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**A DIVISION OF MASSACHUSETTS INSTITUTE OF TECHNOLOGY**  
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LUMINARY MEMO # 232

To: Distribution  
From: D. Eyles  
Date: 16 November 1971  
Subject: Low Thrust Landings

This memo describes runs made to see how the landing works when DPS thrust is deficient, and to find out whether downrange redesignations of the landing site, by means of Noun 69, can be used to compensate and make a successful landing possible. The Apollo 16 vehicle (LM 11) was used, but the site, terrain and trajectory were those of Apollo 15. One or two runs should be repeated later with the Apollo 16 terrain to check these results. Runs were as follows:

1. Nominal.
2. 92% thrust.
3. 90% thrust. (Crash!)
4. 85% thrust. (Crash!)
5. 6000 foot downrange N69 at TIG +120.
6. 90% thrust. 78000 foot downrange N69.
7. 85% thrust. 156000 foot downrange N69.
8. 80% thrust, 250000 foot downrange N69.

Plots attached to the end are keyed to these run numbers, thrust and altitude-rate against time, and altitude against range being furnished for each simulation. Altitude against range, P64 only, is included for some runs.

Note that at throttle-up the descent engine nominally delivers 9905 pounds thrust, 94 1/3% of rated thrust. Thus the 92% case, for example, represents a 2 1/3% low thrust case.

Note that thrust deficiency only counts when the engine is throttled-up. When thrust is within the throttleable region the closed-loop nature of the throttle control routine insures that the desired thrust is obtained.

Note that in these runs the engine functions with the same efficiency when thrust is low. It gets the same bounce (delta-V) to the ounce (of fuel). The environment's Isp is not changed when thrust is lowered. Intuitively, this seems unrealistic. So without input from the engine people one may suspect that the extreme cases might in real life run out of gas before touching down.

Well, with 92% thrust the LM throttles-down 64 seconds later than nominal, and reached P64 34 seconds earlier, reducing time under throttle control from 120 seconds to 22 seconds. P64 initial conditions were only slightly perturbed, at 500 feet the altitude-rate was okay for astronaut takeover, and the landing was successful.

The 90% thrust case, however, behaves quite differently. Throttle-down comes 30 seconds into P64, which began at 13500 feet and -257 f/s, and 13 seconds later the LM lands with an altitude-rate of around -500 f/s, which is outside the LM design limits. Note from plot 3a that eventually the divergence between thrust and desired thrust signal that something is wrong. Needless to say the 85% case without a N69 also hits the moon hard.

Downrange redesignation of the landing site early in the burn using N69 offers a means of averting such occurrences when the thrust deficiency is detected. To get an idea of the N69 magnitude required, a 6000 foot N69 was input at TIG +120 and its effect on throttle-down time observed. This run and the nominal and 92% cases are summarized in the following table:

	Nominal	92% thrust	6000 ft. N69
time of throttle down	376573.62	376637.62	376569.62
time of P63 last pass	376693.62	376659.62	376699.62
time under throttle control	120	22	130
thrust at throttle-up	9905	9660	9905
thrust at throttle-down	10009	9780	10008
P64 initial $\dot{H}$ and $\ddot{H}$	9652	9652	8783
	-219.2	-227.6	-208.1
$\dot{H}$ at 500 feet	-18.5	-17.5	-15.0
Fuel left at 500 feet (pounds)	1894	2107	1831

From this it appeared that to keep time under throttle control constant, the site should be shifted downrange roughly 18000 feet for each percent thrust deficiency. This number was used as a "guideline" for runs 6 through 8, although in runs 7 and 8, it was modified somewhat on the basis of the previous run. Time under throttle control was not held perfectly constant, and pulse-outs occurred in runs 6 and 7, but at least landings were made with 90%, 85% and 80% thrust which were not crashes. These are summarized in the following table:

	Nominal	90% with N69	85% with N69	80% with N69
N69 (per% thrust)	0	78000 (18000)	156000 (16700)	250000 (17400)
time of throttle-down	376573.62	376587.62	376627.62	376719.62
time of P63 last pass	376693.62	376721.62	376737.62	376749.62
pulse-out times (durations)	none	376661.62 (12)	376661.62 (16) 376707.62 (6)	none
time under throttle control	120	122	88	30
thrust at throttle up	9905	9450	8925	8400
thrust at throttle down	10009	9557	9042	8541
P64 initial H and $\dot{H}$	9652 -219.2	5867 -111.2	4796 -76.9	4310 -49.7
$\dot{H}$ at 500 feet	-18.5	-15.9	-15.2	-15.6
Fuel left at 500 feet (pounds)	1894	1928	1920	1994

N69 inputs greater than 99999 feet were input using two or more N69s in succession, requiring for instance 42 keystrokes to input 250000 feet downrange. Bearing in mind that in an upper-order N69 register one bit is worth 1024 meters, keystrokes could be saved by loading octally, for example, to load 250000 feet:

V 21 N 1 E 2635 E 112 E.

However a series of normal N69s is safer.

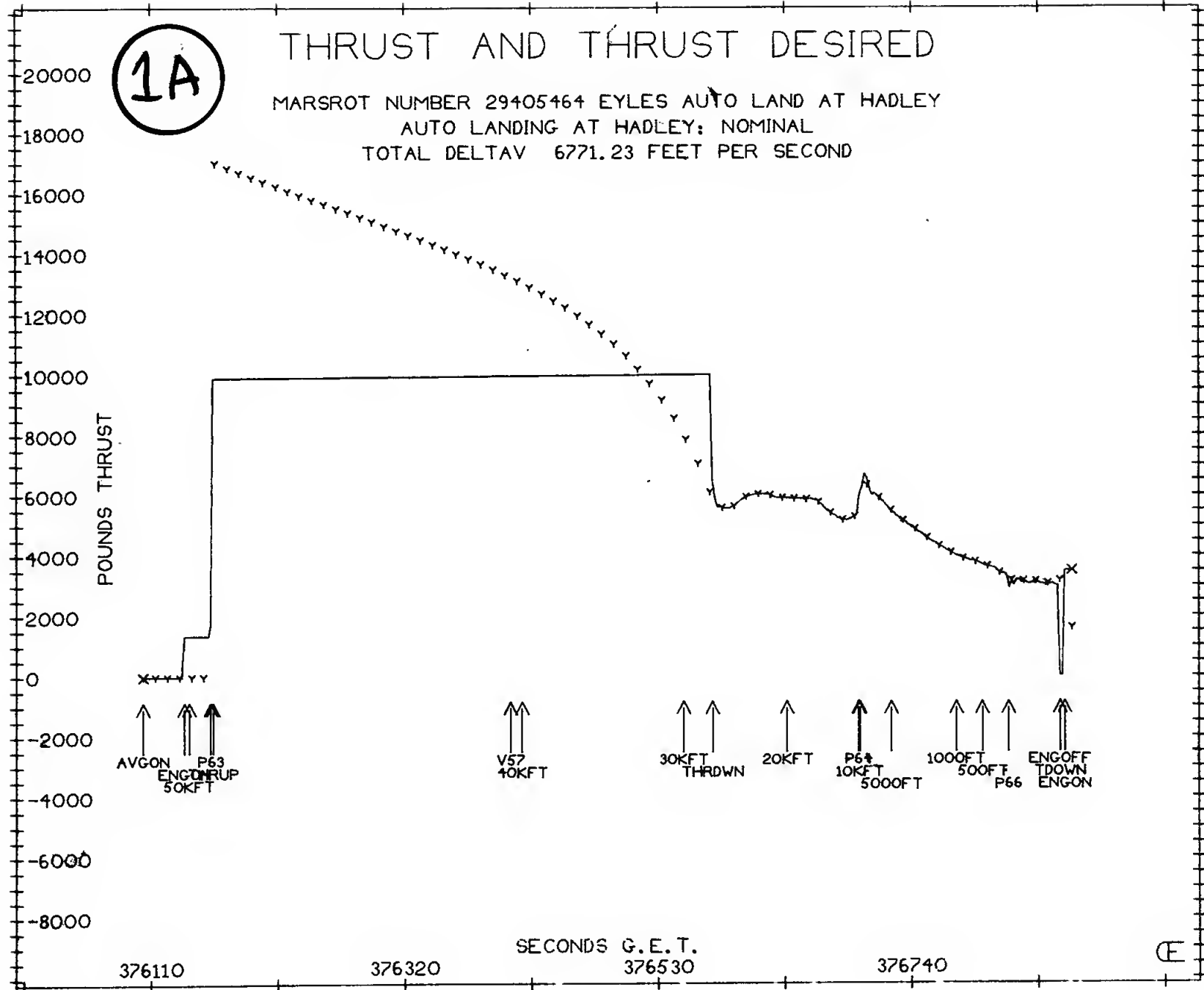
Due to an error in the input deck (the separation of the first and second two N69s by 120 seconds) run 8 has extra interest. As can be observed from plot 8A, desired thrust diverges from actual at first, and after the first N69. It takes the second two N69s (of 150000 feet) to make it converge.

The general conclusion of all this is that if thrust is less than 92% of rated thrust you have to do something, and what you should do is shift the site downrange by about 17000 feet for every percent thrust is below nominal.

1A

# THRUST AND THRUST DESIRED

MARSROT NUMBER 29405464 EYLES AUTO LAND AT HADLEY  
AUTO LANDING AT HADLEY: NOMINAL  
TOTAL DELTAV 6771.23 FEET PER SECOND

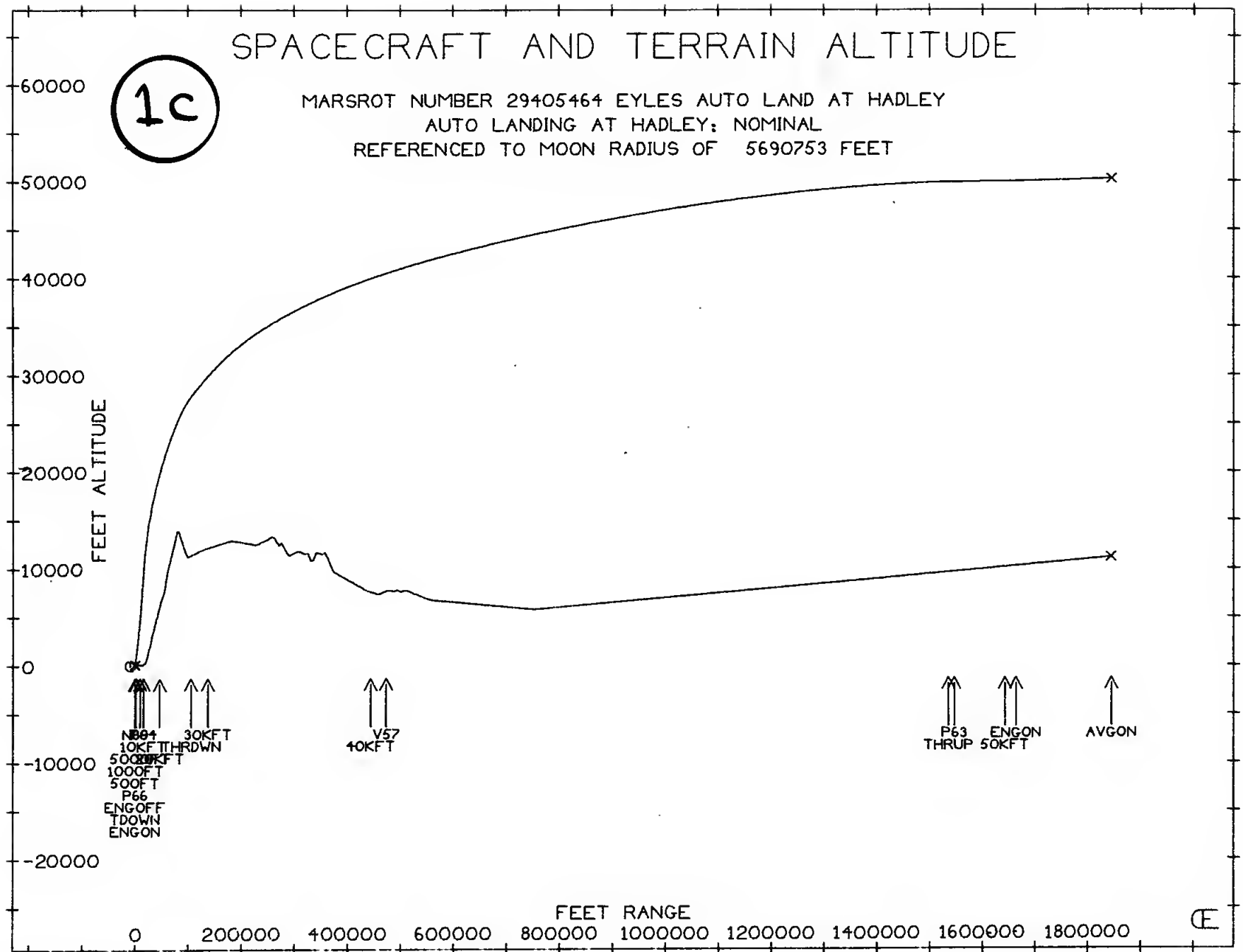




# SPACECRAFT AND TERRAIN ALTITUDE

1c

MARSROT NUMBER 29405464 EYLES AUTO LAND AT HADLEY  
AUTO LANDING AT HADLEY: NOMINAL  
REFERENCED TO MOON RADIUS OF 5690753 FEET



FRAME 003

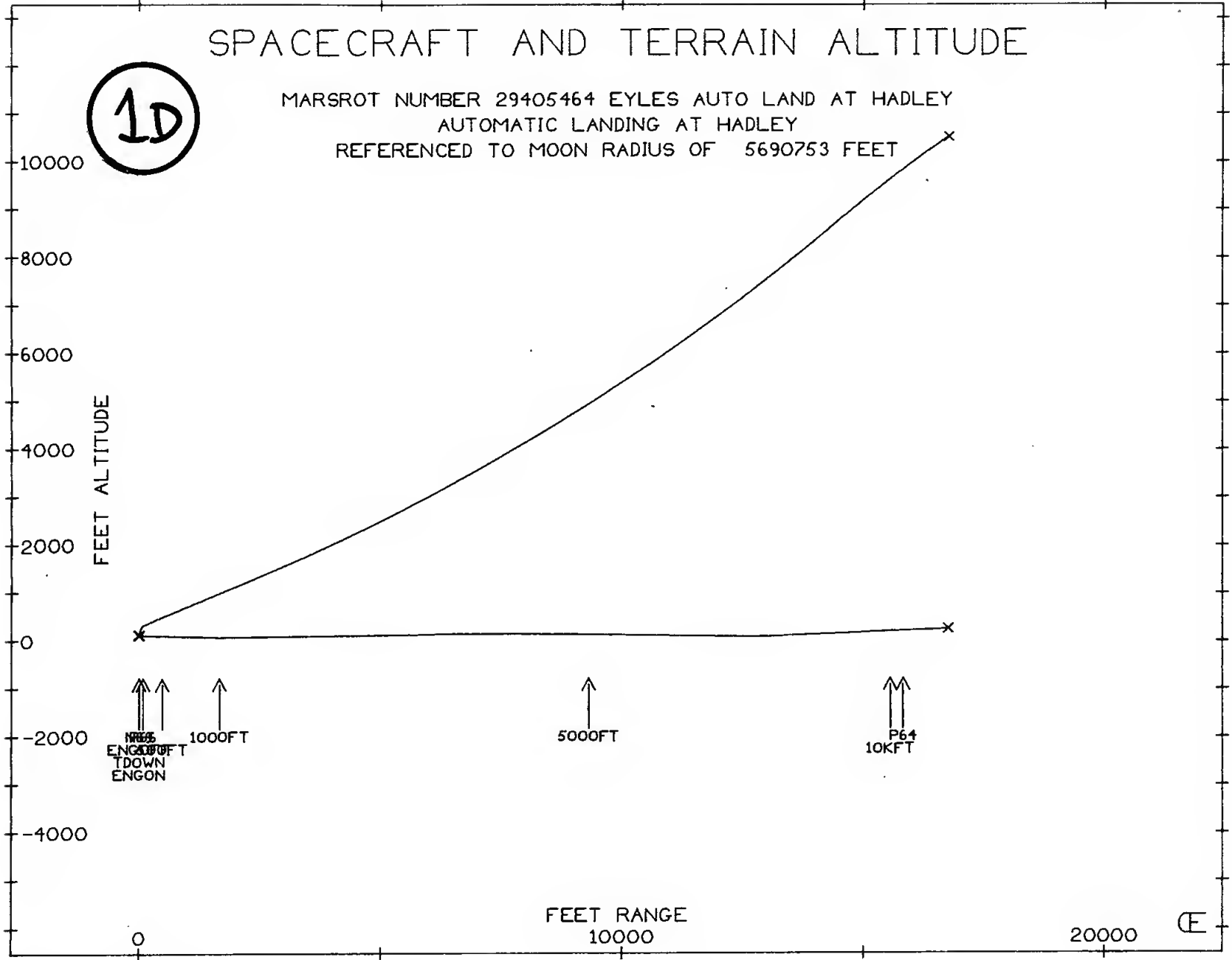
CE



# SPACECRAFT AND TERRAIN ALTITUDE

1D

MARSROT NUMBER 29405464 EYLES AUTO LAND AT HADLEY  
AUTOMATIC LANDING AT HADLEY  
REFERENCED TO MOON RADIUS OF 5690753 FEET



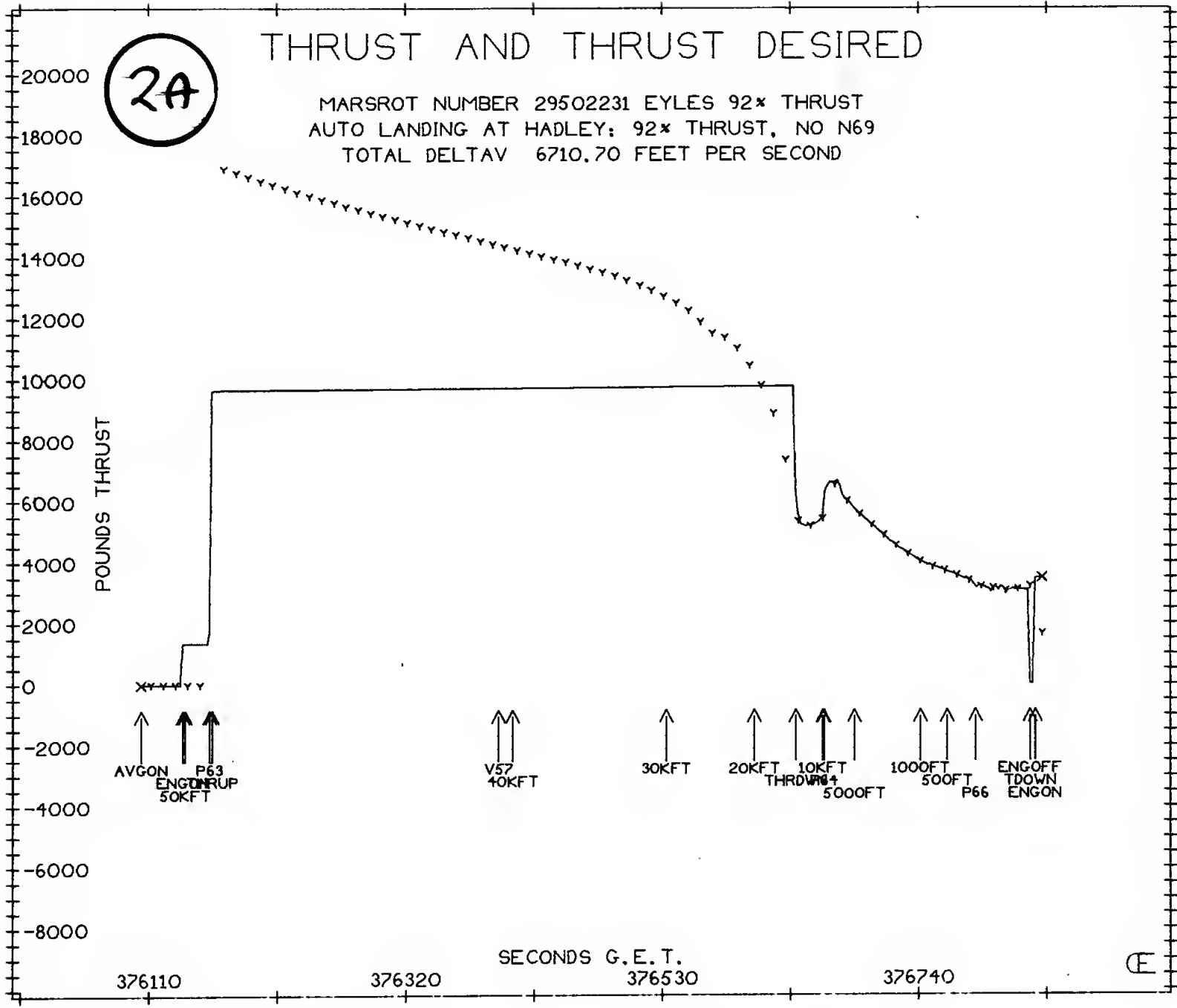
FRAME 006

CE

2A

# THRUST AND THRUST DESIRED

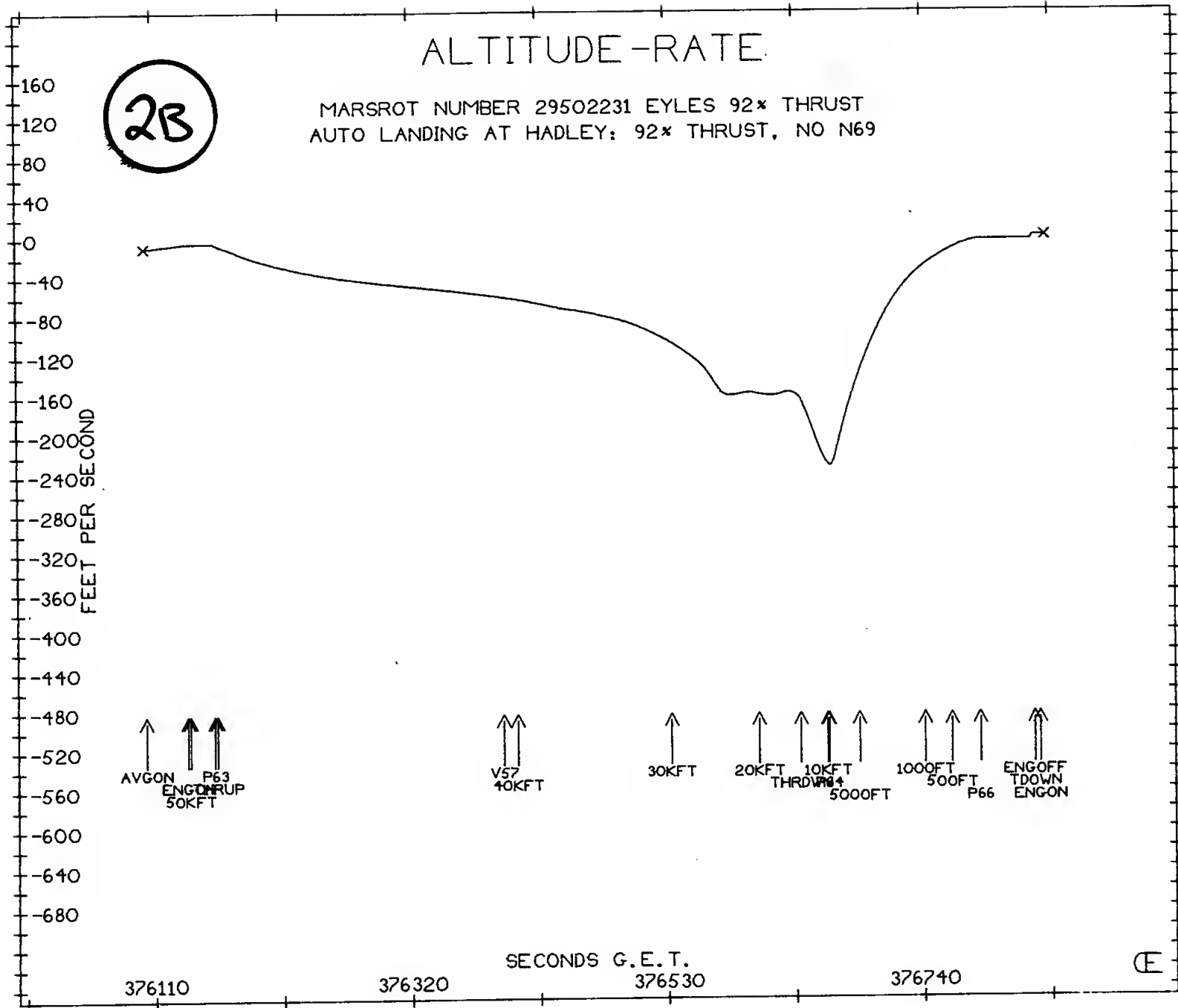
MARSROT NUMBER 29502231 EYLES 92\* THRUST  
AUTO LANDING AT HADLEY: 92\* THRUST, NO N69  
TOTAL DELTAV 6710.70 FEET PER SECOND



# ALTITUDE-RATE.

2B

MARSROT NUMBER 29502231 EYLES 92\* THRUST  
AUTO LANDING AT HADLEY: 92\* THRUST, NO N69



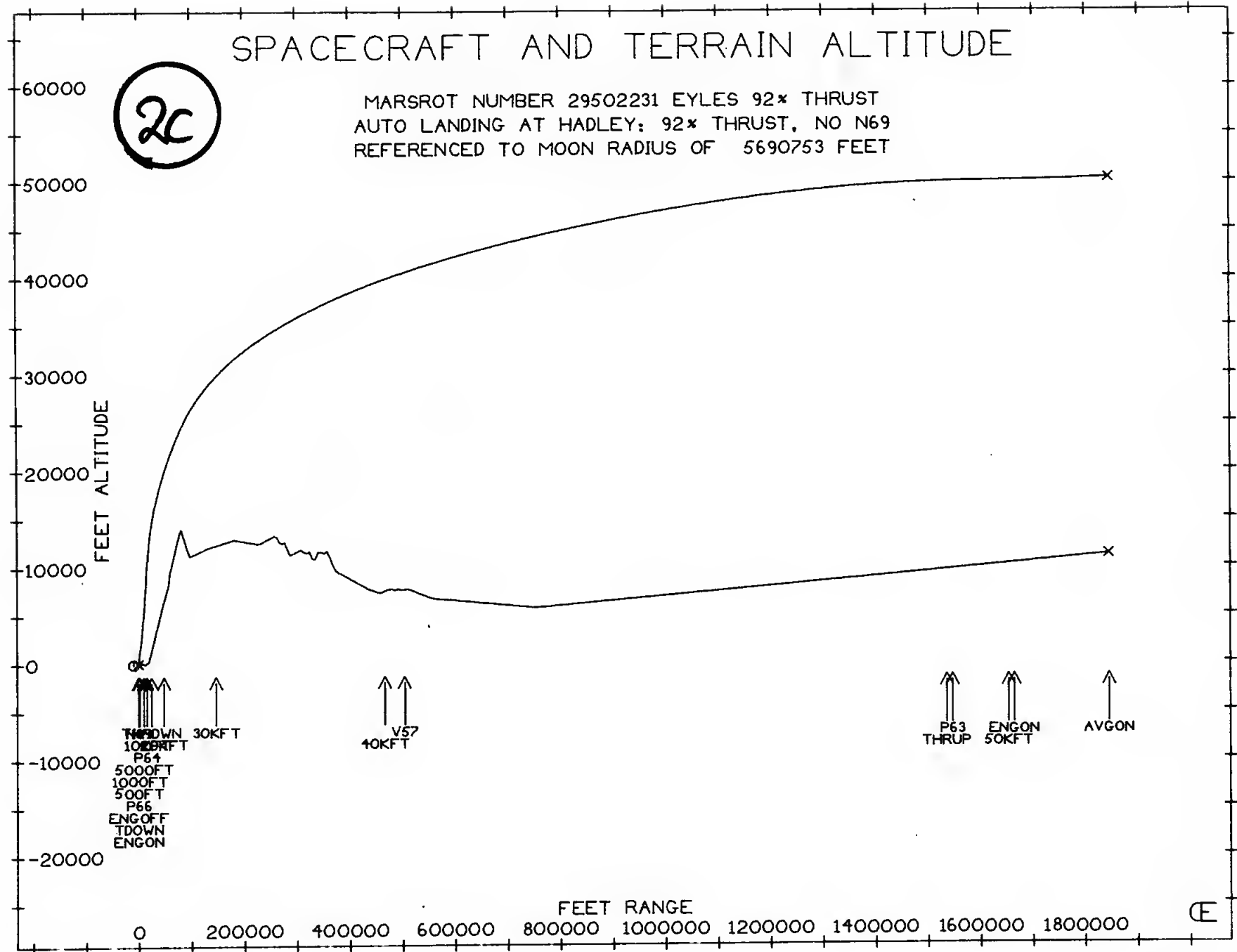
FRAME 002

Ⓔ

# SPACECRAFT AND TERRAIN ALTITUDE

2C

MARSROT NUMBER 29502231 EYLES 92\* THRUST  
AUTO LANDING AT HADLEY: 92\* THRUST, NO N69  
REFERENCED TO MOON RADIUS OF 5690753 FEET



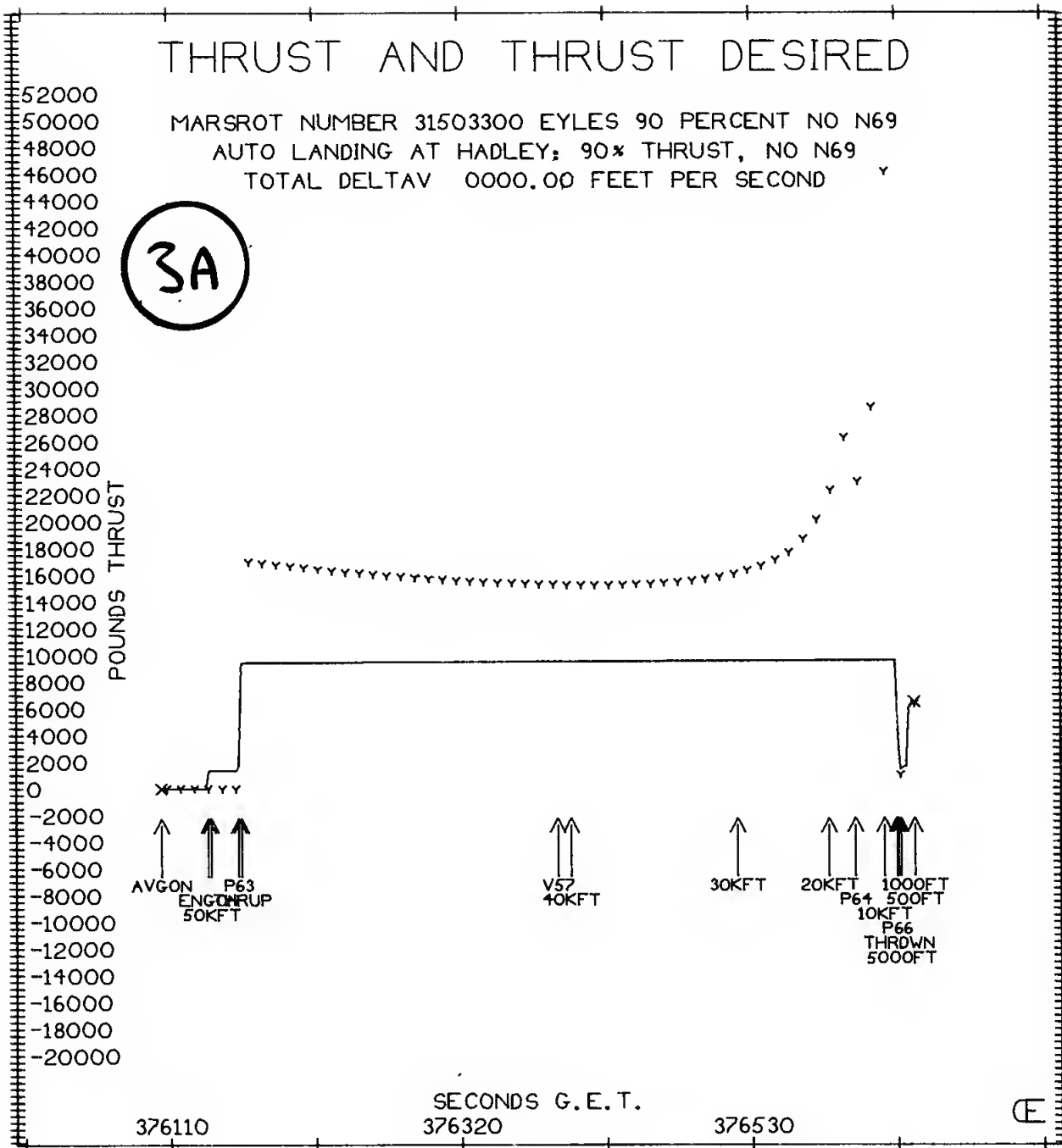
FRAME 003

CE

# THRUST AND THRUST DESIRED

MARSROT NUMBER 31503300 EYLES 90 PERCENT NO N69  
AUTO LANDING AT HADLEY; 90% THRUST, NO N69  
TOTAL DELTAV 0000.00 FEET PER SECOND

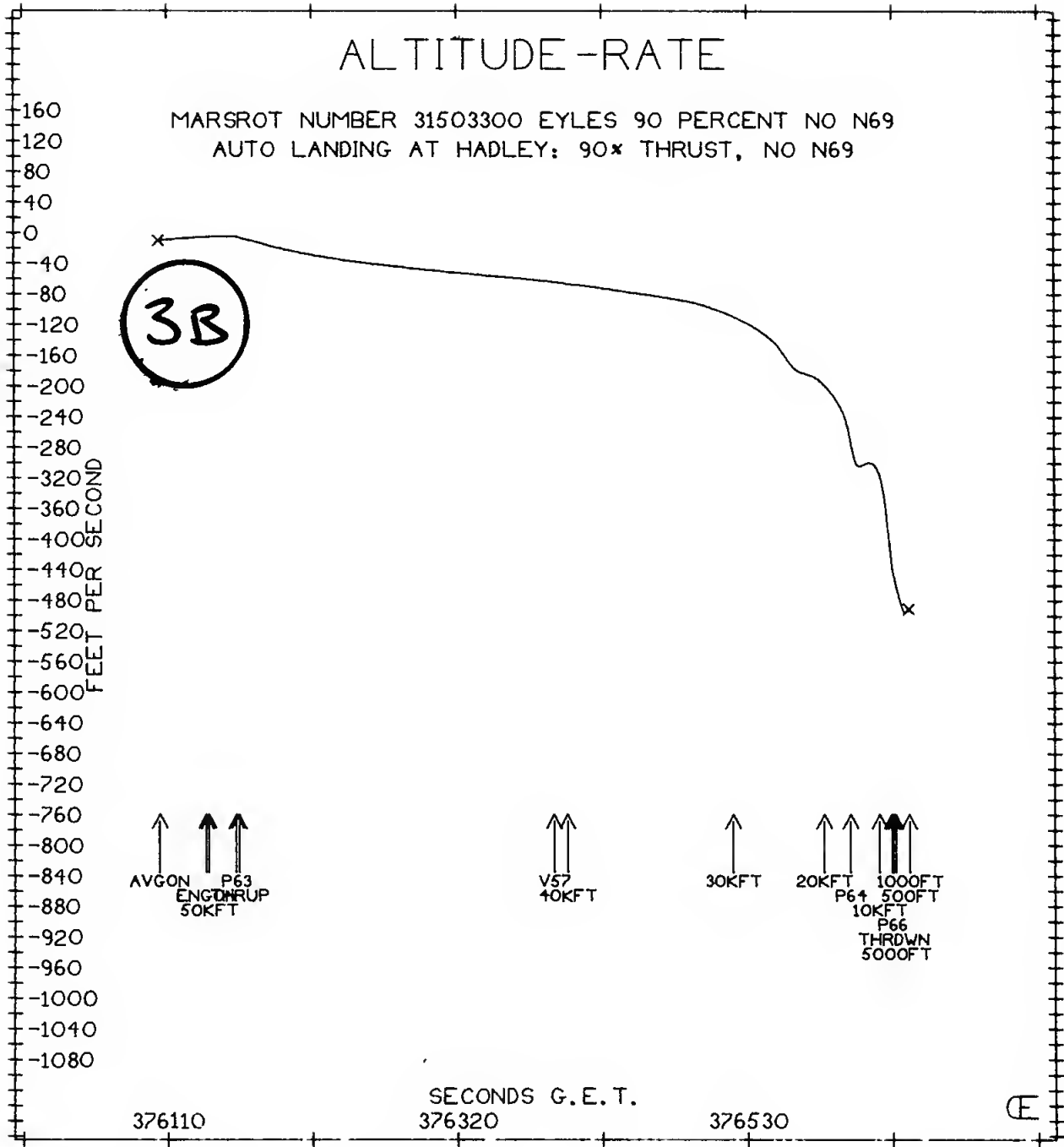
3A



# ALTITUDE-RATE

MARSROT NUMBER 31503300 EYLES 90 PERCENT NO N69  
AUTO LANDING AT HADLEY: 90\* THRUST, NO N69

3B



FRAME 002

E

# SPACECRAFT AND TERRAIN ALTITUDE

3c

MARSROT NUMBER 31503300 EYLES 90 PERCENT NO N69  
AUTO LANDING AT HADLEY; 90x THRUST, NO N69  
REFERENCED TO MOON RADIUS OF 5690753 FEET

FEET ALTITUDE

60000  
50000  
40000  
30000  
20000  
10000  
0  
-10000  
-20000

FEET RANGE

0 200000 400000 600000 800000 1000000 1200000 1400000 1600000 1800000

N6964  
10K20KFT  
P66  
THROWN  
5000FT  
1000FT  
500FT

30KFT

V57  
40KFT

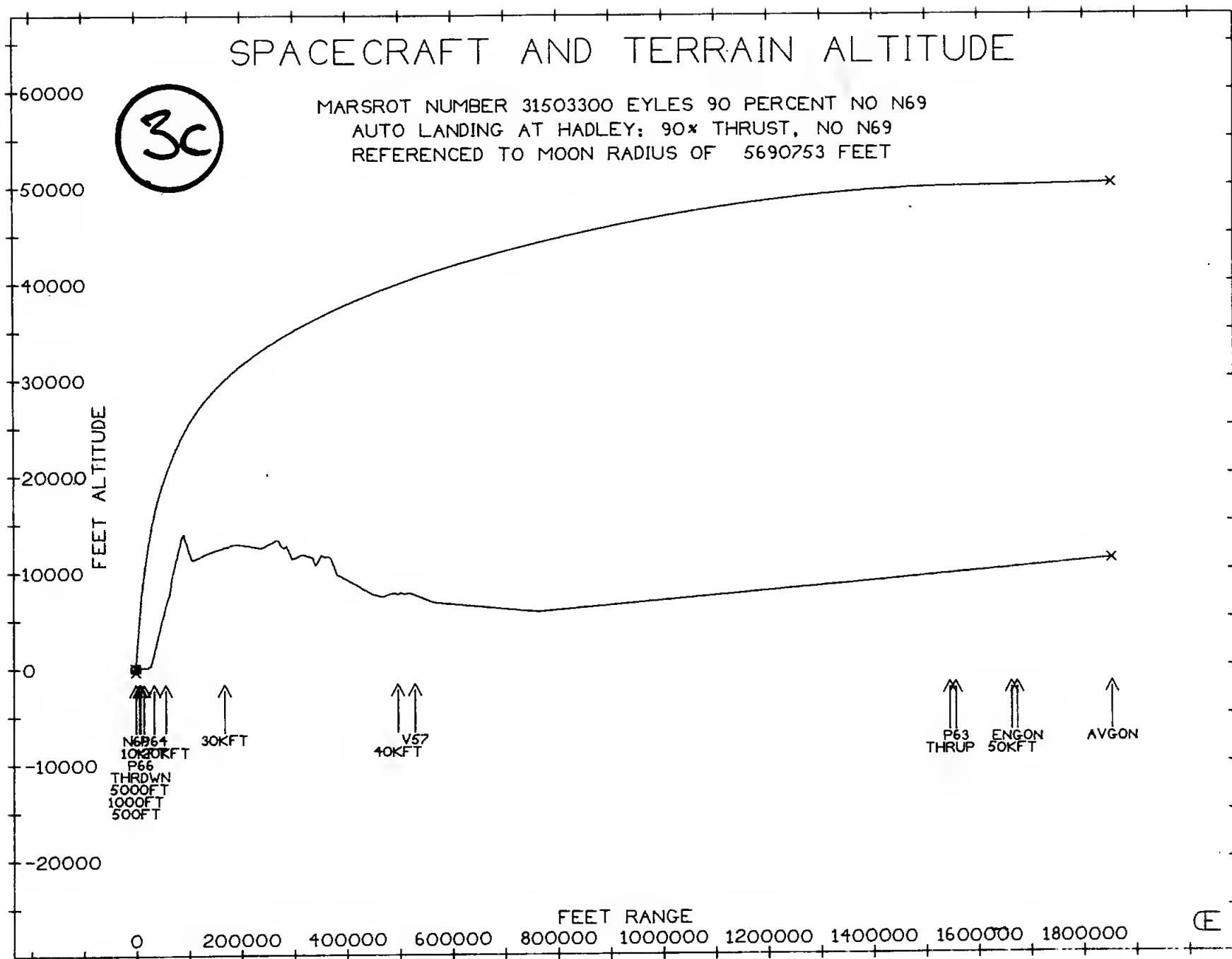
P63  
THRUP

ENGON  
50KFT

AVGON

FRAME 003

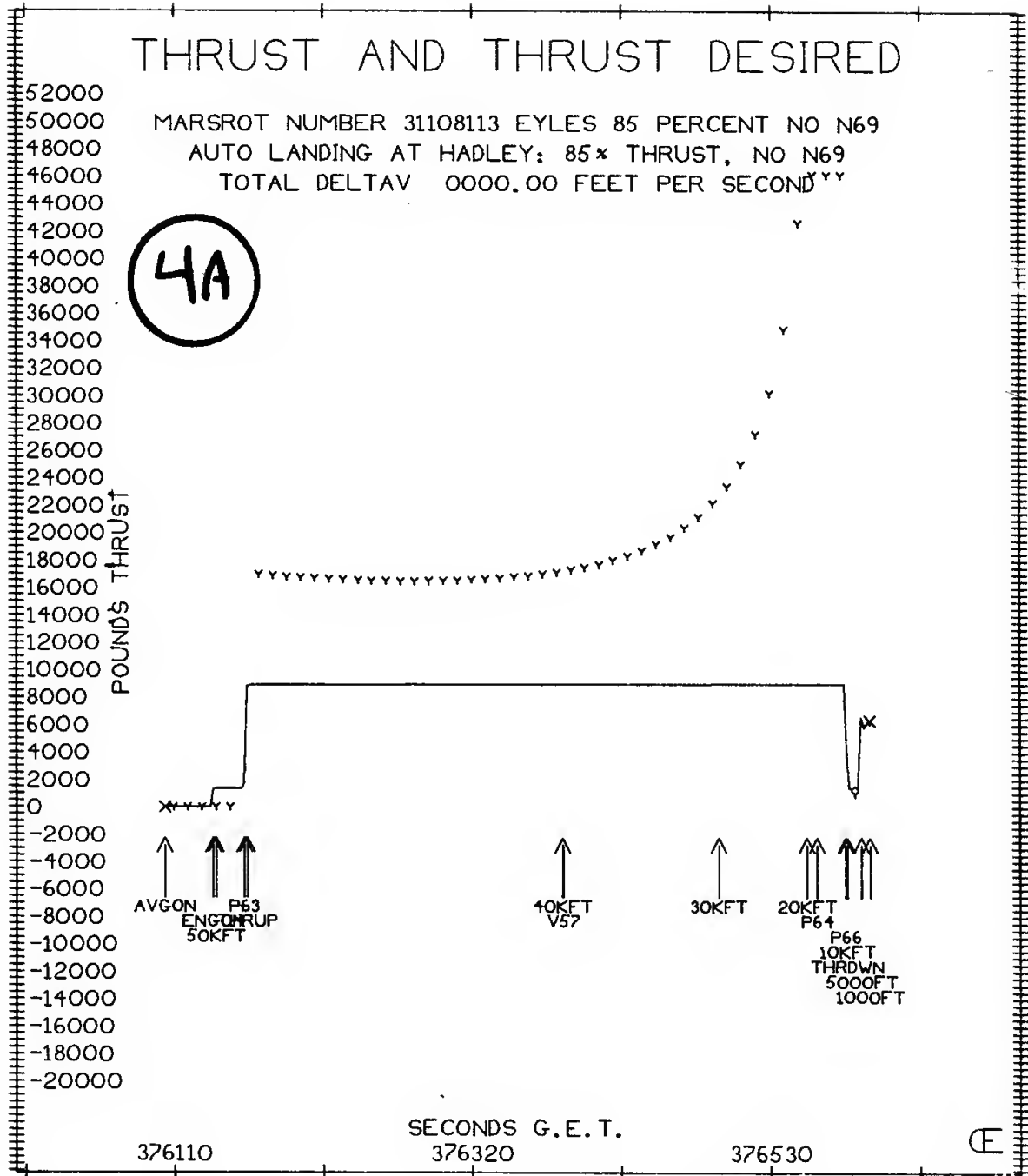
E



# THRUST AND THRUST DESIRED

MARSROT NUMBER 31108113 EYLES 85 PERCENT NO N69  
AUTO LANDING AT HADLEY: 85% THRUST, NO N69  
TOTAL DELTAV 0000.00 FEET PER SECOND

4A

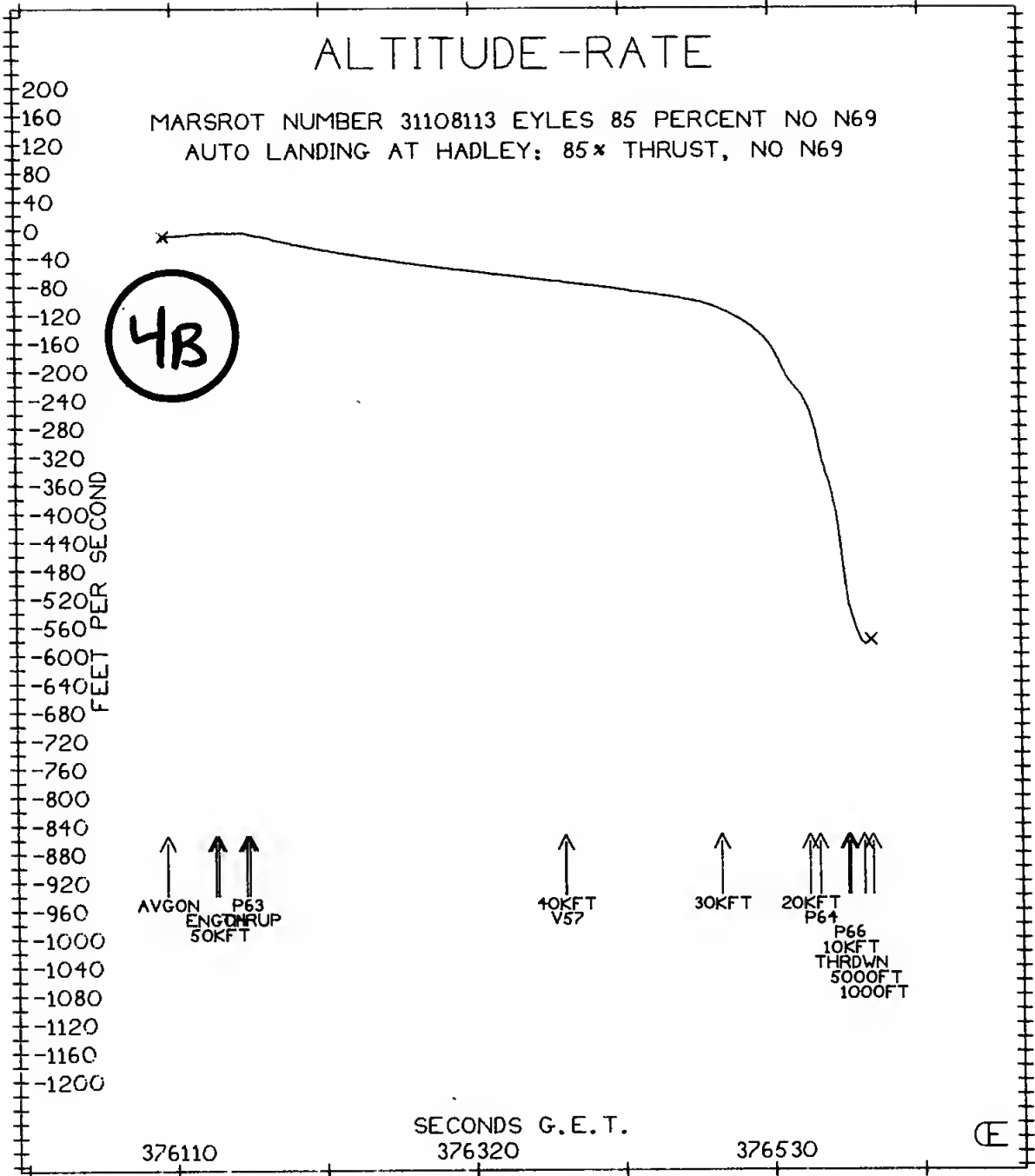




# ALTITUDE-RATE

MARSROT NUMBER 31108113 EYLES 85 PERCENT NO N69  
AUTO LANDING AT HADLEY: 85\* THRUST, NO N69

4B



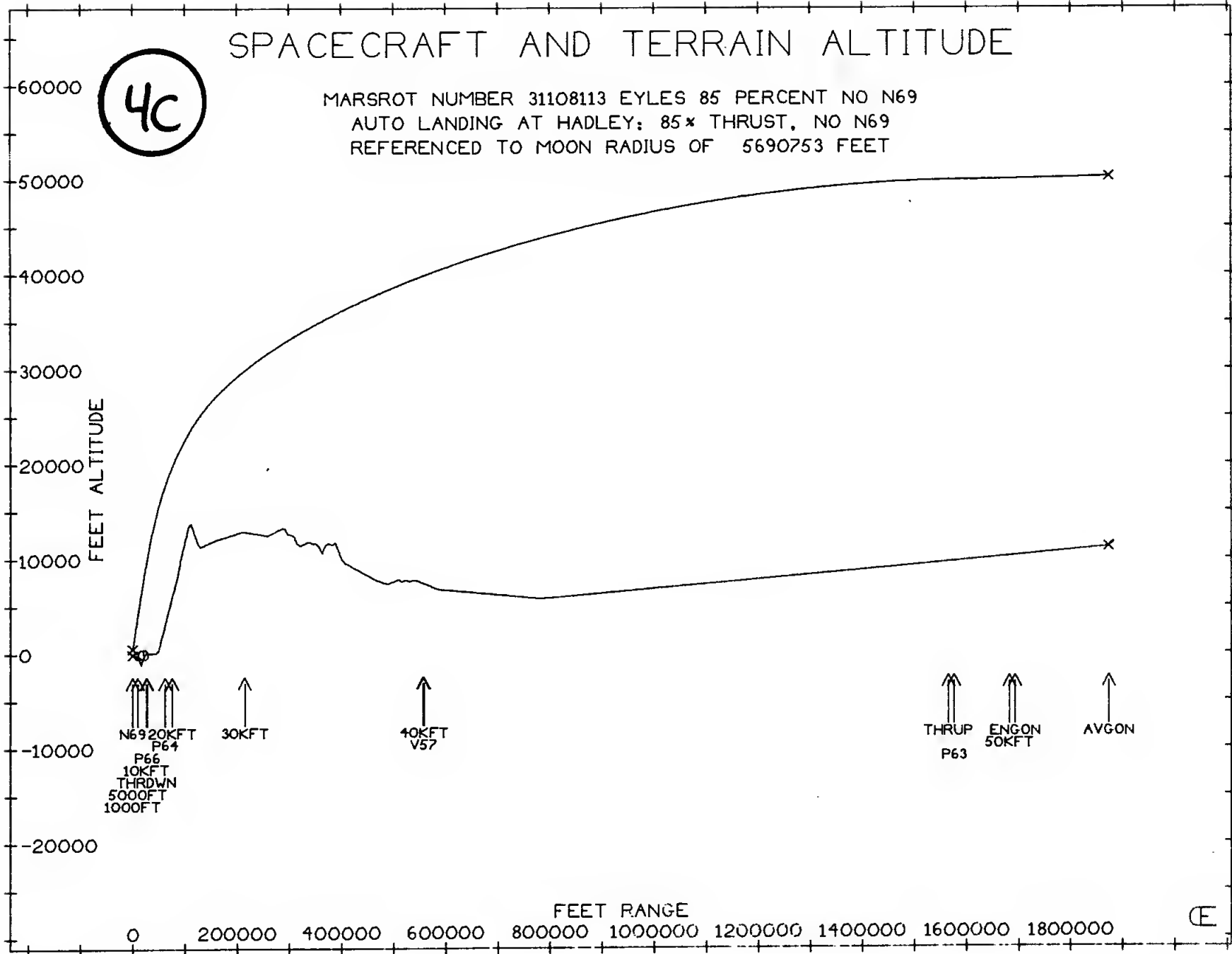
FRAME 002

E

4c

# SPACECRAFT AND TERRAIN ALTITUDE

MARSROT NUMBER 31108113 EYLES 85 PERCENT NO N69  
AUTO LANDING AT HADLEY: 85% THRUST, NO N69  
REFERENCED TO MOON RADIUS OF 5690753 FEET



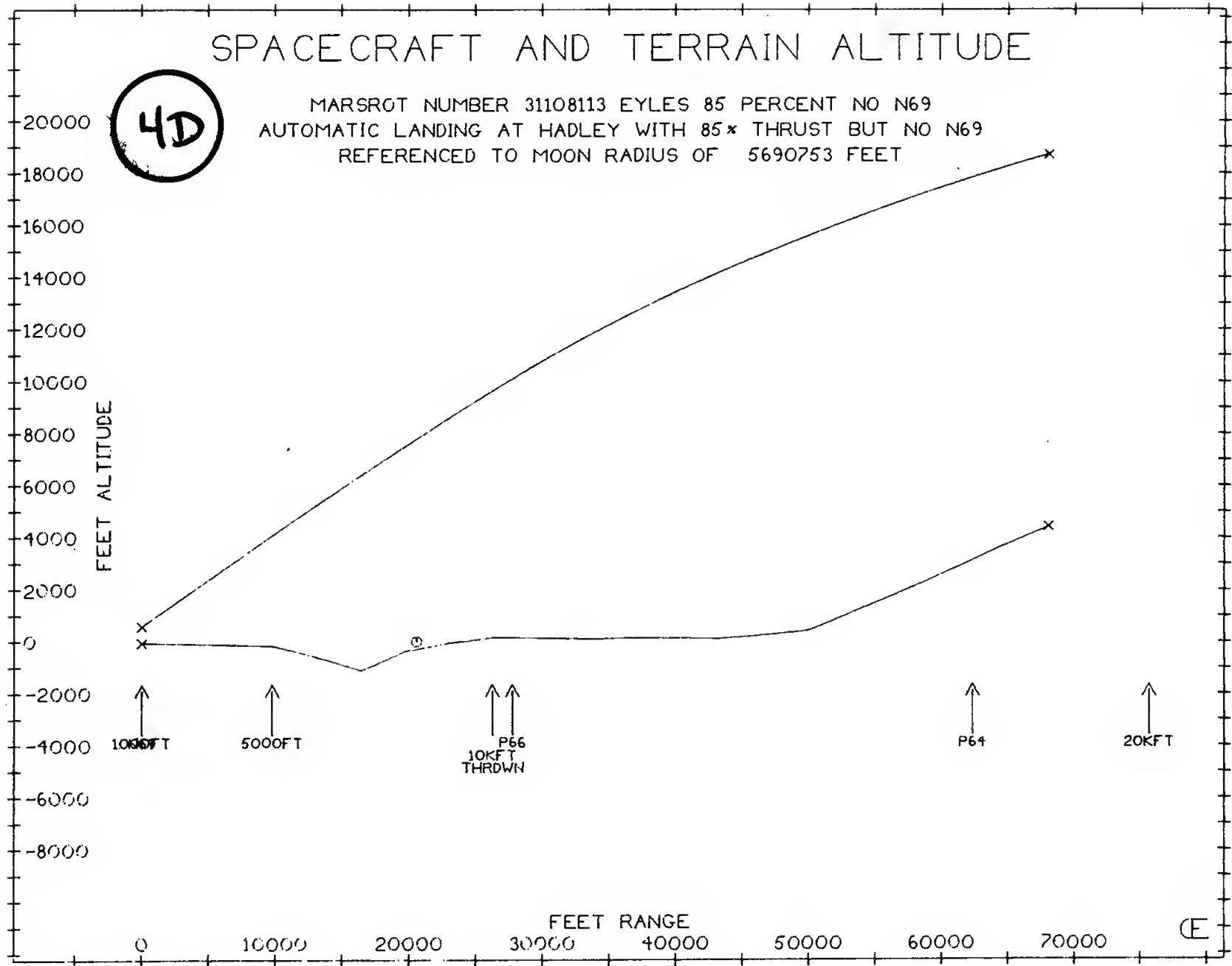
FRAME 003

CE

# SPACECRAFT AND TERRAIN ALTITUDE

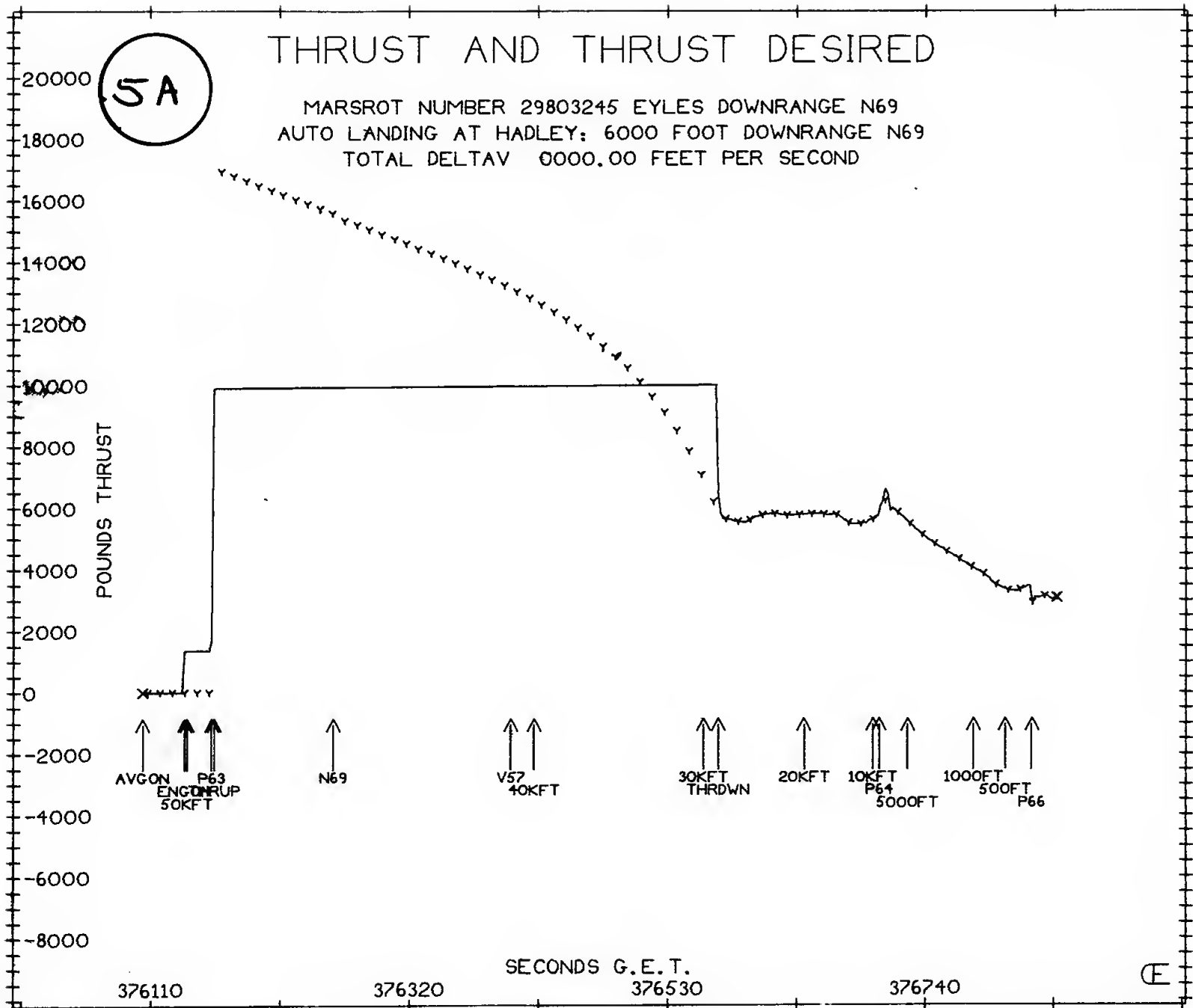
4D

MARSROT NUMBER 31108113 EYLES 85 PERCENT NO N69  
AUTOMATIC LANDING AT HADLEY WITH 85x THRUST BUT NO N69  
REFERENCED TO MOON RADIUS OF 5690753 FEET



FRAME 006

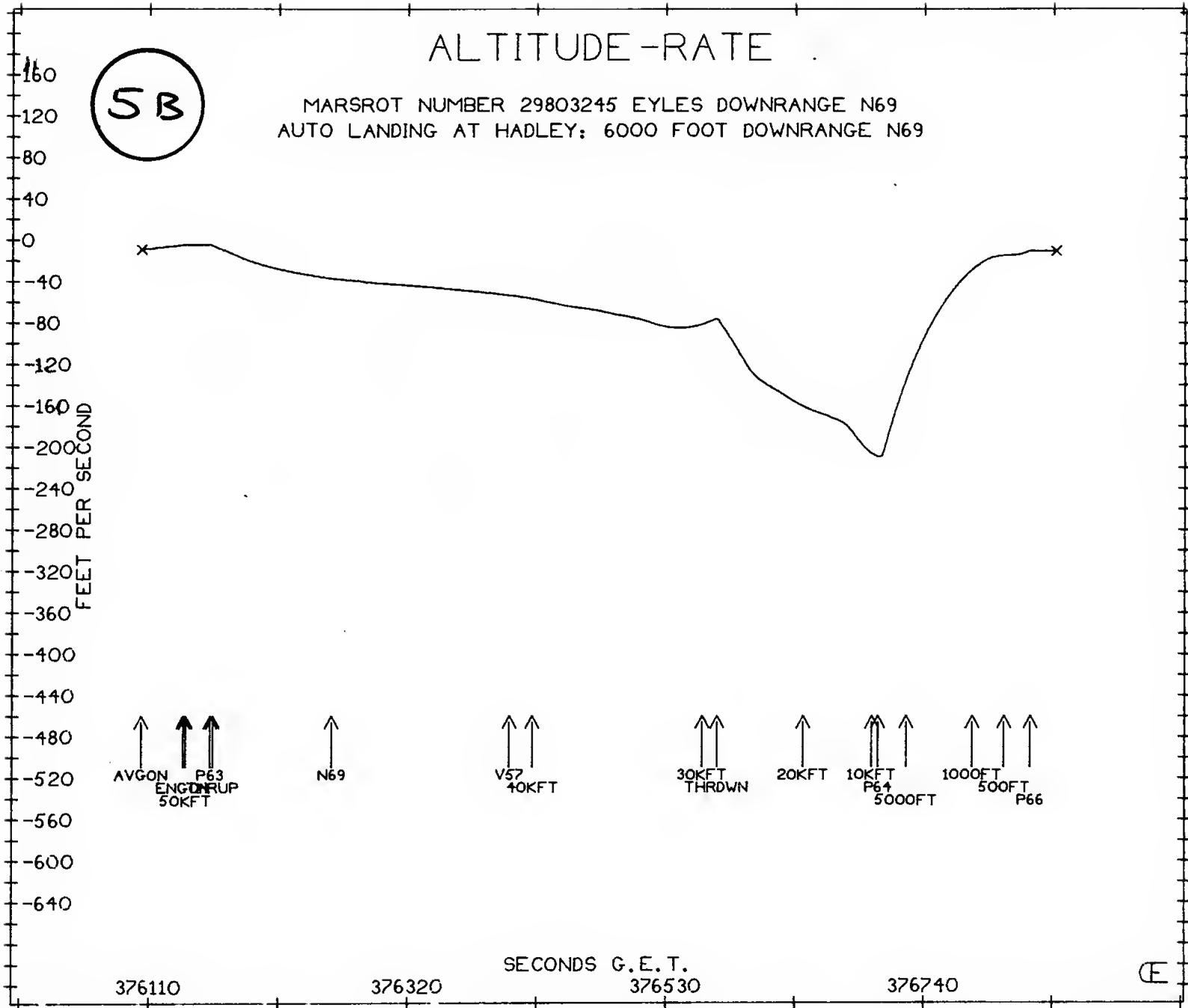
CE



# ALTITUDE-RATE

5B

MARSROT NUMBER 29803245 EYLES DOWNRANGE N69  
AUTO LANDING AT HADLEY: 6000 FOOT DOWNRANGE N69



FRAME 002

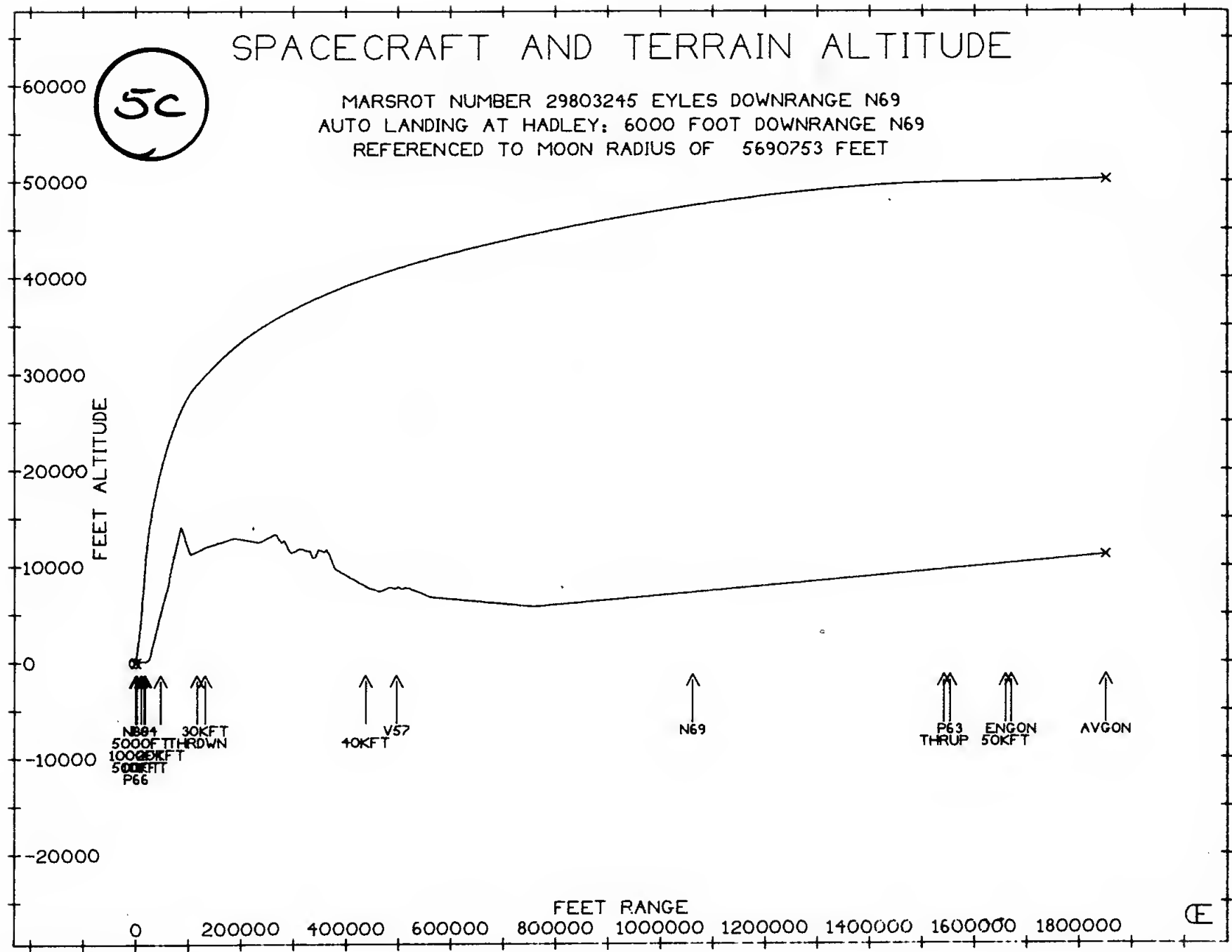
SECONDS G.E.T.  
376530

E

5c

# SPACECRAFT AND TERRAIN ALTITUDE

MARSROT NUMBER 29803245 EYLES DOWNRANGE N69  
AUTO LANDING AT HADLEY: 6000 FOOT DOWNRANGE N69  
REFERENCED TO MOON RADIUS OF 5690753 FEET



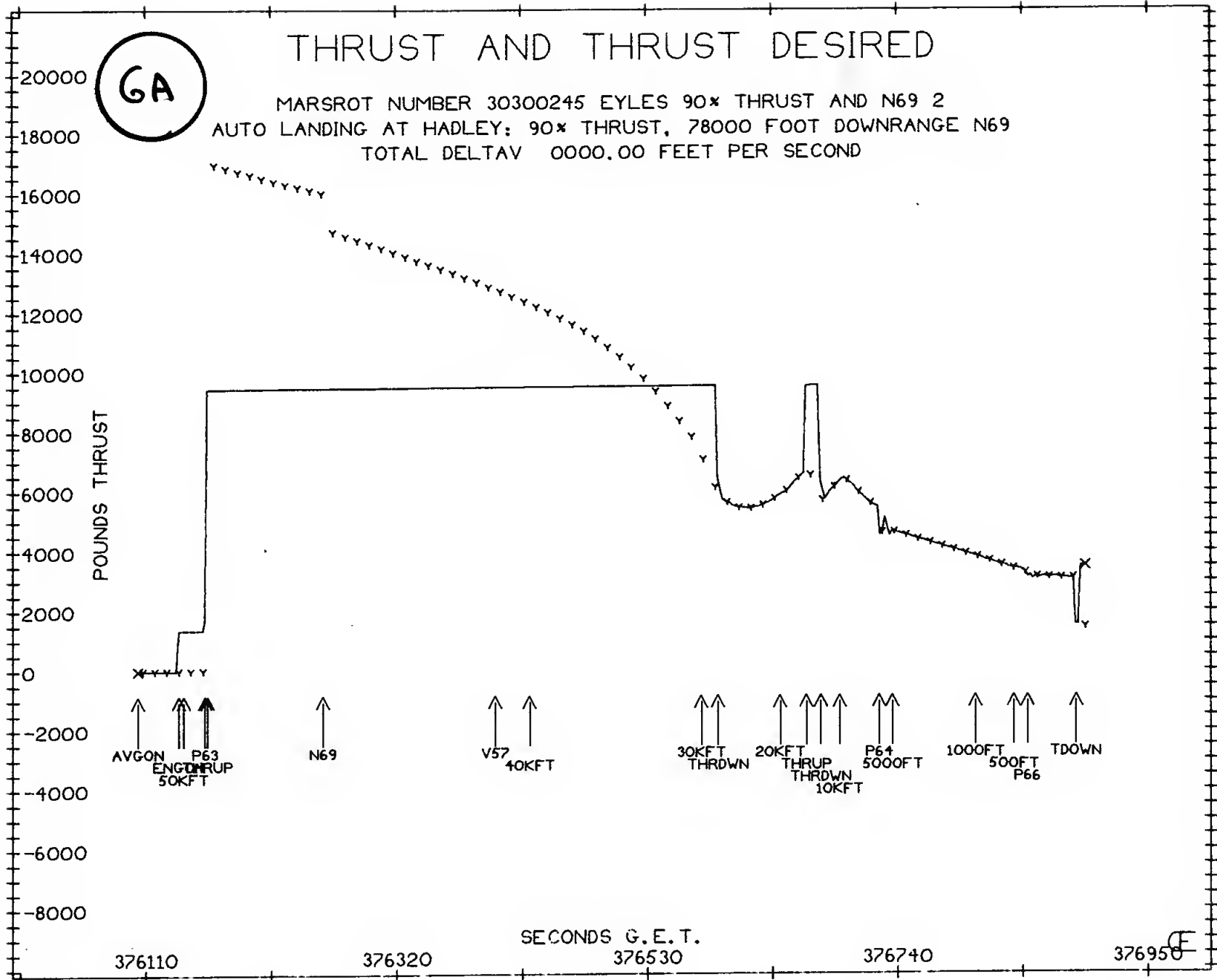
FRAME 003

CE

GA

# THRUST AND THRUST DESIRED

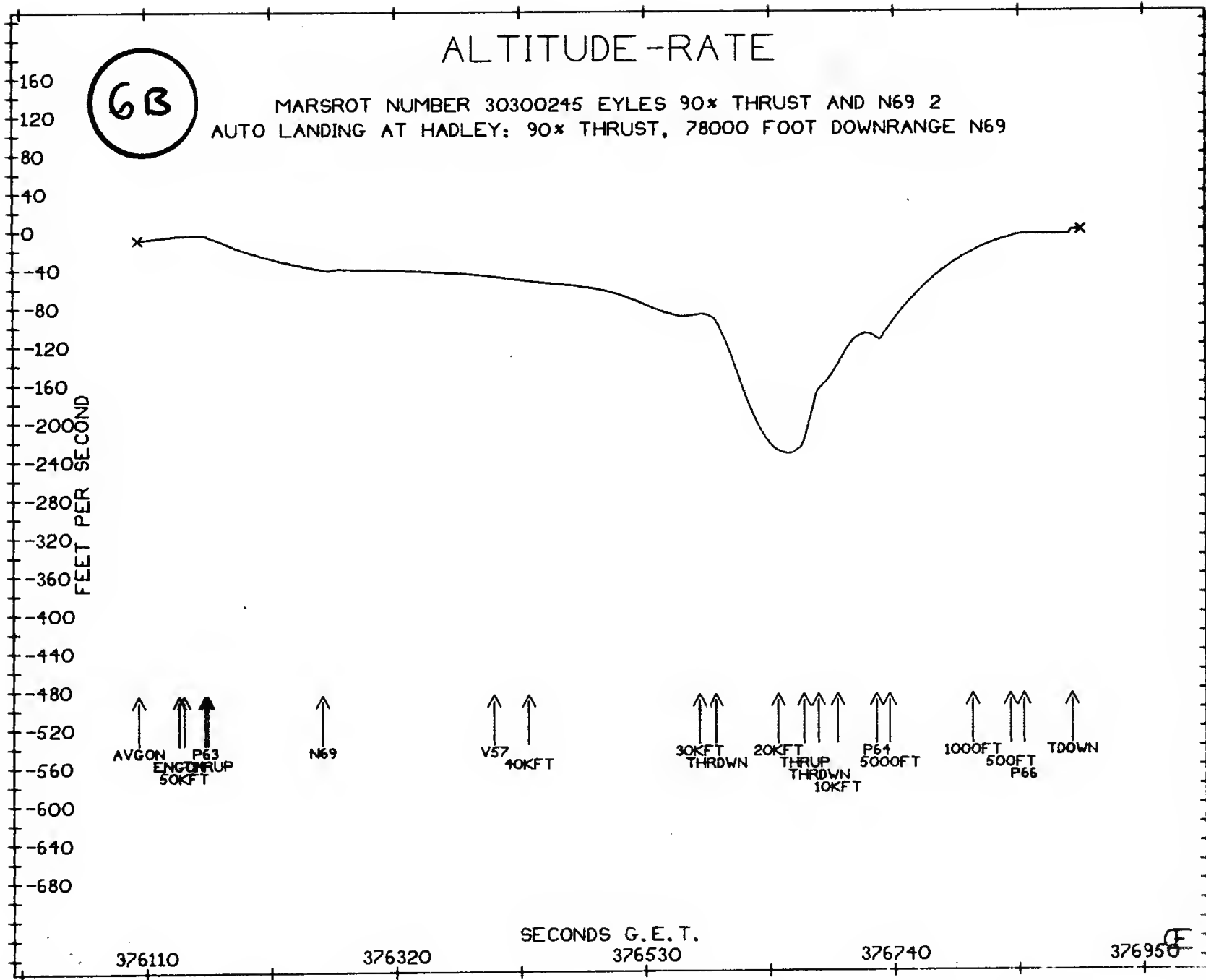
MARSROT NUMBER 30300245 EYLES 90\* THRUST AND N69 2  
AUTO LANDING AT HADLEY: 90\* THRUST, 78000 FOOT DOWNRANGE N69  
TOTAL DELTAV 0000.00 FEET PER SECOND



# ALTITUDE-RATE

6B

MARSROT NUMBER 30300245 EYLES 90\* THRUST AND N69 2  
AUTO LANDING AT HADLEY: 90\* THRUST, 78000 FOOT DOWNRANGE N69



FRAME 002

SECONDS G.E.T.  
376530

376110

376320

376740

376950

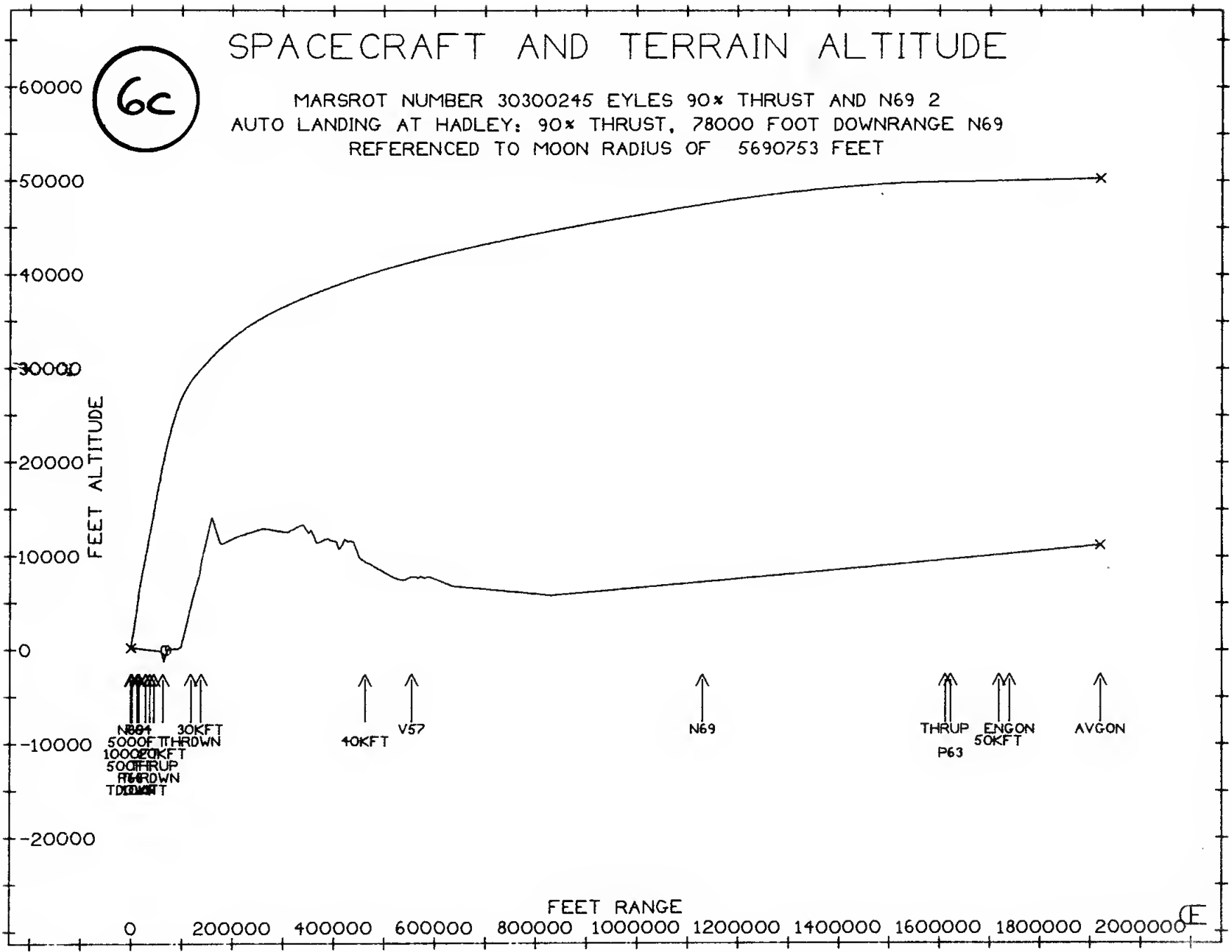
F



6c

# SPACECRAFT AND TERRAIN ALTITUDE

MARSROT NUMBER 30300245 EYLES 90\* THRUST AND N69 2  
AUTO LANDING AT HADLEY: 90\* THRUST, 78000 FOOT DOWNRANGE N69  
REFERENCED TO MOON RADIUS OF 5690753 FEET



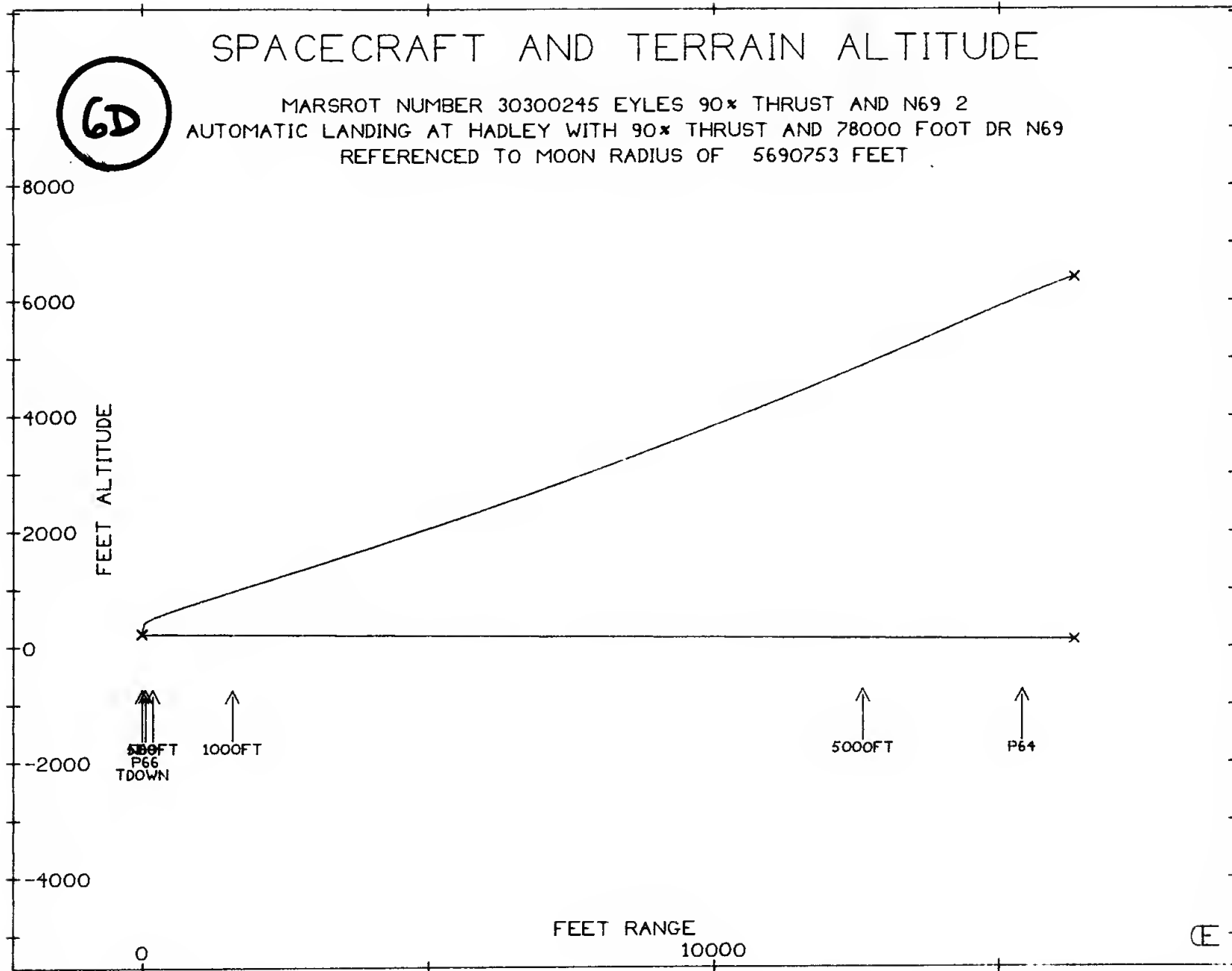
FRAME 003

CE

6D

# SPACECRAFT AND TERRAIN ALTITUDE

MARSROT NUMBER 30300245 EYLES 90\* THRUST AND N69 2  
AUTOMATIC LANDING AT HADLEY WITH 90\* THRUST AND 78000 FOOT DR N69  
REFERENCED TO MOON RADIUS OF 5690753 FEET



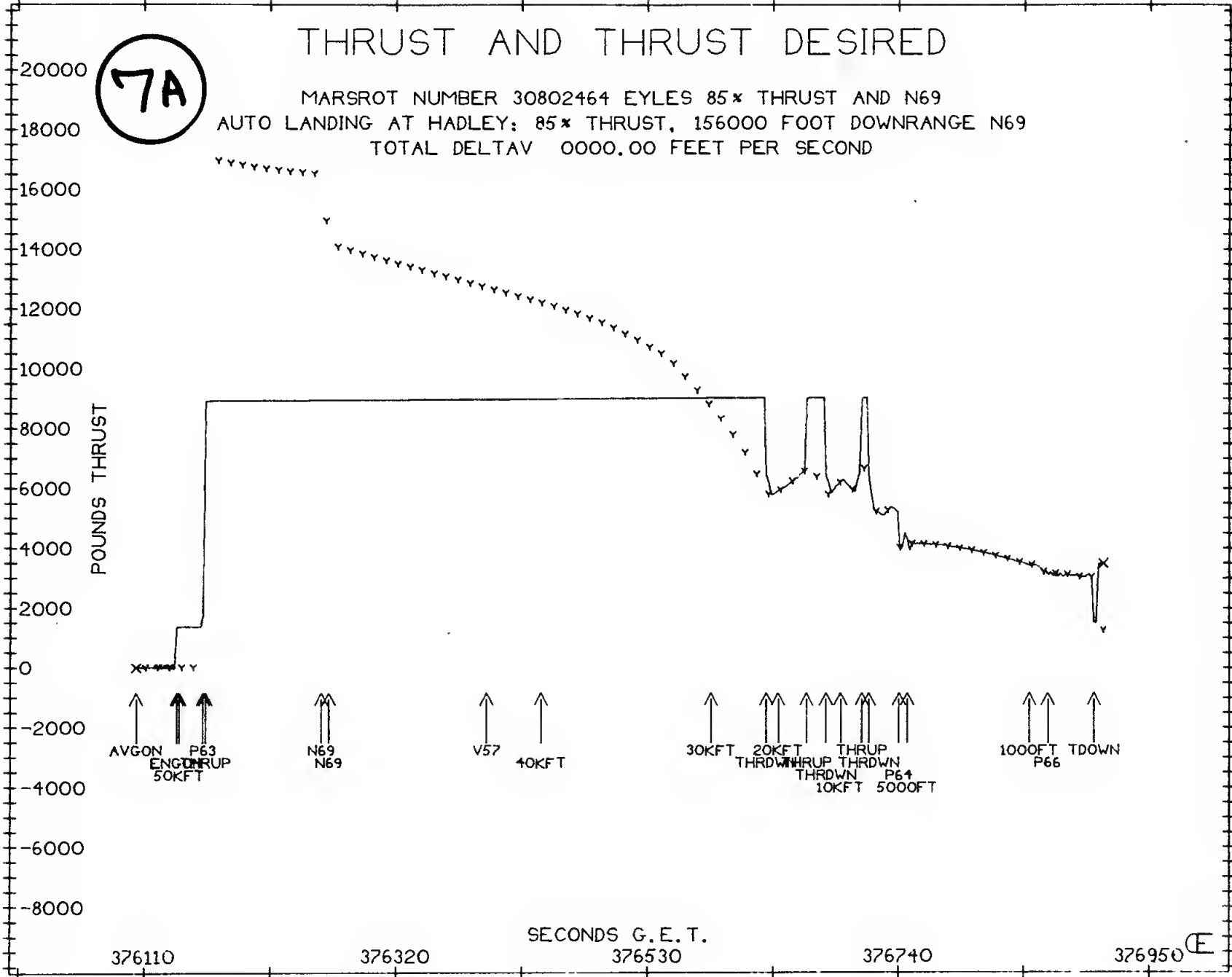
FRAME 006

CE

7A

# THRUST AND THRUST DESIRED

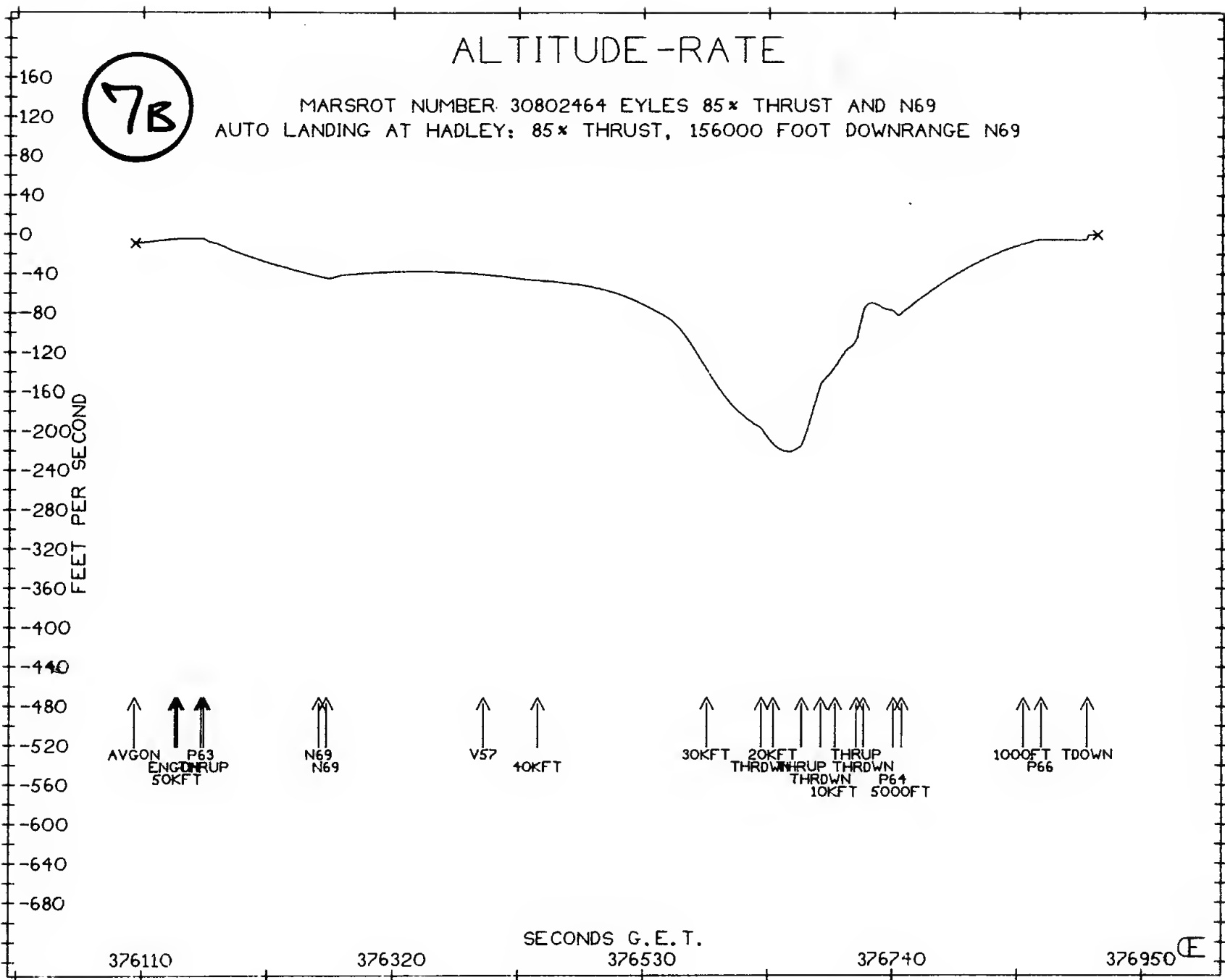
MARSROT NUMBER 30802464 EYLES 85\* THRUST AND N69  
AUTO LANDING AT HADLEY: 85\* THRUST, 156000 FOOT DOWNRANGE N69  
TOTAL DELTAV 0000.00 FEET PER SECOND



# ALTITUDE-RATE

7B

MARSROT NUMBER 30802464 EYLES 85\* THRUST AND N69  
AUTO LANDING AT HADLEY: 85\* THRUST, 156000 FOOT DOWNRANGE N69



FRAME 002

376110

376320

SECONDS G.E.T.  
376530

376740

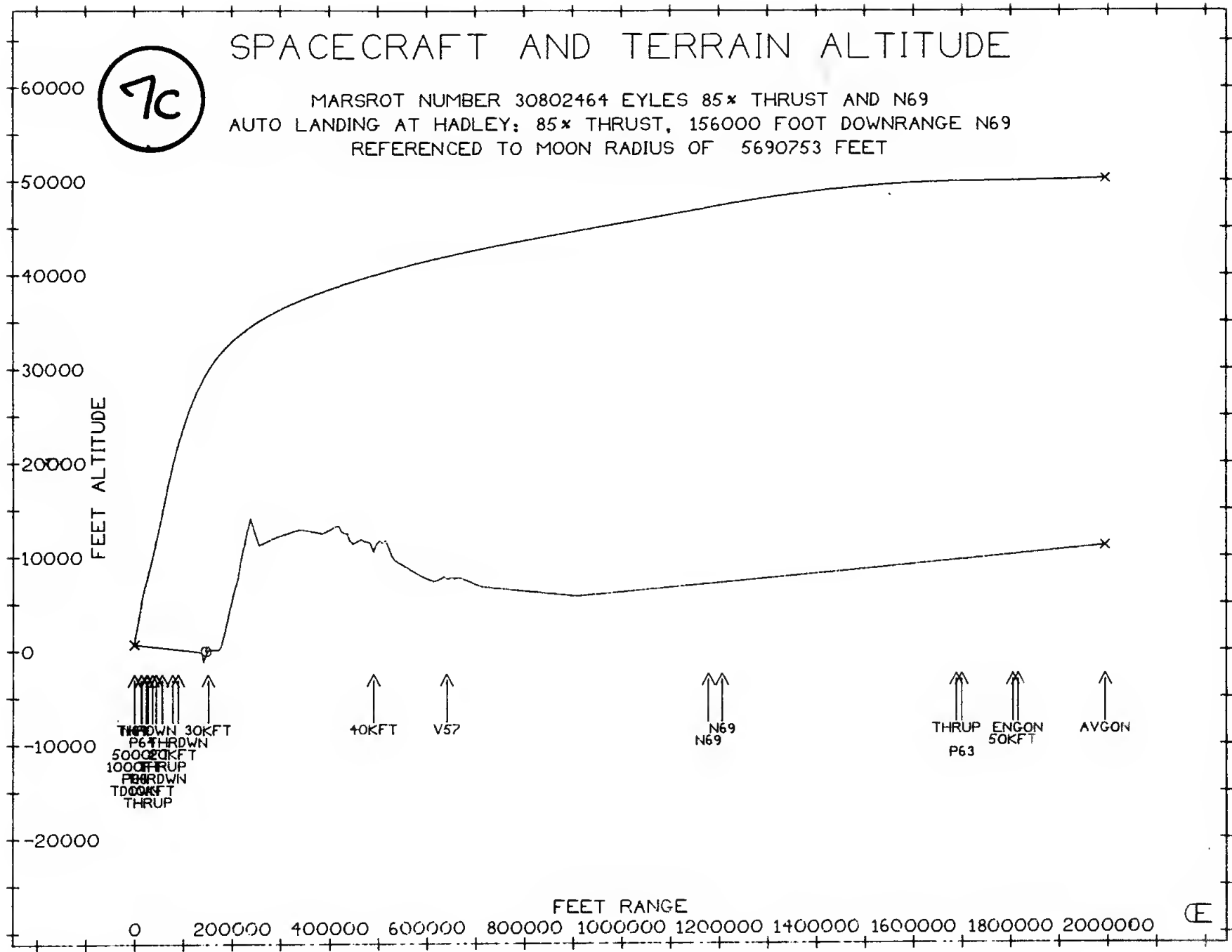
376950

E

7c

# SPACECRAFT AND TERRAIN ALTITUDE

MARSROT NUMBER 30802464 EYLES 85\* THRUST AND N69  
AUTO LANDING AT HADLEY: 85\* THRUST, 156000 FOOT DOWNRANGE N69  
REFERENCED TO MOON RADIUS OF 5690753 FEET



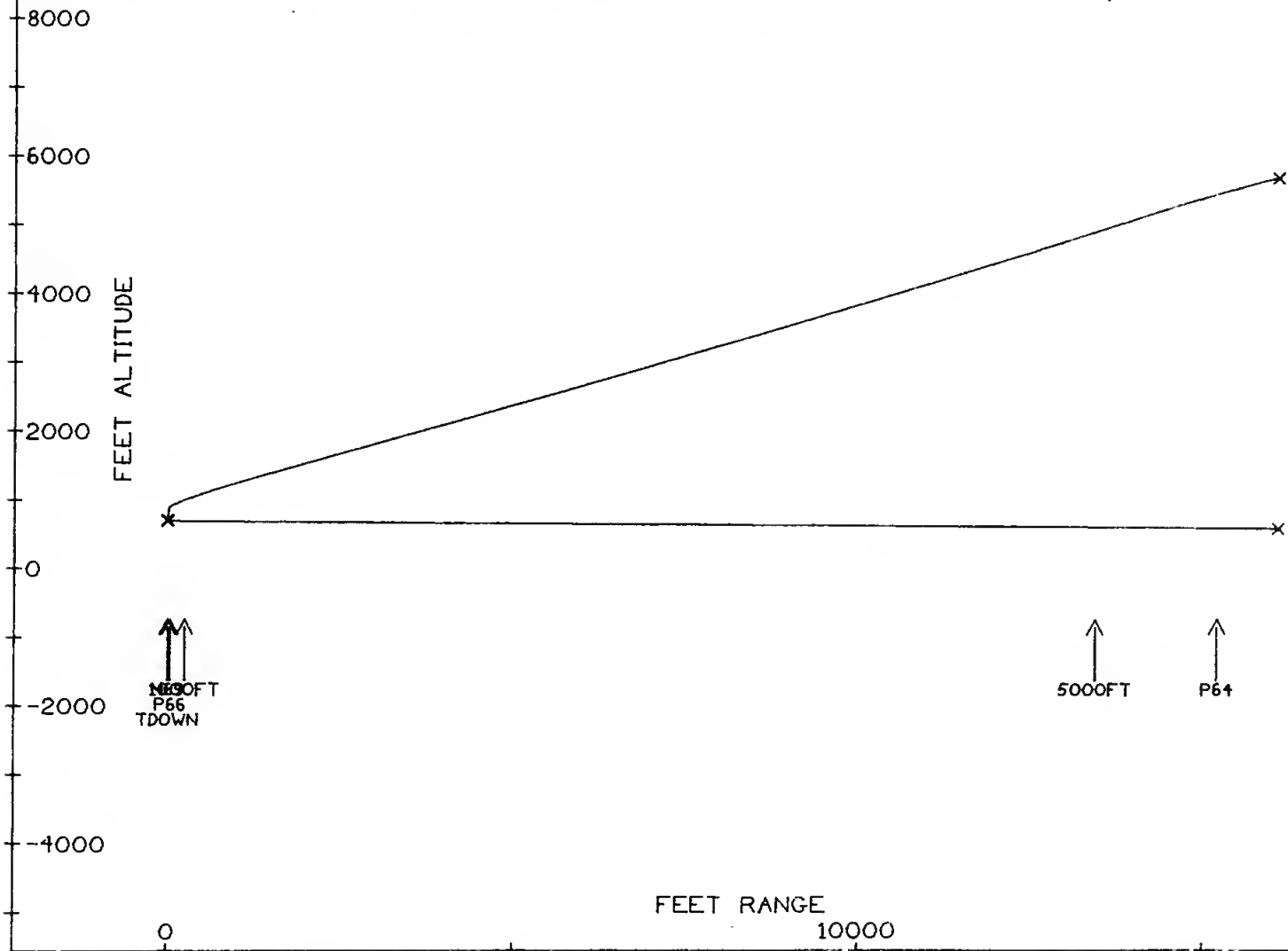
FRAME 003

E

7D

# SPACECRAFT AND TERRAIN ALTITUDE

MARSROT NUMBER 30802464 EYLES 85\* THRUST AND N69  
AUTOMATIC LANDING AT HADLEY WITH 85\* THRUST AND 156000 FOOT DR N69  
REFERENCED TO MOON RADIUS OF 5690753 FEET



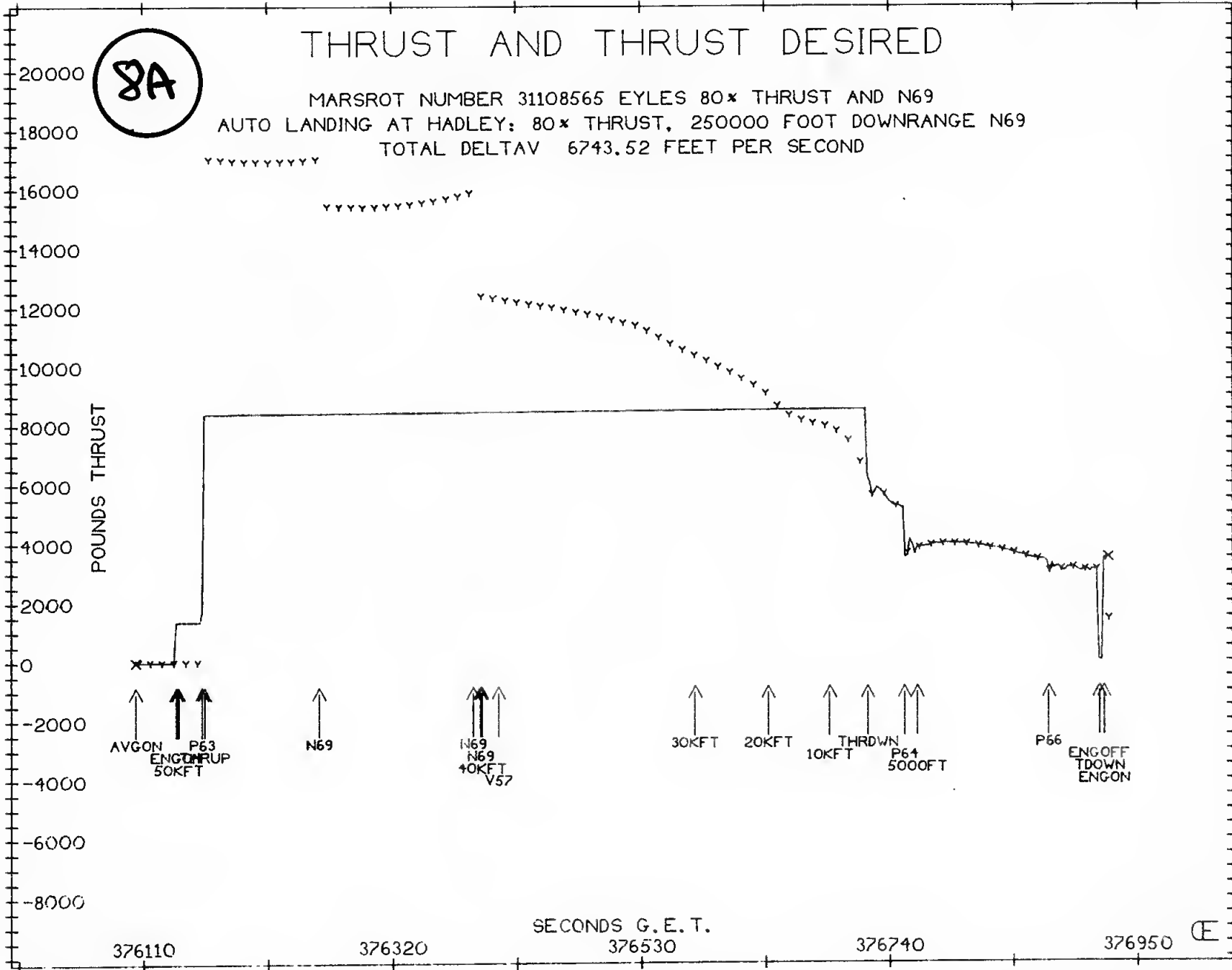
FRAME 006

CE

8A

# THRUST AND THRUST DESIRED

MARSROT NUMBER 31108565 EYLES 80\* THRUST AND N69  
AUTO LANDING AT HADLEY: 80\* THRUST, 250000 FOOT DOWNRANGE N69  
TOTAL DELTAV 6743.52 FEET PER SECOND

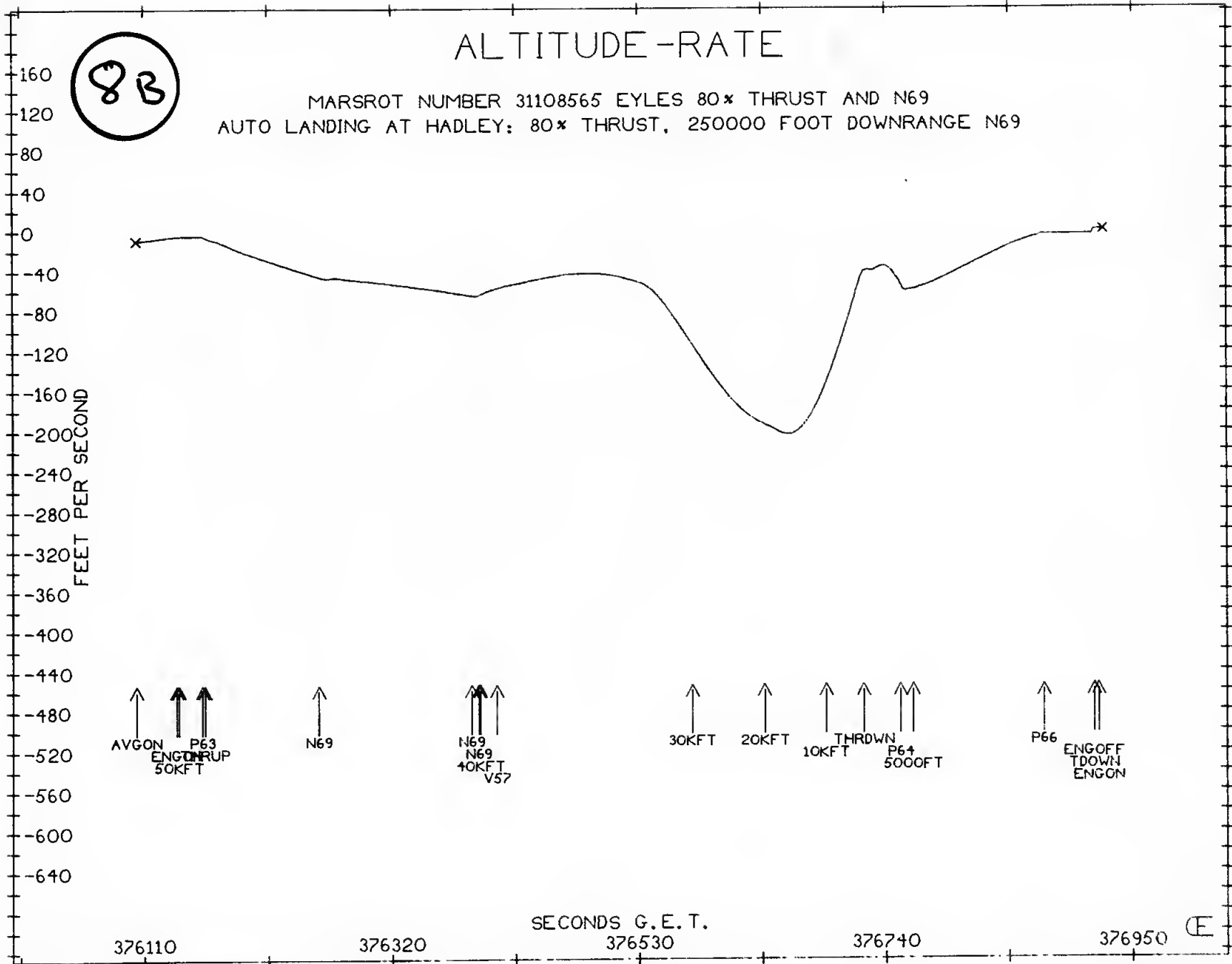


E

8B

# ALTITUDE-RATE

MARSROT NUMBER 31108565 EYLES 80% THRUST AND N69  
AUTO LANDING AT HADLEY: 80% THRUST, 250000 FOOT DOWNRANGE N69



FRAME 002

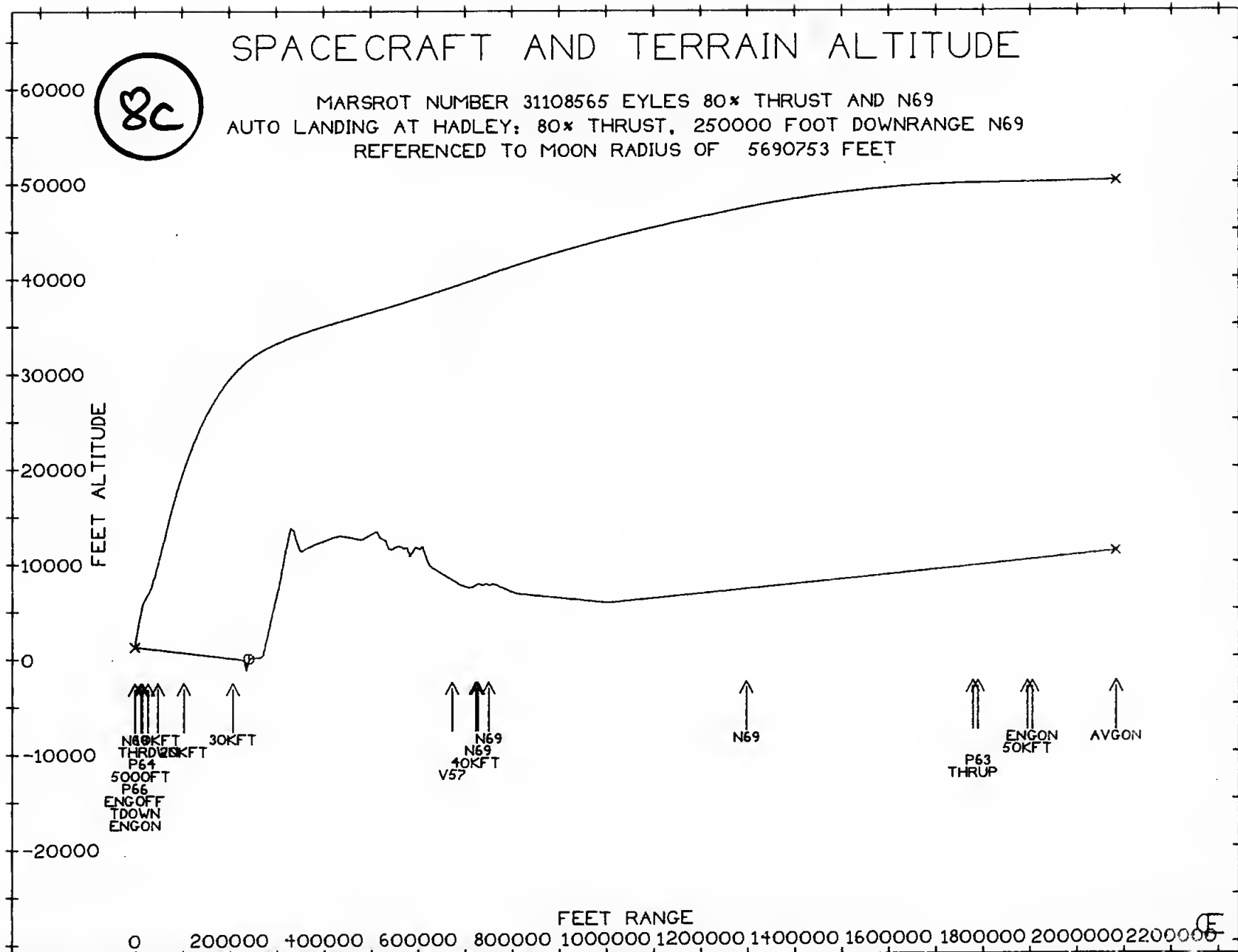
E



8c

# SPACECRAFT AND TERRAIN ALTITUDE

MARSROT NUMBER 31108565 EYLES 80\* THRUST AND N69  
AUTO LANDING AT HADLEY: 80\* THRUST, 250000 FOOT DOWNRANGE N69  
REFERENCED TO MOON RADIUS OF 5690753 FEET



FRAME 003

CE