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DESIGN, DEVELOPMENT AND FLIGHT TEST OF THE SUPER LOKI STABLE BOOSTER ROCKET SYSTEMS

Bruce Bollermann, et al

Space Data Corporation
Phoenix, Arizona

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DESIGN, DEVELOPMENT AND FLIGHT TEST OF THE SUPER LOKI STABLE BOOSTER ROCKET SYSTEMS

by

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1331 South 26th Street
Phoenix, Arizona 85034

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13. ABSTRACT

The Super Loki Stable Booster Rocket Systems have been developed to obtain high altitude temperature, density, and wind measurements by means of small inexpensive rocket systems which have post-burnout stable booster trajectories. These systems can be used at ranges where booster wind drift is a safety problem. The expended rocket booster impacts at a range of about 15,000 feet or 2.46 nautical miles from the launch site. These systems have been developed to replace the Super Loki PWN-10A, PWN-10B, and PWN-12A at launch sites requiring either transponder or falling sphere payloads and stable booster impacts.

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FOREWORD

This report is authorized by Contract No. F19628-72-C-0195 which has been sponsored by the Vertical Sounding Techniques Branch (LYV) of the Meteorology Laboratory, Air Force Cambridge Research Laboratory.

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ABSTRACT

The Super Loki Stable Booster Rocket Systems have been developed to obtain high altitude temperature, density and wind measurements by means of small inexpensive rocket systems which have post-burnout stable booster trajectories. These systems can be used at ranges where booster wind drift is a safety problem. The expended rocket booster impacts at a range of about 15,000 feet or 2.46 nautical miles from the launch site. These systems have been developed to replace the Super Loki PWN-10A, PWN-10B and PWN-12A at launch sites requiring either transponder or falling sphere payloads and stable booster impacts.

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1.

SUMMARY

The Super Loki Stable Booster Rocket Systems have been developed to obtain high altitude temperature, density and wind measurements by means of small inexpensive rocket systems which have post-burnout stable booster trajectories. These systems can be used at ranges where booster wind drift is a safety problem. The expended rocket booster impacts at a range of about 15,000 feet or 2.46 nautical miles from the launch site. These systems have been developed to replace the Super Loki PWN-10A, PWN-10B and PWN-12A at launch sites requiring either transponder, transmitter, or falling sphere payloads and stable booster impacts.

The stable booster rocket motor has been developed by increasing the fin area of the standard Super Loki rocket motor, protecting the booster fins from aerodynamic heating by special leading edge cuffs and an ablative coating, increasing the motor headcap weight and extending the standard motor length by ten inches to incorporate additional propellant to make up for the flight performance losses due to these changes.

The stable booster rocket motors have been successfully flight tested with the 2-1/8-inch diameter instrument dart (PWN-10A, PWN-10B) and the 1-5/8-inch diameter Robin dart (PWN-12). The dart vehicles reached apogees of about 71 km and 106 km respectively.

Reliability of the stable booster trajectories was demonstrated with both the instrument and Robin dart systems. Booster trajectories were reasonable predictable and were demonstrated to eliminate the standard system potential impact hazard.

A Viper 3A rocket vehicle system has also been successfully flight tested in this program. The Viper 3A rocket motor is a scale-up of the Super Loki motor in both diameter and length. The booster was maintained in a stable trajectory after burnout and dart separation by protecting the booster fins with special leading edge cuffs and ablative coating and adding weight to the head end of the rocket motor by means of a solid headcap. The advantage of this system is an improvement in altitude performance over both the standard Super Loki systems or stable booster systems. However, vehicle cost and launch rail diameter increases caused the Air Force to choose the extended length Super Loki rocket motor over the Viper 3A.

2.

INTRODUCTION

The U. S. Air Force has requirements for routine direct measurement of atmospheric temperatures, density and wind profiles from the earth surface to an altitude of 90 km. Balloon-borne radiosondes are used to satisfy these measurement requirements to a ceiling of about 30 km. Rocket systems are required to extend the measured profiles up to 90 km.

From about 1963 to 1969, the Arcas meteorological rocket was used to conduct routine temperature and wind soundings to about 60 km. A transmitter instrument was used with the AN/GMD-1 ground station receiving equipment. Thus, tracking radar was required to obtain space position data. During the mid-1960's, an AN/DMQ-9 transponder instrument was developed for the Arcas rocket so that soundings could be made at remote sites without the need for tracking radar. Soon after this period, the Loki Dart system was developed by the Air Force to replace the more costly Arcas.

Although the transmitter instrument version of the Loki Dart (PWN-8B) was immediately successful, the dart second-stage appeared to be too small to incorporate the larger transponder instrument. Two programs to develop a transponder instrument for the small Loki Dart ended in failure. Because of this, it was proposed to scale the Loki system up in size to make more payload volume available for the transponder instrument. It was decided that a higher apogee altitude should be achieved than for either the Arcas or the Loki, and that a larger decelerator should be developed to achieve reasonable descent rates at the higher altitudes with the transponder instrument. This new system, the Super Loki, was then developed under a previous contract.

During the latter 1960's, the Viper Robin Dart was developed to obtain falling sphere density and wind profiles to 100 km. Although this system was operational for only two years, the Air Force decided to replace it with a smaller and lower cost Super Loki falling sphere system. For the sake of a unified booster system, and logistics simplification, the Air Force also decided to develop a Super Loki transmitter system by eliminating the ranging receiver from the transponder system. Thus, three Super Loki Meteorological rocket vehicles have been developed for altitudes from 20 km to 90 km. The rocket motor is identical for the three vehicles, but the second-stage dart diameter has been adapted to the specific payload and performance requirements for a number of different systems. The payloads include the Robin inflatable sphere, a transponder instrument and two kinds of transmitter instruments. A heavy interstage adapter, as described below, is incorporated in one of the vehicles to maintain a stable or ballistic trajectory after dart separation. This system had been developed for particular launch sites where the wind drift of unstable post-burnout boosters caused safety problems. This stable booster development had been limited to the small Datasonde dart vehicle to provide only temperature and wind soundings where radar is available.

In the use of rocket-dart vehicles, a problem sometimes exists at a range whose geography is such that the prevailing winds cause the spent booster to drift back onto range equipment or buildings. A rocket motor designed to be stable following its burnout at low altitude will insure a ballistic trajectory to down-range impact. A simple solution for this problem with the transmitter system was made by combining the small dart from the older Loki system with a Super Loki motor. In this system, the motor CG was moved forward by use of a heavy front end (Interstage) while the increased performance of the Super Loki motor over the Loki more than made up for the increased weight.

The present program, reported herein, is the development and flight test of a stable booster system which can be used with all of the Super Loki payloads.

The development program goals consist of stabilizing the booster and retaining dart altitude for (1) the transponder system which requires the largest dart and (2) the Robin system. A series of design steps and tests, as described in Section 8, was required to develop the stable configuration. It was found that an increase in motor performance by use of either larger diameter or longer motors was required to make up for the flight performance losses due to the booster stabilizing modification. Sections 3 through 7, following, describe in detail the final configurations.

3.

ROCKET MOTOR DESIGN

3.1 Introduction

The Super Loki rocket motor (SDC P/N 354-15) was developed for the U. S. Air Force by scaling up the Loki motor from a 3.0-inch diameter to a 4.0-inch diameter to provide a significant increase in total impulse. This rocket motor has been previously standardized for the PWN-10A, -10B, -11A, and -12A meteorological rocket systems which are currently in operational use. During the current program, the standard Super Loki rocket motor has been modified by providing larger fins, utilizing thermal protection for the fins, and increasing the weight of the motor headcap. These changes were made to provide a stable booster flight after motor burnout and stage separation. Since dart altitude performance was degraded due to these modifications, the rocket motor length was extended by ten inches and additional propellant was loaded into the extended length. This increase in propellant weight and total impulse makes up for the flight performance losses due to the stability modifications.

3.2 Description

The Stable Super Loki rocket motor (SDC P/N 600-13) shown in Figure 3.1 consists of an aluminum case with internal burning cast-in-case solid propellant. An aluminum headcap and interstage coupling is located at the forward end of the rocket motor. A graphite nozzle insert backed by a steel retaining ring is located at the aft end of the motor. The propellant fuel is a polysulfide polymer with an ammonium perchlorate oxidizer. The igniter consists of two parallel 1 watt/1 ampere no-fire squibs and an ignition charge of cupric oxide and aluminum powder. The igniter which is the same as the original Super Loki igniter is separable from the rocket motor and is installed at the launch site.

A cross-section view of the Stable Super Loki rocket motor is presented in Figure 3.2. Major design characteristics are presented in Table 3.1, and the propellant characteristics are presented in Table 3.2. The propellant burning rate and area ratio curves versus chamber pressure are presented in Figure 3.3. The propellant is the same as that used in the original Super Loki rocket motor.

3.3 Performance

A summary of the rocket motor performance data is presented in Table 3.3. A nominal pressure and thrust versus time curve is presented in Figure 3.4. The added propellant weight of the stable rocket motor has increased the total impulse of the standard rocket motor by 16.8 percent. Although the burning time and chamber pressure of this new design is the same as the standard, the thrust profile is increased (see also Figures 8.3 and 8.4).

3.4 Modifications

The primary modification to the standard Super Loki rocket motor has been an increase in motor length and grain length of ten inches. This has increased the propellant weight from 37.51 pounds to 43.48 pounds. The nozzle throat area was also increased from 2.326 to [illegible]6 square inches to maintain the standard chamber pressure profile.

The rocket motor fin area was increased from 10.0 to 31.40 square inches per panel (four each) to increase the aerodynamic static stability margin. Thermal protection of the rocket motor fins was added by incorporating specially insulated leading edge cuffs and an 0.030-inch thickness of an ablative coating of Thermolag.

The rocket motor headcap weight was increased from 1.438 to 3.180 pounds to increase the aerodynamic static stability margin.

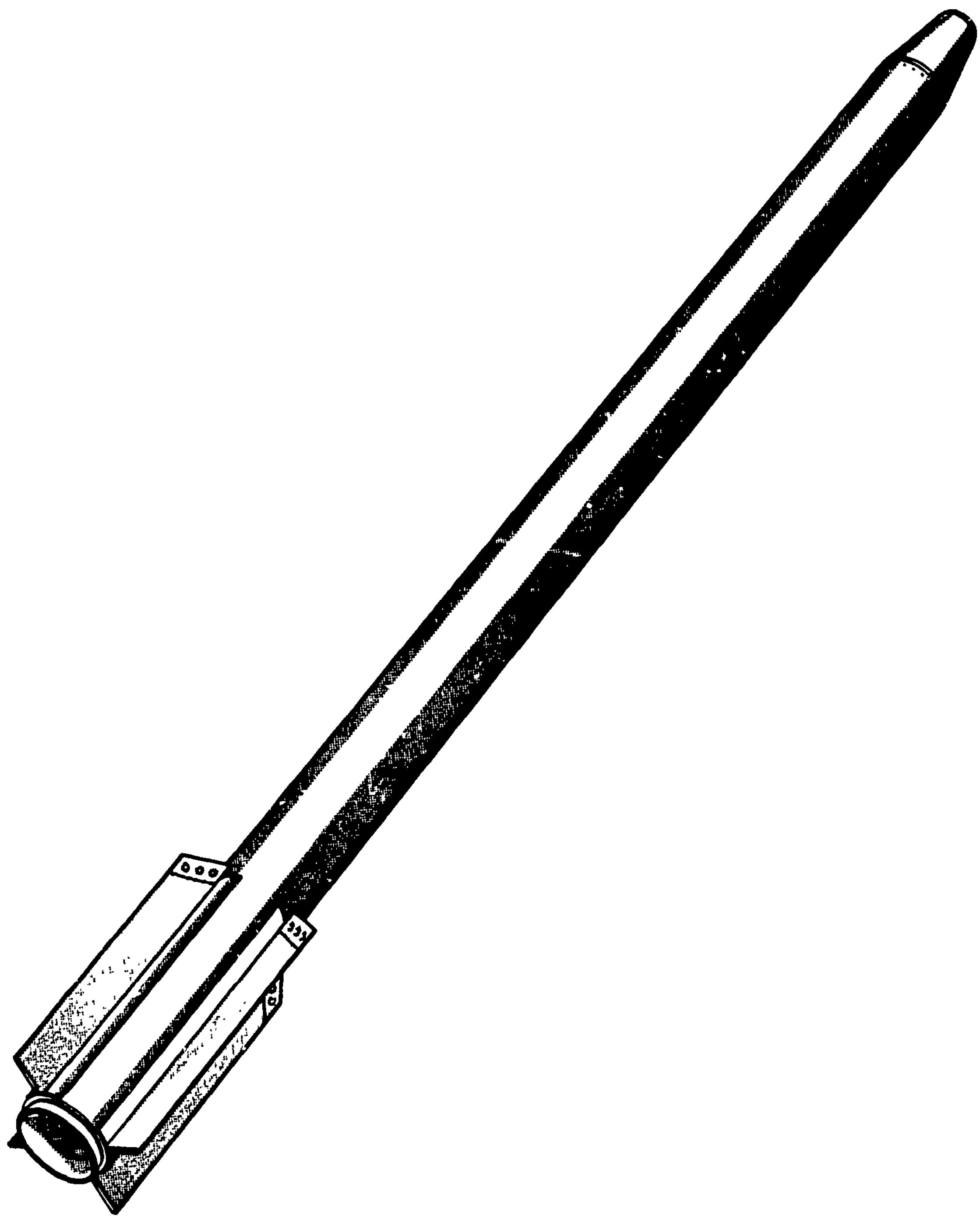


FIGURE 3.1 STABLE SUPER LOKI ROCKET MOTOR

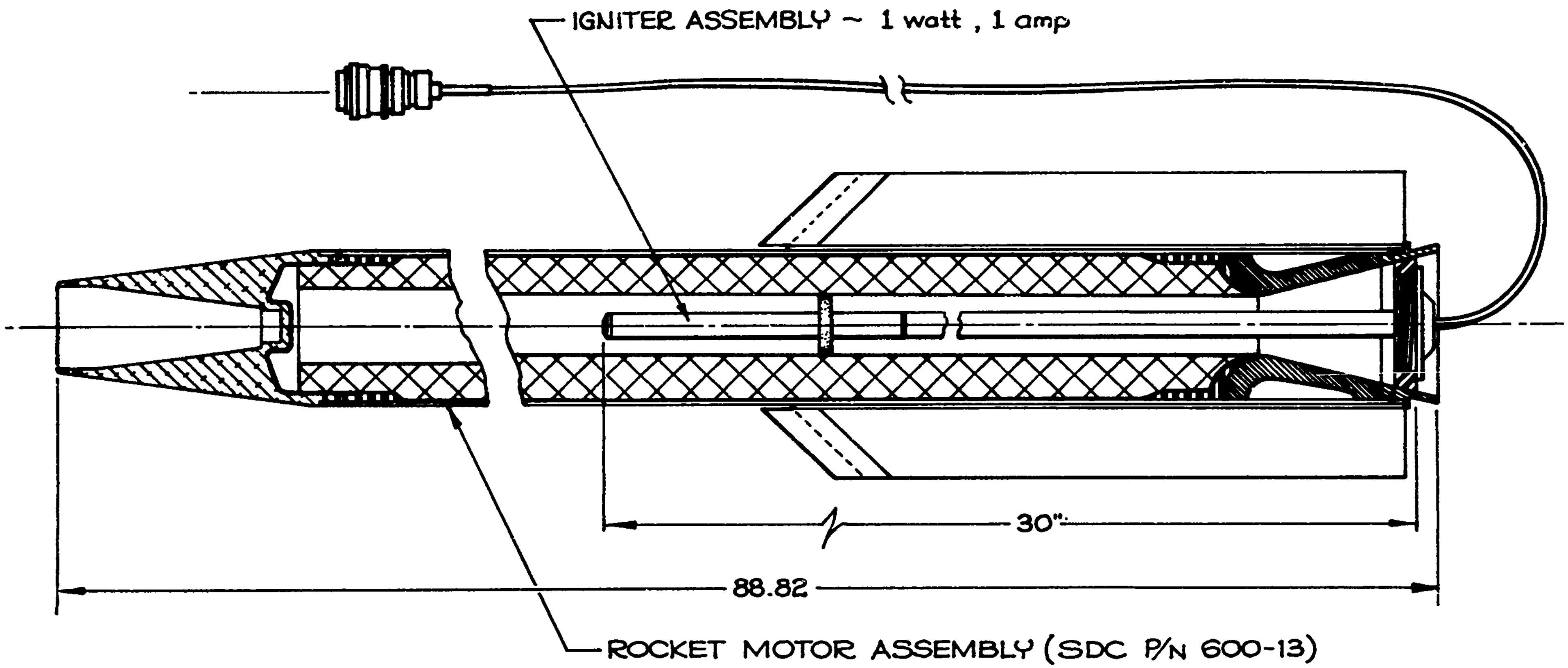


FIGURE 3.2 CROSS-SECTION OF STABLE SUPER LOKI ROCKET MOTOR WITH IGNITER INSTALLED

A-3262

TABLE 3.1

STABLE SUPER LOKI ROCKET MOTOR DESIGN CHARACTERISITCS
(SDC P/N 600-13)

Length	88.3 in.
Diameter	4.0 in.
Fin Span	8.0 in.
Fin Tip Chord	14.8 in.
Fin Root Chord	16.6 in.
Fin Area (each)	31.4 $in.^2$ per fin
Case Weight	12.68 lb.
Liner Weight	0.65 lb.
Lined Case Weight	13.33 lb.
Propellant Weight	43.48 lb.
Loaded Case Weight	56.81 lb.
Headcap and Interstage Weight	3.81 lb.
Overall Rocket Weight	60.62 lb.
Igniter	0.40 lb.
Motor Case Wall	0.083 in. 2014-T6 Aluminum
Motor Case Proof Pressure	1500 psi
Motor Case Yield Pressure (minimum)	2320 psi
Motor Case Curst Pressure	2700 psi
Nozzle Throat Area	2.666 $in.^2$
Storage Temperature Limits	-40°F to +140°F
Operational Temperature Limits	-40°F to +140°F
Storage Life	2 years
Explosive Classification	ICC Class B

TABLE 3.2

PROPELLANT CHARACTERISTICS

Propellant Composition

Material	Purpose	Parts by Weight (Nominal)
Polysulfide Polymer, Liquid	Fuel and Binder	16.40
Quinonedioximine	Curing Agent	1.20
Sulfur, Flowers of	Curing Catlayst	0.10
Diphenylguanidine	Curing Accelerator	0.10
Ammonium Perchlorate (as received)	Oxidizer	46.20
Ammonium Perchlorate (after grinding)	Oxidizer	30.80
Dibutyl Phthalate	Plasticizer	2.80
Magnesium Oxide	Curing Catalyst	0.60
Aluminum	Resonance Supressor	1.80

Grain Size Distribution for Ammonium Perchlorate Blend

As received AP retained on:

	REQUIREMENTS	
	Minimum	Maximum
USS 18%	0	0
USS 50%	3%	11%
USS 100%	50	82
USS 140%	85	98
USS 325%	98	100

Ground AP % Below:

10 Microns	12	32
20 Microns	40	60
30 Microns	58	78

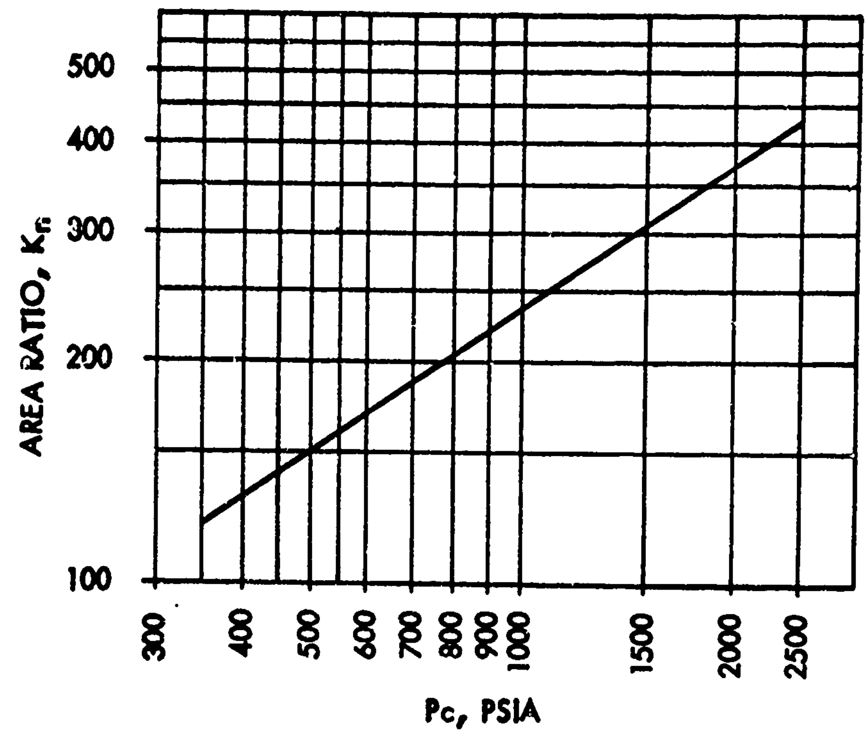
TABLE 3.2
Continued

Ballistic Properties

Temperature coefficient of chamber pressure	0.308 per deg Kelvin
Temperature coefficient of burn rate	0.0488 per deg Kelvin
Pressure exponent	0.435
Characteristic exhaust velocity	4702 fps
Ratio of specific heats	1.217
Heat of Explosion	1200 cal/g
Adiabatic Flame Temperature	2784°K

Physical Properties

Density	0.062 lb/in^3
Hardness	70-90 Shore A
Tensil Strength	200-250 psi maximum
Elongation	18-45% maximum
Modulus	2100-2800 psi
Autoignition Temperature	275°F



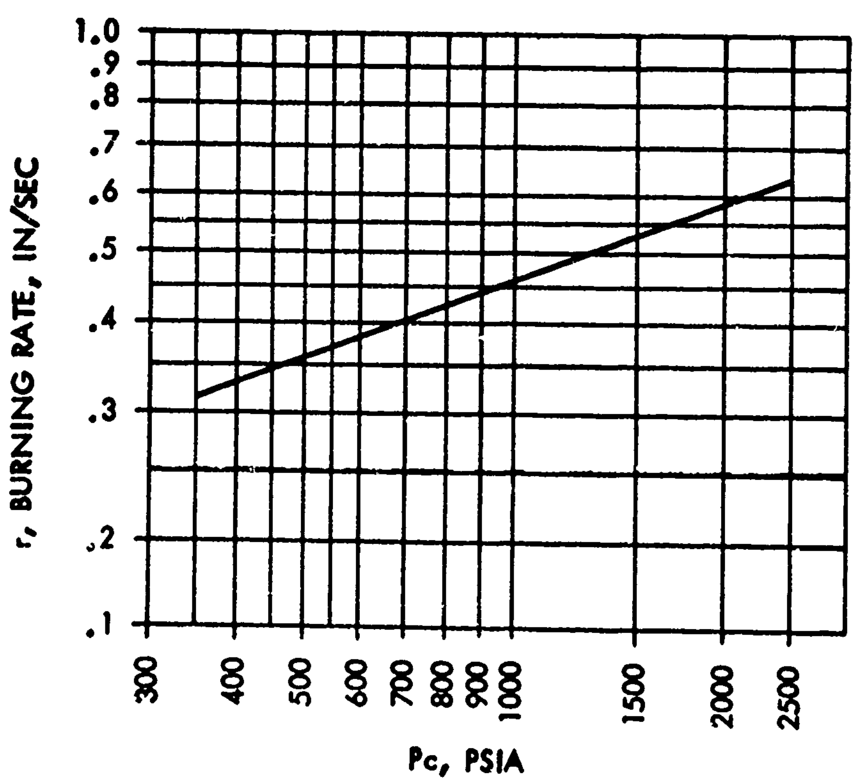


FIGURE 3.3 STABLE SUPER LOKI ROCKET MOTOR INTERNAL BALLISTICS DATA AMBIENT TEMPERATURES

TABLE 3.3

STABLE SUPER LOKI ROCKET MOTOR PERFORMANCE SUMMARY
(SDC P/N 600-13)

SEA LEVEL FIRING

Average Thrust (lbf)	4757
Average Chamber Pressure (psia)	1291
Total Impulse (lbf-sec)	9944
Action Time (sec)	2.09
Maximum Thrust (lbf)	5954
Maximum Chamber Pressure (psia)	1512
Specific Impulse	228.7

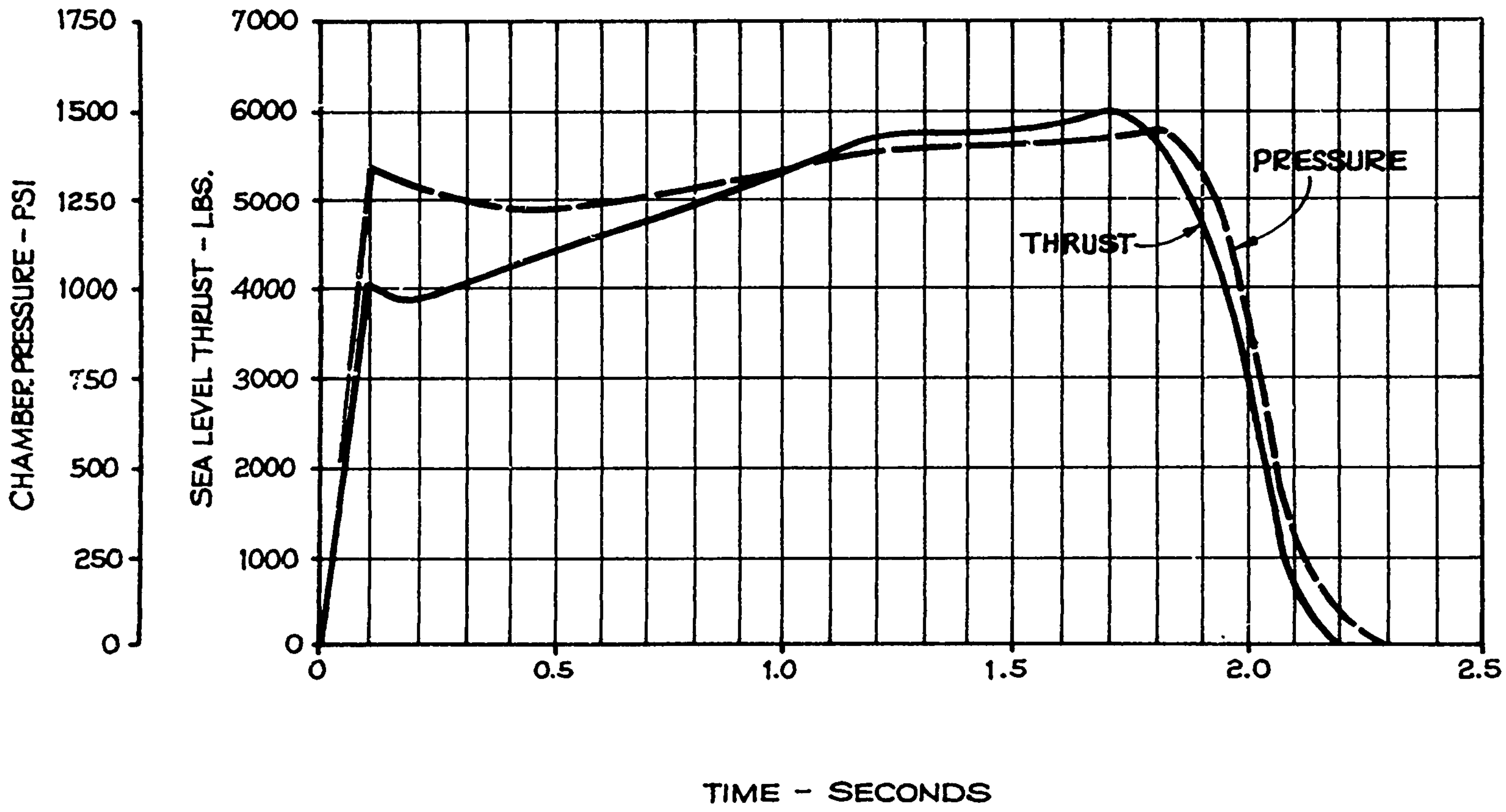


FIGURE 3.4 STABLE SUPER LOKI ROCKET MOTOR (SDC P/N 600-13) SEA LEVEL CHAMBER PRESSURE & THRUST VS. TIME AT +59° F.

4.

ROBIN SYSTEM DESIGN

4.1 Introduction

The Stable Super Loki Robin Dart vehicle consists of a 1.625-inch diameter dart second-stage with the Stable Super Loki rocket motor. The dart body is coated with an ablative material to reduce the effect of rather severe aerodynamic heating upon the inflatable sphere payload. The sphere inflator contains a percussion initiated time delay charge to initiate sphere inflation through a two-stage chamber after deployment from the dart body at an altitude of 106 km. Atmospheric density and wind data are derived from a precise radar track of the descending inflated sphere.

4.2 Vehicle Description

The Super Loki Robin Dart is a two-stage vehicle which consists of the Stable Super Loki rocket motor as the first or booster stage and a non-propulsive 1.625-inch diameter dart second stage. The vehicle configuration is shown in Figure 4.1.

The rocket motor interstage has been designed to accept the larger diameter transponder darts. Therefore, an interstage adapter ring is used with the smaller diameter Robin dart.

A summary of the vehicle mass properties is presented in Table 4.1. The vehicle center-of-gravity versus time is presented in Figure 4.2, and pitch moment-of-inertia versus time is presented in Figure 4.3.

The aerodynamic data for the vehicle are presented as follows:

Figure 4.4	Normal Force Coefficient, First Stage
Figure 4.5	Normal Force Coefficient, Dart
Figure 4.6	Center-of-Pressure, First Stage
Figure 4.7	Center-of-Pressure, Dart
Figure 4.8	Vehicle Drag Coefficient

The Super Loki Robin Dart is stable during two-stage propulsive flight at essentially a zero degree angle of attack. After dart separation at motor burnout, the dart coasts to apogee in a stable flight mode at essentially a zero degree angle of attack in the sensible atmosphere. After rocket motor burnout and stage separation, the expended booster remains stable and follows a ballistic trajectory to impact.

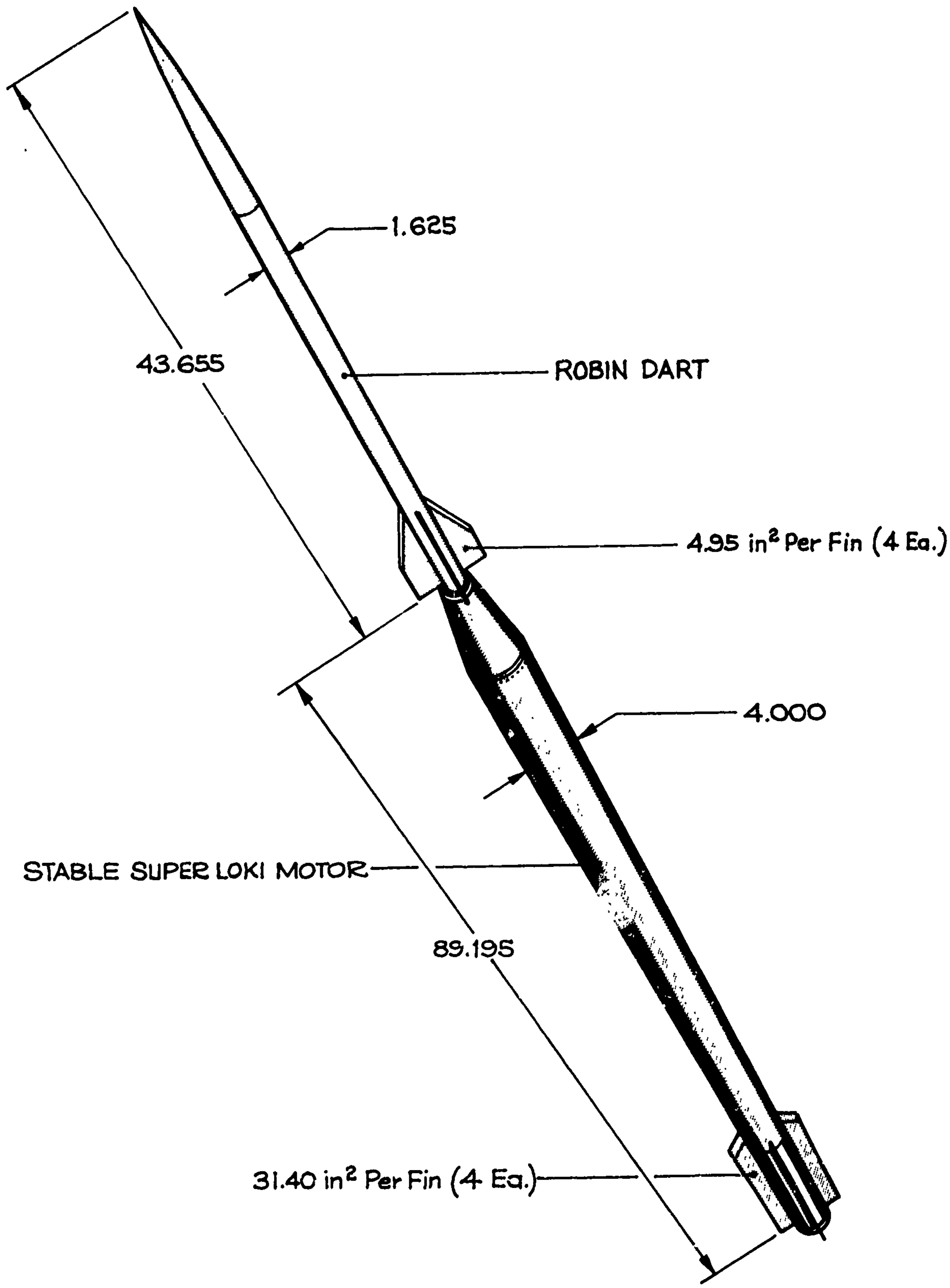


FIGURE 4.1 STABLE SUPER LOKI ROBIN DART VEHICLE

TABLE 4.1

STABLE SUPER LOKI ROBIN DART VEHICLE MASS PROPERTIES

Robin Dart:

Weight	14.15 lb.
Center-of-Gravity	26.5 inches from aft end of dart
Pitch Moment of Inertia	0.475 slug-ft^2

Booster:

Loaded Weight	61.05 lb.
Expended Weight	16.12 lb.
Loaded Center-of-Gravity	42.05 inches from aft end of motor
Expended Center-of-Gravity	41.38 inches from aft end of motor
Loaded Pitch Moment of Inertia	8.292 slug-ft^2
Expended Pitch Moment of Inertia	3.466 slug-ft^2

Vehicle:

Launch Weight	75.15 lb.
Burnout Weight	30.38 lb.
Launch Center-of-Gravity	54.95 inches from aft end of motor
Burnout Center-of-Gravity	74.04 inches from aft end of motor
Launch Pitch Moment of Inertia	20.558 slug-ft^2
Expended Pitch Moment of Inertia	11.824 slug-ft^2

Maximum Vehicle Acceleration 153 g

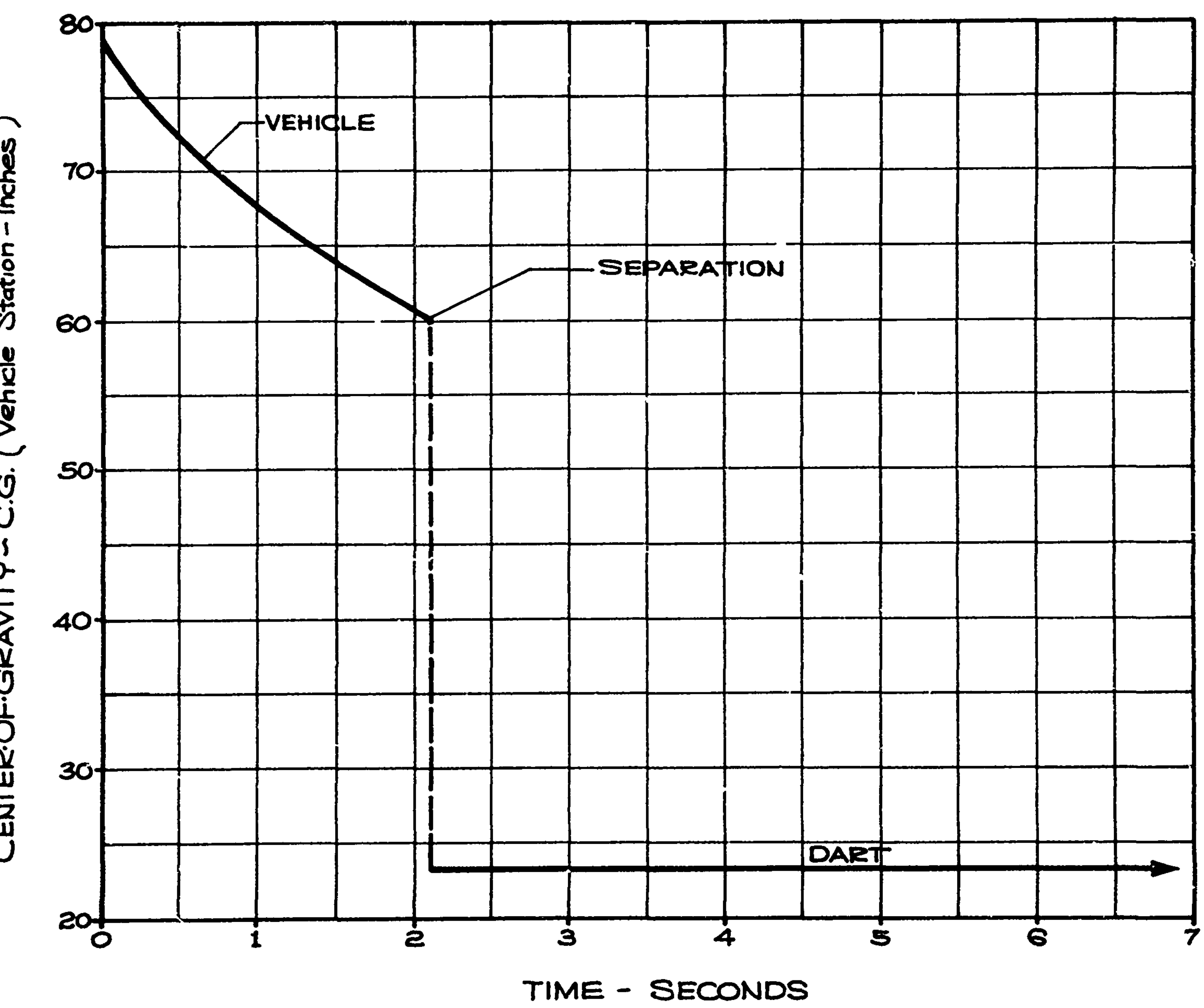


FIGURE 4.2 SUPER LOKI ROBIN DART C.G. VS TIME

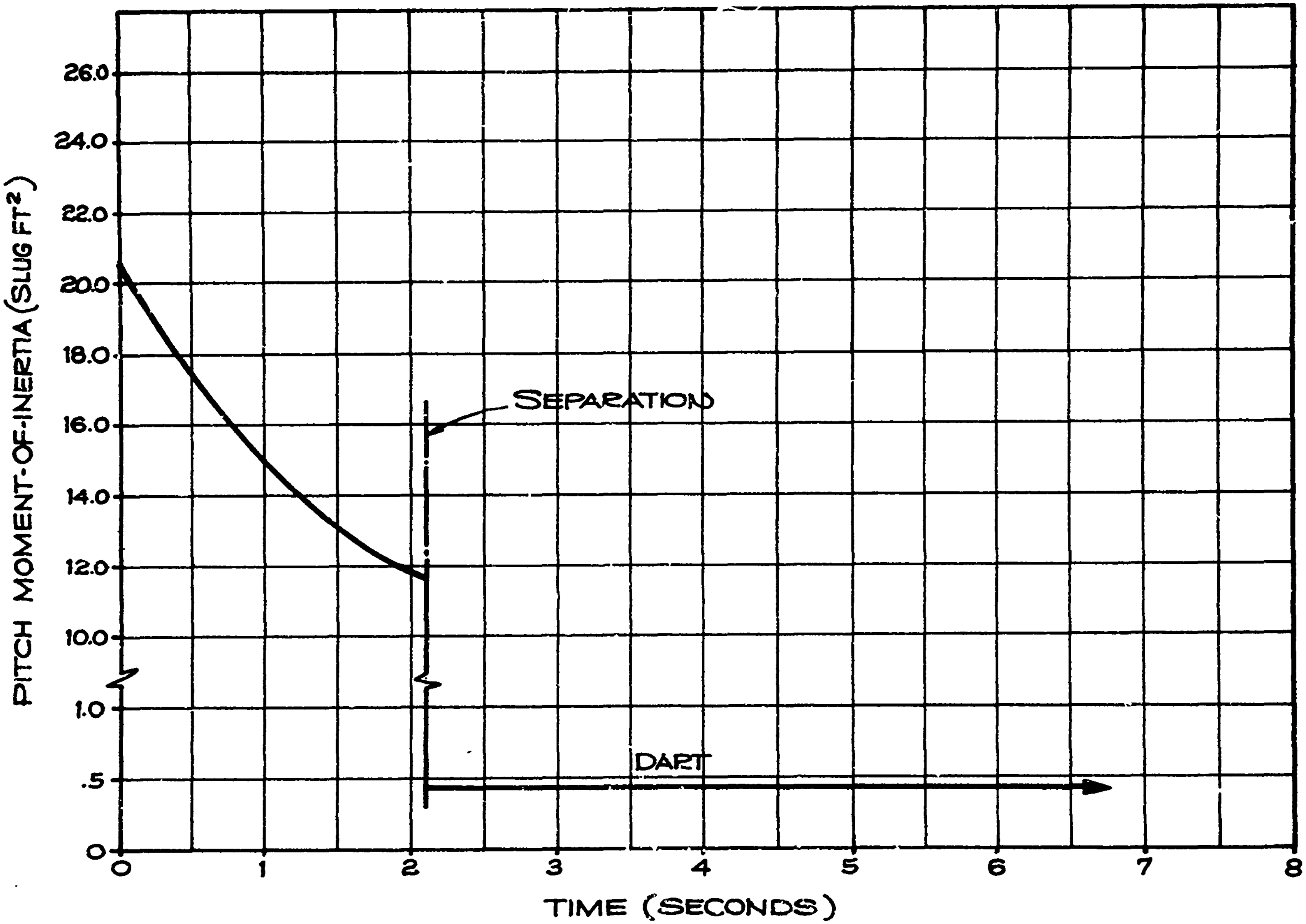


FIGURE 4.3 SUPER LOKI ROBIN DART PITCH MOMENT-OF-INERTIA VS. TIME

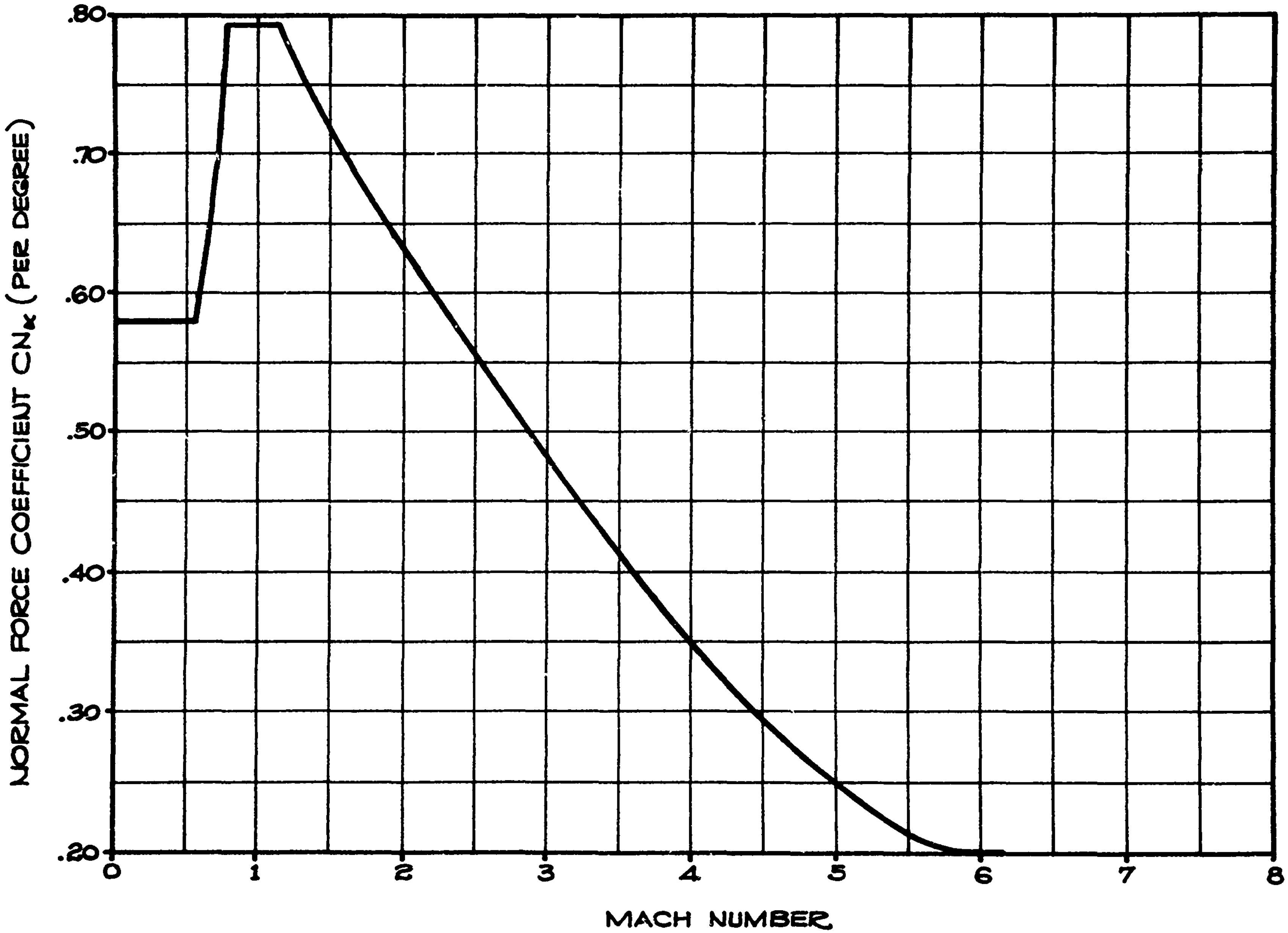


FIGURE 4.4 SUPER LOKI ROBIN DART C_{N_α} VS. MACH NO.
FIRST STAGE (A_{REF} 12.55 IN^2)

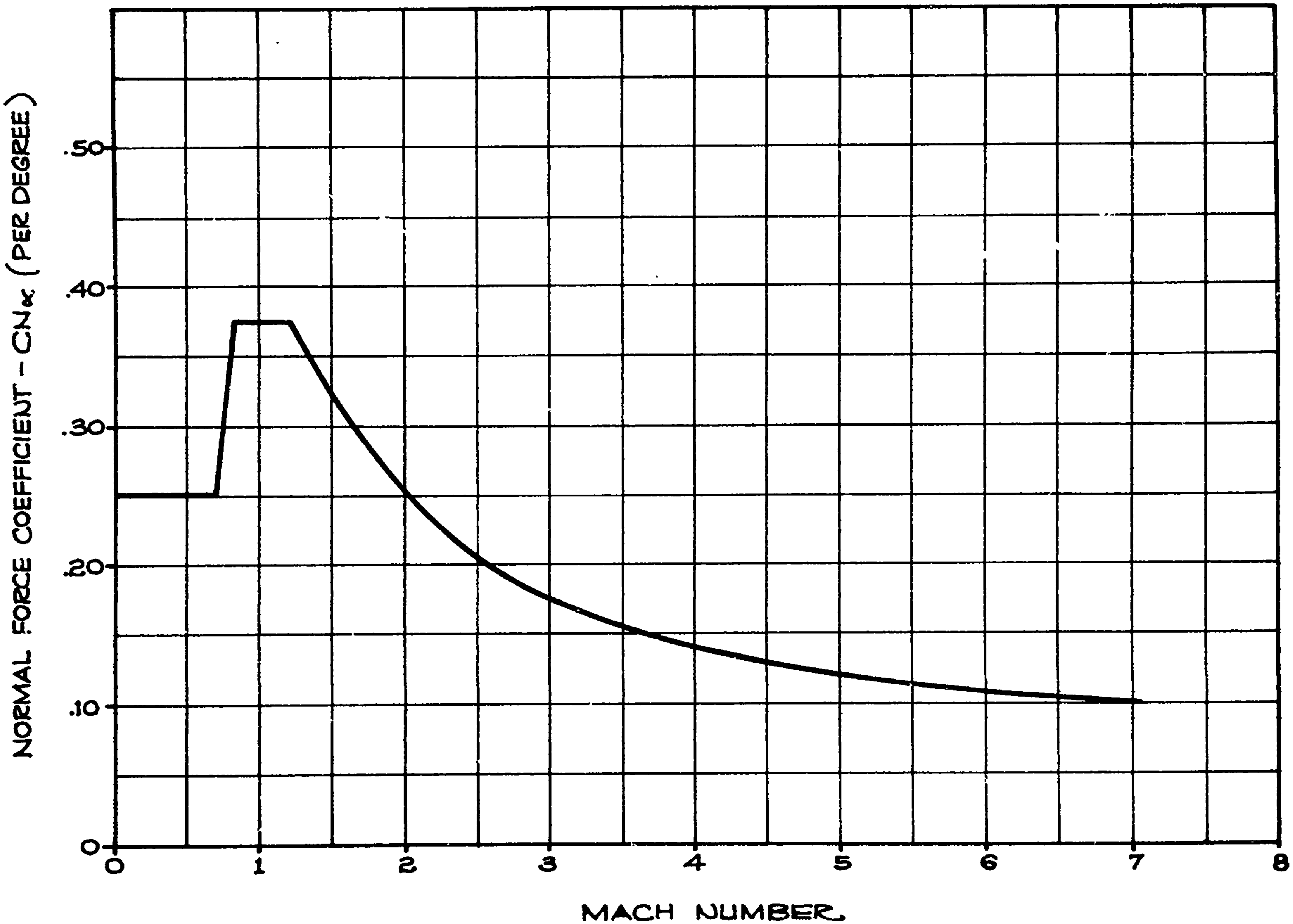


FIGURE 4.5 SUPER LOKI ROBIN DART CN_α VS. MACH NO. - DART

(A_{REF} 2.07 IN^2)

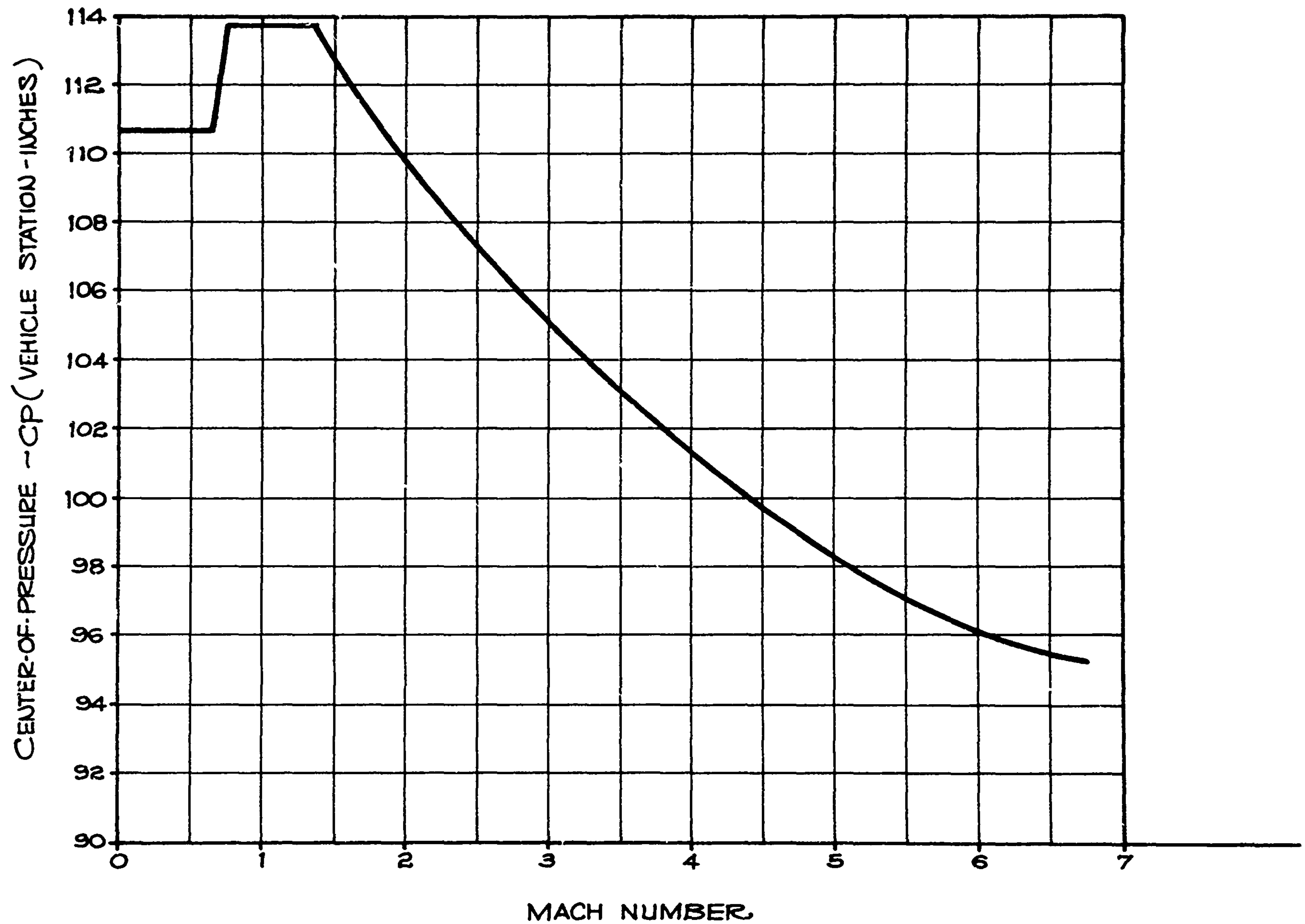


FIGURE 4.6 SUPER LOKI ROBIN DART Cp VS. MACH NO - 1ST STAGE

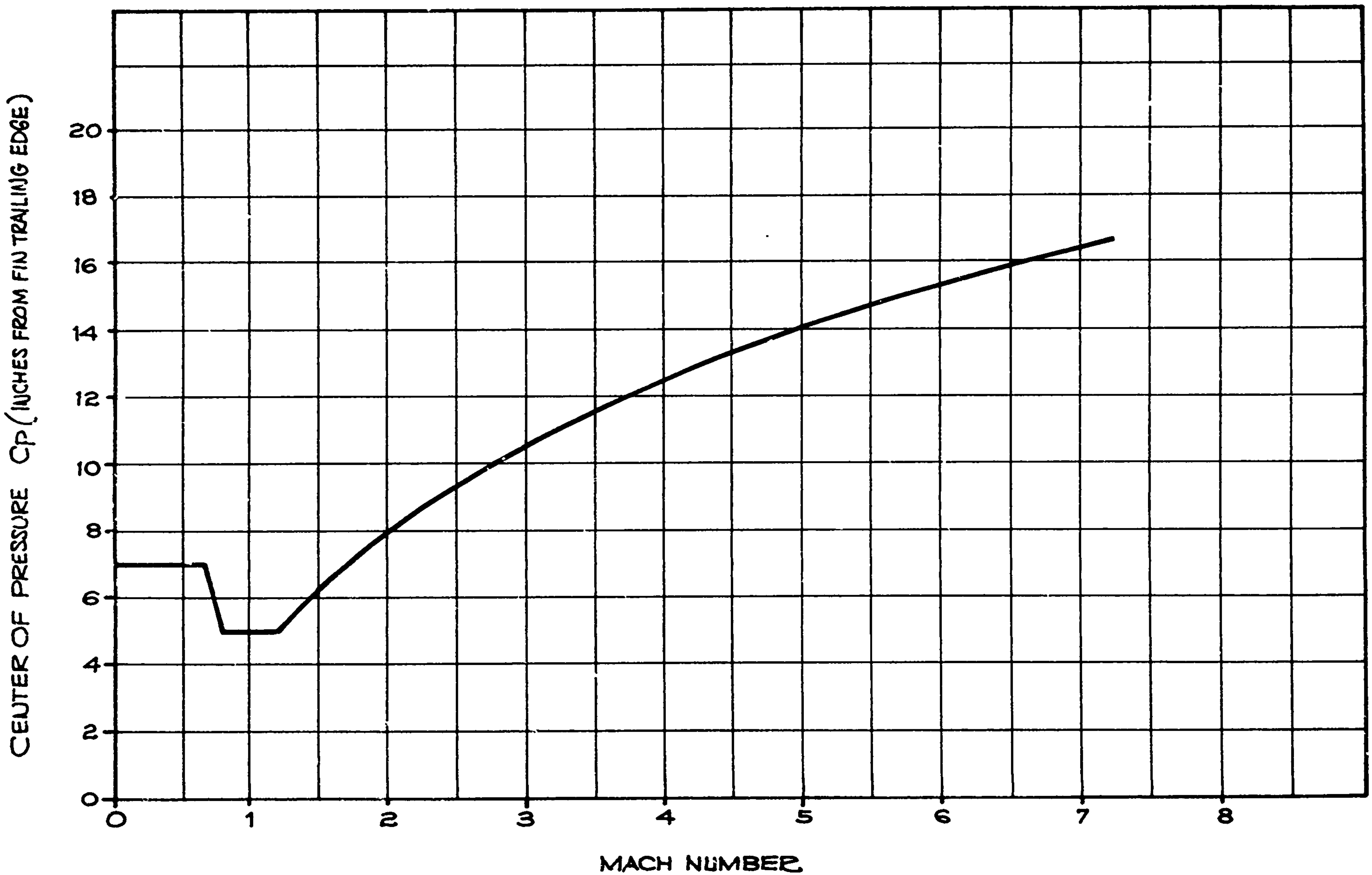


FIGURE 4.7 SUPER LOKI ROBIN DART CP VS. MACH NO. - DART

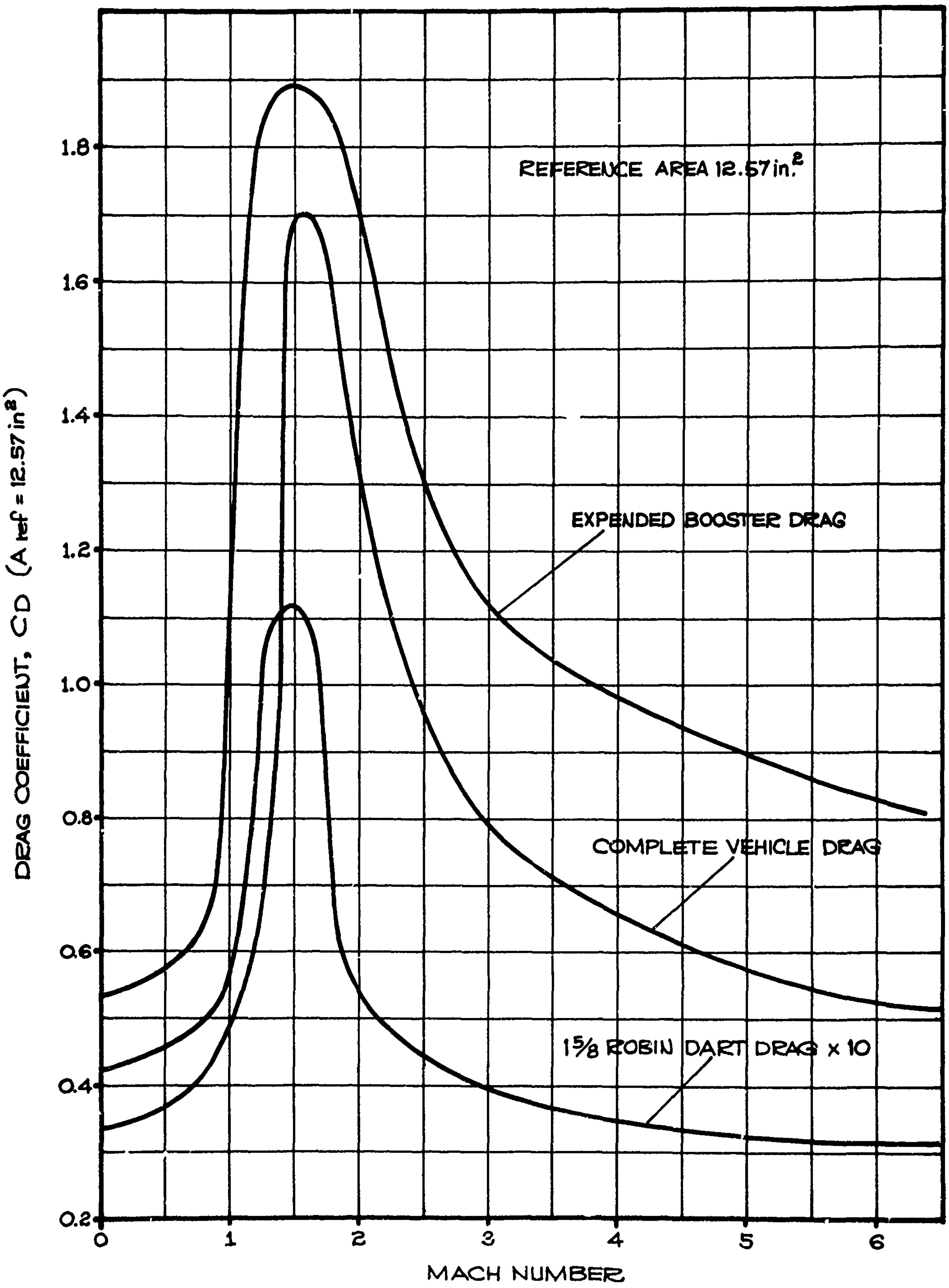


FIGURE 4.8 STABLE SUPER LOKI ROBIN VEHICLE DRAG COEFFICIENTS

4.3 Dart Description

The Super Loki Robin Dart consists of a steel ogive containing lead ballast, a cylindrical steel tubular body and an aluminum tail section which mates to the rocket motor interstage and to which are mounted four steel fins for dart aerodynamic stabilization. The tail section contains an electrically-initiated 145-second pyrotechnic delay and a 3.5 gram $BKNO_3$ pelletized payload separation charge. The body of the dart is coated with 0.075-inch of Thermolag, ablative coating.

The inflatable sphere payload and inflator assembly are packaged within a set of split staves within the dart body. The forward end of the staves terminate at the base of the ogive, and the aft end of the staves terminate at a two-stage payload ejection piston which is located just forward of the separation charge.

Prior to liftoff, the dart tail is energized and the pyrotechnic delay burns during upflight of the rocket and dart. Close to apogee, the dart ignites the separation charge which creates a pressure behind the payload ejection piston. The inner core of the piston moves forward to strike the firing pin of the inflator delay. Subsequently, the outer piston is forced forward against the outer steel staves by means of three brass shear screws. These screws are sheared, and the entire payload assembly and the staves are ejected from the dart body at a speed of about 80 feet per second. Centrifugal force to the vehicle spin forces the staves to separate from the payload as soon as they leave the constraints of the dart body. The forward end of the dart tube or body is slightly constricted on the inner diameter in order to stop the ejection piston within the dart tube. This is to trap the ejection charge hot exhaust gases and burning particles from damaging the sphere payload during deployment.

This dart is identical to the standardized PWN-12A dart and is fully described in Reference 1.

5.

INSTRUMENT SYSTEM DESIGN

5.1 Introduction

The Stable Super Loki Instrument Dart consists of a 2.125-inch diameter dart second-stage with the Stable Super Loki rocket motor. The dart carries a transponder rocketsonde payload to an altitude of 75 km where it is deployed on a Starute (balloon-parachute) decelerator. During its descent, the transpondersonde telemeters atmospheric temperature and position data, including slant range, to an AN/GMD-4 ground station receiving set. This system eliminates the need for radar. In the case of a transmitter sonde, it provides temperature and position data (without slant range) to an AN/GMD-1 ground set.

5.2 Vehicle Description

The Super Loki Instrument Dart is a two-stage vehicle which consists of the Stable Super Loki rocket motor as the first or booster stage and a non-propulsive 2.125-inch diameter dart second stage. The vehicle configuration is shown in Figure 5.1.

A summary of the vehicle mass properties is presented in Table 5.1. The vehicle center-of-gravity versus time is presented in Figure 5.2, and pitch moment-of-inertia is presented in Figure 5.3.

The aerodynamic data for the vehicle are presented as follows:

Figure 5.4	C_{N_α} vs. Mach No., First Stage
Figure 5.5	C_{N_α} vs. Mach No., Dart
Figure 5.6	C_p vs. Mach No., First Stage
Figure 5.7	C_p vs. Mach No., Dart
Figure 5.8	Vehicle Drag Coefficients

The Super Loki Instrument Dart is stable during the two-stage propulsive flight at essentially a zero degree angle of attack. After dart separation at motor burnout, the dart coasts to apogee in a stable flight mode at essentially a zero angle of attack in the sensible atmosphere, After rocket motor burnout and stage separation, the expended booster remains stable and follows a ballistic trajectory to impact.

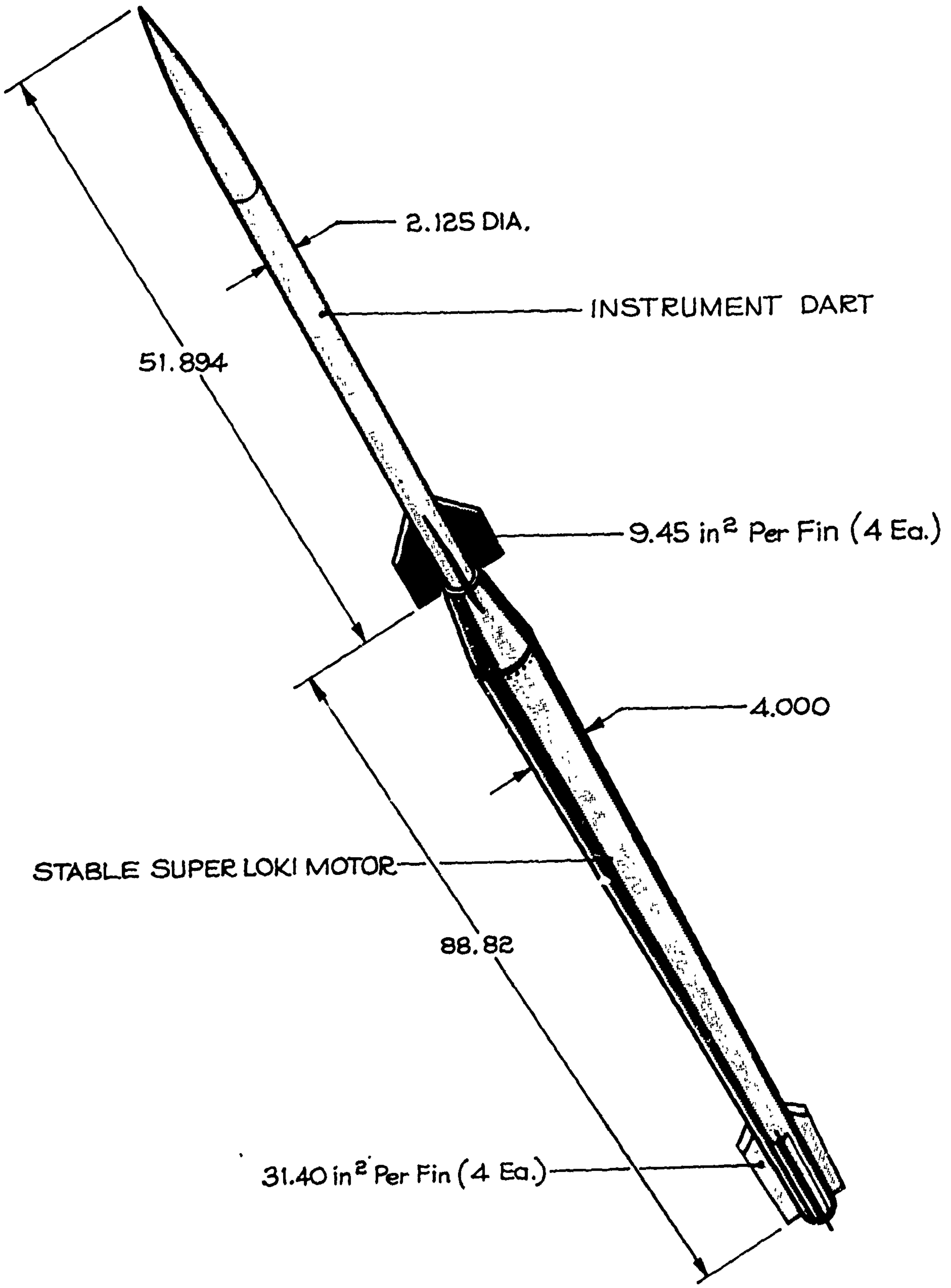


FIGURE 5.1 STABLE SUPER LOKI INSTRUMENT DART VEHICLE CONFIGURATION

TABLE 5.1

STABLE SUPER LOKI INSTRUMENTED DART VEHICLE MASS PROPERTIES

Instrumented Dart:	
Weight	19.00 Lbs.
Center-of-Gravity	31.75 inches from aft end of dart
Pitch Moment of Inertia	0.727 slug-ft^2
Booster:	
Loaded Weight	61.05 Lbs.
Expended Weight	16.12 Lbs.
Loaded Center-of-Gravity	42.16 inches from aft end of motor
Expended Center-of-Gravity	41.38 inches from aft end of motor
Loaded Pitch Moment of Inertia	8.292 slug-ft^2
Expended Pitch Moment of Inertia	3.466 slug-ft^2
Vehicle:	
Launch Weight	79.30 Lbs.
Burnout Weight	34.37 Lbs.
Launch Center-of-Gravity	59.13 inches from aft end of motor
Burnout Center-of-Gravity	80.89 inches from aft end of motor
Launch Pitch Moment of Inertia	25.429 slug-ft^2
Burnout Pitch Moment of Inertia	14.414 slug-ft^2
Maximum Vehicle Acceleration	135 g

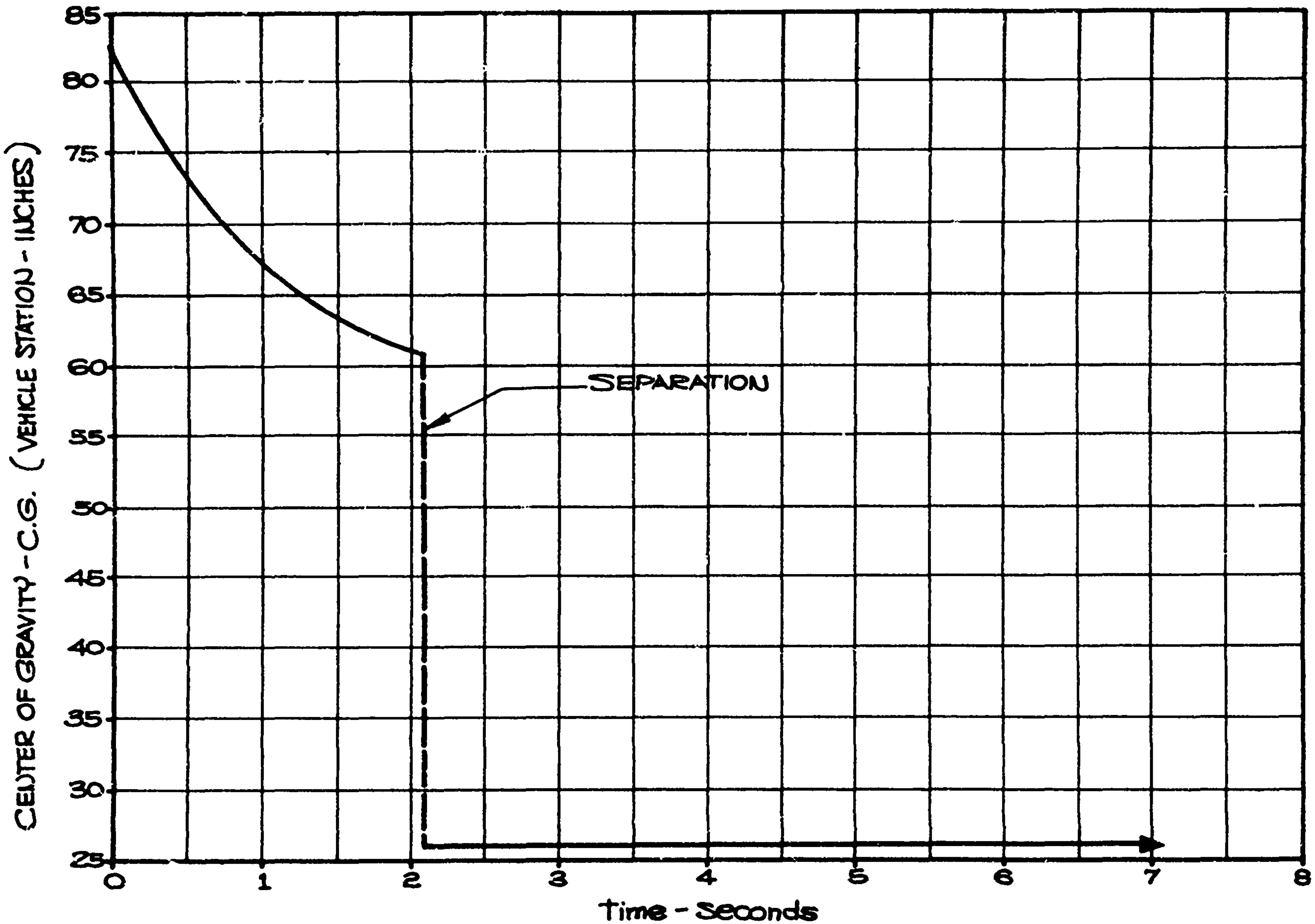


FIGURE 5.2 SUPER LOKI INSTRUMENTED DART VEHICLE C.G. VS. TIME

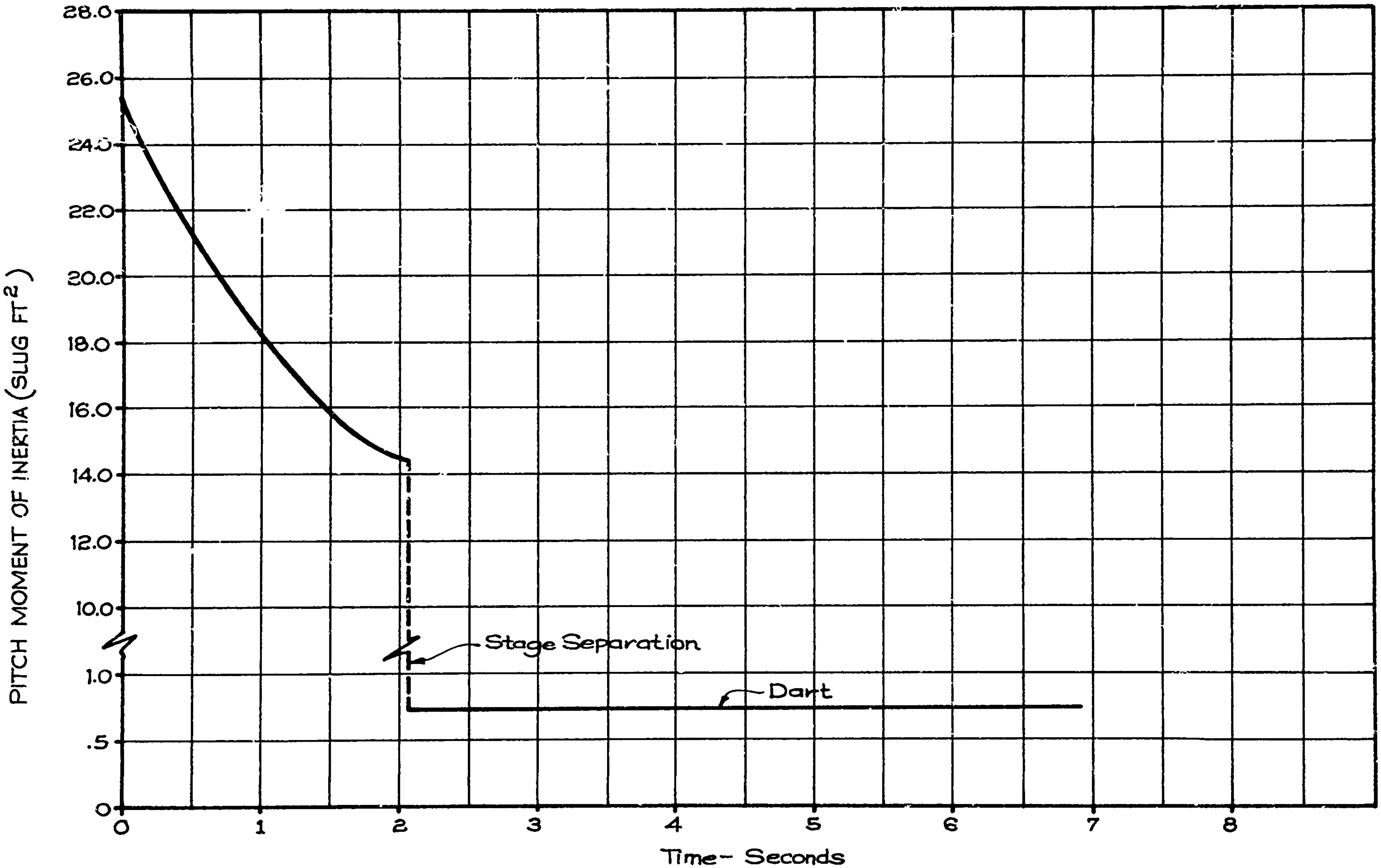


FIGURE 5.3 SUPER LOKI INSTRUMENTED DART VEHICLE
PITCH MOMENT-OF-INERTIA VS. TIME

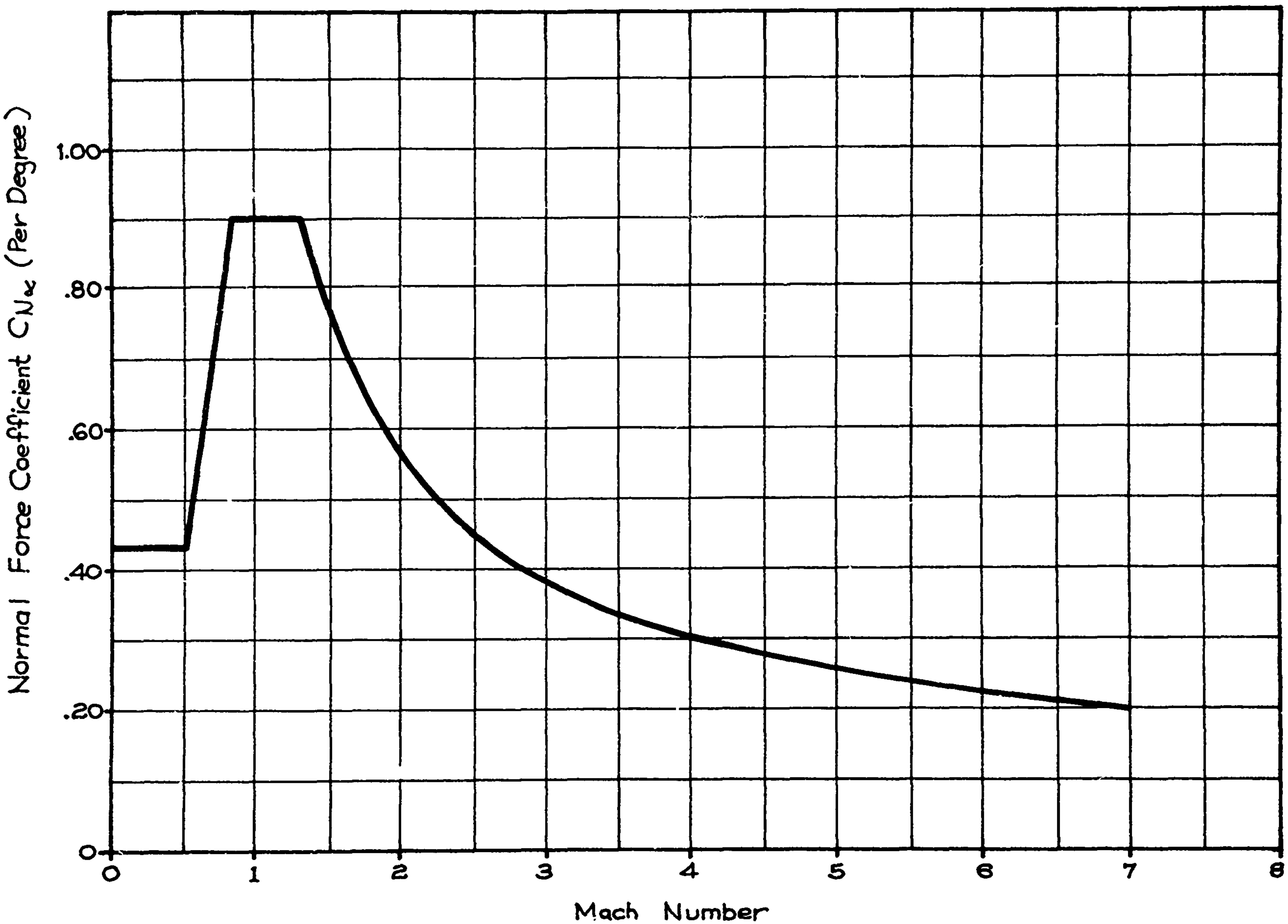


FIGURE 5.4 SUPER LOKI INSTRUMENT DART VS. MACH NO.
FIRST STAGE (A_{REF} 12.57 IN^2)

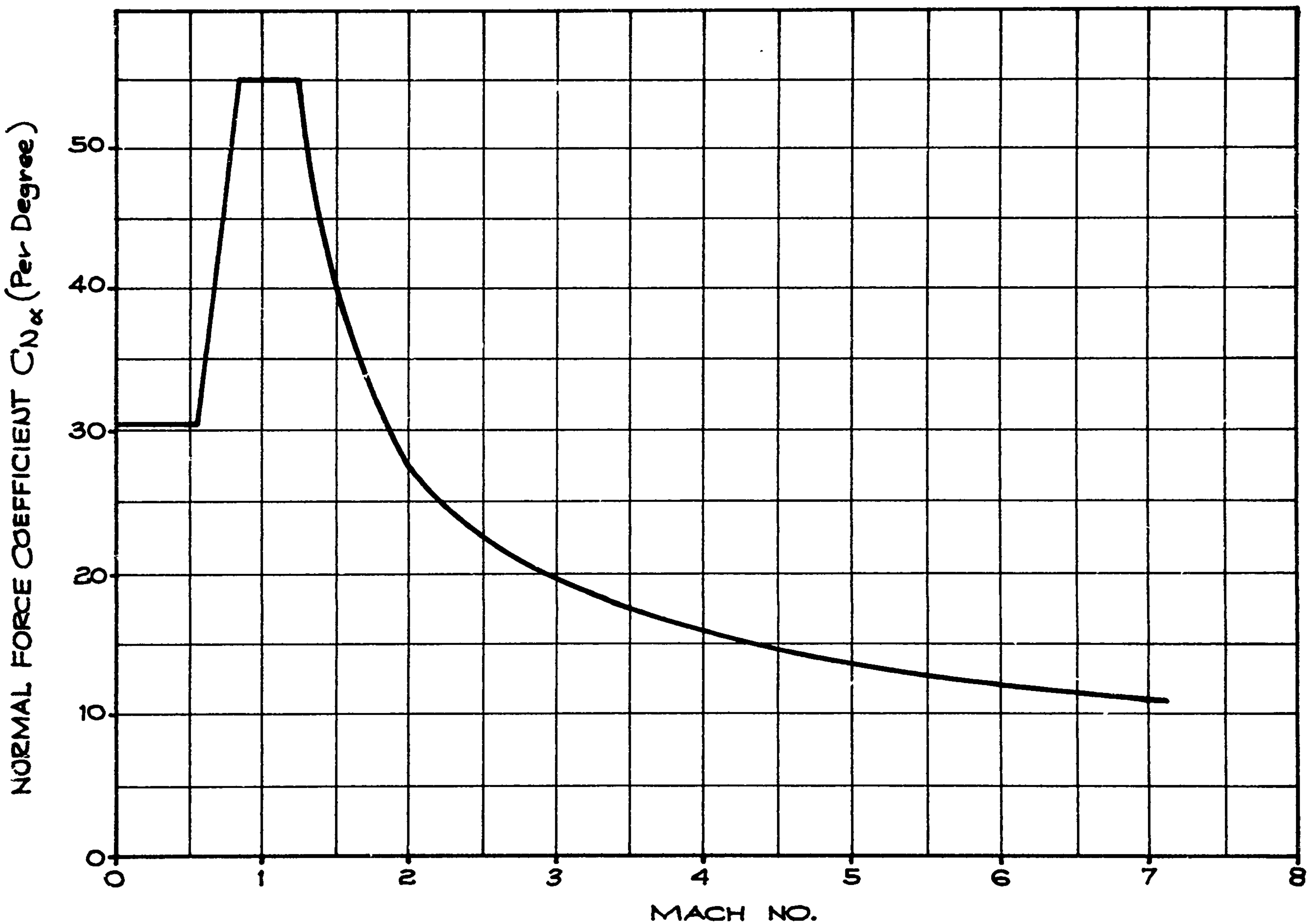


FIGURE 5.5 SUPER LOKI INSTRUMENT DART C_N VS. MACH NO. (DART)
DART SECOND STAGE (A_{REF} 3.54 IN^2)

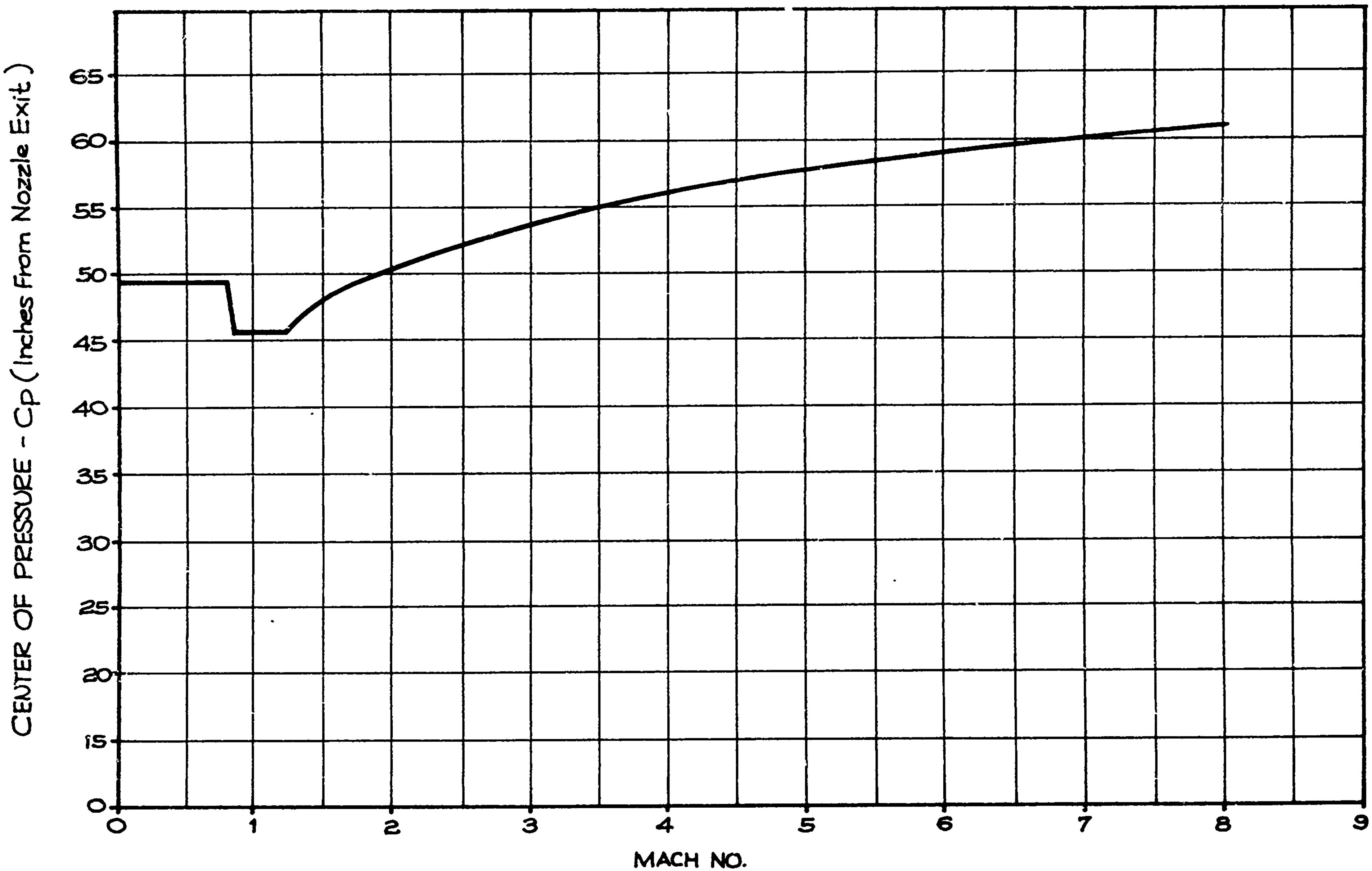


FIGURE 5.6 SUPER LOKI INSTRUMENT DART CP VS. MACH NO.
FIRST STAGE

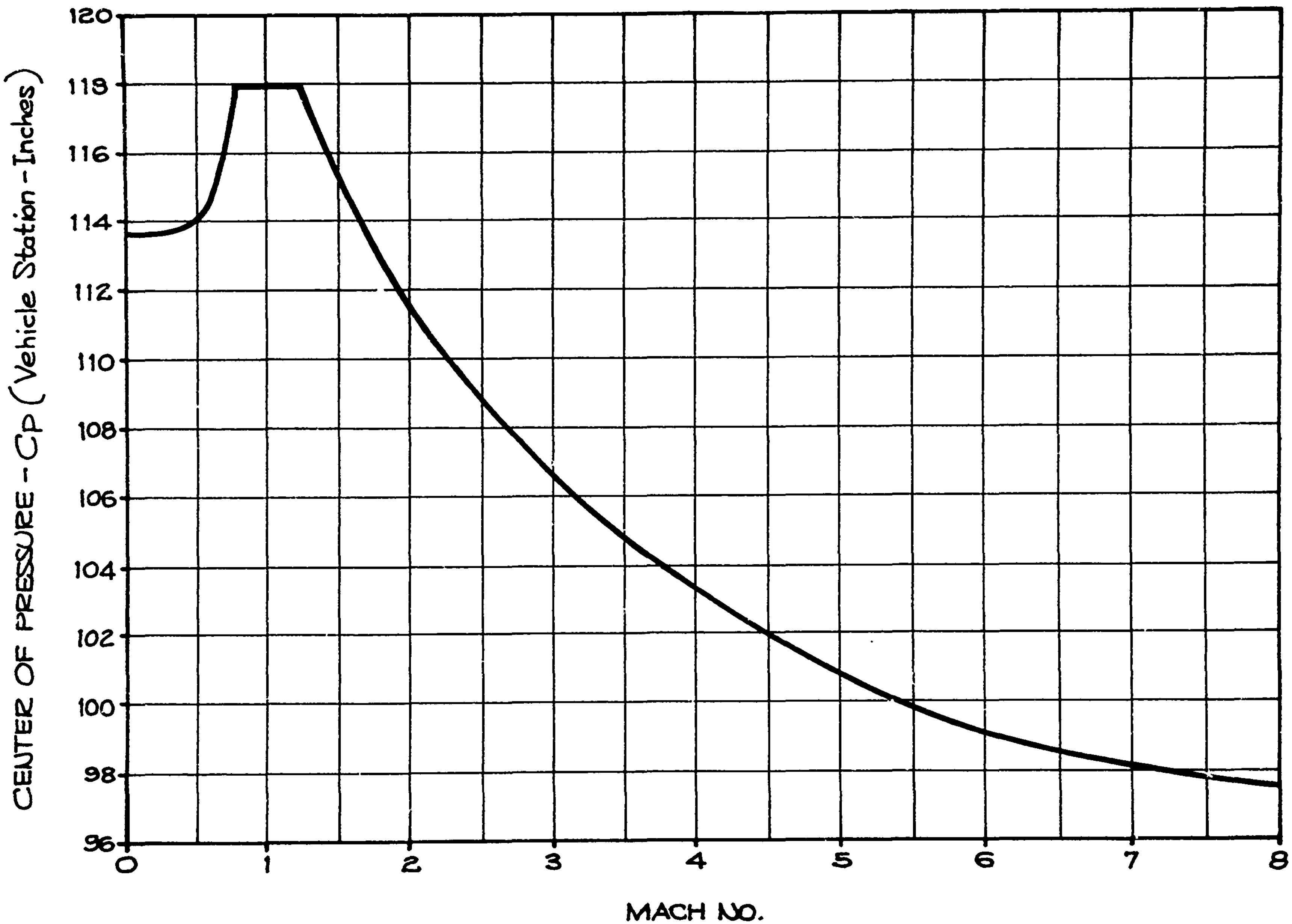


FIGURE 5.7 SUPER LOKI INSTRUMENTED DART - Cp vs. MACH NO.
DART SECOND STAGE

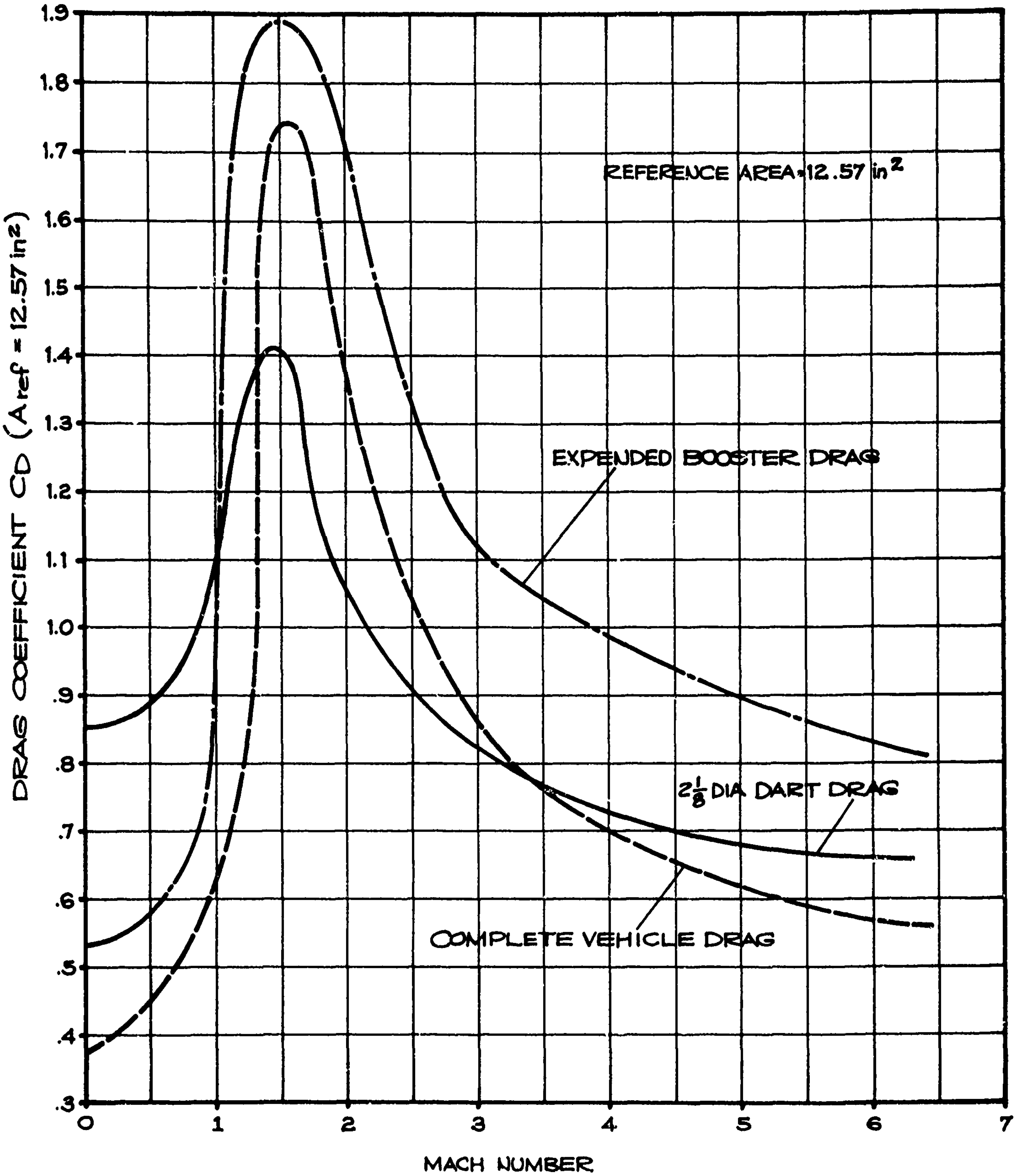


FIGURE 5.8 STABLE SUPER LOKI INSTRUMENT DART VEHICLE DRAG COEFFICIENTS

5.3 Dart Description

The instrumented dart for the Super Loki system consists of a steel cylindrical body with a steel ogive and an aluminum tail piece. The cylindrical body contains the payload which is packaged into split steel staves. The ogive is retained at the forward end of the body with shear screws which are sheared during payload expulsion out from the forward end of the dart. The tail piece contains an electrically-actuated 12-second pyrotechnic time delay and a small payload ejection charge. Four steel fins are roll-pinned into the dart tail for flight stability. The aft end of the dart tail is boattailed to reduce aerodynamic drag and to be used to mate the dart to the booster.

The instrument and Starute decelerator are packaged with two sets of split staves within the dart body. No ablative coating is used on the instrumented dart. Instead, internal air gaps between the payload staves and the dart wall are used to reduce aerodynamic heat transfer to the payload. This configuration was used on all development tests herein. Problems more recently found in production systems, as well as in tests hereunder in Section 8, make use of ablative coating on the dart exterior probable in the future. The forward end of the staves assembly terminates at the base of the ogive, and the aft end terminates at the payload ejection piston which is located just forward of the separation charge.

6.

VEHICLE PERFORMANCE

6.1 General

A series of digital computer trajectories has been run for both the Stable Super Loki Robin Dart and Instrumented Dart vehicles. The results are presented in the sections which follow.

6.2 Instrumented System

A series of Stable Super Loki Instrumented Dart trajectories has been run on a digital computer, and the results are presented as follows:

Table 6.1	Nominal Trajectory Summary, 80° QE
Figure 6.1	Dart Apogee Altitude vs. Apogee Range for Various QE's
Figure 6.2	Dart Altitude vs. Range, 80° QE
Figure 6.3	Dart Altitude vs. Time, 80° QE
Figure 6.4	Dart Velocity vs. Time, 80° QE
Figure 6.5	Dart Impact Range vs. QE
Figure 6.6	Vehicle Roll Rate vs. Time

6.3 Robin System

A series of Super Loki Robin Dart trajectories has been run on a digital computer, and the results are presented as follows:

Table 6.2	Nominal Trajectory Summary
Figure 6.7	Dart Apogee Altitude vs. Apogee Range
Figure 6.8	Dart Altitude vs. Range, 80° QE
Figure 6.9	Dart Altitude vs. Time
Figure 6.10	Dart Velocity vs. Time, 80° QE
Figure 6.11	Impact Range vs. Launch Angle
Figure 6.12	Vehicle Roll Rate vs. Time

TABLE 6.1

NOMINAL TRAJECTORY SUMMARY

SUPER LOKI INSTRUMENTED DART, 80° QE SEA LEVEL LAUNCH

	BOOSTER	DART
Burnout Altitude (ft)	4,731	4,731
Burnout Range (ft)	886	886
Burnout Time (sec)	2.1	2.1
Apogee Altitude (ft)	23,466	232,000
Apogee Range (ft)	6,465	90,000
Apogee Time (sec)	32.3	120
Impact Range (ft)	9,756	165,000
Impact Time (sec)	81	245

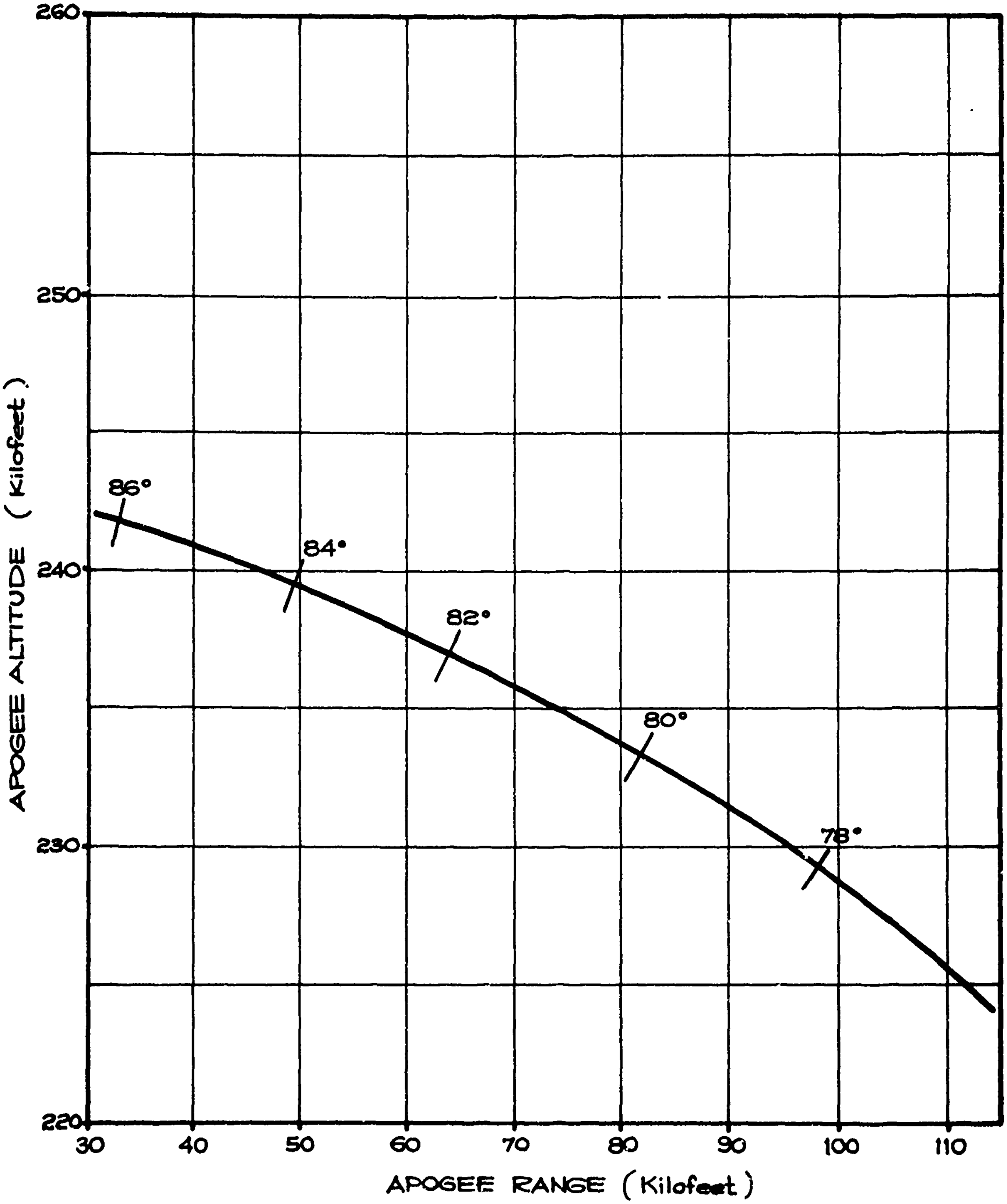


FIGURE 6.1 STABLE SUPER LOKI INSTRUMENT DART ALTITUDE VS. RANGE FOR VARIOUS Q.E.'s

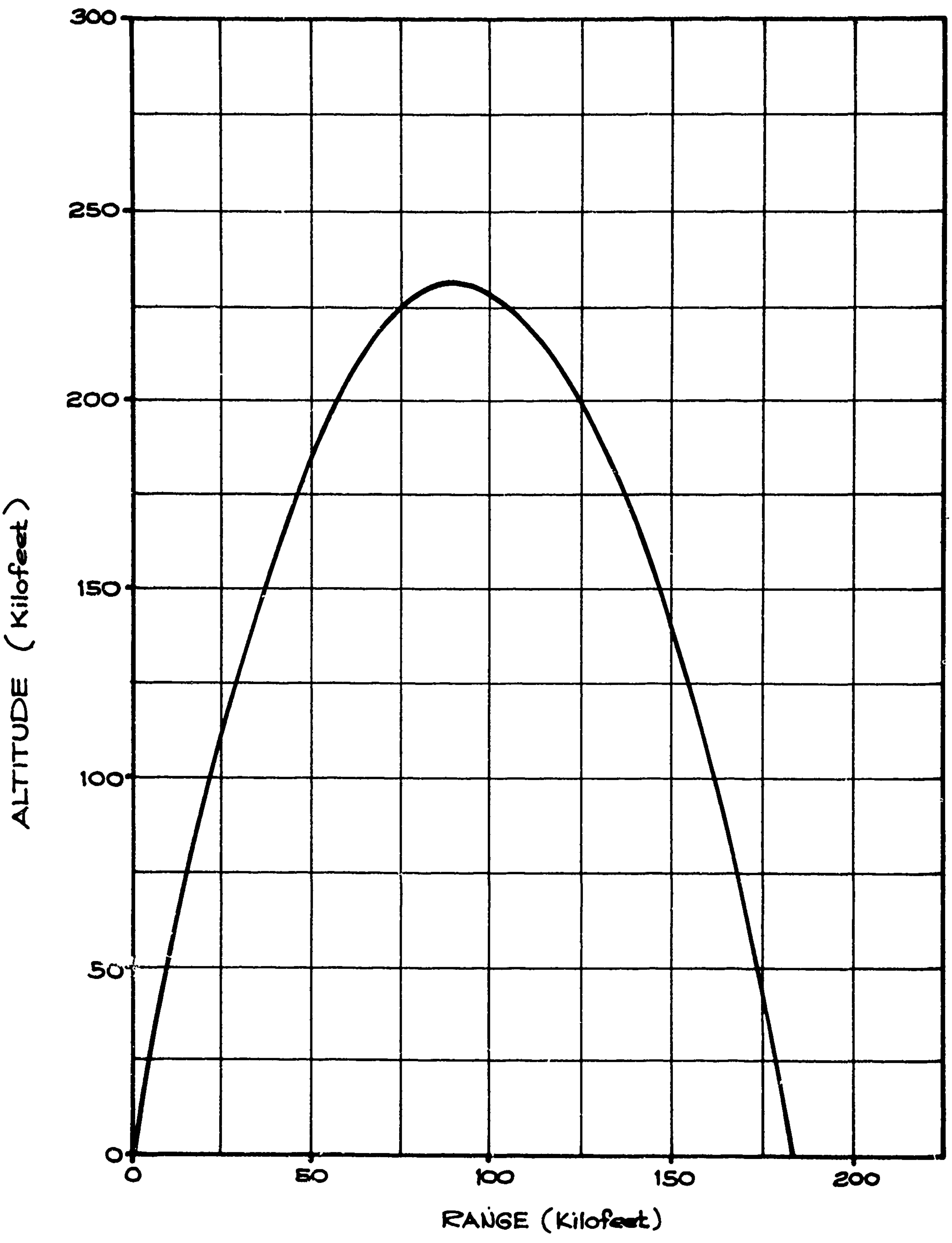


FIGURE 6.2 STABLE SUPER LOKI INSTRUMENT DART
ALTITUDE VS. RANGE - 80° Q.E.

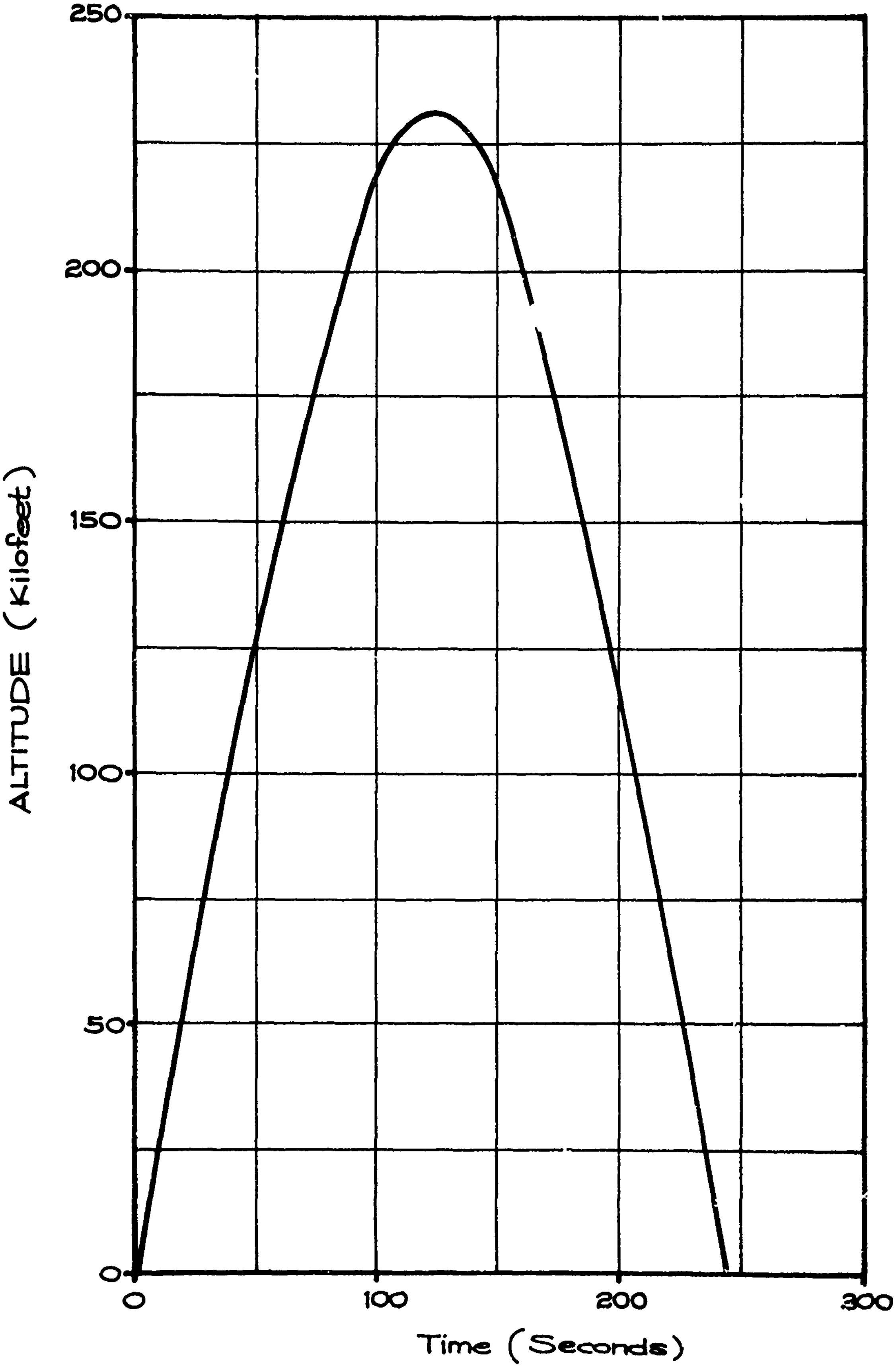


FIGURE 6.3 STABLE SUPER LOKI INSTRUMENT DART ALTITUDE VS. TIME - 80° Q.E.

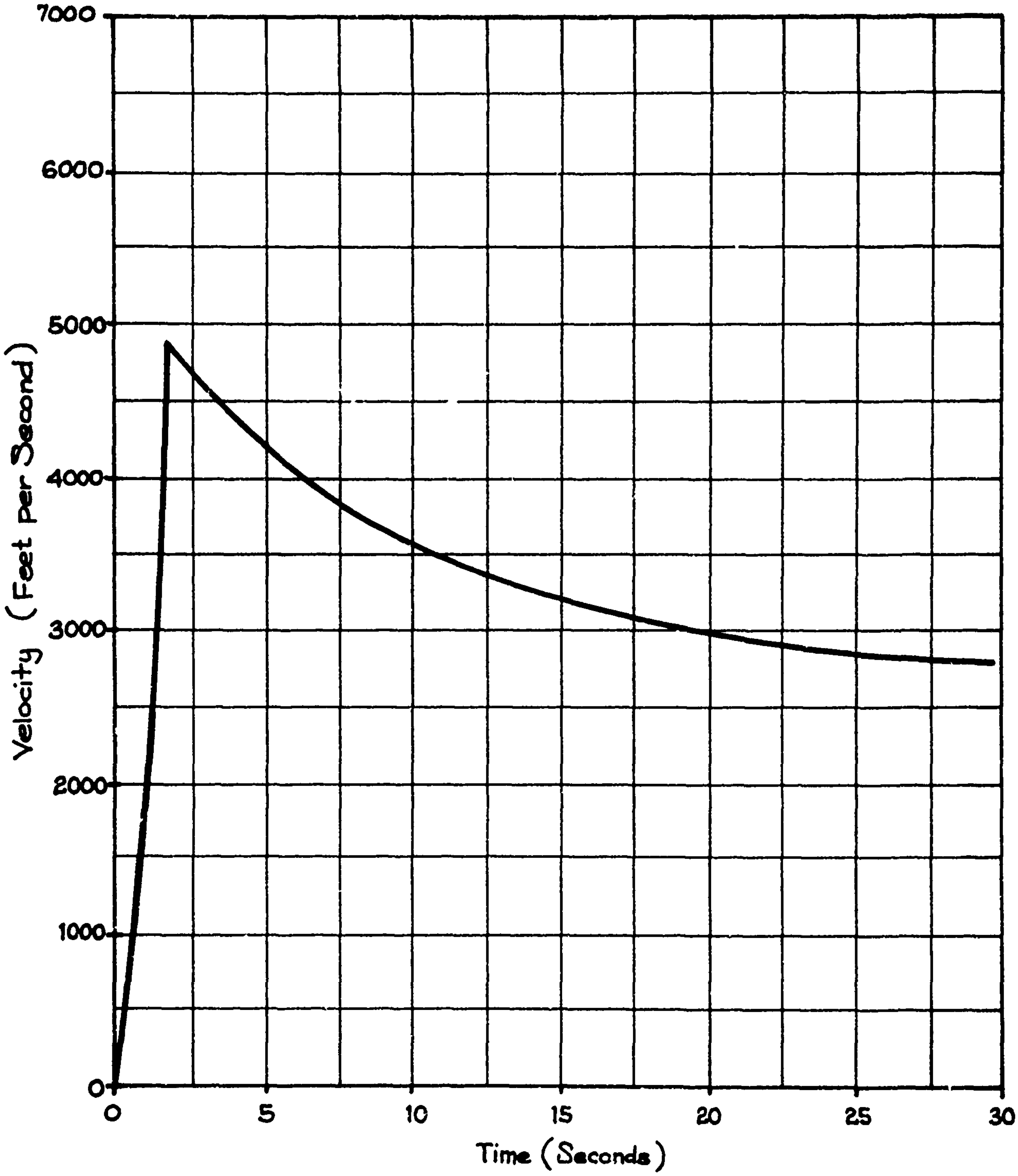


FIGURE 6.4 STABLE SUPER LOKI INSTRUMENT DART
VELOCITY VS. TIME, 80° Q.E.

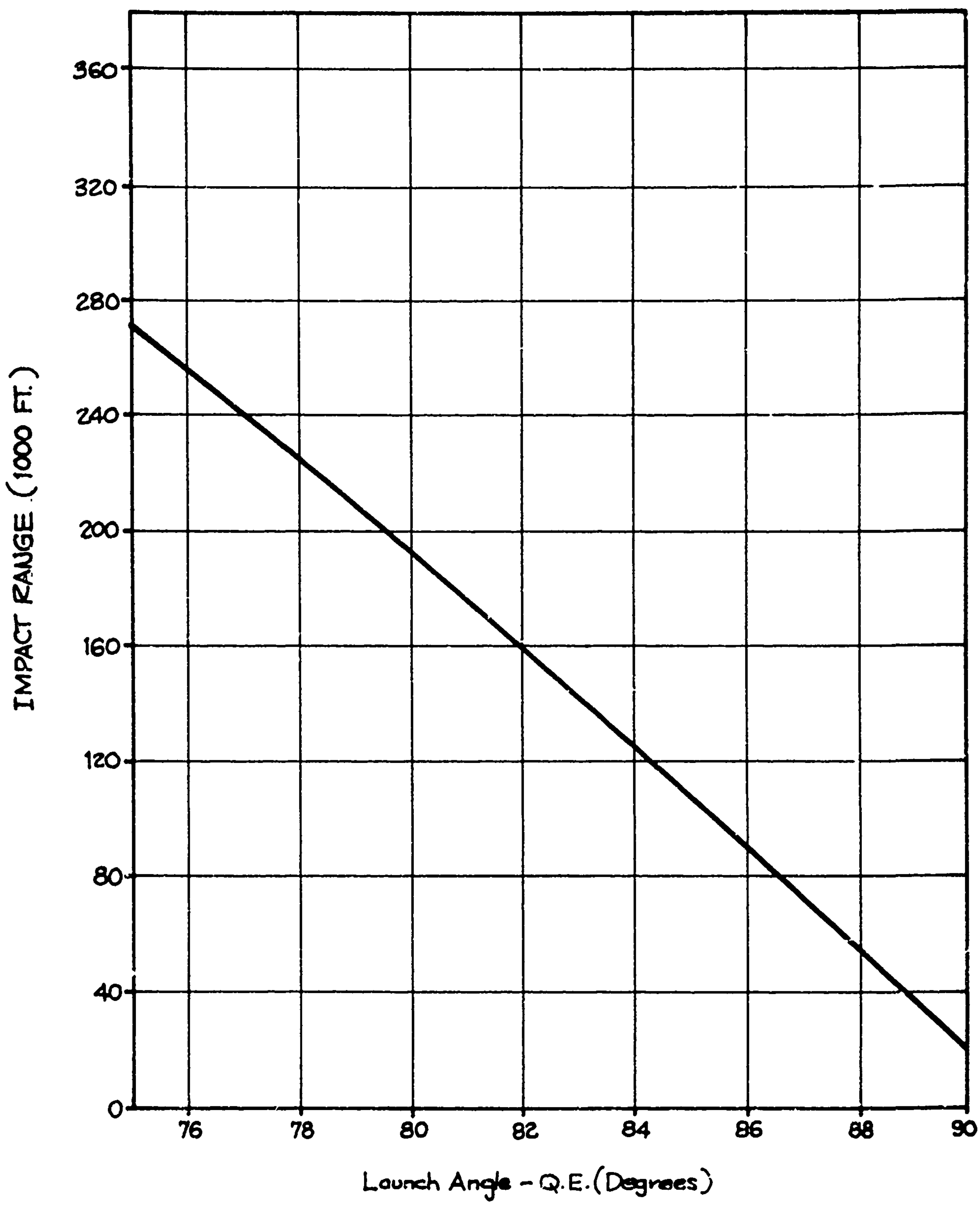


FIGURE 6.5 STABLE SUPER LOKI INSTRUMENT DART IMPACT RANGE VS. Q.E.

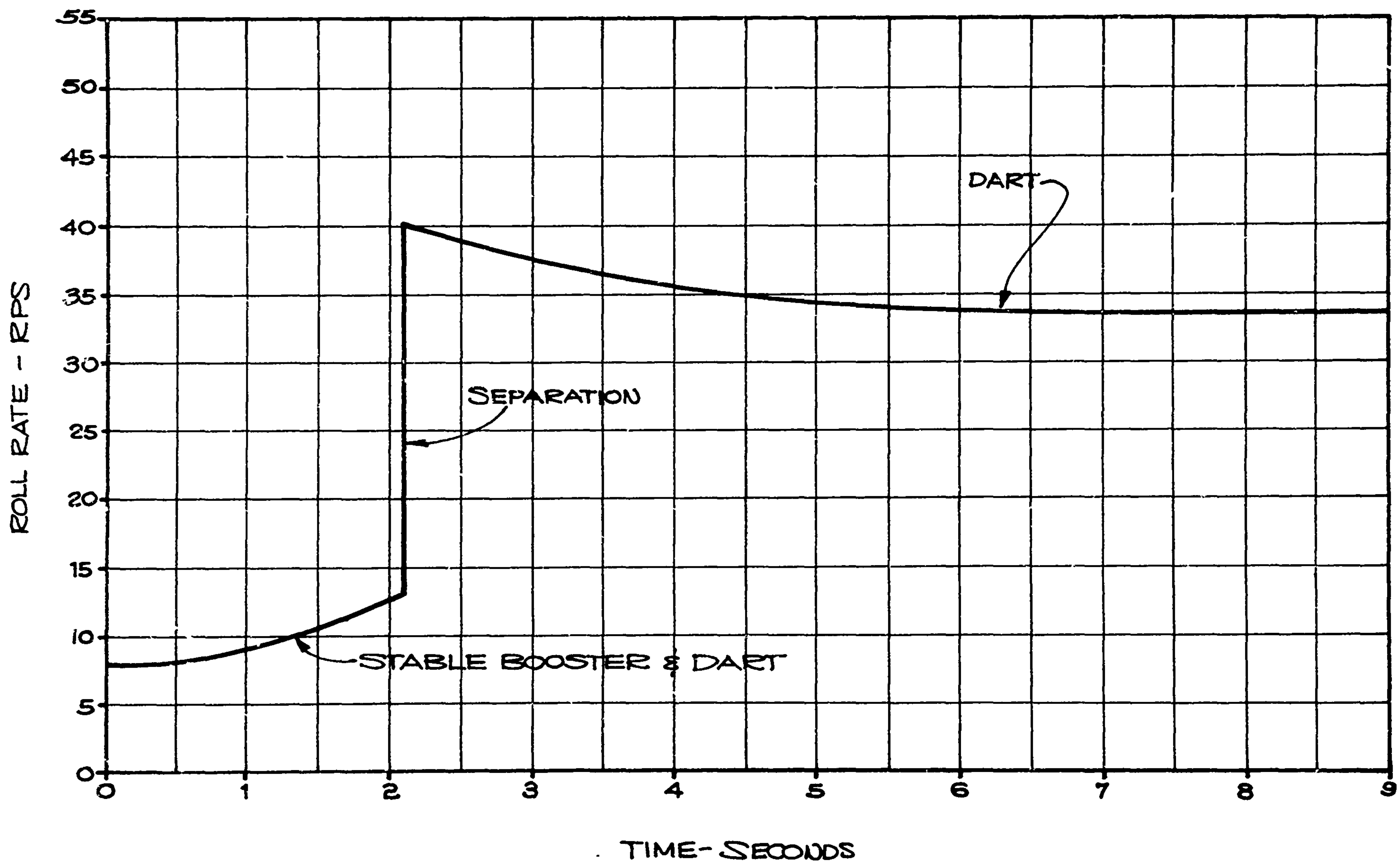


FIGURE 6.6 STABLE SUPER LOKI INSTRUMENTED DART ROLL RATE VS. TIME

TABLE 6.2

NOMINAL TRAJECTORY SUMMARY

SUPER LOKI ROBIN DART, 80° QE SEA LEVEL LAUNCH

	STABLE BOOSTER	DART
Burnout Altitude (ft)	5,119	5,119
Burnout Range (ft)	955	955
Burnout Time (sec)	2.1	2.1
Apogee Altitude (ft)	28,000	348,000
Apogee Range (ft)	7,012	125,000
Apogee Time (sec)	30.3	150
Impact Range (ft)	11,864	245,000
Impact Time (sec)	85	280

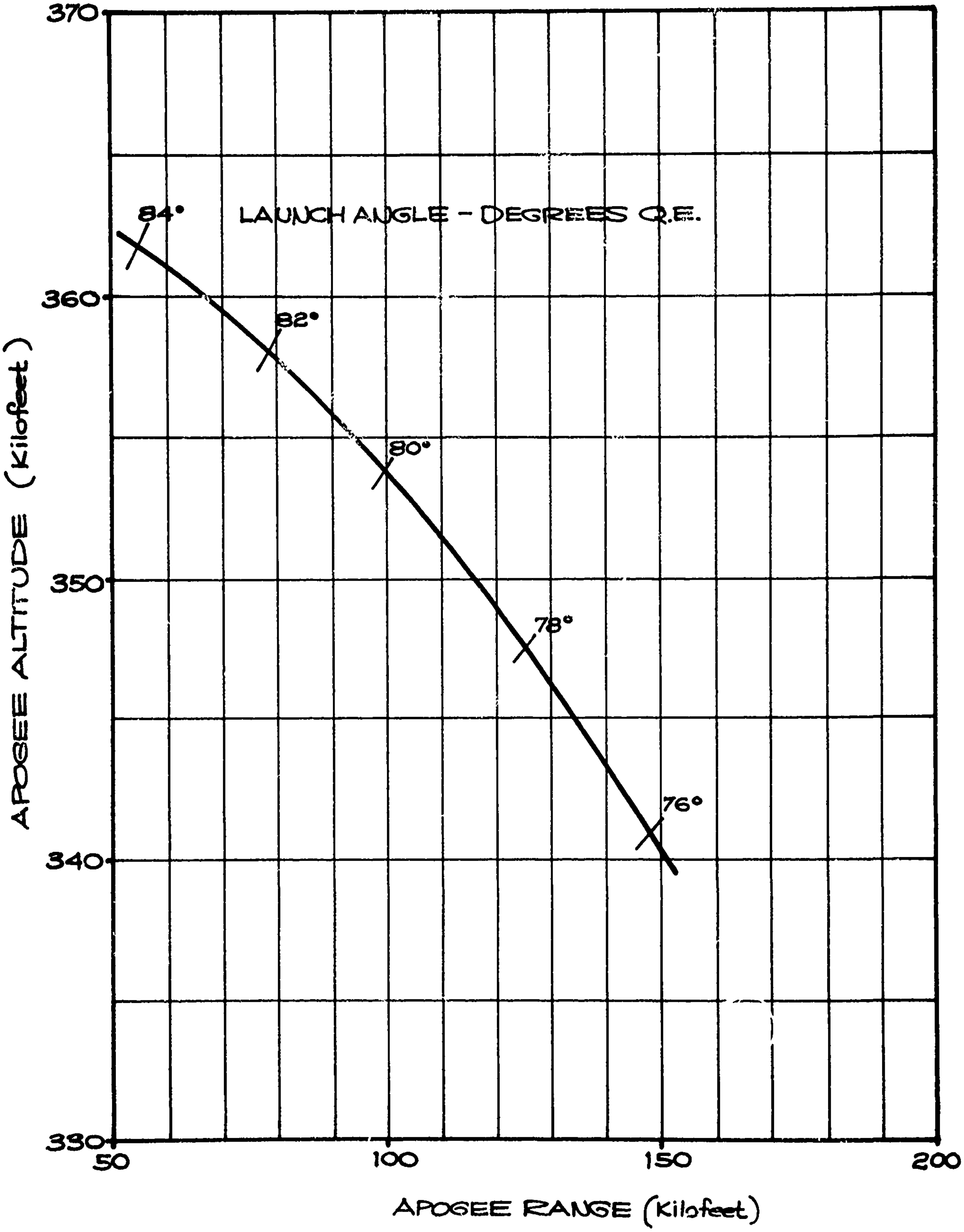


FIGURE 6.7 STABLE SUPER LOKI ROBIN DART
APOGEE ALTITUDE VS. APOGEE RANGE

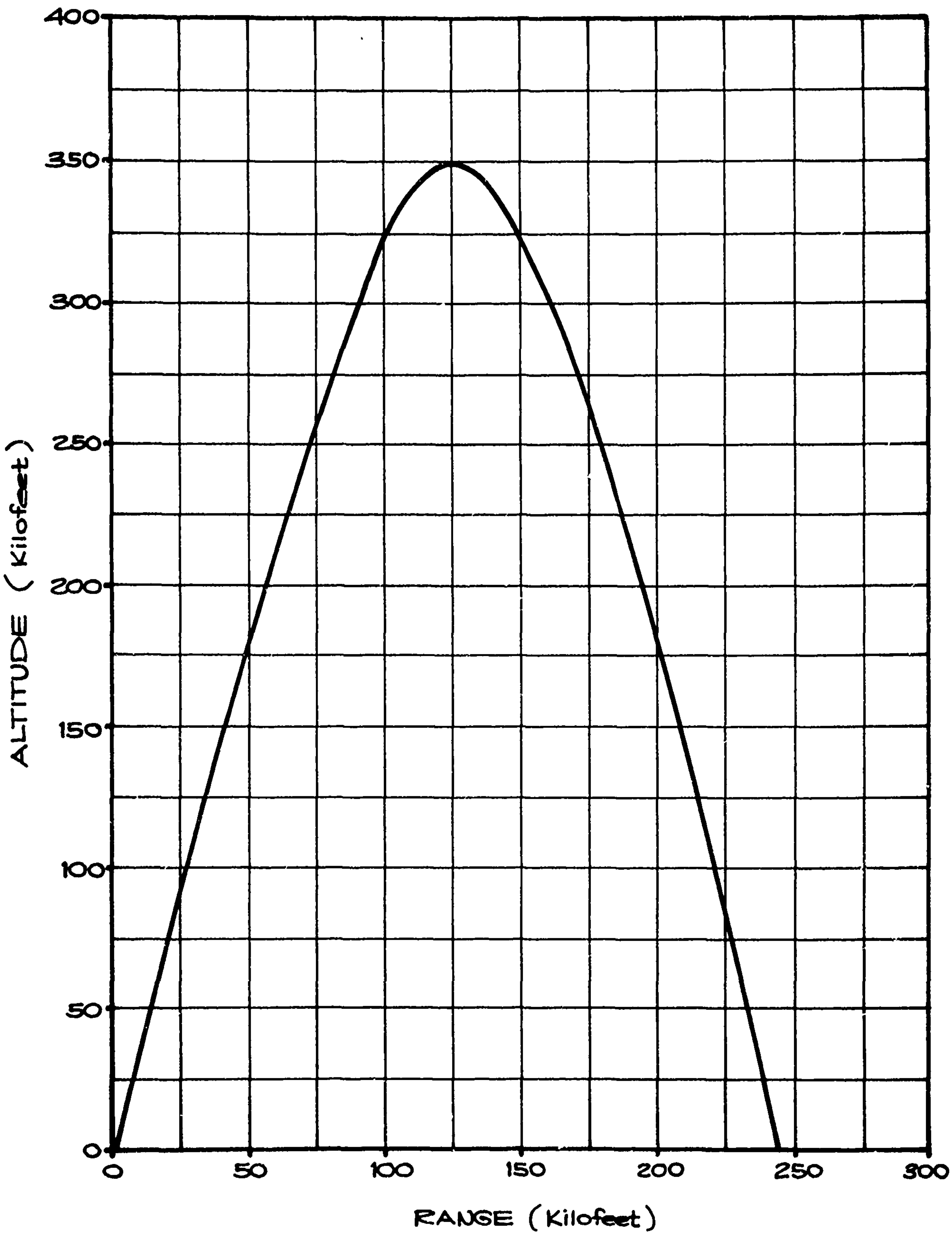


FIGURE 6.8 STABLE SUPER LOKI ROBIN DART-ALTITUDE VS. RANGE - 80° Q.E.

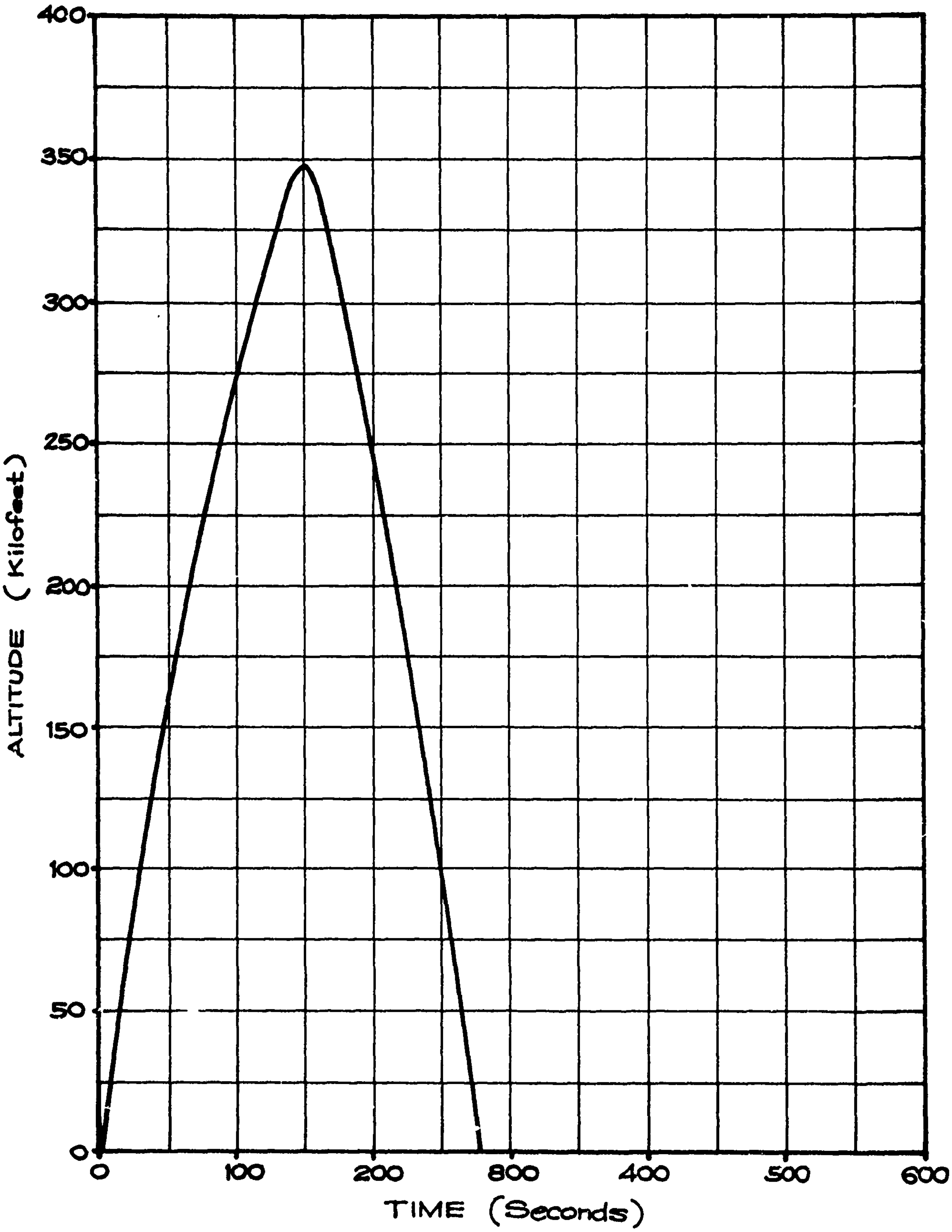


FIGURE 6.9 STABLE SUPER LOKI ROBIN DART ALTITUDE VS. TIME

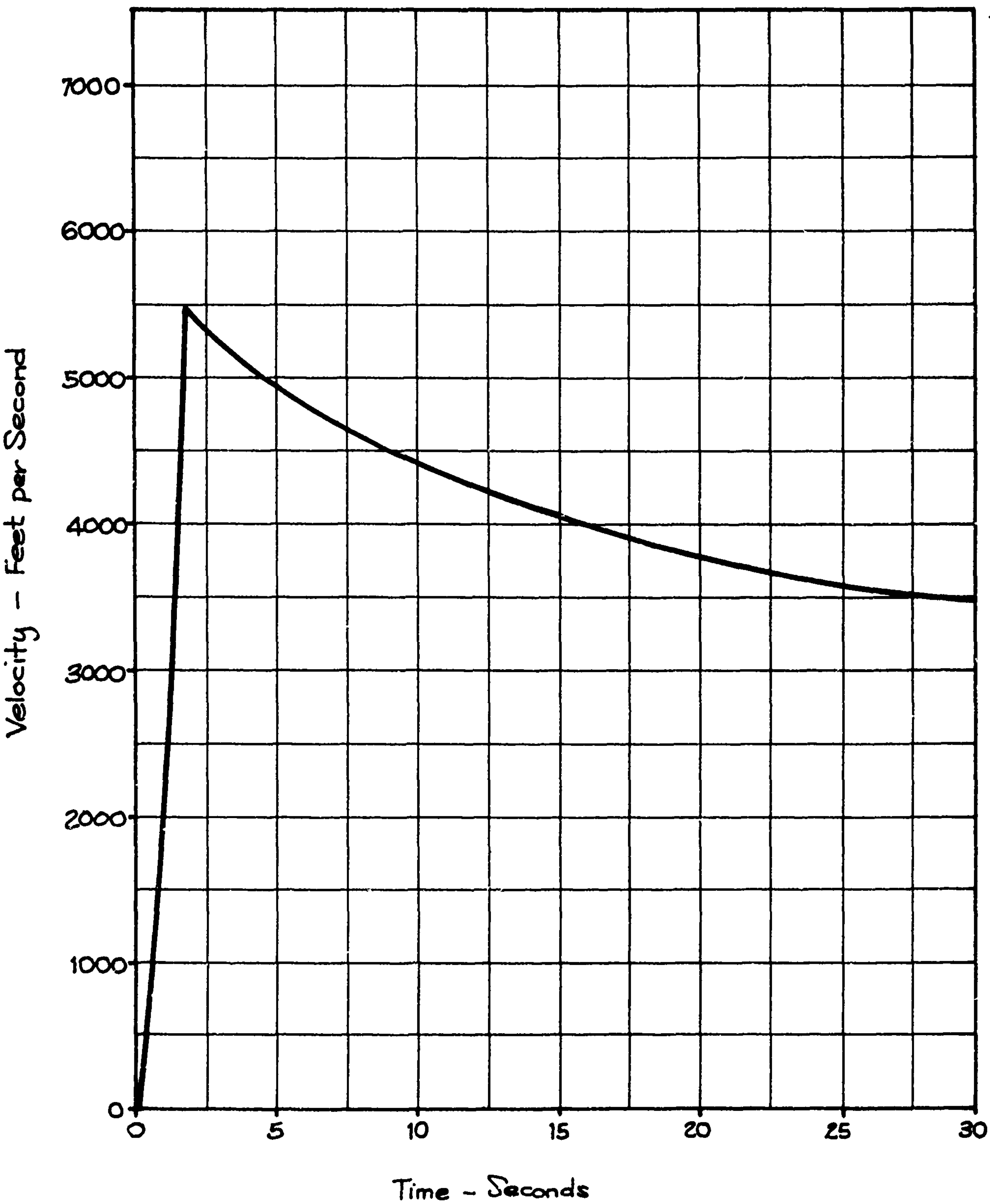


FIGURE 6.10 STABLE SUPER LOKI ROBIN DART-VELOCITY VS. TIME, 80° Q.E.

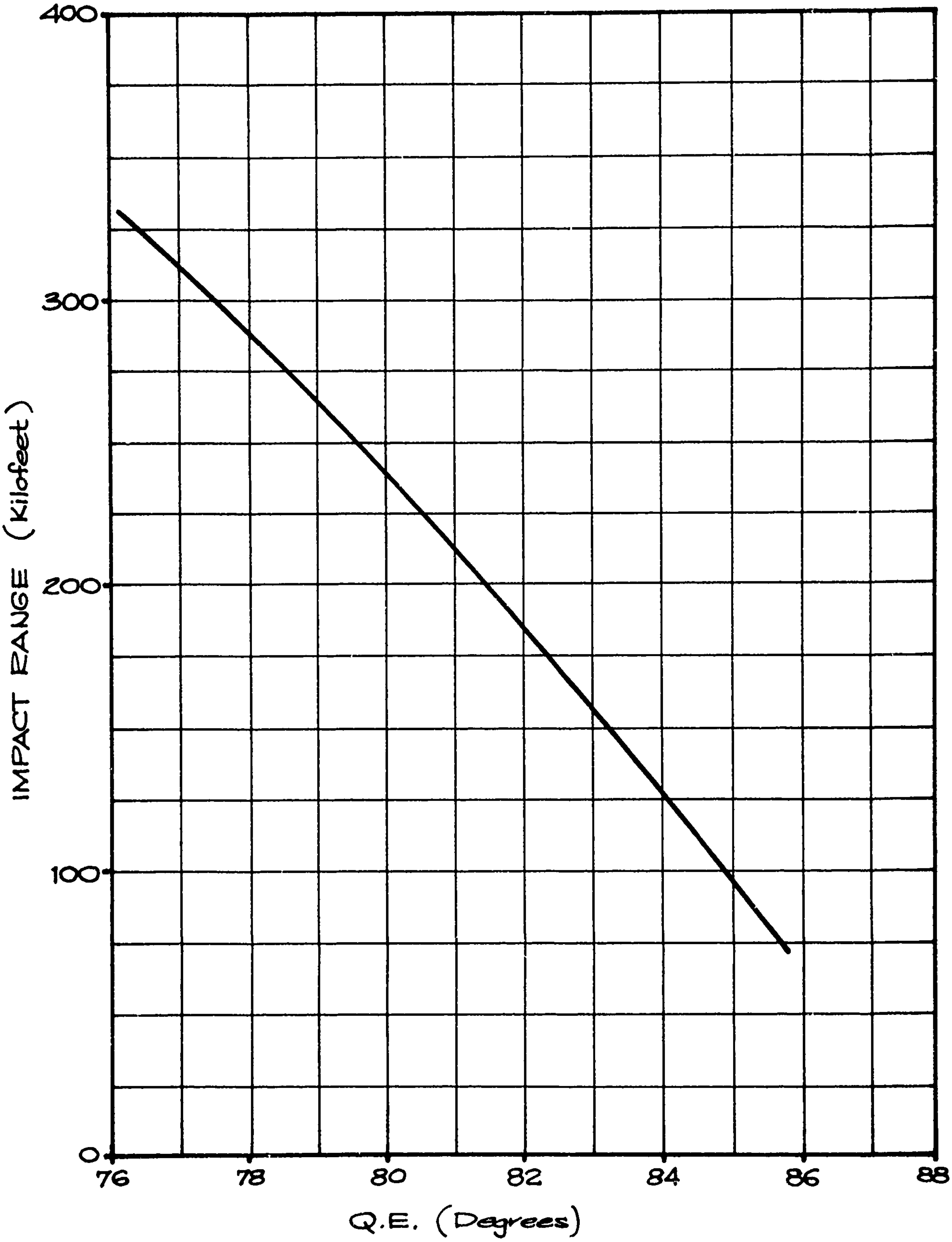


FIGURE 6.11 STABLE SUPER LOKI ROBIN DART IMPACT RANGE VS. LAUNCH ANGLE

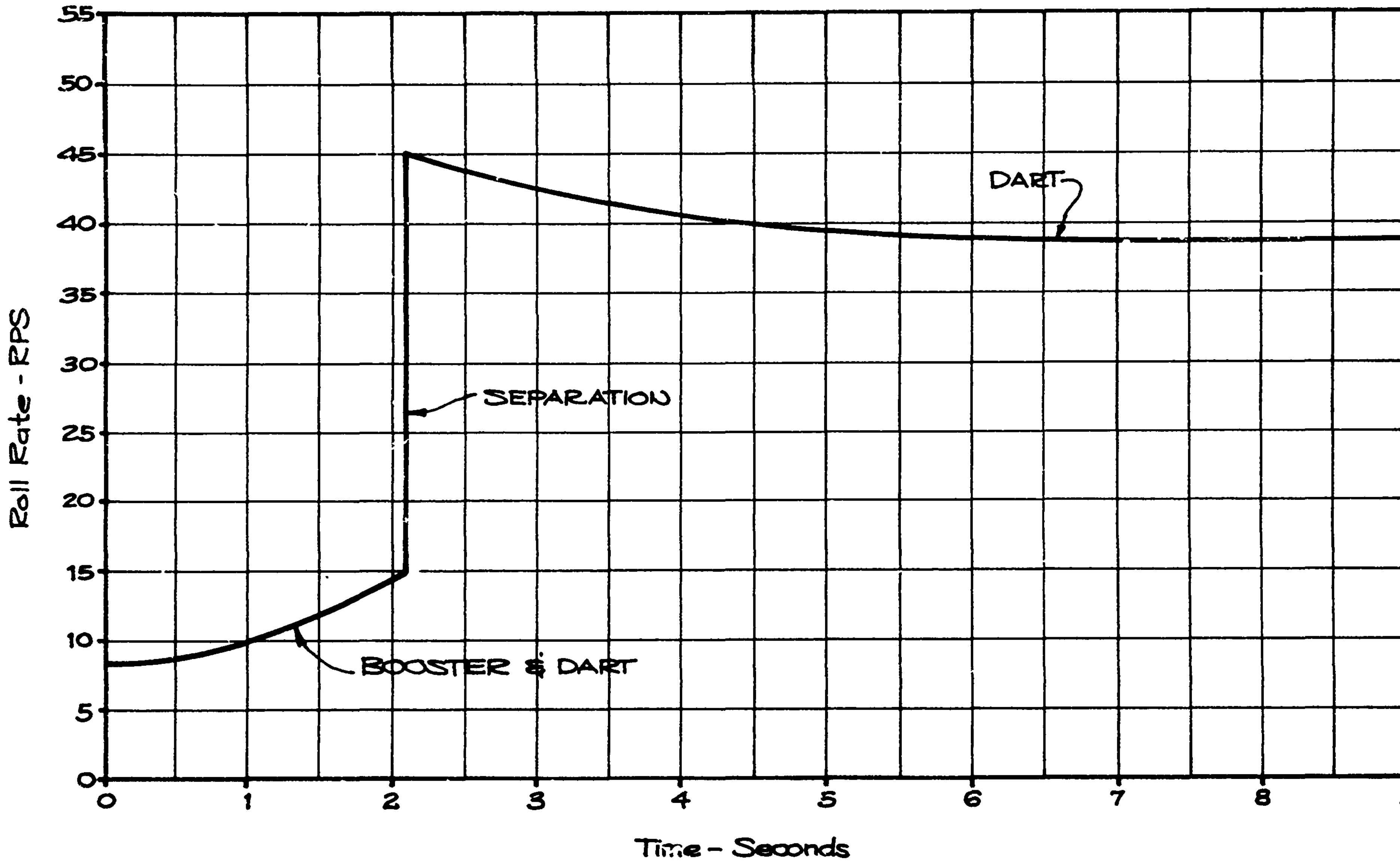


FIGURE 6.12 STABLE SUPER LOKI ROBIN DART - ROLL RATE VS. TIME

7.

RANGE SAFETY DATA

7.1 General

The range safety data presented here consist of booster and trajectory data, vehicle wind-weighting, vehicle impact dispersion estimates and ordnance data. This information is presented in the sections which follow.

7.2 Booster Trajectory Data

Upon rocket motor burnout and dart stage separation, the expended booster follows a stable ballistic trajectory to impact. The expended booster configuration is shown in Figure 7.1. The normal force coefficient is presented in Figure 7.2, and the center-of-pressure is presented in Figure 7.3. The expended booster drag data are presented in Table 7.1.

The expended booster trajectory data are presented for both the Robin and Instrumented systems as follows:

Figure 7.4	Booster Nominal Trajectory
Figure 7.5	Booster Altitude vs. Time
Figure 7.6	Booster Impact Range vs. QE

7.3 Wind-Weighting Data

The wind-weighting data for both of the Super Loki vehicles are presented as follows:

Figure 7.7	Instrumented Dart Wind-Weighting Data
Figure 7.8	Robin Dart Wind-Weighting Data
Figure 7.9	Booster Wind-Weighting Data

7.4 Vehicle Impact Dispersion Data

Impact dispersion three-sigma radii for the instrumented dart and booster are presented in Table 7.2. Impact dispersion three-sigma radii for the Robin Dart and booster are presented in Table 7.3. These data are based upon the dart and booster having been wind-weighted.

7.5 Vehicle Ordnance Data

The vehicle explosive and electroexplosive ordnance data are presented in Table 7.4. The rocket motor is shipped as ICC Class B, and the dart tails are shipped as ICC Class C.

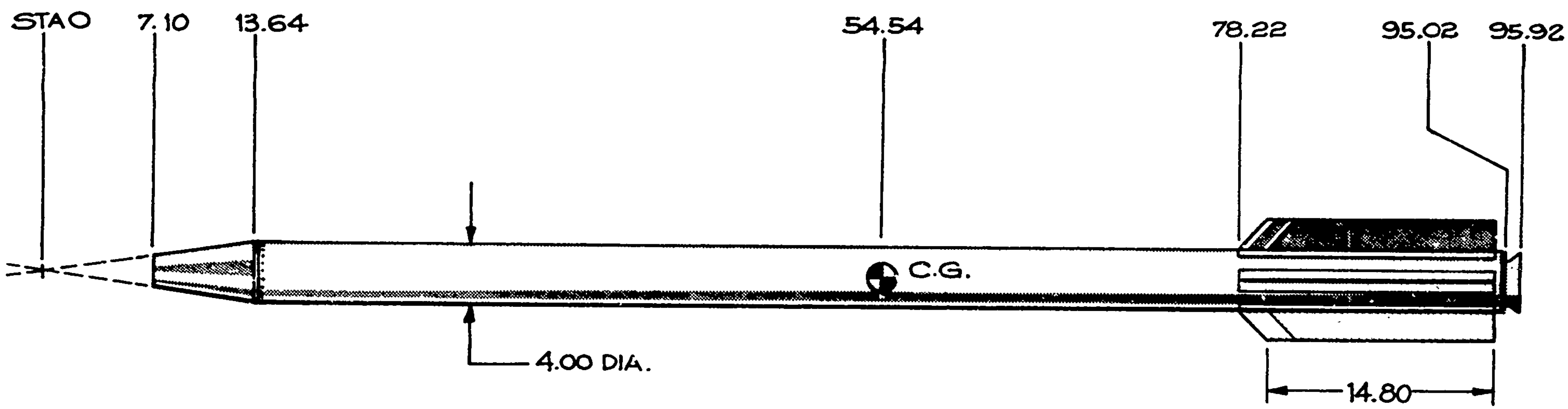


FIGURE 7.1 EXPENDED STABLE BOOSTER CONFIGURATION

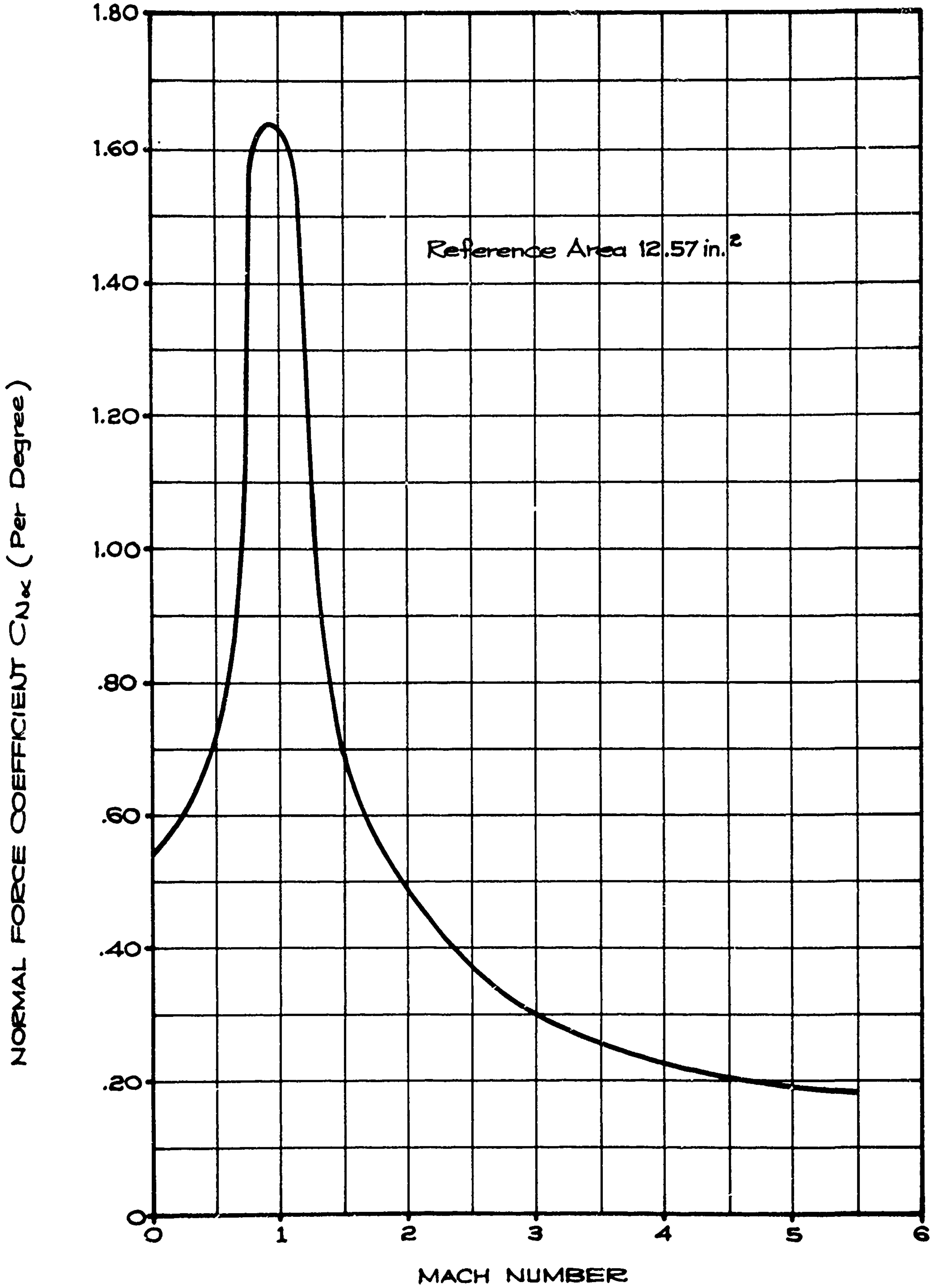


FIGURE 7.2 EXPENDED STABLE BOOSTER-NORMAL FORCE COEFFICIENT

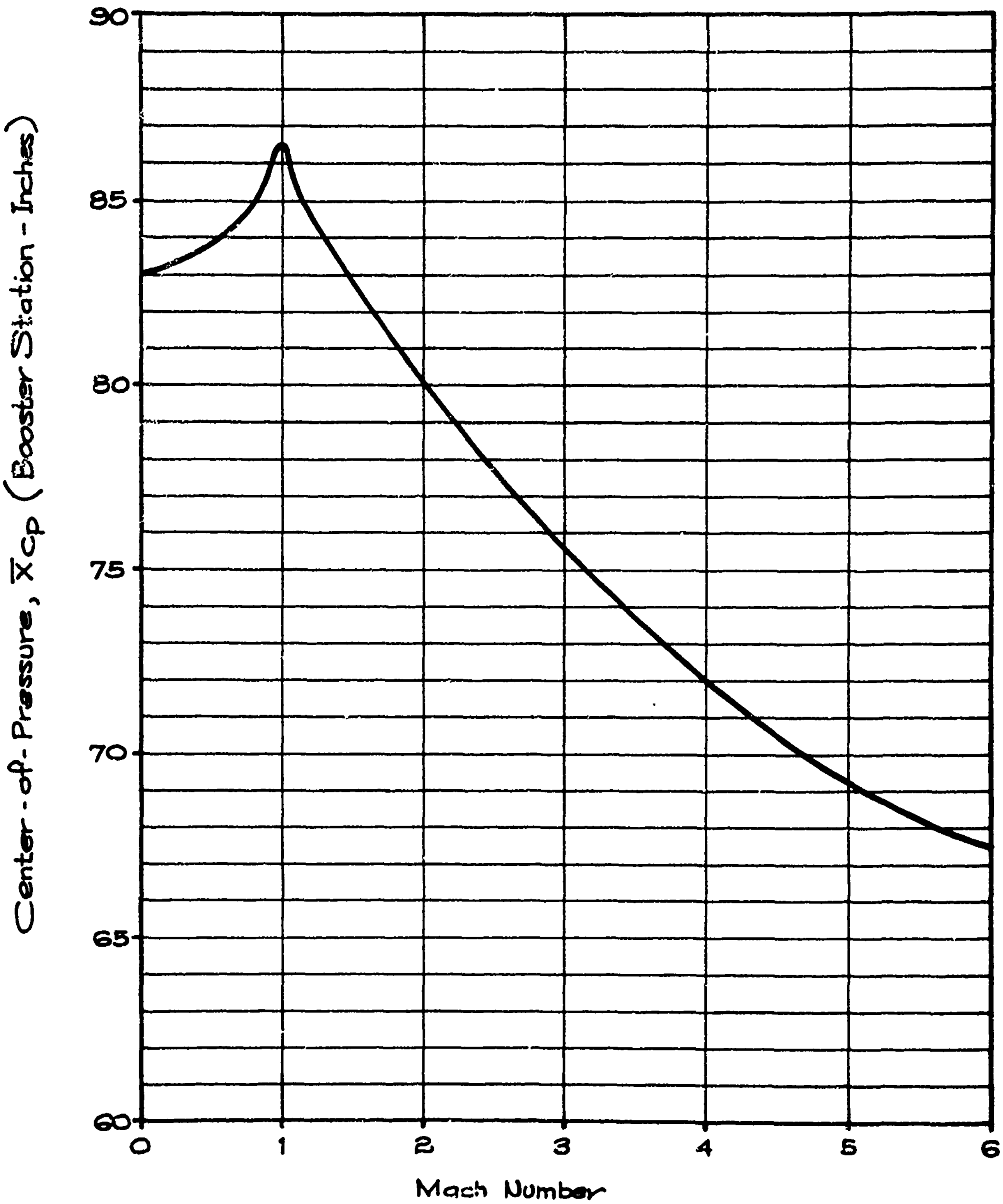


FIGURE 7.3 EXPENDED STABLE SUPER LOKI BOOSTER CENTER-OF-PRESSURE

TABLE 7.1

EXPENDED STABLE SUPER LOKI BOOSTER DRAG COEFFICIENTS

M	C_D
0.	0.54
0.5	0.58
0.8	0.63
1.0	1.0
1.5	1.88
2.5	1.3
3.0	1.1
6.0	0.83

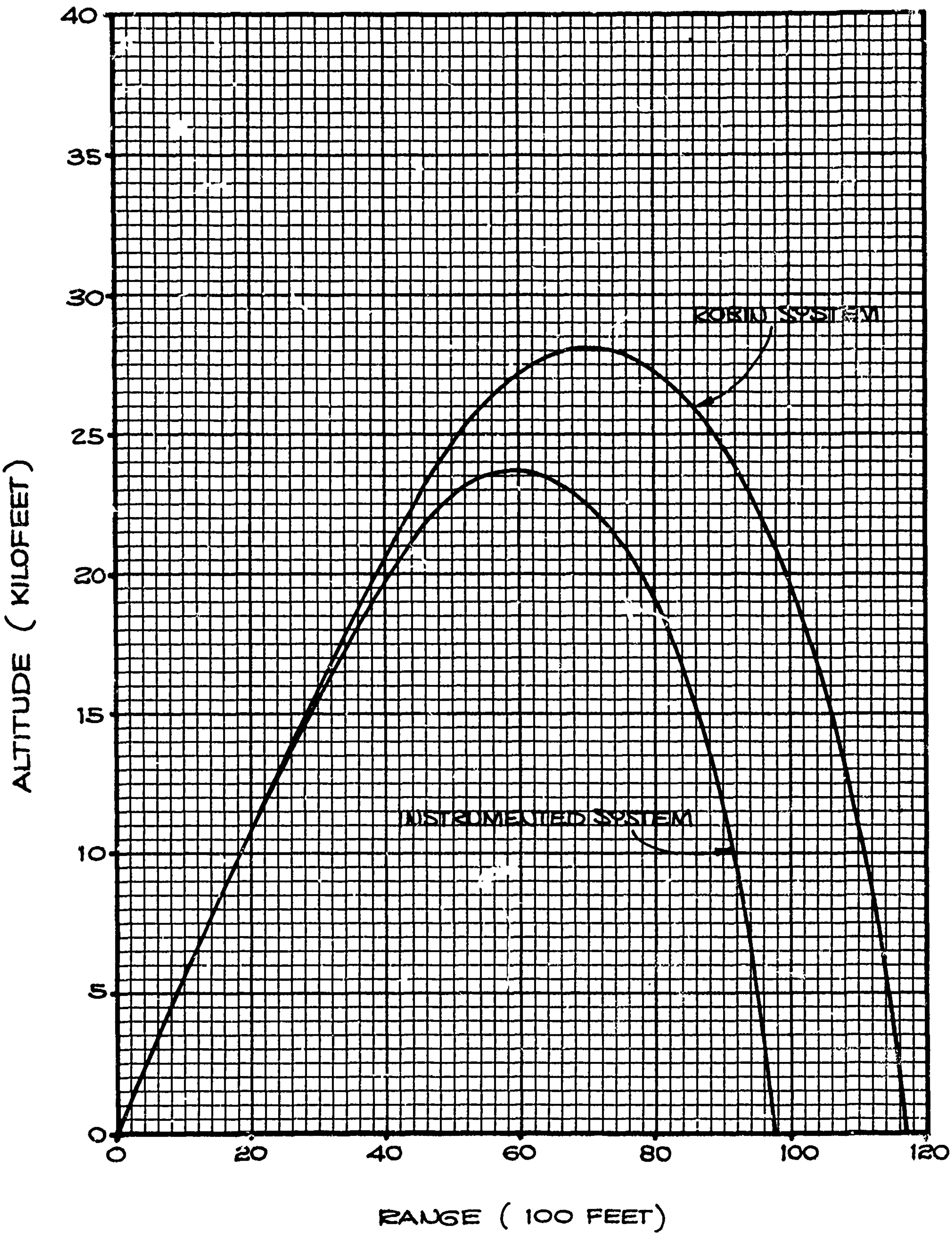


FIGURE 7.4 STABLE SUPER LOKI BOOSTER-ALTITUDE VS. RANGE @ 80° Q.E. (Sea Level Launch)

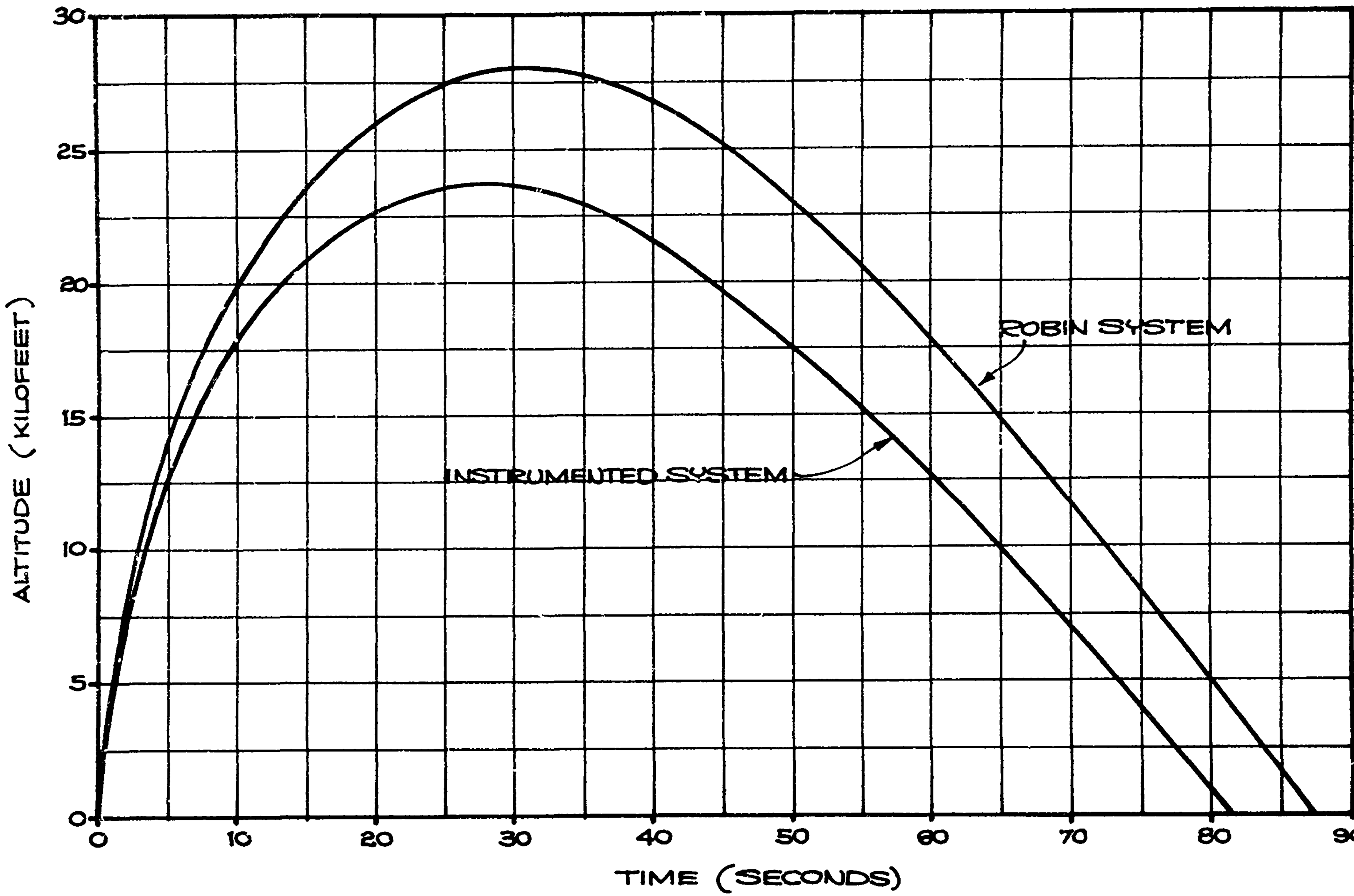


FIGURE 7.5 STABLE SUPER LOKI BOOSTER - ALTITUDE VS. TIME @ 80° S.L. LAUNCH

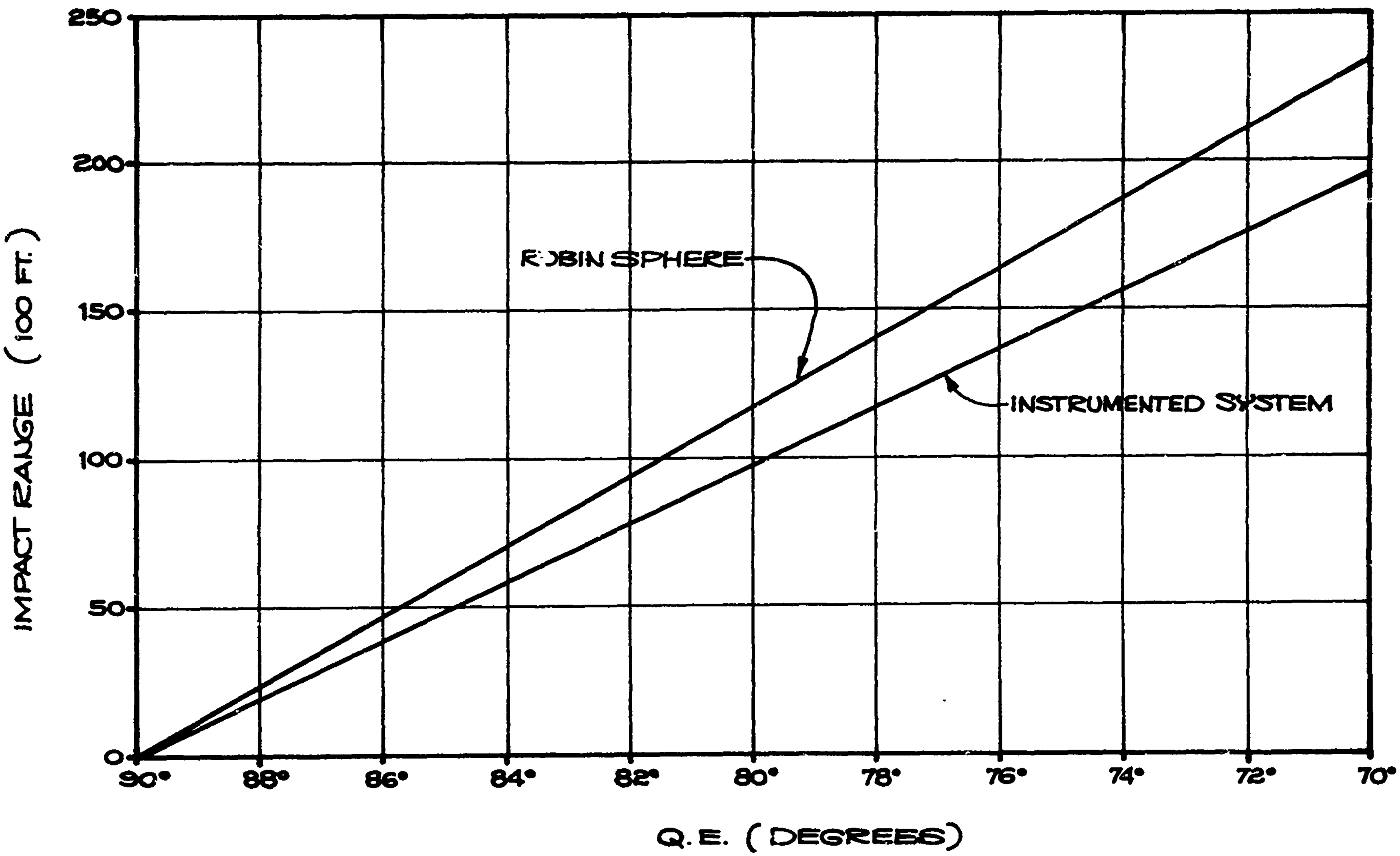


FIGURE 7.6 STABLE SUPER LOKI BOOSTER - IMPACT RANGE VS. Q.E @ S.L. LAUNCH

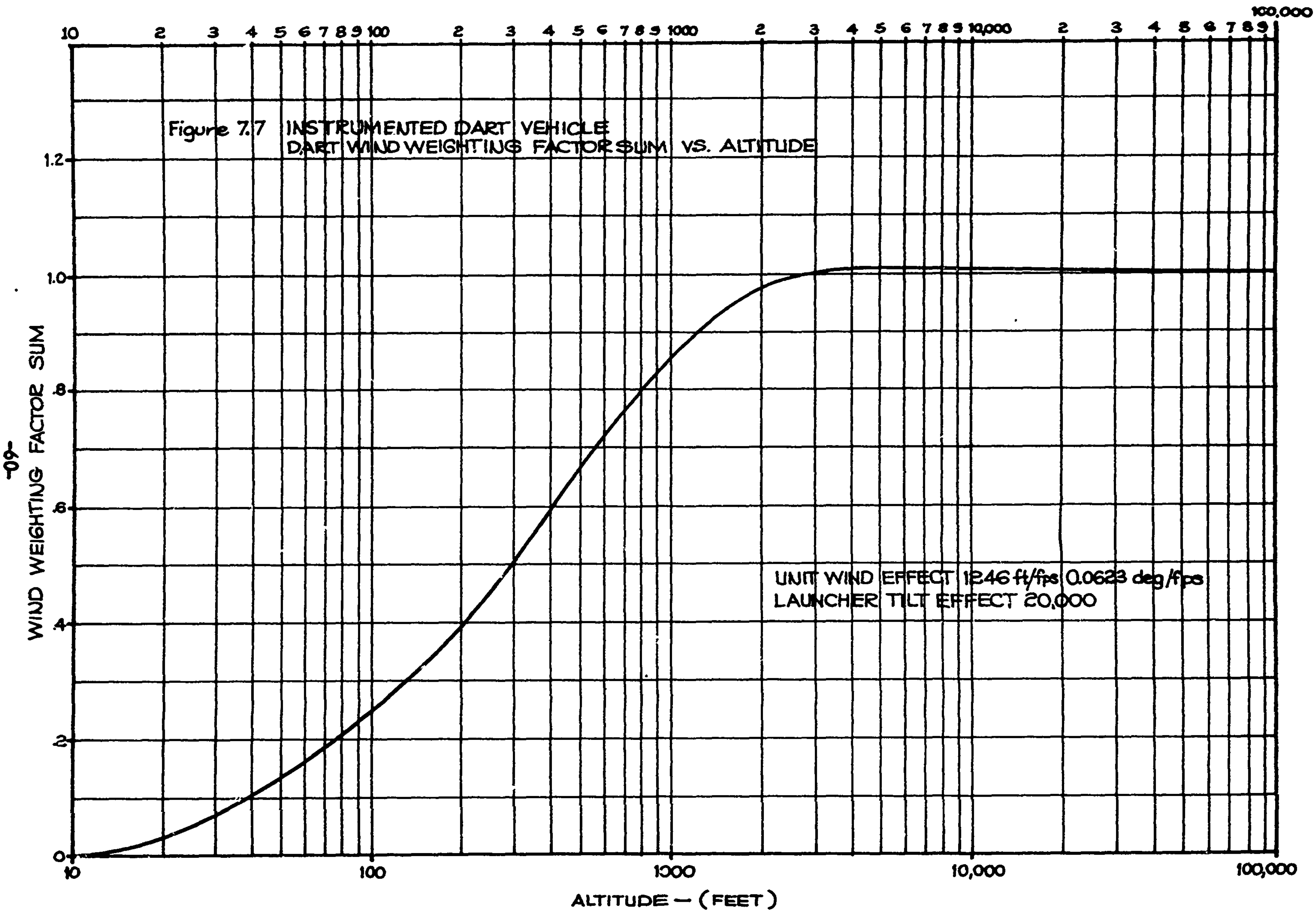


Figure 7.7 INSTRUMENTED DART VEHICLE
DART WIND WEIGHTING FACTOR SUM VS. ALTITUDE

A-3258

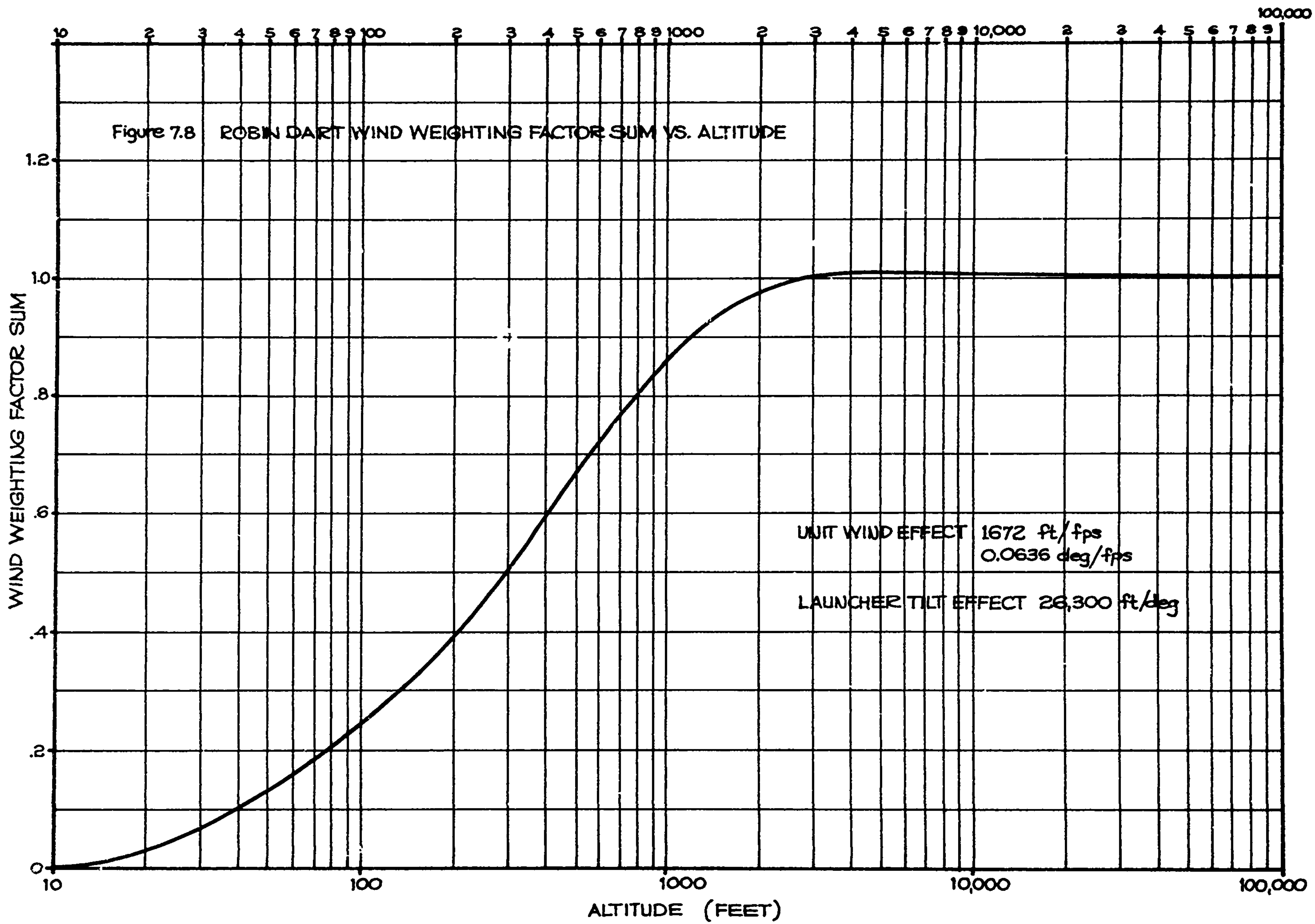


Figure 7.8 ROBIN DART WIND WEIGHTING FACTOR SUM VS. ALTITUDE
UNIT WIND EFFECT 1672 ft/fps
0.0636 deg/fps
LAUNCHER TILT EFFECT 26,300 ft/deg
WIND WEIGHTING FACTOR SUM
ALTITUDE (FEET)

A-3257

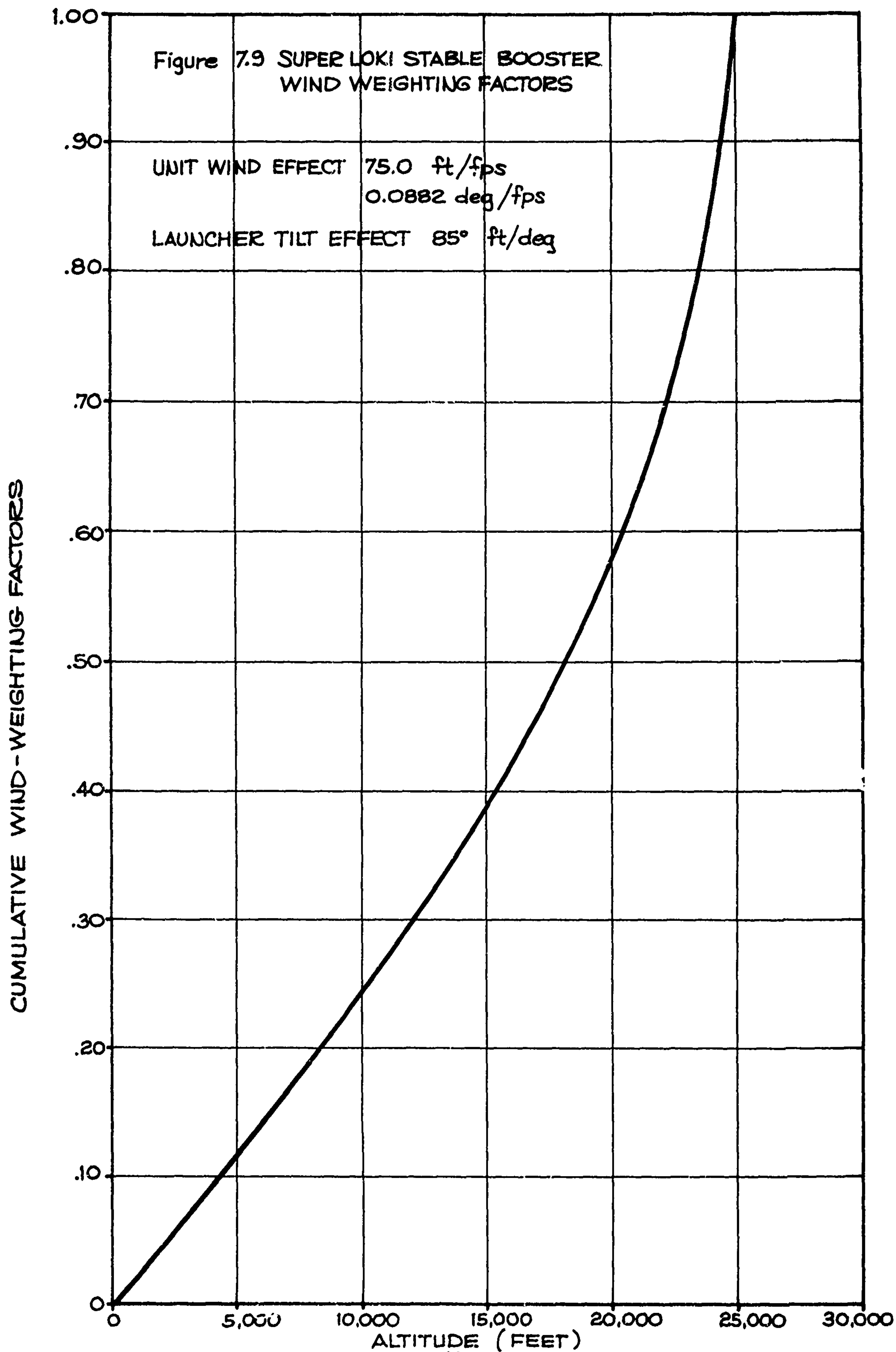


Figure 7.9 SUPER LOKI STABLE BOOSTER
WIND WEIGHTING FACTORS
UNIT WIND EFFECT 75.0 ft/fps
0.0882 deg/fps
LAUNCHER TILT EFFECT 85° ft/deg
1.00
.90
.80
.70
.60
.50
.40
.30
.20
.10
0
CUMULATIVE WIND-WEIGHTING FACTORS
0
5,000
10,000
15,000
20,000
25,000
30,000
ALTITUDE (FEET)

TABLE 7.2

IMPACT DISPERSION DATA (THREE SIGMA)
INSTRUMENTED VEHICLE

VEHICLE STAGE	DART	BOOSTER
80° QE Impact Range	170,679 Feet	9,756 Feet
Maximum Three-Sigma Impact Dispersion Radius	18,600 Feet	1,700 Feet

TABLE 7.3

IMPACT DISPERSION DATA (THREE SIGMA)
ROBIN VEHICLE

VEHICLE	DART	BOOSTER
80° QE Impact Range	275,000 Feet	11,864 Feet
Maximum Three-Sigma Impact Dispersion Radius	31,220 Feet	1,700 Feet

TABLE 7.4

ORDNANCE DATA

ITEM	EXPLOSIVE		ELECTRICAL SQUIB CHARACTERISTICS		
	WEIGHT	TYPE	NO-FIRE	RESISTANCE	ALL-FIRE
Rocket Motor Propellant	43.48 Lb.	Class B Polysulfide Ammonium Perchlorate	---	---	---
Rocket Motor Igniter	50 grams	Class B Cupric Oxide Aluminum Powder	1 watt/1 amp 5-minutes each squib	1.15 ohms ± 0.15 ohm each squib	5.0 amps each squib
Dart Payload Separation Device with Time Delay Transponder, 120-second Robin, 135-second	 8 grams 3.5 grams	Class C Boron Potassium Nitrate	1 watt/1 amp 5-minute	1.05 ohms ± 0.25 ohm	5.0 amps

8.

DEVELOPMENT PROGRAM REVIEW

8.1 General

The purpose of this development program has been to provide a stable booster trajectory for the PWN-10A transponder dart and PWN-12A Robin dart systems without degrading their altitude performance. A preliminary parametric trade-off study indicated that the most efficient way to provide booster stability after stage separation is to increase the rocket motor fin area. To make up for the dart altitude loss due to the added drag and weight of the larger fins, the rocket motor length was extended to provide additional propellant. A small increase in rocket motor headcap weight was subsequently found to be necessary to assure a completely reliable stable booster trajectory.

As a backup system, the Viper 3A was flight tested with a relatively heavy ballast located in the headcap. This system was also successful.

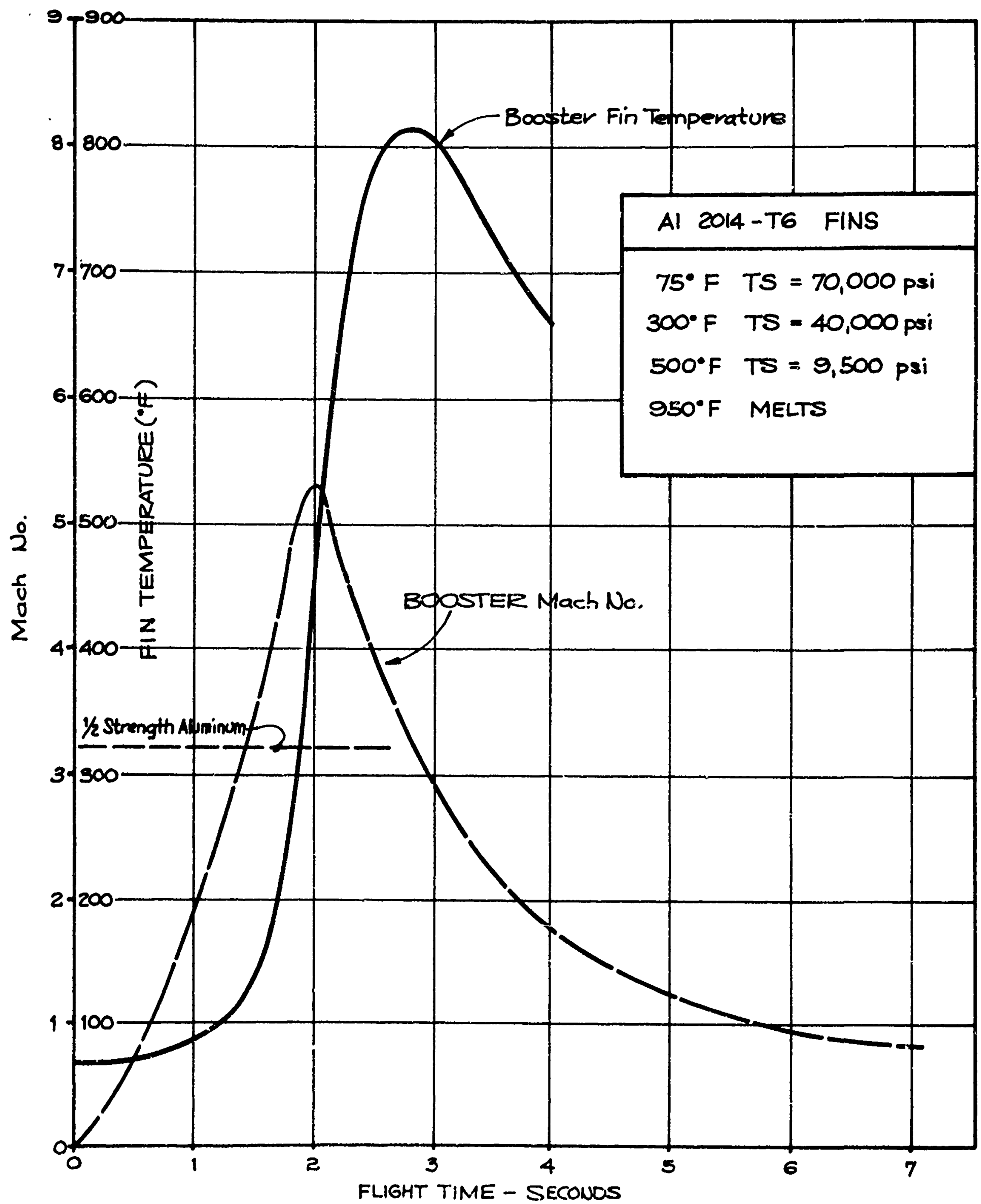
8.2 Rocket Motor Fins

Aerodynamic calculations indicated that the standard Super Loki booster neutral static stability margin should occur at Mach number 3.0. That is, the expended booster should be stable at Mach numbers below 3.0 and unstable above. Since both the PWN-10A and PWN-12A burnout velocities are above Mach 5.0, the booster can be expected to go unstable immediately upon burnout and stage separation.

For this program, the standard Super Loki rocket motor fin areas were increased from 10 in.^{2} each fin (four fins) to 30 in.^{2} each fin. Calculations indicated that this increase in fin area should provide a 7.7 percent static margin at maximum velocity of the intended system. The added fin area could not be gained by increasing the fin span because of the launcher rail constraints. Therefore, the area increase was gained by increasing the fin chords and reducing the sweep angle.

An aerodynamic heating analysis indicated that the booster fin temperatures would rise to an unacceptably high level after stage separation for a stable booster trajectory. The flat plate temperature predictions are shown in Figure 8.1. Leading edge temperatures are significantly higher. Further heat transfer calculations indicated that a 0.015-inch coating of ablative material (Thermolag T-230) would

FIGURE 8.1 STABLE BOOSTER FIN TEMPERATURES WITHOUT THERMAL PROTECTION



keep the booster fin panels to an acceptable temperature level. However, special leading edge cuffs had to be designed, as shown in Figure 8.2, to protect against the more severe leading edge heating and erosion.

With the added fin drag and weight, an altitude loss of about 50,000 feet was predicted for the PWN-12A Robin dart. It was also determined that the altitude loss for the Robin dart would be more severe than for the instrumented dart. Therefore, it was decided to concentrate all initial efforts on the Robin system.

8.3 Rocket Motor Length Extension

Since the initial flight tests with the stable booster fins indicated an altitude loss of about 50,000 feet for the Robin dart, the rocket motor length was increased from 78.08 inches to 88.08 inches to accommodate 5.97 pounds of additional propellant. The nozzle throat diameter was increased by a slight amount to keep the chamber pressure profile essentially the same as the standard Super Loki rocket motor. A comparison of the extended length and standard length motor performance is shown in Figure 8.3. The chamber pressure profiles are shown in Figure 8.4. This extra length (ten inches) motor is the final stable booster configuration.

8.4 Rocket Motor Headcap Weight

During the second flight test series, which included the extra length rocket motor and the stable booster fins, it appeared that the boosters were only marginally stable. Although stage separations appeared stable, booster apogee altitudes were low and impact ranges were short. Therefore, to add a slight amount of static margin to the expended booster, the booster headcap cavities were left solid except for the dart tail port. This added an additional 1.742 pounds to the head-end of the booster. Subsequent flight tests demonstrated that the booster stability is reliable within this added head-end weight.

8.5 Universal Launch Rail Concept

Two different launch rails are required for the standard PWN-10A and PWN-12A vehicles to accept the different dart fin spans in the helical launch rails. There has been a desire by the Air Force to consolidate launchers to a single launch rail. During this program, the dart fin span was increased on the Robin dart so that the PWN-12A Robin system could be launched from the larger PWN-10A launch rail. Two Robin systems were launched in this configuration from the larger rails. Although the boosters performed satisfactorily in both cases, the darts suffered a significant altitude loss. The dart altitude losses (100,000 feet) were much greater than could be attributed to an increase in dart drag due to the larger fin spans. A more probable cause is the increase in bending loads at the dart fin roots during

Ref. SDC DWG # 600-21

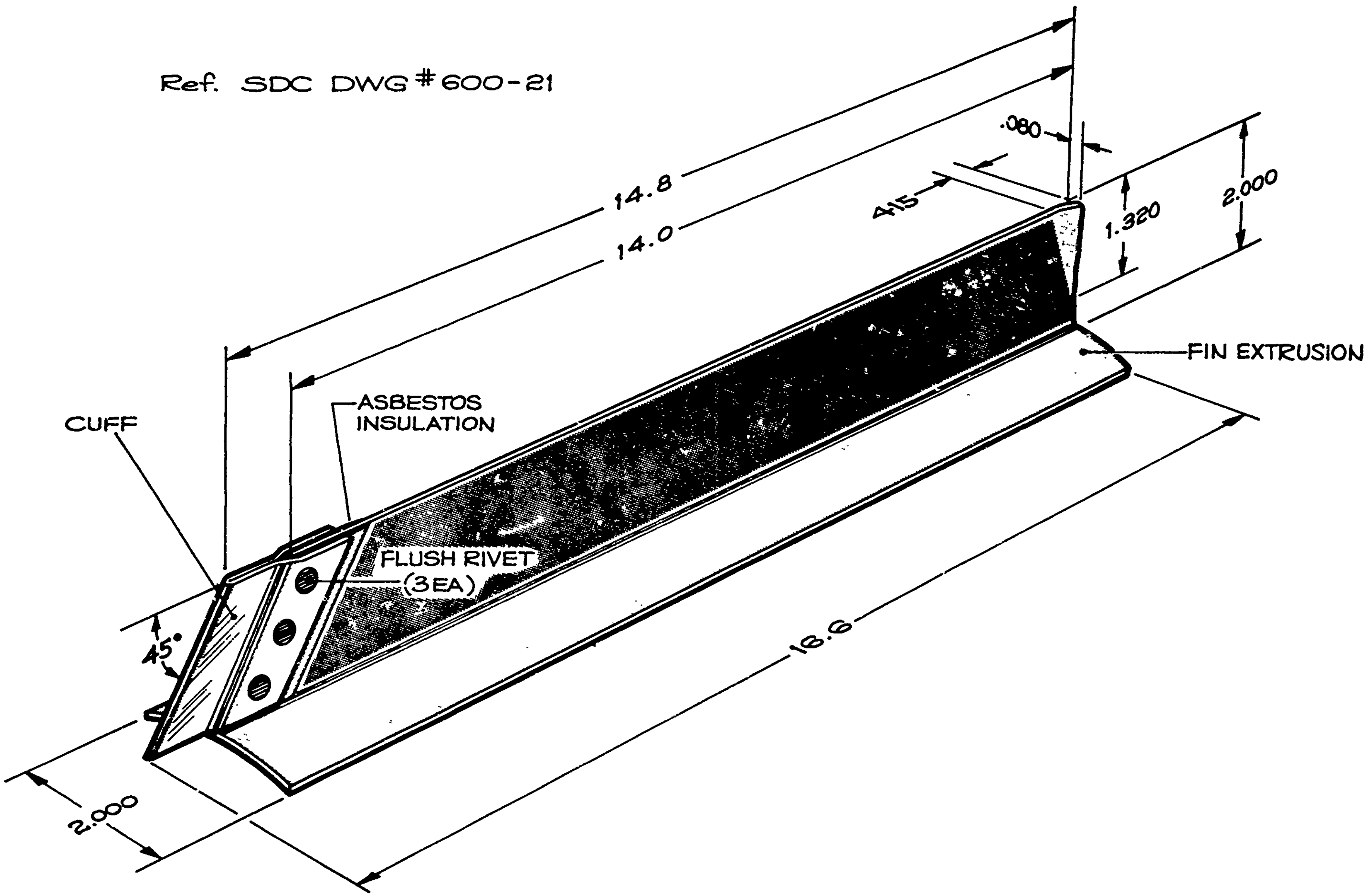


FIGURE 8.2 BOOSTER FINS LEADING EDGE CUFF DESIGN

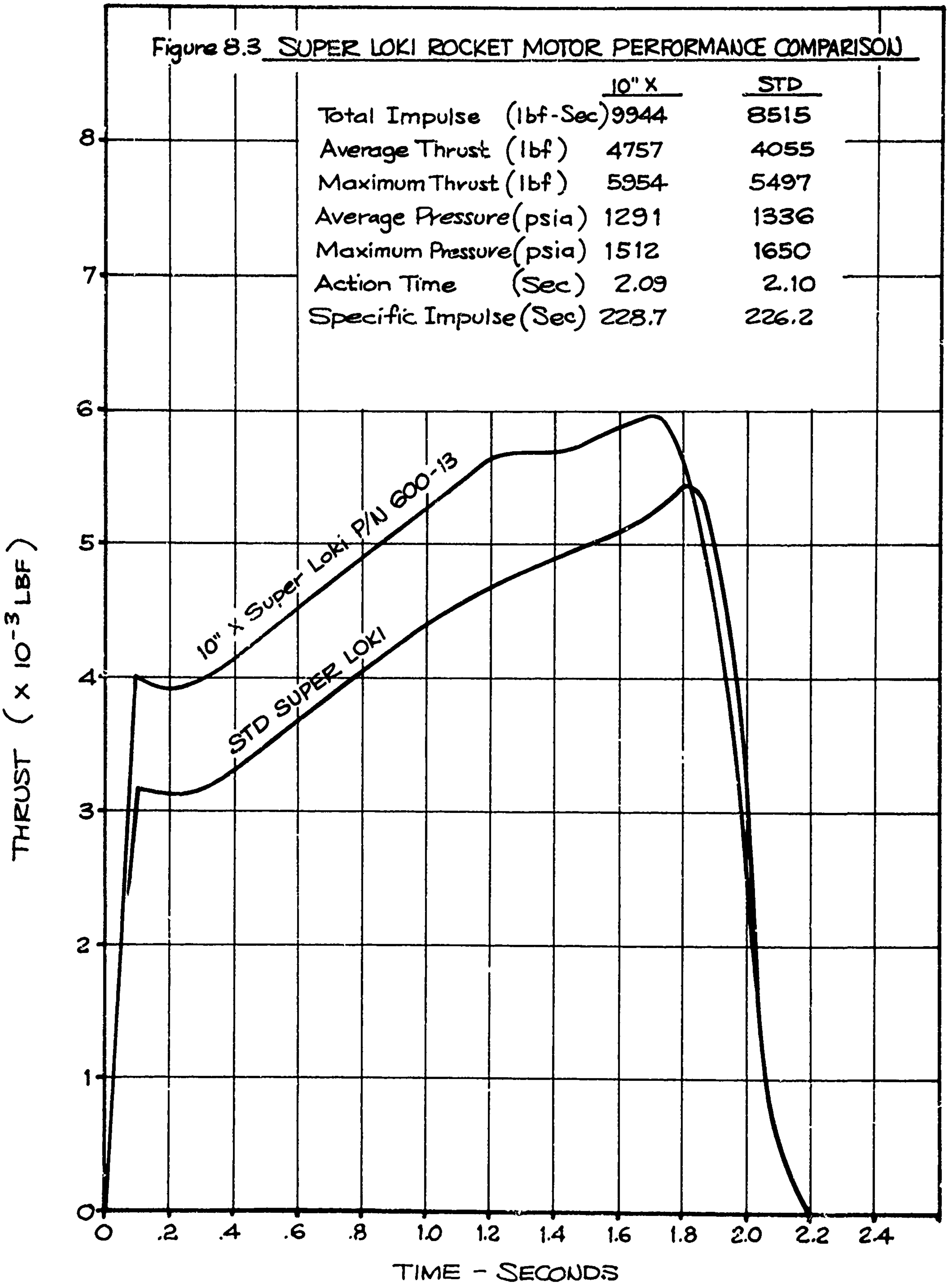
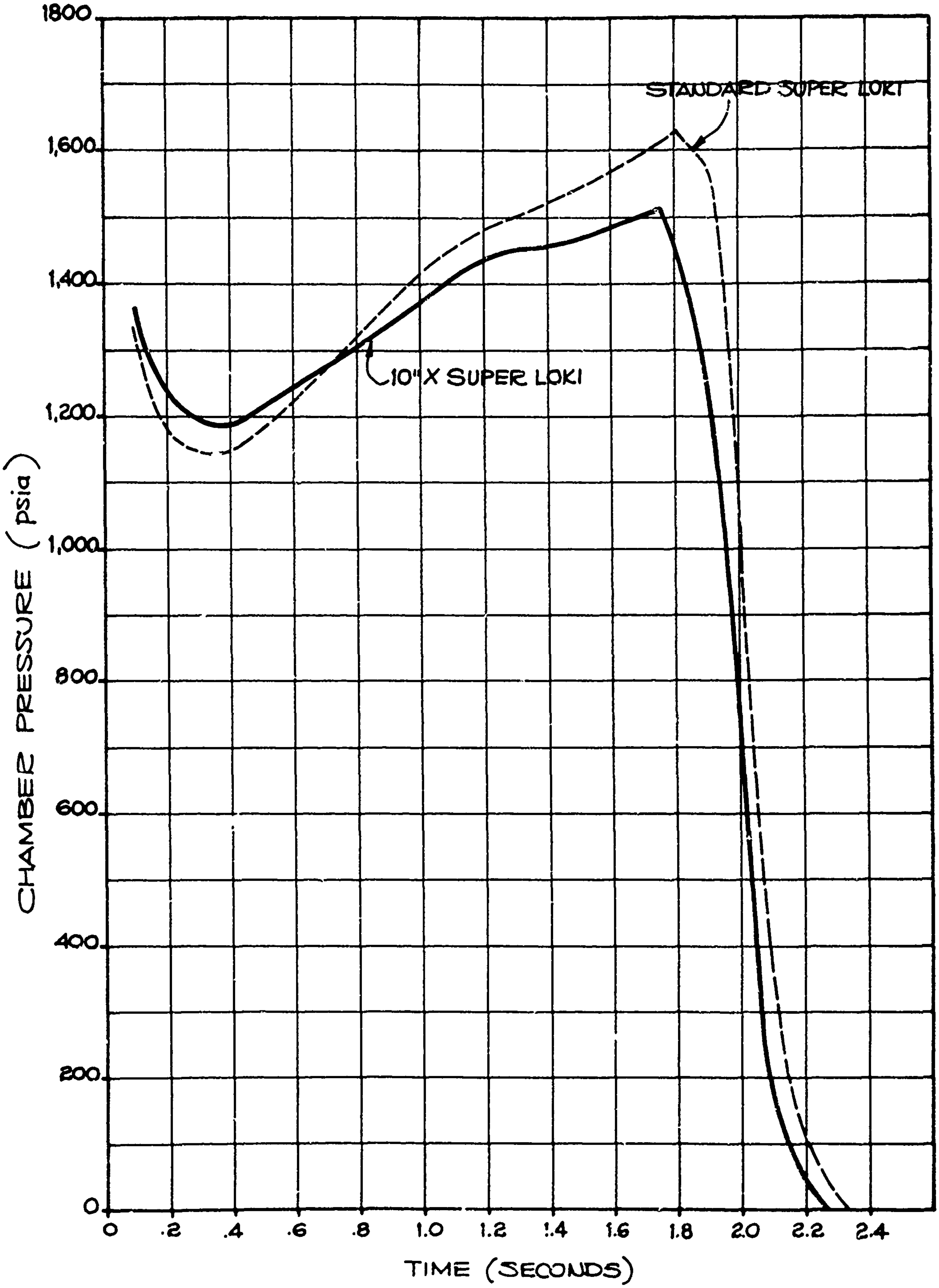


Figure 8.3 SUPER LOKI ROCKET MOTOR PERFORMANCE COMPARISON

Figure 8.4 SUPER LOKI HEAD-END CHAMBER PRESSURE



launch caused mechanical bending of the dart fins. This would cause severe coning of the dart and a high induced drag. This problem may be solved by increasing the thickness of the fin panel.

8.6 Viper 3A Vehicle

The Viper 3A rocket motor was used as a backup for the main Super Loki Stable Booster program. Since the Viper 3A is a larger rocket motor (4.5-inch diameter) it would cost slightly more than the extended length Super Loki. The Viper 3A vehicle developed under this program was immediately successful in demonstrating both extra high dart altitudes and reliable stable booster performance. The only modifications to the standard Viper 3A rocket motor were an increase in booster fin area, thermal protection for the booster fins and a heavy solid-aluminum headcap.

The original Viper 3A Dart is a two-stage sounding rocket vehicle which consists of a solid-propellant rocket motor as the booster or first stage and a non-propulsive dart as the second stage. The Viper 3A rocket motor is a 4.5-inch diameter scaled-up version of the SDC 4.0-inch diameter Super Loki motor. The propellant weight is increased from 37.2 pounds of the standard Super Loki to 57.0 pounds to significantly improve performance. The second stage is the same 1.625-inch diameter Robin dart as is being used with the Super Loki motor. A thirty percent improvement in dart apogee altitude performance over the Super Loki vehicle is made possible with the Viper 3A.

Five flight tests of the original Viper 3A dart vehicle had been previously conducted at the White Sands Missile Range. All of these flights were successful, and design performance of 150 km was achieved in each flight. In the standard configuration, the Viper 3A booster becomes unstable after dart separation as in the standard Loki and Super Loki systems.

Under the current program, a ballast-weighted motor headcap-interstage (4.00 pounds), together with larger booster fins (46.87 in^2 per panel) which were thermally protected in the same manner as the Super Loki Stable Booster, i.e., special leading edge cuffs and ablative coating, were used to reliably produce a stable booster flight after burnout and staging. The Robin dart apogee achieved with this stable booster Viper 3A vehicle configuration is about 120 km.

The Viper 3A Stable Booster vehicle configuration is shown in Figure 8.5. A detailed description is presented in the Appendix.

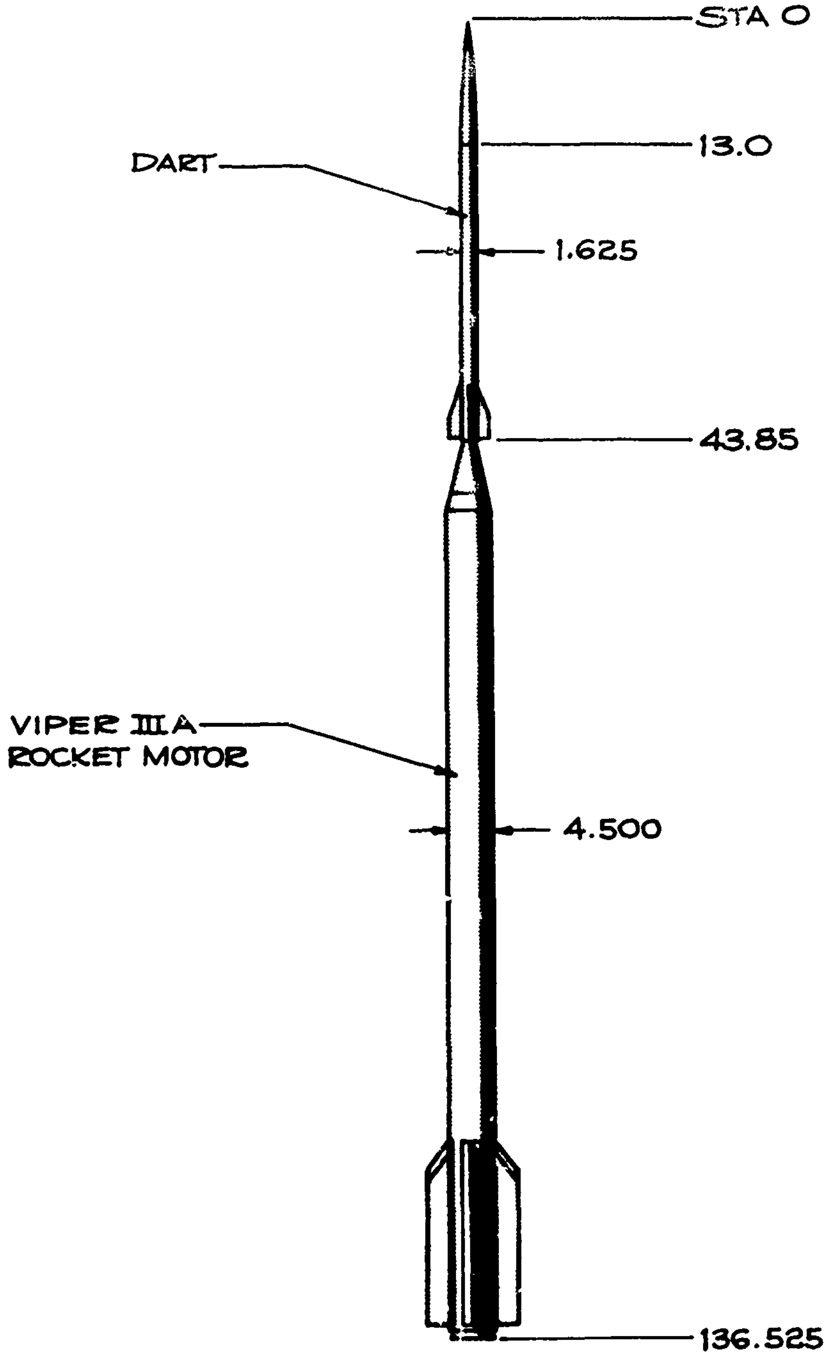


FIGURE 8.5 VIPER IIIA STABLE BOOSTER VEHICLE CONFIGURATION

8.7 Flight Test Results

8.7.1 General

A log of flight test vehicle configurations and test numbers is presented in Table 8.1 for the entire development program. The flight summary for the Super Loki 1-5/8-inch diameter Robin dart systems is presented in Table 8.2. The flight summary for the Super Loki 2-1/8-inch diameter instrument dart systems is presented in Table 8.3. The flight summary for the Viper 3A 1-5/8-inch diameter Robin dart systems is presented in Table 8.4.

8.7.2 Super Loki Robin Dart Flights (Table 8.2)

The standard length Super Loki rocket motor was flown in the first flight series with the large booster fins. As expected, the dart altitudes were lower than the standard system due to heavier and higher drag booster fins. The three flights with the thermally protected booster fins (E4-1) apparently resulted in stable booster flights. The flight with the unprotected booster fins (E4-1A) resulted in an unstable booster flight. This flight series proved the need for additional propulsion capability and thermally protected booster fins.

The extended length Super Loki rocket motor was flown in the second flight series with thermally protected booster fins (E4-2). Dart apogees were consistently 120 km, but the boosters did not remain stable. Evidently the extra length motor case reduced the static stability of the expended booster.

A heavy interstage was used with the extended length motor (E4-3) in the third series and fourth series to improve booster stability. Dart apogees were about 106 km. Flights 3-16 and 3-17 were launched from the larger dart launch rail with increased dart fin spans with very low dart apogees. It is probable that the dart fins yielded and bent due to the launching torque. All boosters for these two flight series remained stable to impact. Thus, the primary objective of the program to provide a reliably stable booster was achieved.

8.7.3 Super Loki Instrument Dart Flights (Table 8.3)

The extended length Super Loki rocket motors with the thermally protected large booster fins (F4-1) were flown with the standard 2.125-inch diameter instrument darts in the third and fourth flight series. Dart apogees were about 71 km except for one low flight where staging failure is suspected. The boosters remained stable for all flights which were tracked by radar.

8.7.4 Viper 3A Robin Dart Flights (Table 8.4)

The Viper 3A rocket motor with a heavy interstage and large thermally protected fins (E4.5-1) were flown with the 1.625-inch diameter Robin darts in the first flight series. The darts all reached an apogee of about 120 km, and the booster remained stable to impact. Unprotected booster fins were used on flight 1-7 (E4.5-1A) which resulted in a late dart separation, extremely low dart apogee and an unstable booster. This flight verified the need for thermal protection of the booster fins.

TABLE 8.1

VEHICLE CONFIGURATIONS

VEHICLE DESIGNATION	DART & PAYLOAD	MOTOR CONFIGURATION	TEST NO. OUR	TEST NO. WALLOPS	APOGEE ALTITUDE (KFT) PREDICTED	APOGEE ALTITUDE (KFT) ACTUAL
E4-1	1-5/8-inch Robin	4" Motor-Fin area increased from 10 to 30 in^2/fin	1-1	D1-6160	372	325
		-M Fins cuffed	1-2	D1-6161	372	?
		-M Fins .015-in. Ablative Coating	1-3	D1-6162	372	?
E4-1A		4" Motor-Fin area increased from 10 to 30 in^2/fin	1-8	D1-6163	372	318
E4.5-1		4.5" Motor-Cuffs on LE on fins	1-4	D1-6164	388	380
		-M Fins .015-in Ablative Coating	1-5	D1-6165	388	397
			1-6	D1-6166	388	394
E4.5-1A		4.5" Motor	1-7	D1-6167	388	39
E4-2		4" Motor-Fin area increased from 10 to 30 in^2/fin	2-9	D1-6168	377	394
		-M Fins cuffed	2-10	D1-6169	377	394+
		-M Fins -in. Ablative Coating	2-11	D1-6170	377	389
		Motor lengthened 10 inches	2-12	D1-6171	377	388
E4-3		4" Motor-Fin area increased from 10 to 30 in^2/fin	3-13	D1-7172	340	340

TABLE 8.1 (Continued)

VEHICLE DESIGNATION	DART & PAYLOAD	MOTOR CONFIGURATION	TEST NO. OURS	TEST NO. WALLOPS	APOGEE ALTITUDE (KFT) PREDICTED	APOGEE ALTITUDE (KFT) ACTUAL
		-M Fins cuffed	3-14	D1-6173	350	349
		-M Fins .035-in Ablative Coating	3-18	D1-6174	360	367
		-Motor lengthened 10 inches				
		-Interstage Weight increased 1.74 lbs.				
E4-4		4" Motor -- Same configurationaas E4-3 above	3-16	D1-6175	350	253
			3-17	D1-6176	350	245
		Dart fin span increased to fit Rail II (2-1/8-in. Dart Rail)		D1-6177	dart, held	
F4-1	2-1/8-inch Dart w/ Sonde & Starute	4" Motor -- Same configuration as E4-3 above	3-15	D1-6178	241	240
			3-19	D1-6478	241	237
F4-1	2-1/8-inch Dart w/ Sonde & Starute	4" Motor -- Same configuration as E4-3 above	4-20	D1-6179		
			4-21	D1-6180		232
			4-22	D1-6181		219
			4-23	D1-6182		230
			4-24	D1-6183		228
E4-3	1-5/8-inch Dart w/ Robin	4" Motor -- Same configurction as E4-3 above	4-25	D1-6184		346

TABLE 8.1 (Continued)

VEHICLE DESIGNATION	DART & PAYLOAD	MOTOR CONFIGURATION	TEST NO.		APOGEE ALTITUDE (KFT)	
			OUR	WALLOPS	PREDICTED	ACTUAL
			4-26	D1-6185		348
			4-27	D1-6186		352
			4-28	D1-6187		340
			4-29	D1-6188		?
			4-30	D1-6189		340

TABLE 8.2

FLIGHT SUMMARY - SUPER LOKI ROBIN DART VEHICLE

FLIGHT	DATE	VEHICLE DESIGNATION	LAUNCH QE (DEG)	PREDICTED DART APOGEE (KFT)	ACTUAL DART APOGEE (KFT)	PAYLOAD PERFORMANCE	BOOSTER APOGEE (FT)	ACTUAL BOOSTER IMPACT RANGE (FT)	PREDICTED BOOSTER IMPACT RANGE (FT)	IMPACT TIME (SEC)	BOOSTER STABLE	COMMENTS
1-1	19 SEP 72	E4-1	80	325	325	Good	13,100	11,000	12,000*	51	Yes	Booster Appeared Straight
1-2	19 SEP 72	E4-1	80	325	Late Aq	Unknown	---	---		--	---	Booster Appeared Straight
1-3	19 SEP 72	E4-1	80	325	Late Aq	Good	12,000	11,197	12,000*	39	Yes	Booster Appeared Straight
1-8	02 OCT 72	E4-1A	80	325	318	Early Collapse	17,000	7,000	12,400*	237	No	Booster in Flat Spin During Descent, No Thermal Protection on Booster Fins
2-9	09 JAN 73	E4-2	80	377	394	Good	6,150	6,100	16,500*	25		
2-10	09 JAN 73	E4-2	80	377	394	Good	6,800	3,800	16,500*	88	No	
2-11	09 JAN 73	E4-2	80	377	389	Good	6,800	4,000	16,500*	91	No	
2-12	09 JAN 73	E4-2	80	377	389	Good	8,350	4,250	16,500*	89	No	
3-13	29 MAR 73	E4-3	78.4	340	340	Early Collapse	27,000	15,382	13,000	86	Yes	Booster Appeared Straight
3-14	29 MAR 73	E4-3	79	350	349	Good	28,500	16,780	12,000	87	Yes	
3-16	30 MAR 73	E4-3	80	360	253*	Good	27,600	13,315	15,000	86	Yes	Large Fins on Dart, Low Dart Large Launch Rail
3-17	30 MAR 73	E4-3	80	350	245*	Good	25,800	15,626	15,000	84	Yes	Large Fins on Dart, Low Dart Large Launch Rail
3-18	30 MAR 73	E4-3	81.5	370	367	Good	28,500	13,741	14,100	90	Yes	
4-25	22 JUN 73	E4-3	80	350	346	Good	28,600	11,500	10,000	89	Yes	Booster Straight
4-26	22 JUN 73	E4-3	79.5	345	348	Good	28,600	12,399	10,500	89	Yes	Booster Straight
4-27	22 JUN 73	E4-3	79.4	345	352	Early Collapse	28,700	10,600	10,600	89	Yes	Booster Straight

*On these predicted impact ranges assumed about 25,000 feet apogee for E4-1 and E4-2 configurations.

TABLE 8.2 (Continued)

FLIGHT	DATE	VEHICLE DESIGNATION	LAUNCH QE (DEG)	PREDICTED DART APOGEE (KFT)	ACTUAL DART APOGEE (KFT)	BOOSTER PERFORMANCE	BOOSTER APOGEE (FT)	ACTUAL BOOSTER IMPACT RANGE (FT)	PREDICTED BOOSTER IMPACT RANGE (FT)	IMPACT TIME (SEC)	BOOSTER STABLE	COMMENTS
4-28	26 JUN 73	E4-3	80	350	342	Good	28,200	10,300	8,700	90	Yes	Booster Straight
4-29	26 JUN 73	E4-3	80	350	Late Radar	Good	21,500	11,000	8,700	70	Yes	Booster Straight - Left Hook Impact 40° L of AZ Pred.
4-30	26 JUN 73	E4-3	80	350	340	Good	25,800	9,000	8,700	83	Yes	Booster Straight

*On the predicted impact ranges assumed about 25,000 feet apogee for E4-1 and E4-2 configurations.

TABLE 8.3

FLIGHT TEST SUMMARY – SUPER LOKI INSTRUMENTED DART VEHICLE

FLIGHT	DATE	VEHICLE DESIGNATION	LAUNCH QE (DEG)	PREDICTED DART APOGEE (KFT)	ACTUAL DART APOGEE (KFT)	PAYLOAD PERFORMANCE	BOOSTER APOGEE (FT)	ACTUAL BOOSTER IMPACT RANGE (FT)	PREDICTED BOOSTER IMPACT RANGE (FT)	IMPACT TIME (SEC)	BOOSTER STABLE	COMMENTS
3-15	29 MAY 73	F4-1	80	241	240	Noisy Telemetry for 8 Minutes, Then Clean (Damaged Starute)	23,800	9,406	11,600	80	Yes	
3-19	02 APR 73	F4-1	81	242	237	Possible Starute-Sonde Separation	No Booster Track	---				
4-20	21 JUN 73	F4-1	80	241	70	No Dart-Booster Separation		---				Coning Before Burnout
4-21	21 JUN 73	F4-1	80	241	235	Starute-Sonde Separation	No Booster Track	---				Booster Straight
4-22	21 JUN 73	F4-1	80	241	219	Starute-Sonde Separation	No Booster Track	---				Booster Straight
4-23	21 JUN 73	F4-1	80	241	230	Starute-Sonde Separation	26,000	8,900	9,900	83	Yes	Booster Straight
4-24	21 JUN 73	F4-1	80	241	230	Starute-Sonde Separation	24,600	9,700	9,900	81	Yes	Booster Straight

TABLE 8.4

FLIGHT TEST SUMMARY - VIPER 3A ROBIN DART VEHICLE

FLIGHT	DATE	VEHICLE DESIGNATION	LAUNCH QE (DEG)	PREDICTED DART APOGEE (KFT)	ACTUAL DART APOGEE (KFT)	PAYLOAD PERFORMANCE	BOOSTER APOGEE (FT)	ACTUAL BOOSTER IMPACT RANGE (FT)	PREDICTED BOOSTER IMPACT RANGE (FT)	IMPACT TIME (SEC)	BOOSTER STABLE	COMMENTS
1-4	27 SEP 72	E4.5-1	80	388	380	Good	25,900	12,500	16,100	82	Yes	Booster Straight
1-5	27 SEP 72	E4.5-1	80	388	397	Early Collapse	36,600	16,600	16,000	100	Yes	Booster Straight
1-6	02 OCT 72	E4.5-1	80	388	394	Good	34,000	18,100	18,300	105	Yes	Booster Straight
1-7	02 OCT 72	E4.5-1	80	388	39	---	27,800	8,900	18,300	227	No	Booster Fishtailing Late Dart Separation No Booster Fin Thermal Protection

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VIPER 3A STABLE BOOSTER VEHICLE DESCRIPTION

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VIPER 3A STABLE BOOSTER VEHICLE DESCRIPTION

General

The Viper 3A Stable Booster vehicle is a two-stage sounding rocket which consists of a Viper 3A solid-propellant rocket motor as the booster or first stage and a non-propulsive dart as the second stage. The Viper 3A rocket motor has relatively large fins which are thermally protected from aerodynamic heating and a heavy headcap-interstage to maintain booster stability after staging. The second stage is a 1.625-inch diameter Robin dart. The major dimensions and mass properties are listed in Table 1. The vehicle center-of-gravity and pitch moment-of-inertia versus flight time are shown in Figures 1 and 2.

Rocket Motor Characteristics

The Viper 3A rocket motor is a scaled-up version of the SDC Super Loki motor with the characteristics listed in Table 2. The thrust-time and pressure-time values are listed in Table 3 and the propellant weight-time is listed in Table 4.

Aerodynamic Data

The Viper 3A Dart first stage drag coefficient data are presented in Table 5. The second stage dart drag coefficient data are presented in Table 6. The normal force coefficient and center-of-pressure data are presented in Table 7 for the first stage and Table 8 for the second stage.

The expended booster normal force coefficient and center-of-pressure data are presented in Table 9.

The static stability margins for the first stage vehicle and second stage dart are plotted against flight time in Figures 3 and 4. The static stability margin for the expended booster is plotted in Figure 5.

Vehicle Performance

The Viper 3A Dart vehicle performance is summarized in Figures 6, 7, and 8. The launch velocity is 145 fps from the 14-foot helical rail, and the launch spin rate is 6.80 rps.

The expended booster stage performance is summarized in Figures 9, 10, and 11.

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Wind-Effects Data

The cumulative wind-weighting factors for the dart, together with the unit wind effect are presented in Figure 12. The booster wind effects data are presented in Table 10, with the cumulative wind-weighting curve presented in Figure 13.

Impact Dispersion Data

Impact dispersion data for both the dart second stage and the expended stable booster are presented in Table 11.

Ordnance Data

The Viper 3A Dart vehicle ordnance data are presented for all explosive and electroexplosive components in Table 12.

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TABLE 1

VIPER 3A DIMENSIONS AND MASS PROPERTIES

Overall Vehicle Length	138.6 in.
Rocket Motor Length	96.0 in.
Dart Length	48.2 in.
Rocket Motor Diameter	4.50 in.
Dart Diameter	1.63 in.
Motor Fin Span	9.50 in.
Dart Fin Span	4.62 in.
Dart Weight	13.50 lb.
Loaded Motor Weight	76.67 lb.
Expended Motor Weight	19.72 lb.
Dart CG From Nose Tip	22.00 in.
Loaded Motor CG from NEP	44.15 in.
Expended Motor CG from NEP	37.71 in.
Dart Pitch Moment-of-Inertia	0.450 slug-ft^2
Loaded Motor Pitch Moment-of-Inertia	11.486 slug-ft^2
Expended Motor Pitch Moment-of-Inertia	4.491 slug-ft^2
Dart Roll Moment-of-Inertia	0.001234 slug-ft^2
Loaded Motor Roll Moment-of-Inertia	0.04115 slug-ft^2
Expended Motor Roll Moment-of-Inertia	0.02011 slug-ft^2
Interstage Ballast Weight	4.00 lb.

Vehicle Mass Properties

Launch Weight	94.17 lb.
Burnout Weight	37.22 lb.
Launch CG Station	78.37 in.
Burnout CG Station	65.68 in.
Launch Pitch Moment-of-Inertia	24.758 slug-ft^2
Burnout Pitch Moment-of-Inertia	15.266 slug-ft^2
Launch Roll Moment-of-Inertia	0.04430 slug-ft^2
Burnout Roll Moment-of-Inertia	0.02405 slug-ft^2

Expended Booster Stage Mass Properties

Booster Stage Weight	23.72 lb.
Booster Stage CG Station	46.54 in.
Booster Stage Pitch Moment-of-Inertia	5.979 slug-ft^2
Booster Stage Roll Moment-of-Inertia	0.02419 slug-ft^2

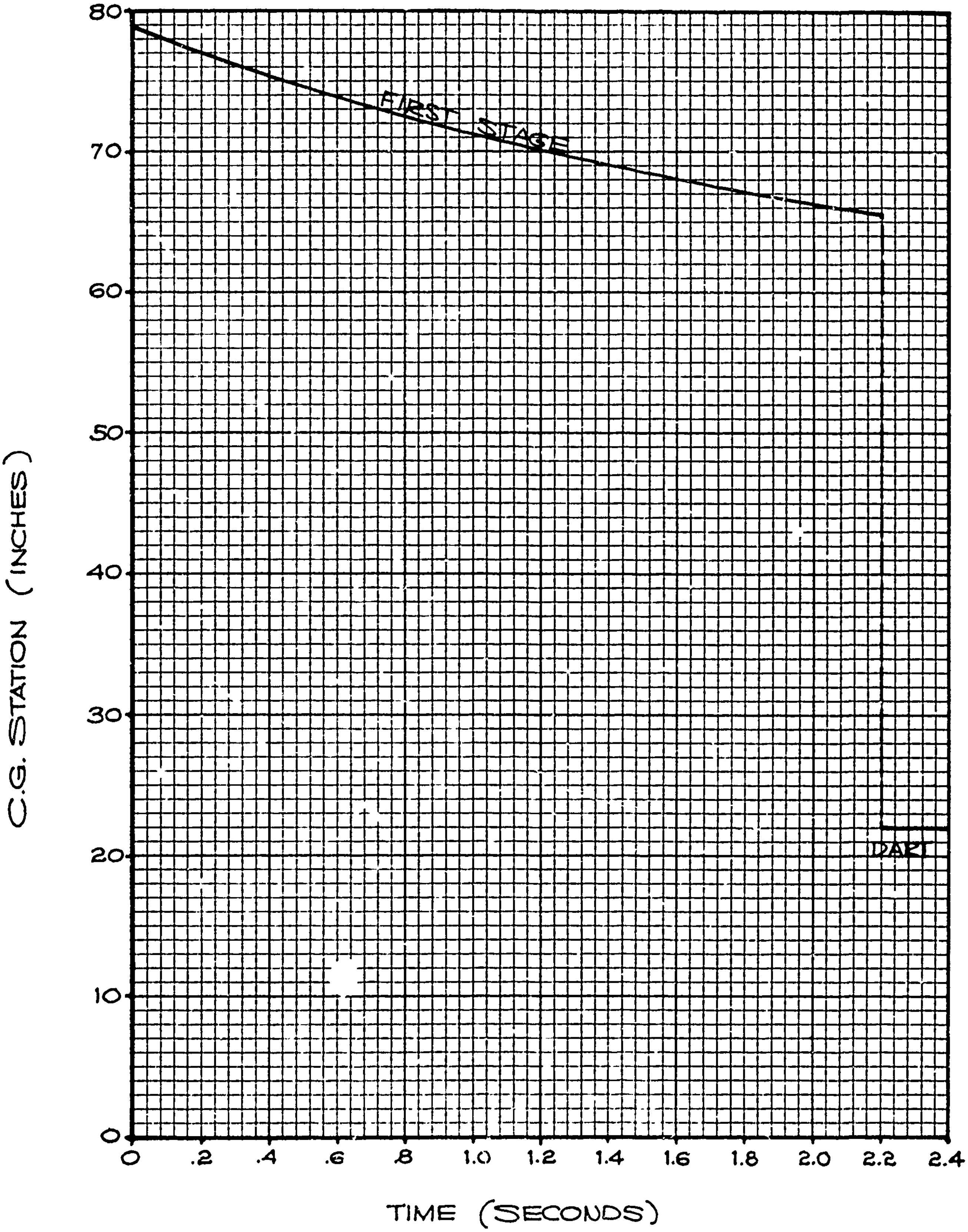

FIGURE 1 VIPER IIIA STABLE BOOSTER DART VEHICLE 1 5/8 DART /13.5 LB. CENTER-OF-GRAVITY

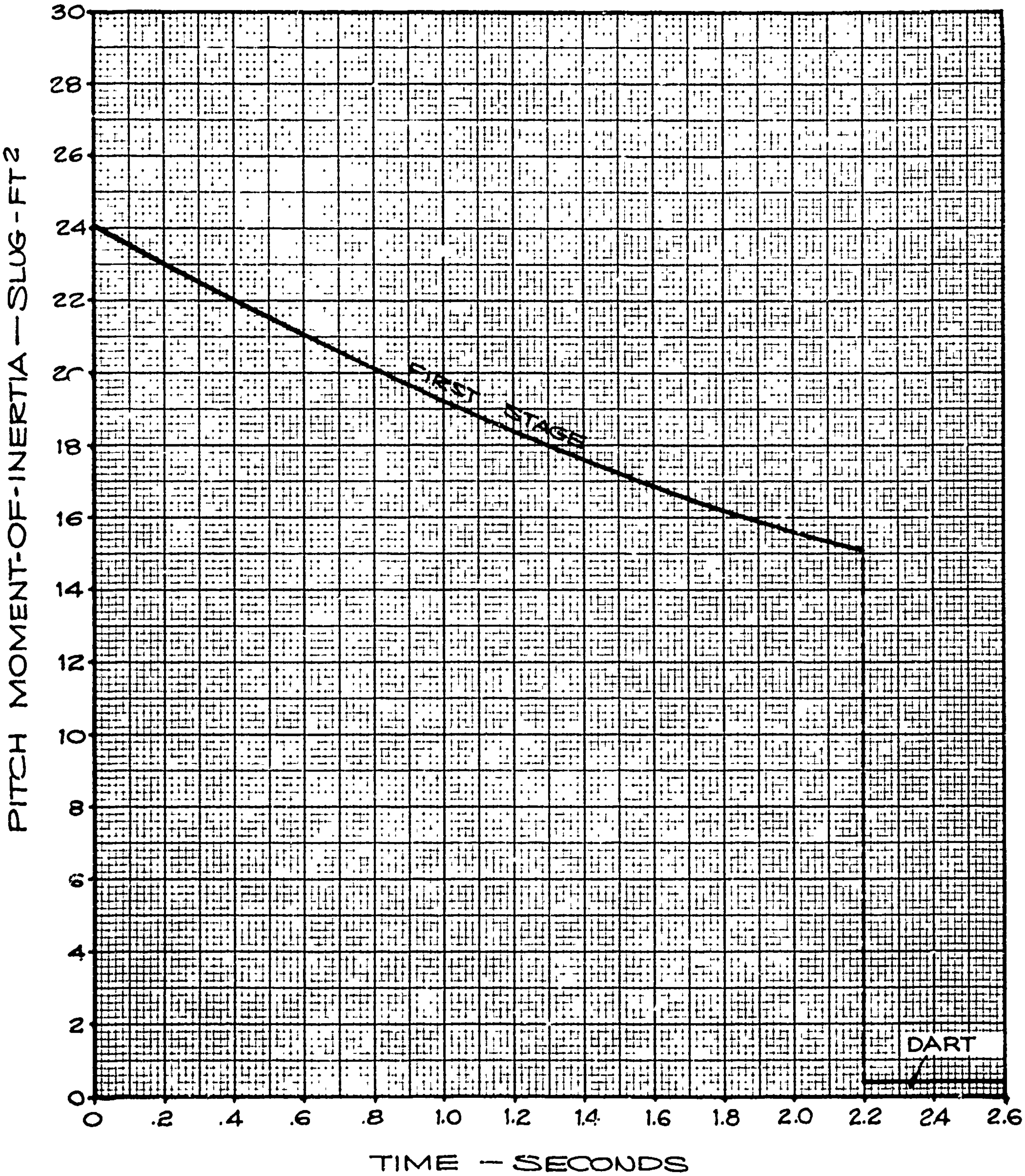

FIGURE 2 VIPER III A STABLE BOOSTER DART VEHICLE 1 5/8 DART/13 LB. PITCH MOMENT-OF-INERTIA

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TABLE 2

VIPER 3A ROCKET MOTOR DATA

Propellant Weight	56.98 lb.
Expended Weight (less fins and interstage)	15.75 lb.
Total Motor Weight	72.73 lb.
Throat Area	3.108 in^2
Exit Area	15.00 in^2
Nozzle Discharge Coefficient	0.940
Total Impulse	13058 lb-sec
Specific Impulse	229.2 sec.
Total Time	2.29 sec.
Action Time	2.21 sec.
Average Thrust	5908 lb.
Maximum Thrust	7410 lb.
Average Pressure	1395 psi
Exhaust Velocity	4496 fps

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TABLE 3

VIPER 3A THRUST AND PRESSURE VS. TIME
(SEA LEVEL)

TIME (SEC)	THRUST (LB)	PRESSURE (PSI)
0.0000	0.000	0.000
0.1000	4424.900	1064.097
0.2000	4566.790	1014.552
0.3000	4721.795	1004.880
0.4000	4930.645	1009.932
0.5000	5143.495	1022.360
0.6000	5368.687	1057.554
0.7000	5602.058	1094.642
0.8000	5897.233	1146.045
0.9000	6192.407	1197.448
1.0000	6473.346	1246.916
1.1000	6702.191	1287.906
1.2000	6866.176	1317.991
1.3000	6986.668	1341.443
1.4000	7078.452	1360.514
1.5000	7188.784	1377.292
1.6000	7311.772	1392.504
1.7000	7354.120	1395.605
1.8000	7376.685	1395.605
1.9000	7407.177	1395.605
2.0000	6346.914	1071.227
2.1000	4031.340	785.171
2.2000	1062.025	214.480

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TABLE 4

VIPER 3A PROPELLANT WEIGHT VS. TIME

TIME (SEC)	PROPELLANT WEIGHT (LBS)
0.0	56.98
0.10	55.99
0.2	54.0
0.3	51.94
0.4	49.80
0.5	47.57
0.6	45.24
0.7	42.80
0.8	40.26
0.9	37.57
1.0	34.77
1.1	31.85
1.2	28.84
1.3	25.77
1.4	22.65
1.5	19.48
1.6	16.27
1.7	13.02
1.8	9.75
1.9	6.47
2.0	3.43
2.1	1.12
2.24	0.0

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TABLE 5

VIPER 3A 1-5/8-INCH DIAMETER DART FIRST STAGE DRAG COEFFICIENTS

M	C_D
0.0	.45
0.5	.47
0.8	.48
0.81	.98
1.4	.98
1.5	.93
1.75	.82
2.0	.73
2.25	.67
2.5	.61
3.0	.535
3.5	.47
4.0	.42
4.5	.38
5.0	.35
5.5	.33
6.0	.31
7.0	.27

Drag Reference Area = 0.116 ft^2

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TABLE 6

VIPER 3A 1-5/8-INCH DIAMETER DART SECOND STAGE DRAG COEFFICIENTS

M	C_D
0.0	.35
0.9	.35
1.0	.5753
1.5	.5758
1.75	.4887
2.0	.4321
2.25	.3933
2.5	.3656
2.75	.3451
3.0	.3294
3.5	.3076
4.0	.2935
4.5	.2839
5.0	.2768
6.0	.2678
7.0	.2623
99.0	.2623

Drag Reference Area = 0.0107 ft^2

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TABLE 7

AERODYNAMIC DATA FOR VIPER 3A 1-5/8-INCH DIAMETER DART, FIRST STAGE

FIN SET NO.	1	AREA	47.50 SQ. IN.	CP STA.	132.50 IN.		
BODY NO.	2	LENGTH	86.00 IN.	DIAMETER	4.50 IN.	CP STA.	94.00
INSTG NO.	3	DMAX	4.50 IN.	DMIN	1.62 IN.	CP STA.	49.00
FIN SET NO.	4	AREA	10.85 SQ. IN.	CP STA	44.00 IN.		
BODY NO.	5	LENGTH	31.50 IN.	DIAMETER	1.62 IN.	CP STA.	28.75
OGIVE NO.	6	DIAMETER	1.62 IN.	CP STA	8.70		

REF. AREA 15.90 SQ. IN. NEP STA. 137.00 IN.

MACH 0.	CNALPHA (1/RAD)	CNALPHA (1/DEG)	CP LOC. (STATION)	CP LOC (IN FWD NEP)
1.50	16.86	0.2943	104.41	32.58
2.00	12.21	0.2131	99.98	37.01
2.50	10.14	0.1770	96.70	40.29
3.00	6.92	0.1558	94.06	42.93
3.50	8.11	0.1416	91.86	45.13
4.00	7.52	0.1313	89.98	47.01
4.50	7.08	0.1236	88.34	48.65
5.00	6.73	0.1175	86.91	50.08
5.50	6.45	0.1125	85.63	51.36
6.00	6.21	0.1085	84.49	52.50

TABLE 8

AERODYNAMIC DATA FOR VIPER 3A 1-5/8-INCH DIAMETER DART, SECOND STAGE

FIN SET NO.	4	AREA	10.85 SQ. IN.	CP STA.	44.00 IN.		
BODY NO.	5	LENGTH	31.50 IN.	DIAMETER	1.62 IN.	CP STA.	28.75
OGIVE NO.	6	DIAMETER	1.62 IN.	CP STA.	8.70		

REF. AREA 2.07 SQ. IN. NEP STA. 50.00 IN.

MACH 0.	CNALPHA (1/RAD)	CNALPHA (1/DEG)	CP LOC. (STATION)	CP LOC. (IN FWD NEP)
1.50	22.31	0.3894	39.76	10.23
2.00	15.66	0.2734	37.96	12.03
2.50	12.71	0.2218	36.56	13.43
3.00	10.97	0.1915	35.38	14.61
3.50	9.81	0.1712	34.36	15.63
4.00	8.97	0.1566	33.47	16.52
4.50	8.34	0.1455	32.66	17.33
5.00	7.84	0.1365	31.94	18.05
5.50	7.43	0.1298	31.29	18.70
6.00	7.10	0.1240	30.70	19.29

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TABLE 9

EXPENDED BOOSTER NORMAL FORCE COEFFICIENT

AND CENTER-OF-PRESSURE

MACH NO.	C_N (PER RAD)	$\bar{X}$ CP (IN STA)
1.2	72.96	90.92
1.5	44.62	89.04
2.0	38.77	88.31
2.5	23.45	84.68
3.0	19.62	82.88
3.5	17.06	81.24
4.0	15.21	79.70
4.5	13.81	78.27
5.0	12.71	76.92
5.5	11.83	75.65

Reference area = 15.90 $in.^2$

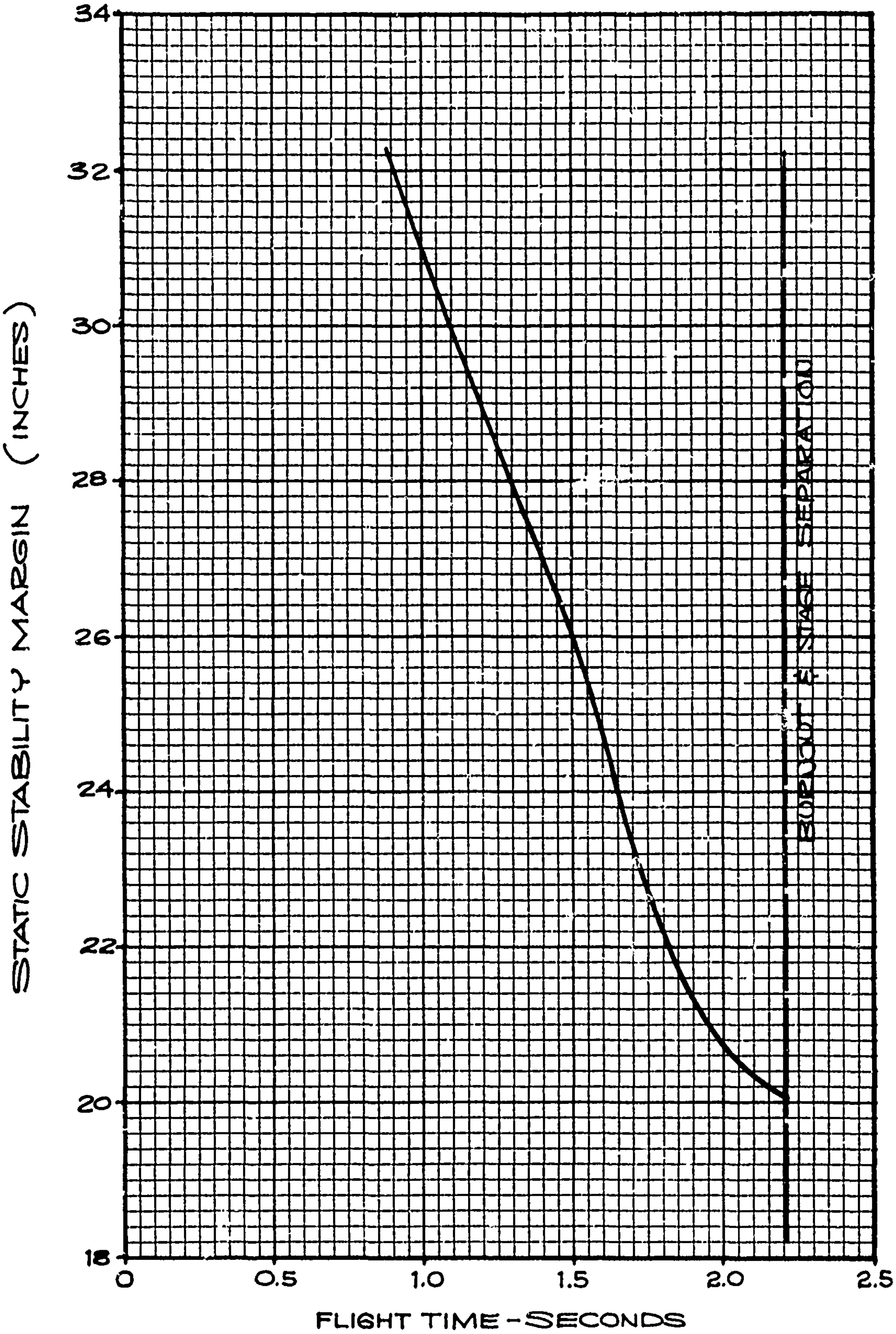

FIGURE 3 FIRST STAGE STABILITY MARGIN

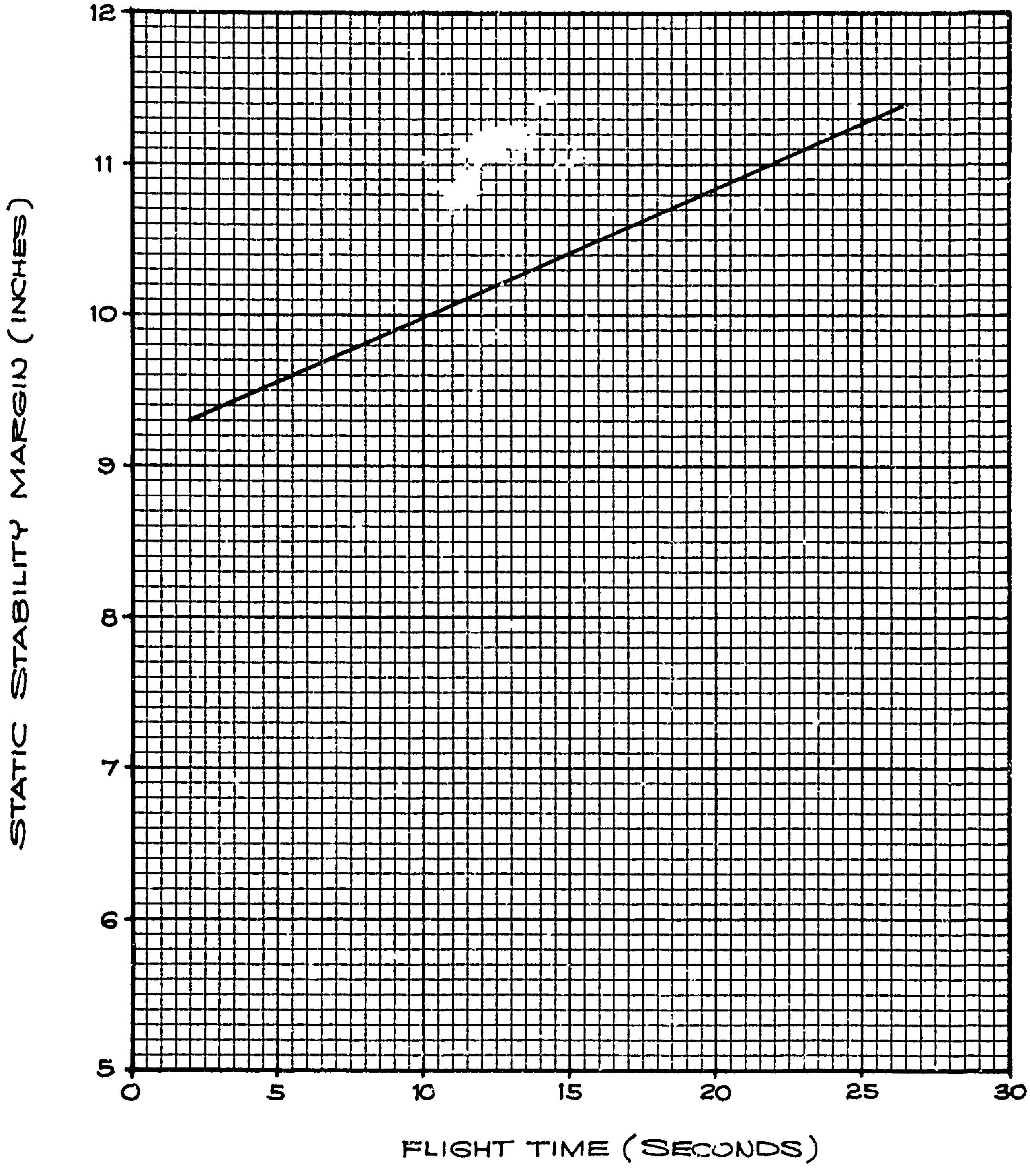

FIGURE 4 SECOND STAGE DART STATIC STABILITY MARGIN

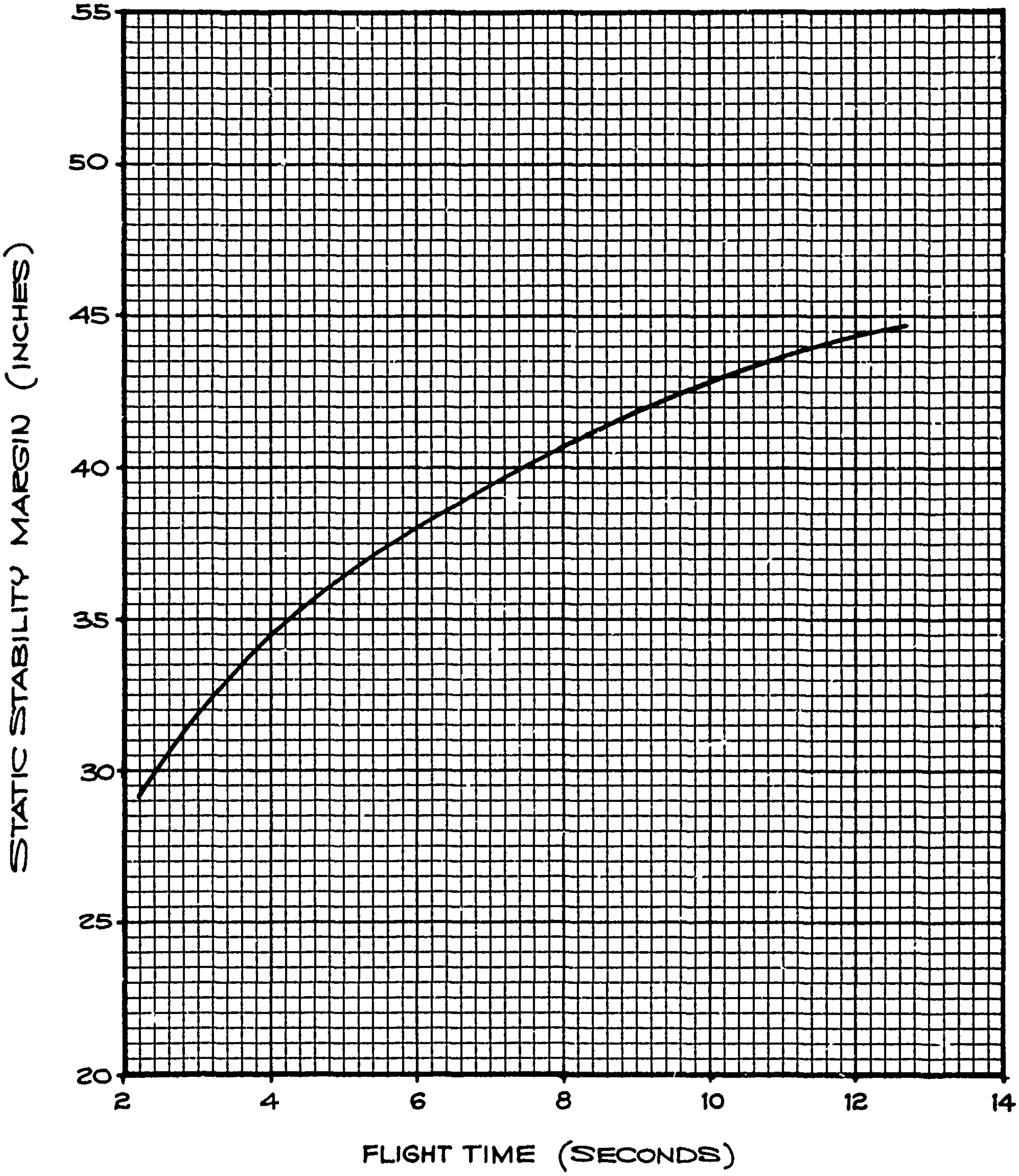

FIGURE 5 EXPENDED BOOSTER STATIC STABILITY MARGIN

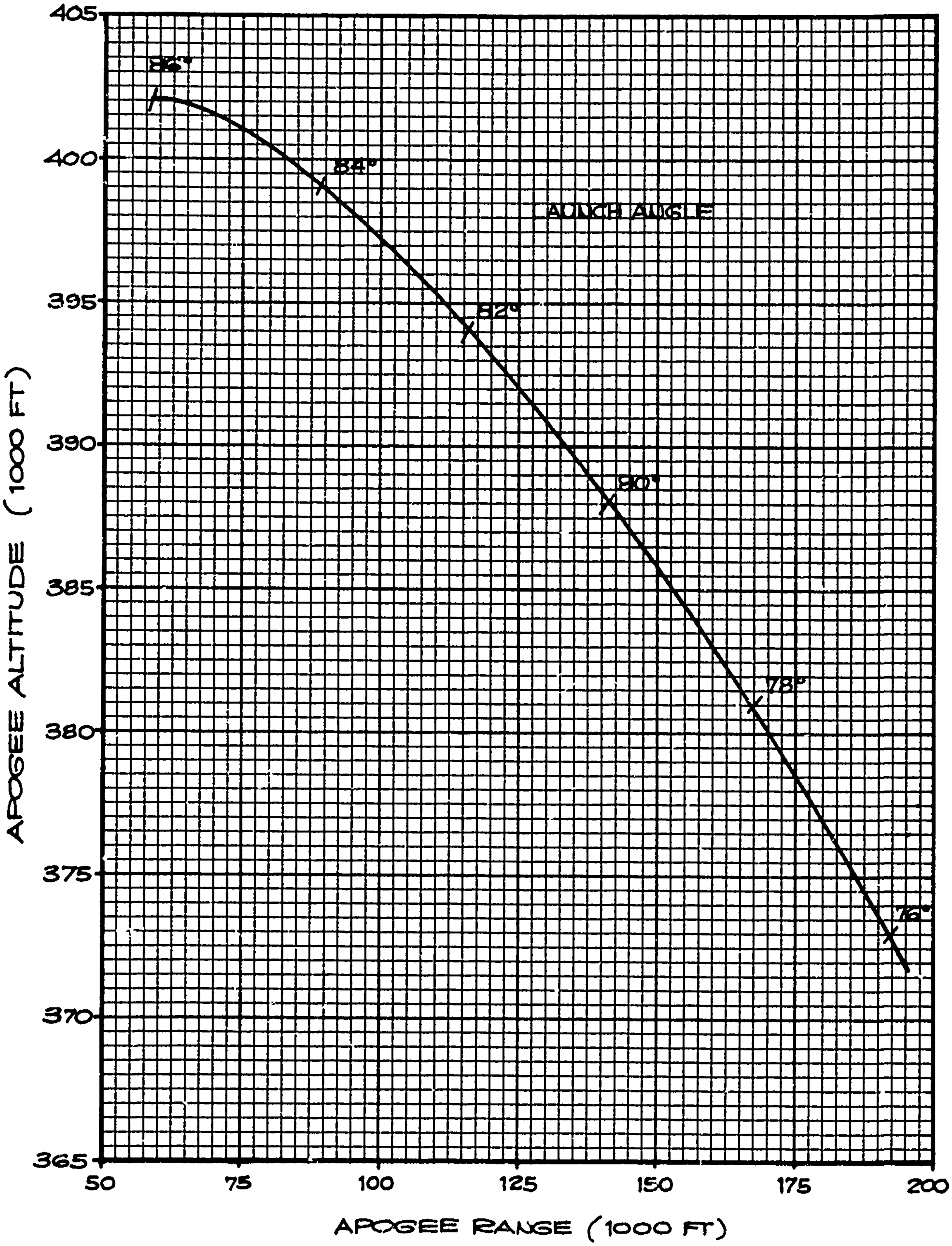

FIGURE 6 VIPER IIIA DART APOGEE PERFORMANCE

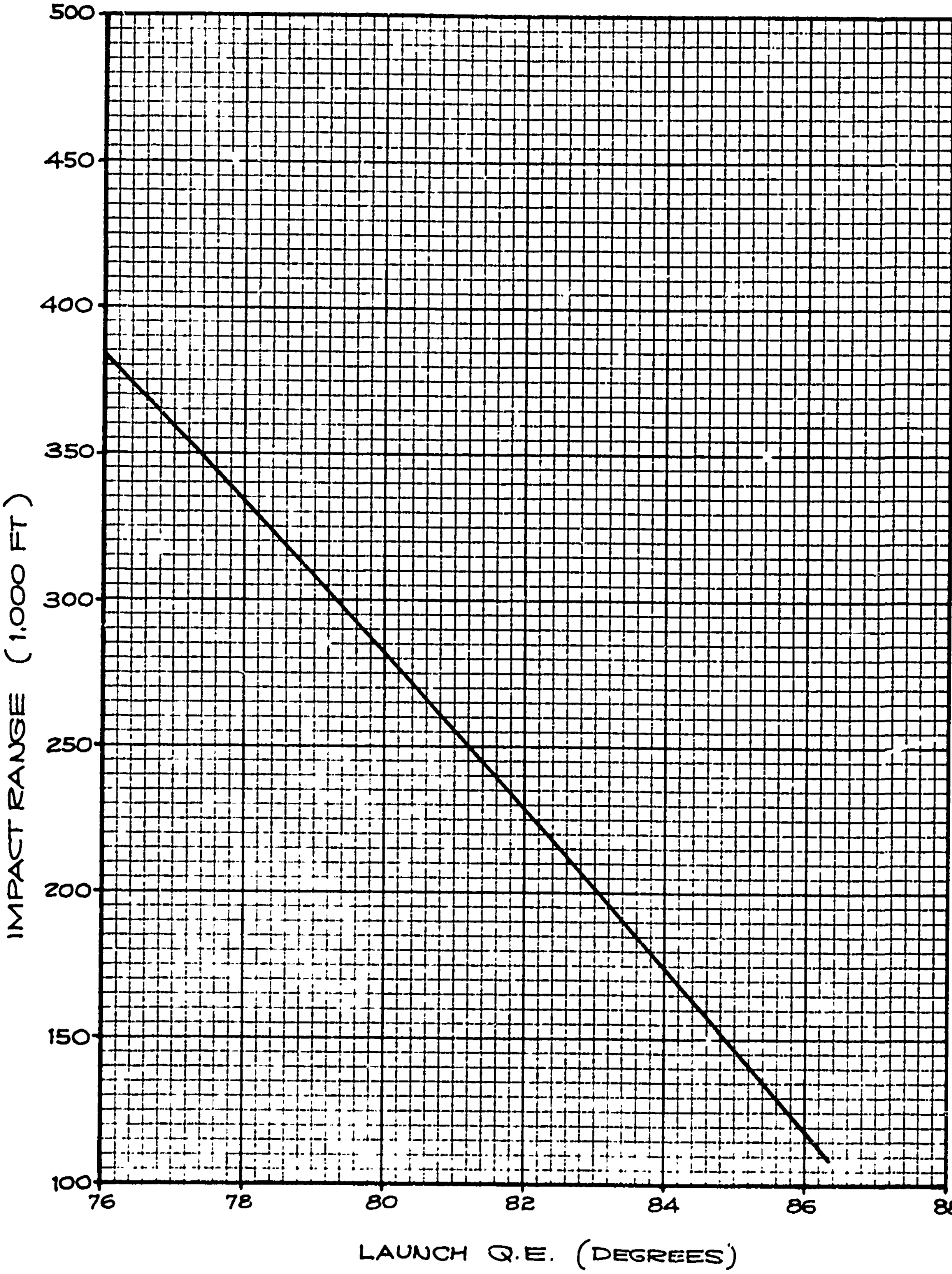

FIGURE 7 VIPER IIIA DART IMPACT RANGE

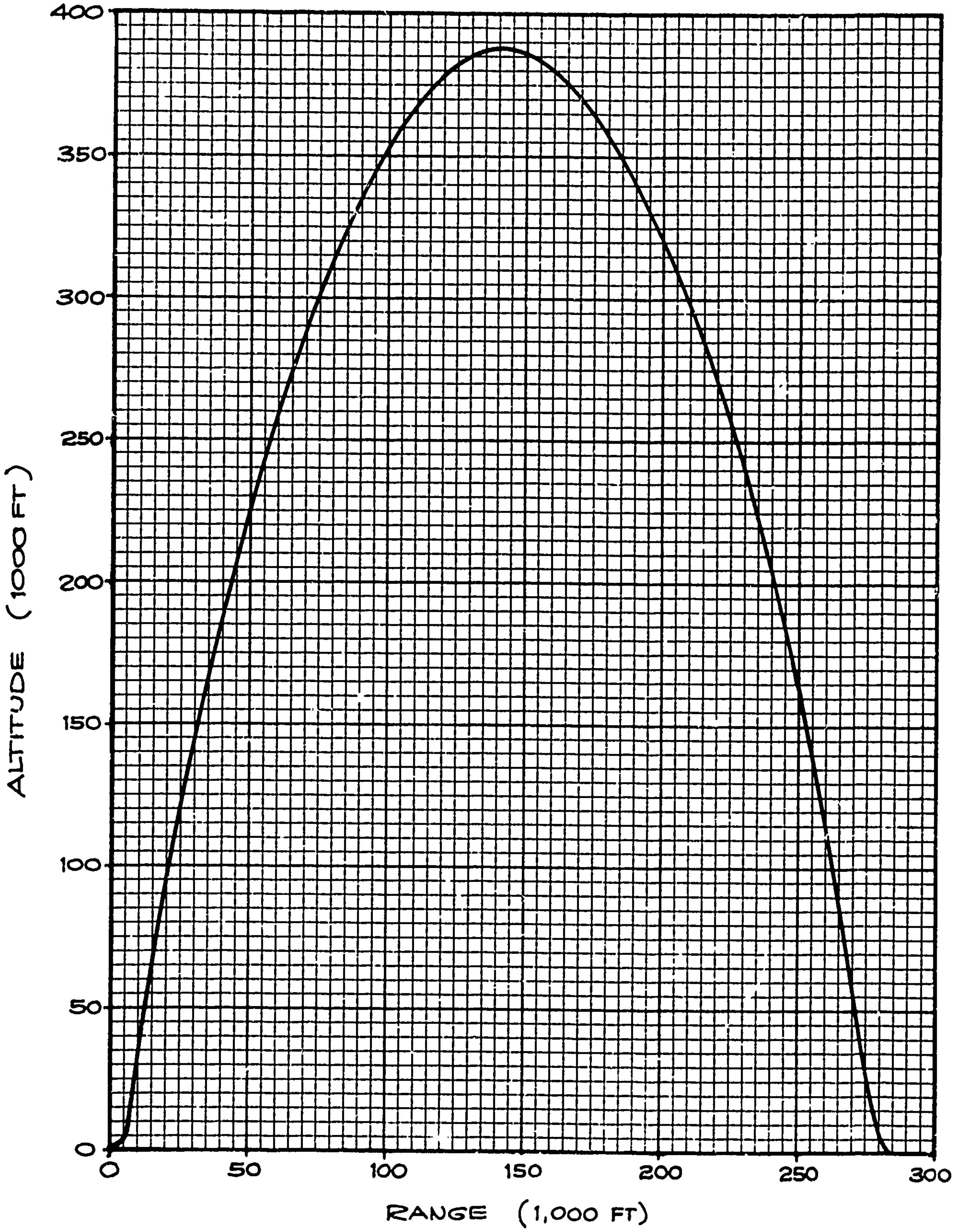

FIGURE 8 VIPER IIIA DART - NOMINAL TRAJECTORY, 80°Q.E., S.L. LAUNCH

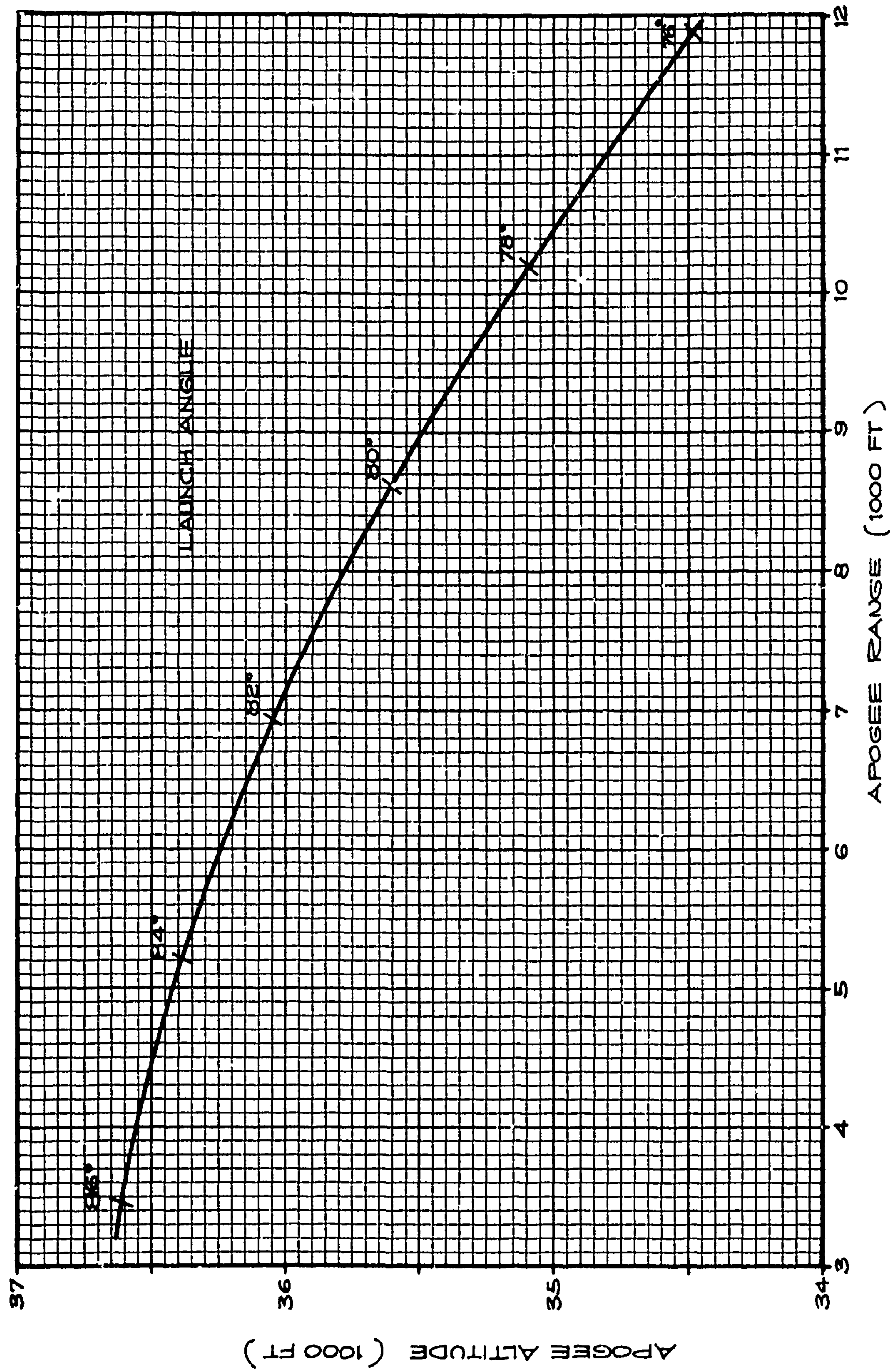

FIGURE 9 VIPER IIIA STABLE BOOSTER APOGEE PERFORMANCE

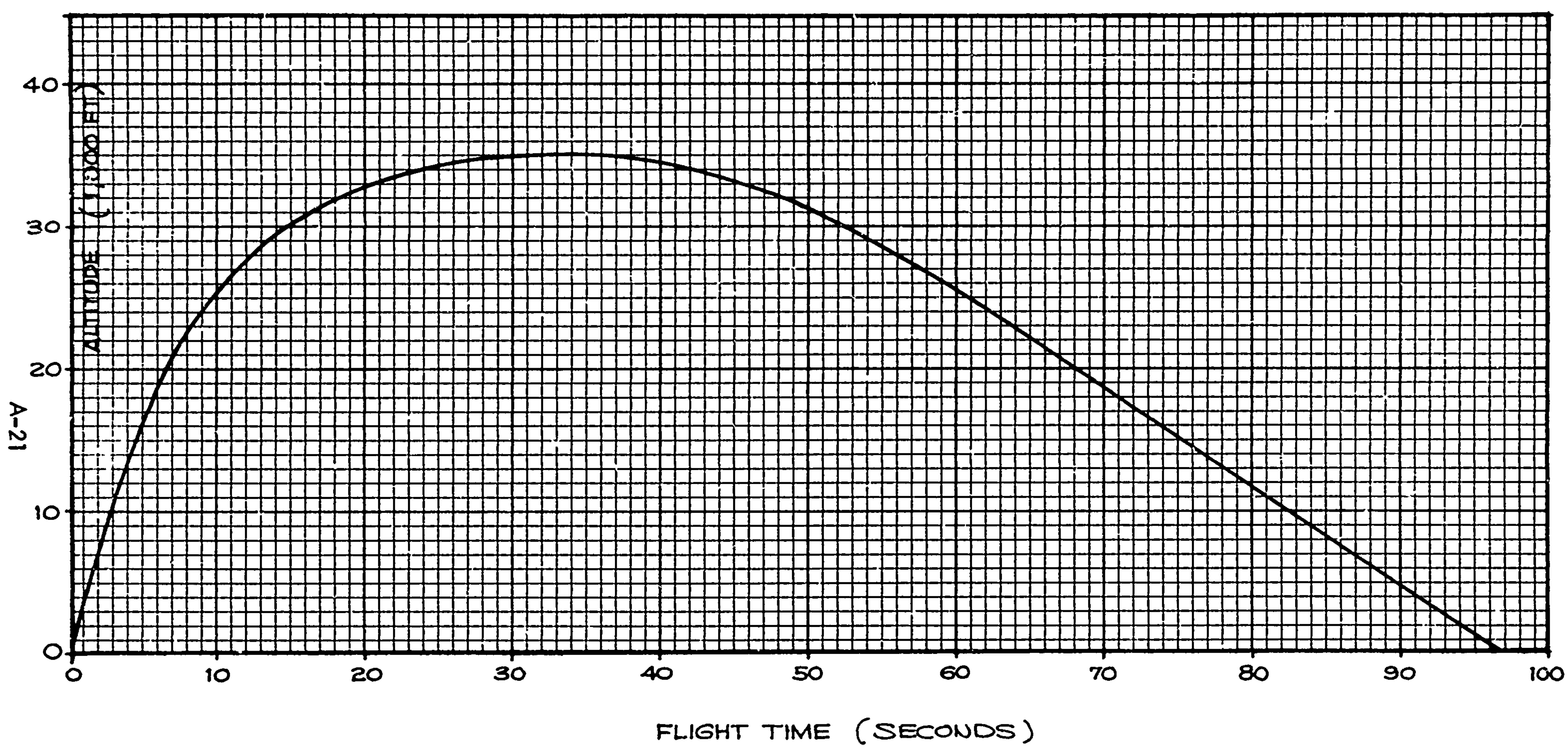

FIGURE 10 VIPER IIIA STABLE BOOSTER NOMINAL TRAJECTORY, 80° Q.E., S.L LAUNCH

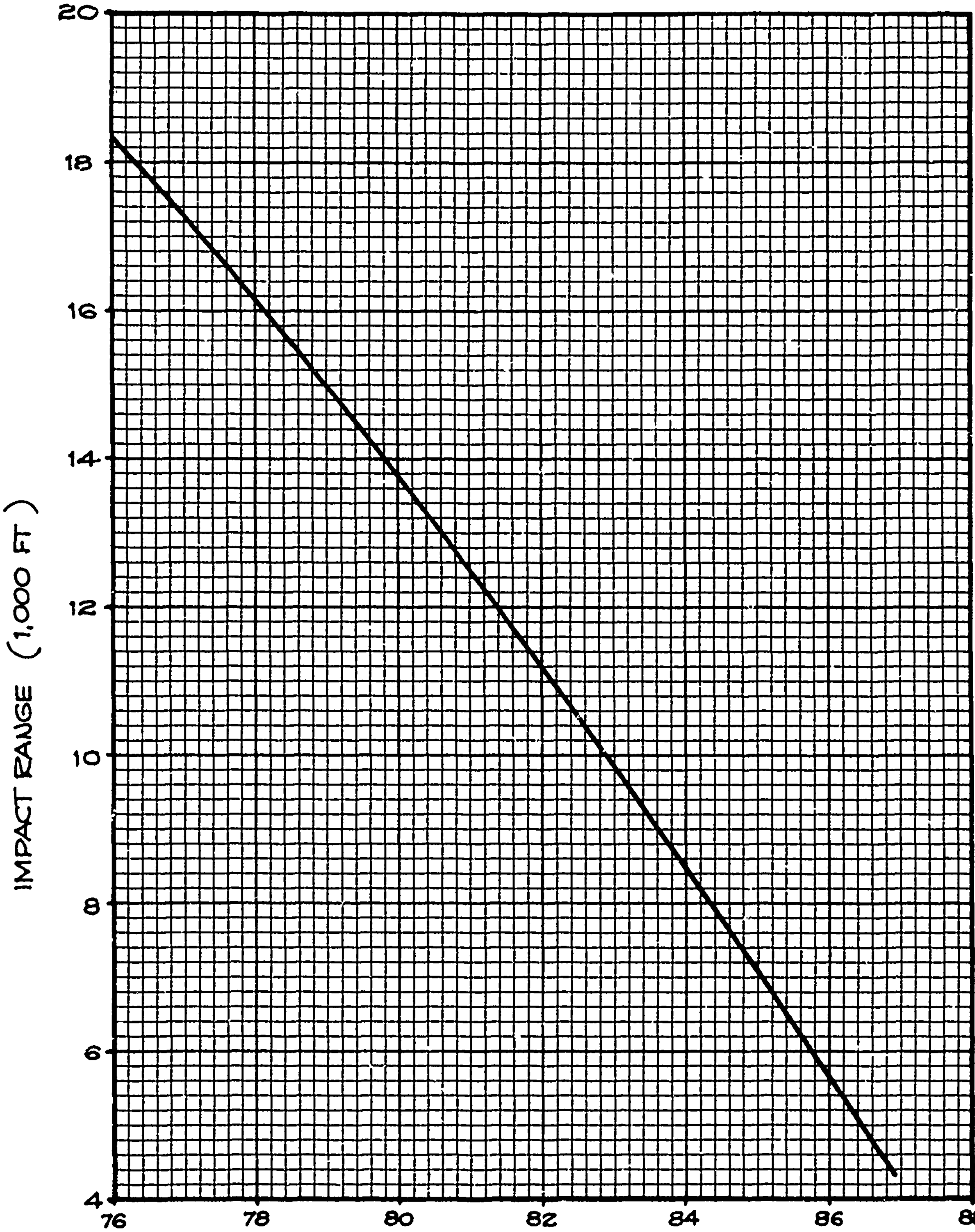

FIGURE 11 VIPER IIIA STABLE BOOSTER IMPACT RANGE VS. LAUNCH ANGLE

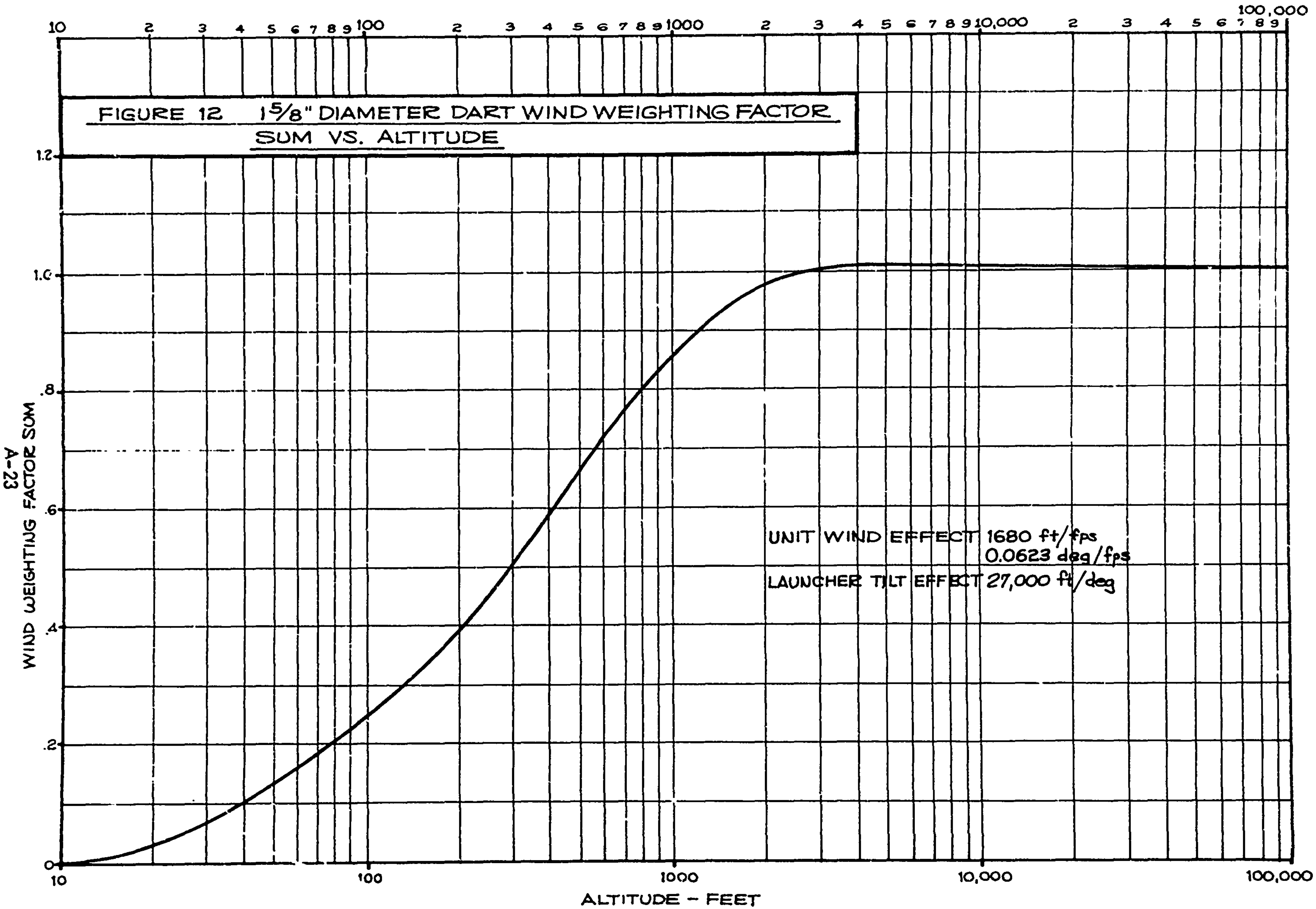
FIGURE 12 1 5/8" DIAMETER DART WIND WEIGHTING FACTOR SUM VS. ALTITUDE
UNIT WIND EFFECT 1680 ft/fps
0.0623 deg/fps
LAUNCHER TILT EFFECT 27,000 ft/deg
WIND WEIGHTING FACTOR SUM
ALTITUDE - FEET
10
100
1000
10,000
100,000
0
.2
.4
.6
.8
1.0
1.2

FIGURE 12

APPENDIX

TABLE 10

VIPER 3A BOOSTER WIND EFFECTS

Flight Time	97.0 Sec.
Unit Wind Drift Effect	99.0 Ft/fps
Tower Tilt Effect	1273 Ft/Deg.
Tower Tilt Correction Factor	0.0706 Deg/fps

Wind Weighting Factors:

ALTITUDE LAYER (FT)	FLIGHT TIME (SEC)	WIND WEIGHTING FACTOR	WIND WEIGHTING CUMULATIVE
0 - 5,000	7.5	0.0789	0.0789
5,000 - 10,000	8.0	0.0842	0.1631
10,000 - 15,000	8.5	0.0895	0.2526
15,000 - 20,000	9.0	0.0947	0.3473
20,000 - 25,000	10.0	0.1053	0.4526
25,000 - 30,000	13.5	0.1421	0.5947
30,000 - 35,000	38.5	0.4053	1.0000
	95.0	1.0000	

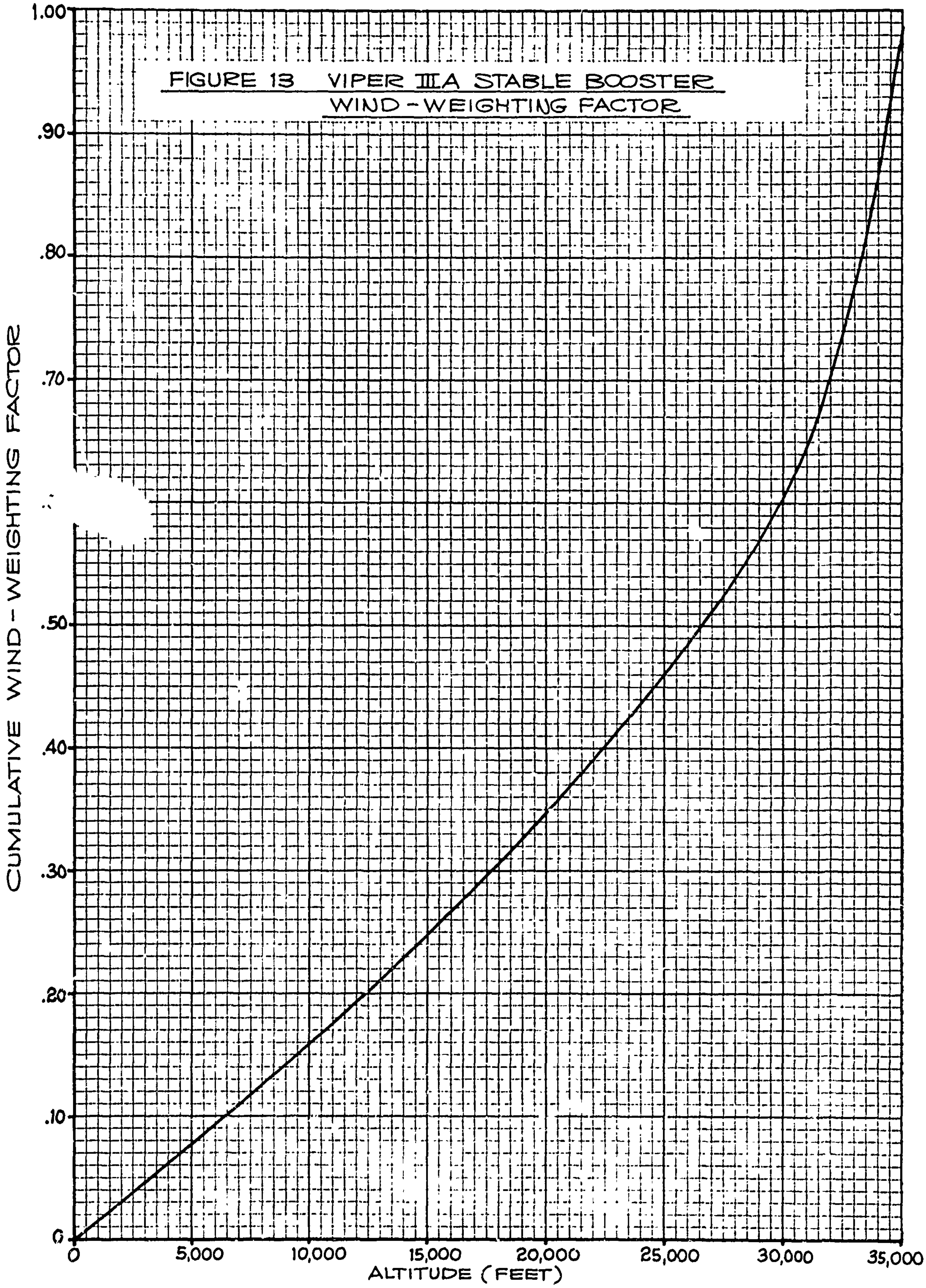
FIGURE 13 VIPER IIIA STABLE BOOSTER
WIND-WEIGHTING FACTOR
CUMULATIVE WIND-WEIGHTING FACTOR
ALTITUDE (FEET)
0
.10
.20
.30
.40
.50
.70
.80
.90
1.00
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000

TABLE 11

IMPACT DISPERSION DATA

VEHICLE STAGE	DART	BOOSTER
80° QE Impact Range	282,290 Ft.	13,604 Ft.
Maximum Three-Sigma Impact Dispersion Radius	28,000 Ft.	2,000 Ft.

TABLE 12

ORDNANCE DATA

ITEM	EXPLOSIVE		ELECTRICAL SQUIB CHARACTERISTICS		
	WEIGHT	TYPE	NO-FIRE	RESISTANCE	ALL-FIRE
Rocket Motor Propellant	56.98 Lb.	Class B Polysulfide Ammonium Perchlorate	---	---	---
Rocket Motor Igniter (2 squibs in parallel)	50 grams	Class B Cupric Oxide Aluminum Powder	1 watt/1 amp 5 minutes each squib	1.15 ohms ±0.15 ohms each squib	5.0 amps each squib
Dart Payload Separation Device with 145-second Time Delay	5 grams	Class C Boron-Potassium Nitrate	1 watt/1 amp 5-minute	-.05 ohms ± 0.25 ohms	5.0 amps

REFERENCES

1. Bollermann, Bruce and Walker, Robert L., Design, Development and Flight Test of the Super Loki Dart Meteorological Rocket Systems, Final Report, AFCRL-72-0382, 30 May 1972.