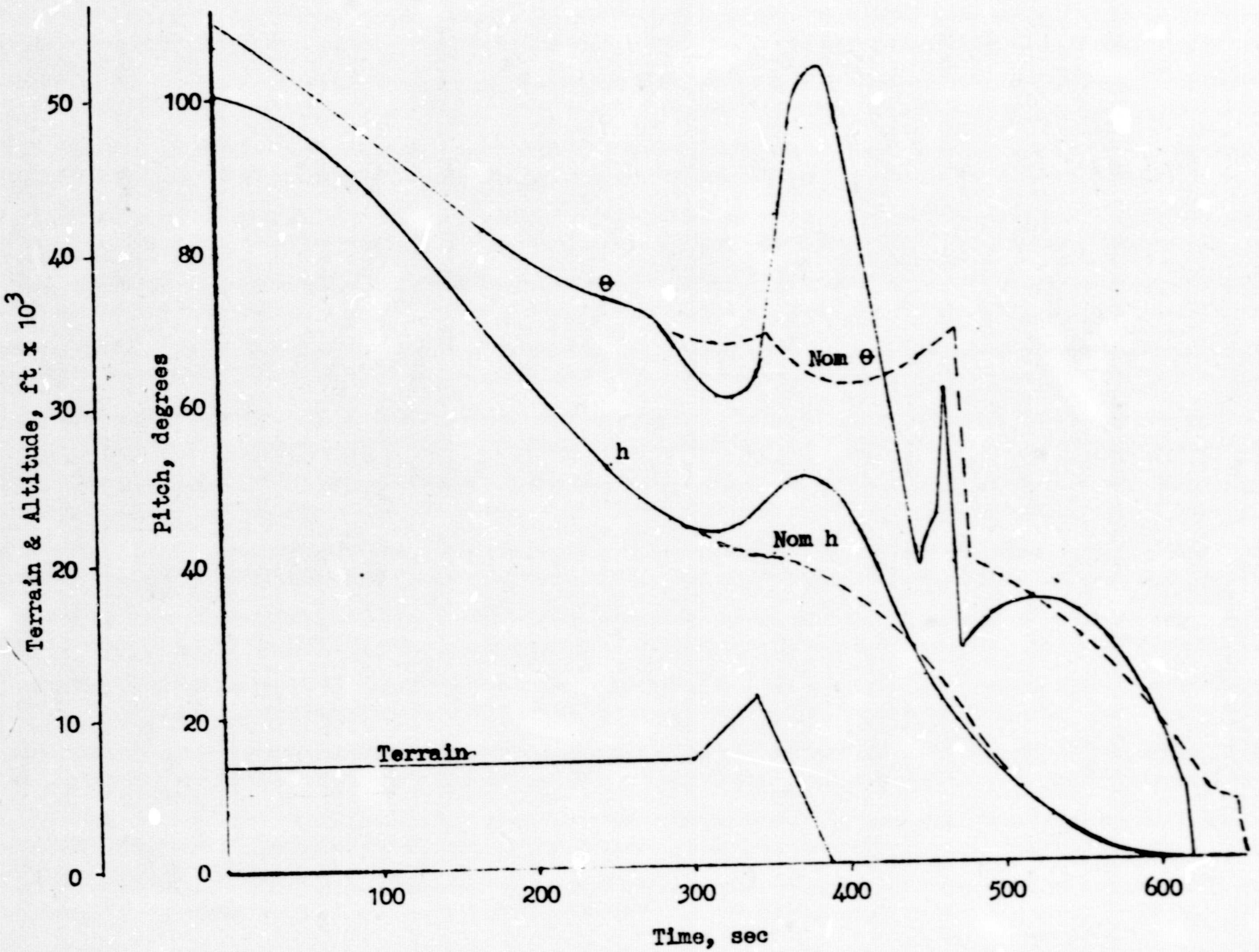

Figure 4b. - Copernicus landing with fixed high gate targeting and perfect radar h&v
V penalty = 124 ft/sec

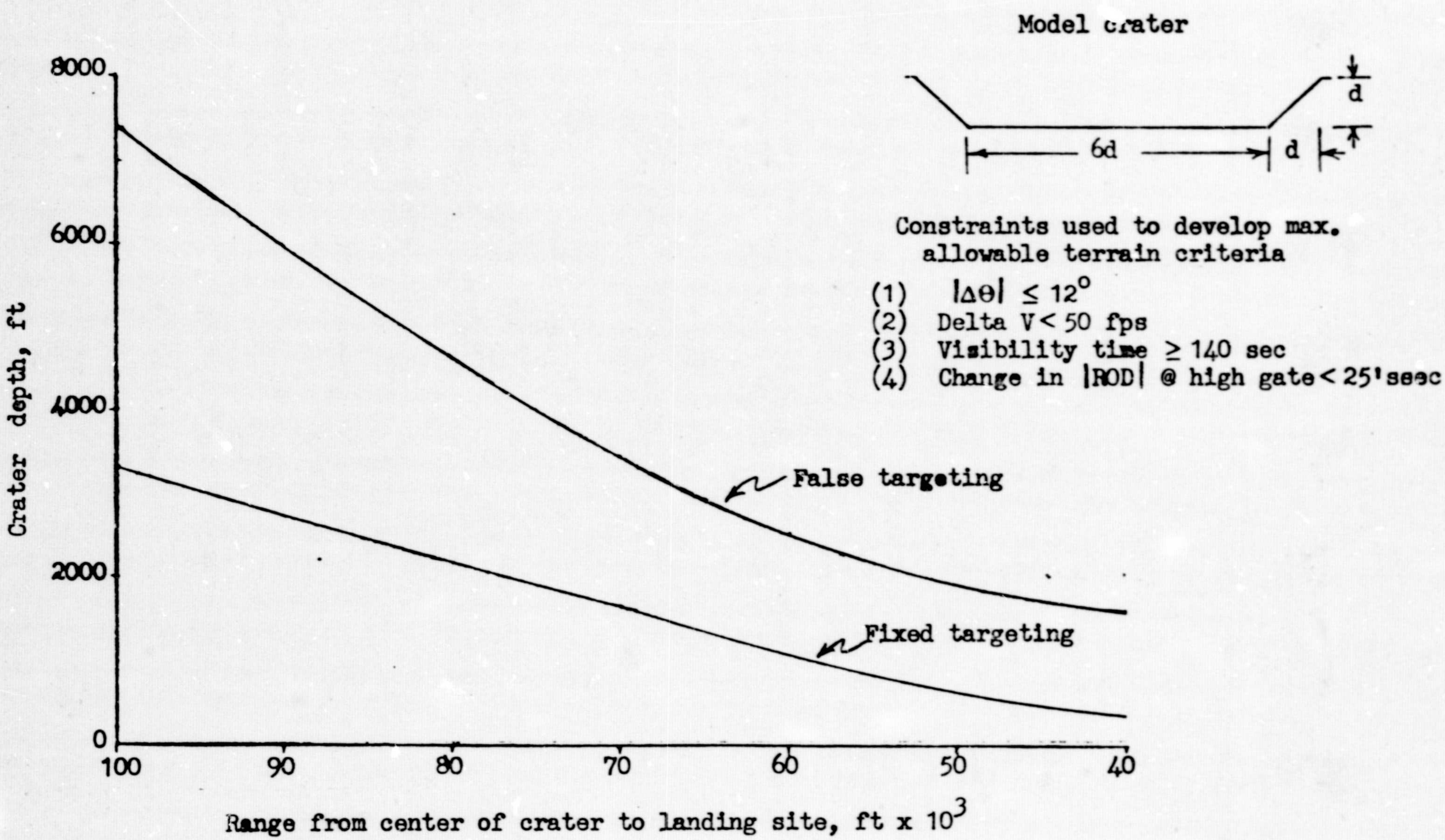

Figure 5. - Maximum allowable crater depth as a function of range from center of crater to landing site

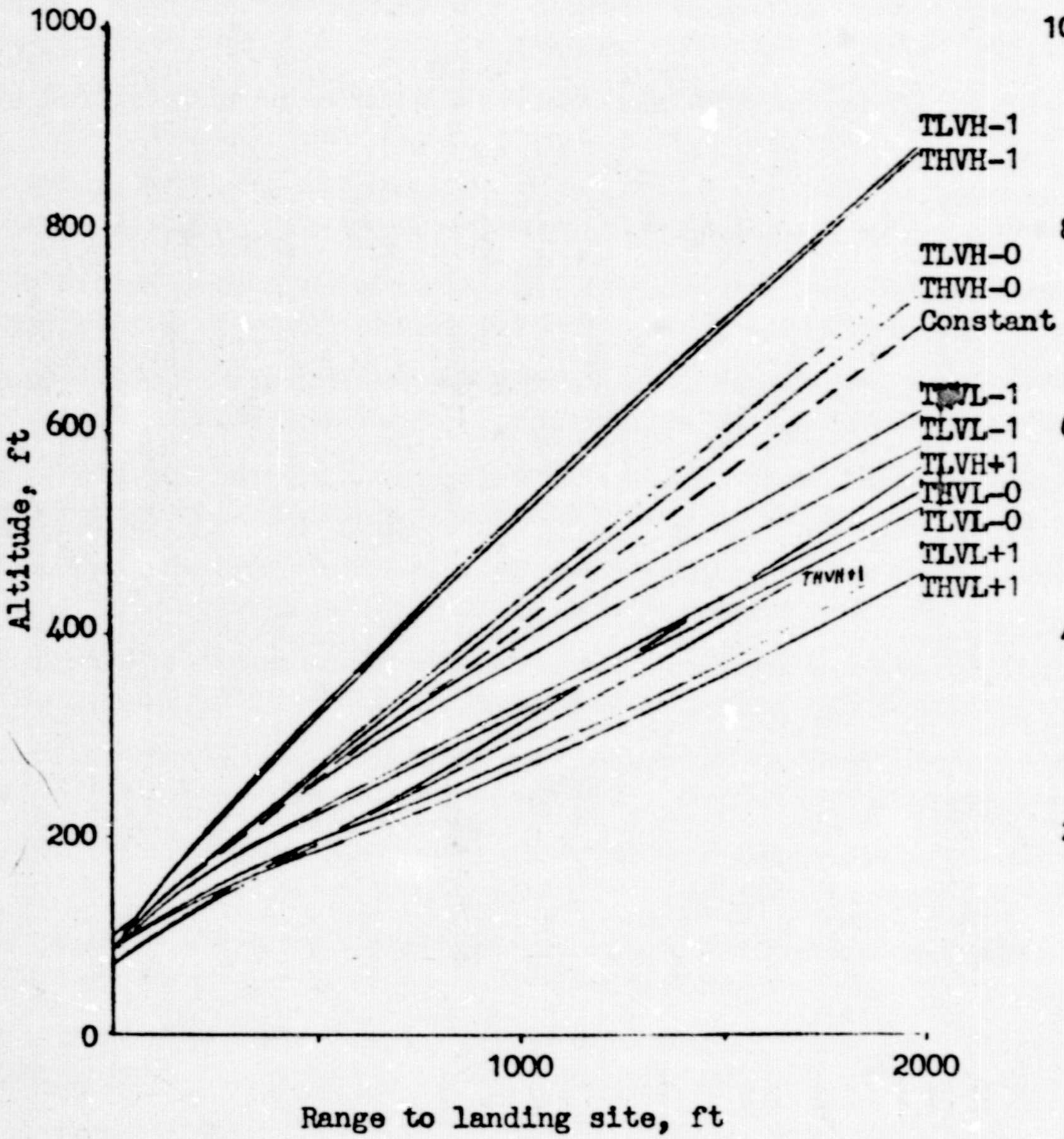

Figure 6a. - Altitude profile during final approach with fixed high gate targeting

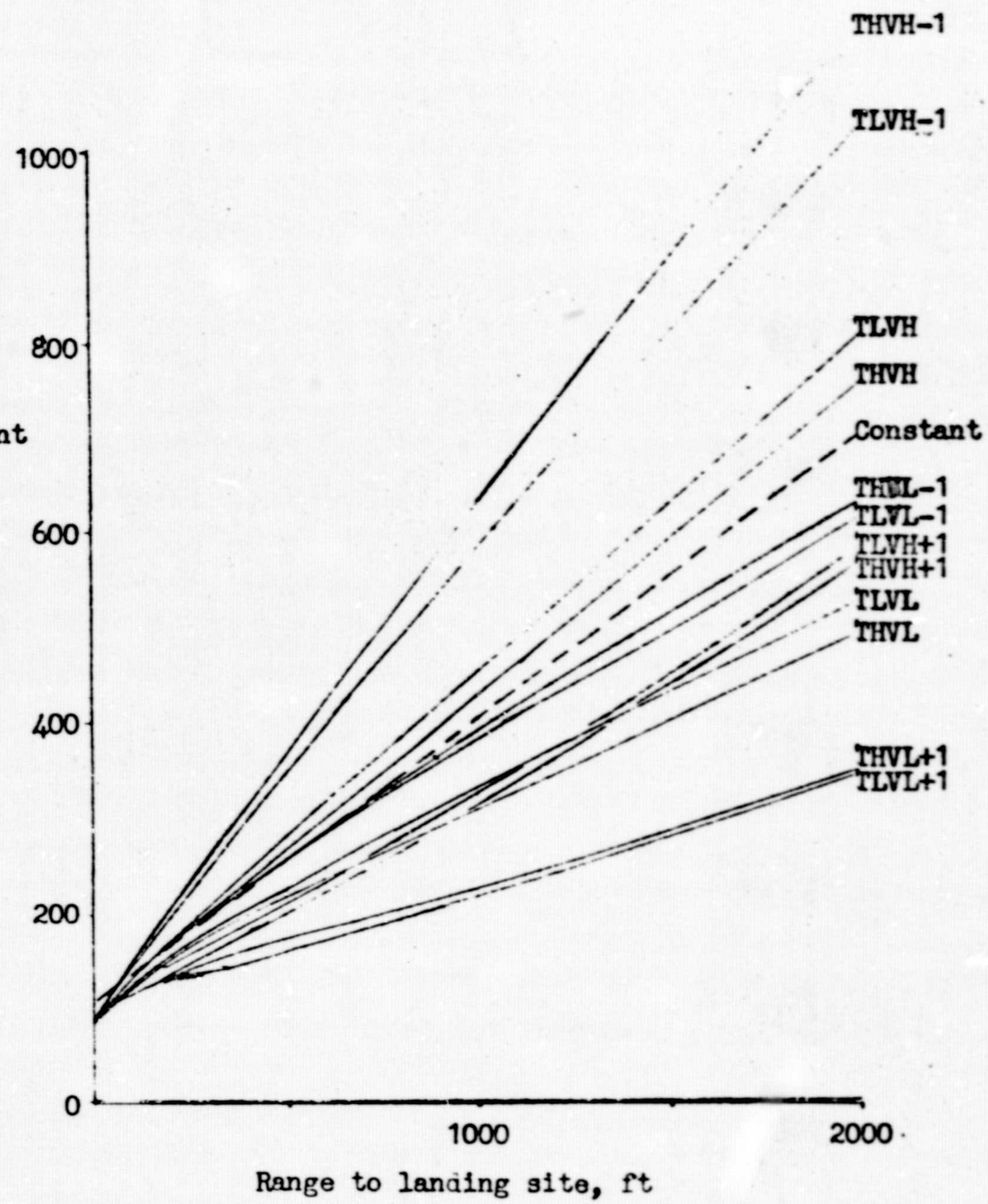

Figure 6b. - Altitude profile during final approach with false high gate targeting

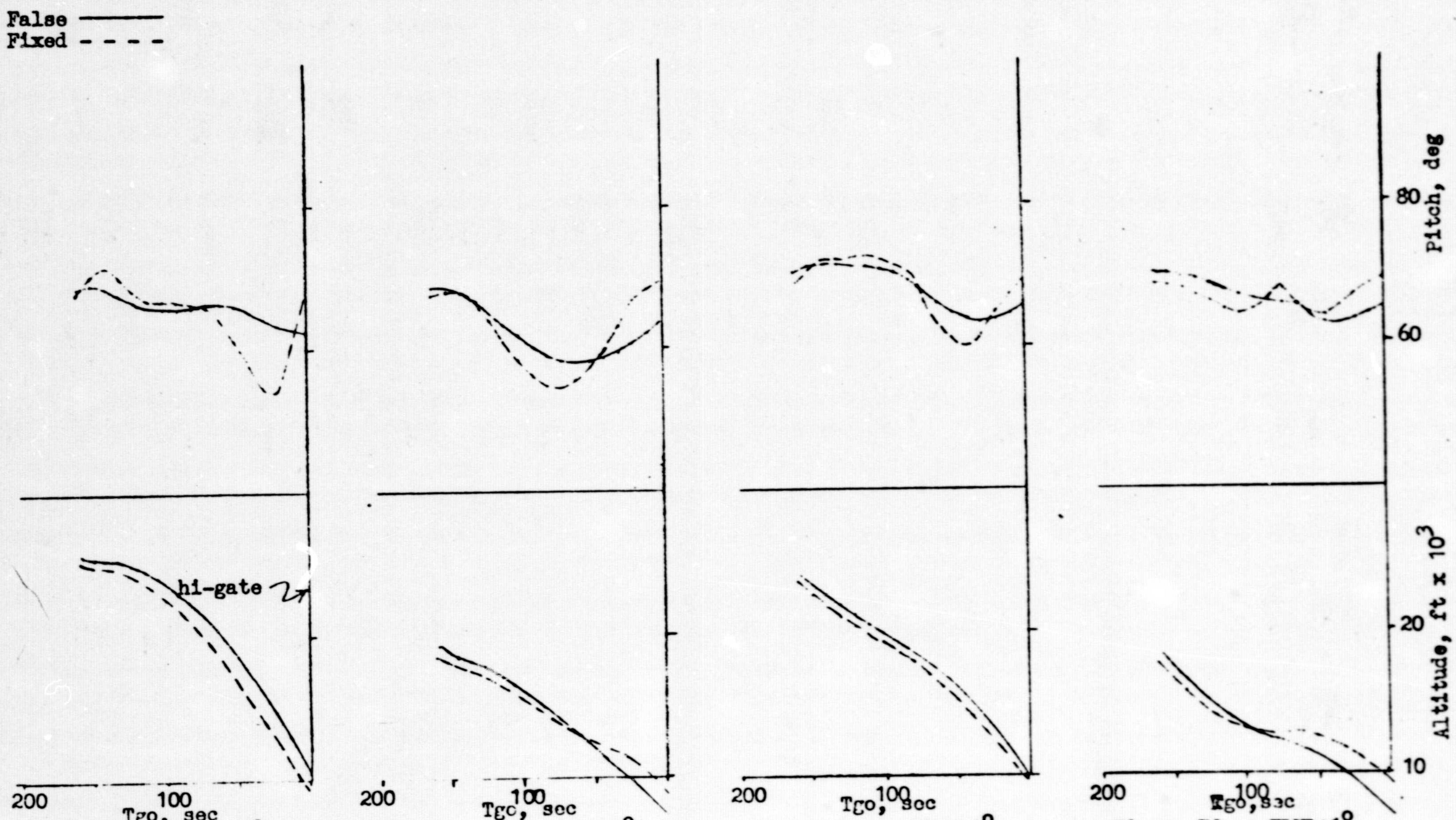

Figure 7a. - THVH+1°

Figure 7b. - THVL+1°

Figure 7c. - TLVH+1°

Figure 7d. - TLVL+1°

Figure 7. - Pitch and altitude profiles during braking phase (after radar altitude acquisition) for a LM descent to a flat surface (no terrain features) with thrust and navigation errors and terrain slope uncertainty

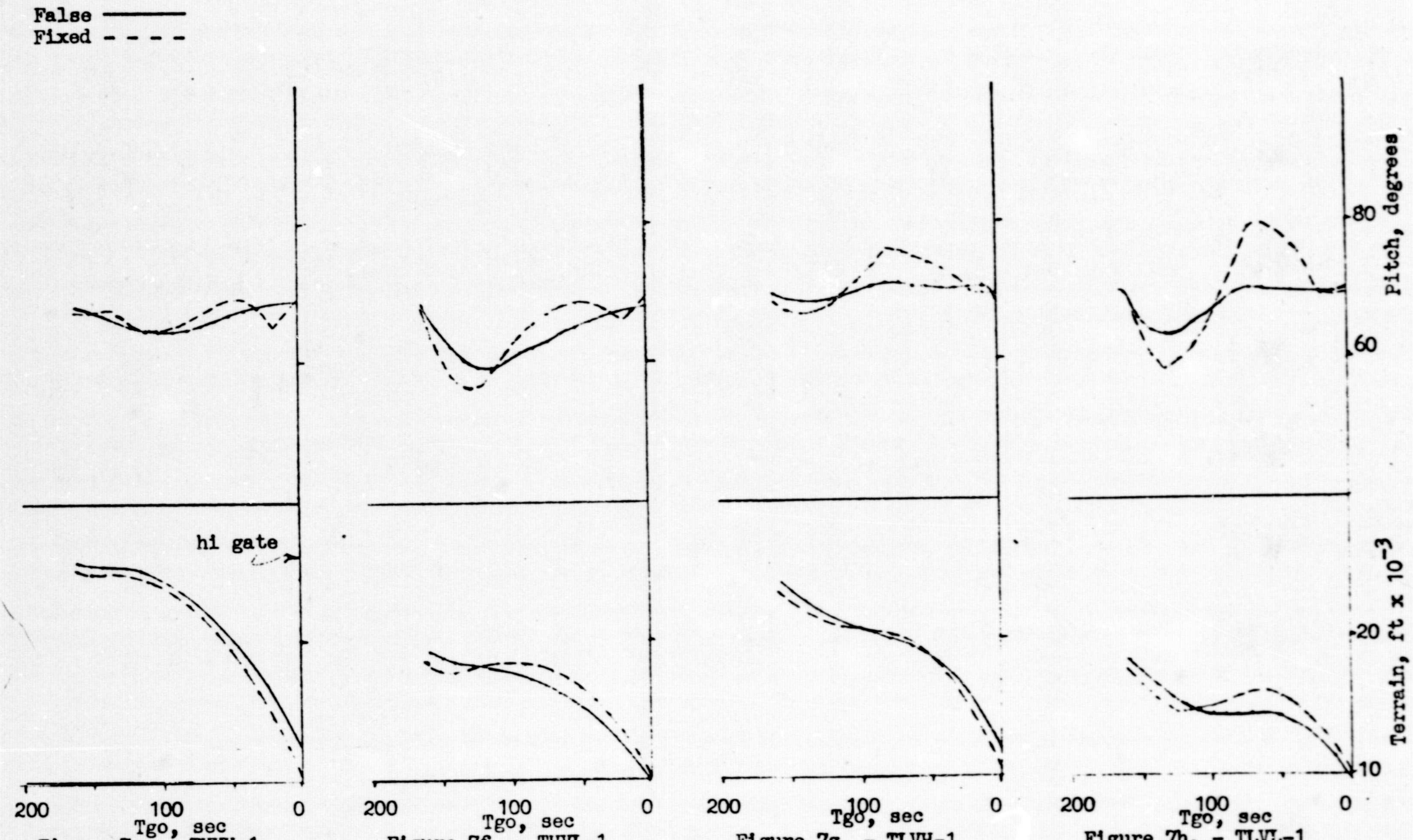

Figure 7e. - THVH-1

Figure 7f. - THVL-1

Figure 7g. - TLVH-1

Figure 7h. - TLVL-1

Figure 7. - Continued

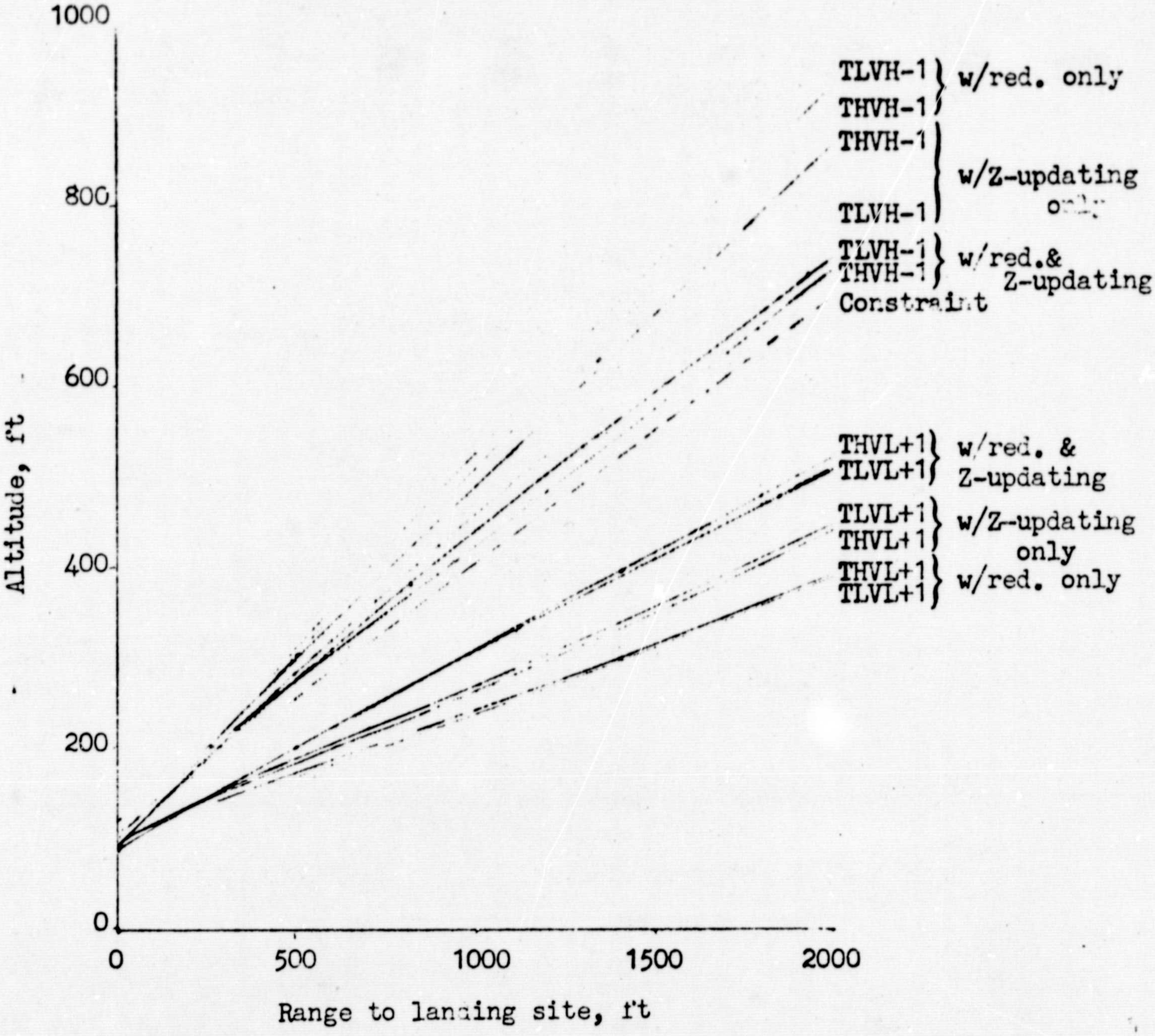

Figure 8. - Altitude vs range during last 2000' of final approach w/FHGT and an automatic redesignation of high gate, Z-updating*, and a combination of both

* Note: Z-updating is a proposal by Bellcomm to reduce LPD sensitivity by updating Z with $\Delta Z = f(\Delta h)$.

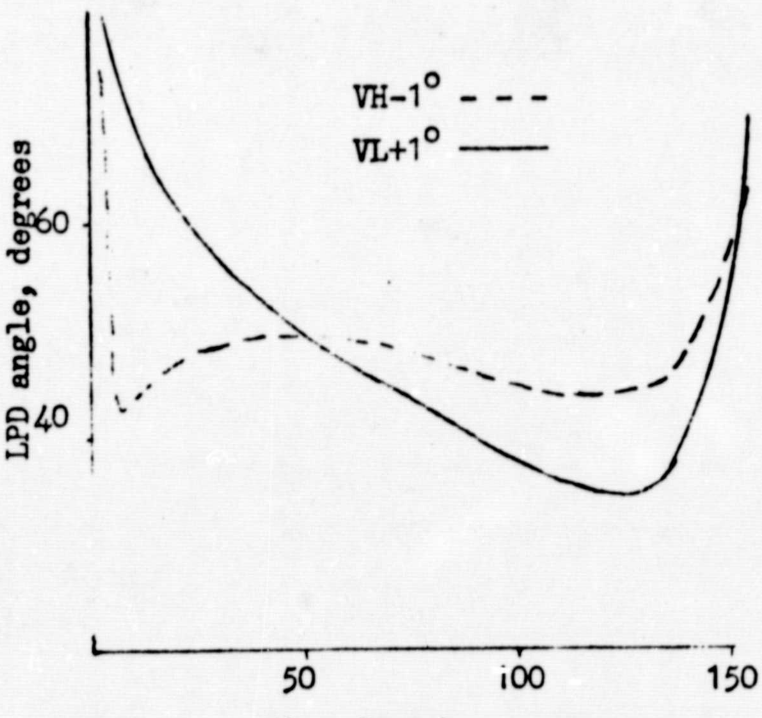

Figure 9a. - Worst cases w/fixed high gate targeting

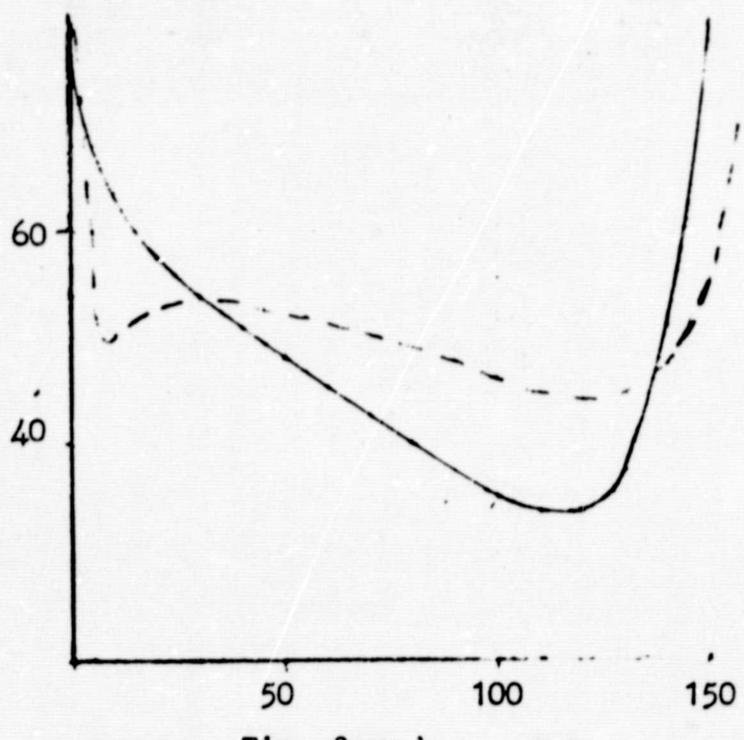

Figure 9b. - Worst case w/false and landing site redesignation

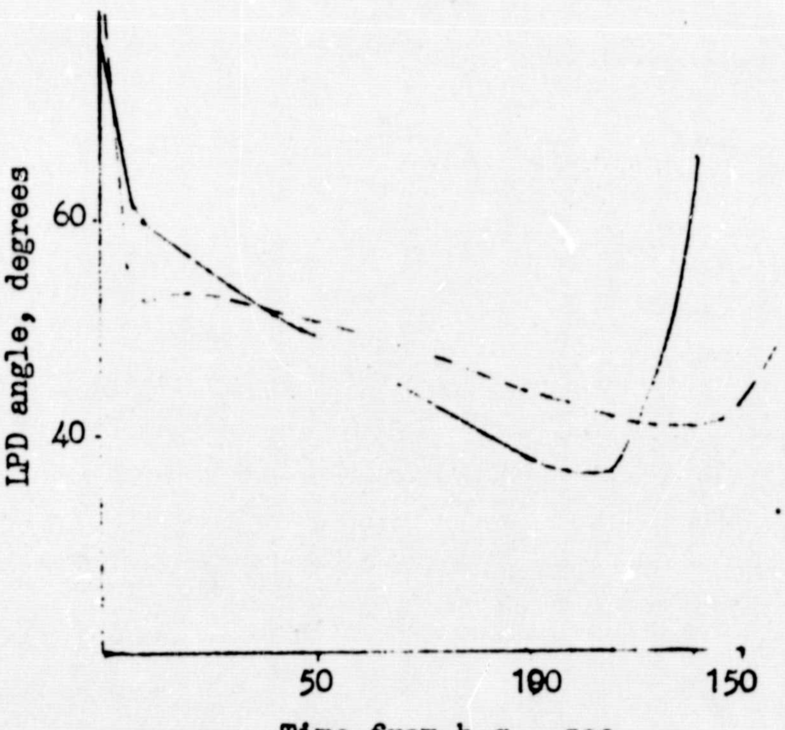

Figure 9c. - Worst cases w/false targeting and Z-updating

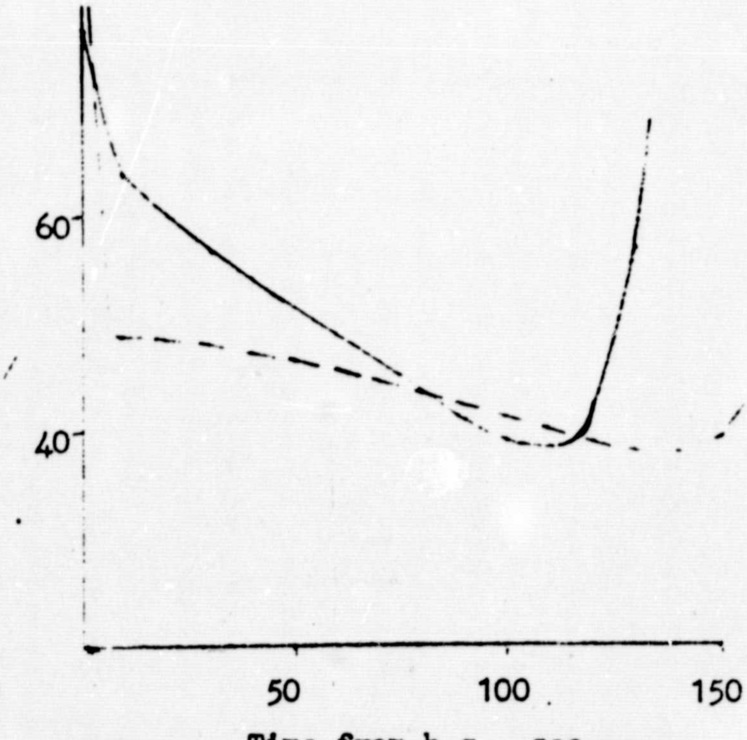

Figure 9d. - Worst cases w/false targeting and combination of Z-updating and L.S. redesignations

Figure 9. - LPD angles for FHGT worst cases

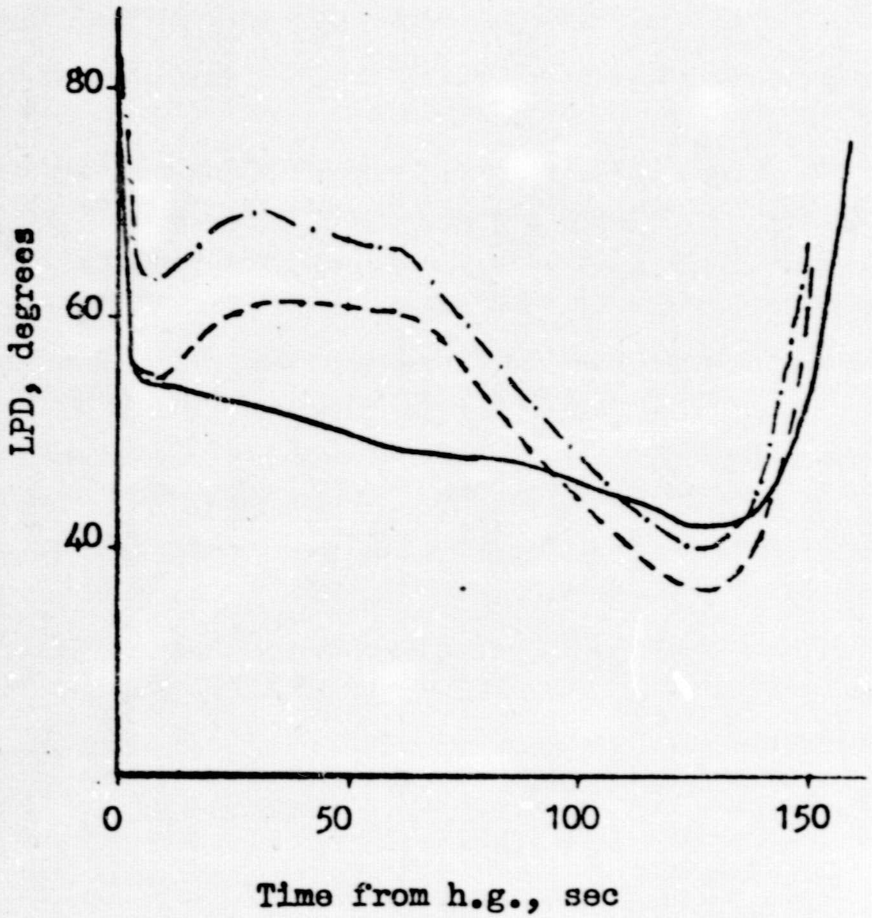

Figure 10a. - Censorinus -C landing w/THVH+1° conditions. LPD profile during visibility phase

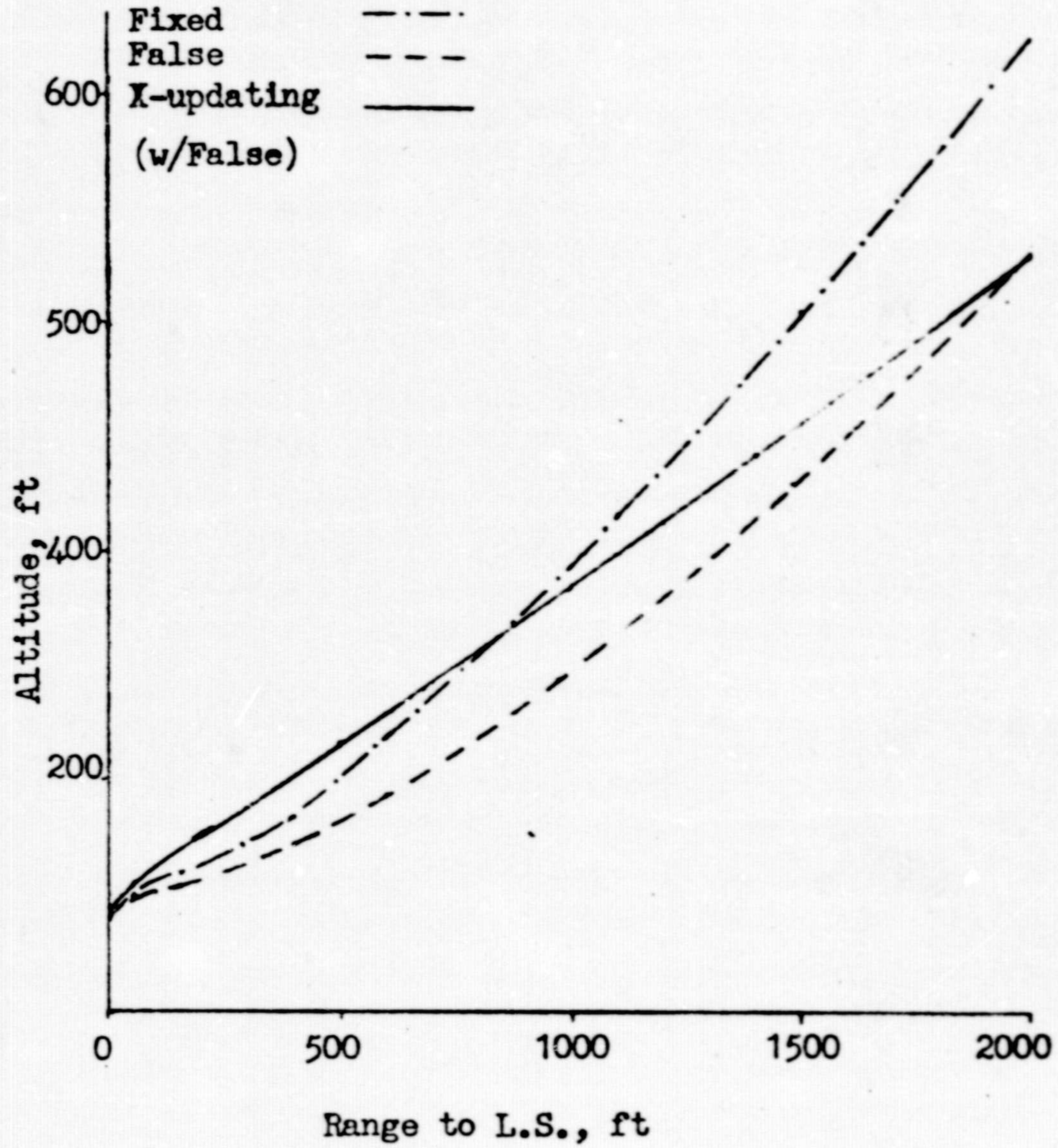

Figure 10b. - Censorinus -C landing w/THVH+1° conditions. Altitude vs range during last 2000 ft of final approach