TECH SERIES

The Aerobee 100, 150, and 300 Series Sounding Rockets

Foreword, ***by Charles E. Rogers***

One of the most important series of sounding rockets in the history of rocketry in the United States were the Aerobee sounding rockets. Aerobee sounding rockets were one of the workhorse sounding rockets during the 1950's and 1960's, and were used extensively for atmospheric science and space research. The Aerobee series of sounding rockets is presented in Figure A. The following article will describe in detail the design, operation, and performance of some of the most important members of the Aerobee family, the Aerobee 100, 150, 150A, 300, and 300A sounding rockets.

The primary sounding rockets used in the United States in the immediate post-World War II period were captured German V-2 missiles. The V-2 had been designed to deliver a warhead weighing 2,200 pounds (one metric ton) and thus had a large payload capability when used as a sounding rocket. If a V-2 was flown with a payload less than 2,200 pounds ballast had to be added to maintain proper stability for the missile. This large payload capability was somewhat of a mixed blessing as it encouraged the research scientists participating in the flights to design large, complex payloads, or to combine several, in some cases incompatible payloads onto the same flight. With the integration task for complex or multiple payloads and the technology of the time it was inevitable that part, or all of a payload package would be likely to fail on any given flight. Additionally the V-2 was a complex guided missile, and as will be seen a guidance system and active flight control are not really required for a simple sounding rocket. It was also obvious that the supply of captured V-2's was limited, and eventually a successor sounding rocket would need to be put into production before the supply of V-2's was exhausted. The approach the Soviet Union used for solving the problem of the limited postwar availability of the V-2 was different from the approach taken by the United States. While the Allies at the end of World War II had captured the top German rocket scientists, such as Wernher von Braun, and large amounts of V-2 hardware including many complete missiles, the Soviet Union ended up with the V-2 production facilities in its captured German territory with many of the lower level technicians and production personnel. The Soviet Union soon had the V-2 back in production, and later designed and produced modified V-2's under the direction of Sergei Korolev. With new missiles such as the Redstone and Viking being designed and soon to be entering production the United States saw no reason to consider remanufacturing V-2's, and the fundamental problem with using any of these rockets as sounding rockets was their size and payloads were too large, and their costs too high to be effectively operated as low cost sounding rockets. As the result of a study by James Van Allen of the John's Hopkins University Applied Physics Laboratory it was decided in 1946 to initiate the development of a new, smaller sounding rocket adapted from the WAC Corporal to replace the V-2. As this new sounding rocket was to be built by the Aerojet Corporation, and used technology from the Navy Bumblebee missile project, the new sounding rocket was given the name Aerobee.

It is of interest to review the overall design of the Aerobee to help in understanding the design philosophies and the design trades which resulted in an excellent sounding rocket. For reduced cost the multiple payloads of the V-2 with a total weight of 2,200 pounds were broken up into single payloads weighing 100-300 pounds that could be flown on separate, individual flights. With the state of solid rocket motor technology in the late 1940's to late 1950's, prior to the revolution of modern composite propellants, liquid fueled rockets had superior performance and reliability for use on sounding rockets. Solid rocket motors typically have shorter burn times and hence higher average thrust, a liquid rocket engine with its longer burn time reduces the accelerations the payload is subjected too, and this "smoother ride" for the payload was, and still is a considerable advantage for more delicate payloads. A sounding rocket must be low cost, and to eliminate high cost turbopumps from the liquid rocket engine the Aerobee sounding rockets were pressure fed. Hypergolic propellants, which are fuels and oxidizers which ignite on contact with each other, were used so that a complex ignition system would not be required. Simple opening of valves in the pressure fed system would bring the fuel and oxidizer together for ignition.

The ideal rocket equation, which when expressed as a function of exhaust velocity is known as the Tsiolkovskiy equation, gives some insight into the overall design philosophy used to maximize the performance of the Aerobee sounding rocket. The Tsiolkovskiy equation is named after the great Russian rocket theoritician Konstantin Eduardovich Tsiolkovskiy who was the first to derive the equation which he published in his book *Exploration of the Universe with Reaction Machines* in 1903. Written in the fol-

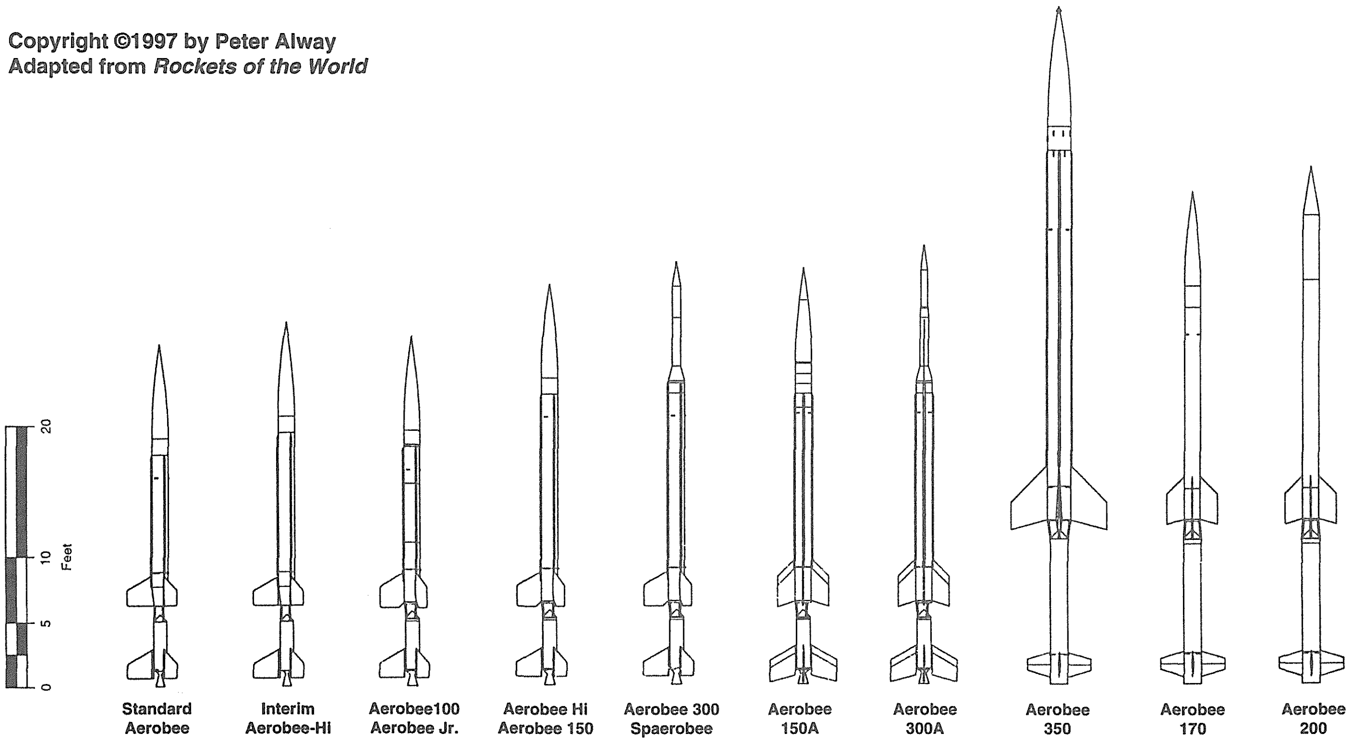

Figure A - Aerobee Sounding Rockets.

lowing form the ideal rocket equation gives the increase in velocity, or ΔV of a rocket in a gravity free and drag free environment given the specific impulse and propellant fraction of the rocket.

$$\Delta V = - I_{sp}\, g_o \ln(1 - P_F)$$

Where:

g_o = 32.174		(ft/sec^2)
I_{sp} = specific impulse		(sec)
ln = natural logarithm		
P_F = propellant fraction		(dimensionless)
ΔV = increase in velocity		(ft/sec)

Given the vacuum Isp of the Aerobee 150 sustainer of 228.3 sec (based on a sea level Isp of 198.0 sec and a nozzle exit area of 42.75 in^2) and a propellant fraction of 0.74 with a 100 pound payload, the Aerobee 150 would have an ideal (gravity free and drag free) ΔV of 9,895 ft/sec, or the sustainer stage would accelerate 9,895 ft/sec beyond the initial 750 ft/sec imparted by the solid propellant booster stage. The actual ΔV of the Aerobee 150 sustainer stage with a 100 pound payload is 6,616 ft/sec, meaning 3,279 ft/sec (33% of the ideal ΔV) is lost due to gravity losses and drag losses, and the lower thrust and Isp of the sustainer engine at low altitudes compared to vacuum. Accurately determining gravity losses and drag losses, and the effect of the variation of thrust and Isp with altitude is why sophisticated flight simulation programs using accurate drag prediction models are used to predict the performance of sounding rockets.

Figure B shows the velocity and altitude versus time for the Aerobee 150 for different payload weights. As can be seen in Figure B the low thrust and long burn time of the Aerobee liquid rocket engine lowers the initial acceleration of the sustainer stage and delays the high velocity phase of the flight until the Aerobee has reached high altitudes, thus minimizing drag losses. As Figure B shows after burnout at an altitude of 100,000-150,000 feet, and in particular during the coast phase above 200,000 feet the atmospheric density is low and thus there is very little aerodynamic drag resulting in the Aerobee essentially decelerating at a -1 g (varied with distance from the center of the Earth) due to gravity ajusted with flightpath angle as the rocket arcs over on the trajectory.

From the ideal rocket equation it's clear that for a given propellant combination, which at a particular mixture ratio (oxidizer to fuel ratio) and chamber pressure has a particular specific impulse, the performance of a sounding rocket will be maximized by maximizing the propellant fraction of the rocket. Maximizing the propellant fraction will increase the burnout velocity, which lengthens the -1 g (approximate) coast phase (at high altitude) of the rocket, which ultimately increases the apogee altitude of the rocket. For a sounding rocket with a liquid rocket engine the propellant fraction can be increased by increasing the amount of propellant onboard, which will decrease the liftoff thrust to weight ratio. Using the ideal rocket equation it's clear that for maximum performance a liquid fuel rocket using a rocket engine of fixed size should have a thrust to weight ratio at liftoff of just barely over 1.0. (The typical thrust to weight ratio at liftoff for liquid fueled orbital launch vehicles is 1.2.) Thrust to weight ratios near 1.0 normally require active guidance,

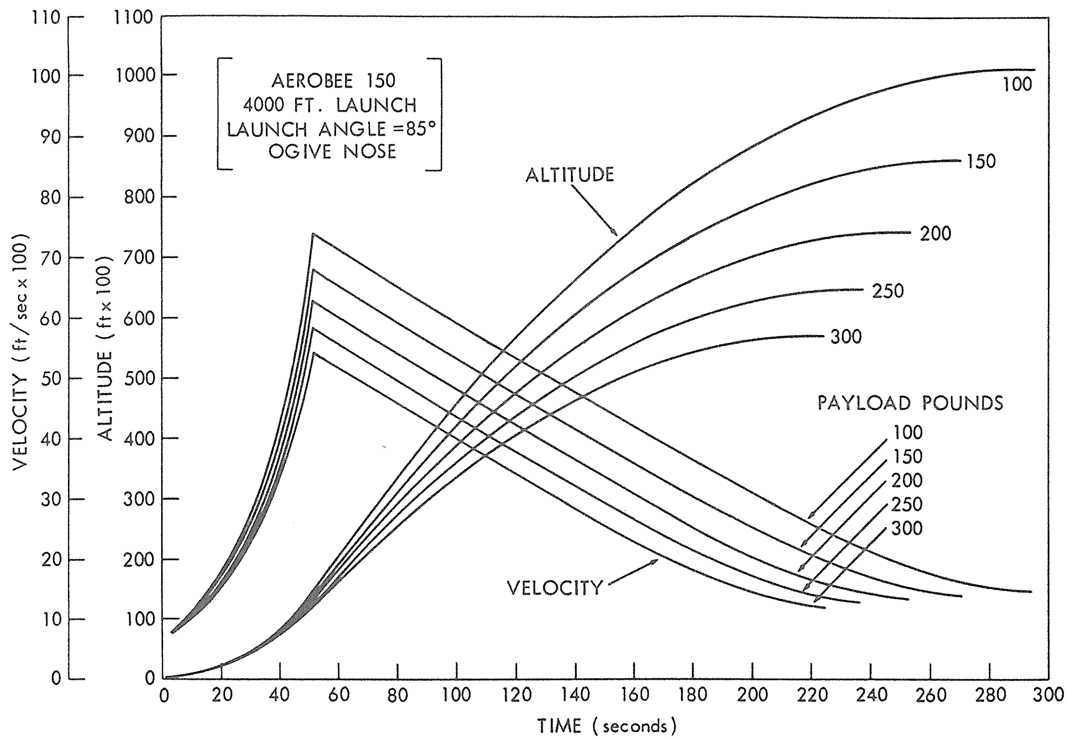

Figure B - Aerobee 150 Velocity and Altitude Versus Time for Various Payload Weights.

which was used on the V-2, but for greatly reduced complexity and cost the Aerobee was to be unguided. The solution was to add a high thrust booster stage which when combined with a long tower allowed the Aerobee sustainer stage to be accelerated to approximately 750 ft/sec (approximately Mach 0.7), a velocity that was more than adequate for the sustainer stage to maintain a stable trajectory despite its low initial acceleration. To further eliminate the need for active guidance the Aerobee was spin stabilized to minimize dispersions in the trajectory from fin and thrust chamber misalignments, and to insure proper orientation of the sustainer stage after burnout after it had left the sensible atmosphere and the fins were no longer effective. The technology required for the solid fueled booster stage was well within the state of the art at the time of the development of the Aerobee as high thrust, short burn solid rocket motors using solid propellants of that era had undergone considerable development for Jet Assisted TakeOff (JATO) units for aircraft. The solid rocket motor used for the Aerobee booster stage was a 1946 design based on a then existing Aerojet JATO motor. Finally, to minimize the complexity inherent in having multiple stages, to reduce the staging transients when staging from the booster stage to the sustainer stage, and to eliminate the risk from having to ignite the sustainer stage at altitude, the sustainer stage was ignited while the Aerobee was still in the launch tower and was operating at full thrust as the Aerobee was being boosted by the booster stage. An open thrust structure with three legs and a thrust ring between the booster stage and the sustainer stage allowed the sustainer exhaust to flow around the booster stage, with the booster stage protected by a short conical nose cone which functioned as a flow deflector.

It is interesting to note Theodore Von Karman's and Frank Malina's thoughts on the approach they used on the WAC Corporal and Aerobee sounding rockets of launching an unguided, spin stabilized rocket from a long tower using a high thrust, short burn booster, relative to the approach used by Robert H. Goddard on his rockets of using gyroscopes and active guidance. In his book *The Wind and Beyond* Von Karman wrote that he and Malina frankly thought that Goddard had wasted a lot of his effort developing gyroscopes and active guidance for his rockets because, while they were of paramount importance for future space launch vehicles (with typical liftoff thrust to weight ratios of 1.2 and the requirement to be accurately guided to specific orbits), they were not really required to build an effective sounding rocket. If Goddard had made the launch tower for his later rockets a little longer he would have been able to launch aerodynamically stabilized rockets with fixed fins, and could have flown his rockets completely unguided with no gyroscopes or guidance system whatsoever.

In the author's opinion one of the best technical reports ever written covering the Aerobee family of sounding rockets was NASA TR R-226, *A Compendium of Aerobee Sounding Rocket Launchings from 1959 through 1963*, by Jon R. Busse and Merrill T. Leffler. This report covers the design, operation, and performance of the Aerobee 150, 150A, 300, and 300A sounding rockets, with some limited information on the Aerobee 100 sounding rocket. As this material was published by the United States Government, under Title 17 of the U.S. Code it has entered the public domain. Many rocketeers do not have access through technical libraries and university libraries to old public domain NASA reports. The author and *High Power Rocketry* are pleased to republish this material and to make it available for current and future generations of model, high power, and experimental rocketeers.

A COMPENDIUM OF AEROBEE SOUNDING ROCKET LAUNCHINGS FROM 1959 THROUGH 1963

by Jon R. Busse and Merrill T. Leffler
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INTRODUCTION

During the past several years the tempo of the Aerobee sounding rocket program has increased considerably. Scientists of the National Aeronautics and Space Administration (NASA) and other government agencies, and experimenters from universities and industry all over the world, have become more and more dependent upon the Aerobee as an effective vehicle for space probes. A variety of payloads carried by Aerobee vehicles have accomplished airglow, aurora and solar x-ray detection, have measured solar ultra-violet radiation and have even collected micrometeoroids. These experiments are but a few of those performed by scientists doing upper atmosphere research.

This report does not discuss the success of the scientific data collected through Aerobee sounding rocket experimentation. Rather, the information presented is intended to provide users with statistics on the performance of past sounding rocket firings, from which Aerobee vehicle capabilities can be evaluated.

Aerobee is the name given to a family of sounding rockets which have gained a reputation as the work horse of the NASA sounding rocket program. This is because the Aerobee, with its relative simplicity and low cost, provides a soft ride vehicle capable of delivering sizable payloads into space with a high degree of performance reliability. Also, the Aerobee provides the support versatility necessary for a variety of upper atmosphere research programs.

Although fourteen Aerobee 100 rockets were fired from 1959 to 1963, the sounding rockets used most extensively today are the Aerobee 150, Aerobee 150A, Aerobee 300, and Aerobee 300A. There are many similarities between Aerobees, and this report will discuss both the similarities and the differences. Since the Aerobee 150A has been the most used member of the Aerobee family, with a total of 52 firings during the period covered by this report this configuration will be considered as the prime vehicle. A typical firing is shown in Figure 1.

DESCRIPTION OF AEROBEE I50A

The Aerobee 150A (Figure 2a) is a four-fin sounding rocket approximately 30 feet long and 15 inches in diameter. The manufacturer, the Space-General Corporation of El Monte, California (then the Aerojet General Corporation), assisted in the first successful flight in February 1960. The rocket is capable of transporting from 100 to more than 300 pounds to altitudes of from 180 to 100 miles while maintaining a stable, near-vertical trajectory. Additionally the Aerobee 150A is a free-flight fin-stabilized tower-launched vehicle using a liquid propellant sustainer and boosted from the tower by a solid propellant booster. During flight the rocket is rolled to reduce dispersion due to thrust and structural misalignments.

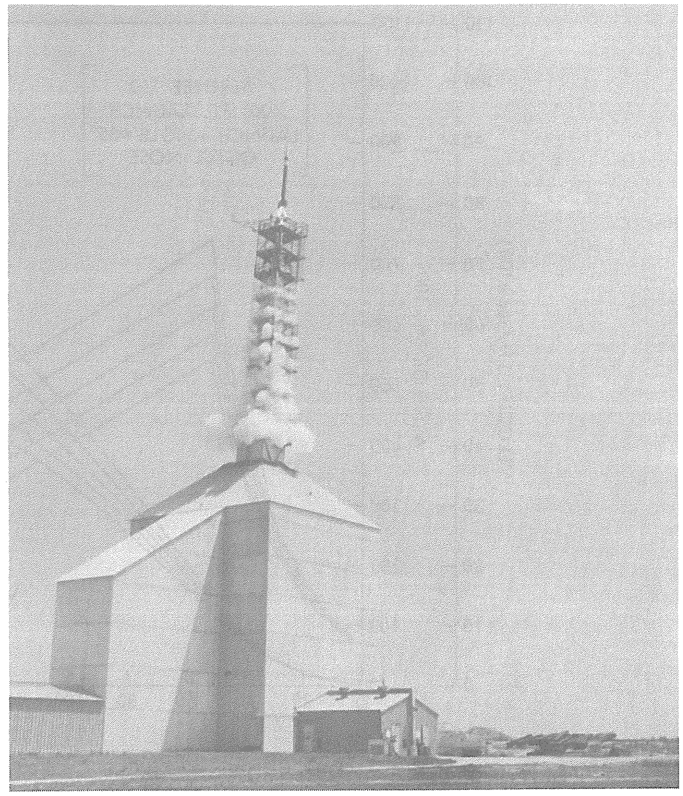


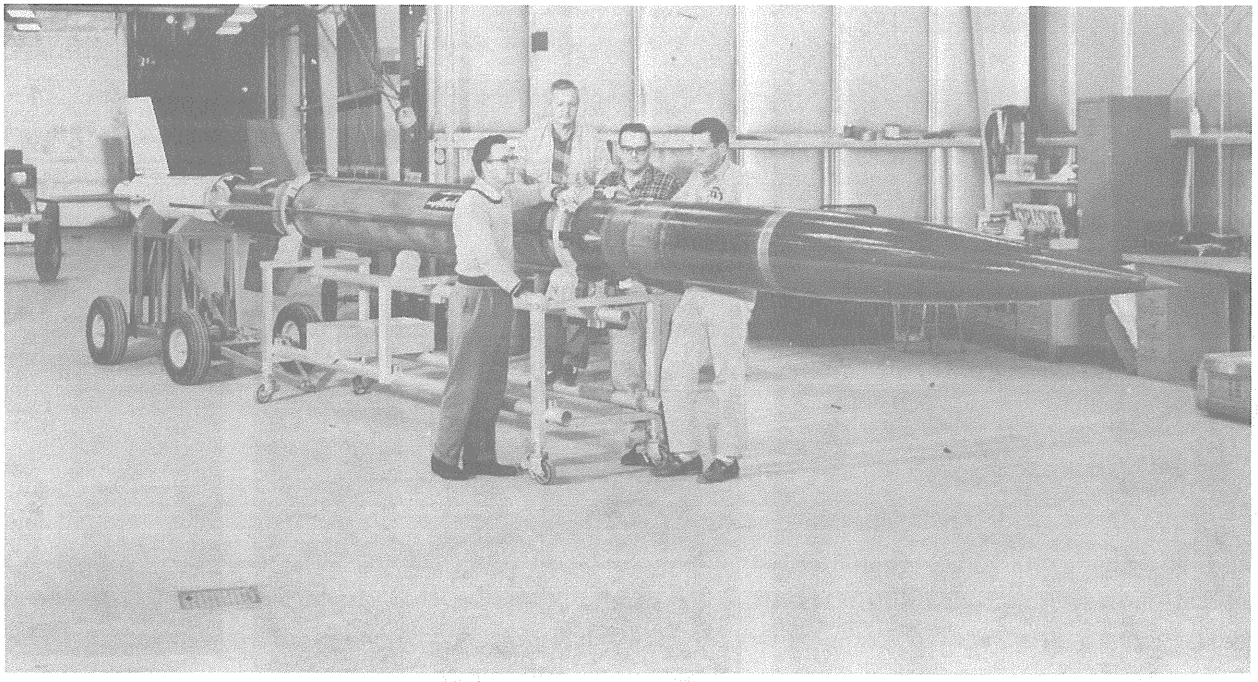
Figure 1 - Aerobee 150A sounding rocket launched from Wallops Island.

Sustainer

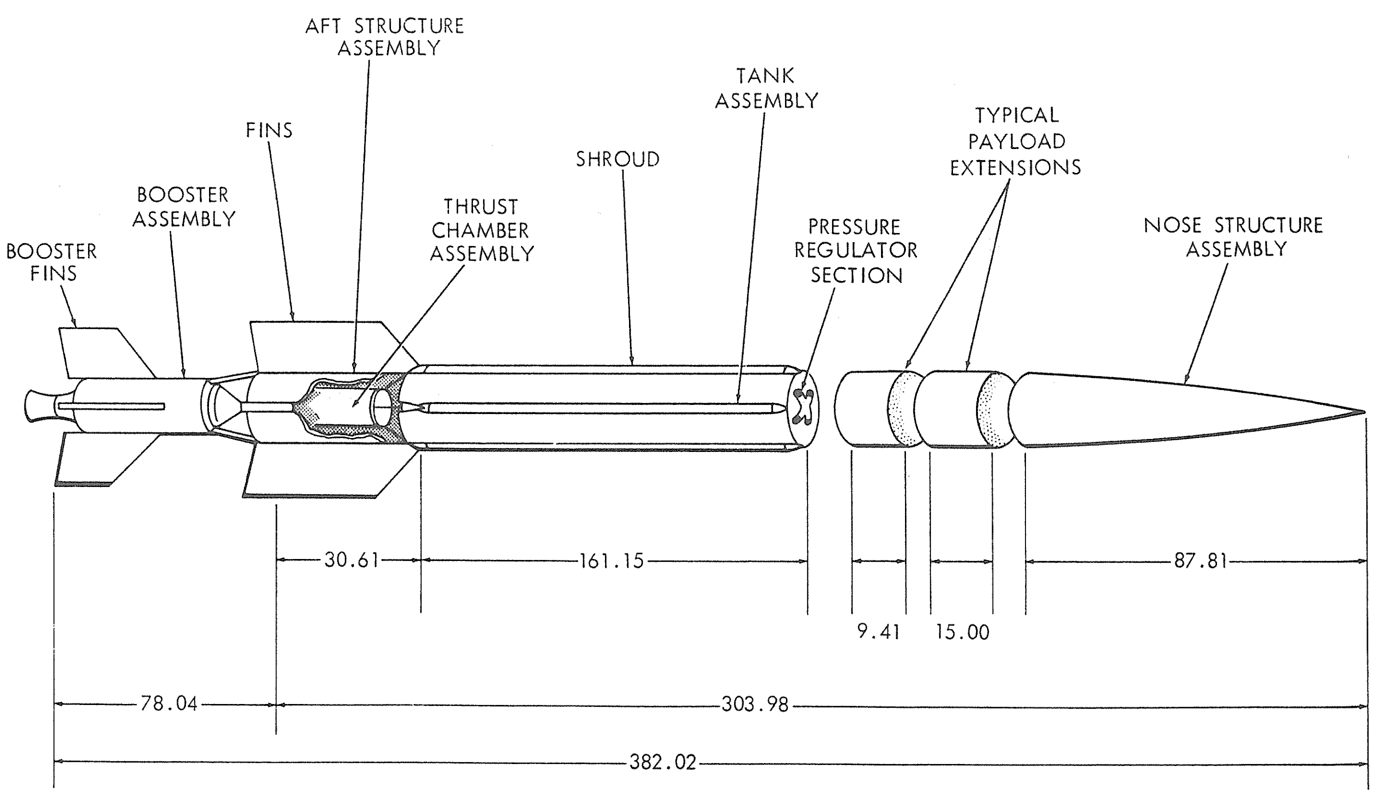
The sustainer portion of the rocket is illustrated in Figure 2b. Basically, the sustainer consists of a nose cone and extensions which house the payload, a forward skirt housing the pressurization system; integral pressurization and propellant tanks which form the main body of the rocket, and an aft structure which houses the thrust chamber and supports the fins. Four shrouds are mounted between the forward skirt and aft structure for propellant tank pressurization lines, instrumentation lines, and antenna cabling. Equidistant between the shrouds, fore and aft, are two sets if riding lugs which support the rocket between the rails in the launch tower. The four-fin configuration of the 150A is the most obvious difference between it and the Aerobee 150.

Nose Cone

The nose cone (Figure 3a) is a 31-caliber aluminum ogive, circular in cross section, formed by spinning. A typical instrumentation payload is shown in Figure 3b. The total assembly is 87.8 inches in length and has a volume of 4.75 cubic feet. The cone is attached to the rocket, or payload extension if used, by 16 screws. Whenever called for by greater volume requirements, a two piece cone-cylinder nose cone is available for use on all Aerobees. The forward section of this two piece assembly is a cone 42.7 inches long with a 20° vertex. The aft section consists of a 44-inch aluminum cylinder 15 inches in diameter.

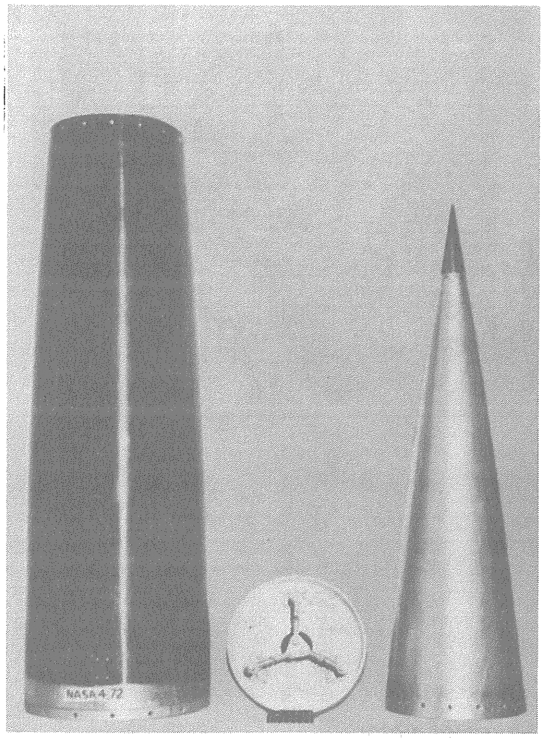


(a) Photo of assembled rocket, payload, and booster motor.

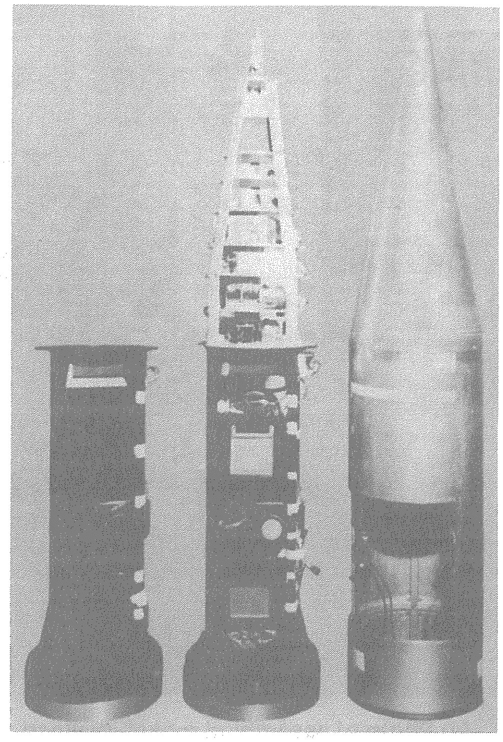


(b) Outline drawing.

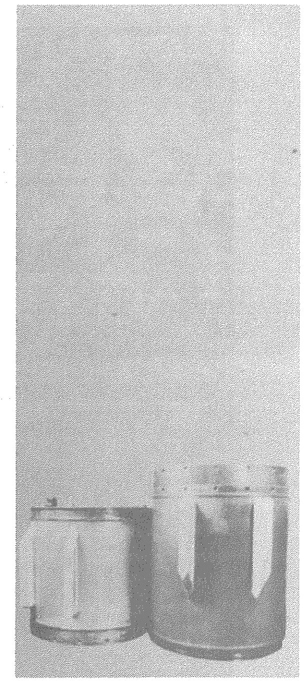
Figure 2 - Aerobee 150A sounding rocket.



(a) Ogive nose cone and ejection mechanism showing aft side of release cam bulkhead.



(b) Typical instrumentation package with cone-cylinder nose cone.



(c) Side view of payload extensions with quadra-loop antennas mounted on outside surface.

Figure 3 - Aerobee rocket payloads.

Payload Extensions and Forward Skirt

Payload extensions (Figure 3c) are rolled and welded magnesium sheets .063 inches thick. They are available for use in cylindrical lengths from six to 45 inches. Extensions are attached to the rocket, or preceding section, in the same manner as the nose cone. The forward skirt, also a magnesium cylinder, contains the pressure regulator valve, overboard bleed port, external pull-away plugs, and internal instrumentation plugs needed to provide access to the shrouds. Figure 4a Provides a top view of the forward skirt which is riveted to the forward end of the tank assembly and includes an access door. On the forward end of the skirt are tapped holes which are used to attach the nose cone, or extension if used, by means of 16 screws. The sustainer contains four stud bolts for attachment of the payload assembly when required. One of these can be viewed in Figure 4a.

Tank Assembly

The tank assembly is a cylinder 161.5 inches long and 15 inches in outside diameter. It is made of three welded tanks for helium, fuel, and oxidizer, arranged fore and aft with the tank walls forming the external skin of the rocket. The aft helium bulkhead and forward fuel bulkhead are common, as are the aft fuel bulkhead and forward oxidizer bulkhead. The assembly is fabricated from type 410 stainless steel and is heat treated to a minimum tensile strength of 142,000 psi.

The helium tank is normally pressurized to 3,450 (±50) psia of gas initially. Gas feed lines emerge through the forward skirt, go down the shrouds and terminate in the ullage portion of the propellant tanks. The fuel feed line extends from the center of the aft fuel bulkhead through the oxidizer tank and out the oxidizer tank head. Baffles at the outlet of each tank stabilize the propellant flow into the feed lines.

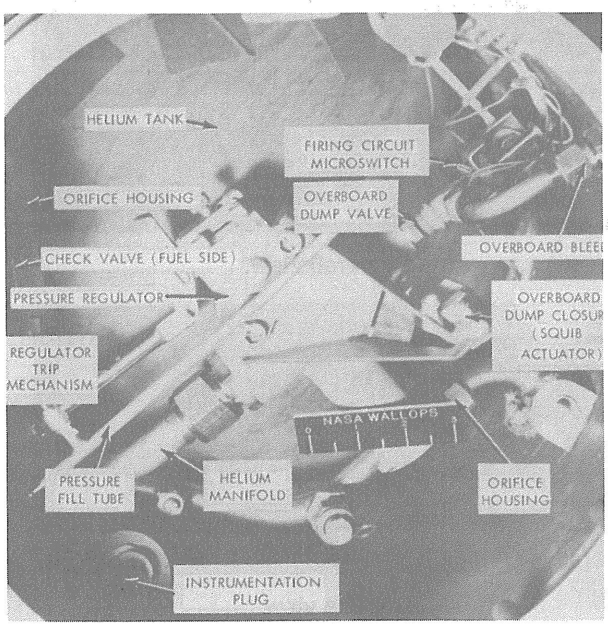
Aft Structure and Shut-off Valves

The aft structure contains the thrust support structure, the modified Nike propellant start valve, the fuel and oxidizer shutoff valves, propellant flex lines, and the regeneratively cooled thrust chamber (Figure 4b).

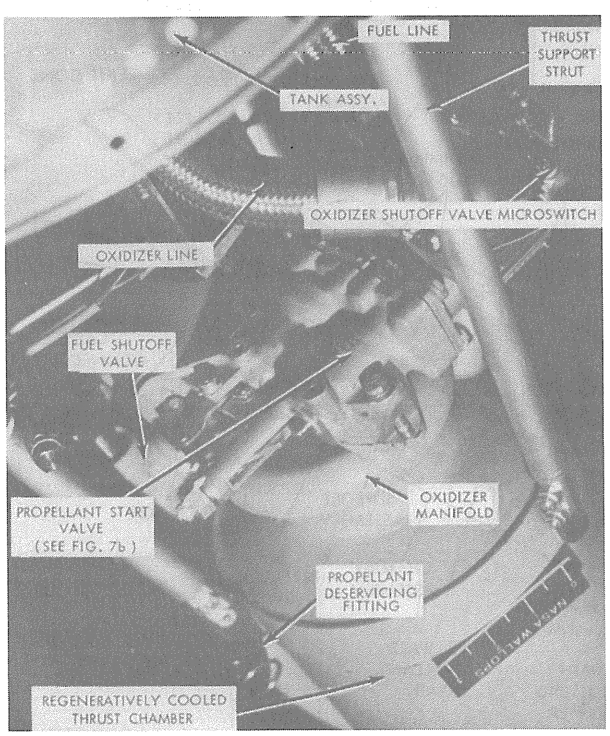
The shutoff valves are poppet-type, normally open, squib actuated valves. They may be closed by ground command to terminate thrust whenever necessary. Frequently they are closed after rocket burnout to conserve the helium for attitude control or despin functions, or to prevent contamination of the experiment by the exhausting gas. Microswitches are presently used to monitor the positions of the valves. The thrust chamber is a welded assembly consisting of four major areas: the fuel coolant jacket; the fuel and oxidizer manifolds; the injector; and the combustion chamber and DeLaval nozzle. The aft skirt is a rolled and welded magnesium cylinder 30.3 inches in length attached to the tank assembly with 16 screws.

Fins

Figure 5 illustrates an Aerobee 150A sustainer fin. Each is a modified single wedge of magnesium skin and spars, an aluminum box structure attachment base, and a stainless steel leading edge cuff .010 inch thick. Each fin has a total fin area of 14.88 sq. ft., weighs seven pounds, and is attached to the aft skirt by means of two half-inch bolts. The fins can be canted up to 20° to induce rolling motion to the rocket.



(a) Forward skirt.



(b) Tail assembly.

Figure 4 - Sustainer components.

Propellants

The Aerobee 150A uses a fuel comprised of a mixture of 65% aniline and 35% furfuryl alcohol (ANFA) and an oxidizer of inhibited red fuming nitric acid (IRFNA). The fuel and oxidizer are hypergolic.

IRFNA is a corrosive, toxic, non-flammable liquid mixture of nitric acid (HNO_3), water, and dissolved nitrogen dioxide (NO_2). The liquid is light orange to orange in color. A small percentage of hydrofluoric acid (HF) is added to inhibit corrosion in the oxidizer tank.

The significant characteristics of IRFNA are:

(1) Water	less than 2%
(2) NO_2	6%-8%
(3) HF	0.6%
(4) HNO_3	Residual (90%+)
(5) Odor	Acrid
(6) Hygroscopic	Yes
(7) Specific gravity	1.54 (68°F)
(8) Freezing point	-49°F
(9) Normal boiling point	+152°F
(10) Approximate maximum decomposition pressure at 80°F and 10% ullage	150 psia

Aniline ($CH\,(CH)_4\,C - NH_2$) is a flammable, non-corrosive, toxic, oily liquid which varies in color from colorless to brown. It has an amine odor, is low in volatility, and is hypergolic with nitric acid. Its significant characteristics are:

(1) Odor	Amine
(2) Boiling point	364°F
(3) Freezing point	22°F
(4) Flash point (closed cup)	168°F
(5) Ignition temperature	1418°F
(6) Specific gravity	1.002 (68°F)

Furfuryl alcohol, also called 2-furancarbinol ($OCH{:}\ CH\ CH{:}\ C\text{-}CH_2\ OH$), is a flammable, non-corrosive, non-toxic liquid which varies in color from straw yellow to dark amber. It has a brine-like odor and is hypergolic with nitric acid. The significant characteristics of furfuryl alcohol are:

(1) Specific gravity	1.136 (60°F)
(2) Hygroscopic	Slightly
(3) Boiling point	332.6°F-343.4°F
(4) Flash point	167°F

Booster

The booster is an Aerojet General type 2.5KS-18,000 motor with a 2.5 sec burning time and high thrust. The motor, which is occasionally used in sled testing, was designed and first used between 1946 and 1948, and reflects the state of the art of that period. Over 850 of these motors have been fired since 1947. The thrust structure consists of three legs and a thrust ring which transmits the booster thrust to the aft structure of the sustainer. The thrust structure is of cast and welded construction and is attached to the booster by 12 screws. It mates with the aft skirt by a shoulder-keyed joint. A flight cone is attached above the igniter firing cap and diverts the sustainer rocket flame away from the booster.

The chamber barrel is rolled and welded from 0.190-inch thick AISI-4130 sheet steel stock. An aft ring and a forward closure are welded to the barrel section, the forward closure containing a boss for installing an adjusting adaptor and igniter assembly. The external surface on the forward closure is machined for attaching a thrust skirt assembly. The aft ring is drilled and tapped for attaching the nozzle assembly. Centering clips are spot welded to the inside of the barrel section for centering the charge assembly. Fin attachment pads and guide lugs are welded to the outside of the chamber. The chamber, heat treated to 150,000 psia minimum ultimate tensile strength, is hydrostatically tested to 2400 psig after fabrication.

The nozzle assembly is primarily composed of an AISI-4130 steel closure and exit cone. The forward ring of the closure is drilled for attaching the assembly to the chamber; the aft end of the closure is threaded for attaching the exit cone. The closure is heat treated to 150,000 minimum ultimate tensile strength and is hydrostatically tested to 2400 psig. A 0.50-inch thick plastic closure is cemented to the entrance section of the nozzle closure to maintain adequate pressure for aiding propellant ignition and bursts between 800 and 1200 psig. The entire nozzle assembly is attached to the chamber with twenty-four ½-inch diameter bolts.

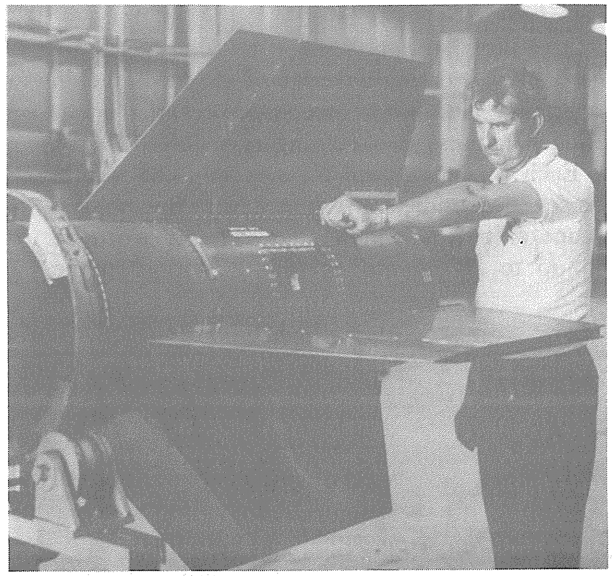
The booster fins are similar to the 150A fins in shape and construction. Each fin is attached to three pads on the booster chamber by means of bolts. The holes are so machined to provide a pre-set fin cant of 2.5°. The fin cant is not adjustable. Figure 6 shows outline dimensions and a cutaway drawing of the booster assembly.

The charge assembly is composed of two internal-external burning grains, a center trap assembly, forward and aft traps, an adjusting adaptor, and igniter guide post with lead wires. The grain assemblies consists of two 130-pound cylindrical AK-14-Mod 1 propellant grains, both ends of which are inhibited with glass laminates. An asbestos sheet is cemented to the glass laminates to preclude radiant ignition, and discs are cemented to the asbestos sheet to allow for compression during assembly. The grain assemblies are torqued to the center trap assembly, using the forward and aft traps as compression plates. The total impulse delivered by the two grains is between 44,375 and 50,000 lb.-sec.

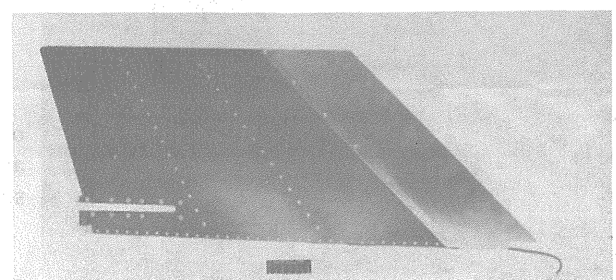
The igniter is designed to produce sufficient pressure and heat to ignite the propellant grain. The main charge, consisting of 180 gm. of sodium nitrate black powder, is contained in a circular frangible plastic container. Two squibs, filled with potassium nitrate black powder, ignite the main charge. A five ampere current is used for reliable ignition.

Firing Sequence

The firing of an Aerobee 150A is accomplished by remote control. Figure 7a illustrates the schematic diagram of the propulsion system. The firing sequence is as follows:

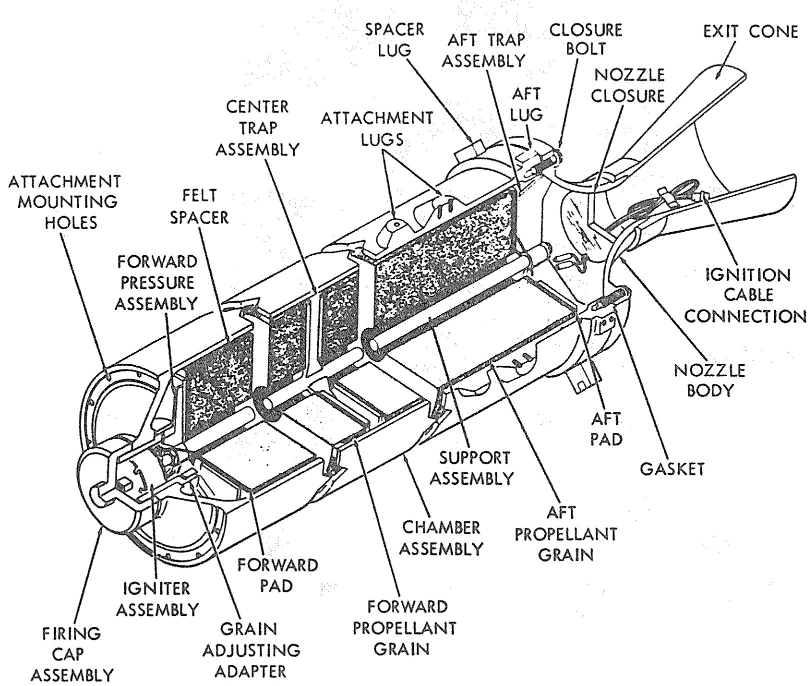


(a) overall view.



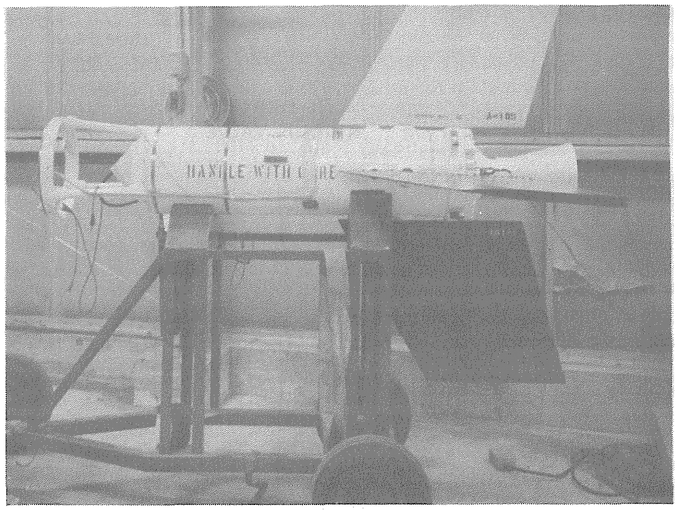
(b) Side view.

Figure 5 - Aerobee 150A sustainer tail fin.

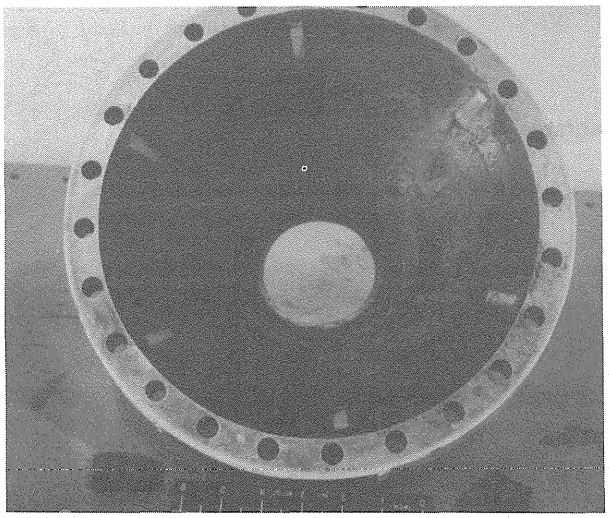


(a) Cutaway view showing major components.

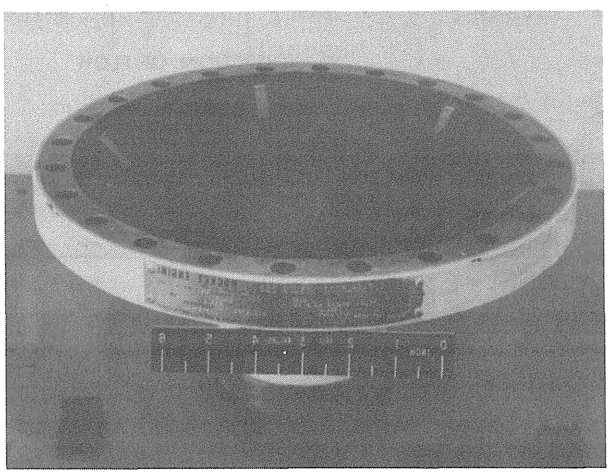
Figure 6 - Aerobee booster motor, type 2.5KS-18000.



(b) Side view.



(c) Inside view of nozzle closure.



(d) Side view of nozzle closure.

Figure 6 - Aerobee booster motor, type 2.5KS-18000.

(1) The helium overboard dump is closed by actuation of a squib-operated mechanism.

(2) After a 200 millisecond delay, the booster igniter is fired.

(3) As the rocket moves vertically, the regulator is actuated by pulling a trip wire.

(4) This action opens the pressure regulator valve (Figure 7a) and feeds helium into the propellant tanks (the regulator reduces the gas from 3450 (±50) psia to approximately 500 psia).

(5) At 160 psig the oxidizer diaphragm in the propellant start valve breaks (Figure 7b).

(6) At 325 psig the fuel diaphragm breaks. The rate of tank pressurization is controlled, by orifices downstream of the regulator. (The fuel tank is pressurized at a rate faster than oxidizer tank pressurization to prevent implosion of the common bulkhead.)

(7) The Nike valve cam holds the pintles in a throttled position to meter the flow of the propellants in the combustion chamber.

(8) When the chamber pressure reaches 100 psig, the propellant start valve actuator releases the cam and pintles and the propellants are in a full flow condition (this is approximately 0.6 second after first booster motion).

(9) At approximately 2.5 seconds the booster burns out and separates from the sustainer.

Nominal Performance Characteristics

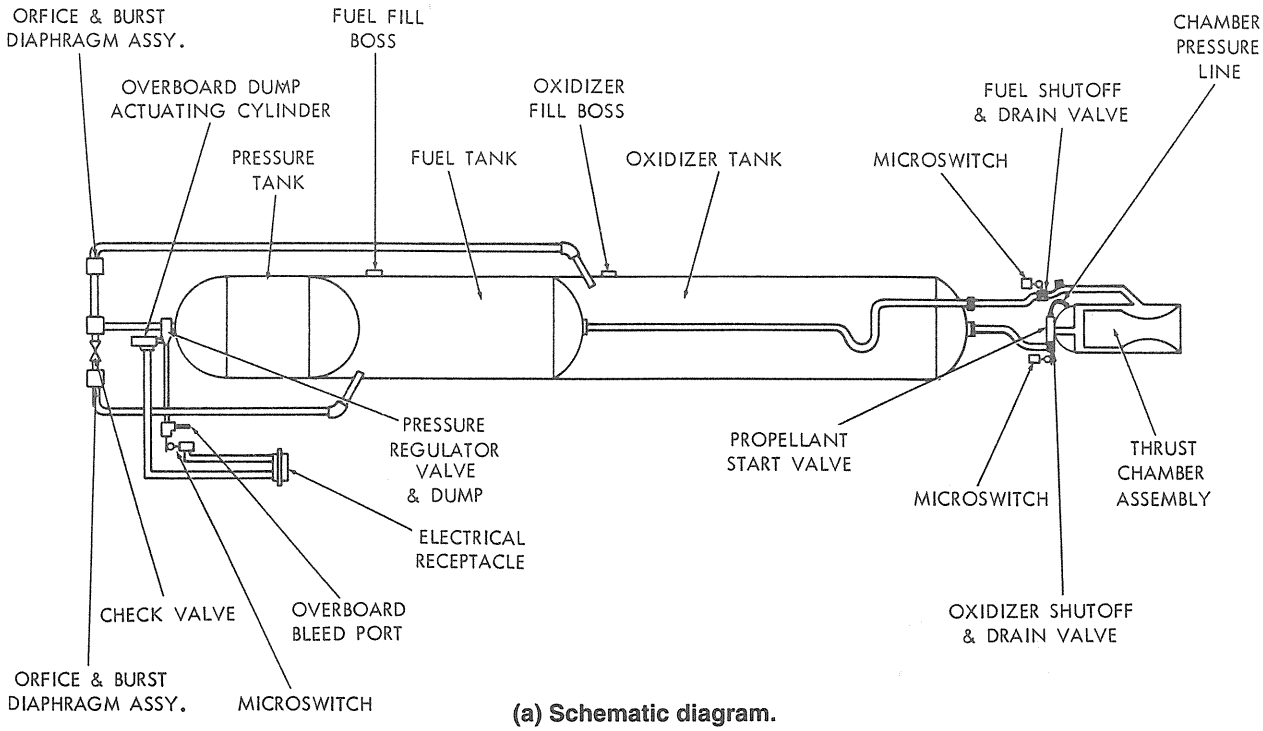
Nominal performance characteristics of the Aerobee 150A are as follows:

Liquid-Propulsion System:

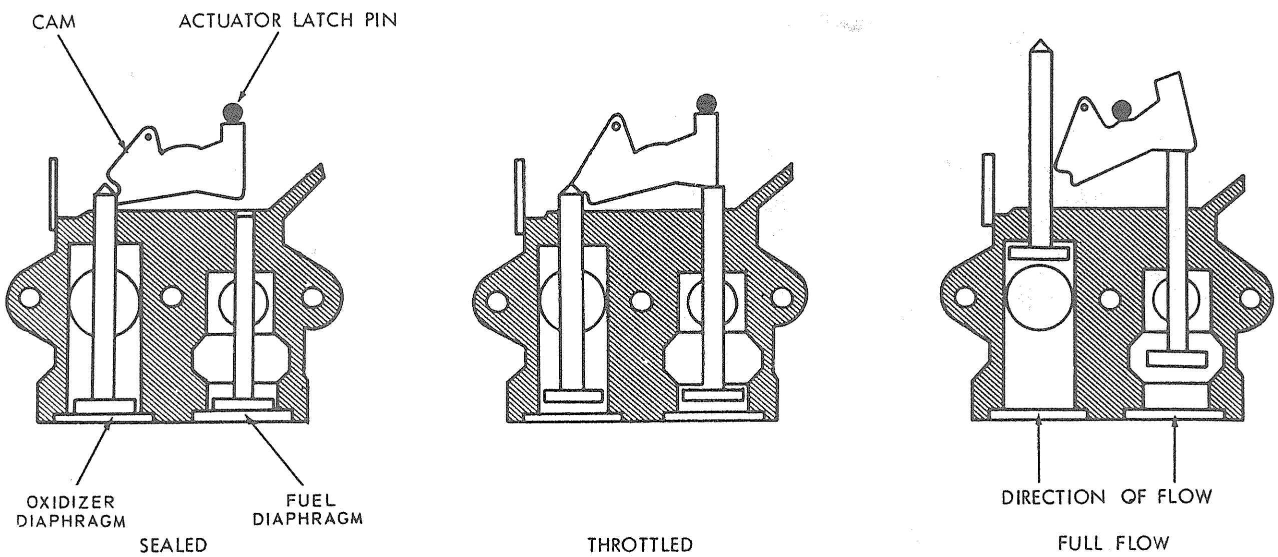
Pressurizing Gas	Helium-Grade A
Oxidizer to fuel ratio	2.56 to 1
Thrust chamber pressure	324.0 psia
Sea level thrust	4100 lb.
Powered duration	51.5 sec.
Propellant flow rate	20.71 lb./sec.
Nozzle expansion ratio	4.6
Specific impulse	198 lb-sec/lb.
Total impulse at sea level	208,690 lb.-sec.

Solid-Propulsion System:

Sea level thrust	18,600 lb.
Powered duration	2.5 sec.
Chamber pressure	1340 psia avg.
Area throat	8.50 in.^{2}
Expansion ratio	7.9
Weight flow rate	104 lb./sec.
Surface-to-Port ratio	74
Specific impulse	178 lb-sec/lb.
Flame temperature	2960°F



(a) Schematic diagram.



(b) Positions of propellant start valve.

Figure 7 - Propulsion system.

*Rocket Performance Characteristics.**

Peak altitude	179	statute miles with 100 pound payload
	101.7	statute miles with 300 pound payload
Burnout velocity	7,094	ft./sec. with 100 lb. payload
	5,260	ft./sec. with 300 lb. payload
Burnout altitude	138,584	ft. with 100 lb. payload
	111,688	ft. with 300 lb. payload
Burnout acceleration	349.44	ft./sec.^{2} with 100 lb. payload
	218.24	ft./sec.^{2} with 300 lb. payload

*Performance characteristics are obtained using an ogive nose cone. The cone-cylinder results in an approximate loss of 4% in altitude (launched at sea level).

Dispersion Factors (150-lb. Payload):

Tower Tilt Factor	94.0 statute miles for 4° tower tilt
Ballistic Factor	5.2 miles/mph ballistic wind

Weights (In Pounds):

Payload	100 to 300
Vehicle Gross Weight (with payload)	2097.5
Rocket (empty)	279.1
Booster (loaded)	520.0
Booster (expended)	260.0
Fins (4)	28.0

Volumes (In Cubic Feet):

Pressure tank	2.57
Fuel Tank	4.46
Oxidizer Tank	7.88
Ullage Space	0.14

Propellant Weights (In Pounds):

Oxidizer	758.2
Fuel	303.3
Helium	5.15

Launch Facility

The Aerobee 150A is only launched from NASA Wallops Station, Wallops Island, Virginia, because at present Wallops has the only tower that can accommodate a four-finned vehicle. The launch tower and preparation facilities (Figure 8) include a launcher 160 feet high which can be adjusted in elevation and in azimuth. The coordinates of Wallops Island are 37° 50' North, 75° 29' West.

AEROBEE 150

The Aerobee 150, being launched from the White Sands Missile Range (WSMR) in Figure 9a, is similar in many ways to the 150A described in the previous section. Obvious physical differences that can be noted are that the Aerobee 150 has a three-fin sustainer and booster. Likewise, the Aerobee 150 has only three shrouds and three riding lugs whereas the 150A configuration has four of each. Also the location of the common oxidizer and fuel bulkhead, the propellant start slug, and the orientation of the pressurization system in the aft structure differ slightly in the Aerobee 150 configuration.

The Aerobee 150 is launched from a three-rail tower such as the tower installation at WSMR (shown in Figure 9b). Fins for the 150 are biconvex and are attached with eight bolts. A comparison between the fin configuration for the Aerobee 150 and the Aerobee 150A is provided in Figure 10. Sustainer fins may be canted to induce roll, and as in the 150A the 150 booster fins are preset at an angle of 2.5° to induce roll.

The 150 sustainer uses a seven pound start slug of 70% furfuryl alcohol and 30% aniline by weight, which provides slightly improved ignition characteristics over the 65% aniline, 35% furfuryl alcohol mixture used in the 150A. The oxidizer tanks on the 150 are located forward of the fuel tanks. The Figure 11 outline drawing shows the location of the oxidizer fill boss, relative to the fuel fill boss. This propellant positioning requires a change in regulated feed pressures, however; thus the system hydraulic pressure drops and in-flight acceleration heads differ from those of the 150A.

Since the Aerobee 150 has only three shrouds and is launched from a three-rail tower, a rearrangement of the pressurization system in the forward skirt is evident. Figure 12 provides a top view of this revised arrangement. The components of the pressurization system are the same, but fewer instrumentation plugs are available in the 150. Only one plug is shown in Figure 12, whereas two are shown in the forward skirt illustration, (Figure 4a) for the Aerobee 150A.

There are some other minor differences. Figure 13 shows an Aerobee 150 tail assembly. Note the use of hard lines, flare fittings and the arrangement of some of the hardware which differs from that in the 150A. Also, low pressure burst diaphragms (50 ±10 psi) provide the initial throttling capability which is afforded by the Nike valve in the 150A configuration. There are no differences in the booster case or grain arrangement.

Some typical performance characteristics of the Aerobee 150 (launched at sea level), with a 150 lb. payload and ogive nose cone are:

Peak altitude	158 statute miles
Burnout altitude	132,000 ft.
Burnout velocity	6580 fps
Thrust at sea level	4100 lbs.
Duration of thrust	51.8 sec.

Aerobee 150 rockets are launched from White Sands, New Mexico (WSMR) and Fort Churchill Research Range, Manitoba, Canada (FC). Figure 9b illustrates the tower installation at WSMR; Figure 14a provides an aerial view of the Fort Churchill launch facility; and Figure 14b shows a close up of the same facility. Coordinates for the FC launch facility are 58° 44' North, 93° 49' West, on the shore of the Hudson Bay. Coordinates of the WSMR facility are 32° 24' North, 106° 20' 30" West, approximately 40 miles north of El Paso, Texas. At WSMR, Aerobee 150's are launched from the Naval Ordnance Missile Test Facility with range services provided by the U.S. Army.

AEROBEE 300A

The Aerobee 300A is an Aerobee 150A with a third stage motor added. All Aerobee 150A volumes, weights, and characteristics, except those pertaining to the payload, are applicable to the 300A. Therefore, discussion regarding the Aerobee 300A will be limited to the third stage and its effects on increasing rocket performance.

The third stage shown in Figure 15 is composed of a 1.8KS-7800 solid propellant motor, a high expansion ratio nozzle, a separation subsystem, and the nose cone. The nose cone has a maximum diameter of eight inches, limited by the diameter of the solid motor. The motor provides a nominal thrust of 7800 pounds for 1.8 seconds. It has the following nominal propulsion system ratings:

Duration	1.8 sec.
Propellant flow rate	32.09 lb./sec.
Chamber pressure	1000 psia
Throat area	4.43 in.^{2}
Area ratio	30
Diameter	8 in.
Thrust coefficient*	1.73
Thrust*	7664 lb.
Total impulse*	16,478 lb.-sec.
Specific impulse*	238.8 lb-sec/lb.

*In vacuum.

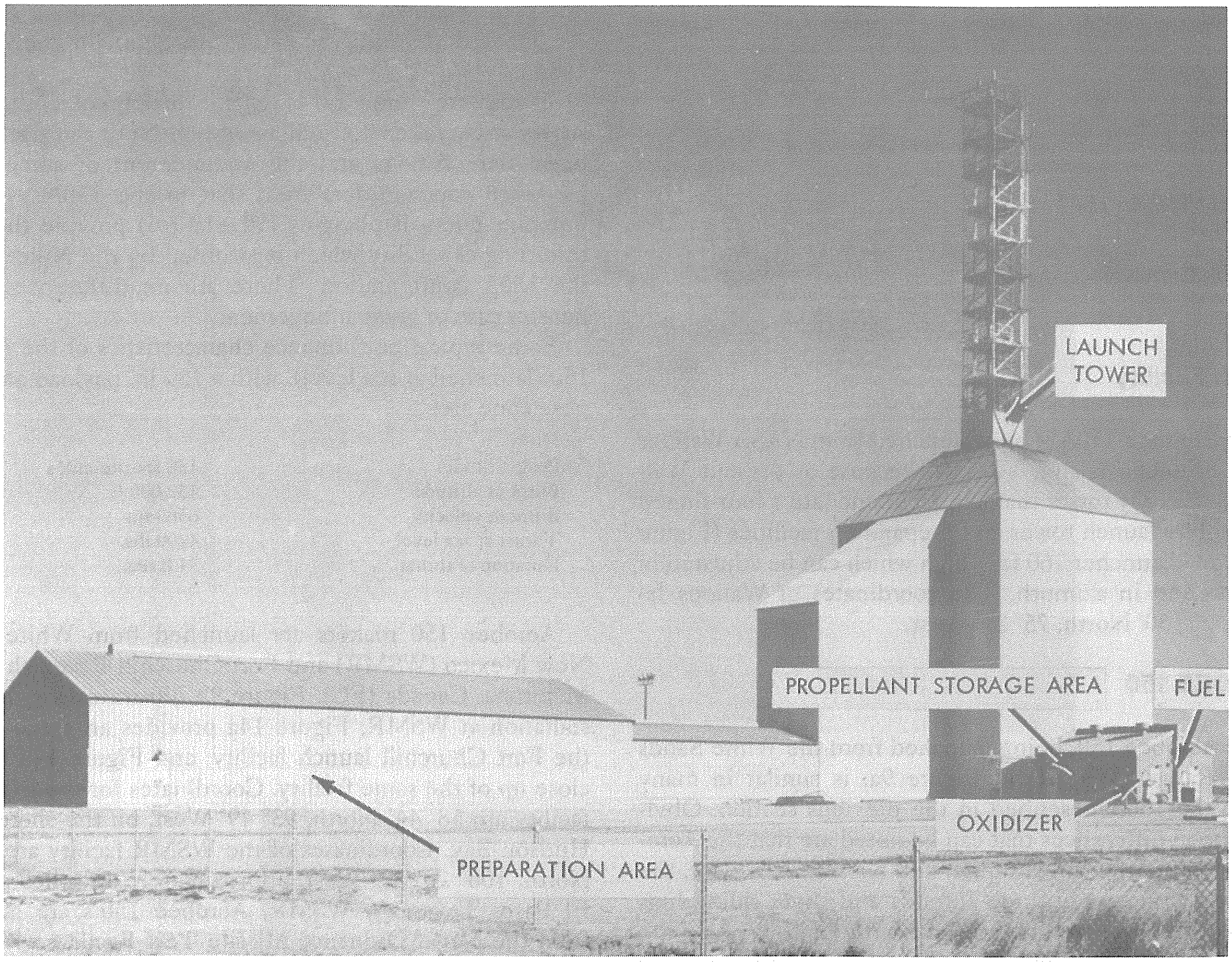
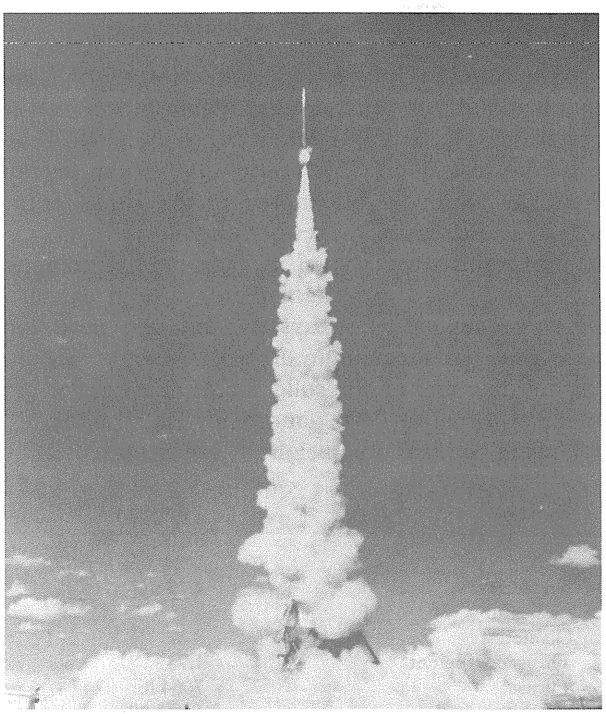
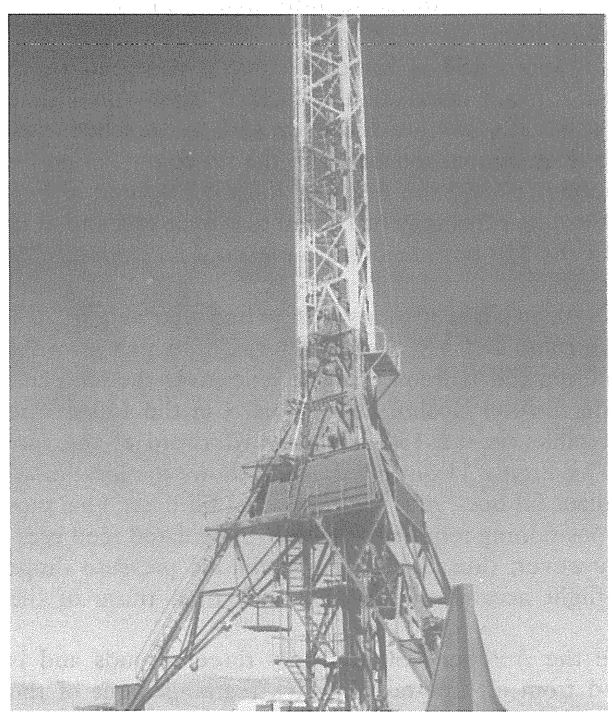


Figure 8 - Aerobee launch facility at Wallops Island.



(a) Typical sounding rocket launch.



(b) Aerobee launch tower installation.

Figure 9 - Aerobee launch facility at White Sands Missile Range.

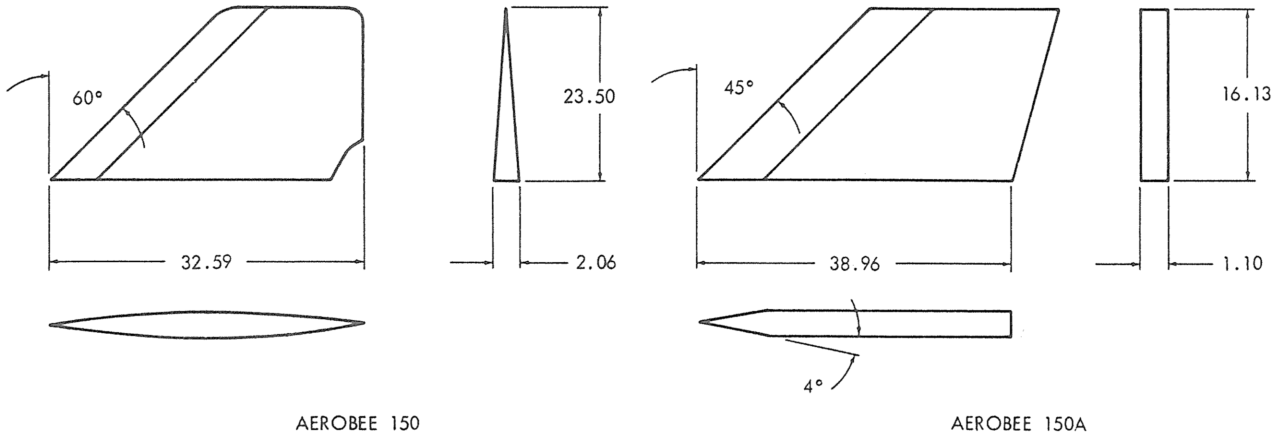


Figure 10 - Aerobee tail fin configuration.

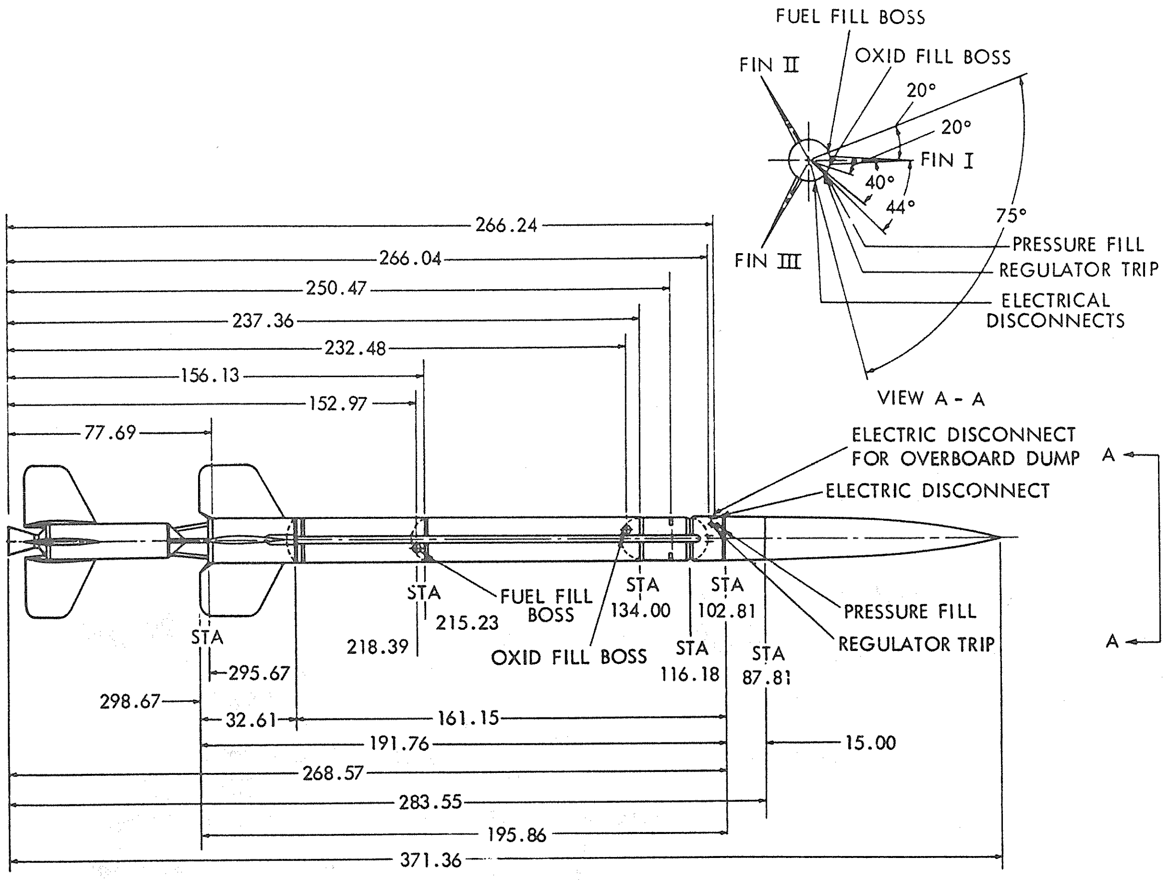


Figure 11 - Aerobee 150 outline drawing, showing dimensions and all umbilical connections.

The high expansion ratio nozzle is used because the motor operates only at high altitudes; thus optimum expansion is closely approached. Aerodynamic stability during third stage burning is provided by the 14.5° half-angle conical transition section housing the 1.8KS-7800 nozzle.

The blowout diaphragm (Figure 16) is used to attach the third stage to the sustainer. Upon sustainer thrust termination, a signal ignites the third stage. When this happens, the energy of the motor exhaust causes the diaphragm to deflect, releasing the mating thread engagement between the sustainer and the third stage, and third stage "fly-away" occurs. Payload volume is nominally 0.9 cubic feet. The following total rocket system performance characteristics are expected when the rocket is carrying a 60 lb. payload:

Peak altitude	265 statute miles
Peak time	350 sec.
Burnout velocity	8770 fps
Burnout altitude	144,000 ft.

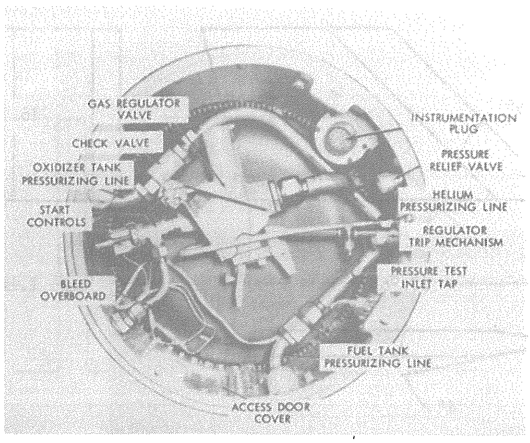


Figure 12 - Aerobee 150 forward skirt, showing locations of pressurizing system components.

The Aerobee 300A, like the 150A, can only be fired from a four-rail tower. Thus all Aerobee 300A launchings must at present take place from Wallops Island, Virginia (WI).

AEROBEE 300

The Aerobee 300 is similar to the Aerobee 300A, with minor physical differences, in the same way that the Aerobee 150 is similar to the 150A. One of the most obvious distinguishing factors differentiating the 150A from the 150 was that the 150A had four fins, while the 150 had only three. This difference is carried into the 300 series, the 300A having four fins and the 300 three. This has been an important factor in determining the point of launch of the rocket. Three-finned rockets must be launched from a three-rail tower, presently available only at Fort Churchill and at White Sands. So far, however, range boundary limitations at WSMR have restricted the launching of Aerobee 300's there. Prior to December 30th, 1963, only two Aerobee 300 rockets had been fired - both from Fort Churchill.

The Aerobee 300 configuration employs an 1.8KS-7800 motor and an Aerobee 150 rocket. The main performance advantages to be gained by using the Aerobee 300 are for experiments requiring the delivery of smaller payloads of 100 pounds or less to altitudes about 30 to 50 miles higher than can be expected from the Aerobee 150. Therefore the 300's available payload weight is about one third that of the Aerobee 150. However, the altitude is increased to provide an apogee of 200 or more statute miles.

AEROBEE 100 (JUNIOR)

The Aerobee 100 sounding rocket was a free flight, fin-stabilized, expendable liquid propellant sounding rocket designed for upper atmosphere research, and is no longer used in the NASA sounding rocket program. Consequently the description presented here is mainly of historical interest, since the last of an Aerojet-General production run of 20 Aerobee 100's has been launched.

The Aerobee 100 was designed as a relatively "simple" rocket, of modular construction and is easily stored because of its non-hypergolic fuel. One of the Aerobee 100's best features was its very high degree of reliability, although for some unexplained reason the vehicle continually failed by several miles to attain predicted peak altitude. At the time of the original Aerobee 100 production run, the NASA sounding rocket program had no other rocket in the series which provided these characteristics, in addition to the "off-the-shelf" availability provided by the Aerobee 100. Today, however, the Nike-Cajun, Nike-Apache, etc. have eliminated the need for this rocket.

The Aerobee 100 (Figure 17) was a cylindrically-shaped vehicle approximately 15 inches in diameter and about 308 inches in over-all length including the 87.8-inch nose cone. The forebody, a 31-caliber ogival nose section, was also the

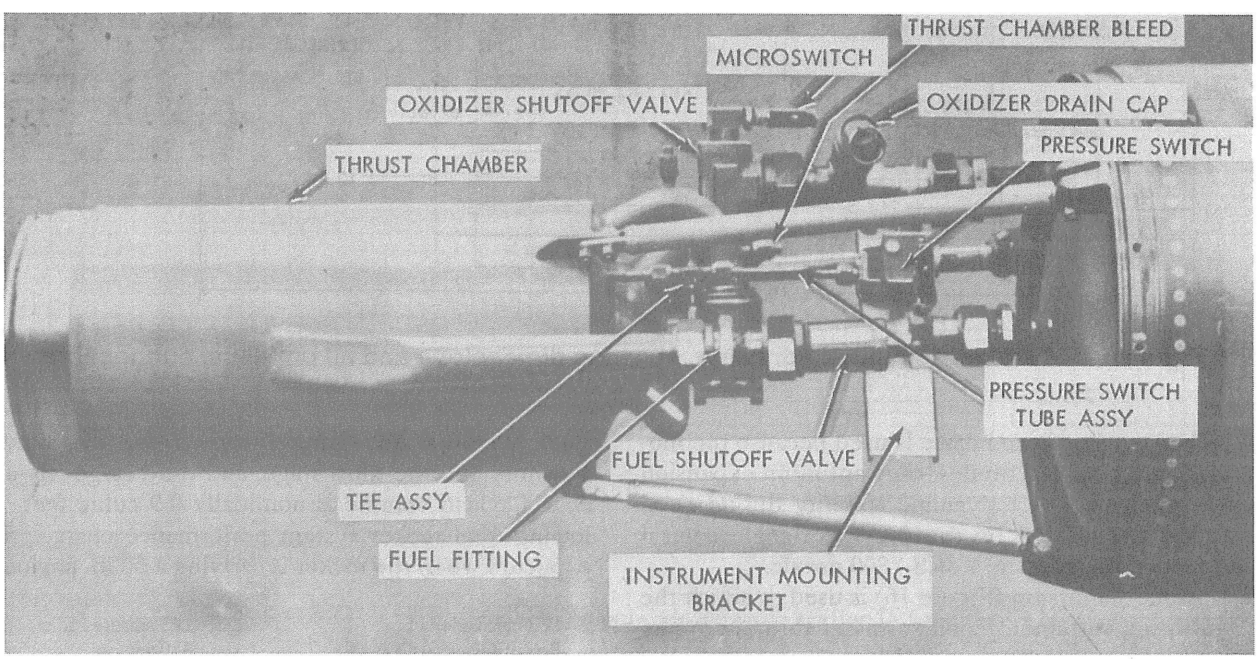
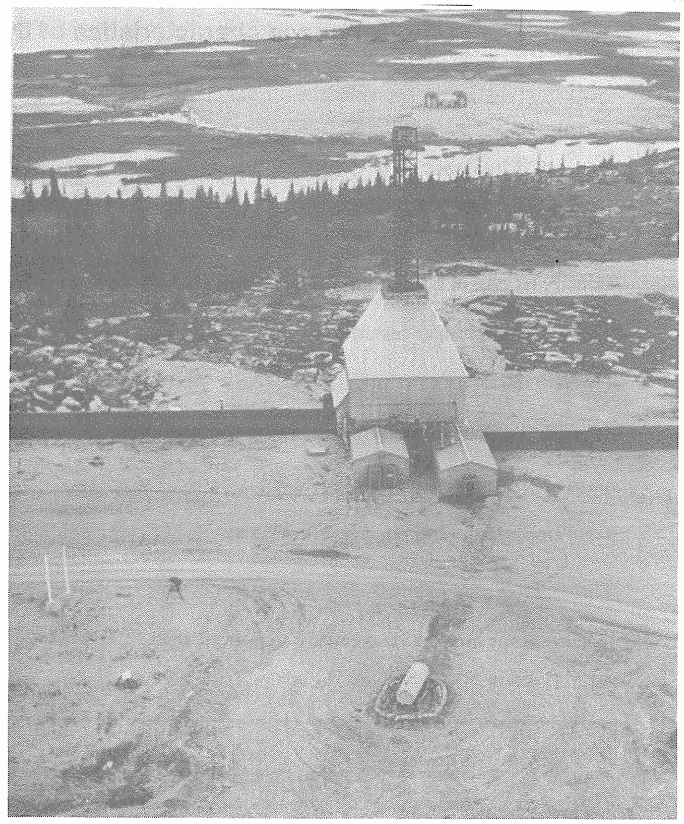


Figure 13 - Aerobee 150 tail assembly, showing locations of propellant control fittings.

(a) Overall view.



(b) Closeup view.

Figure 14 - Aerial view of Fort Churchill launch facility.

payload compartment. Three fixed fins, spaced 120° apart and located at the aft end, furnished aerodynamic stability.

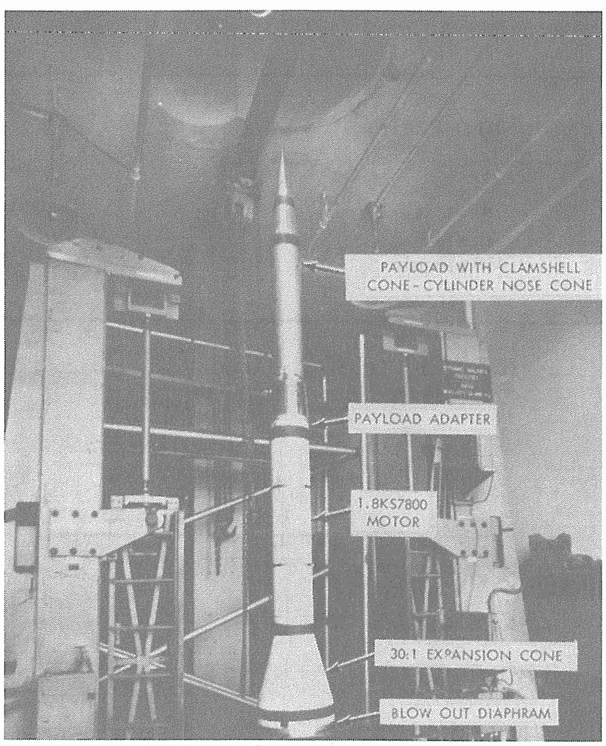


Figure 15 - Third stage of Aerobee 300A in dynamic balance facility.

The engine consisted of a pressurizing tank, thrust chamber assembly, pressure regulator valve, and associated valves and interconnecting plumbing. It started from the hypergolic reaction between inhibited red fuming nitric acid (IRFNA) and a starting slug of unsymmetrical dimethyl hydrazine (UDMH), and operated on IRFNA and JP-4 propellants. It produced a nominal thrust of 2600 pounds for a duration of 40 seconds. The engine, the same as that used in the Nike-Ajax sustainer in combination with a booster, powered the sounding rocket to a zenith altitude of approximately 92 miles with a 40-pound payload when launched from a 4000-foot elevation. The rocket was designed to be launched from a tower in an essentially vertical attitude with initial guidance from fixed rails, and with auxiliary thrust from a 2.5KS-18,000 solid propellant booster rocket (the same booster as that used with the Aerobee 150).

FLIGHT IDENTIFICATION SYSTEM

The NASA flight identification normally consists of five alpha-numeric characters, such as 4.21 GA.

a) The first character, followed by a decimal, denotes the type of Aerobee rocket, thus:

1. = Aerobee 100
4. = Aerobee 150, 150A
6. = Aerobee 300, 300A

Typical performance characteristics of the Aerobee 100 (Junior) with a 40-lb. payload:

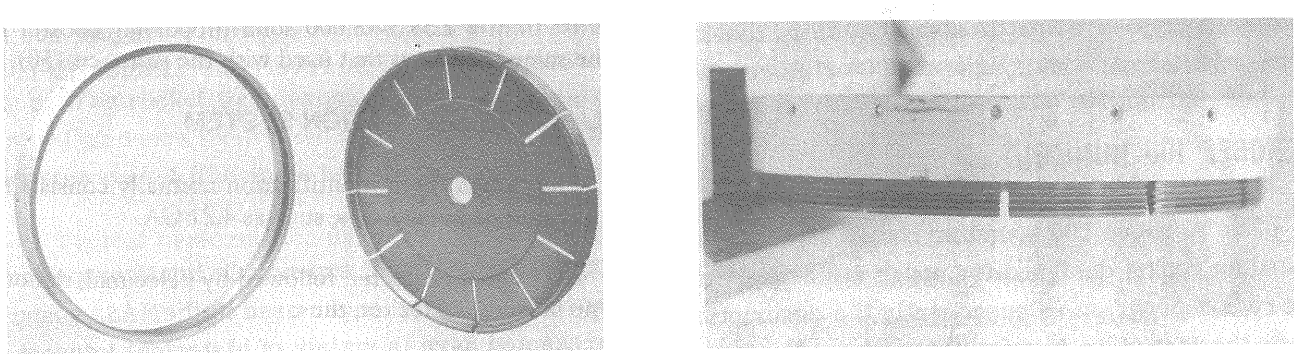
Characteristic	Nominal Rated Value at Launching Elevation: Sea Level	4000 ft.
Altitude (zenith altitude based on vehicle gross weight of 1447 lb.) - miles	79	92
Velocity (at end of boost period) - ft/sec.	1100	1100
Velocity (maximum at cessation of sustaining power in normal flight) - ft/sec.	4660	5000
Time (to trajectory summit) - sec.	187	200
Acceleration (maximum during boost 2½ sec. period) - g	15.2	15.3
Acceleration (maximum during sustaining period) - g	7.7	7.9
Total Impulse, I_t (at ground level) - lb.-sec.	104,000	104,000
Thrust, F (at ground level) - lb.	2600	2600
Instantaneous mixture ratio (steady state static test)	4.35	4.35

Weight breakdown of the Aerobee 100 (Junior) sustainer:

Item	Nominal Weight (pounds)	
Sounding rocket total dry weight (including nose assembly)	260	260
Oxidizer at 68°F (Sp. Gr. of 1.560)	426	---
Fuel at 68°F (Sp. Gr. of 0.785)	96	---
Pressurizing gas (air or nitrogen)	24	---
Total propellant and gas weight	---	546
Total net weight	---	806

Aerobee 100 (Junior) sustainer working pressures:

Pressure tank	3000 ±50 psig
Propellant tank	440 ±10 psig
Fuel circuit	430 ±10 psig
Oxidizer circuit	430 ±10 psig



(a) End view. **(b) Side view.**

Figure 16 - Aerobee 300A blowout diaphragm.

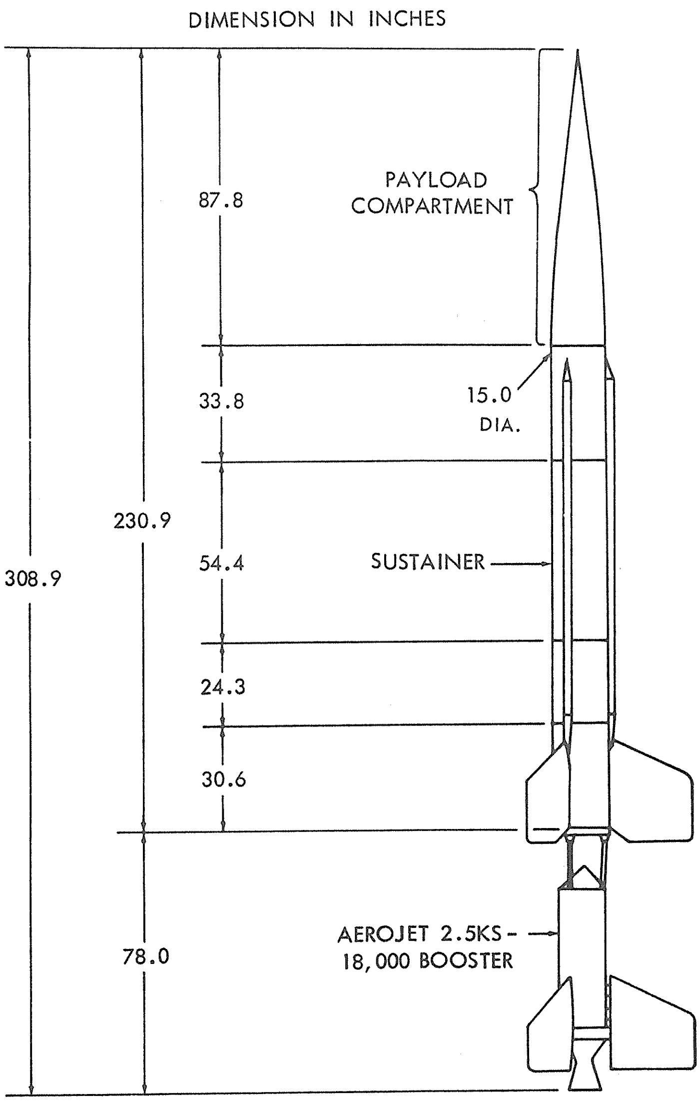


Figure 17 - Aerobee 100 outline drawing.

b) Immediately following the decimal, an identifying two digit number is assigned. This number is peculiar to only one flight.

c) The last two characters in the flight number are the identifying letters. These letters identify, first the instrumenting agency, and second the type-experiment. The listing below provides the coding used:

AGENCY	EXPERIMENT
G - Goddard	A - Aeronomy
N - Other NASA Centers	E - Energetic Particles and Fields
U - College or University	I - Ionospheric Physics
D - DOD	S - Solar Physics
A - Other Government Agency	G - Galactic Astronomy
C - Industrial Corporations	R - Radio Astronomy
I - International	B - Biological
	P - Special Projects
	T - Test and Support

SOUNDING ROCKET PARAMETERS AND CHARACTERISTICS

Tables 1, 2, and 3 (following three pages) describe the various parameters and characteristics of the Aerobee sounding rockets utilized in the various NASA experiment programs. Included are data on performance and physical characteristics of each vehicle type.

ANCILLARY HARDWARE

Attitude Control Systems

The inertial attitude control system (IACS) used in the Aerobee rocket is a ground oriented inertial controlled system built by the Space-General Corporation of El Monte, California (formerly the Aerojet-General Corporation). The IACS controls the vehicle about its roll, pitch and yaw axes during the free-flight portion of the trajectory. Two gyros are used to establish the inertial reference for vehicle alignment, each containing two degrees of freedom. One gyro is used for pitch and roll, the other for yaw. Programed maneuvers are accomplished during flight by changing the inertial attitude of the free gyros. The system senses this change as an error and activates the appropriate jet or jets to correct the error. The vehicle is directed about its axes by eight cold-gas jets; and these jets utilize the residual helium in the propellant pressurization system. Two of the roll jets are used to despin the vehicle, after thrust termination.

Components in the IACS

The following components are used in the IACS:

(1) Power Supply: The battery power supply consists of 20 Yardney HR-1 silver cells. The HR-1 silver cell is a silver/zinc alkaline high-rate discharge battery. The cells, connected in series, supply 28 volts to the ACS unit when the ACS is on internal power.

(2) Static Inverter: The static inverter supplies a 26-volt, 400-cps, 2-phase square wave. The frequency is regulated to ±0.1% and phase angles to 90° ±5%. The inverter supplies power for the free gyros, the rate gyros, the control unit, and the synchronous timer motor.

(3) Programmer: The programmer controls the sequential mode of operation by connecting precision voltages, through associated relays, to the ACS components at a predetermined time. The time increment for each sequence of operation is determined by a motor-driven timer and its multi-lobe cam and micro-switches. The programmer functions through a 24-position multi-wafered stepping switch.

(4) Control Unit: The control unit is a solid-state, phase- and amplitude-sensitive device that accepts error and position data for each channel and provides correction signals in the proper sequence of roll, pitch, and yaw.

(5) Free Gyros: The two gyros used are miniature two-

Table 1 - Sounding Rocket Performance Parameters.

PARAMETER & UNIT OF MEASURE	BOOSTER 2.5KS-18,000	AEROBEE				
		100	150	150A	300**	300A**
Nominal thrust (lb.)*	18,600	2600	4100	4100	7664 (vac.)	7664 (vac.)
Thrust duration (sec.)	2.5	40	51.3	50.9	1.73	1.73
I_{sp} (lb-sec/lb)*	178.8	200	198	198	238.8	238.8
Total impulse (lb./sec.)	46,500	104,000	210,330	208,690	16,478	16,478
Thrust coefficient*	1.58	1.342	1.37	1.37	1.73	1.73
Thrust chamber pressure (psia)	1340	330	324	324	1000	1000
Exhaust velocity (ft./sec.)	-	4800	4650	4650	-	-
Total propellant flow rate, avg. (lb./sec.)	104	13.0	20.71	20.71	32.09	32.09
Fuel flow rate, avg. (lb./sec.)	-	2.36	5.82	5.82	-	-
Oxidizer flow rate, avg. (lb./sec.)	-	10.64	14.89	14.89	-	-
Instantaneous mixture ratio (avg.)	-	4.35	2.56	2.56	-	-
Acceleration max. (g)	15.4	7.9	10.3	10.3	33.0†	33.0†
Sustainer ignition time after launch (sec.)	-	1.0	0.5	0.6	-	-
Ignition time (sec.)	-	-	-	-	51.8	51.5
Flame temperature (°F)	2960°					

*At sea level unless otherwise specified.
†90 lb. payload.
**3rd stage only.

axis non-floating free gyros with synchro and torquer on each gimbal axis. The torquers precess the gyro gimbals to the desired inertial attitude. The synchros supply gimbal position information. The outer gimbal has an unrestricted movement range of 360°, and the inner gimbal has a useful movement range of ±80 to 85°. The torquers, with 26 volts rms applied, are capable of processing their respective gimbals at a rate of 9° per second.

(6) Rate Gyros: Three rate gyros are used in the ACS to determine angular velocity. These gyros are mounted in the roll, pitch, and yaw axes. Their output signals are combined with the respective free gyro position signals (in the programmer) to provide damping.

(7) Remote Adjust Unit: The remote adjust unit consists of three motor-driven variable transformers remotely controlled from the ACS console. Each gimbal torquer in the roll, pitch, and yaw axes has its own signal transformer. The local-vertical correction signal, an input to the transformer prior to launch and at a given time in the program, is supplied to the gyro torquers.

(8) Control Valves and Jets: The ACS has a total of seven control valves and eight cold-gas jets. The aft structure contains the pitch and yaw control valves and jets, and the insert contains the roll control valves and jets. The insert also contains the despin control valve which controls one set of roll jets. At operating altitude the pitch and yaw jets produce five pounds of thrust each, and the roll jets produce one pound each. The despin jets produce 20 pounds of thrust per pair.

Table 2 - Sounding Rocket Propulsion System Characteristics.

PARAMETER & UNIT OF MEASURE	BOOSTER 2.5KS-18,000	AEROBEE				
		100	150	150A	300**	300A**
THRUST CHAMBER						
Nozzle throat area (in.^{2})	8.50	5.87	9.24	9.24	4.43	4.43
Nozzle exit area (in.^{2})	67.2	30.0	42.75	42.75	(133)	(133)
Nozzle exit dia. (in.)	9.24	6.2	7.378	7.378	8	8
Nozzle area ratio	7.9	5.1	4.6	4.6	30	30
Chamber-throat area ratio	-	4.5	3.88	3.88	-	-
PRESSURE TANK						
Volume (ft.^{3})	-	1.72	2.57	2.57	-	-
Max. work press. (psig)	-	3000	3650	3650	-	-
Proof pressure (psig)	-	4000	4000	4000	-	-
OXIDIZER TANK						
Volume, incl. ullage (ft.^{3})	-	4.67	8.02	8.02	-	-
Max. work press. (psig)	-	440	500	500	-	-
Proof pressure (psig)	-	550	550	550	-	-
FUEL TANK						
Volume, incl. ullage (ft.^{3})	-	2.08	4.60	4.60	-	-
Max. work press. (psig)	-	440	500	500	-	-
Proof pressure (psig)	-	550	550	550	-	-
TANK ASSEMBLY						
Total length (in.)	-	-	160.14	161.5	-	-
Diameter (in.)			15	15		

**3rd stage only.

Another model of the ACS incorporates a roll-stabilized platform, used to limit the pitch and yaw gyro drift which results from the rocket roll environment during sustainer burning. The current ACS system orients the rocket to within 1° of a pre-selected target. Currently under development is a Fine Attitude Control System (FACS) that will provide greater pointing accuracies than are capable with any of the present systems.

Despin Systems

A gas despin system designed by Goddard Space Flight Center personnel has been successfully employed on many flights requiring a zero or low roll rate during the data collection period. This attitude control system, mounted for an Aerobee 150 rocket, is pictured in Figure 18a-f.

Table 3 - Sounding Rocket Dimensions and Weights.

PARAMETER & UNIT OF MEASURE	BOOSTER 2.5KS-18,000	AEROBEE				
		100	150	150A	300**	300A**
SUSTAINER						
Weight (lb.)						
Sustainer	-	246.0	256.0	262.7	60	60
Nose cone	-	15.5	15.5	15.5	7	7
Oxidizer	-	426.0	764.4	758.2	-	-
Fuel	-	99.0	304.4	303.3	69	69
Helium	-	2.9	5.1	5.15	-	-
Total net weight	-	789.4	1345.4	1344.8	136	136
BOOSTER						
Booster motor inerts, w/igniter	246	246	246	246	-	-
Booster fin assy	-	27(3)	27(3)	30(4)	-	-
Booster thrust structure	62	62	62	62	-	-
Booster dry weight		333	333	338		
Propellant	260	260	260	260	-	-
Launch weight	-	600	600	600	-	-
DIMENSIONS						
Body length (in.)	78.1	143.0	190.9	191.8	57.6**	57.6**
Body diameter (in.)	13	15	15	15	8.0**	8.0**
Dia. thru riding lugs (in.)		15.75	15.75	15.75		
Fin diameter (in.)		62	62	47.2		
Length o. a. (excl. payload) (in.)		221.1 (18.4ft)	268 (22.38ft)	270.8 (22.47ft)		
Fin cant (min.)	2.5°		0-20'	0-20'		

*3rd stage motor.

**3rd stage only, loaded.

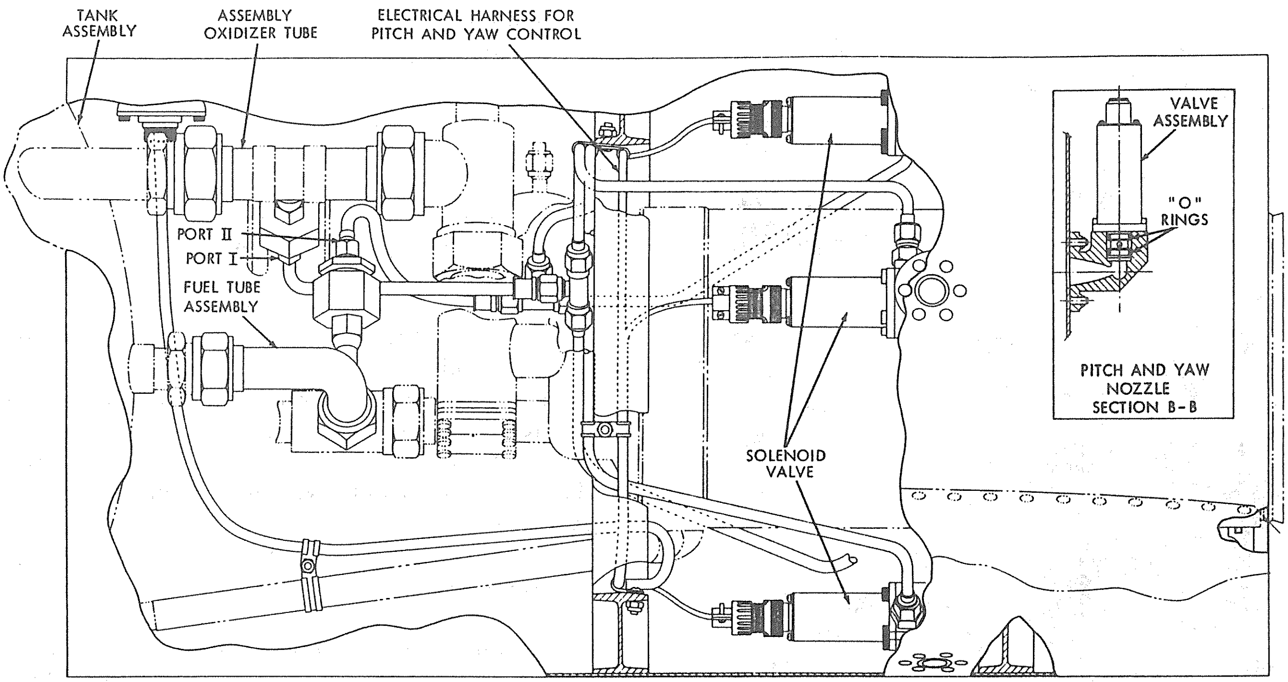
Operational Sequence of the Gas Despin System

The operational sequence of the gas despin system is as follows:

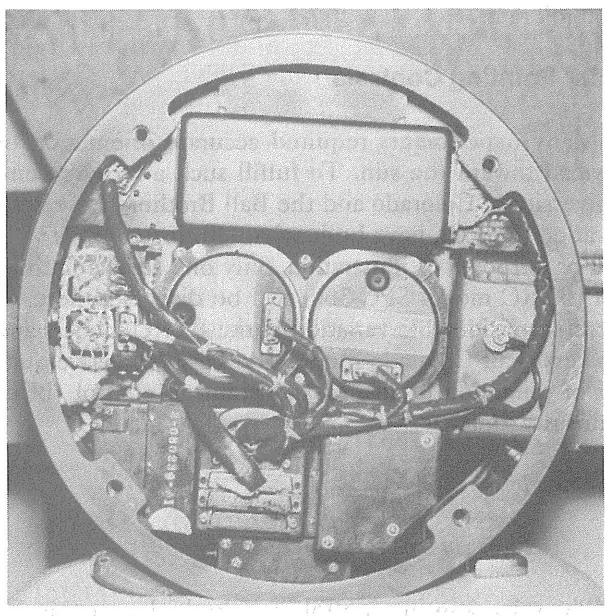
(1) (Liftoff minus one to three minutes) - The gyro rate switch motor is started on 28 VDC. The rate switch motor should be running on internal power at rocket liftoff.

(2) The "G" reduction timer begins timing as vehicle acceleration of greater than 4.0 g releases a mechanical latch on the timer arm.

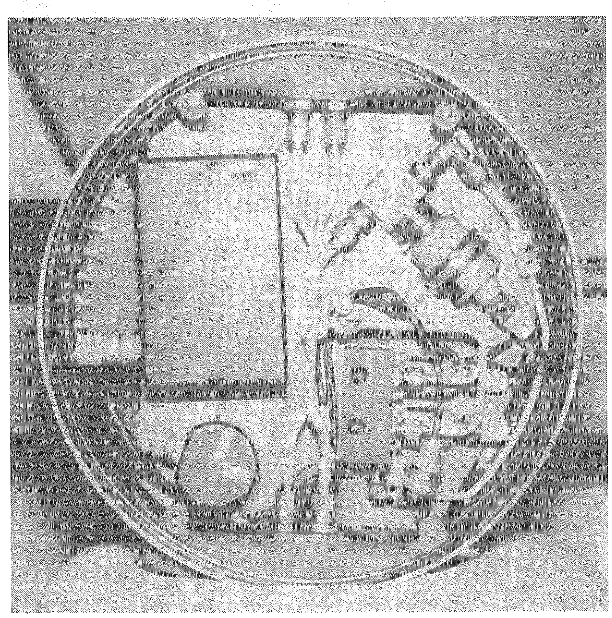
(3) (Liftoff +2.5 seconds) - The booster drops away from the sustainer rocket and thereby allows the booster tail switch (in the sustainer rocket) to arm the rocket shutdown circuit.



(a) Cutaway drawing showing electrical and mechanical installation of ACS pitch and yaw jets in the tail can. (b) Side view of pitch/yaw nozzle.



(c) Top view showing location of parts, routing of plumbing, and orientation between ACS and forward skirt.



(d) Orientation of pitch and yaw nozzles, and plumbing connections, looking aft in the tail can.

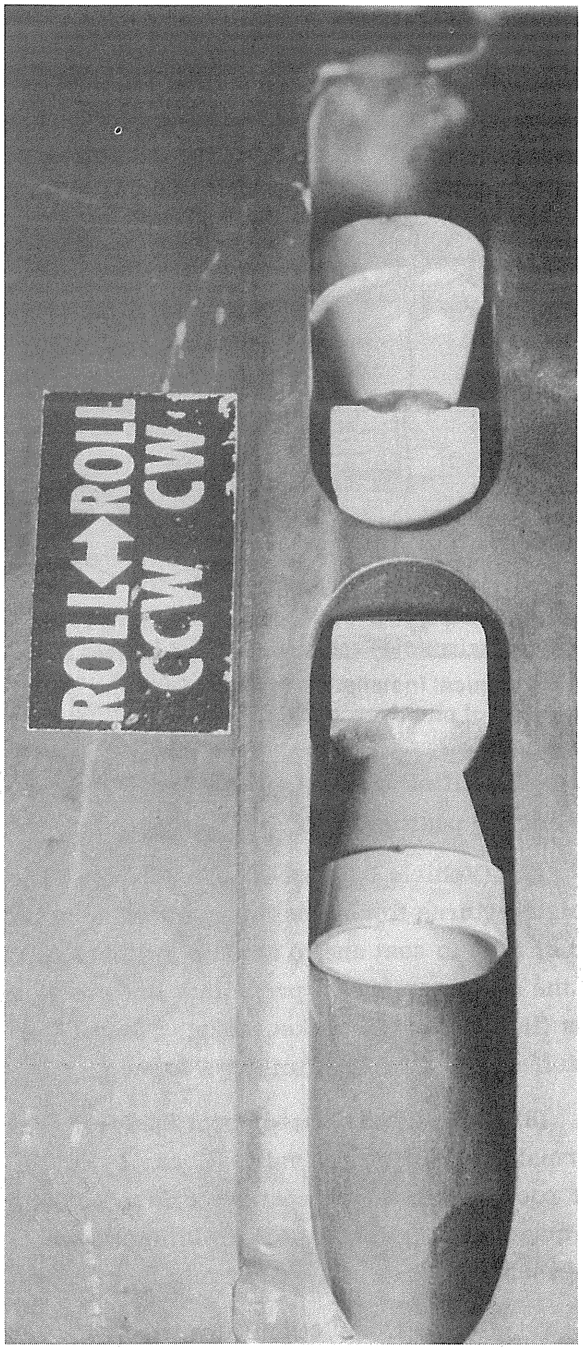
Figure 18 - Attitude control system for the Aerobee 150 sounding rocket.

(4) (Liftoff + approximately 25 seconds) - The sustainer rocket reaches an altitude of approximately thirty thousand feet where the altitude switch energizes the automatic rocket shutdown and despin initiation circuits.

(5) (Liftoff + approximately 30 seconds) - The "G" reduction timer weight moves to a latching or arming position. This is induced by approximately 4.0 g of vehicle acceleration.

(6) (Liftoff + 48 seconds) - The "G" reduction timer arm "times out" and jumps to the armed or latched position where it is stopped by the latching weight mentioned in step 5.

(7) (Vehicle burnout - approximately 52 seconds after liftoff) - The "G" reduction timer latching weight returns to rest position, when the actuating vehicle acceleration is removed, and allows the timer arm to seat and to actuate switches. Power is thereby sent to the pyrotechnic shutoff



(e) View of gas jet nozzles.

Figure 18 - Attitude control system for the Aerobee 150 sounding rocket.

valves in the sustainer rocket propellant lines to shutdown the vehicle and trap residual pressurization gas (Helium) in the rocket tanks. Normal Aerobee shutdown may be commanded via the Aerobee cutoff receiver after liftoff as a backup.

(8) Despin is initiated about 68 seconds after liftoff when a timer switch applies power to the normally closed despin valve (Conax Model SEV-16-4-A). The gas is then allowed to flow from the rocket tanks to the control nozzles on the skin of the rocket, which will exert an average despin torque of approximately 4.9 ft.-lb. on the vehicle. Despin is generally delayed until the vehicle is essentially free of aerodynamic forces.

(9) Despin Completion - The time required for the vehicle to despin to the desired roll rate will depend on the initial and final roll rates and the roll inertia of the rocket. Generally, the despin time is between 15 and 25 seconds. When the rocket roll rate reaches the rate switch setting, the rate switch applies electrical power to the normally open despin valve, cutting gas flow to the control nozzles. The rocket should then remain at nearly the rotational rate at which the control torque was removed. The rate switch (Humphrey, Model RS01-0313-1) is generally used to allow switching rates to be set between 10° and 60° per second. On this particular model, switching accuracy is within ±1° per second of the set rate. Although this accuracy is normally desired, other rate switches of similar design have been used successfully.

In addition to the gas despin system, single-wrap and three-wrap yo-yo type despin systems (Figure 18g) are available. These systems despin the rocket much faster than the gas system, but have less accurate control over the final roll rate.

Solar Pointing Controls

Many experiments required accurate orientation of the payload toward the sun. To fulfill such a requirement, the University of Colorado and the Ball Brothers Research Corporation (BBRC), have built solar pointing controls.

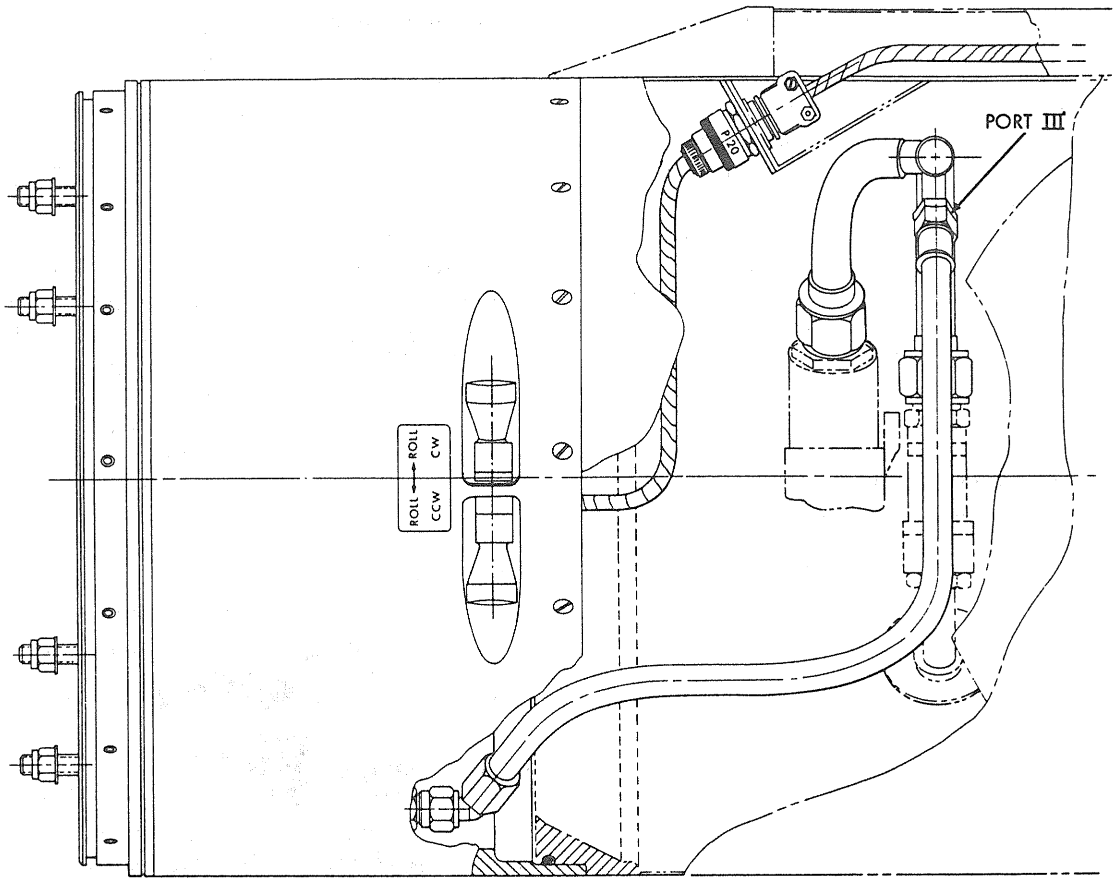
For purposes of illustration, only one solar pointing control (BBRC model SPC-300) will be discussed here. While there is considerable variation in the BBRC models and the University of Colorado model, the basic objective and theory of operation of the biaxial pointing control (BPC) remains the same.

Solar Pointing Control

Theory of Operation

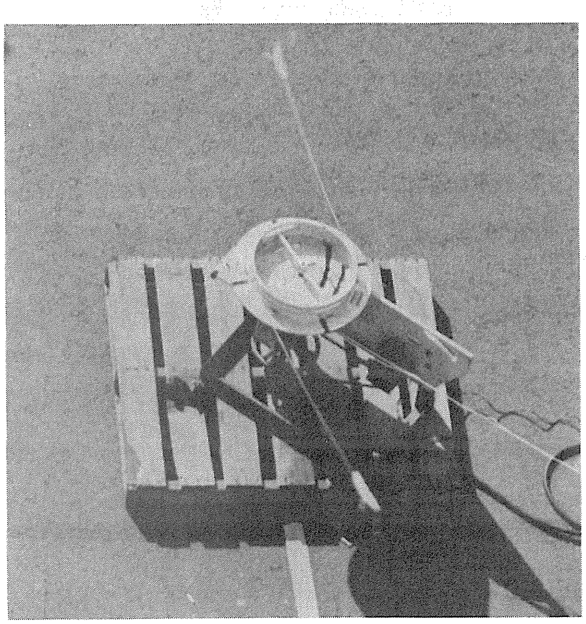
The solar pointing control provides high accuracy, biaxial orientation of instruments toward the sun from Aerobee sounding rockets. The basic configuration is adaptable for use with a broad range of research instrumentation. Payload orientation is provided by two servo systems operating in the vehicle (azimuth) and transverse (elevation) axes. Error sensing is provided by coarse and fine light sensitive detectors in each axis. The fine (high resolution) detectors are attached directly to the pointed instrument and aligned to the desired optical axis.

The solar pointing control utilizes the standard Aerobee nose cone assembly. The maximum instrument size is determined by the cone diameter between stations 24 and 65 (distance in inches from the cone tip). Approximately half of the ogive between these points is reserved for the instrument, attached on one side normally at station 49.5 and rotating about the elevation axis.



(f) Cutaway of ACS and forward skirt, showing the location of roll jets and connections to the helium regulator manifold.

Figure 18 - Attitude control system for the Aerobee 150 sounding rocket.



(g) Ground test of three-wrap yo-yo despin system.

Figure 18 - Attitude control system for the Aerobee 150 sounding rocket.

The solar pointing control type SPC-300A is similar but requires a cone-cylinder assembly in order to accommodate larger pointed instruments. Instrument space available in this configuration is half of a cylinder approximately 40 inches long with a radius of 6.5 inches.

On either configuration, the skin assembly is unlatched at altitudes greater than 350,000 feet, and raised sufficiently to allow the instrument to rotate about the elevation axis. If recovery is desired, the instrument is allowed to point until at approximately 350,000 feet on the down leg of the trajectory; the instrument is then locked into the stow position, the skin assembly is retracted and locked into position for atmospheric re-entry. Specifications for the solar pointing control are as follows:

Pointing error (from solar center)	±10 minutes of arc
Minimum operating altitude	350,000 feet
Maximum vehicle spin rate	3 rps
Length*	87.5 inches
Maximum diameter	15 inches
Weight*	133 pounds
Maximum pointed instrument weight*	40 pounds
Typical zenith altitude†	140 miles
Typical pointing duration†	320 seconds

*Typical configuration.
†Average Aerobee 150 performance with typical pointing control payloads.

Recovery Systems

Land Recovery

When recovery of vehicle and payload is desired, one basic recovery system is often used on Aerobee vehicles. A land recovery system, manufactured by the Space-General Corporation (Figure 19) consists of a 24-foot diameter main parachute, a 57-inch diameter pilot chute, and a severance system initiated by an electrical actuation system. The parachute is contained in a 10-inch diameter canister mounted within a 15-inch diameter magnesium rocket extension. The total length of the recovery system is 14.75 inches.

Water Recovery

A water recovery system can also be used which, in addition to the hardware mentioned above, includes a flotation system. This system is 20 inches in length. Still other means of recovering sustainers and portions of payloads have been employed in the past but these are not described here.

General Recovery Sequence

The following general sequence of events occurs when the recovery system is flown:

a. Both forward and aft initiators are armed by a lanyard trip upon initial vehicle motion.

b. The actuation box is armed on the upward leg of the trajectory.

c. Payload and sustainer severance is signalled by the range safety receiver or by a timer at approximately 300,000 feet altitude on the down leg of the trajectory.

d. The aft initiator is fired, initiating the aft primacord.

e. The primacord cuts all electrical wiring and plumbing and separates the payload from the sustainer.

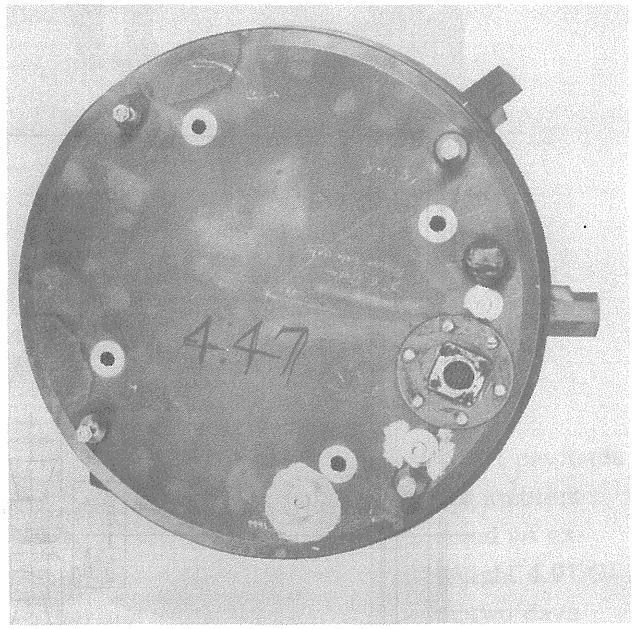
f. The payload tumbles in an approximately flat spin attitude, reducing its velocity to approximately 250 feet per second.

g. At approximately 18,000 feet altitude, the actuation box fires the forward initiator and primacord.

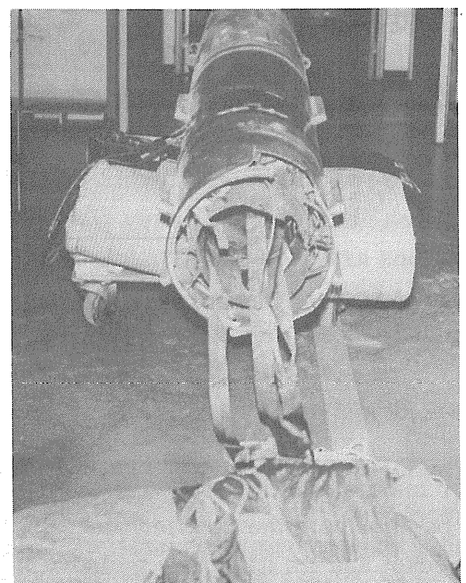
h. The primacord severs the electrical wiring and plumbing routed through the cover and cuts off the cover.

i. The cover is pulled away from the payload by aerodynamic drag, and extracts the pilot chute deployment bag and bridle. Initial movement of the bag initiates the main parachute reefing line cutter timers.

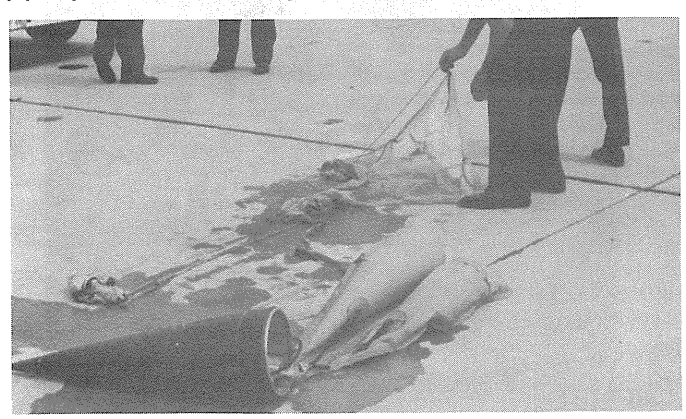
j. The pilot chute is filled and stops the payload tumbling during the next 12 seconds.



(a) Top view of parachute extension bulkhead.



(b) Payload after recovery showing parachute attachments.



(c) Camera (packaged inside nose tip) and recovery package showing deployment of parachute and flotation gear.

Figure 19 - Aerobee payload recovery system.

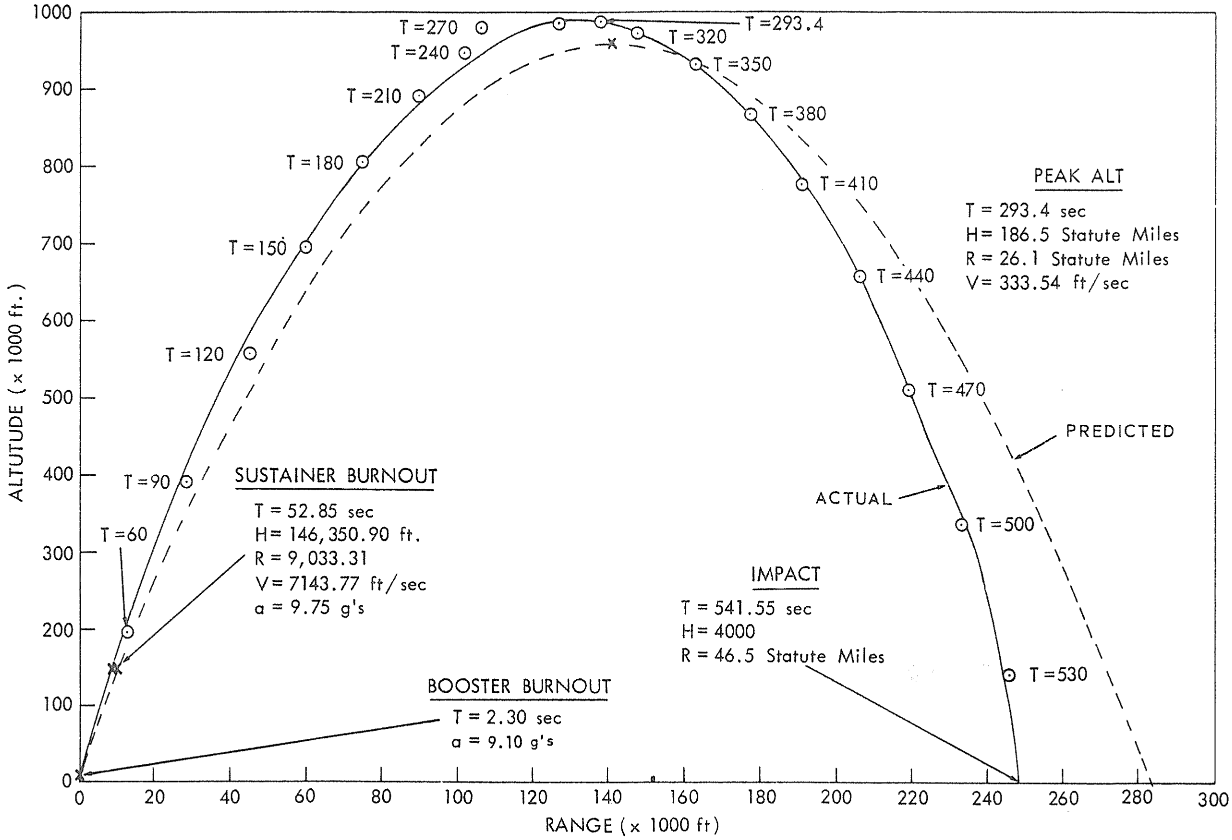


Figure 20 - Flight 4.30 GG - altitude vs. range.

k. The reefing line cutters open the main deployment bag and the pilot chute carries it away.

l. The main chute is deployed by the drag chute and decelerates the payload to a mean descent velocity of 25 feet per second until impact occurs.

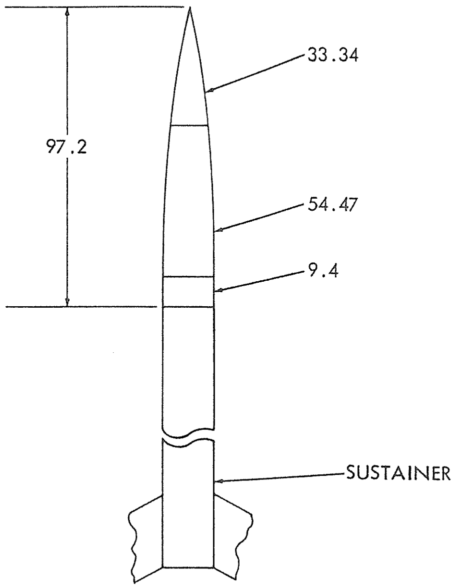
Editor's Note: NASA TR R-226 includes payload dimensions, flight characteristics, and flight descriptions for all of the Aerobee sounding rockets launched from 1959-1963. Data from selected flights is included herein, and the reader is referred to TR R-226 for further information on additional flights.

DATA FROM SELECTED AEROBEE FLIGHTS

The highest apogee altitude ever achieved by an Aerobee 150 was on Flight 4.30 GG which was fired at White Sands on 28 March, 1963. The experiment contained ten ion chambers for measuring intensity and spatial distribution of resonantly-scattered hydrogen Lyman-alpha at 1216 angstroms. The 126-pound payload was considerably lighter than recent Aerobee experiments, resulting in increased vehicle performance and the highest ever Aerobee 150 apogee. Although the standard parachute system was not used, an attempt was made at recovery by initiating severance of the tail can (including fins) at 300,000 feet during re-entry. Loss of the fins induced instability and caused the vehicle to tumble end over end, thereby decelerating enough to effect a relatively "soft" impact. On re-entry the payload broke apart from the sustainer; nevertheless the payload was recovered in relatively good condition. Figure 20 compares the expected and actual trajectories; they are almost coincident, the achieved altitude being 3% greater than the predicted altitude. All instrumentation performed as expected and the gas despin system worked well despinning the vehicle as desired. Figure 21 gives payload dimensions and characteristics of this rocket and its flight.

Payload dimensions and flight characteristics data for other selected Aerobee flights are presented in Figures 22-29, including representative Aerobee 100, 150, 150A, 300, and 300A flights with low and high spin rates, and an Aerobee 150 flight with the cone-cylinder payload extension replacing the usual ogive nose cone.

Figure Number(s)	Flight Description	
22a, 22b	Aerobee 100	near zero roll rate
23	Aerobee 100	1.78 rps roll rate
24	Aerobee 150	0.18 rps roll rate with fin cant angles
25	Aerobee 150	2.0 rps roll rate
26	Aerobee 150	cone-cylinder payload extension
27	Aerobee 150A	
28	Aerobee 300	
29	Aerobee 300A	

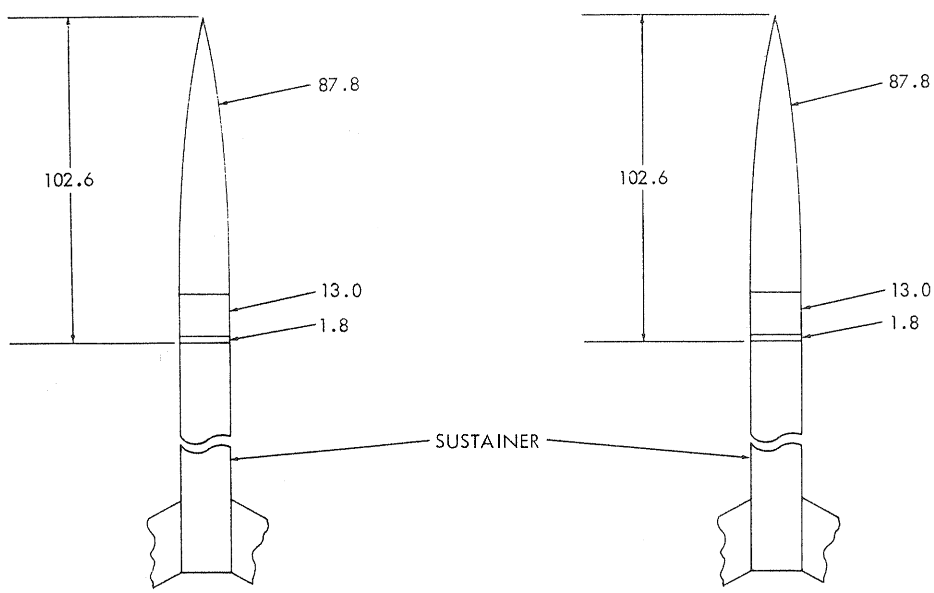


DIMENSIONS IN INCHES

FLIGHT	4.30 GG
FIRING DATE	28 MARCH, 1963
LAUNCH SITE	WSMR
PAYLOAD WT. (LBS.)	126.20
APOGEE (ST. MI.)	186.30
TIME TO APOGEE (SEC.)	255.00
CENTER OF GRAVITY (CAL.)	10.45
CENTER OF PRESSURE (CAL.)	12.25
STATIC MARGIN (CAL.)	1.80
RESTORING MOMENT (PER DEGREE)	−0.174
SUSTAINER BURNOUT TIME (SEC.)	53.80
ROLL RATE AT BURNOUT (RPS)	1.40
TIP EJECT (SEC.)	*
NO. OF JOINTS	3.00

* Tip ejected at 200,000 + feet

Figure 21 - Flight 4.30 GG - payload dimensions and flight characteristics.



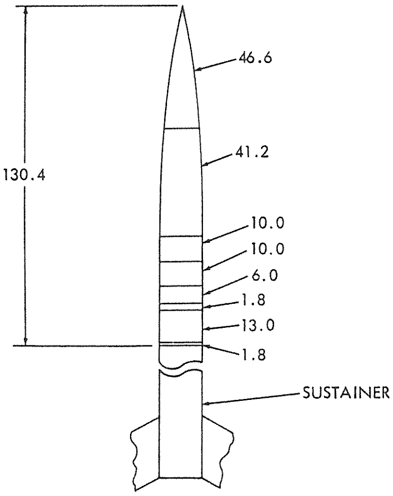
(a) DIMENSIONS IN INCHES (b)

FLIGHT	1.03 GP
FIRING DATE	15 SEPT. 1960
LAUNCH SITE	FC
PAYLOAD WT. (LBS.)	144.75
APOGEE (ST. MI.)	47.30
TIME TO APOGEE (SEC.)	148.00
CENTER OF GRAVITY (CAL.)	9.813
CENTER OF PRESSURE (CAL.)	12.20 (approx.)
STATIC MARGIN (CAL.)	2.39 (approx.)
RESTORING MOMENT (PER DEGREE)	-0.30 (approx.)
SUSTAINER BURNOUT TIME (SEC.)	41.50
ROLL RATE AT BURNOUT (RPS)	unknown *
TIP EJECT (SEC.)	unknown
NO. OF JOINTS	3.00

* Set for 0.0 revolutions per second.

FLIGHT	1.05 GP
FIRING DATE	24 SEPT. 1960
LAUNCH SITE	FC
PAYLOAD WT. (LBS.)	145.00
APOGEE (ST. MI.)	47.20
TIME TO APOGEE (SEC.)	149.20
CENTER OF GRAVITY (CAL.)	9.173
CENTER OF PRESSURE (CAL.)	12.20 (approx.)
STATIC MARGIN (CAL.)	3.03 (approx.)
RESTORING MOMENT (PER DEGREE)	-0.30
SUSTAINER BURNOUT TIME (SEC.)	39.70
ROLL RATE AT BURNOUT (RPS)	-0.054
TIP EJECT (SEC.)	443.00 (approx.)
NO. OF JOINTS	3.00

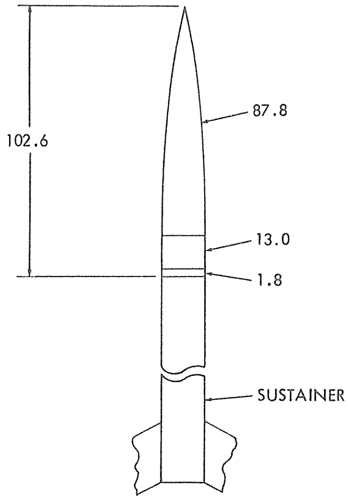
Figure 22 - Flights 1.03 GP and 1.05 GP - payload dimensions and flight characteristics.



DIMENSIONS IN INCHES

FLIGHT	1.13 NP
FIRING DATE	6 SEPT. 1962
LAUNCH SITE	WSMR
PAYLOAD WT. (LBS.)	158.10
APOGEE (ST. MI.)	46.00
TIME TO APOGEE (SEC.)	140.40
CENTER OF GRAVITY (CAL.)	10.00
CENTER OF PRESSURE (CAL.)	12.40
STATIC MARGIN (CAL.)	2.40
RESTORING MOMENT (PER DEGREE)	-0.29
SUSTAINER BURNOUT TIME (SEC.)	37.40
ROLL RATE AT BURNOUT (RPS)	1.78
TIP EJECT (SEC.)	unknown
NO. OF JOINTS	8.00

Figure 23 - Flight 1.13 NP - payload dimensions and flight characteristics.

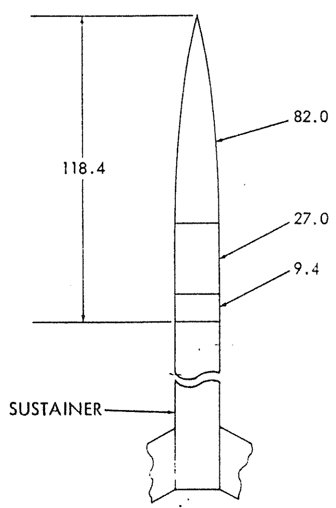


DIMENSIONS IN INCHES

FLIGHT	4.43 GP
FIRING DATE	5 OCT. 1960
LAUNCH SITE	FC
PAYLOAD WT. (LBS.)	137.50
APOGEE (ST. MI.)	140.10
TIME TO APOGEE (SEC.)	253.60
CENTER OF GRAVITY (CAL.)	9.03
CENTER OF PRESSURE (CAL.)	12.60
STATIC MARGIN (CAL.)	3.56
RESTORING MOMENT (PER DEGREE)	-0.360
SUSTAINER BURNOUT TIME (SEC.)	53.00
ROLL RATE AT BURNOUT (RPS)	0.18
TIP EJECT (SEC.)	na
NO. OF JOINTS	3.00

* Fin cant: I, 1.45 min; II, 0.8 min; and III, 1.9 min.

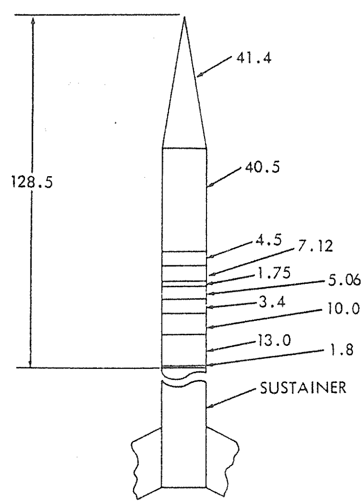
Figure 24 - Flight 4.43 GP - payload dimensions and flight characteristics.



DIMENSIONS IN INCHES

FLIGHT	4.07 GI
FIRING DATE	14 SEPT. 1959
LAUNCH SITE	FC
PAYLOAD WT. (LBS.)	192.25
APOGEE (ST. MI.)	141.00 (radar
TIME TO APOGEE (SEC.)	250.00
CENTER OF GRAVITY (CAL.)	10.73
CENTER OF PRESSURE (CAL.)	13.25
STATIC MARGIN (CAL.)	2.52
RESTORING MOMENT (PER DEGREE)	-0.255
SUSTAINER BURNOUT TIME (SEC.)	53.00
ROLL RATE AT BURNOUT (RPS)	2.00
TIP EJECT (SEC.)	na
NO. OF JOINTS	3.00

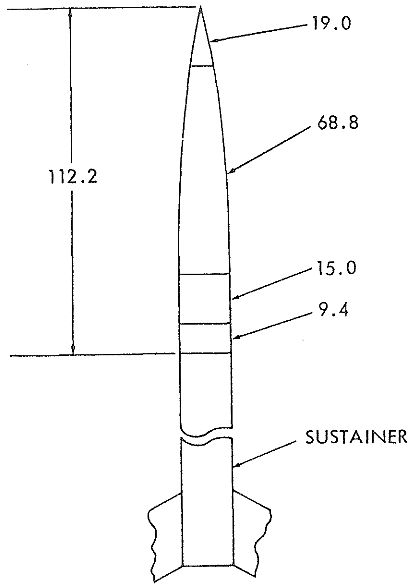
Figure 25 - Flight 4.07 GI - payload dimensions and flight characteristics.



DIMENSIONS IN INCHES

FLIGHT	4.21 US
FIRING DATE	27 NOV. 1962
LAUNCH SITE	WSMR
PAYLOAD WT. (LBS.)	245.00
APOGEE (ST. MI.)	126.00
TIME TO APOGEE (SEC.)	238.00
CENTER OF GRAVITY (CAL.)	10.58
CENTER OF PRESSURE (CAL.)	13.75
STATIC MARGIN (CAL.)	2.17
RESTORING MOMENT (PER DEGREE)	-0.33
SUSTAINER BURNOUT TIME (SEC.)	52.80
ROLL RATE AT BURNOUT (RPS)	2.00
TIP EJECT (SEC.)	na
NO. OF JOINTS	10.00

Figure 26 - Flight 4.21 US - payload dimensions and flight characteristics.



DIMENSIONS IN INCHES

FLIGHT	4.09 GA
FIRING DATE	29 APR. 1960
LAUNCH SITE	WI
PAYLOAD WT. (LBS.)	167.50
APOGEE (ST. MI.)	154.00
TIME TO APOGEE (SEC.)	258.00
CENTER OF GRAVITY (CAL.)	10.30
CENTER OF PRESSURE (CAL.)	13.90
STATIC MARGIN (CAL.)	3.60
RESTORING MOMENT (PER DEGREE)	-0.4608
SUSTAINER BURNOUT TIME (SEC.)	50.50
ROLL RATE AT BURNOUT (RPS)	2.10
TIP EJECT (SEC.)	unknown
NO. OF JOINTS	4.00

Figure 27 - Flight 4.09 GA - payload dimensions and flight characteristics.

FLIGHT	6.01 UI	6.02 UI
FIRING DATE	16 MAR. 1960	15 JUN. 1960
LAUNCH SITE	FC	FC
PAYLOAD WEIGHT, 2ND STAGE (lbs)	245.00	244.50
PAYLOAD WEIGHT, 3RD STAGE (lbs)	65.50	64.75
APOGEE (statute miles)	205.00	195.00
TIME TO APOGEE (seconds)	UNKNOWN	307.00
CENTER OF GRAVITY, SUSTAINER BURNOUT (calculated)	10.733	11.11
CENTER OF PRESSURE, SUSTAINER BURNOUT (calculated)	13.77	13.40
STATIC MARGIN, SUSTAINER BURNOUT (calculated)	3.04	2.29
RESTORING MOMENT, SUSTAINER BURNOUT (per degree)	- 0.341	- 0.252
CENTER OF GRAVITY, 3RD STAGE IGNITION (calculated)	9.20	9.28
CENTER OF PRESSURE, 3RD STAGE IGNITION (calculated)	10.70	10.85
STATIC MARGIN, 3RD STAGE IGNITION (calculated)	1.50	0.97
RESTORING MOMENT, 3RD STAGE IGNITION (per degree)	- 0.0540	- 0.0350
SUSTAINER BURNOUT (seconds)	50.70	54.20
THIRD STAGE BURNOUT (seconds)	54.00 (est.)	56.80
ROLL RATE AT BURNOUT, SUSTAINER (rps)	1.40*	1.00*
ROLL RATE AT BURNOUT, 3RD STAGE (rps)	unknown	unknown
PROBE EJECT (seconds)	80.00	75.00
NUMBER OF JOINTS	7.00	7.00
THIRD STAGE LENGTH (in.)	120.00	120.00
PAYLOAD HOUSING LENGTH X (in.)	68.88	69.88

* AT 50 seconds

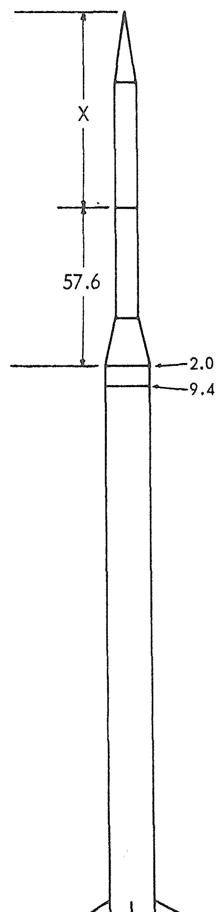


Figure 28 - Flights 6.01 UI and 6.02 UI - payload dimensions and flight characteristics.

FLIGHT	6.03 UI
FIRING DATE	3 AUG. 1960
LAUNCH SITE	WI
PAYLOAD WEIGHT, 2ND STAGE (lbs)	200.30
PAYLOAD WEIGHT, 3RD STAGE (lbs)	55.50
APOGEE (statute miles)	258.00
TIME TO APOGEE (seconds)	370.00
CENTER OF GRAVITY, SUSTAINER BURNOUT (calculated)	10.75
CENTER OF PRESSURE, SUSTAINER BURNOUT (calculated)	14.80
STATIC MARGIN, SUSTAINER BURNOUT (calculated)	4.05
RESTORING MOMENT, SUSTAINER BURNOUT (per degree)	- 0.535
CENTER OF GRAVITY, 3RD STAGE IGNITION (calculated)	8.65
CENTER OF PRESSURE, 3RD STAGE IGNITION (calculated)	10.22
STATIC MARGIN, 3RD STAGE IGNITION (calculated)	1.57
RESTORING MOMENT, 3RD STAGE IGNITION (per degree)	- 0.0565
SUSTAINER BURNOUT (seconds)	53.00
THIRD STAGE BURNOUT (seconds)	55.00
ROLL RATE AT BURNOUT, SUSTAINER (rps)	2.20
ROLL RATE AT BURNOUT, 3RD STAGE (rps)	1.75
PROBE EJECT (seconds)	75.00
NUMBER OF JOINTS	7.00
THIRD STAGE LENGTH (in.)	118.1
PAYLOAD HOUSING LENGTH X (in.)	60.5

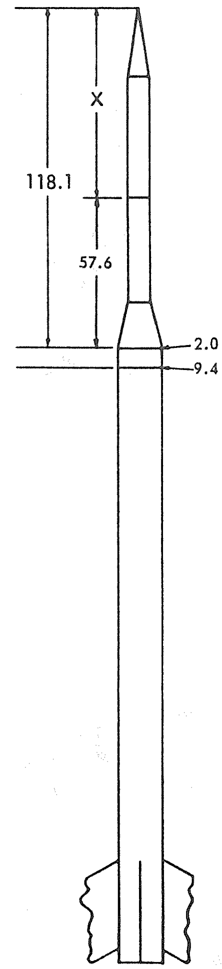


Figure 29 - Flight 6.03 UI - payload dimensions and flight characteristics.

PHOTOGRAPHS

The following pages contain additional photographs of various phases of the sounding rocket program of the Goddard Space Flight Center. The topics covered are listed at right, along with the number of the figures:

Topic	Figure Number
Aerobee instrument packages	30
Aerobee 100 (Junior)	31
Aerobee 300A	32a-32c
Aerobee 150 launch operations	33a-33h
Aerobee 150A launch operations	34a-34j
Nose cone recovery at Fort Churchill	35

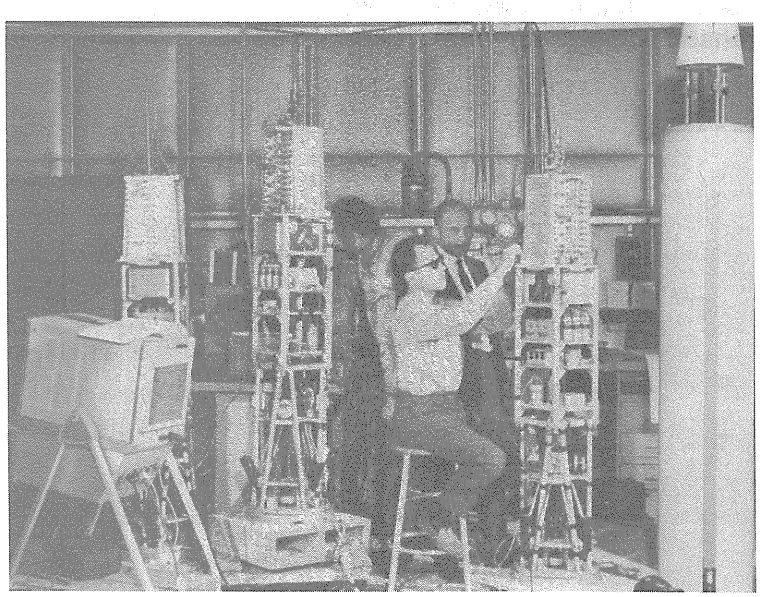


Figure 30 - Aerobee instrument packages.

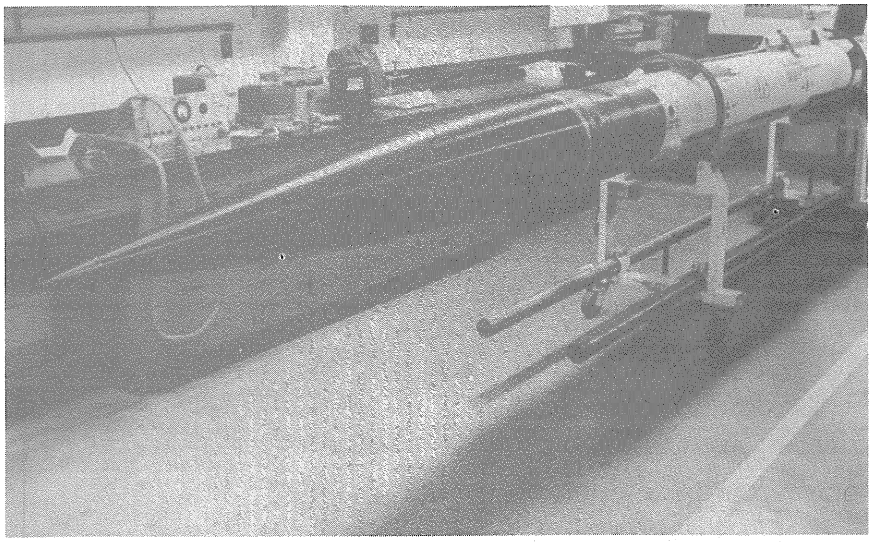


Figure 31 - Aerobee 100 (Junior) on assembly dolly.

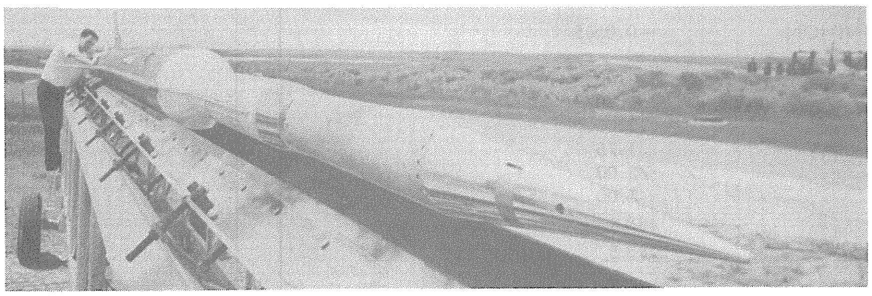
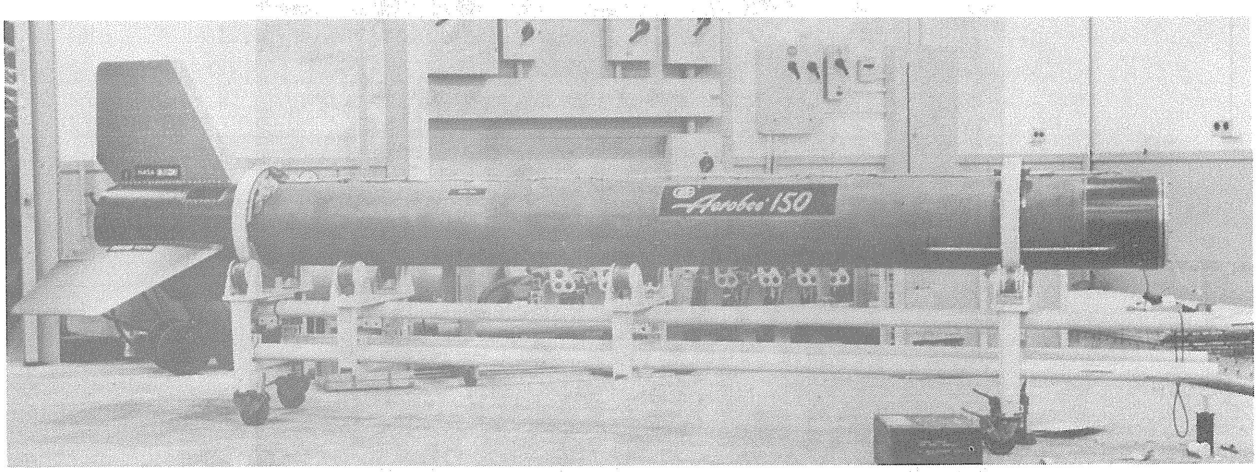


Figure 32a - Aerobee 300A, side view.

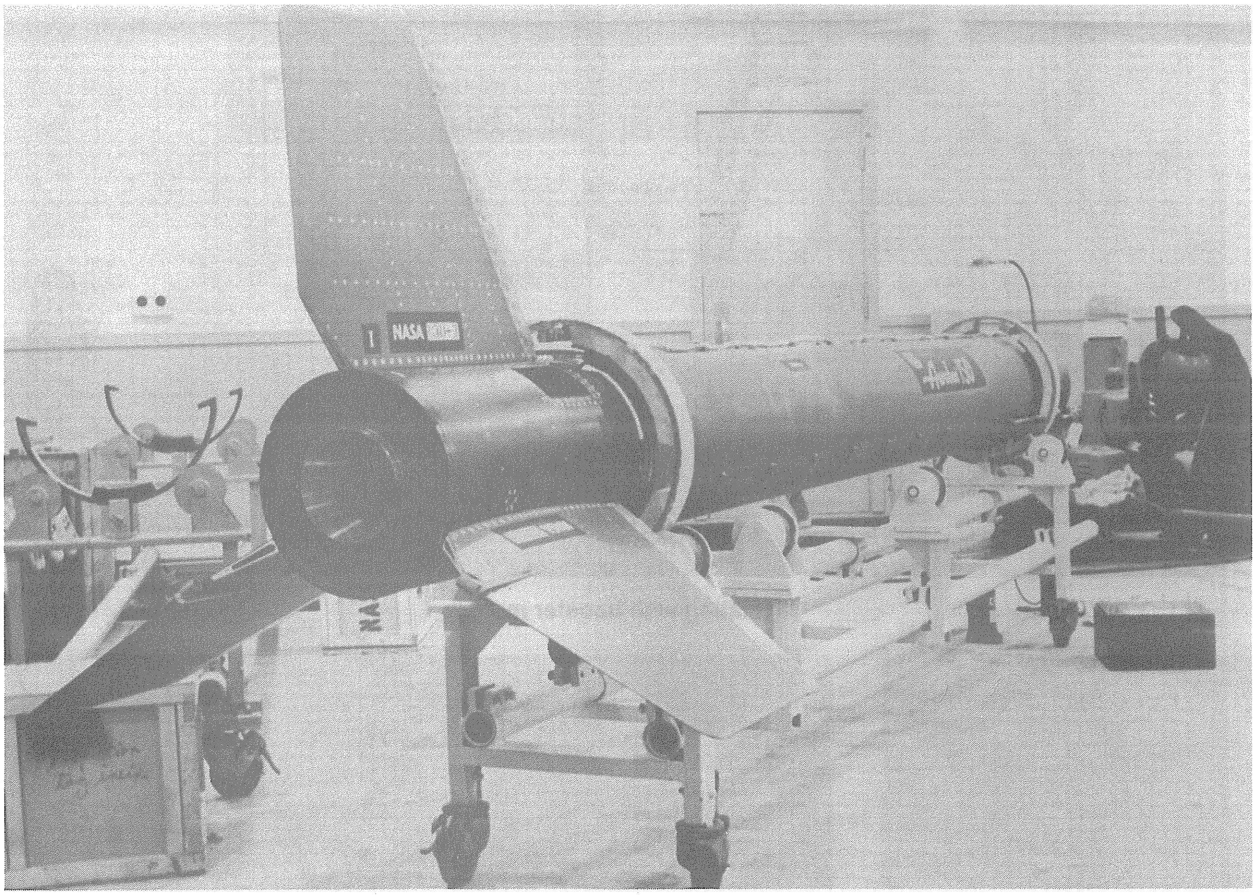
Figure 32c - Aerobee 300A, third stage motor with DOVAP transducers and antennas.

Figure 32b - Aerobee 300A, top view.

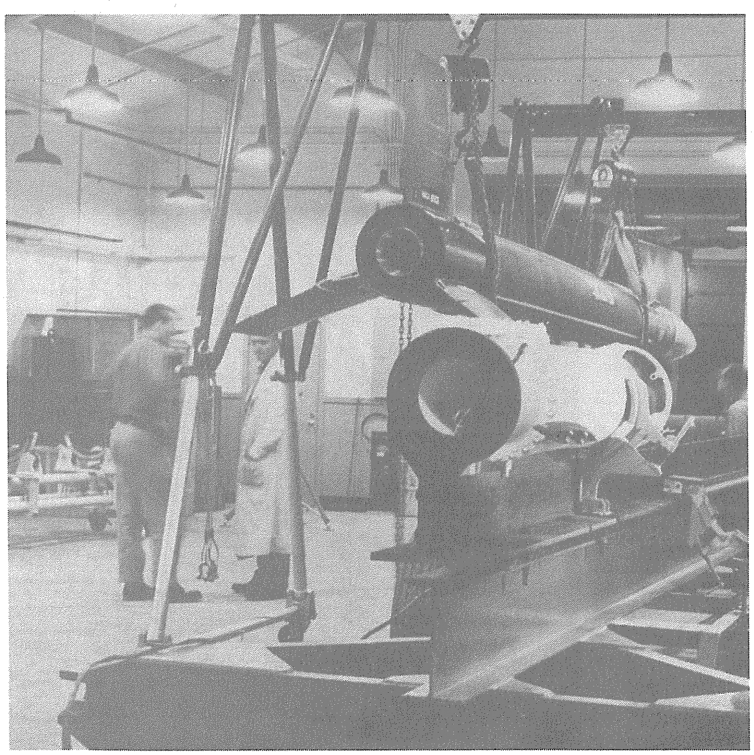


(a) Sustainer motor, side view.

Figure 33 - Aerobee 150 launch operations (Fort Churchill).

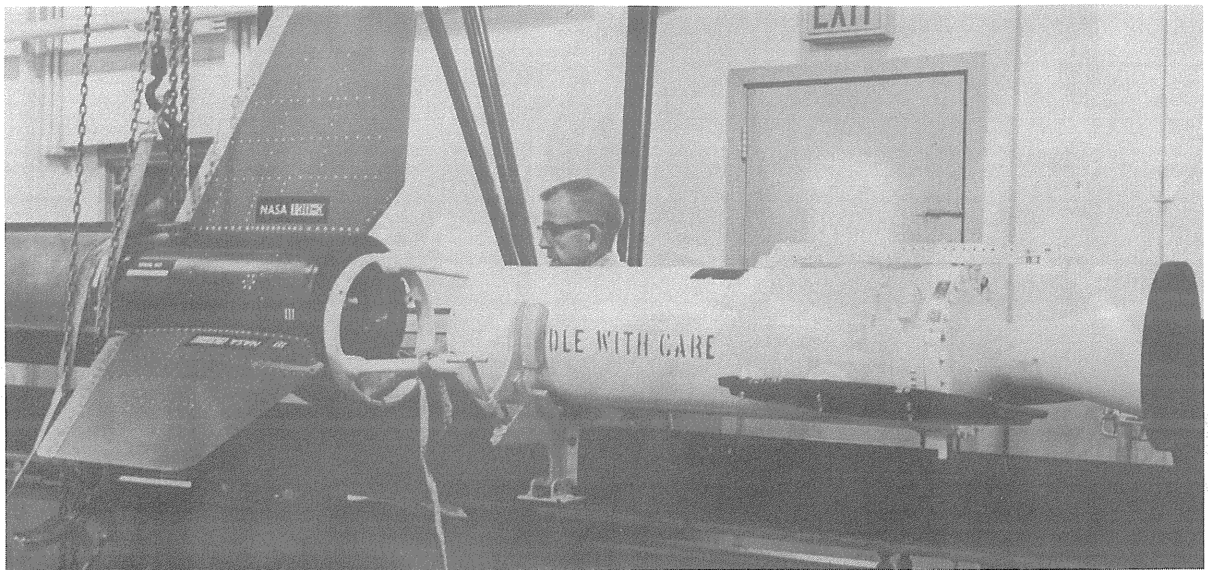


(b) Sustainer motor, end view.

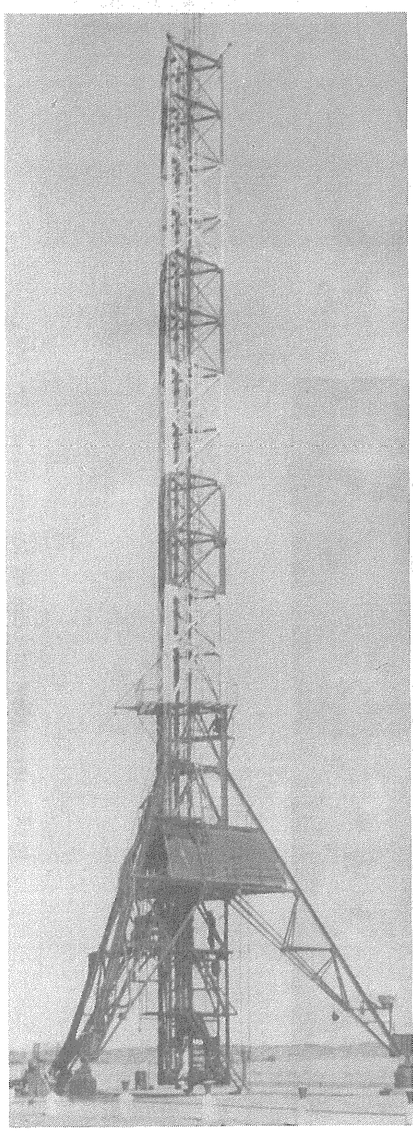


(c) Transfer of rocket from assembly dolly to launch rail dolly.

Figure 33 - Aerobee 150 launch operations (Fort Churchill).



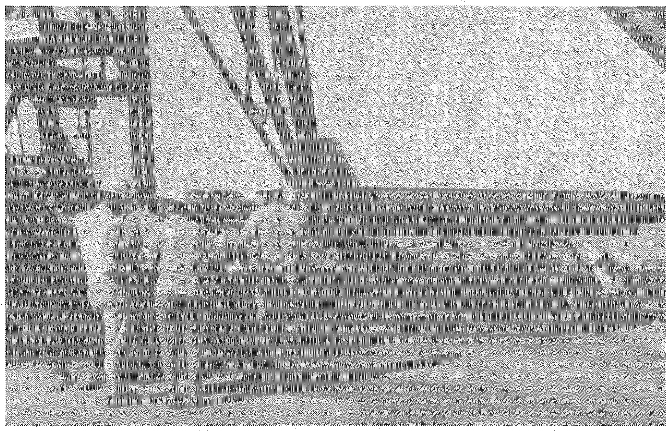
(d) Mating with booster motor.



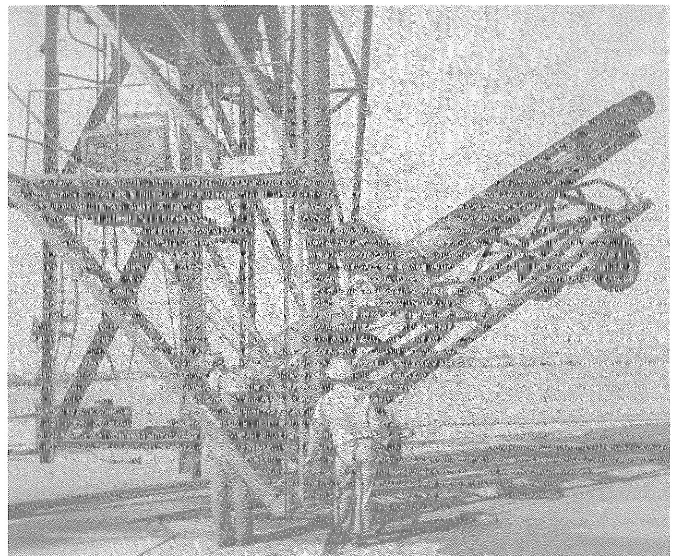
(e) Overall view of launch tower.

(f) Launch tower with sounding rocket ready for installation.

Figure 33 - Aerobee 150 launch operations (WSMR).

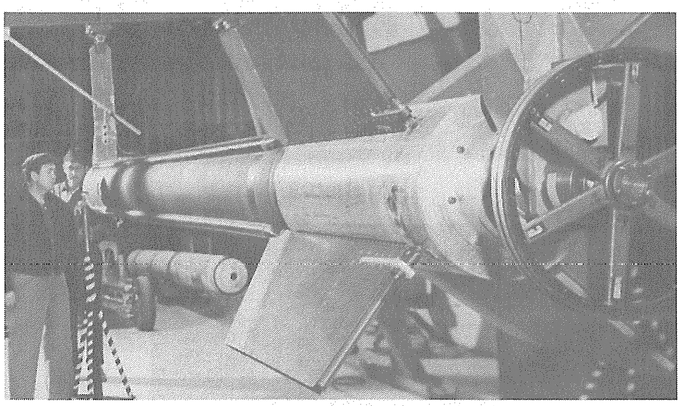


(g) Launch rail dolly backed up to base of launch tower.

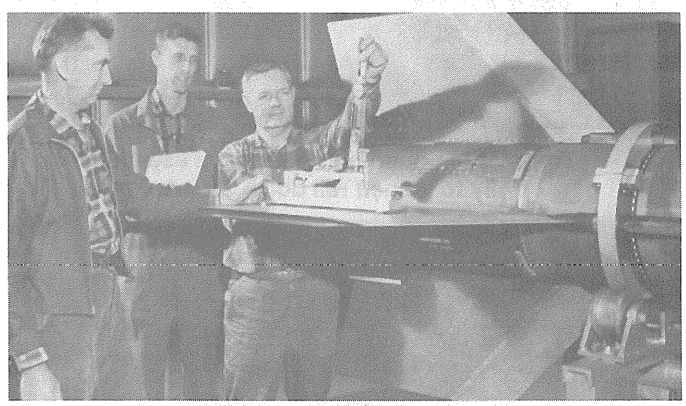


(h) Sounding rocket being lifted into launch tower.

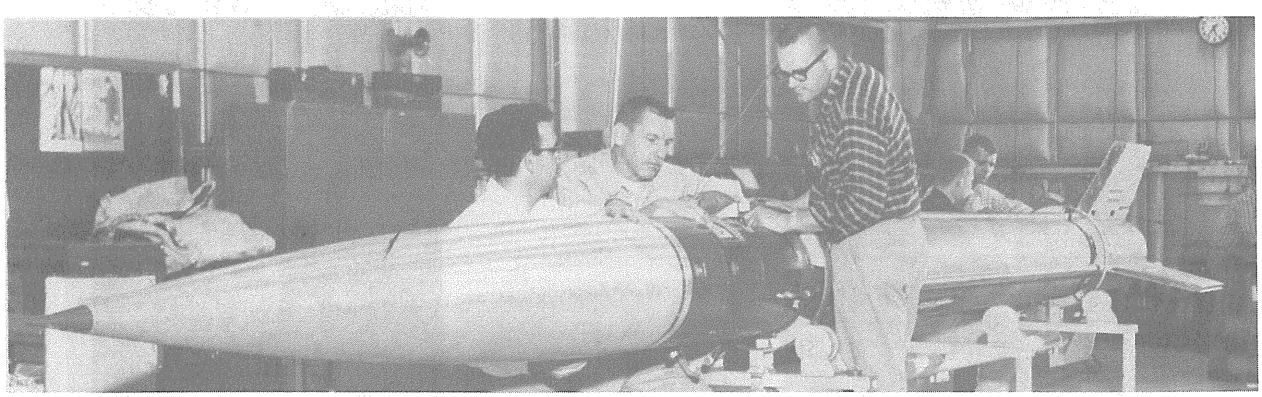
Figure 33 - Aerobee 150 launch operations (WSMR).



(a) Sustainer motor on horizontal spin unit.

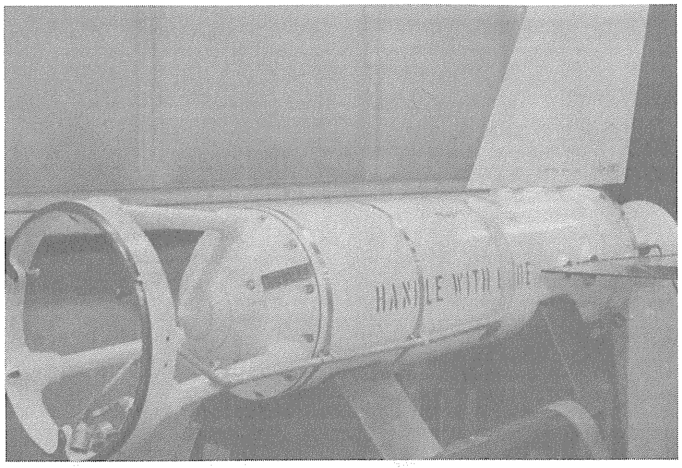


(b) Fin alignment Aerobee 150A.

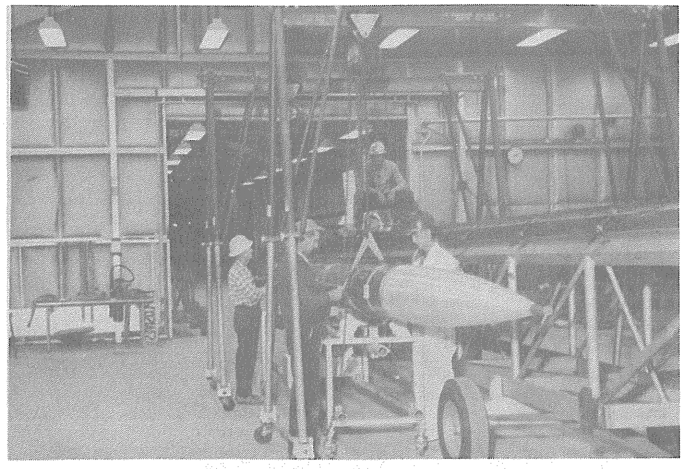


(c) Rocket in checkout room prior to transfer to launch rail dolly.

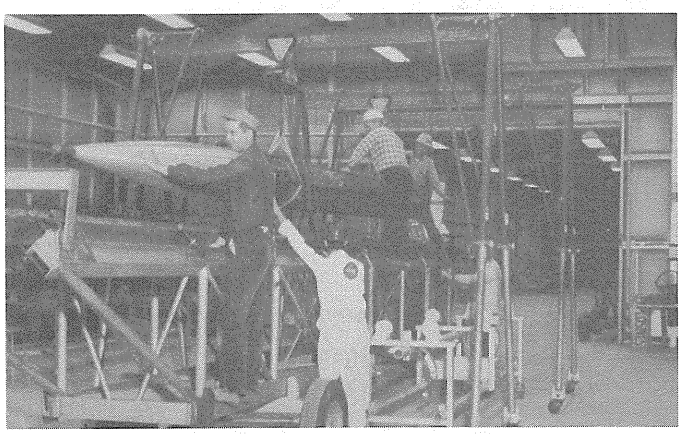
Figure 34 - Aerobee 150A launch operations (WI).



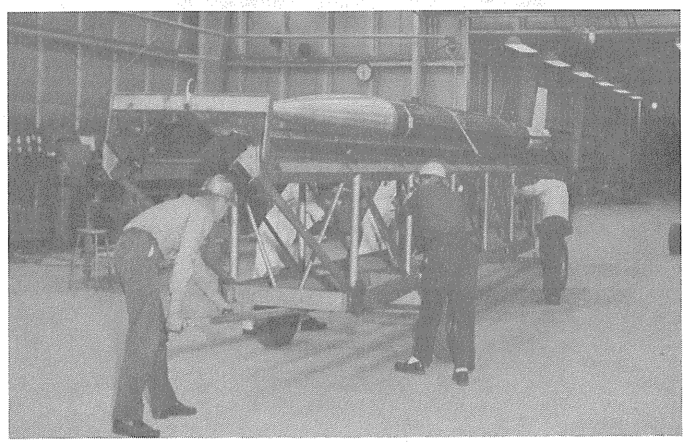
(d) Booster motor.



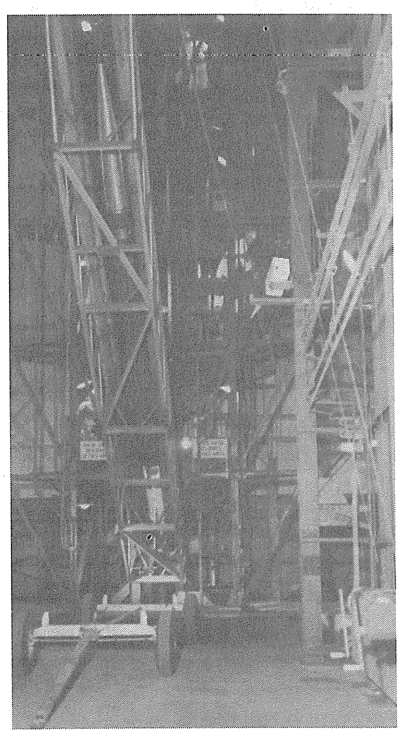
(e) Transfer of sounding rocket from assembly dolly to launch rail dolly, Step 1.



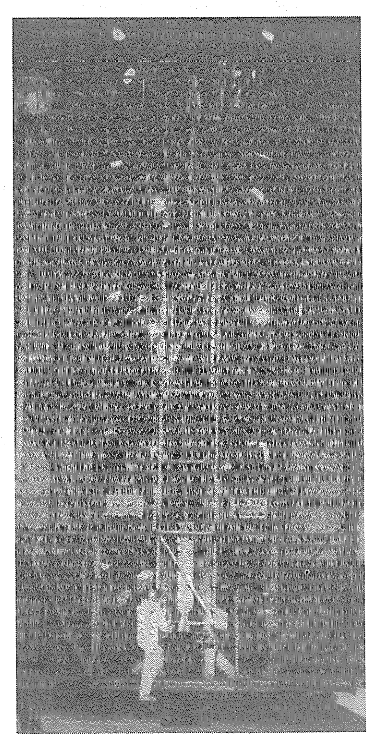
(f) Transfer of sounding rocket from assembly dolly to launch rail dolly, Step 2.



(g) Step 3.

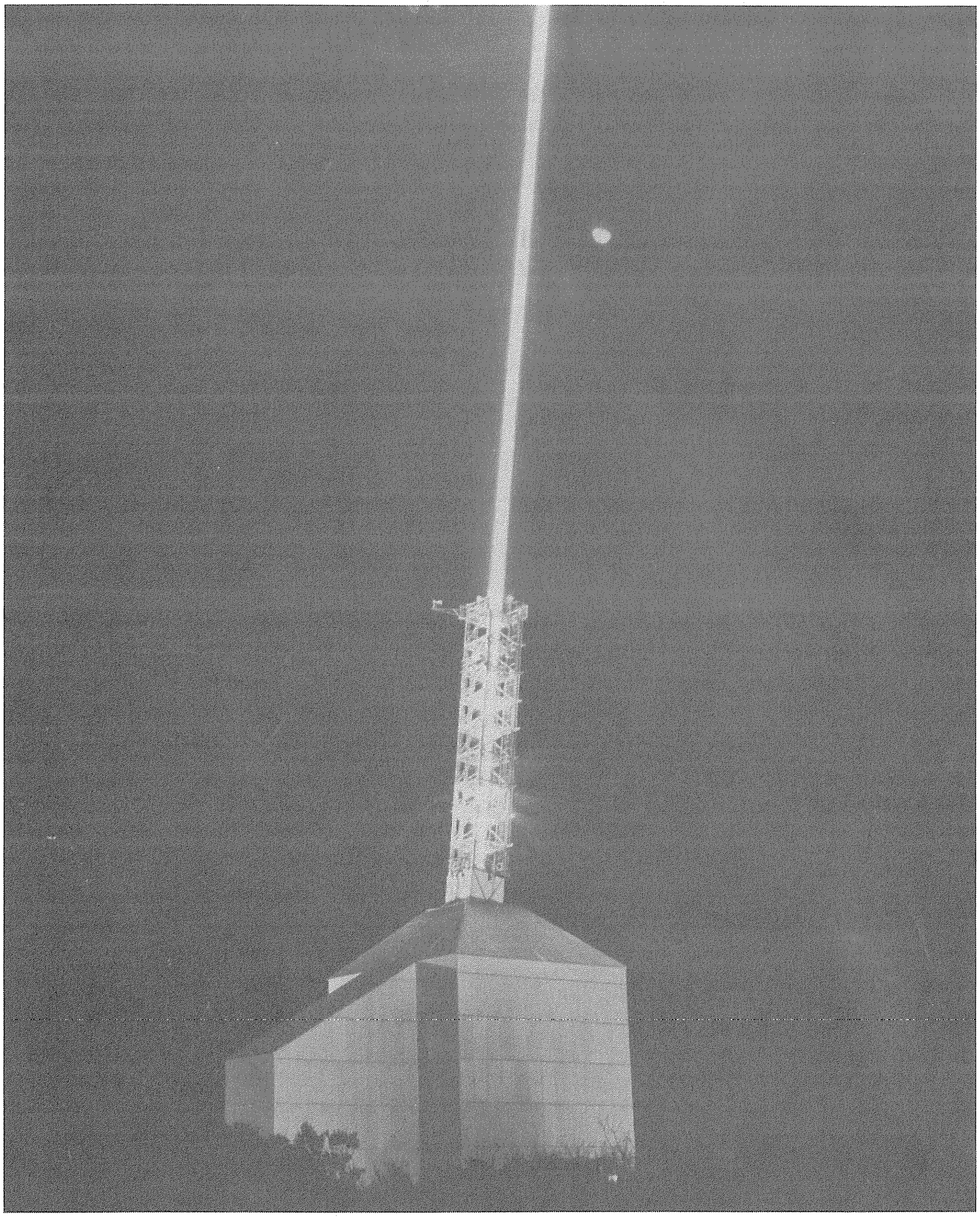


(h) Lifting of launch rail dolly and sounding rocket into launch tower.



(i) Final checkout of rocket.

Figure 34 - Aerobee 150A launch operations (WI).



(j) Night firing of rocket.

Figure 34 - Aerobee 150A launch operations (WI).

CONCLUSIONS

This report summarizes all Aerobee sounding rocket launches by the NASA Goddard Space Flight Center conducted during the period from September 1959 through December 1963 inclusive. Further technical information concerning the types of sounding rockets used may be found in the bibliography.

ACKNOWLEDGMENTS

This work could not have been accomplished without the complete cooperation and support of W. G. Moon, who helped to prepare this manuscript. The authors also wish to acknowledge the use of U. S. Army official photographs (White Sands) and the U. S. Air Force official photographs (Fort Churchill) taken at each range.

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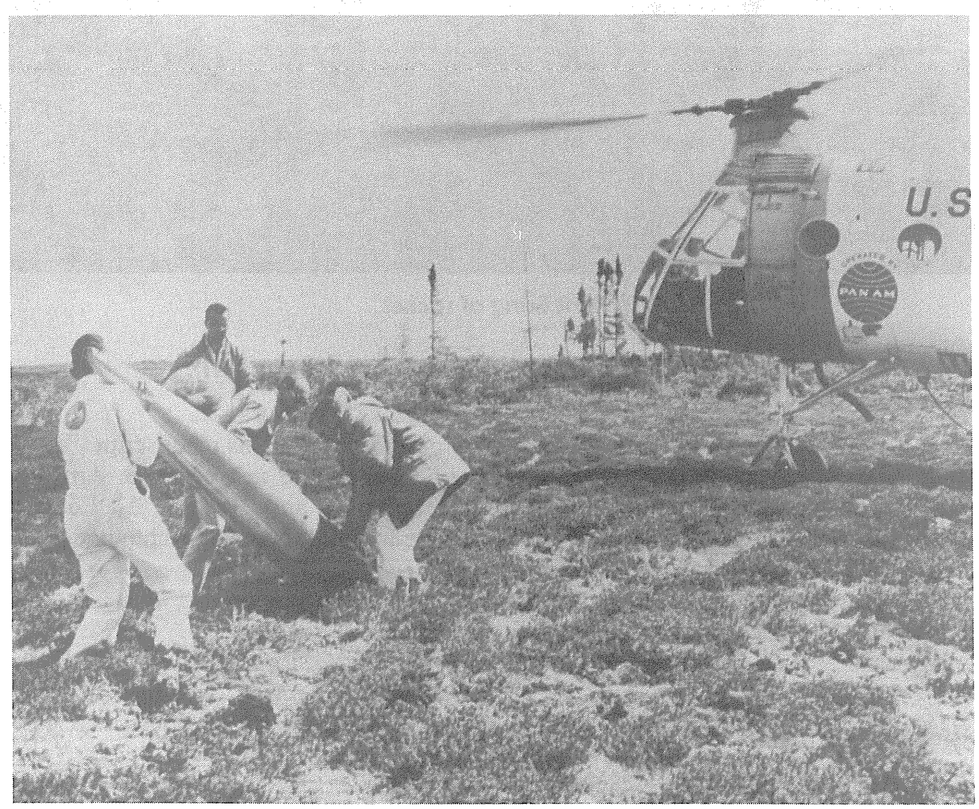

Figure 35 - Recovery of nose cone fired at Fort Churchill.

Appendix A - Performance Characteristics Charts.

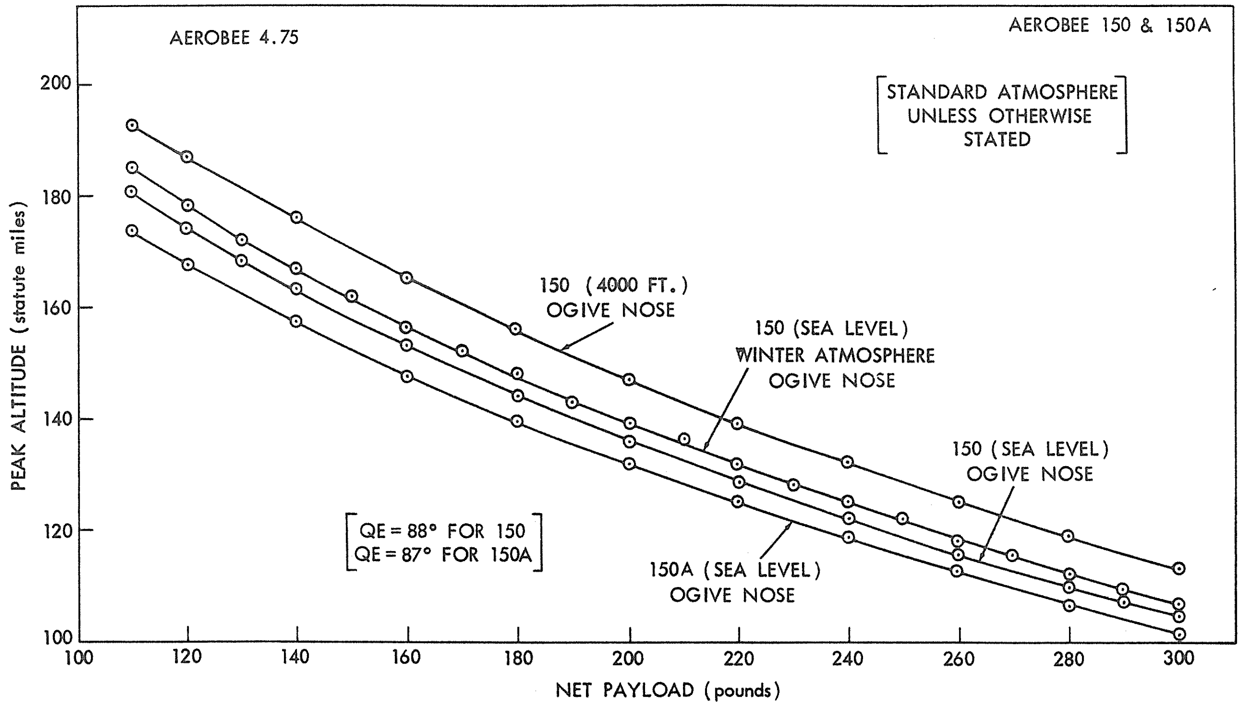

Figure A1 - Peak altitude versus net payload for ogival nose cones.

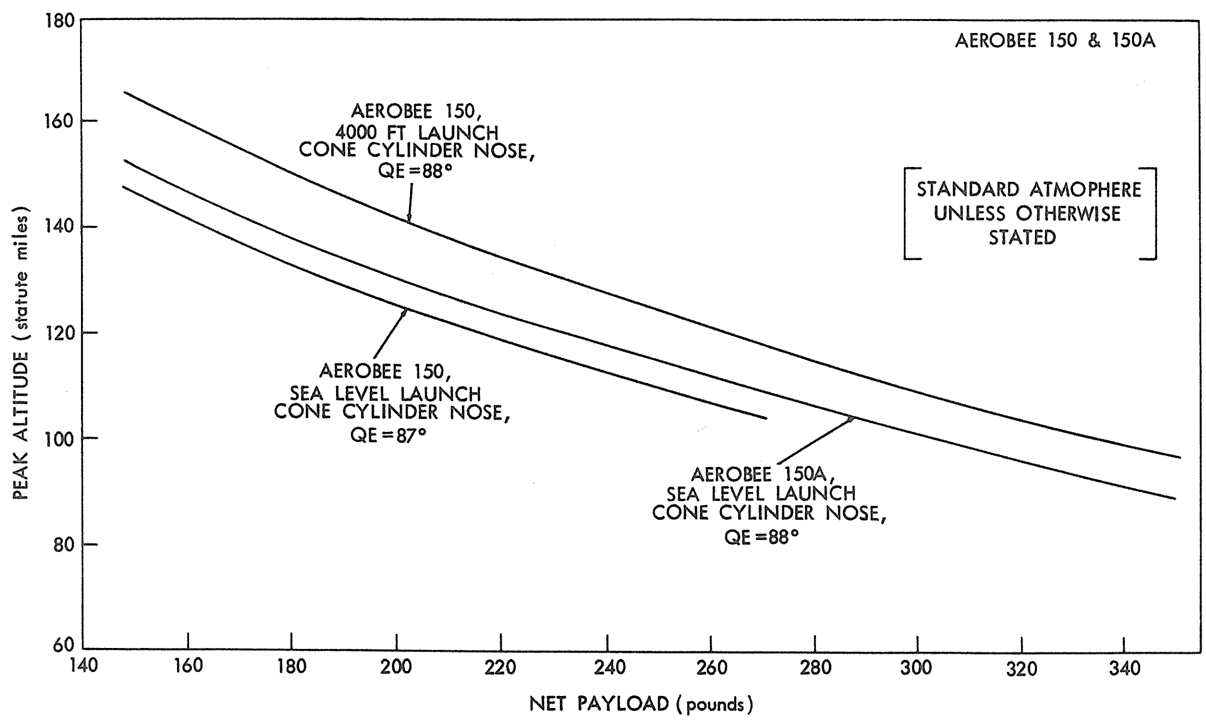

Figure A2 - Peak altitude versus net payload for cone-cylinder nose cones.

Appendix A - Performance Characteristics Charts.

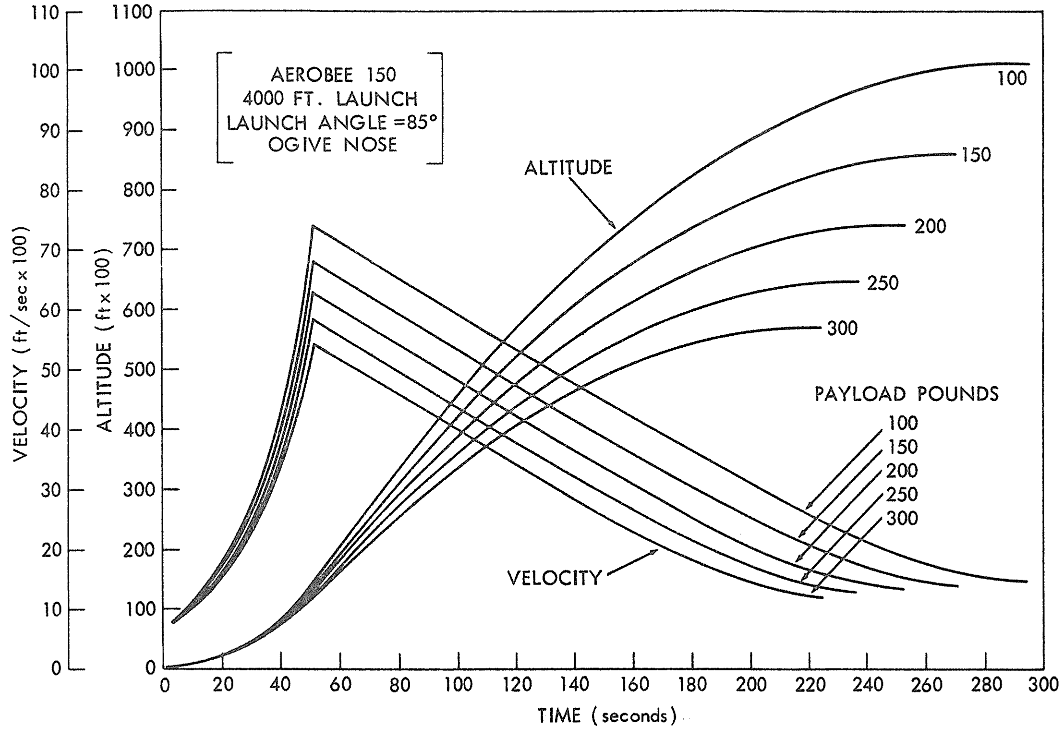

Figure A3 - Aerobee 150 velocity and altitude versus time for various payloads.

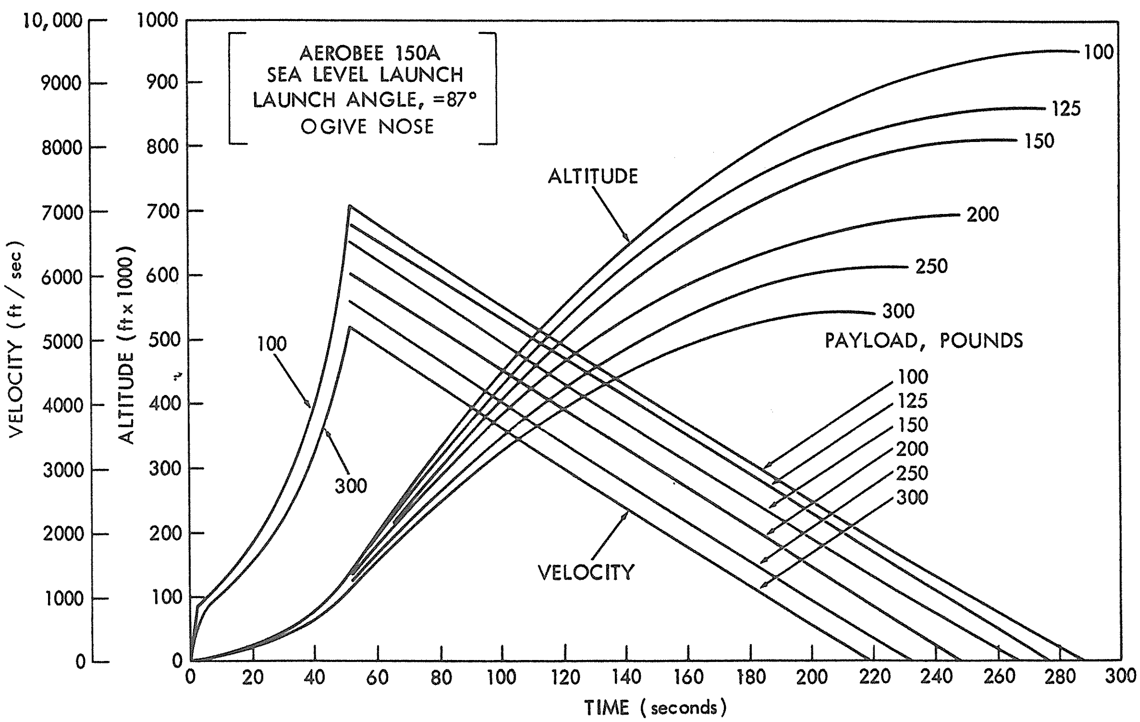

Figure A4 - Aerobee 150A velocity and altitude versus time for various payloads.

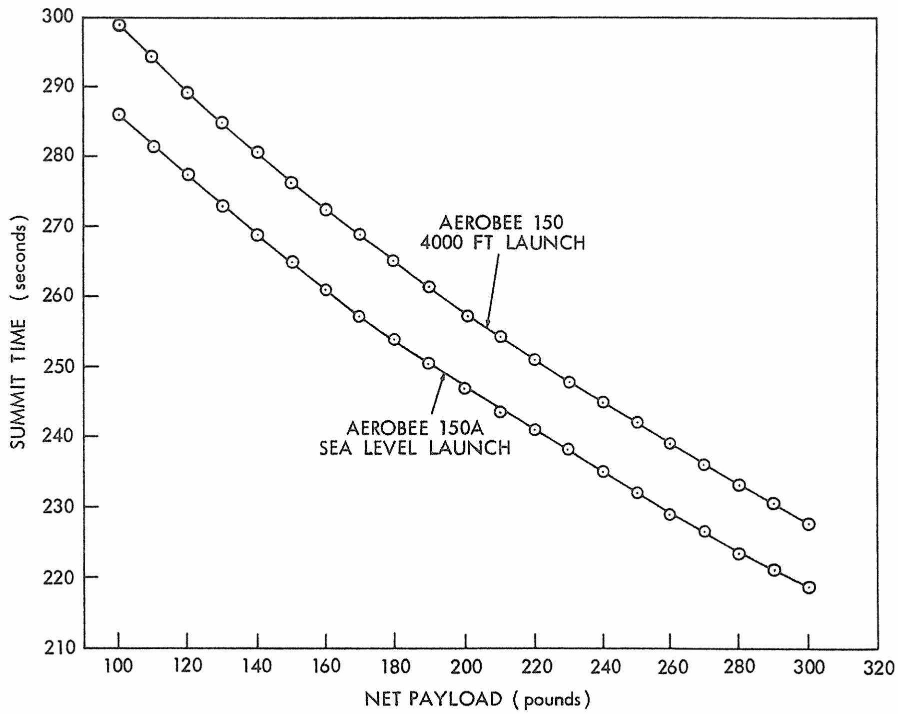

Figure A5 - Summit time versus net payload for Aerobee 150 and 150A sounding rockets with ogival nose cones and a QE = 87º.

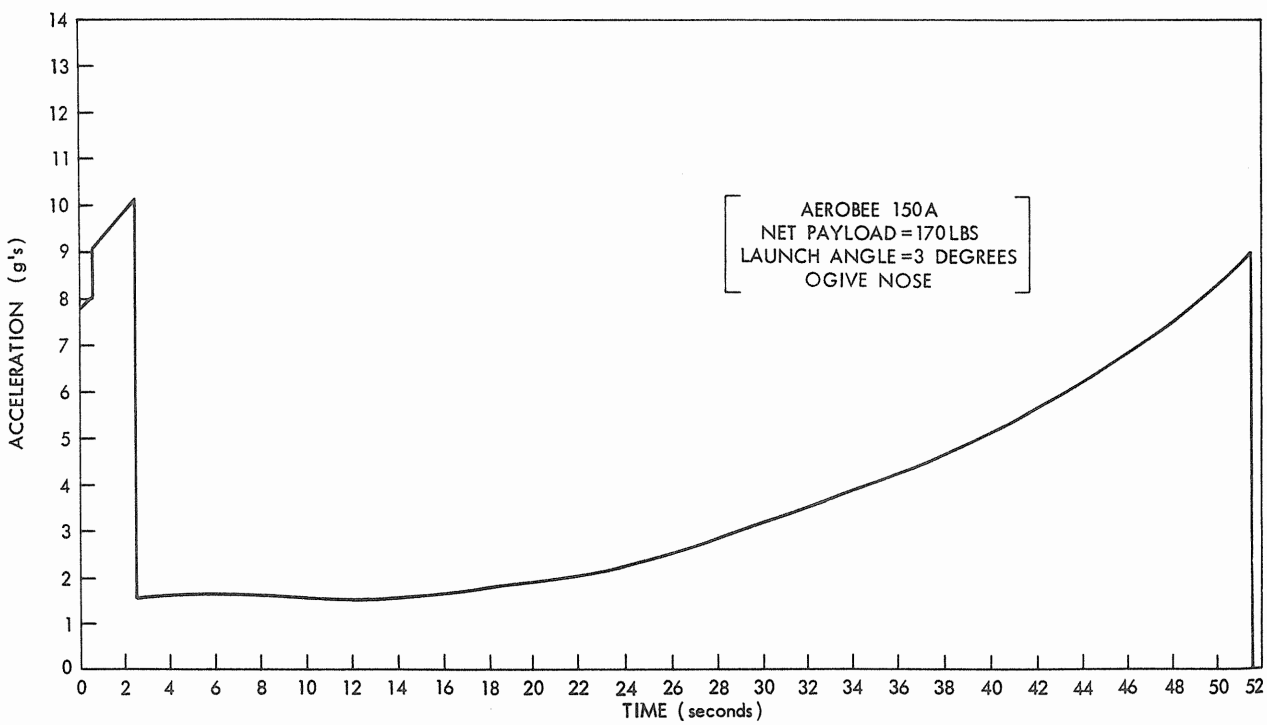

Figure A6 - Acceleration versus time for Aerobee 150A (typical).

Appendix B - Representative Flight Temperatures for Ogival Nose Cones.

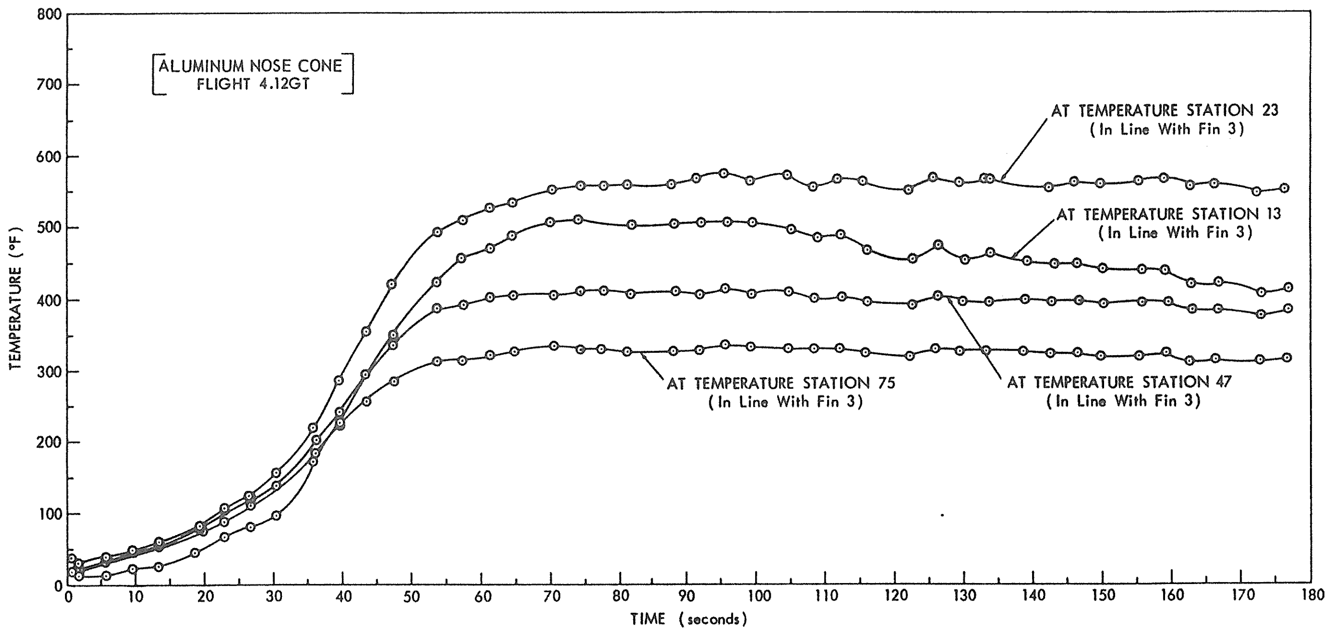

Figure B1 - Representative flight temperatures for ogival nose cones.

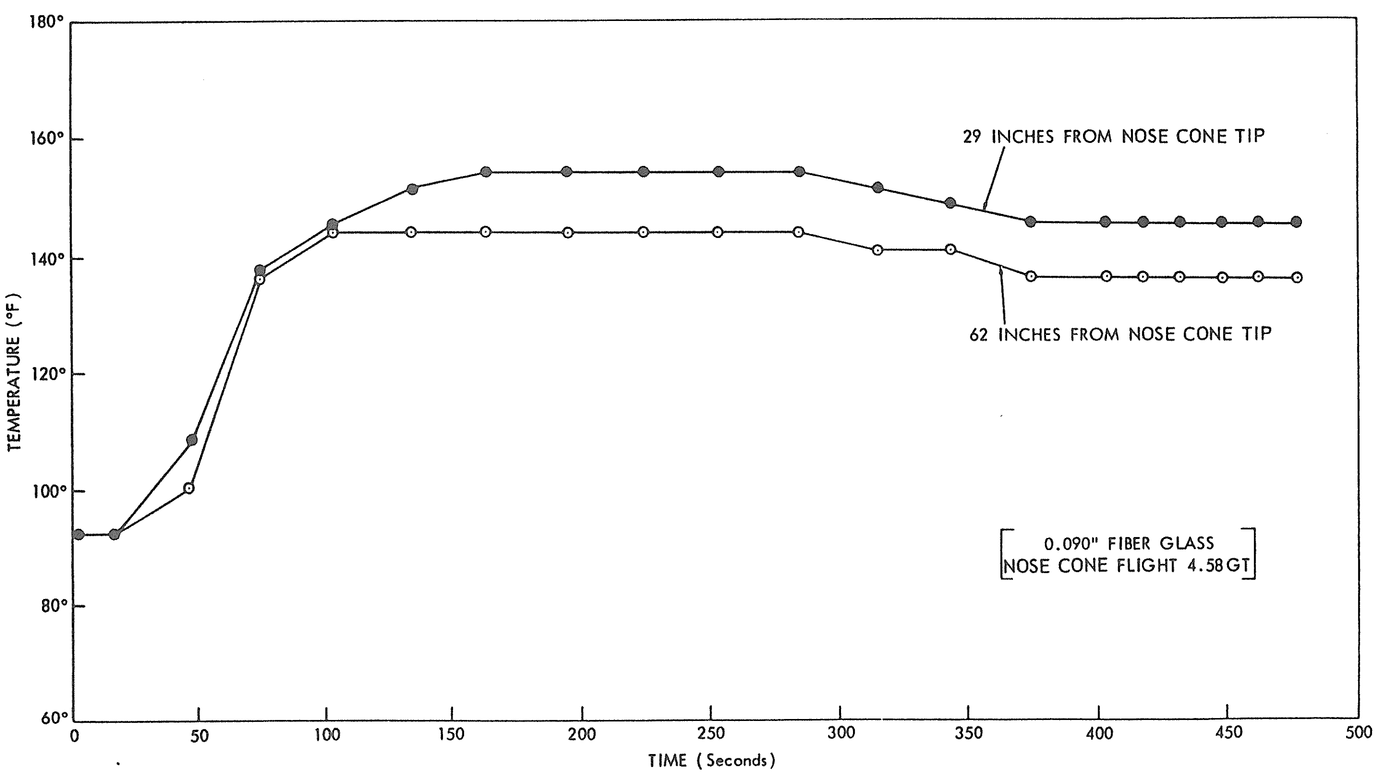

Figure B2 - Representative flight temperatures for ogival nose cones.

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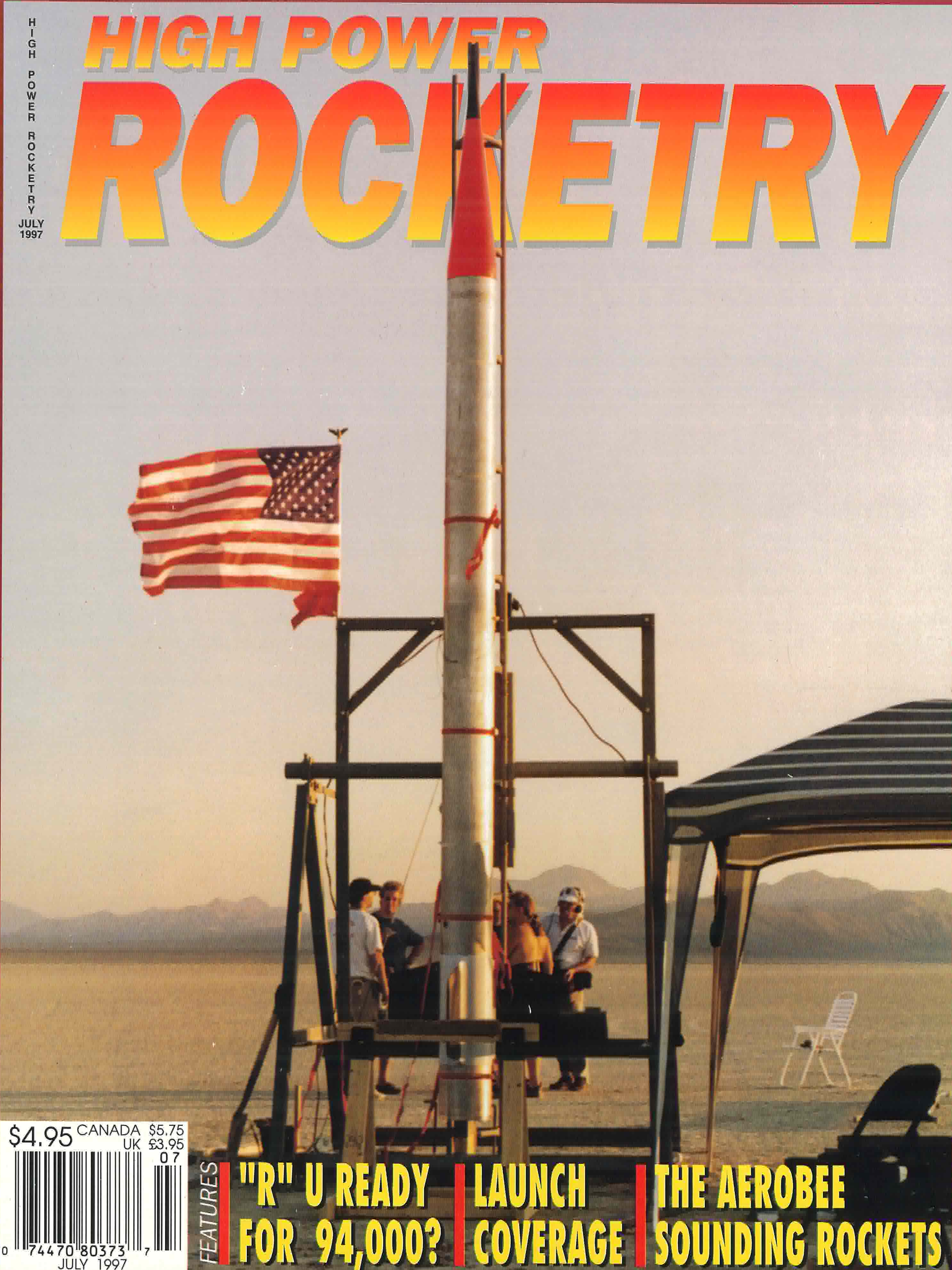

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