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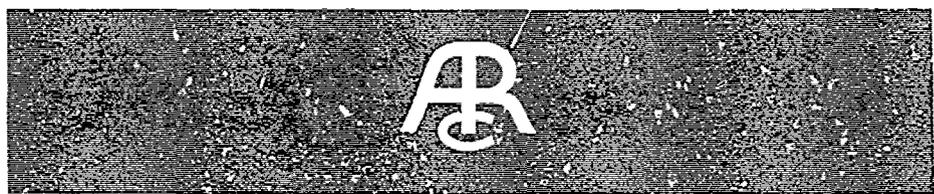
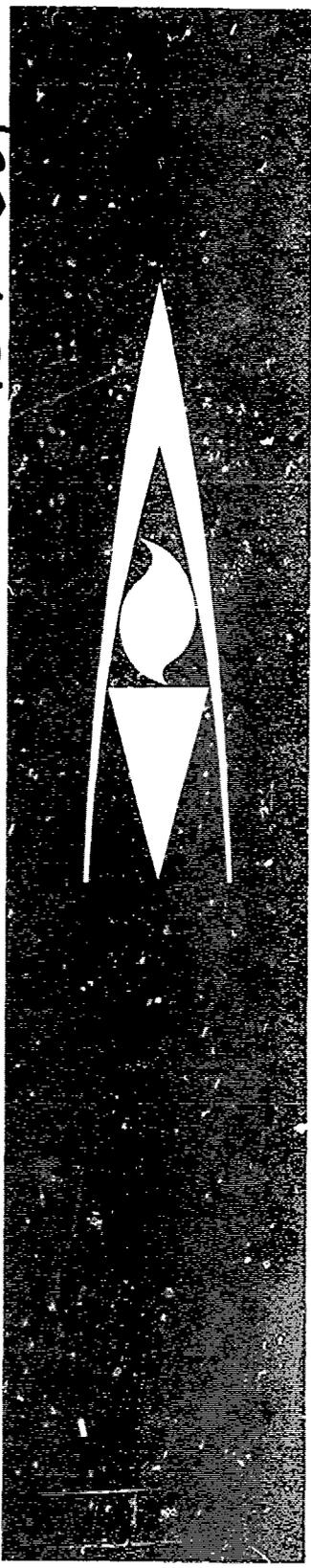
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FABRICATION AND DELIVERY OF ARCAS
SOUNDING ROCKET SYSTEMS
EX 6 MOD 0 AND EX 6 MOD 1

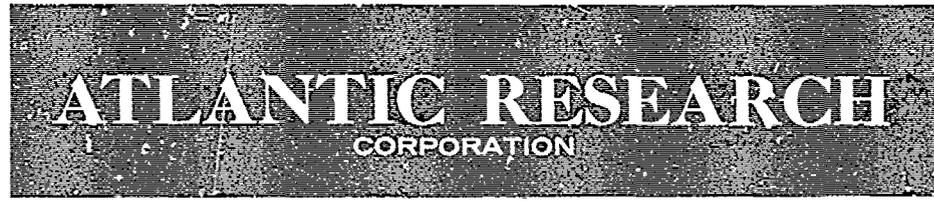
for

Office of Naval Research
Department of the Navy
Washington, D.C.

Contract NOnr-2926(00)

November 5, 1963

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FOREWORD

This report documents the delivery, design refinement, and flight results of ARCAS[®] Sounding Rockets under Contract NOnr 2926(00) with the Office of Naval Research. Work under this contract was initiated on June 1, 1959, and was completed in May 1963.

ABSTRACT

A total of 1,413 ARCAS rocketsondes, including 904 EX 6 MOD 0 ARCAS units, 504 EX 6 MOD 1 ARCAS-Robin units, and 5 EX 6 MOD 2 boosted ARCAS units, were delivered under Contract NOnr 2926(00). During the contract period, flight results were monitored, and design and processing refinement measures were implemented to improve system reliability. Over a dozen significant design modifications were effected, including changes in the insulation sleeve configuration and material and in the procedure and bonding agent used for fin attachment. By the end of the program, over-all system reliability had been increased from 63 percent to 94 percent.

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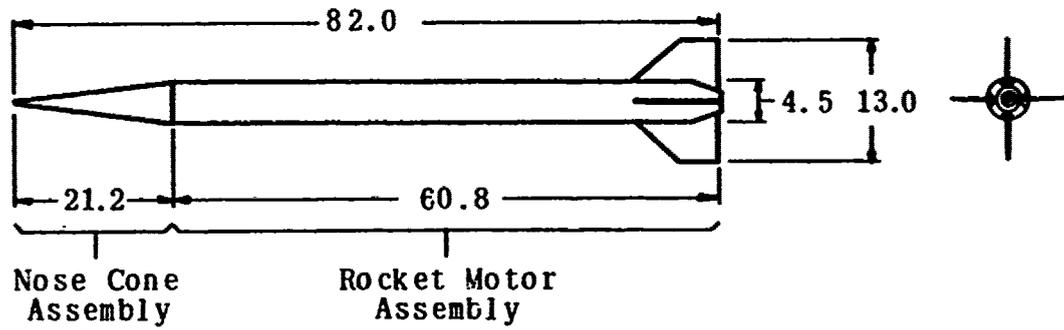
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INTRODUCTION

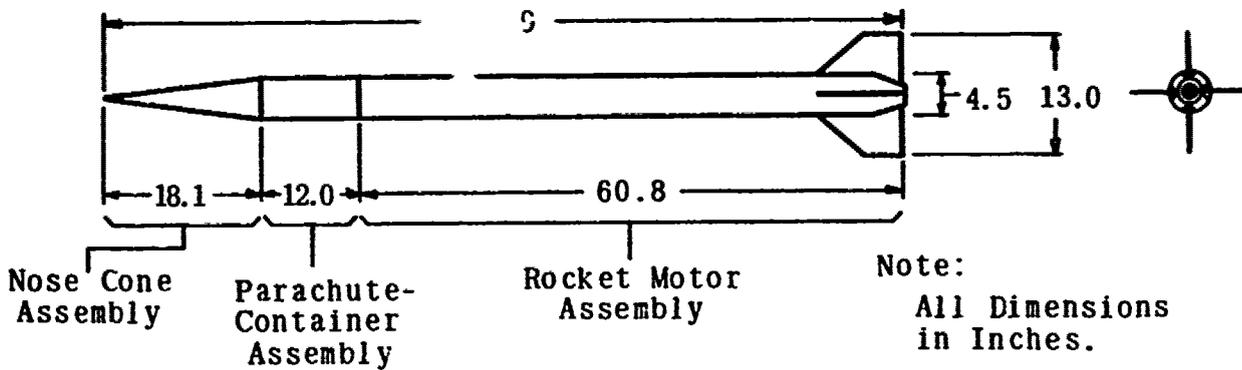
GENERAL DESCRIPTION OF ARCAS ROCKET

The EX 6 Sounding Rocket is a high-performance vehicle designed to carry 5- to 20-pound payloads to altitudes of 40 to 60 miles. The rocket has two basic configurations differing with respect to payload and mission. The EX 6 MOD 0 configuration, designated ARCAS, carries meteorological sensing devices and a small transmitter to altitudes of 40 to 55 miles where the package is separated and descends on a radar-reflective parachute. The MOD 1 configuration, designated ARCAS-Robin, carries a radar-reflective Mylar balloon to an altitude of approximately 60 miles. At this altitude, the balloon is separated, inflated, and its descent is tracked by radar to furnish data on winds and atmospheric density. The over-all dimensions of the two configurations are compared in Figure 1. Both the MOD 0 and MOD 1 rockets are launched from a closed-breech launcher as shown in Figure 2.

The EX 6 rocket motor contains an end-burning, solid-propellant charge of Arcite 373D which delivers an average thrust of 325 pounds over an action time of 29 seconds. The motor case consists of a one-piece, SAE 4130 steel outer casing with an asbestos-phenolic insulating liner. The nozzle structure is a tapered graphite insert supported by the tapered after end of the motor case. A steel retaining ring is used to secure the motor head closure and to provide a threaded joint for attachment of the payload section. A flange is provided at the after end of the motor case for the attachment of the launching piston. The pyrotechnic device used for payload separation is housed within the head closure. A delay column in this device is ignited at the termination of propellant burning. After burning for 100 seconds, the delay column ignites a gas-generating charge, which separates the payload from the expended rocket motor at apogee. Rocket motor performance and dimensional data are summarized in Table I.



Mod 1, ARCAS-Robin



Note:
All Dimensions
in Inches.

Mod 0, ARCAS

Figure 1. Comparison of Mod 0 and Mod 1 Rockets.

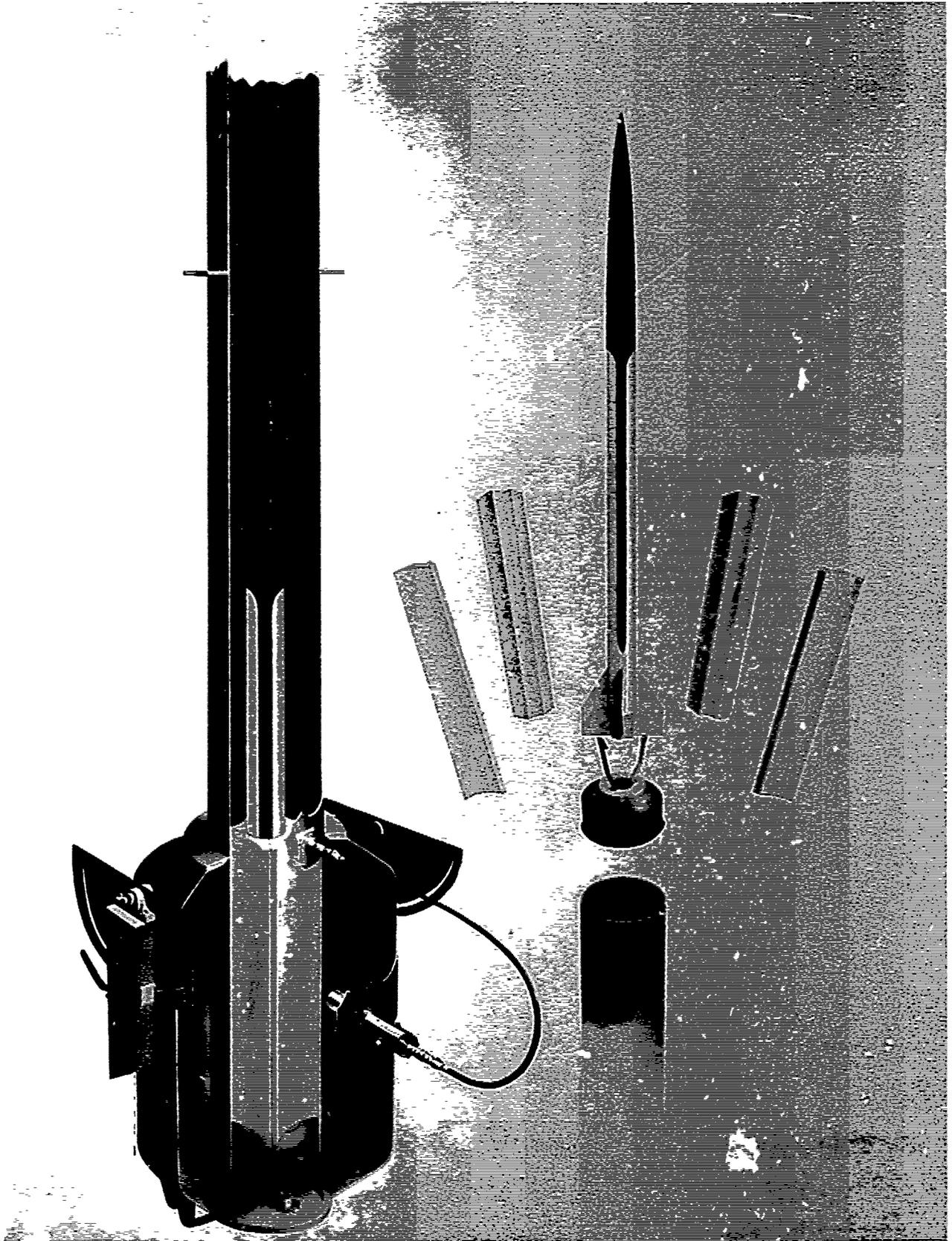


Figure 2. Launching of ARCAS from Closed-Breech Launcher with Auxiliary Gas Generator.

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Table I. Rocket Motor Performance and Design Characteristics.

<u>Item</u>	<u>Value</u>
PERFORMANCE CHARACTERISTICS (Sea Level, 70°F)	
Average thrust, pounds	325
Action time, seconds	29.0
Total impulse, lb-sec	9450
Chamber pressure, psi	1020
DESIGN CHARACTERISTICS	
Length, inches	60.8
Diameter, inches	4.45
Total weight (including fins and payload separation device), pounds	65.0
Nozzle expansion ratio	13:1

SCOPE OF CONTRACT

On June 1, 1959, Atlantic Research Corporation entered into Contract NOnr 2926(00) with the Office of Naval Research to fabricate and deliver 260 EX 6 MOD 0 rocketsondes for a flight program to support the development of the ARCAS Rocket. Increasing activity in the use of sounding rockets for the measurement of atmospheric conditions, however, created a growing demand for ARCAS units. Hence, over the period from June 1, 1959, to June 1, 1962, the contract was amended seven times to culminate in a production total of 1408 rocketsondes, 23 launchers, 5 boosted ARCAS systems, 50 nose cones, and nose cone tooling. In the third amendment, it was specified that 200 rocketsondes were to be delivered with MOD 1 Robin nose cones in place of the standard MOD 0 ARCAS parachute container and nose cone. Amendments 6 and 7 later increased the number of rockets with Robin nose cones to 504. The requirements of the original contract and each of the subsequent amendments are presented in Table II.

During the course of the program, the Office of Naval Research served as the administrative clearing agency for ARCAS orders received from various procuring agencies. These orders were transmitted to Atlantic Research as amendments to the primary contract. Among the principal ARCAS users were the Air Force's Cambridge Research Laboratories, the Army's Air Weather Service, and the White Sands Missile Range. Table II includes a listing of all procuring agencies.

Table II. Schedule of Contractual Requirements.

Amendment Number	Date of Effectivity	Rockets Ordered		Agency	Launchers Ordered	Miscellaneous Orders
		Quantity	Type			
Original Contract	June 1, 1959	255	ARCAS	WSMR	—	—
		5	ARCAS	ARDC		
1	July 30, 1959	150	ARCAS	ONR	2	—
2	October 13, 1959	65	ARCAS	WSMR	—	—
Negotiation	January 11, 1960	- 19	ARCAS	WSMR/ONR	4	—
3	March 4, 1960	200	Robin	AFCRL	2	—
4	June 22, 1960	80	ARCAS	PMR	1	—
		10	ARCAS	ARDC		
		112	ARCAS	WSMR		
5	January 31, 1961	25	ARCAS	ARDC	4	—
		57	ARCAS	WSMR		
6	July 1, 1961	97	ARCAS	WSMR	11	50 Number 8 Nose Cone Assemblies with Tooling
		10	ARCAS	NASA/ONR		
		10	ARCAS	ARGMA		

Table II. Continued.

<u>Amendment Number</u>	<u>Date of Effectivity</u>	<u>Quantity</u>	<u>Type</u>	<u>Agency</u>	<u>Launchers Ordered</u>	<u>Miscellaneous Orders</u>
		92	ARCAS	AFCRL		
		5	ARCAS	ONR		
		200	Robin	AWS		
		100	Robin	AFCRL		
		5	Robin	Pat. Moos		
7	June 1, 1962	- 50	ARCAS		- 1	-
		- 1	Robin			
		5	Boosted ARCAS			
		<u>904</u>	ARCAS		23	50
		504	Robin			
		<u>5</u>	Boosted ARCAS			
		<u>1,413</u>	Rockets			

- Legend:
- WSMR - White Sands Missile Range, White Sands, New Mexico
 - ARDC - Army Research & Development Center, Ft. Monmouth, New Jersey
 - ONR - Office of Naval Research, Washington, D.C.
 - PMR - Pacific Missile Range, Pt. Mugu, California
 - NASA - National Aeronautics and Space Administration, Wallops Island, Virginia
 - ARGMA - Army Rocket and Guided Missile Agency, Huntsville, Alabama
 - AFCRL - Air Force Cambridge Research Laboratories, Bedford, Massachusetts
 - AWS - Air Weather Service, Ogden, Utah
 - Pat. Moos - Patterson - Moos Corporation, New York, New York

PRODUCTION AND DELIVERY

All deliveries were completed by the end of February 1963 except for six EX 6 MOD 0 replacement units shipped in May 1963. Units were delivered to destinations throughout the United States and Canada, including major shipments to White Sands Missile Range, Atlantic Missile Range, Pacific Missile Range, USAS American Mariner, Wallops Island Station, and Fort Churchill, Canada.

A summary of the units delivered per month from contract initiation to termination is presented in Table III. In Figure 3, the actual shipping schedule is compared with the schedule prescribed by each contract amendment. The depicted rate of delivery shows that production increased sharply after the first six months and continued at an average level of 40 units per month for the next two years. As the contract drew to conclusion in late 1962, the production rate decreased slightly. The fin bond and insulation problems noted on the graph were the major difficulties encountered in attempting to increase the rate of delivery sufficiently to compensate for early program slippage. These problems are discussed in detail in the following section on design refinement.

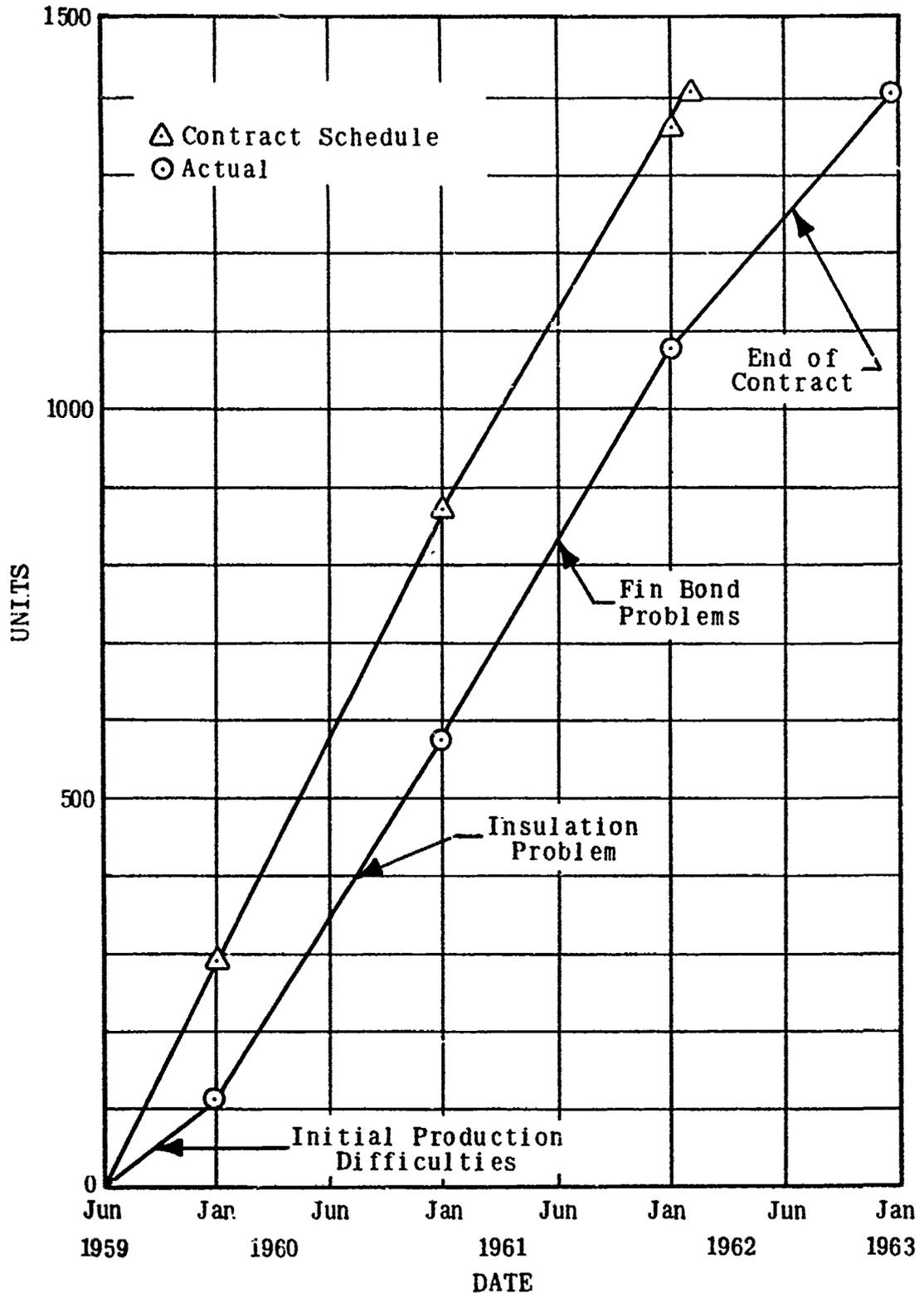


Figure 3. Production Schedule NOnr 2926 (00).

DESIGN REFINEMENT

The ARCAS rocketsonde system was developed as a joint military project during 1958 and 1959 under contract number NOmr 2477(00).¹ By March 1959, the ARCAS rocket motor had been subjected to a 26-unit test program² intended only to qualify it for limited field use until a more comprehensive program could be conducted. The development program also included seven performance evaluation flights and 41 meteorological data-gathering flights. Of the units flown in the latter series, 13 were MOD 0 ARCAS systems and 28 were MOD 1 Robin rockets. Because of inadequate instrumentation and adverse wind conditions, however, the flight tests did not provide sufficient data for a thorough analysis of the aerodynamic, payload separation, and parachute deployment phases of system operation. Hence, when the production program was initiated in June 1959, it was expected that flight failures would occur and that the over-all system reliability would be relatively low until sufficient field data had been compiled for a comprehensive design evaluation.

Throughout the delivery program, flight test results were monitored in an attempt to locate and correct design weaknesses as they became evident. Three- to four-month lag times between production and flight and the lack of adequately detailed field reports, however, made this a rather difficult and prolonged procedure. A formal 52-unit qualification test program was authorized in August 1962 after three years of flight testing. By this time, most of the major problem areas had been disclosed, analyzed, and corrected.

Over a dozen significant modifications have been incorporated into the ARCAS rocket design since the inception of the delivery program in June 1959. These improvements are described below in the chronological order of their effectivity.

1. Insulation. - The insulation problem was the first and, along with the fin bond problem, one of the two most serious motor design weaknesses disclosed during flight testing. Four flights conducted in 1960 failed during motor operation when the case burned through at its nozzle end. The nozzle insulation in these units was fabricated as an integral part of the case insulation sleeve. The sleeve was wrapped on a mandrel and was composed of Raybestos-Manhattan 41 RPD, an asbestos-filled phenolic tape.

An investigation disclosed that in many of the sleeves the density of the insulation material was considerably lower in the nozzle area than in the cylindrical section -- about 1.250 g/cc as compared with a specification minimum of 1.550 g/cc. To ensure adequate nozzle protection, the design was modified to include a separate compression-molded nozzle insulation cone to be bonded onto the cylindrical case sleeve. Fabrication of the nozzle parts from Raybestos-Manhattan 150 RPD asbestos phenolic was initiated in August 1960. A minimum material density of 1.750 g/cc was established for these parts.

A six-unit test program was conducted to prove the new two-piece insulation sleeve. The results of this program were submitted to the Office of Naval Research and the Bureau of Naval Weapons in a report dated March 24, 1961. This report is included as Appendix A.

Later in 1961, Johns-Manville ARP-40 material was evaluated as a replacement for 41 RPD in the cylindrical insulation sleeve. The ARP-40, composed of an asbestos-filled phenolic resin applied to a Kraft paper base, was demonstrated in static firings to possess superior insulating capabilities compared with 41 RPD. As shown in Figure 4, the maximum case temperature at burnout for a 70°F firing was reduced from 310°F to 210°F with ARP-40. Hence, ARP-40 was selected for use in subsequent production motors.

2. Fin Alignment. - Aerodynamic problems experienced in 1960 and early 1961 flights were traced to the occurrence of pitch-roll coupling at spin rates of around 5 rps. To circumvent this problem, the fins were canted by 0.130 inch to increase the spin rate to between 15 and 20 rps.

3. Launch Accessories. - Approximately 2 percent of the flights in 1960 and 1961 failed because of abnormalities in the launching operation. Three corrective measures were implemented in early 1962 to eliminate the possibility of jamming or cocking in the launch tube. First, the launching piston was redesigned from a two-piece, clam-shell unit to an integral piece. In the earlier version, the pressure of the entrapped exhaust gases acting on the piston was relied upon to maintain the piston in a secure position against the bowtail flange on the nozzle end of the motor. In the redesigned piston, a more positive means of temporarily attaching the piston to the motor during

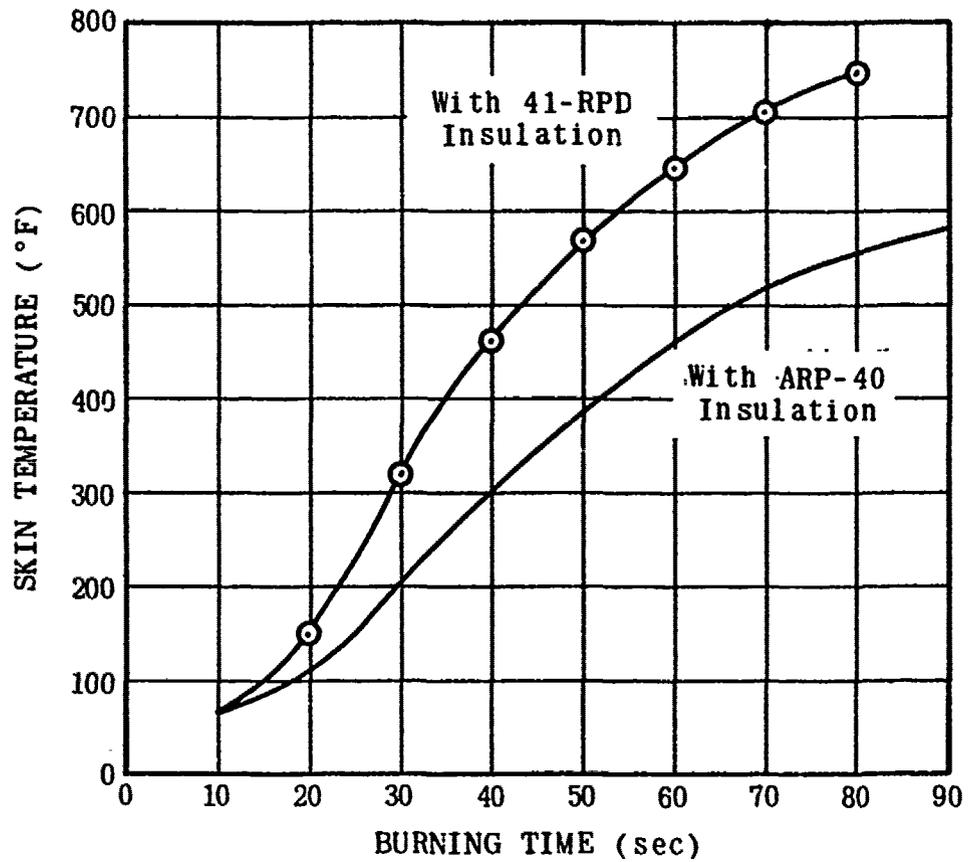


Figure 4. Comparison of Skin Temperatures Obtained with 41-RPD and ARP-40 Insulation Sleeves.

launch was incorporated. Initially, this attachment was effected through set screws housed within rocker arms on top of the piston. Break pins were used in this design to separate the piston from its rocker arms as the rocket left the launch tube. The set screw system was subsequently replaced by straps hinged to the top of the piston. The straps hook over the bowtail flange so as to fall away as the rocket leaves the launcher and the side force from the spacers is removed. The use of straps eliminates potential problems resulting from differences in break pin strength.

The second solution to launch tip-off problems was the incorporation of preformed bows in the styrofoam spacers used to align and support the rocket in the launching tube. A 32-degree circular bow over the length of the spacers and a 22-degree conical bow in the forward end effect a quick release from the rocket after launch.

The third corrective measure was the adoption of an auxiliary gas generator to increase the launch velocity from 160 to 230 ft/sec. The generator is mechanically actuated by pressure transmitted from the launcher by a connecting hose. (See Figure 2.) A propellant charge in the generator ignites and releases additional gas pressure into the launch tube.

4. Inhibitor. - An extremely beneficial design change incorporated in 1962 was the replacement of the polyurethane PUX-500 inhibitor with a nylon wrap impregnated with epoxy-polyamide resin. The nylon inhibitor has four principal advantages over the PUX inhibitor: (1) it is more quickly applied and is thereby less expensive; (2) the nylon-epoxy system is more conducive to the prevention of voids under the inhibitor since it does not react with the moisture during cure as does the PUX; (3) the superior structural strength of the nylon permits the grains to take longitudinal acceleration loads of up to 100 g's; (4) the storage life of nylon-epoxy is longer than that of PUX.

A 26-unit test program was conducted in early 1961 to qualify the nylon-epoxy inhibitor for use in the ARCAS rocket motor. A report covering the results, originally submitted to the Office of Naval Research and the Bureau of Naval Weapons on March 2, 1961, is included as Appendix B.

5. Parachute. - The failure rate of the parachute during 1960 and 1961 was an almost constant 6.0 percent. Failures consisted of parachute streaming, the burning of the parachute and its cords by sparks from the motor exhaust, and the breaking of the cords after deployment. Three design changes were incorporated in early 1962 in an attempt to reduce the frequency of parachute failures: (1) the shroud lines and load lines were strengthened to withstand 1500 pounds rather than 800 pounds; (2) the parachute was packaged in an asbestos bag and the lines were wrapped in asbestos for thermal protection; (3) a swivel connection between the payload and the parachute closure was installed to prevent detachment of the instrument package as it spins during payload separation. As a result of these modifications, the failure rate of the parachute was reduced to 4.5 percent, a figure which appears to be within the present state-of-the-art of parachute technology.

6. Forward Retaining Ring. - A silver soldering process for securing the forward retaining ring in place was adopted in 1962 because of the resulting production time savings and reduced rejection rates. With the spot welding process previously employed, a leak in the forward closure would necessarily mean the rejection of the complete motor subassembly. With the soldered joint, it is possible to reheat the joint and stop the leakage.

.. Fin Bond. - The occurrence of severe aerodynamic deviations in flights conducted in 1961 and early 1962 was attributed to bond failures between the fins and the motor case during the first 60 seconds after launch. Subsequent analysis and test culminated in an improved bonding surface preparation procedure and a change in bonding agent from Resiweld 600 to Shell Epon 931 epoxy resin.

Several bonding materials were subjected to shear tests over the temperature range of -70°F to 500°F. Of particular interest were the tests conducted at 400°F and 500°F, the maximum temperatures experienced by the fin bond within one minute after ignition. The test samples consisted of steel and aluminum strips-- sandblasted, vapor-degreased, and bonded together with a 1/2-inch overlap. All bonding and curing operations complied with the manufacturer's suggested procedures. Test results are presented in Table IV.

Table IV. Fin Bonding Compound Evaluation Results.

ADHESIVE	BOND* SHEAR IN PSI AT TEST TEMPERATURE INDICATED.						
	-70°F	-10°F	Amb	110°F	400°F	500°F	-70° to 170° to Ambient
Exp 31-59 ³	961	1675	1490	-	435	268	1490
EPON 929 ¹	1602	-	2055	-	2372	-	2180
EC 1838	2060	2145	-	1935	-	160	2600
EC 1663 ⁴	360	273	252	-	-	124	358
Raybond ²	805	740	1108	672	370	-	-
B 424 ²	-	471	2015	1075	600	392	-
R 600	-	-	2470	2191	61	52	3200
EPON 931	1328	2195	1650	1758	529	244	2165

1. Requires heat (250°F) cure
 2. Requires heat (300 to 350°F) and pressure for cure; Raybond R-81002 (fluid); Bloomingdale B 424 (Phenolic tape, Fabric carrier)
 3. Availibility questionable
 4. Silicone base adhesive - excellent flexibility
- * Aluminum to steel (sandblasted)

The adhesive degradation of Resiweld 600 at elevated temperatures is quite evident; all other candidate adhesives maintained the required strength characteristics over the temperature range. Epon 931 was selected because of its availability, ambient curing properties, and workability. Before final acceptance, this choice was verified in five successful flight tests at White Sands Missile Range and in 20 fin fracture tests.

8. Impulse Variability. - A continual effort was made during the program to reduce total impulse (i.e., altitude) variability through improved propellant processing procedures. The most significant contribution toward achieving this goal was a tightening of the acceptance limits on grain weight.

9. Separation Device. - Field reports indicated that the payload separation device was failing to function properly in approximately 8 percent of the ARCAS flights in 1960 and 1961. Two material changes were made to improve the reliability of the separation device: (1) aluminum was replaced by steel as the material for the ignition tube; (2) Flare-Northern SM-7 compound was replaced by Flare-Northern IF-10 as the first-fire ignition composition. Seven modified devices were subjected to vibration, thermal cycling, and functioning tests to demonstrate the acceptability of the new materials.

Four units were subjected to transportation vibration, and three to both transportation and random noise vibration. The data from these tests are summarized in Table V below.

TABLE V
SEPARATION DEVICE VIBRATION DATA

<u>Frequency</u> (cps)	<u>Double</u> <u>Amplitude</u> (inch)	<u>Scanning</u> <u>Speed</u> (degrees/min)	<u>Duration</u> (min)
<u>S/N 150, 164, 188, and 195</u>			
10-25	0.060	50	30
25-34	0.040	31	30
34-41	0.026	20	30
41-50	0.018	16	30
<u>S/N 107, 153, and 362</u>			
10-34	0.060	50	15
34-50	0.026	31	15

Plus random noise with mean acceleration level of 40g for 4 minutes.

All seven separation devices were then cycled once between -50°F and 170°F and actuated. All units functioned satisfactorily.

10. Insulation Backup Material. - A more rapid and less costly means of retaining and supporting the insulator in the motor case was developed in mid 1962. This change involves the use of Emerson and Cummings Eccofoam FPH-12-10H in place of polyurethane PUX as the insulation backup material. Test data comparing the compressive strength and thermal stability of Eccofoam FPH-12-10H with that of other candidate foams are presented in Table VI. Thermal stability was evaluated by placing 1/2-inch cubes on a plate heated to 400°F and observing the time and mechanism of degradation. The strength tests consisted of compressing 1-inch cubes on a Tinius-Olsen machine and recording load and percent compression at yield. The Eccofoam FPH-12-10H proved superior in the compression tests and equivalent to two other Eccofoam materials in possessing the best thermal stability properties. Its performance far surpassed the minimum design criteria of 30-psi compressive

Table VI. ARCAS Insulation Foam Evaluation Results.

<u>Foam</u>	<u>Source</u>	<u>Compressive Yield</u>		<u>Thermal Stability at 400°F</u>	
		<u>(psi)</u>	<u>(%)</u>		
HP-FC	Atlantic Research	29.0	7	Smoke @ 0.2 min	Char @ 3 min
HP-FC Mod I	Atlantic Research	24.5	7	Smoke @ 0.2 min	Char @ 3 min
B-8-2	Atlantic Research	39.5	4		Melt @ 0.1 min
B-81-2	Atlantic Research	31	7		Melt @ 0.1 min
Reapoxy-1	Read Plastics	-	-		Melt @ 0.1 min
Eccofoam FP-12-10	Emerson & Cumings	-	-	Smoke @ 0.1 min	Melt @ 0.5 min
Eccofoam FPH-12-4H	Emerson & Cumings	29.2	8		Scorch @ 5 min
Eccofoam FPH-12-6H	Emerson & Cumings	80.4	7		Scorch @ 5 min
Eccofoam FPH-12-10H	Emerson & Cumings	134.6	6		Scorch @ 5 min

strength and thermal stability at 350°F for 10 seconds. The acceptability of this material for motor assembly was subsequently demonstrated in static firing tests.

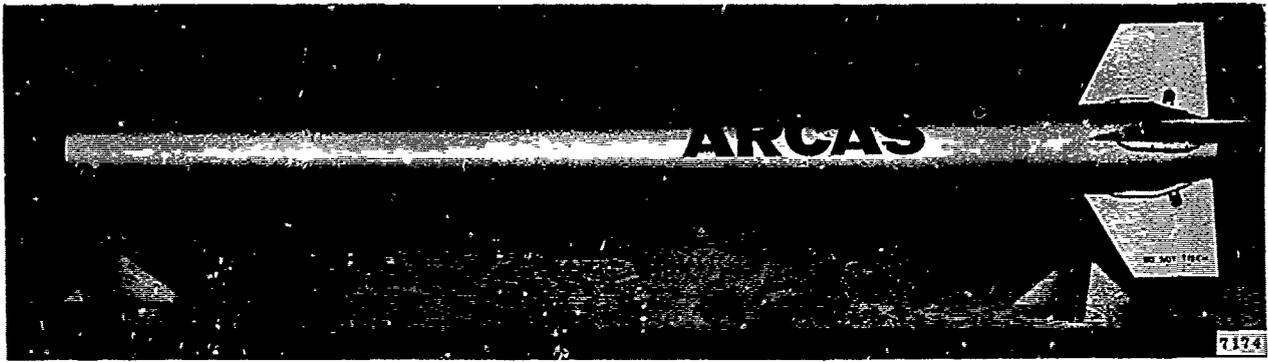
It was initially planned to apply the Eccofoam by allowing it to foam in between the insulator and the case wall. The foam would quickly expand to fill the void volume and effect a sleeve-to-case bond. With the advent of cold weather in late 1962, however, gas leakage behind the insulator during firing began to occur. To ensure an adequate sealing of the void volume under all conditions, the sleeve and case wall are both coated before installation. A reservoir of the Eccofoam material is maintained at the head end of the motor to provide a continuous supply of foam material during the installation process.

11. Head-End Grain Bond. - The rocket motor failure rate, which normally runs around 3 percent, rose to an abnormally high 20 percent in late 1962 and early 1963. This increased rate was found to be a result of bond failures between the propellant grain and the head plate. Six of 44 motors static-fired in the ARCAS qualification program during this period failed for the same reason. A thorough analysis of the problem and an evaluation of the measures proposed to correct it are included in the qualification test report, dated August 20, 1963.³ The results of this study indicated that the existing Resiweld 610 bond would be adequate if certain procedural changes were adopted to improve processing and inspection. These changes included improved bonding surface preparation, curing of the bond with the full weight of the grain pressing against the head plate so as to force any voids to the periphery of the plate, and a sampling plan whereby the head plate is removed from a prescribed percentage of grain assemblies and the quality of the bond is visually examined.

To cover the possibility of recurring head-end bond failures, however, an alternate inhibiting technique was developed as a backup measure. In this design, the Resiweld 610 adhesive is replaced with a nylon cloth cap impregnated with epoxy-polyamide resin. The effectiveness of this cap inhibitor has been demonstrated in laboratory tests, static firings, and flight tests.

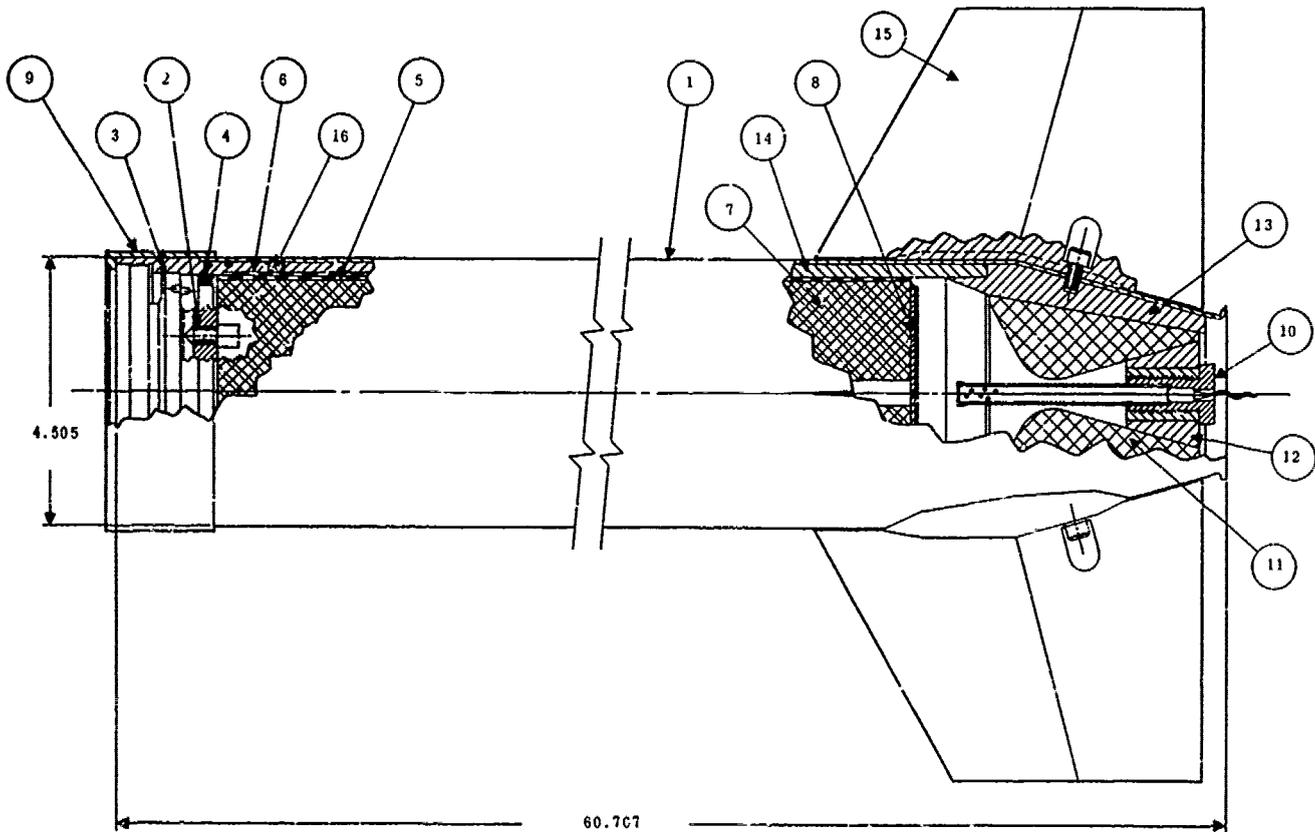
12. Shipping and Storage. - Measures to provide increased protection of the ARCAS rocket motor during shipping and storage were implemented in the latter half of 1962. The entire case surface is painted with Farboil Silver Silicone paint except for the decal which is painted with clear silicone paint. A nozzle shipping plug, consisting of a nylon stud fitted with an O-ring seal, is threaded into the igniter boss. Polyethylene caps are placed over both the forward and after ends of the motor. A dummy motor protected in this manner was immersed in salt water for one week with no evidence of leakage or deterioration.

Design improvements in addition to those discussed above were implemented to correct problems disclosed during the preliminary and formal test phases of the qualification program. These modifications included changes in the shipping crate to afford more adequate support of the rocket, the segmenting of the neoprene sleeve around the forward end of the inhibited grain, and the deletion of the metal oxidant "jelly roll" strip from the primary igniter charge. Detail descriptions of these changes are included in the qualification test report.³ A photograph and cutaway view of an ARCAS rocket motor incorporating all of the current design features are presented in Figure 5.



a. Photograph

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- | | |
|--|---|
| 1. Motor Case, SAE 4130 Steel | 9. Forward-End Protective Closure |
| 2. Separation Device | 10. MK 259 Igniter |
| 3. Retaining Ring | 11. Nozzle Insert, Graphite Per OS10511 |
| 4. O-Ring, AN 8227-45 | 12. Nozzle Closure, Foam |
| 5. Inhibitor, Nylon Scribe Impregnated With Epoxy Polyamide | 13. Nozzle Insulation, Asbestos Phenolic 150RPD |
| 6. Retention Strips, Neoprene Rubber | 14. Case Wall Insulation, Asbestos Phenolic ARP40 |
| 7. Propellant Grain, Arcite 373D-61 | 15. Fin Cast Aluminum Alloy |
| 8. Secondary Ignition Charge, Metal Oxidant Disc Covered With Nylon Scribe | 16. Filler Material, Havel |

Cutaway View

Figure 5. Rocket Motor for ARCAS Systems EX 6 Mod 0 and Mod 1.

FLIGHT PERFORMANCE

SYSTEM RELIABILITY

ARCAS system failure rates are a compound of rocket motor, aerodynamic, payload separation, parachute deployment, telemetry, and sensor failure rates. Thus, the average rocket motor reliability during the program was 96.5 percent, but the over-all system reliability was 66.5 percent. The aerodynamic problems, payload separation device failures, and parachute malfunctions discussed in the DESIGN REFINEMENT section contributed heavily to the degradation of system reliability. Average failure rates plotted for each series of 20 successive flights conducted throughout the duration of the program are presented in the following figures.

1. Figure 6, Rocket Motor Failure Rate
2. Figure 7, Aerodynamic Failure Rate
3. Figure 8, Separation Device Failure Rate
4. Figure 9, Parachute Failure Rate

In computing failure percentages, a rocket motor failure is defined as a catastrophic malfunction of the motor while burning; an aerodynamic failure is defined as the failure of a rocket to reach 80 percent of its predicted altitude, normalized to compensate for differences in payload weight, launch angle, and wind velocities; a separation device failure occurs when the device fails to function within 10 percent of apogee altitude; a parachute failure is defined as a failure to deploy after payload separation or as any occurrence of parachute streaming or cord breakage. Average reliability values for all reported flights are presented below in Table VII.

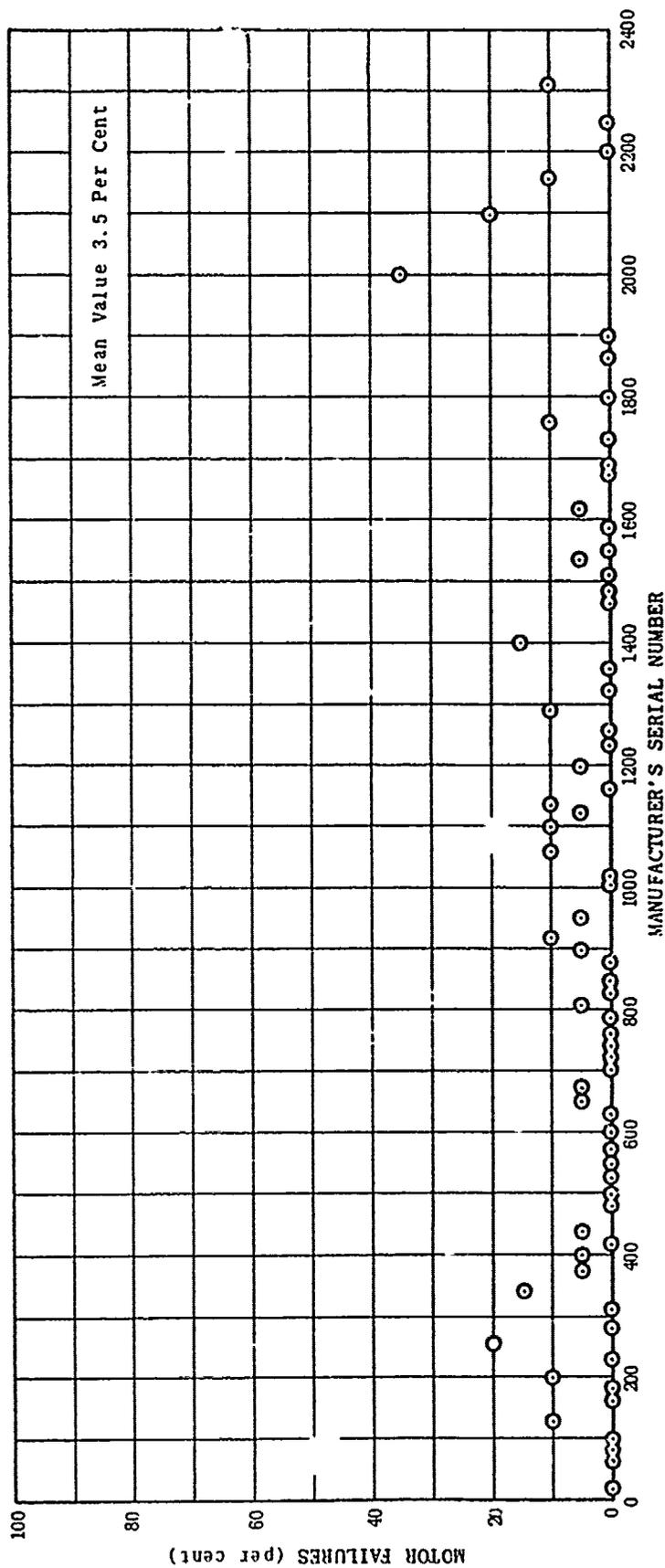


Figure 6. Motor Failures for all ARCAS Flights Reported (each data point represents 20 successive flights).

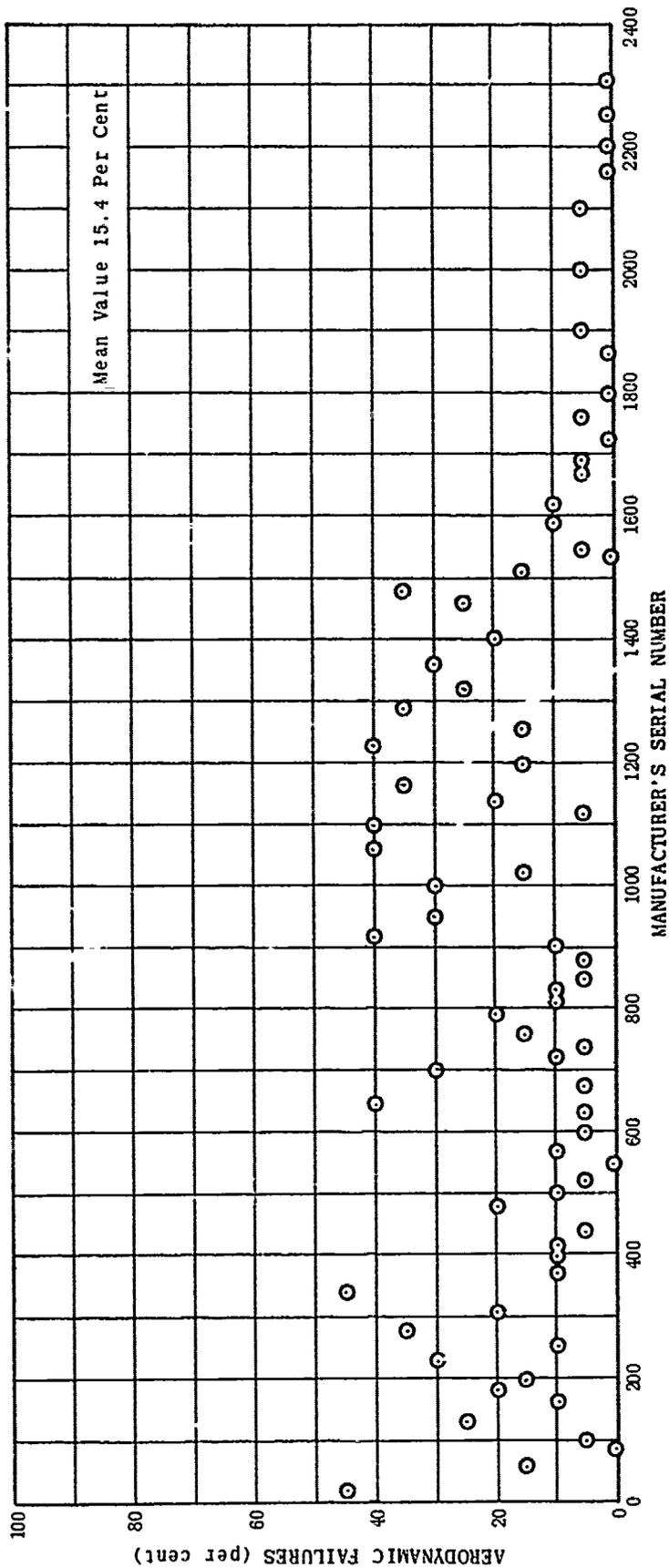


Figure 7. Aerodynamic Failures for all ARCAS Flights Reported (units below 80° performance) (each data point represents 20 successive flights).

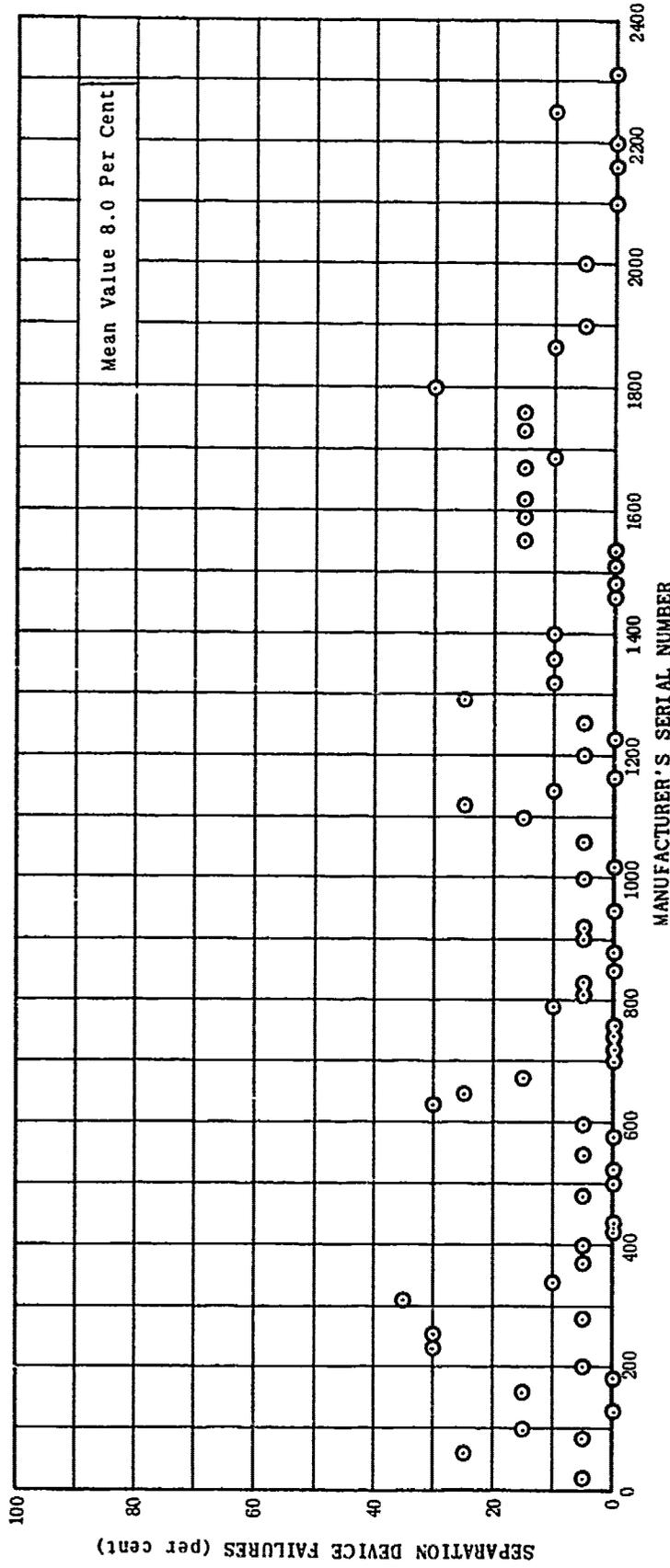


Figure 8. Separation Device Failures for all ARCAS Flights Reported (each data point represents 20 successive flights).

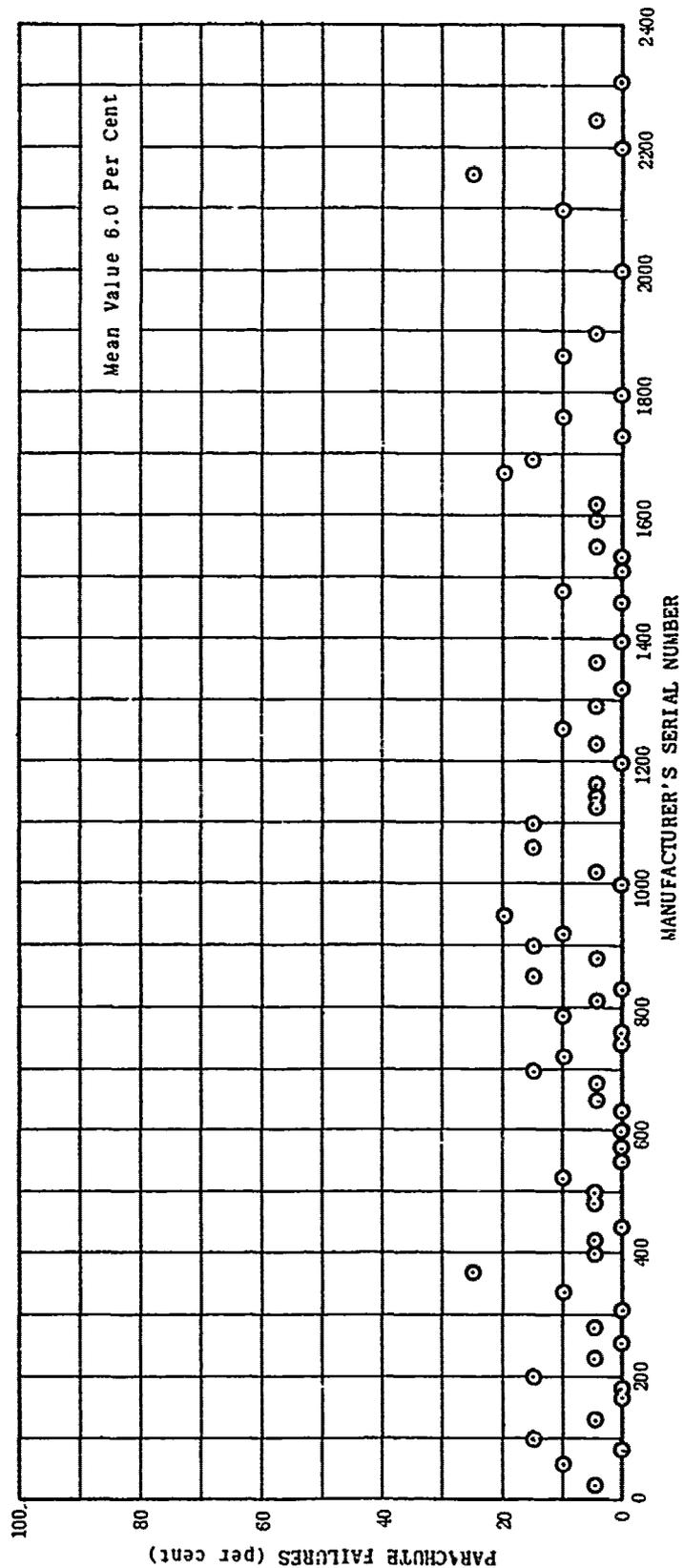


Figure 9. Parachute Failures for all ARCAS Flights Reported (each data point represents 20 successive flights).

TABLE VII
ARCAS RELIABILITY SUMMARY

	<u>Rocket Serial Numbers</u>			
	<u>1-1700</u>	<u>1700-1800</u>	<u>1800-2190</u>	<u>2190-2500</u>
Launch	98%	100%	100%	100%
Rocket Motor	97	97	80	96
Aerodynamic	82	95	97	100
Separation Device	92	95	95	100*
Parachute	94	94	95	98
Over-all System	63	81	67	94

* Does not include failure of two units not having latest design features.

This table shows a marked improvement in reliability in recent flights for all phases of system operation except motor operation. As discussed under DESIGN REFINEMENT, a radical increase in the frequency of rocket motor failures was experienced in late 1962 and early 1963 because of a series of head-end bond failures. This problem has been corrected, and there is no reason to expect that rocket motor reliability will not rise above its normal 97 percent level. The material changes in the fin bonding agent and in the separation device initiator tube and first-fire ignition compound have apparently eliminated the major problem areas degrading aerodynamic and payload separation reliability. Further improvement in parachute reliability will have to await advancement in the state-of-the-art of parachute technology.

INSTRUMENTATION

The procurement of instrumentation packages was not handled under the rocket delivery contract, but was left to the discretion of the using agency. In selecting the instrumentation best suited to a particular application, the user could choose from several payloads available for use with the ARCAS Sounding Rocket. The principal ARCAS payloads are the 1-meter-diameter, radar-reflective, Mylar balloon used in the ARCAS-Robin MOD 1 configuration and the Arcasonde and AN/DMQ-6 (Gamma) radiosonde used in the

MOD 0 configuration. The Arcasonde was developed by Atlantic Research specifically for the ARCAS system; the AN/DMQ-6 was developed by the U.S. Army Signal Research and Development Laboratories and engineered by Atlantic Research. Both are multi-channel telemetry instruments which provide for a variety of meteorological data sensors.

Average failure rates for each of the three principal payloads for each series of 20 successive flights are presented in Figure 10. The over-all ARCAS payload failure rate chart is shown in Figure 11. Mean values for all reported flights are as follows::

	<u>Mean Failure Rate (%)</u>
Robin Balloon	4.6
Arcasonde	8.5
AN/DMQ-6	14.9
Over-all ARCAS payload	10.1

In computing failure rates, an instrumentation failure is defined as the failure of a payload to measure any atmospheric parameter for which it has been instrumented.

ALTITUDE PERFORMANCE

Computed ARCAS flight trajectory data are presented in Figure 12, a plot of apogee altitude versus ground range at apogee, and in Figure 13, a plot of impact range versus launch angle. Actual flight data have agreed closely with predicted performance, as illustrated in Figure 12 by the actual apogee points from several typical flights.

Flight data from all reporting ranges were normalized to sea-level launch conditions for a 10-pound payload at an 83-degree launch angle. All flights not attaining a normalized altitude of 176,000 feet (i.e., 80 percent of the predicted altitude of 220,000 feet) were considered aerodynamic failures. (See Figure 7.) The average and range of normalized altitudes, expressed as a percentage of predicted altitude, is presented in Figure 14.

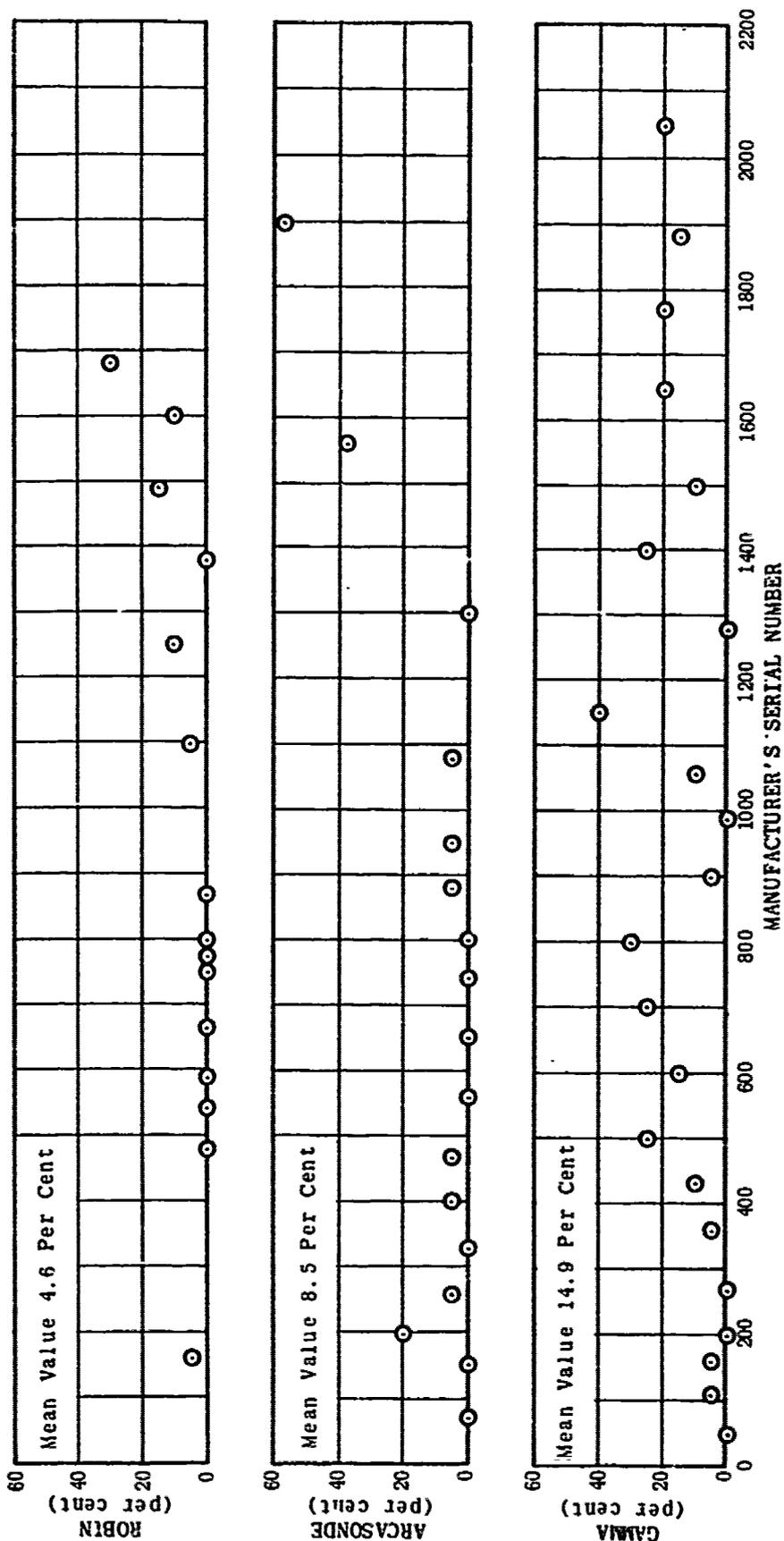


Figure 10. Instrument Failures for all ARCAS Flights Reported.

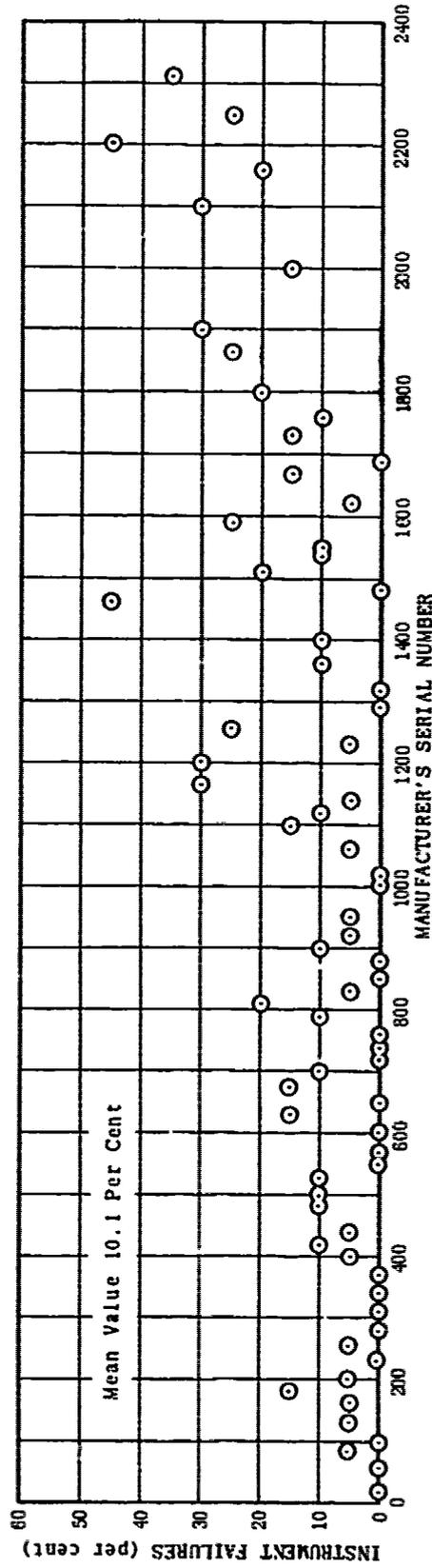


Figure 11. Instrument Failures for all ARCAS Flights Reported (each data point represents 20 successive flights).

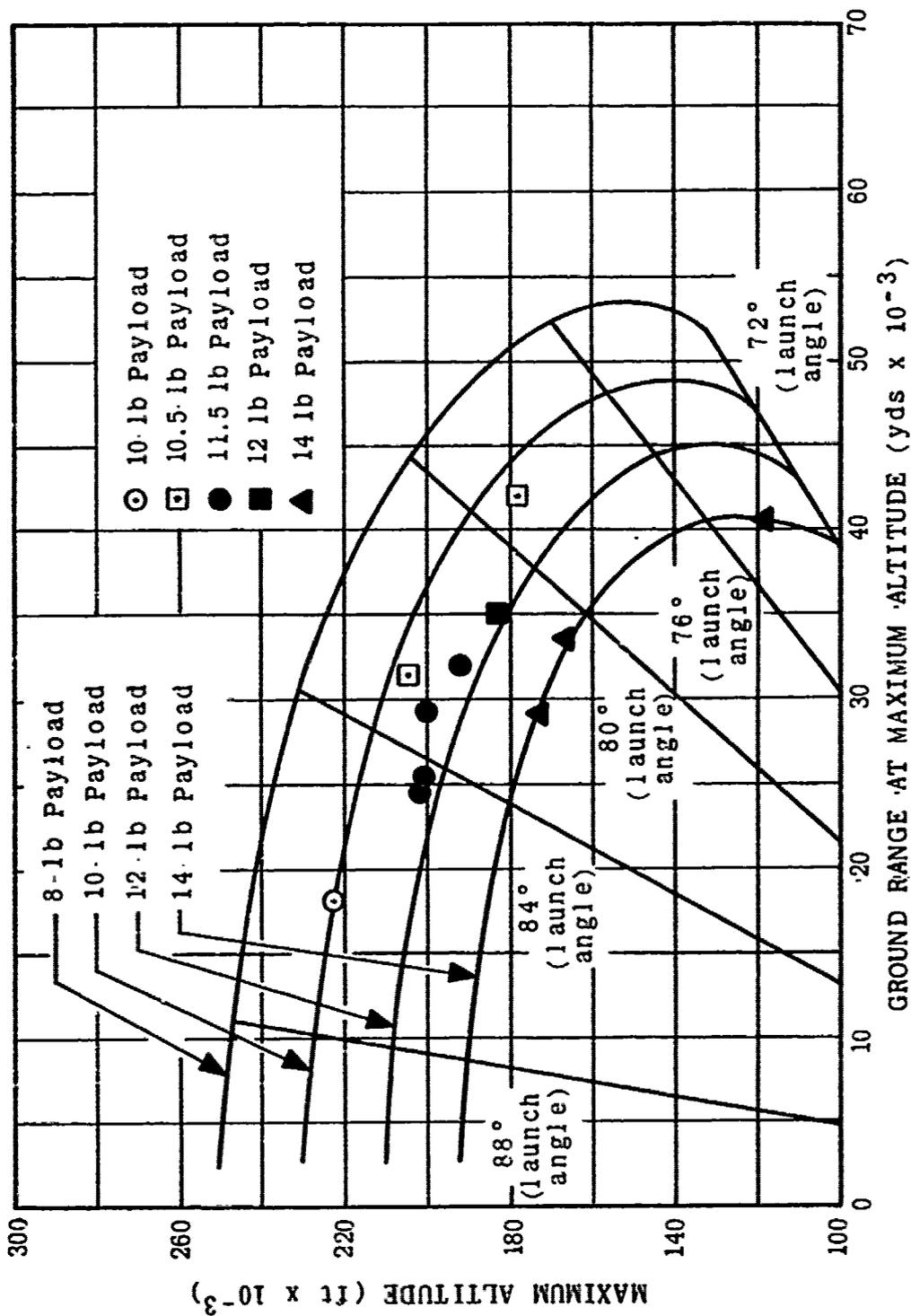


Figure 12. ARCAS Maximum Altitude Versus Ground Range at Apogee.

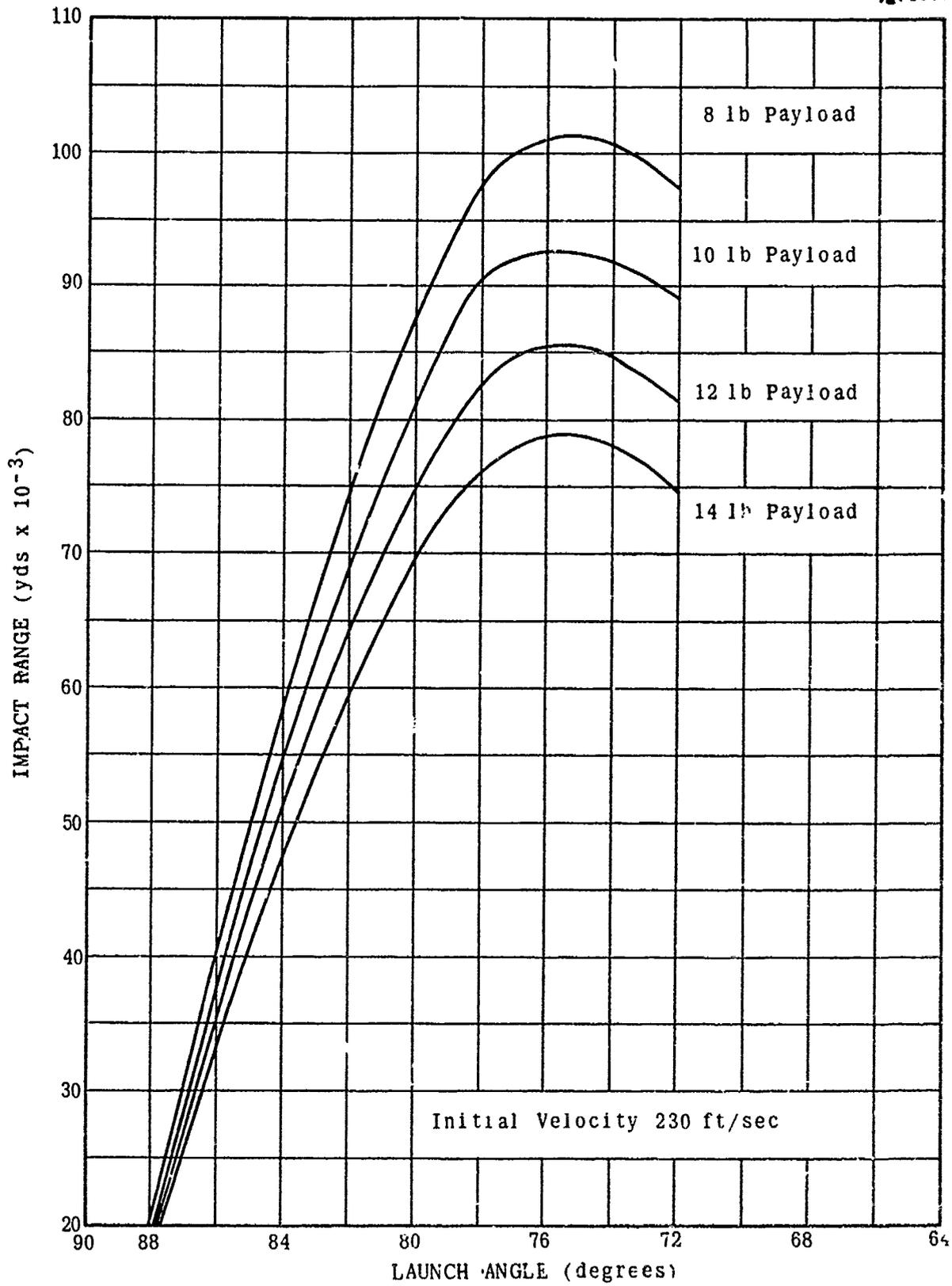


Figure 13. Impact Range Versus Launch Angle.

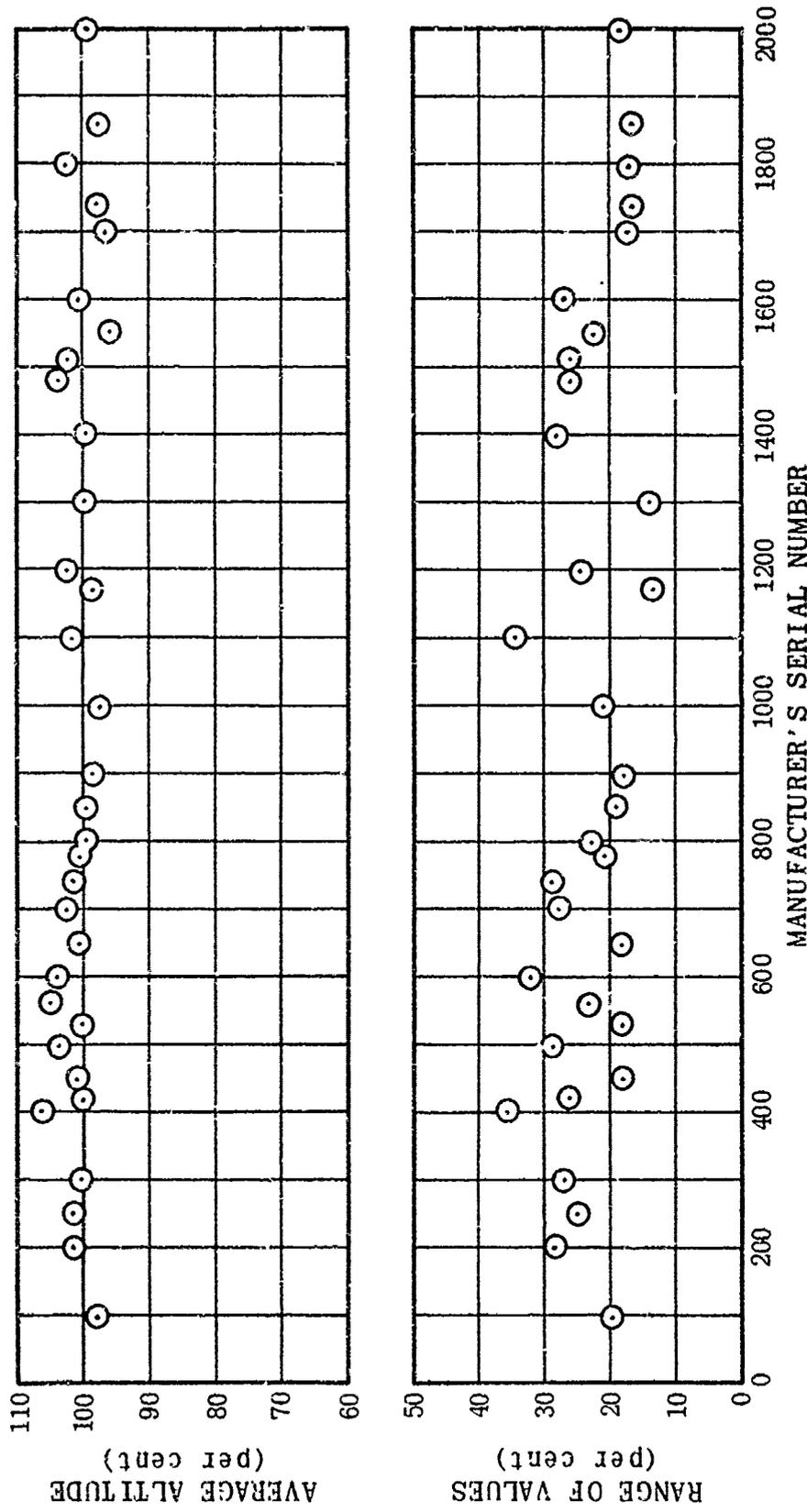


Figure 14. Average Altitude and Range of Values for all ARCAS Flights Reported (each data point represents 20 successive flights).

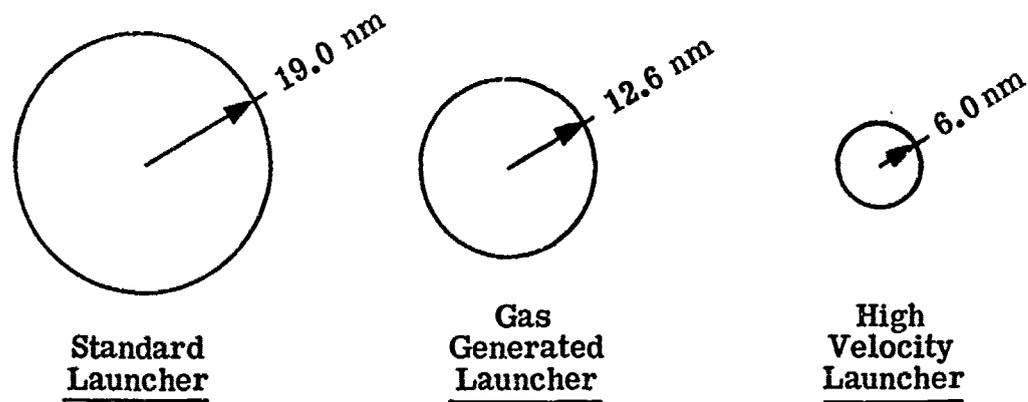
As a result of the significant advancement in ARCAS reliability in recent flights, nose cone ballast can be reduced and missile ranges will be able to increase launch angles to 85 degrees. Hence, through these measures and the use of the smaller instrumentation packages now available, appreciable gains in altitude can be achieved. In addition, a series of boosted ARCAS systems are being developed in which the altitude capability of the basic ARCAS rocket will be enhanced by the use of fast-burning, solid-propellant booster motors. The Sidewinder-ARCAS and the Sparrow-ARCAS represent two such systems.

A third boosted ARCAS system is the Model EX 6 MOD 2 developed under Contract NONr-3369 with the Office of Naval Research.⁴ The booster motor in this system delivers an average thrust of 2,200 pounds over a period of one second and is capable of carrying a standard MOD 0 ARCAS with a 12-pound payload to altitudes in excess of 250,000 feet from a sea level launch. As shown in Table III, five EX 6 MOD 2 systems were delivered under the subject contract.

DISPERSION AND WIND SENSITIVITY

The impact dispersion and wind sensitivity of the ARCAS have been significantly reduced by the increased launch velocities obtained with the gas generator attachment to the ARCAS launcher. With the standard closed-breech launcher, the impact dispersion was nearly circular with a two-sigma radius of 19.0 nautical miles. With the gas-generated launcher, the two-sigma radius was reduced to 12.6 nautical miles, and the wind sensitivity was reduced by approximately 37 percent. A long-tube, high-velocity launcher has recently been designed to reduce sensitivity and dispersion to approximately one-third of that obtained with the standard launcher. This launcher would also permit the ARCAS to be launched into 50-knot ground winds.

ARCAS dispersion circles and launching data for the three types of launchers discussed above are presented in Figure 15. These dispersion values are based solely on empirical impact data which include the short impact ranges obtained in flights affected by aerodynamic problems. Recent flights of rockets with canted or offset fins indicate that significantly smaller impact dispersion radii can be expected in the future.



ARCAS LAUNCHING DATA

Launcher	Velocity	Unit Wind Effect	Dispersion Radius (2σ)
Standard	160 ft/sec	2.46 m/m-hr	19.0 nm
Gas Generator	230 ft/sec	1.54 m/m-hr	12.6 nm
High Velocity	500 ft/sec	0.95 m/m-hr	6.0 nm

Figure 15. ARCAS Dispersion Circles.

TECHNICAL MANUALS

Four technical manuals describing the parts, operation, and maintenance of the ARCAS rocket and launcher were prepared in fulfillment of contractual requirements. The subject and date of issue of each of these manuals are tabulated below.

Rocket Assembly, Service and Maintenance	January 25, 1962
Launcher Operation, Service, and Repair	March 15, 1962
Parts Breakdown - Rocket	January 25, 1962
Parts Breakdown - Launcher	February 15, 1962

CONCLUSIONS

At the inception of the delivery program in June 1959, the development program for the ARCAS rocketsonde system was still underway and a test program to qualify the rocket for limited field use was nearly completed. In the succeeding four years, the ARCAS Sounding Rocket has become a routine vehicle for the measurement of atmospheric wind, temperature, and air density data at ranges throughout North America and elsewhere. A total of approximately 2,500 rockets, including the 1,413 units fabricated under the subject contract, have been delivered during this period. Currently active production contracts include NOW 62-0713c for 626 units (Bureau of Naval Weapons, June 1962), NOW 64-0043 for 550 units (Bureau of Naval Weapons, July 1963), and a contract with the German government to deliver and fly 1,400 ARCAS rockets at Sardinia in the Mediterranean.

In June 1962, work was initiated on a program leading to the formal qualification and documentation of ARCAS Systems EX 6 MOD 0 and MOD 1. This program was completed in early 1963, and the Bureau of Naval Weapons has accepted the ARCAS rocketsondes as fully qualified systems. The production drawings and specifications are currently undergoing final revision.

Under the subject contract, a continual effort was made to improve ARCAS reliability and performance through design modifications and process refinements. Every effort was extended in implementing the required design changes and corrective measures as rapidly and efficiently as possible, and in maintaining a delivery rate reasonably commensurate with contractual requirements. To these ends, more than a \$100,000 in company funds were used in support of the program.

The over-all system reliability of 94 percent for the last 120 reported flights indicate that significant advancements had been achieved in reducing component failure rates. Of the failures experienced in these 120 flights, 8 percent were attributable to rocket motor malfunctions and 2 percent to parachute failures. Recent procedural improvements in effecting the bond between the propellant grain and the head plate should eliminate the primary cause of motor failures. The parachute failure rate is considered to be within the state-of-the-art of parachute technology.

Hence, the status of the ARCAS rocket has advanced to that of a fully qualified and documented production unit with an extensive history of successful flights and a demonstrated capability of performing at a high level of reliability. The design refinements effected under the subject contract and described in this report were critical in the achievement of this status.

REFERENCES

1. Atlantic Research Corporation, Final Report, Development of the ARCAS Rocketsonde System, Contract NOnr-2477(00), Alexandria, Virginia, February 29, 1960
2. Atlantic Research Corporation, Qualification Test Report (Limited Release) for the 4.5 EX2 MOD 0 Rocket Motor (Type C ARCAS), Contract NOnr-2477(00), Alexandria, Virginia, August 27, 1959
3. Atlantic Research Corporation, Qualification of ARCAS Sounding Rocket Systems EX 6 MOD 0 and MOD 1, Contract NOw 62-1106-c, Alexandria, Virginia, August 20, 1963
4. Atlantic Research Corporation, Development of the Boosted ARCAS Sounding Rocket System (U), Contract NOnr-3369, Alexandria, Virginia, April 10, 1963.

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APPENDIXES

APPENDIX A

QUALIFICATION TEST REPORT FOR A TWO-PIECE
ASBESTOS PHENOLIC INSULATION FOR THE
ROCKETSONDE PROPULSION UNIT
TYPE C ARCAS

(Report initially issued to the Office of Naval Research
and the Bureau of Naval Weapons on March 24, 1961)

1. BACKGROUND

During the year 1960, four flights of the Arcas rocketsonde propulsion unit failed as a result of inferior insulation in the nozzle area. These flights are listed below:

<u>Motor No.</u>	<u>Date Fired</u>	<u>Sponsoring Agency</u>	<u>Firing Site</u>	<u>Time to Failure</u>
25322.4XZ	20 April 1960	Patterson-Moos	USAS American Mariner	24 sec
337A210.4GA	19 July 1960	NASA	Wallops Island	17 sec
359N62.4MU	10 August 1960	ONR	Pacific Missile Range	21 sec
402A250AA	16 Sept. 1960	Army	White Sands Missile Range	23 sec

The nozzle insulation in these units was fabricated as an integral part of the case insulation sleeve. The sleeve was wrapped on a mandrel and was composed of Raybestos-Manhattan 41 RPD, an asbestos-filled phenolic tape. An investigation disclosed that in many of the sleeves the density of the insulation was considerably lower in the nozzle area than in the cylindrical section - about 1.250 g/cc as compared with 1.500 g/cc minimum. To ensure sufficient nozzle protection, it was decided to compression-mold the nozzle insulation as a separate part to be bonded onto the case sleeve. Fabrication of the nozzle sections out of Raybestos-Manhattan 150 RPD asbestos phenolic was initiated late in August 1960. The density of these sections was established as 1.800 g/cc minimum.

This report describes the test program conducted by Atlantic Research to qualify an Arcas unit incorporating the two-piece insulation. The Arcas was previously qualified for limited use with the one-piece insulation; reference is made to the "Qualification Test Report for 4.5 EX2 Mod 0 Rocket Motor (Type C Arcas)", dated 27 August 1959, for further information.

2. TEST PROCEDURES

2.1 General

Six Arcas propulsion units were subjected to static firing tests in the qualification program. All conditioning and firings were conducted at the Atlantic Research Pine Ridge facility.

All units were fabricated in accordance with the "Model Specification for the 4.5 EX 2 Mod 0 Rocket Motor (Type C Arcas)", dated 25 August 1959. Insulations consisted of a case sleeve (Part No. AR3-22600-C) and a nozzle section (Part No. AR3-22599-A) bonded together with a Shell Epon VIII adhesive (Assembly Part No. AR4-21122-1). Drawings of the sleeve, nozzle insulation, and insulation assembly are presented in Figures A-1, A-2, and A-3, respectively.

2.2 Static Firing Tests

2.2.1 General

Six units were conditioned as shown below and fired statically.

<u>Motor Serial No.</u>	<u>Conditioning</u>	<u>Firing Temp.</u>
ARX-11	None	70°F
ARX-12	Rough Road Handling	70°F
ARX-15	Temperature Cycling	110°F
ARX-16	Temperature Cycling	-10°F
ARX-17	None	-10°F
ARX-18	None	110°F

2.2.2 Conditioning Procedures

2.2.2.1 Rough Road Handling

The unit in its shipping crate was secured in a truck and driven over rough roads for eight hours.

2.2.2.2 Temperature Cycling

One unit was successively conditioned at -10°F, 110°F, and -10°F, 110°F, -10°F, and 110°F; a second unit was conditioned at 110°F, -10°F, 110°F, -10°F, 110°F, and -10°F. The units were held at each temperature in the sequence for a period of eight hours.

2.2.2.3 Firing Temperature

Each unit was conditioned at its respective firing temperature for a minimum period of eight hours. Each unit was fired within fifteen minutes of removal from the conditioning chamber.

3. TEST RESULTS

3.1 Recorded Data

The ballistic data from all the static firings of this program were in compliance with the Arcas Model Specification, dated 25 August 1959. Skin temperatures were recorded at twelve locations on the aft end of each unit. The maximum temperature attained during burning was approximately 400°F in test ARX-18 at 110°F. Temperature-time characteristics are shown in Figure A-4.

3.2 Photographs

Photographs were taken of the expended motors from firing tests ARX-11, ARX-12, ARX-15, and ARX-16. Nozzle end hardware from each unit are shown in Figures A-5 through A-8, respectively; full-length cross sections of all four motors are shown in Figure A-9.

3.3 Conclusions

The ballistic and thermocouple data from the static firings indicate that the two-piece asbestos phenolic insulation system affords sufficient protection for the nozzle end of the Arcas motor case. A comparison of a nozzle from an expended motor containing the one-piece insulation, as shown in Figure A-10, with one from a motor with the two-piece insulation, as shown in Figures A-5 through A-8, clearly demonstrates the significant improvement achieved.

4. RECOMMENDATIONS

It is recommended that the two-piece asbestos phenolic insulation sleeve assembly shown in Figure A-3 be approved for incorporation into the qualified Arcas rocketsonde propulsion unit.

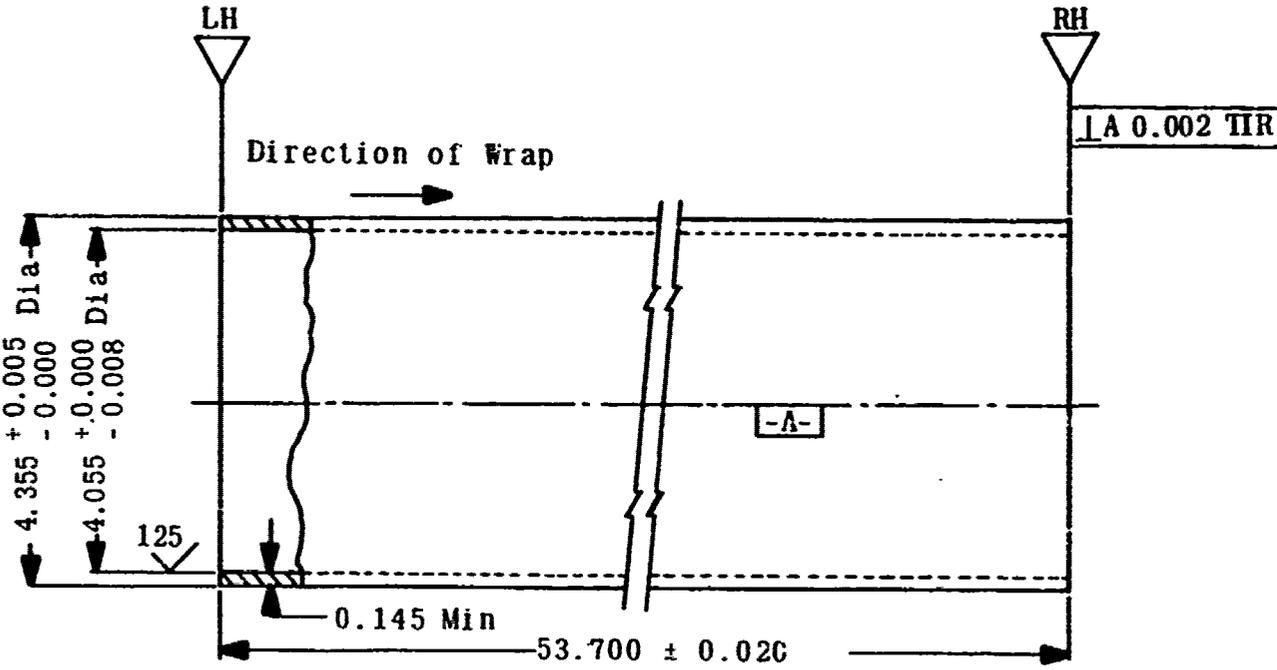


Figure A-1. Insulation Sleeve.

31026

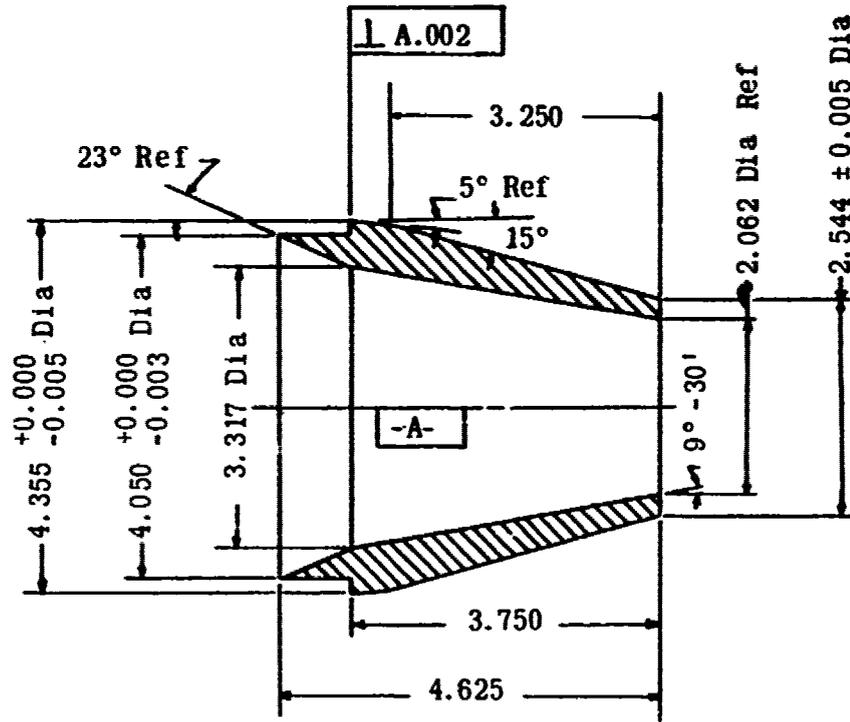


Figure A-2. Nozzle Insulation Insert.

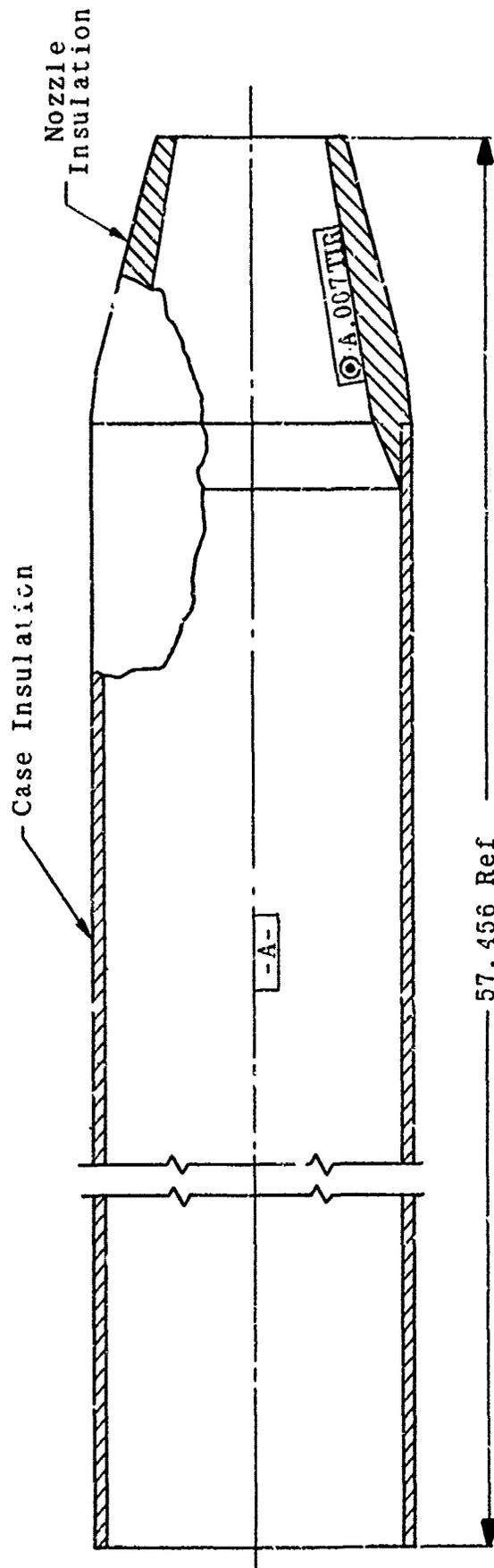


Figure A-3. Insulation Sleeve Assembly.

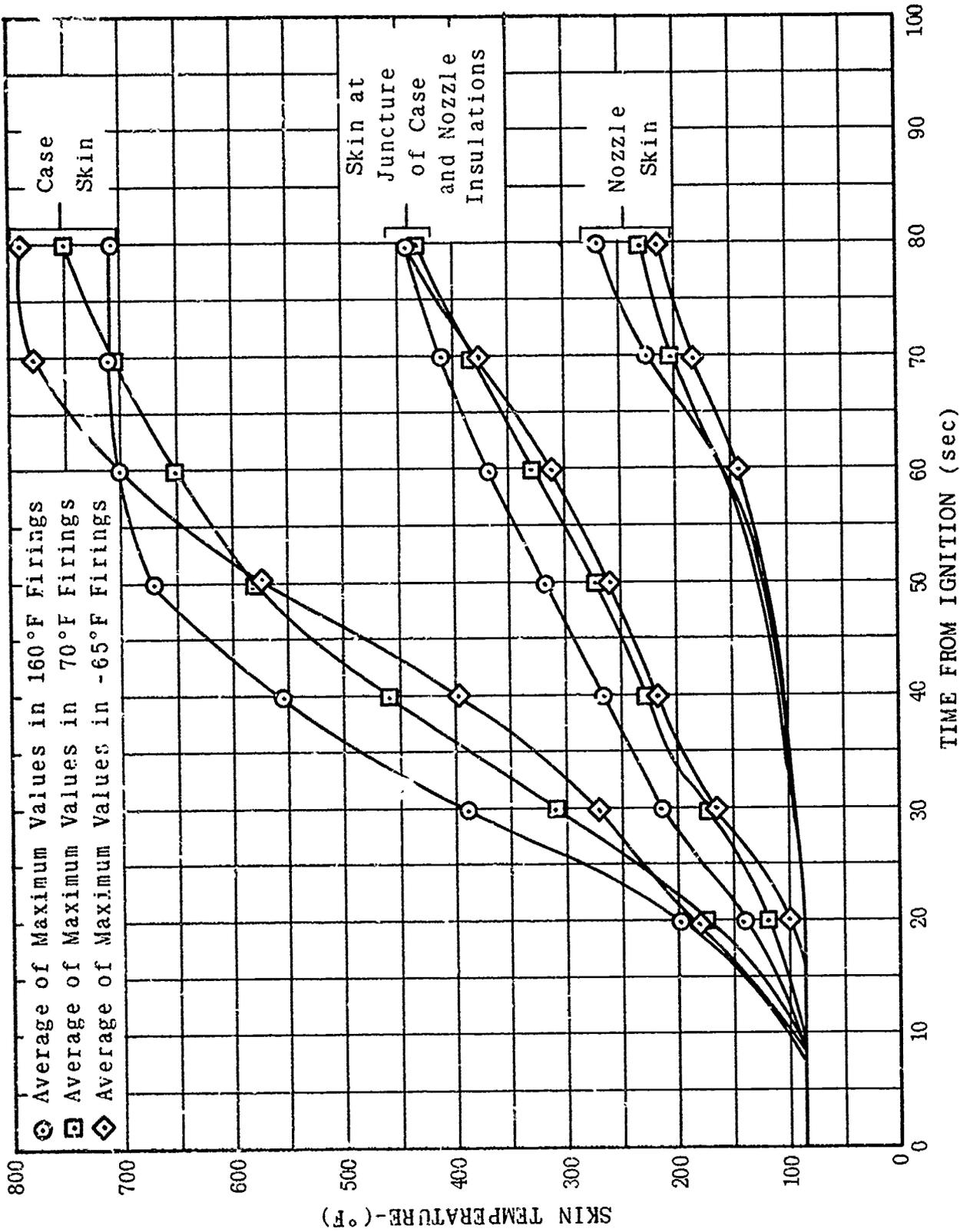
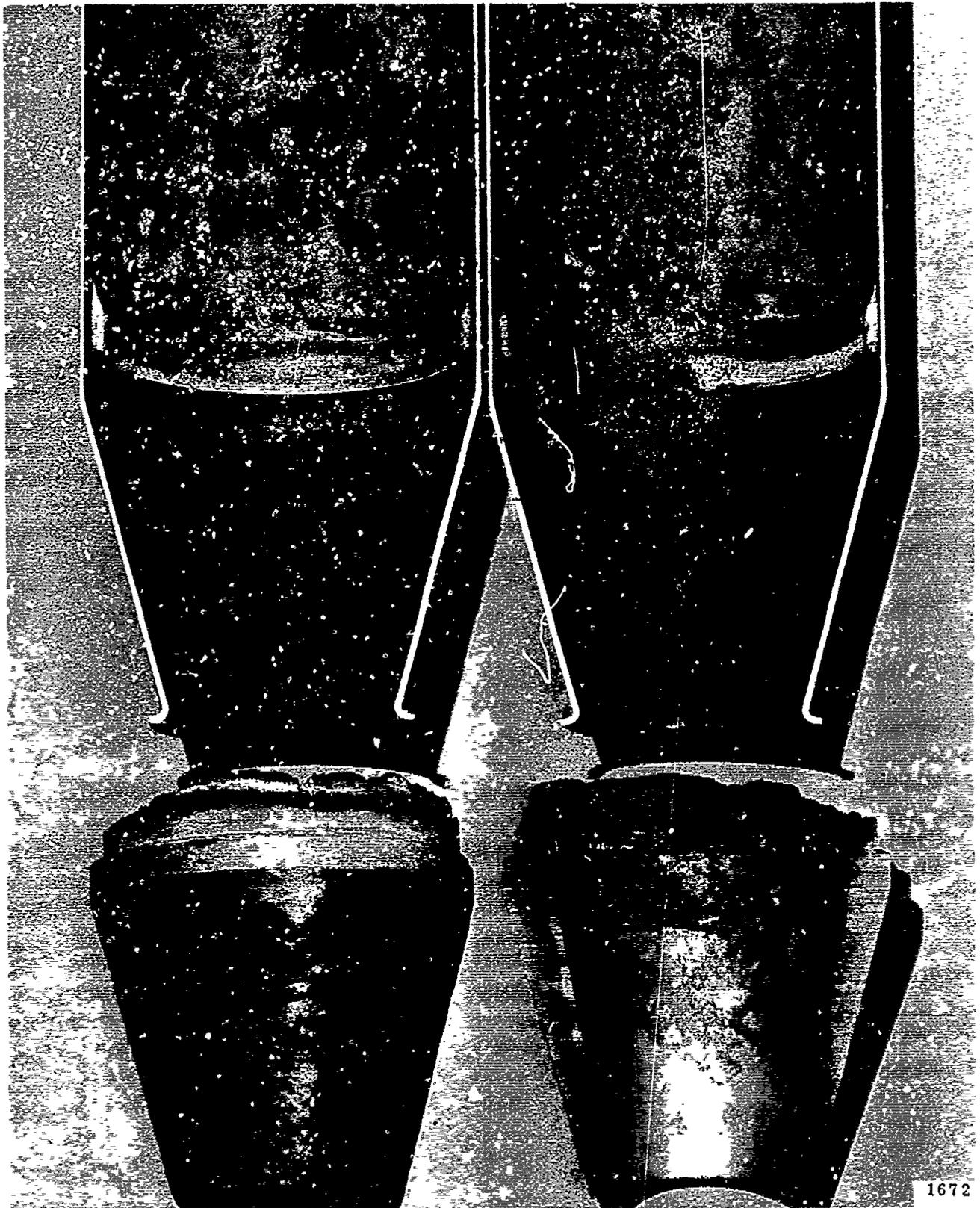


Figure A-4. ARCAS Skin Temperature Characteristics Two-Piece Insulation Qualification Program.



Figure A-5. Nozzle End of Motor ARX-11 After Firing
at 70°F with Two-Piece Insulation Sleeve.



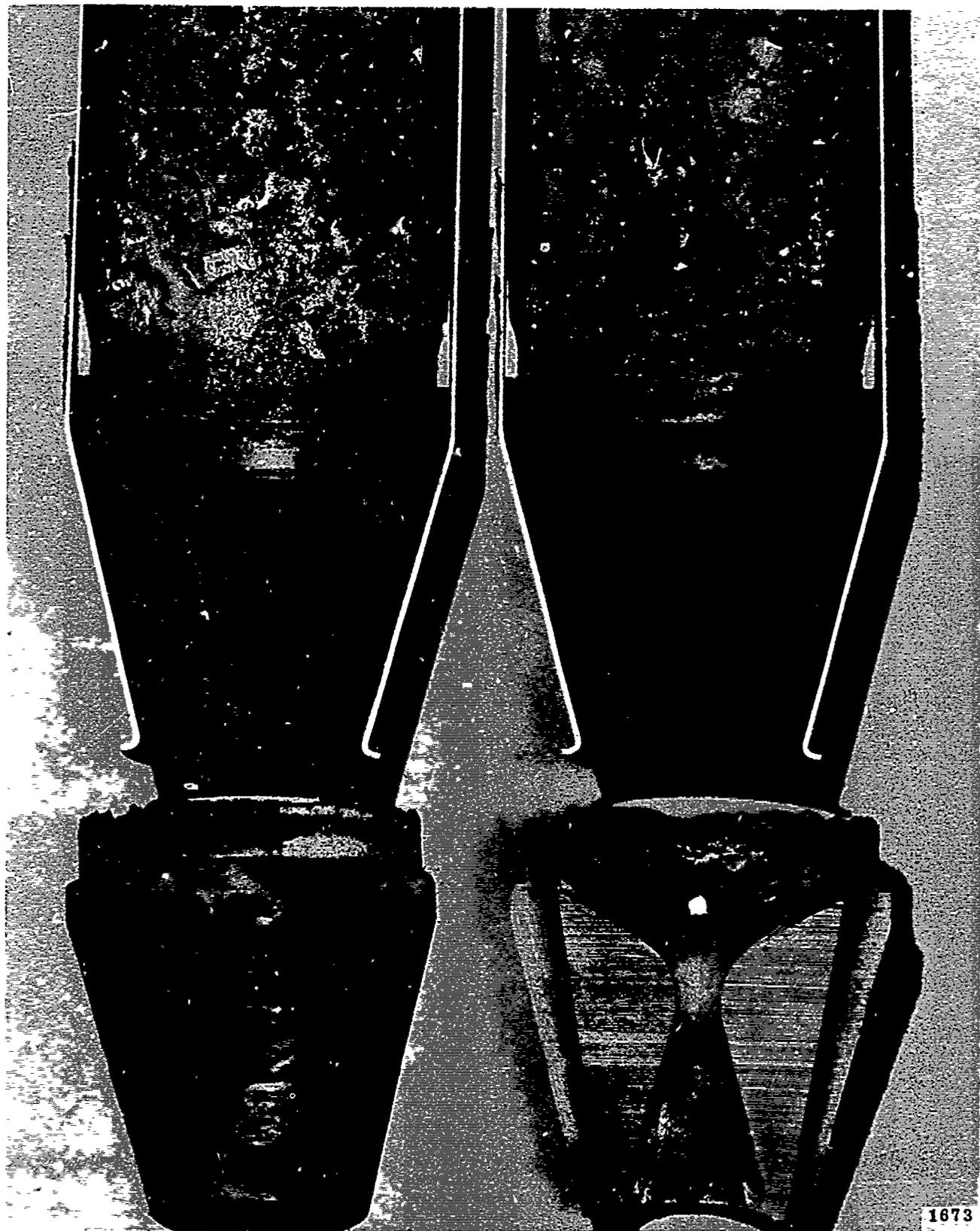
30986

Figure A-6. Nozzle End of Motor ARX-12 After Firing at 70°F with Two-Piece Insulation Sleeve.



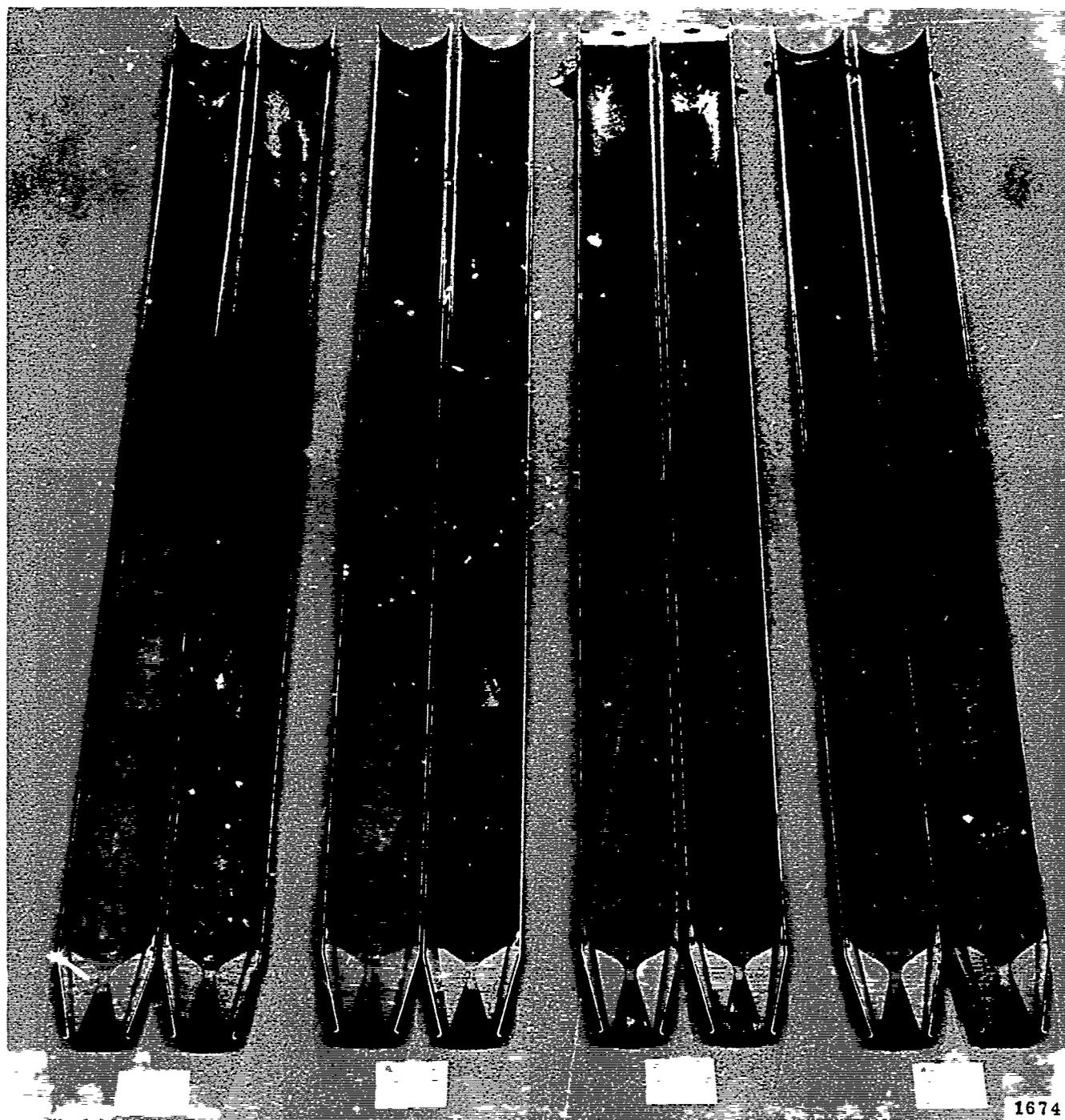
30992

Figure A-7. Nozzle End of Motor ARX-15 After Firing at 110°F with Two-Piece Insulation Sleeve.



3099: 1673

Figure A-8. Nozzle End of Motor ARX-16 After Firing at -10°F with Two-Piece Insulation Sleeve.



1674

AR 30990

Figure A-9. Sectioned Motor Cases from Two-Piece Insulation Test Firings.



1569

ARC 30987

Figure A-10. Nozzle End of Motor After Firing with One-Piece Insulation Sleeve.

APPENDIX B

QUALIFICATION TEST REPORT FOR A NYLON-EPOXY
INHIBITOR IN THE ROCKETSONDE PROPULSION
UNIT TYPE C ARCAS

(Report initially issued to the Office of Naval Research
and the Bureau of Naval Weapons on March 2, 1961)

SUMMARY

This report describes the test program conducted to qualify an Arcas Rocketsonde propulsion unit incorporating an improved, nylon-epoxy inhibitor. Twenty-six Arcas units containing this inhibitor were fired under various conditions: five were fired statically, thirteen were fired in launch tests, and eight were flight-tested. All firings except an early flight test were satisfactory. Later flight tests indicated that the source of discrepancy in the single failure had been eliminated. It was concluded that the nylon-epoxy inhibiting system is at least equivalent to the previously qualified polyurethane PUX-500 inhibitor in ballistic performance, while showing marked advantages in cost, storage life, and Arcas acceleration capability.

1. SCOPE

Under contract to the Office of Naval Research of the Department of the Navy, Atlantic Research Corporation has developed an improved, nylon-epoxy inhibitor for its Arcas rocketsonde propulsion unit. This report describes the test program conducted by Atlantic Research to qualify an Arcas unit incorporating such an inhibitor. The Arcas was previously qualified for limited use with a polyurethane, PUX-500 inhibitor; reference is made to the "Qualification Test Report for 4.5 EX2 Mod 0 Rocket Motor (Type C Arcas)", dated 27 August 1959, for further information.

2. TEST PROCEDURES

2.1 General

The qualification program consisted of five static firings, thirteen launcher firings, and eight flight tests. All conditioning and firings except the flight tests were conducted at the Atlantic Research Pine Ridge facility. The eight flight tests were conducted at the White Sands Missile Range, White Sands, New Mexico.

All Arcas units employed in this program were fabricated in accordance with the "Model Specification for the 4.5 EX2 Mod 0 Rocket Motor (Type C Arcas)", dated 25 August 1959. Propellant grains were inhibited with a 6-ply laminate of nylon and epoxy-polyamid resin wrapped with a 0.062-inch neoprene sleeve over the first four inches of the head end. This grain assembly is shown in Figure B-1.

2.2 Static Firing Tests

2.2.1 General

Five units were conditioned as shown below and static-fired.

TABLE I

<u>Motor Serial No.</u>	<u>Conditioning</u>	<u>Firing Temperature</u>
ANX-1	Rough Road Handling	70°F
ANX-2	Temperature Cycling	-10°F
ANX-3	Temperature Cycling	110°F
ANX-8	None	70°F
ANX-9	None	70°F

2.2.2 Conditioning Procedures

2.2.2.1 Rough Road Handling

The unit in its shipping crate was secured in a truck and driven over rough roads for eight hours.

2.2.2.2 Temperature Cycling

Two units were successively conditioned at -10°F, 110°F, -10°F, 110°F, -10°F and 110°F. The units were held at each temperature in this sequence for a period of eight hours.

2.2.2.3 Firing Temperature

Each unit was conditioned to its respective firing temperature for a minimum period of eight hours. Each unit was fired within fifteen minutes of removal from the conditioning chamber.

2.3 Launcher Firings

Thirteen units were fired from a standard Arcas launcher to demonstrate the ability of the nylon inhibitor to support the grain against acceleration loads encountered during launch. These units incorporated a short propellant charge bonded to a full-length, inert grain, similar in physical properties to the standard Arcas grain. Test conditions and accelerations are shown in Table II.

TABLE II

<u>Motor No.</u>	<u>Firing Temperature, °F</u>	<u>Launch Acceleration, g's</u>
L-1	110	32
L-2	30	32
L-3	70	32
L-4	70	95
L-5	70	105
L-6	70	32
L-7	70	32
L-8	70	32
L-9	70	32
L-10	-10	32
L-11	70	32
L-12	70	55
L-13	70	32

The high accelerations of 95 and 105 g's were obtained through the use of a gas generator to augment the pressure created inside the launcher by the rocket. In motors L-12 and L-13, the grain was partially case-bonded through an epoxy-polyamid resin joining the neoprene sleeve to the case insulation. This bond was shown to be necessary in the flight tests described below.

2.4 Flight Tests

Eight units were flight tested at the White Sands Missile Range as shown in Table III.

TABLE III

<u>Test No.</u>	<u>Motor Serial No.</u>	<u>Date Fired</u>	<u>Total Rocket Weight (lbs)</u>	<u>Peak Altitude (feet)</u>	<u>Motor Impact Range (miles)</u>
1	459A275.AA	18 Oct '60	-	253,000	-
2	460A276.4AA	19 Oct '60	75.4	125,000	6.5
3	461A277.4AA	20 Oct '60	78.2	205,000	15.5
4	666A361.4AA	19 Jan '61	74.6	248,000	20.5
5	667A362.4AA	20 Jan '61	75.8	289,000	18.0
6	668A363.4AA	18 Jan '61	74.5	297,000	24.0
7	689A374.4AA	10 Feb '61	74.5	225,000	-
8	690A375.4AA	2 Feb '61	74.5	287,000	29.0

Grains from Tests Numbers 4 through 8 were partially case-bonded with an epoxy-polyamid resin joining the neoprene sleeve to the case insulation. The resin utilized for this purpose was the same as that employed in the nylon-epoxy inhibitor. The low peak altitude attained in Test Number 2 indicated that this bond might be necessary. Without a means of retention, the neoprene sleeve becomes subject to in-flight displacement as the propellant grain approaches burnout and the neoprene-to-nylon and neoprene-to-head closure bonds are weakened. It is expected that acceleration forces in Test Number 2 pulled the sleeve into the nozzle; the result would be a thrust misalignment and a lowering of altitude. The high peaks attained in Tests 4 through 8 appear to corroborate this theory. However, there is

some indication that the unit employed in Test Number 2 was improperly instrumented and that the center of gravity was too far aft. In this event, the low peak altitude could be attributed to the resulting aerodynamic instability.

3. TEST RESULTS

3.1 Recorded Data

The thrust-time curves and related data for the five static firing tests are presented in Figures B-2 through B-6. Since it is impossible to obtain pressure data in flight-type Arcas units, a curve showing the relationship of pressure to thrust is presented in Figure B-7. This curve was plotted from data obtained in the original Arcas qualification program. Data from the launcher firings are presented as pressure and acceleration versus time curves in Figure B-8. One curve is shown for each of the four different acceleration levels.

3.2 Photographs

Photographs of the expended motors from static firings ANX-8 and ANX-9 are presented as Figures B-9 and B-10, respectively. Each photograph shows the nozzle end of the sectioned motor case, the forward head closure, and the remaining neoprene sleeve.

3.3 Conclusions

The results of all static and launcher firings were satisfactory. The seven flight test units which achieved peak altitudes greater than 200,000 feet were accepted as satisfactory. As discussed in Paragraph 2.4 above, the problem source in the single flight test failure is considered to have been eliminated. Hence, this qualification program has demonstrated that the nylon-epoxy inhibitor shown in Figure B-1 is at least equivalent to the previously qualified polyurethane, PUX-500 inhibitor. However, the following points should be noted as indicating that the new inhibiting system is actually superior to the old: (1) the 95 and 105 g launch accelerations demonstrate that the nylon-epoxy affords increased strength for the propellant grain assembly, (2) similar grains employing the nylon-epoxy have been successfully fired at temperature extremes of

-65°F and 160°F, (3) aging studies at Atlantic Research show the nylon-epoxy to retain its physical characteristics after nine months of storage at 160°F and -65°F. It is, therefore, expected that the present qualification limits of the Arcas unit can be extended through the incorporation of the nylon-epoxy inhibitor.

4. RECOMMENDATIONS

It is recommended that the nylon-epoxy inhibiting system shown in Figure B-1 be approved as an optional substitute for the PUX-500 inhibitor. It is further recommended that the bonding of the neoprene sleeve to the case insulation be adapted as part of the assembly procedure for units incorporating the nylon-epoxy inhibitor.

Nylon Epoxy Reinforced Inhibitor Comprised of 6 Ply of Burlington Mills, Style 9588, Nylon Fabric, Laminated with an Adhesive consisting of 3 Parts Gen Epoxy - 190 - 3, 2 Parts Versamid 140.

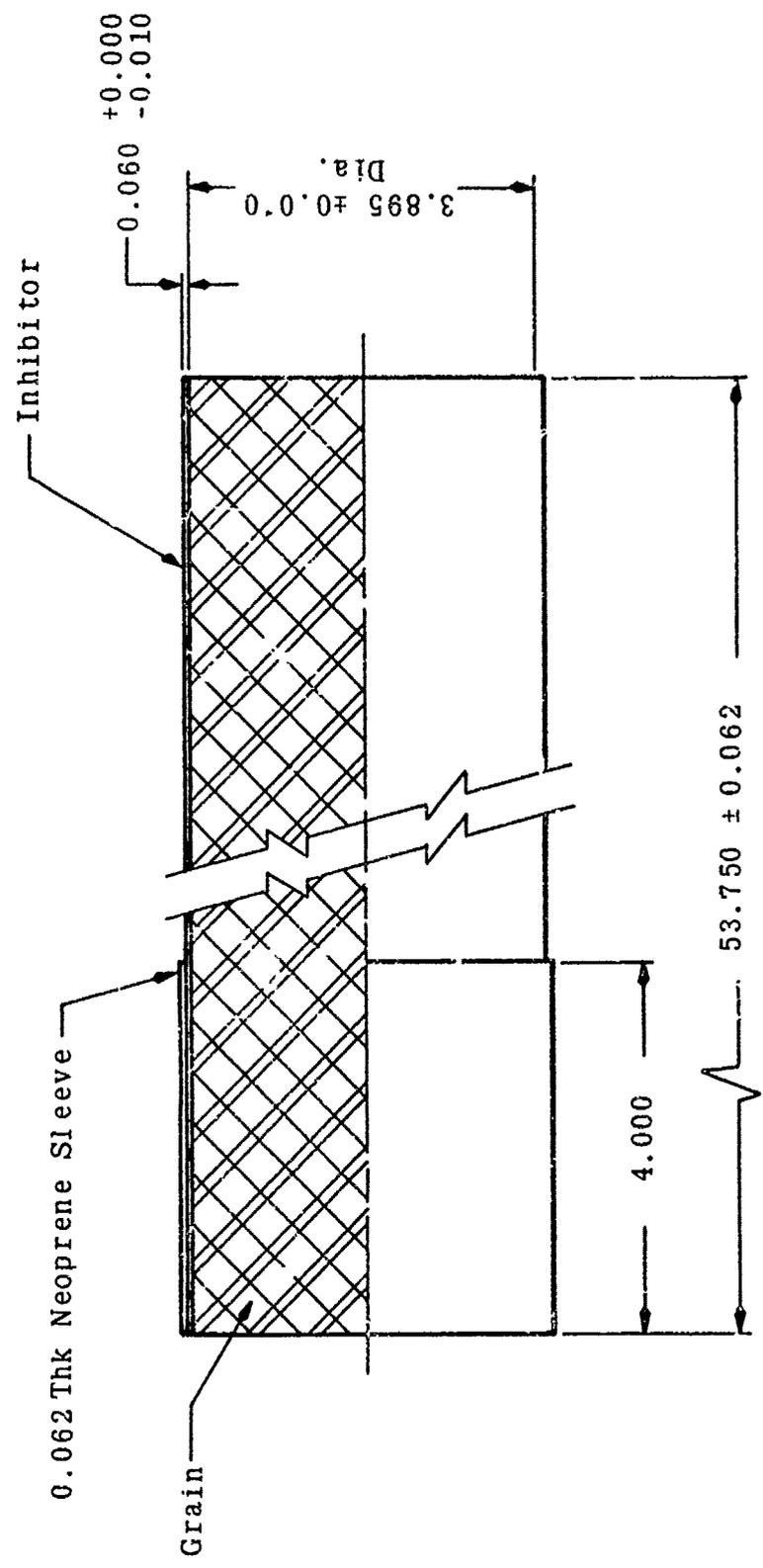
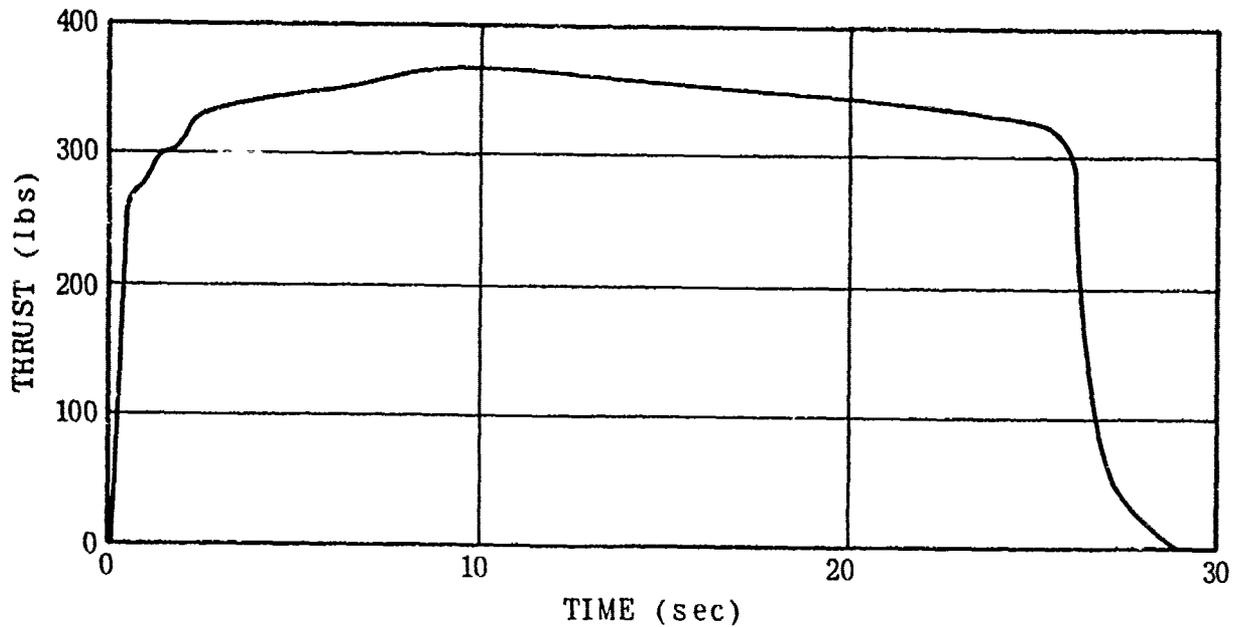
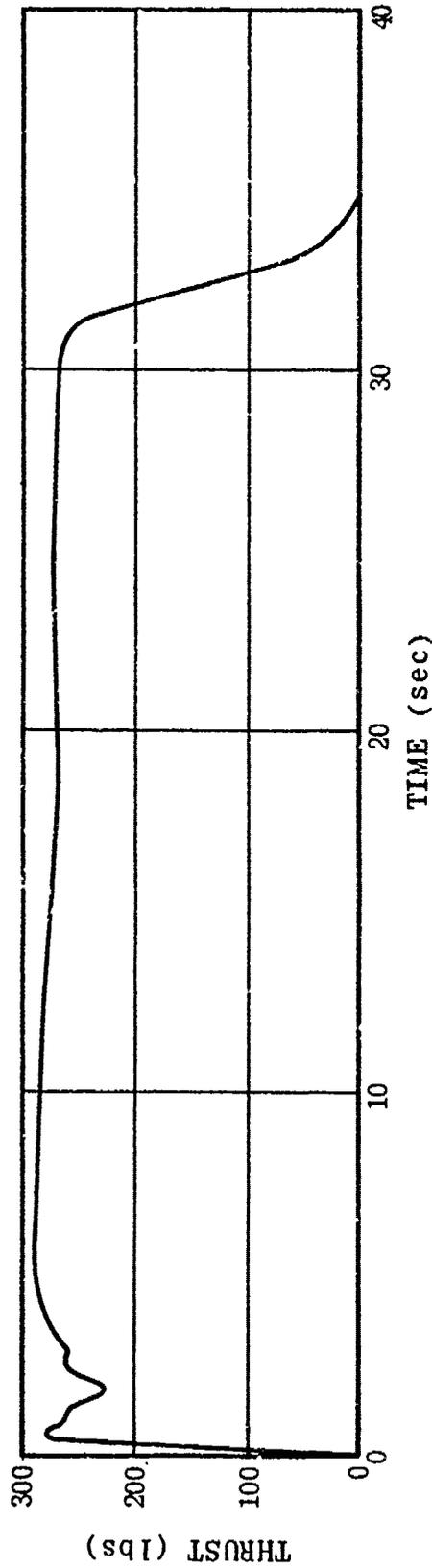


Figure B-1. Standard Configuration ARCAS Nylon Inhibitor.



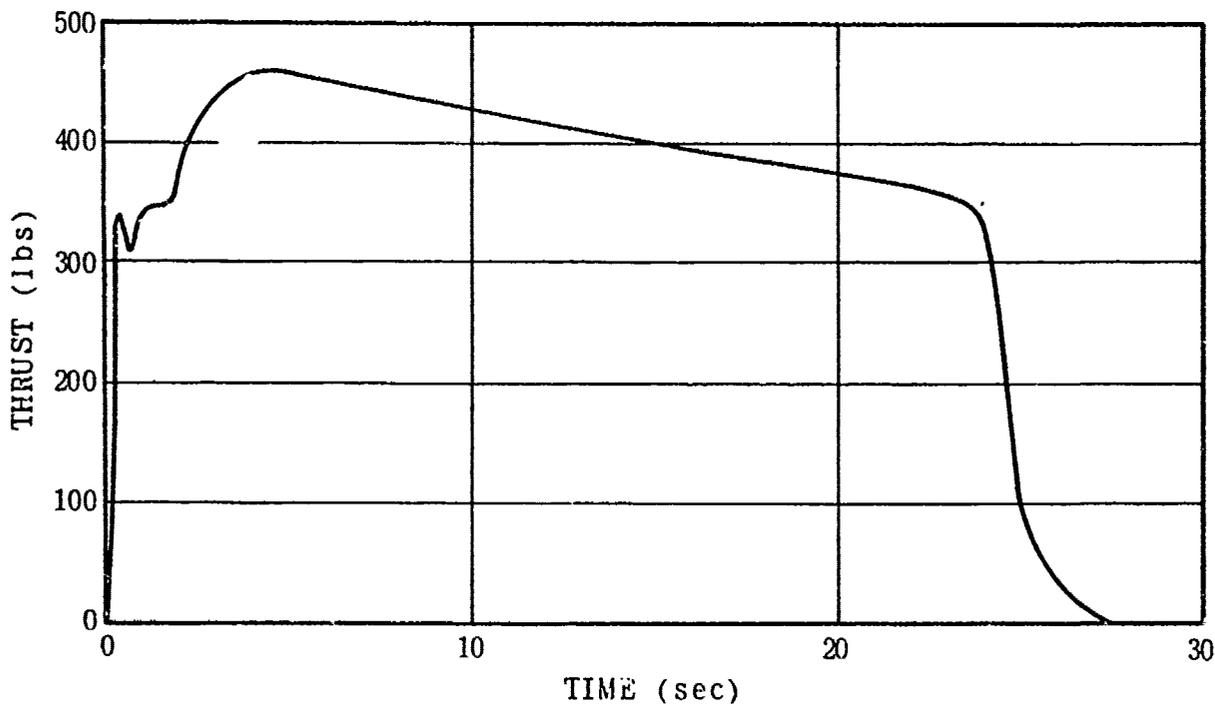
Motor Number ANX-1
Conditioning - Fired at 70°F after rough road handling
Total Impulse, lb-sec 9593
Maximum Thrust, lb 375
Average Thrust, lb 345

Figure B-2. Thrust-Time Curve from Firing ANX-1 at 70°F.



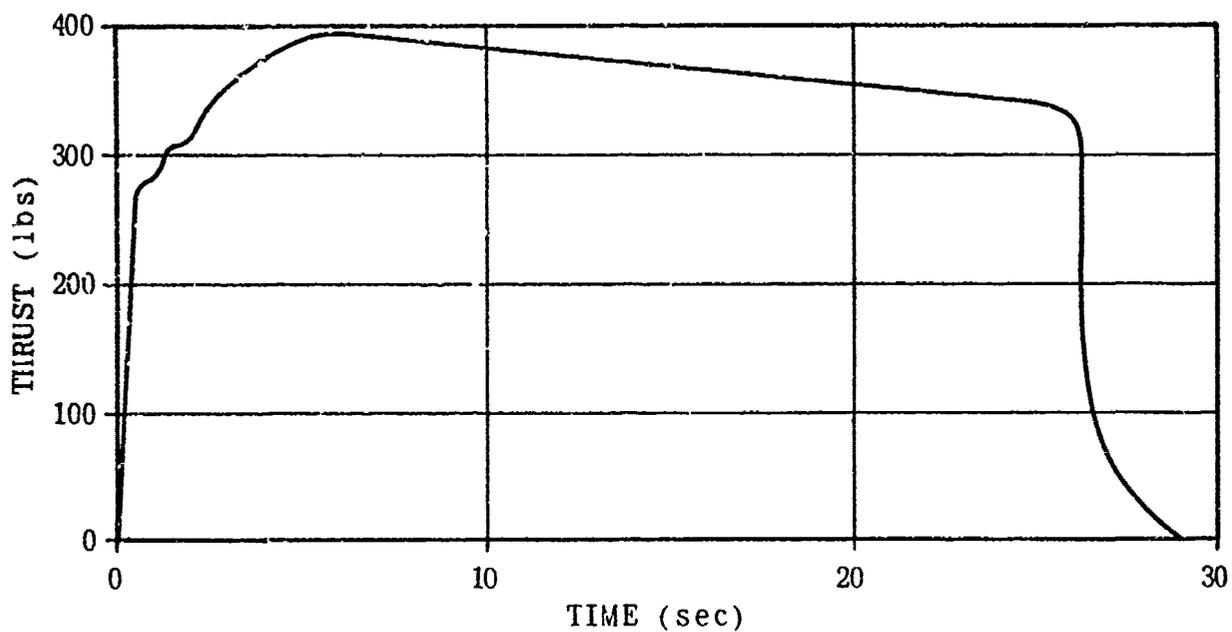
Motor Number ANX-2
 Conditioning - Fired at -10°F after thermal cycling
 Total Impulse, lb-sec 9202
 Maximum Thrust, lb 293
 Average Thrust, lb 270

Figure B-3. Thrust-Time Curve from Firing ANX-2 at -10°F.



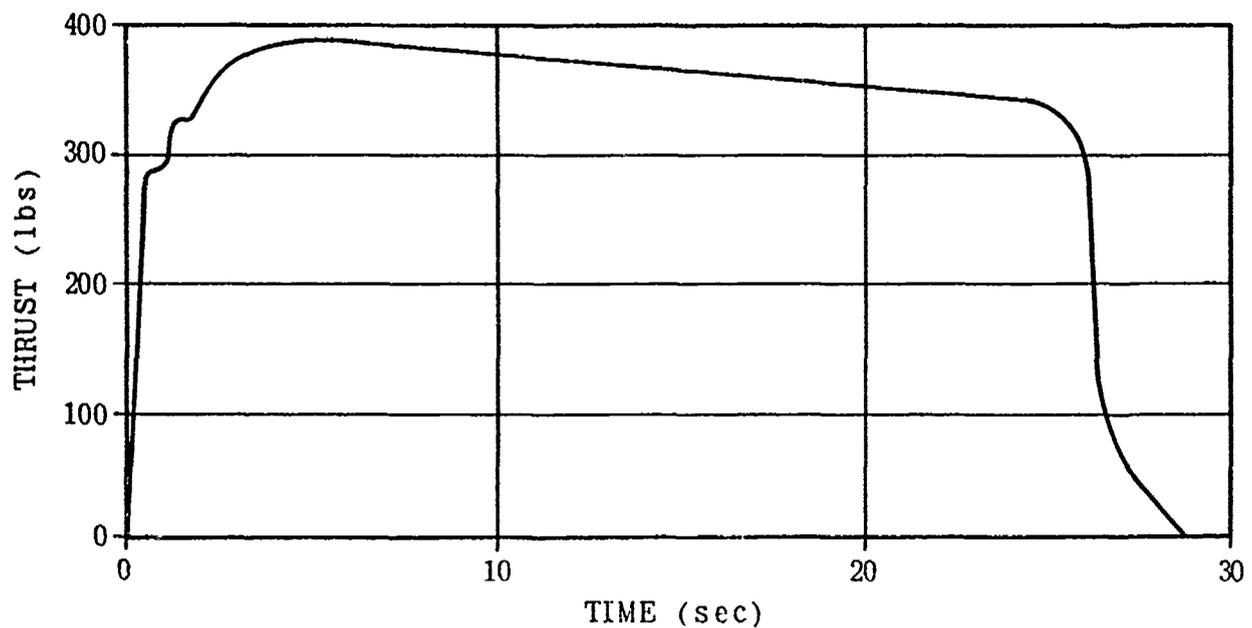
Motor Number	ANX-3
Conditioning - Fired at	110°F after thermal cycling
Total Impulse, lb-sec	9902
Maximum Thrust, lb	446
Average Thrust, lb	391

Figure B-4. Thrust-Time Curve from Firing ANX-3 at 110°F.



Motor Number	ANX-8
Conditioning - Fired at 70°F after thermal cycling	
Total Impulse, lb-sec	9515
Maximum Thrust, lb	398
Average Thrust, lb	351

Figure B-5. Thrust-Time Curve from Firing ANX-8 at 70°F.



Motor Number	ANX-9
Conditioning - Fired at	70°F after thermal cycling
Total Impulse, lb-sec	9551
Maximum Thrust, lb	370
Average Thrust, lb	344

Figure B-6. Thrust-Time Curve from Firing ANX-9 at 70°F.

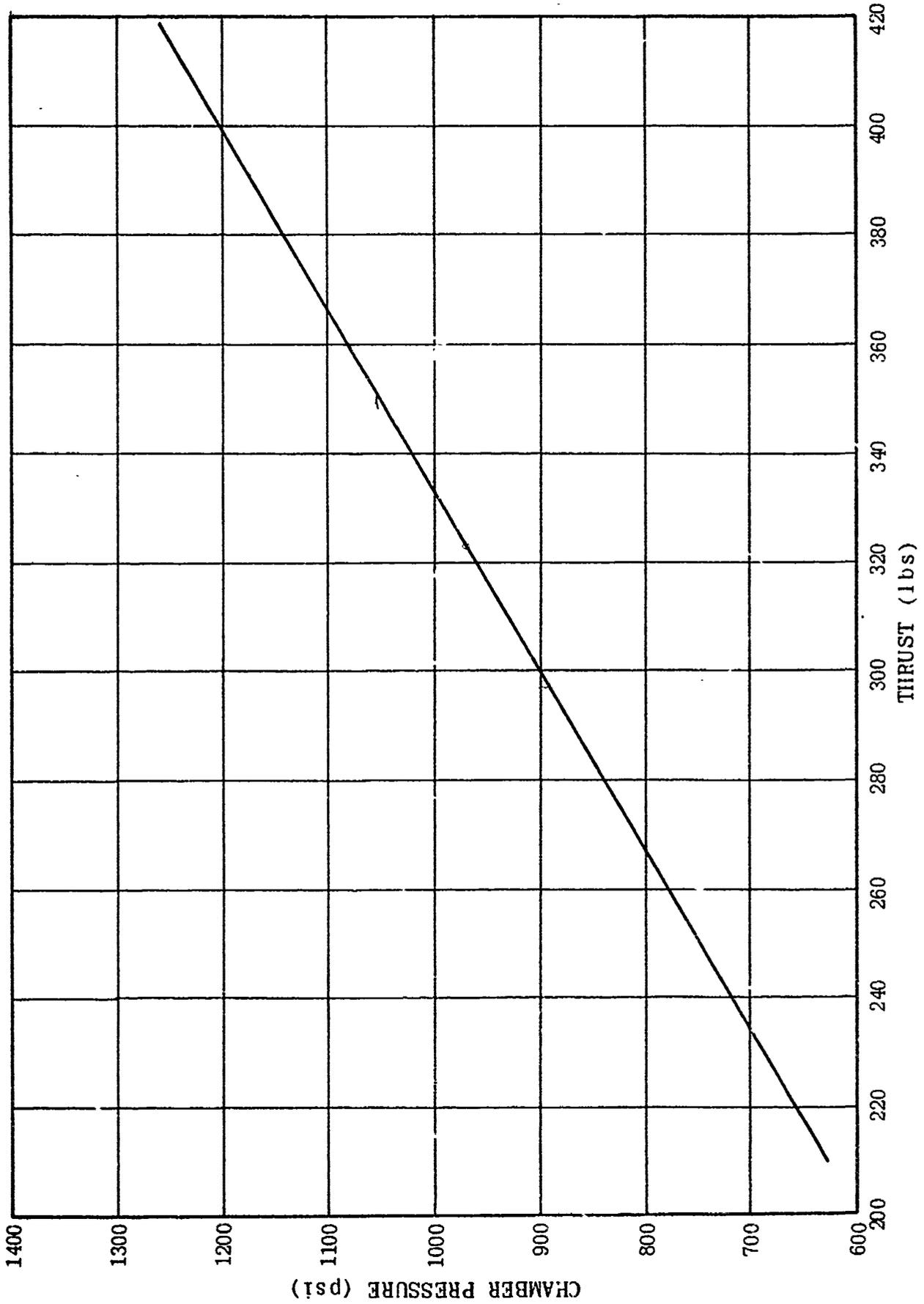


Figure B-7. Thrust Versus Pressure in the 4.5 EX2 Mod O Rocket Motor Determined from Test Firings.

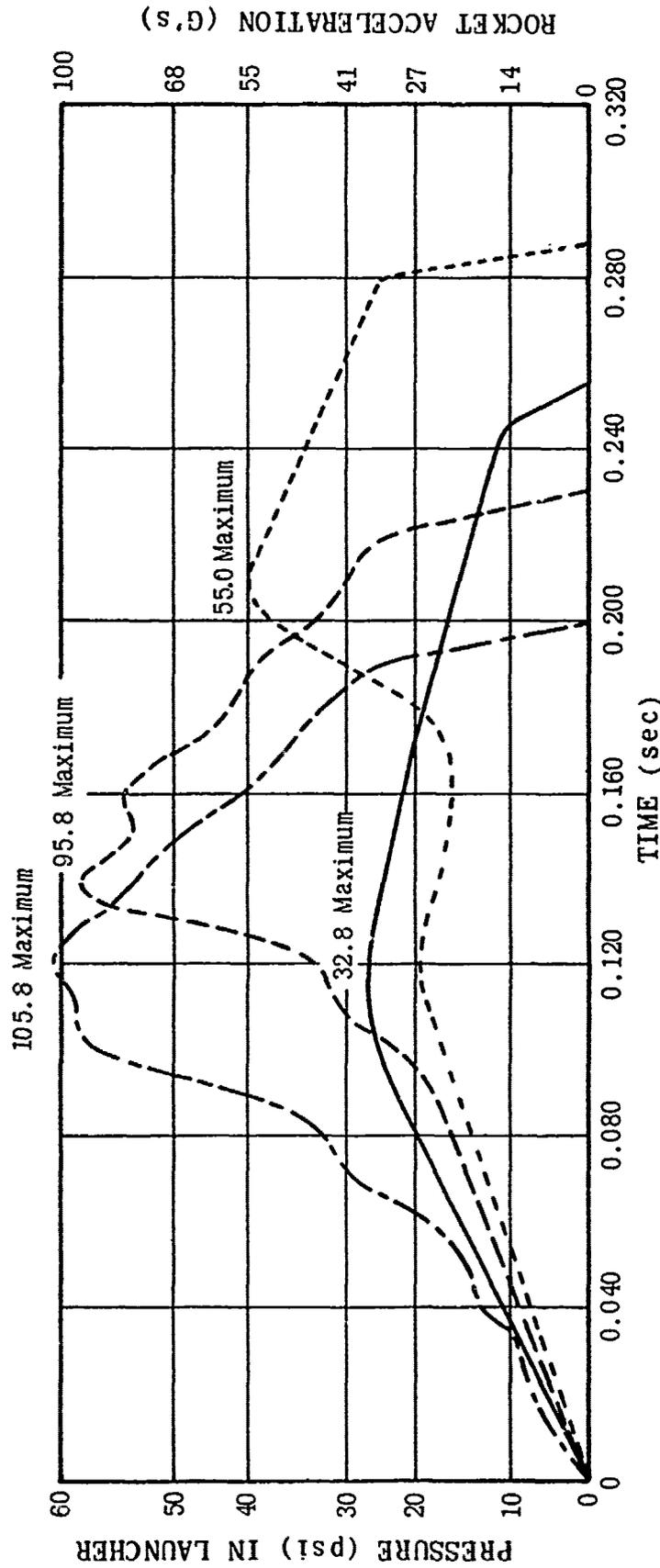
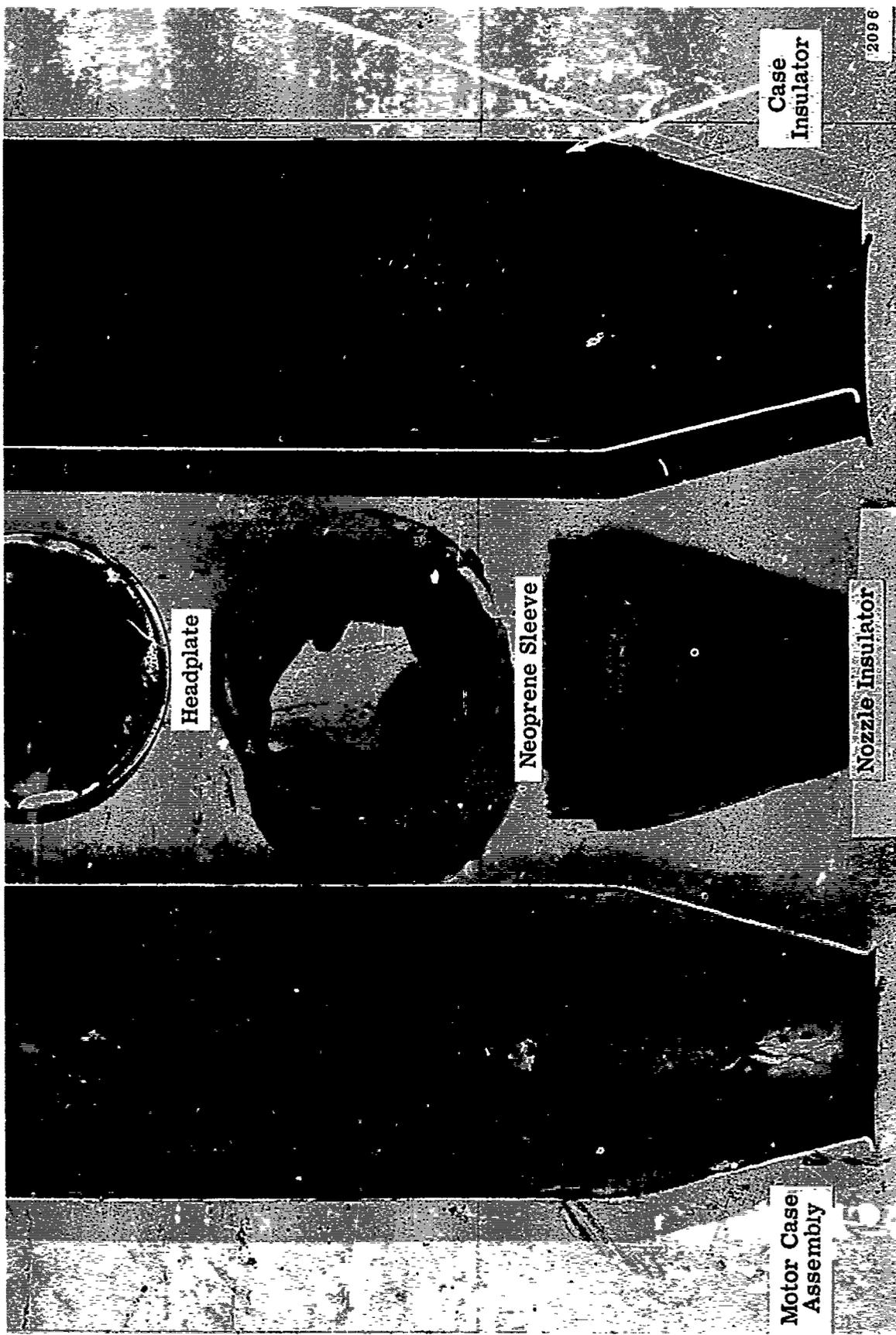


Figure B-8. Launcher Pressure Characteristics for Various Rocket Accelerations.



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Figure B-9. Motor Parts After Firing ANX-8.



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Figure B-10. Motor Parts After Firing ANX-9.