V.2

AEROSPACE ENGINEERING
AE449 Senior Design Project III
Auburn University, Alabama

FINAL STUDY REPORT FOR THE SPACE SHUTTLE II ADVANCED SPACE TRANSPORTATION SYSTEM

Volume II: Technical Report

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1.0 Configuration Determination

To determine the best configuration from all candidate configurations, it was necessary first to calculate minimum system weights and performance. To optimize the design, it is necesary to vary configuration-specific variables such as total system weight, thrust-to-weight ratios, burn durations, total thrust available, and mass fraction for the system. Optimizing each of these variables at the same time is technically unfeasible and not necessarily mathematically possible. However, discrete sets of data can be generated which will eliminate many candidate configurations. From the most promising remaining designs, a final configuration can be selected.

To ease this optimization process an interactive spreadsheet was created. It accepted initial thrust to weight ratios, number of main engines, vehicle dry weight , and initial (pre-separation) burn time. From this information, it calculated maximum weights and propellant mass fractions available for each vehicle and the final post-separation burn time for the orbiter.

After selecting the number of engines and thrust to weight ratios for both the booster and the orbiter, the length of the initial burn was varied to maximize fuel available to the orbiter for the second phase burn. This maximum weight was then used to determine tank sizings which dictated total volume necessary within the booster and orbiter.

Included are the three most important designs considered: one which closely approximates the design criteria set forth in a Marshall Space Flight Center study of the Shuttle II; the configuration used in the initial proposal; and the final configuration presented and analyzed in this report. Note that these three systems represent important iterative steps in our final design.

A listing by cell of the formulas used to generate the aforementioned data is included for reference.

ORBITER DATA ---------------------------

Thrust/Weight	1.2000
Initial Boost Engines	4.00
Total Thrust at Takeoff	1,454,100.00 lbf
Available Takeoff Weight	1,211,750.00 lbm
Dry Weight	180,000.00 lbm
Payload	60,000.00 lbm
RCS Fuel (MMH/NO4)	20,000.00 lbm
Total Orbiter Weight	260,000.00 lbm
Maximum Fuel Weight	951,750.00 lbm
Fuel Available Initially	951,750.00 lbm
Initial Boost Engines	4.00
Initial Fuel Consumed	505,080.80 lbm
Primary Fuel Available	446,669.20 lbm
Auxilliary Fuel	496,952.57 lbm
Total Fuel Available	943,621.77 lbm
Final Boost Engines	4.00
Approximate Final Thrust	1,740,000.00 lbf
Approximate Final T/W	1.4456

BOOSTER DATA ---------------------------

Thrust/Weight	1.4000
Initial Boost Engines	5.00
Total Thrust at Takeoff	1,817,625.00 lbf
Available Takeoff Weight	1,298,303.57 lbm
Dry Weight	160,000.00 lbm
RCS Fuel (MMH/NO4)	10,000.00 lbm
Total Booster Weight	170,000.00 lbm
Fuel Weight	1,128,303.57 lbm
Fuel Available Initially	1,128,303.57 lbm
Initial Boost Engines	5.00
Initial Boost Fuel	631,351.00 lbm
Reservoir Fuel Pumped	496,952.57 lbm

OVERALL DATA ---------------------------

Thrust/Weight	1.3034
Initial Boost Engines	9.00
Total Thrust at Takeoff	3,271,725.00 lbf
Available Takeoff Weight	2,510,053.57 lbm
Dry Weight	340,000.00 lbm
Payload	60,000.00 lbm
RCS Fuel (MMH/NO4)	30,000.00 lbm
Total Dry Weight	430,000.00 lbm
Fuel Weight	2,080,053.57 lbm
Fuel Available Initially	2,080,053.57 lbm
Initial Boost Engines	9.00
Initial Boost Fuel	1,136,431.80 lbm
Fuel Available Finally	943,621.77 lbm

Initial Boost Burn Time	*133.00* sec
Final Boost Burn Time	248.48 sec
Total Burn Time	381.48 sec
Tsl	*363,525.00* lbf
Tvac	*435,000.00* lbf
Wdot	*949.40* lbm/sec
SG - Hydrogen	*0.0700* ft^3
SG - Oxygen	*1.1490* ft^3
Density of Water	*62.43* lbm/ft^3
Max Fuel - Hydrogen	135,964.29 lbm
Max Fuel - Oxygen	815,785.71 lbm
Volume - Hydrogen	31,112.40 ft^3
Volume - Oxygen	11,372.68 ft^3
Total Volume	42,485.07 ft^3
Eq. Hydrogen Tanks	88.0301 ft
Eq. Oxygen Tanks	21.4203 ft
Minimum Length Necessary	109.4504 ft

Max Fuel - Hydrogen	161,186.22 lbm
Max Fuel - Oxygen	967,117.35 lbm
Volume - Hydrogen	36,883.88 ft^3
Volume - Oxygen	13,482.36 ft^3
Total Volume	50,366.23 ft^3
Eq. Hydrogen Tanks	69.4704 ft
Eq. Oxygen Tanks	25.3939 ft
Minimum Length Necessary	94.8643 ft

ORBITER DATA

Thrust/Weight	1.2000
Initial Boost Engines	5.00
Total Thrust at Takeoff	**1,817,625.00** lbf
Available Takeoff Weight	**1,514,687.50** lbm
Dry Weight	180,000.00 lbm
Payload	60,000.00 lbm
RCS Fuel (MMH/NO4)	20,000.00 lbm
Total Orbiter Weight	**260,000.00** lbm
Maximum Fuel Weight	**1,254,687.50** lbm
Fuel Available Initially	**1,254,687.50** lbm
Initial Boost Engines	**5.00**
Initial Fuel Consumed	**564,893.00** lbm
Primary Fuel Available	**689,794.50** lbm
Auxilliary Fuel	**563,410.57** lbm
Total Fuel Available	**1,253,205.07** lbm
Final Boost Engines	4.00
Approximate Final Thrust	**1,740,000.00** lbf
Approximate Final T/W	**1.1499**

Initial Boost Burn Time	*119.00* sec
Final Boost Burn Time	**330.00** sec
Total Burn Time	**449.00** sec
Tsl	*363,525.00* lbf
Tvac	*435,000.00* lbf
Wdot	*949.40* lbm/sec
SG - Hydrogen	*0.0700* ft^3
SG - Oxygen	*1.1490* ft^3
Density of Water	*62.43* lbm/ft^3
Max Fuel - Hydrogen	**179,241.07** lbm
Max Fuel - Oxygen	**1,075,446.43** lbm
Volume - Hydrogen	**41,015.32** ft^3
Volume - Oxygen	**14,992.55** ft^3
Total Volume	**56,007.87** ft^3
Eq. Hydrogen Tanks	**116.0496** ft
Eq. Oxygen Tanks	**28.2383** ft
Minimum Length Necessary	**144.2879** ft

BOOSTER DATA

Thrust/Weight	1.4000
Initial Boost Engines	5.00
Total Thrust at Takeoff	**1,817,625.00** lbf
Available Takeoff Weight	**1,298,303.57** lbm
Dry Weight	160,000.00 lbm
RCS Fuel (MMH/NO4)	10,000.00 lbm
Total Booster Weight	**170,000.00** lbm
Fuel Weight	**1,128,303.57** lbm
Fuel Available Initially	**1,128,303.57** lbm
Initial Boost Engines	5.00
Initial Boost Fuel	**564,893.00** lbm
Reservoir Fuel Pumped	**563,410.57** lbm

Max Fuel - Hydrogen	**161,186.22** lbm
Max Fuel - Oxygen	**967,117.35** lbm
Volume - Hydrogen	**36,883.88** ft^3
Volume - Oxygen	**13,482.36** ft^3
Total Volume	**50,366.23** ft^3
Eq. Hydrogen Tanks	**69.4704** ft
Eq. Oxygen Tanks	**25.3939** ft
Minimum Length Necessary	**94.8643** ft

OVERALL DATA

Thrust/Weight	**1.2923**
Initial Boost Engines	**10.00**
Total Thrust at Takeoff	**3,635,250.00** lbf
Available Takeoff Weight	**2,812,991.07** lbm
Dry Weight	**340,000.00** lbm
Payload	**60,000.00** lbm
RCS Fuel (MMH/NO4)	**30,000.00** lbm
Total Dry Weight	**430,000.00** lbm
Fuel Weight	**2,382,991.07** lbm
Fuel Available Initially	**2,382,991.07** lbm
Initial Boost Engines	**10.00**
Initial Boost Fuel	**1,129,786.00** lbm
Fuel Available Finally	**1,253,205.07** lbm

ORBITER DATA ---------------------------

Thrust/Weight	1.2000	Initial Boost Burn Time	148.00 sec
Initial Boost Engines	4.00	Final Boost Burn Time	246.10 sec
Total Thrust at Takeoff	1,454,100.00 lbf	Total Burn Time	394.10 sec
Available Takeoff Weight	1,211,750.00 lbm		
Dry Weight	180,000.00 lbm	Tsl	363,525.00 lbf
Payload	60,000.00 lbm	Tvac	435,000.00 lbf
RCS Fuel (MMH/NO4)	20,000.00 lbm	Wdot	949.40 lbm/sec
Total Orbiter Weight	260,000.00 lbm	SG - Hydrogen	0.0700 ft^3
Maximum Fuel Weight	951,750.00 lbm	SG - Oxygen	1.1490 ft^3
		Density of Water	62.43 lbm/ft^3
Fuel Available Initially	951,750.00 lbm		
Initial Boost Engines	4.00	Max Fuel - Hydrogen	135,964.29 lbm
Initial Fuel Consumed	562,044.80 lbm	Max Fuel - Oxygen	815,785.71 lbm
Primary Fuel Available	389,705.20 lbm	Volume - Hydrogen	31,112.40 ft^3
Auxilliary Fuel	544,897.09 lbm	Volume - Oxygen	11,372.68 ft^3
Total Fuel Available	934,602.29 lbm	Total Volume	42,485.07 ft^3
Final Boost Engines	4.00	Eq. Hydrogen Tanks	88.0301 ft
Approximate Final Thrust	1,740,000.00 lbf	Eq. Oxygen Tanks	21.4203 ft
Approximate Final T/W	1.4566	Minimum Length Necessary	109.4504 ft

BOOSTER DATA ---------------------------

Thrust/Weight	1.4000		
Initial Boost Engines	6.00		
Total Thrust at Takeoff	2,181,150.00 lbf		
Available Takeoff Weight	1,557,964.29 lbm		
Dry Weight	160,000.00 lbm		
RCS Fuel (MMH/NO4)	10,000.00 lbm	Max Fuel - Hydrogen	198,280.61 lbm
Total Booster Weight	170,000.00 lbm	Max Fuel - Oxygen	1,189,683.67 lbm
Fuel Weight	1,387,964.29 lbm	Volume - Hydrogen	45,372.10 ft^3
		Volume - Oxygen	16,585.10 ft^3
Fuel Available Initially	1,387,964.29 lbm	Total Volume	61,957.20 ft^3
Initial Boost Engines	6.00	Eq. Hydrogen Tanks	85.4579 ft
Initial Boost Fuel	843,067.20 lbm	Eq. Oxygen Tanks	31.2379 ft
Reservoir Fuel Pumped	544,897.09 lbm	Minimum Length Necessary	116.6958 ft

OVERALL DATA ---------------------------

Thrust/Weight	1.3125
Initial Boost Engines	10.00
Total Thrust at Takeoff	3,635,250.00 lbf
Available Takeoff Weight	2,769,714.29 lbm
Dry Weight	340,000.00 lbm
Payload	60,000.00 lbm
RCS Fuel (MMH/NO4)	30,000.00 lbm
Total Dry Weight	430,000.00 lbm
Fuel Weight	2,339,714.29 lbm
Fuel Available Initially	2,339,714.29 lbm
Initial Boost Engines	10.00
Initial Boost Fuel	1,405,112.00 lbm
Fuel Available Finally	934,602.29 lbm

ORBITER DATA --------------------------		
Thrust/Weight	1.2	
Initial Boost Engines	5	
Total Thrust at Takeoff	**=B3*E6**	lbf
Available Takeoff Weight	**=B4/B2**	lbm
Dry Weight	180000	lbm
Payload	60000	lbm
RCS Fuel (MMH/NO4)	20000	lbm
Total Orbiter Weight	**=B6+B7+B8**	lbm
Maximum Fuel Weight	**=B5-B9**	lbm
Fuel Available Initially	**=B10**	lbm
Initial Boost Engines	**=B3**	
Initial Fuel Consumed	**=B13*E8*E2**	lbm
Primary Fuel Available	**=B12-B14**	lbm
Auxilliary Fuel	**=B34**	lbm
Total Fuel Available	**=B15+B16**	lbm
Final Boost Engines	4	
Approximate Final Thrust	**=B18*E7**	lbf
Approximate Final T/W	**=B19/(B9+B17)**	
BOOSTER DATA --------------------------		
Thrust/Weight	1.4	
Initial Boost Engines	5	
Total Thrust at Takeoff	**=B23*E6**	lbf
Available Takeoff Weight	**=B24/B22**	lbm
Dry Weight	160000	lbm
RCS Fuel (MMH/NO4)	10000	lbm
Total Booster Weight	**=B26+B27**	lbm
Fuel Weight	**=B25-B28**	lbm
Fuel Available Initially	**=B29**	lbm
Initial Boost Engines	=B23	
Initial Boost Fuel	**=B32*E8*E2**	lbm
Reservoir Fuel Pumped	**=B31-B33**	lbm
OVERALL DATA --------------------------		
Thrust/Weight	**=(B4+B24)/(B5+B25)**	
Initial Boost Engines	**=B3+B23**	
Total Thrust at Takeoff	**=B4+B24**	lbf
Available Takeoff Weight	**=B38/B36**	lbm
Dry Weight	**=B6+B26**	lbm
Payload	**=B7**	lbm
RCS Fuel (MMH/NO4)	**=B8+B27**	lbm
Total Dry Weight	**=B40+B41+B42**	lbm
Fuel Weight	**=B10+B29**	lbm
Fuel Available Initially	**=B12+B31**	lbm
Initial Boost Engines	**=B37**	
Initial Boost Fuel	**=B47*E2*E8**	lbm
Fuel Available Finally	**=B46-B48**	lbm

Initial Boost Burn Time	*119*	sec
Final Boost Burn Time	**=B17/(B18*E8)**	sec
Total Burn Time	**=E2+E3**	sec
Tsl	*363525*	lbf
Tvac	*435000*	lbf
Wdot	*949.4*	lbm/sec
SG - Hydrogen	*0.07*	ft^3
SG - Oxygen	*1.149*	ft^3
Density of Water	*62.43*	lbm/ft^3
Max Fuel - Hydrogen	**=B12/7**	lbm
Max Fuel - Oxygen	**=B12*6/7**	lbm
Volume - Hydrogen	**=E13/(E9*E11)**	ft^3
Volume - Oxygen	**=E14/(E10*E11)**	ft^3
Total Volume	**=E15+E16**	ft^3
Eq. Hydrogen Tanks	**=E15/(PI()/4*15^2)/2**	ft
Eq. Oxygen Tanks	**=E16/(PI()/4*26^2)**	ft
Minimum Length Necessary	**=E18+E19**	ft

Max Fuel - Hydrogen	**=B29/7**	lbm
Max Fuel - Oxygen	**=B29*6/7**	lbm
Volume - Hydrogen	**=E27/(E9*E11)**	ft^3
Volume - Oxygen	**=E28/(E10*E11)**	ft^3
Total Volume	**=E29+E30**	ft^3
Eq. Hydrogen Tanks	**=E29/(PI()/4*26^2)**	ft
Eq. Oxygen Tanks	**=E30/(PI()/4*26^2)**	ft
Minimum Length Necessary	**=E32+E33**	ft

2.0 STME Performance Calculation Summary

A model of the total thrust available from the Space Transportation Main Engines used on the Shuttle II was necessary to evaluate its launch profile. Thrust is a function of many variables, including nozzle expansion ratio, exit velocity, ambient pressure and exit pressure. Since the STME uses a translatable skirt, the expansion ratio of the engine could be set at discrete values of 35:1, 70:1, and 150:1. To insure that the engine operated most efficiently during all points in the launch, it was necessary to calculate the altitudes at which the skirt should be translated. This analysis was performed by calculating thrust coefficients for all three nozzles and finding the points of intersection.

These calculations were based on the data presented in the Aeroject contractor's report for the STME. The 1962 standard atmosphere was used as a model for pressure and density as functions of altitude. Most of the engine data was solved using simple, iterative techniques, isentropic relations, and graphical methods.

2.1 Analysis

Given an expansion ratio for a particular nozzle and an appropriate value for the coefficient of specific heats, the exit Mach number may be determined.

Assuming $\gamma = 1.24$ for a mixture of liquid oxygen and liquid hydrogen in a 6:1 mass ratio, and the first (fixed) nozzle expansion ratio of 35:1, this isentropic relation holds:

$$\frac{A_e}{A^*} = \frac{1}{M_e}\left[\frac{1+\frac{\gamma-1}{2}M_e^2}{\frac{\gamma+1}{2}}\right]^{\frac{\gamma+1}{2(\gamma-1)}}$$

This function may be solved iteratively to obtain exit Mach numbers for the nozzles. This was solved using the included iterative, and the following were obtained as the exit Mach numbers:

Nozzle Expansion Ratio	Exit Mach Number
35:1	4.369
70:1	4.931
150:1	5.581

Next, the flow in a nozzle may be assumed to be very nearly isentropic, such that the chamber pressure may be related to the nozzle exit pressure through the isentropic relation

$$\frac{P_{Tot}}{P_e} = \left(1 + \frac{\gamma-1}{2}M_e^2\right)^{\frac{\gamma}{\gamma-1}}$$

Given a chamber pressure of 2385 psia under normal power levels and 3125 psia under emergency conditions, the following exit pressures were obtained:

	Pe (NPL)	Pe (EPL)
For e = 35:1	5.069	6.642
For e = 70:1	2.058	2.696
For e = 150:1	0.771	1.010

For a given expansion ratio, a nozzle will have a maximum efficiency at a certain design altitude. At this altitude, the exit pressure is equal to the ambient pressure of the atmosphere. From the 1962 standard atmosphere, the design altitudes were determined to be

	hd (Normal Power Level)	(Emergency Power Levels)
For e = 35:1	26,700 ft	20,400 ft
For e = 70:1	45,800 ft	40,200 ft
For e = 150:1	66,300 ft	60,600 ft

In order to obtain the proper altitudes at which the sections of the nozzle should be extended, the following procedure is followed.

The thrust coefficient is defined as:

$$C_T = \frac{T}{P_T A^*}$$

Since thrust varies with altutde, this expression may be rewritten as:

$$C_T = \sqrt{\left(\frac{2\gamma^2}{\gamma-1}\right)\left(\frac{2}{\gamma+1}\right)^{\frac{\gamma+1}{\gamma-1}}\left[1-\left(\frac{P_e}{P_T}\right)^{\frac{\gamma-1}{\gamma}}\right]} + \left(\frac{P_e}{P_T} - \frac{P_a}{P_T}\right)\frac{A_e}{A^*}$$

For example, consider the nozzle with an expansion ratio of 70:1 at an altitude of 50,000 feet.

$$C_T = \sqrt{(12.8133)(.34724)\left[1 - \left(\frac{2.058}{2385}\right)^{.19355}\right]} + \frac{2.058 \cdot 1.682}{2385}(70) = 1.5314$$

Similarly, thrust coefficients for other nozzle and atmospheric conditions may be calculated. As shown in Figure 2.1.1, the points where these graphs cross indicate the altitudes where the nozzles should be translated for maximum efficiency.

For Normal Power Levels, the translation altitudes were found to be 36,900 feet and 56,500 feet. For Emergency Power Levels, the altitudes were 31,100 feet and 50,800 feet.

	A	B	C	D	E	F	G	H
1	titude	Pa	NPL,E=35	EPL,E=35	NPL,E=70	EPL,E=70	NPL,E=150	EPL,E=150
2	0	14.7000	1.6185	1.6696	1.4493	1.5515	0.9975	1.2164
3	1000	14.1700	1.6263	1.6756	1.4649	1.5633	1.0308	1.2419
4	2000	13.6600	1.6338	1.6813	1.4798	1.5748	1.0629	1.2664
5	3000	13.1700	1.6410	1.6868	1.4942	1.5857	1.0937	1.2899
6	4000	12.6900	1.6480	1.6921	1.5083	1.5965	1.1239	1.3129
7	5000	12.2300	1.6548	1.6973	1.5218	1.6068	1.1529	1.3350
8	6000	11.7800	1.6614	1.7023	1.5350	1.6169	1.1812	1.3566
9	7000	11.3400	1.6679	1.7073	1.5479	1.6267	1.2088	1.3777
10	8000	10.9200	1.6740	1.7120	1.5602	1.6361	1.2352	1.3979
11	9000	10.5000	1.6802	1.7167	1.5726	1.6455	1.2617	1.4180
12	10000	10.1100	1.6859	1.7210	1.5840	1.6543	1.2862	1.4368
13	11000	9.7200	1.6916	1.7254	1.5955	1.6630	1.3107	1.4555
14	12000	9.3460	1.6971	1.7296	1.6064	1.6714	1.3342	1.4734
15	13000	8.9840	1.7024	1.7336	1.6171	1.6795	1.3570	1.4908
16	14000	8.6330	1.7076	1.7376	1.6274	1.6874	1.3791	1.5077
17	15000	8.2940	1.7126	1.7414	1.6373	1.6950	1.4004	1.5239
18	16000	7.9650	1.7174	1.7451	1.6470	1.7023	1.4211	1.5397
19	17000	7.6470	1.7220	1.7486	1.6563	1.7094	1.4411	1.5550
20	18000	7.3390	1.7266	1.7521	1.6653	1.7163	1.4605	1.5698
21	19000	7.0410	1.7309	1.7554	1.6741	1.7230	1.4792	1.5841
22	20000	6.7540	1.7352	1.7586	1.6825	1.7295	1.4973	1.5978
23	21000	6.4750	1.7392	1.7617	1.6907	1.7357	1.5148	1.6112
24	22000	6.2070	1.7432	1.7647	1.6986	1.7417	1.5317	1.6241
25	23000	5.9470	1.7470	1.7677	1.7062	1.7475	1.5480	1.6366
26	24000	5.6960	1.7507	1.7705	1.7136	1.7532	1.5638	1.6486
27	25000	5.4540	1.7542	1.7732	1.7207	1.7586	1.5790	1.6602
28	26000	5.2200	1.7577	1.7758	1.7275	1.7638	1.5937	1.6715
29	27000	4.9940	1.7610	1.7783	1.7342	1.7689	1.6079	1.6823
30	28000	4.7770	1.7642	1.7808	1.7405	1.7737	1.6216	1.6927
31	29000	4.5670	1.7672	1.7831	1.7467	1.7784	1.6348	1.7028
32	30000	4.3640	1.7702	1.7854	1.7527	1.7830	1.6476	1.7126
33	31000	4.1690	1.7731	1.7876	1.7584	1.7874	1.6598	1.7219
34	32000	3.9810	1.7758	1.7897	1.7639	1.7916	1.6717	1.7309
35	33000	3.8000	1.7785	1.7917	1.7692	1.7956	1.6830	1.7396
36	34000	3.6260	1.7811	1.7937	1.7743	1.7995	1.6940	1.7480
37	35000	3.4580	1.7835	1.7955	1.7793	1.8033	1.7046	1.7561
38	36000	3.2970	1.7859	1.7973	1.7840	1.8069	1.7147	1.7638
39	37000	3.1420	1.7882	1.7991	1.7885	1.8104	1.7244	1.7712
40	38000	2.9940	1.7903	1.8007	1.7929	1.8137	1.7337	1.7783
41	39000	2.8540	1.7924	1.8023	1.7970	1.8168	1.7425	1.7850
42	40000	2.7200	1.7943	1.8038	1.8009	1.8198	1.7510	1.7915
43	41000	2.5920	1.7962	1.8052	1.8047	1.8227	1.7590	1.7976
44	42000	2.4710	1.7980	1.8066	1.8082	1.8254	1.7666	1.8034
45	43000	2.3550	1.7997	1.8079	1.8116	1.8280	1.7739	1.8090
46	44000	2.2440	1.8013	1.8091	1.8149	1.8305	1.7809	1.8143
47	45000	2.1390	1.8029	1.8103	1.8180	1.8328	1.7875	1.8194
48	46000	2.0390	1.8043	1.8114	1.8209	1.8351	1.7938	1.8242
49	47000	1.9430	1.8058	1.8125	1.8237	1.8372	1.7998	1.8288
50	48000	1.8520	1.8071	1.8135	1.8264	1.8393	1.8056	1.8331
51	49000	1.7650	1.8084	1.8145	1.8289	1.8412	1.8110	1.8373
52	50000	1.6820	1.8096	1.8154	1.8314	1.8431	1.8163	1.8413
53	51000	1.6030	1.8107	1.8163	1.8337	1.8448	1.8212	1.8451
54	52000	1.5280	1.8118	1.8172	1.8359	1.8465	1.8259	1.8487
55	53000	1.4560	1.8129	1.8180	1.8380	1.8481	1.8305	1.8521
56	54000	1.3880	1.8139	1.8187	1.8400	1.8497	1.8347	1.8554
57	55000	1.3230	1.8149	1.8194	1.8419	1.8511	1.8388	1.8585

	A	B	C	D	E	F	G	H
58	56000	1.2610	1.8158	1.8201	1.8437	1.8525	1.8427	1.8615
59	57000	1.2010	1.8166	1.8208	1.8455	1.8538	1.8465	1.8644
60	58000	1.1450	1.8175	1.8214	1.8471	1.8551	1.8500	1.8671
61	59000	1.0910	1.8183	1.8220	1.8487	1.8563	1.8534	1.8697
62	60000	1.0400	1.8190	1.8226	1.8502	1.8574	1.8566	1.8721
63	61000	0.9913	1.8197	1.8232	1.8516	1.8585	1.8597	1.8745
64	62000	0.9448	1.8204	1.8237	1.8530	1.8596	1.8626	1.8767
65	63000	0.9005	1.8211	1.8242	1.8543	1.8606	1.8654	1.8788
66	64000	0.8582	1.8217	1.8247	1.8556	1.8615	1.8681	1.8808
67	65000	0.8179	1.8223	1.8251	1.8567	1.8624	1.8706	1.8828
68	65617	0.7941	1.8226	1.8254	1.8574	1.8630	1.8721	1.8839
69	70000	0.6437	1.8248	1.8271	1.8619	1.8663	1.8816	1.8911
70	75000	0.5073	1.8268	1.8286	1.8659	1.8694	1.8901	1.8977
71	infinti	0.0000	1.8343	1.8343	1.8807	1.8807	1.9220	1.9220

Figure 2.1.1: Plot of Thust Coefficients vs. Altitude (NPL)

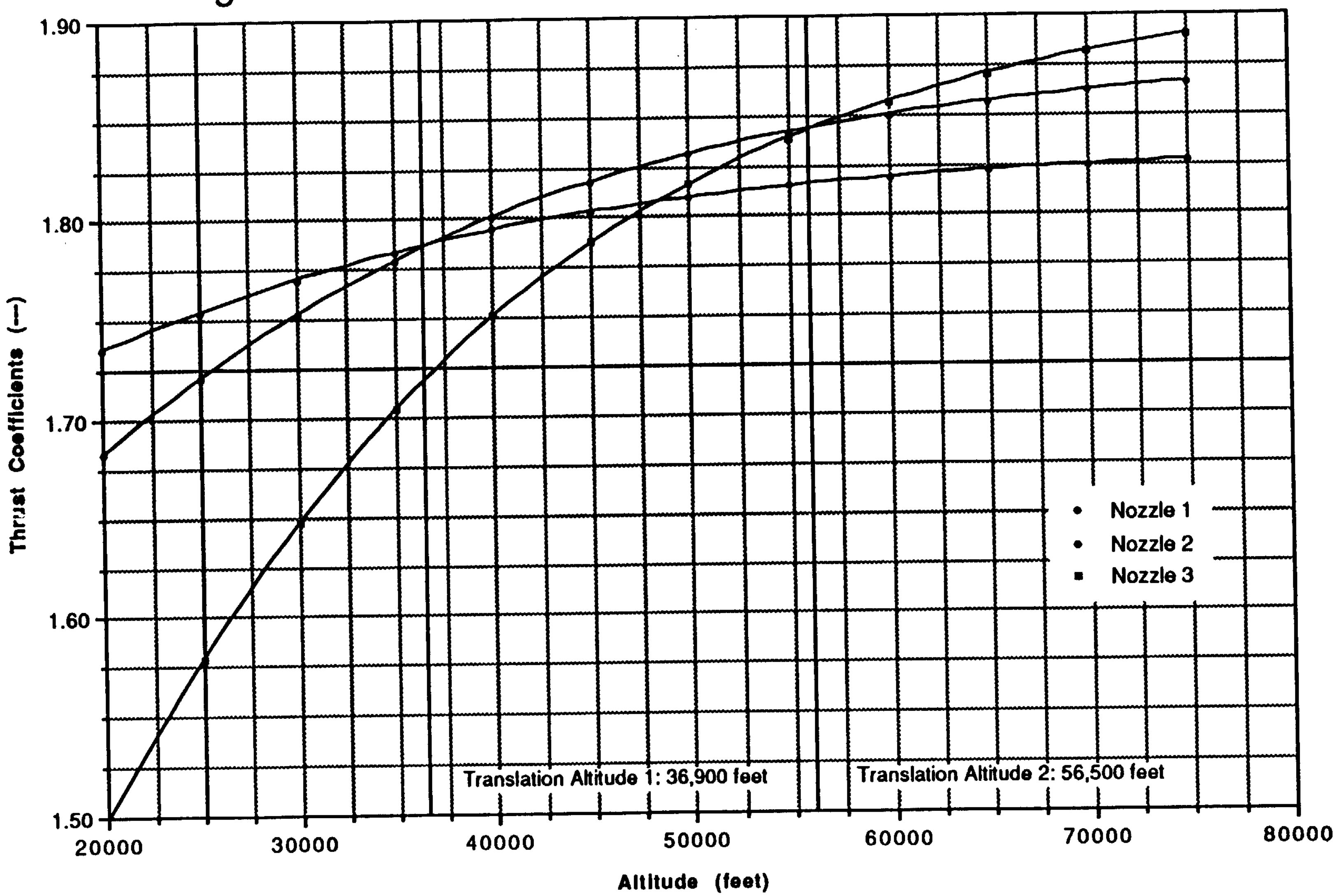
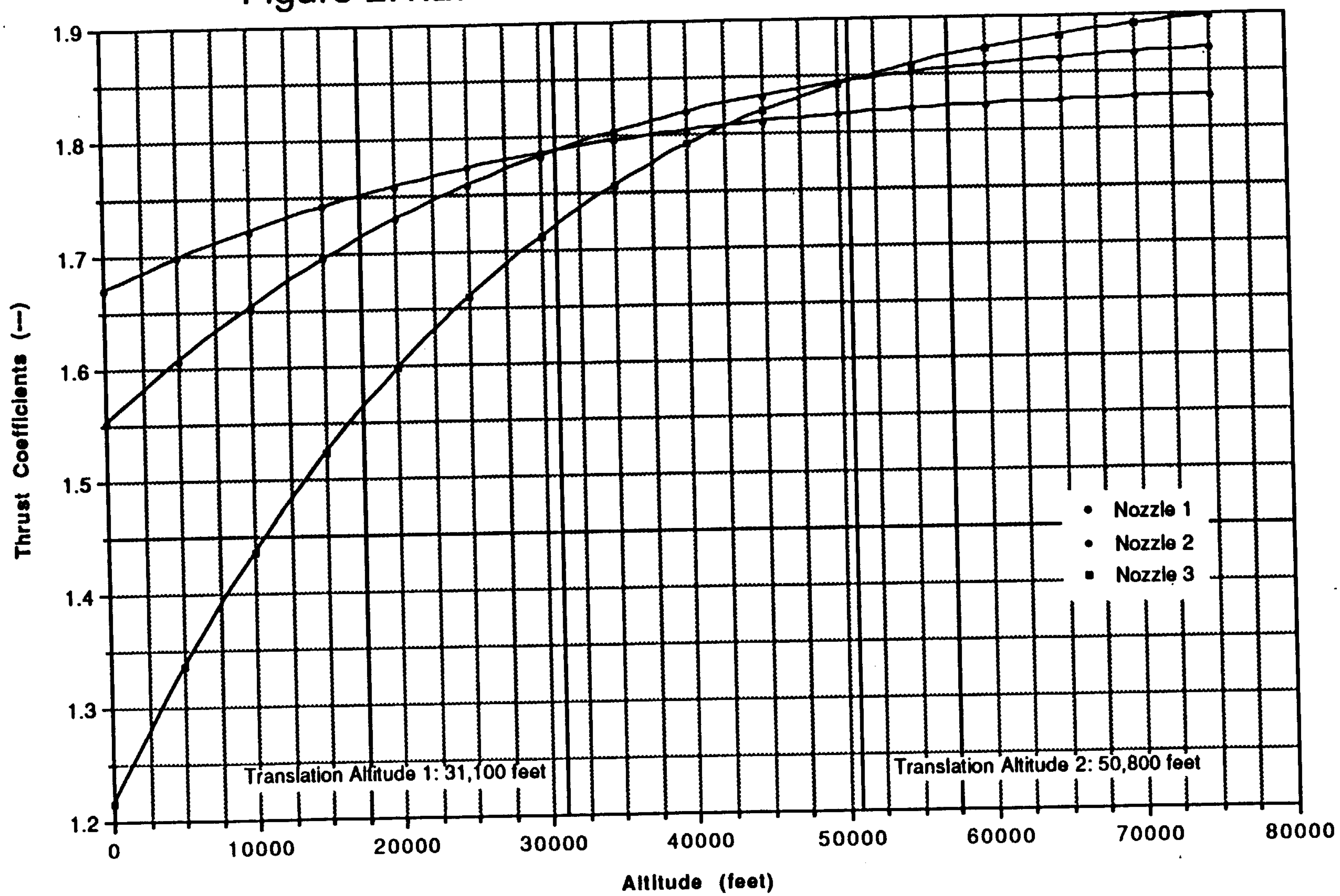


Figure 2.1.2: Thust Coefficients vs. Altitude (EPL)



3.0 Mission Analysis

To prove the flight worthiness and technical feasibility of the ASTS as proposed, a launch profile was constructed and simulated. This simulation consisited of a dynamic model of the vehicle's instantaneous position, velocity, acceleration, thrust, weight, orientation, and flight path with respect to the horizon. In addition to this vehicle-specific data, atmospheric conditions such as temperature, pressure, and density were modeled.

The basic format of this simulation was a fourth-order Runge-Kutta integration scheme. A number of asumptions were necessary to develop this model of the launch trajectory. First, the model is constrained by a run time of approximate seven minutes and a total distance downrange not exceeding 800 nautical miles, so the surface of the earth was modeled as being flat. In addition, rotational effects of the earth were neglected. This assumption cannot degrade the validity of results, since it could only create conditions more favorable to a due east launch from Kennedy Space Center. Drag forces were neglected for two principal reasons: they can be considered small in comparison to thrust forces necessary for a ballistic trajectory, and they would not exceed the advantages gained by incorporating the earth's rotation.

All initial conditions were set based on values calculated from the design process outlined in Section 1.0. Burn times, initial weights, total thrust available, and fuel available are the the most noteworthy examples. Thrust was computed as a funciton of altitude, based on translation altitudes for the extendable skirt on the STME nozzles, pressure forces, and known values of sea level and vacuum values. It was estimated that the maximum acceptable pitch rate was 0.5 degrees per second to retain stability during launch. This is the value used in the program for all pitch manuevers.

Before finalizing the launch profile, it was necessary to establish the range of orbits into which the orbiter could be successfully launched. Based on current STS mission analyses and estimations of maximum altitude and velocity available at this altitude, our launch goal was projected to be an altitude of 100 nautical miles and a velocity equal to that of the local circular speed. Inclination was varied during flight both to achieve this orbit and to place the booster in an alignment practical for separation.

```
program AE447Prog;

{$MC68020+}
{$MC68881+}
{$SETC Elems881:=true}

(*
==========================================================================
Written by Del Johnson (in TML Pascal II v1.00 under MPW v2.02)
==========================================================================
Written for AE447-AE449 Shuttle II design group (Fall 1988 - Spring 1989)
==========================================================================
This program is designed to model the flight of design configurations for the
Shuttle II Launch System. Design data was used in the model. Results from the
execution of these programs was used in an iterative process to fine-tune the
model as presented in the report.
==========================================================================
Definition of variables u[i]:

{ Integral variables… }
u[ 1] = u[x]      = Location along the x-axis
u[ 2] = u[xd]     = Time rate of change of location along the x-axis
u[ 3] = u[y]      = Location along the y-axis
u[ 4] = u[yd]     = Time rate of change of location along the y-axis
u[ 5] = u[th]     = Angle with respect to the y-axis
u[ 6] = u[thd]    = Time rate of change of angle with respect to the y-axis

{ Other variables… }
u[  ] = u[alpha]= Angle of attack
u[  ] = u[gamma]= Flight path angle
u[  ] = u[wt]     = Total vehicle weight
u[  ] = u[wtd]    = Time rate of change of total vehicle weight
u[  ] = u[dens] = Density of the atmosphere
u[  ] = u[press] = Density of the atmosphere
u[  ] = u[ thrust] = Thrust produced by all engines firing

==========================================================================
*)

uses MemTypes,SANE;
{=========================================================================}

const

{ Number of equations… }

      numIntEquations =  6;
      numTotEquations = 11;

{ Time Considerations… }

      tbegin     =    0.00; { seconds }
      tend       =  420.00; { seconds }
      dt         =    0.10; { seconds }
      cint       =      10;
      cols       =       4;

{ Subscripts of the variables of motion… }
```

```
    xd        =  1;
    x         =  2;
    yd        =  3;
    y         =  4;
    wt        =  5;
    th        =  6;

    vtot      =  7;
    gamma     =  8;
    thrust    =  9;
    press     = 10;
    dens      = 11;

    Separation   = 1;
    Shutdown     = 2;
    StartPitch1  = 3;
    StopPitch1   = 4;
    StartPitch2  = 5;
    StopPitch2   = 6;

{ Constants related to the problem...  }

{ Mathematical constants... }
    conv      =  57.29577951; { degrees/radians }

{ Physical constants... }
    Re        = 20938912.00000; { feet }
    g0        =       32.17400; { feet/second^2 }
    rho       =        0.0023768; { pound-mass/feet^3 }
    rho0      =        0.0023768; { pound-mass/feet^3 }
    Psl       =       14.70000; { pound-force/inches^2 }

{ Vehicle characteristics... }
    thr0      =   363535.00000; { lbf }
    wtd0      =     -949.40000; { lbm/sec }

    pressAlt  =    25000.00000; { feet }
    densAlt   =    25000.00000; { feet }

    Ae1       =     3247.22085; { inches^2 }
    Ae2       =     6503.88219; { inches^2 }
    Ae3       =    14526.72443; { inches^2 }

    designAlt1NPL =  26700.00000; { feet }
    designAlt2NPL =  45800.00000; { feet }
    designAlt3NPL =  66300.00000; { feet }
    designAlt1EPL =  20400.00000; { feet }
    designAlt2EPL =  40200.00000; { feet }
    designAlt3EPL =  60600.00000; { feet }

    transAlt1NPL = 36900.0000; { feet }
    transAlt2NPL = 56500.0000; { feet }
    transAlt1EPL = 31100.0000; { feet }
    transAlt2EPL = 50800.0000; { feet }

    Pe1NPL = 5.069; { lbf/feet^2 }
    Pe2NPL = 2.058; { lbf/feet^2 }
```

```
      Pe3NPL = 0.771; { lbf/feet^2 }
      Pe1EPL = 6.642; { lbf/feet^2 }
      Pe2EPL = 6.296; { lbf/feet^2 }
      Pe3EPL = 1.010; { lbf/feet^2 }

      thrMax1NPL = 411259.15000;
      thrMax2NPL = 424577.04000;
      thrMax3NPL = 435000.00000;

      thrMax1EPL = 545789.15000;
      thrMax2EPL = 556312.08000;
      thrMax3EPL = 580000.00000;

{ Problem intial conditions… }
      xd0      =   0.00; { feet/second }
      x0       =   0.00; { feet }
      yd0      =   0.00; { feet/second }
      y0       =   0.00; { feet }
      th0      =  90.00; { degrees }
      vtot0    =   0.00; { feet/second }

type
      uArray     = array [1..numTotEquations] of extended;
      nameArray  = array [1..numTotEquations] of str255;
      printrange = 1..32;

var
      outfile   : text;
      tab       : char;
      sp        : array [1..numTotEquations] of integer;
      DryWtBooster, DryWtOrbiter,wt0 : extended;
      t         : extended;
      time      : array [1..6] of extended;
      k         : array [1..4,1..numIntEquations] of extended;
      u,uu      : uArray;
      i,j,m,n   : integer;
      printset  : set of printrange;

 { Variables of motion… }

      wtd, thr, thd     : extended;
      thrMax : extended;

{==========================================================================}
function g(alt : extended): extended;
begin
      g := g0*sqr(Re)/sqr(Re+alt);
end;
{==========================================================================}
function density(alt : extended): extended;
begin
      density := rho0*exp(-alt/densAlt);
end;
{==========================================================================}
function pressure(alt : extended): extended;
begin
      pressure := Psl*exp(-alt/pressAlt);
end;
```

```
{=============================================================================}
function pitchRate(t : extended): extended;
begin
      if    (t <  Time[StartPitch1]) then pitchRate :=  0.00 else
             if (t <  Time[StopPitch1] ) then pitchRate := -0.50 else
             if (t <  Time[StartPitch2]) then pitchRate :=  0.00 else
             if (t <  Time[StopPitch2] ) then pitchRate := -0.50 else
             if (t <   tend) then pitchRate :=  0.00;
end;
{=============================================================================}
function thrustAvail(alt : extended): extended;
var
      Ae,thr1 : extended;
begin
      if (alt<transAlt1NPL) then begin
            Ae := Ae1;
            thr1 := thrMax1NPL;
      end
      else
            if (alt<transAlt2NPL) then begin
                  Ae := Ae2;
                  thr1 := thrMax2NPL;
            end
            else begin
                  Ae := Ae3;
                  thr1 := thrMax3NPL;
            end;
      thrustAvail := thr1 - pressure(alt)*Ae;
end;
{=============================================================================}
procedure initVariables;
begin
      t := tbegin;
      u[yd] := yd0;
      u[y]  := y0;
      u[xd] := xd0;
      u[x]  := x0;
      u[wt] := wt0;
      u[th] := th0;
      u[gamma] := 90;
      u[vtot] := sqrt(sqr(u[yd])+sqr(u[xd]));
      u[press] := pressure(u[y]);
      u[dens]  := density(u[y]);
end;
{=============================================================================}
procedure print(style : integer);
var
   i : integer;
begin
   case style of
      1 : begin
               write(outfile,'t = ',t:6:2);
               for i := 1 to numTotEquations do begin
                  if (i in printset) then write(outfile,'    u[',i:2,']
=',u[i]:12:2);
                  if (i in printset) then write(        '    u[',i:2,']
=',u[i]:12:2);
               end;
```

```
            writeln(outfile);
            writeln;
         end;
    2 : begin
            i := 0;
            writeln(outfile,'Time  = ',t:7:2);
            writeln(         'Time  = ',t:7:2);
            for j := 1 to numTotEquations do
               if (j in printset) then begin
                  i := i+1;
                  write(outfile,'u[',j:2,'] =',u[j]:12:2,'      ');
                  write(        'u[',j:2,'] =',u[j]:12:2,'      ');
                  if (i mod cols = 0) then begin
                     i := 0;
                     writeln(outfile);
                     writeln;
                  end;
               end;
            if (i<>0) then begin
               writeln(outfile);
               writeln;
            end;
         end;
    3 : begin
            write(outfile,t:7:2,tab);
            for j := 1 to numTotEquations do
               if (j in printSet) then write(outfile,u[j]:12:sp[j],tab);
            writeln(outfile);
         end;
    otherwise;
  end; {case}
end;
{=============================================================================}
{ Total function defining variables in terms of one another... }
function f(j: integer; t: extended; u: uArray): extended;
begin
    case j of
        xd   : f := thr*cos(u[th]/conv)*g(u[y])/u[wt];
        x    : f := u[xd];
        yd   : f := thr*sin(u[th]/conv)*g(u[y])/u[wt] - g(u[y]);
        y    : f := u[yd];
        wt   : f := wtd;
        th   : f := thd;
        otherwise;
    end;
end;
{=============================================================================}

begin
    Textbook(nil);
    tab := chr(09);
    for j := 1 to numTotEquations do
        sp[j] := 2;
    sp[press] := 8;
    sp[dens]  := 8;

    open    (outfile,'1/AE448prog.dat );
    rewrite(outfile);
```

```
     m := numIntEquations;             { Number of integration equations }
     n := trunc((tend-tbegin)/dt);     { Number of steps }

{ Set names of all variables... }
     printset := [xd,x,yd,y,wt,vtot,th,gamma,thrust,press,dens];

{ Set design variables... }
     wt0              := 2769714.29; { lbf }
     DryWtBooster  :=  170000.00; { lbf }
     DryWtOrbiter  :=  260000.00; { lbf }
     Time[Separation]   := 148.00; { seconds }
     Time[Shutdown]     := 394.00; { seconds }
     Time[StartPitch1] :=  20.00; { seconds }
     Time[StopPitch1]  := 140.00; { seconds }
     Time[StartPitch2] := 160.00; { seconds }
     Time[StopPitch2]  := Time[StartPitch2] + 38.00; { seconds }

{ Set initial conditions of all variables... }
     initVariables;

{ Echo initial conditions of all variables in the printing set... }
     print(3);

{ Beginning of time-step loop... }
     for i := 1 to n do begin

{ Computation of other, non time-dependent variables... }

          if (t  = Time[Separation]) then u[wt] := u[wt] - DryWtBooster;

          thrMax := thrustAvail(u[y]);
          if    (t < Time[Separation]) then thr := 10*thrMax else
             if (t < Time[Shutdown]   ) then thr :=  4*thrMax else
                 if (t < tend) then thr := 0*thrMax;

          u[press] := pressure(u[y]);
          u[dens]  := density(u[y]);

          u[thrust] := thr;

       if    (t < Time[Separation]) then wtd := 10*wtd0 else
              if (t < Time[Shutdown]   ) then wtd :=  4*wtd0 else
                  if (t < tend) then wtd := 0;

          thd := pitchRate(t);

          if (u[th] >  360.00) then u[th] := u[th] - 360.00;
          if (u[th] < -360.00) then u[th] := u[th] + 360.00;

{ Runge-Kutta 4th-Order integration loop of all variables... }

          for j := 1 to m do
                k[1,j] := dt*f(j,t,u);
          for j := 1 to m do
                uu[j] := u[j] + k[1,j]/2;
          for j := 1 to m do
                k[2,j] := dt*f(j,t+dt/2,uu);
```

```
            for j := 1 to m do
                  uu[j] := u[j] + k[2,j]/2;
            for j := 1 to m do
                  k[3,j] := dt*f(j,t+dt/2,uu);
            for j := 1 to m do
                  uu[j] := u[j] + k[3,j];
            for j := 1 to m do
                  k[4,j] := dt*f(j,t+dt,uu);
            for j := 1 to m do
                  u[j] := u[j] + (k[1,j]+2*k[2,j]+2*k[3,j]+k[4,j])/6;

            t := tbegin + i*dt;

            u[vtot] := sqrt(sqr(u[xd])+sqr(u[yd]));
            if (u[xd] > 0) then u[gamma] := arctan(u[yd]/u[xd])*conv else
u[gamma] := 90.00;

{ Printing parameters... }

            if (i mod cint = 0) and (printset <> []) then print(3);

      end;

      close(outfile);

end.
```

	A	B	C	D	E	F
1	Time	X-Vel	X-Pos	Y-Vel	Y-Pos	Weight
2	0.00	0.00	0.00	0.00	0.00	2769714.29
3	1.00	0.00	0.00	10.13	5.05	2760220.29
4	2.00	0.00	0.00	20.40	20.30	2750726.29
5	3.00	0.00	0.00	30.83	45.91	2741232.29
6	4.00	0.00	0.00	41.41	82.01	2731738.29
7	5.00	0.00	0.00	52.15	128.78	2722244.29
8	6.00	0.00	0.00	63.05	186.36	2712750.29
9	7.00	0.00	0.00	74.11	254.93	2703256.29
10	8.00	0.00	0.00	85.35	334.65	2693762.29
11	9.00	0.00	0.00	96.75	425.68	2684268.29
12	10.00	0.00	0.00	108.34	528.22	2674774.29
13	11.00	0.00	0.00	120.10	642.42	2665280.29
14	12.00	0.00	0.00	132.04	768.47	2655786.29
15	13.00	0.00	0.00	144.18	906.57	2646292.29
16	14.00	0.00	0.00	156.50	1056.89	2636798.29
17	15.00	0.00	0.00	169.02	1219.64	2627304.29
18	16.00	0.00	0.00	181.74	1395.00	2617810.29
19	17.00	0.00	0.00	194.66	1583.18	2608316.29
20	18.00	0.00	0.00	207.79	1784.39	2598822.29
21	19.00	0.00	0.00	221.13	1998.83	2589328.29
22	20.00	0.00	0.00	234.69	2226.72	2579834.29
23	21.00	0.20	0.07	248.46	2468.28	2570340.29
24	22.00	0.81	0.54	262.45	2723.71	2560846.29
25	23.00	1.82	1.81	276.67	2993.25	2551352.29
26	24.00	3.24	4.31	291.10	3277.12	2541858.29
27	25.00	5.08	8.43	305.76	3575.53	2532364.29
28	26.00	7.34	14.61	320.64	3888.72	2522870.29
29	27.00	10.02	23.26	335.74	4216.88	2513376.29
30	28.00	13.14	34.80	351.06	4560.27	2503882.29
31	29.00	16.68	49.67	366.61	4919.08	2494388.29
32	30.00	20.66	68.31	382.37	5293.55	2484894.29
33	31.00	25.09	91.15	398.36	5683.90	2475400.29
34	32.00	29.96	118.64	414.58	6090.35	2465906.29
35	33.00	35.28	151.22	431.01	6513.13	2456412.29
36	34.00	41.06	189.35	447.66	6952.45	2446918.29
37	35.00	47.30	233.49	464.54	7408.53	2437424.29
38	36.00	54.00	284.10	481.64	7881.60	2427930.29
39	37.00	61.17	341.64	498.95	8371.88	2418436.29
40	38.00	68.82	406.60	516.49	8879.58	2408942.29
41	39.00	76.94	479.44	534.24	9404.93	2399448.29
42	40.00	85.56	560.65	552.21	9948.13	2389954.29
43	41.00	94.66	650.71	570.39	10509.42	2380460.29
44	42.00	104.25	750.12	588.79	11088.99	2370966.29
45	43.00	114.35	859.38	607.40	11687.07	2361472.29
46	44.00	124.94	978.98	626.22	12303.86	2351978.29
47	45.00	136.05	1109.44	645.25	12939.58	2342484.29
48	46.00	147.68	1251.26	664.48	13594.42	2332990.29
49	47.00	159.82	1404.97	683.91	14268.60	2323496.29
50	48.00	172.49	1571.07	703.55	14962.32	2314002.29
51	49.00	185.68	1750.12	723.39	15675.77	2304508.29
52	50.00	199.42	1942.62	743.42	16409.16	2295014.29
53	51.00	213.69	2149.13	763.64	17162.67	2285520.29

	A	B	C	D	E	F
54	52.00	228.50	2370.17	784.05	17936.50	2276026.29
55	53.00	243.87	2606.31	804.65	18730.83	2266532.29
56	54.00	259.79	2858.09	825.42	19545.85	2257038.29
57	55.00	276.26	3126.07	846.38	20381.74	2247544.29
58	56.00	293.31	3410.81	867.51	21238.67	2238050.29
59	57.00	310.92	3712.87	888.81	22116.82	2228556.29
60	58.00	329.10	4032.84	910.28	23016.35	2219062.29
61	59.00	347.87	4371.28	931.90	23937.43	2209568.29
62	60.00	367.21	4728.77	953.69	24880.21	2200074.29
63	61.00	387.15	5105.90	975.62	25844.85	2190580.29
64	62.00	407.67	5503.26	997.71	26831.51	2181086.29
65	63.00	428.79	5921.44	1019.93	27840.31	2171592.29
66	64.00	450.52	6361.05	1042.29	28871.41	2162098.29
67	65.00	472.84	6822.68	1064.78	29924.94	2152604.29
68	66.00	495.78	7306.94	1087.40	31001.02	2143110.29
69	67.00	519.33	7814.45	1110.14	32099.78	2133616.29
70	68.00	543.50	8345.81	1132.99	33221.33	2124122.29
71	69.00	568.29	8901.66	1155.95	34365.80	2114628.29
72	70.00	593.71	9482.60	1179.02	35533.27	2105134.29
73	71.00	619.75	10089.28	1202.18	36723.86	2095640.29
74	72.00	646.57	10722.38	1225.72	37937.77	2086146.29
75	73.00	674.10	11382.66	1249.47	39175.35	2076652.29
76	74.00	702.30	12070.80	1273.38	40436.77	2067158.29
77	75.00	731.19	12787.49	1297.42	41722.16	2057664.29
78	76.00	760.77	13533.41	1321.60	43031.66	2048170.29
79	77.00	791.04	14309.26	1345.89	44365.40	2038676.29
80	78.00	822.01	15115.72	1370.30	45723.49	2029182.29
81	79.00	853.68	15953.51	1394.82	47106.04	2019688.29
82	80.00	886.05	16823.31	1419.43	48513.15	2010194.29
83	81.00	919.12	17725.83	1444.12	49944.92	2000700.29
84	82.00	952.91	18661.79	1468.90	51401.43	1991206.29
85	83.00	987.41	19631.90	1493.74	52882.74	1981712.29
86	84.00	1022.63	20636.86	1518.64	54388.92	1972218.29
87	85.00	1058.57	21677.40	1543.59	55920.03	1962724.29
88	86.00	1095.14	22754.22	1568.45	57476.08	1953230.29
89	87.00	1132.43	23867.94	1593.33	59056.96	1943736.29
90	88.00	1170.51	25019.34	1618.33	60662.78	1934242.29
91	89.00	1209.39	26209.23	1643.44	62293.65	1924748.29
92	90.00	1249.06	27438.39	1668.64	63949.69	1915254.29
93	91.00	1289.53	28707.62	1693.93	65630.97	1905760.29
94	92.00	1330.80	30017.71	1719.28	67337.57	1896266.29
95	93.00	1372.87	31369.48	1744.69	69069.56	1886772.29
96	94.00	1415.74	32763.71	1770.14	70826.97	1877278.29
97	95.00	1459.41	34201.22	1795.63	72609.86	1867784.29
98	96.00	1503.90	35682.81	1821.12	74418.23	1858290.29
99	97.00	1549.18	37209.28	1846.63	76252.11	1848796.29
100	98.00	1595.28	38781.45	1872.13	78111.49	1839302.29
101	99.00	1642.19	40400.11	1897.60	79996.35	1829808.29
102	100.00	1689.91	42066.09	1923.05	81906.68	1820314.29
103	101.00	1738.44	43780.20	1948.46	83842.44	1810820.29
104	102.00	1787.78	45543.24	1973.81	85803.58	1801326.29
105	103.00	1837.94	47356.03	1999.10	87790.04	1791832.29
106	104.00	1888.92	49219.40	2024.31	89801.75	1782338.29

	A	B	C	D	E	F
107	105.00	1940.72	51134.15	2049.44	91838.63	1772844.29
108	106.00	1993.34	53101.11	2074.47	93900.60	1763350.29
109	107.00	2046.78	55121.10	2099.40	95987.54	1753856.29
110	108.00	2101.05	57194.95	2124.20	98099.35	1744362.29
111	109.00	2156.14	59323.47	2148.89	100235.90	1734868.29
112	110.00	2212.06	61507.50	2173.43	102397.07	1725374.29
113	111.00	2268.81	63747.86	2197.83	104582.72	1715880.29
114	112.00	2326.39	66045.40	2222.07	106792.68	1706386.29
115	113.00	2384.81	68400.93	2246.15	109026.81	1696892.29
116	114.00	2444.07	70815.30	2270.06	111284.93	1687398.29
117	115.00	2504.16	73289.34	2293.78	113566.86	1677904.29
118	116.00	2565.10	75823.90	2317.30	115872.41	1668410.29
119	117.00	2626.88	78419.83	2340.63	118201.40	1658916.29
120	118.00	2689.52	81077.96	2363.74	120553.60	1649422.29
121	119.00	2753.00	83799.14	2386.64	122928.81	1639928.29
122	120.00	2817.33	86584.24	2409.31	125326.81	1630434.29
123	121.00	2882.53	89434.10	2431.74	127747.35	1620940.29
124	122.00	2948.58	92349.58	2453.93	130190.21	1611446.29
125	123.00	3015.50	95331.55	2475.86	132655.12	1601952.29
126	124.00	3083.28	98380.86	2497.53	135141.84	1592458.29
127	125.00	3151.94	101498.40	2518.93	137650.09	1582964.29
128	126.00	3221.47	104685.03	2540.05	140179.60	1573470.29
129	127.00	3291.88	107941.63	2560.88	142730.09	1563976.29
130	128.00	3363.17	111269.08	2581.42	145301.26	1554482.29
131	129.00	3435.34	114668.26	2601.65	147892.82	1544988.29
132	130.00	3508.41	118140.06	2621.57	150504.45	1535494.29
133	131.00	3582.37	121685.38	2641.16	153135.84	1526000.29
134	132.00	3657.23	125305.10	2660.43	155786.66	1516506.29
135	133.00	3733.00	129000.14	2679.35	158456.58	1507012.29
136	134.00	3809.67	132771.40	2697.93	161145.26	1497518.29
137	135.00	3887.26	136619.79	2716.16	163852.33	1488024.29
138	136.00	3965.76	140546.22	2734.02	166577.45	1478530.29
139	137.00	4045.19	144551.61	2751.50	169320.24	1469036.29
140	138.00	4125.54	148636.90	2768.61	172080.33	1459542.29
141	139.00	4206.83	152803.00	2785.32	174857.33	1450048.29
142	140.00	4289.05	157050.86	2801.63	177650.84	1440554.29
143	141.00	4372.01	161381.35	2817.90	180460.57	1431060.29
144	142.00	4455.50	165795.06	2834.48	183286.74	1421566.29
145	143.00	4539.54	170292.53	2851.38	186129.64	1412072.29
146	144.00	4624.12	174874.31	2868.61	188989.61	1402578.29
147	145.00	4709.25	179540.95	2886.17	191866.97	1393084.29
148	146.00	4794.94	184293.00	2904.05	194762.05	1383590.29
149	147.00	4881.21	189131.03	2922.28	197675.19	1374096.29
150	148.00	4968.05	194055.61	2940.84	200606.72	1364602.29
151	149.00	5007.92	199043.58	2932.30	203543.29	1190804.69
152	150.00	5047.90	204071.48	2923.83	206471.35	1187007.09
153	151.00	5088.01	209139.43	2915.44	209390.98	1183209.49
154	152.00	5128.23	214247.54	2907.13	212302.26	1179411.89
155	153.00	5168.57	219395.93	2898.90	215205.27	1175614.29
156	154.00	5209.03	224584.72	2890.74	218100.08	1171816.69
157	155.00	5249.62	229814.04	2882.66	220986.77	1168019.09
158	156.00	5290.32	235084.00	2874.66	223865.42	1164221.49
159	157.00	5331.15	240394.72	2866.74	226736.11	1160423.89

	A	B	C	D	E	F
160	158.00	5372.10	245746.33	2858.89	229598.92	1156626.29
161	159.00	5413.17	251138.95	2851.13	232453.93	1152828.69
162	160.00	5454.37	256572.71	2843.45	235301.21	1149031.09
163	161.00	5495.79	262047.76	2835.67	238140.79	1145233.49
164	162.00	5537.55	267564.41	2827.60	240972.45	1141435.89
165	163.00	5579.64	273122.98	2819.25	243795.90	1137638.29
166	164.00	5622.06	278723.80	2810.61	246610.86	1133840.69
167	165.00	5664.81	284367.21	2801.68	249417.03	1130043.09
168	166.00	5707.89	290053.53	2792.45	252214.12	1126245.49
169	167.00	5751.29	295783.09	2782.92	255001.83	1122447.89
170	168.00	5795.02	301556.22	2773.08	257779.85	1118650.29
171	169.00	5839.08	307373.25	2762.94	260547.89	1114852.69
172	170.00	5883.45	313234.48	2752.48	263305.62	1111055.09
173	171.00	5928.15	319140.26	2741.71	266052.75	1107257.49
174	172.00	5973.17	325090.89	2730.63	268788.95	1103459.89
175	173.00	6018.51	331086.71	2719.22	271513.89	1099662.29
176	174.00	6064.17	337128.02	2707.48	274227.27	1095864.69
177	175.00	6110.14	343215.15	2695.42	276928.75	1092067.09
178	176.00	6156.43	349348.41	2683.02	279617.99	1088269.49
179	177.00	6203.04	355528.12	2670.28	282294.67	1084471.89
180	178.00	6249.95	361754.59	2657.21	284958.44	1080674.29
181	179.00	6297.18	368028.13	2643.79	287608.97	1076876.69
182	180.00	6344.72	374349.06	2630.02	290245.91	1073079.09
183	181.00	6392.57	380717.67	2615.90	292868.90	1069281.49
184	182.00	6440.72	387134.29	2601.43	295477.60	1065483.89
185	183.00	6489.18	393599.21	2586.60	298071.64	1061686.29
186	184.00	6537.94	400112.75	2571.41	300650.68	1057888.69
187	185.00	6587.01	406675.19	2555.85	303214.34	1054091.09
188	186.00	6636.37	413286.86	2539.92	305762.25	1050293.49
189	187.00	6686.04	419948.04	2523.61	308294.04	1046495.89
190	188.00	6736.00	426659.03	2506.93	310809.35	1042698.29
191	189.00	6786.26	433420.14	2489.87	313307.78	1038900.69
192	190.00	6836.81	440231.65	2472.42	315788.96	1035103.09
193	191.00	6887.66	447093.87	2454.59	318252.50	1031305.49
194	192.00	6938.80	454007.07	2436.36	320698.01	1027507.89
195	193.00	6990.23	460971.56	2417.74	323125.10	1023710.29
196	194.00	7041.94	467987.62	2398.72	325533.36	1019912.69
197	195.00	7093.94	475055.53	2379.29	327922.40	1016115.09
198	196.00	7146.23	482175.59	2359.46	330291.80	1012317.49
199	197.00	7198.79	489348.08	2339.21	332641.17	1008519.89
200	198.00	7251.64	496573.27	2318.55	334970.09	1004722.29
201	199.00	7304.72	503851.44	2297.70	337278.21	1000924.69
202	200.00	7357.99	511182.78	2276.90	339565.51	997127.09
203	201.00	7411.46	518567.49	2256.14	341832.03	993329.49
204	202.00	7465.11	526005.76	2235.42	344077.80	989531.89
205	203.00	7518.97	533497.78	2214.75	346302.89	985734.29
206	204.00	7573.01	541043.75	2194.13	348507.33	981936.69
207	205.00	7627.26	548643.88	2173.55	350691.16	978139.09
208	206.00	7681.71	556298.34	2153.01	352854.43	974341.49
209	207.00	7736.36	564007.36	2132.52	354997.19	970543.89
210	208.00	7791.21	571771.13	2112.07	357119.49	966746.29
211	209.00	7846.27	579589.85	2091.68	359221.36	962948.69
212	210.00	7901.53	587463.73	2071.32	361302.85	959151.09

	A	B	C	D	E	F
213	211.00	7957.00	595392.98	2051.02	363364.02	955353.49
214	212.00	8012.68	603377.80	2030.76	365404.90	951555.89
215	213.00	8068.58	611418.41	2010.54	367425.55	947758.29
216	214.00	8124.69	619515.03	1990.38	369426.01	943960.69
217	215.00	8181.01	627667.86	1970.26	371406.32	940163.09
218	216.00	8237.55	635877.12	1950.19	373366.55	936365.49
219	217.00	8294.31	644143.03	1930.17	375306.73	932567.89
220	218.00	8351.29	652465.81	1910.20	377226.91	928770.29
221	219.00	8408.50	660845.69	1890.28	379127.15	924972.69
222	220.00	8465.93	669282.88	1870.40	381007.49	921175.09
223	221.00	8523.59	677777.62	1850.58	382867.97	917377.49
224	222.00	8581.47	686330.13	1830.81	384708.66	913579.89
225	223.00	8639.59	694940.64	1811.08	386529.60	909782.29
226	224.00	8697.94	703609.39	1791.41	388330.85	905984.69
227	225.00	8756.53	712336.60	1771.79	390112.44	902187.09
228	226.00	8815.35	721122.52	1752.22	391874.44	898389.49
229	227.00	8874.41	729967.38	1732.70	393616.89	894591.89
230	228.00	8933.72	738871.42	1713.23	395339.85	890794.29
231	229.00	8993.27	747834.89	1693.81	397043.36	886996.69
232	230.00	9053.06	756858.03	1674.45	398727.49	883199.09
233	231.00	9113.10	765941.09	1655.14	400392.28	879401.49
234	232.00	9173.40	775084.32	1635.89	402037.79	875603.89
235	233.00	9233.94	784287.97	1616.68	403664.07	871806.29
236	234.00	9294.74	793552.29	1597.54	405271.18	868008.69
237	235.00	9355.80	802877.54	1578.44	406859.16	864211.09
238	236.00	9417.12	812263.98	1559.41	408428.08	860413.49
239	237.00	9478.70	821711.86	1540.42	409977.99	856615.89
240	238.00	9540.54	831221.46	1521.50	411508.95	852818.29
241	239.00	9602.66	840793.04	1502.63	413021.01	849020.69
242	240.00	9665.04	850426.86	1483.81	414514.22	845223.09
243	241.00	9727.69	860123.21	1465.06	415988.65	841425.49
244	242.00	9790.62	869882.34	1446.36	417444.36	837627.89
245	243.00	9853.83	879704.54	1427.72	418881.39	833830.29
246	244.00	9917.31	889590.09	1409.14	420299.81	830032.69
247	245.00	9981.08	899539.26	1390.61	421699.68	826235.09
248	246.00	10045.14	909552.35	1372.15	423081.06	822437.49
249	247.00	10109.48	919629.64	1353.75	424444.00	818639.89
250	248.00	10174.11	929771.41	1335.40	425788.57	814842.29
251	249.00	10239.04	939977.96	1317.12	427114.83	811044.69
252	250.00	10304.27	950249.59	1298.90	428422.84	807247.09
253	251.00	10369.79	960586.59	1280.74	429712.66	803449.49
254	252.00	10435.62	970989.27	1262.65	430984.35	799651.89
255	253.00	10501.75	981457.93	1244.62	432237.98	795854.29
256	254.00	10568.19	991992.87	1226.65	433473.60	792056.69
257	255.00	10634.94	1002594.41	1208.74	434691.29	788259.09
258	256.00	10702.01	1013262.86	1190.90	435891.11	784461.49
259	257.00	10769.39	1023998.53	1173.13	437073.12	780663.89
260	258.00	10837.10	1034801.75	1155.42	438237.38	776866.29
261	259.00	10905.13	1045672.84	1137.77	439383.97	773068.69
262	260.00	10973.49	1056612.12	1120.20	440512.95	769271.09
263	261.00	11042.18	1067619.92	1102.69	441624.39	765473.49
264	262.00	11111.20	1078696.58	1085.25	442718.35	761675.89
265	263.00	11180.56	1089842.43	1067.88	443794.91	757878.29

	A	B	C	D	E	F
266	264.00	11250.27	1101057.82	1050.58	444854.13	754080.69
267	265.00	11320.31	1112343.08	1033.34	445896.09	750283.09
268	266.00	11390.71	1123698.56	1016.18	446920.84	746485.49
269	267.00	11461.46	1135124.62	999.09	447928.48	742687.89
270	268.00	11532.57	1146621.60	982.08	448919.06	738890.29
271	269.00	11604.03	1158189.87	965.13	449892.65	735092.69
272	270.00	11675.86	1169829.78	948.26	450849.34	731295.09
273	271.00	11748.06	1181541.71	931.46	451789.20	727497.49
274	272.00	11820.62	1193326.02	914.74	452712.30	723699.89
275	273.00	11893.57	1205183.08	898.09	453618.71	719902.29
276	274.00	11966.89	1217113.28	881.52	454508.51	716104.69
277	275.00	12040.60	1229116.99	865.03	455381.78	712307.09
278	276.00	12114.69	1241194.60	848.62	456238.60	708509.49
279	277.00	12189.18	1253346.50	832.28	457079.04	704711.89
280	278.00	12264.06	1265573.09	816.02	457903.18	700914.29
281	279.00	12339.35	1277874.76	799.85	458711.11	697116.69
282	280.00	12415.04	1290251.92	783.75	459502.91	693319.09
283	281.00	12491.14	1302704.98	767.74	460278.64	689521.49
284	282.00	12567.66	1315234.34	751.81	461038.41	685723.89
285	283.00	12644.59	1327840.43	735.96	461782.28	681926.29
286	284.00	12721.95	1340523.66	720.20	462510.36	678128.69
287	285.00	12799.74	1353284.47	704.52	463222.71	674331.09
288	286.00	12877.96	1366123.29	688.93	463919.43	670533.49
289	287.00	12956.62	1379040.54	673.43	464600.60	666735.89
290	288.00	13035.73	1392036.68	658.01	465266.31	662938.29
291	289.00	13115.29	1405112.15	642.69	465916.66	659140.69
292	290.00	13195.30	1418267.40	627.45	466551.72	655343.09
293	291.00	13275.77	1431502.90	612.31	467171.59	651545.49
294	292.00	13356.70	1444819.09	597.26	467776.37	647747.89
295	293.00	13438.11	1458216.46	582.30	468366.14	643950.29
296	294.00	13520.00	1471695.48	567.44	468941.00	640152.69
297	295.00	13602.37	1485256.62	552.67	469501.04	636355.09
298	296.00	13685.22	1498900.37	537.99	470046.36	632557.49
299	297.00	13768.57	1512627.23	523.42	470577.06	628759.89
300	298.00	13852.43	1526437.69	508.95	471093.24	624962.29
301	299.00	13936.79	1540332.25	494.57	471594.99	621164.69
302	300.00	14021.66	1554311.43	480.30	472082.41	617367.09
303	301.00	14107.05	1568375.74	466.13	472555.61	613569.49
304	302.00	14192.97	1582525.71	452.06	473014.70	609771.89
305	303.00	14279.42	1596761.86	438.09	473459.76	605974.29
306	304.00	14366.42	1611084.74	424.24	473890.92	602176.69
307	305.00	14453.96	1625494.88	410.49	474308.27	598379.09
308	306.00	14542.05	1639992.83	396.85	474711.93	594581.49
309	307.00	14630.70	1654579.16	383.32	475102.01	590783.89
310	308.00	14719.93	1669254.43	369.90	475478.61	586986.29
311	309.00	14809.72	1684019.21	356.59	475841.85	583188.69
312	310.00	14900.11	1698874.07	343.40	476191.83	579391.09
313	311.00	14991.08	1713819.62	330.33	476528.69	575593.49
314	312.00	15082.65	1728856.44	317.37	476852.53	571795.89
315	313.00	15174.84	1743985.13	304.53	477163.47	567998.29
316	314.00	15267.63	1759206.31	291.81	477461.64	564200.69
317	315.00	15361.05	1774520.60	279.22	477747.14	560403.09
318	316.00	15455.11	1789928.63	266.75	478020.11	556605.49

	A	B	C	D	E	F
319	317.00	15549.80	1805431.03	254.40	478280.68	552807.89
320	318.00	15645.15	1821028.45	242.18	478528.96	549010.29
321	319.00	15741.15	1836721.54	230.09	478765.08	545212.69
322	320.00	15837.83	1852510.98	218.13	478989.18	541415.09
323	321.00	15935.18	1868397.42	206.30	479201.39	537617.49
324	322.00	16033.22	1884381.57	194.61	479401.83	533819.89
325	323.00	16131.96	1900464.10	183.05	479590.65	530022.29
326	324.00	16231.41	1916645.72	171.64	479767.98	526224.69
327	325.00	16331.57	1932927.15	160.36	479933.97	522427.09
328	326.00	16432.47	1949309.11	149.22	480088.74	518629.49
329	327.00	16534.10	1965792.33	138.23	480232.46	514831.89
330	328.00	16636.49	1982377.57	127.38	480365.25	511034.29
331	329.00	16739.64	1999065.57	116.69	480487.28	507236.69
332	330.00	16843.56	2015857.11	106.14	480598.68	503439.09
333	331.00	16948.27	2032752.96	95.75	480699.61	499641.49
334	332.00	17053.78	2049753.92	85.51	480790.23	495843.89
335	333.00	17160.10	2066860.79	75.43	480870.68	492046.29
336	334.00	17267.24	2084074.38	65.51	480941.14	488248.69
337	335.00	17375.21	2101395.54	55.75	481001.76	484451.09
338	336.00	17484.04	2118825.09	46.16	481052.71	480653.49
339	337.00	17593.73	2136363.90	36.74	481094.14	476855.89
340	338.00	17704.29	2154012.84	27.49	481126.24	473058.29
341	339.00	17815.75	2171772.78	18.41	481149.17	469260.69
342	340.00	17928.11	2189644.63	9.50	481163.11	465463.09
343	341.00	18041.39	2207629.31	0.78	481168.24	461665.49
344	342.00	18155.61	2225727.73	-7.77	481164.73	457867.89
345	343.00	18270.78	2243940.84	-16.12	481152.77	454070.29
346	344.00	18386.91	2262269.60	-24.29	481132.54	450272.69
347	345.00	18504.03	2280714.99	-32.27	481104.24	446475.09
348	346.00	18622.15	2299278.00	-40.06	481068.06	442677.49
349	347.00	18741.29	2317959.63	-47.65	481024.19	438879.89
350	348.00	18861.47	2336760.93	-55.03	480972.83	435082.29
351	349.00	18982.70	2355682.92	-62.21	480914.20	431284.69
352	350.00	19105.00	2374726.68	-69.18	480848.48	427487.09
353	351.00	19228.39	2393893.28	-75.94	480775.90	423689.49
354	352.00	19352.90	2413183.83	-82.49	480696.66	419891.89
355	353.00	19478.54	2432599.45	-88.81	480610.99	416094.29
356	354.00	19605.33	2452141.29	-94.91	480519.11	412296.69
357	355.00	19733.29	2471810.50	-100.79	480421.24	408499.09
358	356.00	19862.46	2491608.27	-106.43	480317.61	404701.49
359	357.00	19992.84	2511535.82	-111.83	480208.46	400903.89
360	358.00	20124.46	2531594.36	-116.99	480094.03	397106.29
361	359.00	20257.35	2551785.16	-121.91	479974.56	393308.69
362	360.00	20391.53	2572109.49	-126.58	479850.29	389511.09
363	361.00	20527.03	2592568.66	-130.99	479721.49	385713.49
364	362.00	20663.87	2613163.99	-135.14	479588.40	381915.89
365	363.00	20802.07	2633896.84	-139.02	479451.30	378118.29
366	364.00	20941.68	2654768.60	-142.64	479310.45	374320.69
367	365.00	21082.71	2675780.68	-145.97	479166.12	370523.09
368	366.00	21225.20	2696934.51	-149.03	479018.59	366725.49
369	367.00	21369.17	2718231.56	-151.79	478868.16	362927.89
370	368.00	21514.65	2739673.35	-154.27	478715.10	359130.29
371	369.00	21661.69	2761261.39	-156.44	478559.73	355332.69

	A	B	C	D	E	F
372	370.00	21810.31	2782997.25	-158.30	478402.33	351535.09
373	371.00	21960.54	2804882.54	-159.85	478243.23	347737.49
374	372.00	22112.43	2826918.89	-161.08	478082.74	343939.89
375	373.00	22266.00	2849107.96	-161.98	477921.18	340142.29
376	374.00	22421.31	2871451.47	-162.55	477758.89	336344.69
377	375.00	22578.37	2893951.17	-162.77	477596.20	332547.09
378	376.00	22737.25	2916608.82	-162.65	477433.46	328749.49
379	377.00	22897.97	2939426.28	-162.16	477271.02	324951.89
380	378.00	23060.59	2962405.40	-161.31	477109.26	321154.29
381	379.00	23225.14	2985548.10	-160.08	476948.54	317356.69
382	380.00	23391.67	3008856.33	-158.46	476789.23	313559.09
383	381.00	23560.24	3032332.12	-156.46	476631.74	309761.49
384	382.00	23730.89	3055977.50	-154.04	476476.45	305963.89
385	383.00	23903.67	3079794.60	-151.22	476323.79	302166.29
386	384.00	24078.64	3103785.57	-147.96	476174.16	298368.69
387	385.00	24255.85	3127952.63	-144.28	476028.01	294571.09
388	386.00	24435.37	3152298.05	-140.14	475885.76	290773.49
389	387.00	24617.25	3176824.16	-135.55	475747.87	286975.89
390	388.00	24801.55	3201533.35	-130.48	475614.82	283178.29
391	389.00	24988.35	3226428.09	-124.94	475487.07	279380.69
392	390.00	25177.70	3251510.89	-118.89	475365.11	275583.09
393	391.00	25369.68	3276784.36	-112.33	475249.45	271785.49
394	392.00	25564.37	3302251.16	-105.25	475140.62	267987.89
395	393.00	25761.83	3327914.02	-97.63	475039.13	264190.29
396	394.00	25962.16	3353775.78	-89.46	474945.54	260392.69
397	395.00	25962.16	3379737.94	-120.22	474840.70	260392.69
398	396.00	25962.16	3405700.10	-150.98	474705.10	260392.69
399	397.00	25962.16	3431662.26	-181.74	474538.74	260392.69
400	398.00	25962.16	3457624.42	-212.51	474341.61	260392.69
401	399.00	25962.16	3483586.58	-243.27	474113.72	260392.69
402	400.00	25962.16	3509548.74	-274.04	473855.07	260392.69
403	401.00	25962.16	3535510.91	-304.80	473565.64	260392.69
404	402.00	25962.16	3561473.07	-335.57	473245.46	260392.69
405	403.00	25962.16	3587435.23	-366.34	472894.50	260392.69
406	404.00	25962.16	3613397.39	-397.11	472512.78	260392.69
407	405.00	25962.16	3639359.55	-427.88	472100.28	260392.69
408	406.00	25962.16	3665321.71	-458.65	471657.02	260392.69
409	407.00	25962.16	3691283.87	-489.42	471182.98	260392.69
410	408.00	25962.16	3717246.03	-520.20	470678.17	260392.69
411	409.00	25962.16	3743208.19	-550.97	470142.58	260392.69
412	410.00	25962.16	3769170.36	-581.75	469576.22	260392.69
413	411.00	25962.16	3795132.52	-612.53	468979.08	260392.69
414	412.00	25962.16	3821094.68	-643.31	468351.16	260392.69
415	413.00	25962.16	3847056.84	-674.09	467692.46	260392.69
416	414.00	25962.16	3873019.00	-704.88	467002.98	260392.69
417	415.00	25962.16	3898981.16	-735.66	466282.71	260392.69
418	416.00	25962.16	3924943.32	-766.45	465531.65	260392.69
419	417.00	25962.16	3950905.48	-797.24	464749.80	260392.69
420	418.00	25962.16	3976867.64	-828.04	463937.16	260392.69
421	419.00	25962.16	4002829.81	-858.83	463093.73	260392.69
422	420.00	25962.16	4028791.97	-889.63	462219.50	260392.69

	G	H	I	J	K	L
1	Inc	Vtotal	Gamma	Thrust	Pressure	Density
2	90.00	0.00	90.00	0.00	14.700000	0.002377
3	90.00	10.13	90.00	3635328.12	14.697595	0.002376
4	90.00	20.40	90.00	3635599.61	14.689235	0.002375
5	90.00	30.83	90.00	3636068.00	14.674810	0.002373
6	90.00	41.41	90.00	3636735.59	14.654251	0.002369
7	90.00	52.15	90.00	3637604.52	14.627492	0.002365
8	90.00	63.05	90.00	3638676.70	14.594474	0.002360
9	90.00	74.11	90.00	3639953.82	14.555144	0.002353
10	90.00	85.35	90.00	3641437.35	14.509458	0.002346
11	90.00	96.75	90.00	3643128.53	14.457377	0.002338
12	90.00	108.34	90.00	3645028.31	14.398872	0.002328
13	90.00	120.10	90.00	3647137.44	14.333921	0.002318
14	90.00	132.04	90.00	3649456.35	14.262509	0.002306
15	90.00	144.18	90.00	3651985.22	14.184631	0.002293
16	90.00	156.50	90.00	3654723.95	14.100290	0.002280
17	90.00	169.02	90.00	3657672.12	14.009499	0.002265
18	90.00	181.74	90.00	3660829.04	13.912280	0.002249
19	90.00	194.66	90.00	3664193.67	13.808664	0.002233
20	90.00	207.79	90.00	3667764.69	13.698693	0.002215
21	90.00	221.13	90.00	3671540.44	13.582416	0.002196
22	90.00	234.69	90.00	3675518.93	13.459897	0.002176
23	89.50	248.46	89.95	3679697.82	13.331205	0.002155
24	89.00	262.45	89.82	3684074.43	13.196425	0.002134
25	88.50	276.67	89.62	3688645.66	13.055651	0.002111
26	88.00	291.12	89.36	3693408.02	12.908992	0.002087
27	87.50	305.80	89.05	3698357.60	12.756567	0.002063
28	87.00	320.72	88.69	3703490.10	12.598509	0.002037
29	86.50	335.89	88.29	3708800.82	12.434962	0.002011
30	86.00	351.31	87.86	3714284.68	12.266083	0.001983
31	85.50	366.99	87.39	3719936.20	12.092042	0.001955
32	85.00	382.93	86.91	3725749.52	11.913017	0.001926
33	84.50	399.15	86.40	3731718.41	11.729202	0.001896
34	84.00	415.66	85.87	3737836.31	11.540798	0.001866
35	83.50	432.45	85.32	3744096.28	11.348018	0.001835
36	83.00	449.54	84.76	3750491.08	11.151087	0.001803
37	82.50	466.94	84.19	3757013.13	10.950237	0.001771
38	82.00	484.65	83.60	3763654.57	10.745710	0.001737
39	81.50	502.69	83.01	3770407.26	10.537757	0.001704
40	81.00	521.05	82.41	3777262.78	10.326637	0.001670
41	80.50	539.75	81.80	3784212.51	10.112616	0.001635
42	80.00	558.80	81.19	3791247.58	9.895967	0.001600
43	79.50	578.19	80.58	3798358.96	9.676969	0.001565
44	79.00	597.95	79.96	3805537.43	9.455903	0.001529
45	78.50	618.07	79.34	3812773.65	9.233060	0.001493
46	78.00	638.56	78.72	3820058.15	9.008730	0.001457
47	77.50	659.43	78.09	3827381.39	8.783206	0.001420
48	77.00	680.69	77.47	3834733.78	8.556786	0.001384
49	76.50	702.34	76.85	3842105.67	8.329764	0.001347
50	76.00	724.39	76.22	3849487.46	8.102438	0.001310
51	75.50	746.84	75.60	3856869.55	7.875102	0.001273
52	75.00	769.70	74.98	3864242.41	7.648051	0.001237
53	74.50	792.97	74.37	3871596.60	7.421574	0.001200

	G	H	I	J	K	L
54	74.00	816.67	73.75	3878922.82	7.195959	0.001163
55	73.50	840.79	73.14	3886211.90	6.971488	0.001127
56	73.00	865.34	72.53	3893454.85	6.748437	0.001091
57	72.50	890.33	71.92	3900642.90	6.527077	0.001055
58	72.00	915.75	71.32	3907767.51	6.307670	0.001020
59	71.50	941.62	70.72	3914820.40	6.090473	0.000985
60	71.00	967.94	70.12	3921793.57	5.875730	0.000950
61	70.50	994.71	69.53	3928679.34	5.663679	0.000916
62	70.00	1021.94	68.94	3935470.33	5.454546	0.000882
63	69.50	1049.63	68.36	3942159.56	5.248548	0.000849
64	69.00	1077.78	67.77	3948740.37	5.045888	0.000816
65	68.50	1106.40	67.20	3955206.52	4.846759	0.000784
66	68.00	1135.49	66.62	3961552.16	4.651342	0.000752
67	67.50	1165.05	66.06	3967771.84	4.459803	0.000721
68	67.00	1195.09	65.49	3973860.55	4.272298	0.000691
69	66.50	1225.61	64.93	3979813.71	4.088967	0.000661
70	66.00	1256.61	64.37	3985627.17	3.909938	0.000632
71	65.50	1288.09	63.82	3991297.25	3.735325	0.000604
72	65.00	1320.06	63.27	3996820.67	3.565228	0.000576
73	64.50	1352.53	62.73	4002194.65	3.399733	0.000550
74	64.00	1385.80	62.19	4035115.95	3.238903	0.000524
75	63.50	1419.72	61.65	4045271.09	3.082764	0.000498
76	63.00	1454.21	61.12	4055118.40	2.931357	0.000474
77	62.50	1489.28	60.60	4064655.73	2.784716	0.000450
78	62.00	1524.92	60.07	4073881.73	2.642863	0.000427
79	61.50	1561.15	59.56	4082795.75	2.505806	0.000405
80	61.00	1597.95	59.04	4091397.87	2.373544	0.000384
81	60.50	1635.32	58.53	4099688.91	2.246066	0.000363
82	60.00	1673.28	58.03	4107670.35	2.123348	0.000343
83	59.50	1711.81	57.52	4115344.34	2.005357	0.000324
84	59.00	1750.91	57.03	4122713.67	1.892050	0.000306
85	58.50	1790.60	56.53	4129781.75	1.783376	0.000288
86	58.00	1830.86	56.04	4136552.54	1.679272	0.000272
87	57.50	1871.70	55.56	4143030.57	1.579669	0.000255
88	57.00	1912.95	55.08	4134351.81	1.484493	0.000240
89	56.50	1954.76	54.60	4147546.01	1.393666	0.000225
90	56.00	1997.27	54.12	4160122.37	1.307092	0.000211
91	55.50	2040.47	53.65	4172095.81	1.224668	0.000198
92	55.00	2084.35	53.18	4183481.81	1.146289	0.000185
93	54.50	2128.92	52.72	4194296.37	1.071843	0.000173
94	54.00	2174.16	52.26	4204555.91	1.001217	0.000162
95	53.50	2220.07	51.80	4214277.28	0.934297	0.000151
96	53.00	2266.66	51.35	4223477.63	0.870963	0.000141
97	52.50	2313.91	50.90	4232174.38	0.811096	0.000131
98	52.00	2361.82	50.45	4240385.16	0.754574	0.000122
99	51.50	2410.40	50.01	4248127.74	0.701275	0.000113
100	51.00	2459.63	49.56	4255419.95	0.651076	0.000105
101	50.50	2509.52	49.13	4262279.66	0.603855	0.000098
102	50.00	2560.06	48.69	4268724.68	0.559488	0.000090
103	49.50	2611.25	48.26	4274772.73	0.517854	0.000084
104	49.00	2663.10	47.83	4280441.39	0.478832	0.000077
105	48.50	2715.59	47.40	4285748.03	0.442302	0.000072
106	48.00	2768.73	46.98	4290709.75	0.408146	0.000066

	G	H	I	J	K	L
107	47.50	2822.52	46.56	4295343.40	0.376249	0.000061
108	47.00	2876.95	46.14	4299665.45	0.346496	0.000056
109	46.50	2932.03	45.73	4303692.05	0.318778	0.000052
110	46.00	2987.75	45.31	4307438.91	0.292985	0.000047
111	45.50	3044.12	44.90	4310921.32	0.269012	0.000044
112	45.00	3101.13	44.50	4314154.13	0.246758	0.000040
113	44.50	3158.79	44.09	4317151.69	0.226123	0.000037
114	44.00	3217.10	43.69	4319927.87	0.207012	0.000033
115	43.50	3276.05	43.28	4322496.04	0.189334	0.000031
116	43.00	3335.66	42.89	4324869.03	0.172998	0.000028
117	42.50	3395.91	42.49	4327059.16	0.157922	0.000026
118	42.00	3456.82	42.09	4329078.22	0.144023	0.000023
119	41.50	3518.39	41.70	4330937.47	0.131224	0.000021
120	41.00	3580.61	41.31	4332647.63	0.119451	0.000019
121	40.50	3643.49	40.92	4334218.91	0.108635	0.000018
122	40.00	3707.04	40.54	4335661.00	0.098708	0.000016
123	39.50	3771.25	40.15	4336983.07	0.089607	0.000014
124	39.00	3836.13	39.77	4338193.79	0.081272	0.000013
125	38.50	3901.68	39.39	4339301.36	0.073648	0.000012
126	38.00	3967.91	39.01	4340313.48	0.066681	0.000011
127	37.50	4034.81	38.63	4341237.42	0.060320	0.000010
128	37.00	4102.40	38.25	4342079.97	0.054520	0.000009
129	36.50	4170.68	37.88	4342847.52	0.049237	0.000008
130	36.00	4239.65	37.51	4343546.04	0.044428	0.000007
131	35.50	4309.31	37.14	4344181.09	0.040057	0.000006
132	35.00	4379.67	36.77	4344757.88	0.036086	0.000006
133	34.50	4450.74	36.40	4345281.22	0.032483	0.000005
134	34.00	4522.52	36.03	4345755.63	0.029218	0.000005
135	33.50	4595.02	35.67	4346185.26	0.026260	0.000004
136	33.00	4668.24	35.31	4346573.98	0.023584	0.000004
137	32.50	4742.18	34.94	4346925.35	0.021165	0.000003
138	32.00	4816.86	34.58	4347242.69	0.018981	0.000003
139	31.50	4892.27	34.22	4347529.02	0.017010	0.000003
140	31.00	4968.43	33.87	4347787.15	0.015233	0.000002
141	30.50	5045.33	33.51	4348019.66	0.013632	0.000002
142	30.00	5123.00	33.15	4348228.91	0.012192	0.000002
143	30.00	5201.44	32.80	4348417.09	0.010897	0.000002
144	30.00	5280.70	32.46	4348586.19	0.009732	0.000002
145	30.00	5360.76	32.13	4348738.07	0.008687	0.000001
146	30.00	5441.63	31.81	4348874.41	0.007748	0.000001
147	30.00	5523.31	31.50	4348996.71	0.006907	0.000001
148	30.00	5605.80	31.20	4349106.36	0.006152	0.000001
149	30.00	5689.10	30.91	4349204.59	0.005475	0.000001
150	30.00	5773.22	30.62	4349292.55	0.004870	0.000001
151	30.00	5803.24	30.35	1739748.39	0.004330	0.000001
152	30.00	5833.54	30.08	1739776.21	0.003851	0.000001
153	30.00	5864.10	29.81	1739800.88	0.003427	0.000001
154	30.00	5894.93	29.55	1739822.77	0.003050	0.000000
155	30.00	5926.02	29.29	1739842.21	0.002716	0.000000
156	30.00	5957.38	29.03	1739859.47	0.002419	0.000000
157	30.00	5989.01	28.77	1739874.80	0.002155	0.000000
158	30.00	6020.89	28.52	1739888.42	0.001920	0.000000
159	30.00	6053.04	28.27	1739900.52	0.001712	0.000000

	G	H	I	J	K	L
160	30.00	6085.45	28.02	1739911.29	0.001527	0.000000
161	30.00	6118.12	27.78	1739920.87	0.001362	0.000000
162	30.00	6151.04	27.53	1739929.39	0.001215	0.000000
163	29.50	6184.23	27.29	1739936.97	0.001085	0.000000
164	29.00	6217.70	27.05	1739943.72	0.000969	0.000000
165	28.50	6251.45	26.81	1739949.73	0.000865	0.000000
166	28.00	6285.47	26.56	1739955.09	0.000773	0.000000
167	27.50	6319.77	26.32	1739959.86	0.000691	0.000000
168	27.00	6354.35	26.07	1739964.11	0.000618	0.000000
169	26.50	6389.21	25.82	1739967.90	0.000552	0.000000
170	26.00	6424.35	25.57	1739971.27	0.000494	0.000000
171	25.50	6459.77	25.32	1739974.29	0.000443	0.000000
172	25.00	6495.47	25.07	1739976.97	0.000396	0.000000
173	24.50	6531.46	24.82	1739979.37	0.000355	0.000000
174	24.00	6567.73	24.57	1739981.51	0.000318	0.000000
175	23.50	6604.29	24.31	1739983.42	0.000285	0.000000
176	23.00	6641.13	24.06	1739985.13	0.000256	0.000000
177	22.50	6678.26	23.80	1739986.65	0.000230	0.000000
178	22.00	6715.67	23.55	1739988.01	0.000206	0.000000
179	21.50	6753.38	23.29	1739989.23	0.000185	0.000000
180	21.00	6791.37	23.03	1739990.32	0.000167	0.000000
181	20.50	6829.65	22.77	1739991.29	0.000150	0.000000
182	20.00	6868.22	22.52	1739992.17	0.000135	0.000000
183	19.50	6907.09	22.25	1739992.95	0.000121	0.000000
184	19.00	6946.24	21.99	1739993.65	0.000109	0.000000
185	18.50	6985.69	21.73	1739994.27	0.000099	0.000000
186	18.00	7025.44	21.47	1739994.83	0.000089	0.000000
187	17.50	7065.48	21.21	1739995.34	0.000080	0.000000
188	17.00	7105.82	20.94	1739995.79	0.000072	0.000000
189	16.50	7146.45	20.68	1739996.20	0.000065	0.000000
190	16.00	7187.38	20.41	1739996.56	0.000059	0.000000
191	15.50	7228.61	20.15	1739996.89	0.000054	0.000000
192	15.00	7270.14	19.88	1739997.18	0.000049	0.000000
193	14.50	7311.97	19.61	1739997.45	0.000044	0.000000
194	14.00	7354.10	19.35	1739997.68	0.000040	0.000000
195	13.50	7396.53	19.08	1739997.90	0.000036	0.000000
196	13.00	7439.27	18.81	1739998.09	0.000033	0.000000
197	12.50	7482.31	18.54	1739998.27	0.000030	0.000000
198	12.00	7525.66	18.27	1739998.42	0.000027	0.000000
199	11.50	7569.31	18.00	1739998.56	0.000025	0.000000
200	11.00	7613.27	17.73	1739998.69	0.000023	0.000000
201	11.00	7657.57	17.46	1739998.81	0.000021	0.000000
202	11.00	7702.23	17.19	1739998.91	0.000019	0.000000
203	11.00	7747.25	16.93	1739999.01	0.000017	0.000000
204	11.00	7792.63	16.67	1739999.09	0.000016	0.000000
205	11.00	7838.37	16.41	1739999.17	0.000014	0.000000
206	11.00	7884.46	16.16	1739999.24	0.000013	0.000000
207	11.00	7930.92	15.91	1739999.30	0.000012	0.000000
208	11.00	7977.73	15.66	1739999.36	0.000011	0.000000
209	11.00	8024.89	15.41	1739999.41	0.000010	0.000000
210	11.00	8072.41	15.17	1739999.46	0.000009	0.000000
211	11.00	8120.28	14.93	1739999.50	0.000009	0.000000
212	11.00	8168.51	14.69	1739999.54	0.000008	0.000000

	G	H	I	J	K	L
213	11.00	8217.09	14.45	1739999.58	0.000007	0.000000
214	11.00	8266.02	14.22	1739999.61	0.000007	0.000000
215	11.00	8315.30	13.99	1739999.64	0.000006	0.000000
216	11.00	8364.93	13.77	1739999.67	0.000006	0.000000
217	11.00	8414.92	13.54	1739999.70	0.000005	0.000000
218	11.00	8465.25	13.32	1739999.72	0.000005	0.000000
219	11.00	8515.94	13.10	1739999.74	0.000004	0.000000
220	11.00	8566.97	12.88	1739999.76	0.000004	0.000000
221	11.00	8618.35	12.67	1739999.78	0.000004	0.000000
222	11.00	8670.08	12.46	1739999.79	0.000004	0.000000
223	11.00	8722.16	12.25	1739999.81	0.000003	0.000000
224	11.00	8774.59	12.04	1739999.82	0.000003	0.000000
225	11.00	8827.37	11.84	1739999.83	0.000003	0.000000
226	11.00	8880.50	11.64	1739999.85	0.000003	0.000000
227	11.00	8933.98	11.44	1739999.86	0.000002	0.000000
228	11.00	8987.81	11.24	1739999.87	0.000002	0.000000
229	11.00	9041.98	11.05	1739999.88	0.000002	0.000000
230	11.00	9096.51	10.86	1739999.88	0.000002	0.000000
231	11.00	9151.38	10.67	1739999.89	0.000002	0.000000
232	11.00	9206.61	10.48	1739999.90	0.000002	0.000000
233	11.00	9262.19	10.29	1739999.90	0.000002	0.000000
234	11.00	9318.12	10.11	1739999.91	0.000002	0.000000
235	11.00	9374.40	9.93	1739999.92	0.000001	0.000000
236	11.00	9431.03	9.75	1739999.92	0.000001	0.000000
237	11.00	9488.02	9.58	1739999.93	0.000001	0.000000
238	11.00	9545.36	9.40	1739999.93	0.000001	0.000000
239	11.00	9603.05	9.23	1739999.94	0.000001	0.000000
240	11.00	9661.10	9.06	1739999.94	0.000001	0.000000
241	11.00	9719.51	8.89	1739999.94	0.000001	0.000000
242	11.00	9778.28	8.73	1739999.95	0.000001	0.000000
243	11.00	9837.40	8.56	1739999.95	0.000001	0.000000
244	11.00	9896.88	8.40	1739999.95	0.000001	0.000000
245	11.00	9956.72	8.24	1739999.95	0.000001	0.000000
246	11.00	10016.92	8.09	1739999.96	0.000001	0.000000
247	11.00	10077.49	7.93	1739999.96	0.000001	0.000000
248	11.00	10138.42	7.78	1739999.96	0.000001	0.000000
249	11.00	10199.72	7.63	1739999.96	0.000001	0.000000
250	11.00	10261.38	7.48	1739999.97	0.000001	0.000000
251	11.00	10323.41	7.33	1739999.97	0.000001	0.000000
252	11.00	10385.81	7.18	1739999.97	0.000001	0.000000
253	11.00	10448.58	7.04	1739999.97	0.000001	0.000000
254	11.00	10511.73	6.90	1739999.97	0.000000	0.000000
255	11.00	10575.24	6.76	1739999.97	0.000000	0.000000
256	11.00	10639.14	6.62	1739999.97	0.000000	0.000000
257	11.00	10703.41	6.48	1739999.98	0.000000	0.000000
258	11.00	10768.06	6.35	1739999.98	0.000000	0.000000
259	11.00	10833.10	6.22	1739999.98	0.000000	0.000000
260	11.00	10898.52	6.09	1739999.98	0.000000	0.000000
261	11.00	10964.32	5.96	1739999.98	0.000000	0.000000
262	11.00	11030.52	5.83	1739999.98	0.000000	0.000000
263	11.00	11097.10	5.70	1739999.98	0.000000	0.000000
264	11.00	11164.07	5.58	1739999.98	0.000000	0.000000
265	11.00	11231.44	5.46	1739999.98	0.000000	0.000000

	G	H	I	J	K	L
266	11.00	11299.21	5.33	1739999.98	0.000000	0.000000
267	11.00	11367.38	5.22	1739999.98	0.000000	0.000000
268	11.00	11435.95	5.10	1739999.99	0.000000	0.000000
269	11.00	11504.92	4.98	1739999.99	0.000000	0.000000
270	11.00	11574.30	4.87	1739999.99	0.000000	0.000000
271	11.00	11644.10	4.75	1739999.99	0.000000	0.000000
272	11.00	11714.30	4.64	1739999.99	0.000000	0.000000
273	11.00	11784.92	4.53	1739999.99	0.000000	0.000000
274	11.00	11855.96	4.43	1739999.99	0.000000	0.000000
275	11.00	11927.43	4.32	1739999.99	0.000000	0.000000
276	11.00	11999.31	4.21	1739999.99	0.000000	0.000000
277	11.00	12071.63	4.11	1739999.99	0.000000	0.000000
278	11.00	12144.38	4.01	1739999.99	0.000000	0.000000
279	11.00	12217.56	3.91	1739999.99	0.000000	0.000000
280	11.00	12291.18	3.81	1739999.99	0.000000	0.000000
281	11.00	12365.24	3.71	1739999.99	0.000000	0.000000
282	11.00	12439.75	3.61	1739999.99	0.000000	0.000000
283	11.00	12514.71	3.52	1739999.99	0.000000	0.000000
284	11.00	12590.12	3.42	1739999.99	0.000000	0.000000
285	11.00	12665.99	3.33	1739999.99	0.000000	0.000000
286	11.00	12742.32	3.24	1739999.99	0.000000	0.000000
287	11.00	12819.11	3.15	1739999.99	0.000000	0.000000
288	11.00	12896.38	3.06	1739999.99	0.000000	0.000000
289	11.00	12974.11	2.98	1739999.99	0.000000	0.000000
290	11.00	13052.33	2.89	1739999.99	0.000000	0.000000
291	11.00	13131.02	2.81	1739999.99	0.000000	0.000000
292	11.00	13210.21	2.72	1739999.99	0.000000	0.000000
293	11.00	13289.88	2.64	1739999.99	0.000000	0.000000
294	11.00	13370.05	2.56	1739999.99	0.000000	0.000000
295	11.00	13450.72	2.48	1739999.99	0.000000	0.000000
296	11.00	13531.90	2.40	1739999.99	0.000000	0.000000
297	11.00	13613.59	2.33	1739999.99	0.000000	0.000000
298	11.00	13695.79	2.25	1739999.99	0.000000	0.000000
299	11.00	13778.52	2.18	1739999.99	0.000000	0.000000
300	11.00	13861.77	2.10	1739999.99	0.000000	0.000000
301	11.00	13945.56	2.03	1739999.99	0.000000	0.000000
302	11.00	14029.88	1.96	1739999.99	0.000000	0.000000
303	11.00	14114.75	1.89	1739999.99	0.000000	0.000000
304	11.00	14200.17	1.82	1739999.99	0.000000	0.000000
305	11.00	14286.14	1.76	1739999.99	0.000000	0.000000
306	11.00	14372.68	1.69	1739999.99	0.000000	0.000000
307	11.00	14459.78	1.63	1740000.00	0.000000	0.000000
308	11.00	14547.46	1.56	1740000.00	0.000000	0.000000
309	11.00	14635.72	1.50	1740000.00	0.000000	0.000000
310	11.00	14724.57	1.44	1740000.00	0.000000	0.000000
311	11.00	14814.02	1.38	1740000.00	0.000000	0.000000
312	11.00	14904.06	1.32	1740000.00	0.000000	0.000000
313	11.00	14994.72	1.26	1740000.00	0.000000	0.000000
314	11.00	15085.99	1.21	1740000.00	0.000000	0.000000
315	11.00	15177.89	1.15	1740000.00	0.000000	0.000000
316	11.00	15270.42	1.09	1740000.00	0.000000	0.000000
317	11.00	15363.59	1.04	1740000.00	0.000000	0.000000
318	11.00	15457.41	0.99	1740000.00	0.000000	0.000000

	G	H	I	J	K	L
319	11.00	15551.88	0.94	1740000.00	0.000000	0.000000
320	11.00	15647.02	0.89	1740000.00	0.000000	0.000000
321	11.00	15742.83	0.84	1740000.00	0.000000	0.000000
322	11.00	15839.33	0.79	1740000.00	0.000000	0.000000
323	11.00	15936.51	0.74	1740000.00	0.000000	0.000000
324	11.00	16034.40	0.70	1740000.00	0.000000	0.000000
325	11.00	16133.00	0.65	1740000.00	0.000000	0.000000
326	11.00	16232.31	0.61	1740000.00	0.000000	0.000000
327	11.00	16332.36	0.56	1740000.00	0.000000	0.000000
328	11.00	16433.15	0.52	1740000.00	0.000000	0.000000
329	11.00	16534.68	0.48	1740000.00	0.000000	0.000000
330	11.00	16636.98	0.44	1740000.00	0.000000	0.000000
331	11.00	16740.05	0.40	1740000.00	0.000000	0.000000
332	11.00	16843.90	0.36	1740000.00	0.000000	0.000000
333	11.00	16948.54	0.32	1740000.00	0.000000	0.000000
334	11.00	17053.99	0.29	1740000.00	0.000000	0.000000
335	11.00	17160.26	0.25	1740000.00	0.000000	0.000000
336	11.00	17267.36	0.22	1740000.00	0.000000	0.000000
337	11.00	17375.30	0.18	1740000.00	0.000000	0.000000
338	11.00	17484.10	0.15	1740000.00	0.000000	0.000000
339	11.00	17593.76	0.12	1740000.00	0.000000	0.000000
340	11.00	17704.31	0.09	1740000.00	0.000000	0.000000
341	11.00	17815.76	0.06	1740000.00	0.000000	0.000000
342	11.00	17928.11	0.03	1740000.00	0.000000	0.000000
343	11.00	18041.39	0.00	1740000.00	0.000000	0.000000
344	11.00	18155.61	-0.02	1740000.00	0.000000	0.000000
345	11.00	18270.78	-0.05	1740000.00	0.000000	0.000000
346	11.00	18386.93	-0.08	1740000.00	0.000000	0.000000
347	11.00	18504.06	-0.10	1740000.00	0.000000	0.000000
348	11.00	18622.20	-0.12	1740000.00	0.000000	0.000000
349	11.00	18741.35	-0.15	1740000.00	0.000000	0.000000
350	11.00	18861.55	-0.17	1740000.00	0.000000	0.000000
351	11.00	18982.80	-0.19	1740000.00	0.000000	0.000000
352	11.00	19105.12	-0.21	1740000.00	0.000000	0.000000
353	11.00	19228.54	-0.23	1740000.00	0.000000	0.000000
354	11.00	19353.07	-0.24	1740000.00	0.000000	0.000000
355	11.00	19478.74	-0.26	1740000.00	0.000000	0.000000
356	11.00	19605.56	-0.28	1740000.00	0.000000	0.000000
357	11.00	19733.55	-0.29	1740000.00	0.000000	0.000000
358	11.00	19862.74	-0.31	1740000.00	0.000000	0.000000
359	11.00	19993.15	-0.32	1740000.00	0.000000	0.000000
360	11.00	20124.80	-0.33	1740000.00	0.000000	0.000000
361	11.00	20257.72	-0.34	1740000.00	0.000000	0.000000
362	11.00	20391.92	-0.36	1740000.00	0.000000	0.000000
363	11.00	20527.44	-0.37	1740000.00	0.000000	0.000000
364	11.00	20664.31	-0.37	1740000.00	0.000000	0.000000
365	11.00	20802.54	-0.38	1740000.00	0.000000	0.000000
366	11.00	20942.16	-0.39	1740000.00	0.000000	0.000000
367	11.00	21083.22	-0.40	1740000.00	0.000000	0.000000
368	11.00	21225.72	-0.40	1740000.00	0.000000	0.000000
369	11.00	21369.71	-0.41	1740000.00	0.000000	0.000000
370	11.00	21515.21	-0.41	1740000.00	0.000000	0.000000
371	11.00	21662.25	-0.41	1740000.00	0.000000	0.000000

	G	H	I	J	K	L
372	11.00	21810.88	-0.42	1740000.00	0.000000	0.000000
373	11.00	21961.12	-0.42	1740000.00	0.000000	0.000000
374	11.00	22113.02	-0.42	1740000.00	0.000000	0.000000
375	11.00	22266.59	-0.42	1740000.00	0.000000	0.000000
376	11.00	22421.90	-0.42	1740000.00	0.000000	0.000000
377	11.00	22578.96	-0.41	1740000.00	0.000000	0.000000
378	11.00	22737.83	-0.41	1740000.00	0.000000	0.000000
379	11.00	22898.55	-0.41	1740000.00	0.000000	0.000000
380	11.00	23061.15	-0.40	1740000.00	0.000000	0.000000
381	11.00	23225.69	-0.39	1740000.00	0.000000	0.000000
382	11.00	23392.21	-0.39	1740000.00	0.000000	0.000000
383	11.00	23560.76	-0.38	1740000.00	0.000000	0.000000
384	11.00	23731.39	-0.37	1740000.00	0.000000	0.000000
385	11.00	23904.15	-0.36	1740000.00	0.000000	0.000000
386	11.00	24079.09	-0.35	1740000.00	0.000000	0.000000
387	11.00	24256.28	-0.34	1740000.00	0.000000	0.000000
388	11.00	24435.77	-0.33	1740000.00	0.000000	0.000000
389	11.00	24617.62	-0.32	1740000.00	0.000000	0.000000
390	11.00	24801.89	-0.30	1740000.00	0.000000	0.000000
391	11.00	24988.66	-0.29	1740000.00	0.000000	0.000000
392	11.00	25177.98	-0.27	1740000.00	0.000000	0.000000
393	11.00	25369.93	-0.25	1740000.00	0.000000	0.000000
394	11.00	25564.58	-0.24	1740000.00	0.000000	0.000000
395	11.00	25762.02	-0.22	1740000.00	0.000000	0.000000
396	11.00	25962.32	-0.20	1740000.00	0.000000	0.000000
397	11.00	25962.44	-0.27	0.00	0.000000	0.000000
398	11.00	25962.60	-0.33	0.00	0.000000	0.000000
399	11.00	25962.80	-0.40	0.00	0.000000	0.000000
400	11.00	25963.03	-0.47	0.00	0.000000	0.000000
401	11.00	25963.30	-0.54	0.00	0.000000	0.000000
402	11.00	25963.61	-0.60	0.00	0.000000	0.000000
403	11.00	25963.95	-0.67	0.00	0.000000	0.000000
404	11.00	25964.33	-0.74	0.00	0.000000	0.000000
405	11.00	25964.75	-0.81	0.00	0.000000	0.000000
406	11.00	25965.20	-0.88	0.00	0.000000	0.000000
407	11.00	25965.69	-0.94	0.00	0.000000	0.000000
408	11.00	25966.21	-1.01	0.00	0.000000	0.000000
409	11.00	25966.77	-1.08	0.00	0.000000	0.000000
410	11.00	25967.37	-1.15	0.00	0.000000	0.000000
411	11.00	25968.01	-1.22	0.00	0.000000	0.000000
412	11.00	25968.68	-1.28	0.00	0.000000	0.000000
413	11.00	25969.39	-1.35	0.00	0.000000	0.000000
414	11.00	25970.13	-1.42	0.00	0.000000	0.000000
415	11.00	25970.91	-1.49	0.00	0.000000	0.000000
416	11.00	25971.73	-1.56	0.00	0.000000	0.000000
417	11.00	25972.58	-1.62	0.00	0.000000	0.000000
418	11.00	25973.47	-1.69	0.00	0.000000	0.000000
419	11.00	25974.40	-1.76	0.00	0.000000	0.000000
420	11.00	25975.36	-1.83	0.00	0.000000	0.000000
421	11.00	25976.36	-1.89	0.00	0.000000	0.000000
422	11.00	25977.40	-1.96	0.00	0.000000	0.000000

Figure 3.0.1: Plot of X-Velocity vs. Time

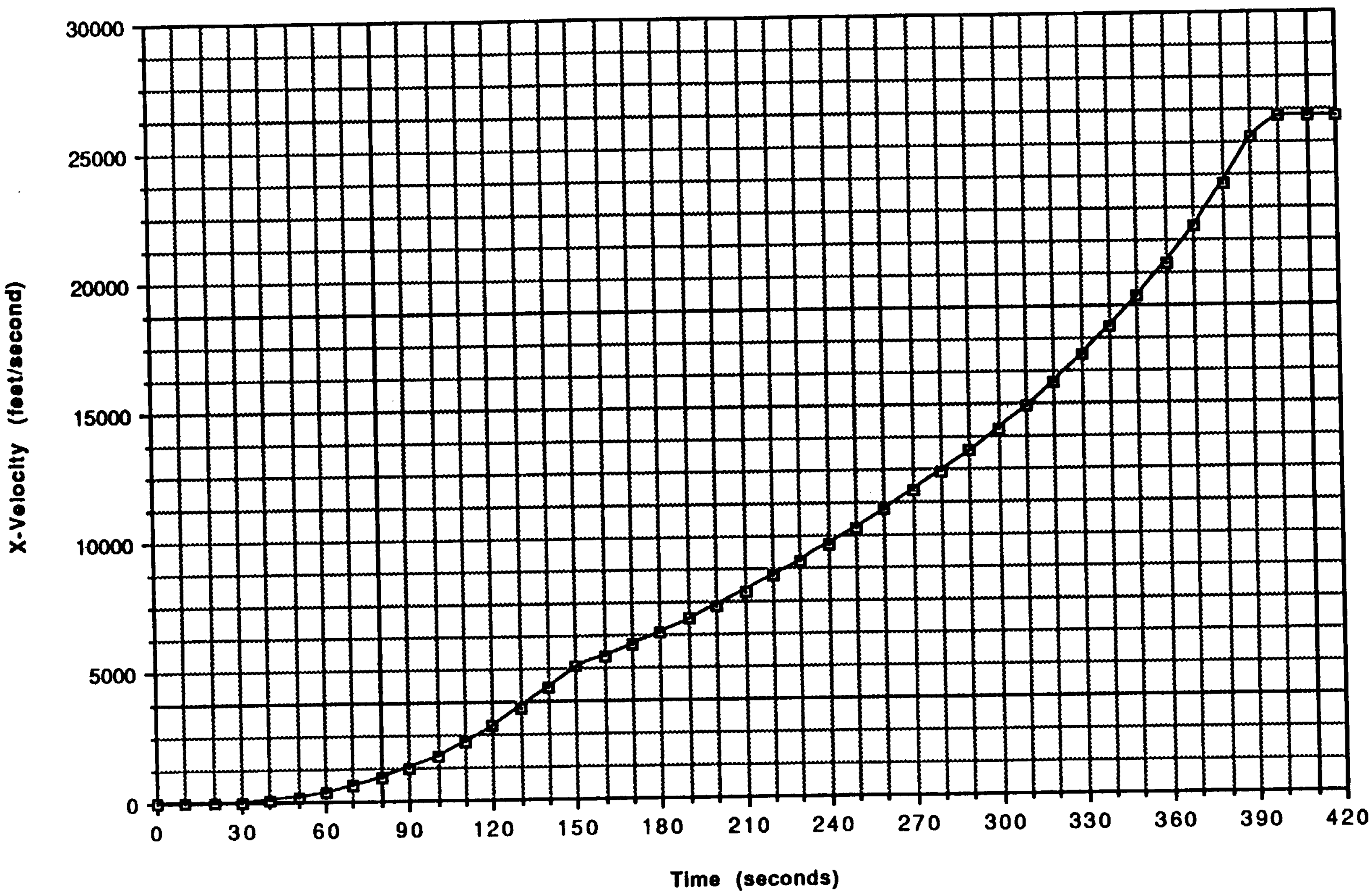


Figure 3.0.2: Plot of X-Position vs. Time

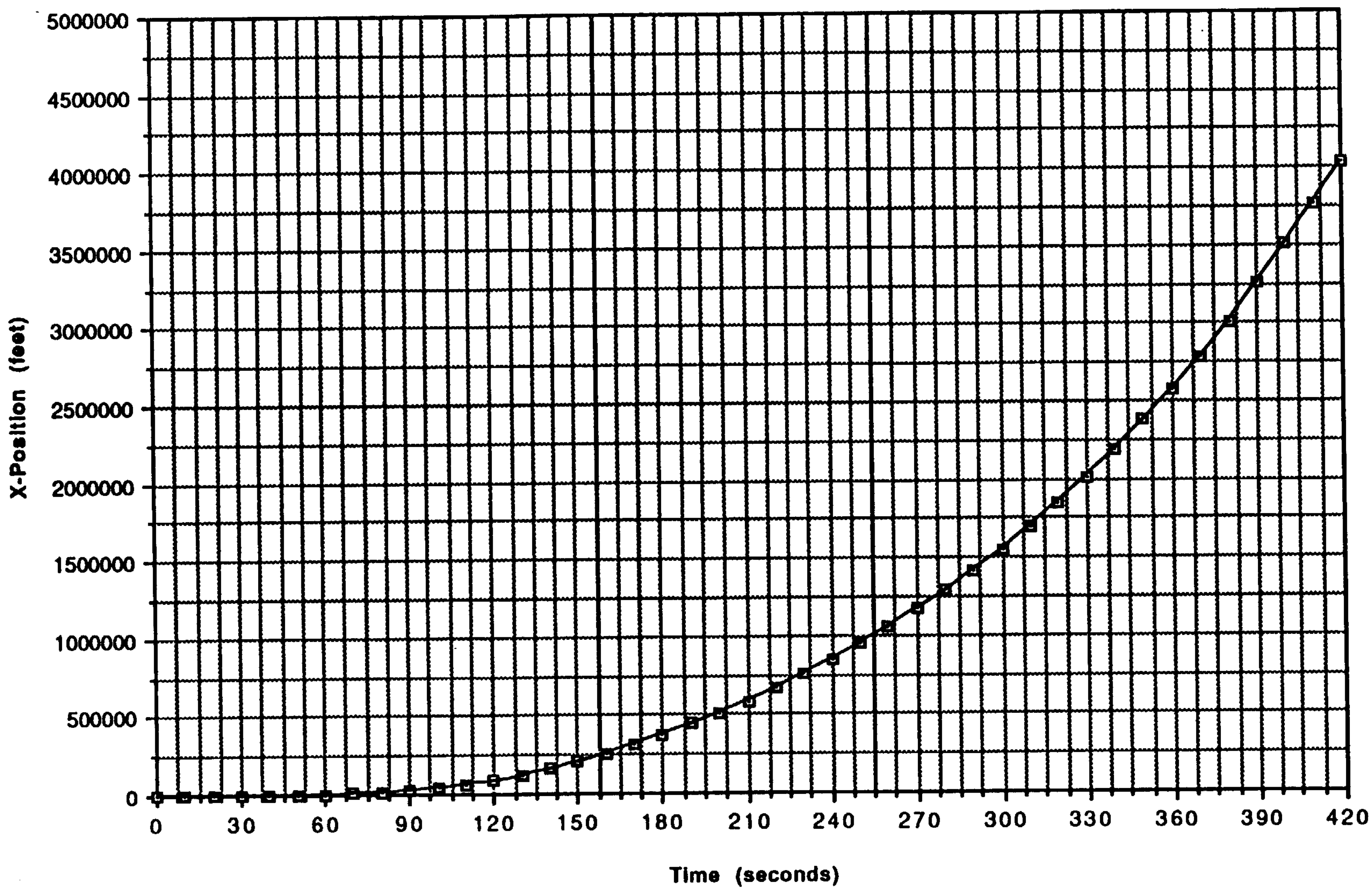


Figure 3.0.3: Plot of Y-Velocity vs. Time

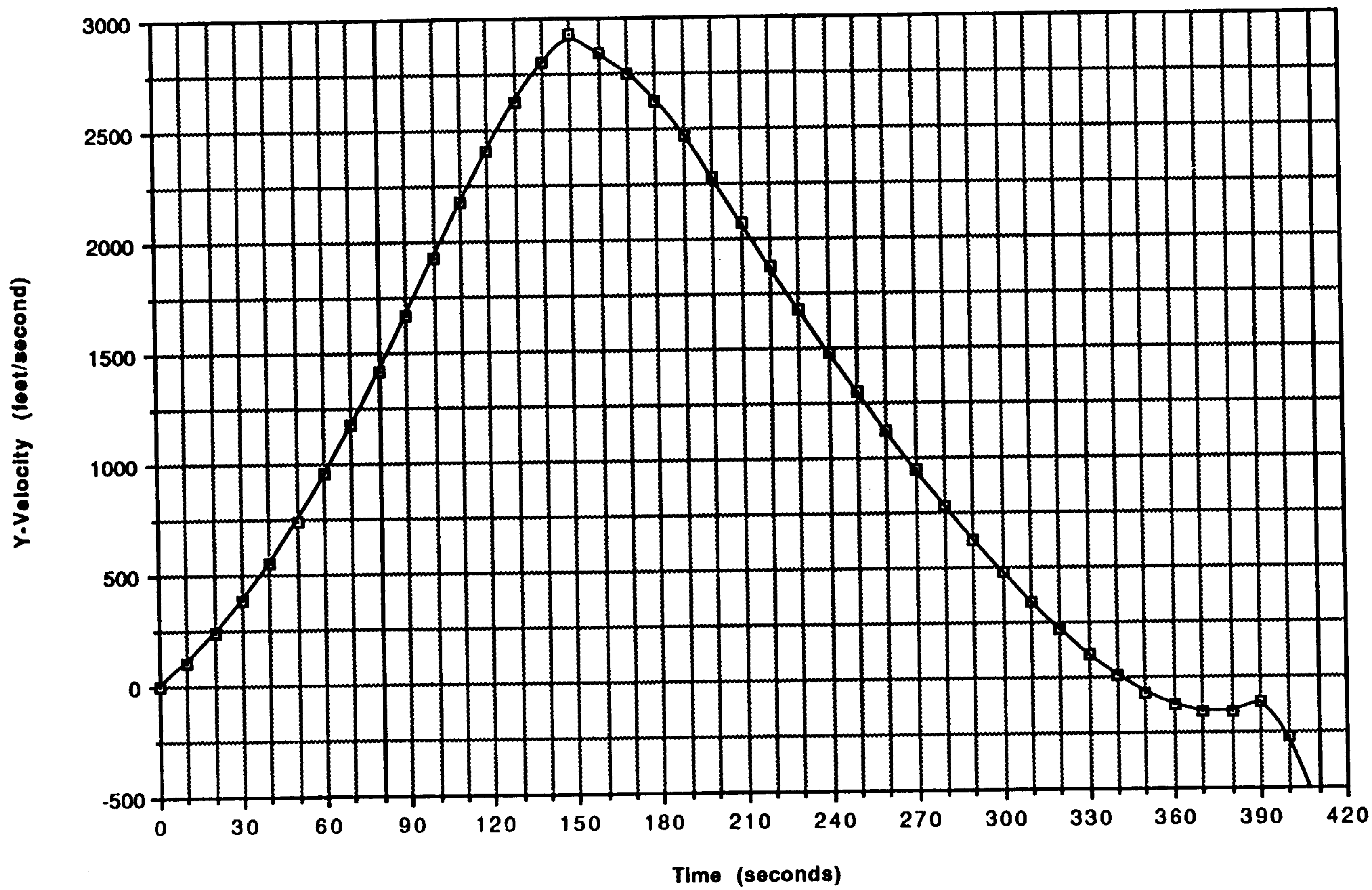


Figure 3.0.4: Plot of Y-Position vs. Time

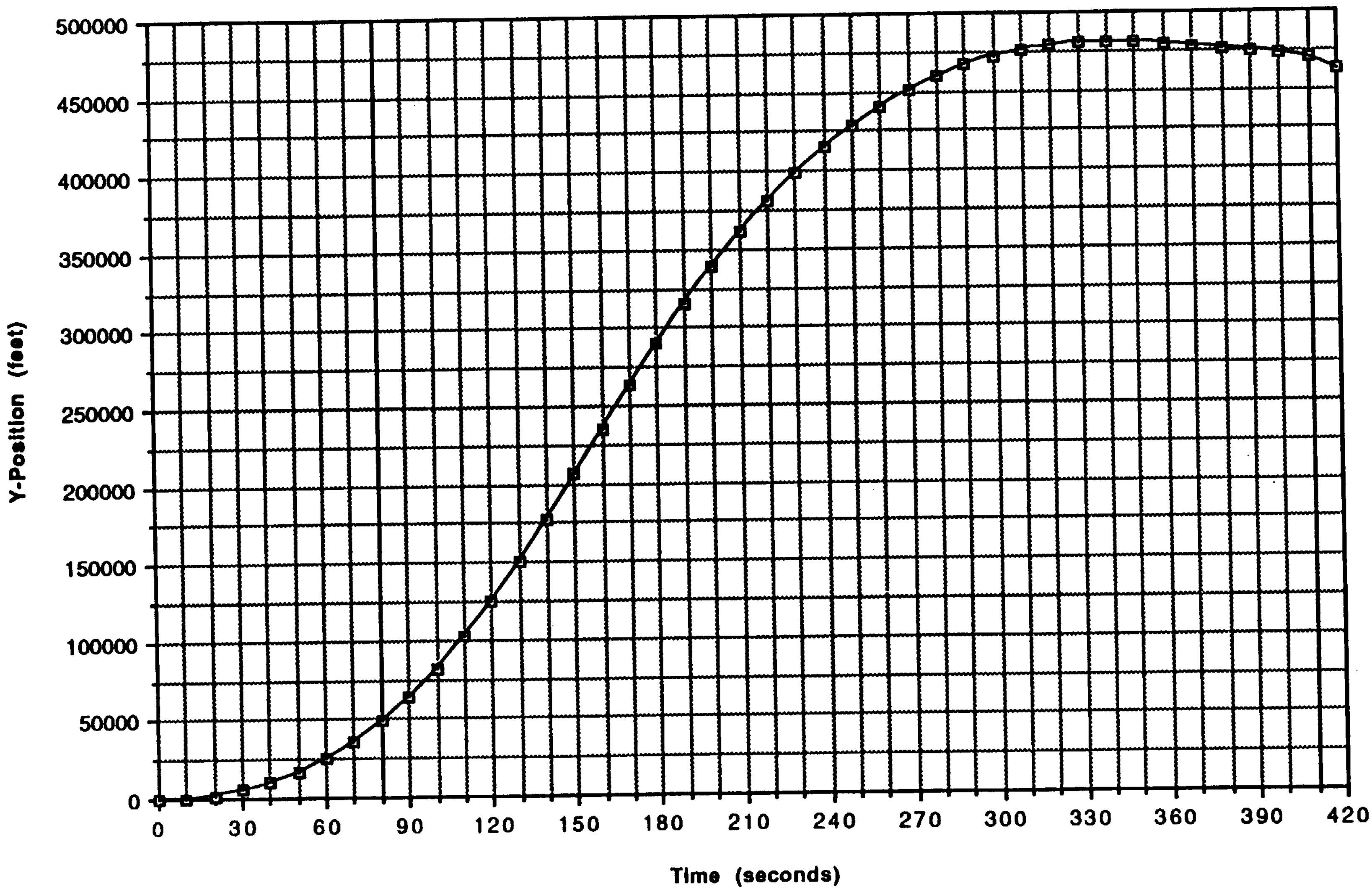


Figure 3.0.5: Plot of Weight vs. Time

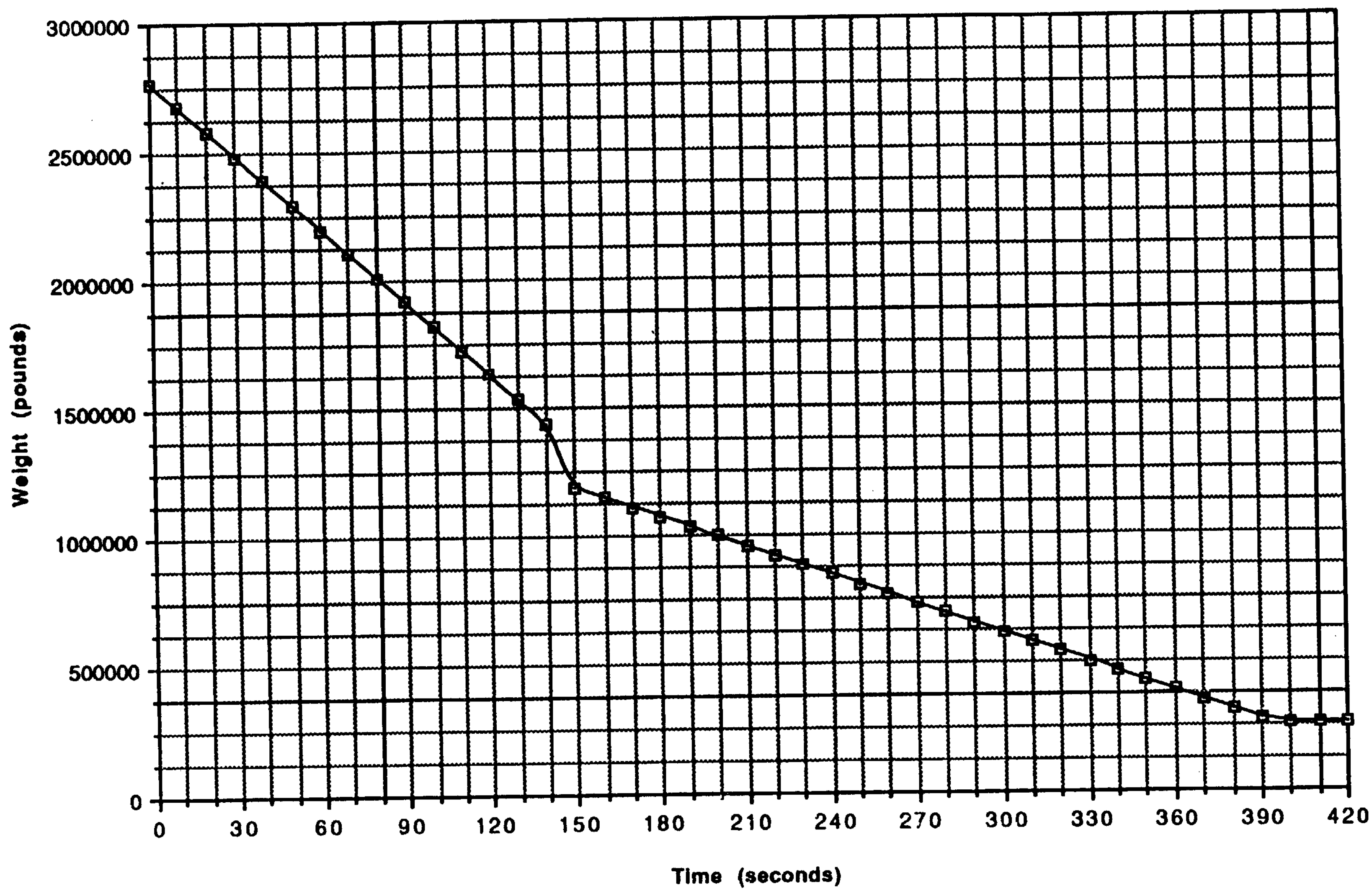


Figure 3.0.6: Plot of Inclination vs. Time

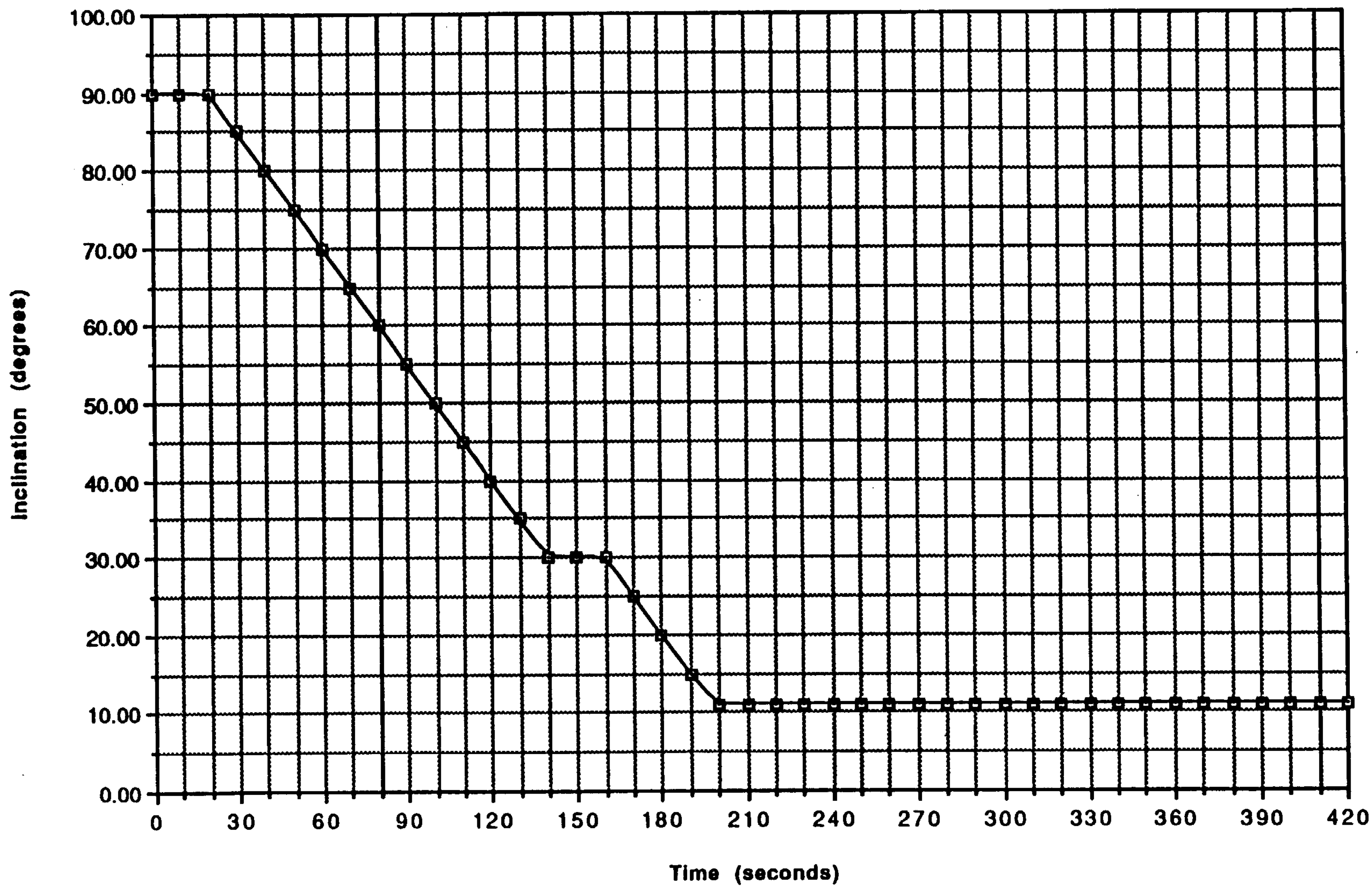


Figure 3.0.7: Plot of Total Velocity vs. Time

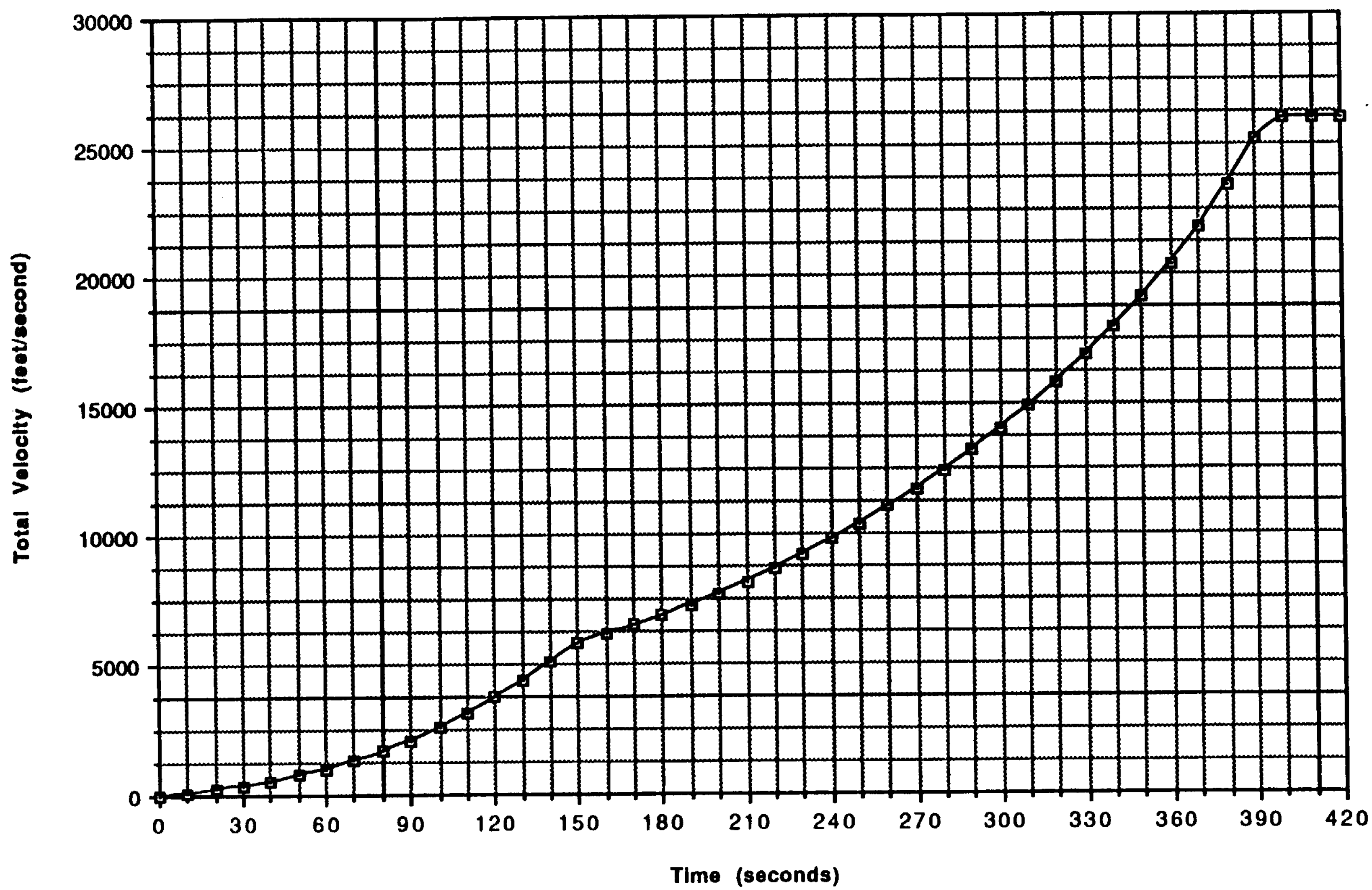


Figure 3.0.8: Plot of Flight-Path Angle vs. Time

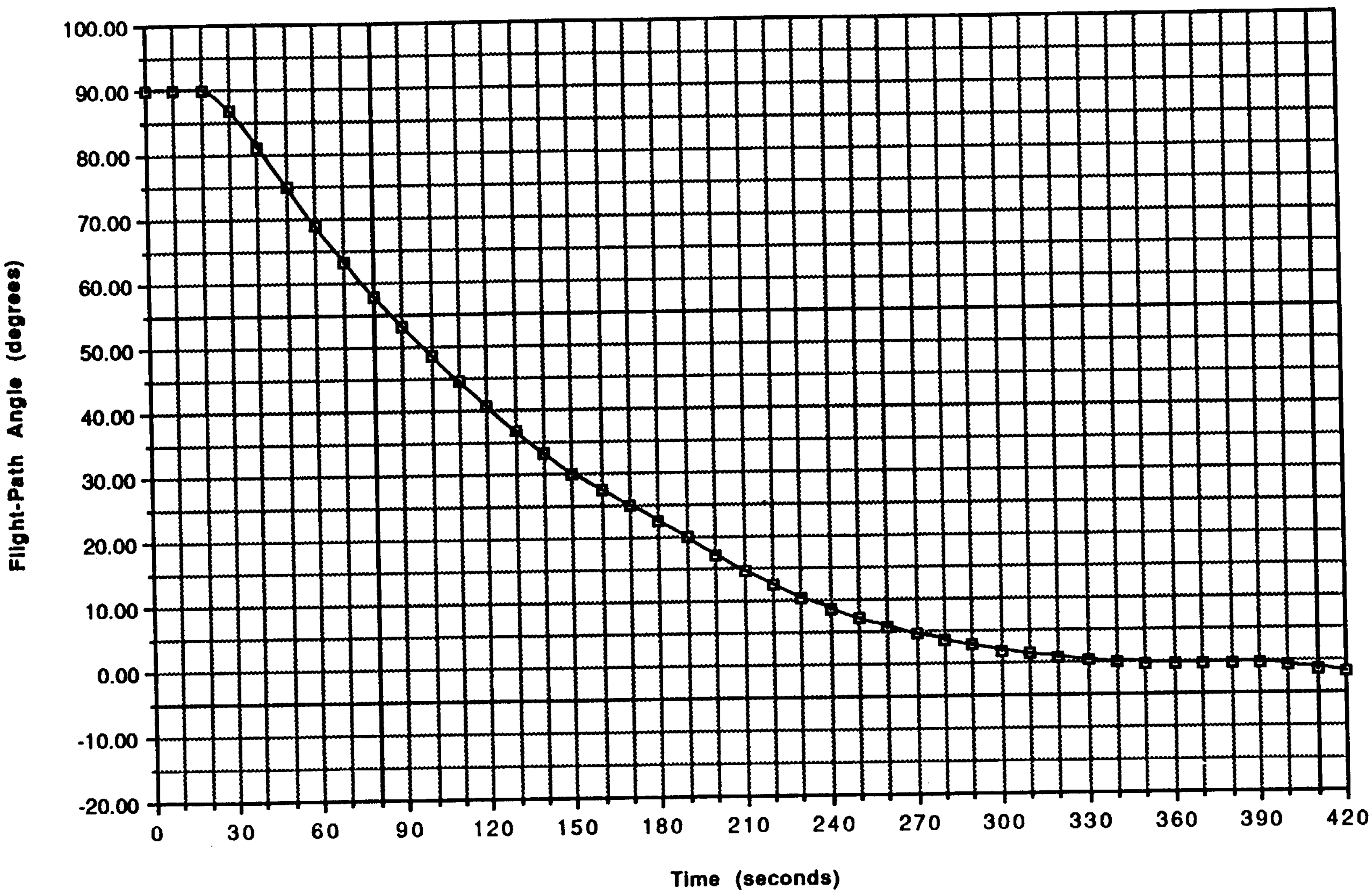


Figure 3.0.9: Plot of Thrust vs. Time

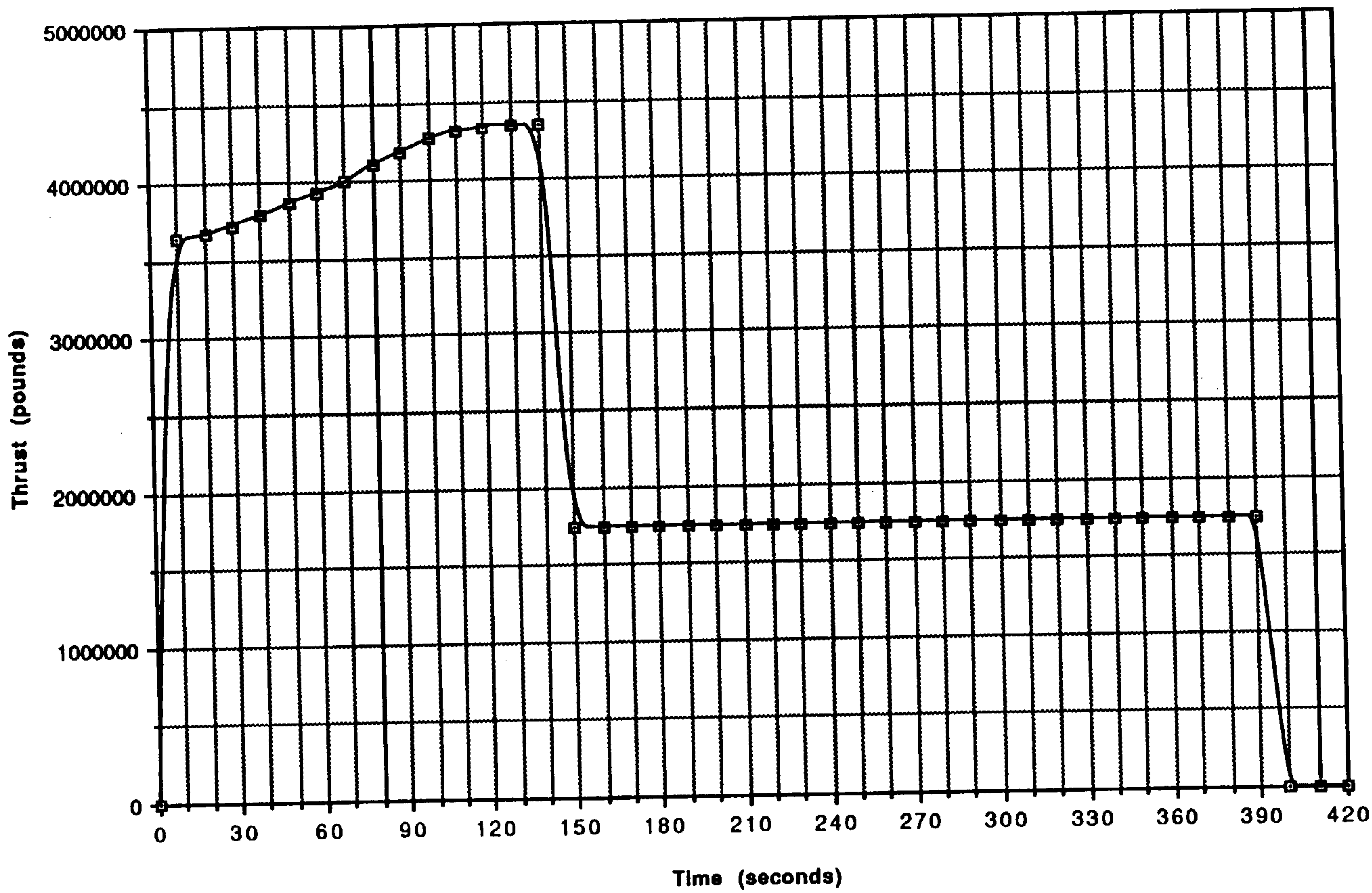


Figure 3.0.10: Plot of Thrust/Weight Ratio vs. Time

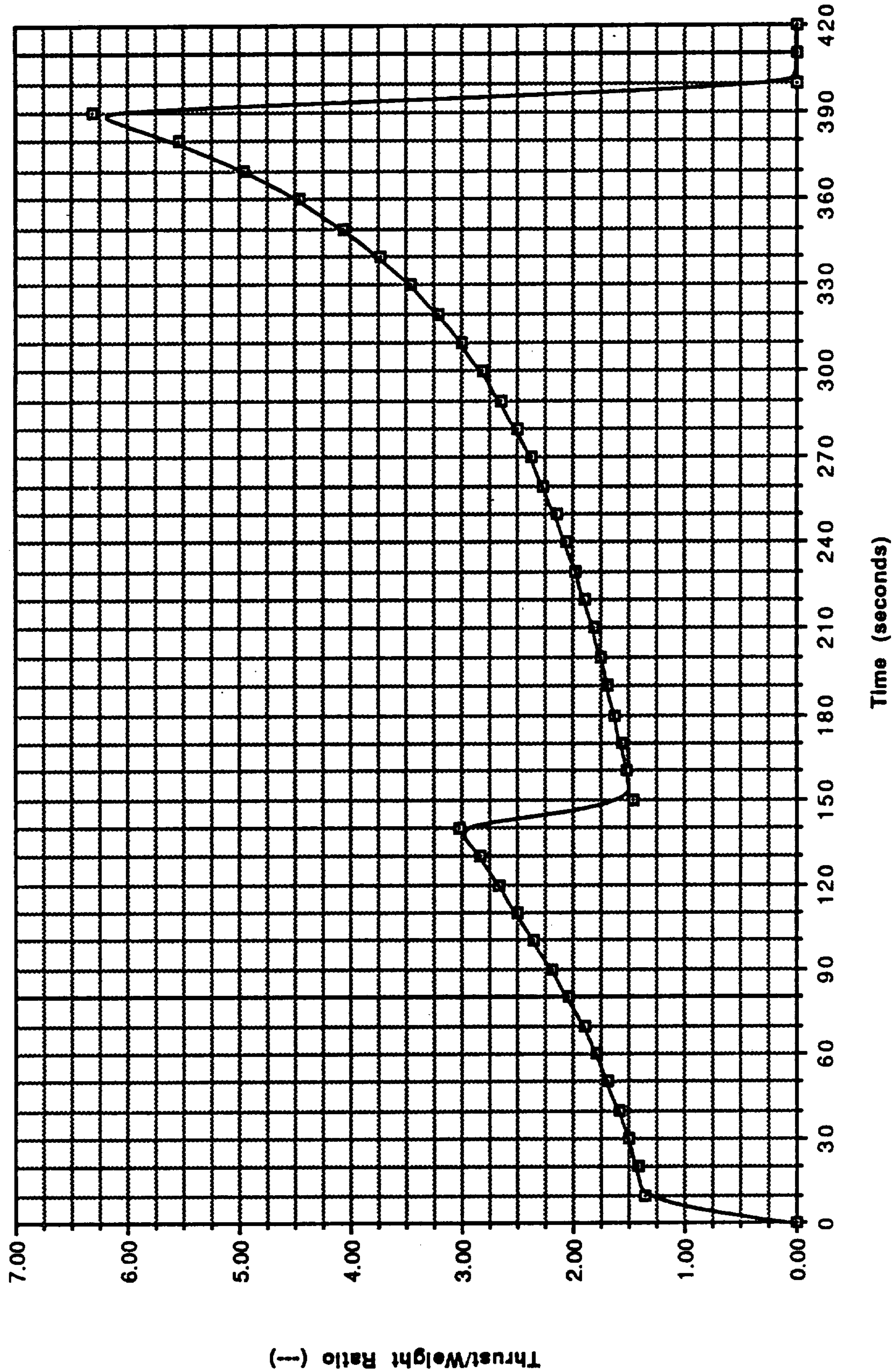
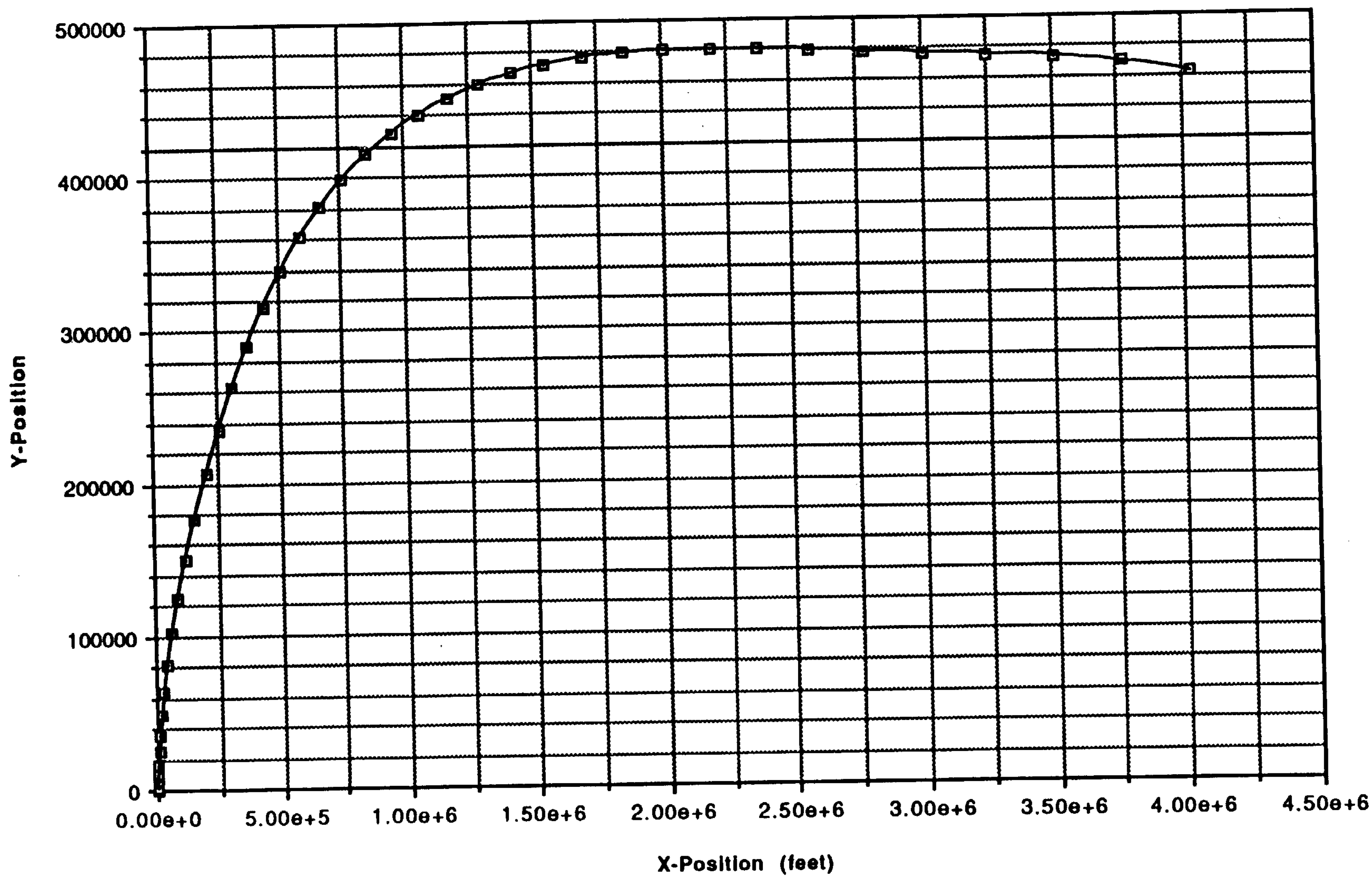


Figure 3.0.11: Plot of Y-Position vs. X-Position



4.0 Orbital Analysis

The NASA ground rules for the Shuttle II specified two orbits into which the orbiter must be capable of launching: a 270 nautical mile orbit due east of Kennedy Space Center, and a 150 nautical mile polar orbit. To verify the feasibility of the proposed ASTS configuration, it was necessary to determine the types and magnitudes of the orbital maneuvers that would be necessary for orbit inserton. As a starting point, the output data for the final position and velocity from the launch simulation program was used. This data places the orbiter at an initial altitude of 78.1 nautical miles with a velocity of 25,962 feet per second.

4.1 The Insertion Orbit

The initial position and velocity of the orbiter place the orbiter originally at the perigee of an elliptical orbit. The semi major axis of this orbit, a_1, was calculated using the Vis-Viva equation:

$$V_1^2 = \mu_E \left(\frac{2}{r_1} - \frac{1}{a_1} \right)$$

where r_1 is the sum of the altitude of the orbit and the radius of the earth (20925672.57 feet).

The eccentricity of this first orbit , and the altitude and velocity at the apogee of this orbit were calculated using simple geometric relationships. The pertinent data on the first orbit is as follows:

$e_1 = .02473$
$a_1 = 21{,}943{,}244$ feet
$r_{1ap} = 22{,}485{,}871$ feet
$V_{1ap} = 24{,}709$ feet/second

4.2 The 270 Nautical Mile Orbit

In order to provide a minimum energy transfer between the insertion orbit and the 270 nmi orbit, an elliptical transfer orbit was used (see figure 4.2).

The 270 nmi orbit has a radius of $a_2 = 22{,}567{,}272$ ft. The semi major axis of the transfer ellipse, a_t, has a value of $(a_1 + a_2)/2 = 22{,}255{,}258$ ft.

The velocities at periapsis and apoapsis of the transfer ellipse, as well as the velocity for the circular orbit were calculated using the Vis-Viva equation again.

$$V_p^2 = \mu_E \left(\frac{2}{r_1} - \frac{1}{a_T} \right) \qquad V_a^2 = \mu_E \left(\frac{2}{r_2} - \frac{1}{a_T} \right)$$

The following values were calculated for the velocities and the velocity changes needed for insertion into a 270 nmi orbit:

V_{1ap}	24,709 ft/sec
V_{t1}	24,890 ft/sec
dV_1	181 ft/sec
V_{t2}	24,799 ft/sec
V_{270}	24,975 ft/sec
dV_2	176 ft/sec

The total impulsice change in velocity for this orbital maneuver is 351 ft/sec.

4.3 The 150 Nautical Mile Orbit

The path of the elliptical orbit transfer orbit used for this maneuver is shown in figure 4.3.

The velocity and radius of the 150 nmi orbit are found to be

r_{150}	21837672 ft
V_{150}	25389 ft/sec

Following the sane procedure as before in order to obtain the velocity changes necessary yields the following information:

V_{1ap}	24709 ft/sec
V_{t1}	24678 ft/sec
dV_1	-31 ft/sec
V_{t2}	25419 ft/sec
V_{150}	25389 ft/sec
dV_2	-30 ft/sec

The total impulsive change in velocity for this orbital transfer is -61 ft/sec. These two velocity changes would have to be made in a direction opposite to the direction of travel of the shuttle.

	A	B	C	D
1	Re	20925672.57	Rot Speed	1525.9259
2	Mu	1.4076469E+16		
3	Altitude	Velocity		
4	700000	25513.0306		
5	710000	25507.1339		
6	720000	25501.2412		
7	730000	25495.3526		
8	740000	25489.4681		
9	750000	25483.5877		
10	760000	25477.7114		
11	770000	25471.8391		
12	780000	25465.9709		
13	790000	25460.1067		
14	800000	25454.2465		
15	810000	25448.3905		
16	820000	25442.5384		
17	830000	25436.6904		
18	840000	25430.8464		
19	850000	25425.0065		
20	860000	25419.1706		
21	870000	25413.3387		
22	880000	25407.5108		
23	890000	25401.6869		

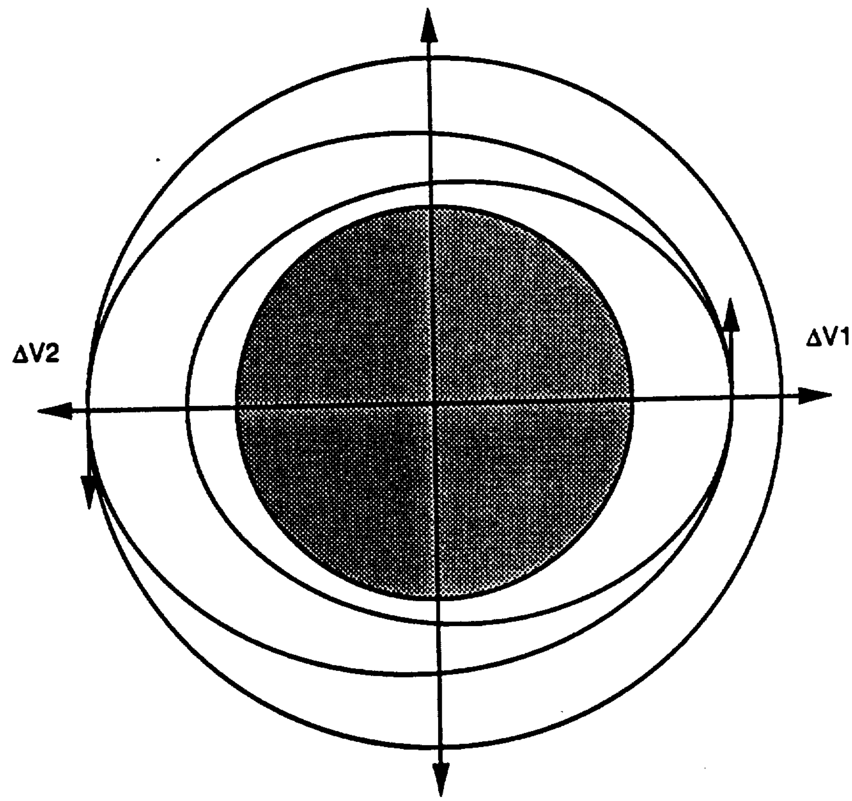


Figure 4.2.1: 270 Nautical Mile Orbital Transfer

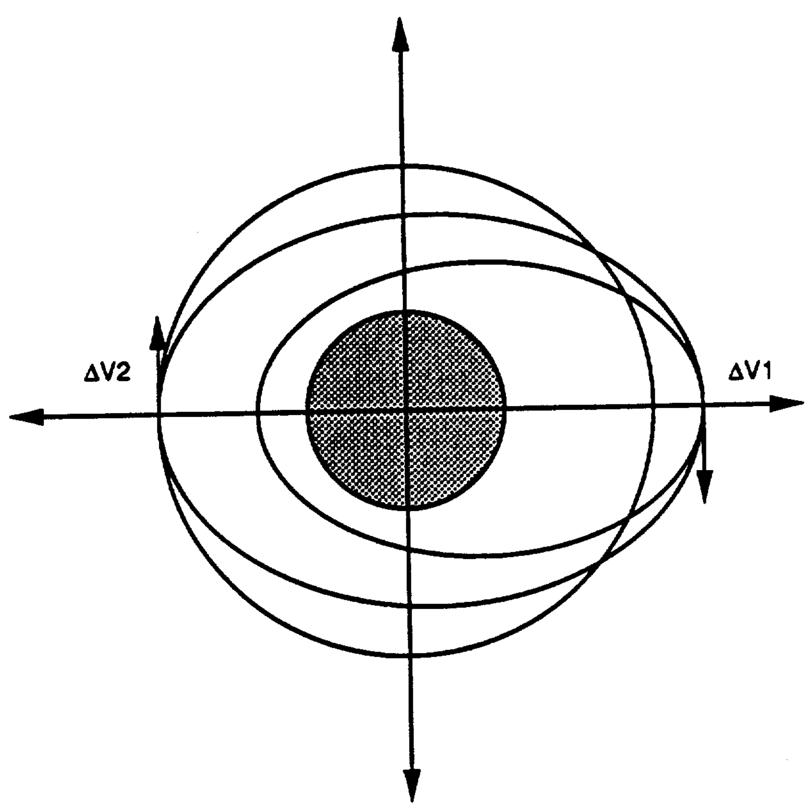


Figure 4.3.1: 150 Nautical Mile Polar Orbital Transfer

5.0 Stability and Control Analysis

Stability and Control Analysis for the Advanced Space Transportation System was performed using geometric Shuttle data and empirical and graphical methods given by Etkin, Roskam and Smetana. The geometric parameters used to perform the analysis included physical data for the wing, the body, and the vertical tail.

In order to determine stability and control derivatives, the geometric data for the Shuttle II must be used to determine aerodynamic parameters such as aspect ratio, wing taper ratio, and the mean aerodynamic chord.

'A' is the aspect ratio and is defined to be equal to b^2/S; b is the wing span and S is the wing planform area. 'S' can be easily determined using the following formula: $S=(c_r+c_t)(b/2)$, where c_r is the wing root chord and c_t is the wing tip chord. The ratio of the wing tip chord to the wing root chord is in itself and important physical parameter known simply as the taper ratio, λ. The value of the mean aerodynamic chord (the wing chord which passes through the centroid of either half -wing) can be found by integrating the equation for the square of the wing chord: $c^2 = \{c_r - [(c_r-c_t)/(b/2)]y\}^2$ over the span of half a wing and multiplying by 2/S. All of these aerodynamic parameters have been calculated and are found in the Executive Summary in Tables 3.2.1 and 3.3.1.

5.1 Determination of $C_{L\alpha}$

$C_{L\alpha}$ is an extremely important stability derivative describing the change in lift of an aircraft due to variation in angle of attack.

Roskam gives the following formula for determining $C_{L\alpha}$:

$$C_{L\alpha} = K_{wb}C_{L\alpha w}$$

where $K_{wb} = 1 - .25(d/b)^2 + 0.25(d/b)$

and $C_{L\alpha w} = 2\pi A/\{2+[(A^2B^2/K^2)(1+\tan^2\Lambda_{c/2}/B^2)+4]^{1/2}\}$

In these equations:
- d = body diameter at root chord = 30 ft.
- b = wing span = 127.7 ft.
- A = wing aspect ratio = 2.8
- β = compressibility parameter = $(1 - M^2)^{1/2}$ (for subsonic flight)
- K = ratio of actual wing section left curve slope to 2π
- $\Lambda_{c/2}$ = sweep of the wing half-chord line = 34°

Since these equations are useful only for Mach numbers less than the critical Mach number, K is assumed to be approximately 1. Hence, the following values for $C_{L\alpha}$ are obtained:

M range	β^2	$C_{L\alpha}$ (/rad)
0.0 - 0.3	1.0	2.97
0.3 - 0.6	0.775	3.09
0.6-Mcr	0.415	3.33

It is apparent that these values alone for the lift-curve slope (although correct) cannot be used to represent $C_{L\alpha}$ for the ASTS. For this reason, methods of estimating $C_{L\alpha}$ at higher Mach numbers and varying Reynolds numbers (from *Dynamics of Flight*, by Etkin) were employed.

Etkin presents a graphical method by which the lift-curve slope of an aircraft may be obtained as a function of its geometrical parameters. Before incorporating Etkin's method, values for t/c and τ (defined in Figure 5.1.1) were assumed to be 0.06 and 5°, respectively.

Using Figure 5.1.1 the following section lift curve slopes were obtained:

Rn	$(a_1)_0/(a_1)_{0T}$	$(a_1)_0$ (/rad)
10^6	0.87	5.74
10^7	0.93	6.14
10^8	0.95	6.27

It follows that these values for the actual lift curve slope are good approximations for transition both at the leading edge and at c/2.

These values of $(a_1)_0$ were then used in conjunction with Figure 5.1.2 to estimate the overall aircraft lift curve slope. Also, Etkin defines K as $[(a_1)_{0m}/2\pi]\beta$ and Λ_β as the compressibility sweep parameter equal to $\tan^{-1}(\tan\Lambda_{c/4}/\beta)$.

Table 5.1.1. $C_{L\alpha}$ of ASTS for M < Mcr

M Range	β	Λ_B (°)	Rn	K	$\beta A/k$	$\beta C_{L\alpha}/K$ (/°)	$C_{L\alpha}$ (/rad)
0.0 - 0.3	1	42	10^6	0.914	3.06	0.051	2.67
0.0 - 0.3	1	42	10^7	0.977	2.81	0.050	2.80
0.0-0.3	1	42	10^8	0.998	2.805	0.049	2.80
0.3 - 0.6	0.88	46	10^6	0.804	3.06	0.049	2.57
0.3 - 0.6	0.88	46	10^7	0.860	2.87	0.048	2.69
0.3 - 0.6	0.88	46	10^8	0.878	2.81	0.048	2.74
0.6 - Mcr	0.644	54	10^6	0.589	3.06	0.045	2.36
0.6 - Mcr	0.644	54	10^7	0.629	2.87	0.043	2.41
0.6 - Mcr	0.644	54	10^8	0.643	2.80	0.043	2.46

Note that these values of $C_{L\alpha}$ are slightly higher than those estimated using the method outlined by Roskam.

Etkin presents a system for predicting $C_{L\alpha}$ for Mach numbers greater than the critical Mach number using the graphical method shown in Figure 5.1.3 which is a function of A, M, λ, and $\Lambda_{c/2}$. Results using this figure are listed in Table 5.1.2.

Table 5.1.2. $C_{L\alpha}$ of ASTS for M > Mcr

Mrange	$A\tan\Lambda_{c/2}$	$A(M^2-1)^{1/2}$	$C_{L\alpha}$ (/rad)
1.0 - 1.3	1.89	1.64	4.14
1.3 - 1.6	1.89	2.97	3.42
1.6 - 1.9	1.89	4.04	2.72
1.9 - 2.2	1.89	5.02	2.21
2.2 - 2.5	1.89	5.97	1.82
2.5 - 2.8	1.89	6.88	1.62

Prediction of $C_{L\alpha}$ for Mach numbers greater than approximately 2.8 was not possible due to the lack of a proper estimation technique.

5.2 Determination of the Neutral Point, hn

The overall aircraft neutral point, hn, is defined as the point where the pitching moment is invariant with angle of attack. It is further defined geometrically by Figure 5.2.1. Roskam gives the following relationship for determining the neutral point :

$$hn = hnw + \Delta hn_B \qquad \text{(for tail-less configurations)}$$

where $hnw = k_1[(Xac'/c_r)-k_2]$
and $\Delta hn_B = -(dM/d\alpha)/(qScC_{L\alpha w})$
where $dM/da = (q/36.5)\ S\ Wf^2(Xi)d\varepsilon/d\alpha\Delta Xi$

Note that Roskam defines both the neutral point, hn, and the aerodynamic center, Xac/c, as the same quantity.

Using the relationships for Δhn_B, it was found that the body had little or no effect on the overall aircraft neutral point. Therefore, determination of the neutral point is reduced to the following form:

$$hn = k_1[(Xac'/c_r)-k_2]$$

Xac'/c_r, k_1, and k_2 are found using Figures 5.2.2, 5.2.3, and 5.2.4, respectively. Using these figures together with known geometric data and the relationship for hn, the following results were obtained.

Table 5.2.1. Neutral Point of the ASTS for M < Mcr

M range	β	Xac'/c_r	k_1	k_2	hn
0.0 - 0.3	1.0	0.58	1.43	0.39	0.27
0.3 - 0.6	0.88	0.59	1.43	0.39	0.29
0.6 - Mcr	0.64	0.60	1.43	0.39	0.30

These values for hn show that as the Mach is increased, the neutral point begins to move gradually aft. This finding agrees with most aerodynamic data on similar aircraft.

It is important to determine the characteristics of a flight vehicle in as many of its flight regimes as possible. Therefore, methods given by Etkin were used to find values of hn for Mach numbers greater than the critical Mach number.

Etkin gives a graphical method shown in Figure 5.2.5 for determining hn as a function of A, M, λ, and $\Lambda_{c/2}$. Using these variables and Figure 5.2.5, the following data was obtained.

Table 5.2.2. Neutral Point of the ASTS for 0 < M < 2.8

M range	A tan $\Lambda_{c/2}$	$A(1-M^2)^{1/2}$	hn
0.0 - 0.3	1.9	2.8	0.28
0.3 - 0.6	1.9	2.5	0.29
0.6 - Mcr	1.9	1.8	0.31
1.0 - 1.3	1.9	1.6	0.44
1.3 - 1.6	1.9	3.0	0.44
1.6 - 1.9	1.9	4.0	0.48
1.9 - 2.2	1.9	5.0	0.48
2.2 - 2.5	1.9	6.0	0.49
2.5 - 2.8	1.9	6.9	0.49

Again, these numbers show that (as expected) the neutral point starts out relatively close to the quarter-chord for low subsonic Mach numbers and moves aft approaching the half-chord at higher supersonic Mach numbers.

5.3 Determination of $C_{M\alpha}$

$C_{m\alpha}$ is an extremely important stability derivative which dictates whether or not a configuration has positive or negative static stability. $C_{m\alpha}$ is determined through the following equation:

$$C_{m\alpha} = C_{L\alpha}(h - hn)$$

where h represents the non-dimensional location of the aircraft center of gravity. For a configuration to be statically stable, $C_{m\alpha}$ must be negative; this requires that the quantity (h - hn) must be negative. Xcg was determined by considering the location and weight of the components of the ASTS. The distance between the center of gravity and the leading edge of the mean aerodynamic chord (non-dimensionalized by dividing by the mean aerodynamic chord) is defined as h. Upon completion of these calculations, it is found that h = 0.136.

Hence, $C_{m\alpha} = C_{L\alpha}(0.136 - hn)$

5.4 $C_{L\alpha}$ of Vertical Tail

The lift curve slope of the vertical tail is determined by the geometric characteristics of the vertical tail and is influenced by the change in flow characteristics due to the presence of the wing and body combination. Figure 5.4.1 shows the relationship between $(a_F)_B/a_1$ for a vertical tail on a body of circular cross section. Using a value of 1 for D/h, $(a_F)_B/a_1$ is approximately 2.9.

Values of C_{La} for the vertical tail are determined using the same procedure as before for the wing. When this value is obtained it is multiplied by the factor $(a_F)_B/a_1$ to correct for its location in the flow field relative the the wing and body. It is assumed that the vertical tail has approximately the same values of t/c and τ as the wing so that both the wing and vertical tail have the same values for $(a_1)_0$. Using the geometric parameters for the vertical tail and Figures 5.1.2 and 5.1.3 the following is found.

Table 5.4.1. Corrected $C_{L\alpha}$ values for the ASTS Vertical Tail

M range	Rn	$C_{L\alpha}$ (rad^{-1})	$C_{L\alpha}$ corrected (rad^{-1})
0.0 - 0.3	10^6	2.93	8.20
0.0 - 0.3	10^7	3.08	8.60
0.0 - 0.3	10^8	3.14	8.80
0.3 - 0.6	10^6	2.62	7.30
0.3 - 0.6	10^7	2.74	7.70
0.3 - 0.6	10^8	2.75	7.70
0.6 - Mcr	10^6	2.36	6.60
0.6 - Mcr	10^7	2.46	6.90
0.6 - Mcr	10^8	2.46	6.90
1.0 - 1.3	---	4.58	12.80
1.3 - 1.6	---	4.35	12.20

Determination of $C_{L\alpha}$ corrected for the vertical tail beyond a Mach number of approximately 1.6 was not possible.

5.5 Determination of C_{lp}

C_{lp} is the change in rolling moment due to a variation in rolling velocity. C_{lp} is often referred to as the rolling moment damping derivative. Etkin provides a graphical method by which C_{lp} can be calculated based on the following parameters: β, K,A,λ,and Λe (which is defined as $\tan^{-1}[(1/\beta)\tan\Lambda_{c/4}]$). Etkin's method is presented here in Figure 5.5.1. Table 5.5.1 contains the values of C_{lp} found using Etkin's method.

Table 5.5.1. C_{lp} values of ASTS for M < Mcr

M range	β	Λe (°)	Rn	K	C_{lp} (/rad)
0.0 - 0.3	1.0	42	10^6	0.914	-0.219
0.0 - 0.3	1.0	42	10^7	0.977	-0.225
0.0 - 0.3	1.0	42	10^8	0.998	-0.230
0.3 - 0.6	0.88	46	10^6	0.804	-0.215
0.3 - 0.6	0.88	46	10^7	0.860	-0.225
0.3 - 0.6	0.88	46	10^8	0.878	-0.229
0.6 - Mcr	0.644	54	10^6	0.589	-0.201
0.6 - Mcr	0.644	54	10^7	0.629	-0.210
0.6 - Mcr	0.644	54	10^8	0.643	-0.215

C_{lp} does not vary greatly with Mach number, and is always negative.

5.6 Determination of $C_{l\beta}$

$C_{l\beta}$ represents the change in rolling moment due to a change in sideslip angle, β. $C_{l\beta}$ is primarily governed by the wing dihedral angle, the body and the vertical tail. For this reason, $C_{l\beta}$ is often referred to as the effective dihedral derivative. Etkin presents a graphical method of determining $C_{l\beta}$ based on the effects of the wing, the body and the vertical tail. This method utilizes Figure 5.6.1. Using this figure, it was found that $C_{l\beta w} = -.32\ C_L$.

The effect of the body on $C_{l\beta}$ is found using the equation:

$$(\Delta C_{l\beta})_B = 1.2\ (A)1/2\ Zw\ (h+w)/b^2$$

where Zw = vertical distance of c/4 point below fuselage centerline = 11.0 ft.
h = average fuselage height at wing root = 28.0 ft.
w = average fuselage width at wing root = 30.0 ft.

Using this information: $(\Delta C_{l\beta})B = 0.08$.

The effect of the vertical tail on $C_{l\beta}$ is found using the equation:

$$(\Delta C_{l\beta})_F = -a_F\ (1 - d\sigma/d\beta)(V_F/V)2\ S_F\ Z_F/(S\ b)$$

where Z_F = vertical distance between vertical tail AC and aircraft CG = 41.0 ft.
S_F = Vertical Tail planform area = 603 ft^2.

Using this equation under the assumption that $d\sigma/d\beta$ is negligible and V_F/V is approximately equal to 1: $(\Delta C_{l\beta})_F = -0.033\ a_F$

Combining components: $C_{l\beta} = -0.32\ C_L + 0.08 - 0.033a_F$

This equation holds for all Mach numbers below the critical Mach number.

5.7 Determination of C_{lr}

C_{lr} represents the change in rolling moment due to yawing velocity, or simply rolling moment due to yaw. Etkin divides C_{lr} into two components: C_{lr} due to the wing and C_{lr} due to the vertical tail. Using Figure 5.7.1, $(C_{lr})_B = 0.23\ C_L$.

The contribution of the vertical tail on C_{lr} is shown through the following formula:

$$(C_{lr})_F = a_F\ S_F\ Z_F\ [z + (l_f/b)]/(S\ b)$$

where l_f = distance between vertical tail AC and the aircraft CG = 48.0 ft.

Hence, $(C_{lr})_F = 0.079\ a_F$

Combining components: $C_{lr} = 0.23\ C_L + 0.079\ a_F$

This equation holds for all Mach numbers below the critical Mach number.

5.8 Determination of $C_{n\beta}$

$C_{n\beta}$ is defined to represent the change in yawing moment due to sideslip angle, β. $C_{n\beta}$ is a very important stability derivative since it alone determines whether or not an aircraft has positive weathercock stability; for positive weathercock stability, $C_{n\beta}$ must be positive.

Figure 5.8.1 shows the variation of $C_{n\beta}/C_L^2$ as a function of wing aspect ratio, A, and wing quarter-chord sweep angle, Λ.

Using Figure 5.8.1, $C_{n\beta} = 0.07\ C_L^2$

5.9 Determination of C_{np}

C_{np} is a cross derivative defined as the change in yawing moment due to rolling velocity. Etkin presents the following equation for determining C_{np}:

$$C_{np} = [(\Delta C_{np})_1/C_L]\ C_L + [(\Delta C_{np})_2/(C_{D0})_\alpha]\ (C_{D0})_\alpha$$

where $(\Delta C_{np})_1/C_L$ and $(\Delta C_{np})_2/(C_{D0})_\alpha$ are found from Figure 5.9.1

From Figure 5.9.1, $(\Delta C_{np})_1/C_L = -0.17$ and $(\Delta C_{np})_2/(C_{D0})_\alpha = 19$, so that C_{np} may be written as

$$C_{np} = -0.17\ C_L + 19\ (C_{D0})_\alpha.$$

5.10 Determination of C_{nr}

C_{nr} is defined to be the change in yawing moment due to yawing velocity and is often referred to as the damping in yaw derivative. Etkin presents the following equation for determining C_{nr}:

$$C_{nr} = [(\Delta C_{nr})_1/C_L^2]C_L^2 + [(\Delta C_{nr})_2/C_{D0}]C_{D0}$$

where $[(\Delta C_{nr})_1/C_L^2]$ and $[(\Delta C_{nr})_2/C_{D0}]$ are found from Figure 5.10.1

Figure 5.10.1 reveals that $[(\Delta C_{nr})_1/C_L^2] = -0.02$ and $[(\Delta C_{nr})_2/C_{D0}] = -0.48$, so that C_{nr} may be written as

$$C_{nr} = -0.02\ C_L^2 - 0.48\ C_{D0}$$

5.11 Determination of C_{Mq}

C_{mq} is defined as the variation in pitching moment due to pitch velocity or simply as the damping in pitch. Smetana gives the following relationship for C_{mq} :

$$C_{mq} = -2\ x'\ |x'|\ C_{L\alpha}/c^2$$

where x' = distance from CG to wing quarter-chord (positive for forward CG) = -6.97 ft.

After substituting the proper geometric and stability parameters, C_{mq} can be written as

$$C_{mq} = 0.0372\ C_{L\alpha}$$

5.12 Determination of C_{Lq}

C_{Lq} is defined as the change in lift coefficient due to pitch velocity. Smetana gives the following relationship for C_{Lq} :

$$C_{Lq} = 2\ x'\ C_{L\alpha}/c$$

Upon substitution of known geometric parameters, C_{Lq} is written as

$$C_{Lq} = -0.2727\ C_{L\alpha}$$

5.13 Determination of $C_{D\alpha}$

$C_{D\alpha}$ is defined as the change in drag coefficient due to a change in the angle of attack. Smetana gives the following relationship for CDa:

$$C_{D\alpha} = (dC_{D0}/d\alpha) + [2\ C_L/(\pi A)]\ C_{L\alpha}$$

Since $(dC_{D0}/d\alpha)$ is usually small, $C_{D\alpha}$ may be written simply as $[2\ C_L/(\pi A)]\ C_{L\alpha}$.

Therefore, $C_{D\alpha}$ may be expressed as

$$C_{D\alpha} = 0.2274\ C_L\ C_{L\alpha}.$$

5.14 Determination of $C_{y\beta}$

$C_{y\beta}$ is defined as the change in side force,y, due to a change in sideslip angle, β. Smetana breaks $C_{y\beta}$ up into 3 components: that of the wing, body, and vertical tail.

$$(C_{y\beta})_w = C_L^2\ (6 \tan\Lambda \sin\Lambda)/[A(A + 4 \cos\Lambda)]$$

Upon substitution, $(C_{y\beta})_w = 0.2232\ C_L^2$

$(C_{y\beta})_B = -ki\,(C_{L\alpha})_B\,(S_B/S)$

where S_B = body reference area = 3733 ft^2
ki = interference factor determined from Figure 5.14.1

Figure 5.14.1 gives ki as a function of $Z_w/(d/2)$ where Z_w is the distance from body centerline to quarter-chord point of exposed wing root chord (positive for quarter-chord point below body centerline) and d is the max body height at wing/body intersection.

Z_w = 11.0 ft.
d = 25.0 ft.

From Figure 5.14.1, ki = 1.44

Smetana gives the following values of $(C_{L\alpha})_B$:
$(C_{L\alpha})$ circular body = 0.0525 rad^{-1}
$(C_{L\alpha})$ rectangular body = 0.1253 rad^{-1}

Since the ASTS configuration is a combination of these two shapes, let $(C_{L\alpha})_B$ = 0.08 rad^{-1}

Now that all values needed are known, $(C_{y\beta})_B$ = -0.074

$(C_{y\beta})_F = -k\,(C_{L\alpha})_F\,(1 + d\sigma/d\beta)\,S_F/S$

k is found from Figure 5.14.2 and is a function of $[b_v/(2r_1)]$.

b_v = vertical tail span = 29.0 ft.
r_1 = fuselage diameter in tail area = 30 ft.

From Figure 5.14.2, k = 0.75

If it is assumed that $d\sigma/dB$ is negligible then $(C_{y\beta})_F$ may be expressed as
$(C_{y\beta})_F = -0.078\,a_F$

Combining all components: $C_{y\beta} = 0.2232\,C_L^2 - 0.074 - 0.078\,a_F$

5.15 Determination of C_{yp}

C_{yp} represents the change in side force due to rolling velocity. Smetana expresses C_{yp} as the sum of the contributions due to the wing and the vertical tail.

$(C_{yp})_w = C_L\,\{[(A + \cos\Lambda)\tan\Lambda/(A + 4\cos\Lambda)] + 1/A\}$

Substitution into $(C_{yp})_w$ yields $(C_{yp})_w = 0.91\,C_L$

$(C_{yp})_F = -2\,a_F\,S_F\,Z_F/(S\,b)$

All of these parameters have been defined previously so that $(C_{yp})_F = -0.067\,a_F$

Combining these two: $C_{yp} = 0.91\,C_L - 0.067\,a_F$

5.16 Determination of C_{yr}

C_{yr} is defined as the change in side force due to yawing velocity. Smetana expresses C_{yr} as the sum of the contributions due to the wing and the vertical tail.

$$(C_{yr})_w = 0.143\ C_L - 0.05$$

$$(C_{yr})_F = -2\ l_f\ (C_{yr})_F/b = -0.752\ (C_{yr})_F$$

So that, $C_{yr} = 0.143\ C_L - 0.05 - 0.752\ (C_{yr})_F$

5.17 Dynamic Stability Matrices

Once the proper stability derivatives have been determined, it is possible to use them to investigate the dynamic stability of the configuration. Presented here are the longitudinal and lateral stability matrices corresponding to the non-dimensional, controls fixed, linearized equations of motion for a rigid aircraft.

Longitudinal Equations:

$Dx = Ax$ where $x = (u\ \ \alpha\ \ q\ \ \theta)^T$

$A(1,1) = (C_{Xu} + 2\ C_{L0} \tan\Theta_0)/2\mu$
$A(1,2) = C_{X\alpha}/2\mu$
$A(1,3) = 0.0$
$A(1,4) = -C_{L0}/2\mu$
$A(2,1) = (C_{Zu} - 2\ C_{L0})/(2\mu - C_{Z\dot\alpha})$
$A(2,2) = C_{Z\alpha}/(2\mu - C_{Z\dot\alpha})$
$A(2,3) = (2\mu + C_{Zq})/(2\mu - C_{Z\dot\alpha})$
$A(2,4) = -C_{L0} \tan\Theta_0/(2\mu - C_{Z\dot\alpha})$
$A(3,1) = (C_{Mu} + C_{m\dot\alpha}\ A(2,1))/i_B$
$A(3,2) = (C_{M\alpha} + C_{m\dot\alpha}\ A(2,2))/i_B$
$A(3,3) = (C_{Mq} + C_{m\dot\alpha}\ A(2,3))/i_B$
$A(3,4) = C_{m\dot\alpha}\ A(2,4)/i_B$
$A(4,1) = 0.0$
$A(4,2) = 0.0$
$A(4,3) = 1.0$
$A(4,4) = 0.0$

where $\mu = m/(\rho\ S\ c/2)$
$i_B = I_{yy}/[\rho\ S\ (c/2)^3]$
$C_{X\alpha} = C_{L0} - C_{D\alpha}$
$C_{Z\alpha} = -C_{L\alpha} - C_{D0}$
$C_{Zu} = -\ (M^2/1\text{-}M^2)\ C^{L0}$
$C_{Zq} = -C_{Lq}$
$C_{Dm} = C_{Du}/M$
$C_{Xu} = -2\ (C_{D0} + C_{L0} \tan\Theta_0) - M\ C_{Dm}$
$C_{Z\dot\alpha} = 0.0$

Lateral Equations:

$Dy = By$ where $y = (B\ p\ r\ \Phi)^T$

$B(1,1) = C_{y\beta}/2\mu$
$B(1,2) = C_{yp}/2\mu$
$B(1,3) = -(2\mu - C_{yr})/2\mu$
$B(1,4) = C_{L0}/2\mu$
$B(2,1) = (i_C\, C_{l\beta} + i_E\, C_{n\beta})/\Delta$
$B(2,2) = (i_C\, C_{lp} + i_E\, C_{np})/\Delta$
$B(2,3) = (i_C\, C_{lr} + i_E\, C_{nr})/\Delta$
$B(2,4) = 0.0$
$B(3,1) = (i_A\, C_{n\beta} + i_E\, C_{l\beta})/\Delta$
$B(3,2) = (i_A\, C_{np} + i_E\, C_{lp})/\Delta$
$B(3,3) = (i_A\, C_{nr} + i_E\, C_{lr})/\Delta$
$B(3,4) = 0.0$
$B(4,1) = 0.0$
$B(4,2) = 1.0$
$B(4,3) = \tan\Theta_0$
$B(4,4) = 0.0$

where $\mu = m/(\rho\ S\ b/2)$
$\Delta = i_A\, i_C - i_E^2$
$i_A = Ixx/[\rho\ S\ (b/2)^3]$
$i_C = Izz/[\rho\ S\ (b/2)^3]$
$i_E = Ixz/[\rho\ S\ (b/2)^3]$

Once the matrices A and B are found, their Eigen Values can be determined. These Eigen values reflect whether or not the system is stable. For a system to asymptotically stable, all of its Eigen values must have negative real parts.

The matrices A and B were calculated using a computer program written in FORTRAN. The program and results of the investigation of the dynamic stability for landing (assuming $\Theta_0 = 10°$ and $U_0 = 300$ ft/sec and L = W) are listed on pages 66 and 71.

5.18 Determination of $C_{l\delta\alpha}$

$C_{l\delta\alpha}$ describes the variation in rolling moment with change in aileron deflection; often, this stability derivative is referred to as the aileron power. Smetana gives the following equation for $C_{l\delta\alpha}$:

$$C_{l\delta\alpha} = [2\ C_{L\alpha}\ \tau/(S\ b)] \int_a^b c\ y\ dy$$

where c is the equation for the wing chord as a function of wing span, y:

$$c = c_r - [(c_r - c_t)/(b/2)]\ y = 73.125 - 0.863\ y$$

and a and b represent the spanwise distance for the body centerline to the inner and outer aileron points, respectively.

$a = 27.0$ ft. $\quad b = 58.5$ ft.

τ is a correction factor which is a function of the aileron chord to wing chord ratio. τ is determined from Figure 5.18.1. Since the ratio of aileron chord to wing chord is not constant over the span of the aileron, the average value was used to determine τ.

$(c_a/c_w)_{avg} = 0.33 \qquad t{=}0.57$

Upon integration and substitution of the proper values,

$C_{l\delta\alpha} = 0.071\ C_{L\alpha}$.

5.19 Determination of $C_{l\delta r}$

$C_{l\delta r}$ is the variation in rolling moment coefficient with change in rudder deflection. Smetana gives the following formula for estimating $C_{l\delta r}$:

$C_{l\delta r} = a_F\ \tau\ S_F\ Z_F/(S\ b)$

Here, τ is a function of the rudder area to vertical tail area ratio.

$S_r = 157.5$ ft2 $\quad S_F = 603$ ft2

Hence, $S_r/S_F = 0.261$ so that from Figure 5.19.1, $\tau = 0.48$.

Substitution into the equation for $C_{l\delta r}$ results in

$C_{l\delta r} = 0.0158\ a_F$.

5.20 Determination of $C_{n\delta r}$

$C_{n\delta r}$ is the variation in yawing moment coefficient with a change in rudder deflection and is often referred to as the rudder power. Smetana gives the following relationship for $C_{n\delta r}$

$C_{n\delta r} = -a_F\ \tau\ S_F\ l_f/(S\ b)$

As with $C_{l\delta r}$, the value of τ is determined from Figure 5.19.1 and has a value of 0.48 so that $C_{n\delta r}$ may be expressed as

$C_{n\delta r} = -0.0187\ a_F$

AE448 CG Locations/1

	A	B	C	D
1	**Component**	**X-Location**	**Weight**	**Y-Moment**
2	Wing	116.60	28,300	3,299,780
3	Vertical Tail	140.00	3,200	448,000
4	Forward Body	28.90	27,000	780,300
5	Mid Body	80.00	23,600	1,888,000
6	Aft Body	128.00	13,200	1,689,600
7	Main Engines	137.00	22,800	3,123,600
8	OMS	138.00	3,700	510,600
9	RCS	138.00	1,600	220,800
10	Control Systems	48.00	4,000	192,000
11	Avionics	22.00	3,100	68,200
12	Personnel	35.00	1,600	56,000
13	Stores	42.00	600	25,200
14	Engine Accessories	125.00	6,200	775,000
15	Hydrogen Tanks	64.00	24,000	1,536,000
16	Oxygen Tank	121.00	11,000	1,331,000
17	TPS	96.30	6,100	587,430
18	**Totals**		180,000	16,531,510
19	**Centroids**	**91.84**		

```
C *** CONTROLS FIXED LONGITUDINAL AND LATERAL
C *** DYNAMIC STABILITY AND CONTROL PROGRAM
C *** FOR THE SECOND GENERATION SPACE
C *** TRANSPORTATION SYSTEM.
C
C *** WRITTEN BY: PHILIP BENEFIELD & DEL JOHNSON
C
      DOUBLE PRECISION G,S,W,WS,CBAR,UO,RHO,THETAO
      DOUBLE PRECISION B,A,C,E,CLO,CDO,CMU,CMA
      DOUBLE PRECISION CMAD,CMQ,CLA,CLQ,CDA,CDU
      DOUBLE PRECISION CLB,CLP,CLR,CNB,CNP,CNR
      DOUBLE PRECISION CYB,CYP,CYR,LLONG,MULONG,IBLONG
      DOUBLE PRECISION CXA,CZA,SOUND,M,CZU,CZQ,CDM
      DOUBLE PRECISION CXU,CZAD,ALONG(4,4),LLAT
      DOUBLE PRECISION IALAT,ICLAT,IELAT,MULAT
      DOUBLE PRECISION DEL,ALAT(4,4)
C
      OPEN(UNIT=9,FILE='STAB1IN.DAT',STATUS='OLD')
      OPEN(UNIT=10,FILE='STAB1OUT.DAT',STATUS='UNKNOWN')
C
      READ(9,*) G,S,W,WS,CBAR,UO,RHO,THETAO
      READ(9,*) B,A,C,E,CLO,CDO
      READ(9,*) CMU,CMA,CMAD,CMQ
      READ(9,*) CLA,CLQ,CDA,CDU
      READ(9,*) CLB,CLP,CLR
      READ(9,*) CNB,CNP,CNR,CYB,CYP,CYR
C
300   FORMAT(1X,A40,' = ',F16.6)
20    FORMAT(////////,10X,'GEOMETRICAL,INERTIAL & EQUILIBRIUM',
     *         ' CHARACTERISTICS: ',//)
C
      WRITE(10,20)
      WRITE(10,300) 'GRAVITATIONAL ACCELERATION (FT/SEC^2)',G
      WRITE(10,300) 'WING AREA (FT^2)',S
      WRITE(10,300) 'WEIGHT (LB)',W
      WRITE(10,300) 'WING SPAN (FT)',WS
      WRITE(10,300) 'MEAN AERODYNAMIC CHORD (FT)',CBAR
      WRITE(10,300) 'AIRSPEED (FT/SEC)',UO
      WRITE(10,300) 'AIR DENSITY (SLUGS/FT^3)',RHO
      WRITE(10,300) 'INITIAL THETA (RAD)',THETAO
      WRITE(10,300) 'IYY (SLUG-FT^2)',B
      WRITE(10,300) 'IXX (SLUG-FT^2)',A
      WRITE(10,300) 'IZZ (SLUG-FT^2)',C
      WRITE(10,300) 'IXZ (SLUG-FT^2)',E
      WRITE(10,300) 'CLO  (---)',CLO
      WRITE(10,300) 'CDO  (---)',CDO
C
30    FORMAT(////,10X,'NON-DIMENSIONAL STABILITY DERIVATIVES:',/)
      WRITE(10,30)
      WRITE(10,300) 'CMU  (---)',CMU
      WRITE(10,300) 'CMA  (---)',CMA
      WRITE(10,300) 'CMAD (---)',CMAD
      WRITE(10,300) 'CMQ  (---)',CMQ
      WRITE(10,300) 'CLA  (---)',CLA
      WRITE(10,300) 'CLQ  (---)',CLQ
      WRITE(10,300) 'CDA  (---)',CDA
      WRITE(10,300) 'CDU  (---)',CDU
```

ORIGINAL PAGE IS
OF POOR QUALITY

```
40    FORMAT(////,10X,'LATERAL-DIRECTIONAL DERIVATIVES:',/)
      WRITE(10,40)
      WRITE(10,300) 'CLB (/RAD)',CLB
      WRITE(10,300) 'CLP (/RAD)',CLP
      WRITE(10,300) 'CLR (/RAD)',CLR
      WRITE(10,300) 'CNB (/RAD)',CNB
      WRITE(10,300) 'CNP (/RAD)',CNP
      WRITE(10,300) 'CNR (/RAD)',CNR
      WRITE(10,300) 'CYB (/RAD)',CYB
      WRITE(10,300) 'CYP (/RAD)',CYP
      WRITE(10,300) 'CYR (/RAD)',CYR
C
C *** CALCULATIONS FOR LONGITUDINAL MOTION
C
      LLONG=CBAR/2.0
      MULONG=(W/G)/(RHO*S*LLONG)
      IBLONG=B/(RHO*S*(LLONG**3))
      CXA=CLO-CDA
      CZA=-CLA-CDO
      SOUND=1116.4
      M=UO/SOUND
      CZU=-((M*M)/(1.0-M*M))*CLO
      CZQ=-CLQ
      CDM=CDU/M
      CXU=-(2.0*(CDO+CLO*TAN(THETAO)))-(M*CDM)
      CZAD=0.0
C
      ALONG(1,1)=(CXU+2.0*CLO*TAN(THETAO))/(2.0*MULONG)
      ALONG(1,2)=CXA/(2.0*MULONG)
      ALONG(1,3)=0.0
      ALONG(1,4)=-CLO/(2.0*MULONG)
      ALONG(2,1)=(CZU-2.0*CLO)/(2.0*MULONG-CZAD)
      ALONG(2,2)=CZA/(2.0*MULONG-CZAD)
      ALONG(2,3)=(2.0*MULONG+CZQ)/(2.0*MULONG-CZAD)
      ALONG(2,4)=(-CLO*TAN(THETAO))/(2.0*MULONG-CZAD)
      ALONG(3,1)=(CMU+CMAD*ALONG(2,1))/IBLONG
      ALONG(3,2)=(CMA+CMAD*ALONG(2,2))/IBLONG
      ALONG(3,3)=(CMQ+CMAD*ALONG(2,3))/IBLONG
      ALONG(3,4)=CMAD*ALONG(2,4)/IBLONG
      ALONG(4,1)=0.0
      ALONG(4,2)=0.0
      ALONG(4,3)=1.0
      ALONG(4,4)=0.0
C
C *** CALCULATIONS FOR LATERAL MOTION
C
      LLAT=WS/2.0
      MULAT=(W/G)/(RHO*S*LLAT)
      IALAT=A/(RHO*S*LLAT**3)
      ICLAT=C/(RHO*S*LLAT**3)
      IELAT=E/(RHO*S*LLAT**3)
      DEL=(IALAT*ICLAT)-IELAT**2
C
```

```
      ALAT(1,1)=CYB/(2.0*MULAT)
      ALAT(1,2)=CYP/(2.0*MULAT)
      ALAT(1,3)=-(2.0*MULAT-CYR)/(2.0*MULAT)
      ALAT(1,4)=CLO/(2.0*MULAT)
      ALAT(2,1)=(ICLAT*CLB+IELAT*CNB)/DEL
      ALAT(2,2)=(ICLAT*CLP+IELAT*CNP)/DEL
      ALAT(2,3)=(ICLAT*CLR+IELAT*CNR)/DEL
      ALAT(2,4)=0.0
      ALAT(3,1)=(IALAT*CNB+IELAT*CLB)/DEL
      ALAT(3,2)=(IALAT*CNP+IELAT*CLP)/DEL
      ALAT(3,3)=(IALAT*CNR+IELAT*CLR)/DEL
      ALAT(3,4)=0.0
      ALAT(4,1)=0.0
      ALAT(4,2)=1.0
      ALAT(4,3)=TAN(THETAO)
      ALAT(4,4)=0.0
C
      WRITE(10,100)
      DO 10 J=1,4
        WRITE(10,200) (ALONG(J,K), K=1,4)
        IF(J.NE.4) WRITE (10,201)
10    CONTINUE
C
      WRITE(10,101)
      DO 15 J=1,4
        WRITE(10,200) (ALAT(J,K), K=1,4)
        IF(J.NE.4) WRITE (10,201)
15    CONTINUE
C
100   FORMAT(//////,25X,'THE STABILITY MATRIX CORRESPONDING TO',/,
     * 20X,'THE NONDIMENSIONAL, CONTROLS FIXED, LINEARIZED,',/,
     * 25X,'LONGITUDINAL EQUATIONS OF MOTION FOR',/,
     * 35X,'A RIGID AIRPLANE',//)
101   FORMAT(////,25X,'THE STABILITY MATRIX CORRESPONDING TO',/,
     * 20X,'THE NONDIMENSIONAL, CONTROLS FIXED, LINEARIZED,',/,
     * 28X,'LATERAL EQUATIONS OF MOTION FOR',/,
     * 35X,'A RIGID AIRPLANE',//)
200   FORMAT(5X,'| ',4(F12.8,6X),' |')
201   FORMAT(5X,'|',74X,'|')
C
      CLOSE(9)
      CLOSE(10)
      STOP
      END
```

GEOMETRICAL,INERTIAL & EQUILIBRIUM CHARACTERISTICS:

GRAVITATIONAL ACCELERATION (FT/SEC^2)	=	32.174000
WING AREA (FT^2)	=	5818.000000
WEIGHT (LB)	=	180000.000000
WING SPAN (FT)	=	127.692000
MEAN AERODYNAMIC CHORD (FT)	=	51.120000
AIRSPEED (FT/SEC)	=	300.000000
AIR DENSITY (SLUGS/FT^3)	=	0.002377
INITIAL THETA (RAD)	=	0.174500
IYY (SLUG-FT^2)	=	12490393.000000
IXX (SLUG-FT^2)	=	1686164.000000
IZZ (SLUG-FT^2)	=	13399266.000000
IXZ (SLUG-FT^2)	=	795369.000000
CLO (---)	=	0.418000
CDO (---)	=	0.050000

NON-DIMENSIONAL STABILITY DERIVATIVES:

CMU (---)	=	0.000000
CMA (---)	=	-0.403200
CMAD (---)	=	0.000000
CMQ (---)	=	0.104200
CLA (---)	=	2.800000
CLQ (---)	=	-0.763500
CDA (---)	=	0.266000
CDU (---)	=	0.000000

LATERAL-DIRECTIONAL DERIVATIVES:

CLB (/RAD)	=	-0.338000
CLP (/RAD)	=	-0.225000
CLR (/RAD)	=	0.775500
CNB (/RAD)	=	0.012000
CNP (/RAD)	=	-0.070000
CNR (/RAD)	=	-0.030000
CYB (/RAD)	=	-0.706000
CYP (/RAD)	=	-0.195800
CYR (/RAD)	=	0.514200

THE STABILITY MATRIX CORRESPONDING TO
THE NONDIMENSIONAL, CONTROLS FIXED, LINEARIZED,
LONGITUDINAL EQUATIONS OF MOTION FOR
A RIGID AIRPLANE

-0.00315899	0.00480166	0.00000000	-0.01320457
-0.02743687	-0.09003117	1.02411888	-0.00232787
0.00000000	-0.00745438	0.00192645	0.00000000
0.00000000	0.00000000	1.00000000	0.00000000

THE STABILITY MATRIX CORRESPONDING TO
THE NONDIMENSIONAL, CONTROLS FIXED, LINEARIZED,
LATERAL EQUATIONS OF MOTION FOR
A RIGID AIRPLANE

-0.05570903	-0.01545018	-0.95942552	0.03298353
-0.74066202	-0.50320992	1.69903754	0.00000000
-0.04074188	-0.04867205	0.09279544	0.00000000
0.00000000	1.00000000	0.17629303	0.00000000

User Name: Shuttle II Design Group   Date: 3/2/99
Problem Identification: Dynamic Stability

LINEAR SYSTEM ANALYSIS RESULTS

****

THE A MATRIX

-3.1590E-03	4.9017E-03	0.0000E+00	-1.3205E-02
-2.7437E-02	-9.0031E-02	1.0241E+00	-2.3279E-03
0.0000E+00	-7.4544E-03	1.9264E-03	0.0000E+00
0.0000E+00	0.0000E+00	1.0000E+00	0.0000E+00

****

CHARACTERISTIC POLYNOMIAL COEFFICIENTS - ASCENDING POWERS OF S

2.6459E-06 5.9619E-06 7.8708E-03 9.1264E-02 1.0000E+00

****

THE EIGENVALUES OF THE A MATRIX

REAL PART	IMAGINARY PART
1.6523E-03	1.8289E-02
1.6523E-03	-1.8289E-02
-4.7284E-02	7.4902E-02
-4.7284E-02	-7.4902E-02

User Name: Shuttle II Design Group   Date: 3/2/99
Problem Identification: Dynamic Stability

LINEAR SYSTEM ANALYSIS RESULTS

****

THE A MATRIX

-5.5705E-02	-1.5451E-02	-9.5943E-01	3.2984E-02
-7.4066E-01	-5.0022E-01	1.6990E+00	0.0000E+00
-4.0742E-02	-4.3572E-02	9.2795E-02	0.0000E+00
0.0000E+00	1.0000E+00	1.7629E-01	0.0000E+00

****

CHARACTERISTIC POLYNOMIAL COEFFICIENTS - ASCENDING POWERS OF S

-7.4133E-05 4.1531E-02 3.7717E-02 4.6612E-01 1.0000E+00

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THE EIGENVALUES OF THE A MATRIX

REAL PART	IMAGINARY PART
1.7834E-03	0.0000E+00
5.4534E-02	2.6291E-01
5.4534E-02	-2.6291E-01
-5.7499E-01	0.0000E+00

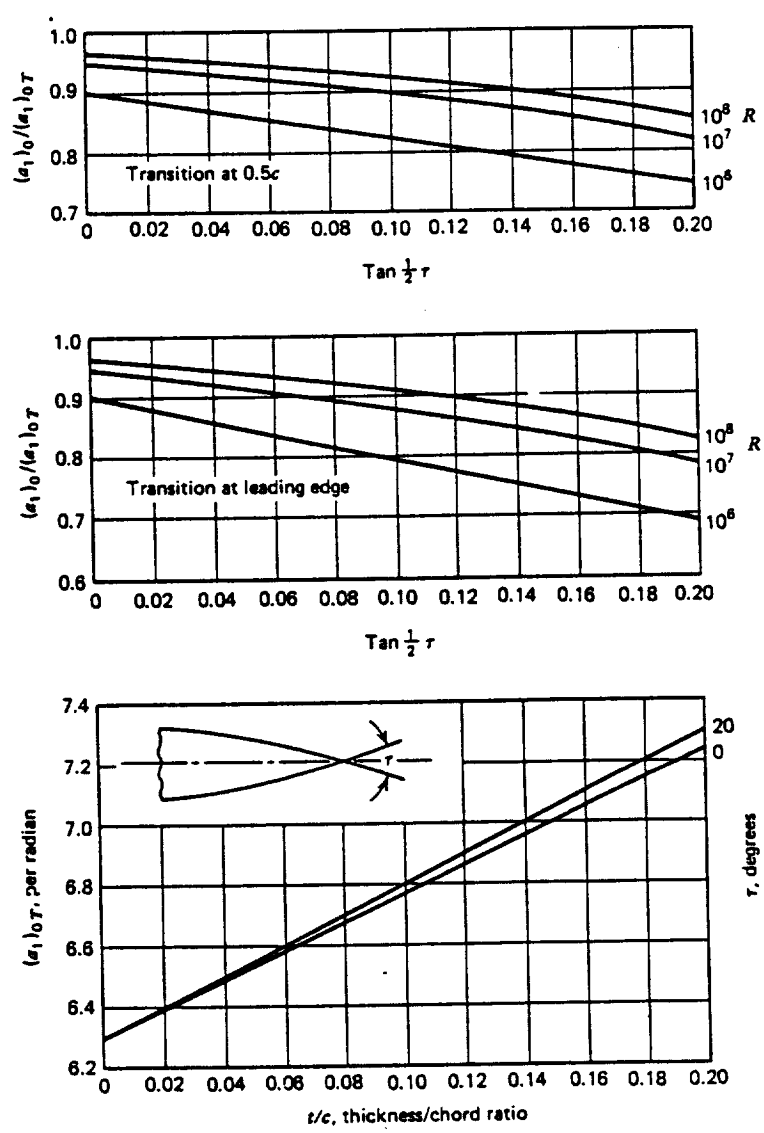

Figure 5.1.1. Lift curve slopes for two-dimensional incompressible flow.

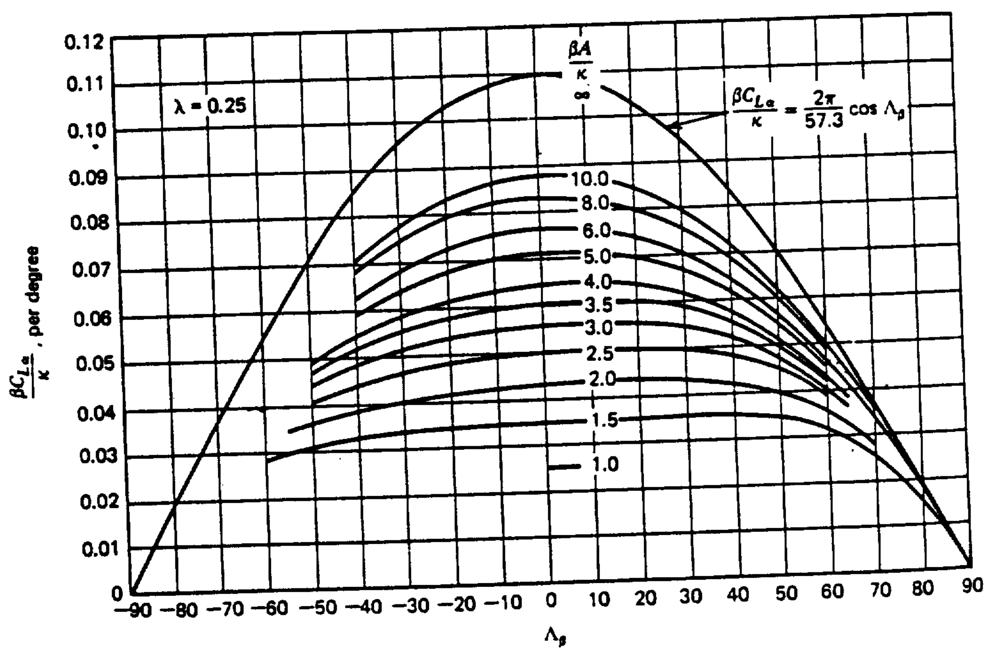

Figure 5.1.2.Lift-curve slope for swept and tapered wings at speeds below critical Mach number.

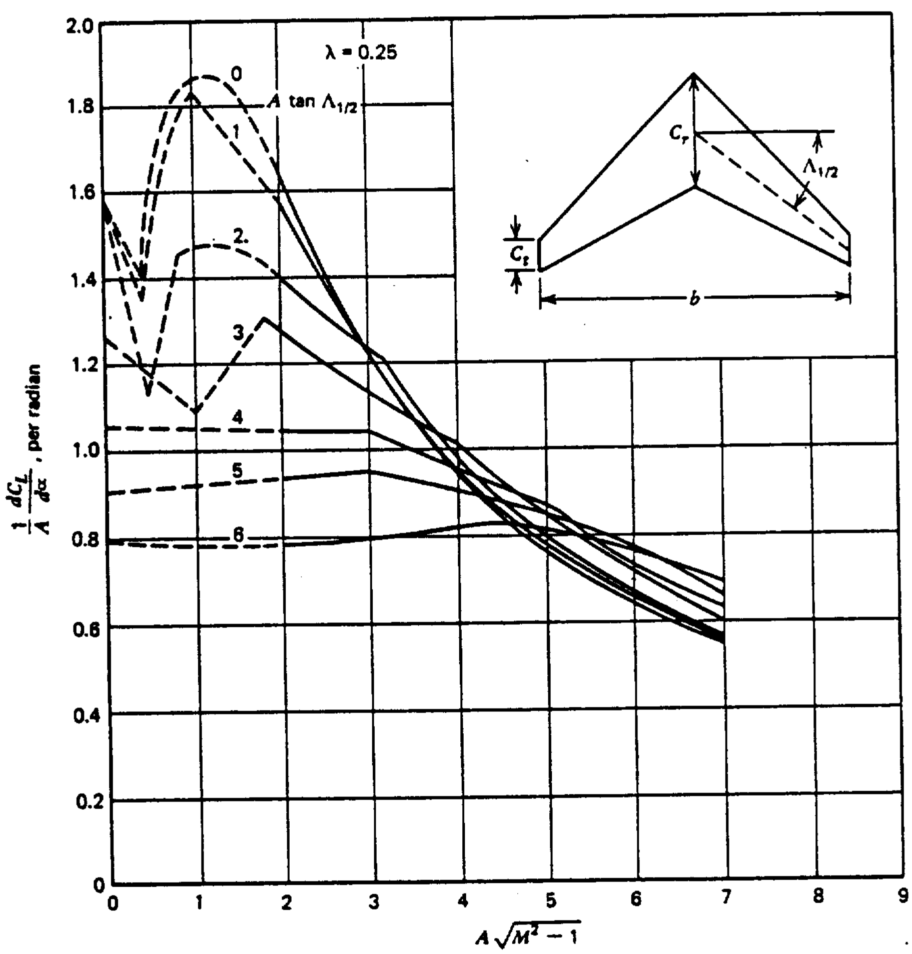

Figure 5.1.3. Lift-curve slope for swept and tapered wings at supersonic speeds.

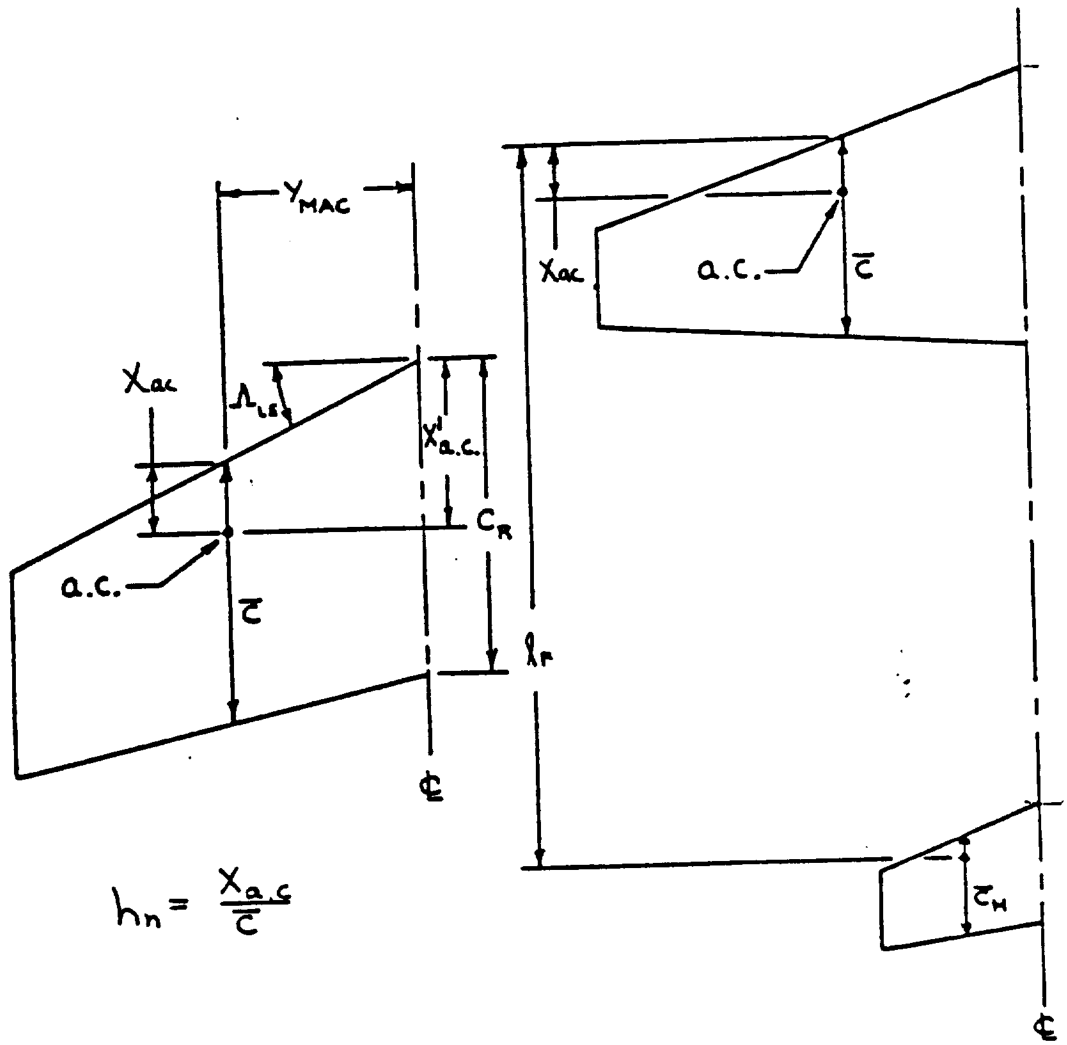

Figure 5.2.1. Definitions of Dimensional and Non-Dimensional Aerodynamic Center (Neutral Point) Locations.

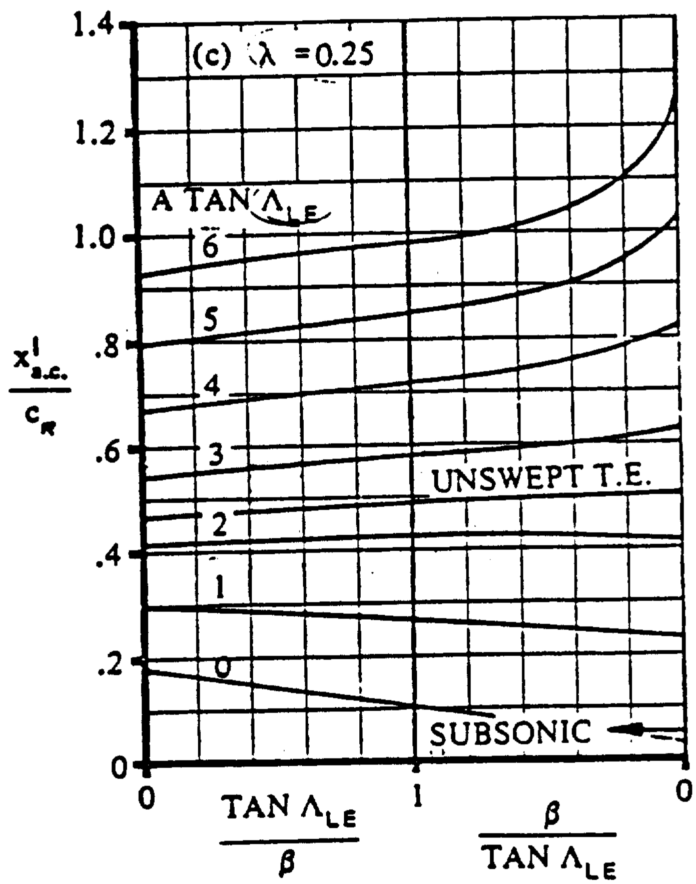

Figure 5.2.2. Aerodynamic Center Location of Lifting Surfaces.

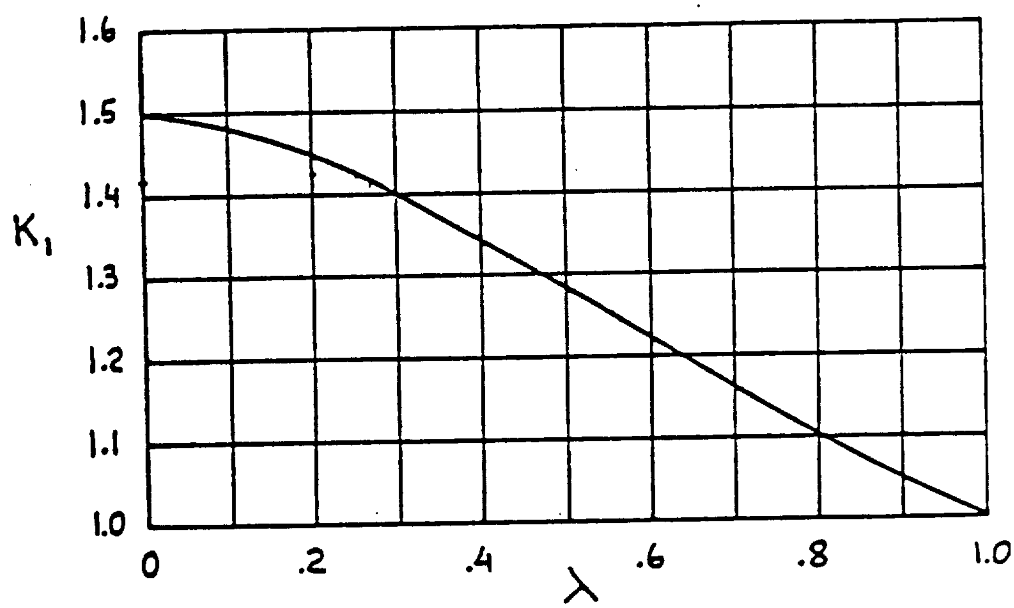

Figure 5.2.3. Aerodynamic Center Transformation Constant K_1

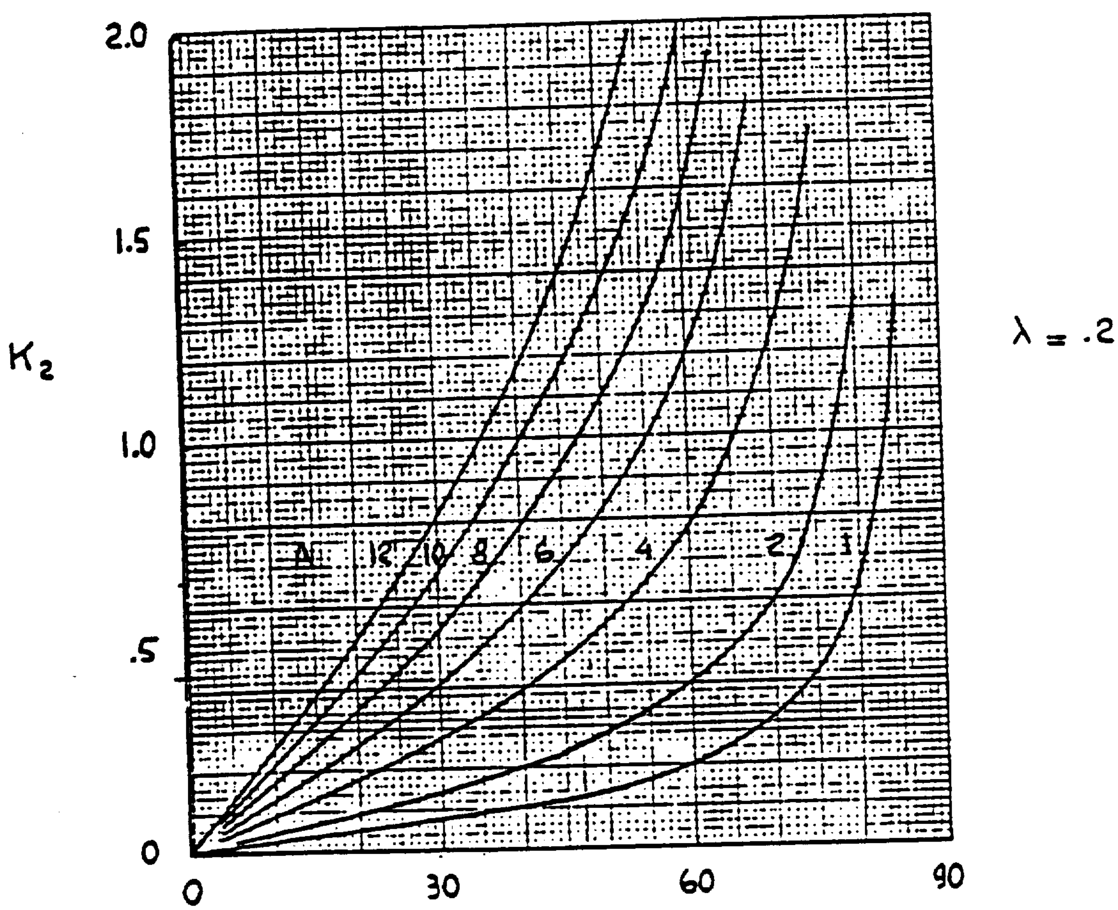

Figure 5.2.4. Aerodynamic Center Transformation Constant K_2

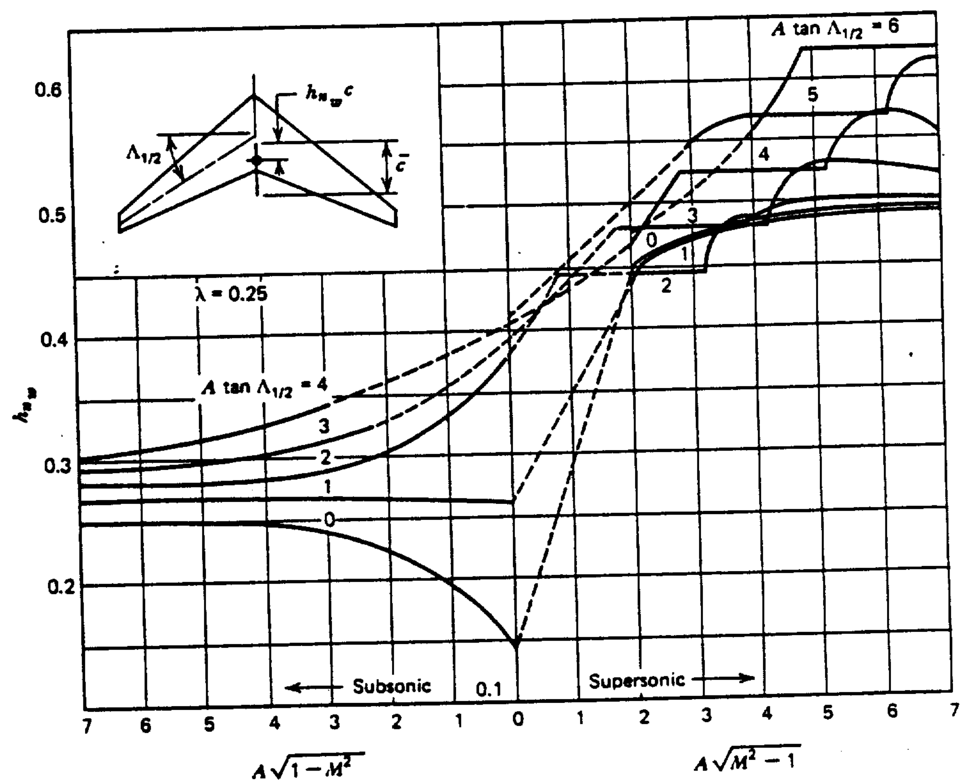

Figure 5.2.5. Chordwise position of the mean aerodynamic center of swept and tapered wings at high speeds expressed as a fraction of the mean aerodynamic chord.

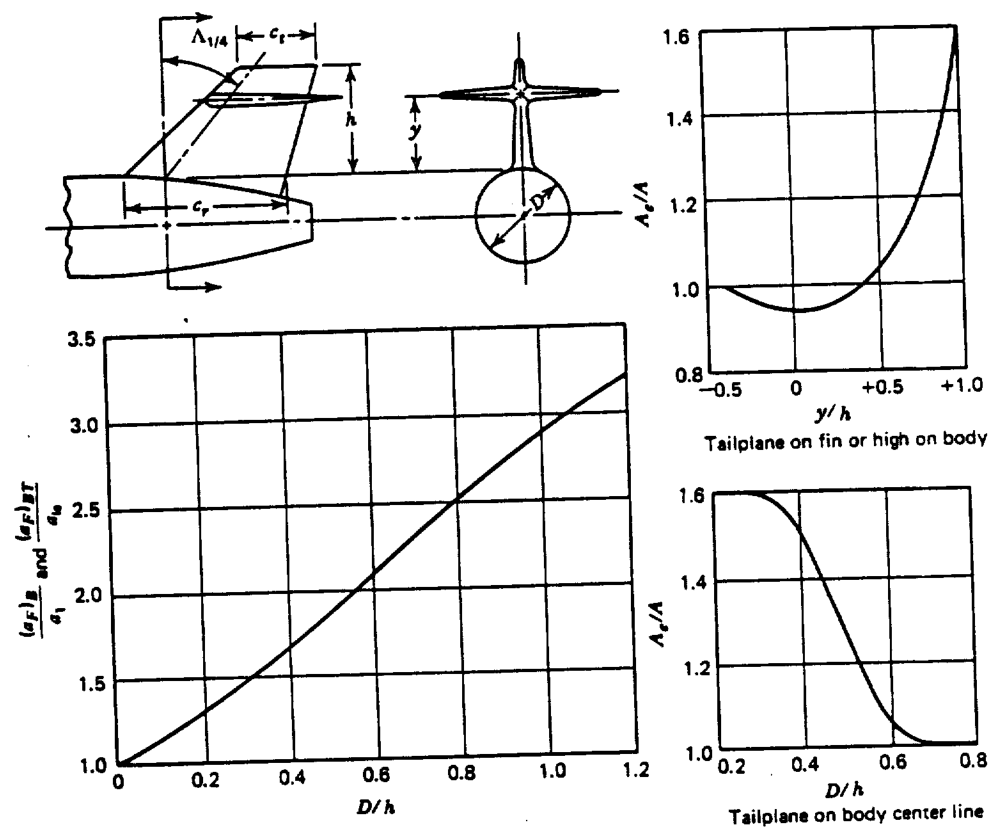

Figure 5.4.1. Lift-curve slope for single fin and rudder on a body of circular cross section.

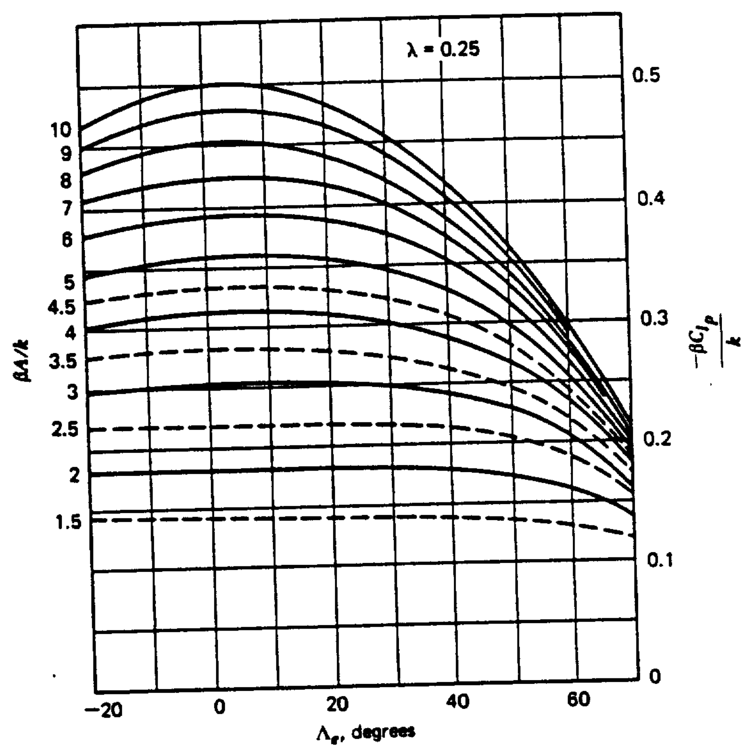

Figure 5.5.1. C_{l_p} for straight-tapered wings.

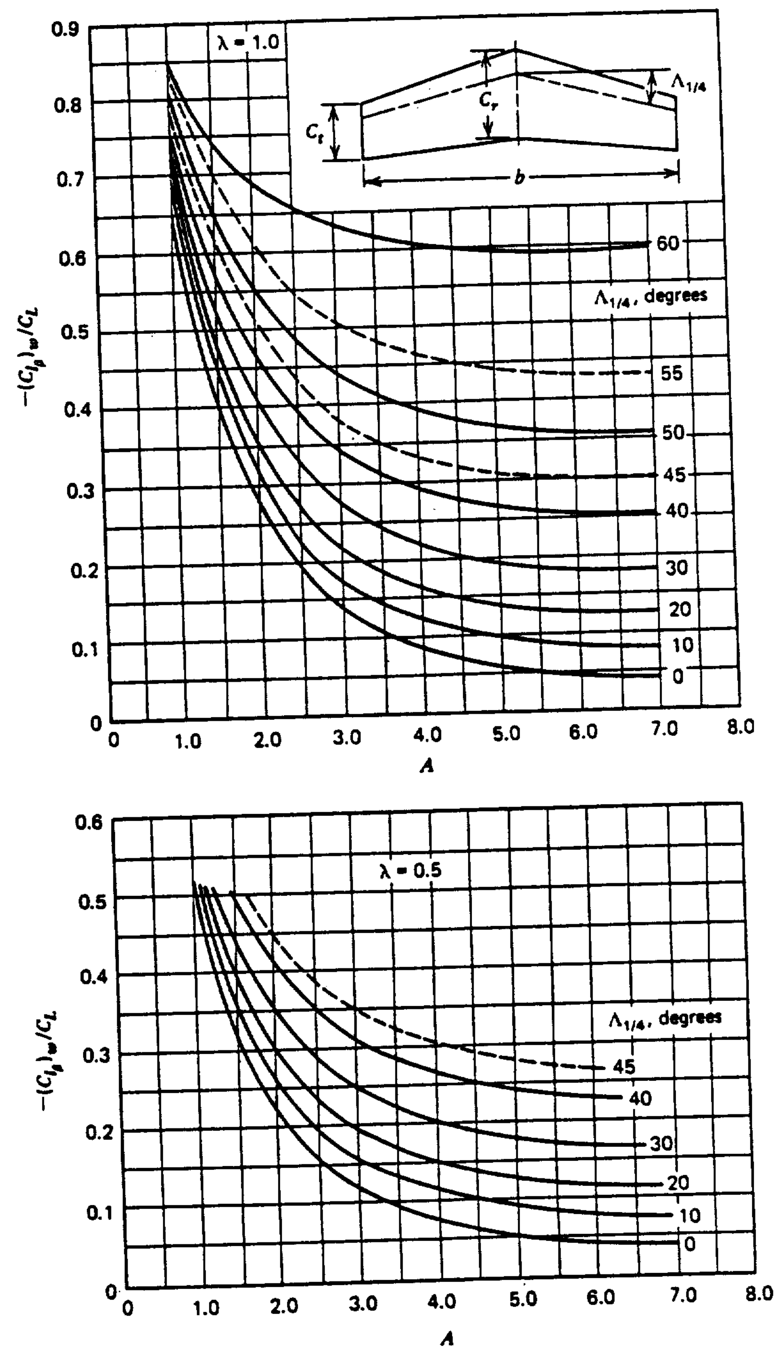

Figure 5.6.1. $C_{l\beta}$ for straight-tapered wings with no dihedral.

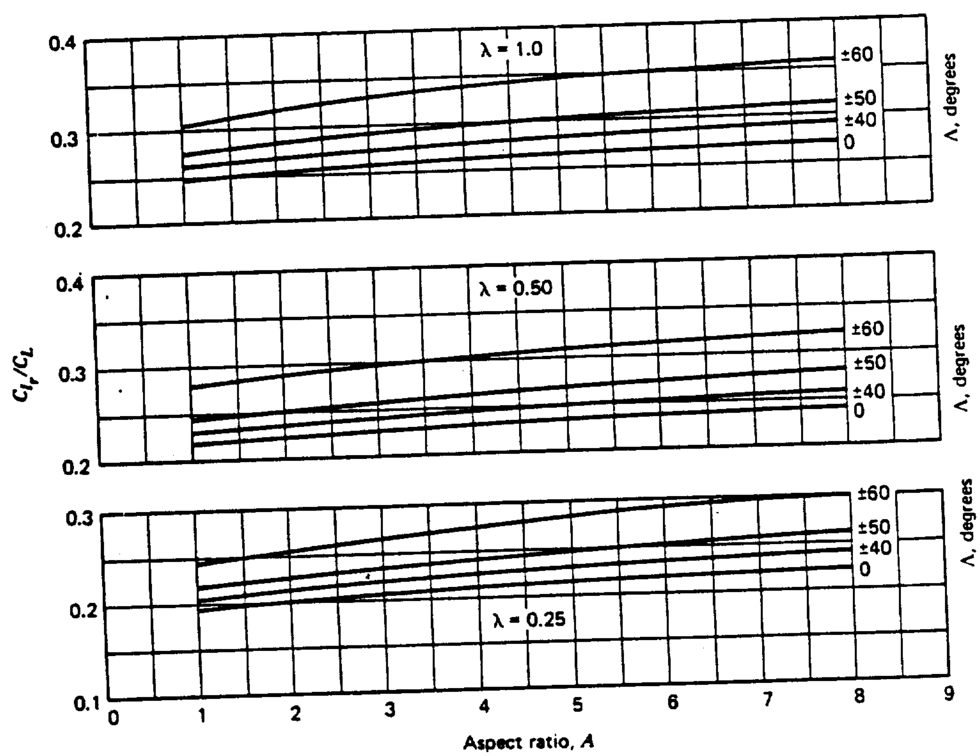

Figure 5.7.1. Charts for estimating C_{l_r} for subsonic incompressible flow.

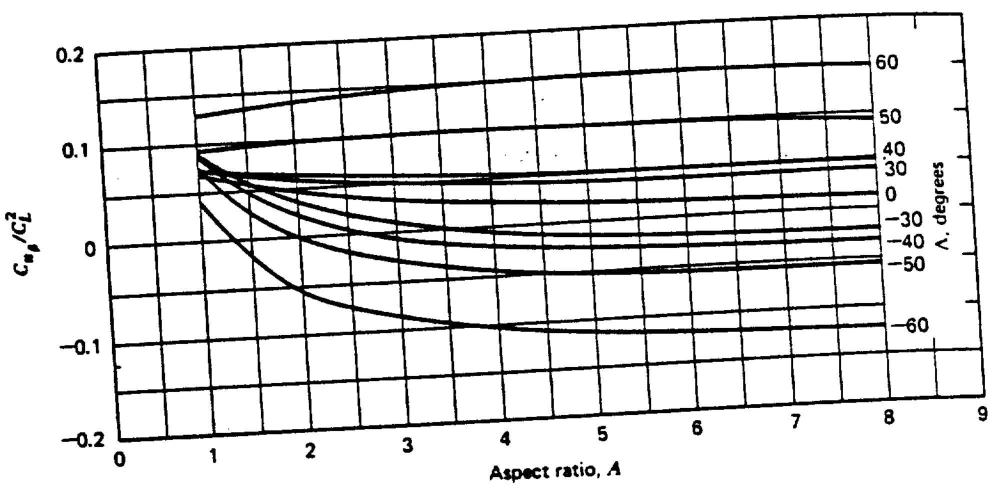

Figure 5.8.1. Variation of $C_{n\beta}/C_L^2$ with aspect ratio and sweep for subsonic incompressible flow

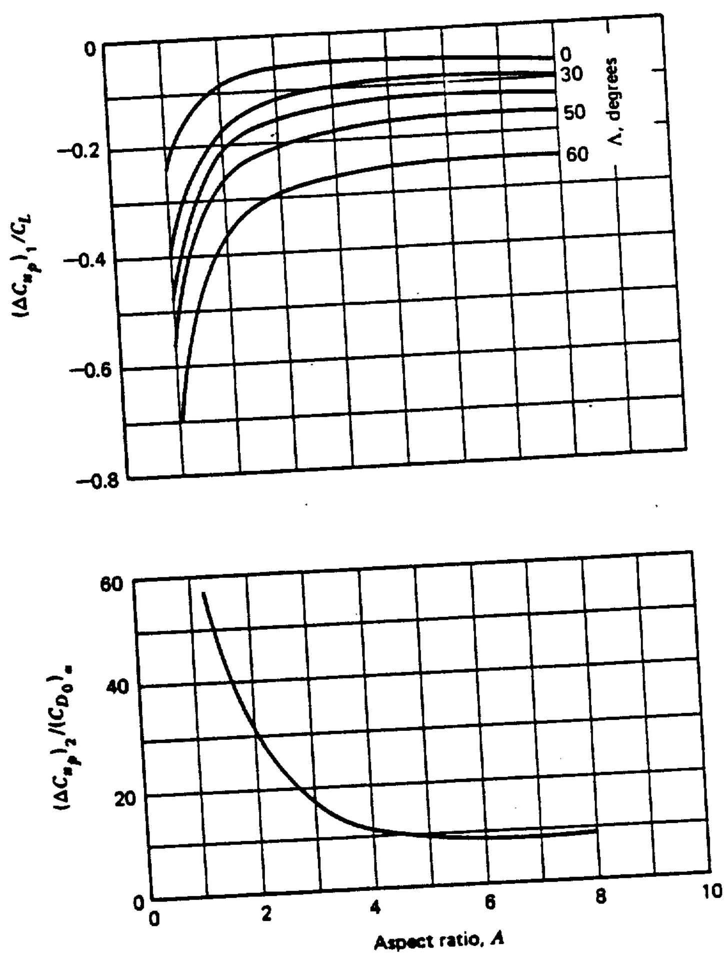

Figure 5.9.1. Variation of $(\Delta C_{np})_1/C_L$ and $(\Delta C_{np})_2/(C_{D0})\alpha$ with aspect ratio for subsonic incompressible flow.

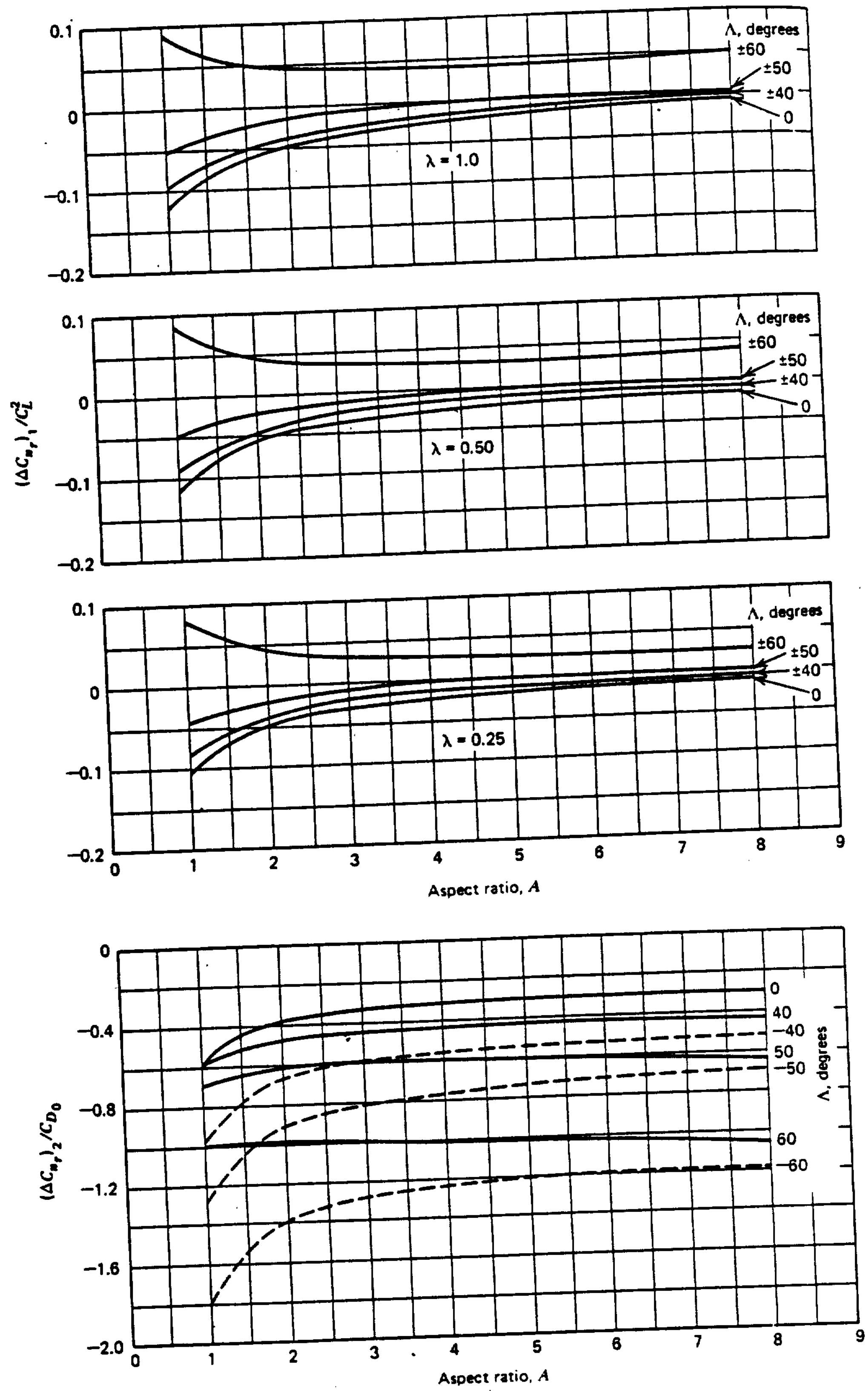

Figure 5.10.1. Charts for estimating $(\Delta C_{nr})_1/C_L{}^2$ and $(\Delta C_{nr})_2/C_{D0}$

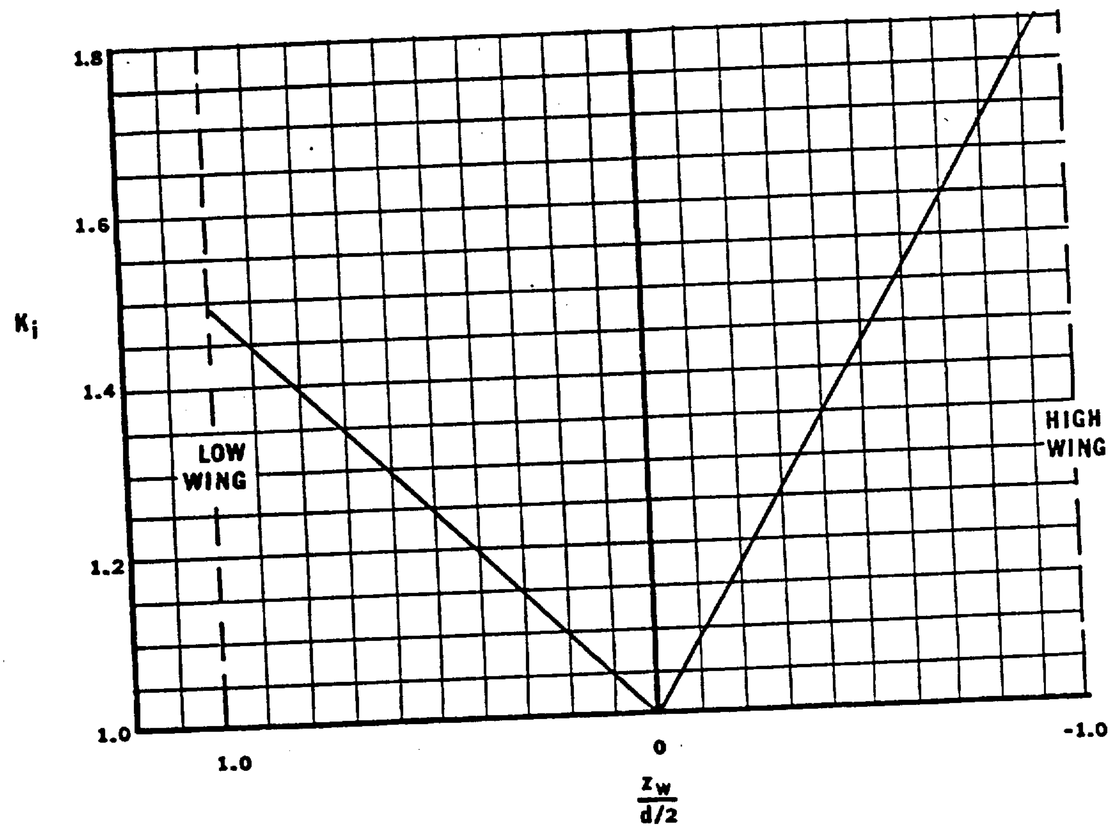

Figure 5.14.1. Values for wing-fuselage interference factor.

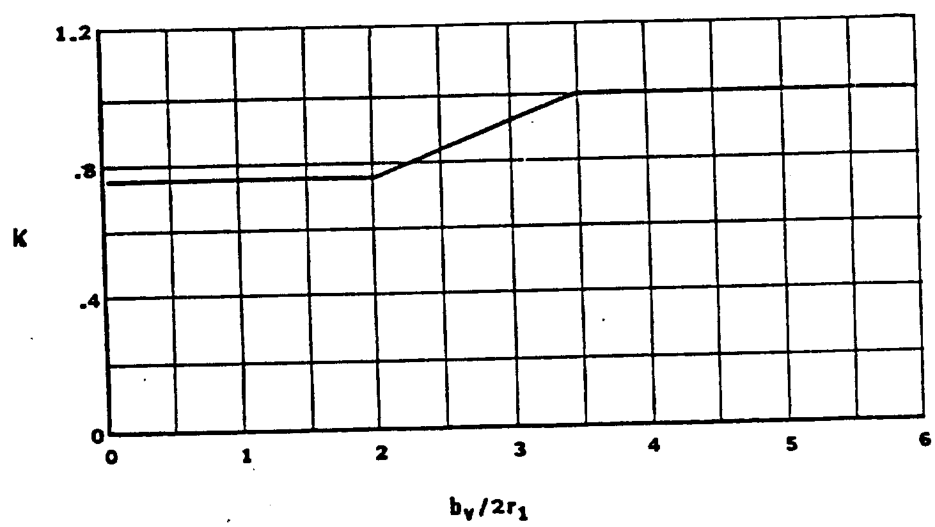

Figure 5.14.2. Values for k as a function of the ratio of vertical tail span to fuselage diamter in the tail region.

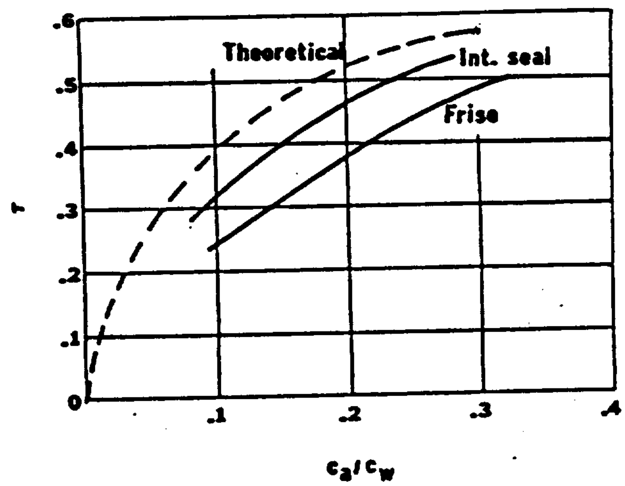

Figure 5.18.1.Values for τ as a function of aileron chord to wing chord ratio.

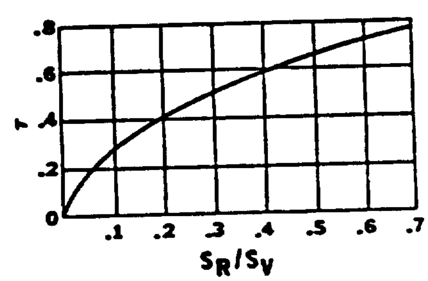

Figure 5.19.1. Values for τ as a function of rudder area to vertical tail area ratio.