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EVALUATION OF THE MARC 7G1 AUXILIARY ROCKET MOTOR FOR USE ON THE ATLAS-CENTAUR VEHICLE

by

N. C. Jasper, A. D. Mattox, and E. E. Elzufon

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FINAL REPORT

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Technical Management
NASA Lewis Research Center
Cleveland, Ohio
Centaur Project Office
Ralph F. Schmiedlin and Henry Synor

ATLANTIC RESEARCH CORPORATION
Alexandria, Virginia

FOREWORD

This report covers the work performed by Atlantic Research Corporation to evaluate the MARC 7G1 auxiliary rocket motor for use on the ATLAS-CENTAUR vehicle. The program was conducted under Contract NAS 3-7128-H with the NASA Lewis Research Center. Mr. R.F. Schmiedlin and Mr. H. Synor of the Center's Centaur Project Office served as technical monitors for NASA. Work was initiated in March 1965 and completed in October 1965.

The program was directed at Atlantic Research Corporation by the Program Management Group of the Engineering Division, Propulsion and Chemical Systems. Major contributors, in addition to the authors, were N. Sublett in program management; J. Walker, J. Leland, and M. Jones in design; K. Lai in ballistic analysis; and H. Kaehler in stress analysis.

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ABSTRACT

The MARC 7G1, 1-KS-420 rocket motor was evaluated to determine its suitability for use as a retrograde thrust generator on the ATLAS-CENTAUR space vehicle. An igniter proof test series and a motor environmental and static firing program were conducted. The igniter was found capable of withstanding 1-ampere, 1-watt for 10 seconds without initiation. Ten motors each were fired at -30°F and 160°F, and at simulated altitudes above 100,000 feet. Measured motor ballistic data were within design objectives. Impulse reproducibility was excellent, particularly at the higher temperature. Although burning reproducibly, nine of the ten -30°F motors exhibited abnormal ballistics due to excessive strain of the propellant web during startup pressurization. Design changes eliminating this problem proved successful in two additional tests at -30°F.

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1.0 SUMMARY

The MARC 7 rockets comprise a family of solid-propellant motors used for auxiliary thrusting functions on large missiles and flight vehicles. The latest rocket in this family, the MARC 7G1, was modified for use on the ATLAS-CENTAUR space vehicle. This rocket weighs 5.07 pounds, measures 14.7 inches in length by 2.9 inches in diameter, and delivers approximately 400 pounds of thrust for 1 second at an altitude of 100,000 feet. Its Model 502 igniter meets the 1.0-ampere, 1-watt no-fire requirement of the Atlantic Missile Range.

Twenty motors were tested to evaluate the suitability of the MARC 7G1 for use on the ATLAS-CENTAUR. These units were subjected to an environmental test sequence consisting of temperature-humidity, altitude, operating vibration, shock, and temperature shock. Half of the motors were then fired at -30° F, and half at 160° F. All motors were fired in a reduced pressure environment simulating an altitude greater than 100,000 feet.

Ballistic results from the 20 evaluation firings were within design objectives. Standard deviations on total delivered impulse were 0.18 per cent at 160° F and 0.41 per cent -30° F. Thrust- and pressure-time records in nine of the ten low temperature firings, however, indicated that the motor was performing abnormally at -30° F. Post-test examination, corroborated by ballistic and stress analyses, showed that the grain was cracking radially through the web during ignition.

Additional tests were conducted to reduce the pressure differential occurring across the web at the head end of the motor during ignition. Changes in the igniter body rupture disc and in the amount of ignition charge were first evaluated. Although reducing the pressure contributed by the igniter, these modifications failed to prevent the grain from cracking at -30° F. The motor firing temperature was then raised to 0° F to enhance the capability of the propellant to withstand the pressure differential. The grain cracked in two of three firings at this temperature. Reducing the ignition pressure

differential at the head end of the grain was thus determined not to be a feasible means of eliminating propellant cracking.

The final solution attacked the problem through two avenues: (1) providing the grain with more circumferential support by replacing the rubber inhibitor with a nylon shell impregnated with epoxy-polyamide resin; (2) greatly reducing the magnitude of the initial pressure differential across the grain web by venting gases to the outside of the grain at both ends of the motor. (In the original design, the outside of the grain was vented only at the aft end.) These design changes were incorporated into two motors fired at -30°F and simulated altitudes above 100,000 feet. Also evaluated in these tests was the use of epoxy-fiberglass tabs as aft end spacers in place of the original spring-steel wave washer. This change was made to promote the unrestricted flow of gases to the outside of the grain at the aft end of the motor. Motor performance was satisfactory in both tests. There was no evidence that the propellant had been strained beyond its capacity. Further, there were no adverse effects from the flow of gases through the annulus between the uninsulated motor case wall and the inhibited grain. The revisions evaluated in these two firings are, therefore, recommended for future MARC 7G1 motors.

The Model 502 igniter employs a Hercules Powder Company Model S-228A2 squib and a main charge of boron-potassium-nitrate pellets. Twenty-five squibs were tested in a lot acceptance sequence consisting of the following: (1) inspection; (2) helium leak rate; (3) insulation resistance; (4) Bruceton analysis; (5) functioning time. Six complete igniters were then fired in a closed bomb to evaluate the Model 502 igniter before use in the motor evaluation program.

Functional tests of the igniter were conducted during the motor test sequence to verify its ability to withstand repeated applications of 1 ampere for 10 seconds without firing. The motors were grouped so that ten igniters were subjected to only three functional tests, while another ten

igniters were subjected to 17 tests. No igniter actuated in these tests, and motor ignition performance was unaffected by the number of functional tests prior to firing. The igniter functioned reliably with a current of 5.0 amperes applied to either of the two squib bridgewires.

2.0 INTRODUCTION

A solid-propellant, internal-burning motor, the MARC 7G1 (Figure 1) represents the most advanced model in Atlantic Research Corporation's family of MARC 7 auxiliary rockets. The original prototype model, the MARC 7A1, was designed and qualified for use on the ATLAS in 1958. Recently, MARC 7D and 7E models have been employed on the Air Force's TITAN ballistic missile and ATHENA re-entry test vehicle.

The current program was conducted to determine the suitability of MARC 7G1 for use as a retrograde auxiliary rocket on the ATLAS-CENTAUR space vehicle. Eight such rockets, spaced around the base of the ATLAS, are used to retard the first stage during separation from the CENTAUR stage. Significant design features introduced in the MARC 7G1 motor for this application include:

- A 1.0-ampere, 1-watt no-fire igniter which meets Atlantic Missile Range safety requirements.
- An extruded, five-point-star propellant grain that affords reproducible ballistic performance.
- A trapped grain system which provides a reliable, economical means of retention.
- An easily applied translucent rubber inhibitor which permits visual inspection of the inhibitor-to-propellant bond.
- A styrofoam plug, faced with aluminum foil and rubber to form a nozzle closure affording reproducible start-ups free of excessive pressure peaks.

Two series of tests were conducted to evaluate the performance of the MARC 7G1 motor: (1) an igniter proof test program; (2) a 20-round environmental and static firing motor evaluation program. Pertinent results from these tests are covered in this report.

3.0 DESCRIPTION OF TEST UNIT

3.1 MOTOR ASSEMBLY

Fully assembled, the MARC 7G1 motor weighs 5.07 pounds and measures 14.7 inches in over-all length by 2.9 inches in maximum diameter. With an 8.98-to-1 nozzle expansion ratio, the motor, operating at 100,000 feet and 75° F, delivers an average thrust of 400 pounds over a web burning time of 1.0 second.

Components of the MARC 7G1 motor are depicted in the exploded view photograph of Figure 2 and the cutaway schematic of Figure 3. The internal-burning, 2.13-pound grain is extruded into a five-point star configuration. Its Arcite 377A propellant is a plastisol composite having the following formulation:

Ingredient	Function	Weight Per Cent
Ammonium Perchlorate	Oxidizer	73.89
Polyvinyl Chloride	Resin	12.31
Dioctyl Adipate	Plasticizer	12.31
Carbon Black	Ballistic Modifier	0.99
Ferro 1203	Stabilizer	0.50

Ballistic properties of the propellant are shown in Table I.

The minimum allowable web on the extruded propellant is 0.382 inch. After extrusion, the grain is cut to a length of 8.410 to 8.470 inches. The outside diameter is held within 2.525 to 2.545 inches. Nominal weight of the finished grain is 2.135 pounds.

The grain is inhibited on its outside circumferential surface with a translucent rubber sleeve, bonded to the propellant with an epoxy-polyamide resin. A laminated epoxy-fiberglass disc at the aft end and a silicone rubber cap at the head end complete the propellant inhibiting system. Epoxy-polyamide resin is used as the propellant bonding agent for both end inhibitors. The aft surface of the silicone cap is also treated with a special Dow Corning adhesive prior to bonding.

Table I. Ballistic Properties of Arcite 377A Propellant.

Theoretical Performance at ϵ = 8.1 and P_c = 1000 psia

Ratio of Specific Heats, γ	1.247
Discharge Coefficient, C_D (lb/lb-sec)	0.00716
Specific Impulse, I_{sp} (lb-sec/lb)	
Frozen Equilibrium, Sea Level	218
Shifting Equilibrium, Sea Level	220
Shifting Equilibrium, Vacuum	236
Flame Temperature at 1000 psia, T_P (°K)	2316

Strand Burning Rate at 1000 psia

Burning Rate, r (in/sec)	0.36
Burning Rate Exponent, n	0.44
Temperature Coefficient of Pressure at Constant K, π_K (%/°F)	0.20

Combustion Product Composition (mols/100 gm)

	Arcite 377A	
	Chamber	Exhaust
H	0.0022	0.0000
Cl	0.0019	0.0000
CO	0.9446	0.5867
CO_2	0.2788	0.6354
CH_4	0.0000	0.0013
H_2	0.6973	1.0497
H_2O	1.1483	0.7935
HCl	0.8234	0.8258
OH	0.0007	0.0000
N_2	0.3144	0.3144
$AlCl_3$	0.0002	0.0000
Al_2O_3 (liquid)	0.0023	0.0000
Al_2O_3 (solid)	0.0000	0.0024

Both the motor case and nozzle are fabricated from AISI 4130 steel. The inhibited grain is cartridge loaded into the case from the nozzle end. A spring steel wave washer is placed on the aft end of the grain. The nozzle threads into the case so that its forward end compresses the wave washer against the grain. The grain is thereby captured between the wave washer at its aft end and the silicone cap at its forward end. American Sealants' Loctite seals and secures the threaded joint between the case and the nozzle.

Before assembly into the case, the nozzle is fitted with an ATJ graphite throat insert and a three-piece closure. A styrofoam plug and two discs — one of aluminum foil and one of rubber — comprise the closure assembly. The plug seats within the insert and the discs seat against the steel entrance cone. The three pieces are bonded together with an epoxy-polyamide adhesive. The same resin also bonds the rubber disc to the nozzle wall.

3.2 IGNITER ASSEMBLY

The motor is ignited with a Model 502 igniter, depicted in Figure 4. It consists of three major components: (1) the squib; (2) the housing; and (3) the main charge. The igniter, with O-ring seals, threads into the head end of the motor case.

The squib is a Model S-228A2 developed and manufactured by the Hercules Powder Company in Port Ewen, New York, to comply with the 1.0-ampere, 1.0-watt no-fire requirement of AMFTC-P-80-2. It contains two bridgewires, each capable of initiating the igniter. Its gold plated steel body uses ceramic-to-metal seals to insulate and mount the four connector pins. The output end has a 1/2-20 UNF mounting thread; the forward end is designed to mate with an MS-3116-8-4S connector (Bendix PT06P-8-4S).

The igniter housing is a steel body externally threaded for installation into the rocket motor. Its output end is perforated with seven 3/16-inch-diameter holes through which the main charge vents onto the propellant grain ignition surface. These holes are sealed by means of a 0.002-inch-thick

brass disc brazed onto the outside surface. Moisture resistance is assured by subjecting each seal to a helium leak test requiring less than 1.0×10^{-7} cc/sec leakage at a 1.0-atmosphere pressure differential.

The housing perforations are sized empirically so that the pellets burn in the igniter chamber at approximately 1500 psi and vent into the main rocket chamber at sonic velocities. The products of combustion then impinge on the propellant grain ignition surface in a reproducible manner affording fast, reliable ignition over a wide temperature range.

The main charge consists of 17 Flare-Northern 2D pellets, weighing a total of 2.5 grams. These pellets are 1/4-inch-diameter tablets of the boron-potassium-nitrate composition used throughout the rocket industry.

3.3 DESIGN CONFIRMATION FIRINGS

Four prototype motors (DX-1 through DX-4) were fabricated and tested to confirm the MARC 7G1 design prior to evaluation testing. All motors were fired at simulated altitudes greater than 100,000 feet. Each motor ignited and burned full duration without incident. Measured ignition and ballistic data agreed closely with predicted performance values. Motor and igniter configurations were as described above, with two exceptions:

a. In Motors DX-1 and DX-2, a nylon-epoxy disc was used to inhibit the aft end of the grain pending receipt of laminated fiberglass-epoxy material.

b. An experimental polyvinyl chloride inhibitor, extruded together with the propellant, was evaluated in Motor DX-3. Although this firing was successful, the extruded inhibitor was not used for evaluation testing because of processing uncertainties.

Pertinent data from the four design confirmation firings are presented in Table II. These results verified that at ambient temperatures between 70° F and 80° F the nominal web burning time at 1000 psi is 1.0 second. The action time total impulse also fell well within the design

Table II. Design Confirmation Firing Results.

Motor Number	DX-1	DX-2	DX-3	DX-4
Grain Number	2474-R2-10A	2474-R2-8B	2836-R4-4D	2474-R2-13B
Date Fired	6-15-65	6-28-65	6-28-65	7-20-65
Propellant Weight (lb)	2.132	2.135	2.156	2.152
Web (in)	0.415	0.412	0.412	0.406
Motor Temperature (°F)	70	80	80	70
Throat Area Before (sq in)	0.2419	0.2419	0.2419	0.2419
Throat Area After (sq in)	0.2408	0.2410	0.2410	0.2417
Average Throat Area (sq in)	0.2414	0.2415	0.2415	0.2418
Action Time, t_a (sec)	1.610	1.524	1.577	1.514
Burning Time, t_b (sec)	—	0.967	0.969	1.069
Rise Time, t_r (sec)	—	0.003	0.003	0.005
Ignition Delay, t_d (sec)	0.005	0.005	0.005	0.005
Average Burning Rate, r (in/sec)	—	0.426	0.425	0.380
Maximum Pressure, P_{max} (psia)	1096	1096	1050	1076
Ignition Pressure, P_{ign} (psia)	1354	1380	1274	1336
Average Pressure, P_a (psia)	730.0	779.5	724.2	781.4
Average Pressure, P_b (psia)	932.3	1012	973.2	984.1
Maximum Thrust, F_{max} (lb)	452.8	434.5	437.7	421.2
Average Thrust, F_a (lb)	298.3	318.2	304.8	322.3
Average Thrust, F_b (lb)	—	410.0	402.0	390.9
Total Impulse, I_a (lb-sec)	480.3	484.9	480.6	488.0
Deliverable Total Impulse, I_{0-0} (lb-sec)	—	494.5	489.3	496.9
Propellant Specific Impulse, I_{sp} (lb-sec/lb)	—	231.6	226.9	230.9

objective range of 360 to 500 pound-seconds. Ignition characteristics were highly reproducible: rise times fell between 0.003 and 0.005 second, and the ignition delay for all firings was 0.005 second.

4.0 MOTOR EVALUATION TESTS

4.1 GENERAL

The evaluation test plan for the MARC 7G1 motor is shown in Table III. As indicated, 20 motors were subjected to environmental tests of temperature-humidity, altitude, operating vibration, shock, and temperature shock and then static fired at -30°F or 160°F. An additional motor, Serial Number Q-21, was instrumented with thermocouples to determine temperature stabilization times and the effects of radiant heating.

All static firings were conducted at Atlantic Research Corporation's Pine Ridge Facility in Gainesville, Virginia. The motors were fired in a vacuum chamber test facility (Figure 5) used to simulate high altitudes greater than 100,000 feet. Environmental testing was subcontracted to the TRW Inc. Roanoke Laboratory, Rocky Mount, Virginia.

4.2 ACCEPTANCE TESTS

Three MARC 7G1 motors were static fired at 75°F and simulated altitudes above 100,000 feet to accept Arcite 377A Batch 2474 for use in the evaluation program. Motor ballistics, summarized in Table IV, correspond closely to the data measured in the design confirmation tests. Thrust- and pressure-time curves from the three firings are presented in Appendix A.

All motor cases and squib bodies designated for use in the program were subjected to respective hydrostatic proof pressures of 3500 and 10,000 psi. Additional squib acceptance testing at the Hercules Powder Company is discussed in Section 5.1.

4.3 RADIANT HEAT AND THERMAL GRADIENT TESTS

A radiant heat test was conducted to determine the motor's "maximum non-operating temperature" (MNOT). In this test, the motor was subjected to 125°F for 5 hours, with radiant heat applied to the largest surface area for the last 4 hours at a rate of 360 Btu/sq ft/hr. The MNOT point is defined as the highest temperature recorded immediately under the exposed case surface at the end of this time.

Table III. MARC 7G1 Motor Evaluation Test Program.

Tests	Rocket Motor Number 1-5	6-10	11-15	16-20
Functional Test (Proof Cycle B[a])	X	X	X	X
Temperature-Humidity				
With Proof Cycle B	X	–	X	–
Omit Proof Cycle B	–	X	–	X
Altitude Test				
With Proof Cycle B	X	–	X	–
Omit Proof Cycle B	–	X	–	X
Visual Inspection	X	X	X	X
Operating Vibration (3 axes)				
-30°F With Proof Cycle B	X	–	–	–
-30°F Omit Proof Cycle B	–	X	–	–
+160°F With Proof Cycle B	–	–	X	–
+160°F Omit Proof Cycle B	–	–	–	X
Shock Tests				
With Proof Cycle B	X	–	X	–
Omit Proof Cycle B	–	X	–	X
Temperature Shock Test				
With Proof Cycle B	X	–	X	–
Omit Proof Cycle B	–	X	–	X
High Temperature Firing (160°F)				
Standard Nozzle Closure	3	8	14,15	19,20
Vented Closure (just prior to firing)	1	6	11	16
Low Temperature Firing (-30°F)				
Standard Nozzle Closure	4,5	9,10	13	18
Vented Closure (just prior to firing)	2	7	12	17

a. Proof Cycle B consists of applying 1.0 ampere per bridgewire for 10 seconds.

Table IV. Batch Acceptance Firing Data.

Motor Number	BC-22	BC-23	BC-24
Grain Number	2474-R3-7A	2474-R2-10A	2474-R3-7B
Date Fired	7-9-65	7-9-65	7-9-65
Propellant Weight (lb)	2.128	2.146	2.142
Web (in)	0.407	0.417	0.410
Motor Temperature (°F)	75	75	75
Throat Area Before (sq in)	0.2419	0.2410	0.2410
Throat Area After (sq in)	0.2419	0.2410	0.2410
Average Throat Area (sq in)	0.2415	0.2410	0.2410
Action Time, t_a (sec)	1.578	1.544	1.525
Burning Time, t_b (sec)	1.067	0.963	0.963
Rise Time, t_r (sec)	0.008	0.007	0.008
Ignition Delay, t_d (sec)	0.004	0.004	0.003
Average Burning Rate, r (in/sec)	0.381	0.433	0.425
Maximum Pressure, P_{max} (psia)	1054	1108	1093
Ignition Pressure, P_{ign} (psia)	1346	1238	1232
Average Pressure, P_a (psia)	761.1	786.9	790.8
Average Pressure, P_b (psia)	973.8	1023	1031
Maximum Thrust, F_{max} (lb)	414.0	437.9	436.2
Average Thrust, F_a (lb)	304.0	314.4	315.9
Average Thrust, F_b (lb)	387.6	407.1	409.8
Total Impulse, I_a (lb-sec)	479.7	485.5	481.8
Deliverable Total Impulse, I_{0-0} (lb-sec)	489.5	495.8	493.0
Propellant Specific Impulse, I_{sp} (lb-sec/lb)	230.0	231.0	230.2

Motor Number Q-21 was instrumented with five iron-constantan thermocouples located on the grain as shown in Figure 6. The motor was then placed in a controlled temperature conditioning chamber at 125°F. After one hour, radiant heat was applied with five 300-watt, R-40 reflector, incandescent lamps mounted 38 inches from the motor. (See Figure 7.) The thermocouples were continuously monitored throughout the test.

A MNOT point of 141°F was measured by Thermocouple Number 3. Since this MNOT value is less than the specified firing temperature of 160°F, the latter was used as the upper limit in the thermal gradient study.

After the radiant heat test, Motor Q-21 was subjected to thermal cycling to determine the stabilization times for various operating temperature environments. For this test, thermal stabilization was assumed to have occurred when all five thermocouple readings fell within 5°F of the ambient temperature of the motor. Test results were as follows:

Initial Temperature (°F)	Final Temperature (°F)	Stabilization Time (hr-min)
- 65	70	4-10
- 65	160	2-20
70	- 65	2-50
70	160	3-20
160	- 65	2-10
160	70	3-40

The thermocouple outputs were continuously recorded during the test. Temperature versus time plots for the six sets of conditions are presented in Appendix B.

4.4 ENVIRONMENTAL TESTS

Environmental test equipment, procedures, and results are detailed in the TRW report, Atlantic Research Corporation Report Number TR-PL-8634A. A brief description of each test is presented below.

4.4.1 Proof Cycle B

A functional test of the igniter circuit was performed on all motors before and after the environmental test series. In addition, ten of the twenty motors were subjected to the same test following exposure to each environment. (See Table III.) For this test, designated "Proof Cycle B," a current of 1.0 plus or minus 0.1 amperes was applied to each bridgewire circuit for 10 seconds. This test was performed at an atmospheric pressure between 28 and 32 inches of mercury, a temperature between 60°F and 95°F, and a relative humidity of less than 90 per cent. Current, voltage, squib resistance, and time of current application were recorded.

Results of the Proof Cycle B tests are summarized in Figure 8. This graph depicts the change in mean total squib resistance (sum of both bridgewire resistances) for each of the four motor test groups defined in Table III. A comparison of acceptance and final inspection results shows a net increase in resistance as a result of the environmental tests. Further, the increase for the two groups subjected to two cycles was less than that of the two groups subjected to 16 cycles (2 and 5 per cent compared with 6 and 9 per cent). This difference is insufficient to have any practical effect on either firing current sensitivity or motor ignition characteristics (Section 3.5).

The squib resistance of Motor Q-3 varied considerably and ran appreciably higher than that of the other motors in the same group. Its resistance reached a peak of 3.478 ohms after vibration in the longitudinal axis at -30°F. Before firing, however, the resistance dropped to 2.255 ohms, a value only slightly above the initial acceptance reading of 2.157 ohms. Figure 8 includes a plot of resistances for Motors Q-1, Q-2, Q-4 and Q-5 to show the general trend of squib resistances for this group excluding Motor Q-3.

The average resistance for Motors Q-11 through Q-15 also rose sharply after exposure to temperature-humidity at 160°F and again in final inspection at TRW. In both instances the rise was essentially uniform throughout the group and could not be attributed to specific units. This group also

showed a drop in average resistance from 2.294 ohms in final inspection at TRW to 2.212 ohms in prefiring inspection at Atlantic Research Corporation.

4.4.2 Temperature-Humidity Test

The test unit was placed in a conditioning chamber, and the temperature was reduced to -65°F. This temperature was maintained for 8 hours. The chamber was then raised to -30°F and held at this temperature for 4 hours. The temperature was then increased to 160°F. After 6 hours at 160°F, the chamber was maintained at 141°F (the MNOT point) and a relative humidity above 95 per cent for 8 hours. The chamber temperature was then reduced to 40°F at the same relative humidity and held at this condition for 6 hours. At the end of 6 hours, the chamber was returned to standard atmospheric conditions. A temperature change rate of 0.75 to 1.25°F/min was used throughout the test.

4.4.3 Altitude Test

The test unit was placed in a pressure chamber, and the pressure was reduced to 3.44 inches of mercury for one hour. The pressure was then returned to approximately 30 inches of mercury, reduced to less than one millimeter within 10 minutes, and brought back to 30 inches.

4.4.4 Sinusoidal Vibration

Each unit was conditioned for 8 hours at the appropriate temperature shown in Table III. Each motor was then subjected to a slow scanning sweep of sinusoidal vibration along each of three mutually perpendicular axes. Frequencies and amplitude are shown in Figure 9; the sweep period is depicted in Figure 10. Output acceleration was continuously recorded at one mounting interface in the direction of input force. The input force was continuously recorded with a filtered control accelerometer.

4.4.5 Shock

The test motor was subjected to a 1-inch free fall and a 4-inch pivot drop on to a hardwood surface. Each shock was performed once in each of

three mutually perpendicular axes. The unit was then packaged for shipment and dropped on a flat concrete surface from a height of 36 inches. This test was also conducted once in each of three mutually perpendicular axes.

4.4.6 Temperature Shock

The test unit was placed in a temperature chamber and conditioned to 70°F. The motor was then removed from this chamber and placed in a chamber at 160°F. After being held at 160°F for 8 hours, the motor was placed in a -65°F chamber and maintained at this temperature for 8 hours. The unit was then returned to standard atmospheric conditions. The time required to remove a motor from one chamber and place it in another was held to less than 2 minutes.

4.4.7 Inspection

Before and after each test, each motor was inspected for damage. This inspection included:

a. A visual inspection of the motor surface for damage such as peeling, flaking, or corrosion.

b. A visual inspection of the forward and aft seals and closures for evidence of leakage or damage.

c. A gentle shaking to detect evidence of loose or dislocated internal components.

No detrimental effects were observed in any inspection.

4.5 STATIC FIRINGS

4.5.1 Procedure and Equipment

Before firing, the 20 environmentally tested motors were subjected to visual examination, X-ray, and Proof Cycle B at Atlantic Research Corporation. No evidence of damage was found either visually or by X-ray. Squib resistances, measured at the motor firing temperature, ranged from

0.950 to 1.300 ohms. (See Table V.) Two circuits had resistances slightly above the maximum design tolerance of 1.20 ohms: (1) the resistance of circuit C-D in Motor Q-7 was 1.300 ohms; (2) the resistance of circuit A-B in Motor Q-12 was 1.230 ohms. Both Motors Q-7 and Q-12 had been conditioned to -30°F before being subjected to Proof Cycle B. Difficulties in obtaining a good electric contact at this temperature could have introduced spurious resistances into the measurement circuit.

Ten motors each were conditioned for at least four hours at respective temperatures of -30°F and 160°F. (See Table III.) Within 15 minutes after removal from its conditioning chamber, each motor was instrumented for test and static fired at a reduced pressure simulating an altitude in excess of 100,000 feet. A current of 5.0 to 5.5 amperes was applied to each squib bridgewire for ignition.

Static test equipment is listed in Table VI. The firing facility consists of a right circular horizontal vacuum chamber (approximately 1000 cubic feet) with a directly coupled inner diffuser tube (approximately 10 cubic feet). This system permits access to the diffuser tube without degradation of the altitude environment in the main chamber. The larger chamber is first evacuated to the desired altitude. The motor is then attached to its thrust stand and secured to the end plate of the diffuser tube (Figure 11). This assembly is inserted into the tube, which is then sealed and evacuated to the desired altitude (Figure 12). The inner access port between the diffuser tube and the main vacuum chamber is opened (Figure 13), and the motor is ignited.

4.5.2 Test Results

All motors ignited within 0.006 second after current application. The ballistic records for the ten high temperature firings exhibited the slightly regressive burning history and the long tail-off times characteristic of the star-ported grain design. Nine of the ten -30°F motors, however, exhibited abnormal ballistic behavior.

Table V. Prefiring Squib Resistances.

Motor Number	Test Temperature (°F)	Circuit Resistances A-B (ohm)	Circuit Resistances C-D (ohm)
Q-1	160	1.070	1.100
Q-3	160	1.145	1.110
Q-6	160	1.000	1.000
Q-8	160	1.190	1.140
Q-11	160	1.080	0.990
Q-14	160	1.100	1.030
Q-15	160	1.190	1.120
Q-16	160	1.160	1.120
Q-19	160	1.120	1.190
Q-20	160	1.110	1.100
Q-2	-30	1.150	1.050
Q-4	-30	1.150	1.070
Q-5	-30	1.150	1.190
Q-7	-30	0.970	1.300
Q-9	-30	1.150	1.080
Q-10	-30	1.150	0.950
Q-12	-30	1.230	1.120
Q-13	-30	1.160	1.040
Q-17	-30	1.150	0.970
Q-18	-30	1.130	1.130

Table VI. Static Test Equipment List.

Item	Manufacturer	Model No.	Serial No.	Calibration
Visicorder	Heiland Division of Minneapolis Honeywell	1508	15-279	System
Amplifier	Computer Engineering Associates	A-1233B	1472	System
Amplifier	Computer Engineering Associates	A-1233B	1466	System
Amplifier	Computer Engineering Associates	A-1233B	1763	System
Recording Oscillograph	Consolidated Electrodynamics	5-119-P4	20099	System
Firing Current Time Control	Atlantic Research Corporation	TC-1	--	System
Dual Load Cell	Allegany Instrument Company	Series 36	31228	System
Temperature Recorder	Leeds & Northrup	Speedomax	62-28946-1-1	NCR[a]
Thrust Stand	Atlantic Research Corporation	--	--	NCR
Mercury Manometer	Welch Scientific	--	--	NCR
Open Eng Manometer 90CM	Fischer Scientific	--	--	NCR
Variac Autotransformer	General Radio	W10MT3	--	NCR

a. No Certification Required.

Table VI. (continued)

Item	Manufacturer	Model No.	Serial No.	Calibration
Stokes Vacuum Gage (McLeod Type)	Stokes Corporation	276AC	3-87363	NCR[a]
Tod Vacuum Gage (McLeod Type)	Universal	--	316070	NCR
Microvac Vacuum Pump	Stokes Corporation	412H-10	--	NCR
Microvac Vacuum Pump	Stokes Corporation	412H-10	--	NCR
Vacuum Chamber	Atlantic Research Corporation	--	--	NCR
Diffuser Tube	Atlantic Research Corporation	--	--	NCR
Sling Psychrometer	Bacharach	--	--	NCR
Conditioning Box	Atlantic Research Corporation	--	--	NCR
Millivolt Potentiometer	Leeds & Northrup	8690	1610289	NCR
Vacuum Gage	Statham	PA-731-TC-1-350	11765	System
Pressure Transducer (Motor)	Allegany Instrument Company	151-AJF-1	21890	System

a. No Certification Required.

Ignition pressures and regressivity were excessive for all low temperature motors except Q-17, which performed normally. Examination of the nine motors which performed abnormally disclosed a boiling away of the cadmium plating on one side of eight of the motor cases and on two sides of one case. The cases of Motor Q-17 and the ten units fired at 160°F were free of hot spots. (See Figures 14 and 15.)

Ballistic data for all 20 firings fell within design objectives. Impulse reproducibility was excellent. The percentage standard deviation on total deliverable impulse at 160°F was only plus or minus 0.18 per cent. Impulse reproducibility in the ten low temperature firings was somewhat degraded by variations in chamber pressure due to the abnormal ballistics discussed above. The total impulse standard deviation for these tests was 0.41 per cent.

Table VII statistically compares ignition data from motors subjected to three Proof Cycle B tests and those subjected to 17 Proof Cycle B tests. The samples studied were grouped by firing temperature to isolate the effect of this variable. As indicated, the number of Proof Cycle B tests was found to have no significant effect on motor ignition characteristics.

A summary of ballistic data from the 20 evaluation firings is presented in Table VIII. Individual static test data sheets, showing the thrust- and pressure-time curves and all pertinent motor and ballistic data for each firing, are included in Appendix C.

4.6 ANALYSIS OF ABNORMAL BEHAVIOR AT -30°F

4.6.1 Post-Firing Examination

The nine discolored motor cases were dimensionally inspected after test. No evidence of deformation was found to have resulted from overheating.

	IGNITION RISE TIME (milsec)				IGNITION DELAY TIME (milsec)			
	160°F Firings		-30°F Firings		160°F Firings		-30°F Firings	
	3 Proof Cycles	17 Proof Cycles	3 Proof Cycles	17 Proof Cycles	3 Proof Cycles	17 Proof Cycles	3 Proof Cycles	17 Proof Cycles
Sample Size, n	5	5	5	5	5	5	5	5
Mean, $\bar{x}$	4.6	4.4	4.8	5.8	4.0	3.6	4.2	5.0
Variance, S^2 [a]	6.8	6.3	2.7	3.7	0.5	1.3	1.2	1.0
Standard Deviation, S	2.6	2.5	1.6	1.9	0.7	1.1	1.1	1.0
Variance Test								
1. Calculated "F" [b]	1.08		1.37		2.58		1.20	
2. "F" at α = 5 per cent	6.39		6.39		6.39		6.39	
3. $F_1 > F_2$? [c]	NO		NO		NO		NO	
Mean Test								
1. Calculated "t" [d]	0.11		0.79		0.60		1.08	
2. "t" at α = 5 per cent	1.86		1.86		1.86		1.86	
3. $t_1 > t_2$? [c]	NO		NO		NO		NO	

a. $S^2 = \frac{n\Sigma x^2 - (\Sigma x)^2}{n(n-1)}$

b. "F" = $\hat{\sigma}_1^2 / \hat{\sigma}_2^2$ where $\hat{\sigma}^2 = \left(\frac{n}{n-1}\right) S^2$ at n - 1 d.f.

c. "NO" answers indicate no significant difference at 5 per cent probability level (α).

d. "t" = $(\bar{x}_2 - \bar{x}_1)/\hat{\sigma}_w$, where $\hat{\sigma}_w = \left(\sqrt{\frac{n_1 S_1^2 + n_2 S_2^2}{n_1 + n_2 - 2}}\right)\left(\sqrt{\frac{1}{n_1} + \frac{1}{n_2}}\right)$ at $n_1 + n_2 - 2$ d.f.

Table VII. Statistical Comparison of Ignition Data.

Table VIII. MARC 7G1 Motor Evaluation Firing Data Summary.

Motor No.	Grain No.	Grain Weight (lb)	t_a (sec)	t_b (sec)	t_r (sec)	t_d (sec)	$\bar{r}$ (in/sec)	P_{max} (psia)	P_a (psia)	P_b (psia)	Action Impulse		0-0 Impulse		F_{max} (lb)	F_a (lb)	F_b (lb)	$\bar{P}_t$ (psia)
											I_a (lb-sec)	I_{sp} (lb-sec/lb)	I_{0-0} (lb-sec)	I_{sp} (lb-sec/lb)				
-30° F Motor Temperature																		
Q-2[b]	2474-R-2-6B	2.127	1.768	0.817	0.007	0.004	0.5075	940.1	648.7	931.8	476.2	223.9	483.8	227.4	395.5	269.3	381.2	0.0468
Q-4	2474-R-3-10	2.176	1.774	0.765	0.005	0.006	0.5425	1032	678.2	1004	476.4	218.9	485.5	223.1	406.3	268.5	396.9	0.0542
Q-5	2474-R-3-6B	2.136	1.829	0.871	0.006	0.006	0.4696	958.5	649.5	914.4	476.6	223.1	484.4	226.8	383.8	260.6	365.4	0.0514
Q-7[b]	2474-R-3-9A	2.141	1.787	0.849	0.003	0.004	0.4834	981.6	669.8	939.7	477.6	223.1	485.6	226.8	388.5	267.3	373.3	0.0466
Q-9	2474-R-2-4A	2.131	1.692	0.757	0.003	0.006	0.5368	1032	688.6	1002	477.2	223.9	487.4	228.7	425.9	282.0	406.1	0.0526
Q-10	2474-R-3-4B	2.140	1.721	0.789	0.006	0.004	0.5189	1025	692.0	1009	474.5	221.7	482.8	225.6	406.7	275.7	400.0	—[a]
Q-12[b]	2474-R-3-5A	2.138	1.731	0.821	0.003	0.005	0.4994	1023	694.9	984.0	479.5	224.3	489.4	228.9	407.2	277.0	391.0	0.0497
Q-13	2474-R-2-6A	2.134	1.709	0.816	0.008	0.004	0.5081	1034	698.2	988.8	477.4	223.7	487.4	228.4	458.2	279.3	392.8	0.0499
Q-17[b]	2474-R-3-3B	2.135	1.818	1.292	0.006	0.004	0.3172	907.9	671.2	838.7	479.8	224.7	487.2	228.2	355.7	263.9	330.5	0.0534
Q-18	2474-R-2-1B	2.126	1.645	0.617	0.006	0.003	0.6626	1147	711.8	1157	473.7	222.8	485.4	228.3	461.0	288.0	459.5	0.0491
+160° F Motor Temperature																		
Q-1[b]	2474-R-3-2A	2.142	1.453	0.910	0.006	0.004	0.4512	1180	839.1	1097	489.2	228.4	498.4	232.7	468.1	336.7	439.7	0.0571
Q-3	2474-R-3-5B	2.127	1.394	0.955	0.003	0.005	0.4290	1194	869.4	1111	485.1	228.1	495.9	233.1	479.8	348.0	444.2	0.0539
Q-6[b]	2474-R-2-2B	2.126	1.411	0.861	0.009	0.004	0.4799	1221	860.4	1134	486.7	228.9	496.6	233.6	491.5	344.9	453.4	0.0580
Q-8	2474-R-3-8A	2.141	1.427	0.949	0.004	0.004	0.4312	1227	857.3	1132	488.3	228.1	498.4	232.8	480.0	342.2	445.9	0.0536
Q-11[b]	2474-R-2-7A	2.128	1.420	0.873	0.002	0.002	0.4806	1212	856.3	1128	487.5	229.1	497.4	233.7	482.1	343.3	451.9	0.0555
Q-14	2474-R-3-4A	2.137	1.382	0.908	0.003	0.004	0.4510	1207	880.6	1124	486.4	227.6	497.8	232.9	479.8	352.0	449.8	0.0589
Q-15	2474-R-2-3B	2.131	1.403	0.826	0.003	0.003	0.4944	1235	872.6	1144	487.7	228.9	498.3	233.8	491.5	347.7	455.8	0.0578
Q-16[b]	2474-R-2-1A	2.132	1.389	0.798	0.002	0.005	0.5123	1240	873.3	1155	485.7	227.8	496.8	233.0	493.8	349.7	461.5	0.0549
Q-19	2474-R-2-5A	2.130	1.350	0.805	0.004	0.004	0.5060	1253	895.6	1170	485.2	227.8	497.6	233.6	500.8	359.4	468.7	0.0556
Q-20	2474-R-2-4B	2.125	1.422	0.843	0.004	0.003	0.4821	1203	850.1	1124	486.6	229.0	496.3	233.6	486.8	342.2	451.6	0.0565

a. Pressure transducer failure.

b. Nozzle closure vented just before firing with 1/8-inch hole.

A sectioned case with a hot spot was found to contain four full propellant slivers and one half sliver corresponding to the five port star points. The hot spot on the case was located adjacent to the partial sliver. Further, the inhibitor was intact except in the area adjacent to the hot spot, where it was charred and burnt. The interiors of the other eight motors with hot spots were visually examined through the igniter ports. The condition of the propellant slivers in these units appeared to be similar to that of the slivers in the sectioned case.

The above physical data indicate that the grain had cracked radially through the web in one star point. The failure initiated at the head end of the grain on ignition and immediately propagated longitudinally down the full length of the grain. In the motor with two hot spots (Q-2), cracking evidently started in two star points, but relaxed in one location after the other crack had propagated the full length of the grain.

4.6.2 Ballistic Analysis

To substantiate the above conclusion, the ballistic properties of a grain cracked through the web were analyzed. The maximum chamber pressure of the normal motor, Q-17, was 908 psia. The average maximum pressure for the nine abnormal motors was 1019 psia. If it is assumed that all ten motors have the same throat areas, the following equation applies:

$$\frac{P_1}{P_2} = \left(\frac{S_1}{S_2}\right)^{\frac{1}{1-n}}$$

Here, the subscript 1 applies to the normal motor and subscript 2 to the average of the abnormal motors. The parameters P and S represent the maximum chamber pressure and the propellant burning surface, respectively. The burning rate exponent, n, is 0.44. Maximum pressure is used in this analysis rather than ignition pressure since the latter is affected by the erosive burning experienced in the narrow propellant crack during

ignition. (Maximum pressure, defined as the highest pressure excluding ignition, occurs immediately after the ignition peak.)

The percentage increase in surface area required to yield a rise in pressure from 908 to 1019 psia was calculated to be 6.8 per cent. The theoretical initial surface area for a normal grain is 81 square inches. A single plane radial crack through the web, running the full length of the grain, increases the burning surface area by 6.9 square inches, or 8.5 per cent. In actual operation, a complete, full-length crack would not be experienced. Thus, percentage increase calculated from ballistic considerations is in reasonable agreement with that derived from geometric considerations.

The surface-web burning histories for both a normal and a cracked grain are presented in Figure 16. This plot indicates that a cracked grain will result in more regressive burning than a normal grain. The initial-to-final pressure ratio for a normal grain is about 1.2; for a cracked grain it is 1.7.

Both the physical observations and analytical results support the conclusion that a radial crack occurred in the grain web on ignition. The cause of the crack is attributed to a pressure differential across the web at the head end of the grain. The resulting increase in burning area and change in grain geometry caused the abnormal ballistic performance of the nine -30°F motors. The ballistic records and total impulse values for these motors, however, indicate that there was no loss of propellant.

4.6.3 Stress Analysis

The structural behavior of the grain was also examined. The critical condition for a star-ported, internal-burning grain, retained as in the MARC 7G1 motor, occurs during the ignition transient interval. The rapid pressurization of the port during ignition produces a radial pressure gradient across the web of the grain. This condition occurs before the grain-to-case annulus is fully pressurized. During this period, the propellant tube has negligible radial stiffness and is, thus, easily deformed outwards toward the case wall.

Figure 17 compares the differential pressure required to expand the grain out to the case wall with that required to strain the propellant to its yield and rupture points. At -30°F, a differential of 76 psi is required before the grain expands to meet the case, whereas only 36 psi is sufficient to strain the propellant to the limit of its capacity. Thus, excessive propellant strains may be anticipated in the low temperature region. At higher temperatures, the motor case limits the maximum propellant strain to acceptable values.

4.7 IGNITION PRESSURE REDUCTION TESTS

4.7.1 Test Objectives

A limited series of tests was conducted to determine if the pressure differential occurring across the web at ignition could be sufficiently reduced by lowering the pressure generated by the igniter. This study was divided into three stages, as follows:

- Hydrostatic pressure tests of igniter bodies with various rupture discs to reduce the internal igniter pressure required for the disc to fail.
- Bomb tests of igniters with various rupture discs and ignition charges to reduce the peak pressure generated by the igniter.
- Static firing tests of motors using modified igniters to evaluate the effect of the changes resulting from the above tests.

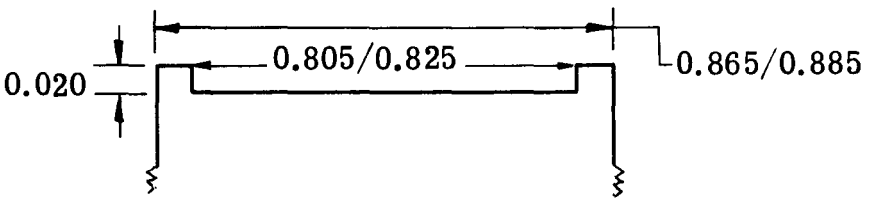
To assist in this program, the NASA Lewis Research Center returned four of 12 MARC 7G1 motors delivered earlier by Atlantic Research Corporation. Serial numbers of these units were D-31, D-34, D-35, and D-36.

4.7.2 Hydrostatic Pressure Tests

The first three hydrostatic pressure tests were conducted with igniter bodies similar to those used in the motor evaluation test program.

The rupture discs consisted of 2-mil-thick brass, induction soldered across the output end of the pellet chamber. Maximum rupture pressures of 400, 1000, and 1500 psi were measured in the three tests. In all three tests, failure occurred at the solder joint. The intensity of the initial break, however, varied considerably. (See Figure 18.) Examination of the units after test indicated that the wide variation in rupture pressure and intensity of failure resulted from differing degrees of solder flow across the surface of the disc.

The igniter body was then modified to afford more uniform, reproducible solder joints. A 20-mil countersink was introduced to isolate the surface over which the solder could flow. The revised aft end of the igniter body is depicted below:



Two igniter bodies of this configuration, each with a 2-mil brass disc, were hydrotested. Solder joint failures occurred at pressures of 130 and 135 psi.

Four tests were then conducted with 1-mil aluminum discs bonded over countersunk igniter body ends with EC 1838 epoxy-polyamide adhesive (a product of the Minnesota Mining and Manufacturing Company). In two units, the disc was bonded only on the outer peripheral surface of the countersink. The discs in the other two units were pressed in place to conform to the countersink and bonded over the full end surface. Reproducible rupture pressures were obtained with both configurations. Maximum pressures of 30 psi were measured in both edge bond tests. Values of 60 and 63 psi were obtained in the full-surface bond tests.

4.7.3 Igniter Bomb Tests

Five igniter bomb tests were conducted to measure peak pressures generated by igniters with bonded, 1-mil aluminum rupture discs. Free volume of the bomb was 3.75 cubic inches. Boron-potassium-nitrate 2D pellets were used as the main charge in the first three tests. Results were as follows:

Number of 2D Pellets	Disc Bond Surface	P_{max} (psi)
12	Full	1637
17	Full	1815
17	Edge	1933

Igniters with inert pellet charges were used in the last two bomb tests. One-mil aluminum discs with full-surface bonds were employed in both tests. No pressure was measured in the first test; the main objective here was to determine the effect of the squib on the pellets and the rupture disc. Post-test examination showed that the squib had caused the disc to fail and the ignition pellets to be consumed. The test was then repeated and pressure monitored. A maximum pressure of 300 psi was recorded.

4.7.4 Static Firings

Four motors were static fired to determine if the above reductions in igniter pressure generation would prevent the grain from cracking at low temperatures. All motors were fired with vented closures at a simulated altitude of more than 100,000 feet.

The igniter in the first motor, Number D-36, was loaded with eleven 2D pellets and had an edge-bonded, 1-mil aluminum rupture disc. The motor was conditioned to -30°F before firing. On application of ignition current, the igniter functioned, but the propellant failed to ignite. X-ray, followed by disassembly and visual examination, showed that the grain had cracked radially through its web in one star point. The crack initiated 3 inches from the head end and propagated longitudinally to the aft end of the grain. The

crack may be seen in the aft end view of the motor chamber shown in Figure 19. Peak pressure generated by the igniter in this test was determined to be only 247 psia.

The results of firing D-36 showed that igniter brisance could not be reduced sufficiently to prevent grain cracking and still ignite the propellant at -30°F. Thus, the firing temperature for the next three motors was increased to 0°F. The igniters in these motors all contained seventeen 2D ignition pellets. One motor, D-35, was not modified before firing. Its igniter body was subjected to three 800-psi hydrostatic proof tests to assure that the brass disc solder joint could withstand operating pressures of the same magnitude.

Test results from the three 0°F firings are summarized below.

Motor Number	Rupture Disc Material	Disc Joint	P_{max} (psia)	Grain Cracked
D-34	1-mil Aluminum	Edge Bond	991	No
D-35	2-mil Brass	Solder	948	Yes
D-31	1-mil Aluminum	Edge Bond	1000	Yes

These data indicated that the reduced pressure contributed by the igniter at 0°F was still sufficient to cause propellant cracking. Thus, no further tests were conducted in this series.

4.8 REDESIGN OF PROPELLANT GRAIN AND RETENTION SYSTEM

Detailed stress and gas dynamics analyses indicated that eliminating the low temperature grain fracture would require either constraining the radial deformation of the grain during pressurization or greatly reducing the web pressure differential. Modifications designed to effect these changes were evaluated in three motors tested at -30°F and a simulated altitude in excess of 100,000 feet. The hardware for these tests consisted of refurbished components from the original program.

On November 19, 1965, Motor DX-5 was tested to evaluate the effectiveness of a six-ply nylon cloth inhibitor impregnated with epoxy-polyamide resin. This inhibitor is the same as that used in the MARC 7 motors employed on the TITAN and ATHENA vehicles. The output end of the igniter body was countersunk as described above. The igniter was otherwise identical to those used in the original motor evaluation firings: a 2-mil brass disc was soldered over the aft end, and the ignition charge consisted of seventeen 2D pellets. The motor burned for 1.009 seconds (web time), producing an ignition pressure peak of 1257 psia and a maximum pressure of 1024 psia. These values, the regressive shape of the ballistic records, and the post-test appearance of the motor case indicated that the grain had cracked during startup. This result showed that increasing the inhibitor strength alone does not impart sufficient radial support to eliminate web fracturing at low temperature.

The motor configuration for the next two tests, DX-6 and DX-7, is shown in Figure 20. Design revisions evaluated in these firings were as follows:

- A vented silicone rubber cap bonded to a laminated epoxy-fiberglass inhibitor disc on the head end of the grain.
- A six-ply, nylon-epoxy circumferential inhibitor.
- An igniter body with a 2-inch brass rupture disc soldered to a countersunk aft end.
- Three 1/2- by 1/4-inch, epoxy-fiberglass rectangular tabs bonded to the aft end of the grain.

In the original motor design, the outside of the grain was vented only at its aft end. The introduction of channels in the silicone head cap thus permitted gases to vent to the outside of the grain at both ends of the motor. This change greatly reduces the web pressure differential since the

maximum time required to sense pressure in the annulus is approximately halved. Such a design solution had been considered earlier, but was not adopted because of the possibility of creating a thermal problem. Venting both ends of the grain results in an axial pressure differential, which causes the gases to flow down the motor between the outside of the grain and the inside of the motor case. The flow could possibly have an adverse effect on either the effectiveness of the grain inhibiting system or the integrity of the uninsulated motor case, or both.

The epoxy-fiberglass tabs served as spacers between the aft end of the grain and the forward shoulder of the nozzle body. Their adoption permitted the spring-steel wave washer to be deleted. The washer, if sufficiently compressed, could act as a gasket and restrict the free flow of gases into the annulus around the grain.

Both motors performed satisfactorily. Maximum ignition pressures were only slightly above 1000 psia and the web burning times of 1.18 and 1.21 seconds were as expected for a normally operating motor at -30°F. The relatively neutral ballistic traces and the normal, unheated appearance of the motor cases confirmed that the grains had not cracked. Thrust- and pressure-time traces and test data sheets for these two firings are presented in Appendix D.

5.0 IGNITER PROOF TESTS

5.1 SQUIB ACCEPTANCE TESTS

The igniter is initiated with a redundant squib system capable of withstanding 1.0 ampere or 1.0 watt for 5 minutes without firing. For this contract, the Hercules Powder Company produced over sixty S-228A2 squibs, of which 35 were delivered and 25 expended in a lot acceptance test program. The acceptance test sequence was as follows:

a. Inspection - The entire squib lot was checked for workmanship and dimensional quality and then serialized starting with 00001.

b. Hermetic Seal - Each squib was tested in accordance with MIL-STD-202, Method 112, procedure IIIa, for conformance to the maximum helium leak rate requirement of less than 1.0×10^{-7} cc/sec. Three units failed this test and were removed from the lot.

c. Insulation-Resistance - The insulation resistance of the first 33 squibs was measured at 1000 V.D.C. Thirty squibs had resistances of more than 50 megohms; however, the other three units fired when the insulation resistance broke down. The remainder of the units were tested at 500 V.D.C. Insulation resistance for these squibs were all in excess of 50 megohms. With Atlantic Research concurrence, Hercules agreed to certify all future units to 50 megohms at 500 V.D.C.

d. Bruceton - A 25-unit sample was selected from those squibs which had passed all previous tests and inspections. A Bruceton test series was then conducted starting at 1.275 amperes and increasing the current in 0.075-ampere increments. Current was applied to one bridgewire for 30 seconds in each test. The first firing occurred at 2.250 amperes. (See Table IX.) As a result of the low initial current, no firing current data were obtained for the first 13 units. Thus, the Bruceton analysis was conducted on data from only the five units which fired. Based on these data, a rough estimate of the 50 per cent firing point is 2.33 amperes with a standard deviation of

Table IX. Bruceton Test Results.

Squib S/N:	00069	00033	00075	00052	00030	00071	00077	00085	00020	00057	00005	00079	00087	00003	00054	00073	00007	00081	00064	00068	00072	00013	00002	00066	00074
Current Level (amp)																									
1.275	0																								
1.350		0																							
1.425			0																						
1.500				0																					
1.575					0																				
1.650						0																			
1.725							0																		
1.800								0																	
1.875									0																
1.950										0															
2.025											0														
2.100												0													
2.175													0		0		0								
2.250														X		X		0						0	
2.325																			0		0		X		0
2.400																				X		X			
2.475																									
2.550																									

0 = No Fire
X = Fire

0.22 ampere. Plus or minus three standard deviations results in a maximum no-fire level of 1.67 amperes and a minum all-fire level of 2.99 amperes.

e. Function Time - Ten of the unfired units from the Bruceton test series were fired with currents of 3.0, 4.0, or 5.0 amperes applied to one bridgewire. Results were as follows:

Unit S/N	Current Level (amperes)	Time (milliseconds)
00075	3.0	22.86
00033	3.0	10.47
00020	3.0	22.47
00077	3.0	10.00
00071	3.0	no fire after 30 milliseconds
00057	4.0	4.44
00085	5.0	3.21
00007	5.0	3.42
00073	5.0	3.17
00005	5.0	3.08
00071	5.0	3.65[1]

5.2 CLOSED BOMB FIRINGS

Six fully assembled igniters were fired to evaluate the following:

- Ability of the squib to reliably ignite 2D pellets.
- Ability of the main charge to reliably ignite Arcite propellant.
- Ability of the igniter assembly to withstand motor operating pressures when threaded in the motor case.

Each of the six test igniters was threaded into a closed right circular cylinder with a 3.75-cubic-inch free volume. A propellant charge was also placed in the bomb to effect a maximum chamber pressure of

1. After no fire at 3.0 amperes.

6000 psi. A current of 5 amperes was applied to each bridgewire, and the current and bomb pressure were recorded. The firing curves are presented in Figure 21 the data are summarized in Table X. Parameter definitions are as follows:

- t_d - Delay from switch-on to 10 per cent P_{max}
- t_i - Delay from switch-on to 90 per cent P_{max}
- t_r - Time from 10 to 90 per cent P_{max}
- P_{max} - Maximum pressure
- P_r - Residual pressure at 0.5 second after current application
- ΔP - Pressure loss in 0.5 second due to cooling

The first firing was a preliminary test to determine the propellant charge required to achieve a 6000-psi pressure. The 2.25-gram charge resulted in a maximum pressure of only 4360 psi. The charge was thus increased to 2.75 grams in the remaining five tests. These firings were all successful: all data were within specifications and indicated that the igniter would perform its required function.

An additional eight igniters were subjected to proof cycle "B" for 10 seconds. One ampere was applied to both bridgewires connected in series. No detrimental effects were observed. One of these igniters was then subjected to a current soak test in which one ampere was applied to both bridgewires in series for 5 minutes. Post-test observations revealed no change in resistance, and the squib did not ignite.

Table X. Igniter Performance in Closed Bomb Tests.

Test Number	Propellant Weight (gm)	t_d (sec)	t_i (sec)	t_r (sec)	P_{max} (psia)	P_r (psia)	ΔP (psia)
1	2.25	0.002	0.088	0.086	4360	2430	1930
2	2.75	0.004	0.100	0.096	6229	3340	2889
3	2.75	0.004	0.076	0.072	6091	3710	2381
4	2.75	0.005	0.068	0.063	7352	5150	2202
5	2.75	0.005	0.077	0.072	5977	3460	2517
6	2.75	0.004	0.077	0.073	6343	4420[a]	1923[a]

a. Recording machine shut off prematurely; P_r measured at 0.3 second.

6.0 CONCLUSIONS

The MARC 7G1 motor, as described in this report, was proven capable of withstanding the prefiring and operating environments required for use on the ATLAS-CENTAUR vehicle. Ballistic perfornamce measured in the 20-round motor evaluation program was within design objectives. The ten motors fired at 160°F afforded highly reproducible impulse performance. At -30°F, nine of the ten motors performed abnormally; however, total impulse values were still acceptable and reproducible.

Abnormal low-temperature ballistics were attributed to radial cracking of the propellant through the grain web. The crack, caused by a pressure differential across the web during ignition, was propagating longitudinally from the head end of the grain. Two design changes — a stiffer, nylon-epoxy inhibitor and the venting of gases from both ends of the motor into the annulus between the inhibited grain and the motor case — were shown to eliminate fracturing of the web at -30°F. It is thus recommended that the design changes shown in Figure 20 be incorporated into the MARC 7G1 motor prior to use on the ATLAS-CENTAUR.

Pertinent design and performance ratings for the MARC 7G1 motor are presented in Table XI. These data represent nominal values derived from: (1) batch acceptance firings at 75°F; (2) evaluation program firings at 160°F; (3) the firings of Motors Q-17, DX-6, and DX-7 at -30°F.

The Model 502 igniter was shown to be capable of withstanding 1.0 ampere (i.e., 1.0 watt) without firing and of functioning reliably with a current of 5.0 amperes applied to either bridgewire. Ignition delays and rise times obtained with this igniter were reproducible and unaffected by the number of functional tests prior to firing.

Table XI. Design and Performance Ratings for the MARC 7G1 Rocket Motor.

GRAIN PARAMETERS			
Type	Arcite 377A-9C		
Length (in)	8.440		
Weight (lb)	2.135		
Outside Diameter (in)	2.535		
Web (in)	0.4106		
Initial Surface Area (sq in)	81		
NOZZLE DIMENSIONS			
Throat Diameter (in)	0.555		
Throat Area (sq in)	0.2419		
Exit Diameter (in)	1.663		
Exit Area (sq in)	2.172		
Expansion Ratio	9.01		
OVER-ALL MOTOR PARAMETERS			
Length (in)	14.7		
Maximum Outside Diameter (in)	2.9		
Weight (lb)	5.07		
BALLISTIC PARAMETERS	**-30°F**	**75°F**	**160°F**
Ignition Delay, t_d (sec)	0.0053	0.0037	0.0038
Rise Time, t_r (sec)	0.009	0.008	0.004
Action Time, t_a (sec)	1.791	1.549	1.405
Burning Time, t_b (sec)	1.226	0.997	0.873
Maximum Pressure, P_{max} (psia)	922.4	1085	1217
Ignition Pressure, P_{ign} (psia)	1052	1348	1530
Average Action Time Pressure, P_a (psia)	663.3	779.6	865.5
Average Burning Time Pressure, P_b (psia)	850.3	1009	1132
Maximum Thrust, F_{max} (lb)	358.7	429.4	485.4
Ignition Thrust, F_{ign} (lb)	406.2	532.1	607.6

Table XI. (Continued)

BALLISTIC PARAMETERS (cont'd)	-30°F	75°F	160°F
Average Action Time Thrust, F_a (lb)	263.6	311.4	346.6
Average Burning Time Thrust, F_b (lb)	337.7	401.8	452.3
Action Time Total Impulse, I_a (lb-sec)	472.1	482.7	486.8
Deliverable Total Impulse, I_{0-0} (lb-sec)	479.1	492.7	497.4
Propellant Specific Impulse, I_{sp} (lb-sec/lb)	221.3	230.3	233.3

GLOSSARY OF BALLISTIC DEFINITIONS

t_a = Action time, defined as beginning when the pressure has risen to 10 per cent of the maximum chamber pressure and ending when the pressure has fallen to 10 per cent of the maximum chamber pressure.

t_b = Burning time, defined as beginning when the pressure has risen to 10 per cent of the maximum chamber pressure and ending when the pressure has dropped to 75 per cent of the maximum chamber pressure.

t_r = Rise time, defined as the time required for the pressure to rise from 10 per cent of the maximum chamber pressure to 75 per cent of the maximum chamber pressure.

t_d = Ignition delay, defined as the time from switch-on to the point on the pressure trace when the pressure has risen to 10 per cent of the maximum chamber pressure.

r = Average burning rate, defined as the average web thickness divided by the burning time.

P_{max} (F_{max}) = Maximum pressure (thrust), defined as the highest chamber pressure (thrust) developed by the rocket motor under any normal operating condition, excluding ignition.

P_a (F_a) = Average action time pressure (thrust), defined as the area under the pressure (thrust)-time curve between the action time limits divided by the action time.

P_b(F_b) = Average burning time pressure (thrust), defined as the area under the pressure (thrust)-time curve between the burning time limits divided by the burning time.

P_{ign} (F_{ign}) = Ignition pressure (thrust), defined as the highest chamber pressure (thrust) developed by the rocket motor during ignition.

C_d = Discharge coefficient, calculated by the following formula:

$$C_d = \frac{W_p}{\bar{A}_t \int P_a dt_a}$$

where

W_p = Initial propellant weight

$\bar{A}_t$ = Average of mean throat areas before and after firing as determined from throat diameters measured at three equally spaced locations around the throat.

C^* = Characteristic exhaust velocity, calculated by the following formula:

$$C^* = \frac{g\bar{A}_t}{W_p} \int_0^0 P dt$$

I_a = Action time total impulse, defined as the area under the thrust-time curve between the action time limits.

I_{0-0} = Deliverable total impulse, defined as the total area under the thrust-time curve.

I_{sp_a} = Action time specific impulse, defined as the action time total impulse divided by the initial propellant weight.

$I_{sp_{0-0}}$ (Propellant) = Propellant specific impulse, defined as the deliverable total impulse divided by the initial propellant weight.

$I_{sp_{0-0}}$ (Motor) = Over-all specific impulse, defined as the deliverable total impulse divided by the initial motor weight.

C_F = Thrust coefficient, defined as the product of the discharge coefficient and the action time specific impulse.

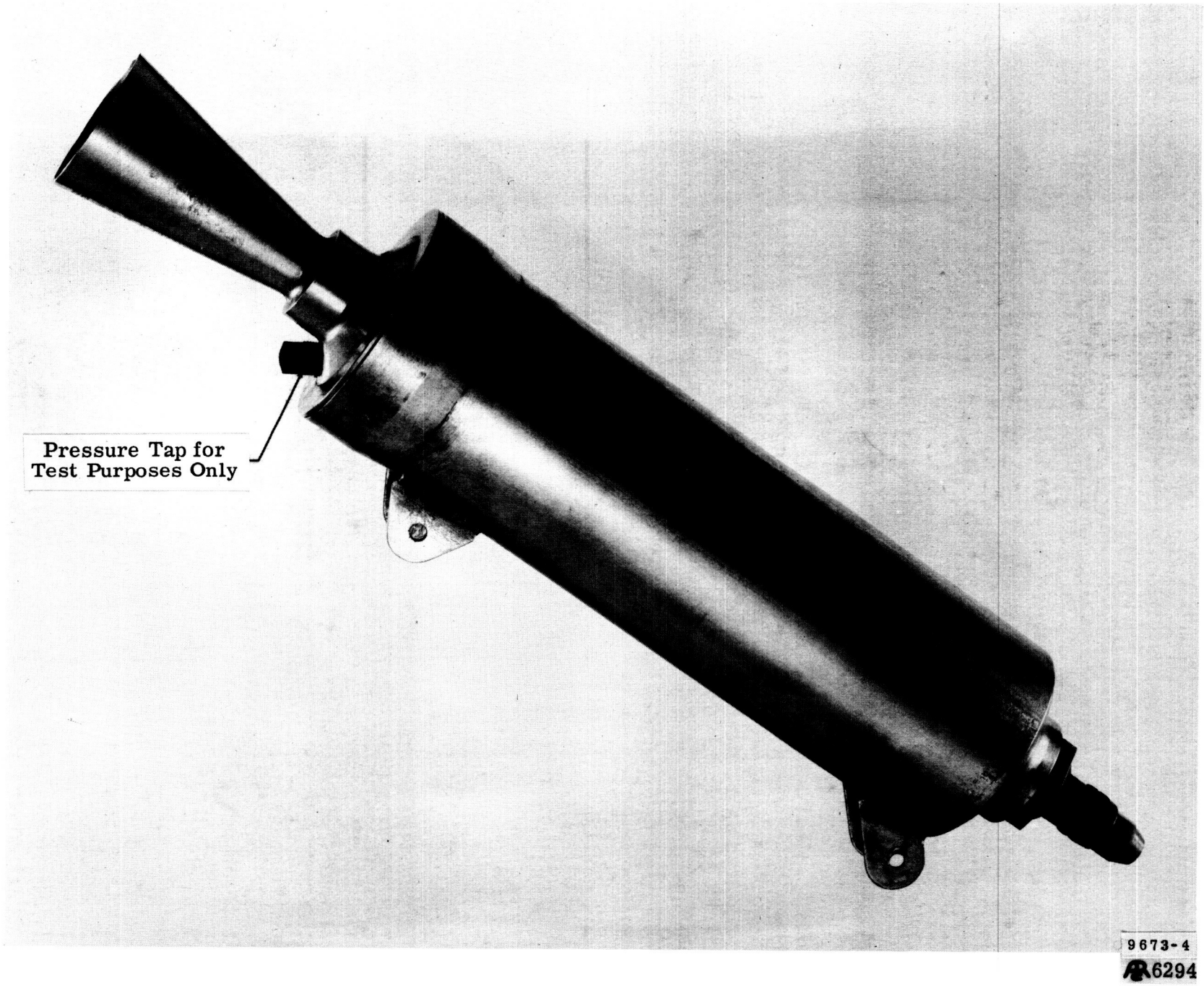


Figure 1. MARC 7G1 Rocket Motor.

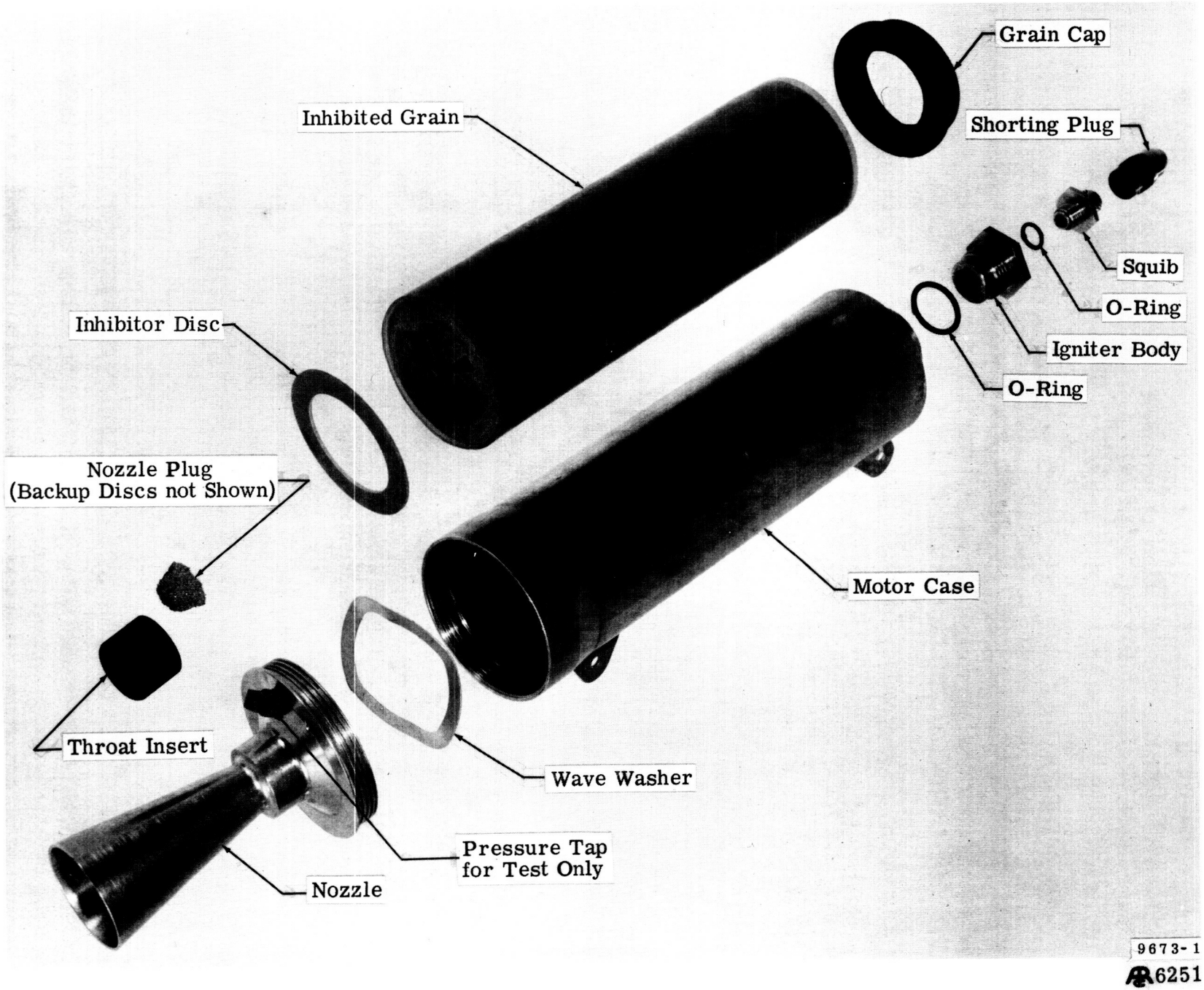


Figure 2. Major Components of MARC 7G1 Rocket Motor Tested in Original Evaluation Program.

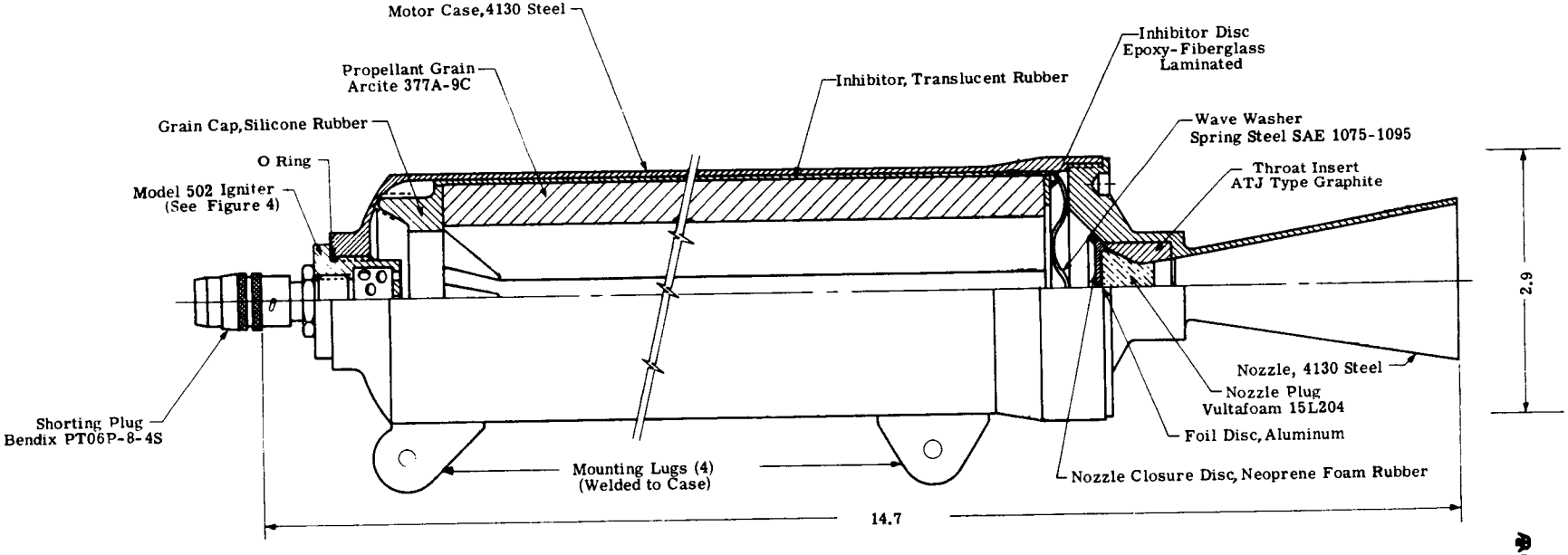


Figure 3. Cutaway View of MARC 7G1 Rocket Motor Assembly Tested in Original Evaluation Program.

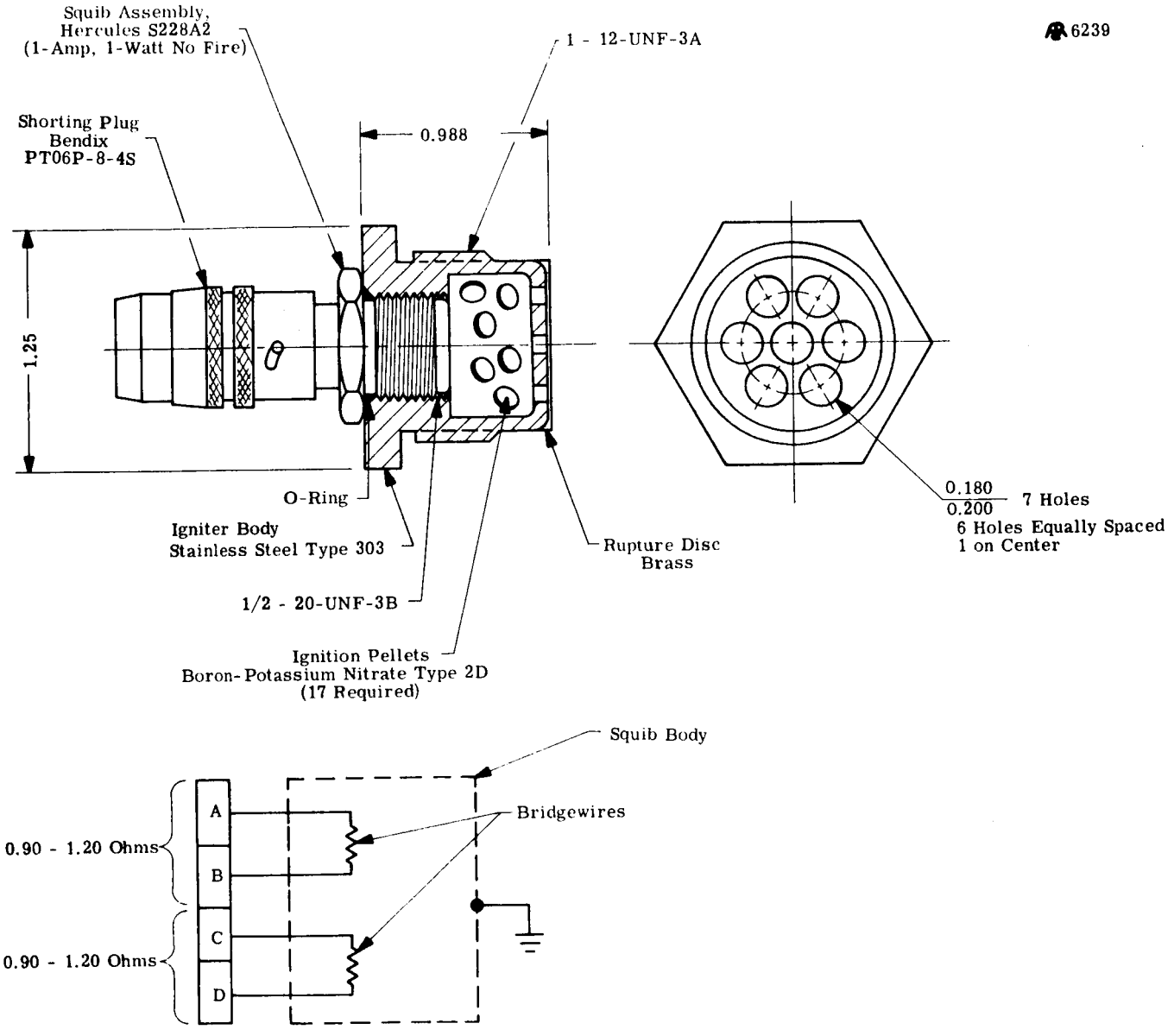


Figure 4. Cross Section and Circuit Schematic of Igniter Model 502 Tested in Original Evaluation Program.

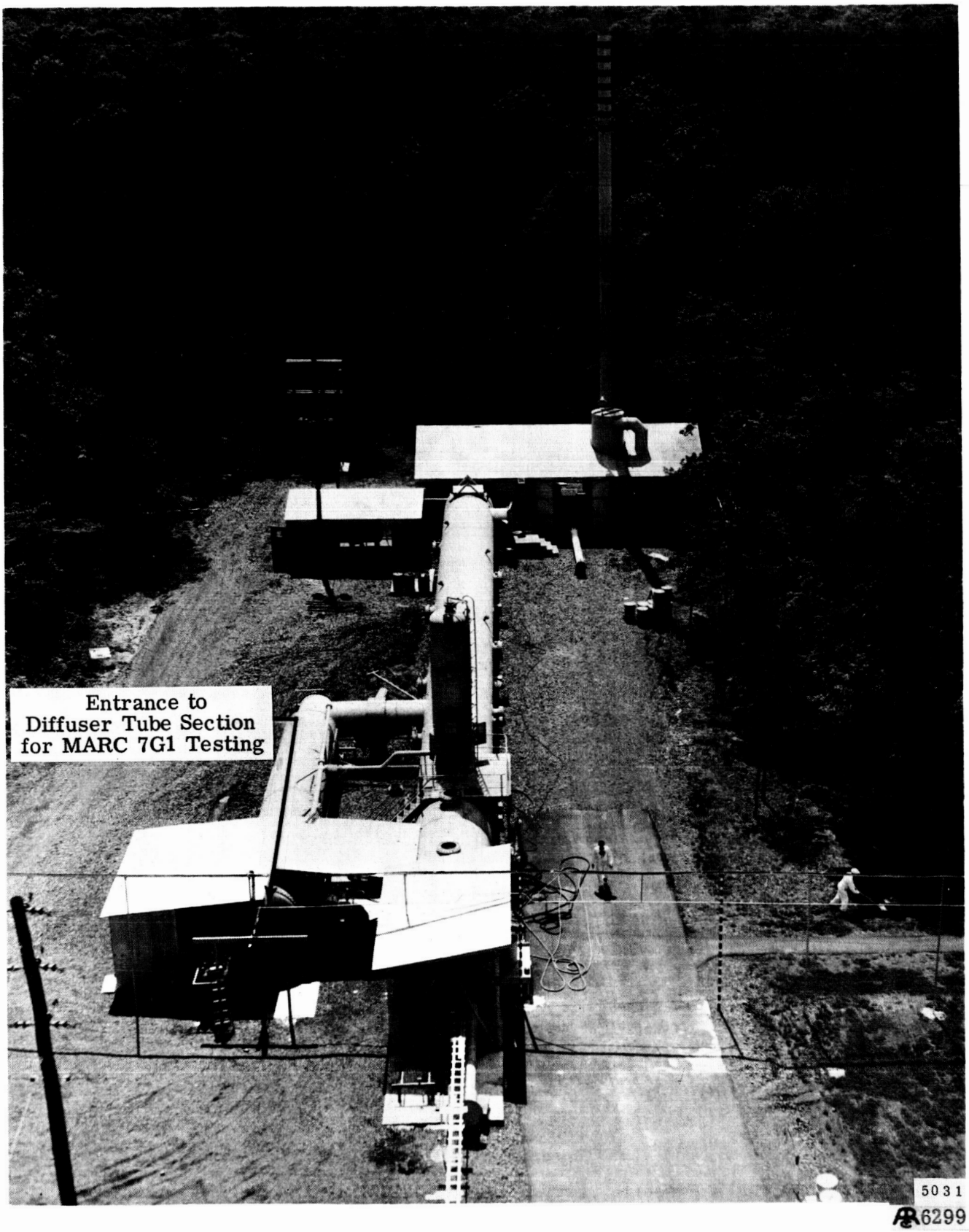


Figure 5. Vacuum Test Facility at Gainesville, Virginia.

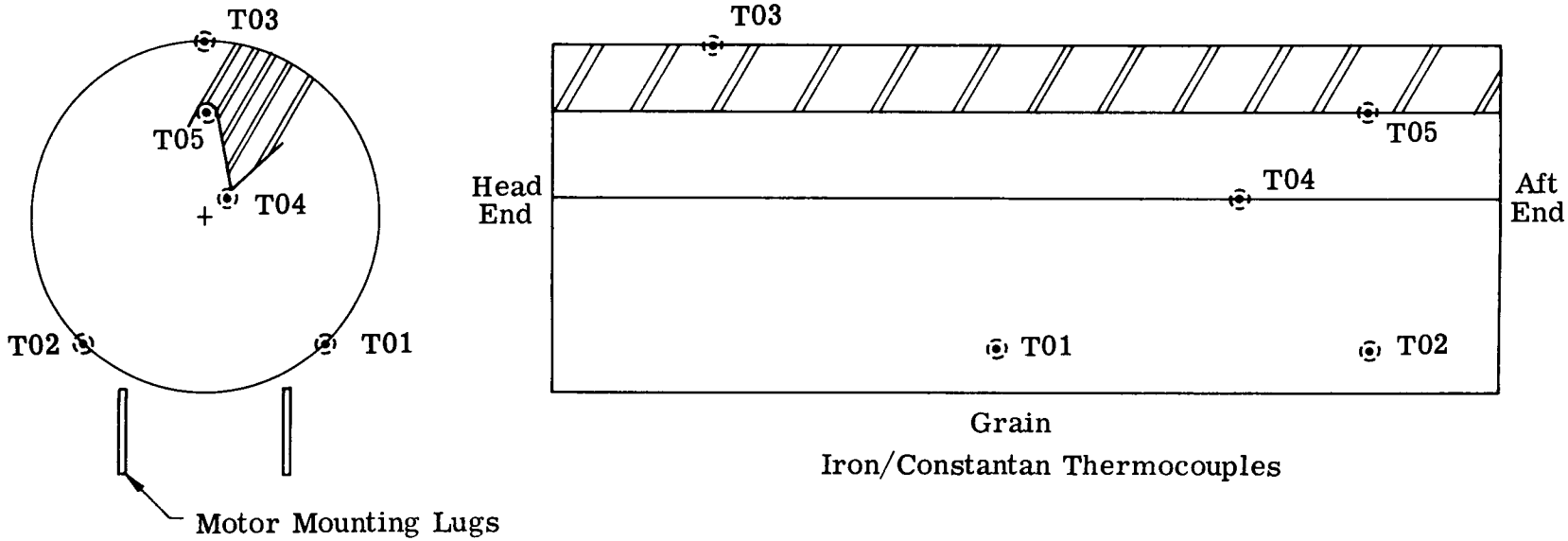


Figure 6. Thermocoupled MARC 7G1 Grain Configuration for Radiant Heat and Temperature Gradient Study.

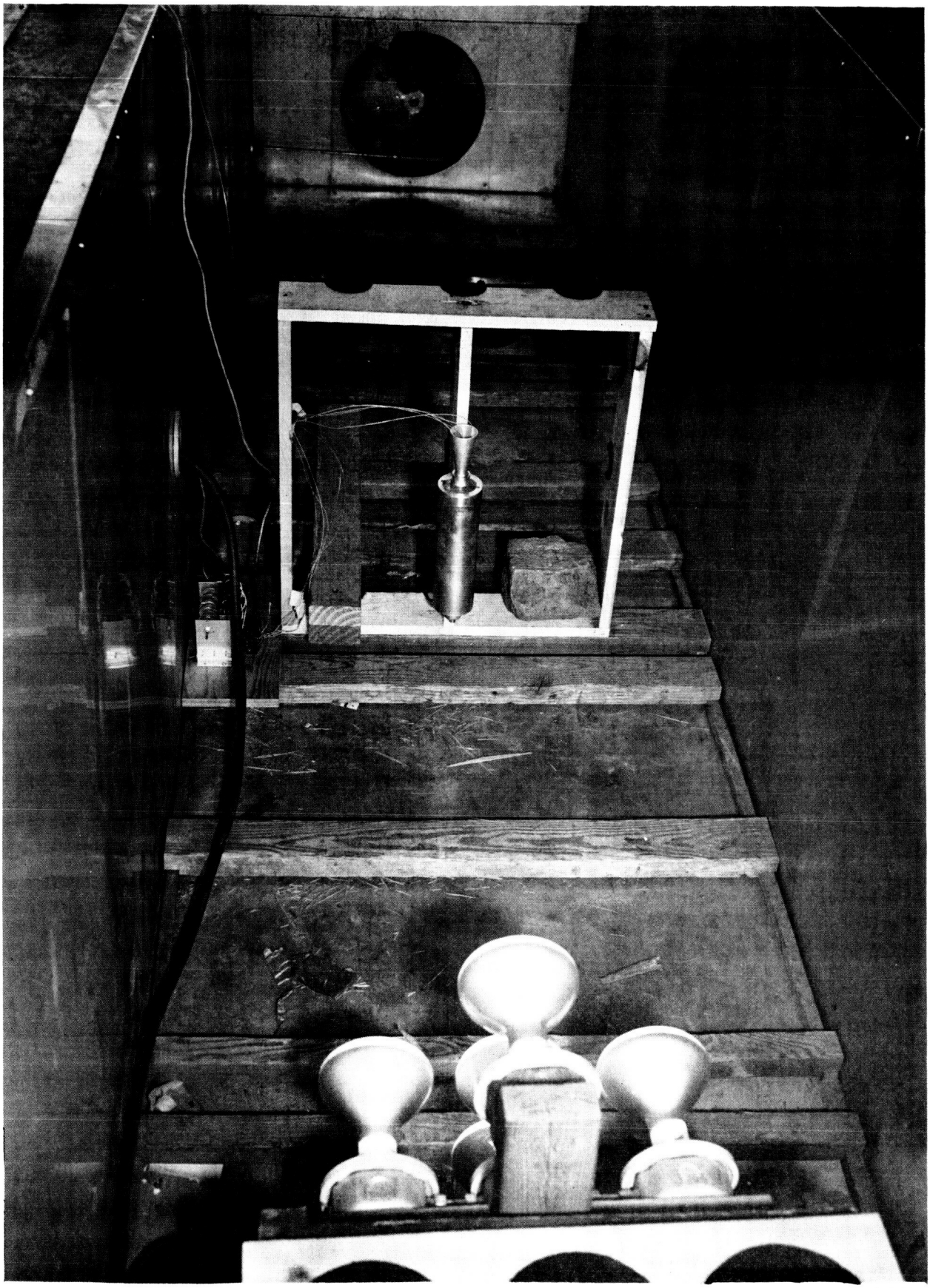


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Figure 7. Radiant Heat Test Arrangement.

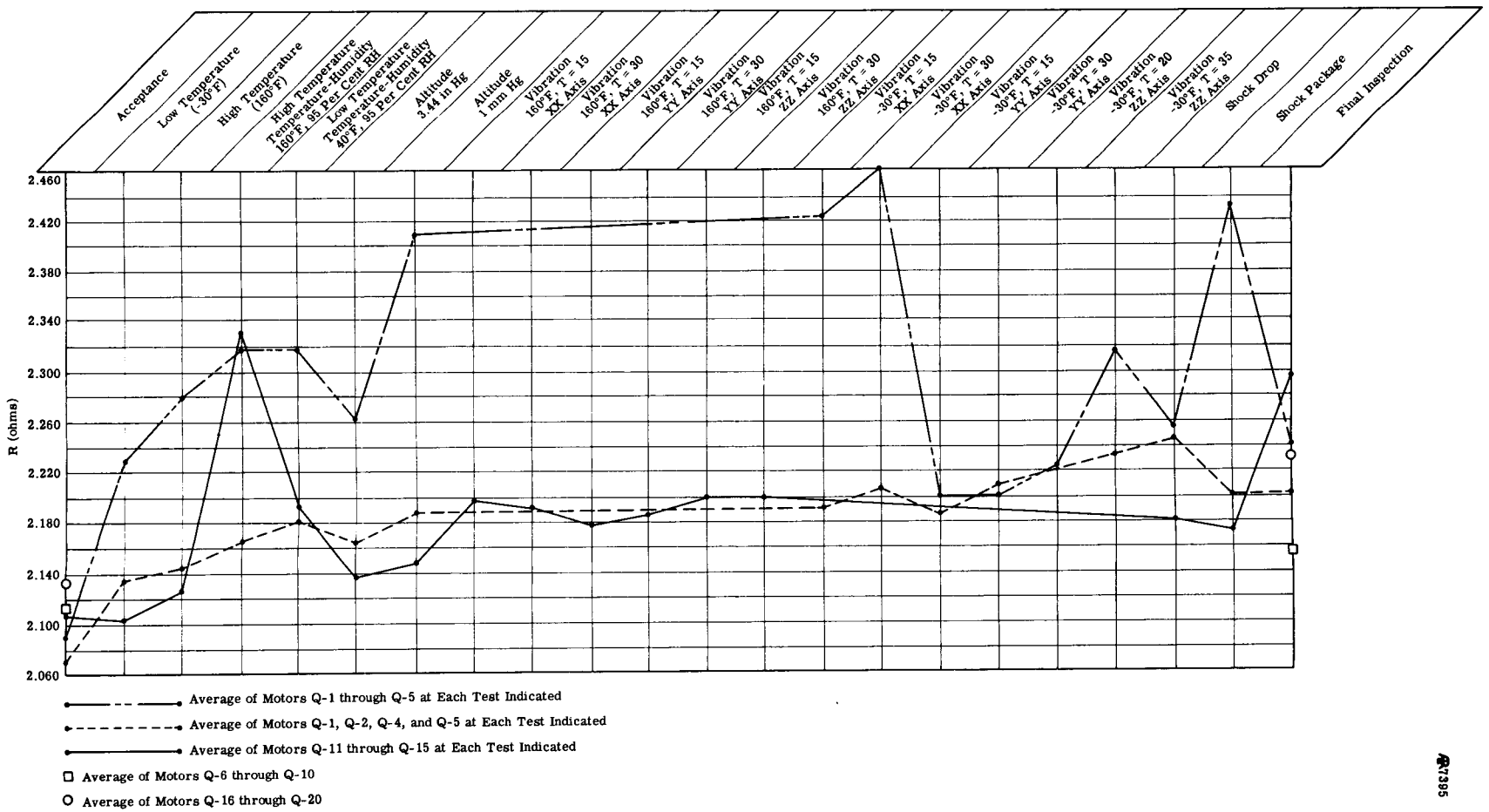


Figure 8. Change in Igniter Resistance During Environmental Test Sequence.

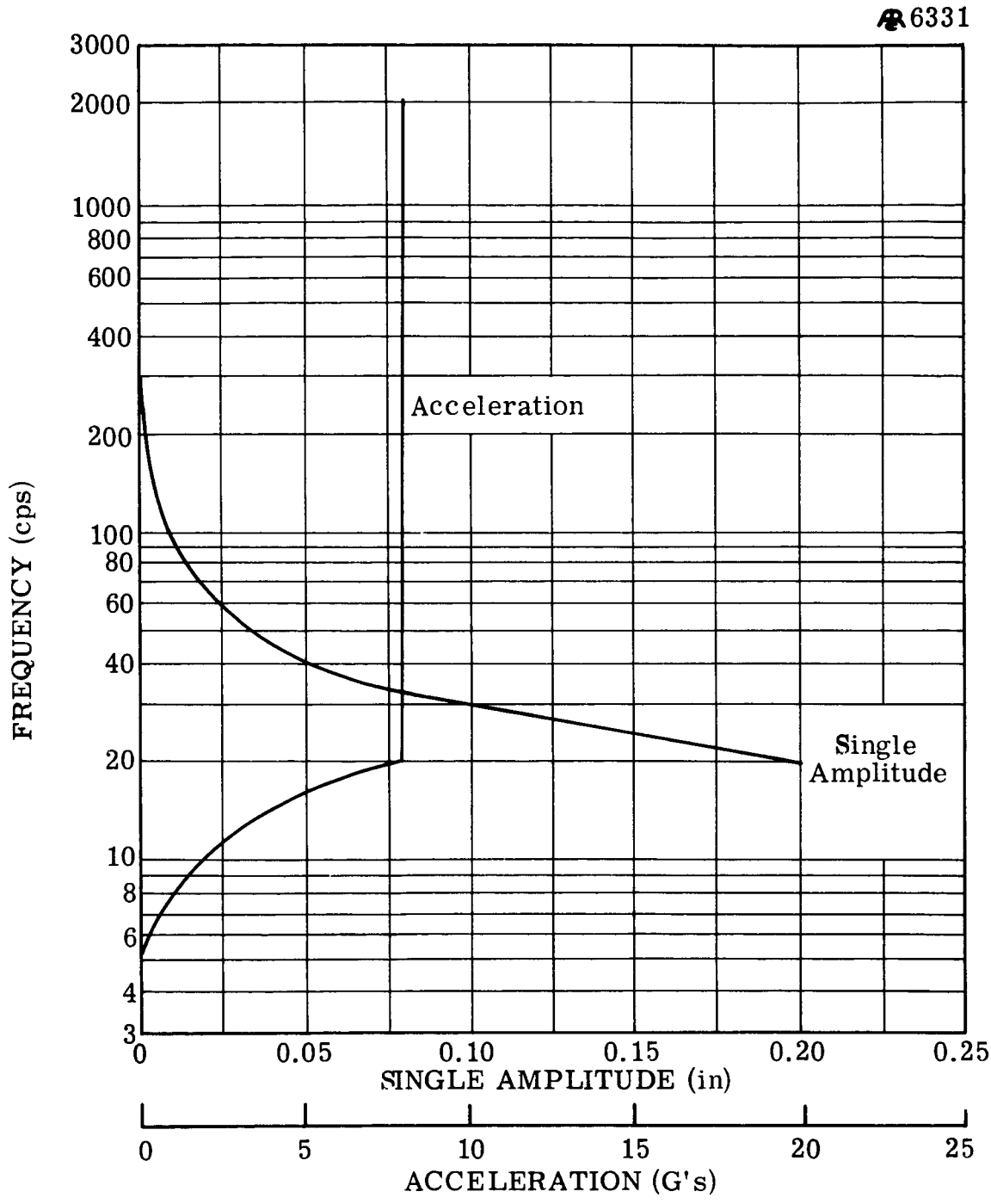


Figure 9. Sinusoidal Vibration Frequencies and Amplitudes.

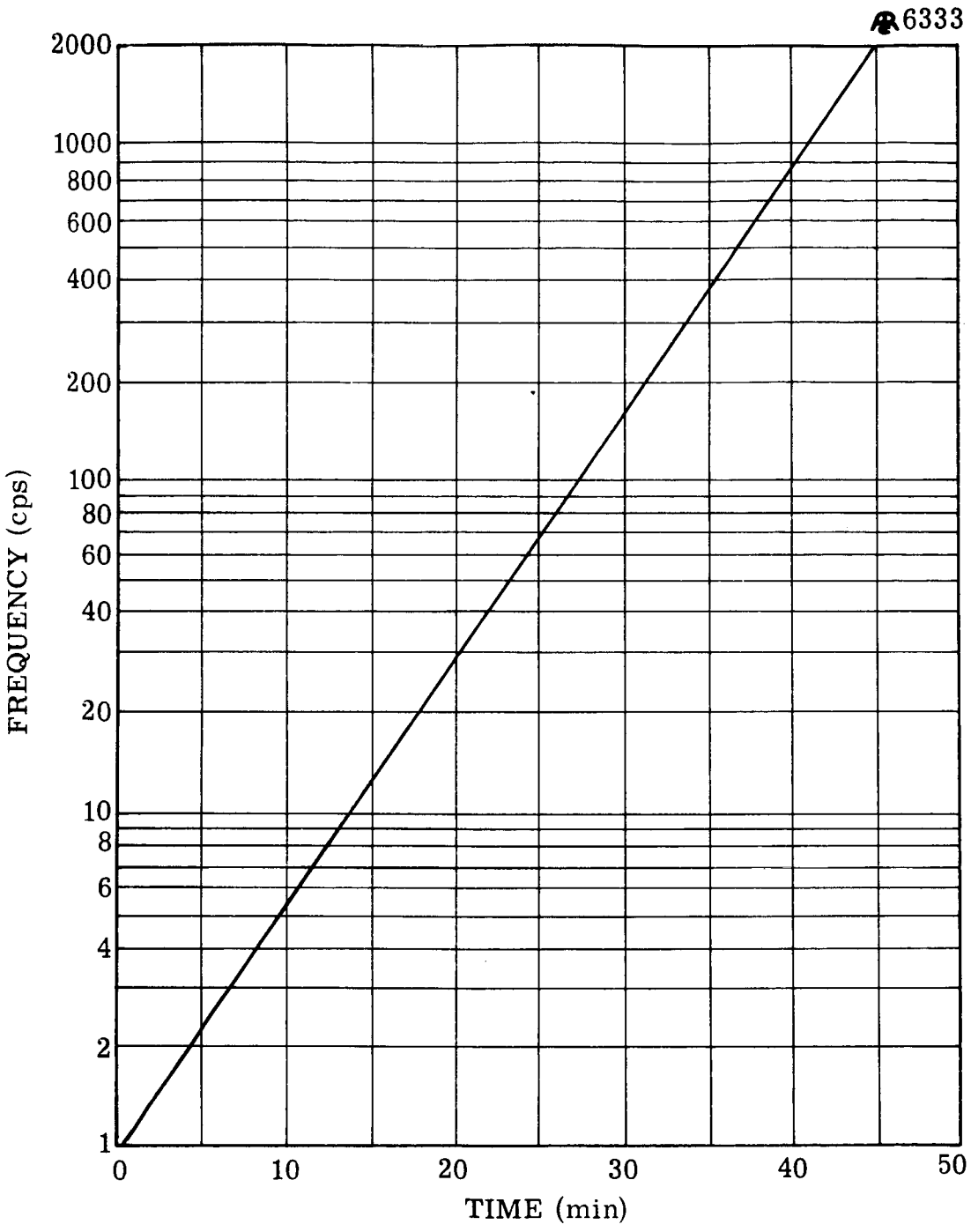


Figure 10. Sinusoidal Sweep Rate.

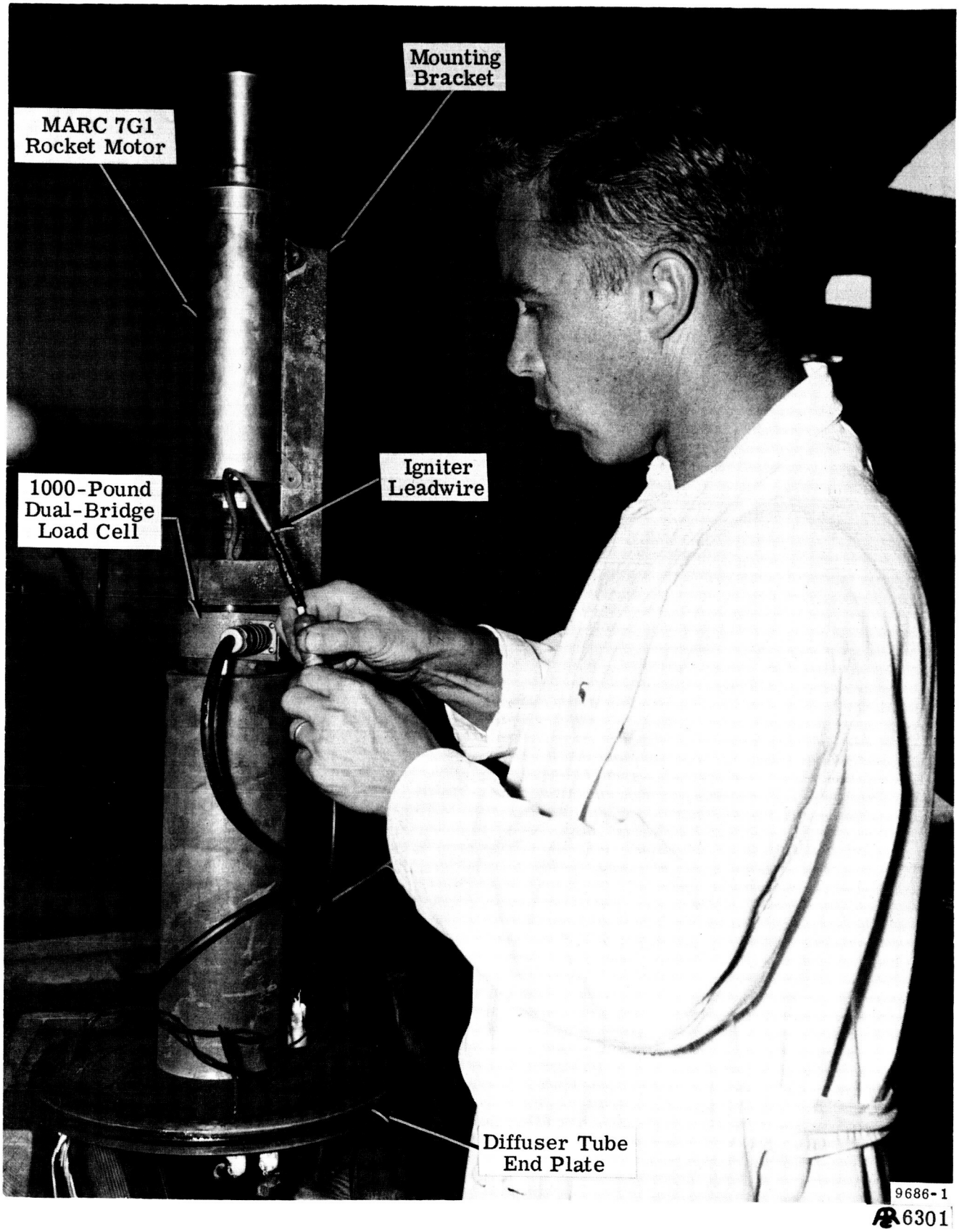
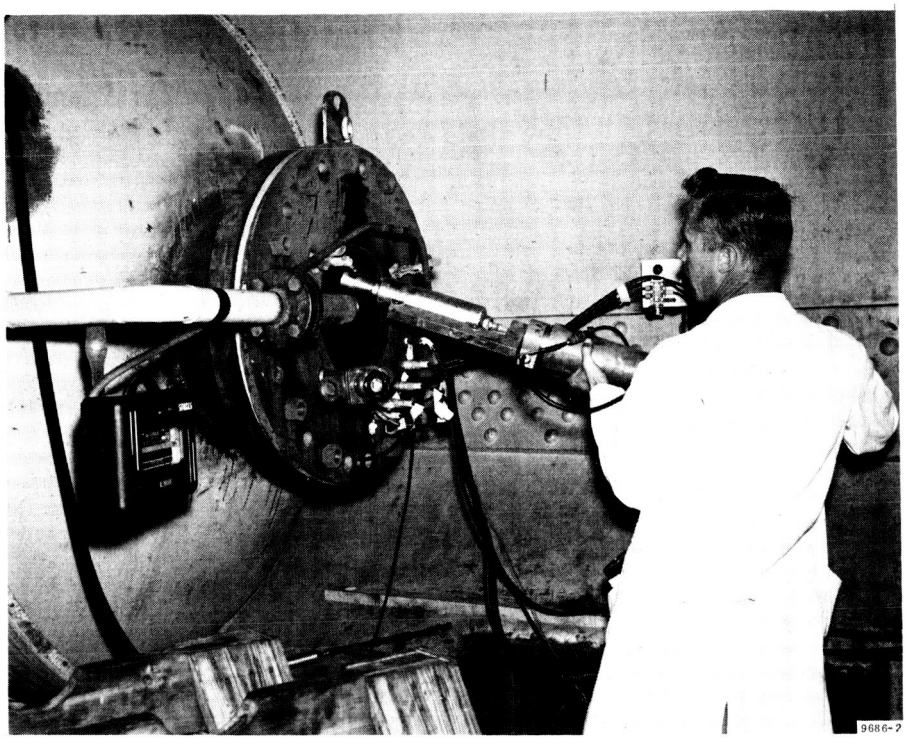
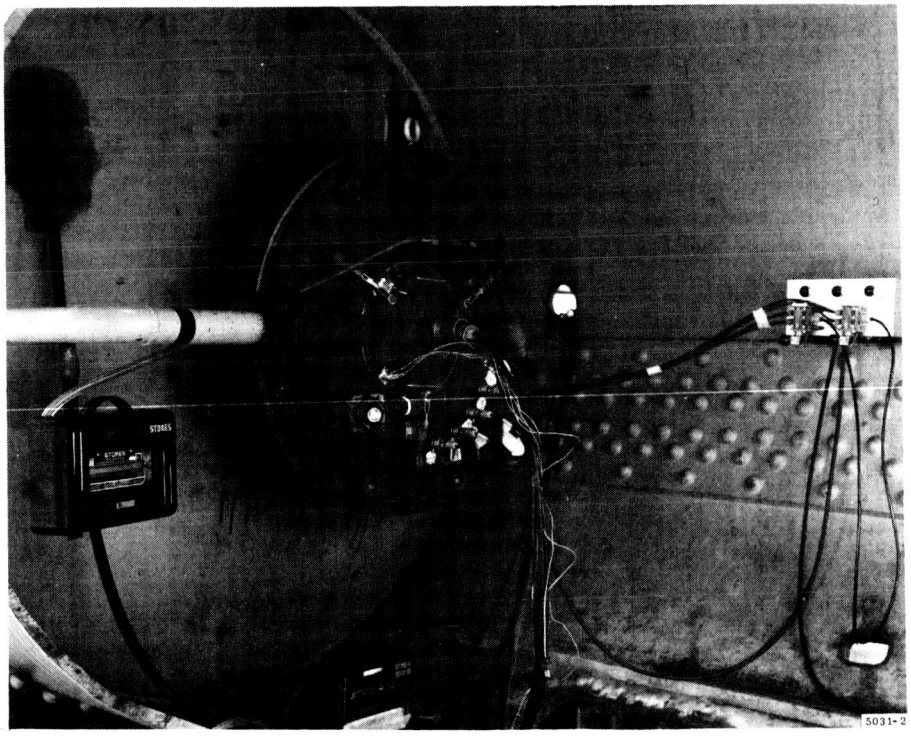


Figure 11. Instrumentation of Rocket Motor for Static Firing.



a. Insertion into Diffuser Tube.



b. Diffuser Tube Sealed for Firing. AR6290

Figure 12. Installation of Rocket Motor into Vacuum Chamber for Firing.

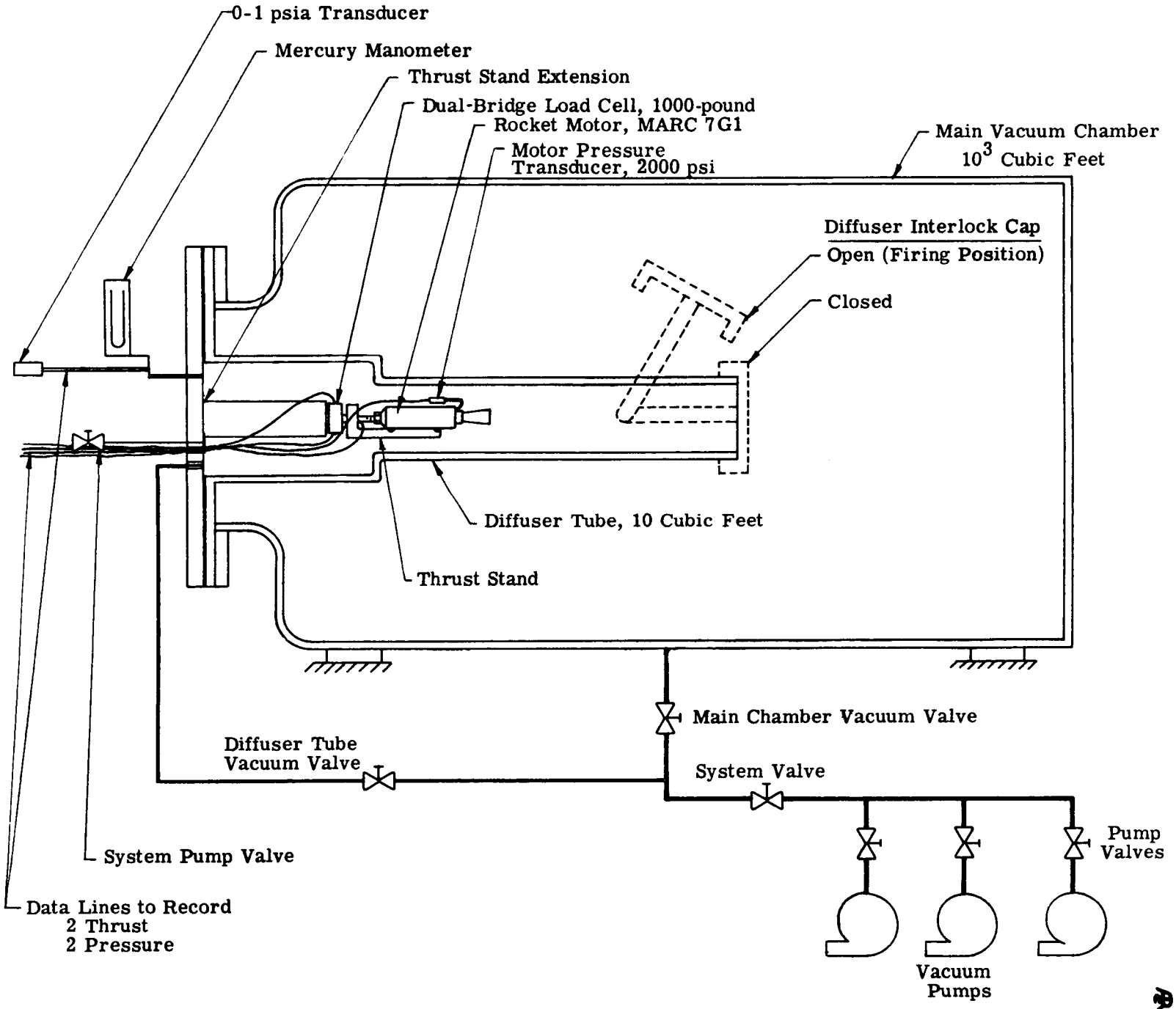


Figure 13. Schematic, Static Test Arrangement.

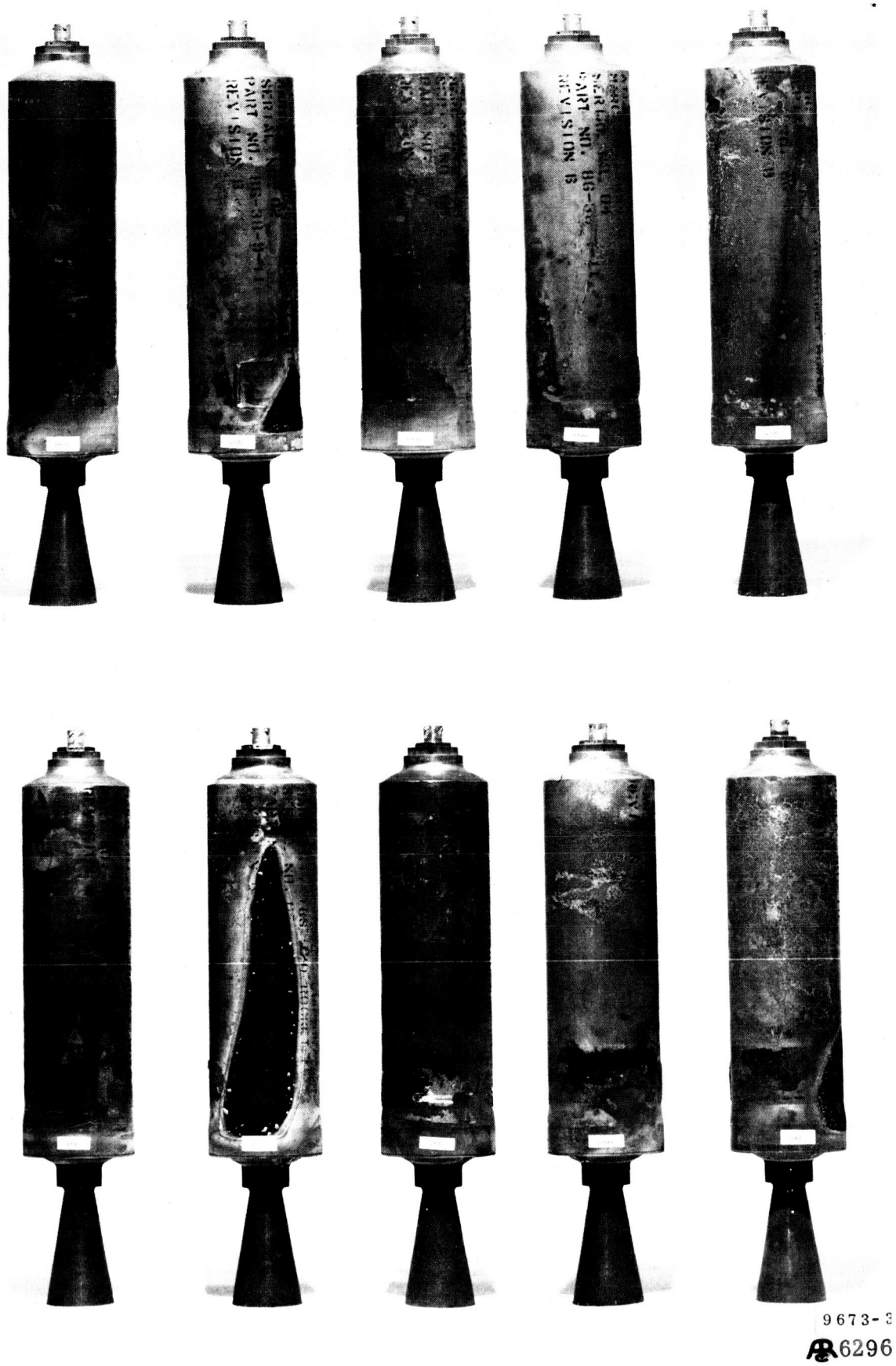


Figure 14. Rocket Motors Q-1 Through Q-10 After Firing.

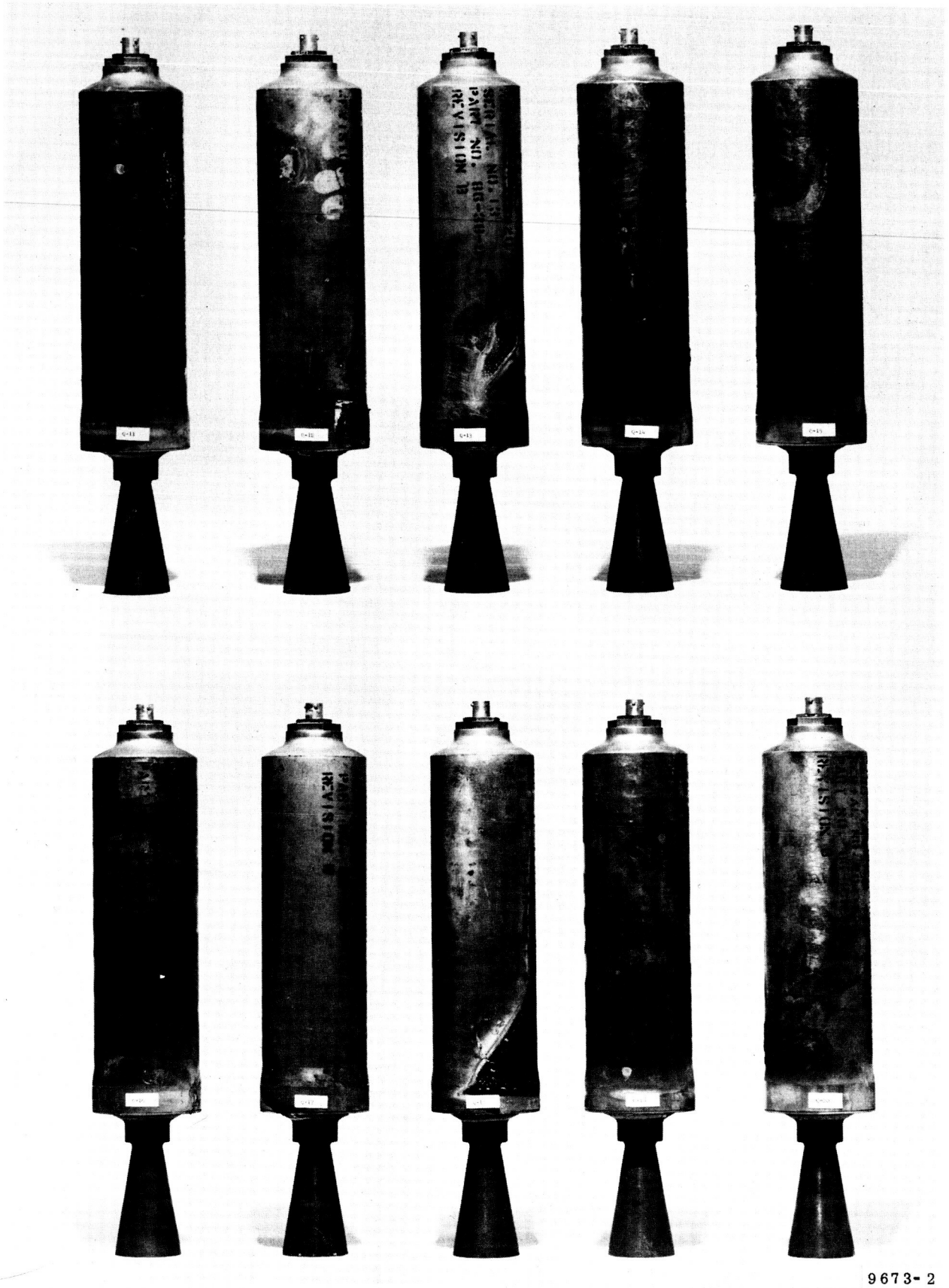


Figure 15. Rocket Motors Q-11 Through Q-20 After Firing.

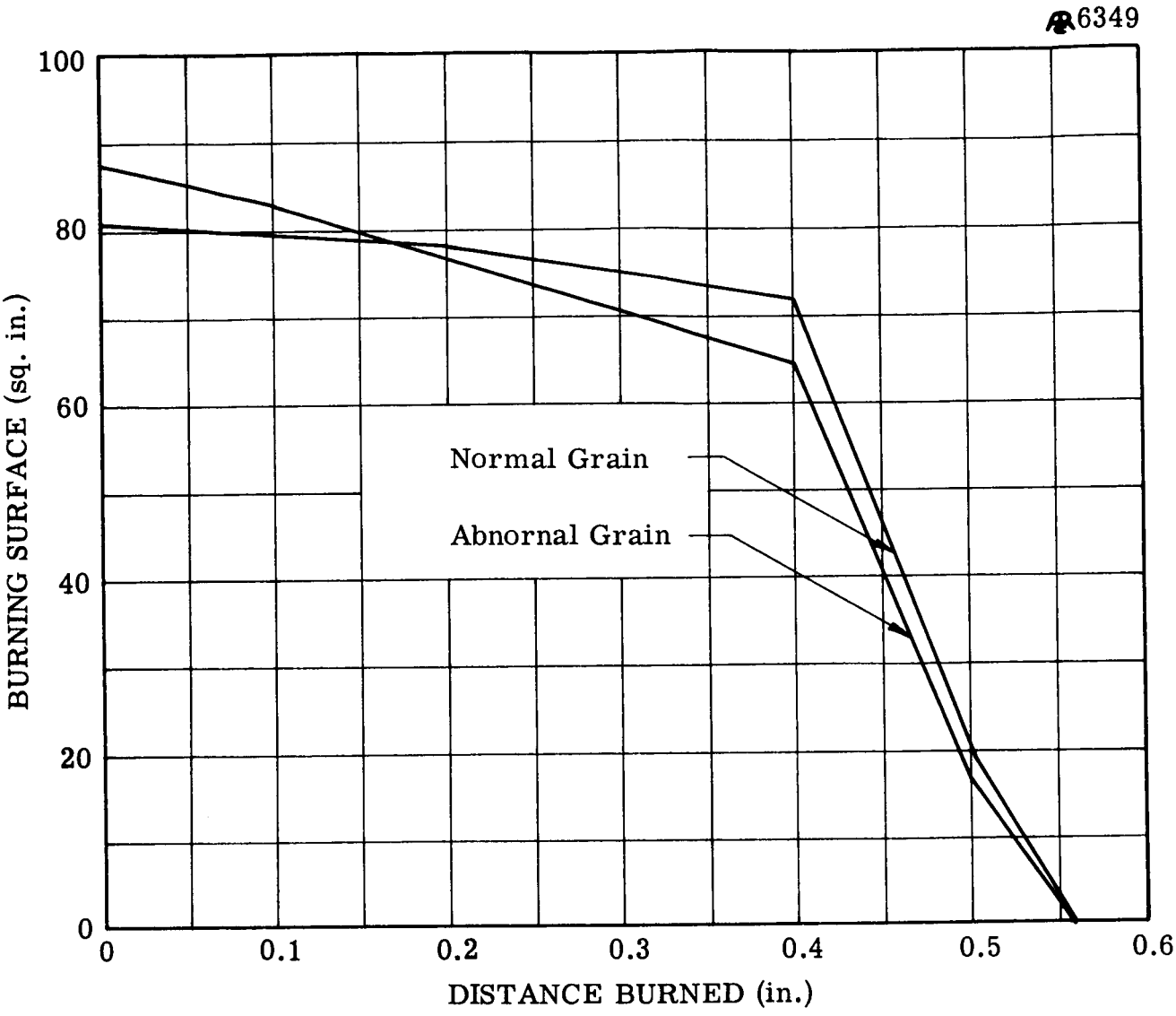


Figure 16. Effect of Cracked Grain on Surface-Web Burning History.

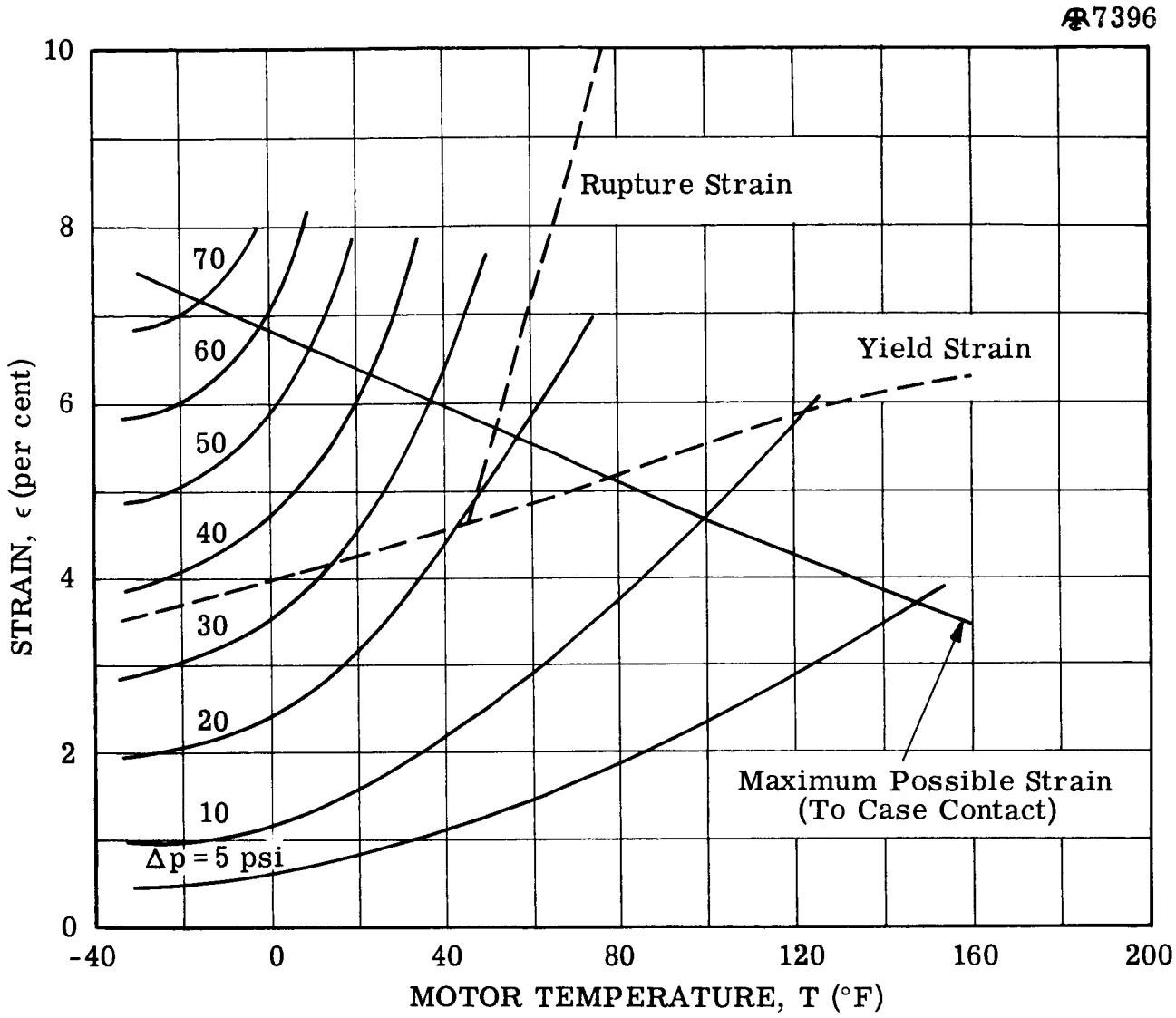
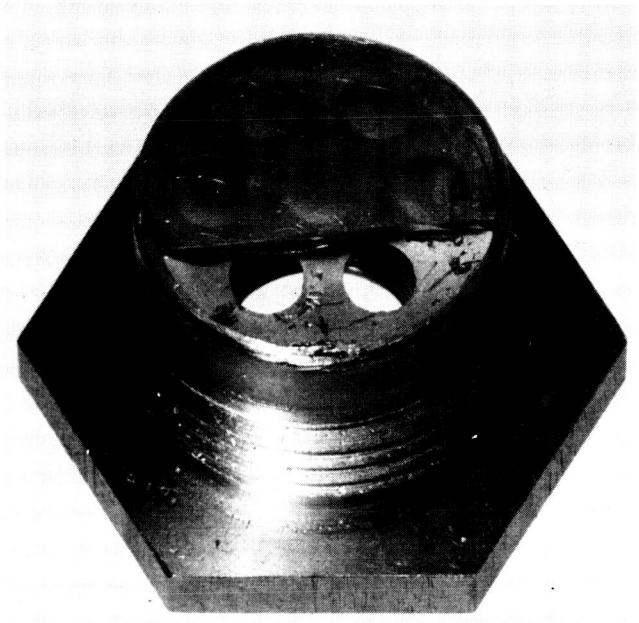
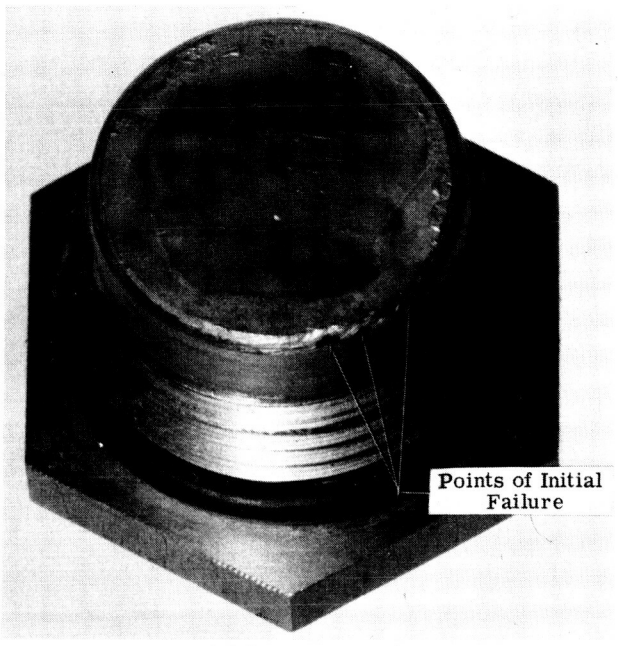


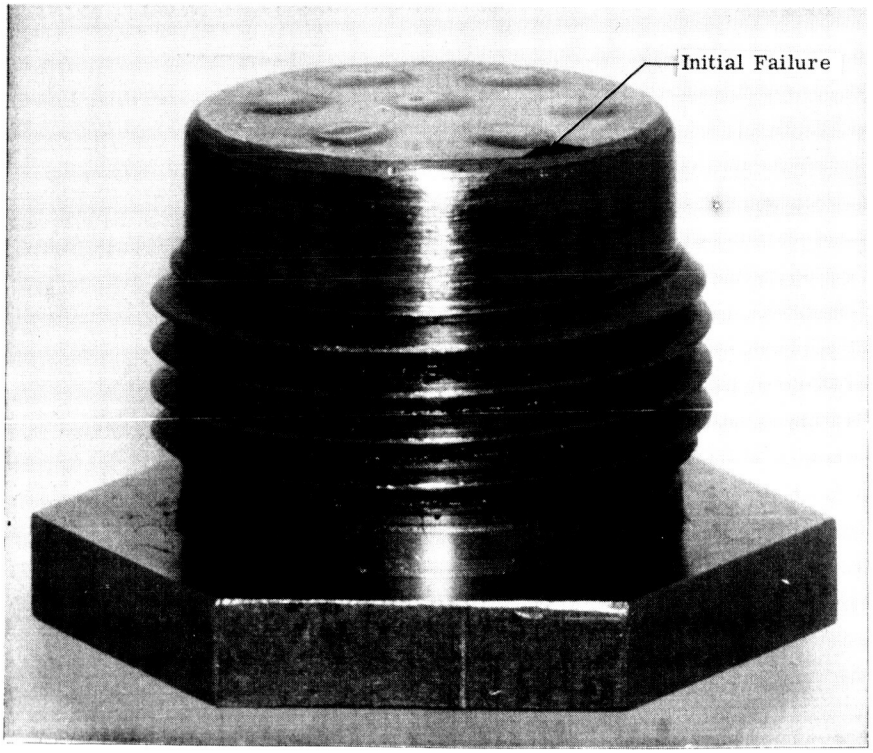
Figure 17. Comparison of Propellant Yield and Rupture Strains with Maximum Possible Strain Over Firing Temperature Range.



a. 400-psi Failure



b. 1000-psi Failure



c. 1500-psi Failure

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Figure 18. Igniter Bodies After Hydrostatic Burst Pressure Tests.

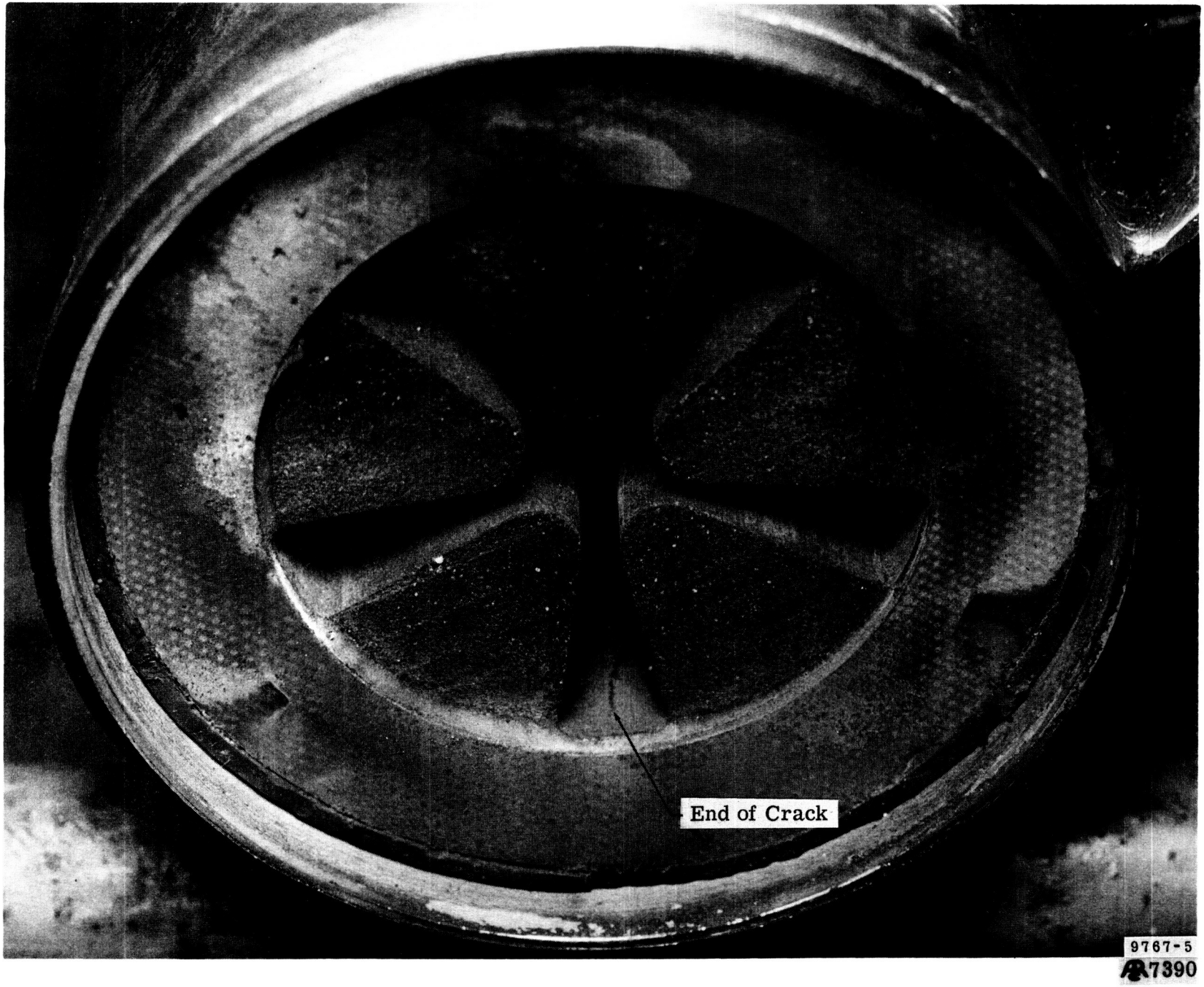


Figure 19. Cracked Propellant from Firing of Motor D-36 at -30°F.

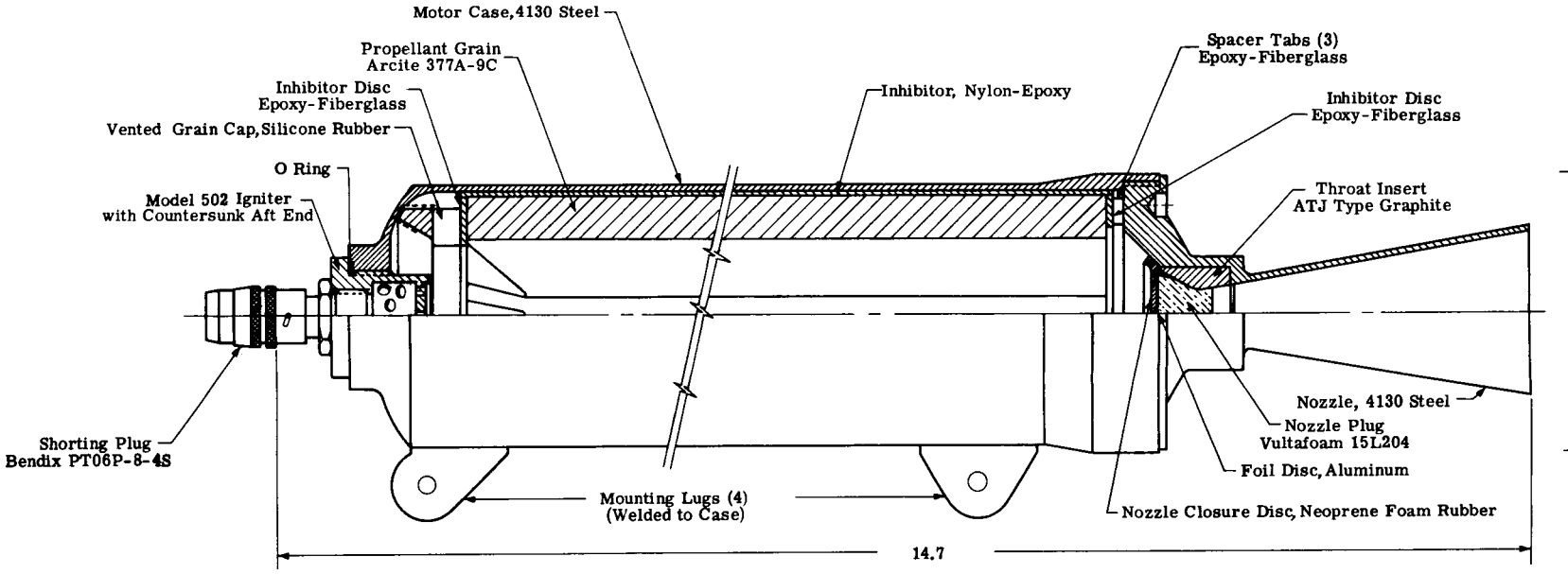


Figure 20. MARC 7G1 Motor With Recommended Design Changes Evaluated in Tests DX-6 and DX-7.

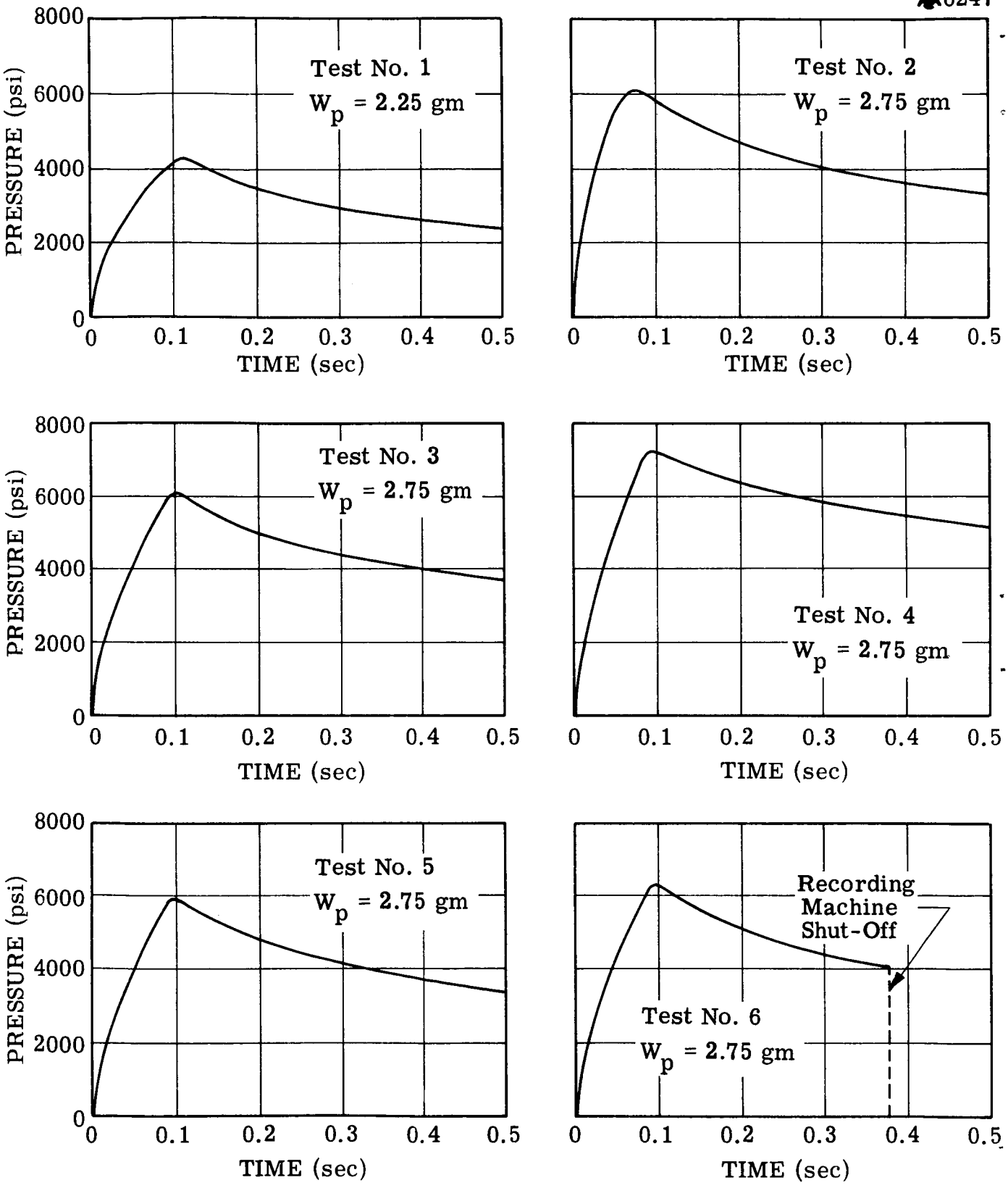


Figure 21. Pressure-Time Traces from Closed-Bomb Igniter Firings.

APPENDIX A

BALLISTIC RECORDS FOR BATCH ACCEPTANCE FIRINGS

(Data tabulated in Table IV)

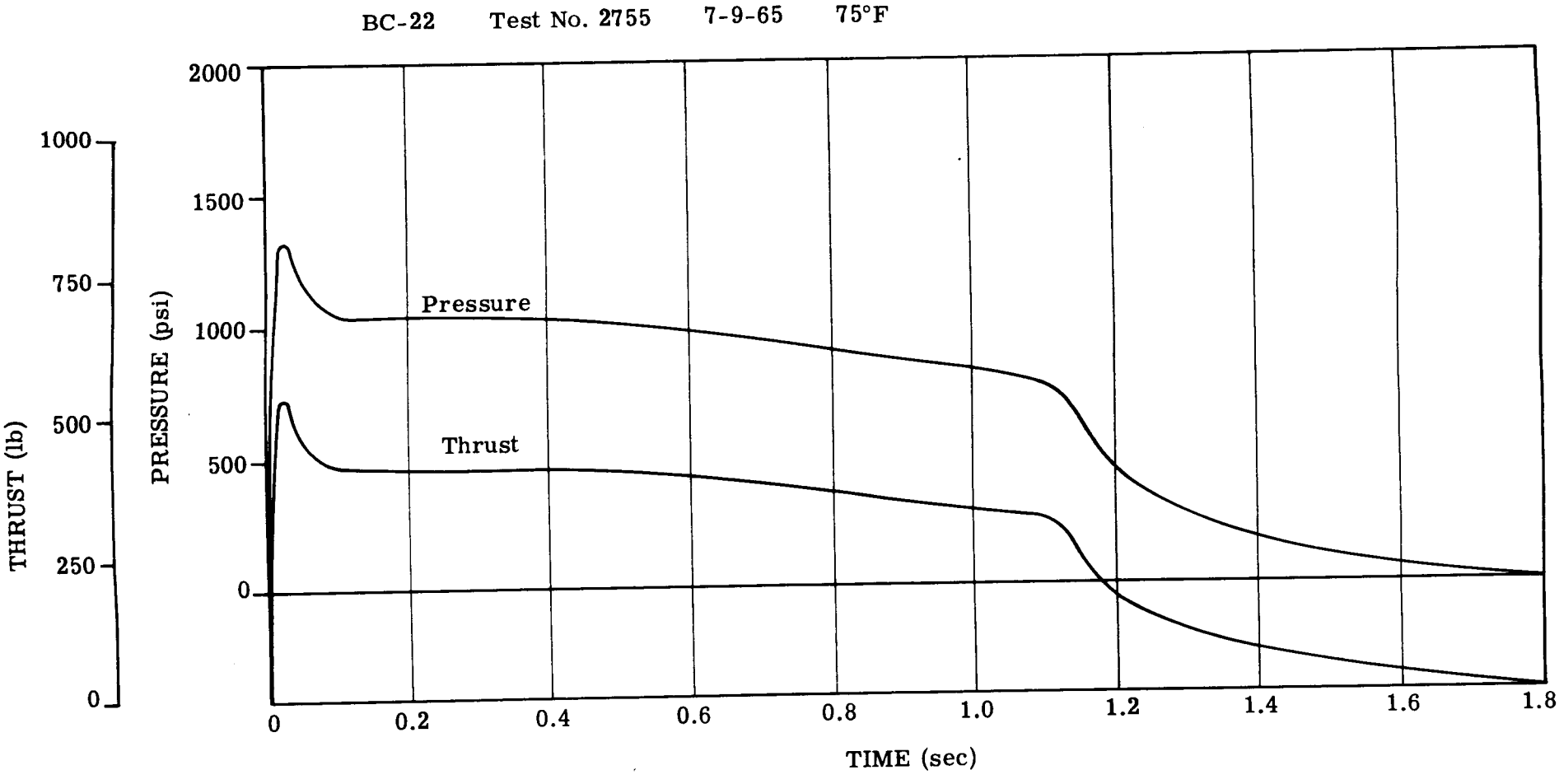


Figure A.1. Ballistic Records for Test BC-22.

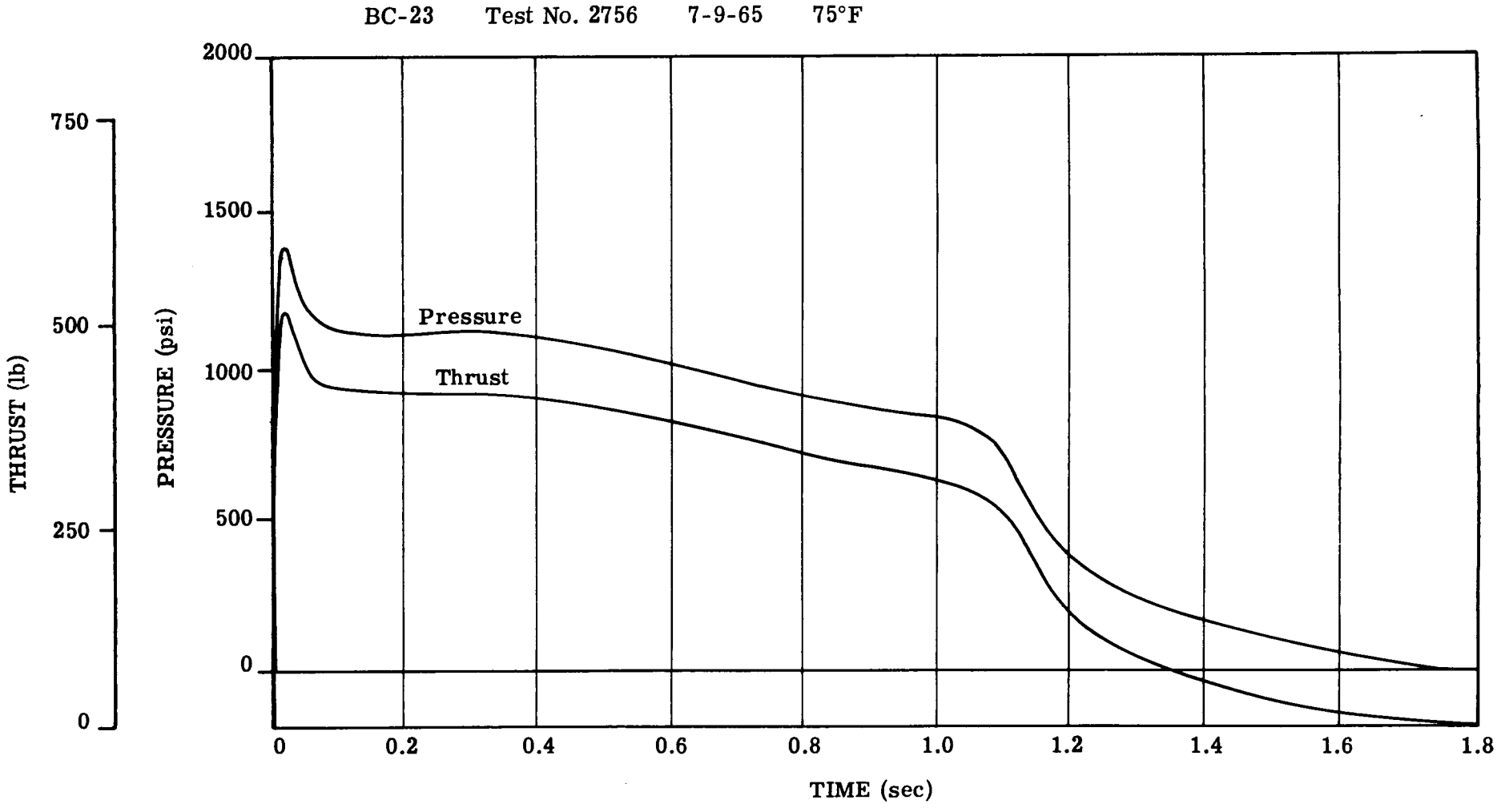


Figure A.2. Ballistic Records for Test BC-23.

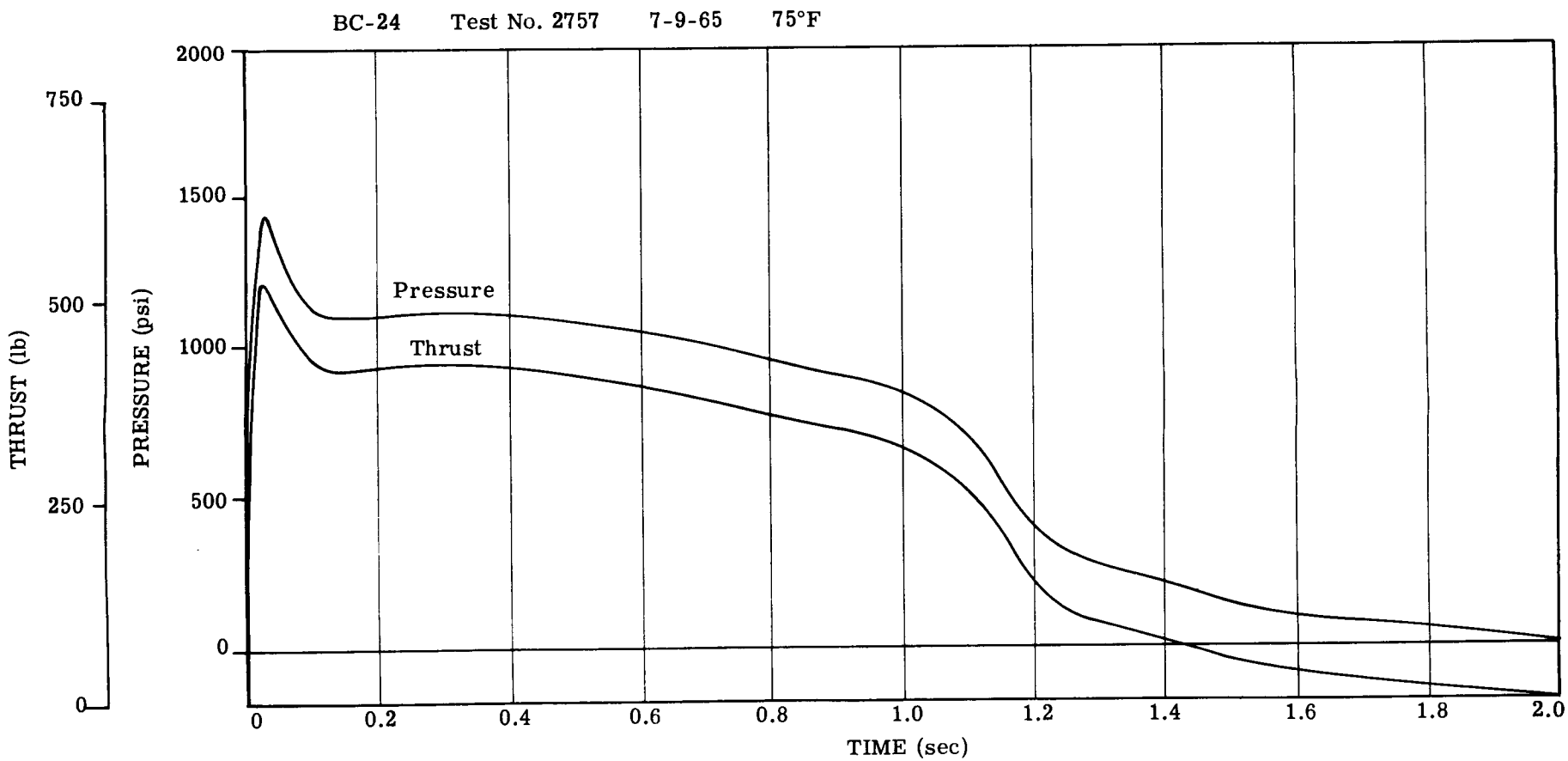


Figure A.3. Ballistic Records for Test BC-24.

APPENDIX B

TEMPERATURE-TIME PLOTS FROM THERMAL GRADIENT TESTS

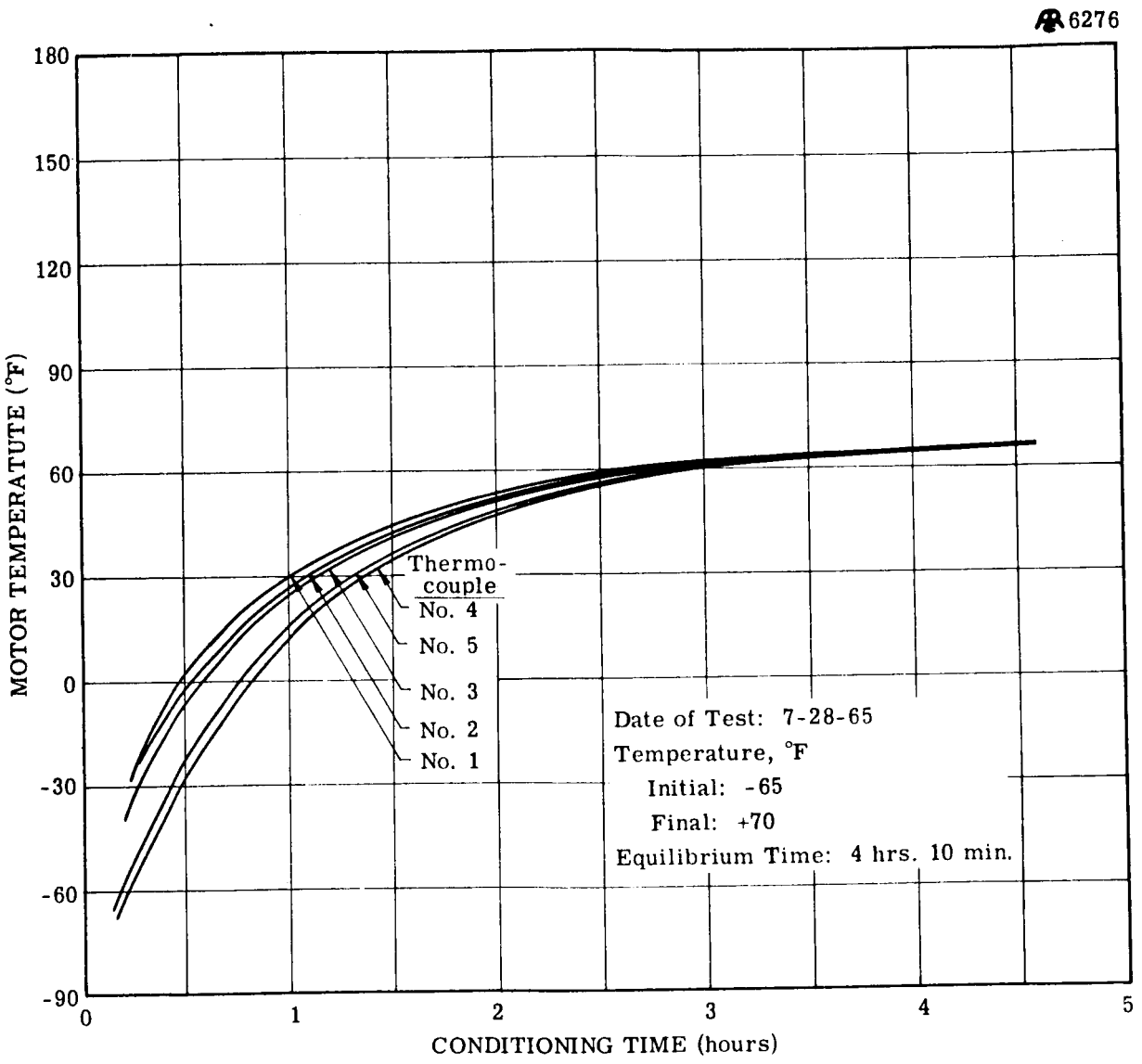


Figure B-1. Thermal Gradient Test of the MARC 7G1 Motor Number 21, -65°F to 70°F.

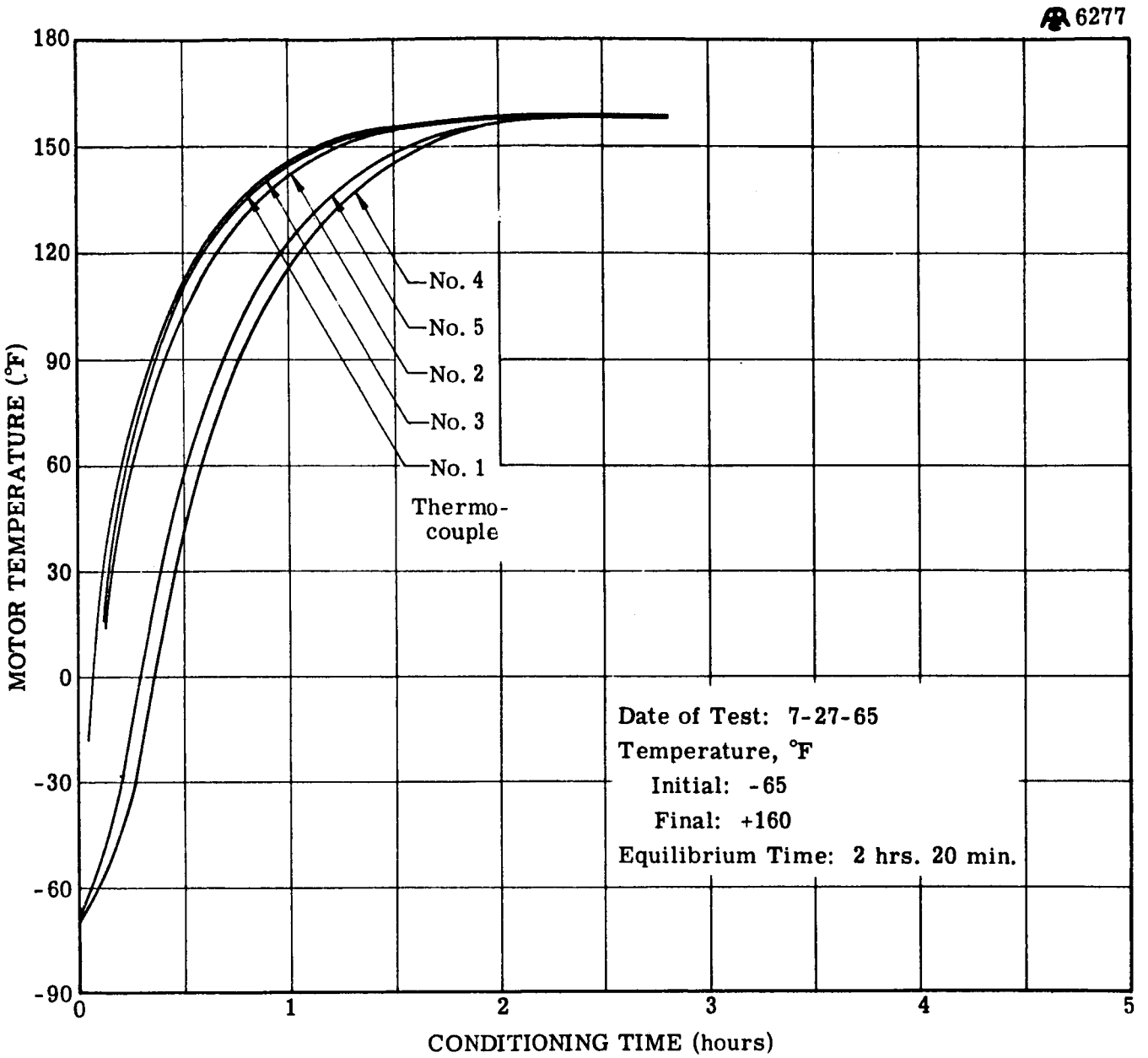


Figure B-2. Thermal Gradient Test of the MARC 7G1 Motor Number 21, -65°F to 160°F.

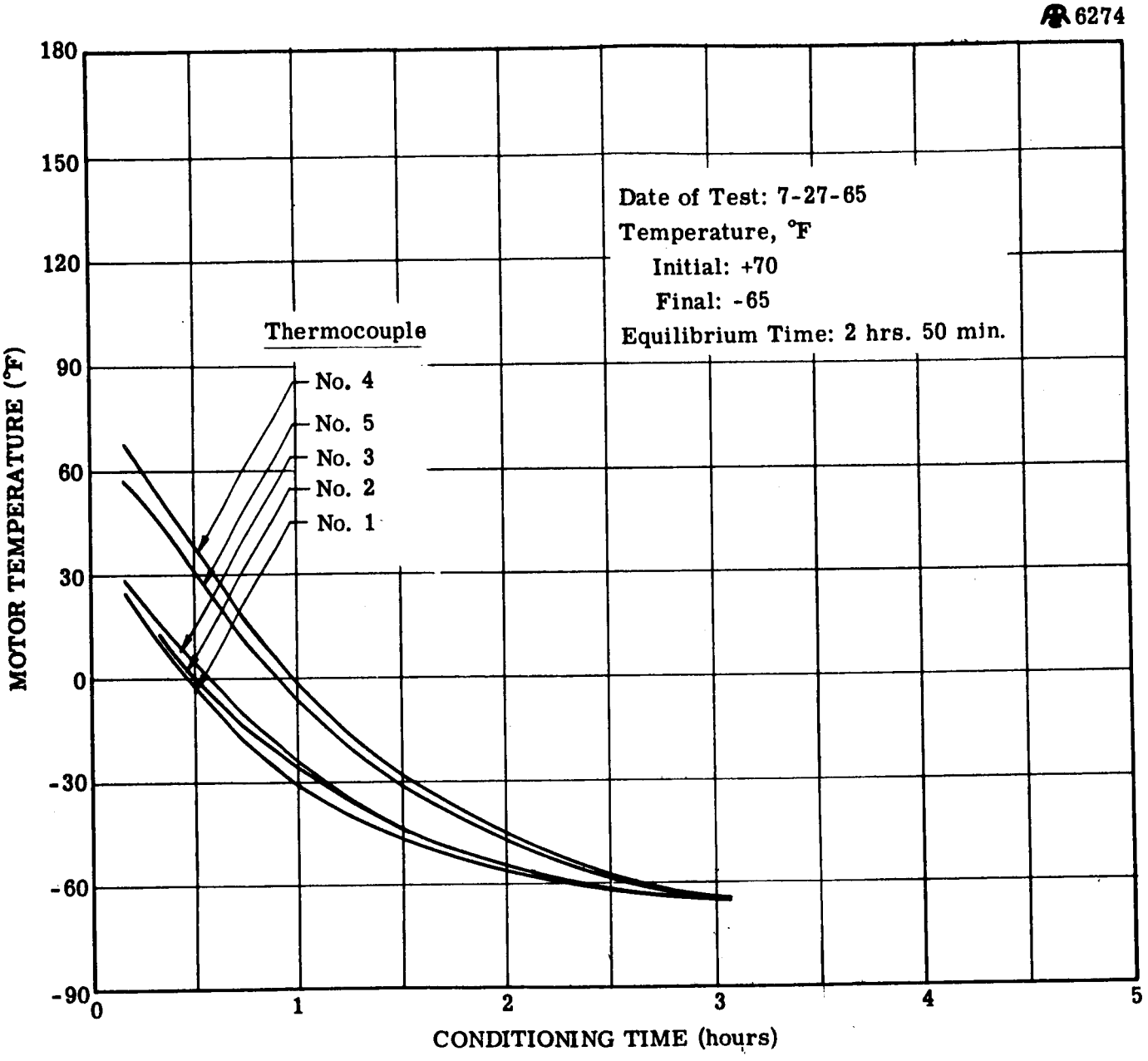


Figure B-3. Thermal Gradient Test of the MARC 7G1 Motor Number 21, 70°F to -65°F.

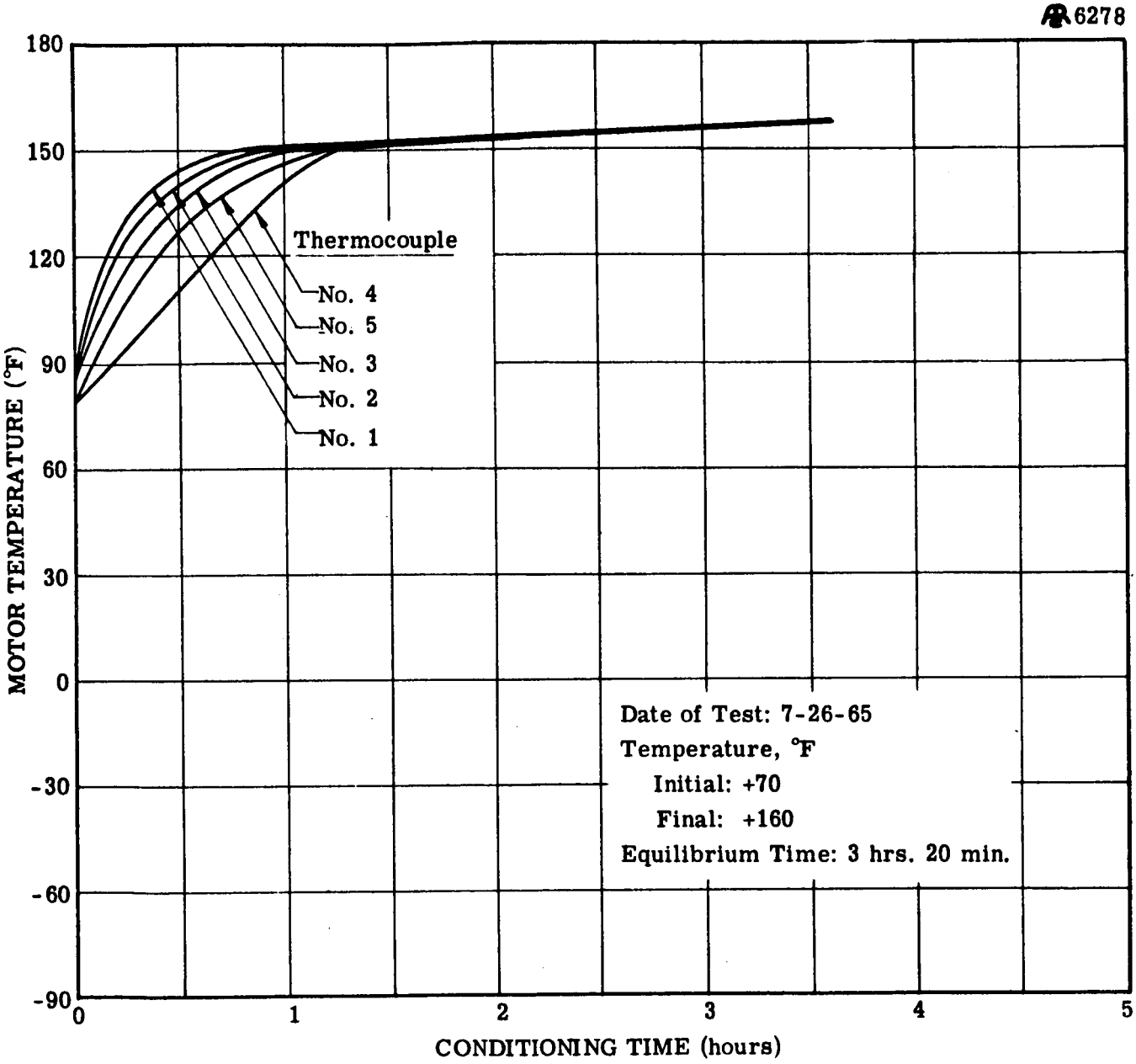


Figure B-4. Thermal Gradient Test of the MARC 7G1 Motor Number 21, 70°F to 160°F.

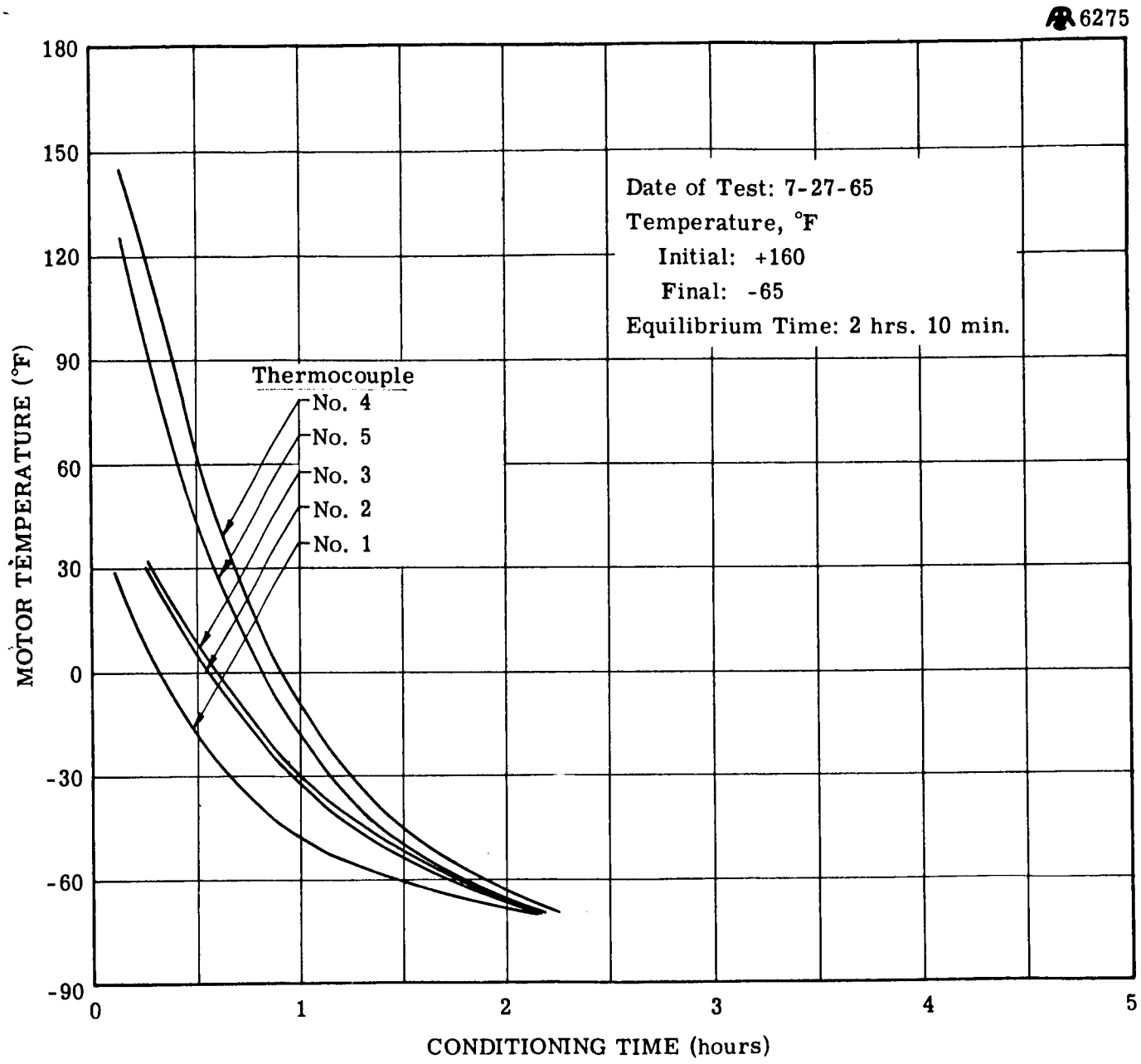


Figure B.5. Thermal Gradient Test of the MARC 7G1 Motor Number 21. 160° F to -65° F.

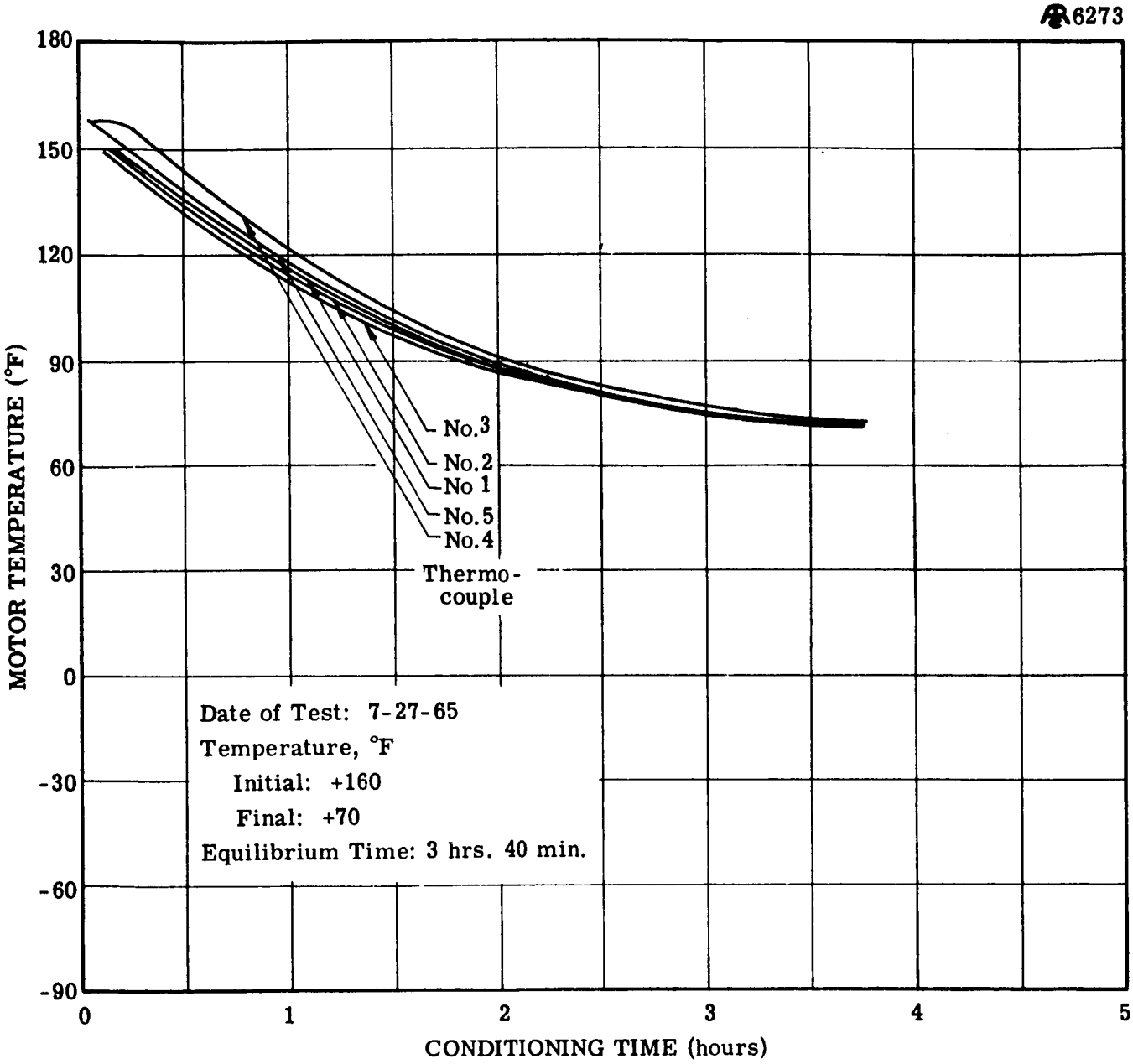
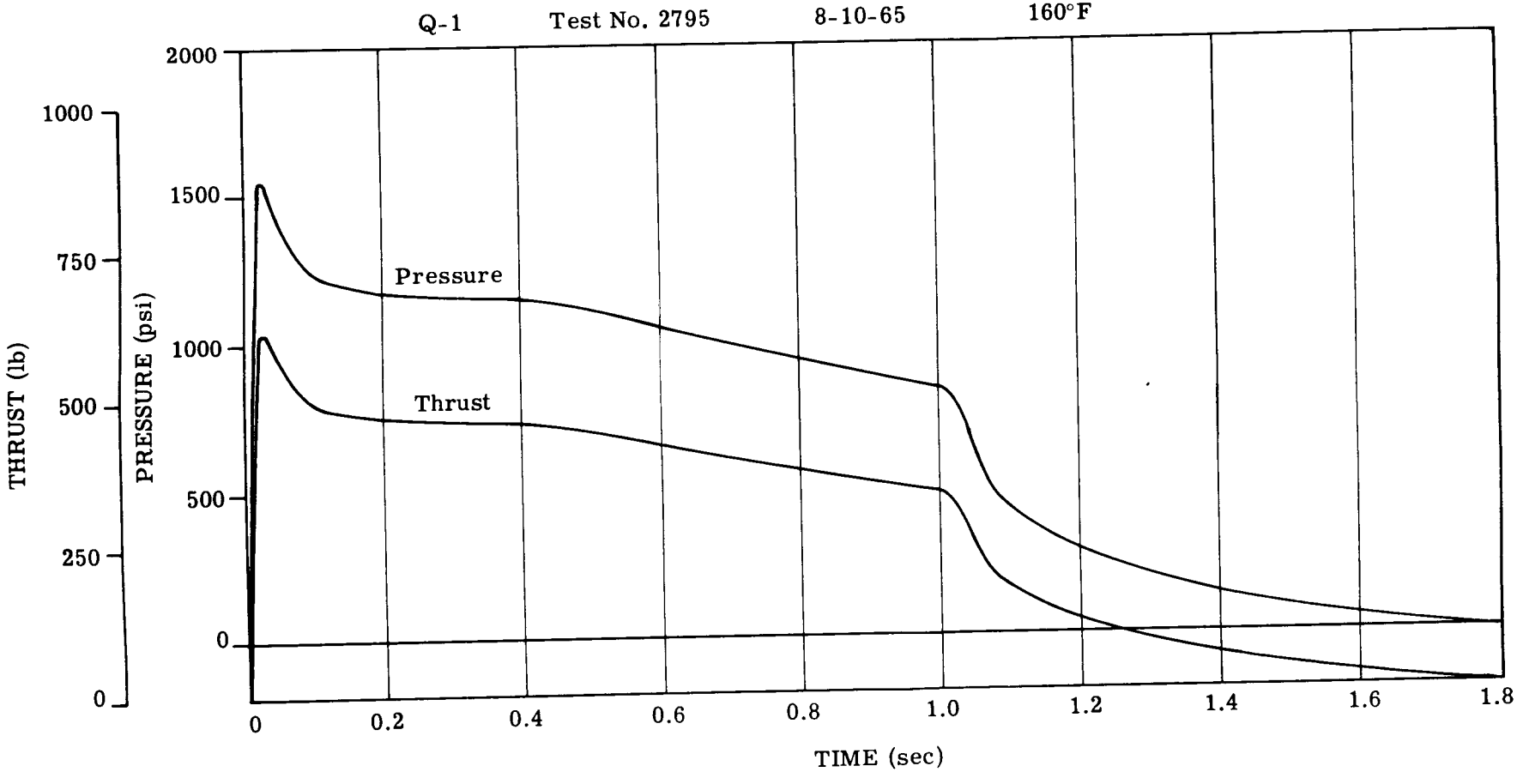


Figure B-6. Thermal Gradient Test of the MARC 7G1 Motor Number 21, 160°F to 70°F.

APPENDIX C

BALLISTIC RECORDS AND STATIC TEST DATA SHEETS FOR EVALUATION FIRINGS


Q-1
Test No. 2795
8-10-65
160°F
THRUST (lb)
1000
750
500
250
0
PRESSURE (psi)
2000
1500
1000
500
0
Pressure
Thrust
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
TIME (sec)

MOTOR DATA

Atlantic Research Part No. P-86-38-9

Customer Part No. —

Motor Serial No. Q-1

Grain Type Arcite 377A-9C

Grain No. 2474-R3-2A

IGNITER DATA

Model No. ARC 502

Atlantic Research Part No. P-86-32-2

Lot No. —

Serial No. 19

Resistances: Circuit A-B 1.070 ohms

Circuit C-D 1.100 ohms

BALLISTIC PARAMETERS

Nozzle Exit Area 2.172 sq in

Propellant Weight 2.142 lb

Inhibited Grain Weight — lb

Average Web 0.4106 in

Grain O.D. 2.551/2.513/2.536 in

Grain Length 8.456 in

TEST DATA

Conditioning Temperature 160 °F for ≥ 4 hrs

Time Out of Box 2006

Time Fired 2013 Time Elapsed 7 min

Ambient Temperature 77 °F

Relative Humidity 60 %

Barometric Pressure 29.53 in Hg

Ignition Current A-B: 5.03 C-D: 4.84 amps

Pre-Test Environmental Conditions Temperature-Humidity, Altitude, Vibration at -30°F, Shock, Temperature Shock

Tunnel Pressure: In. 0.0125, Av 0.0571, Final 0.0433 psia

IgnitionVoltage A-B: 26.2 C-D: 27.4 volts

Nozzle closure vented before firing.

Prefiring Examination:

Motor Weight 5.08 lb

Throat Diameter 0.555 in

Post Firing Examination

Motor Weight 2.92 lb

Throat Diameter 0.555/0.554/0.554 in

Average Throat Area 0.2415 sq in

Average A_e/A_t 9.01

BALLISTIC DATA

Action Time, t_a 1.453 sec

Burning Time, t_b 0.910 sec

Rise Time, t_r 0.006 sec

Ignition Delay, t_d 0.004 sec

Average Burning Rate, r 0.4512 in/sec

Maximum Pressure, P_{max} 1180 psia

Pressure-Time Integral, PTI_a 1219 psia-sec

Average Pressure, P_a 839.1 psia

Average Pressure, P_b 1097 psia

Ignition Pressure, P_{ign} 1525 psia

Discharge Coefficient, C_d 0.00728 lbm/lbf-sec

Characteristic Exhaust Velocity, C* 4513 ft/sec

O-O Pressure Integral 1244 psia-sec

	Measured	Abs. Vac.	
Total Impulse, I_a	489.2		lbf-sec
Specific Impulse, I_{sp}	228.4		lbf-sec/lbm
Maximum Thrust, F_{max}	468.1		lbf
Average Thrust, F_a	336.7		lbf
Average Thrust, F_b	439.7		lbf
Ignition Thrust, F_{ign}	613.2		lbf
Thrust Coefficient, C_F	1.6628		
O-O Thrust Integral	498.4		lbf-sec

I_{sp} (0-0), Motor 98.11 lbf-sec/lbm

I_{sp} (0-0), Propellant 232.7 lbf-sec/lbm

ADMINISTRATIVE DATA

Rocket Type and Model 1-KS-420 MARC 7G1

Contract No. NAS 3-7128-H

Customer NASA Lewis Research Center

Purpose of Test: Motor Evaluation

Test No. 2795

Date of Test: 8/10/65

Test Agency: Rocket Test Group Atlantic Research Corporation

Prepared by: James E. Dukate

Date: 8/16/65

Approved by: A. D. Mattox

Date: 8/18/65

Report No. TR-PL-8634-00-1

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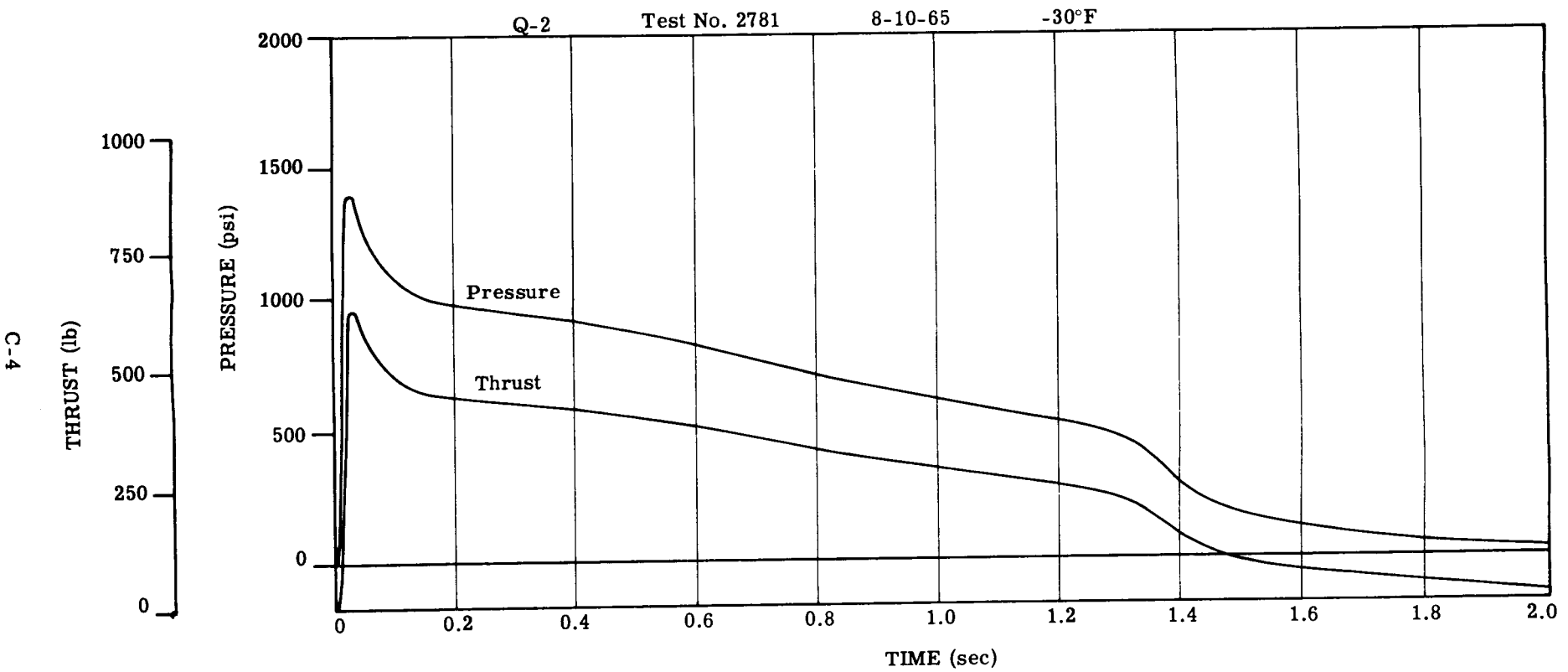
Q-2
Test No. 2781
8-10-65
-30°F
PRESSURE (psi)
2000
1500
1000
500
0
THRUST (lb)
1000
750
500
250
0
Pressure
Thrust
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
TIME (sec)

MOTOR DATA

Atlantic Research Part No. P-86-38-9
Customer Part No. —
Motor Serial No. Q-2
Grain Type Arcite 377A-9C
Grain No. 2474-R-2-6B

IGNITER DATA

Model No. ARC 502
Atlantic Research Part No. P-86-32-2
Lot No. —
Serial No. 48
Resistances: Circuit A-B 1.150 ohms
Circuit C-D 1.050 ohms

BALLISTIC PARAMETERS

Nozzle Exit Area 2.172 sq in
Propellant Weight 2.127 lb
Inhibited Grain Weight — lb
Average Web 0.4146 in
Grain O.D. 2.547/2.511/2.531 in
Grain Length 8.452 in

TEST DATA

Conditioning Temperature -30 °F for ≥ 4 hrs
Time Out of Box 1553
Time Fired 1602 Time Elapsed 9 min
Ambient Temperature 83 °F
Relative Humidity 55 %
Barometric Pressure 29.54 in Hg
Ignition Current A-B: 5.20 C-D: 5.01 amps
Pre-Test Environmental Conditions Temperature-Humidity, Altitude, Vibration at -30°F Shock, Temperature Shock.
Tunnel Pressure: Init 0.0077, Av. 0.0468, Final 0.0425 psia, Ignition Voltage A-B: 26.0 C-D 27.4 volts
Nozzle closure vented before firing.

Prefiring Examination:
Motor Weight 5.11 lb
Throat Diameter 0.555 in

Post Firing Examination
Motor Weight 2.97 lb
Throat Diameter 0.554 in
Average Throat Area 0.2416 sq in
Average A_e/A_t 8.99

BALLISTIC DATA

Action Time, t_a 1.768 sec
Burning Time, t_b 0.817 sec
Rise Time, t_r 0.007 sec
Ignition Delay, t_d 0.004 sec
Average Burning Rate, r 0.5075 in/sec
Maximum Pressure, P_{max} 940.1 psia
Pressure-Time Integral, PTI_a 1147 psia-sec
Average Pressure, P_a 648.7 psia
Average Pressure, P_b 931.8 psia
Ignition Pressure, P_{ign} 1396 psia
Discharge Coefficient, C_d 0.00758 lbm/lbf-sec
Characteristic Exhaust Velocity, C* 4243 ft/sec
O-O Pressure Integral 1161 psia-sec

	Measured	Abs. Vac.	
Total Impulse, I_a	476.2		lbf-sec
Specific Impulse, I_{sp}	223.9		lbf-sec/lbm
Maximum Thrust, F_{max}	395.5		lbf
Average Thrust, F_a	269.3		lbf
Average Thrust, F_b	381.2		lbf
Ignition Thrust, F_{ign}	573.4		lbf
Thrust Coefficient, C_F	1.7237		
O-O Thrust Integral	483.8		lbf-sec

I_{sp}(0-0), Motor 94.68 lbf-sec/lbm
I_{sp} (0-0), Propellant 227.4 lbf-sec/lbm

ADMINISTRATIVE DATA

Rocket Type and Model 1-KS-420 MARC 7G1
Contract No. NAS 3-7128-H
Customer NASA Lewis Research Center
Purpose of Test: Motor Evaluation
Test No. 2781
Date of Test: 8/10/65
Test Agency: Rocket Test Group Atlantic Research Corporation
Prepared by: A. Johnson
Date: 8/13/65
Approved by: A. D. Mattox
Date: 8/18/65

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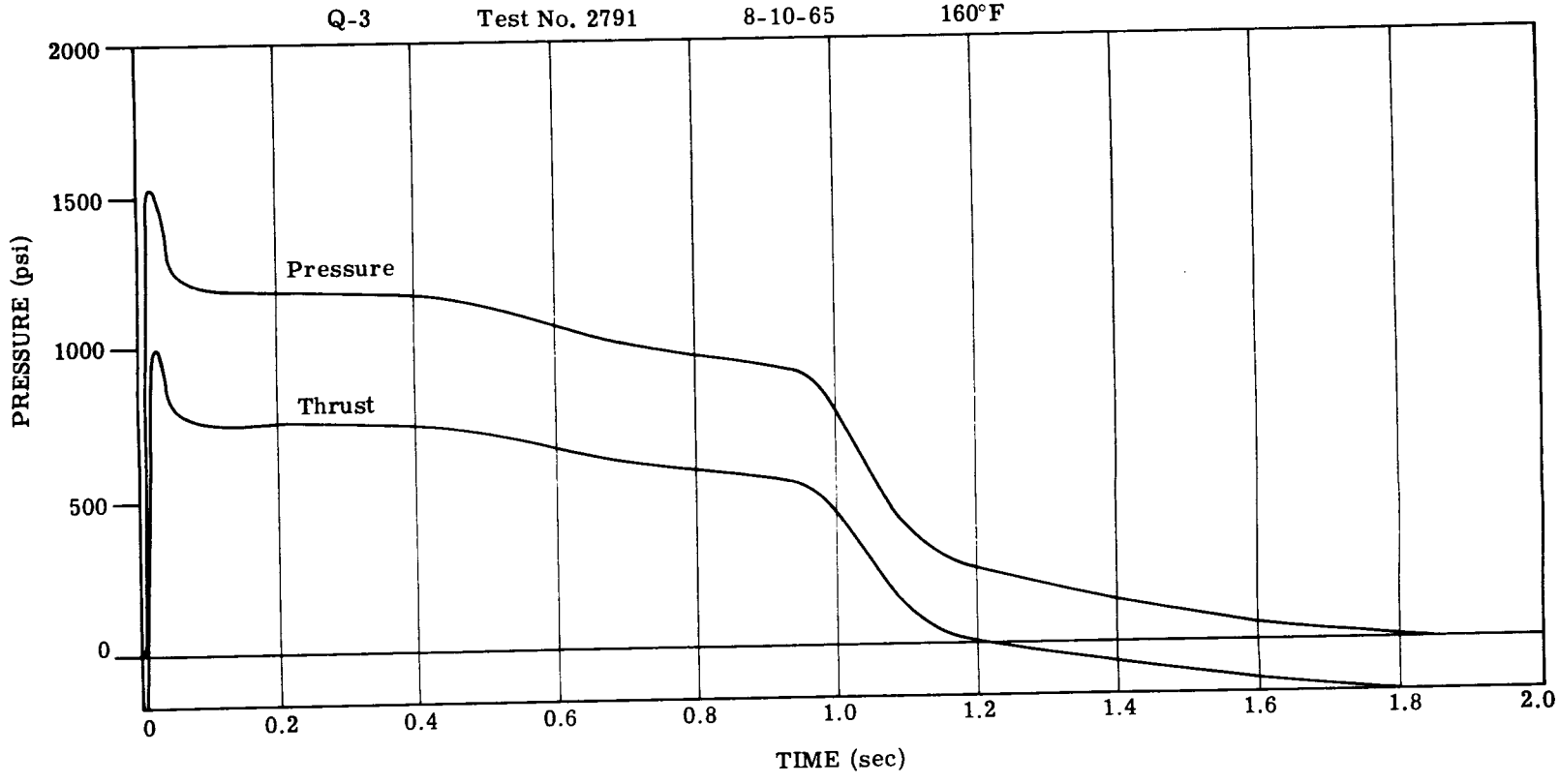
Q-3
Test No. 2791
8-10-65
160°F
2000
1500
1000
500
0
PRESSURE (psi)
Pressure
Thrust
1000
750
500
250
0
THRUST (lb)
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
TIME (sec)

MOTOR DATA

Atlantic Research Part No. P-86-38-9

Customer Part No. —

Motor Serial No. Q-3

Grain Type Arcite 377A-9C

Grain No. 2474-R-3-5B

IGNITER DATA

Model No. ARC 502

Atlantic Research Part No. P-86-32-2

Lot No. —

Serial No. 28

Resistances: Circuit A-B 1.145 ohms

Circuit C-D 1.110 ohms

BALLISTIC PARAMETERS

Nozzle Exit Area 2.172 sq in

Propellant Weight 2.127 lb

Inhibited Grain Weight — lb

Average Web 0.4100 in

Grain O.D. 2.542/2.515/2.533 in

Grain Length 8.460 in

TEST DATA

Conditioning Temperature +160 °F for ≥ 4 hrs

Time Out of Box 1919

Time Fired 1925 Time Elapsed 6 min

Ambient Temperature 80 °F

Relative Humidity 60 %

Barometric Pressure 29.53 in Hg

Ignition Current A-B: 5.30 C-D: 5.13 amps

Pre-Test Environmental Conditions Temperature - Humidity, Altitude, Vibration at -30°F, Shock, Temperature Shock,

Tunnel Pressure: Init 0.0073, Av 0.0539, Final 0.0460 psia

Ignition Voltage A-B: 26.2, C-D: 27.4 volts

Prefiring Examination:

Motor Weight 5.03 lb

Throat Diameter 0.555 in

Post Firing Examination

Motor Weight 2.89 lb

Throat Diameter 0.554 in

Average Throat Area 0.2415 sq in

Average A_e/A_t 8.99

BALLISTIC DATA

Action Time, t_a 1.394 sec

Burning Time, t_b 0.955 sec

Rise Time, t_r 0.003 sec

Ignition Delay, t_d 0.005 sec

Average Burning Rate, r 0.429 in/sec

Maximum Pressure, P_{max} 1194 psia

Pressure-Time Integral, PTI_a 1212 psia-sec

Average Pressure, P_a 869.4 psia

Average Pressure, P_b 1111 psia

Ignition Pressure, P_{ign} 1521 psia

Discharge Coefficient, C_d 0.00727 lbm/lbf-sec

Characteristic Exhaust Velocity, C* 4533 ft/sec

O-O Pressure Integral 1241 psia-sec

	Measured	Abs. Vac.	
Total Impulse, I_a	485.1		lbf-sec
Specific Impulse, I_{sp}	228.1		lbf-sec/lbm
Maximum Thrust, F_{max}	479.8		lbf
Average Thrust, F_a	348.0		lbf
Average Thrust, F_b	444.2		lbf
Ignition Thrust, F_{ign}	596.8		lbf
Thrust Coefficient, C_F	1.6583		
O-O Thrust Integral	495.9		lbf-sec

I_{sp} (0-0), Motor 98.59 lbf-sec/lbm

I_{sp} (0-0), Propellant 233.1 lbf-sec/lbm

ADMINISTRATIVE DATA

Rocket Type and Model 1-KS-420 MARC 7G1

Contract No. NAS 3-7128-H

Customer NASA Lewis Research Center

Purpose of Test: Motor Evaluation

Test No. 2791

Date of Test: 8/10/65

Test Agency: Rocket Test Group Atlantic Research Corporation

Prepared by: J. R. Wertz

Date: 8/16165

Approved by: A. D. Mattox

Date: 8/18165

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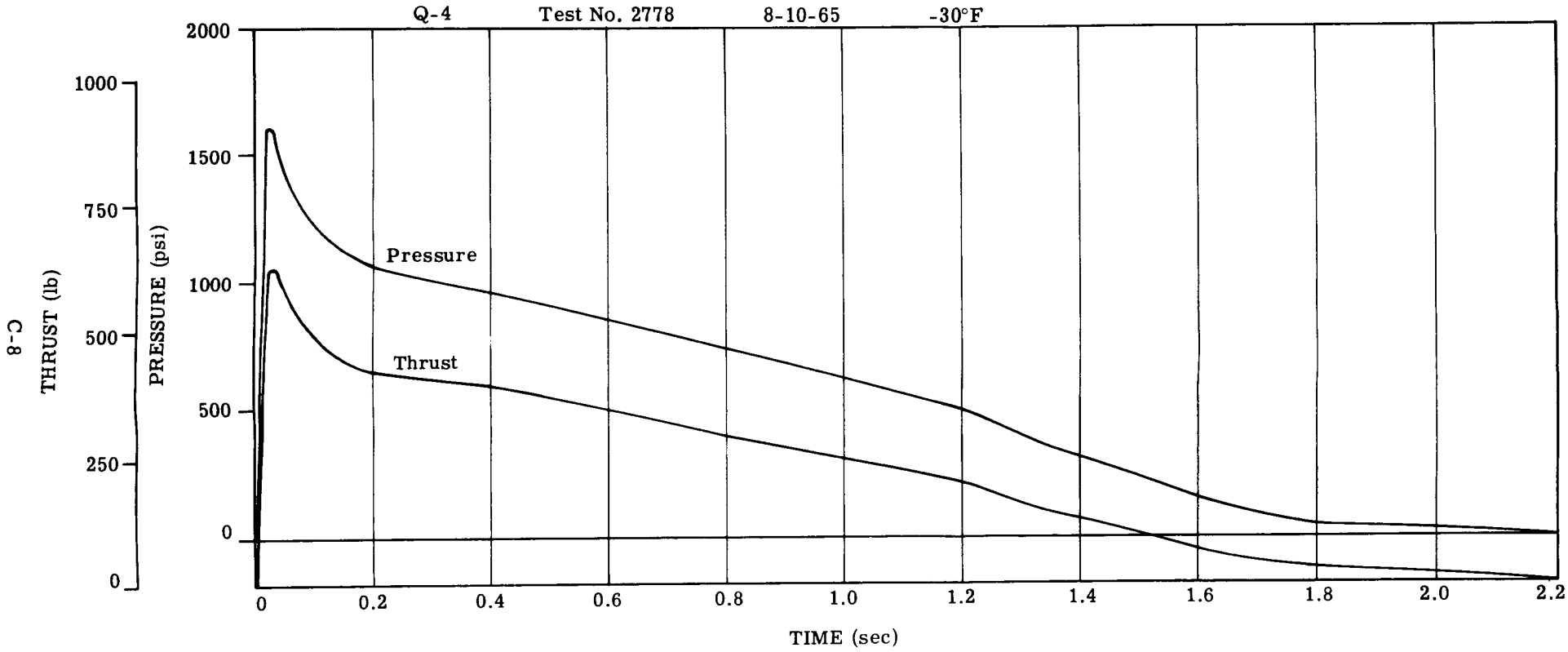
Q-4 Test No. 2778 8-10-65 -30°F
THRUST (lb)
PRESSURE (psi)
1000
750
500
250
0
2000
1500
1000
500
0
Pressure
Thrust
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
TIME (sec)

MOTOR DATA

Atlantic Research Part No. P-86-38-9

Customer Part No. —

Motor Serial No. Q-4

Grain Type Arcite 377A-9C

Grain No. 2474-R-3-10

IGNITER DATA

Model No. ARC 502

Atlantic Research Part No. P-86-32-2

Lot No. —

Serial No. 15

Resistances: Circuit A-B 1.150 ohms

Circuit C-D 1.070 ohms

BALLISTIC PARAMETERS

Nozzle Exit Area 2.172 sq in

Propellant Weight 2.176 lb

Inhibited Grain Weight — lb

Average Web 0.415 in

Grain O.D. 2.542/2.522/2.532 in

Grain Length 8.462 in

TEST DATA

Conditioning Temperature -30 °F for ≥ 4 hrs

Time Out of Box 1504

Time Fired 1515 Time Elapsed 11 min

Ambient Temperature 83 °F

Relative Humidity 50 %

Barometric Pressure 29.54 in Hg

Ignition Current A-B: 4.49 C-D: 4.42 amps

Pre-Test Environmental Conditions Temperature - Humidity, Altitude, Vibration at -30°F, Shock, Temperature Shock,

Tunnel Pressure: Init 0.0070, Av 0.0542, Final 0.0470 psia

Ignition Voltage A-B: 26.5, C-D: 27.0 volts

Prefiring Examination:

Motor Weight 5.05 lb

Throat Diameter 0.555 in

Post Firing Examination

Motor Weight 2.90 lb

Throat Diameter 0.554 in

Average Throat Area 0.2414 sq in

Average A_e/A_t 8.99

BALLISTIC DATA

Action Time, t_a 1.774 sec

Burning Time, t_b 0.765 sec

Rise Time, t_r 0.005 sec

Ignition Delay, t_d 0.006 sec

Average Burning Rate, r 0.5425 in/sec

Maximum Pressure, P_{max} 1032 psia

Pressure-Time Integral, PTI_a 1203 psia-sec

Average Pressure, P_a 678.2 psia

Average Pressure, P_b 1004 psia

Ignition Pressure, P_{ign} 1592 psia

Discharge Coefficient, C_d 0.00734 lbm/lbf-sec

Characteristic Exhaust Velocity, C* 4383 ft/sec

O-O Pressure Integral 1228 psia-sec

	Measured	Abs. Vac.	
Total Impulse, I_a	476.4		lbf-sec
Specific Impulse, I_{sp}	218.9		lbf-sec/lbm
Maximum Thrust, F_{max}	406.3		lbf
Average Thrust, F_a	268.5		lbf
Average Thrust, F_b	396.9		lbf
Ignition Thrust, F_{ign}	616.4		lbf
Thrust Coefficient, C_F	1.6376		
O-O Thrust Integral	485.5		lbf-sec

I_{sp} (0-0), Motor 96.14 lbf-sec/lbm

I_{sp} (0-0), Propellant 223.1 lbf-sec/lbm

ADMINISTRATIVE DATA

Rocket Type and Model 1-KS-420 MARC 7G1

Contract No. NAS 3-7128-H

Customer NASA Lewis Research Center

Purpose of Test: Motor Evaluation

Test No. 2778

Date of Test: 8/10/65

Test Agency: Rocket Test Group Atlantic Research Corporation

Prepared by: A. Johnson

Date: 8/12/65

Approved by: A. D. Mattox

Date: 8/18/65

Report No. TR-PL-8634-00-1

Appendix C

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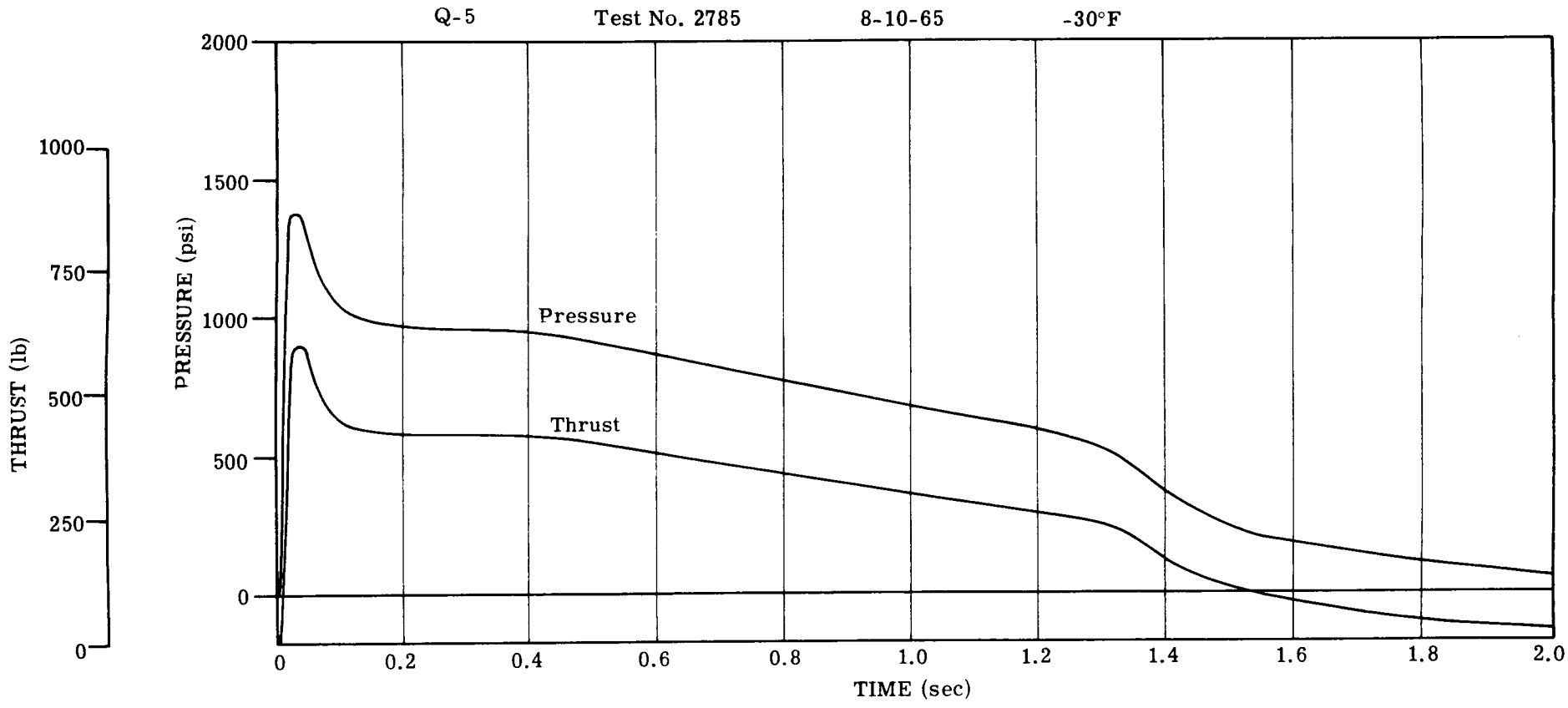
Q-5
Test No. 2785
8-10-65
-30°F
PRESSURE (psi)
2000
1500
1000
500
0
Pressure
Thrust
THRUST (lb)
1000
750
500
250
0
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
TIME (sec)

MOTOR DATA

Atlantic Research Part No. P-86-38-9

Customer Part No. —

Motor Serial No. Q-5

Grain Type Arcite 377A-9C

Grain No. 2474-R-3-6B

IGNITER DATA

Model No. ARC 502

Atlantic Research Part No. P-86-32-2

Lot No. —

Serial No. 20

Resistances: Circuit A-B 1.150 ohms

Circuit D-C 1.190 ohms

BALLISTIC PARAMETERS

Nozzle Exit Area 2.172 sq in

Propellant Weight 2.136 lb

Inhibited Grain Weight — lb

Average Web 0.4090 in

Grain O.D. 2.542/2.515/2.532 in

Grain Length 8.459 in

TEST DATA

Conditioning Temperature -30 °F for ≥ 4 hrs

Time Out of Box 1708

Time Fired 1716 Time Elapsed 8 min

Ambient Temperature 83 °F

Relative Humidity 55 %

Barometric Pressure 29.54 in Hg

Ignition Current A-B: 5.08 C-D: 5.19 amps

Pre-Test Environmental Conditions Temperature - Humidity, Altitude, Vibration at -30°F, Shock, Temperature Shock, Tunnel Pressure: Init 0.0126, Av 0.0514, Final 0.0460 psia

Ignition Voltage A-B: 23.2, C-D: 27.4 volts

Prefiring Examination:

Motor Weight 5.10 lb

Throat Diameter 0.555 in

Post Firing Examination

Motor Weight 2.92 lb

Throat Diameter 0.553 in

Average Throat Area 0.2412 sq in

Average A_e/A_t 9.00

BALLISTIC DATA

Action Time, t_a 1.829 sec

Burning Time, t_b 0.871 sec

Rise Time, t_r 0.006 sec

Ignition Delay, t_d 0.006 sec

Average Burning Rate, r 0.4696 in/sec

Maximum Pressure, P_{max} 958.5 psia

Pressure-Time Integral, PTI_a 1188 psia-sec

Average Pressure, P_a 649.5 psia

Average Pressure, P_b 914.4 psia

Ignition Pressure, P_{ign} 1359 psia

Discharge Coefficient, C_d 0.00734 lbm/lbf-sec

Characteristic Exhaust Velocity, C* 4382 ft/sec

O-O Pressure Integral 1206 psia-sec

	Measured	Abs. Vac.	
Total Impulse, I_a	476.6		lbf-sec
Specific Impulse, I_{sp}	223.1		lbf-sec/lbm
Maximum Thrust, F_{max}	383.8		lbf
Average Thrust, F_a	260.6		lbf
Average Thrust, F_b	365.4		lbf
Ignition Thrust, F_{ign}	538.3		lbf
Thrust Coefficient, C_F	1.6647		
O-O Thrust Integral	484.4		lbf-sec

I_{sp}(0-0), Motor 94.98 lbf-sec/lbm

I_{sp} (0-0), Propellant 226.8 lbf-sec/lbm

ADMINISTRATIVE DATA

Rocket Type and Model 1-KS-420 MARC 7G1

Contract No. NAS 3-7128-H

Customer NASA Lewis Research Center

Purpose of Test: Motor Evaluation

Test No. 2785

Date of Test: 8/10/65

Test Agency: Rocket Test Group Atlantic Research Corporation

Prepared by: A. Johnson

Date: 8/16/65

Approved by: A. D. Mattox

Date: 8/18/65

Report No. TR-PL-8634-00-1

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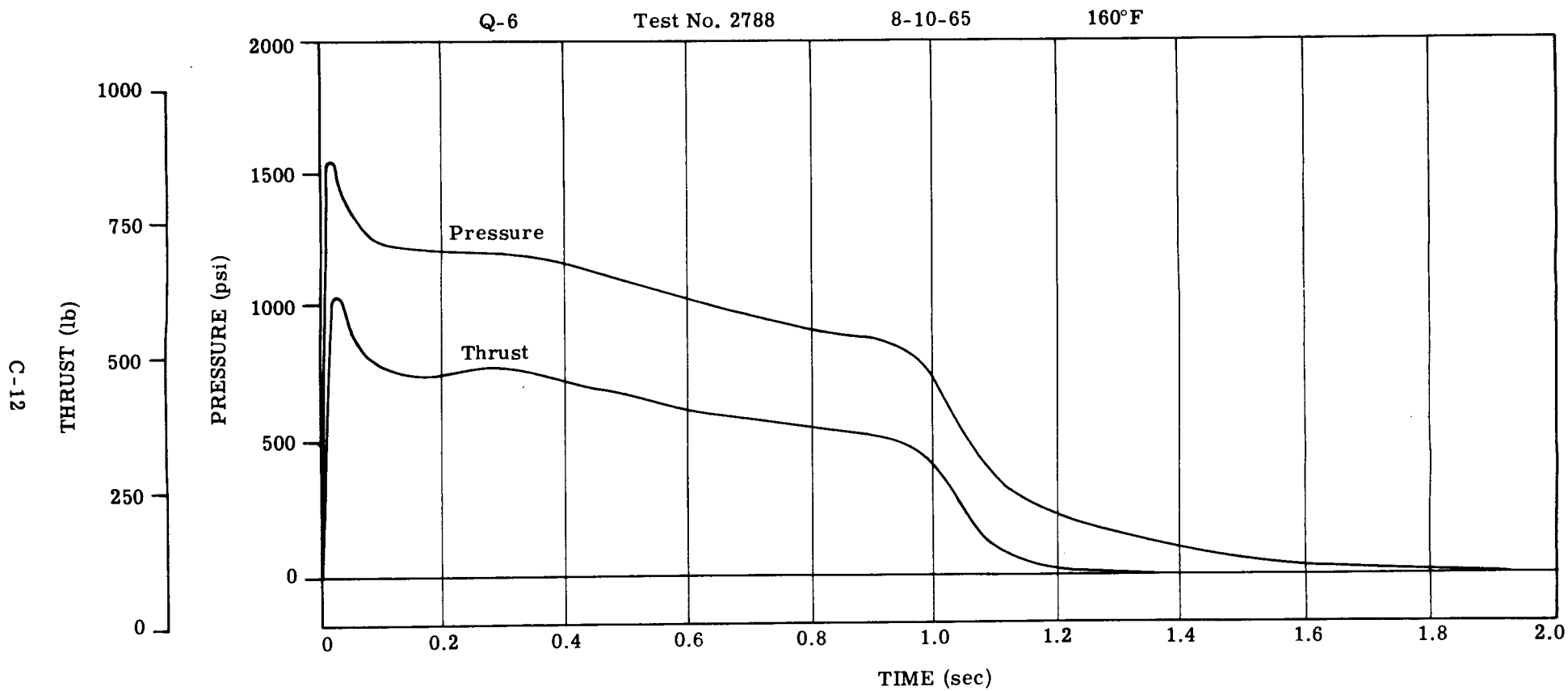
F129-6/65-2C


Q-6
Test No. 2788
8-10-65
160°F
THRUST (lb)
1000
750
500
250
0
PRESSURE (psi)
2000
1500
1000
500
0
Pressure
Thrust
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
TIME (sec)

MOTOR DATA

Atlantic Research Part No. P-86-38-9

Customer Part No. —

Motor Serial No. Q-6

Grain Type Arcite 377A-9C

Grain No. 2474-R-2-2B

IGNITER DATA

Model No. ARC 502

Atlantic Research Part No. P-86-32-2

Lot No. —

Serial No. 29

Resistances: Circuit A-B 1.000 ohms

Circuit C-D 1.000 ohms

BALLISTIC PARAMETERS

Nozzle Exit Area 2.172 sq in

Propellant Weight 2.126 lb

Inhibited Grain Weight — lb

Average Web 0.4132 in

Grain O.D. 2.548/2.520/2.532 in

Grain Length 8.464 in

TEST DATA

Conditioning Temperature +160 °F for ≥ 4 hrs

Time Out of Box 1807

Time Fired 1815 Time Elapsed 8 min

Ambient Temperature 83 °F

Relative Humidity 53 %

Barometric Pressure 29.54 in Hg

Ignition Current A-B: 5.16 C-D: 5.09 amps

Pre-Test Environmental Conditions Temperature - Humidity, Altitude, Vibration at -30°F, Shock, Temperature Shock, Tunnel Pressure: Init 0.0135, Av 0.0580, Final 0.0536 psia, Ignition Voltage A-B: 26.1, C-D: 27.3 volts

Nozzle closure vented before firing.

Prefiring Examination:

Motor Weight 5.07 lb

Throat Diameter 0.555 in

Post Firing Examination

Motor Weight 2.93 lb

Throat Diameter 0.554 in

Average Throat Area 0.2414 sq in

Average A_e/A_t 8.99

BALLISTIC DATA

Action Time, t_a 1.411 sec

Burning Time, t_b 0.861 sec

Rise Time, t_r 0.009 sec

Ignition Delay, t_d 0.004 sec

Average Burning Rate, r 0.4799 in/sec

Maximum Pressure, P_{max} 1221 psia

Pressure-Time Integral, PTI_a 1214 psia-sec

Average Pressure, P_a 860.4 psia

Average Pressure, P_b 1134 psia

Ignition Pressure, P_{ign} 1558 psia

Discharge Coefficient, C_d 0.00711 lbm/lbf-sec

Characteristic Exhaust Velocity, C* 4526 ft/sec

O-O Pressure Integral 1239 psia-sec

	Measured	Abs. Vac.	
Total Impulse, I_a	486.7		lbf-sec
Specific Impulse, I_{sp}	228.9		lbf-sec/lbm
Maximum Thrust, F_{max}	491.5		lbf
Average Thrust, F_a	344.9		lbf
Average Thrust, F_b	453.4		lbf
Ignition Thrust, F_{ign}	615.5		lbf
Thrust Coefficient, C_F	1.6609		
O-O Thrust Integral	496.6		lbf-sec

I_{sp} (0-0), Motor 97.95 lbf-sec/lbm

I_{sp} (0-0), Propellant 233.6 lbf-sec/lbm

ADMINISTRATIVE DATA

Rocket Type and Model 1-KS-420 MARC 7G1

Contract No. NAS 3-7128-H

Customer NASA Lewis Research Center

Purpose of Test: Motor Evaluation

Test No. 2788

Date of Test: 8/10/65

Test Agency: Rocket Test Group Atlantic Research Corporation

Prepared by: A. Johnson

Date: 8/16/65

Approved by: A. D. Mattox

Date: 8/18/65

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Appendix C

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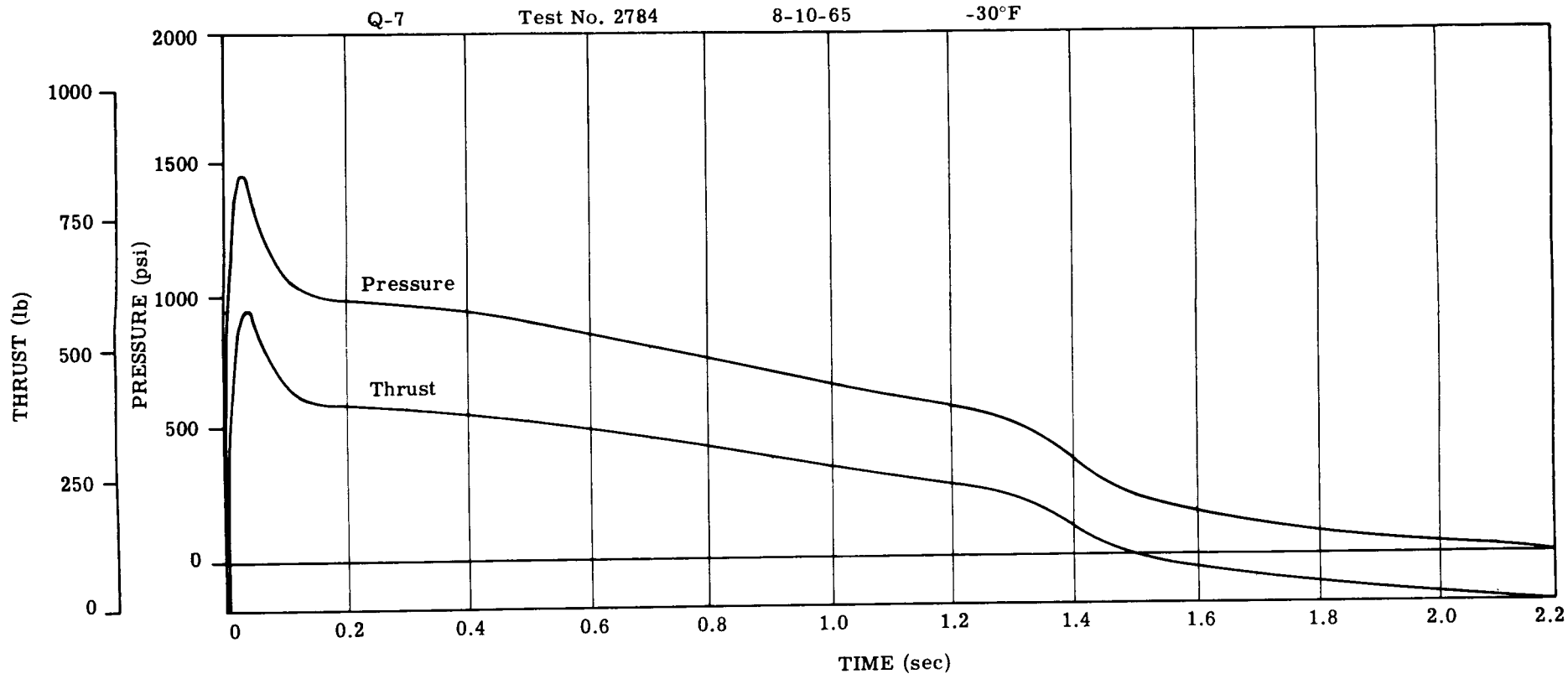
F129-6/65-2C


Q-7
Test No. 2784
8-10-65
-30°F
THRUST (lb)
PRESSURE (psi)
2000
1000
1500
750
1000
500
500
250
0
0
Pressure
Thrust
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
TIME (sec)

MOTOR DATA

Atlantic Research Part No. P-86-38-9
Customer Part No. —
Motor Serial No. Q-7
Grain Type Arcite 377A-9C
Grain No. 2474-R-3-9A

IGNITER DATA

Model No. ARC 502
Atlantic Research Part No. P-86-32-2
Lot No. —
Serial No. 50
Resistances: Circuit A-B 0.970 ohms
Circuit C-D 1.300 ohms

BALLISTIC PARAMETERS

Nozzle Exit Area 2.172 sq in
Propellant Weight 2.141 lb
Inhibited Grain Weight — lb
Average Web 0.4104 in
Grain O.D. 2.550/2.510/2.533 in
Grain Length 8.462 in

TEST DATA

Conditioning Temperature -30 °F for ≥ 4 hrs
Time Out of Box 1655
Time Fired 1703 Time Elapsed 8 min
Ambient Temperature 83 °F
Relative Humidity 55 %
Barometric Pressure 29.54 in Hg
Ignition Current A-B: 5.05 C-D: 5.19 amps
Pre-Test Environmental Conditions Temperature - Humidity, Altitude, Vibration at -30°F, Shock, Temperature Shock, Tunnel Pressure: Init 0.0093, Av 0.0466, Final 0.0427 psia
Ignition Voltage A-B: 26.2, C-D: 27.2 volts
Nozzle closure vented before firing.
Prefiring Examination:
Motor Weight 5.10 lb
Throat Diameter 0.555 in
Post Firing Examination
Motor Weight 2.94 lb
Throat Diameter 0.553 in
Average Throat Area 0.2409 sq in
Average A_e/A_t 9.02

BALLISTIC DATA

Action Time, t_a 1.787 sec
Burning Time, t_b 0.849 sec
Rise Time, t_r 0.003 sec
Ignition Delay, t_d 0.004 sec
Average Burning Rate, r 0.4834 in/sec
Maximum Pressure, P_{max} 981.6 psia
Pressure-Time Integral, PTI_a 1197 psia-sec
Average Pressure, P_a 669.8 psia
Average Pressure, P_b 939.7 psia
Ignition Pressure, P_{ign} 1465 psia
Discharge Coefficient, C_d 0.00730 lbm/lbf-sec
Characteristic Exhaust Velocity, C* 4409 ft/sec
O-O Pressure Integral 1218 psia-sec

	Measured	Abs. Vac.	
Total Impulse, I_a	477.6		lbf-sec
Specific Impulse, I_{sp}	223.1		lbf-sec/lbm
Maximum Thrust, F_{max}	388.5		lbf
Average Thrust, F_a	267.3		lbf
Average Thrust, F_b	373.3		lbf
Ignition Thrust, F_{ign}	573.4		lbf
Thrust Coefficient, C_F	1.6556		
O-O Thrust Integral	485.6		lbf-sec

I_{sp} (0-0), Motor 95.22 lbf-sec/lbm
I_{sp} (0-0), Propellant 226.8 lbf-sec/lbm

ADMINISTRATIVE DATA

Rocket Type and Model 1-KS-420 MARC 7G1
Contract No. NAS 3-7128-H
Customer NASA Lewis Research Center
Purpose of Test: Motor Evaluation
Test No. 2784
Date of Test: 8/10/65
Test Agency: Rocket Test Group Atlantic Research Corporation
Prepared by: A. Johnson
Date: 8/16/65
Approved by: A. D. Mattox
Date: 8/18/65

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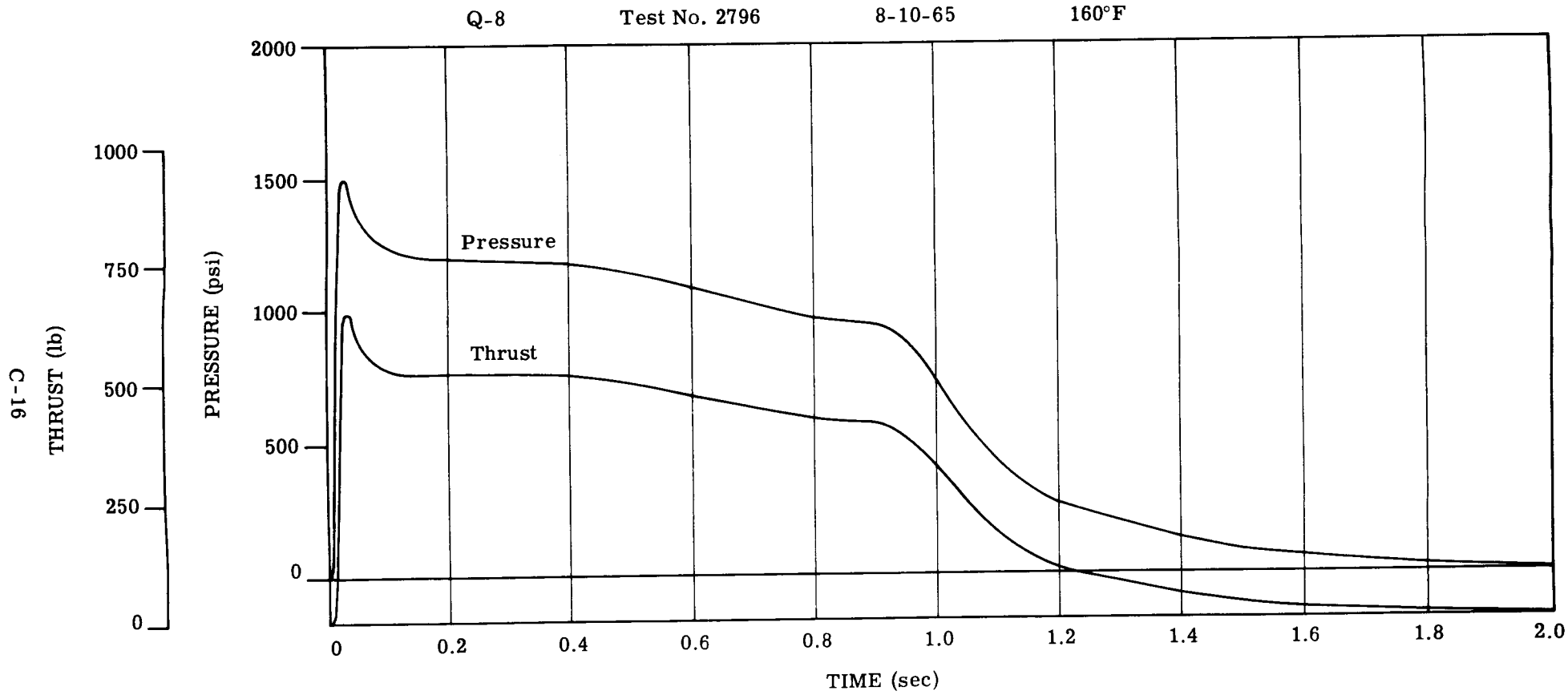
Q-8
Test No. 2796
8-10-65
160°F
2000
1500
1000
500
0
Pressure
Thrust
PRESSURE (psi)
1000
750
500
250
0
THRUST (lb)
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
TIME (sec)

MOTOR DATA

Atlantic Research Part No. P-86-38-9
Customer Part No. —
Motor Serial No. Q-8
Grain Type Arcite 377A-9C
Grain No. 2474-R-3-8A

IGNITER DATA

Model No. ARC 502
Atlantic Research Part No. P-86-32-2
Lot No. —
Serial No. 27
Resistances: Circuit A-B 1.190 ohms
Circuit C-D 1.140 ohms

BALLISTIC PARAMETERS

Nozzle Exit Area 2.172 sq in
Propellant Weight 2.141 lb
Inhibited Grain Weight — lb
Average Web 0.4092 in
Grain O.D. 2.548/2.515/2.532 in
Grain Length 8.463 in

TEST DATA

Conditioning Temperature +160 °F for ≥ 4 hrs
Time Out of Box —
Time Fired — Time Elapsed 8 min
Ambient Temperature 77 °F
Relative Humidity 65 %
Barometric Pressure 29.54 in Hg
Ignition Current A-B: 5.01 C-D: 4.83 amps
Pre-Test Environmental Conditions Temperature - Humidity, Altitude, Vibration at -30°F, Shock, Temperature Shock, Tunnel Pressure: Init 0.0135, Av 0.0536, Final 0.0414 psia, Ignition Voltage A-B: 26.2 C-D: 27.0 volts

Prefiring Examination:
Motor Weight 5.07 lb
Throat Diameter 0.555 in

Post Firing Examination
Motor Weight 2.93 lb
Throat Diameter 0.554 in
Average Throat Area 0.2414 sq in
Average A_e/A_t 8.99

BALLISTIC DATA

Action Time, t_a 1.427 sec
Burning Time, t_b 0.949 sec
Rise Time, t_r 0.004 sec
Ignition Delay, t_d 0.004 sec
Average Burning Rate, r 0.4312 in/sec
Maximum Pressure, P_{max} 1227 psia
Pressure-Time Integral, PTI_a 1223 psia-sec
Average Pressure, P_a 857.3 psia
Average Pressure, P_b 1132 psia
Ignition Pressure, P_{ign} 1494 psia
Discharge Coefficient, C_d 0.00725 lbm/lbf-sec
Characteristic Exhaust Velocity, C* 4649 ft/sec
O-O Pressure Integral 1281 psia-sec

	Measured	Abs. Vac.	
Total Impulse, I_a	488.3		lbf-sec
Specific Impulse, I_{sp}	228.1		lbf-sec/lbm
Maximum Thrust, F_{max}	480.0		lbf
Average Thrust, F_a	342.2		lbf
Average Thrust, F_b	445.9		lbf
Ignition Thrust, F_{ign}	587.4		lbf
Thrust Coefficient, C_F	1.6537		
O-O Thrust Integral	498.4		lbf-sec

I_{sp}(0-0), Motor 98.5 lbf-sec/lbm
I_{sp} (0-0), Propellant 232.8 lbf-sec/lbm

ADMINISTRATIVE DATA

Rocket Type and Model 1-KS-420 MARC 7G1
Contract No. NAS 3-7128-H
Customer NASA Lewis Research Center
Purpose of Test: Motor Evaluation
Test No. 2796
Date of Test: 8/10/65
Test Agency: Rocket Test Group Atlantic Research Corporation
Prepared by: J. E. Dukate
Date: 8/12/65
Approved by: A. D. Mattox
Date: 8/18/65

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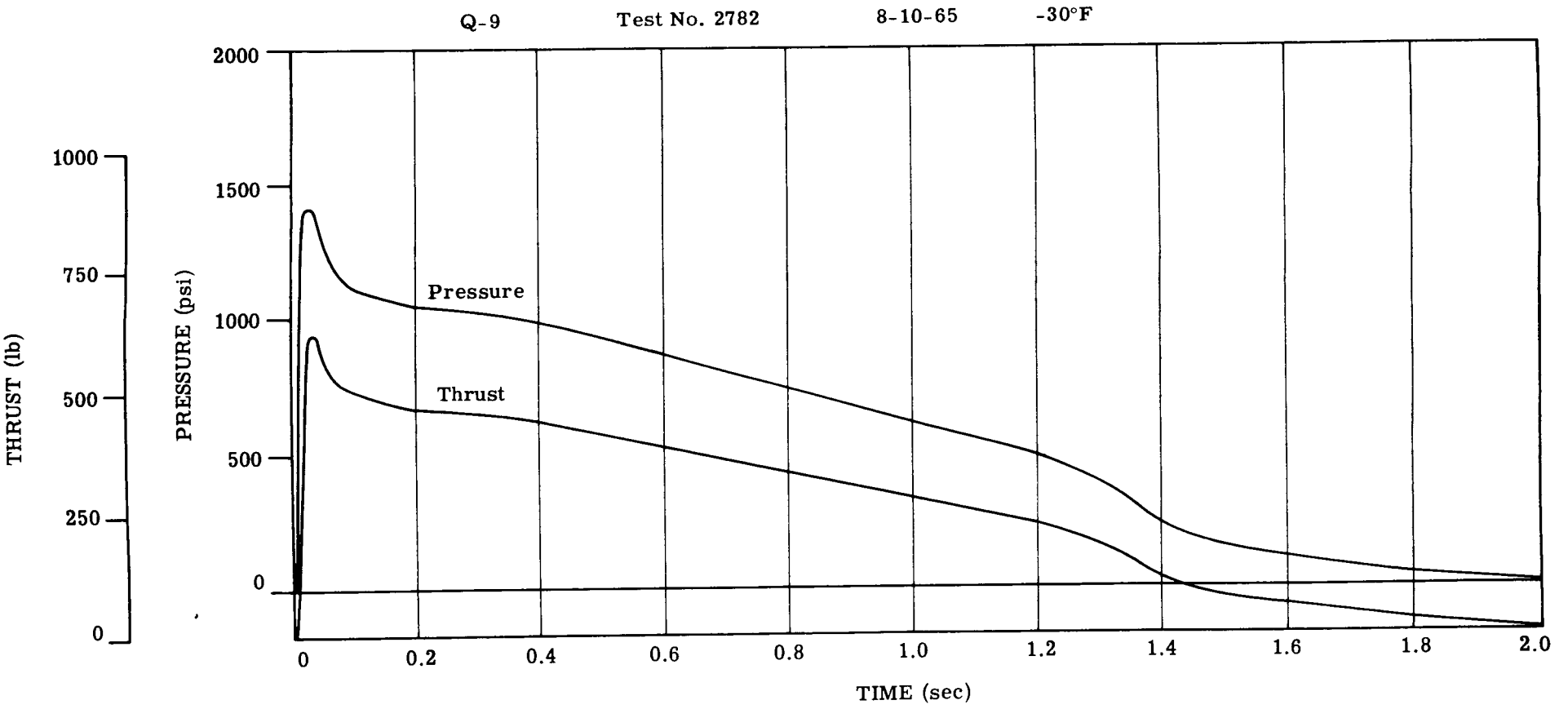
Q-9
Test No. 2782
8-10-65
-30°F
2000
1500
1000
500
0
PRESSURE (psi)
Pressure
Thrust
1000
750
500
250
0
THRUST (lb)
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
TIME (sec)

MOTOR DATA

Atlantic Research Part No. P-86-38-9
Customer Part No. —
Motor Serial No. Q-9
Grain Type Arcite 377A-9C
Grain No. 2474-R-2-4A

IGNITER DATA

Model No. ARC 502
Atlantic Research Part No. P-86-32-2
Lot No. —
Serial No. 24
Resistances: Circuit A-B 1.150 ohms
Circuit C-D 1.080 ohms

BALLISTIC PARAMETERS

Nozzle Exit Area 2.172 sq in
Propellant Weight 2.131 lb
Inhibited Grain Weight — lb
Average Web 0.4064 in
Grain O.D. 2.540/2.514/2.536 in
Grain Length 8.460 in

TEST DATA

Conditioning Temperature -30 °F for ≥ 4 hrs
Time Out of Box 1613
Time Fired 1621 Time Elapsed 8 min
Ambient Temperature 83 °F
Relative Humidity 55 %
Barometric Pressure 29.54 in Hg
Ignition Current A-B: 5.20, C-D: 5.06 amps
Pre-Test Environmental Conditions Temperature-Humidity, Altitude, Vibration at -30°F, Shock, Temperature Shock, Tunnel Pressure: Init 0.0077, Av 0.0526, Final 0.0451 psia
Ignition Voltage A-B: 26.2, C-D: 27.2 volts

Prefiring Examination:
Motor Weight 5.10 lb
Throat Diameter 0.555 in

Post Firing Examination
Motor Weight 2.95 lb
Throat Diameter 0.553 in
Average Throat Area 0.2410 sq in
Average A_e/A_t 9.01

BALLISTIC DATA

Action Time, t_a 1.692 sec
Burning Time, t_b 0.757 sec
Rise Time, t_r 0.003 sec
Ignition Delay, t_d 0.006 sec
Average Burning Rate, r 0.5368 in/sec
Maximum Pressure, P_{max} 1032 psia
Pressure-Time Integral, PTI_a 1165 psia-sec
Average Pressure, P_a 688.6 psia
Average Pressure, P_b 1002 psia
Ignition Pressure, P_{ign} 1401 psia
Discharge Coefficient, C_d 0.00746 lbm/lbf-sec
Characteristic Exhaust Velocity, C* 4312 ft/sec
O-O Pressure Integral 1185 psia-sec

	Measured	Abs. Vac.	
Total Impulse, I_a	477.2		lbf-sec
Specific Impulse, I_{sp}	223.9		lbf-sec/lbm
Maximum Thrust, F_{max}	425.9		lbf
Average Thrust, F_a	282.0		lbf
Average Thrust, F_b	406.1		lbf
Ignition Thrust, F_{ign}	566.4		lbf
Thrust Coefficient, C_F	1.6703		
O-O Thrust Integral	487.4		lbf-sec

I_{sp} (0-0), Motor 95.57 lbf-sec/lbm
I_{sp} (0-0), Propellant 228.7 lbf-sec/lbm

ADMINISTRATIVE DATA

Rocket Type and Model 1-KS-420 MARC 7G1
Contract No. NAS 3-7128-H
Customer NASA Lewis Research Center
Purpose of Test: Motor Evaluation
Test No. 2782
Date of Test: 8/10/65
Test Agency: Rocket Test Group Atlantic Research Corporation
Prepared by: A. Johnson
Date: 8/13/65
Approved by: A. D. Mattox
Date: 8/18/65

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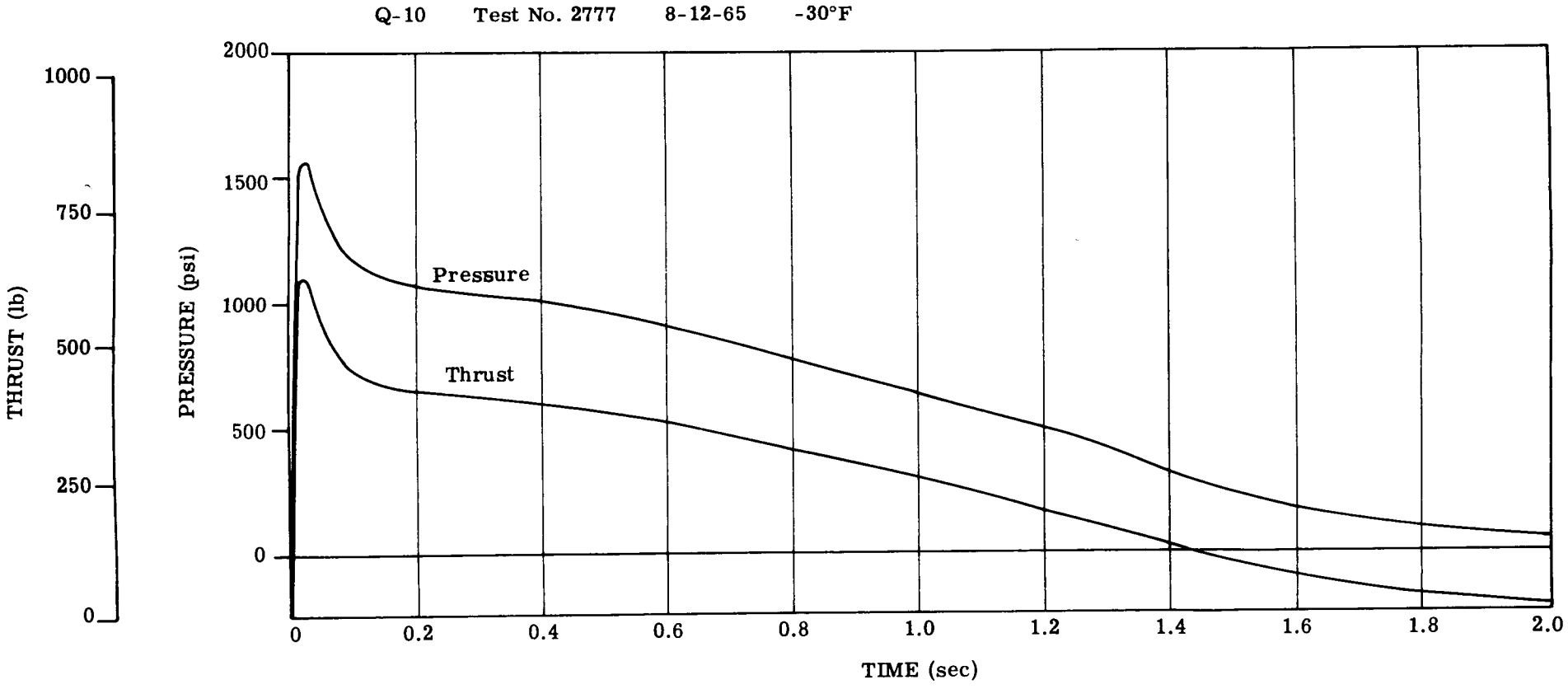
Q-10 Test No. 2777 8-12-65 -30°F
THRUST (lb)
1000
750
500
250
0
PRESSURE (psi)
2000
1500
1000
500
0
Pressure
Thrust
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
TIME (sec)

MOTOR DATA

Atlantic Research Part No. P-86-38-9

Customer Part No. —

Motor Serial No. Q-10

Grain Type Arcite 377A-9C

Grain No. 2474-R-3-4B

IGNITER DATA

Model No. ARC 502

Atlantic Research Part No. P-86-32-2

Lot No. —

Serial No. 22

Resistances: Circuit A-B 1.150 ohms

Circuit C-D 0.950 ohms

BALLISTIC PARAMETERS

Nozzle Exit Area 2.172 sq in

Propellant Weight 2.140 lb

Inhibited Grain Weight — lb

Average Web 0.4094 in

Grain O.D. 2.543/2.514/2.534 in

Grain Length 8.461 in

TEST DATA

Conditioning Temperature -30 °F for ≥ 4 hrs

Time Out of Box 0850

Time Fired 0904 Time Elapsed 14 min

Ambient Temperature 80 °F

Relative Humidity 60 %

Barometric Pressure 29.59 in Hg

Ignition Current A-B: 5.43 C-D: 5.38 amps

Pre-Test Environmental Conditions Temperature-Humidity, Altitude, Vibration at -30°F, Shock, Temperature Shock, Tunnel Pressure: Init 0.0058, Av *, Final * psia, Ignition Voltage A-B: 26.5, C-D: 27.0 volts

Prefiring Examination:

Motor Weight 5.08 lb

Throat Diameter 0.555 in

Post Firing Examination

Motor Weight 2.94 lb

Throat Diameter 0.554 in

Average Throat Area 0.2416 sq in

Average A_e/A_t 8.99

*Tunnel pressure lost due to malfunction of pressure transducer.

BALLISTIC DATA

Action Time, t_a 1.721 sec

Burning Time, t_b 0.789 sec

Rise Time, t_r 0.006 sec

Ignition Delay, t_d 0.004 sec

Average Burning Rate, r 0.5189 in/sec

Maximum Pressure, P_{max} 1025 psia

Pressure-Time Integral, PTI_a 1191 psia-sec

Average Pressure, P_a 692.0 psia

Average Pressure, P_b 1009 psia

Ignition Pressure, P_{ign} 1570 psia

Discharge Coefficient, C_d 0.00731 lbm/lbf-sec

Characteristic Exhaust Velocity, C* 4402 ft/sec

O-O Pressure Integral 1212 psia-sec

	Measured	Abs. Vac.	
Total Impulse, I_a	474.5		lbf-sec
Specific Impulse, I_{sp}	221.7		lbf-sec/lbm
Maximum Thrust, F_{max}	406.7		lbf
Average Thrust, F_a	275.7		lbf
Average Thrust, F_b	400.0		lbf
Ignition Thrust, F_{ign}	622.8		lbf
Thrust Coefficient, C_F	1.6491		
O-O Thrust Integral	482.8		lbf-sec

I_{sp} (0-0), Motor 95.04 lbf-sec/lbm

I_{sp} (0-0), Propellant 225.6 lbf-sec/lbm

ADMINISTRATIVE DATA

Rocket Type and Model 1-KS-420 MARC 7G1

Contract No. NAS 3-7128-H

Customer NASA Lewis Research Center

Purpose of Test: Motor Evaluation

Test No. 2777

Date of Test: 8/10/65

Test Agency: Rocket Test Group Atlantic Research Corporation

Prepared by: A. Johnson

Date: 8/12/65

Approved by: A. D. Mattox

Date: 8/18/65

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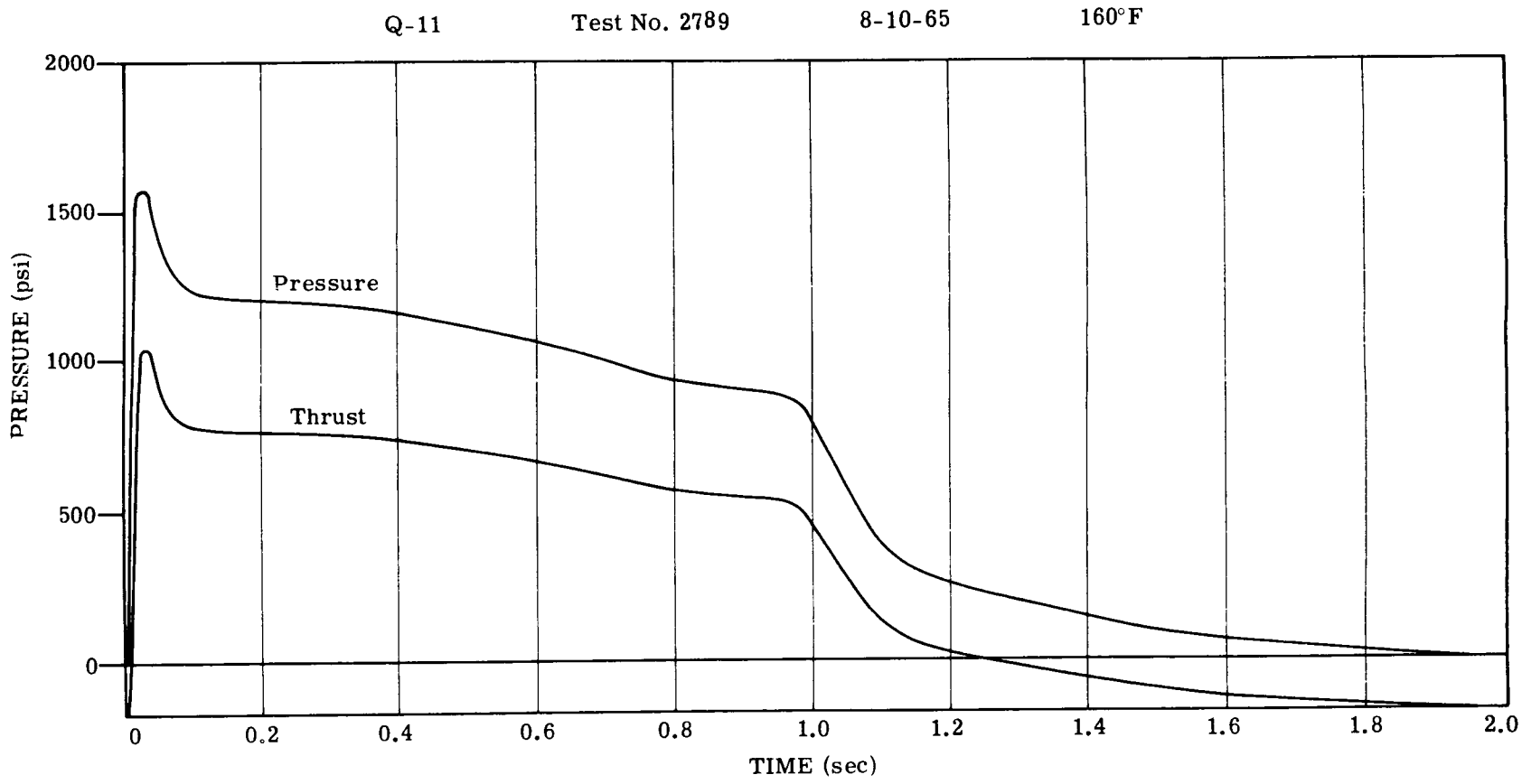
Q-11
Test No. 2789
8-10-65
160°F
2000
1500
1000
500
0
PRESSURE (psi)
Pressure
Thrust
1000
750
500
250
0
THRUST (lb)
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
TIME (sec)

MOTOR DATA

Atlantic Research Part No. P-86-38-9
Customer Part No. —
Motor Serial No. Q-11
Grain Type Arcite 377A-9C
Grain No. 2474-R-2-7A

IGNITER DATA

Model No. ARC 502
Atlantic Research Part No. P-86-32-2
Lot No. —
Serial No. 35
Resistances: Circuit A-B 1.080 ohms
Circuit C-D 0.990 ohms

BALLISTIC PARAMETERS

Nozzle Exit Area 2.172 sq in
Propellant Weight 2.128 lb
Inhibited Grain Weight — lb
Average Web 0.4196 in
Grain O.D. 2.552/2.530/2.535 in
Grain Length 8.462 in

TEST DATA

Conditioning Temperature +160 °F for ≥ 4 hrs
Time Out of Box 1820
Time Fired 1826 Time Elapsed 6 min
Ambient Temperature 60 °F
Relative Humidity 55 %
Barometric Pressure 29.53 in Hg
Ignition Current A-B: 5.23, C-D: 5.18 amps
Pre-Test Environmental Conditions Temperature-Humidity, Altitude, Vibration at 160°F, Shock, Temperature Shock, Tunnel Pressure: Init 0.0135, Av 0.0555, Final 0.0665 psia
Ignition Voltage A-B: 25.1, C-D: 27.4 volts
Nozzle closure vented before firing.
Prefiring Examination:
Motor Weight 5.06 lb
Throat Diameter 0.555 in
Post Firing Examination
Motor Weight 2.91 lb
Throat Diameter 0.555 in
Average Throat Area 0.2419 sq in
Average A_e/A_t 8.98

BALLISTIC DATA

Action Time, t_a 1.420 sec
Burning Time, t_b 0.873 sec
Rise Time, t_r 0.002 sec
Ignition Delay, t_d 0.002 sec
Average Burning Rate, r 0.4806 in/sec
Maximum Pressure, P_{max} 1212 psia
Pressure-Time Integral, PTI_a 1216 psia-sec
Average Pressure, P_a 856.3 psia
Average Pressure, P_b 1128 psia
Ignition Pressure, P_{ign} 1562 psia
Discharge Coefficient, C_d 0.00723 lbm/lbf-sec
Characteristic Exhaust Velocity, C* 4550 ft/sec
O-O Pressure Integral 1244 psia-sec

	Measured	Abs. Vac.	
Total Impulse, I_a	487.5		lbf-sec
Specific Impulse, I_{sp}	229.1		lbf-sec/lbm
Maximum Thrust, F_{max}	482.1		lbf
Average Thrust, F_a	343.3		lbf
Average Thrust, F_b	451.9		lbf
Ignition Thrust, F_{ign}	620.2		lbf
Thrust Coefficient, C_F	1.6564		
O-O Thrust Integral	497.4		lbf-sec

I_{sp} (0-0), Motor 98.30 lbf-sec/lbm
I_{sp} (0-0), Propellant 233.7 lbf-sec/lbm

ADMINISTRATIVE DATA

Rocket Type and Model 1-KS-420 MARC 7G1
Contract No. NAS 3-7128-H
Customer NASA Lewis Research Center
Purpose of Test: Motor Evaluation
Test No. 2789
Date of Test: 8/10/65
Test Agency: Rocket Test Group Atlantic Research Corporation
Prepared by: J. E. Dukate
Date: 8/16/65
Approved by: A. D. Mattox
Date: 8/18/65

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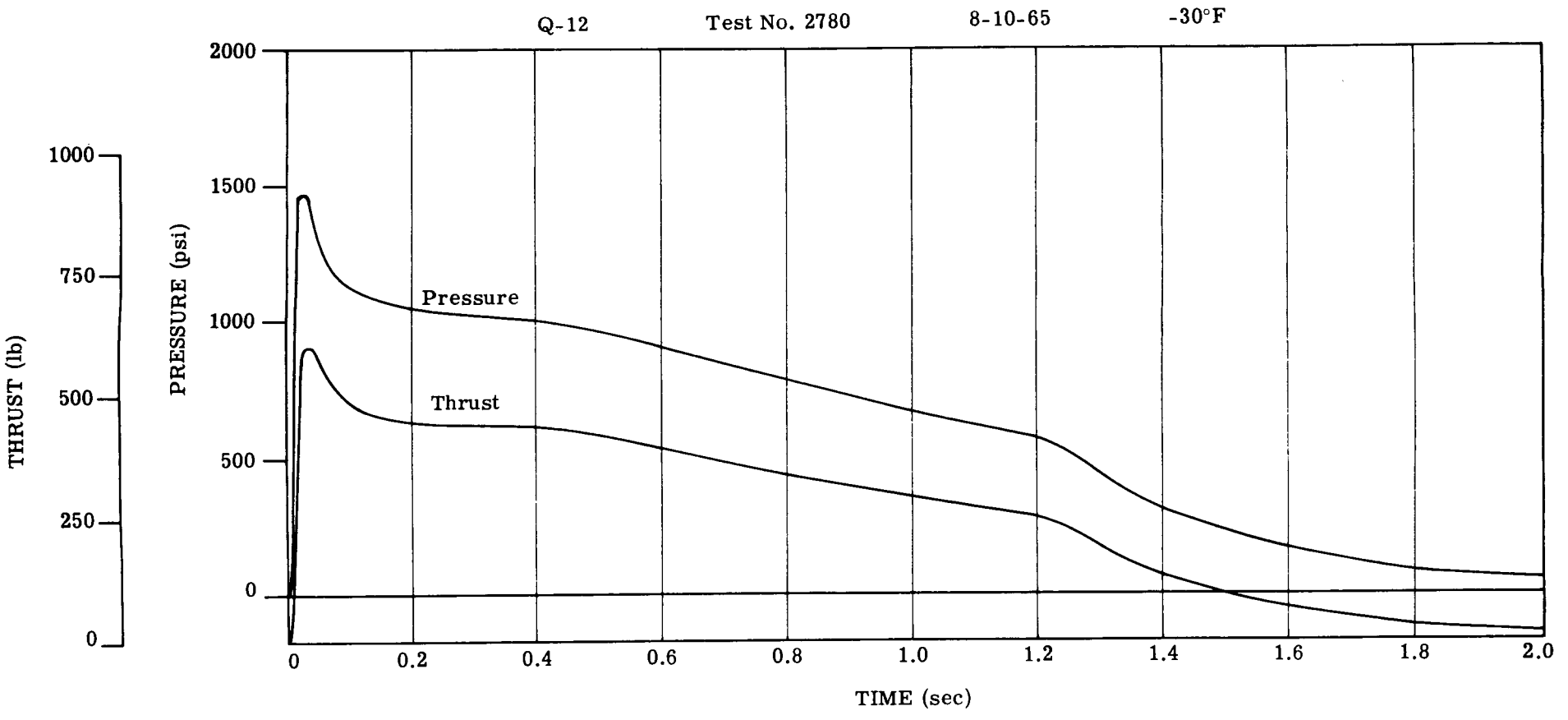
Q-12
Test No. 2780
8-10-65
-30°F
PRESSURE (psi)
2000
1500
1000
500
0
THRUST (lb)
1000
750
500
250
0
Pressure
Thrust
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
TIME (sec)

MOTOR DATA

Atlantic Research Part No. P-86-38-9
Customer Part No. —
Motor Serial No. Q-12
Grain Type Arcite 377A-9C
Grain No. 2474-R-3-5A

IGNITER DATA

Model No. ARC 502
Atlantic Research Part No. P-86-32-2
Lot No. —
Serial No. 13
Resistances: Circuit A-B 1.230 ohms
Circuit C-D 1.120 ohms

BALLISTIC PARAMETERS

Nozzle Exit Area 2.172 sq in
Propellant Weight 2.138 lb
Inhibited Grain Weight — lb
Average Web 0.4100 in
Grain O.D. 2.542/2.515/2.533 in
Grain Length 8.463 in

TEST DATA

Conditioning Temperature -30 °F for ≥ 4 hrs
Time Out of Box 1537
Time Fired 1548 Time Elapsed 11 min
Ambient Temperature 83 °F
Relative Humidity 55 %
Barometric Pressure 29.54 in Hg
Ignition Current A-B: 5.27 C-D: 5.12 amps
Pre-Test Environmental Conditions Temperature-Humidity, Altitude, Vibration at 160°F, Shock, Temperature Shock, Tunnel Pressure: Init 0.0079, Av 0.0497, Final 0.0441 psia
Ignition Voltage A-B: 26.0, C-D: 27.3 volts
Nozzle closure vented before firing.

Prefiring Examination:

Motor Weight 5.08 lb
Throat Diameter 0.555 in

Post Firing Examination

Motor Weight 2.91 lb
Throat Diameter 0.554 in
Average Throat Area 2.414 sq in
Average A_e/A_t 8.99

BALLISTIC DATA

Action Time, t_a 1.731 sec
Burning Time, t_b 0.821 sec
Rise Time, t_r 0.003 sec
Ignition Delay, t_d 0.005 sec
Average Burning Rate, r 0.4994 in/sec
Maximum Pressure, P_{max} 1023 psia
Pressure-Time Integral, PTI_a 1203 psia-sec
Average Pressure, P_a 694.9 psia
Average Pressure, P_b 984.0 psia
Ignition Pressure, P_{ign} 1475 psia
Discharge Coefficient, C_d 0.00721 lbm/lbf-sec
Characteristic Exhaust Velocity, C* 4461 ft/sec
O-O Pressure Integral 1228 psia-sec

	Measured	Abs. Vac.	
Total Impulse, I_a	479.5		lbf-sec
Specific Impulse, I_{sp}	224.3		lbf-sec/lbm
Maximum Thrust, F_{max}	407.2		lbf
Average Thrust, F_a	277.0		lbf
Average Thrust, F_b	391.0		lbf
Ignition Thrust, F_{ign}	582.8		lbf
Thrust Coefficient, C_F	1.6504		
O-O Thrust Integral	489.4		lbf-sec

I_{sp} (0-0), Motor 96.34 lbf-sec/lbm
I_{sp} (0-0), Propellant 228.9 lbf-sec/lbm

ADMINISTRATIVE DATA

Rocket Type and Model 1-KS-420 MARC 7G1
Contract No. NAS 3-7128-H
Customer NASA Lewis Research Center
Purpose of Test: Motor Evaluation
Test No. 2780
Date of Test: 8/10/65
Test Agency: Rocket Test Group Atlantic Research Corporation
Prepared by: A. Johnson
Date: 8/12/65
Approved by: A. D. Mattox
Date: 8/18/65

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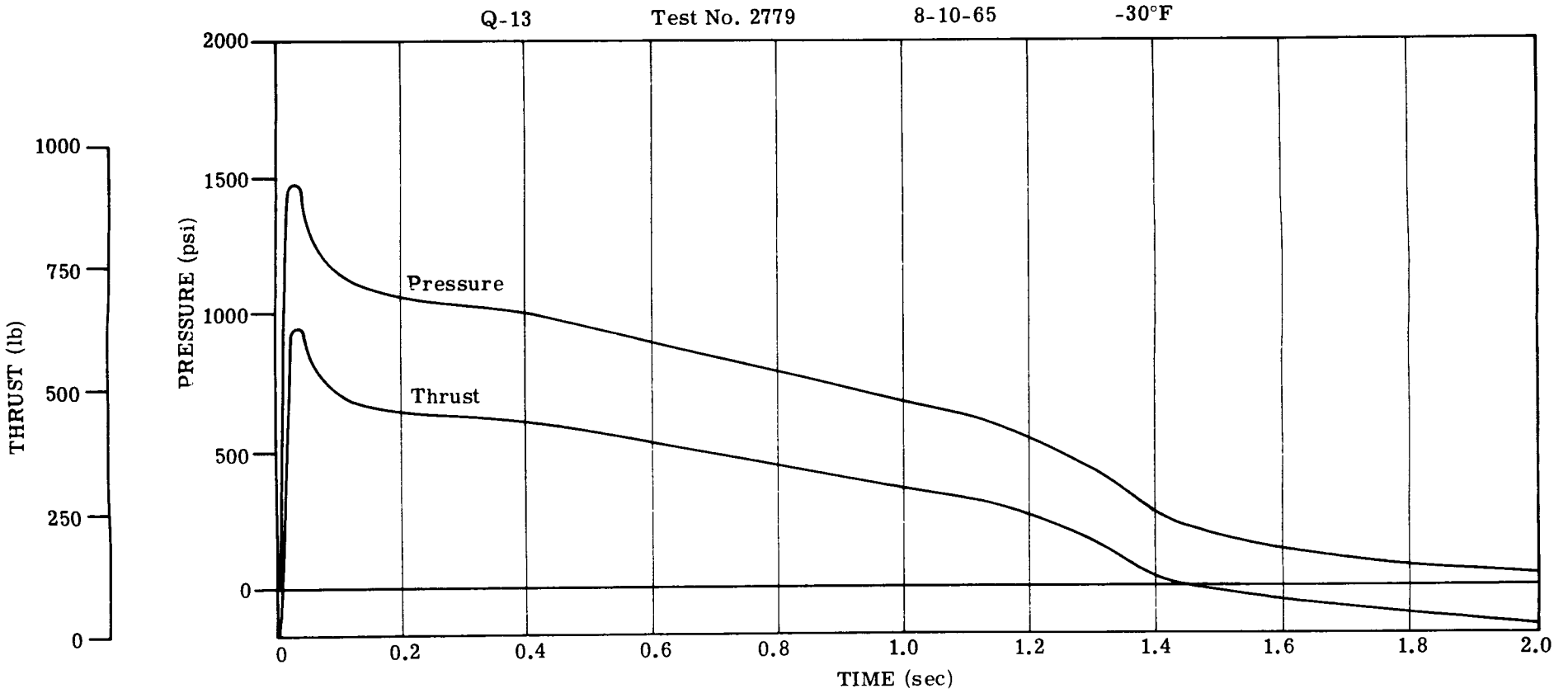
Q-13
Test No. 2779
8-10-65
-30°F
2000
1500
1000
500
0
PRESSURE (psi)
Pressure
Thrust
1000
750
500
250
0
THRUST (lb)
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
TIME (sec)

MOTOR DATA

Atlantic Research Part No. P-86-38-9
Customer Part No. —
Motor Serial No. Q-13
Grain Type Arcite 377A-9C
Grain No. 2474-R-2-6A

IGNITER DATA

Model No. ARC 502
Atlantic Research Part No. P-86-32-2
Lot No. —
Serial No. 30
Resistances: Circuit A-B 1.160 ohms
Circuit C-D 1.040 ohms

BALLISTIC PARAMETERS

Nozzle Exit Area 2.172 sq in
Propellant Weight 2.134 lb
Inhibited Grain Weight — lb
Average Web 0.4146 in
Grain O.D. 2.547/2.811/2.531 in
Grain Length 8.457 in

TEST DATA

Conditioning Temperature -30 °F for ≥ 4 hrs
Time Out of Box 1522
Time Fired 1533 Time Elapsed 11 min
Ambient Temperature 83 °F
Relative Humidity 50 %
Barometric Pressure 29.54 in Hg
Ignition Current A-B: 5.43 C-D: 5.19 amps
Pre-Test Environmental Conditions Temperature-Humidity, Altitude, Vibration at 160°F, Shock, Temperature Shock, Tunnel Pressure: Init 0.0060, Av 0.0499, Final 0.0447 psia, Ignition Voltage A-B: 26.0 C-D: 27.5 volts

Prefiring Examination:
Motor Weight 5.06 lb
Throat Diameter 0.555 in

Post Firing Examination
Motor Weight 2.92 lb
Throat Diameter 0.553 in
Average Throat Area 0.2410 sq in
Average A_e/A_t 9.01

BALLISTIC DATA

Action Time, t_a 1.709 sec
Burning Time, t_b 0.816 sec
Rise Time, t_r 0.008 sec
Ignition Delay, t_d 0.004 sec
Average Burning Rate, r 0.5081 in/sec
Maximum Pressure, P_{max} 1034 psia
Pressure-Time Integral, PTI_a 1193 psia-sec
Average Pressure, P_a 698.2 psia
Average Pressure, P_b 988.8 psia
Ignition Pressure, P_{ign} 1471 psia
Discharge Coefficient, C_d 0.00728 lbm/lbf-sec
Characteristic Exhaust Velocity, C* 4422 ft/sec
O-O Pressure Integral 1217 psia-sec

	Measured	Abs. Vac.	
Total Impulse, I_a	477.4		lbf-sec
Specific Impulse, I_{sp}	223.7		lbf-sec/lbm
Maximum Thrust, F_{max}	458.2		lbf
Average Thrust, F_a	279.3		lbf
Average Thrust, F_b	392.8		lbf
Ignition Thrust, F_{ign}	637.8		lbf
Thrust Coefficient, C_F	1.6628		
O-O Thrust Integral	487.4		lbf-sec

I_{sp} (0-0), Motor 96.32 lbf-sec/lbm
I_{sp} (0-0), Propellant 228.4 lbf-sec/lbm

ADMINISTRATIVE DATA

Rocket Type and Model 1-KS-420 MARC 7G1
Contract No. NAS 3-7128-H
Customer NASA Lewis Research Center
Purpose of Test: Motor Evaluation
Test No. 2779
Date of Test: 8/10/65
Test Agency: Rocket Test Group Atlantic Research Corporation
Prepared by: A. Johnson
Date: 8/12/65
Approved by: A. D. Mattox
Date: 8/18/65

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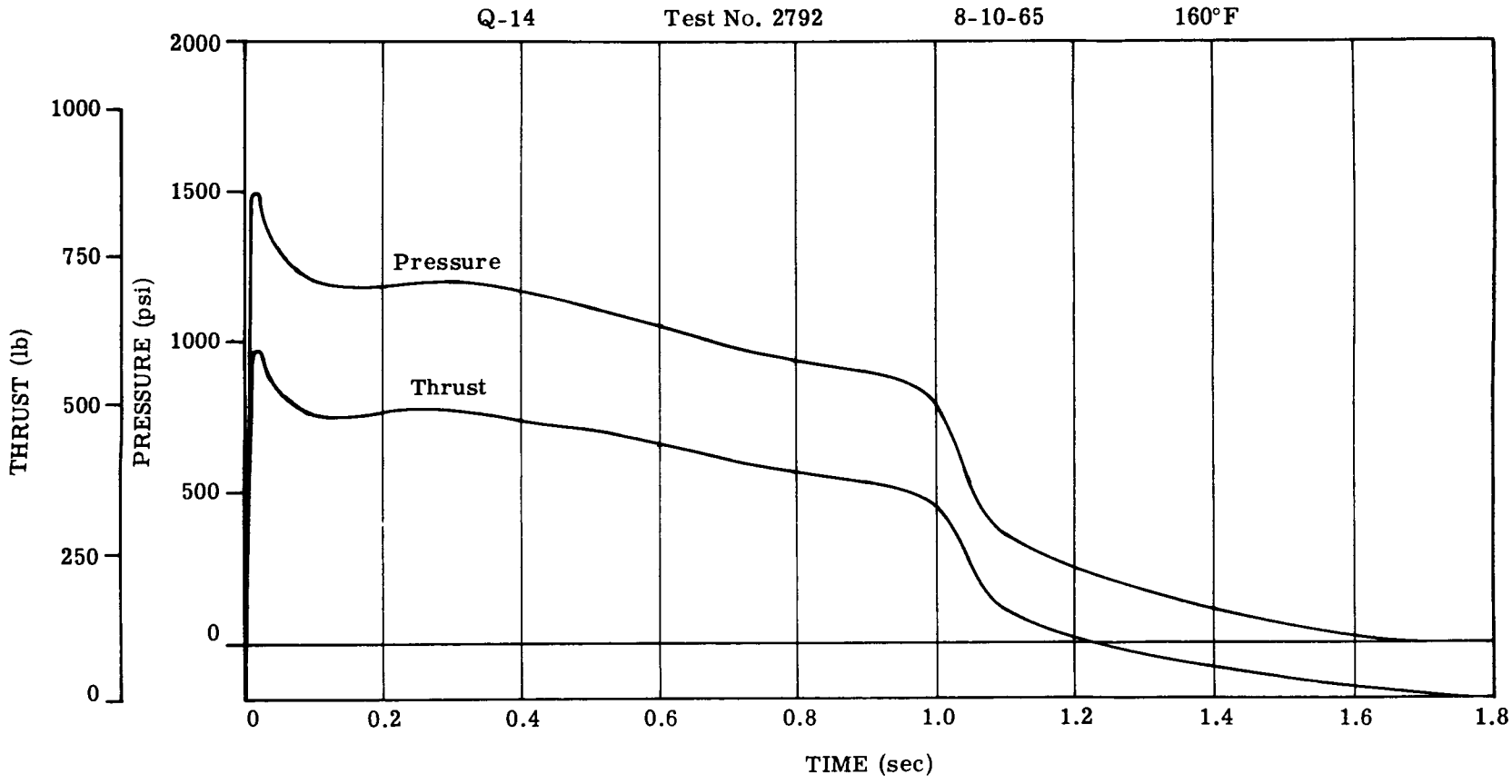
Q-14
Test No. 2792
8-10-65
160°F
THRUST (lb)
PRESSURE (psi)
1000
750
500
250
0
2000
1500
1000
500
0
Pressure
Thrust
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
TIME (sec)

MOTOR DATA

Atlantic Research Part No. P-86-38-9
Customer Part No. —
Motor Serial No. Q-14
Grain Type Arcite 377A-9C
Grain No. 2474-R-3-4A

IGNITER DATA

Model No. ARC 502
Atlantic Research Part No. P-86-32-2
Lot No. —
Serial No. 32
Resistances: Circuit A-B 1.100 ohms
Circuit C-D 1.030 ohms

BALLISTIC PARAMETERS

Nozzle Exit Area 2.172 sq in
Propellant Weight 2.137 lb
Inhibited Grain Weight — lb
Average Web 0.494 in
Grain O.D. 2.545/2.511/2.533 in
Grain Length 8.465 in

TEST DATA

Conditioning Temperature +160 °F for ≥ 4 hrs
Time Out of Box 1929
Time Fired 1936 Time Elapsed 7 min
Ambient Temperature 80 °F
Relative Humidity 60 %
Barometric Pressure 29.53 in Hg
Ignition Current A-B: 5.07 C-D: 5.30 amps
Pre-Test Environmental Conditions Temperature-Humidity, Altitude, Vibration at 160°F, Shock, Temperature Shock, Tunnel Pressure: Init 0.0155, Av 0.0589, Final 0.0460 psia, Ignition Voltage, A-B: 26.2, C-D 27.4 volts

Prefiring Examination:
Motor Weight 5.06 lb
Throat Diameter 0.555 in

Post Firing Examination
Motor Weight 2.91 lb
Throat Diameter 0.553 in
Average Throat Area 0.2411 sq in
Average A_e/A_t 9.01

BALLISTIC DATA

Action Time, t_a 1.382 sec
Burning Time, t_b 0.908 sec
Rise Time, t_r 0.003 sec
Ignition Delay, t_d 0.004 sec
Average Burning Rate, r 0.451 in/sec
Maximum Pressure, P_{max} 1207 psia
Pressure-Time Integral, PTI_a 1217 psia-sec
Average Pressure, P_a 880.6 psia
Average Pressure, P_b 1124 psia
Ignition Pressure, P_{ign} 1488 psia
Discharge Coefficient, C_d 0.00728 lbm/lbf-sec
Characteristic Exhaust Velocity, C* 4516 ft/sec
O-O Pressure Integral 1244 psia-sec

	Measured	Abs. Vac.	
Total Impulse, I_a	486.4		lbf-sec
Specific Impulse, I_{sp}	227.6		lbf-sec/lbm
Maximum Thrust, F_{max}	479.8		lbf
Average Thrust, F_a	352.0		lbf
Average Thrust, F_b	449.8		lbf
Ignition Thrust, F_{ign}	589.8		lbf
Thrust Coefficient, C_F	1.6569		
O-O Thrust Integral	497.8		lbf-sec

I_{sp} (0-0), Motor 98.38 lbf-sec/lbm
I_{sp} (0-0), Propellant 232.9 lbf-sec/lbm

ADMINISTRATIVE DATA

Rocket Type and Model 1-KS-420 MARC 7G1
Contract No. NAS 3-7128-H
Customer NASA Lewis Research Center
Purpose of Test: Motor Evaluation
Test No. 2792
Date of Test: 8/10/65
Test Agency: Rocket Test Group Atlantic Research Corporation
Prepared by: J. R. Wertz
Date: 8/16/65
Approved by: A. D. Mattox
Date: 8/18/65

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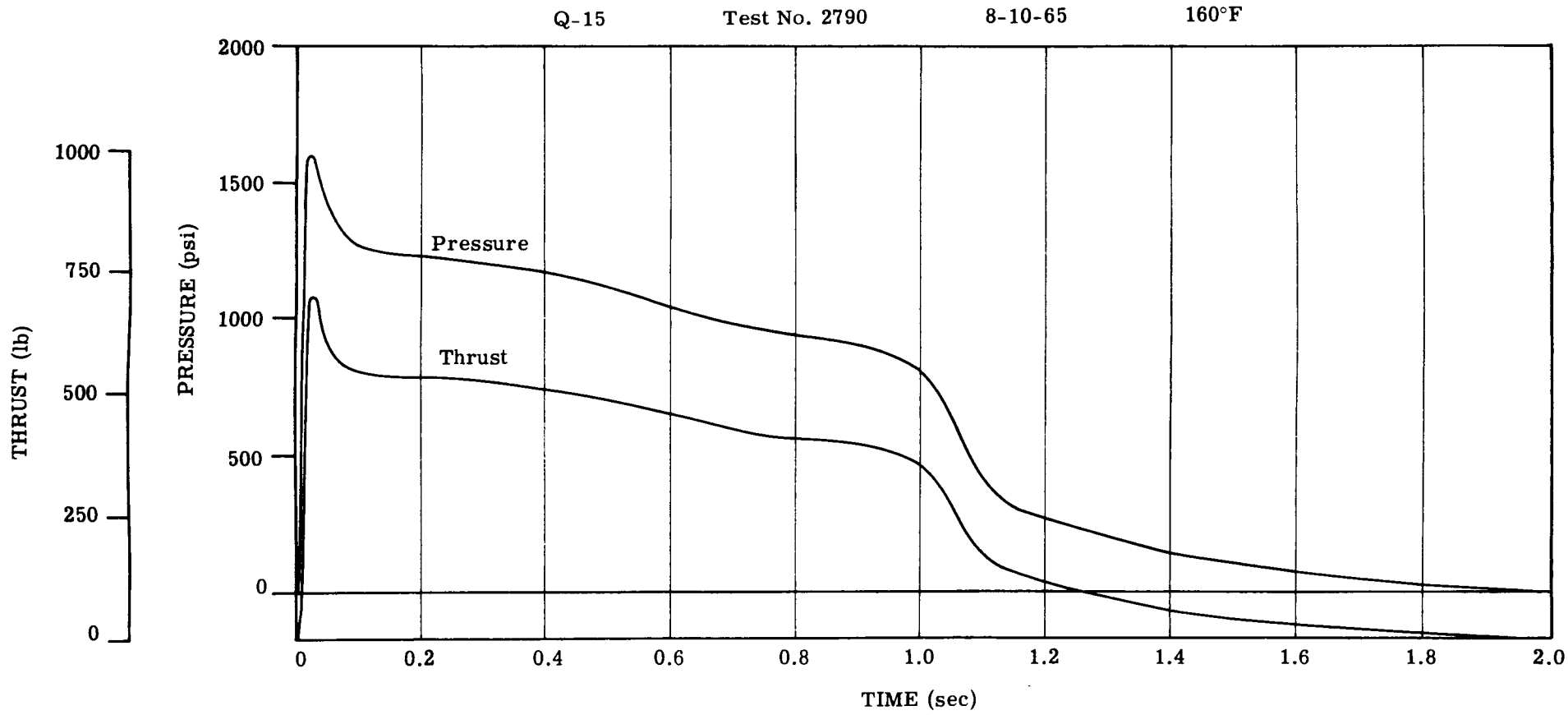
Q-15
Test No. 2790
8-10-65
160°F
2000
1500
1000
500
0
PRESSURE (psi)
Pressure
Thrust
1000
750
500
250
0
THRUST (lb)
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
TIME (sec)

MOTOR DATA

Atlantic Research Part No. P-86-38-9
Customer Part No. —
Motor Serial No. Q-15
Grain Type Arcite 377A-9C
Grain No. 2474-R-2-3B

IGNITER DATA

Model No. ARC 502
Atlantic Research Part No. P-86-32-2
Lot No. —
Serial No. 25
Resistances: Circuit A-B 1.190 ohms
Circuit C-D 1.120 ohms

BALLISTIC PARAMETERS

Nozzle Exit Area 2.172 sq in
Propellant Weight 2.131 lb
Inhibited Grain Weight — lb
Average Web 0.4084 in
Grain O.D. 2.546/2.512/2.532 in
Grain Length 8.466 in

TEST DATA

Conditioning Temperature +160 °F for ≥ 4 hrs
Time Out of Box —
Time Fired — Time Elapsed 8 min
Ambient Temperature 80 °F
Relative Humidity 50 %
Barometric Pressure 29.54 in Hg
Ignition Current A-B: 5.03 C-D: 5.01 amps
Pre-Test Environmental Conditions Temperature-Humidity, Altitude, Vibration at 160°F, Shock, Temperature Shock, Tunnel Pressure: Init 0.0126, Av 0.0578, Final 0.0423 psia, Ignition Voltage A-B: 26.2, C-D: 27.5 volts

Prefiring Examination:
Motor Weight 5.09 lb
Throat Diameter 0.555 in

Post Firing Examination
Motor Weight 2.92 lb
Throat Diameter 0.554 in
Average Throat Area 0.2415 sq in
Average A_e/A_t 8.99

BALLISTIC DATA

Action Time, t_a 1.403 sec
Burning Time, t_b 0.826 sec
Rise Time, t_r 0.003 sec
Ignition Delay, t_d 0.003 sec
Average Burning Rate, r 0.4944 in/sec
Maximum Pressure, P_{max} 1235 psia
Pressure-Time Integral, PTI_a 1224 psia-sec
Average Pressure, P_a 872.6 psia
Average Pressure, P_b 1144 psia
Ignition Pressure, P_{ign} 1581 psia
Discharge Coefficient, C_d 0.00721 lbm/lbf-sec
Characteristic Exhaust Velocity, C* 4572 ft/sec
O-O Pressure Integral 1254 psia-sec

	Measured	Abs. Vac.	
Total Impulse, I_a	487.7		lbf-sec
Specific Impulse, I_{sp}	228.9		lbf-sec/lbm
Maximum Thrust, F_{max}	491.5		lbf
Average Thrust, F_a	347.7		lbf
Average Thrust, F_b	455.8		lbf
Ignition Thrust, F_{ign}	629.6		lbf
Thrust Coefficient, C_F	1.6504		
O-O Thrust Integral	498.3		lbf-sec

I_{sp} (0-0), Motor 97.90 lbf-sec/lbm
I_{sp} (0-0), Propellant 233.8 lbf-sec/lbm

ADMINISTRATIVE DATA

Rocket Type and Model 1-KS-420 MARC 7G1
Contract No. NAS 3-7128-H
Customer NASA Lewis Research Center
Purpose of Test: Motor Evaluation
Test No. 2790
Date of Test: 8/10/65
Test Agency: Rocket Test Group Atlantic Research Corporation
Prepared by: J. E. Dukate
Date: 8/16/65
Approved by: A. D. Mattox
Date: 8/18/65

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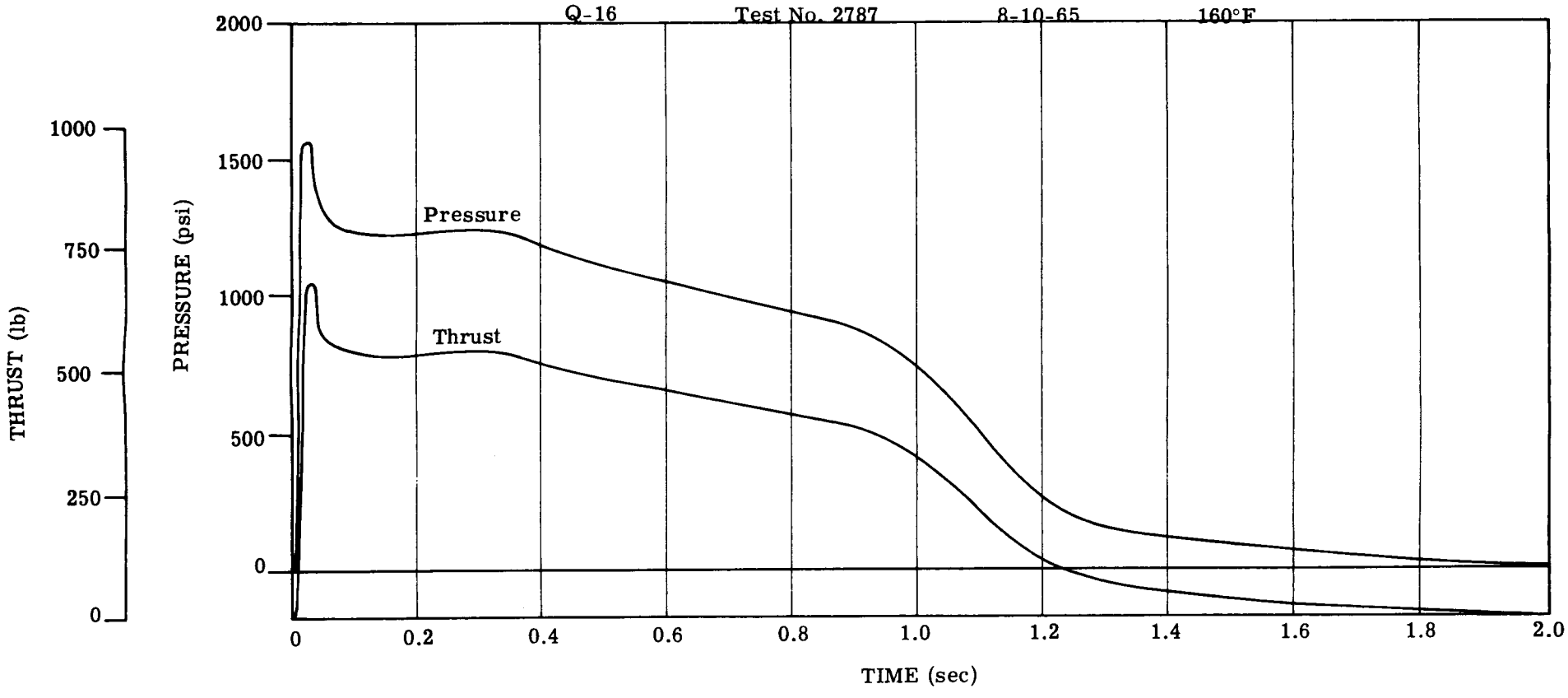
Q-16
Test No. 2787
8-10-65
160°F
2000
1500
1000
500
0
PRESSURE (psi)
Pressure
Thrust
1000
750
500
250
0
THRUST (lb)
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
TIME (sec)

MOTOR DATA

Atlantic Research Part No. P-86-38-9

Customer Part No. —

Motor Serial No. Q-16

Grain Type Arcite 377A-9C

Grain No. 2474-R-2-1B

IGNITER DATA

Model No. ARC 502

Atlantic Research Part No. P-86-32-2

Lot No. —

Serial No. 18

Resistances: Circuit A-B 1.160 ohms

Circuit C-D 1.120 ohms

BALLISTIC PARAMETERS

Nozzle Exit Area 2.172 sq in

Propellant Weight 2.132 lb

Inhibited Grain Weight — lb

Average Web 0.4088 in

Grain O.D. 2.548/2.511/2.529 in

Grain Length 8.466 in

TEST DATA

Conditioning Temperature +160 °F for ≥ 4 hrs

Time Out of Box 1756

Time Fired 1804 Time Elapsed 8 min

Ambient Temperature 83 °F

Relative Humidity 53 %

Barometric Pressure 29.54 in Hg

Ignition Current A-B: 5.05 C-D: 5.12 amps

Pre-Test Environmental Conditions Temperature-Humidity, Altitude, Vibration at 160°F, Shock, Temperature Shock, Tunnel Pressure: Init 0.0077, Av 0.0549, Final 0.0510 psia, Ignition Voltage A-B: 26.2, C-D: 27.3 volts

Nozzle closure vented before firing.

Prefiring Examination:

Motor Weight 5.08 lb

Throat Diameter 0.555 in

Post Firing Examination

Motor Weight 2.94 lb

Throat Diameter 0.553 in

Average Throat Area 0.2410 sq in

Average A_e/A_t 9.01

BALLISTIC DATA

Action Time, t_a	1.389	sec
Burning Time, t_b	0.798	sec
Rise Time, t_r	0.002	sec
Ignition Delay, t_d	0.005	sec
Average Burning Rate, r	0.5123	in/sec
Maximum Pressure, P_{max}	1240	psia
Pressure-Time Integral, PTI_a	1213	psia-sec
Average Pressure, P_a	873.3	psia
Average Pressure, P_b	1155	psia
Ignition Pressure, P_{ign}	1553	psia
Discharge Coefficient, C_d	0.00714	lbm/lbf-sec
Characteristic Exhaust Velocity, C*	4510	ft/sec
O-O Pressure Integral	1240	psia-sec

	Measured	Abs. Vac.	
Total Impulse, I_a	485.7		lbf-sec
Specific Impulse, I_{sp}	227.8		lbf-sec/lbm
Maximum Thrust, F_{max}	493.8		lbf
Average Thrust, F_a	349.7		lbf
Average Thrust, F_b	461.5		lbf
Ignition Thrust, F_{ign}	617.9		lbf
Thrust Coefficient, C_F	1.6636		
O-O Thrust Integral	496.8		lbf-sec

I_{sp} (0-0), Motor 97.80 lbf-sec/lbm

I_{sp} (0-0), Propellant 233.0 lbf-sec/lbm

ADMINISTRATIVE DATA

Rocket Type and Model 1-KS-420 MARC 7G1

Contract No. NAS 3-7128-H

Customer NASA Lewis Research Center

Purpose of Test: Motor Evaluation

Test No. 2787

Date of Test: 8/10/65

Test Agency: Rocket Test Group Atlantic Research Corporation

Prepared by: A. Johnson

Date: 8/16/65

Approved by: A. D. Mattox

Date: 8/18/65

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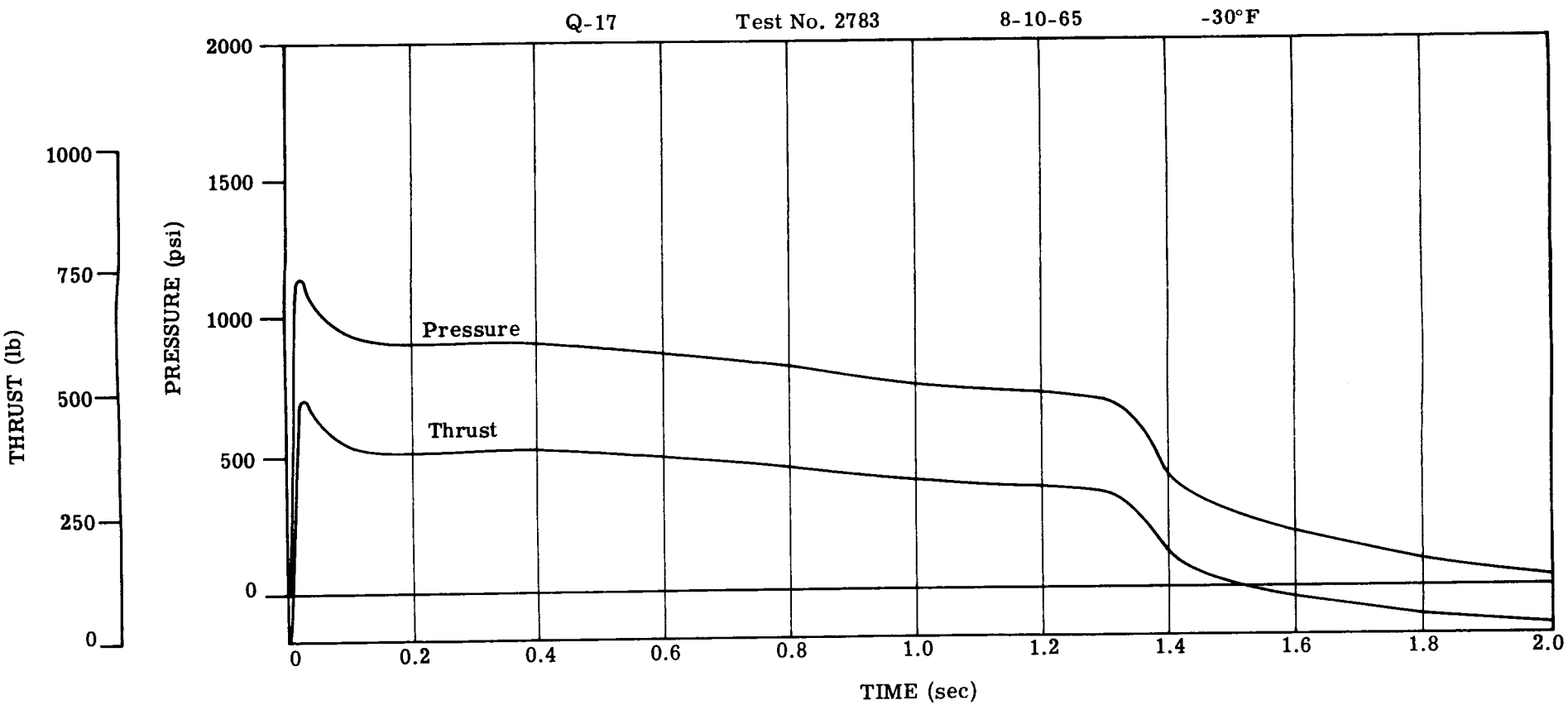
Q-17
Test No. 2783
8-10-65
-30°F
2000
1500
1000
500
0
PRESSURE (psi)
1000
750
500
250
0
THRUST (lb)
Pressure
Thrust
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
TIME (sec)

MOTOR DATA

Atlantic Research Part No. P-86-38-9

Customer Part No. —

Motor Serial No. Q-17

Grain Type Arcite 377A-9C

Grain No. 2474-R-3-3B

IGNITER DATA

Model No. ARC 502

Atlantic Research Part No. P-86-32-2

Lot No. —

Serial No. 44

Resistances: Circuit A-B 1.150 ohms

Circuit C-D 0.970 ohms

BALLISTIC PARAMETERS

Nozzle Exit Area 2.172 sq in

Propellant Weight 2.135 lb

Inhibited Grain Weight — lb

Average Web 0.4098 in

Grain O.D. 2.545/2.514/2.534 in

Grain Length 8.460 in

TEST DATA

Conditioning Temperature -30 °F for ≥ 4 hrs

Time Out of Box 1633

Time Fired 1646 Time Elapsed 13 min

Ambient Temperature 83 °F

Relative Humidity 55 %

Barometric Pressure 29.54 in Hg

Ignition Current A-B: 5.23 C-D: 5.07 amps

Pre-Test Environmental Conditions Temperature-Humidity, Altitude, Vibration at 160°F, Shock, Temperature Shock, Tunnel Pressure: Init 0.0097, Av 0.0534, Final 0.0497 psia, Ignition Voltage A-B: 26.1, C-D: 27.2 volts

Nozzle closure vented before firing.

Prefiring Examination:

Motor Weight 5.09 lb

Throat Diameter 0.555 in

Post Firing Examination

Motor Weight 2.93 lb

Throat Diameter 0.554 in

Average Throat Area 0.2416 sq in

Average A_e/A_t 8.99

BALLISTIC DATA

Action Time, t_a 1.818 sec

Burning Time, t_b 1.292 sec

Rise Time, t_r 0.006 sec

Ignition Delay, t_d 0.004 sec

Average Burning Rate, r 0.3172 in/sec

Maximum Pressure, P_{max} 907.9 psia

Pressure-Time Integral, PTI_a 1220 psia-sec

Average Pressure, P_a 671.2 psia

Average Pressure, P_b 838.7 psia

Ignition Pressure, P_{ign} 1124 psia

Discharge Coefficient, C_d 0.00710 lbm/lbf-sec

Characteristic Exhaust Velocity, C* 4529 ft/sec

O-O Pressure Integral 1244 psia-sec

	Measured	Abs. Vac.	
Total Impulse, I_a	479.8		lbf-sec
Specific Impulse, I_{sp}	224.7		lbf-sec/lbm
Maximum Thrust, F_{max}	355.7		lbf
Average Thrust, F_a	263.9		lbf
Average Thrust, F_b	330.5		lbf
Ignition Thrust, F_{ign}	437.6		lbf
Thrust Coefficient, C_F	1.6202		
O-O Thrust Integral	487.2		lbf-sec

I_{sp} (0-0), Motor 96.09 lbf-sec/lbm

I_{sp} (0-0), Propellant 228.2 lbf-sec/lbm

ADMINISTRATIVE DATA

Rocket Type and Model 1-KS-420 MARC 7G1

Contract No. NAS 3-7128-H

Customer NASA Lewis Research Center

Purpose of Test: Motor Evaluation

Test No. 2783

Date of Test: 8/10/65

Test Agency: Rocket Test Group Atlantic Research Corporation

Prepared by: A. Johnson

Date: 8/13/65

Approved by: A. D. Mattox

Date: 8/18/65

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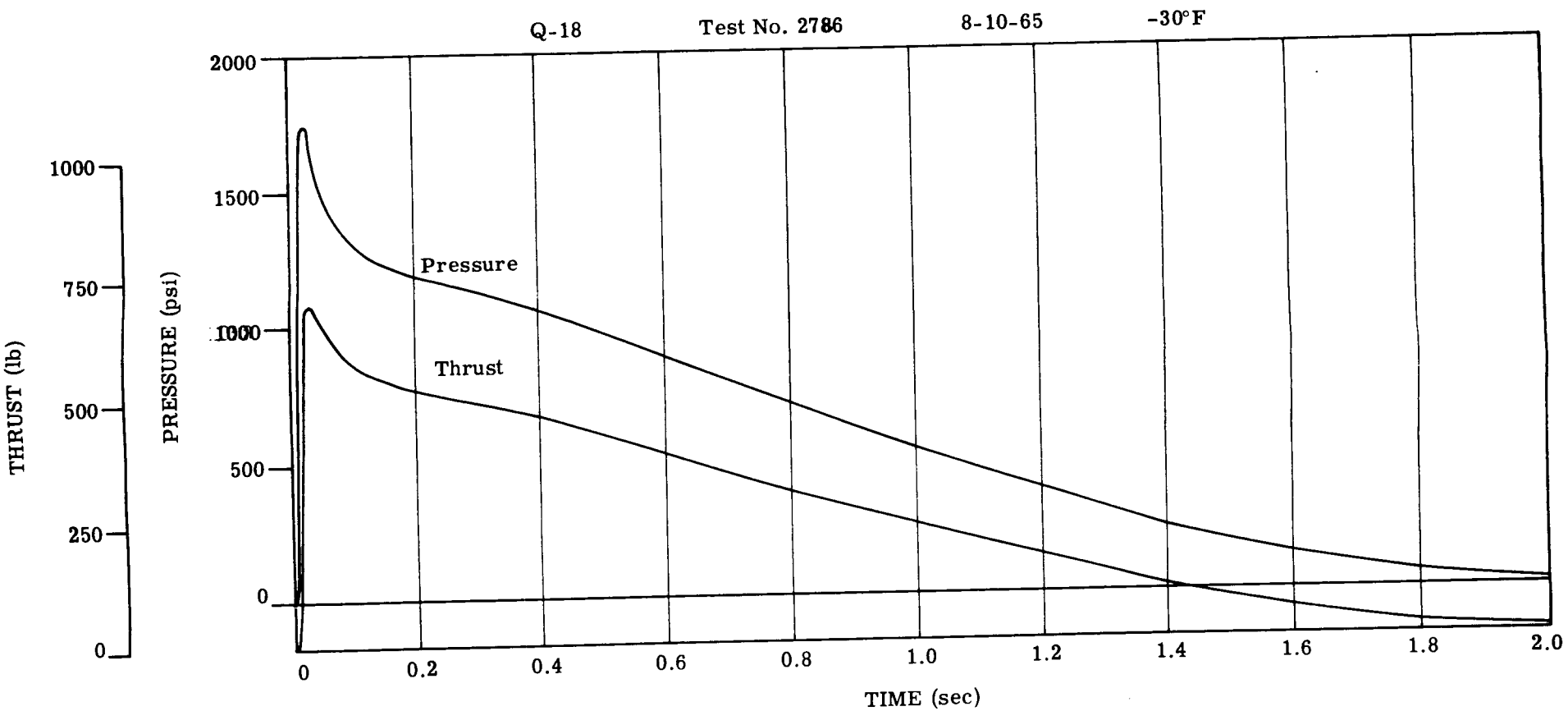
Q-18
Test No. 2786
8-10-65
-30°F
2000
1500
1000
500
0
PRESSURE (psi)
1000
750
500
250
0
THRUST (lb)
Pressure
Thrust
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
TIME (sec)

MOTOR DATA

Atlantic Research Part No. P-86-38-9
Customer Part No. —
Motor Serial No. Q-18
Grain Type Arcite 377A-9C
Grain No. 2474-R-2-1B

IGNITER DATA

Model No. ARC 502
Atlantic Research Part No. P-86-32-2
Lot No. —
Serial No. 34
Resistances: Circuit A-B 1.130 ohms
Circuit C-D 1.130 ohms

BALLISTIC PARAMETERS

Nozzle Exit Area 2.172 sq in
Propellant Weight 2.126 lb
Inhibited Grain Weight — lb
Average Web 0.4088 in
Grain O.D. 2.548/2.511/2.529 in
Grain Length 8.466 in

TEST DATA

Conditioning Temperature -30 °F for ≥ 4 hrs
Time Out of Box 1716
Time Fired 1727 Time Elapsed 11 min
Ambient Temperature 83 °F
Relative Humidity 55 %
Barometric Pressure 29.53 in Hg
Ignition Current A-B: 5.22 C-D: 5.04 amps
Pre-Test Environmental Conditions Temperature-Humidity, Altitude, Vibration at 160°F, Shock, Temperature Shock, Tunnel Pressure: Init 0.0135, Av 0.0491, Final 0.0393 psia, Ignition Voltage A-B: 26.2, C-D: 27.4 volts

Prefiring Examination:
Motor Weight 5.06 lb
Throat Diameter 0.555 in

Post Firing Examination
Motor Weight 2.90 lb
Throat Diameter 0.554 in
Average Throat Area 0.2414 sq in
Average A_e/A_t 8.99

BALLISTIC DATA

Action Time, t_a 1.645 sec
Burning Time, t_b 0.617 sec
Rise Time, t_r 0.006 sec
Ignition Delay, t_d 0.003 sec
Average Burning Rate, r 0.6626 in/sec
Maximum Pressure, P_{max} 1147 psia
Pressure-Time Integral, PTI_a 1171 psia-sec
Average Pressure, P_a 711.8 psia
Average Pressure, P_b 1157 psia
Ignition Pressure, P_{ign} 1728 psia
Discharge Coefficient, C_d 0.00736 lbm/lbf-sec
Characteristic Exhaust Velocity, C* 4369 ft/sec
O-O Pressure Integral 1196 psia-sec

	Measured	Abs. Vac.	
Total Impulse, I_a	473.7		lbf-sec
Specific Impulse, I_{sp}	222.8		lbf-sec/lbm
Maximum Thrust, F_{max}	461.0		lbf
Average Thrust, F_a	288.0		lbf
Average Thrust, F_b	459.5		lbf
Ignition Thrust, F_{ign}	692.8		lbf
Thrust Coefficient, C_F	1.6398		
O-O Thrust Integral	485.4		lbf-sec

I_{sp} (0-0), Motor 95.93 lbf-sec/lbm
I_{sp} (0-0), Propellant 228.3 lbf-sec/lbm

ADMINISTRATIVE DATA

Rocket Type and Model 1-KS-420 MARC 7G1
Contract No. NAS 3-7128-H
Customer NASA Lewis Research Center
Purpose of Test: Motor Evaluation
Test No. 2786
Date of Test: 8/10/65
Test Agency: Rocket Test Group Atlantic Research Corporation
Prepared by: A. Johnson
Date: 8/16/65
Approved by: A. D. Mattox
Date: 8/18/65

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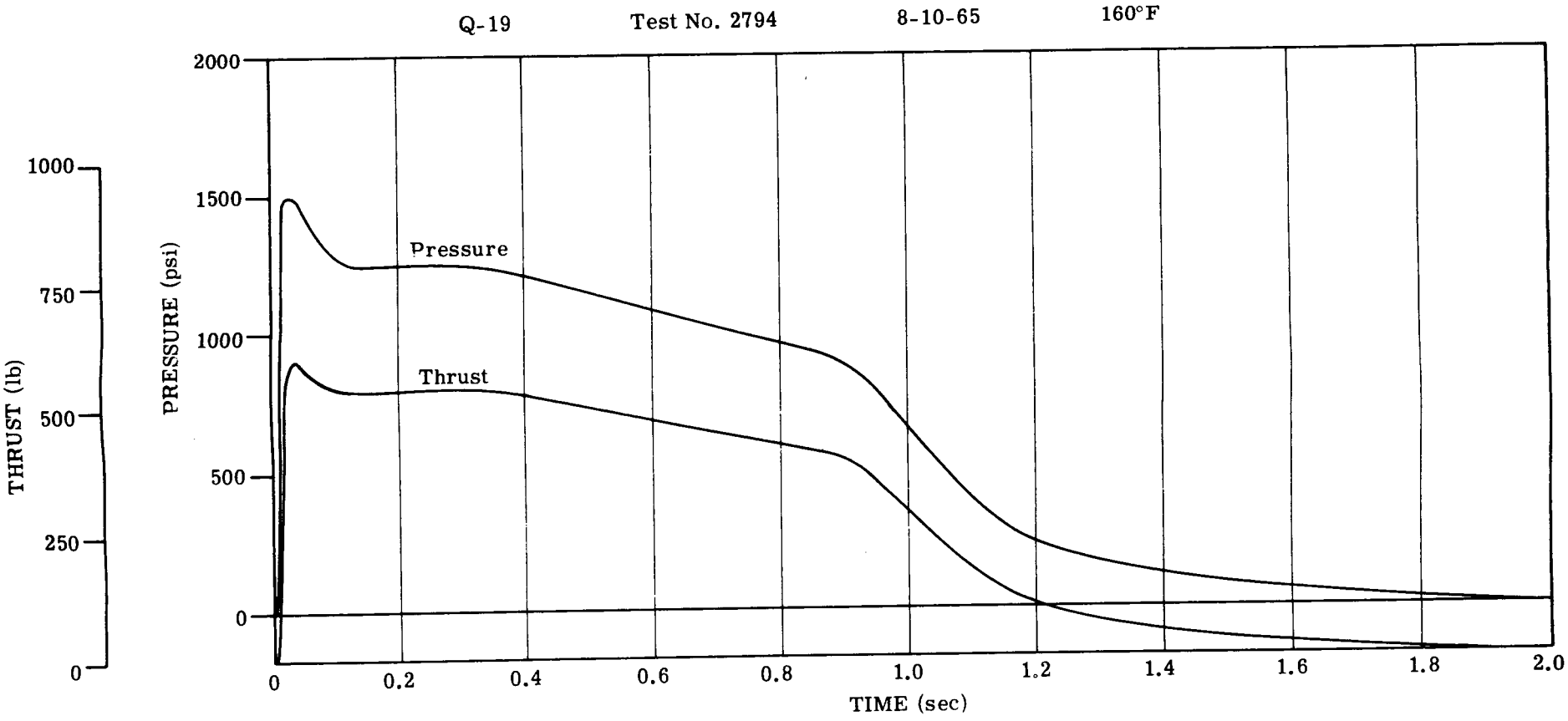
Q-19
Test No. 2794
8-10-65
160°F
2000
1500
1000
500
0
PRESSURE (psi)
Pressure
Thrust
1000
750
500
250
0
THRUST (lb)
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
TIME (sec)

MOTOR DATA

Atlantic Research Part No. P-86-38-9

Customer Part No. —

Motor Serial No. Q-19

Grain Type Arcite 377A-9C

Grain No. 2474-R-2-5A

IGNITER DATA

Model No. ARC 502

Atlantic Research Part No. P-86-32-2

Lot No. —

Serial No. 33

Resistances: Circuit A-B 1.120 ohms

Circuit C-D 1.190 ohms

BALLISTIC PARAMETERS

Nozzle Exit Area 2.172 sq in

Propellant Weight 2.130 lb

Inhibited Grain Weight — lb

Average Web 0.4076 in

Grain O.D. 2.545/2.513/2.531 in

Grain Length 8.451 in

TEST DATA

Conditioning Temperature +160 °F for ≥ 4 hrs

Time Out of Box 1952

Time Fired 1959 Time Elapsed 7 min

Ambient Temperature 77 °F

Relative Humidity 60 %

Barometric Pressure 29.53 in Hg

Ignition Current A-B: 5.07, C-D: 4.80 amps

Pre-Test Environmental Conditions Temperature-Humidity, Altitude, Vibration at 160°F, Shock, Temperature Shock, Tunnel Pressure: Init 0.0145, Av 0.0556, Final 0.0454 psia, Ignition Voltage A-B: 26.2, C-D: 27.3 volts

Prefiring Examination:

Motor Weight 5.02 lb

Throat Diameter 0.555 in

Post Firing Examination

Motor Weight 2.93 lb

Throat Diameter 0.555 in

Average Throat Area 0.2419 sq in

Average A_e/A_t 8.98

BALLISTIC DATA

Action Time, t_a 1.350 sec

Burning Time, t_b 0.805 sec

Rise Time, t_r 0.004 sec

Ignition Delay, t_d 0.004 sec

Average Burning Rate, r 0.506 in/sec

Maximum Pressure, P_{max} 1253 psia

Pressure-Time Integral, PTI_a 1209 psia-sec

Average Pressure, P_a 895.6 psia

Average Pressure, P_b 1170 psia

Ignition Pressure, P_{ign} 1484 psia

Discharge Coefficient, C_d 0.00728 lbm/lbf-sec

Characteristic Exhaust Velocity, C* 4531 ft/sec

O-O Pressure Integral 1240 psia-sec

	Measured	Abs. Vac.	
Total Impulse, I_a	485.2		lbf-sec
Specific Impulse, I_{sp}	227.8		lbf-sec/lbm
Maximum Thrust, F_{max}	500.8		lbf
Average Thrust, F_a	359.4		lbf
Average Thrust, F_b	468.7		lbf
Ignition Thrust, F_{ign}	592.1		lbf
Thrust Coefficient, C_F	1.6584		
O-O Thrust Integral	497.6		lbf-sec

I_{sp} (0-0), Motor 99.12

I_{sp} (0-0), Propellant 233.6

ADMINISTRATIVE DATA

Rocket Type and Model 1-KS-420 MARC 7G1

Contract No. NAS 3-7128-H

Customer NASA Lewis Research Center

Purpose of Test: Motor Evaluation

Test No. 2794

Date of Test: 8/10/65

Test Agency: Rocket Test Group Atlantic Research Corporation

Prepared by: J. R. Wertz

Date: 8/16/65

Approved by: A. D. Mattox

Date: 8/18/65

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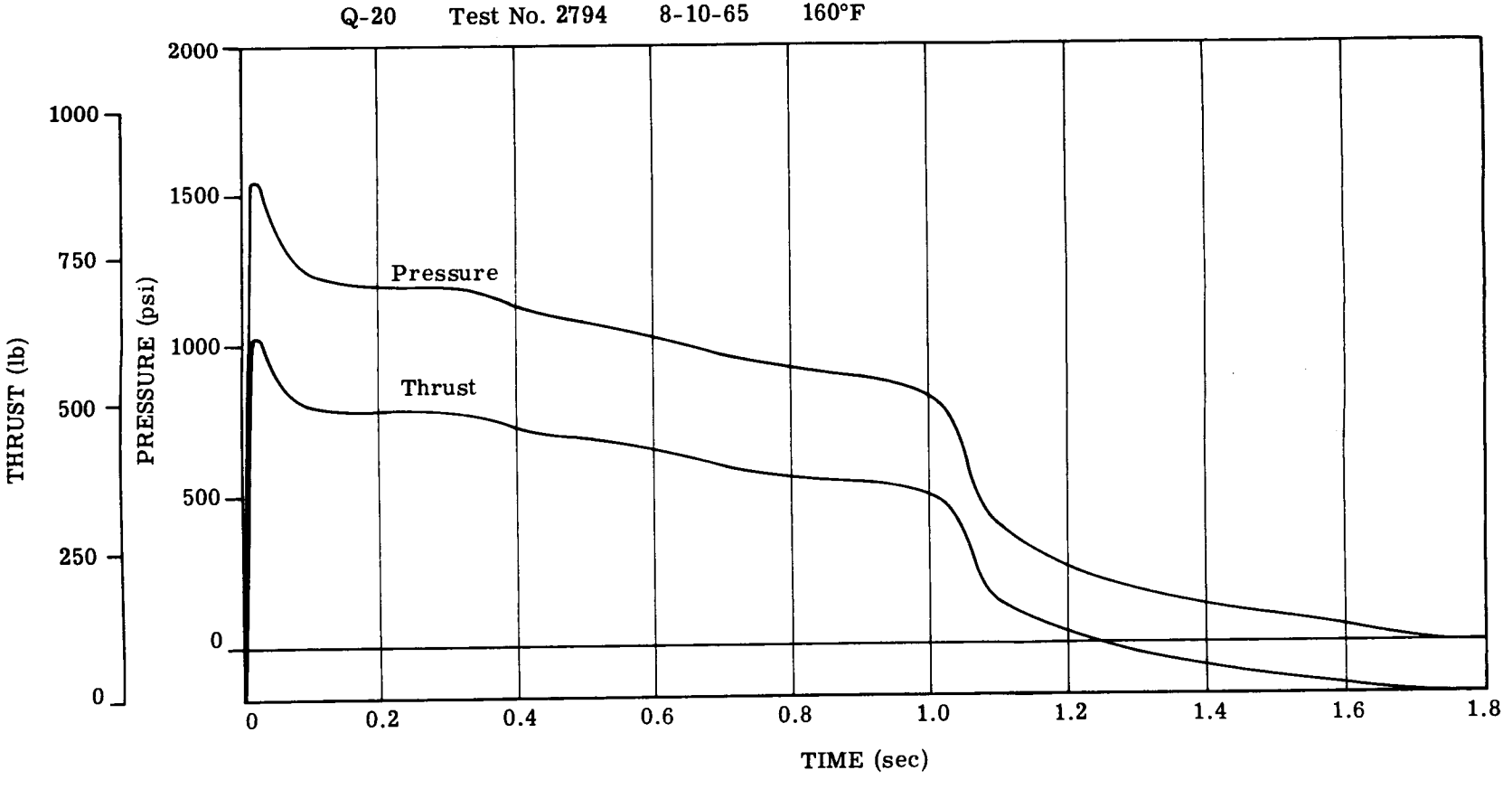
Q-20 Test No. 2794 8-10-65 160°F
THRUST (lb)
1000
750
500
250
0
PRESSURE (psi)
2000
1500
1000
500
0
Pressure
Thrust
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
TIME (sec)

MOTOR DATA

Atlantic Research Part No. P-86-38-9
Customer Part No. —
Motor Serial No. Q-20
Grain Type Arcite 377A-9C
Grain No. 2474-R-2-4B

IGNITER DATA

Model No. ARC 502
Atlantic Research Part No. P-86-32-2
Lot No. —
Serial No. 14
Resistances: Circuit A-B 1.110 ohms
Circuit C-D 1.100 ohms

BALLISTIC PARAMETERS

Nozzle Exit Area 2.172 sq in
Propellant Weight 2.125 lb
Inhibited Grain Weight — lb
Average Web 0.4064 in
Grain O.D. 2.540/2.514/2.536 in
Grain Length 8.462 in

TEST DATA

Conditioning Temperature +160 °F for ≥ 4 hrs
Time Out of Box 1940
Time Fired 1947 Time Elapsed 7 min
Ambient Temperature 80 °F
Relative Humidity 60 %
Barometric Pressure 29.54 in Hg
Ignition Current A-B: 5.03 C-D: 4.86 amps
Pre-Test Environmental Conditions Temperature-Humidity, Altitude, Vibration at 160°F, Shock, Temperature Shock, Tunnel Pressure: Init 0.0159, Av 0.0565, Final 0.0416 psia, Ignition Voltage A-B: 26.3, C-D: 27.2 volts

Prefiring Examination:
Motor Weight 5.07 lb
Throat Diameter 0.555 in

Post Firing Examination
Motor Weight 2.93 lb
Throat Diameter 0.554 in
Average Throat Area 0.2419 sq in
Average A_e/A_t 8.98

BALLISTIC DATA

Action Time, t_a 1.422 sec
Burning Time, t_b 0.843 sec
Rise Time, t_r 0.004 sec
Ignition Delay, t_d 0.003 sec
Average Burning Rate, r 0.4821 in/sec
Maximum Pressure, P_{max} 1203 psia
Pressure-Time Integral, PTI_a 1209 psia-sec
Average Pressure, P_a 850.1 psia
Average Pressure, P_b 1124 psia
Ignition Pressure, P_{ign} 1535 psia
Discharge Coefficient, C_d 0.00727 lbm/lbf-sec
Characteristic Exhaust Velocity, C* 4512 ft/sec
O-O Pressure Integral 1232 psia-sec

	Measured	Abs. Vac.	
Total Impulse, I_a	486.6		lbf-sec
Specific Impulse, I_{sp}	229.0		lbf-sec/lbm
Maximum Thrust, F_{max}	486.8		lbf
Average Thrust, F_a	342.2		lbf
Average Thrust, F_b	451.6		lbf
Ignition Thrust, F_{ign}	613.2		lbf
Thrust Coefficient, C_F	1.6648		
O-O Thrust Integral	496.3		lbf-sec

I_{sp} (0-0), Motor 97.89 lbf-sec/lbm
I_{sp} (0-0), Propellant 233.6 lbf-sec/lbm

ADMINISTRATIVE DATA

Rocket Type and Model 1-KS-420 MARC 7G1
Contract No. NAS 3-7128-H
Customer NASA Lewis Research Center
Purpose of Test: Motor Evaluation
Test No. 2793
Date of Test: 8/10/65
Test Agency: Rocket Test Group Atlantic Research Corporation
Prepared by: J. E. Dukate
Date: 8/16/65
Approved by: A. D. Mattox
Date: 8/18/65

Report No. TR-PL-8634-00-1
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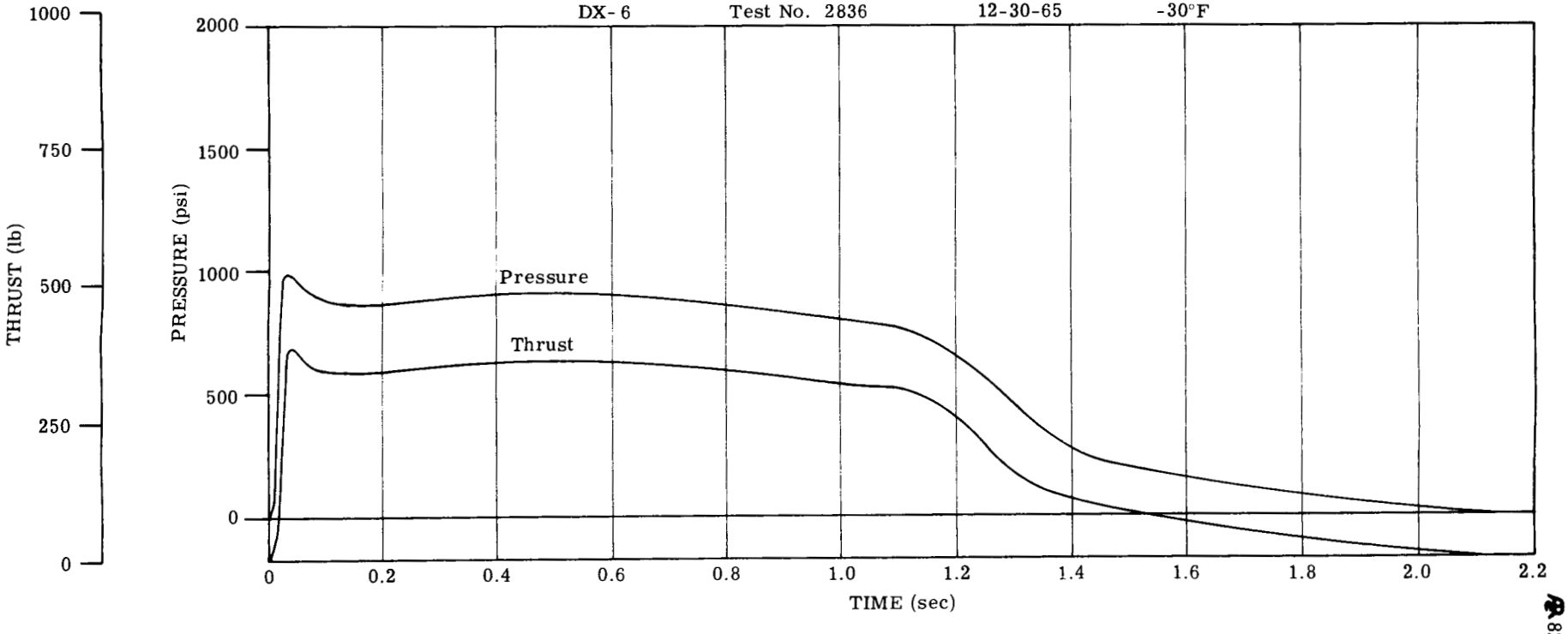
APPENDIX D

BALLISTIC RECORDS AND STATIC TEST DATA SHEETS FOR MOTORS WITH RECOMMENDED DESIGN CHANGES


DX-6
Test No. 2836
12-30-65
-30°F
THRUST (lb)
1000
750
500
250
0
PRESSURE (psi)
2000
1500
1000
500
0
Pressure
Thrust
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
TIME (sec)

MOTOR DATA

Atlantic Research Part No. Z-709A

Customer Part No. —

Motor Serial No. DX-6

Grain Type Arcite 377A-9C

Grain No. 2836-R5-9B

IGNITER DATA

Model No. ARC 502

Atlantic Research Part No. Z-710

Lot No. —

Serial No. —

Resistances: Circuit A-B — ohms

Circuit C-D — ohms

BALLISTIC PARAMETERS

Nozzle Exit Area 2.172 sq in

Propellant Weight 2.180 lb

Inhibited Grain Weight 2.28 lb

Average Web 0.392 in

Grain O.D. 2.535 in

Grain Length 8.44 in

TEST DATA

Conditioning Temperature -30 °F for ≥ 4 hrs

Time Out of Box 1115

Time Fired 1135 Time Elapsed 20 min

Ambient Temperature 46 °F

Relative Humidity — %

Barometric Pressure 30.06 in Hg

Ignition Current 5.0 (per bridgewire) amps

Pre-Test Environmental Conditions Temperature only;

Tunnel Pressure: Initial 0.0367 psia

Final 0.0915 psia

Nozzle closure vented before firing.

Prefiring Examination:

Motor Weight 5.06 lb

Throat Diameter 0.555 in

Post Firing Examination

Motor Weight 2.94 lb

Throat Diameter 0.553 in

Average Throat Area 0.2411 sq in

Average A_e/A_t 9.009

BALLISTIC DATA

Action Time, t_a 1.774 sec

Burning Time, t_b 1.181 sec

Rise Time, t_r 0.012 sec

Ignition Delay, t_d 0.006 sec

Average Burning Rate, r 0.3319 in/sec

Maximum Pressure, P_{max} 930.3 psia

Pressure-Time Integral, PTI_a 1170 psia-sec

Average Pressure, P_a 659.6 psia

Average Pressure, P_b 861.0 psia

Ignition Pressure, P_{ign} 1001 psia

Discharge Coefficient, C_d 0.00773 lbm/lbf-sec

Characteristic Exhaust Velocity, C* 4220 ft/sec

O-O Pressure Integral 1186 psia-sec

	Measured	Abs. Vac.	
Total Impulse, I_a	466.3		lbf-sec
Specific Impulse, I_{sp}	213.9		lbf-sec/lbm
Maximum Thrust, F_{max}	362.9		lbf
Average Thrust, F_a	262.9		lbf
Average Thrust, F_b	342.5		lbf
Ignition Thrust, F_{ign}	383.8		lbf
Thrust Coefficient, C_F	1.6534		
O-O Thrust Integral	472.8		lbf-sec
I_{sp}(O-O), Motor	93.44		lbf-sec/lbm
I_{sp}(O-O), Propellant	216.9		lbf-sec/lbm

ADMINISTRATIVE DATA

Rocket Type and Model 1-KS-420 MARC 7G1 (Modified)

Contract No. NAS 3-7128-H

Customer NASA Lewis Research Center

Purpose of Test: Evaluate design changes

Test No. 2892

Date of Test: 12/30/65

Test Agency: Rocket Test Group, Atlantic Research Corporation

Prepared by: James E. Dukate

Date: 1/3/66

Approved by: R. Naismith

Date: 1/3/66

Report No. TR-PL-8634-00-1

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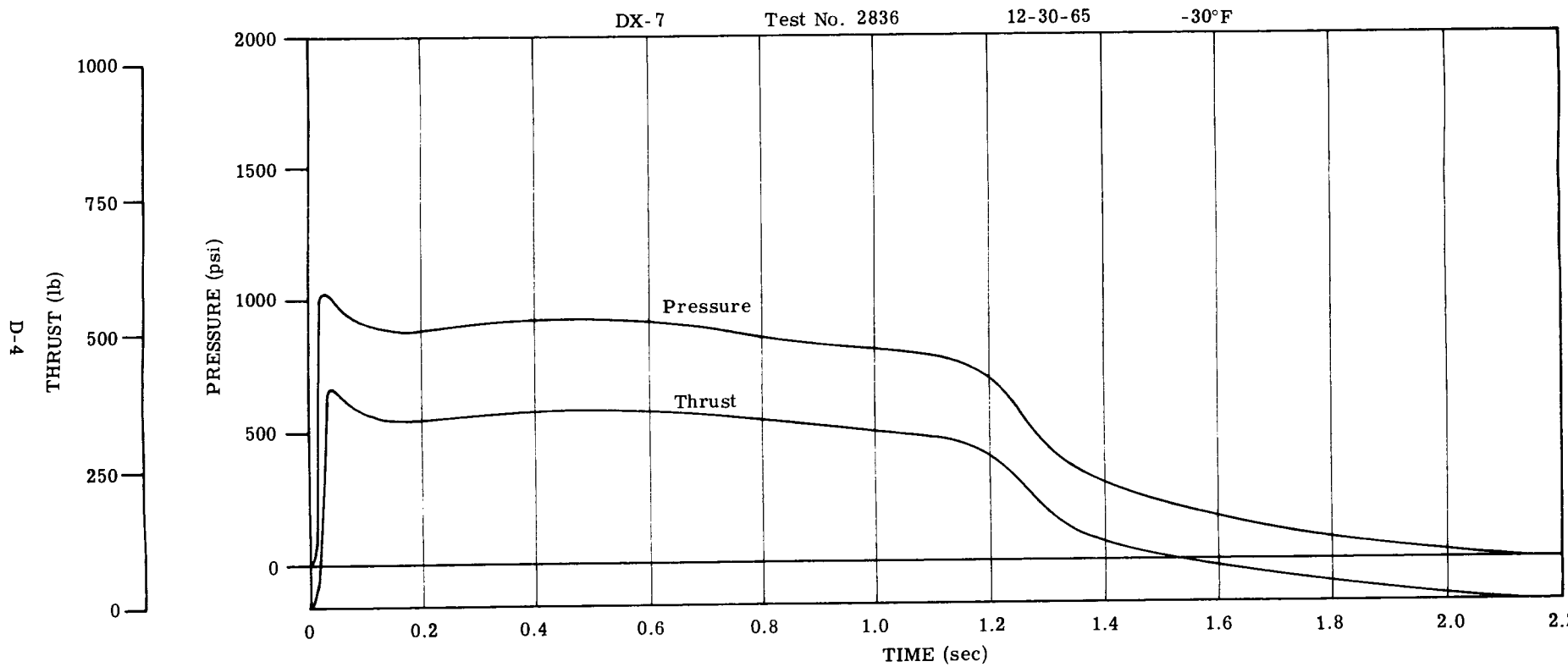
DX-7
Test No. 2836
12-30-65
-30°F
PRESSURE (psi)
THRUST (lb)
Pressure
Thrust
TIME (sec)
2000
1500
1000
500
0
1000
750
500
250
0
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2

MOTOR DATA

Atlantic Research Part No. Z-709A

Customer Part No. —

Motor Serial No. DX-7

Grain Type Arcite 377A-9C

Grain No. 2836-R5-39A

IGNITER DATA

Model No. ARC 502

Atlantic Research Part No. Z-710

Lot No. —

Serial No. —

Resistances: Circuit A-B — ohms

Circuit C-D — ohms

BALLISTIC PARAMETERS

Nozzle Exit Area 2.172 sq in

Propellant Weight 2.180 lb

Inhibited Grain Weight 2.28 lb

Average Web 0.400 in

Grain O.D. 2.534 in

Grain Length 8.47 in

TEST DATA

Conditioning Temperature -30 °F for ≥ 4 hrs

Time Out of Box 1557

Time Fired 1605 Time Elapsed 8 min

Ambient Temperature 60 °F

Relative Humidity — %

Barometric Pressure 29.97 in Hg

Ignition Current 5.0 (per bridgewire) amps

Pre-Test Environmental Conditions Temperature only;

Tunnel Pressure: Initial 0.0367 psia

Final 0.0915 psia

Nozzle closure vented before firing.

Prefiring Examination:

Motor Weight 5.06 lb

Throat Diameter 0.555 in

Post Firing Examination

Motor Weight 2.94 lb

Throat Diameter 0.554 in

Average Throat Area 0.2414 sq in

Average A_e/A_t 8.998

BALLISTIC DATA

Action Time, t_a 1.781 sec

Burning Time, t_b 1.205 sec

Rise Time, t_r 0.009 sec

Ignition Delay, t_d 0.006 sec

Average Burning Rate, r 0.3320 in/sec

Maximum Pressure, P_{max} 929.1 psia

Pressure-Time Integral, PTI_a 1174 psia-sec

Average Pressure, P_a 659.0 psia

Average Pressure, P_b 851.2 psia

Ignition Pressure, P_{ign} 397.2 psia

Discharge Coefficient, C_d 0.00769 lbm/lbf-sec

Characteristic Exhaust Velocity, C* 4243 ft/sec

O-O Pressure Integral 1191 psia-sec

	Measured	Abs. Vac.	
Total Impulse, I_a	470.1		lbf-sec
Specific Impulse, I_{sp}	215.6		lbf-sec/lbm
Maximum Thrust, F_{max}	357.4		lbf
Average Thrust, F_a	264.0		lbf
Average Thrust, F_b	340.2		lbf
Ignition Thrust, F_{ign}	397.2		lbf
Thrust Coefficient, C_F	1.6580		
O-O Thrust Integral	477.3		lbf-sec
I_{sp} (O-O), Motor	94.33		lbf-sec/lbm
I_{sp} (O-O), Propellant	218.9		lbf-sec/lbm

ADMINISTRATIVE DATA

Rocket Type and Model 1-KS-420 MARC 7G1 (Modified)

Contract No. NAS 3-7128-H

Customer NASA Lewis Research Center

Purpose of Test: Evaluate design changes

Test No. 2894

Date of Test: 12/30/65

Test Agency: Rocket Test Group, Atlantic Research Corporation

Prepared by: Alan Johnson

Date: 1/3/66

Approved by: R. Naismith

Date: 1/3/66

Report No. TR-PL-8634-00-1

Appendix D

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