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PERFORMANCE SUMMARY FOR THE AEROBEE 150A SOUNDING ROCKET VEHICLE

REPORT NO. AST/E1R-13319

18 April 1961

This report was prepared by Vought Astronautics, a Division of Chance Vought Corporation, Dallas, Texas, under Contract No. NAS1-1013 administered by NASA, Langley Research Center.

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FOR THE

AEROBEE 150A
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Checked By

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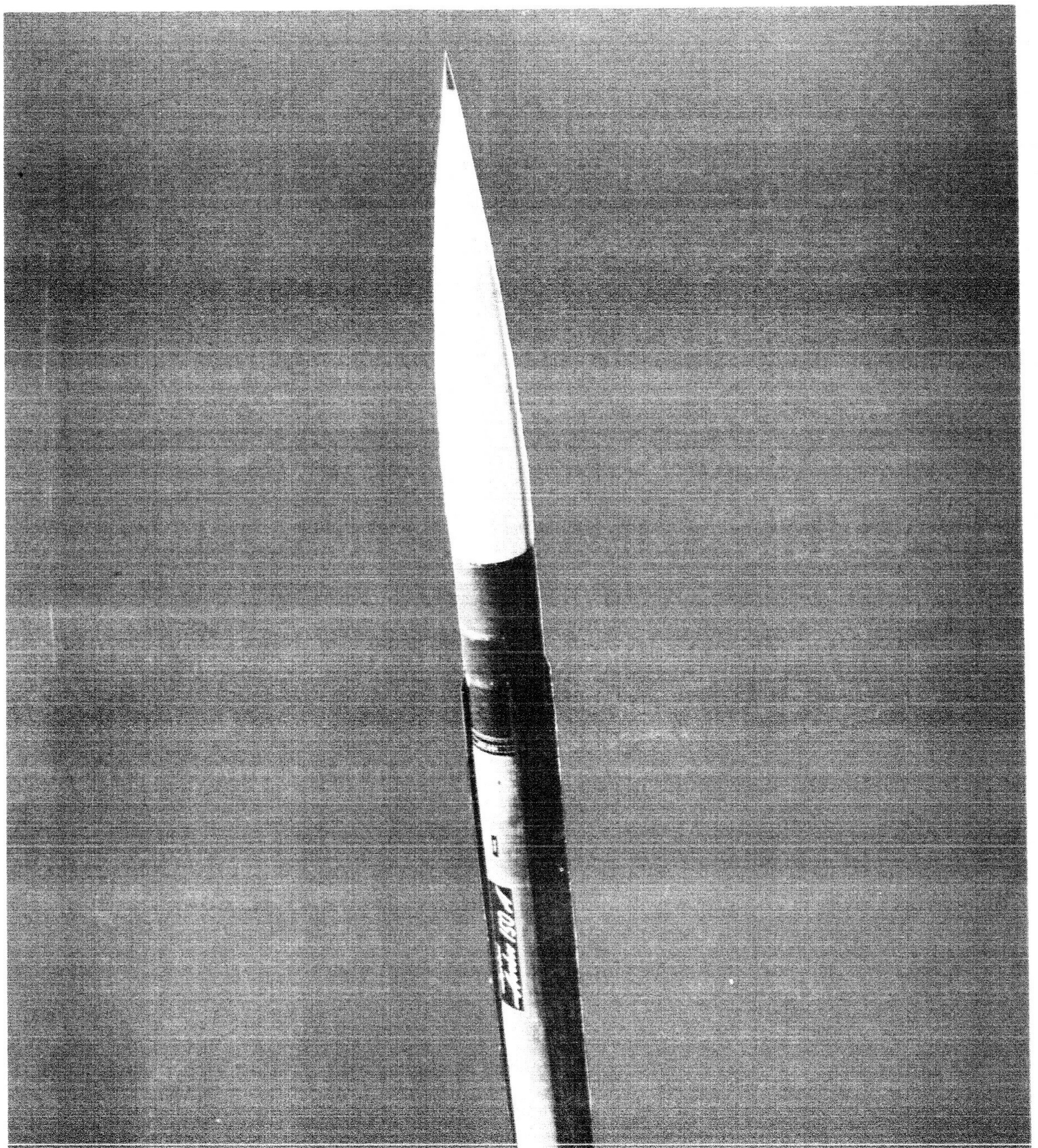

INTRODUCTION

This Sounding Rocket Handbook report is one of a series prepared by Vought Astronautics, a Division of Chance Vought Corporation, for the National Aeronautics and Space Administration under Contract No. NAS1-1013. This contract was administered by the Langley Research Center under the technical direction of Hal T. Baber, Jr., of the Vehicle Performance Branch, Applied Materials and Physics Division, Langley Research Center. This report presents data for one of the eighteen vehicle systems listed below:

Vehicle	Handbook No.	Vehicle	Handbook No.
Aerobee 100	AST/E1R-13318	Journeyman	AST/E1R-13327
Aerobee 150A	AST/E1R-13319	Journeyman B	AST/E1R-13328
Aerobee 300A	AST/E1R-13320	Jaguar	AST/E1R-13329
Arcas	AST/E1R-13321	Little Joe	AST/E1R-13330
Arcon	AST/E1R-13322	Nike-Asp	AST/E1R-13331
Exos	AST/E1R-13323	Nike-Cajun	AST/E1R-13332
Iris	AST/E1R-13324	Shotput	AST/E1R-13333
Jason	AST/E1R-13325	Skylark	AST//1R-13334
Javelin	AST/E1R-13326	Strongarm	AST/E1R-13335

In addition to the handbooks on each vehicle, the following handbooks have been prepared:

Handbook	Handbook Number
Summary Report	AST/E1R-13337
Rocket Motor Ballistic Data Report	AST/E1R-13336 (Confidential)
Cost and Reliability Summary	AST/E1R-13338

FOREWORD

The primary purpose of this report is to aid in the preliminary selection of a vehicle for a specific payload mission. Performance data in this report show a broad flight regime and have not been modified by restraint items such as aerodynamic heating, range safety and other detail factors. In fact, this cannot be done until a mission has been established. Thus, caution must be used in extracting detail data. It is believed that the information presented will allow the user to consider all the major aspects of the booster system, and will serve as a guide in payload system integration.

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NOMENCLATURE

REFERENCES

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VEHICLE DESCRIPTION

Summary

NAME OF VEHICLE	AEROBEE 150A
DESIGNATION	FOUR-FINNED AEROBEE HI
MANUFACTURER	AEROJET-GENERAL CORPORATION AZUSA, CALIFORNIA
NUMBER OF STAGES	2
LAUNCH WEIGHT (No Payload)	1947.5 POUNDS
OVER-ALL LENGTH	367.0 INCHES
MAXIMUM DIAMETER	15.0 INCHES
PRIME USERS	NASA
NET PAYLOAD	
NOMINAL	200.0
MINIMUM	100.0
MAXIMUM	300.0
VOLUME	4.75 CU. FT. (Ogive nose only - No extensions)
PERFORMANCE AT NOMINAL NET PAYLOAD	
APOGEE ALTITUDE (VERTICAL LAUNCH)	117 NAUTICAL MILES
ACCELERATION, MAX.	11 'g'

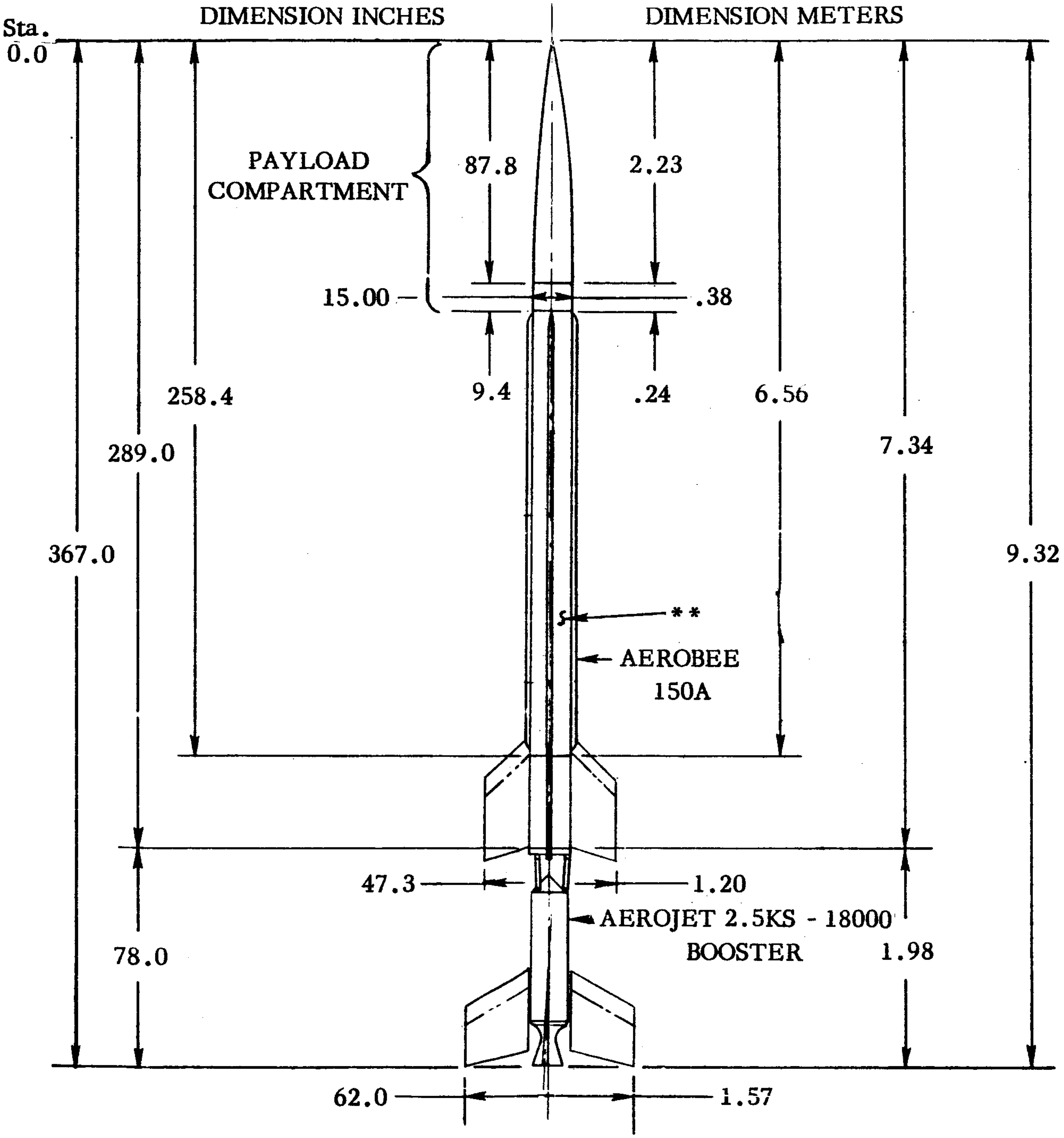
The vehicle assembly and staging weight is shown in Figure 1. Figure 2 shows the aerodynamic outline of the payload compartment used in the analysis and the associated usable volume.

Background

The Aerobee 150A (Model AJ60-13) is a 2-stage, free-flight, fin-stabilized sounding rocket. The first step motor is a 2.5 KS - 18000 solid propellant rocket. The second step motor assembly consists of an integral tank assembly for helium, fuel and oxidizer; a forward section with forward skirt, pressure regulator valve and associated components; and the aft section consisting of thrust chamber and aft structure assembly.

Four fixed fins, spaced 90 degrees apart around the aft end of each stage, provide aerodynamic stability. The first step fins are presently installed at 2°30' to impart a roll rate as the vehicle leaves the 4 rail launching tower. The second step fins are adjustable and may be canted from 0°0' to 0°20' for a desired roll rate. The two steps are position-mated by a thrust structure and remain together by overriding step one thrust. The step one motor is ignited at zero time. After .3 of a second the step two motor ignites and both burn for the remaining 2.2 seconds of stage one operation. At 2.5 seconds after launch the step one motor burns out and falls away. Stage two operation then, utilizes only the step two motor. The payload is mounted inside the 31-caliber, ogival nose structure and, if desired in a payload and camera extension. There have been over 10 firings of the 150A and 94 of its 3-finned counterpart, the Aerobee 150.

AEROBEE 150A



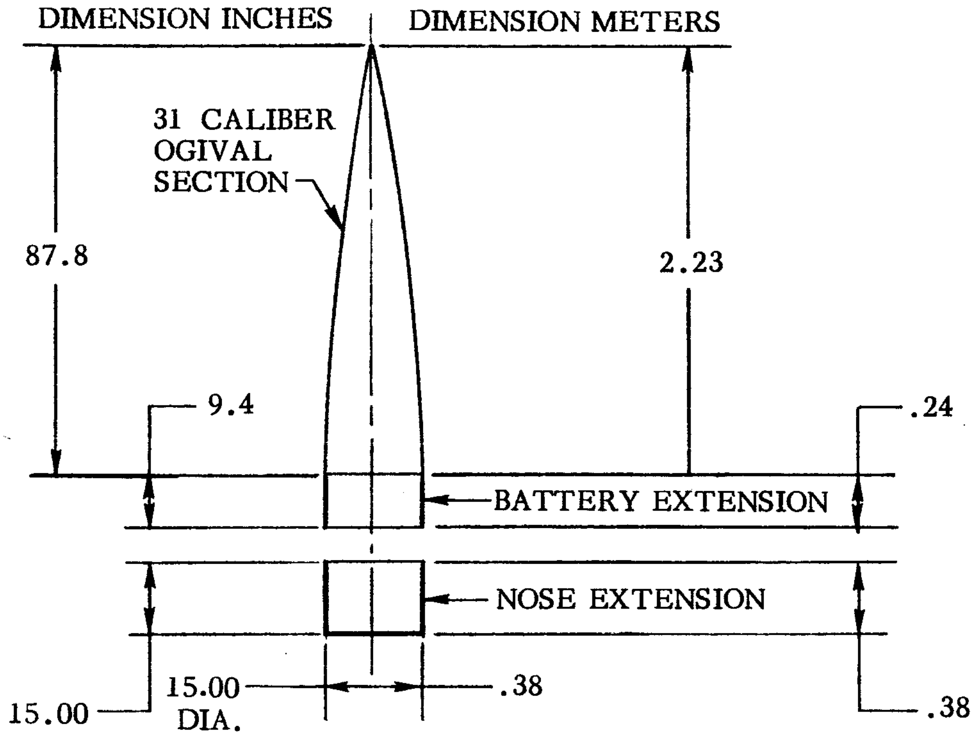
PERFORMANCE WEIGHTS
LESS PAYLOAD *

POUNDS		KILOGRAMS
1947.5	Launch	883.4
1916.1	Fire 2nd Stage	869.1
1638.4	B. O. 1st Stage	743.2
1300.4	Drop 1st Step	589.9
293.1	B. O. 2nd Stage	132.9

*Excluding optional payload extension weighing 14 pounds (9.4 inches long)

** Aerodynamic Reference Area = 1.228 ft^2

FIGURE 1 VEHICLE ASSEMBLY AND STAGING WEIGHTS



NOMINAL AVAILABLE PAYLOAD VOLUME
(INCLUDING EXTENSIONS) = 6.90 CU. FT. (.195 CU. METERS)

FIGURE 2 PAYLOAD COMPARTMENT

FLIGHT PERFORMANCE

The flight performance data presented in this study show a very broad flight regime for each vehicle. Modifications to the data have not been made to account for factors such as the launch site, launcher elevation limits, range safety, and vehicle-payload environment. Consideration of these factors usually results in limitations being placed on the flight regime. Some limitations may be removed by minor modifications, while in the case of range safety, the limitations may be revised with no modification as the vehicle builds a good operational history. If the flight performance data were based on a set of firm limits, it would be very difficult to extrapolate the data. However, it is rather easy to restrict, when necessary, the broad flight regime shown in Figures 3 thru 16. Some degree of caution must be exercised in interpreting these figures. For example, the vehicle was considered to be a "clean" aerodynamic configuration, i.e., it was assumed to have no external antennae, even though certain experiments in the past may have been flown with antennae. Further, all performance is presented for net payload, as defined in the Nomenclature.

Flight performance calculations were conducted with an IBM 704 digital computer using two degree of freedom analysis on a spherical, non-rotating earth. The routine considered aerodynamic coefficients to be Mach number-dependent, while thrust was computed by correcting time-dependent vacuum thrust for ambient pressure. The 1959 ARDC model atmosphere was used.

Trajectory

Actual gravity turn (sometimes called zero lift) trajectories were calculated for the Aerobee 150A vehicle at launch angles of 70, 80, and 88 degrees, each at net payloads of 100, 200, and 300 pounds. The launch angles were chosen to show a very broad flight regime, while the payloads were estimated to be minimum, nominal and maximum.

Dispersion

Aerobee 150A impact point dispersion data were not received from the vehicle contractor, so calculations were conducted on the IBM 704 digital computer, using the results of the performance calculations as a starting point. To achieve consistency with the other vehicles in the study, the following values were used as one sigma variations at burnout:

a. Pitch flight path angle, ± 2°
b. Yaw flight path angle, ± 2°
c. Velocity, ± 1 percent

Trajectories were computed from burnout to impact for each of these conditions for an 85° launch angle and a nominal payload. Dispersion was then calculated as the root mean square of the individual contributions. Step one dispersion was not considered, since step one range to impact is small. The dispersion radius for step two is thus approximately 13 nautical miles.

The dispersion data presented here are too small if arbitrary winds at launch are considered. Since wind dispersion can be a very serious problem for an unguided vehicle of this type, detailed study would be required.

Actual and Ideal Velocity

Incremental actual and ideal velocity as a function of payload are shown in Figure 17 and Figure 18, while Figure 19 shows both this data, at a nominal payload, and the velocity losses due to drag and gravity. All this information is presented for an 88° launch angle. Incremental actual velocity was obtained directly from the computer runs. Incremental ideal velocity was computed in the standard manner;

$$\Delta V_{ID} = (I_{sp})_{AVG} \; g_s \ln \mu$$

where average specific impulse was determined by integration of the thrust-time trace from the computer runs, and dividing the result by the consumed weight.

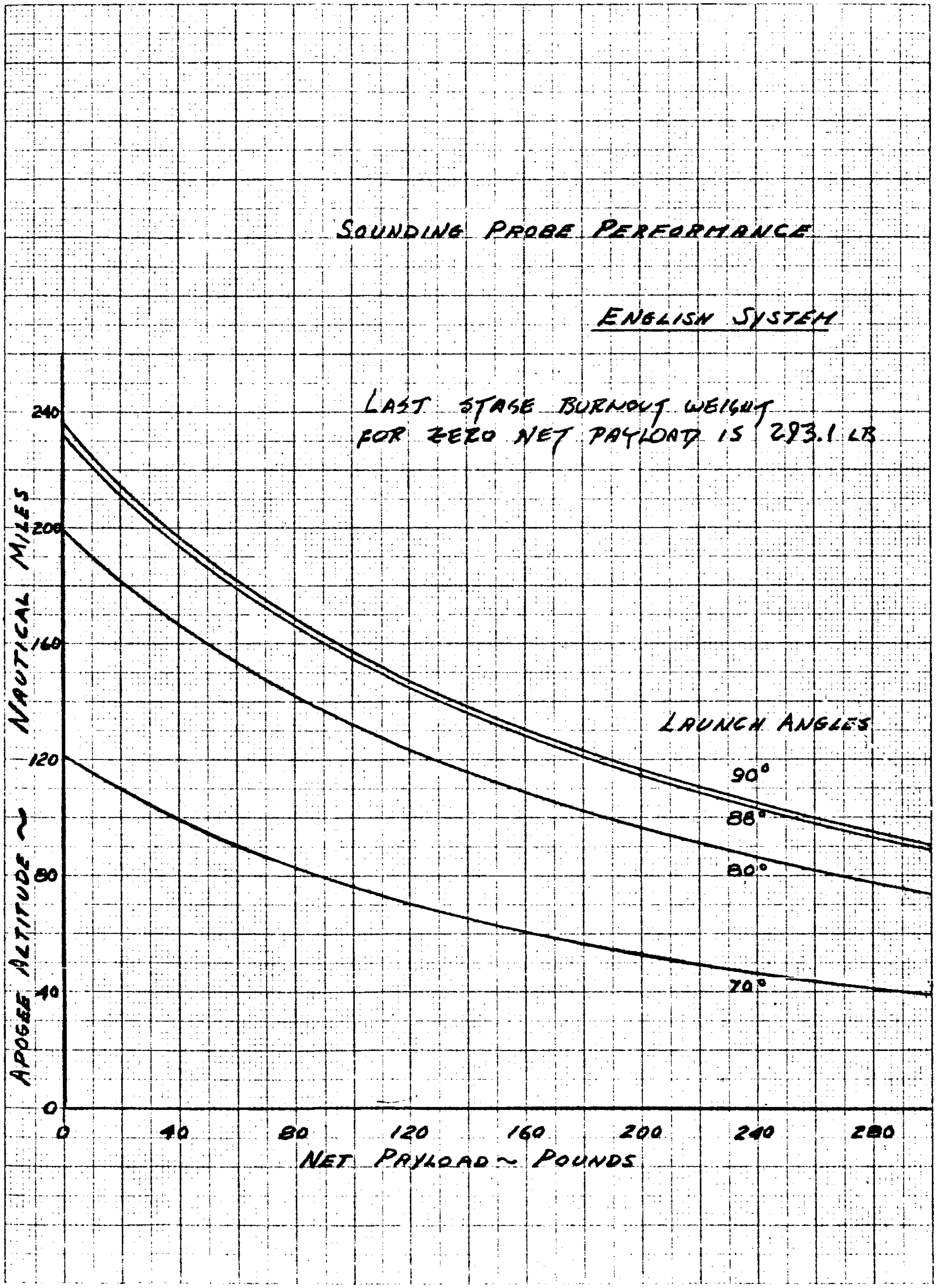


FIGURE 3 SOUNDING PROBE PERFORMANCE (ENGLISH SYSTEM)

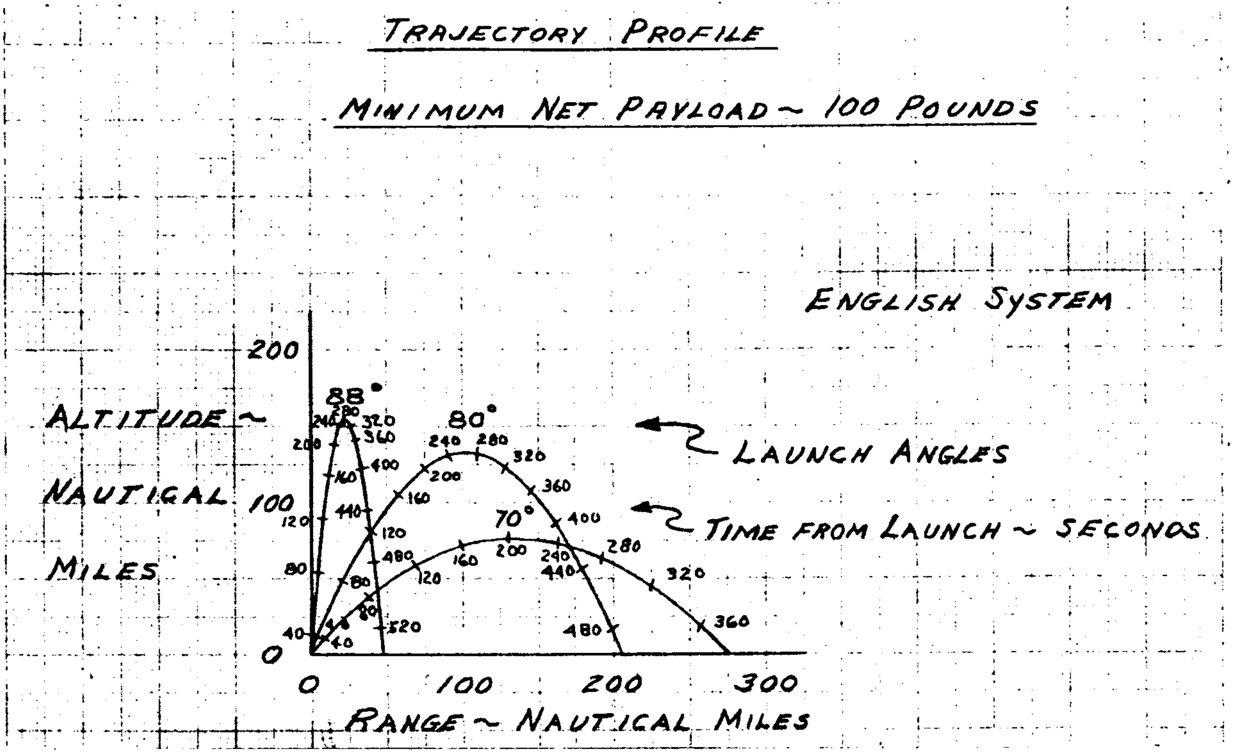


FIGURE 4 TRAJECTORY PROFILE, MINIMUM NET PAYLOAD 100 POUNDS (ENGLISH SYSTEM)

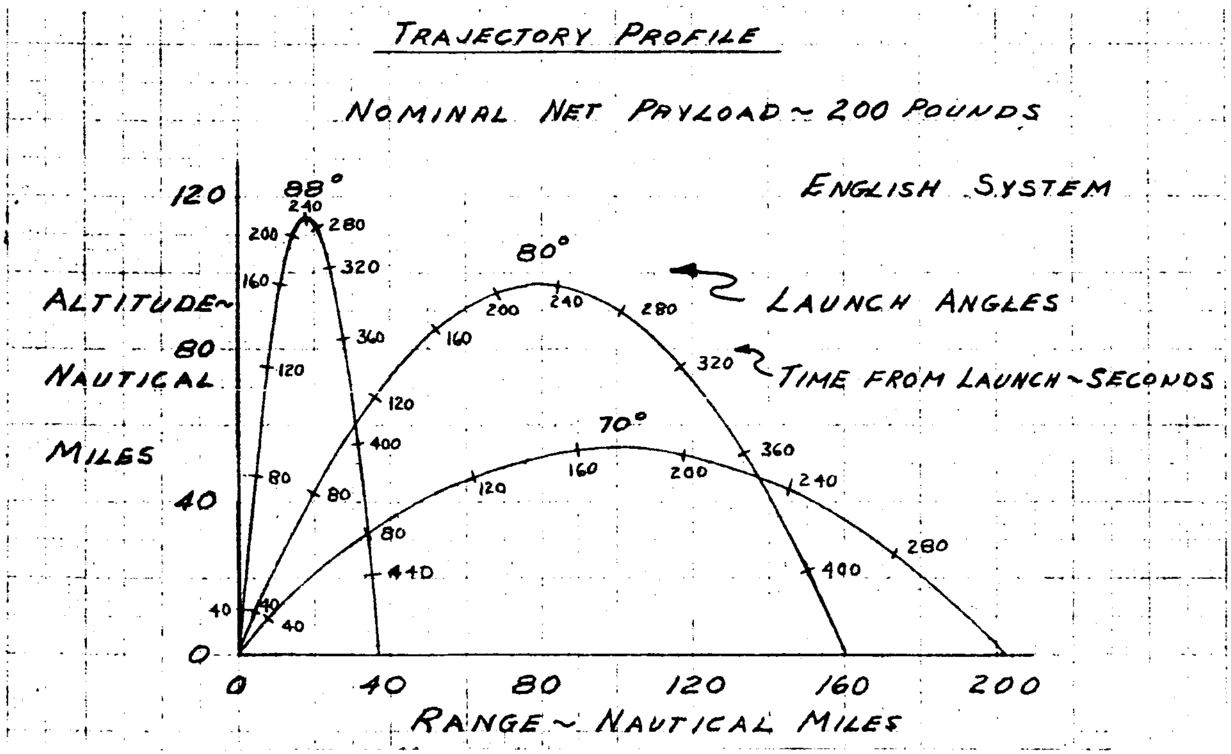


FIGURE 5 TRAJECTORY PROFILE, NOMINAL NET PAYLOAD 200 POUNDS (ENGLISH SYSTEM)

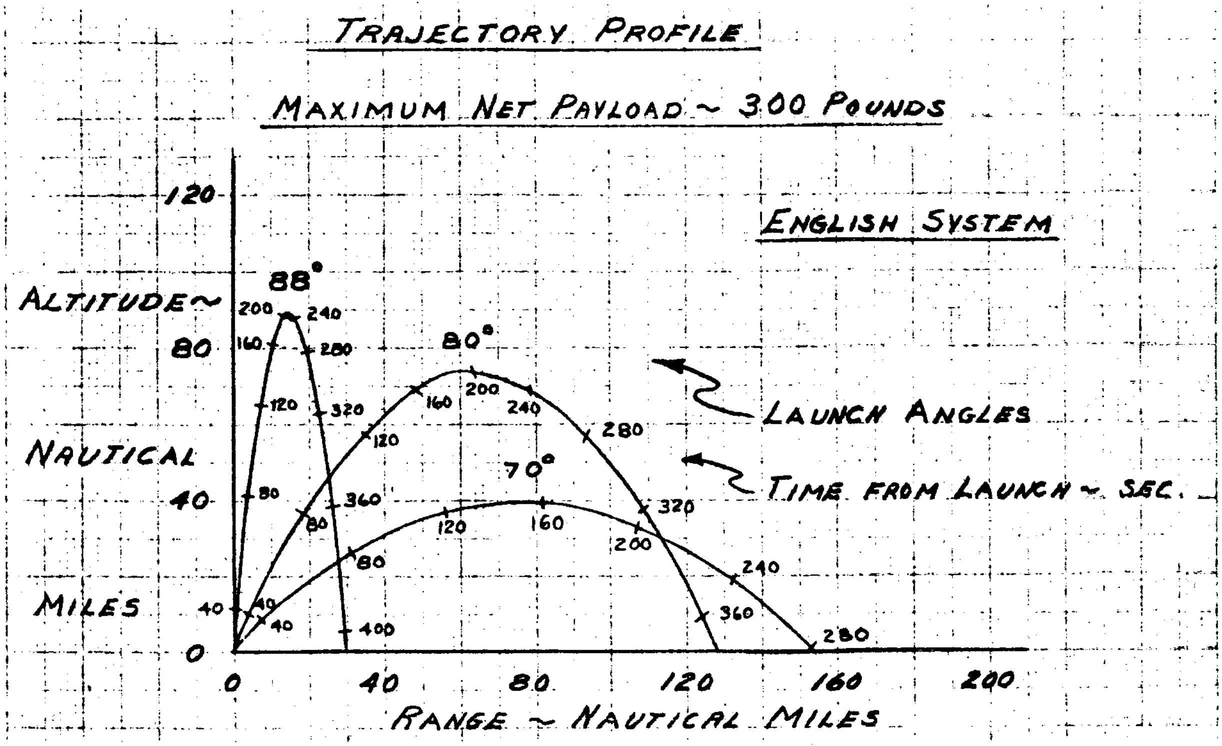


FIGURE 6 TRAJECTORY PROFILE, MAXIMUM NET PAYLOAD 300 POUNDS (ENGLISH SYSTEM)

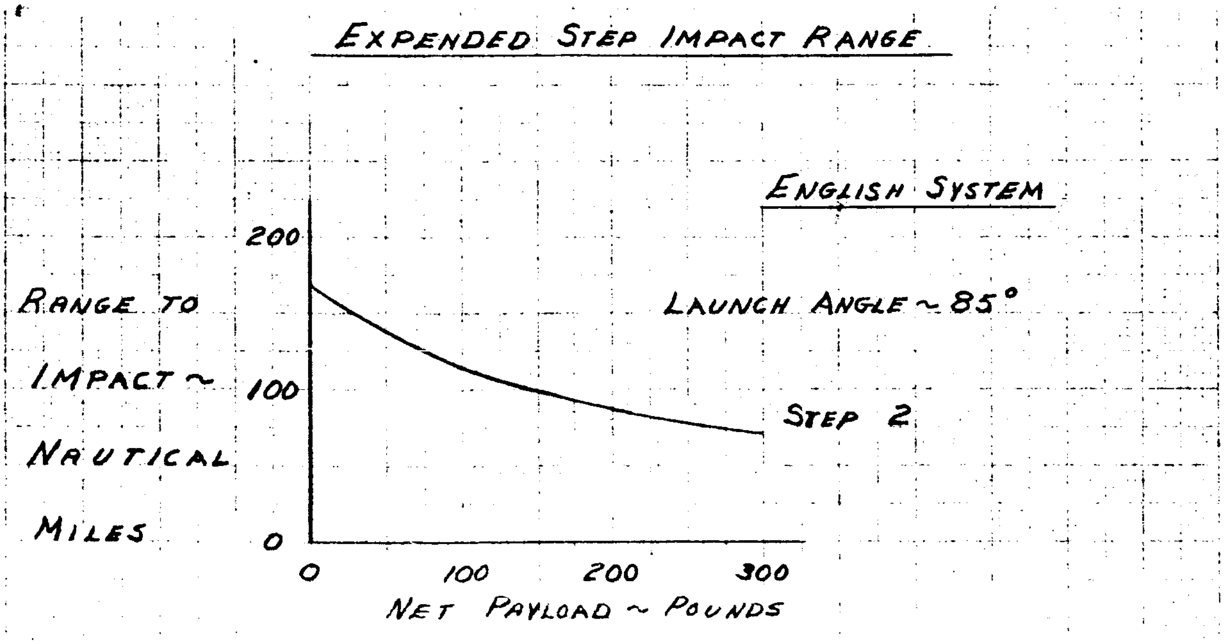


FIGURE 7 EXPENDED STEP IMPACT RANGE (ENGLISH SYSTEM)

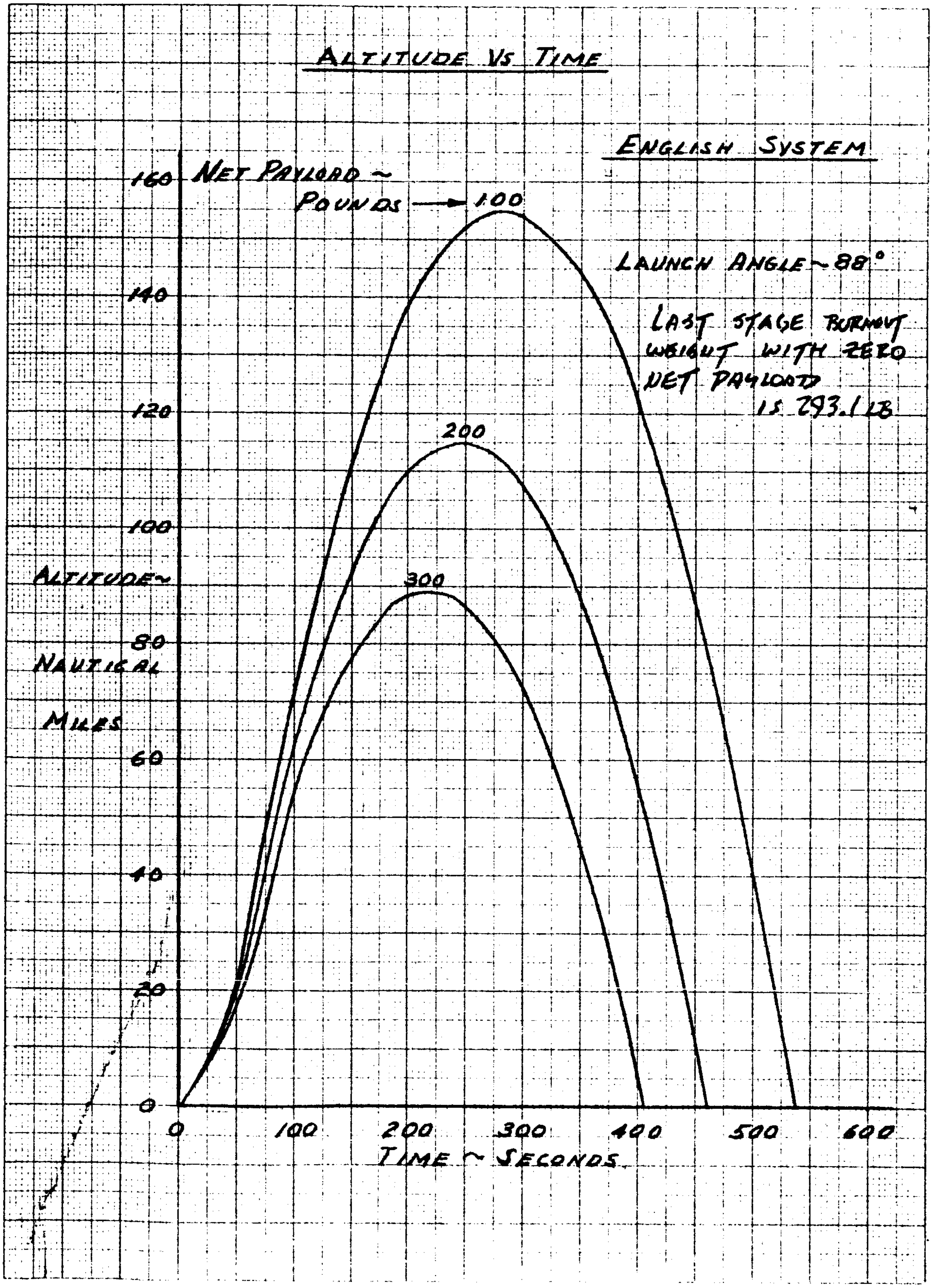


FIGURE 8 ALTITUDE VS. TIME (ENGLISH SYSTEM)

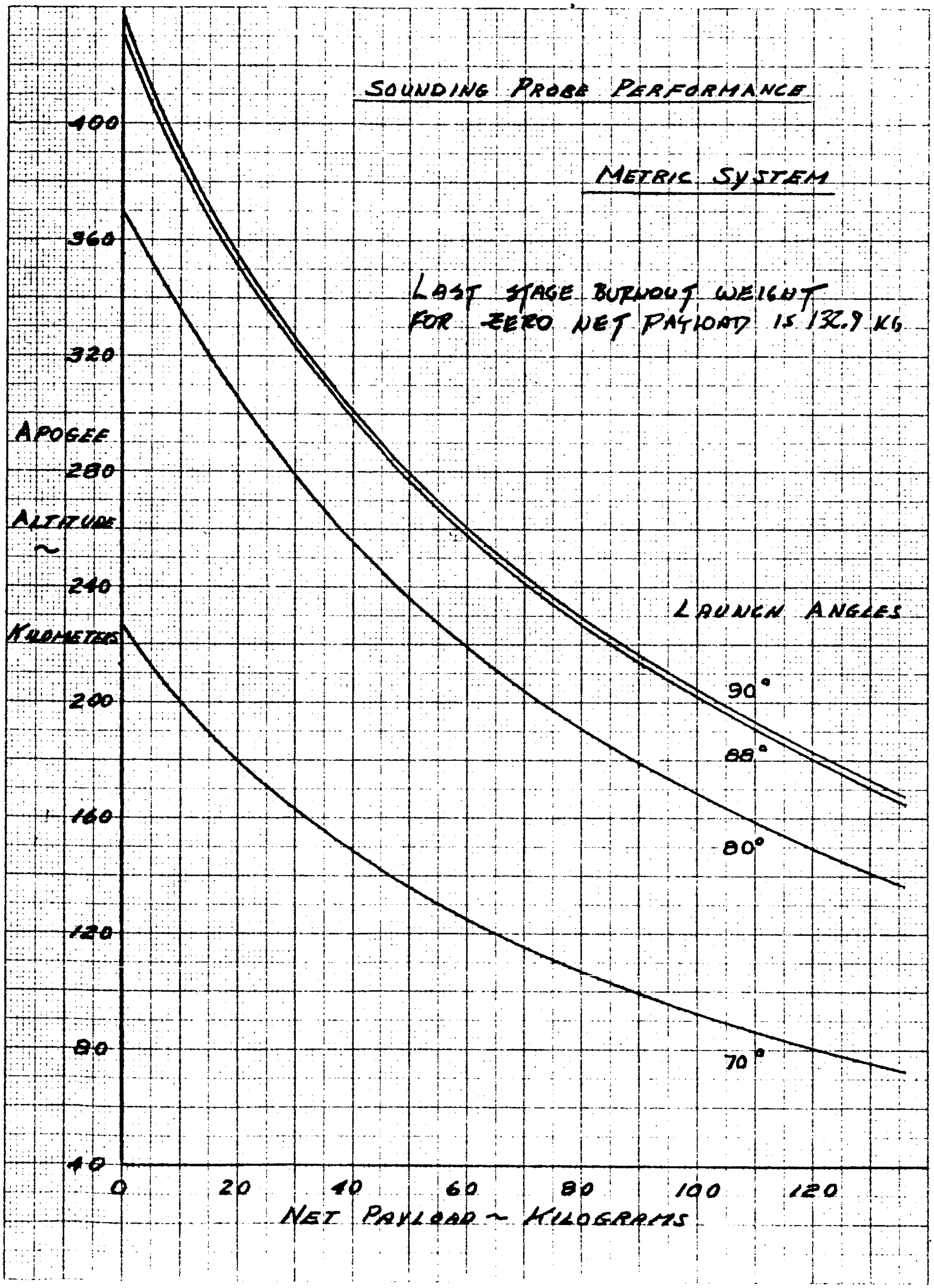


FIGURE 9 SOUNDING PROBE PERFORMANCE (METRIC SYSTEM)

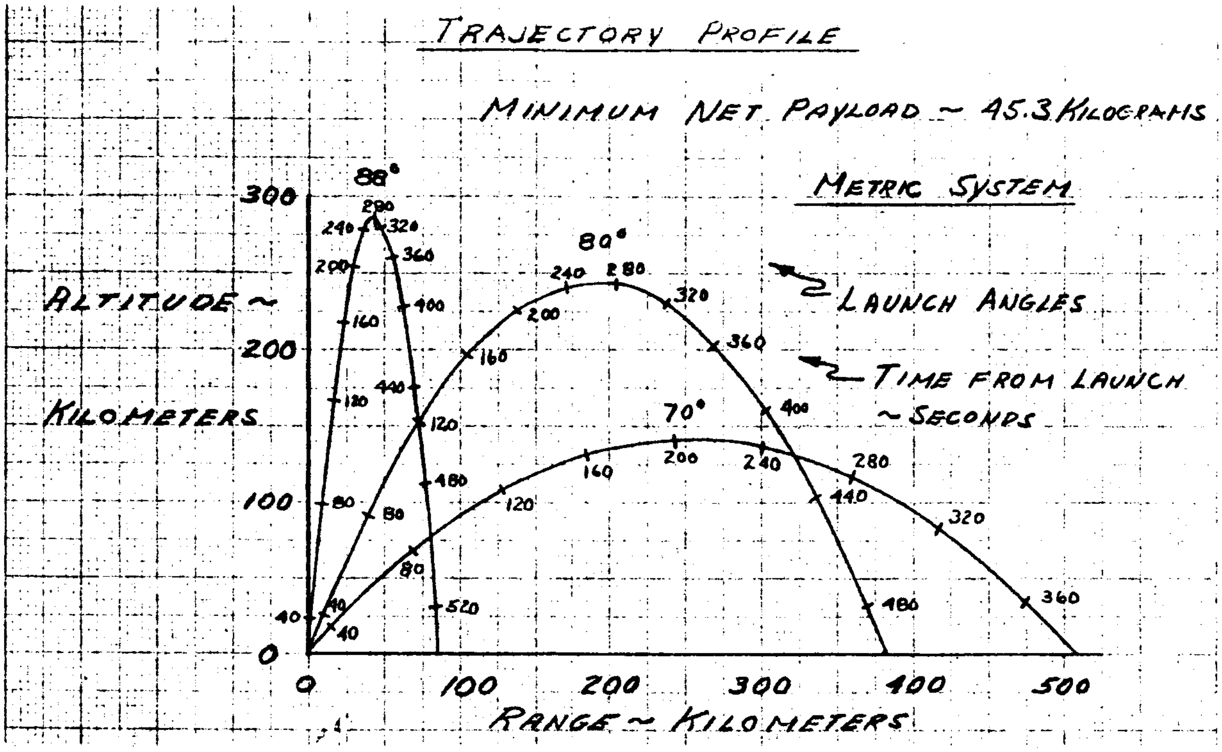


FIGURE 10 TRAJECTORY PROFILE, MINIMUM NET PAYLOAD 45.3 KILOGRAMS (METRIC SYSTEM)

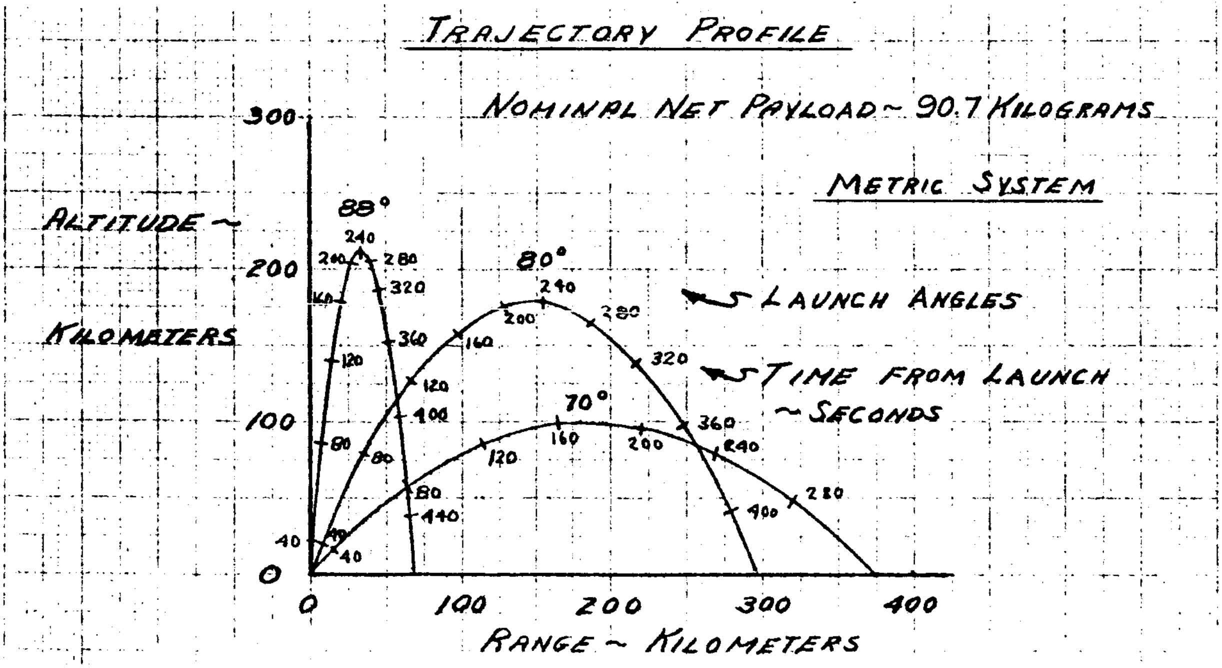


FIGURE 11 TRAJECTORY PROFILE, NOMINAL NET PAYLOAD 90.7 KILOGRAMS (METRIC SYSTEM)

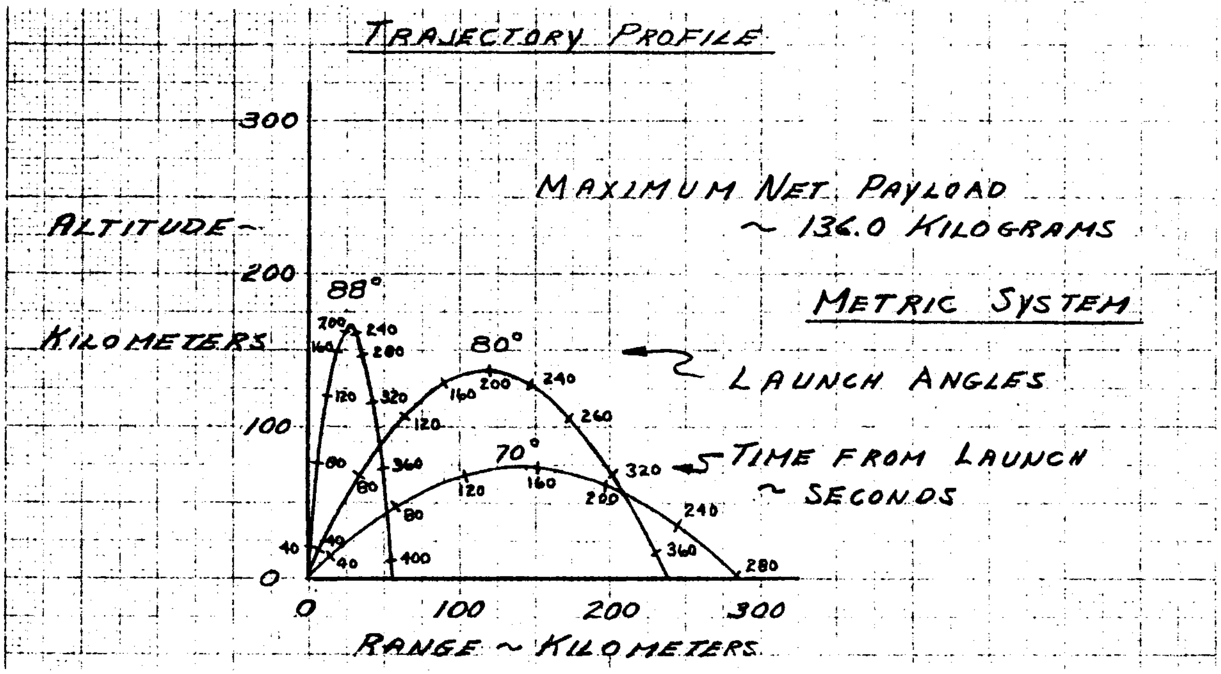


FIGURE 12 TRAJECTORY PROFILE, MAXIMUM NET PAYLOAD 136.0 KILOGRAMS (METRIC SYSTEM)

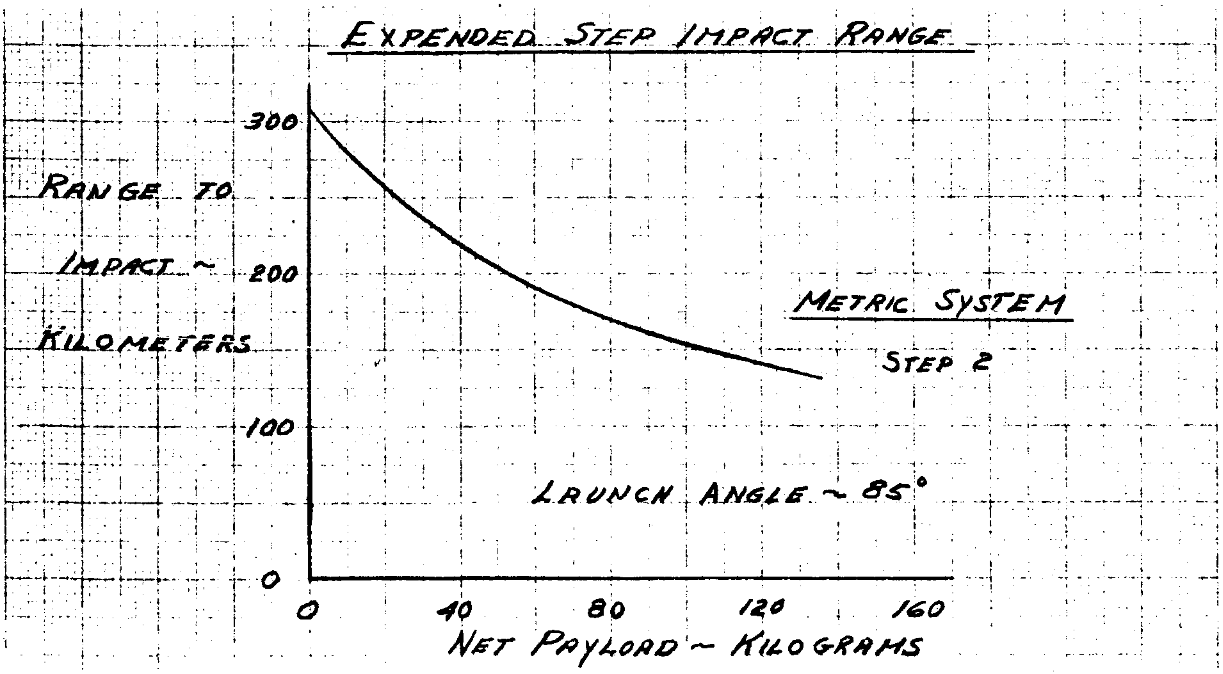


FIGURE 13 EXPENDED STEP IMPACT RANGE (METRIC SYSTEM)

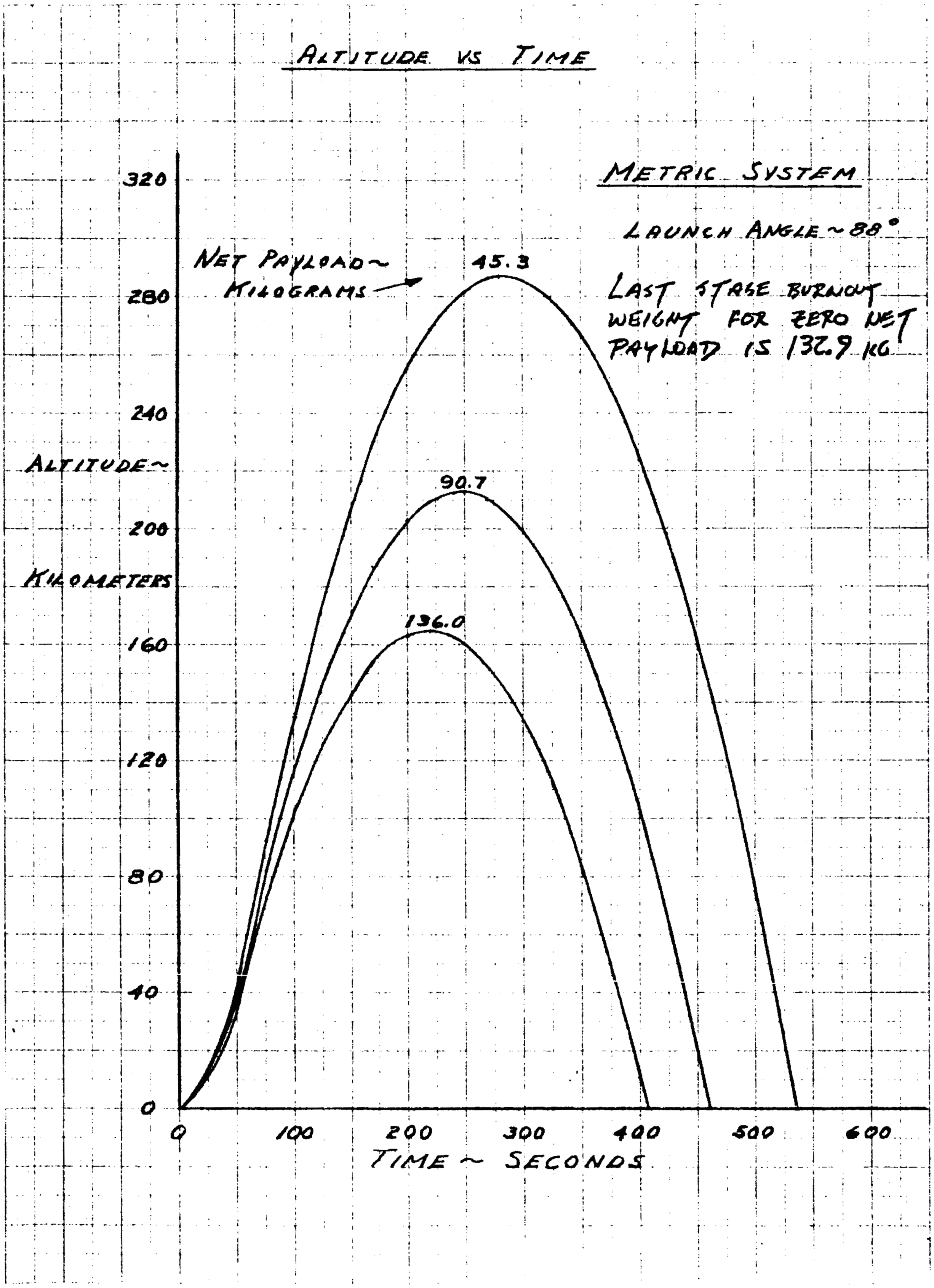
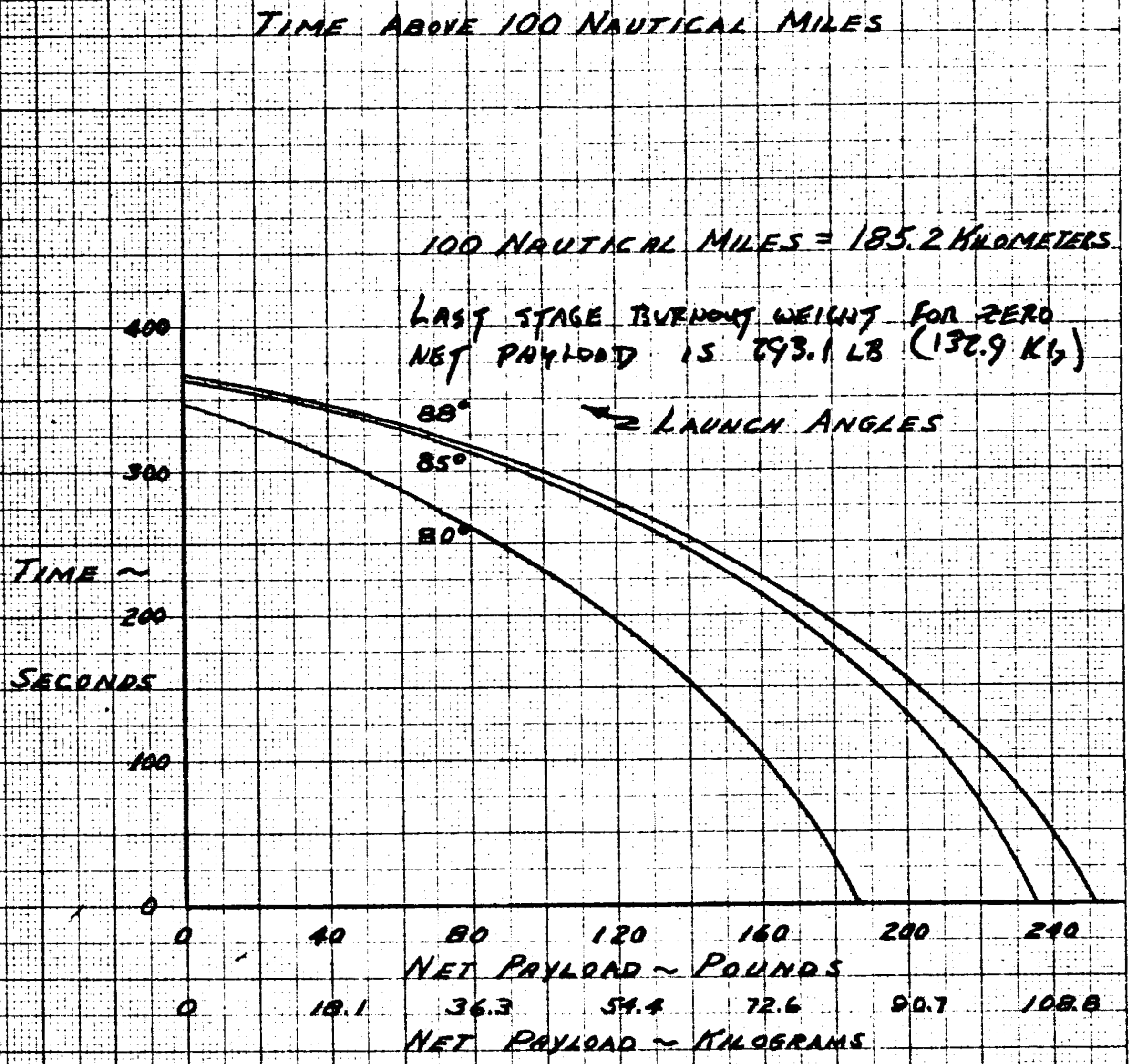


FIGURE 14 ALTITUDE VS. TIME (METRIC SYSTEM)



TIME ABOVE 100 NAUTICAL MILES

100 NAUTICAL MILES = 185.2 KILOMETERS

LAST STAGE BURNOUT WEIGHT FOR ZERO NET PAYLOAD IS 293.1 LB (132.9 Kg)

FIGURE 15 TIME ABOVE 100 NAUTICAL MILES

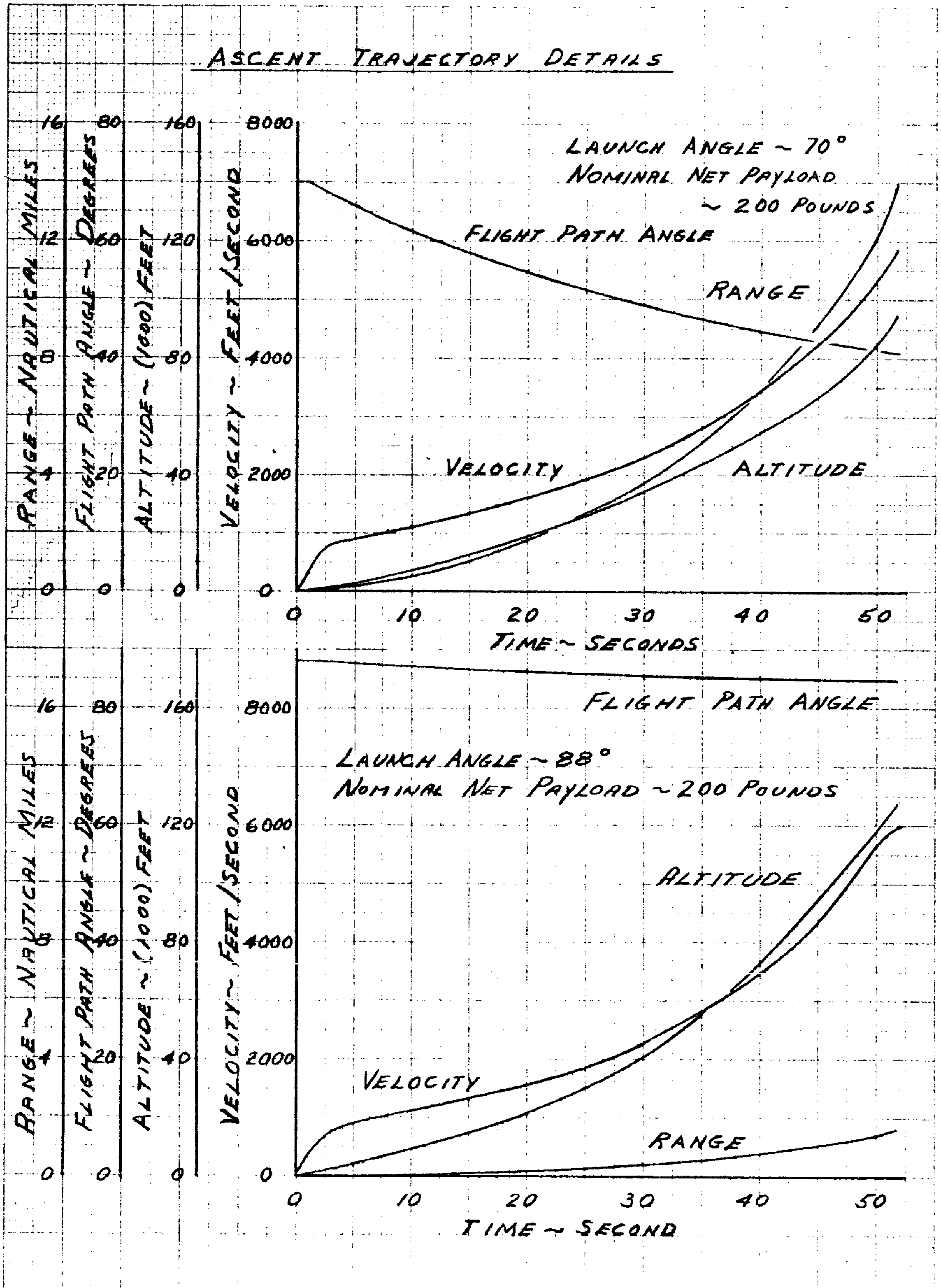


FIGURE 16 ASCENT TRAJECTORY DETAILS (70° and 88° LAUNCH)

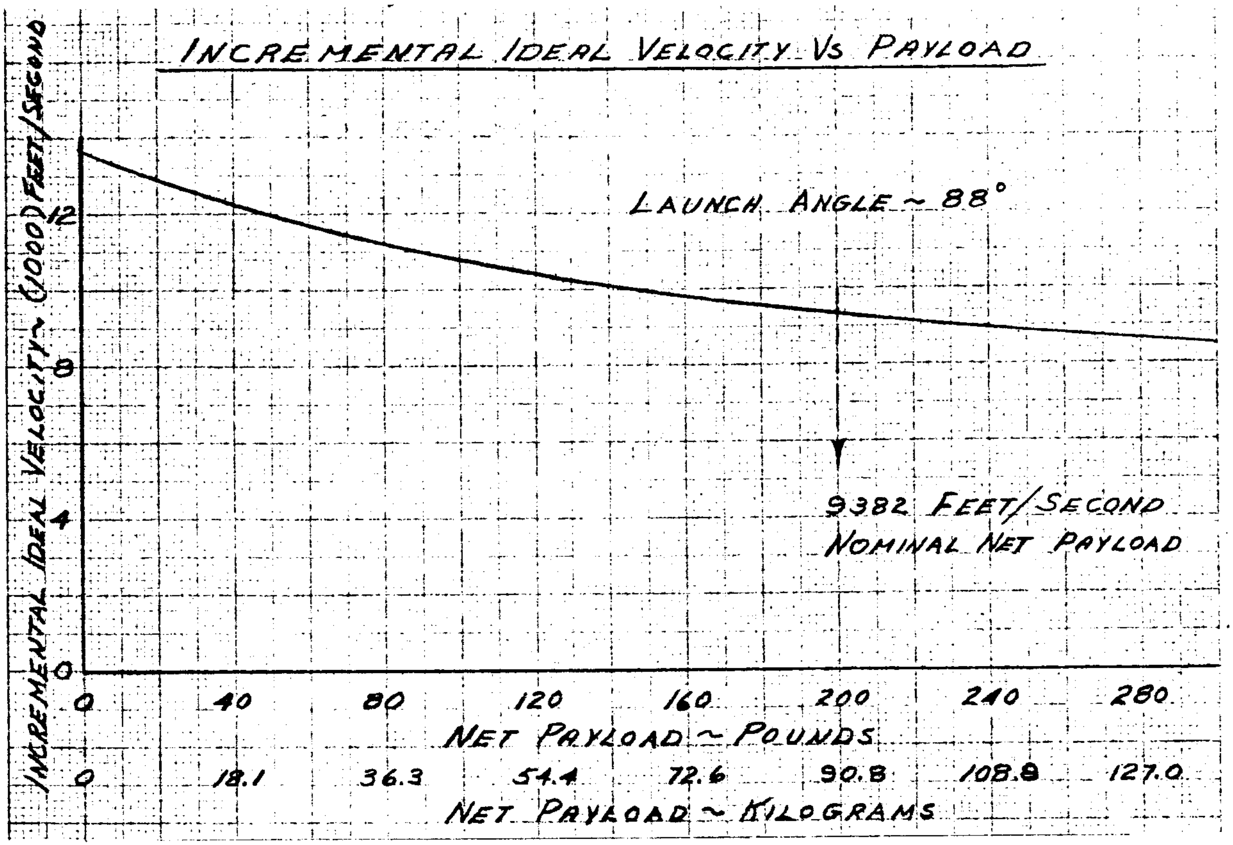


FIGURE 17 INCREMENTAL IDEAL VELOCITY VS. PAYLOAD

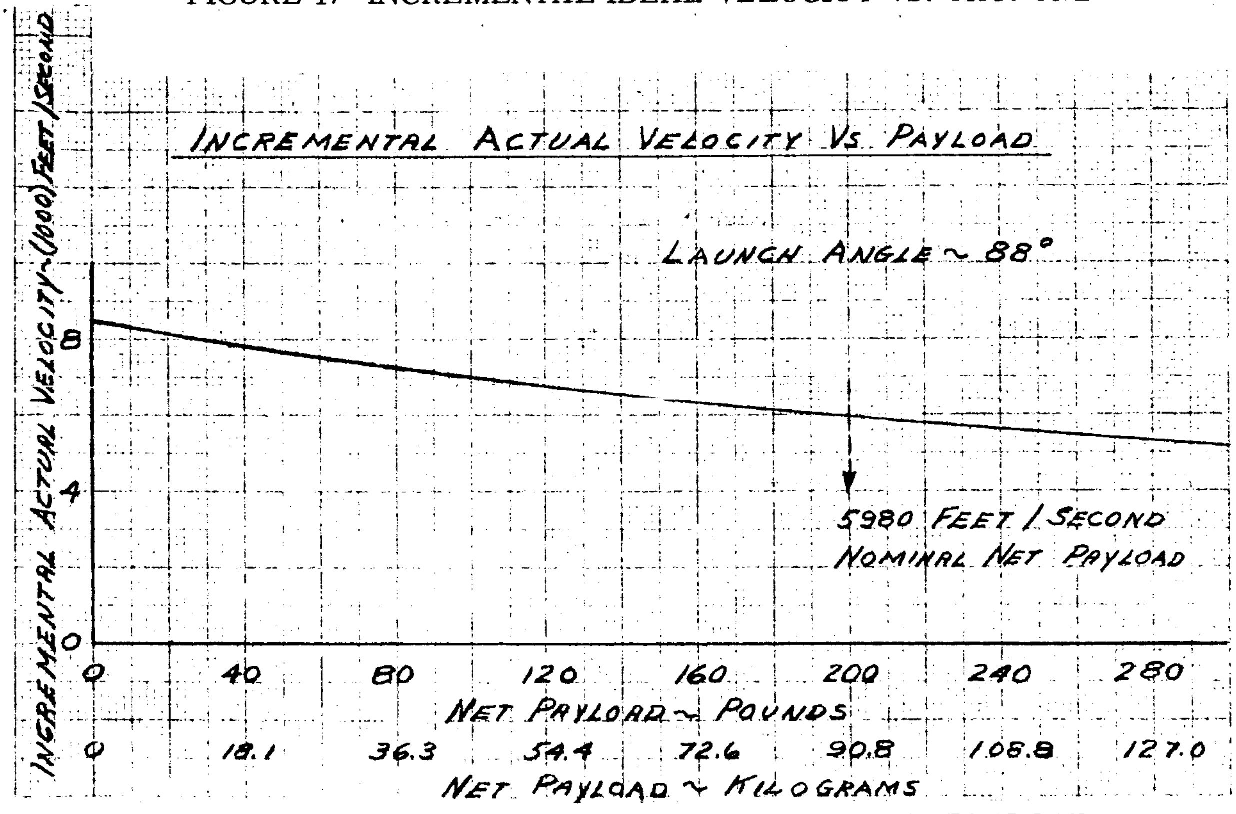


FIGURE 18 INCREMENTAL ACTUAL VELOCITY VS. PAYLOAD

IDEAL AND ACTUAL VELOCITY TABULATION

LAUNCH ANGLE = 88°

NOMINAL NET PAYLOAD = 200 POUNDS

PHASE OF FLIGHT	AVERAGE SPECIFIC IMPULSE (SECONDS)	MASS RATIO	IDEAL VELOCITY INCREMENT	VELOCITY LOST TO DRAG AND GRAVITY (FT/SEC)	COAST VELOCITY LOST (FT/SEC)	ACTUAL VELOCITY INCREMENT (FT/SEC)
STAGE 1* BOOST	167	1.2	850	83	0	767
STAGE 2 BOOST	209	3.6	8532	3319	0	5213
TOTALS	-	-	9382	3402	0	5980

* Step 1 motor burns for 2.5 secs. At t = .3 seconds, Step 2 motor ignites and thrusts concurrently 2.2 seconds.

FIGURE 19 IDEAL AND ACTUAL VELOCITY TABULATION

BASIC DATA

Weight

Detail Weight Breakdown

The following detail weight breakdown was used as a basis for all weight, c.g. and inertia calculations. This data was taken from Reference 1.

A consolidation of this information into major components for c.g. and local moment of inertia presentation is tabulated on the following pages,while overall vehicle weights, c.g., and inertia data versus time are presented in Figures 20 and 21.

Second Step

Inert Weight:

Nose Cone	17.0
Tank Assembly	163.0
Shrouds	6.6
Fairings	.5
Aft Structure	15.5
Fins	28.0
Regulator Valve	3.0
Regulator Manifold	1.0
Thrust Chamber Assembly	(32.1)
Chamber	25.5
Nike Valve	2.9
Flex Lines	2.0
Shutoff Valves	1.7
Miscellaneous (lugs, etc.)	12.4
Helium	7.0
Unuseable Fuel	7.0
Total Inert	293.1

Consumed Weight:

Fuel	296.2
Oxidizer	758.2
Total Loaded	1347.5

First Step

(For information only - not utilized in c.g. or inertia calculations).

Inert Weight (Including Fins)	338.0
Consumed Weight	262.0
Total Loaded	600.0
Launch Gross (Less Payload)	1947.5

Center of Gravity and Inertia Data

Item	Weight Pounds	C.G. In. from Ref. Sta. 0.0	Local Roll Moment of Inertia Slug-Ft^2	Local Pitch or Yaw Moment of Inertia Slug-Ft^2
Second Step				
Nose Cone	17.0	49.1	.1028	1.630
Payload Extension (Opt.)	14.0	82.6	.1693	.1073
Tanks and Shrouds	170.1	178.2	1.808	80.35
Thrust Chamber	32.1	272.0	.1950	.7276
Aft Shell	15.5	265.5	.1883	.3981
Fins	28.0	278.0	1.874	1.511
Head End Plumbing	4.0	94.0	.0242	.0127
Miscellaneous Lugs, etc.	12.4	168.0	.1507	
Helium	7.0	108.0	.0425	.1345
Fuel (Unused)	7.0	170.0		
Step Total - Empty	307.1	187.8		
Fuel Consumed	296.2	147.0	1.789	13.17
Oxidizer Consumed	758.2	212.0	4.582	94.02
Step Total - Loaded	1361.5	192.4		
Payloads:				
Minimum	100.0	56.0	.6045	14.23
Nominal	200.0	56.0	1.209	28.45
Maximum	300.0	56.0	1.814	42.68

Notes:

1. Empty vehicle c.g. from Reference 1.
2. Station 0.0 is 9.4 inches aft of the tip of the nose cone. Vehicle length is 367.0 inches, including an optional 9.4 inch extension. Performance calcualtions are based on a vehicle which does not include either the 9.4 inch or 15 inch optional payload extension. In order to present an "average" vehicle, Figures 20 and 21 present data for a "nominal" vehicle plus the 9.4 inch extension.

3. The local roll moment of inertia of the fins is about the vehicle centerline.
4. All other data calculated.

Aerodynamics

The basic aerodynamic data at zero angle of attack is shown in Figure 22. Results of wind tunnel data supplied by the manufacturer indicate a forward shift of center of pressure of about one body diameter for an angle of attack of about ten degrees at supersonic Mach numbers. The center of pressure shift appears to be less pronounced at higher Mach numbers. The data also indicate that at subsonic speeds a very small center of pressure shift (about ten percent of one diameter) would be expected at an angle of attack of ten degrees for the vehicle with booster attached.

The increase in drag with angle of attack is moderate for this vehicle. A representative datum point is taken at Mach number of four where the vehicle drag is doubled at an angle of attack of eight degrees.

The Aerobee 150A makes use of spinning to reduce the effects of misalignments. The spin rate of the sustainer is variable since the sustainer fin incidence can be adjusted to produce whatever spin rate is desired. Flight test data available do not indicate any significant effect of pitch-roll coupling on drag.

Propulsion

Since the rocket motor ballistic data for some of the motors used on the 18 vehicles of this sounding rocket study series are classified, all of the ballistic data, both classified and unclassified, were consolidated into report no. AST/E1R-13336 so that all of the individual vehicle reports would remain unclassified. As a result, even though a portion of the ballistic data applicable to this vehicle are unclassified, it will be found in report no. AST/E1R-13336.

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Date 18 April 1961
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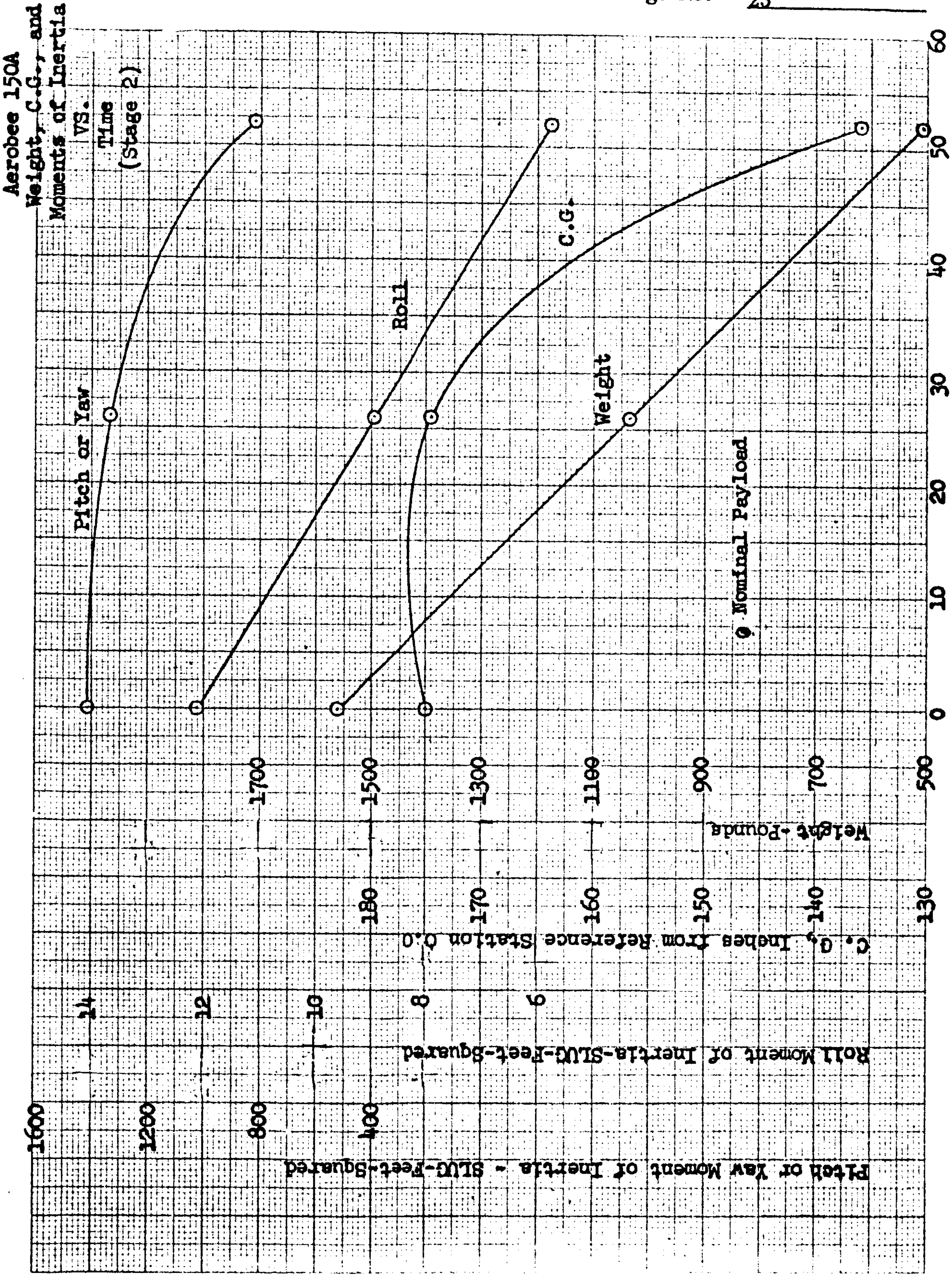


FIGURE 20 WEIGHT, CENTER OF GRAVITY AND MOMENTS OF INERTIA VS. TIME (STAGE 2)

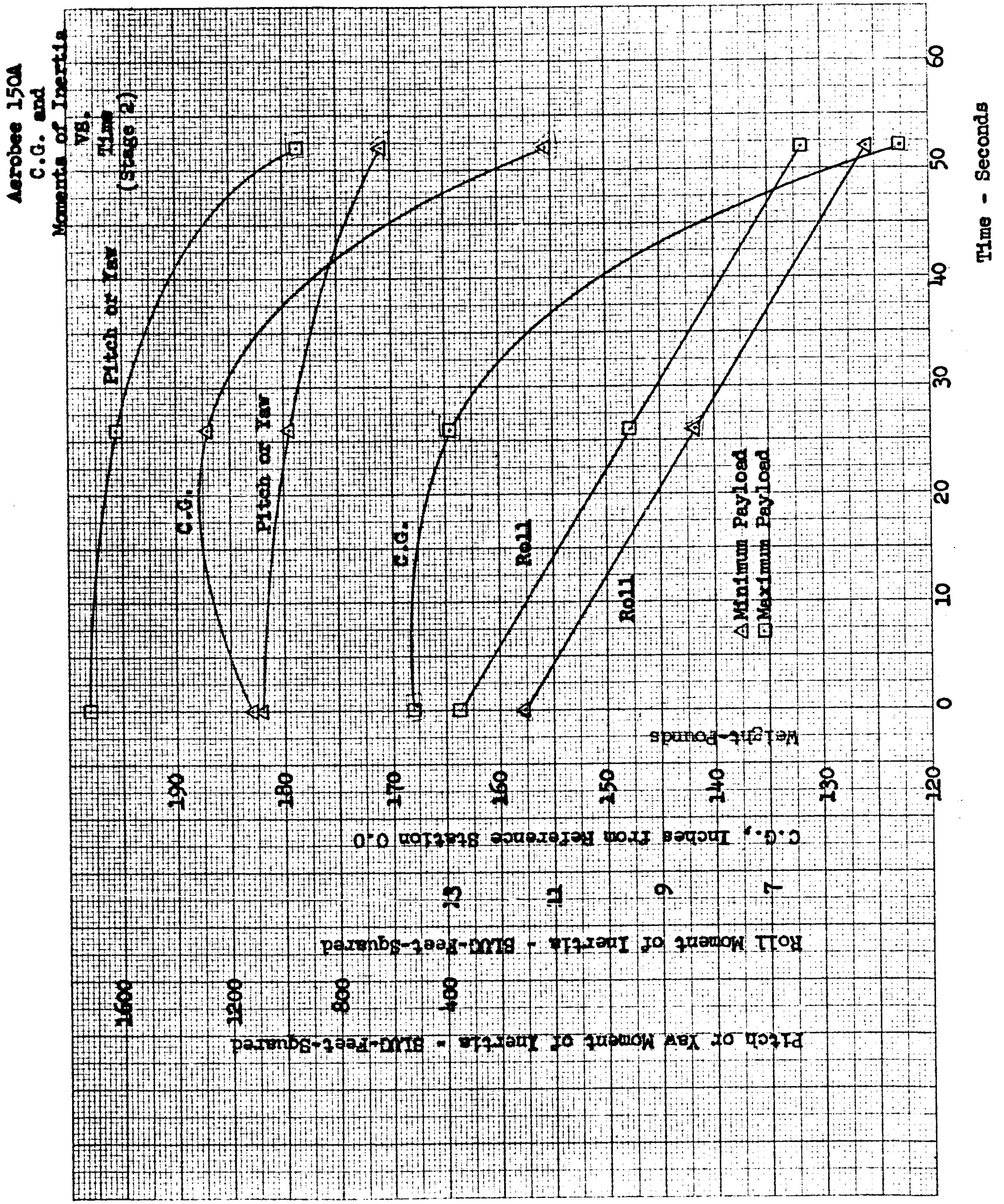


FIGURE 21 CENTER OF GRAVITY AND MOMENTS OF INERTIA VS. TIME (STAGE 2)

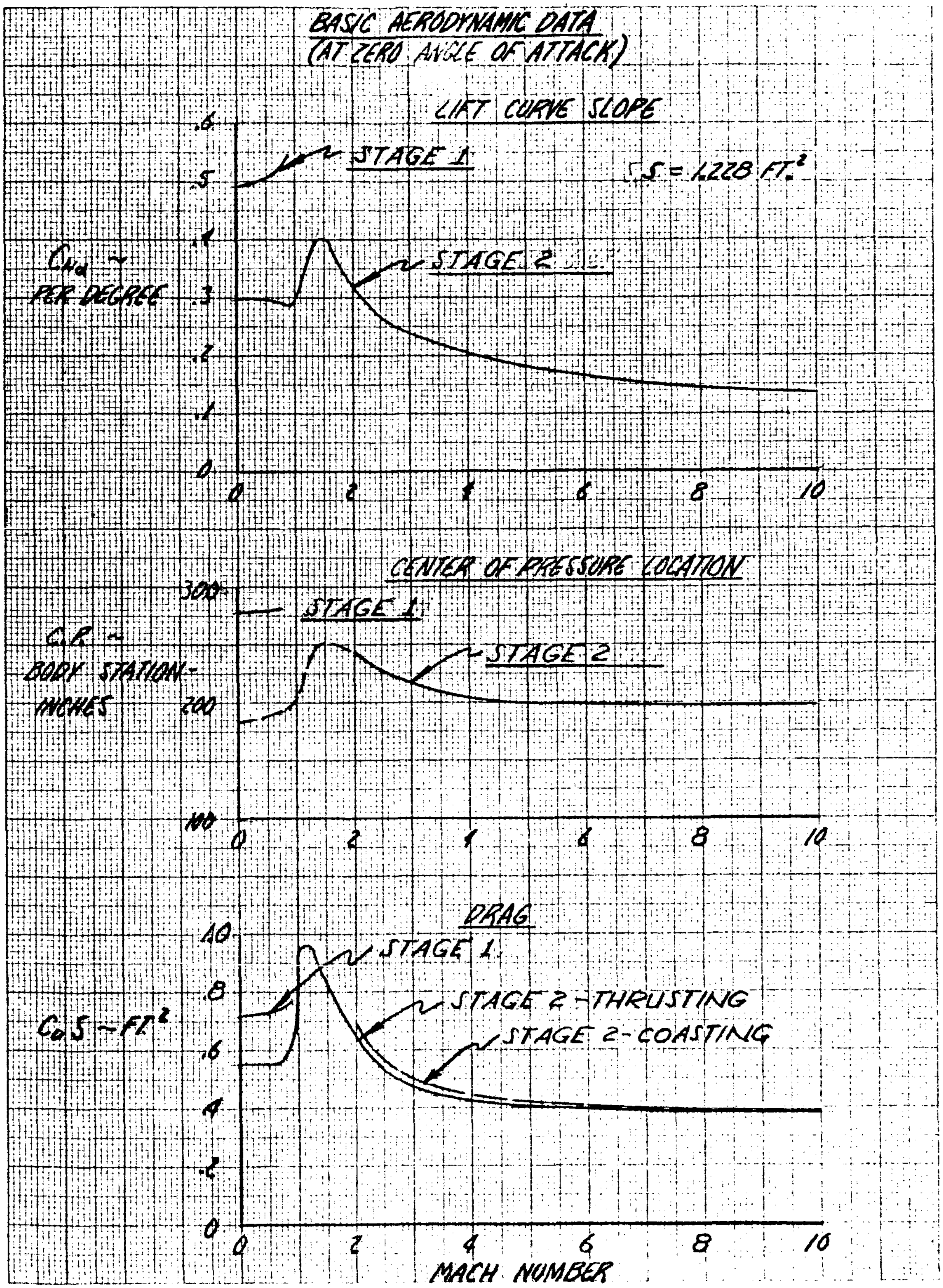


FIGURE 22 BASIC AERODYNAMIC DATA (LIFT, CP, DRAG)

ENVIRONMENT

Axial Acceleration

The axial acceleration time history of the Aerobee 150A vehicle at a launch angle of 88 degrees is shown in Figure 23.

Roll Rate

The Aerobee 150A roll rate time history is shown in Figure 24. Tangential acceleration during booster burning is higher than for most rocket systems, and could possibly be an important loads criteria. There is no indication in the data available that pitch-roll coupling causes a serious loads problem.

Structural Dynamic Analysis

The flexible booster structure is subjected to a number of loading environments which produce significant dynamic responses. The load inputs occur from ground handling, launch, atmospheric disturbances, control commands, stage separation, and structural and thrust misalignments. The spin stabilized vehicle experiences additional loading phenomena arising from dynamic coupling. Atmospheric disturbances in the form of winds and gusts require an extensive analysis for structural loads determination. This involves a trajectory analysis of the flexible vehicle, taking into consideration time variations in weight and aerodynamic load distributions. Atmospheric winds and gusts are defined statistically so that ultimately the analysis produces a missile loading criteria in terms of probability of structural failure.

The weight distribution may be obtained from available information but other information necessary to determine the structural dynamic characteristics of the Aerobee 150A vehicle have not been received. However, the manufacturer guarantees no permanent deformation and satisfactory operation strength for flight maneuver loads of + 12g parallel to rocket longitudinal axis and 3g in any direction normal to the rocket longitudinal axis. There is little likelihood of encountering flutter in the trajectory.

Vibration

In order to obtain the vibration environment in the payload compartment, it is necessary to know the vibration characteristics of the sources, such as, rocket motor(s), aerodynamic boundary layer noise, and launch noise. The structure-borne and airborne transmission path characteristics of these sources of vibrations must also be known in order to establish payload base vibration environment. Payload base input vibrations normally would be expressed as a function of vibration amplitude versus frequency for significant flight times, and with the characteristics of the vibration (i.e., sinusoidal, random, mixed) indicated. The resulting payload vibration environment will depend upon the structural dynamic response characteristics of the payload itself, in addition to the payload base input vibration environment.

No indications were found in the data received of any payload compartment vibration instrumentation provisions having been made for the Aerobee 150A.

Temperature

External Temperature

To determine the temperature effects on this vehicle it was necessary to select a given trajectory and specific components to be investigated. The 70° launch angle and nominal payload were selected as a limiting condition which would emphasize possible mission restrictions that result from skin heating. A vehicle which has been used satisfactorally at launch angles above 80° might be inadequate for a 70° launch. This is shown to be the case for the Aerobee 150A vehicle from the temperatures curves of Figure 25.

The components investigated include the nose cone and fin stagnation areas, the nose cone fairing in the payload area, and the fin panels as shown in Figure 25. While these areas normally experience maximum heating, this does not imply that other areas on the vehicle, such as rocket cases, do not require investigation for a particular mission.

The nose cone thickness, .051 in., shown in Figure 25 was assumed. Materials and other skin gages were obtained from the manufacturer's reports. For the nose tip which contained an internal heat sink locally, average stagnation temperatures were obtained by treating the tip as a one dimensional problem where the skin thickness was arbitrarily computed as one quarter of the length of the heat sink. This approach was considered satisfactory,but the resulting temperatures in this area are recognized as being approximate.

The physical properties for the transient temperature analysis, using digital computer methods, are shown below:

Material	Aluminum	Inconel	Magnesium
Density (lb/ft^3):	173.	484.	106.
Specific Heat (Btu/Lb-°F):	.24	.125	.28
Emissivity:	.35	.7	.6

To properly evaluate the structural reliability of any vehicle, the load-temperature relationship with respect to time must be considered. This relationship cannot be adequately defined until a specific mission requirement has been selected. For example, a component may experience severe reduction in strength allowables due to temperature, but if the elevated temperature occurs at times when the load is negligible, the condition may be acceptable.

The 70 degree launch trajectory does not appear suitable for this vehicle. This trajectory resulted in Mach 5.0 velocity at under 80,000 feet altitude. These high velocities at the relatively low altitudes produced skin temperatures indivative of possible negative margins of safety for the anticipated air loads for these conditions. The aluminum fairing strength was reduced to 30 percent and the magnesium fin skins to about 10 percent of room temperature values at sustainer rocket burnout. Probe shots at higher launch angles would effectively reduce the skin temperatures to more acceptable values. For the launch angle shown, material substitutions would be indicated, (See Figure 25).

Internal Heating of Payload Compartment

The payload compartment temperature while the vehicle is on the launch pad is a function of the ambient temperature, location of the launch pad, time on the launch pad, and the heat output of the payload.

To determine the payload compartment temperature on the launch pad, an average payload of one hundred (100) pounds with an area-weight ratio of 0.1 ft^2/lb. was considered. The compartment walls were assumed to be gold-coated (due to the low emissivity of gold) and the compartment subject to an ambient temperature of 100°F. The compartment temperatures were calcualted for payload power outputs of 10, 100, and 200 watts which correspond to payload power densities of 0.1, 1.0 and 2.0 watts/lb., respectively. The compartment temperatures were calculated considering convection, radiation, and storage of heat by the payload. Considering these conditions, payloads with a power density of 2.0 watts/lb. or above, will require additional cooling to hold the compartment temperature to 150°F or below if they remain on the launch pad with power on from one to two hours prior to launch (which is generally not normal procedure). The usual pre-launch "power on" condition is of relatively short duration and therefore pre-launch temperature is not normally a problem. The maximum compartment temperature limit for most electronic equipment is 150°F. Additional cooling of the payload compartment, if necessary, may be accomplished by forced ventilation, cooling to a subcooled state prior to launch, and by the addition of heat sinks to the payload.

The heating of the payload compartment after launch is a function of the compartment temperature prior to launch, vehicle flight path, duration of flight, heat output of the payload, and compartment configuration.

To determine the payload compartment temperature after launch, payloads of the same magnitude as above were considered. A nominal atmospheric trajectory was used to determine the effects of aerodynamic heating on the compartment. Since the flight ime of the Aerobee 150A vehicle is of short duration (approximately 8.3 minutes), the payload compartment temperature rise due to aerodynamic heating will be small. Therefore, if the payload compartment temperature is 125°F or below prior to launch for payload power densities of 2.0 watts/lb. or below, no additional cooling of the payload should be necessary. However, since the payload compartment temperature is a function of the conditions previously mentioned, the environment of each payload should be further analyzed with respect to the conditions stated in paragraph 3 prior to establishing the payload cooling requirements.

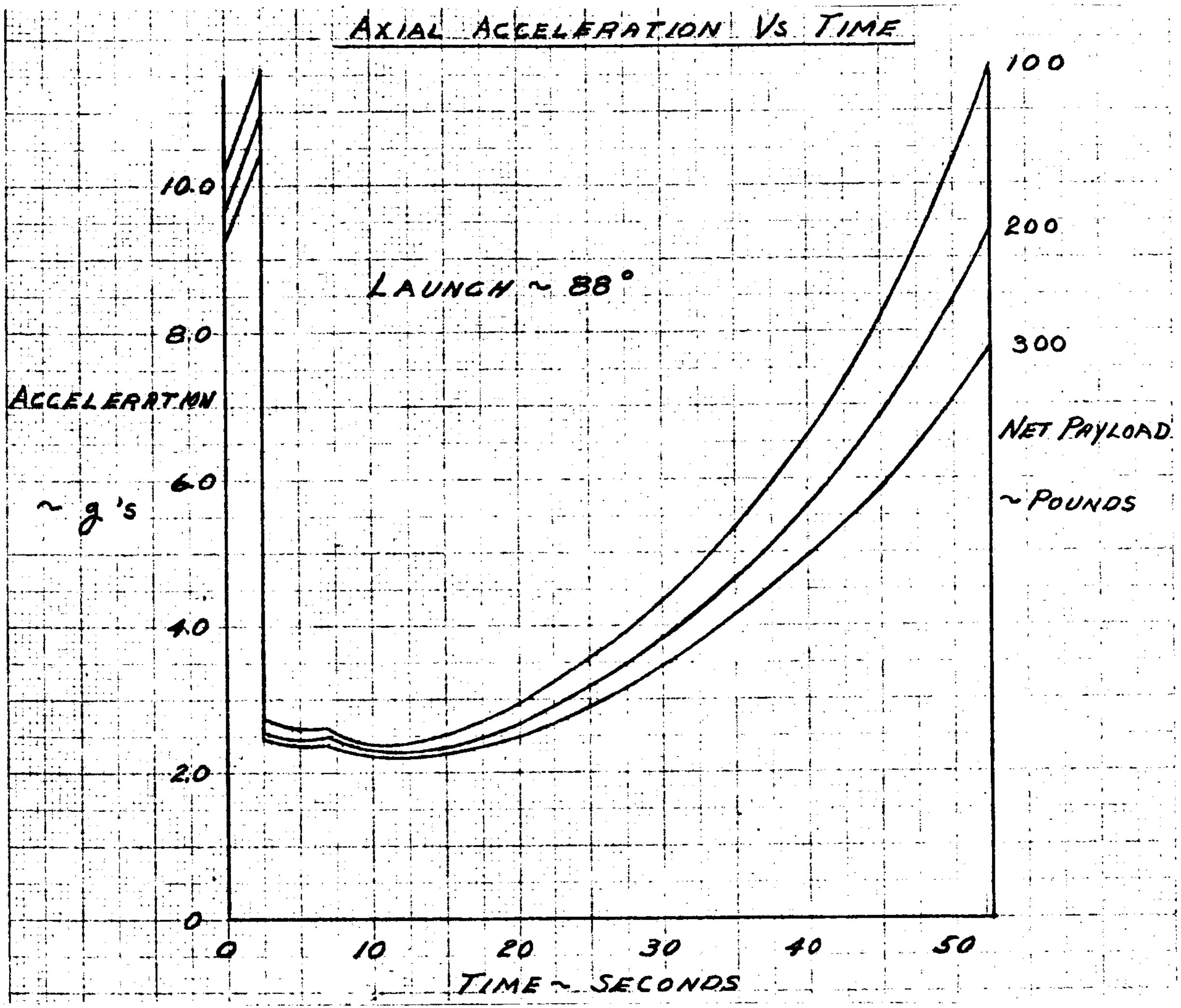


FIGURE 23 AXIAL ACCELERATION VS. TIME

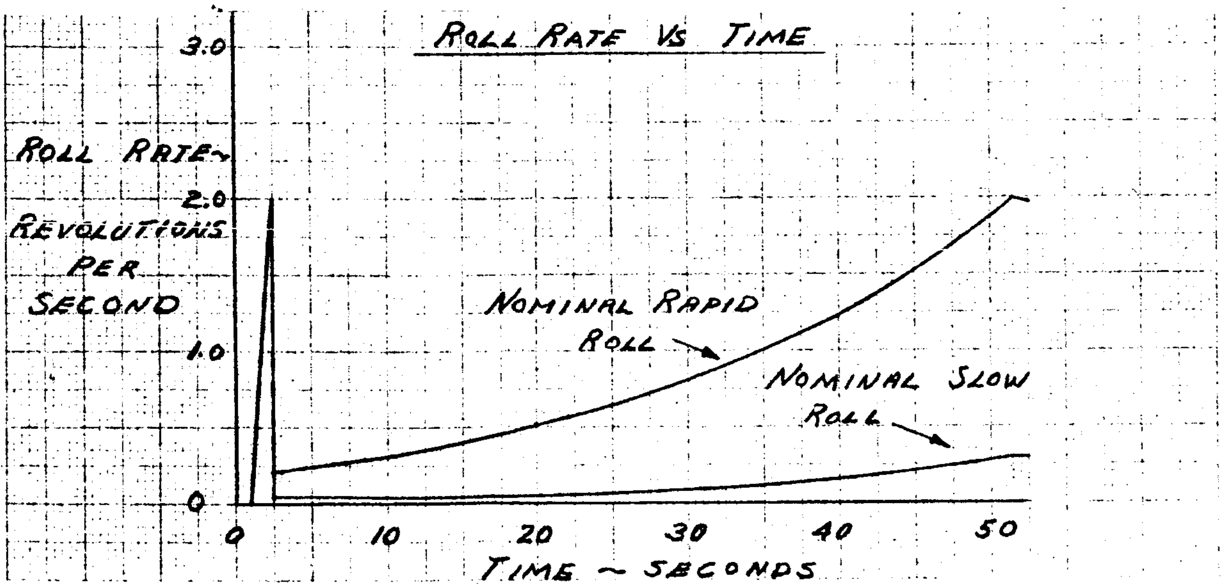


FIGURE 24 ROLL RATE VS. TIME

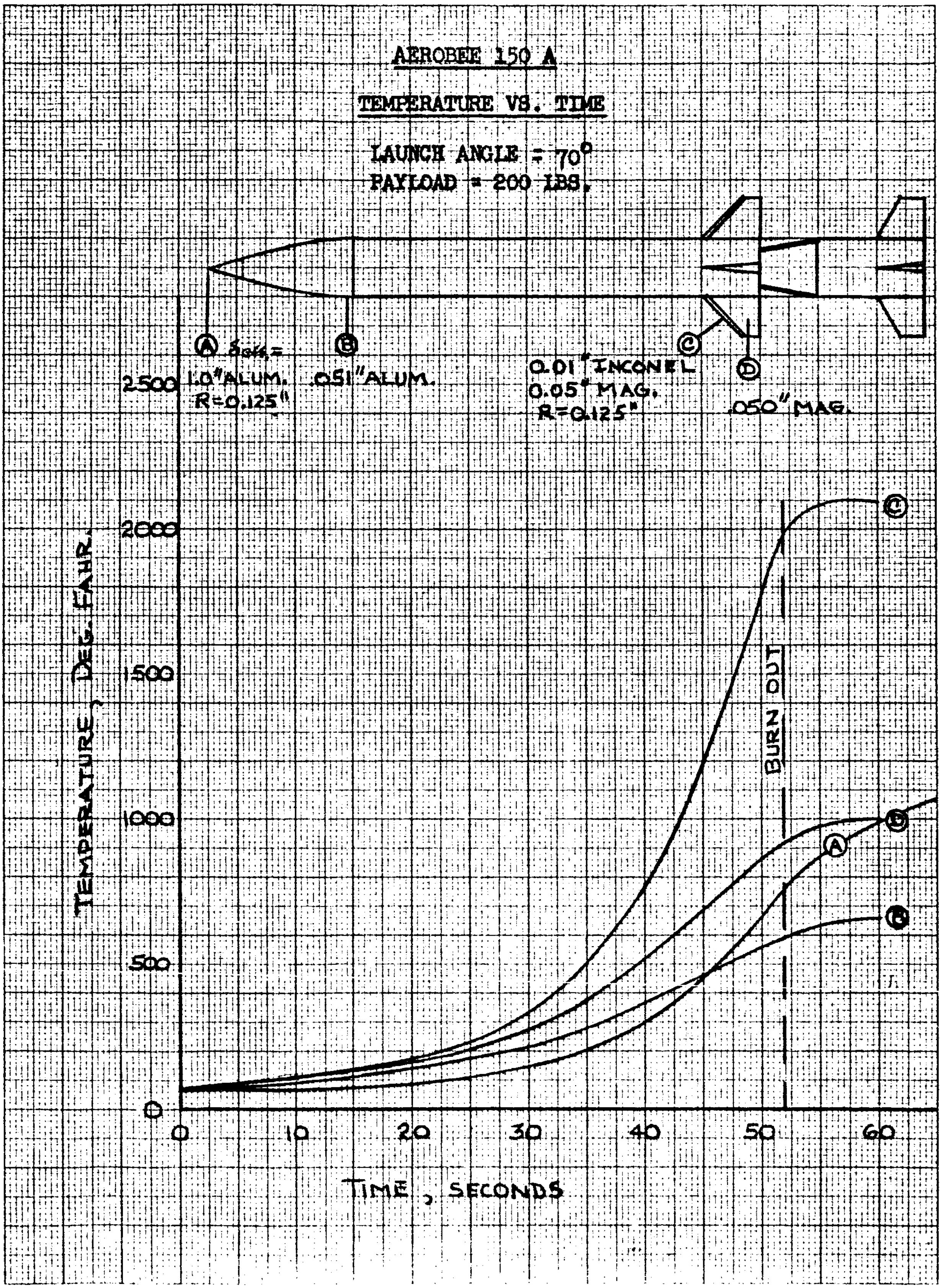


FIGURE 25 TEMPERATURE VS. TIME

OPERATIONAL FACTORS

Ground Support Equipment

Mechanical Support Equipment

The launching tower is the NASA Aerobee Tower at Wallops Island, Virginia (Figure 26). The tower may also be used to launch the Aerobee 300A and the four-finned Iris. Details of the facility were not received. The three-finned Aerobee 150 and the three-finned Aerobee 300 may be launched from White Sands Proving Ground, New Mexico, Holloman AFB, New Mexico and Fort Churchill, Canada.

Other major items of mechanical support equipment are:

1. Aerobee 150A Vehicle Handling Trailer (Figure 27) to transport the vehicle and to erect it into the tower. The upper framework of the trailer becomes a part of the launching tower and provides two of the launching rails at the base of the tower.

2. Aerobee Gas-Proof-and-Leak-Test Panel which provides pneumatic circuits for pressure checking the flight vehicle tankage.

3. Helium pressurization console which consists of regulators, values, gages, electrical controls and plumbing to provide pressure regulation for various operations of the vehicle.

Electrical Support Equipment

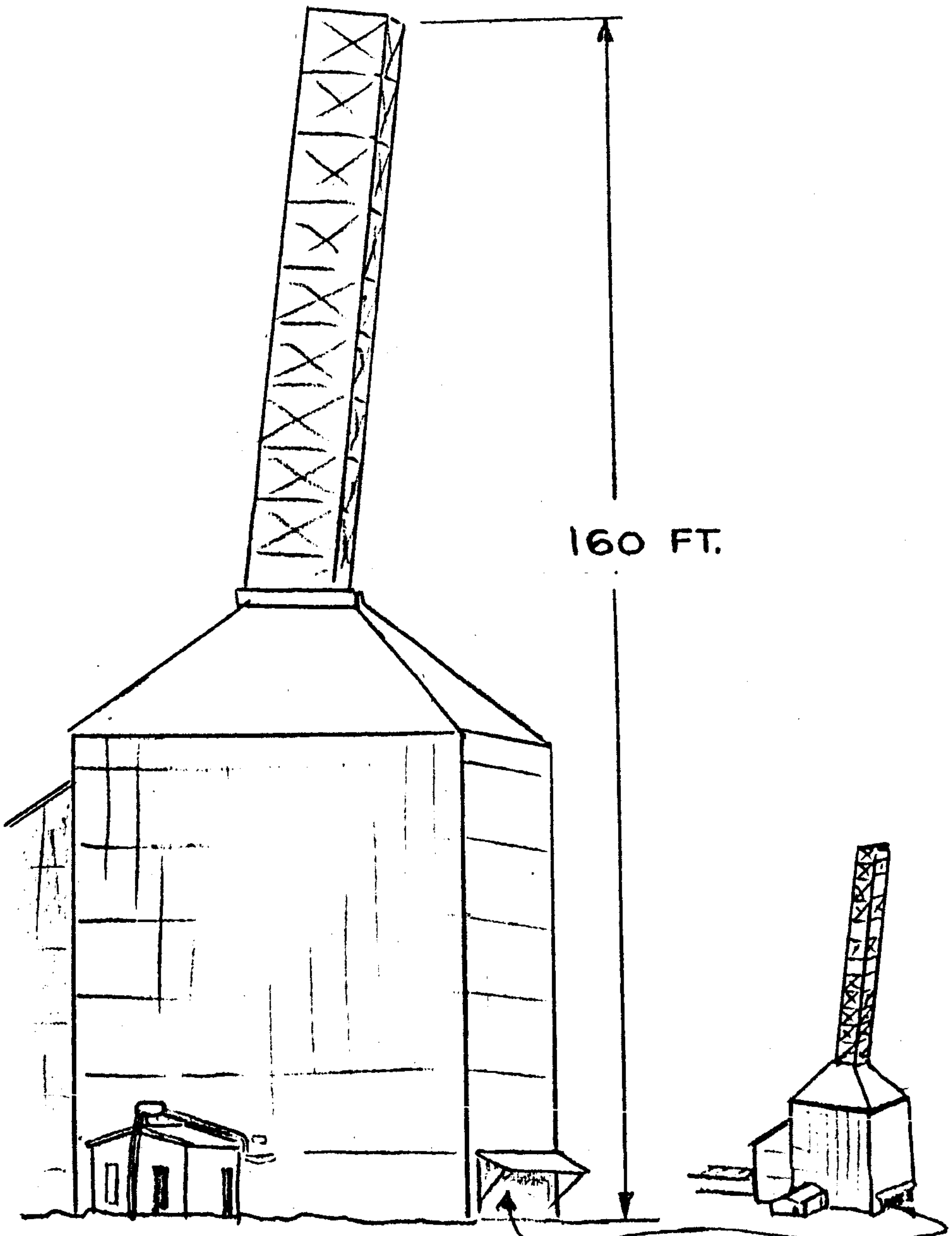
Checkout of the radio controlled fuel shut-off system is required, and the first motion switch circuitry must be checked.

A squib tester is required to test the booster ignition squibs and the fuel shut-off squibs.

Instrumentation

The majority of sounding rocket vehicle flights to date did not require vehicle instrumentation since they had fixed fins, were unguided, and range safety requirements were not critical. Instrumentation may be desired on future flights to supplement payload data, verify trajectory characteristics, record staging sequences, monitor critical environment conditions, and assure command thrust termination capability. Generally the information necessary to evaluate the instrumentation required would be: type of measurement desired, range, accuracy, frequency response and resolution. Consideration must also be given to environmental requirement, the type of ground data gathering equipment already available, and duration of operation.

The Aerobee 150A is known to have utilized performance telemetry, however, no detailed system information is available at this time.



NOTE: ABOVE SKETCH FROM FEB 1961 "WESTERN AVIATION"

FIGURE 26 WALLOPS ISLAND LAUNCHING TOWER

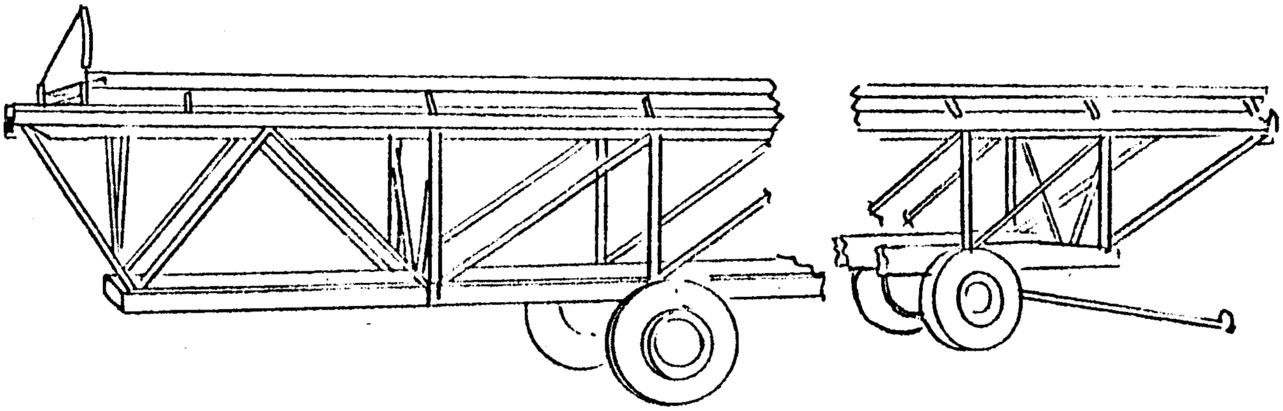


FIGURE 27 AEROBEE 150A VEHICLE HANDLING TRAILER

NOMENCLATURE

Symbol	Definition	Units
CL_a	Lift curve slope	per degree
C_D	Drag coefficient	
c. g.	Center of gravity from reference datum	in.
C. P.	Center of pressure from reference datum	in.
g	Gravitational acceleration	ft/sec^2
g_o	Gravitational acceleration at earth's surface*	ft/sec^2
g_s	Standard or normal gravitational acceleration	32. 174 ft/sec^2
G	Vibrational acceleration	ft/sec^2
I_{TOT}	Total impulse	lb-sec
(I_{sp}) AVG	Average specific impulse, $\frac{I_{TOT}}{wc}$	sec
w_c	Total consumed weight	lb
w_p	Weight of propellant	lb
w_o	Weight of stage	lb
R_o	Earth radius*	ft
S	Aerodynamic reference area	ft^2
ΔV_{ID}	Ideal incremental velocity	ft/sec
α	Angle of attack	degrees
μ	Mass ratio, $\frac{w_o}{w_o - w_c}$	

* Where g_o and R_o represent conditions at a geodetic latitude of 35° on the International Ellipsoid of Reference:

g_o = 32. 14389 ft/sec^2 = 9.797459 m/sec^2

R_o = 20, 903, 307 feet = 6371. 328 kilometers

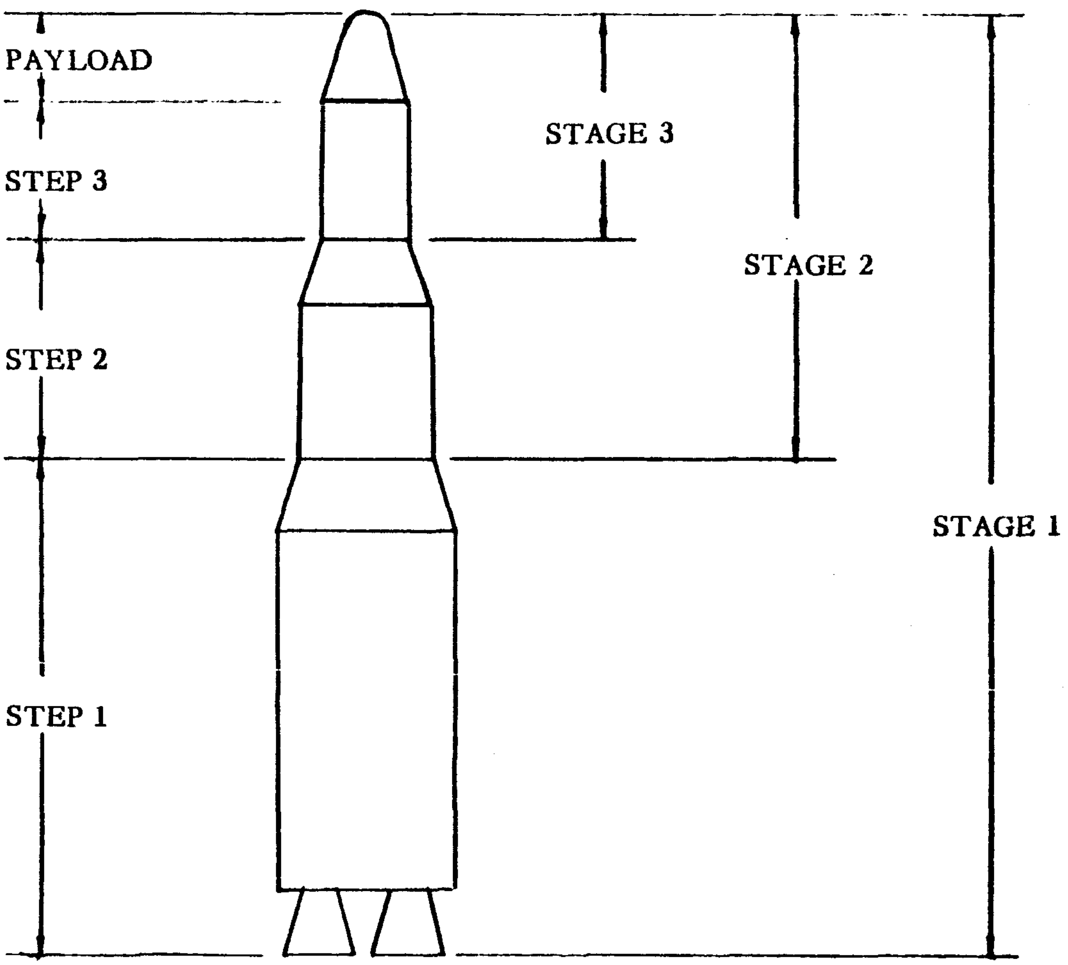
PAYLOAD DEFINITIONS

NET PAYLOAD: All weight not essential to the flying of the vehicle when the payload carrying stage is thrusting, but not including weight which is essential to the operation of a previous stage and which happens to remain attached to the payload carrying stage during its thrusting period.

GROSS PAYLOAD: All weight attached to the final payload carrying stage or rocket motor (tank weight shall be considered part of motor weight for liquid fuel systems).

GROSS EXPERIMENT PAYLOAD: Actual weight of instruments, batteries, telemeters, and associated bracketry that is carried while the payload carrying stage is thrusting.

VEHICLE STAGING DEFINITION



"Stage" is the preferred nomenclature when referring to system operation. "Step" is the preferred nomenclature when referring to the precise location or to the weight of a specific component.

REFERENCES

1. Chalfant, C. P., Thomas, E. S., and Thornstensen, B. A., "Development of a Four-Fin Aerobee Sounding Vehicle," Report No. 1640, Aerojet-General Corporation, Azusa, California, dated June 1960.

2. Thomas, E. S., "Wind Tunnel Tests of the Aerobee 150A (Model AJ60-13)," Report No. 1784, Aerojet-General Corporation, Azusa, California, dated March 1960.

3. "Technical Manual, Service Instructions, Aerobee 150A Sounding Rocket, Model A560-13," Publication No. HS-520104; Aerojet-General Corporation, Azusa, California, dated June 1960.