

Basic Objectives for LM Powered-Landing
Guidance-and-Navigation System

- Safely land vehicle at a selected site on the moon with essentially zero velocity
- Accomplish the above objectives under the following conditions:
 - (1.) DPS propellant utilized in an efficient manner
 - (2.) Landing site visible to astronaut for at least 75 sec.
 - (3.) Limited range of throttle settings over which DPS can be operated
 - (4.) Provide manual site-redesignation capability to astronaut when site is visible
 - (5.) Approach-phase trajectory constraints to permit easy astronaut take-over if desired

Landing Maneuver Phases

| Number | Phase Name | LGC Programs | Starting time | Starting altitude | Starting speed |
|--------|---------------------|---------------|------------------|-------------------|----------------|
| -2 | Pre-ignition | P63 | >-30 min | | |
| -1 | DPS ullage and trim | P63 | -33.5 sec | | |
| 0 | Braking | P63 | 0 | 50,000 ft | 5545 f/s |
| 1 | Visibility | P64 | 464 sec | 7200 ft | 516 f/s |
| 2 | Final descent | P65, P66, P67 | 633 sec (P65) | 150 ft | 6 f/s |

P63 -- Braking phase program (cannot reenter from P65 or P67)

P64 -- Approach phase program (cannot reenter from P66 or P67)

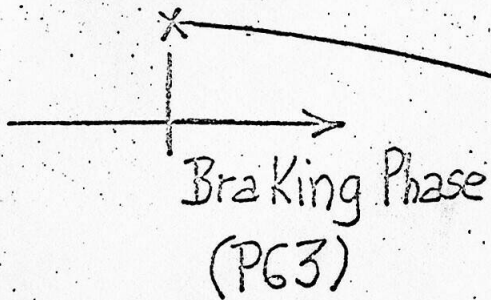
P65 -- Landing phase automatic program

P66 -- Landing phase rate-of-descent program

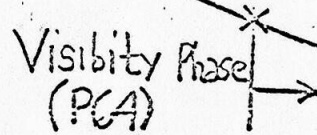
P67 -- Landing phase manual program

Nominal Lunar-Landing Geometry

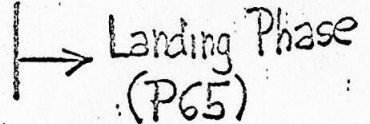
$h = 50,000 \text{ ft}$
 $V = 5545 \text{ ft/s}, \gamma = 0$
 $t = 0; \text{RGO} = 232 \text{ n.m.}$



$h = 7500 \text{ ft}$
 $V = 550 \text{ ft/s}, \gamma = -15 \text{ deg.}$
 $t = 464 \text{ s}, \text{RGO} = 4.3 \text{ n.m.}$



$h = 150 \text{ ft}$
 $V = 6 \text{ ft/s}, \gamma = -34 \text{ deg}$
 $t = 626 \text{ s}, \text{RGO} = 15 \text{ ft}$



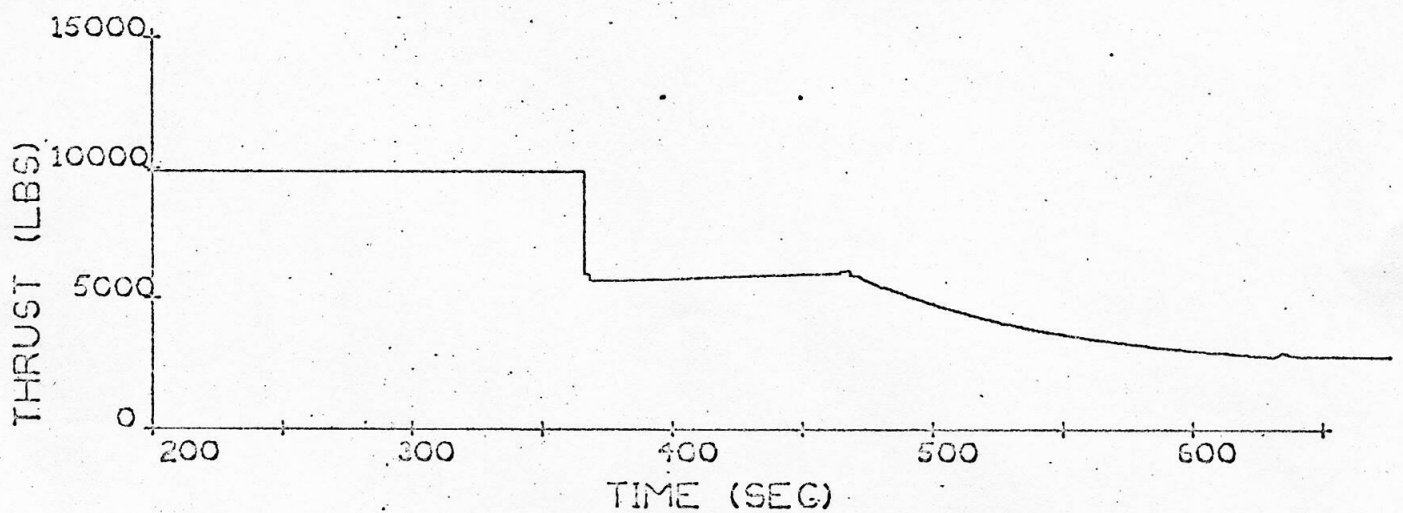
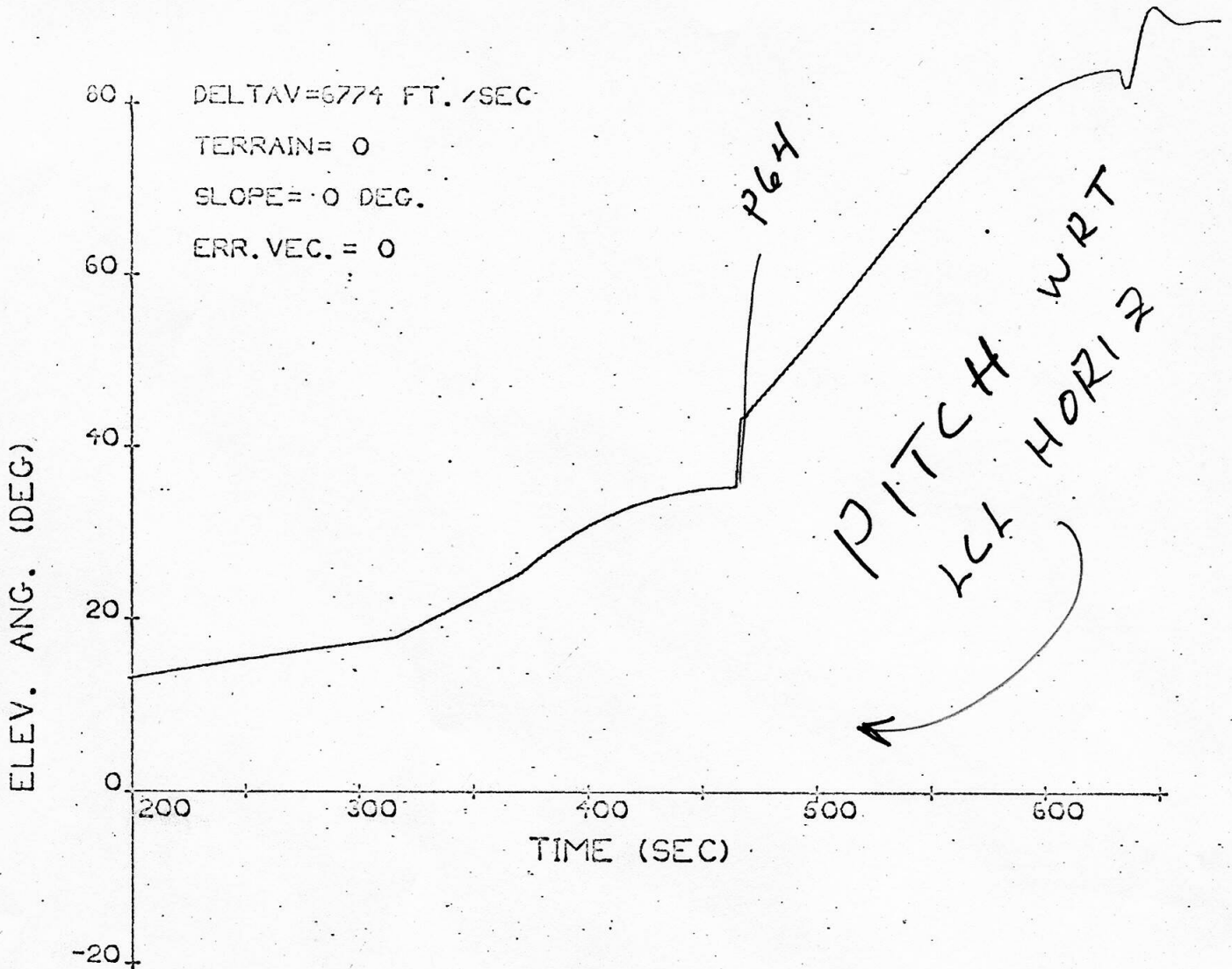
Landing Maneuver Displays

DSKY

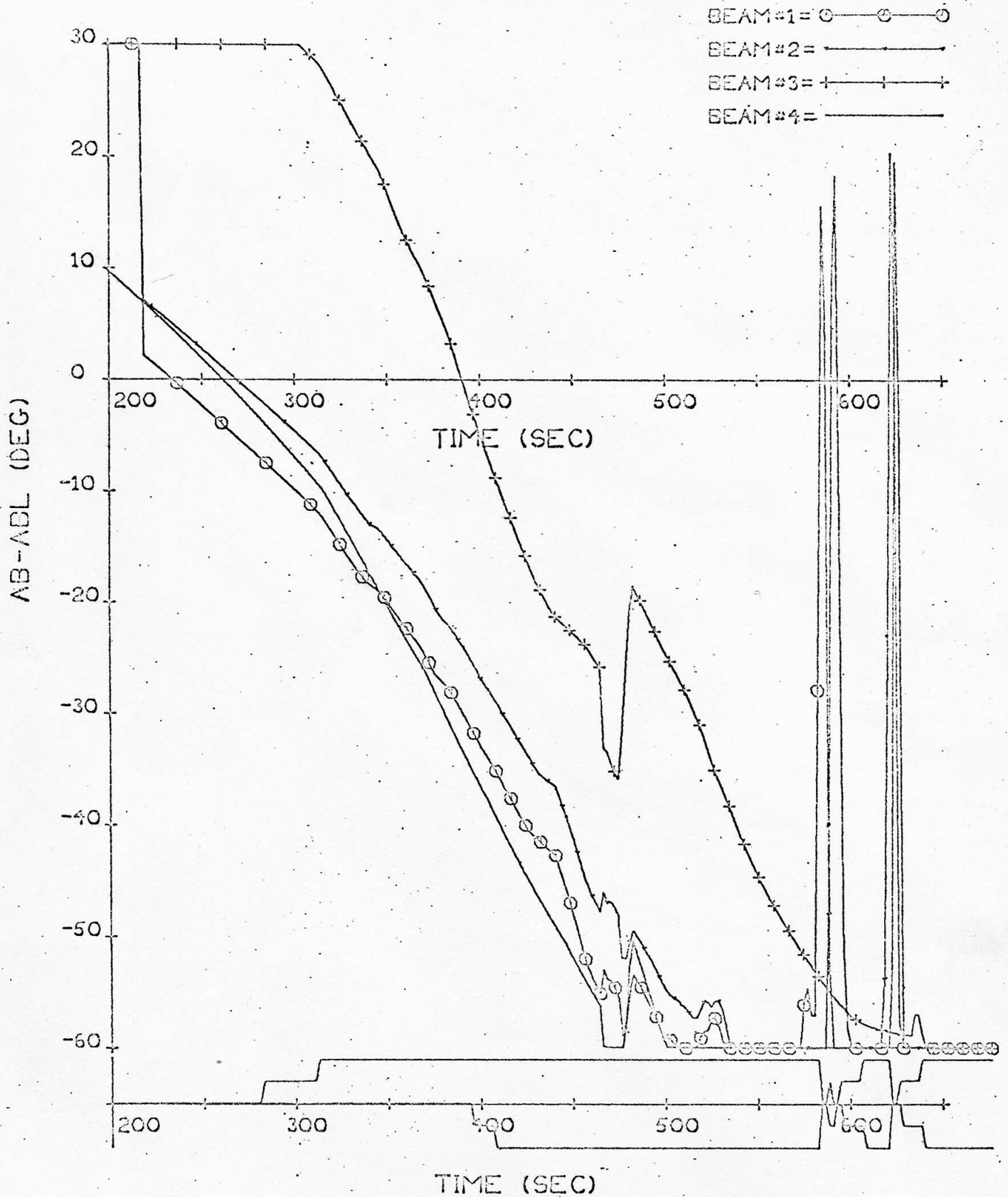
| Loc. | Preignition | TIG-30 | Start of Brake R. | Any Time in P63 | Visibility Phase | Final Descent |
|------|-------------|----------------|-------------------|-----------------|------------------|----------------|
| R1 | TGO | V _p | V _p | RANGE | TGO/LPD | V _H |
| R2 | TFI | TFI | HDOT | TGO | HDOT | HDOT |
| R3 | CR | ΔV_M | H | DELH | H | H |
| Call | VO6NG1 | VO6NG2 | VO6NG3 | VIGNG8E | VO6NG4 | VO6NG0 |

Analog Displays : H, HDOT, V_{HF}, V_{VF}

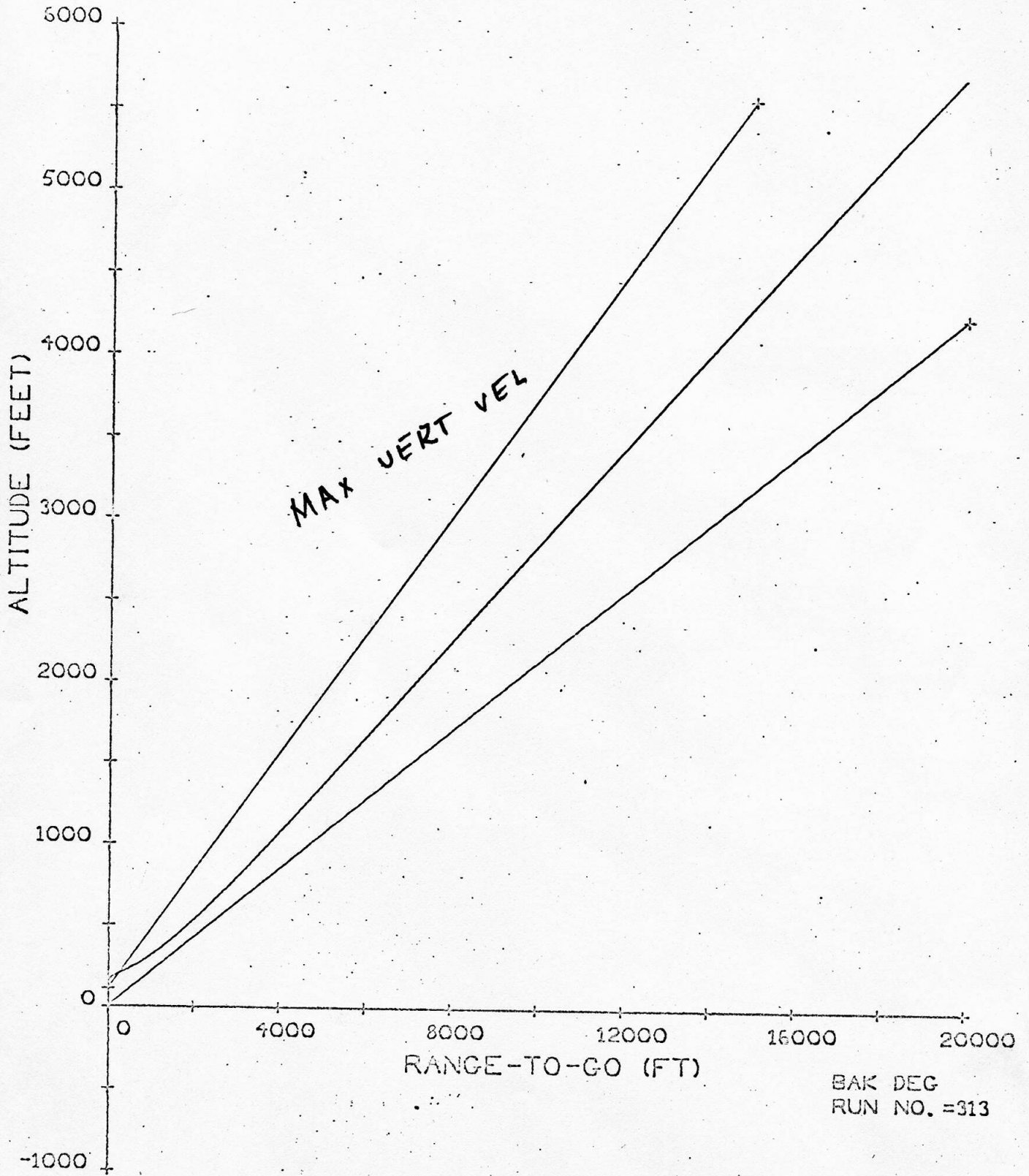
Thrust-Vector Elevation and Magnitude: Nominal



LR Beam Angles w.r.t Dropout Boundaries : Nominal

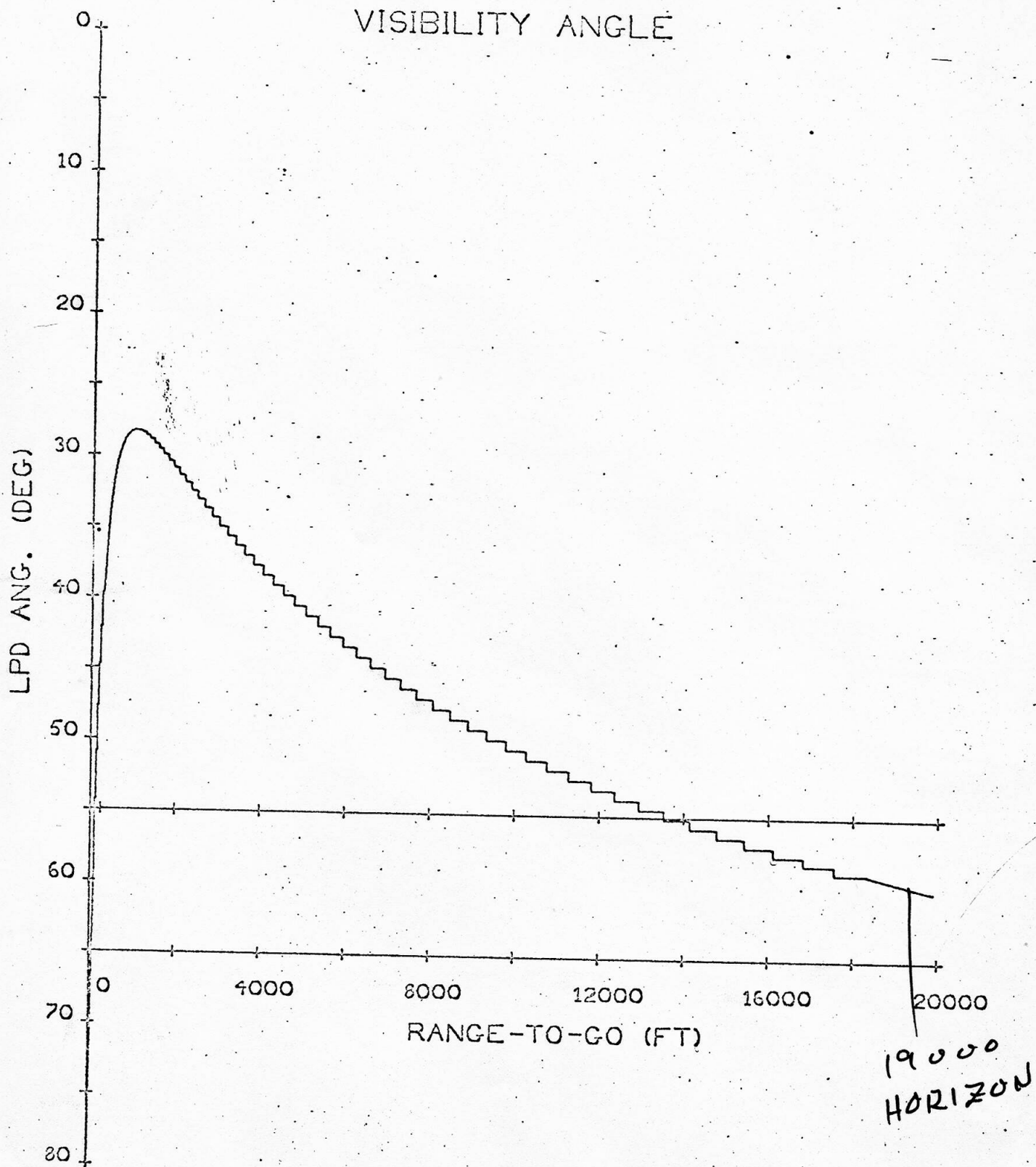


Altitude Profile for Last 20,000 ft: Nominal.

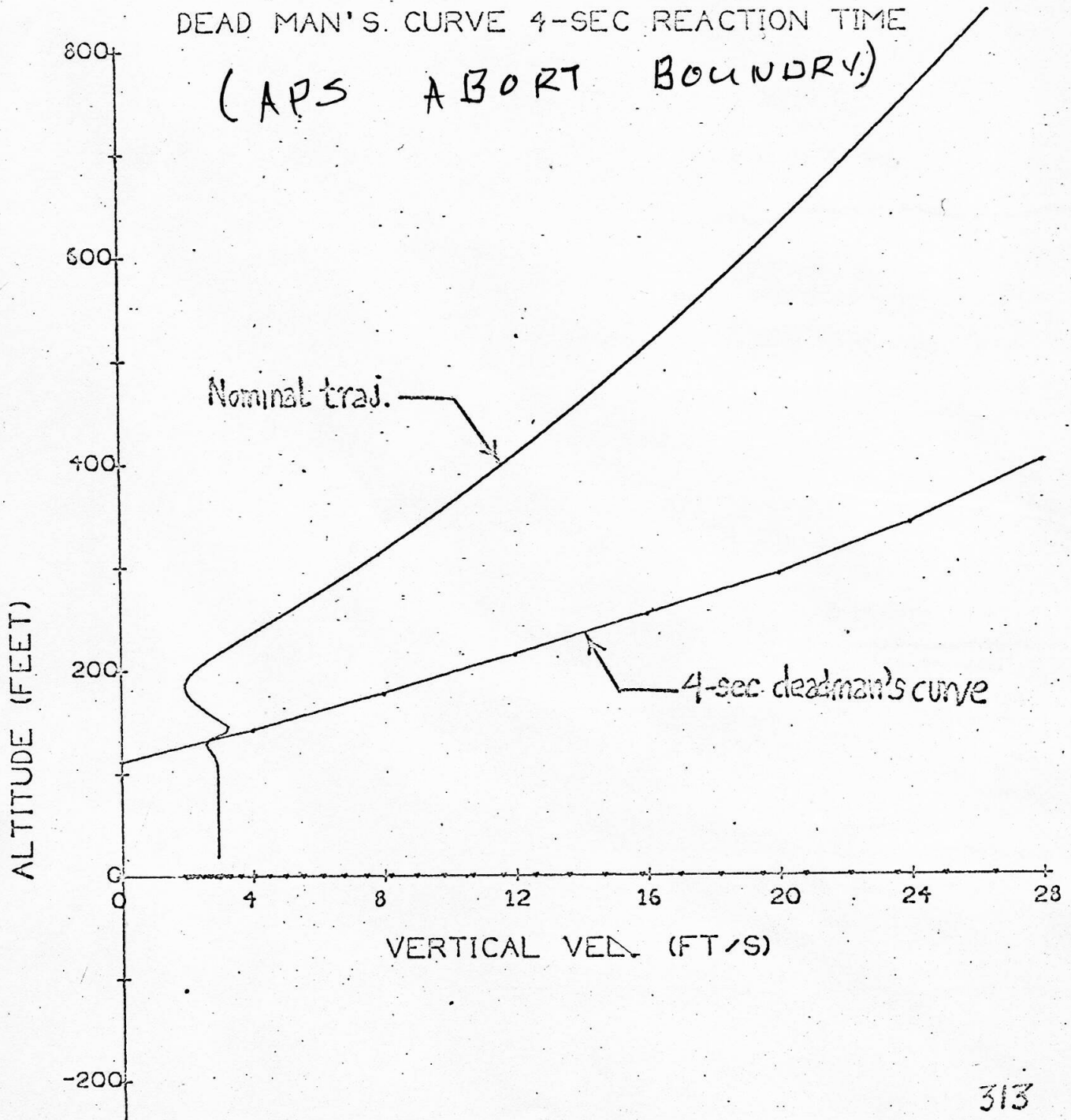


BAK DEG
RUN NO. = 313

LPD Angle on Nominal Trajectory



Altitude vs. Vertical Velocity: Nominal



Scope of State-Vector Routine Talk

- Navigation sensor performance characteristics --- IMU and LR on nominal trajectory, propagation of initial errors
- Description of routine -- general functions, tests, layout
- Various tests relating to the incorporation of LR data -- flags to set, alarms, DSKY Lights
- Updating relations and weighting functions
- LR acquisition and dropouts on nominal and off-nominal trajectories
- Data reasonableness tests -- possible lockouts of LR data
- System performance data for simulated automatic landings to sites II-P-6 and/or II-P-2, including terrain profiles, terrain slopes, initial condition errors, DPS thrust-acceleration variations, LR & IMU errors

Descent State-Vector Routine R-12

Basic Functions :

- Extrapolate the LM state estimate $(\underline{r}_p, \underline{v}_p)$ forward one time step using the current PIPA output data
- Update the extrapolated position estimate with LR altitude data, provided that certain tests are passed
- Update the extrapolated velocity estimate with LR velocity-component data, provided that certain tests are passed

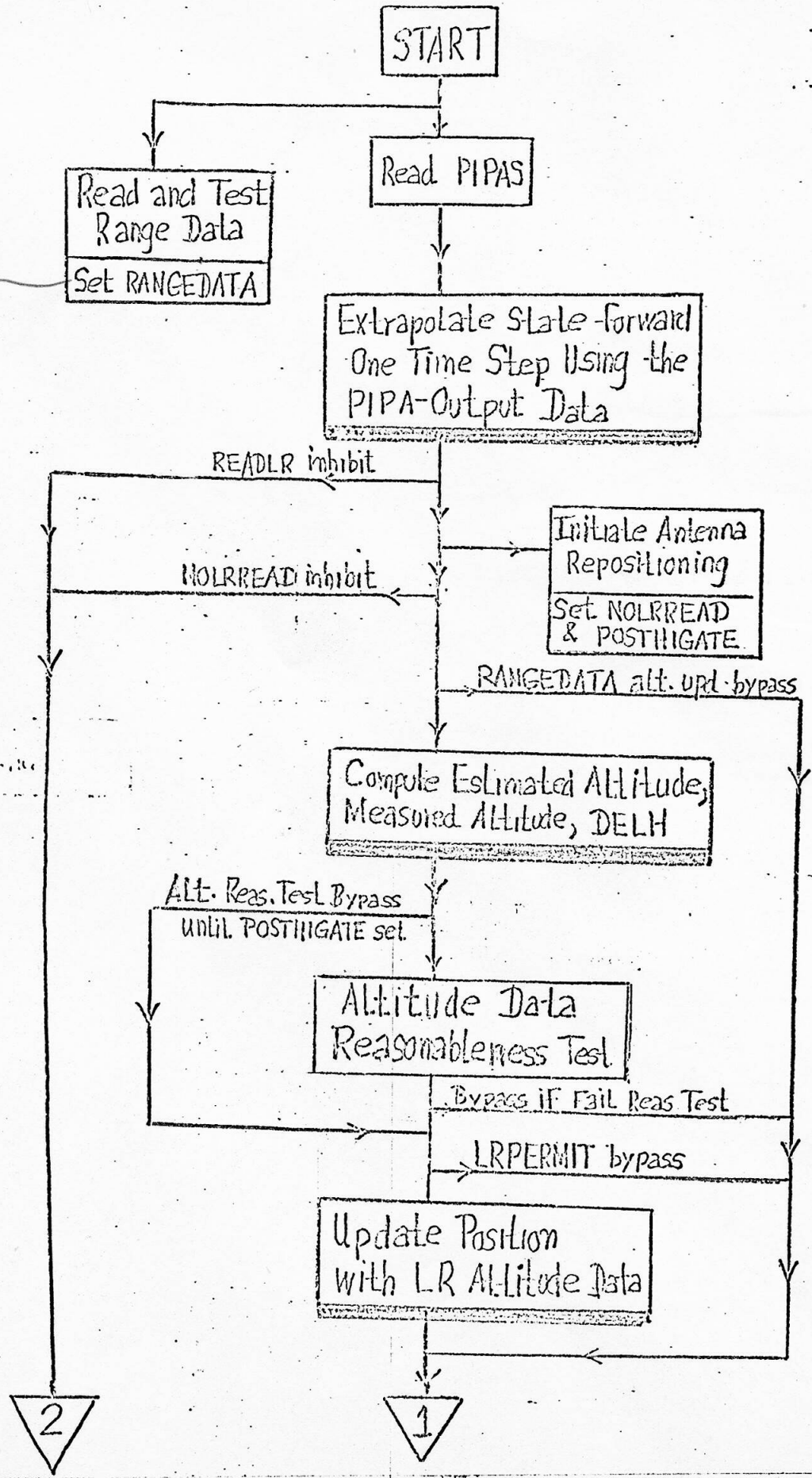
Primary Inputs : PIPA output data $(\Delta \tilde{\underline{v}}_p)$, LR range, LR velocity-component measurements

Primary Outputs : Up-to-date estimates of LM position (\underline{r}_p) and velocity (\underline{v}_p) in stable-member coordinates

Descent State-Vector Routine R-12

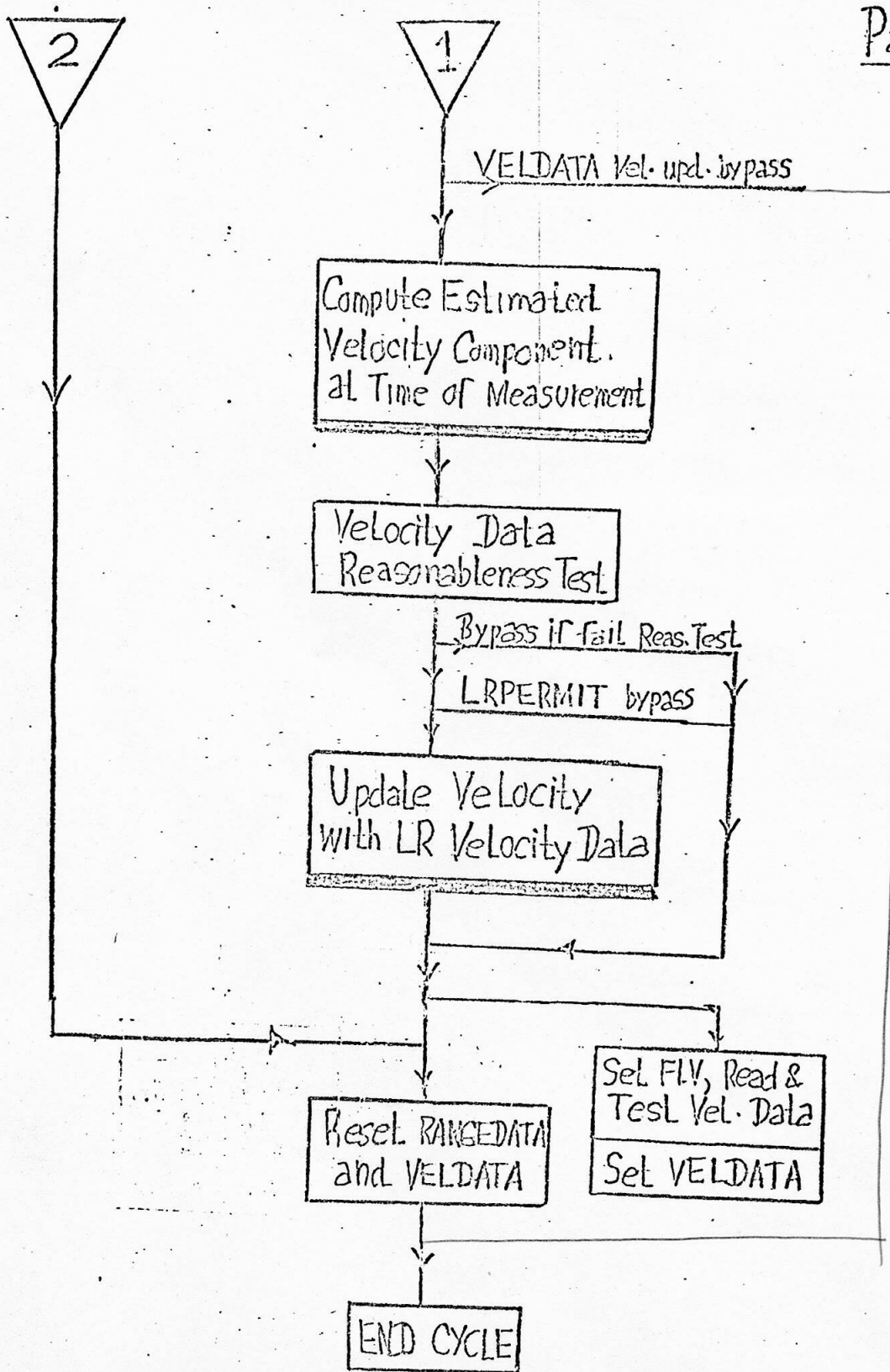
Part 1

if equal



Descent State-Vector Routine R-12

Part 2



LR Updating Relations

Altitude:

every 2 sec

$$\underline{r}_p = \underline{r}_p + W_H (\text{DELH}) \underline{u}_{HP}$$

$$\text{DELH} = \hat{q}^* - q' \text{ --- --- DSKY (DELH)}$$

$$\hat{q}^* = -\hat{q} (\underline{u}_{RBP} \cdot \underline{u}_{HP})$$

$$q' = r_p - r_{LS} \text{ --- --- DSKY (H)}$$

$$\hat{q}_{LR}^* = \hat{q} \cos(15^\circ) \text{ --- --- TAPEMETER (H)}$$

in meter

Superscripts

\sim = raw meas.

' = estimate

* = computed from meas.

Velocity:

*x every 6
y every 6
z every 6*

$$\underline{v}_p = \underline{v}_p + W_V (\delta q_u) \underline{u}_{APu}$$

$$\delta q_u = \hat{q}_u - q'_u$$

$$q'_u = \underline{v}'_u - \underline{\omega}_p \times \underline{r}_p$$

*x y z x
(z (z' z)*

Landing Radar Weighting Functions

Altitude:

| Selection Criterion | Weighting Function |
|---------------------|---|
| $R' > LRHMAX$ | $W=0$ |
| $R' \leq LRHMAX$ | $W = LRWH \left(1 - \frac{R'}{LRHMAX}\right)$ |

| Present Erasable Values | |
|-------------------------|----------|
| LRHMAX | 50000 FT |
| LRWH | .35 |

Velocity:

| Programs | Selection Criterion | Weighting Function |
|-----------------|-------------------------|---|
| P63 P64 | $V' > LRVMAX$ | $W=0$ |
| | $LRVMAX \geq V' > LRVF$ | $W = C \left(1 - \frac{V'}{LRVMAX}\right)$ $C = LRWVX, Y, Z$ |
| | $V' \leq LRVF$ | $W = C$ $C = LRWVFX, Y, Z$ |
| P65, P66 P67 | | $W = LRWVFF$ |

| Present Erasable Values | |
|-------------------------|----------|
| LRVMAX | 2000 F/G |
| LRVF | 200 F/G |
| LRWVX | .3 |
| LRWVY | .3 |
| LRWVZ | .3 |
| LRWVFX | .2 |
| LRWVFY | .2 |
| LRWVFZ | .2 |
| LRWVFF | .1 |

Tests Relating to Incorporation of LR Data

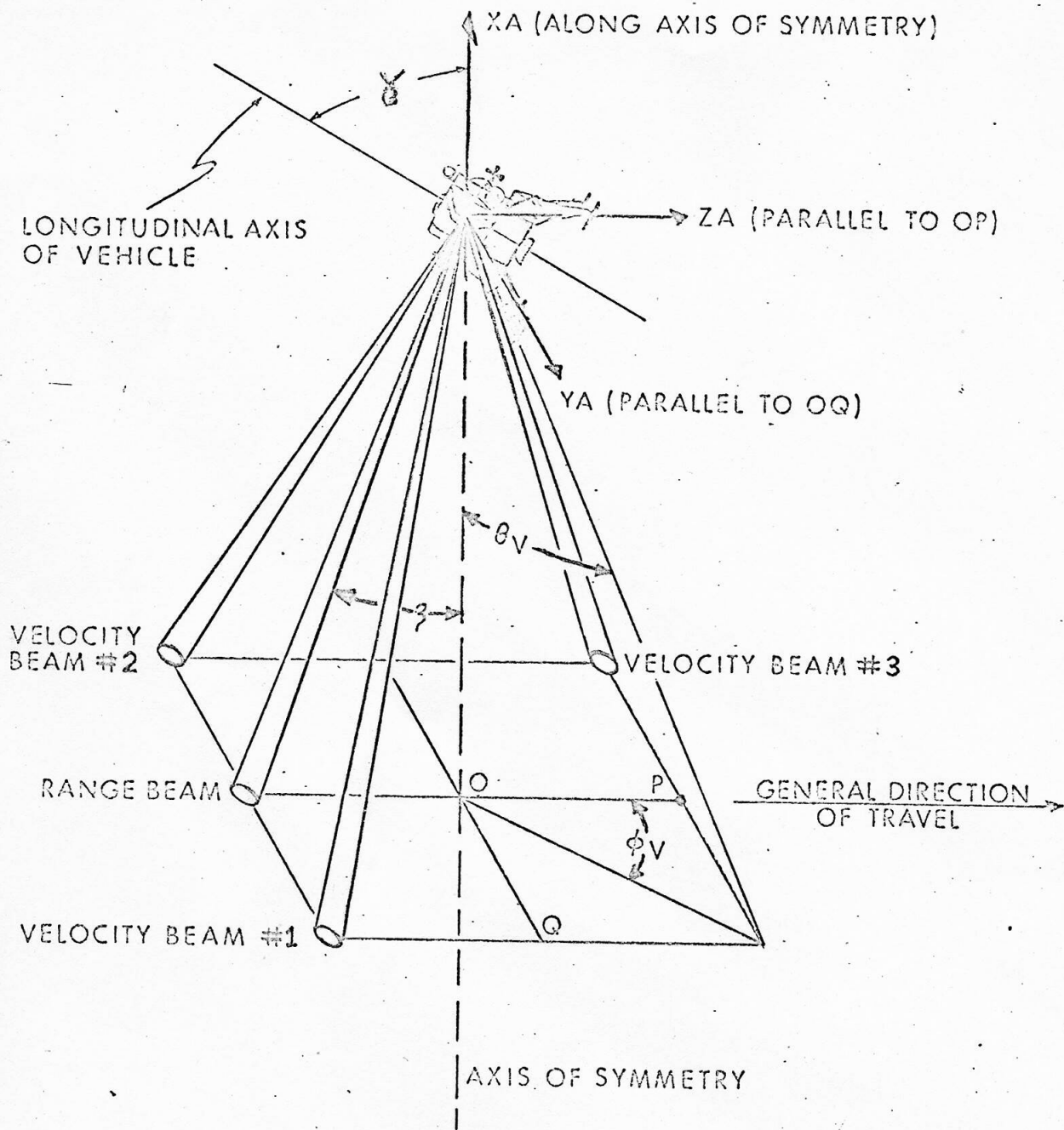
| Test or Flag to set | Purpose | How Set |
|---------------------|--|--|
| LRPERMIT | Inhibit or allow LR updatings | Astronaut-- use of V_{57} Permits V_{58} Inhibit |
| LRBYPASS | Inhibit LR updatings | LGC during P12, P70, P71 |
| READLR | Permits LR data to be read | LGC-- $h' < HUP$ (50,000 ft) |
| READVEL | Permits LR velocity data to be read | LGC-- $V' < VUP$ (2000 F/s) |
| NOLRREAD | Inhibits LR updatings and the reading of LR data | LGC-- Set when antenna repositioning is started, reset when Position-2 discrete obtained |
| POSTHIGATE | Cause computer to check for Position-2 Discrete | LGC-- $t_{GO} < t_{SW}$ & $U_{XBXP} > G_{SW}$ |
| FLAUTOX | Inhibits X-axis over-ride option | LGC-- $h' < 30,000$ ft |
| RANGEDATA | Inhibits LR altitude updatings if not set | LGC -- Range data-good discrete on <u>two</u> consecutive measurements |
| VELDATA | Inhibits LR velocity updatings if not set | LGC -- Velocity data-good discrete on <u>two</u> consecutive measurements |

FLV

Lights and Alarms Relating to Operation of LR

| Problem | Indication |
|---|---|
| No LR Range Data-Good Discrete | DSKY Altitude-Fail Light ON Steady (range data-good discrete turns off if range > 2481') |
| No LR Velocity Data-Good Discrete | DSKY Velocity-Fail Light ON Steady (vel. data-good discrete turns off) |
| No Range Low-Scale Discrete after LR Range < 2481 feet | DSKY Altitude-Fail Light ON Steady (range low-scale discrete turns off) |
| No Position-2 Discrete after 22 sec from time LR Position Command Discrete is issued to the LR. | Program Alarm |
| No Position-1 Discrete before LR Pos. Command Discrete is issued to the LR | Program Alarm |
| Two of last four altitude meas. failed reasonableness test | Flash LR Altitude Fail Light. (will not flash if test passed) |
| Two of last four velocity meas. failed reasonableness test | Flash LR Velocity Fail Light (will not flash if test passed) |

multiply by 1000
 2000 ft/sec



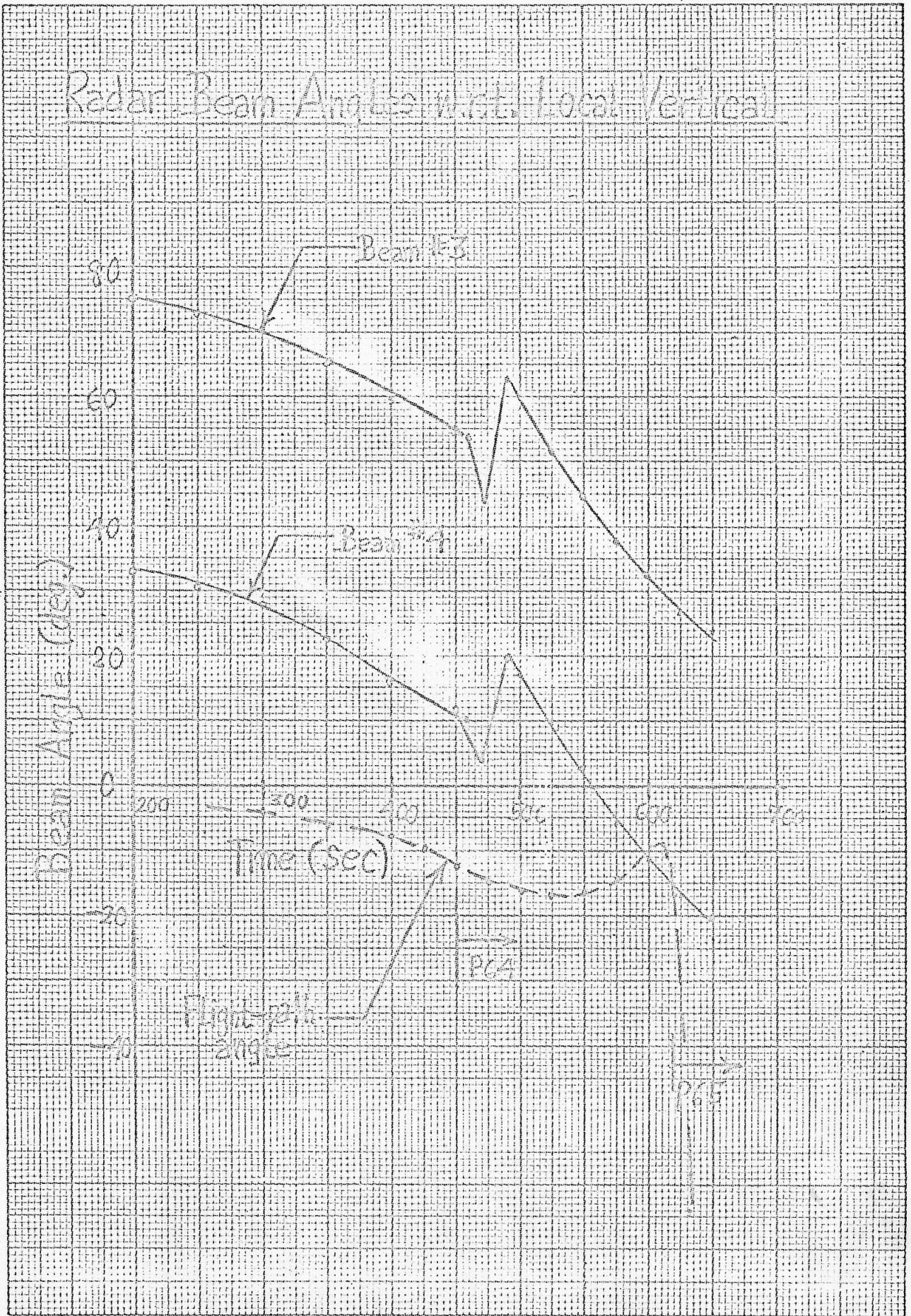
$$z = 20.4^\circ$$

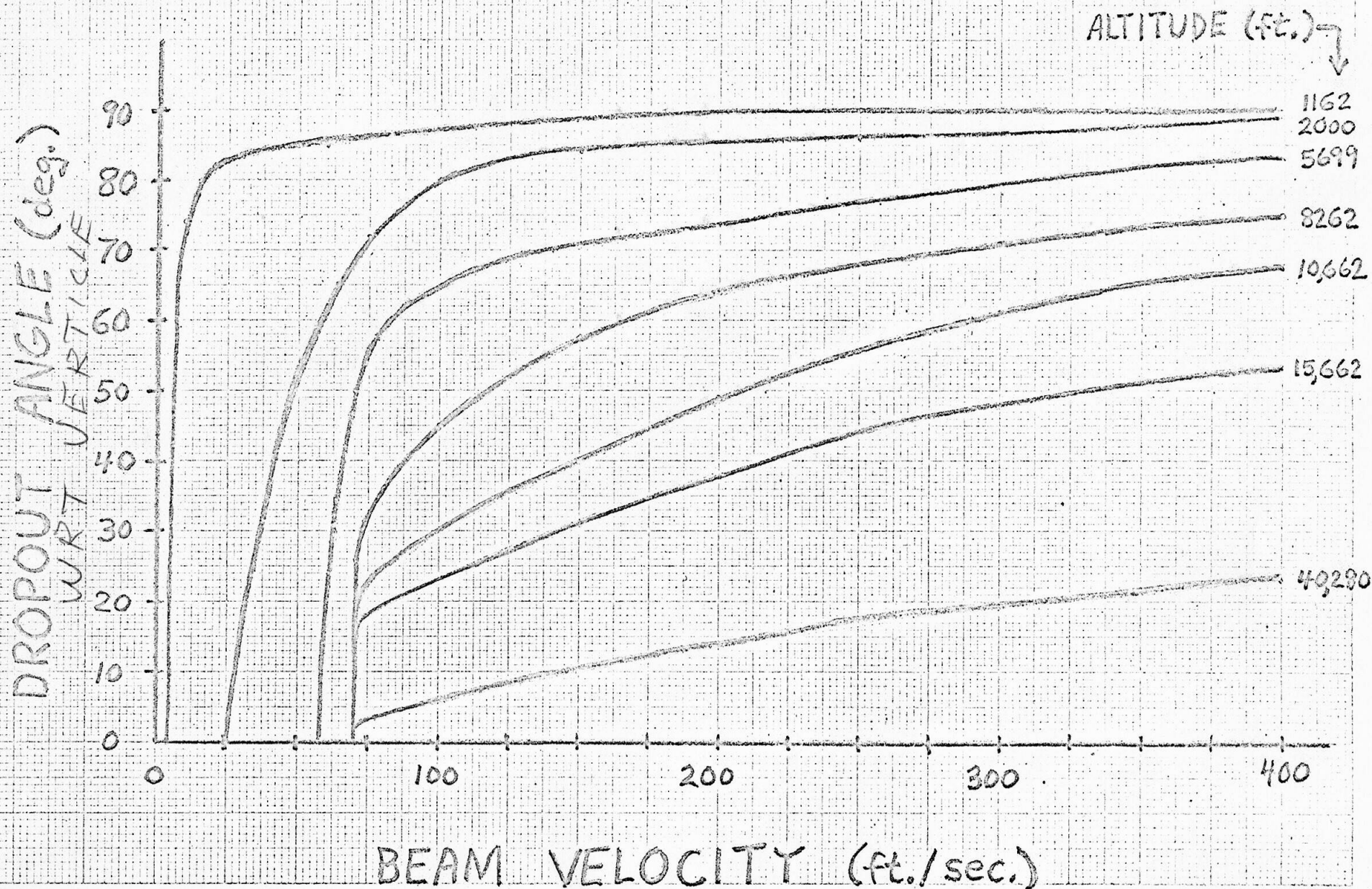
$$\theta_v = 24.6^\circ$$

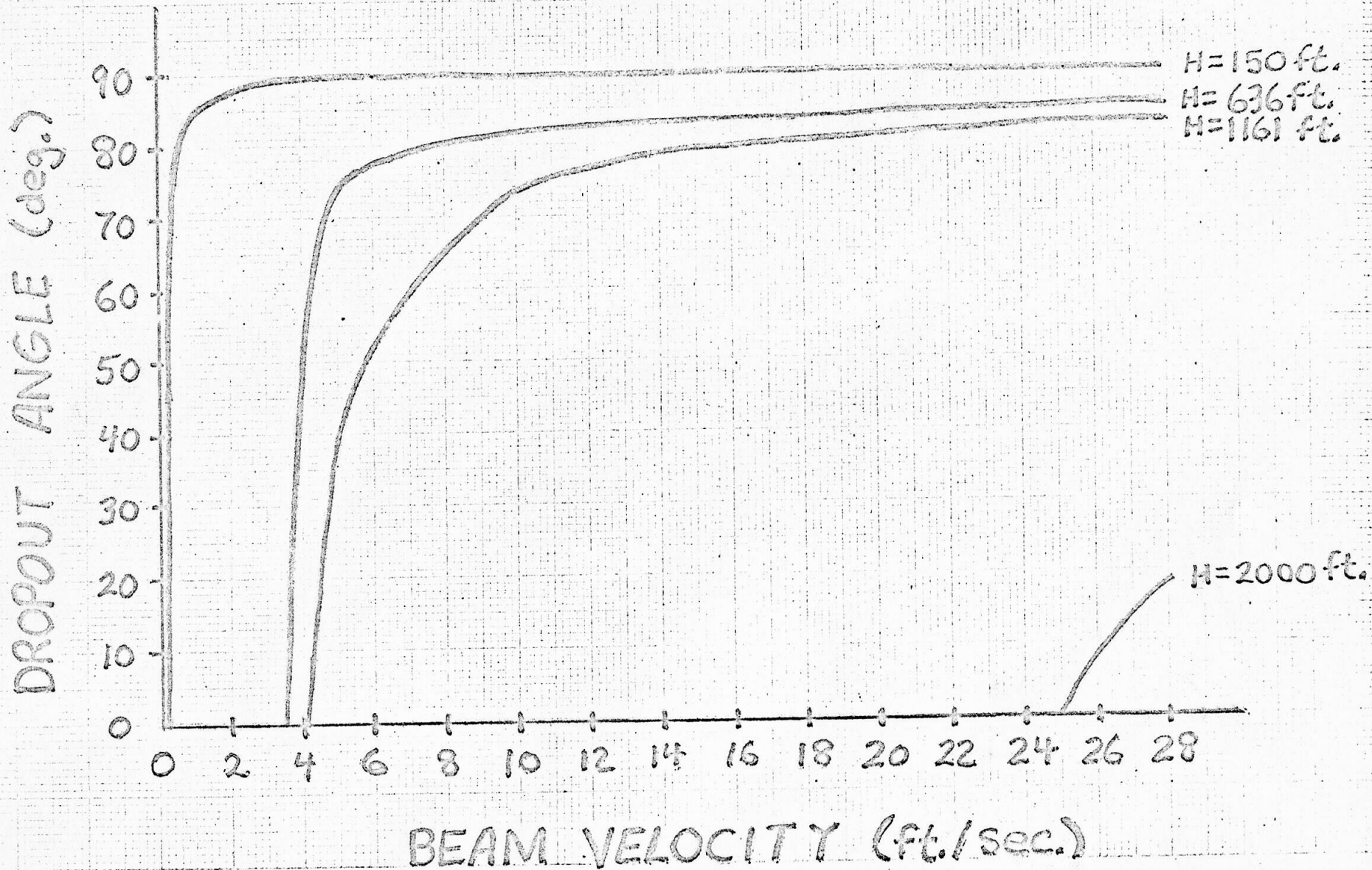
$$\phi_v = 35.6^\circ$$

$$\gamma = \begin{cases} 24.0^\circ & ; \text{ POSITION ONE} \\ 0.0^\circ & ; \text{ POSITION TWO} \end{cases}$$

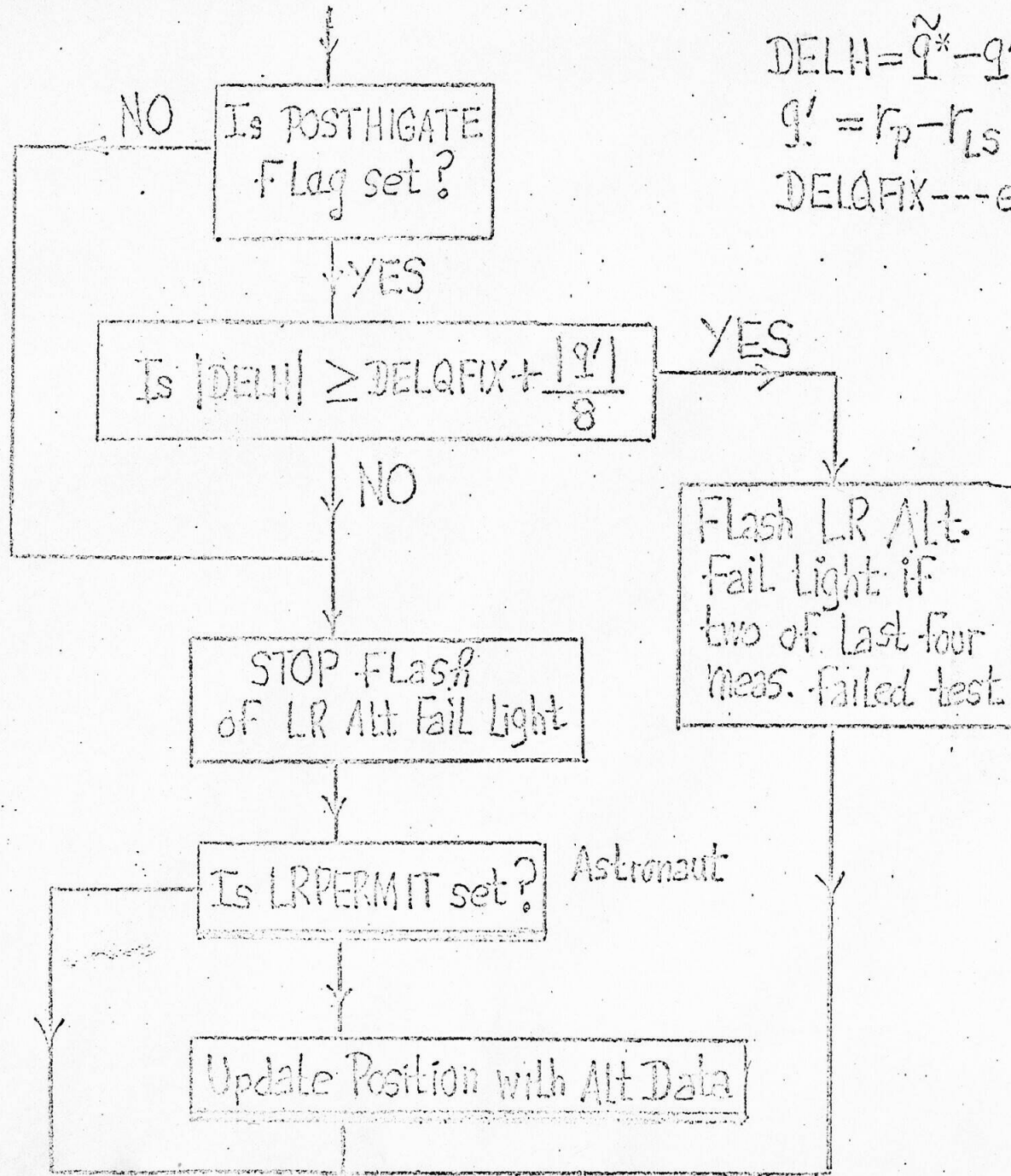
LANDING RADAR GEOMETRY







Altitude Data Reasonableness Test



$$DELH = \tilde{q}^* - q' \text{ --- DSKY}$$

$$q' = r_p - r_{Ls}$$

DELQFIX --- erasable. (100 FT)

NO
Is POSTHIGATE Flag set?

YES
Is $|DELH| \geq DELQFIX + \frac{|q'|}{8}$

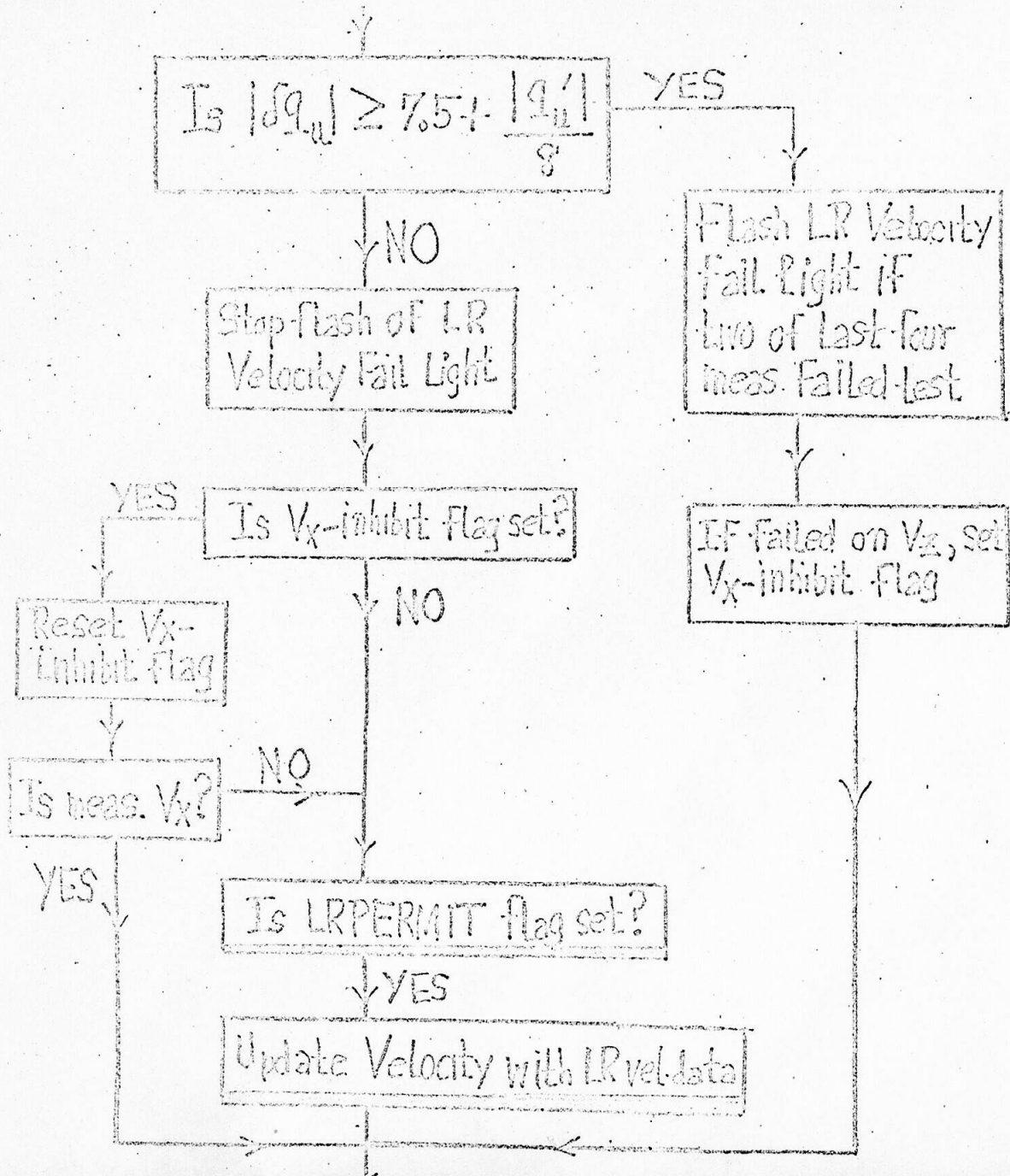
YES
Flash LR Alt. Fail Light if two of last four meas. failed test.

NO
STOP Flash of LR Alt Fail Light

Is LRPERMIT set? Astronaut

Update Position with Alt Data

Velocity Data Reasonableness Test



$$\delta q_u = \tilde{q}_u - q'_u$$

$$q'_u = (V'_u - \omega_p \times r_p) \cdot \underline{u}_{AP_u}$$

Superscripts

\sim = measured

' = estimated

Subscripts

u = meas. time

P = platform coords

A = antenna axis

X, Y, Z = vel. components along ant. axes

Landing Simulation Assumptions

Initial-Condition

Est. Errors:

1191.1

| | Position (Ft) | Vel (F/s) |
|---|---------------|-----------|
| X | 1906 | 6.8 |
| Y | 4400 | 8.1 |
| Z | -6287 | -4.2 |

(IMU coord - of LS)

Terrains: II-P-6, Profile 3

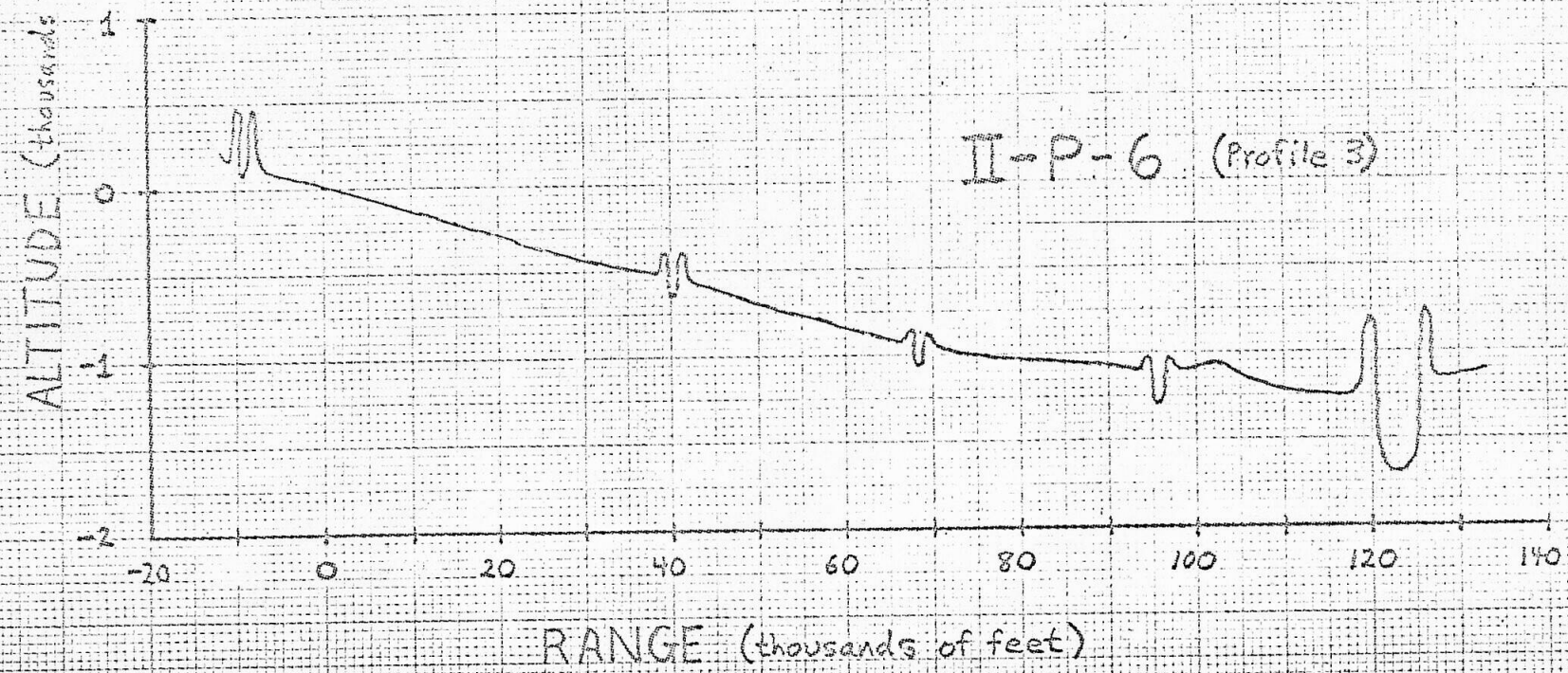
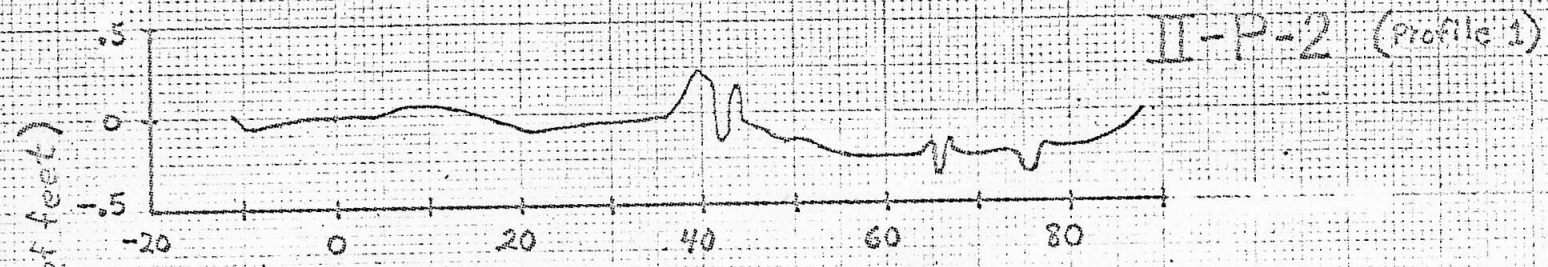
II-P-2 Profile 1

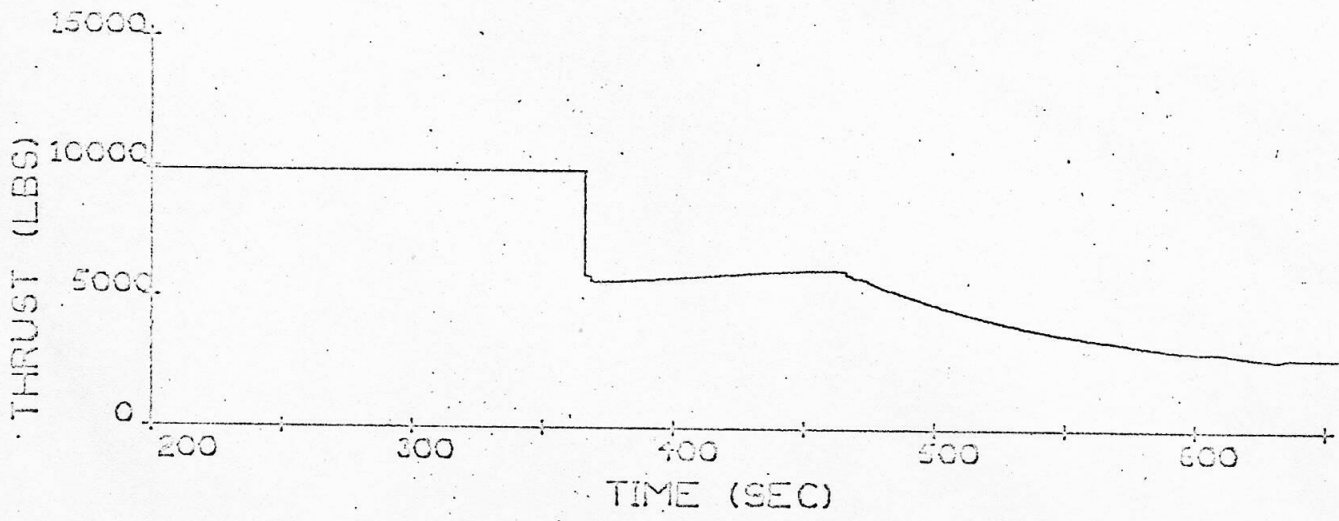
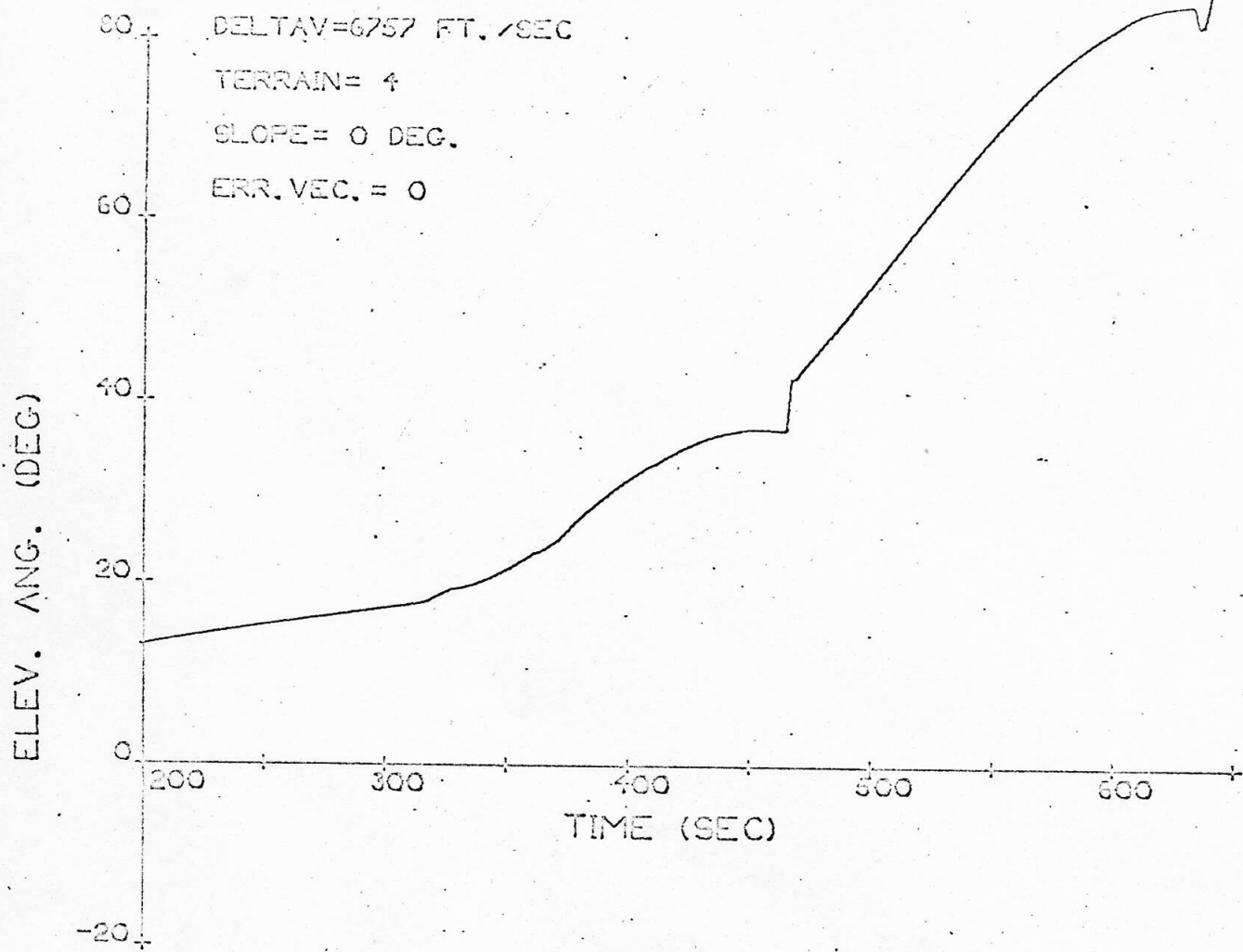
Slopes: ± 1 deg to maximum of 5000 feet

Thrust Acc. $+1\%$

Vars. : -2.5%

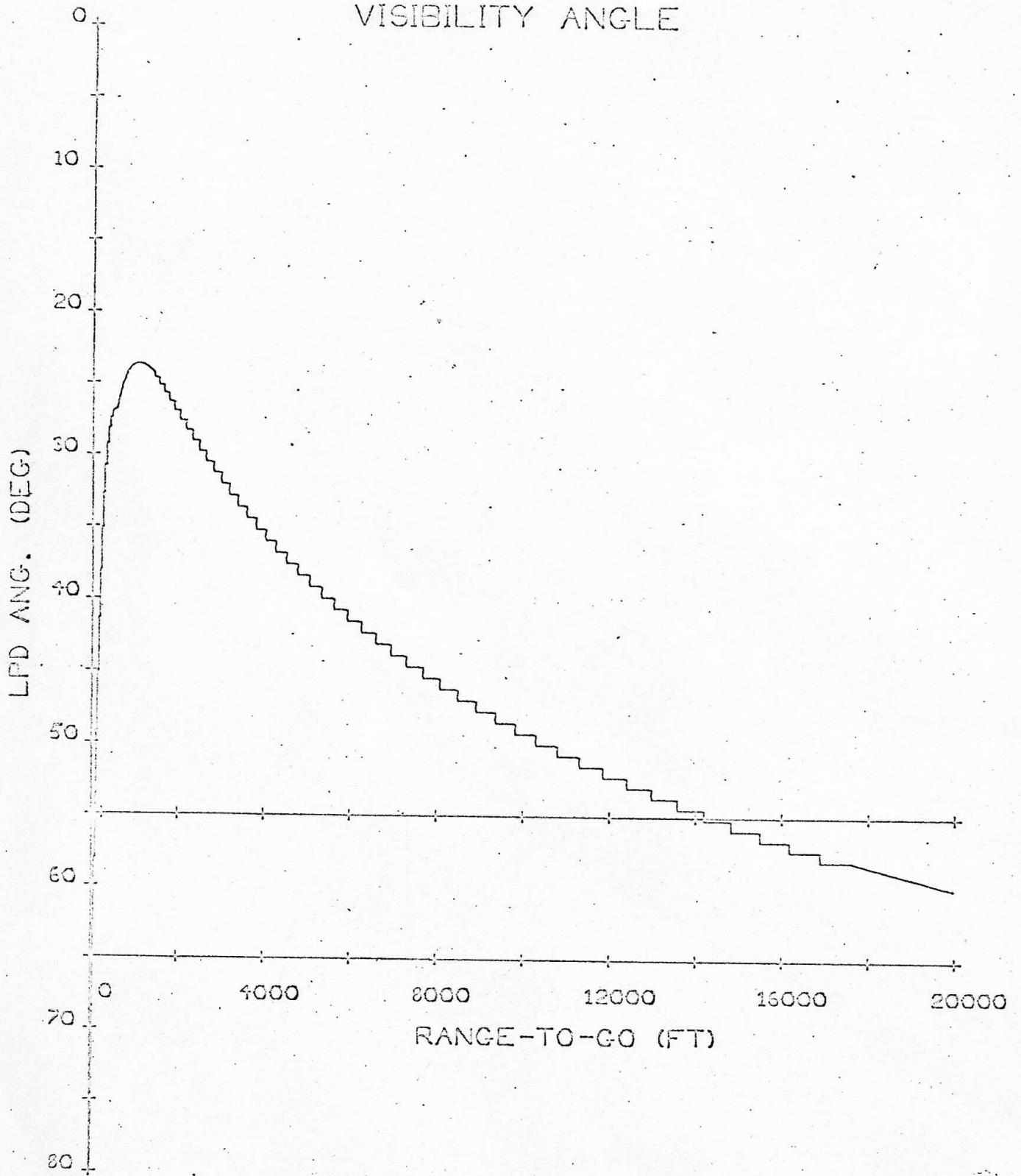
TERRAIN PROFILES 2 *Dimensions*



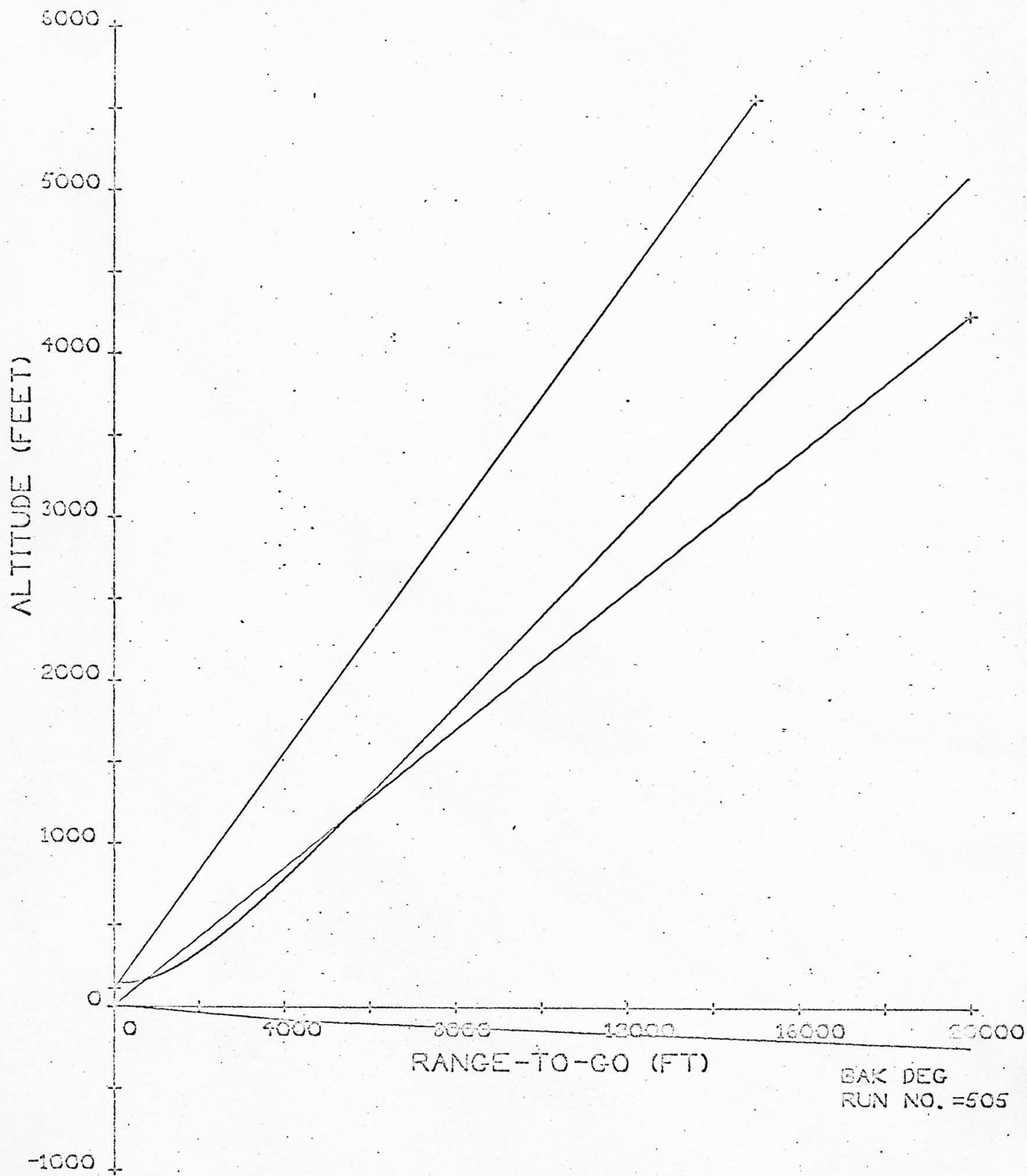


BAK DEG
RUN NO. =505

VISIBILITY ANGLE

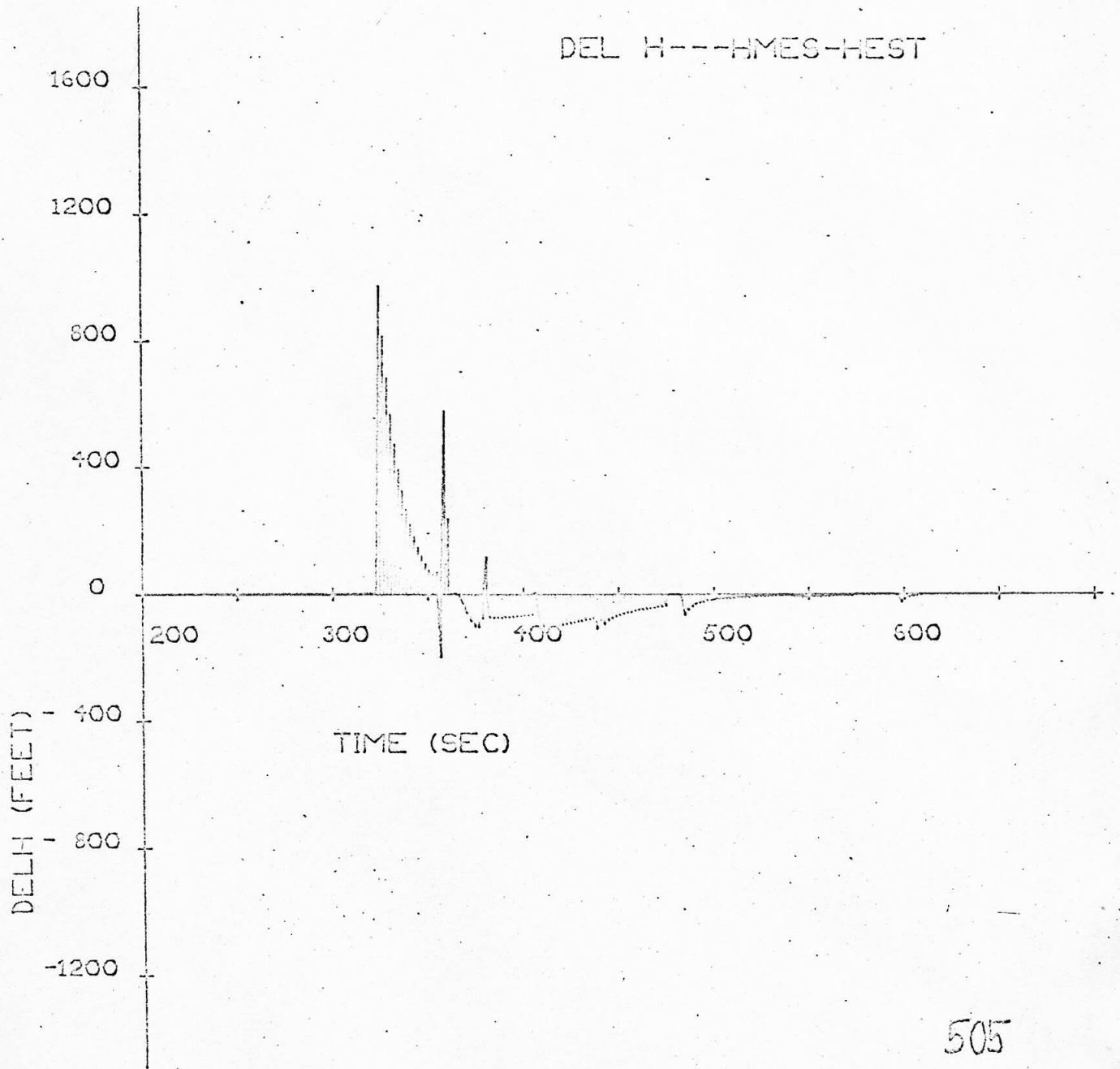


BAK DEG
RUN NO. =505

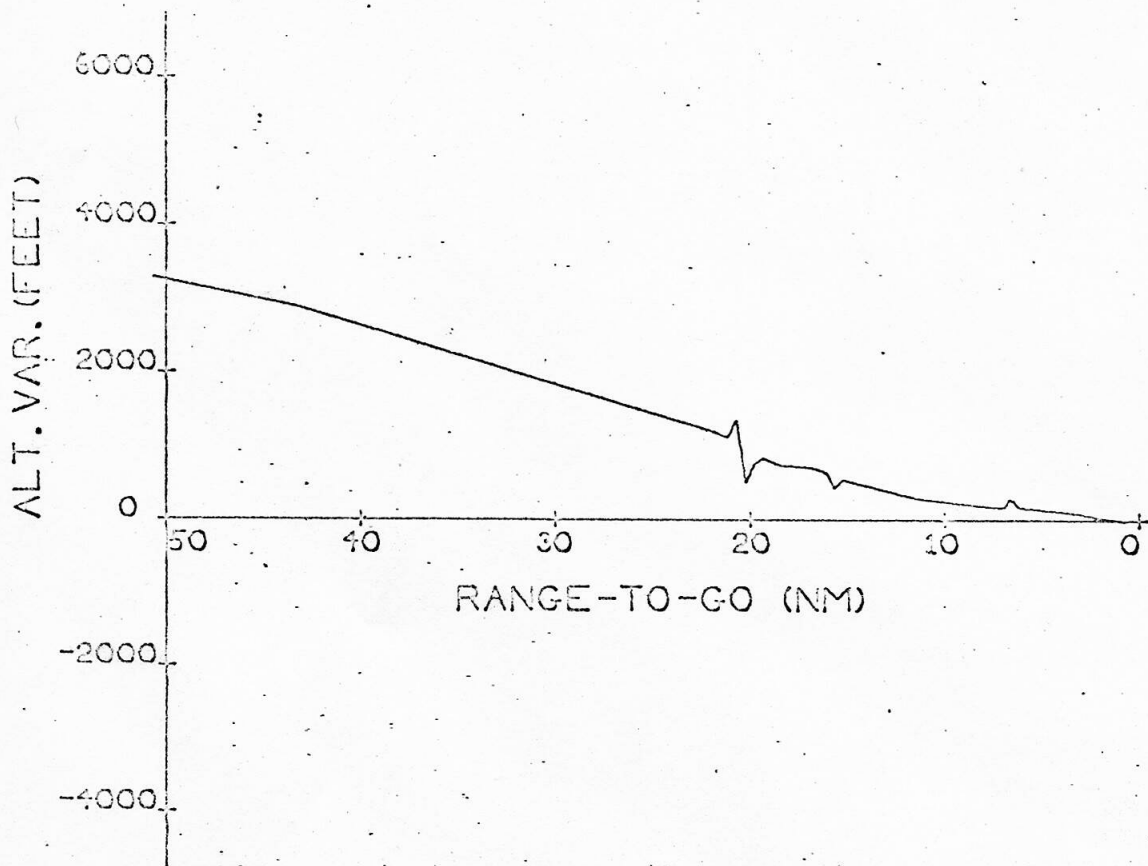


DELH for Error-Free Case II-P-6 Profile 3

No Slope

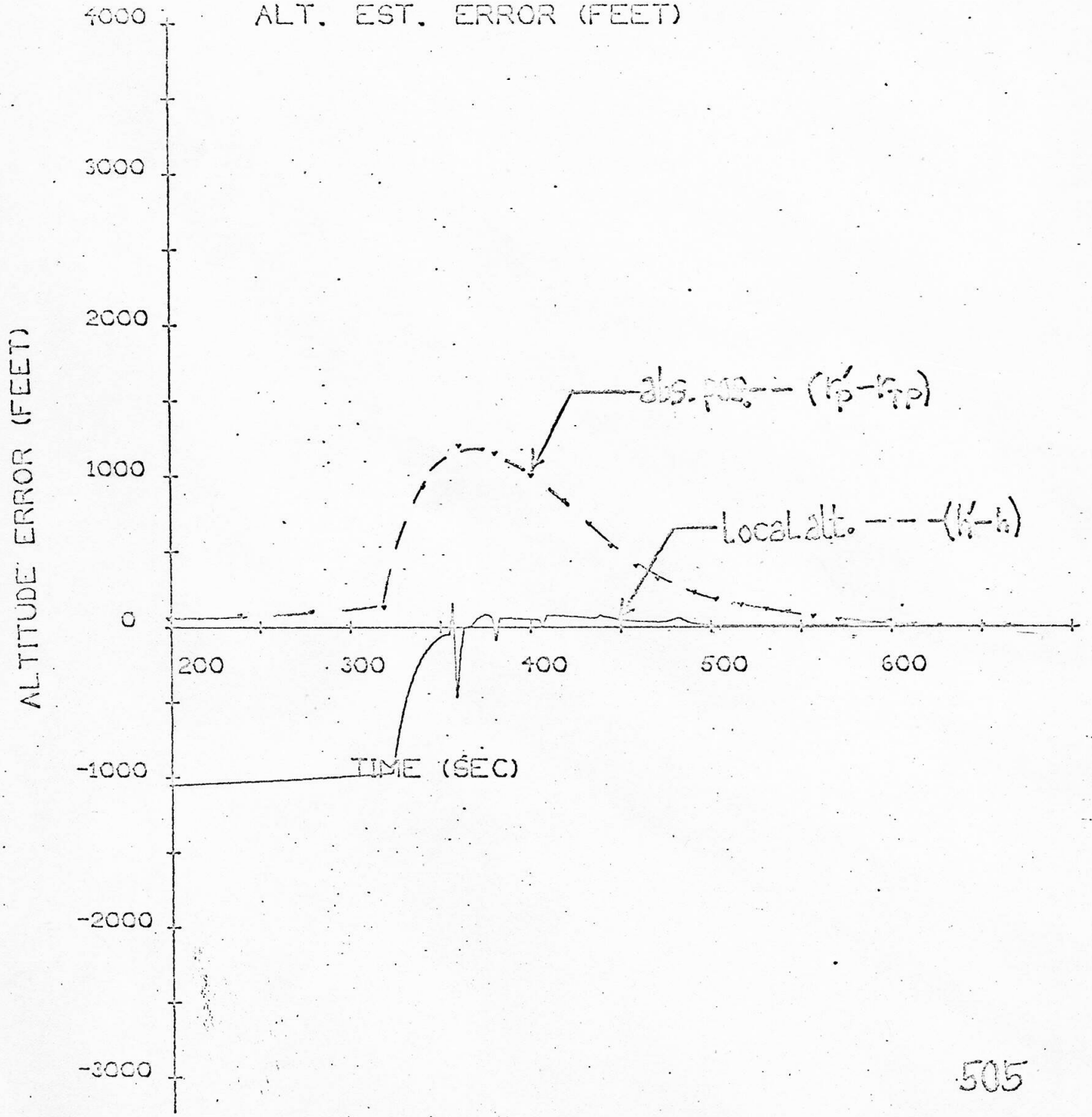


Terrain II-P-6, Profile 3, 1-deg Slope

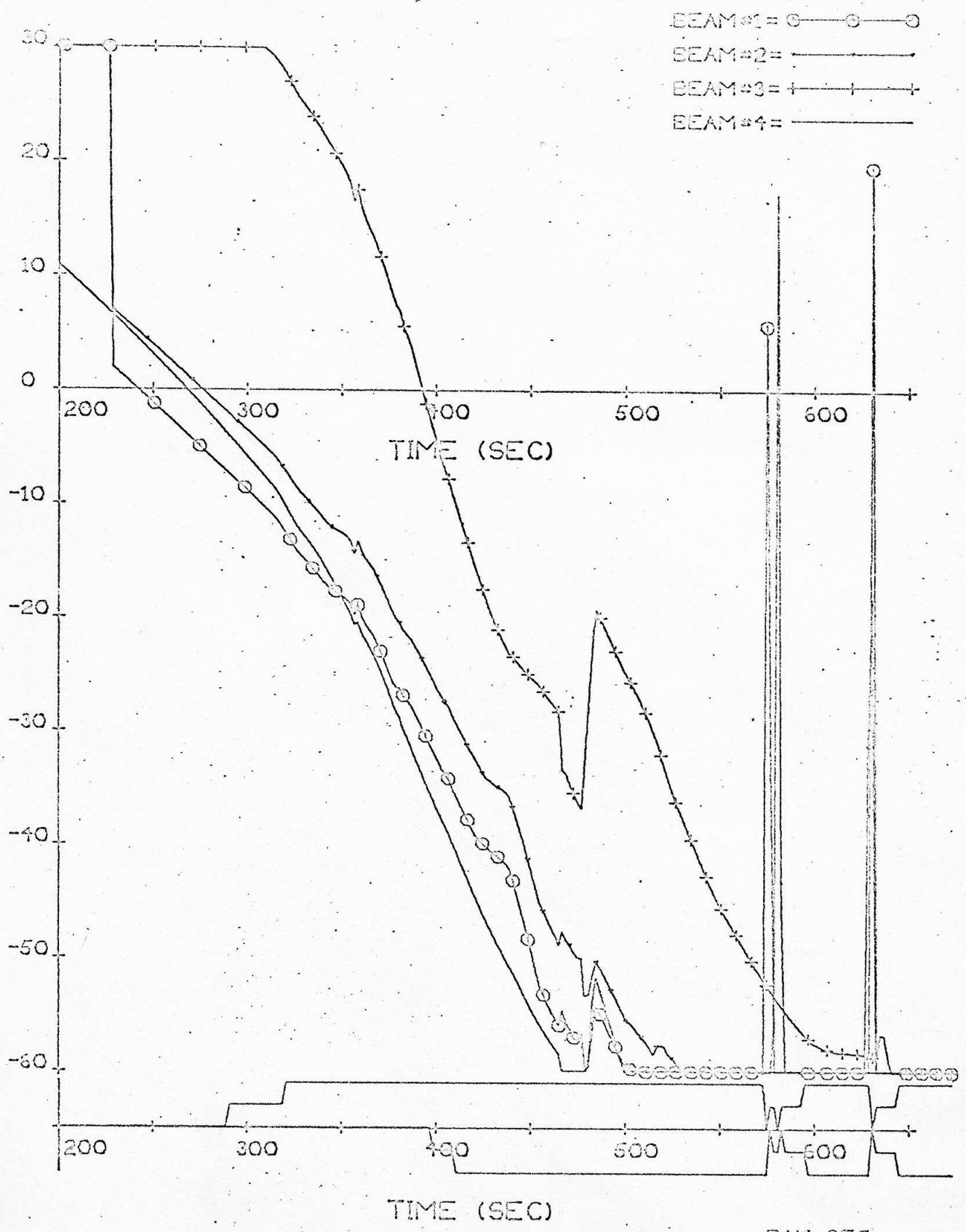


506

ALT. EST. ERROR (FEET)



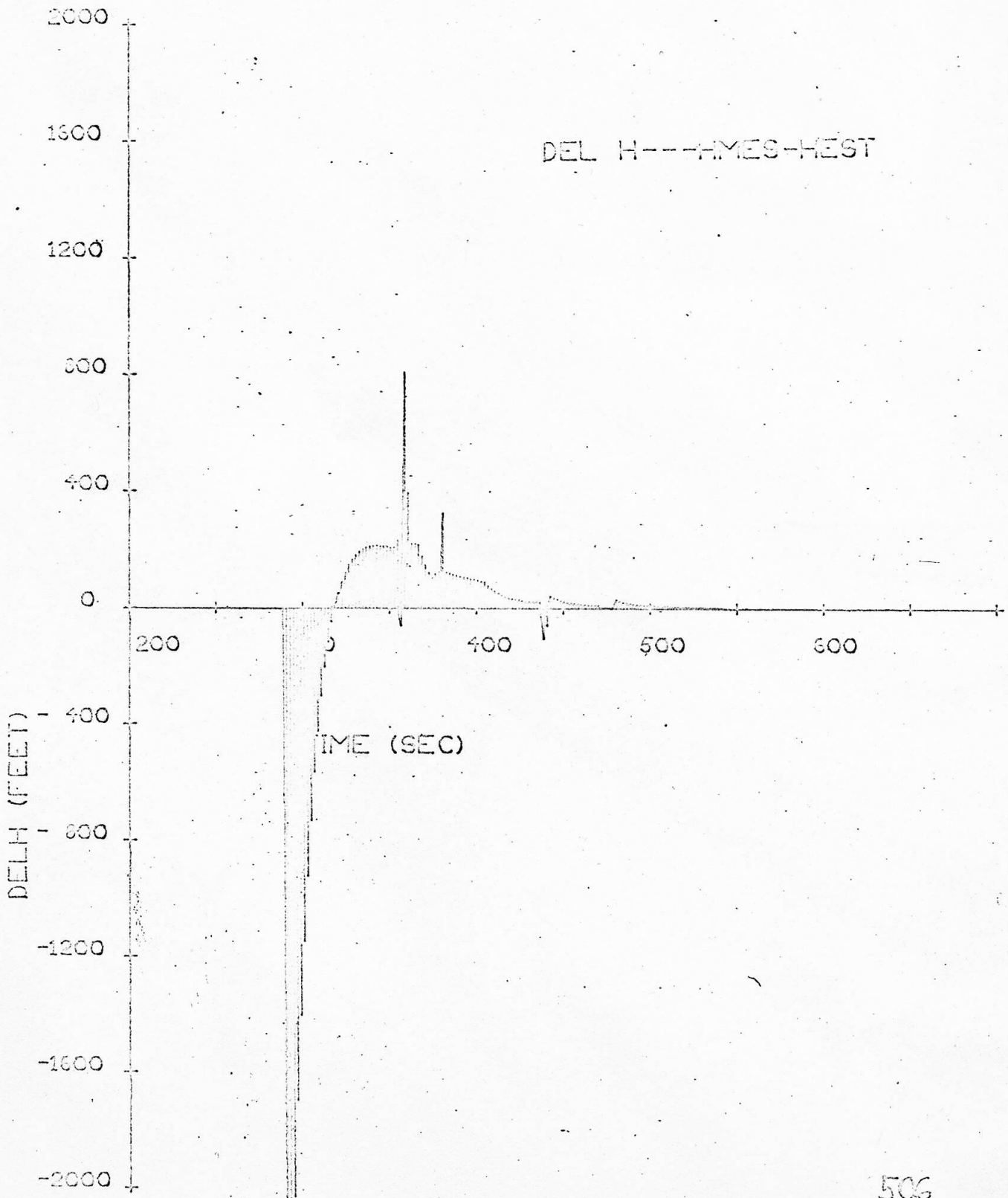
LR Beam Angles w RT Drogant Bombardier, Normal



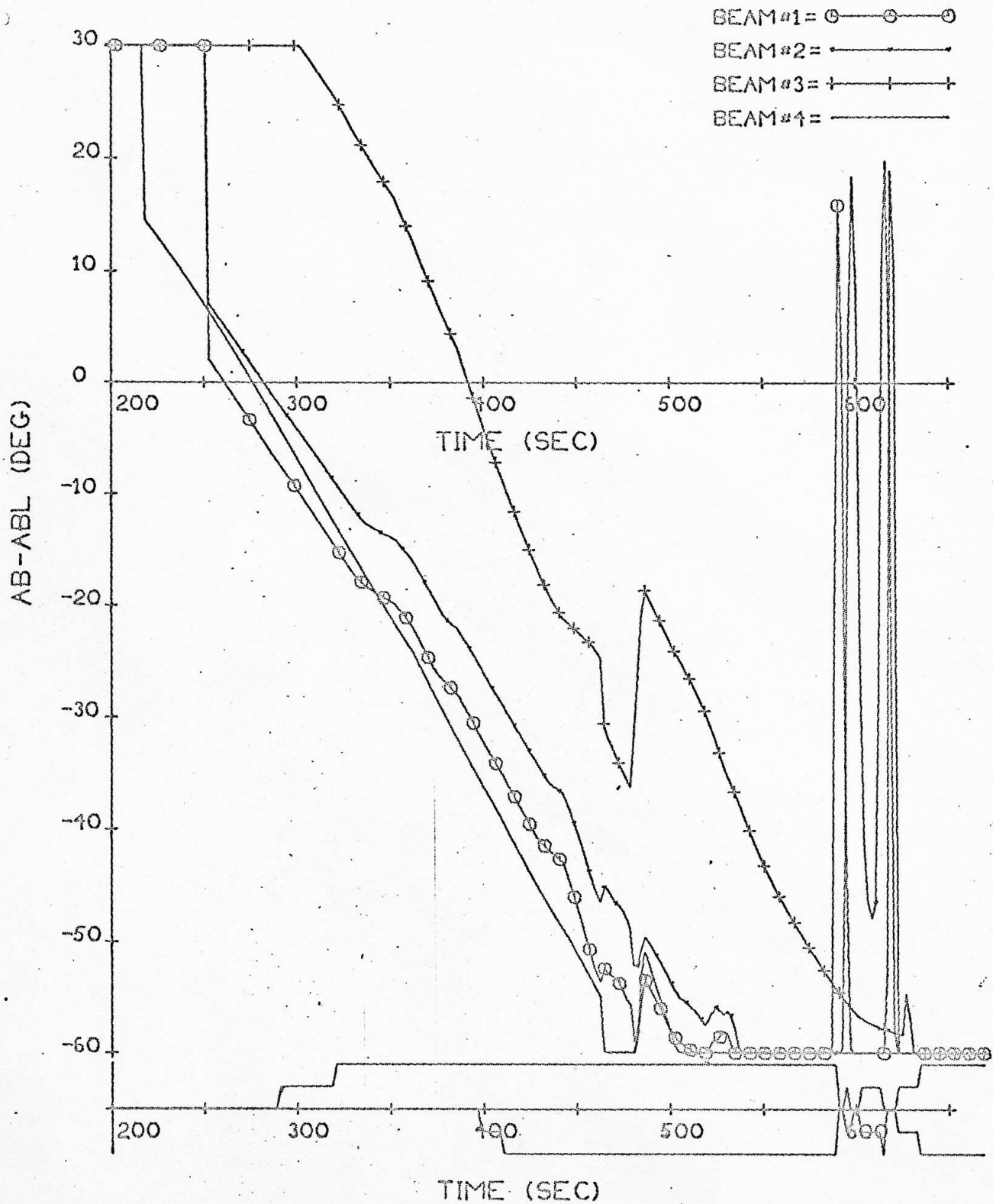
BAK DEG
RUN NO. = 505

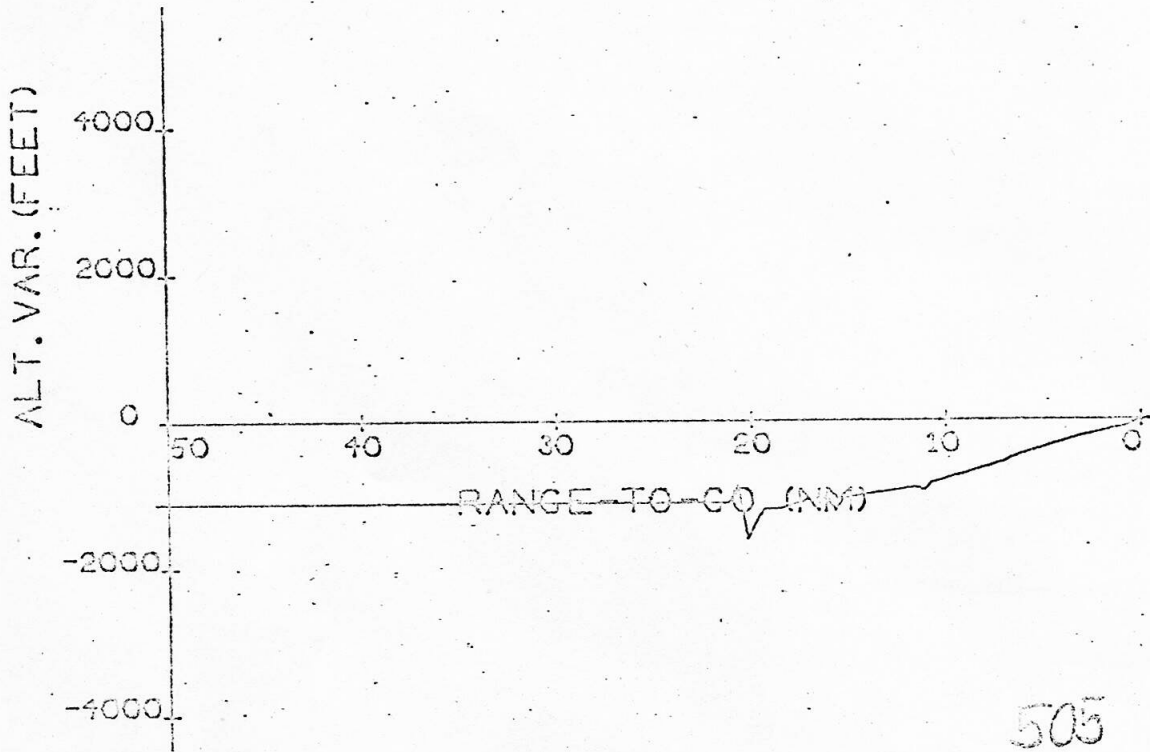
DELH for Error-Free Case II-P-6 Profile 3

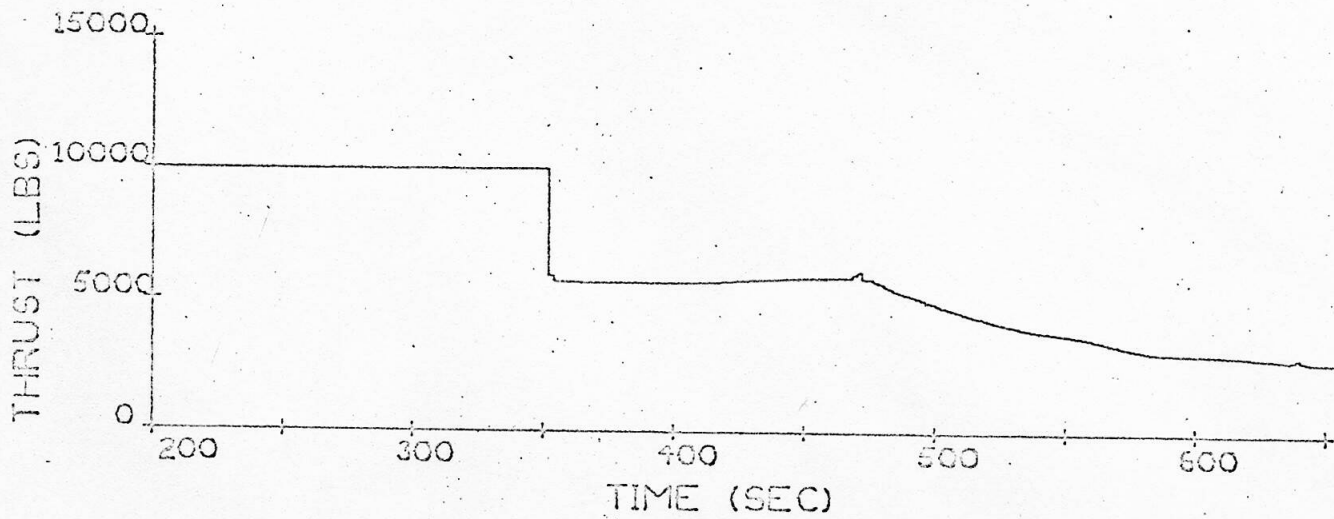
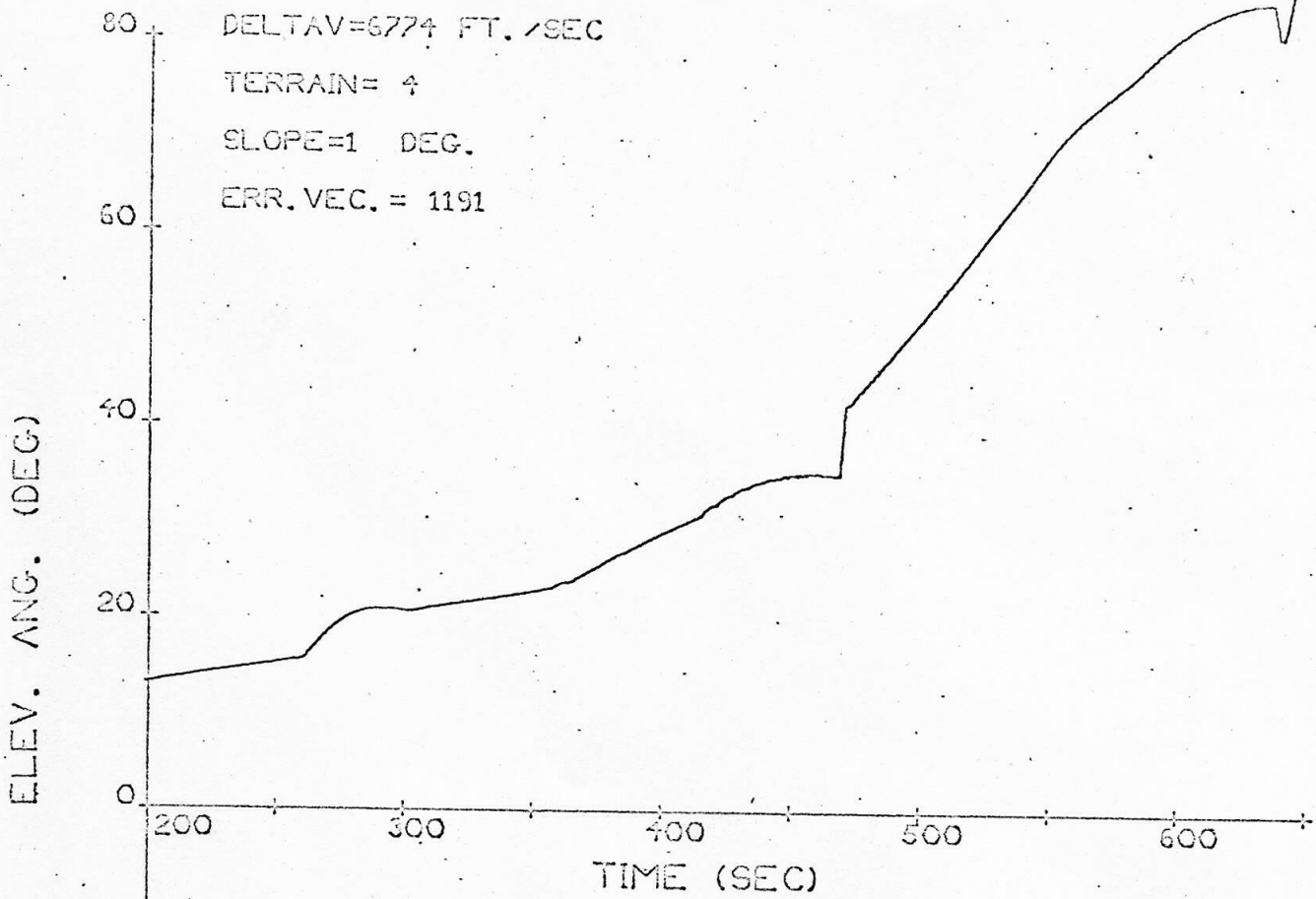
1-Deg. Slope



Displacement of LR Beams from Dropout Boundaries

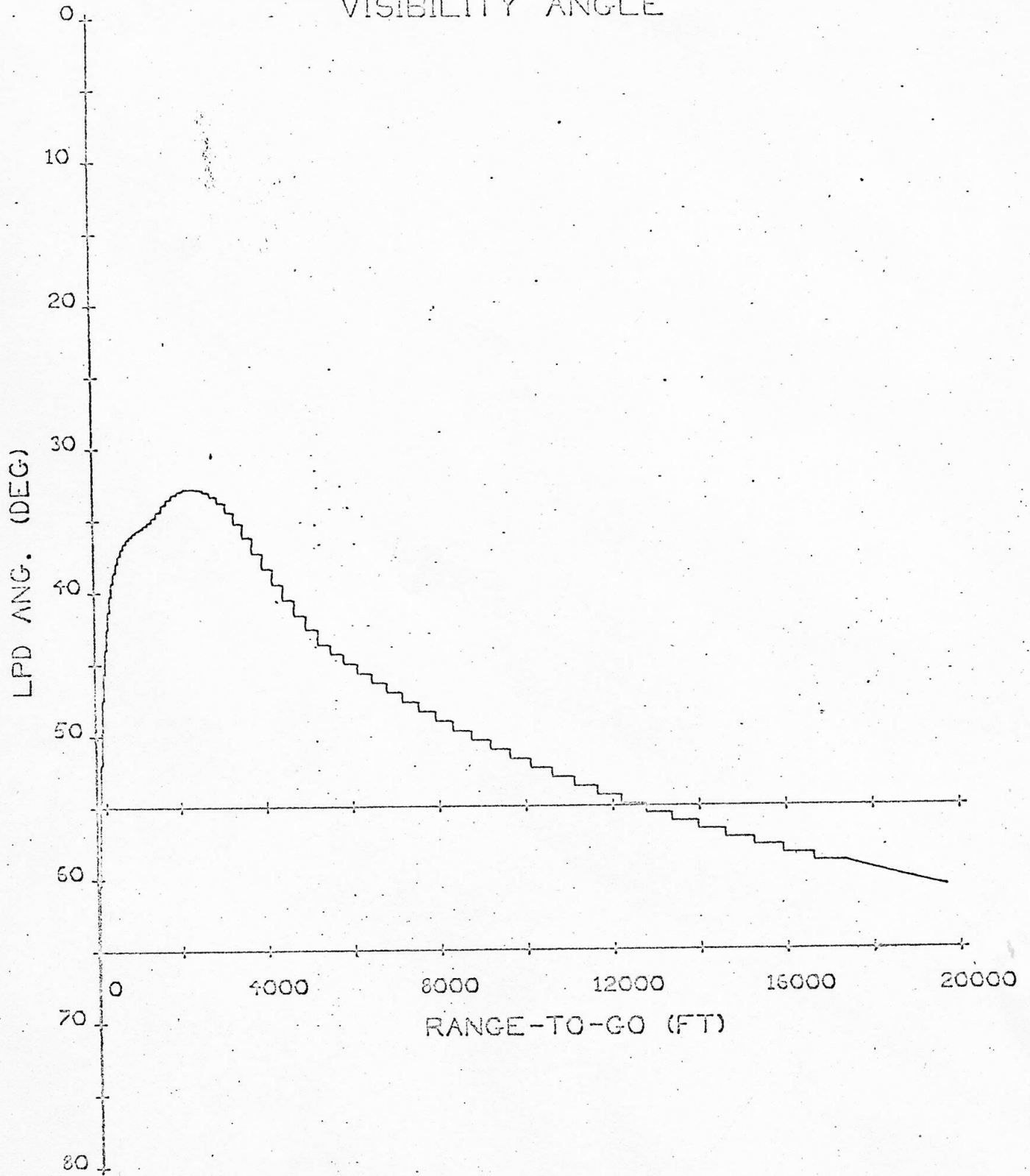




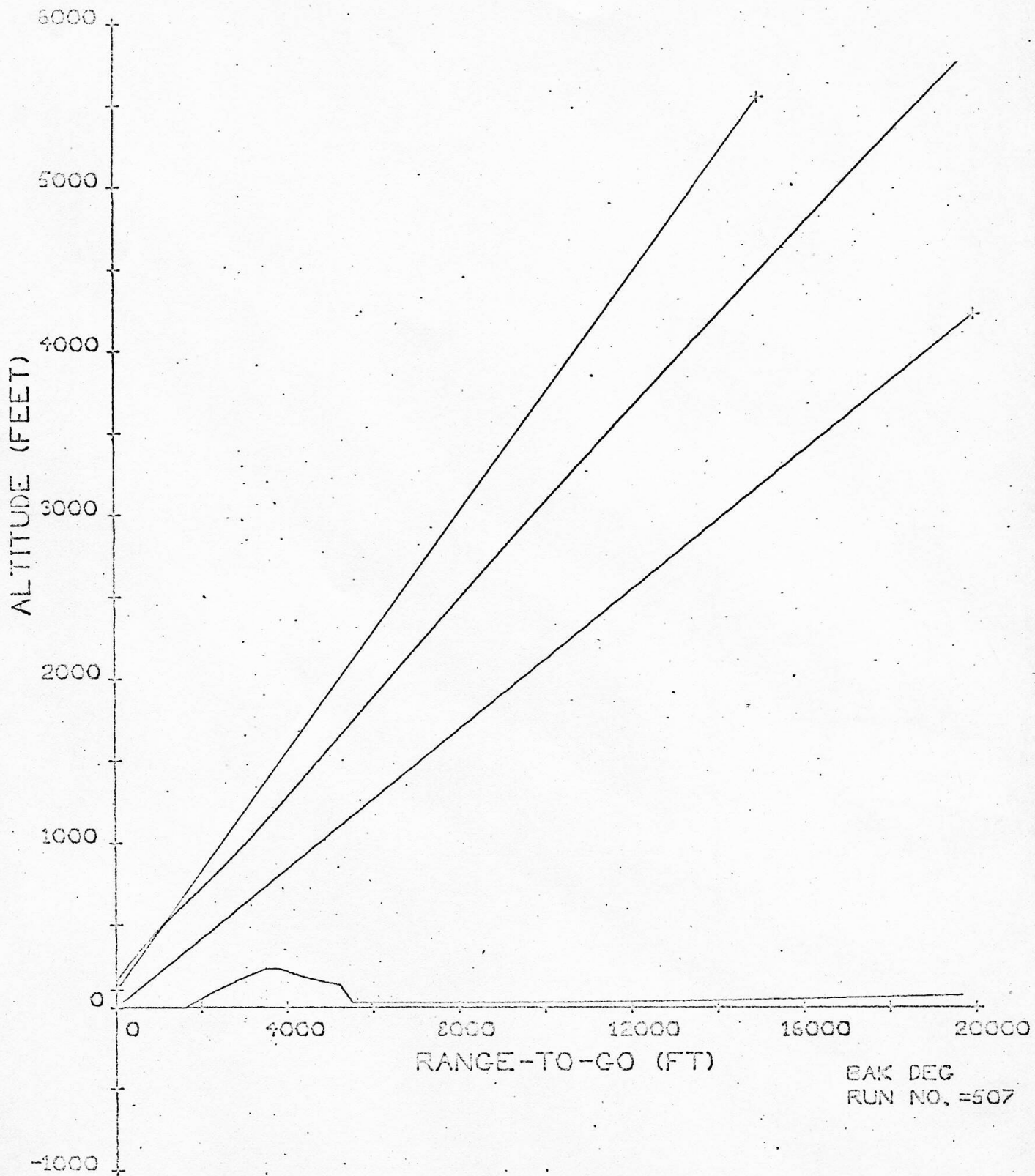


BAK DEG
RUN NO. =507

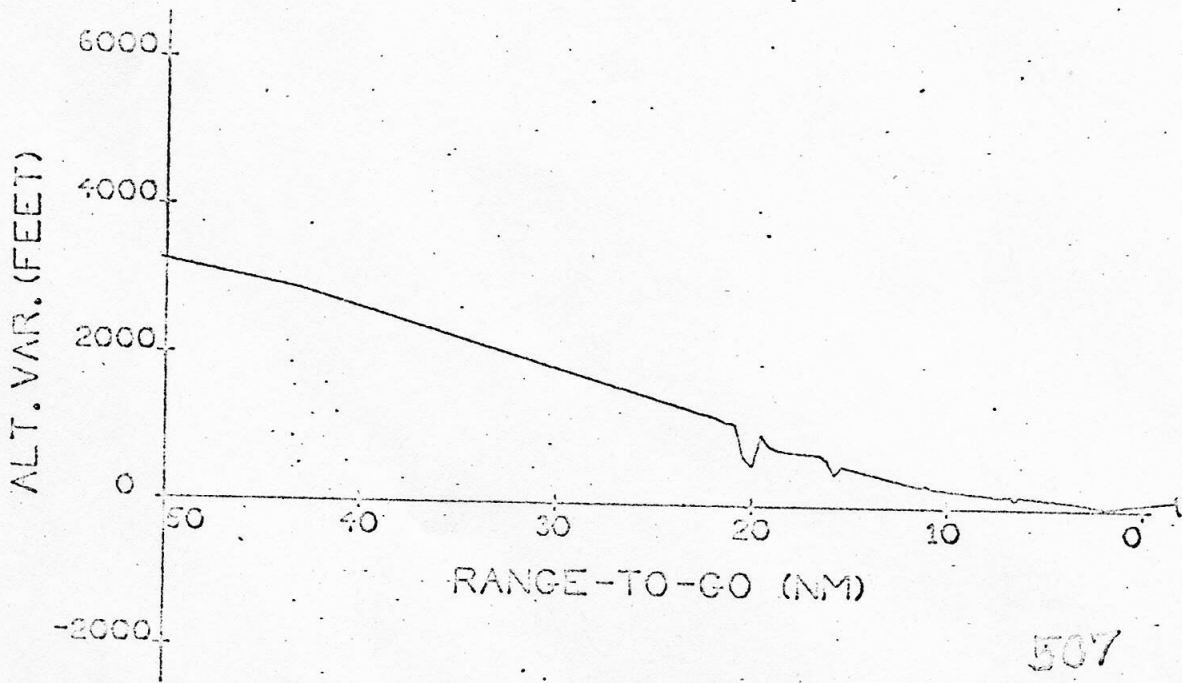
VISIBILITY ANGLE



BAK DEG
RUN NO. =507



II-P-6 Profile 3, +1-Deg. Slope.



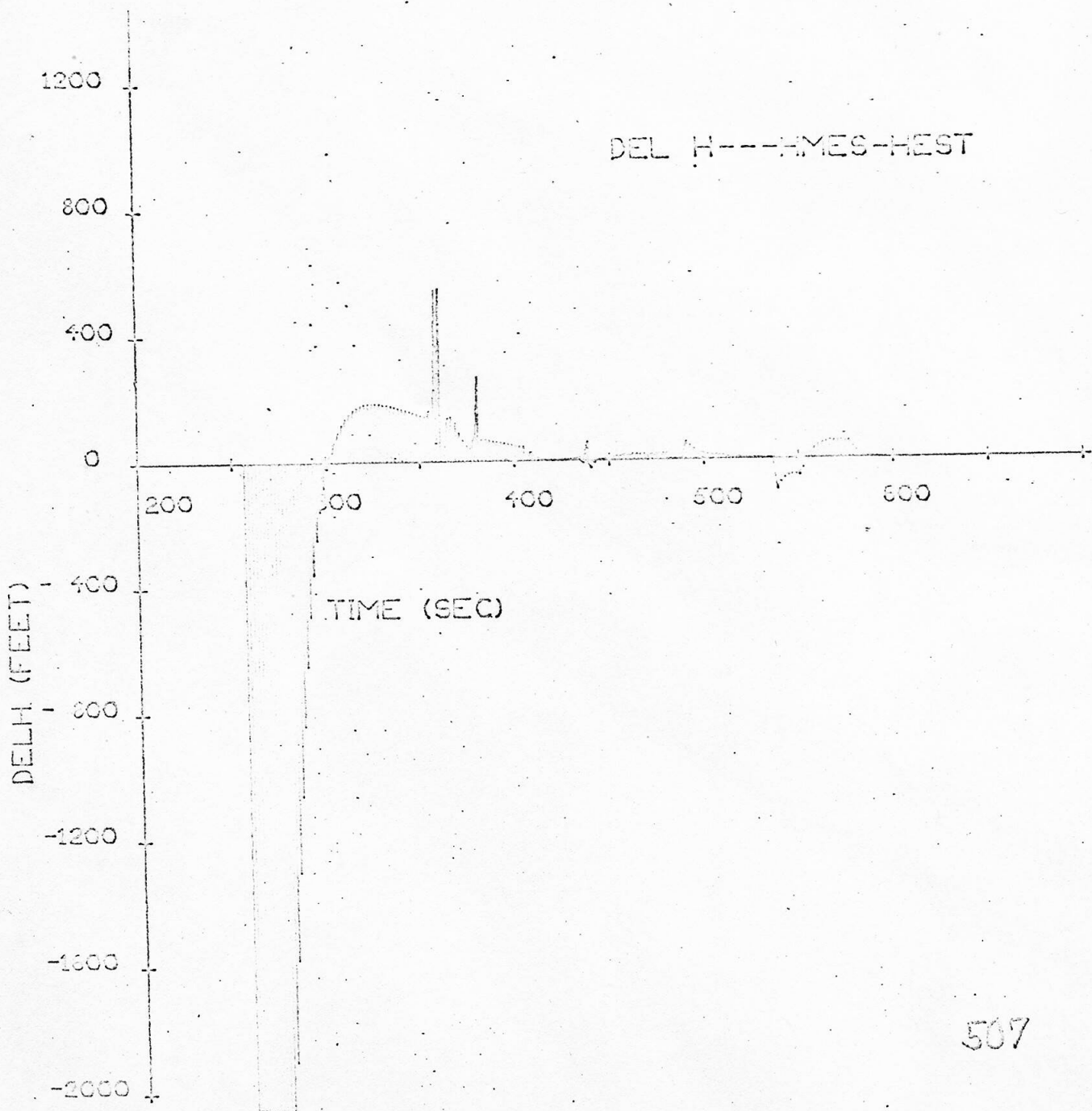
DELH vs. Time :

I-P-6 Profile 5, 1-der slope

Initial Est: Errors -- Vehicle low
and down range

1-sigma LR & IMU bias errors.

Thrust acc. $\pm 1\%$ at FTP



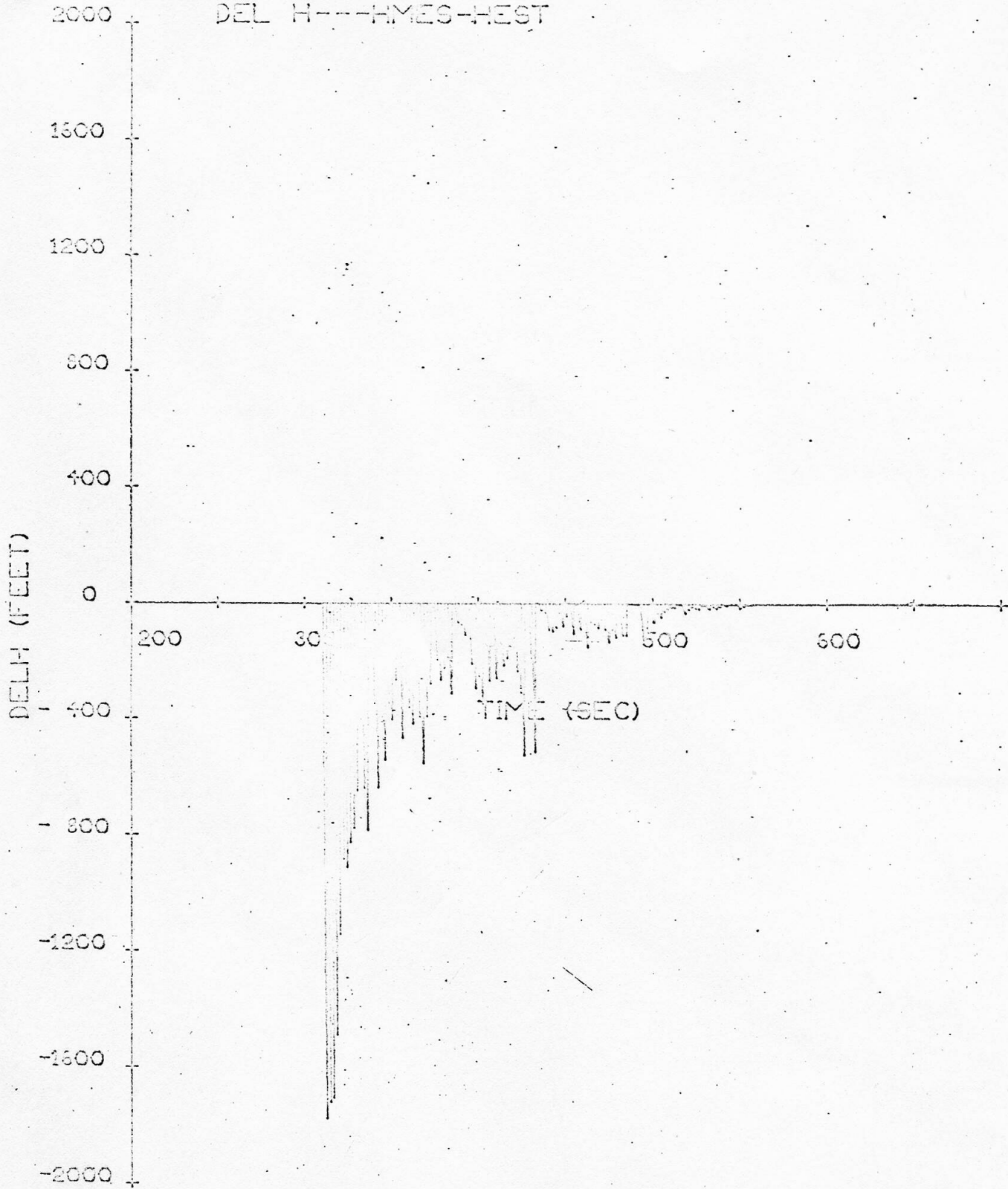
507

Summary of Simulated Landings

Terminal Errors in FLand-File

| Description | SP min | Start Date | Site Name | First Date | First Time | SV Quality | Site/Lead Ind. Loc. | Interval | Notes |
|--|-----------|---------------|--------------|---------------|---------------|---------------|------------------------|----------|-------|
| 1) 1-Digit L.C. Profile | 0 | 0 | | | | | 18,000 | 138 | |
| 2) 1-Digit L.C., IMU & LR errors, Site II-P-6 - File 3 | +1 | 1/23 | 11311 | 137 | 5001 | .4 | 15,100 | 134 | 702 |
| | -1 | | | 1000 | 5170 | 1.5 | 15,800 | 133 | 703 |
| | +1 | 1 | 11311 | 140 | 5060 | .5 | 16,100 | 140 | 700 |
| | -1 | | | 140 | 5050 | .7 | 15,000 | 132 | 701 |
| | +1 | 1 | 11311 | 137 | 5000 | 1.0 | 13,700 | 140 | 705 |
| | -1 | | | 1000 | 5170 | .6 | 13,000 | 142 | 707 |
| | +1 | 1 | 11311 | | | | 21,000 | 150 | 707 |
| | -1 | | | | | | | 705 | |
| 3) Same as 2) for Site II-P-2 Profile 1 | 0 | 1 | 11311 | 137 | 5000 | .5 | 16,500 | 136 | 721 |
| | 0 | -1 | | 1000 | 5190 | .7 | 16,000 | 138 | 723 |
| | 0 | 1 | 11311 | 137 | 5100 | .6 | 16,500 | 137 | 725 |
| | 0 | -1 | | 1000 | 5170 | .5 | 16,500 | 141 | 726 |

DEL H---HMES-HEST



BAK DEG
RUN NO. =851

80
60
40
20
0
-20

DELTA V = 6824 FT./SEC
TERRAIN = 3
SLOPE = -0 DEG.
ERR. VEC. = 1191

ELEV. ANG. (DEG)

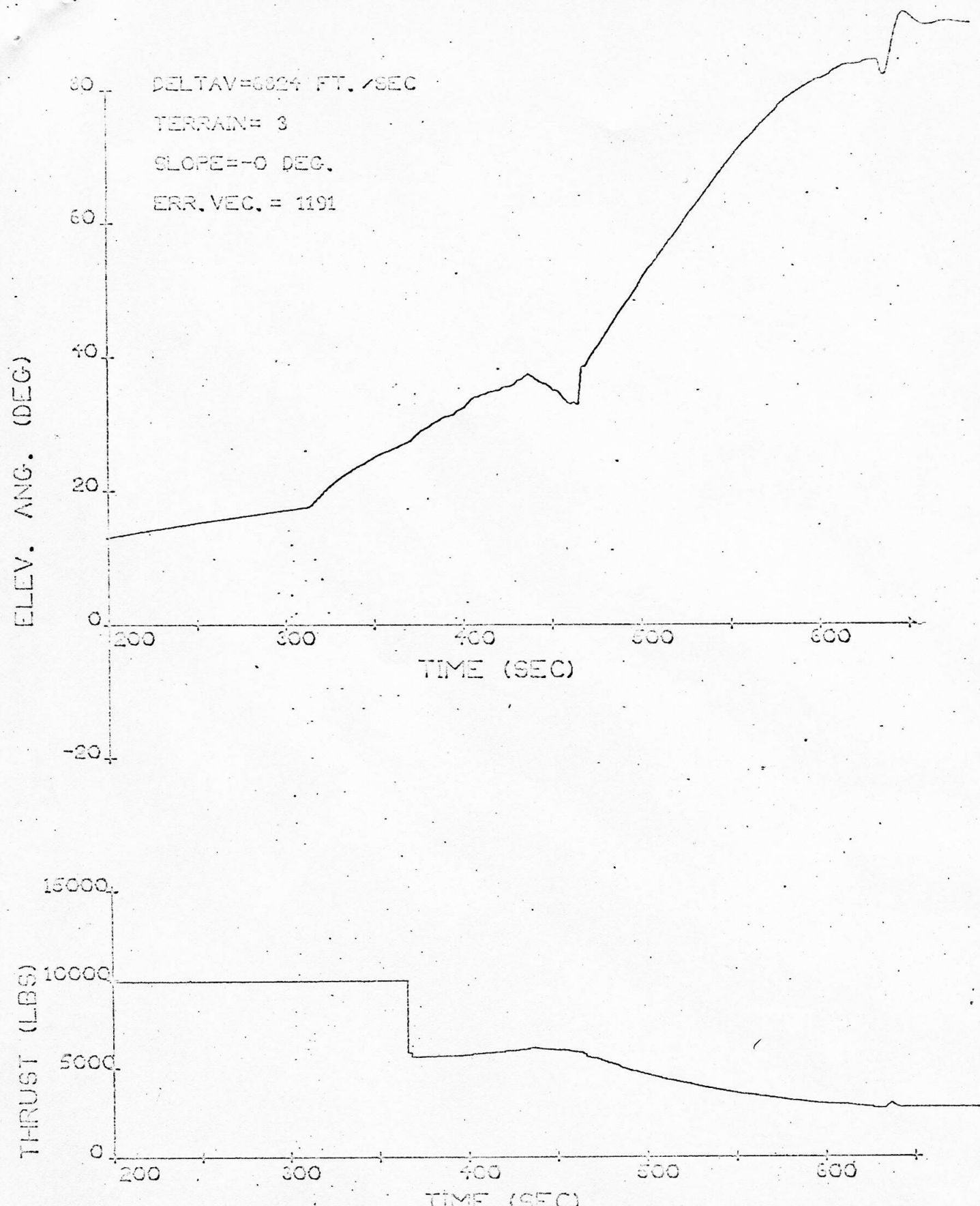
200 300 400 500 600
TIME (SEC)

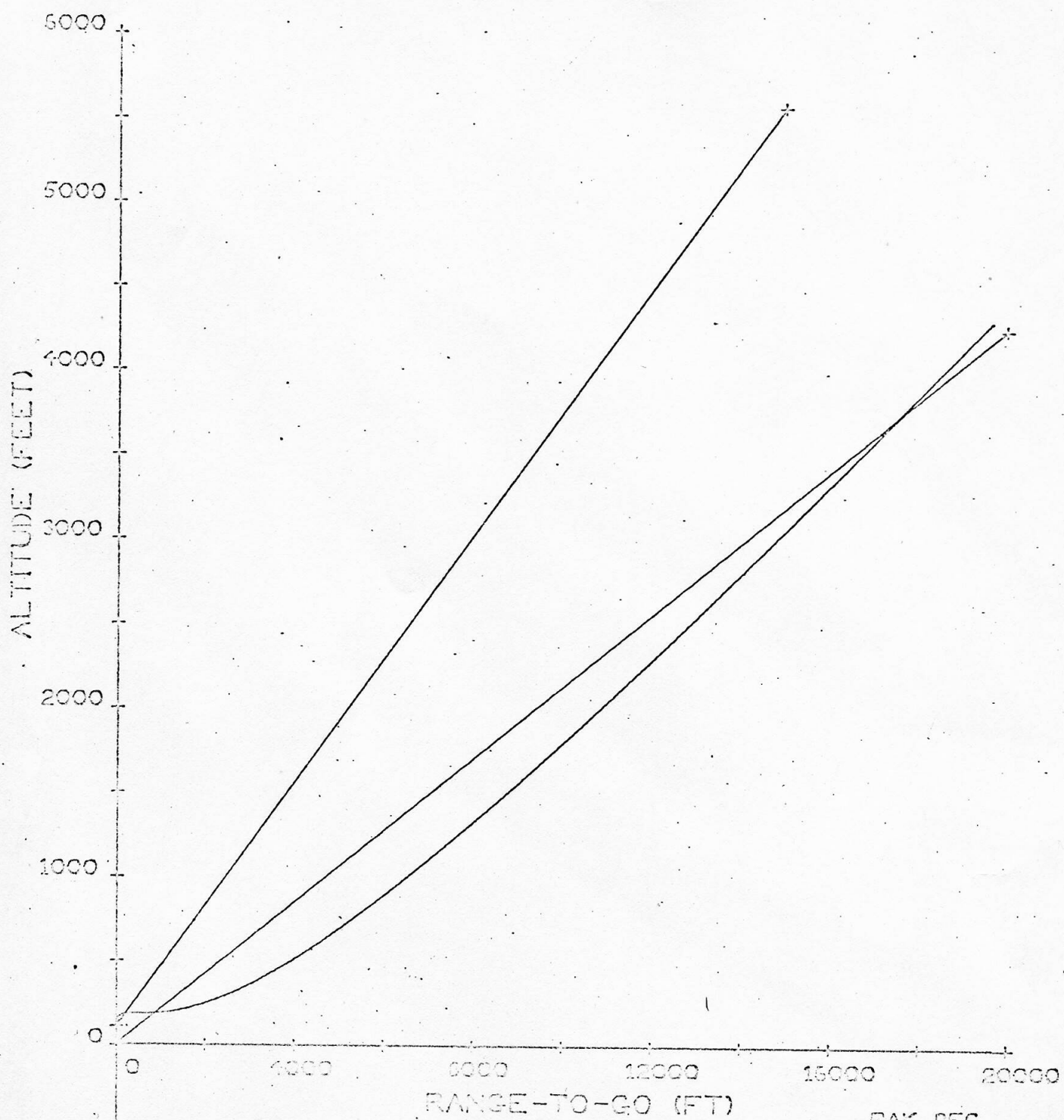
15000
10000
5000
0

THRUST (LBS)

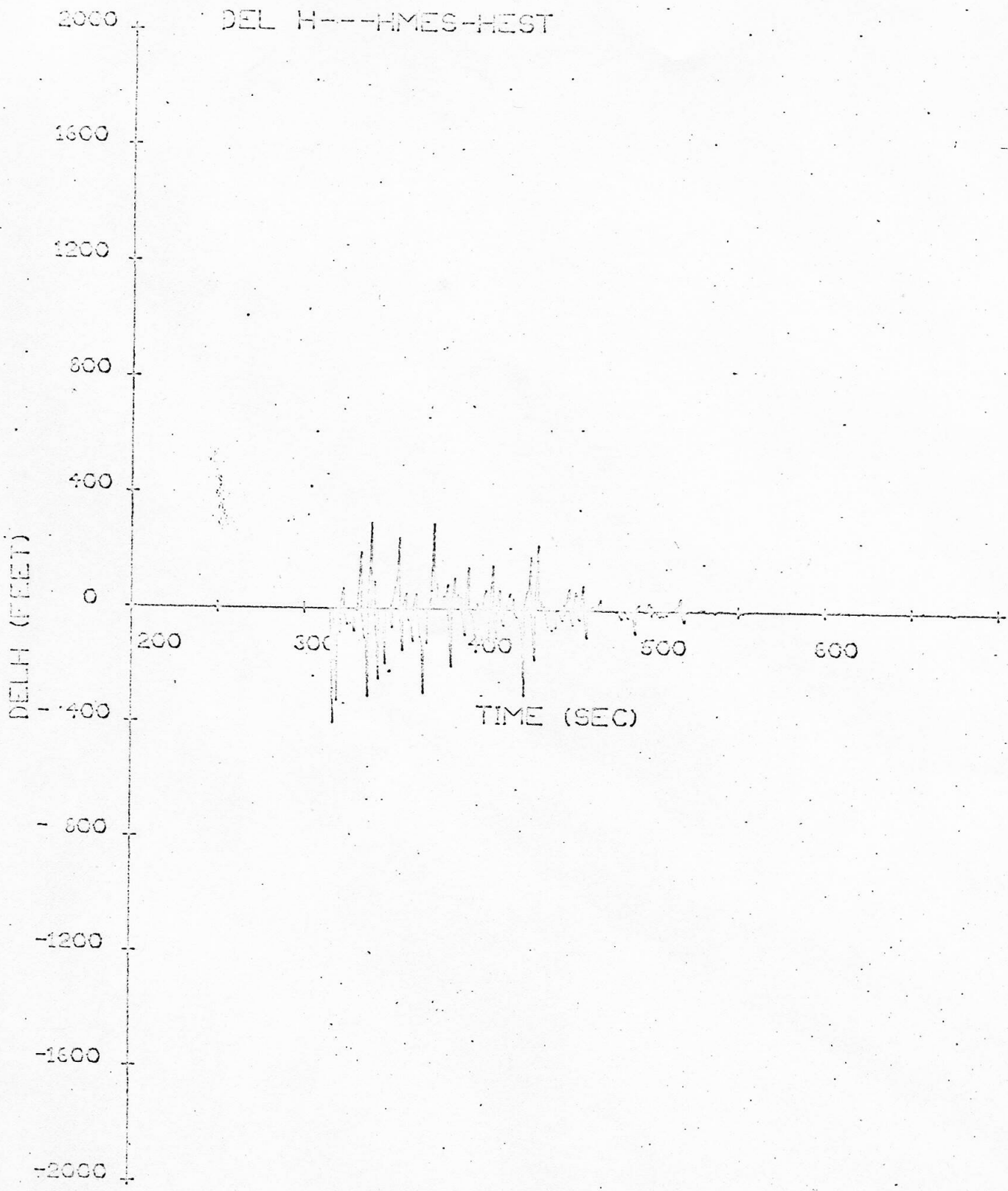
200 300 400 500 600
TIME (SEC)

BAK DEG
RUN NO. = 851

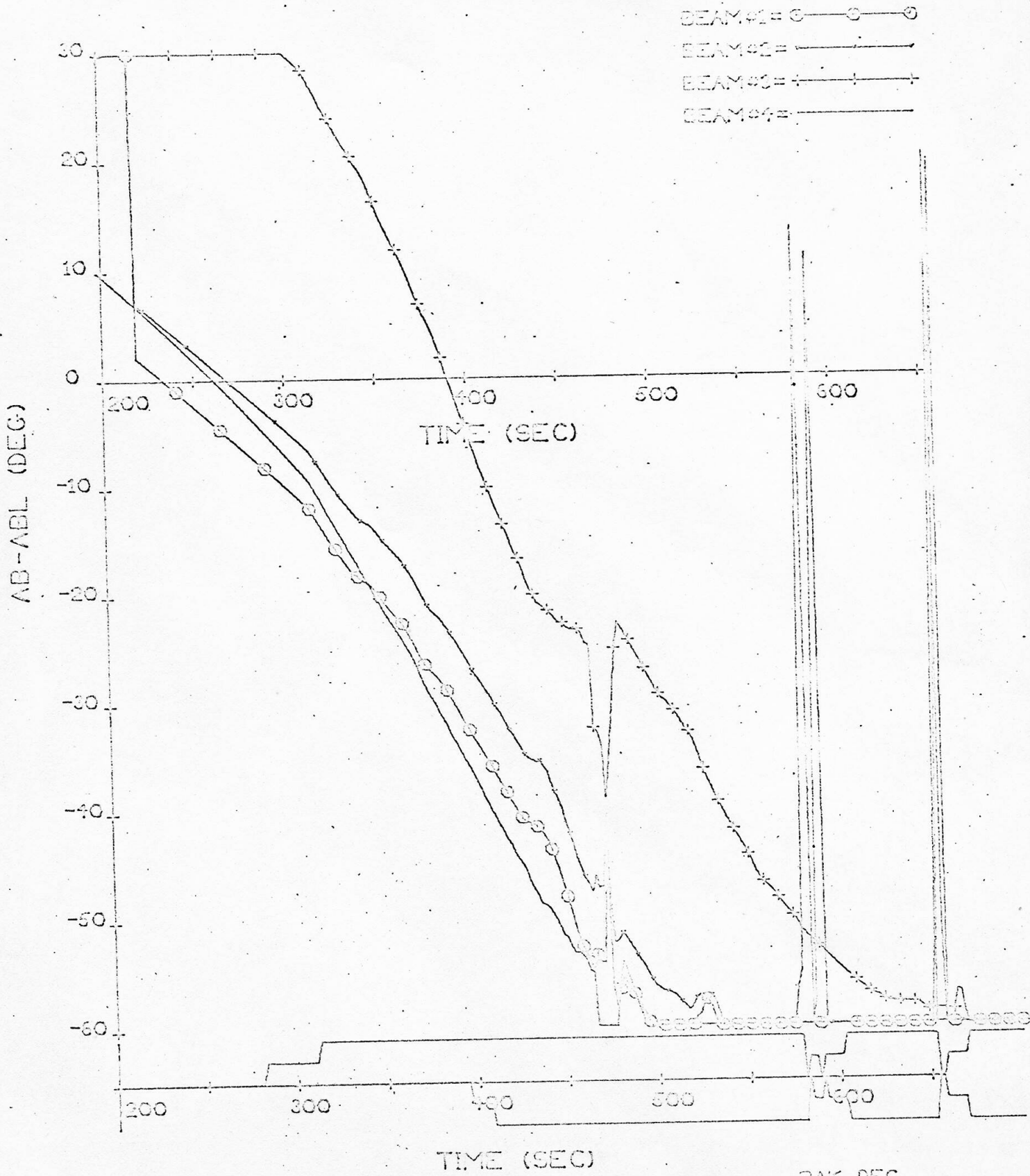




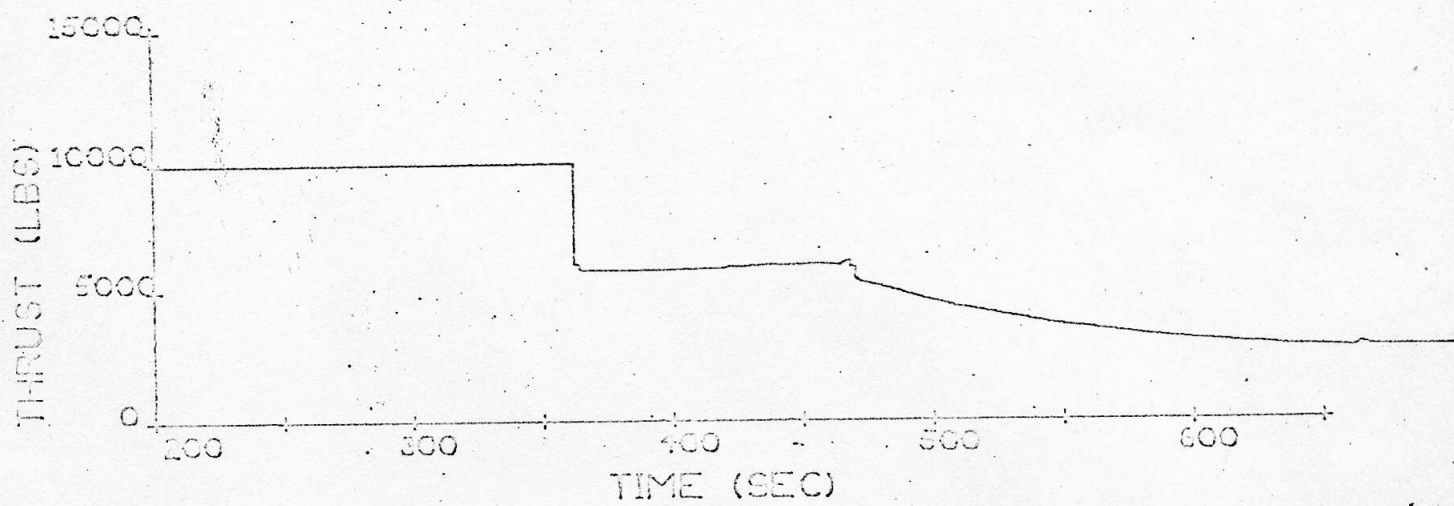
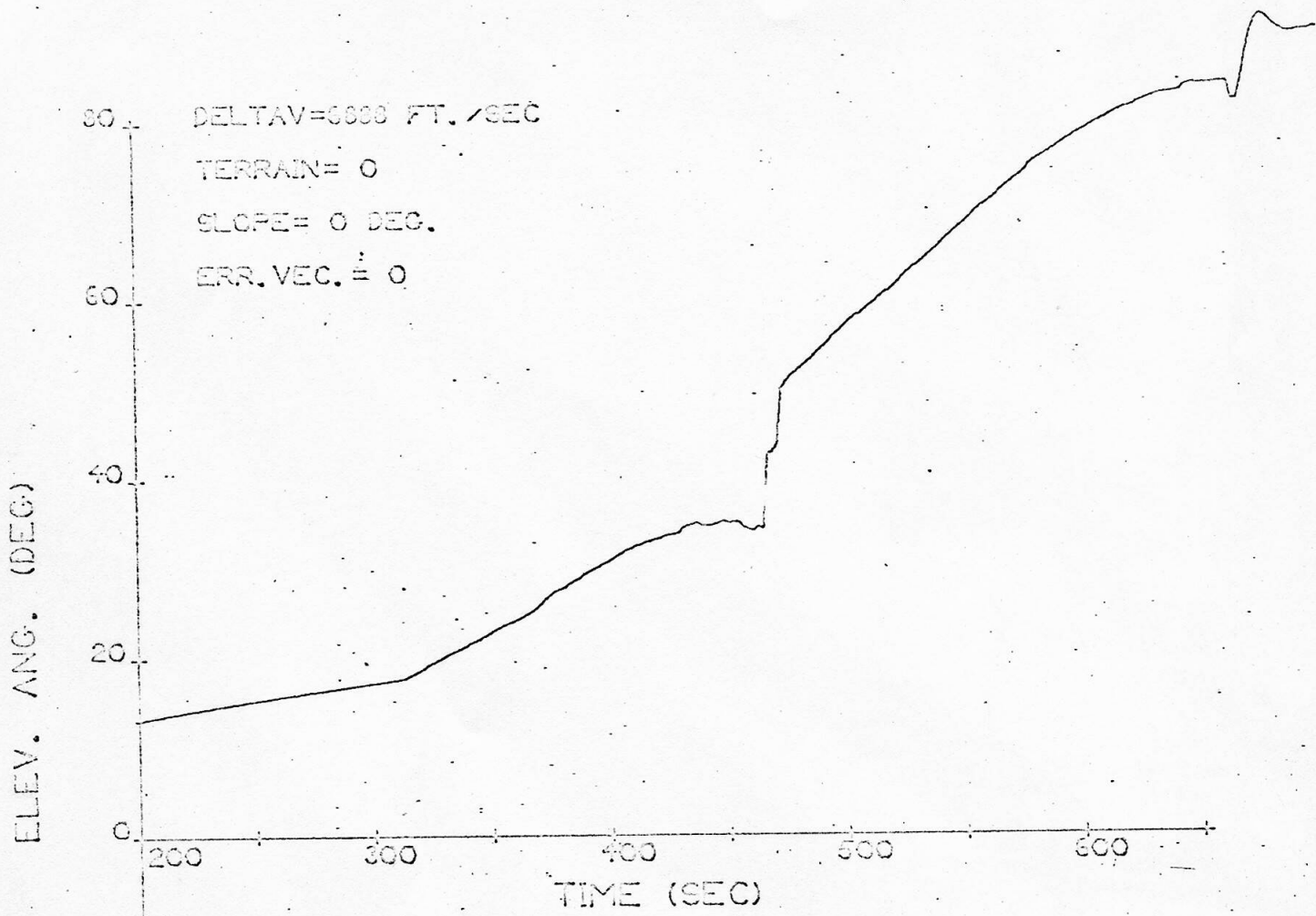
BAK DEG
RUN NO. = 850



BAK DEG
RUN NO. =850

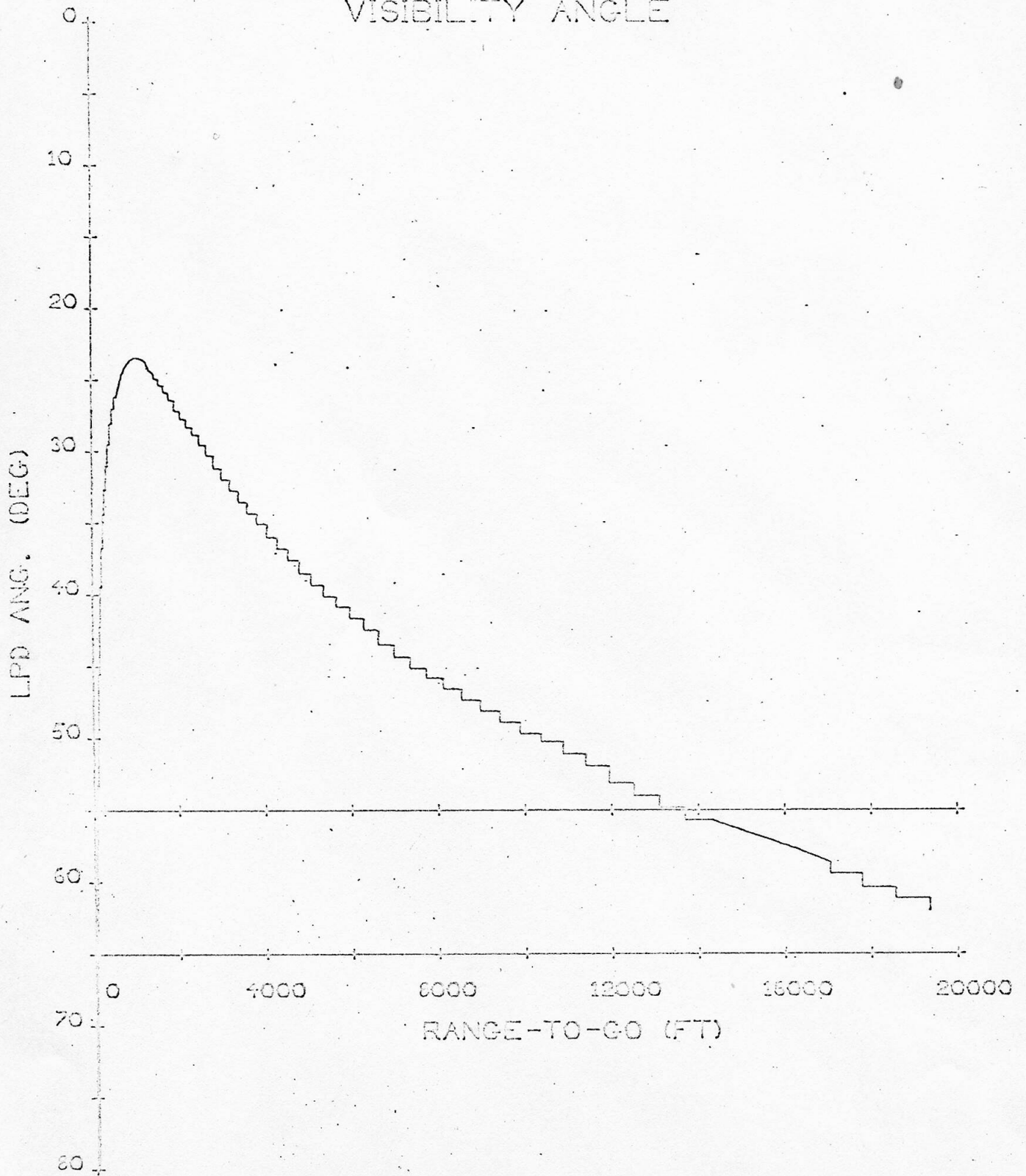


BAK DEG
 RUN NO. = 850

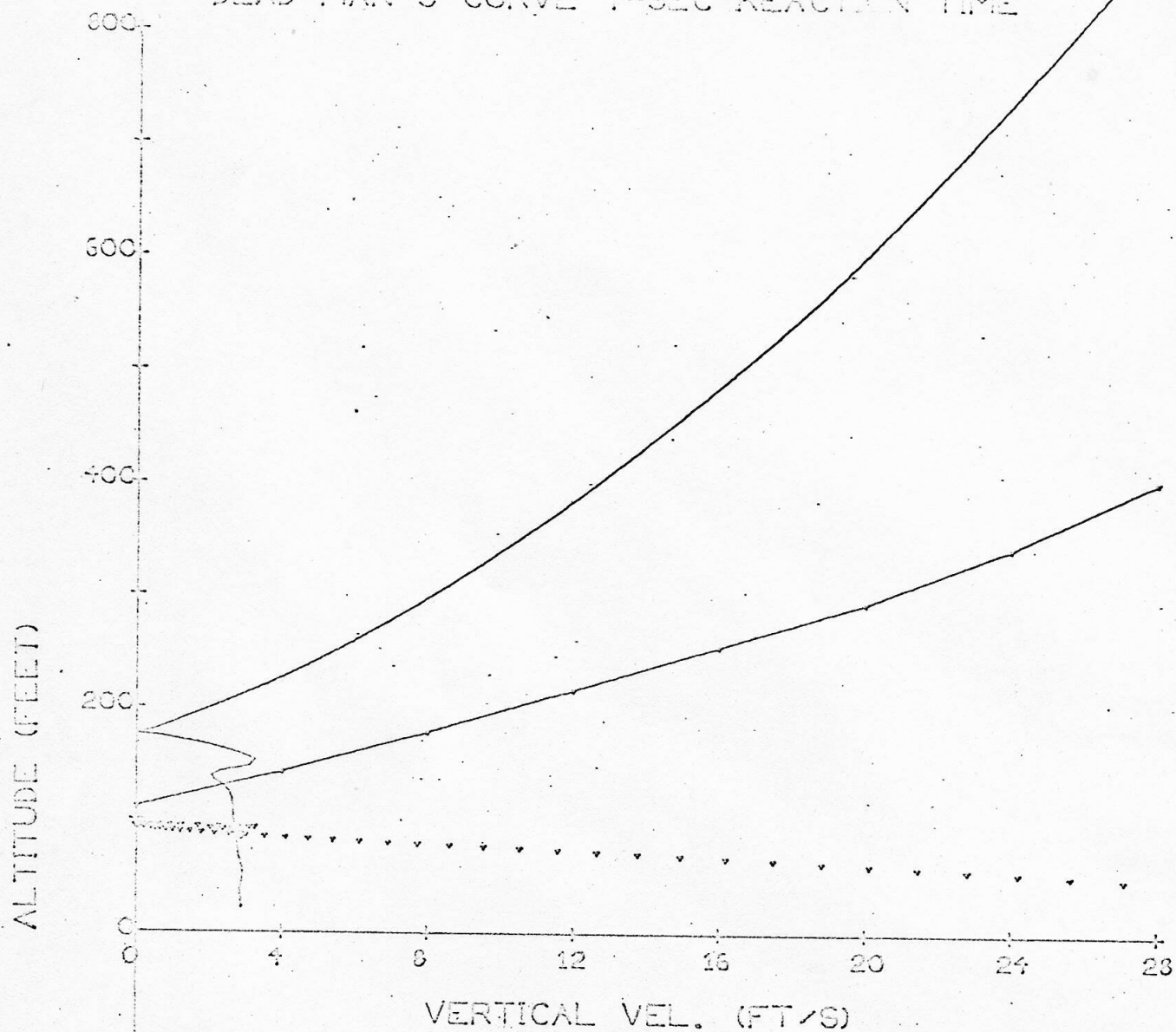


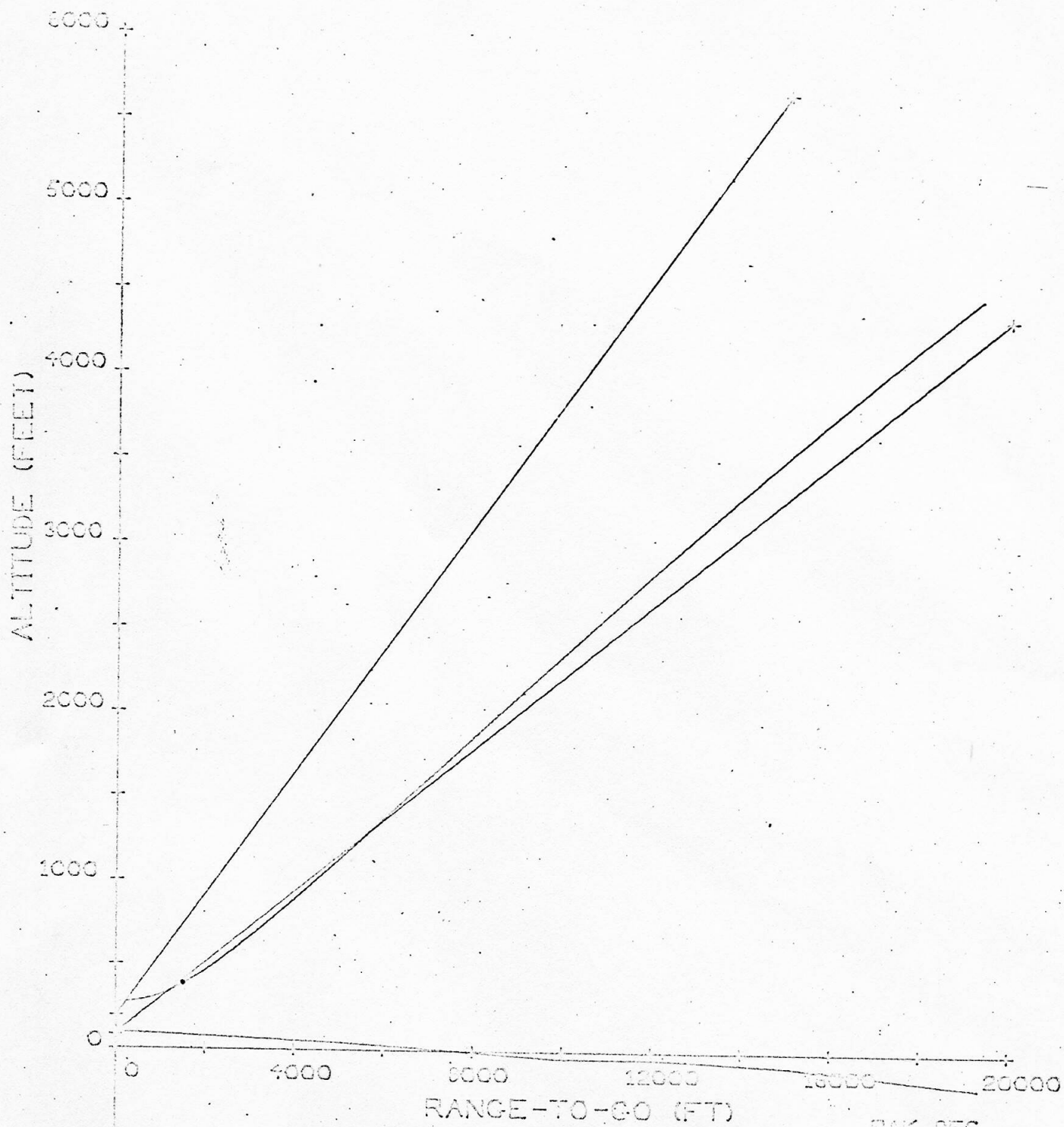
BAK DEG
RUN NO. = 850

VISIBILITY ANGLE



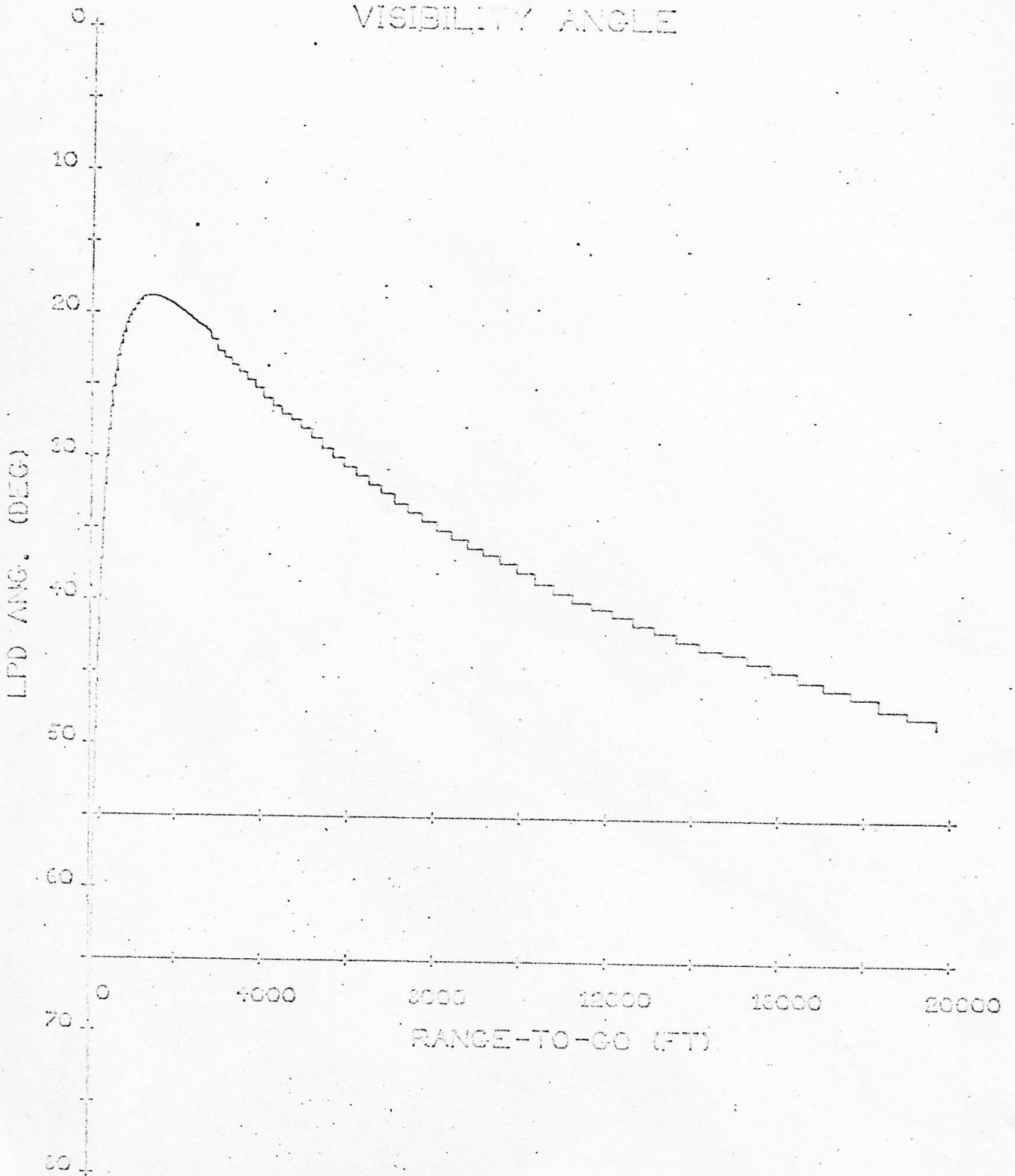
DEAD MAN'S CURVE 4-SEC REACTION TIME

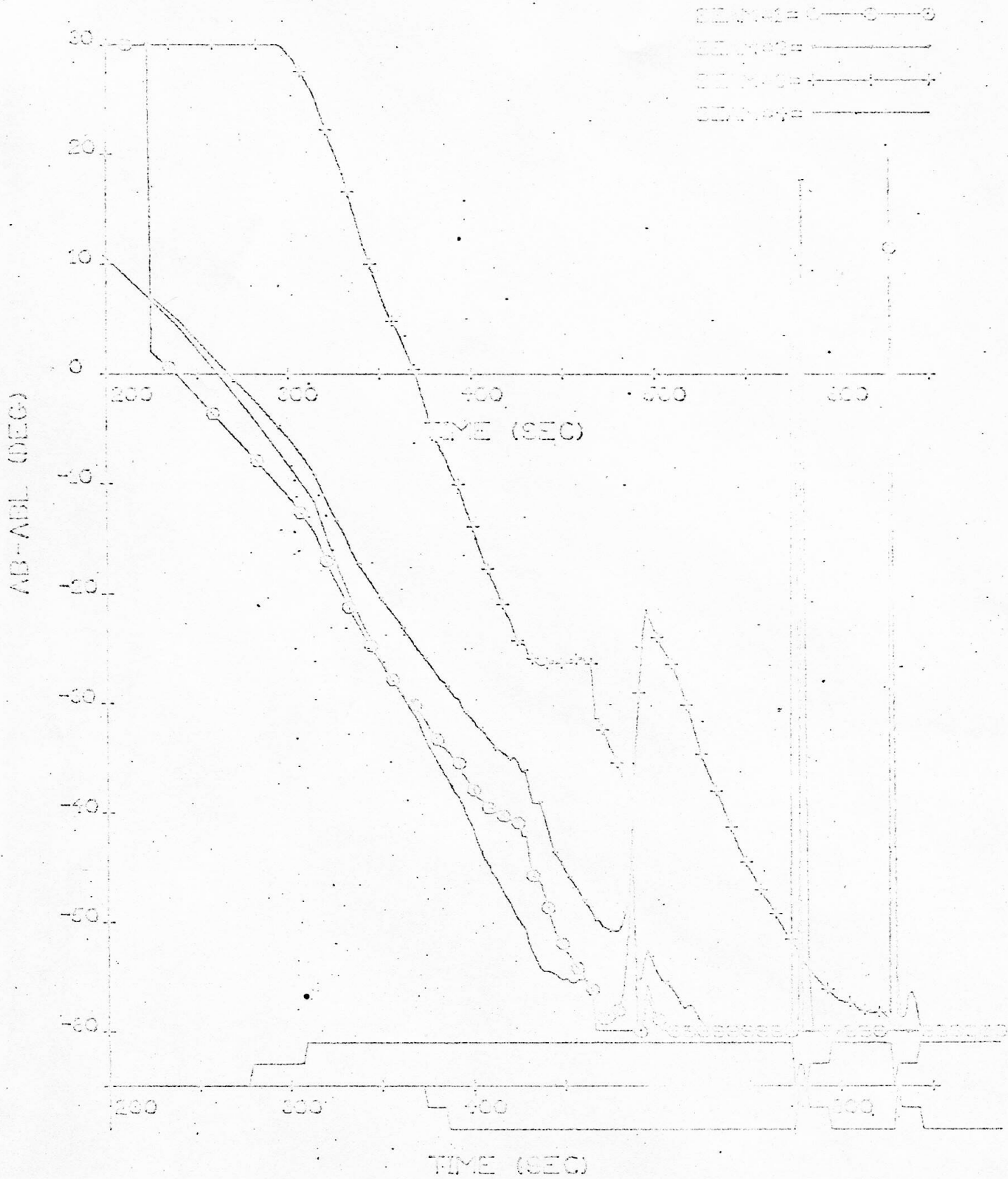




BAK DEG
RUN NO. = 851

VISIBILITY ANGLE





BAK DEC
 RUN NO. = 351