(NASA-CR-150970) EARLIEST ABORT ONCE AROUND TIME FOR THE FIRST ORBITAL FLIGHT TEST MISSION (McDonnell-Douglas Technical Services) 31 p HC $4.00 CSCL 22B

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SPACE SHUTTLE ENGINEERING AND OPERATIONS SUPPORT

DESIGN NOTE NO. 1.4-7-15

EARLIEST ABORT ONCE AROUND TIME FOR THE FIRST ORBITAL FLIGHT TEST MISSION

MISSION PLANNING, MISSION ANALYSIS AND SOFTWARE FORMULATION

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1.0 Introduction

A study has been conducted to determine the earliest abort once around (AOA) time for the first orbital flight test (OFT-1) mission. The study uses latest estimates of vehicle weights and propulsion for OFT-1. Trade analyses to indicate variations in AOA time for shuttle subsystem changes (such as orbital maneuvering system (OMS) or reaction control system (RCS) propellant loadings) are included in this paper. In addition, the effects of first stage attitude steering as a function of relative velocity for a nominal profile are presented. Data are presented to indicate the effect of designing first stage steering for earliest AOA time and then having engine out at times after the design point.

2.0 Groundrules and Constraints

This earliest AOA analysis is for OFT-1. Vehicle weights used in the analysis are indicated in Tables I through III. Data are presented in the tables for nominal and AOA profiles. Table I contains weight evaluations for dry weights, propellant residuals, reserve propellants, and for the solid rocket booster (SRB). Tables II and III contain main propulsion system (MPS) propellant weights and OMS and RCS weights, respectively.

Some of the significant groundrules and constraints used in this analysis are:

a. three-degree-of-freedom flight (3 DOF) is simulated.

b. no loads or maximum dynamic pressure limits are imposed on the trajectory simulations

c. launch from KSC

d. payload is 10000 pounds

e. orbit inclination is 38. degrees, launch azimuth of approximately 62. degrees

f. the 270-75 solid rocket motors (SRM) are used (Table IV)

g. 100% space shuttle main engine (SSME) thrust from liftoff to AOA

h. SSME throttled to 109% thrust following main engine out (AOA)

i. OMS and RCS are not required for nominal flight to main engine cutoff (MECO)

j. OMS and RCS ignition at SRB separation in AOA simulations

k. MECO targets are

60. NMI	Altitude
0.5 DEG	Flight-Path Angle
25668. FT/SEC	Inertial Velocity

for both nominal and AOA

l. OMS and RCS propellant post MECO for AOA are:

OMS	6276 LB (approximately 280 FT/SEC)
RCS	5780 LB

m. nominal profile is optimized for earliest AOA

n. maximum acceleration limit is 3 g's

The Space Vehicle Dynamics Simulation (SVDS) Program is the simulation tool used in this study. The 3-DOF simulation mode of the program is used with no winds or yaw biasing being simulated. Co-planar flight is simulated from liftoff to MECO.

3.0 Earliest AOA Analysis

In order to determine the earliest AOA time for the shuttle vehicle as configured in this study, first stage steering (including the pitch over maneuver) is optimized for various engine out times. The earliest engine out time for which the given MECO conditions can be achieved is defined as the earliest AOA time.

First stage steering for the AOA is simulated by

a. vertical flight to tower clearance

b. vehicle pitch over at a constant body rate for 10.0 seconds

c. zero angle of attack flight from time of pitch over termination to SRB separation

Figure 1 contains SSME propellant at MECO for various engine out times and pitch over rates. The data constitutes an optimization of pitch over rate for each of the engine out times and indicates that the earliest engine out time for which MECO conditions can be achieved is approximately 24. seconds ~~from liftoff~~. Examination of the optimum pitch over rate data indicates a rate of change of .003 DEG/SEC/SEC of AOA time.

Parametric trajectory data for the simulation cases of Figure 1 are presented in Figures 2 through 5. Figures 2 through 4 contain SRB staging data (staging altitude, inertial velocity, and inertial flight-path angle, respectively) as a function of pitch over rate and engine out time. Figure 5 contains down range position at MECO. The data are for an AOA profile and evaluations of the parameters at the optimum pitch over rates are indicated for each engine out time. Data of Figure 2 indicate that SRB staging altitude changes at the rate of .23 K·FT/SEC of AOA time when the pitch over maneuver is optimized for the engine out. Figure 6 contains range at MECO and staging altitude as a function of engine out time. The data are based on optimum pitch over rate for each engine out time.

4.0 Earliest AOA Variation For Subsystem Changes

Figure 7 contains data indicating SSME propellant at MECO as a function of engine out time. The data indicate that the rate of change of SSME propellant at MECO to AOA time variations is 250 LB/SEC. That is, 250 pounds of SSME propellant (at MECO) is required to change the AOA time by 1. second. Based upon the current estimate of OFT-1 weights and propulsion, earliest AOA time is 24.4 seconds. This implies SSME propellant depletion at MECO of the AOA profile. An additional 6100 pounds of SSME propellant at MECO (250 LB/SEC * 24.4 SEC) is required to reduce earliest AOA to liftoff. This 6100 pounds of SSME propellant at MECO is equivalent to a 6600 pound reduction in payload (1.08 LB Payload/LB SSME prop * 6100 LB). AOA capability off the pad is available for a payload of 3400 pounds (10000 - 6600) for current OFT-1 weight and propulsion data.

One control element which may be used to provide earlier AOA capability while keeping the payload fixed (at 10000 pounds) is to vary the OMS and RCS loadings. This may be done in either of two ways:

a. reduction of the total OMS and RCS loading with reduction in the post-MECO propellant requirement

b. fixed OMS and RCS loading with more propellant allotted for pre-MECO burn

Consider AOA time capability variation by method (a). A 1000-pound OMS and RCS off loading (with 1000 LB post-MECO requirement reduction) results in an increase of 926 pounds of SSME propellant at MECO. This is equivalent to a 3.7 second reduction in earliest AOA time.

Using method (b) as a control element with fixed OMS and RCS loadings, allowing 1000 pounds more propellant to be burned pre-MECO results in 1130 pounds of SSME propellant at MECO. This is equivalent to a 4.52 second reduction in earliest AOA time.

It should be noted that extremely large variations in the OMS and RCS loadings are required if this would be the only element employed to reduce earliest AOA time from its present value to liftoff.

5.0 Nominal Profile

As part of this analysis, a nominal profile was developed. The first stage steering profile for the nominal trajectory is the attitude/relative velocity history of the AOA trajectory. This results in a lofted profile for the nominal trajectory. Figure 8 illustrates the altitude histories for the nominal and AOA profiles. One result of the lofted nominal trajectory is a reduction in maximum dynamic pressure. Figure 9 contains dynamic pressure histories for the nominal and AOA trajectories. Tables V and VI contain trajectory data for the two boost profiles. Table V contains data for the time of maximum dynamic pressure and Table VI contains data for MECO. The targeted guidance cutoff conditions are also included in Table VI. Data of Table V indicate a 600 ft/sec variation in staging velocity between the nominal and AOA profiles. Since first stage steering for the nominal trajectory is derived from the AOA profile, nominal steering commands for the last 600 ft/sec velocity region had to be obtained. Figure 10 contains vehicle attitude commands as a function of relative velocity. Five candidate profiles are indicated to cover the velocity gap from AOA SRB separation to nominal SRB separation.

The attitude profile numbered 5 in Figure 10 is selected for use in the nominal trajectory of this study. Selection of profile 5 is based on obtaining a continuous pitch over rate during the region in question. However, profile 5 does not provide maximum nominal performance. Figures 11 and 12 indicate the effects of using steering profiles 1 through 5.

Profiles 1 through 4 are indicative of a pitch down maneuver. Since the nominal trajectory has been lofted by optimum AOA steering commands up to a velocity of 3600 ft/sec, a pitch down maneuver during the terminal phase of first stage flight increases vehicle performance. (See SSME propellant at MECO, Figure 11.) The data of Figures 11 and 12 indicate pitching the vehicle down during the last portion of SRB flight has the following effects:

a. increases performance

b. decreases separation altitude and flight-path angle

c. increases separation velocity and dynamic pressure

d. decreases the initial guidance pitch command

Since the nominal profile in this study is not performance critical, no further investigation of the pitch down maneuver was conducted. This item may be pursued at a later date when the definition of acceptable SRB staging conditions are obtained.

6.0 Effects of Engine Out at Later Than Design Times

As previously stated, the profiles in this study are designed for the engine out case. The nominal trajectory uses first stage steering commands from the engine out (AOA) profile. Several trajectories were simulated to evaluate the effects of designing first stage steering for earliest AOA time and having the engine go out at a later time.

Figures 13 and 14 illustrate the effects of engine out after the design (earliest) point. Figure 13 indicates the variation in vehicle state at SRB separation as a function of engine out time. The first stage steering profile used in all the simulations is optimized for an engine out time of 24 seconds. Data are presented in the figure to indicate staging velocity, flight-path angle and altitude of the nominal trajectory, the nominal profile being the limiting case for delayed engine out (i.e.

time of delayed engine out is MECO time). Similarly, Figure 14 presents variations at MECO for engine out later than the earliest AOA time. The data indicate performance increases (SSME propellant at MECO) from the zero value for engine out at 24.4 seconds toward the nominal trajectory value. Range at MECO shows little variation for the engine out times of Figure 14.

7.0 Conclusions and Recommendations

The earliest AOA time for OFT-1 is 24.4 seconds as the vehicle is currently configured (10000 pound payload). Engine out off the pad capability has been reduced to a payload of approximately 3400 pounds. The increase in earliest AOA time and decrease in maximum payload for engine out on the pad are a result of updated evaluations of 1) aerodynamic predictions and vehicle weights and 2) a change in groundrules governing SSME operation. The trade factors for earliest AOA time as a function of SSME propellant at MECO and the parametric data of this report should provide a data base for predicting AOA time as updates are made in the OFT-1 vehicle.

It is recommended that the engine out and nominal profiles of this study be evaluated relative to load constraints. Throttling may be necessary to reduce maximum dynamic pressure in the nominal trajectory. The earliest AOA time may be effected by having to adhere to a constraint profile.

TABLE I FIRST MANNED ORBITAL FLIGHT

SUMMARY WEIGHT STATEMENT

	Nominal - LB		AOA - LB
Payload (Development Flight Instrumentation (DFI) Pallet etc.)	10,000		10,000
Personnel	1,000		1,000
Orbiter - Empty	132,597		132,597
- Non Propulsive Consumables	4,175		4,175
- Usable RCS	5,534		4,852
- RCS Reserves	1,209		0
- RCS Residuals	394		394
- OMS Propellant (On Orbit)	3,468		0
- OMS Propellant (De-Orbit)	5,213		0
- OMS Reserves	800		800
- OMS Residuals	557		557
SSME Empty	19,338		19,338
Trapped L H_2 at OMS 1 Cutoff	0		0
Trapped L OX at OMS 2 Cutoff	0		0
Orbiter at OMS 2 Cutoff	(184,285)		(173,713)
MECO OMS Cutoff - OMS 2 Propellant	2,598	(141 FT/SEC)	0
- OMS 1 Propellant	2,537	(133 FT/SEC)	4,919
- RCS Propellant	0		280
Trapped MPS Propellant - Orbiter	1,075		1,804
- SSME	1,366		1,366
Flight Performance Reserve (FPR) - Orbiter	2,584		1,854
Orbiter at OMS 1 Ignition	(194,445)		(183,936)
RCS Propellant	254		254
External Tank (ET) - Empty	75,633		75,633
- Residuals	4,055		4,341
Flight Performance Reserve - ET	2,616		3,346
Fuel Bias	1,225		1,100
Excess MPS Propellant	(1)		(1)
Expelled MPS Propellant (Tailoff)	183		122
Injected Weight at MECO	((2))		((2))

TABLE I SUMMARY WEIGHT STATEMENT (cont.)

	Nominal	AOA
Propellant Burned -		
AOA/RTLS (Return to Launch Site) to MECO		
MPS	①	①
OMS	0	8,897
RCS	0	1,611
OMS Propellant Dumped (RCS Burn)	0	0
Expelled MPS Propellant	0	51
Weight at AOA/RTLS	(②)	
MPS Propellant Burned (SRB Sep to AOA/RTLS)	①	
Weight After SRB Separation	(②)	
SRB Structure and Recovery System	69,200	
SRM Inert Weight	281,680	
SRM Residual Propellant	550	
Inerts Consumed	10,138	
SRM Propellant Consumed	2,211,570	
MPS Propellant Burned (Liftoff to SRS Sep)	①	
Liftoff (Thrust/Weight = 1.0)	4,399,184	
SRB Propellants	1,236	
SRB Inerts	2	
MPS Propellant	976	
SRB Ignition Command (T-0)	4,401,398	
MPS Thrust Buildup	3,039	
LO_2 Overboard Bleed (3 minutes)	2,160	
Non-Propulsive Consumables	51	
Prelaunch Weight (T-5 min.)	4,406,648	

① - The sum of these weights should be equal to total usable MPS Prop.

② - These weights can only be determined after the trajectory is flown.

TABLE II <u>OFT MPS PROPELLANT SUMMARY</u>

	Nominal - LB	AOA - LB
TOTAL LOADED MPS	1,561,715	1,561,715
RESIDUALS - ET	- 4,055	- 4,341
TRAPPED SSME MPS	- 1,366	- 1,366
TRAPPED ORBITER MPS	- 1,075	- 1,804
EXPELLED MPS	- 183	- 183
FPR - ET	- 2,616	- 3,346
FPR - ORBITER	- 2,584	- 1,854
SRB IGNITION TO LIFTOFF	- 976	- 976
FUEL BIAS	- 1,225	- 1,100
USABLE MPS PROPELLANT	1,547,635	1,546,745

TABLE III OFT OMS PROPELLANT SUMMARY

	Nominal - LB	AOA - LB
ON ORBIT OMS	3,468	0
DEORBIT OMS	5,213	0
OMS RESERVES	800	800
MECO OMS 2	2,598	0
MECO OMS 1	2,537	4,919
AOA/RTLS TO MECO	0	8,897
TOTAL OMS LOAD	15,173	15,173

OFT RCS PROPELLANT SUMMARY

	Nominal - LB	AOA - LB
USABLE RCS	5,534	4,852
RCS RESERVES	1,209	0
RCS RESIDUALS	394	394
MECO RCS	0	280
ET SEPARATION RCS	254	254
AOA/RTLS TO MECO	0	1,611
TOTAL RCS LOAD	7,391	7,391

TABLE IV SOLID ROCKET MOTOR PROPULSION DATA
(270 - 75 SRM)

70 SRM THRUST AND FLOW RATE

TIME	THRUST	FLOW RATE	WEIGHT(LBS)	PROP.	TOTAL PROP.
0.090000	26.4	0.1	1287188.0	0.0	0.0
0.098497	108640.3	414.3	[illegible]	20.4	20.4
0.196993	525940.9	2001.2	1287048.6	119.0	139.4
[illegible]	[illegible]	6944.2	[illegible]	[illegible]	[illegible]
[illegible]	1929127.0	7322.5	[illegible]	105.4	[illegible]
[illegible]	2498727.1	9485.3	1285799.1	703.6	1388.9
[illegible]	2760682.3	10481.3	1284015.8	983.3	2372.2
0.590980	2875414.6	10918.6	1283761.9	1053.9	3426.1
0.689477	2927196.4	11115.2	1282676.7	1085.1	4511.3
0.787973	2951564.3	11208.5	1281577.3	1099.4	5610.7
0.886470	2962732.9	11255.2	1280471.0	1106.3	6717.0
0.984970	2977455.2	11312.0	1279359.6	1111.4	7928.4
1.969931	3002830.5	11421.0	1268164.0	11195.6	19024.0
3.939872	3055635.6	11629.0	1245460.4	22703.6	41727.6
5.909803	3101325.5	11801.9	1222381.8	23078.6	64806.2
7.879734	3125693.4	11895.1	1199041.1	23340.7	88146.9
9.849704	3150061.3	11990.1	1175514.5	23526.6	111673.5
11.819605	3170367.9	12066.5	1151819.9	23694.6	135368.1
13.789507	3188643.9	12138.0	1127979.7	23840.2	159208.3
15.759507	3205904.5	12206.4	1104000.5	23979.2	183187.5
17.729408	3223165.1	12274.9	1079887.6	24112.9	207300.4
19.699310	3232947.9	12317.4	1055665.4	24222.2	231522.6
21.669211	3114270.9	11872.2	1031839.9	23825.5	255348.1
23.505560	3024343.2	11536.2	1010347.0	21492.9	276841.0
25.342007	2935583.0	11205.0	989465.5	20881.5	297722.5
27.178356	2884095.6	11015.5	969063.3	20402.3	318124.7
29.014705	2835613.6	10837.7	948998.2	20065.1	338189.8
30.851053	2788665.7	10659.3	929260.1	19738.1	357927.9
32.687501	2739350.2	10480.2	909849.2	19410.9	377338.8
34.523849	2669820.4	10217.8	890844.8	19004.4	396343.2
36.360198	2601377.0	9960.8	872317.4	18527.4	414870.6
38.196547	2531847.2	9697.5	854267.7	18049.7	432920.3
40.032896	2463403.8	9440.1	836696.0	17571.7	450492.0
41.869244	2407997.2	9233.1	819550.7	17145.3	467637.3
43.705593	2369973.1	9088.4	802728.4	16822.3	484459.6

TABLE IV SOLID ROCKET MOTOR PROPULSION DATA (con't.)

45.541942	2331949.0	8943.9	786171.7	16556.8	501016.3
47.378291	2293924.9	8800.8	[illegible]	16292.7	517309.1
49.214640	2255900.8	8658.8	753846.0	16031.0	533340.0
51.051087	2270024.0	8707.0	737902.2	15945.7	549285.8
52.887436	2289579.3	8784.4	721842.1	16060.2	565345.9
54.723784	2302616.1	8833.4	705665.8	16176.2	581522.2
56.560133	2315653.0	8881.7	689400.3	16265.6	597787.7
58.396580	2328689.8	8928.3	673046.6	16353.6	614141.4
60.342353	2352590.7	9022.8	655583.2	17463.5	631604.8
62.287820	2380837.2	9131.7	637922.7	17660.4	649265.3
64.233500	2410170.0	9240.4	620049.7	17873.0	667138.3
66.179272	2439502.9	9352.0	601961.4	18088.3	685226.6
68.124945	2463403.8	9445.6	583674.4	18287.0	703513.6
70.070617	2482959.1	9518.4	565225.6	18448.8	721962.4
72.016192	2501427.9	9592.0	546635.3	18590.3	740552.7
73.961865	2520083.2	9664.8	527901.5	18733.8	759286.5
75.907636	2540538.4	9738.7	509024.1	18877.4	778163.9
77.853309	2555748.1	9796.3	490019.8	19004.3	797168.2
78.797146	2563129.5	9826.2	480759.7	9260.1	806428.3
88.[illegible]	2351608.4	9019.4	388001.8	92757.9	899186.2
98.[illegible]	2140598.9	8212.1	303145.0	84856.8	99[illegible]043.0
110.[illegible]	1877680.2	7207.9	20867[illegible]	94471.9	1078514.9
111.138251	1852713.3	7111.6	205845.4	2827.7	1081342.6
112.[illegible]152	1677905.1	6445.5	199169.2	6676.2	1088018.8
113.168054	1453465.2	5585.9	193244.3	5924.9	10[illegible]943.7
114.[illegible]	11[illegible]8	4398.9	18[illegible]27.2	[illegible]17.0	10[illegible]860.8
115.[illegible]	9[illegible].0	365[illegible].0	18[illegible]	[illegible].6	[illegible]
116.[illegible]	771149.2	2977.3	181694.0	3264.6	1106094.0
117.[illegible]	558351.3	2159.4	178564.4	2529.6	1108623.6
118.[illegible]	305531.1	1187.6	176316.2	1643.2	1110271.8
118.[illegible]	197100.1	767.7	176434.7	481.4	1110753.[illegible]
119.[illegible]	120064.8	465.5	176130.3	304.4	[illegible]
119.264673	97613.8	381.8	176025.6	104.7	1111162.4
119.510398	74186.1	290.9	175942.0	82.8	1111245.2
120.003349	43926.2	172.7	175828.7	114.1	1111359.3
120.495799	27331.7	109.3	175759.2	69.4	1111428.8
120.959314	19897.8	79.6	175715.4	43.8	1111472.6

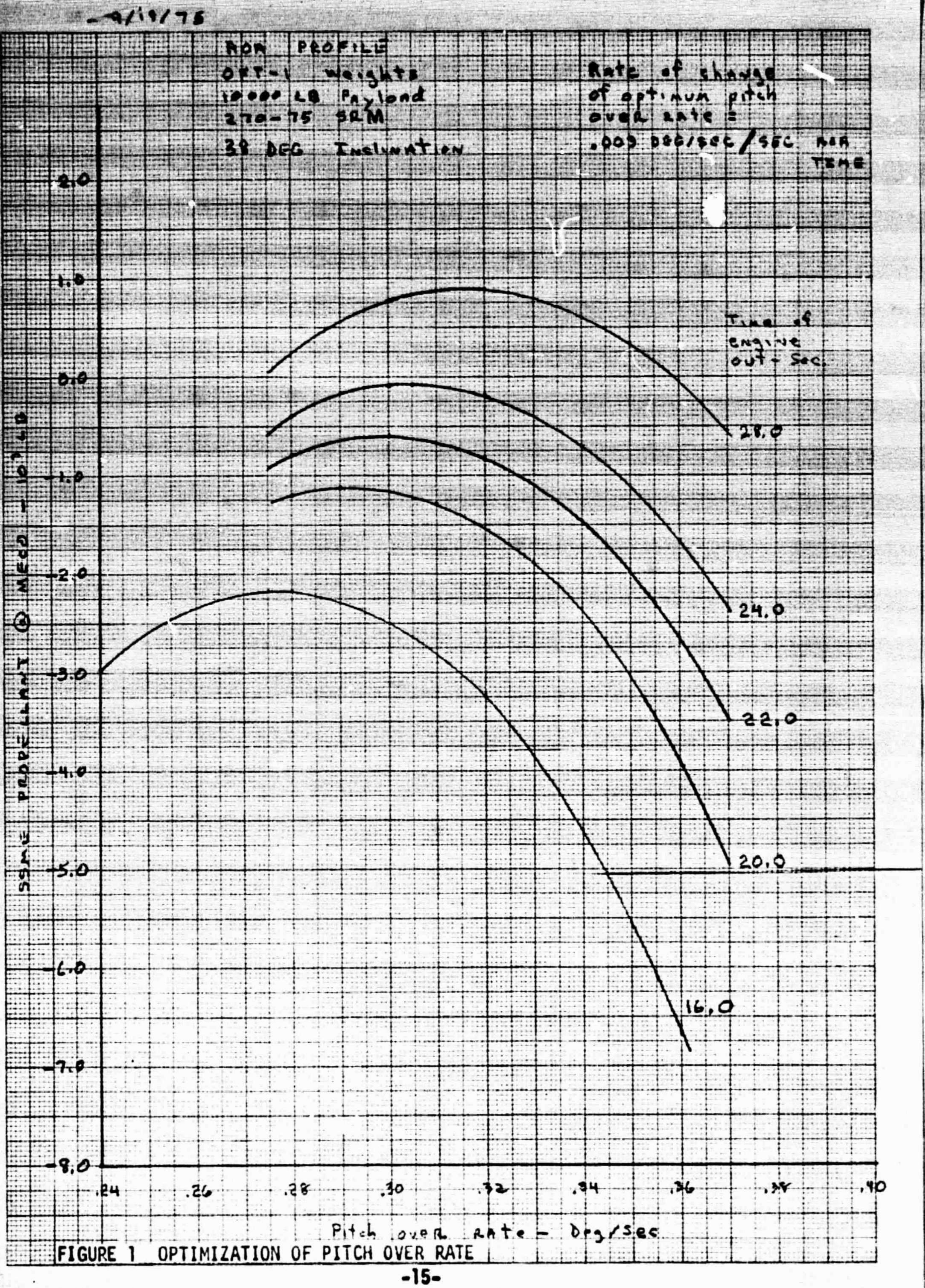

FIGURE 1 OPTIMIZATION OF PITCH OVER RATE

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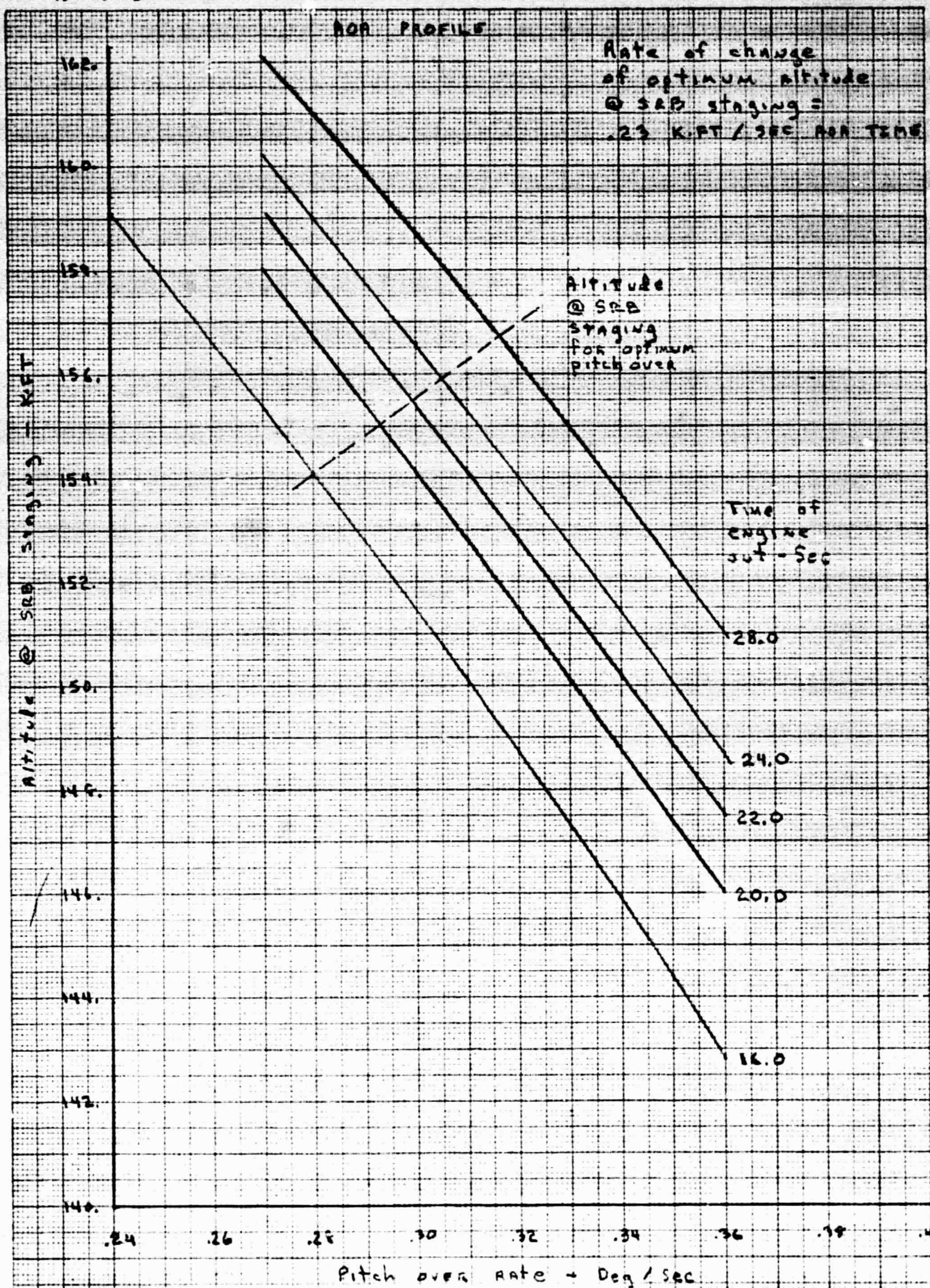

FIGURE 2 VARIATION IN SRB STAGING ALTITUDE

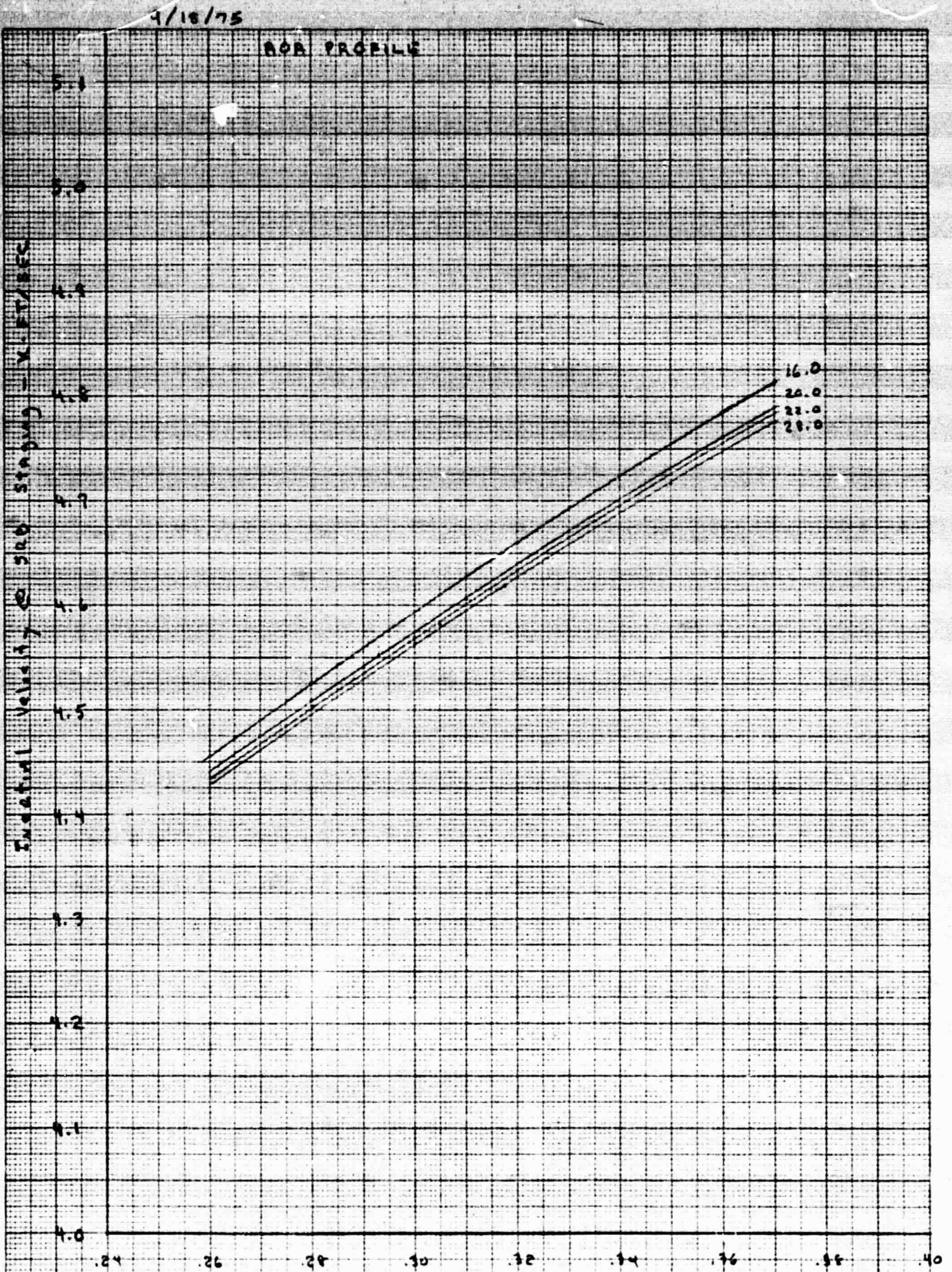

FIGURE 3 VARIATION IN SRB STAGING VELOCITY

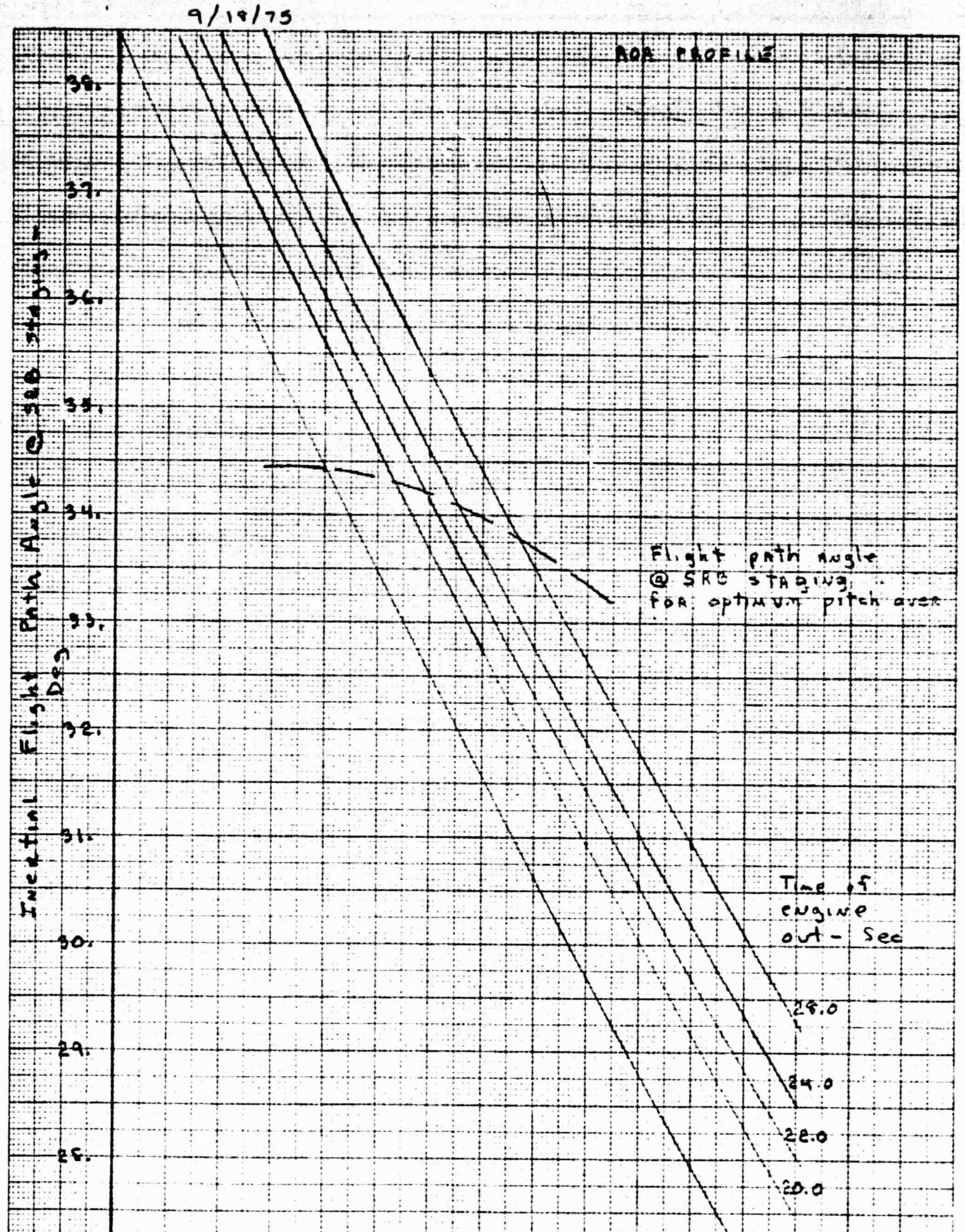

FIGURE 4 VARIATION IN SRB STAGING FLIGHT-PATH ANGLE

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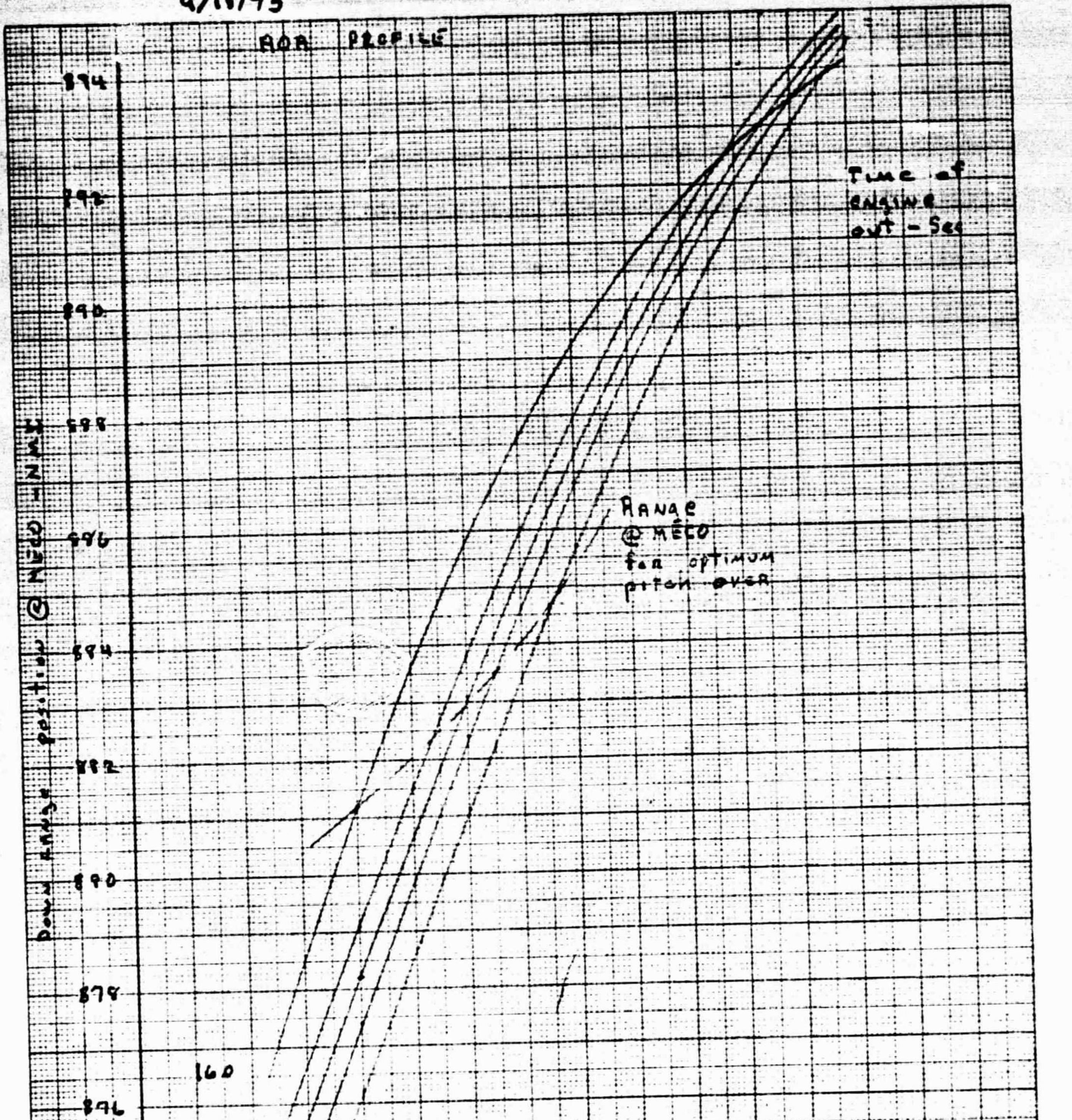

FIGURE 5 VARIATION IN DOWNRANGE POSITION AT MECO

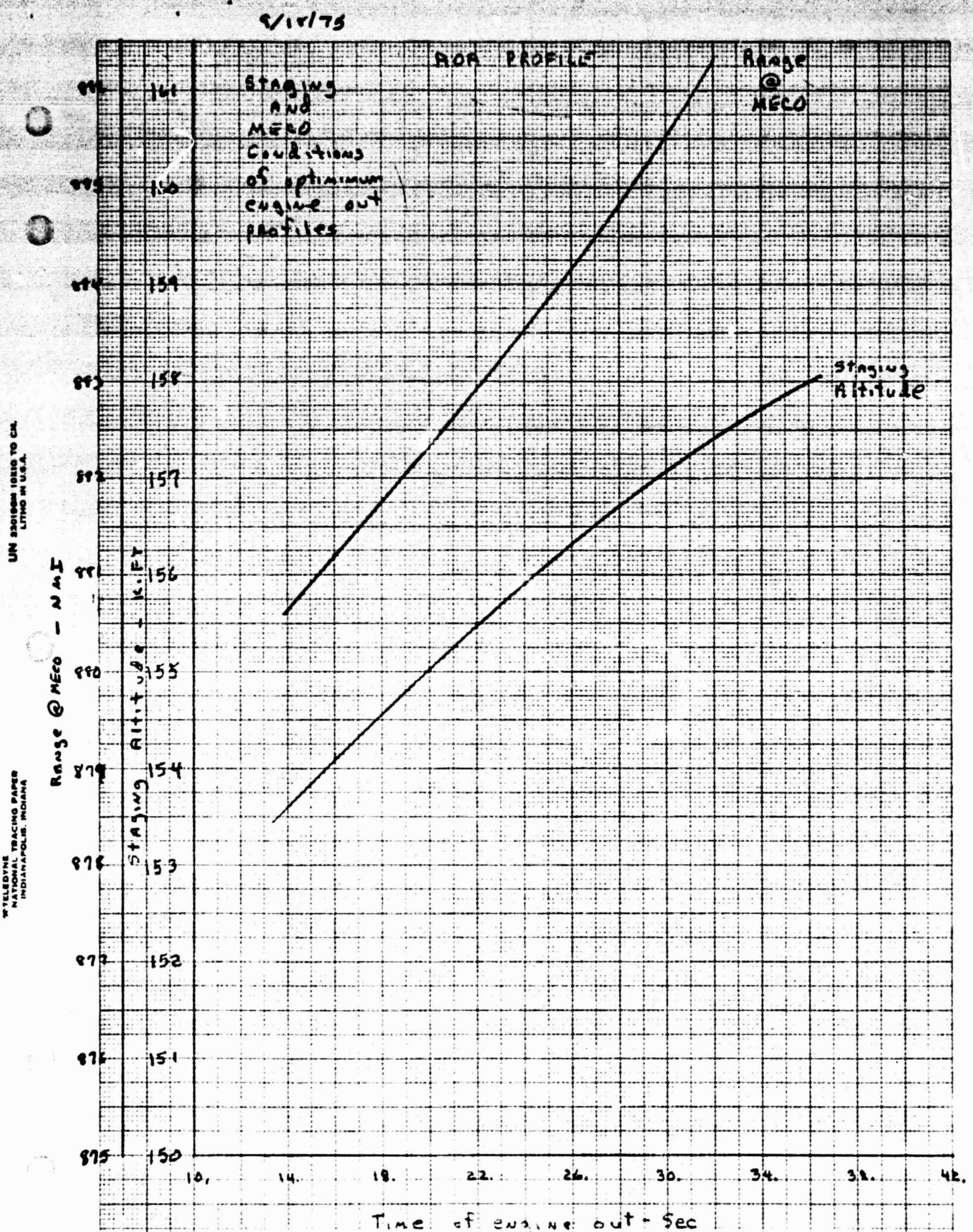

FIGURE 6 MECO RANGE AND STAGING ALTITUDE FOR ENGINE OUT TIMES

9/10/75

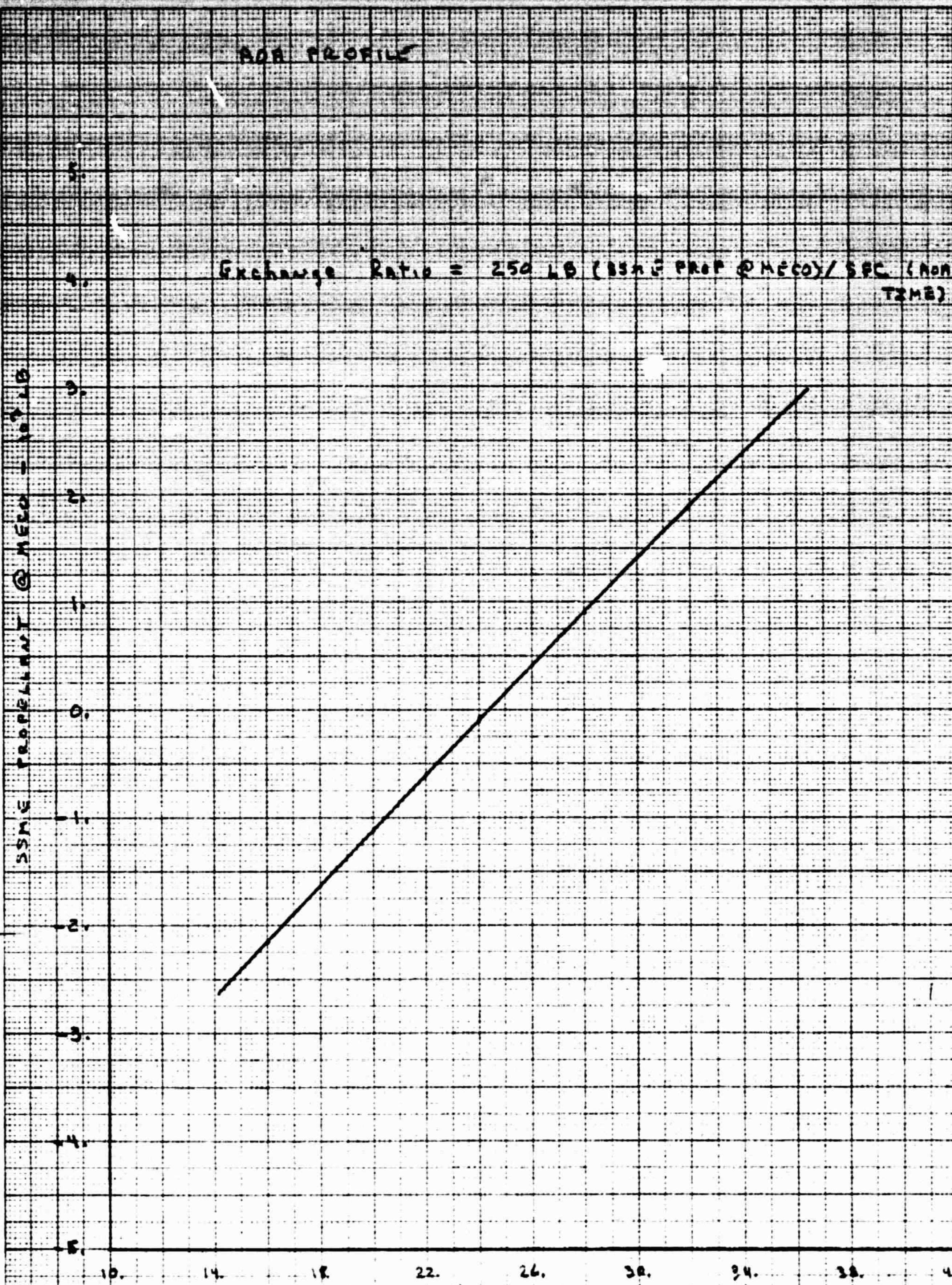

FIGURE 7 SSME PROPELLANT AT MECO FOR AOA

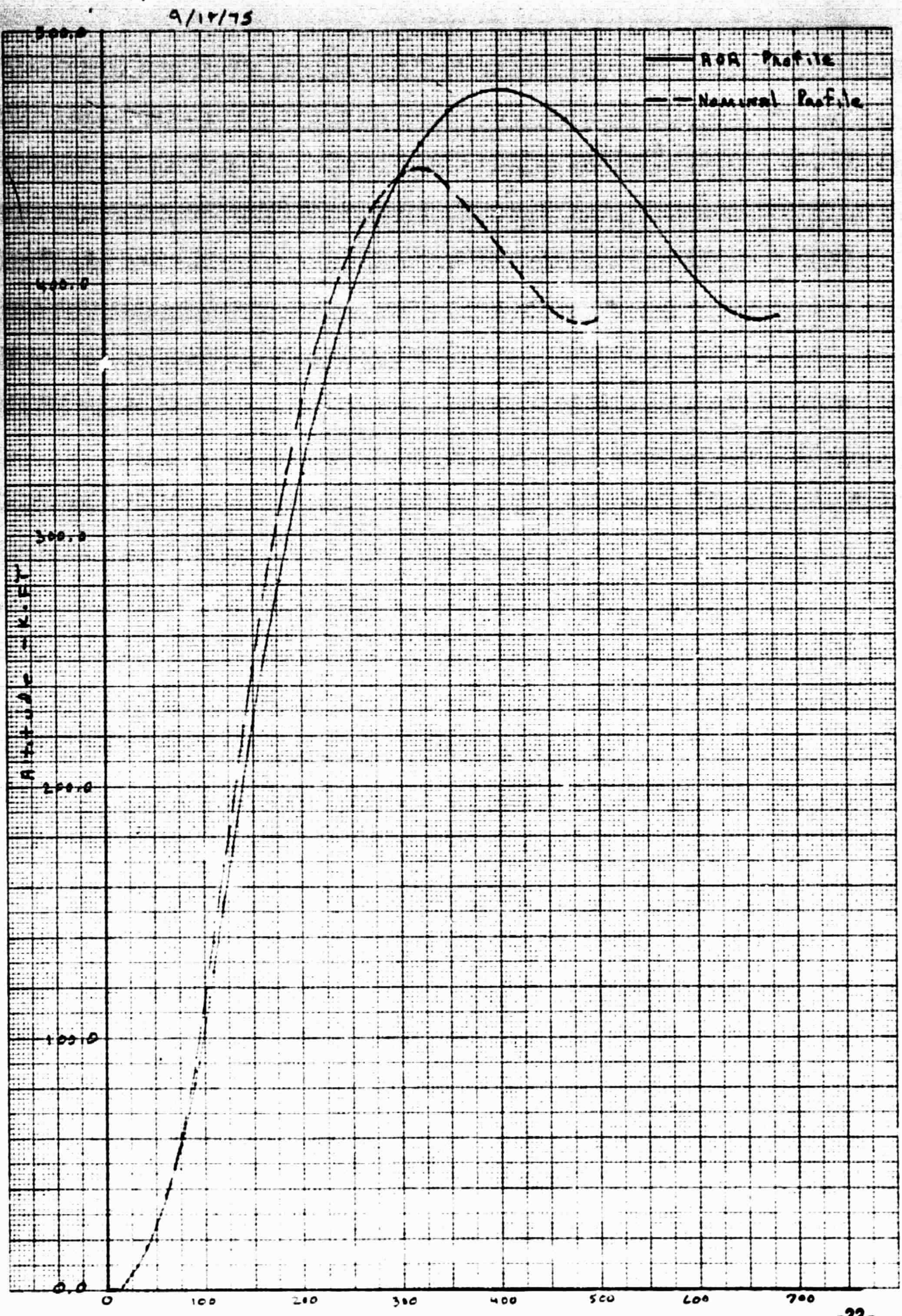

FIGURE 8 ALTITUDE HISTORY - NOMINAL AND AOA

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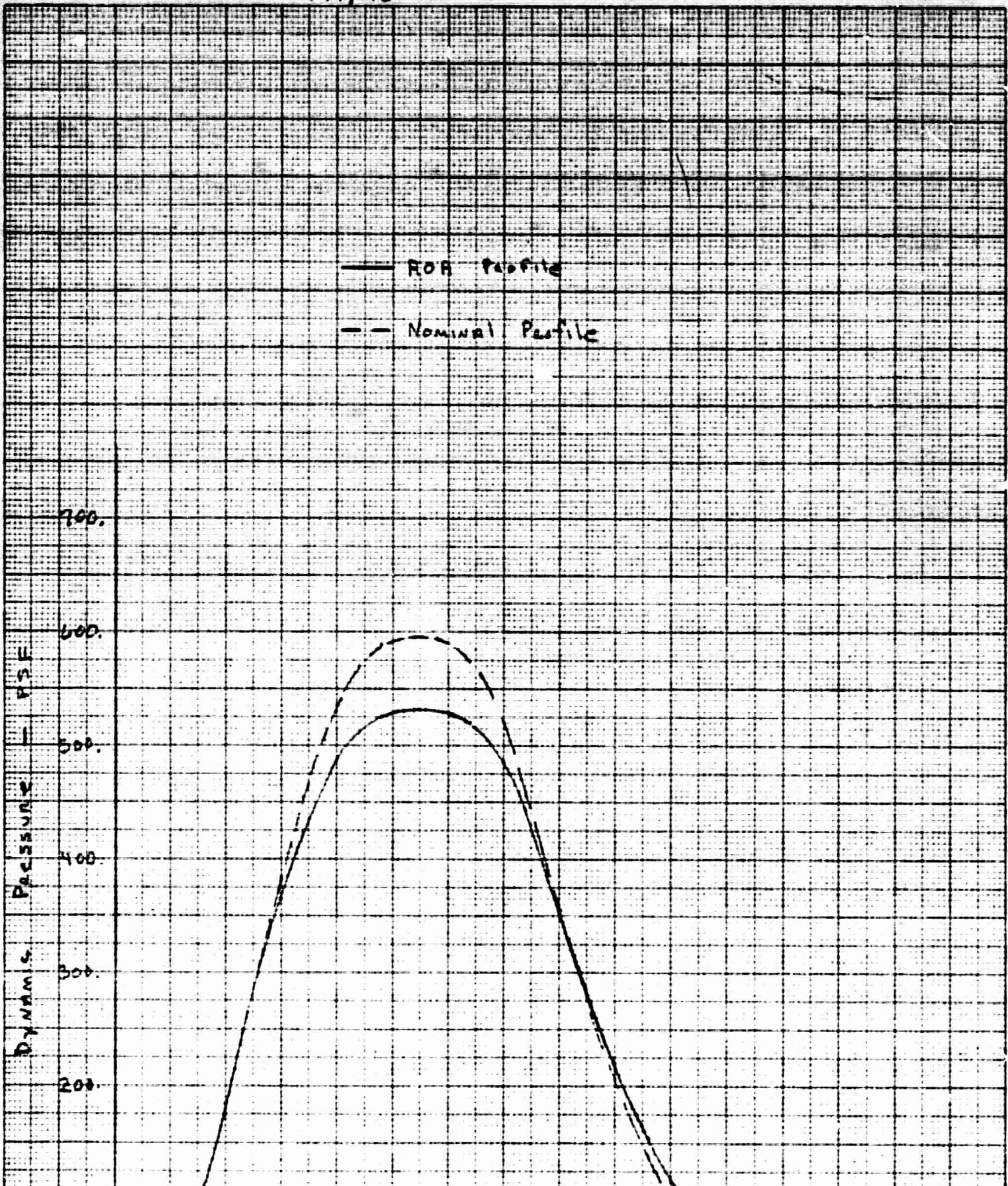

FIGURE 9 DYNAMIC PRESSURE HISTORY - NOMINAL AND AOA

TABLE V

VEHICLE STATE AT MAXIMUM DYNAMIC PRESSURE AND SOLID ROCKET BOOSTER STAGING

I. Maximum Dynamic Pressure

	Nominal	AOA
Time - SEC	56.	56.
Altitude - FT	33144.	31769.
Inertial Velocity - FT/SEC	2042.	1959.
Inertial Flight-Path Angle - DEG	34.30	33.03
Dynamic Pressure - LB/FT^2	596.	532.

II. SRB Staging

	Nominal	AOA
Time - SEC	121.23	121.23
Altitude - FT	171046.	156132.
Inertial Velocity - FT/SEC	5153.	4579.
Inertial Flight-Path Angle - DEG	34.63	34.21
Dynamic Pressure - LB/FT^2	15.	19.
Range - NMI	[illegible].59	15.11

TABLE VI

VEHICLE STATE AT MAIN ENGINE CUTOFF (MECO)

I. Trajectory Cutoff Conditions

Altitude	60. NMI
Inertial Flight-Path Angle	0.5 DEG
Inertial Velocity	25668. FT/SEC

II. Vehicle MECO State

	Nominal	AOA
Time - SEC	498.184	682.610
Weight - LB	315639.	268733.
Inertial Velocity - FT/SEC	25667.1	25667.6
Inertial Flight-Path Angle - DEG	0.506	0.502
Inclination - DEG	38.01	37.92
Latitude - DEG		
Geocentric	33.2721	34.2679
Geodetic	33.4456	34.4439
Longitude - DEG	-68.1931	-64.7499
Radius - FT	21290308.	21290308.
Inertial Azimuth - DEG	70.4650	72.6569
Range - NMI	701.62	883.46

9/18/75

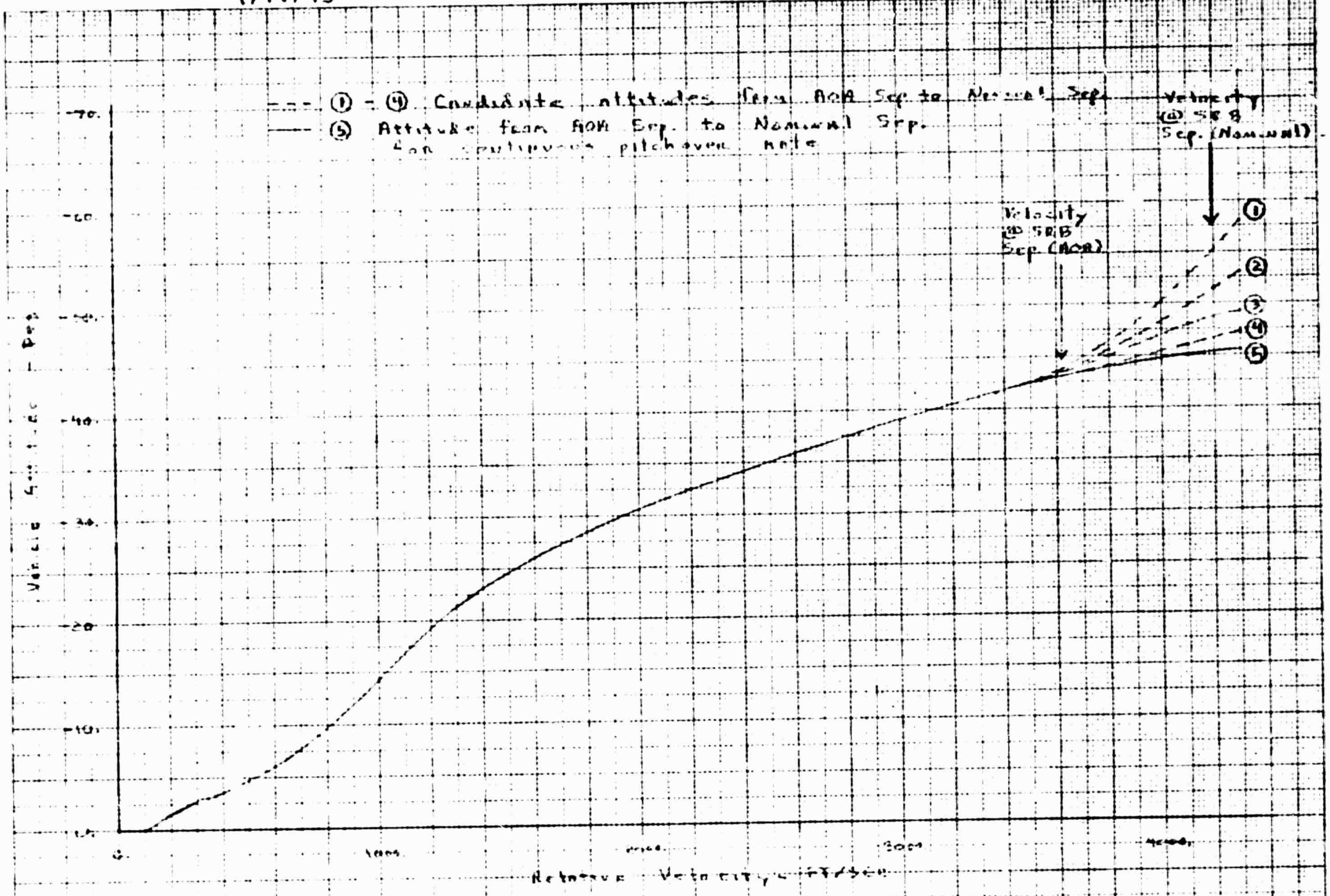

FIGURE 10 VEHICLE FIRST STAGE ATTITUDE HISTORY

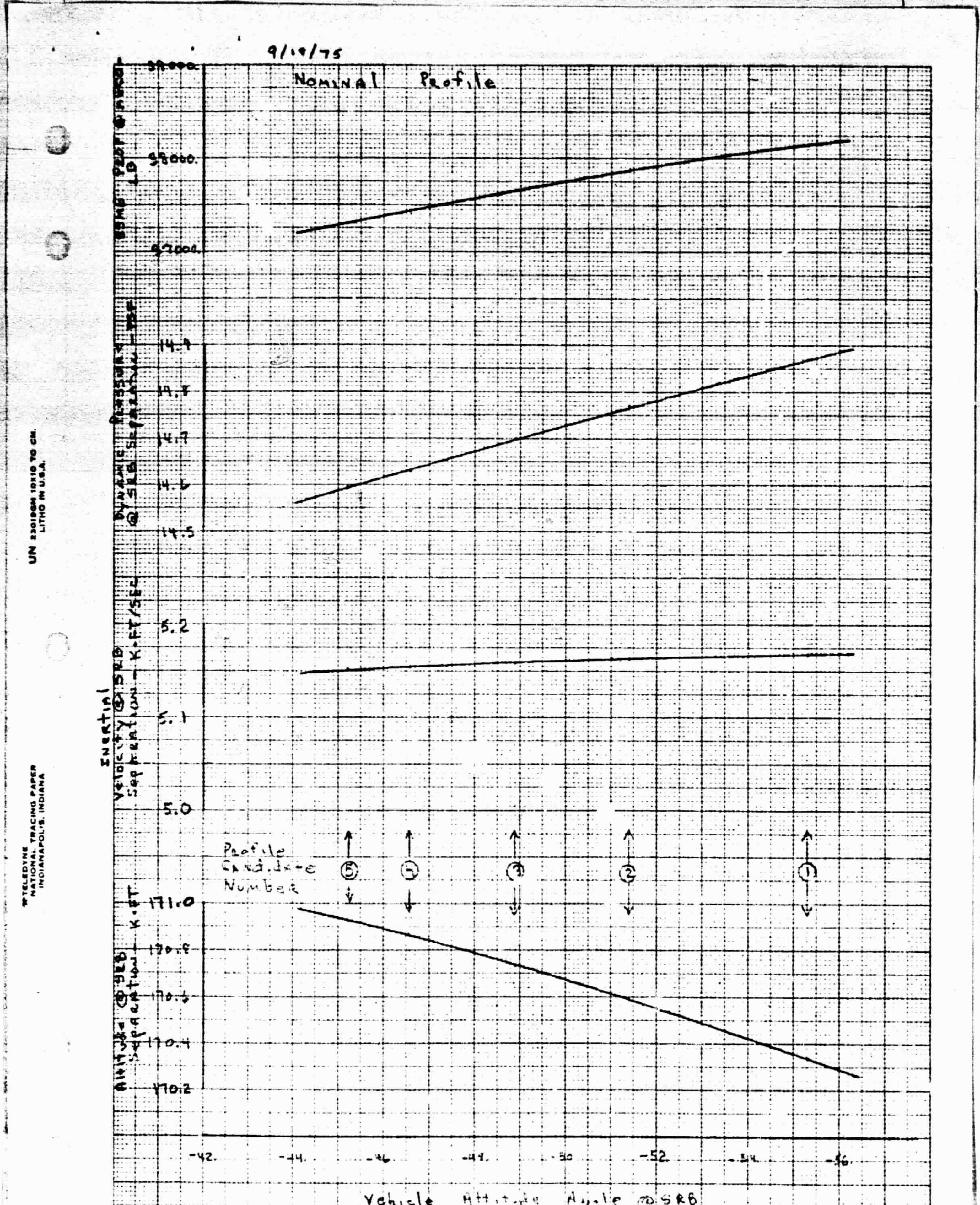

FIGURE 11 RESULTS OF ATTITUDE STEERING ANALYSIS - 1

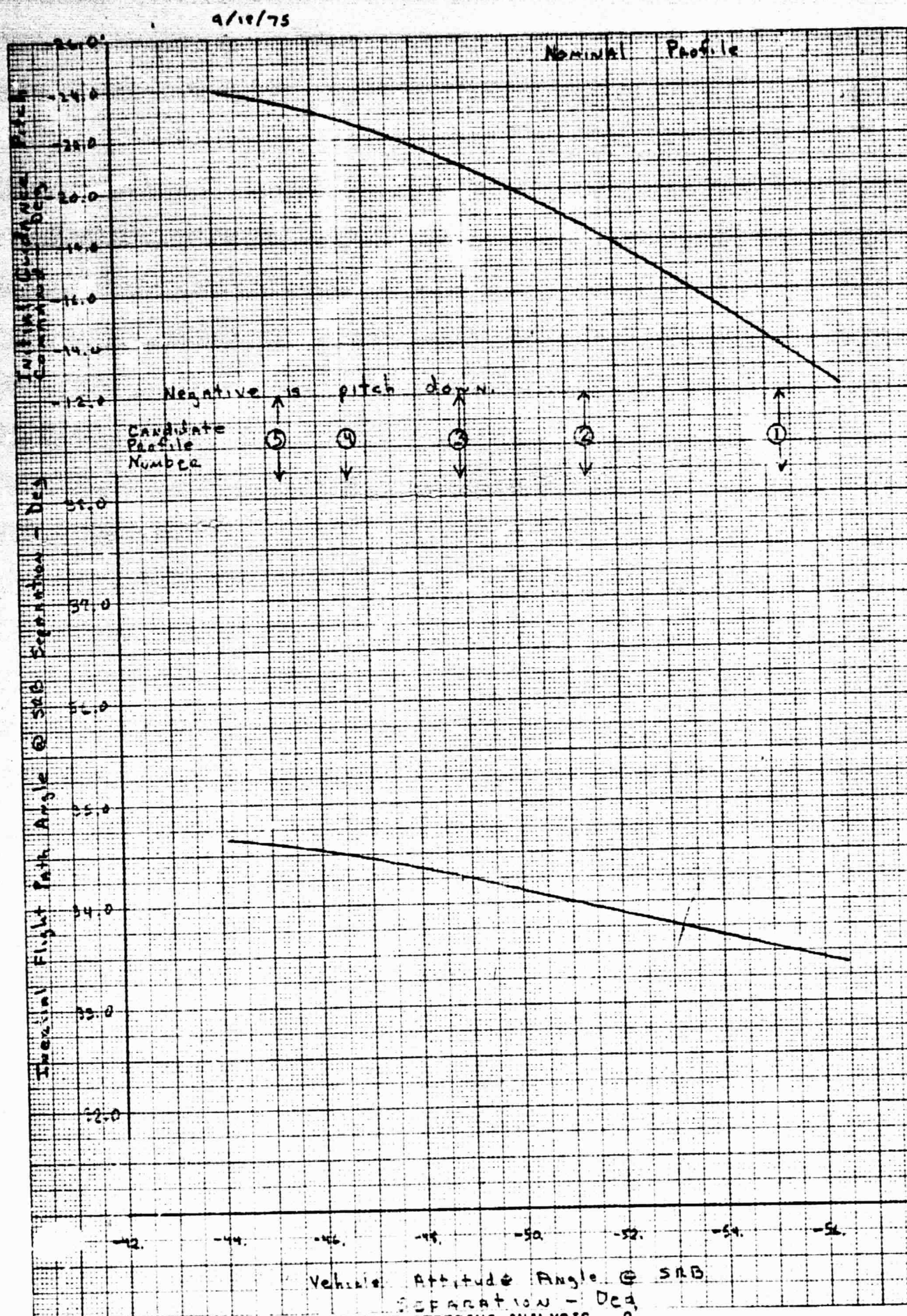

FIGURE 12 RESULTS OF ATTITUDE STEERING ANALYSIS - 2

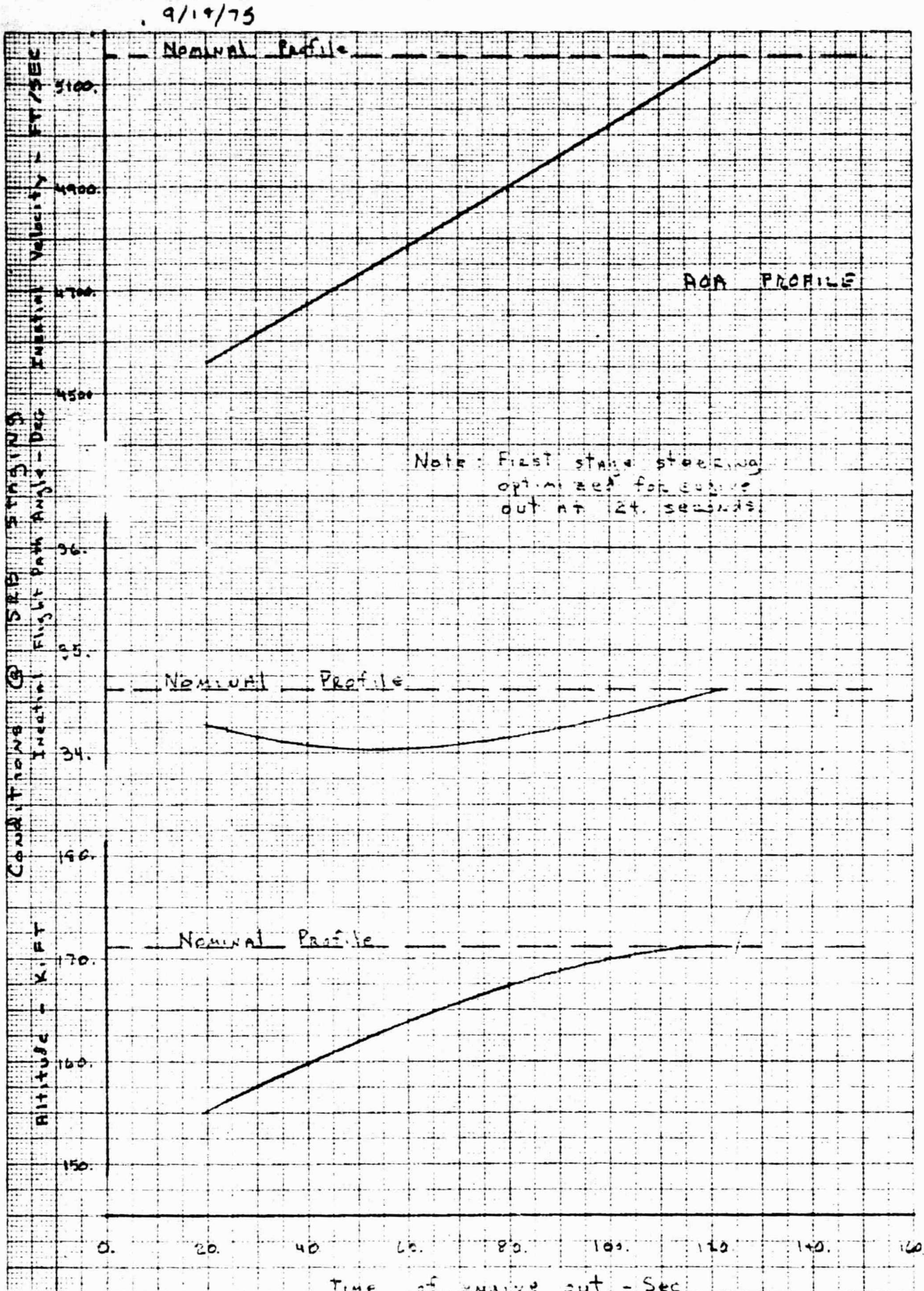

FIGURE 13 VEHICLE STATE AT SRB SEPARATION

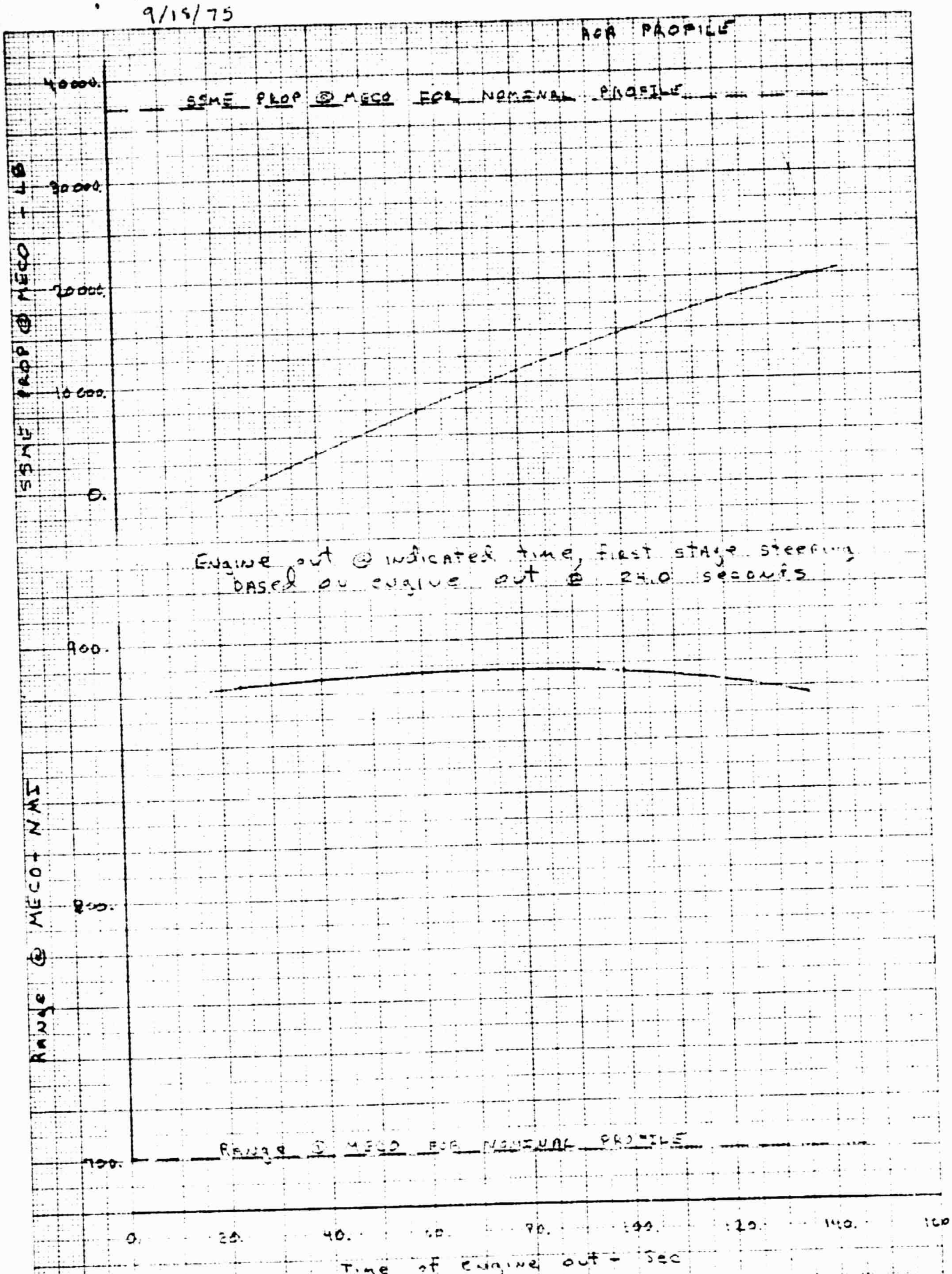

FIGURE 14 VARIATIONS AT MECO FOR DELAYED ENGINE OUT

END

DATE

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