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## ROCKET MOTOR SPIN DATA SUMMARY

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## SUMMARY

The performance characteristics of some solid-propellant rocket motors have been shown in free flight and ground testing to be appreciably affected by the dynamic environment encountered during their thrusting period. Principal effects noted are (1) ballistic, associated with alterations to the propellant combustion and flow processes and (2) thermal, resulting from deposition of hot exhaust residue within the motor chamber. The NASA Langley Research Center has conducted extensive testing on a wide range of solid rockets subjecting full-scale flight units to the dynamic spin or roll environments normally encountered in flight use. This paper describes these tests on rockets ranging in weight from 100 to 2800 pounds, diameters to 30 inches, and lengths to 147 inches at roll rates from 100 to 900 rpm under both sea-level and simulated altitude conditions. Details presented on each solid rocket tested include a description of the rocket motor with propellant composition and configuration, the test environment, and the test results. Results indicate a high degree of ballistic sensitivity with severe thermal rocket degradation in some types of motors tested ranging down to essentially no effect in other types of units tested. Free-flight results are presented where available. No attempt is made to formulate firm general conclusions on the effects of dynamic environments due to the low number of samples of each type tested. The data presented herein were principally obtained from the spin qualification of motors for flight and is not a systematic study of the parameters involved.

## INTRODUCTION

The NASA Langley Research Center has for many years conducted extensive research in the areas of aerodynamics, materials, communications, reentry physics, etc., through the use of various multistage rocket-powered free-flight vehicles. Many of these vehicles require spinning of one or more boost stages for inertial stabilization or impact dispersion control. Until the advent of the metallic additive in solid propellants a few years ago, no problems had been encountered by NASA - LRC in these free-flight studies resulting from spin effects on rocket motor performance. In 1959, however, limited spin testing of the Hercules - Allegany Ballistic Laboratory X-248 rocket motor by the manufacturer, reference 1, in support of the development of the four-stage Javelin Vehicle did indicate a definite spin sensitivity, especially in the range of 9 to 12 cycles per second (540 to 720 rpm) as shown in figure 1. This sensitivity under spinning conditions has been confirmed in numerous NASA - LRC flights employing this motor as shown in figure 2. The aluminum content of the X-248 propellant, a cast double base, is 3 percent.

The NASA Project Fire Vehicle utilizing an Atlas - ABL X-259 two-stage propulsion system, the latter stage of which was spun at 155 rpm initially for stabilization, established a firm requirement for determining the spin performance of the X-259 rocket motor through ground testing prior to commitment to flight use in this environment. The X-259 is approximately 30 inches in diameter and contains about 2500 pounds of a highly aluminized composite modified double-base propellant. Due to the basic similarity of the X-248 and X-259 rocket motors in type of construction, internal grain configuration, and basic type of propellant, a possible problem area was anticipated which required thorough evaluation. An apparatus capable of spin testing an X-259 rocket motor about its own principal axis at 200 rpm was designed and fabricated, reference 2. This paper describes the results of that initial X-259 rocket spin test and presents similar information obtained on a wide range of full-scale solid rockets subsequently tested on the LRC spin-test apparatus.

### DESCRIPTION OF TEST APPARATUS

All of the tests to be reported herein were conducted on a specialized spin-test apparatus designed and fabricated by NASA Langley Research Center. Details of the test apparatus are presented in reference 2. Figure 3 shows the entire test apparatus as used in the testing of a CYGNUS-15 spherical rocket motor. A conventional dual-bridge thrust transducer is employed for thrust measurement. A tapered roller bearing, as shown in figure 3, is employed to transmit the motor thrust while eliminating the rotational motion. The test rocket motor and associated attachment hardware are supported fore and aft by bearing assemblies. The forward bearing is a roller type and provides a rigid support for the spin drive input. The aft bearing is a ball type and is oil-sprayed for cooling and lubrication. As shown in figure 3, three linear bearings are employed to support the aft bearing assembly structure and provide for linear expansion of the test rocket motor up to 1 inch.

A small thrust preload is maintained on the floating rotating assembly against the forward tapered roller thrust bearing through the use of three equally spaced springs with adjustable tension. As shown in figure 3, these springs connect the rigid portion of the test apparatus and the aft bearing assembly which floats on the linear bearing cited previously.

The transmission of power to rotate the test assembly is accomplished using a timing belt drive system from the electric drive motor to the spin shaft. The power is supplied by a constant-speed 10-horsepower eddy-current, coupled squirrel-cage induction motor. Integral to this motor is an electromagnetic coupling and brake with a regulated speed of the output shaft of 30 to 1200 rpm. Output speed, or torque, may be regulated to provide a constant test roll rate,  $\pm 2$  percent, despite load changes within the system. The drive unit contains an integrally mounted tachometer to measure shaft output rotation rate.

A reluctance pickup is employed as shown in figure 3 to continuously monitor the spin rate of the test assembly. Ten equally spaced steel pins are so

oriented on the rotating structure, as shown, as to pass within the field of the sensing pickup, generating a pulse. Ten pulses per revolution are obtained and directly recorded for spin rate determination. Rocket motor instrumentation of pressure, strain, and temperature are accomplished through the use of a high-quality slipring assembly of 36 low-noise silver sliprings. This slipring assembly is shown in figure 3 mounted on the spin shaft. Two sliprings are allotted to provide ignition current; the remaining 34 may be utilized as required.

For safety purposes in installation and checkout operations, an ignition shorting block is employed, providing a dead short for both the rocket initiator system and the firing power supply. The shorting plug is manually removed prior to final system spinup for test.

The entire test apparatus assembly, including the drive motor system, is rigidly mounted to a heavy I-beam rail structure as shown in figure 3 which permits easy transportation and setup in various test cells as required. The basic assembly is highly amendable to modification as required for the various tests herein reported. Spacing of the forward and aft bearing assemblies to accommodate rocket motors of various lengths is accomplished by positioning the aft bearing structure on the I-beam rails as required. For very long rocket motors a third bearing assembly as shown in figure 4 is employed. This bearing does not normally contact the motor case and is primarily an anti-flight safety measure to retain the casing should excessive deflection or failure occur.

Conventional instrumentation was employed and is detailed in reference 2.

## DISCUSSION OF TESTS AND RESULTS

A summary of the tests conducted on the LRC rocket spin-test apparatus is presented in table 1. Included are tests performed at the NASA Langley Research Center, Virginia, at the Vacuum Test Facility of the Arnold Engineering and Development Center, Tennessee, and at the Solid Rocket Plant of Aerojet General Corporation, Sacramento, California. Rocket motors covering a wide range of propellant weights, configurations, and compositions have been fired while spinning over a range of roll rates at both sea-level, ambient, and simulated altitude conditions. Some test results are formally reported in references 3 through 12. This paper presents the results of the NASA-LRC effort in this field for the past several years.

The range of propellant weight for motors tested is from 100 pounds for a CYGNUS-15 (15-inch-diameter spherical rocket) to 2500 pounds for a Hercules X-259 motor. The X-259 with a 30-inch-diameter motor represents the maximum diameter tested. The Lockheed HYDAC rocket motor with a length of 147 inches is the longest tested and required the use of the third bearing previously mentioned. The roll rate range has varied from 100 rpm to 900 rpm to meet test requirements. Roll rate is not varied during a given test run and was held by the test apparatus to within 2 percent of the set rate even while under thrusting operation. The thrust levels of the motors tested have ranged from a force of several hundred pounds to a force of over 20,000 pounds.

Details of the individual tests are separately reported in subsequent paragraphs. It should be noted that the data presented were principally obtained from the spin qualification of full-scale rocket motors for flight use and does not comprise a systematic study of the parameters involved. No attempt has been made to present an analytical or theoretical model of the mechanisms involved which would explain the wide range of test results obtained.

## I. ABL X-259 Static Spin Tests

Prior to its use on Project Fire Vehicle, the ABL X-259 rocket motor was spin qualified for flight at 200 rpm. This vehicle consists of an Atlas first stage and an X-259 second stage. The X-259 rocket motor was to be spun at an initial spin rate of 155 rpm to control impact dispersion and for inertial stabilization as mentioned previously. Due to the similarity of the X-259 and X-248 rocket motors and performance characteristics of the X-248 in a spinning environment, ballistic problems were anticipated with the X-259 (ref. 1).

Because of the availability of an X-259 motor (HPC 104), it was decided that data were needed on this motor at a spin rate of 300 rpm. A research program was instituted to spin qualify the motor at the higher rate using a motor which was acceptable for static firing only.

Motor description.- The X-259 is 30.05 inches in diameter, 113.8 inches in overall length, contains 2555 pounds of ABL CYI-75 propellant which is a highly aluminized composite modified double-base propellant with a partially submerged graphite nozzle and a finocyl grain configuration as shown in figure 5. A more detailed motor and propellant description appears in the Hercules Chemical Propulsion Handbook (ref. 13).

Test conditions.- Motors were tested at sea level, ambient conditions, and spin rates of 200 and 300 rpm.

Test results.- Figure 6 is a comparison of the spin and nonspin vacuum thrust histories of the X-259 motor which clearly illustrate there is no significant ballistic change due to spinning this motor at 200 and 300 rpm. Also there was no abnormal case heating effect due to the spinning environment. There was a difference noted in the erosion pattern on the graphite throat. Erosion was more severe in the regions in line with the grain slots on the nonspin tests. During the 200 and 300 rpm spin tests, the nozzle eroded more uniformly as there was no evidence of severe erosion opposite the grain slots.

## II. ABL X-258 Static Spin Tests

Several ABL X-258 rocket motors have been static spin tested at LRC and AEDC to qualify the motor for use on the NASA Scout and Thor-Delta Vehicles. It should be noted that this motor had already completed its PFRT program and was considered ready for flight use when the static spin tests were begun.

Motor description.- The ABL X-258 is 18 inches in diameter, 59.25 inches in overall length, contains 500 pounds of ABL CYI-75 propellant which is a highly aluminized composite modified double-base propellant with a partially submerged graphite nozzle and a finocyl grain configuration as shown in figure 7. A more detailed description of this motor and propellant appears in the Hercules Chemical Propulsion Handbook (ref. 13). The propellant contains approximately 20 percent of aluminum powder.

Test conditions.- The seven X-258 motors tested were fired at ambient temperature, sea level, and simulated altitude (110 K feet), and at rates of 100, 200, and 250 rpm.

Test results.- The first motor tested (s/n RH50) was spun at 250 rpm. At 22.3 seconds, a chamber burn-through occurred and this is illustrated in figure 8 (post-fire condition of RH50 X-258). This motor operated at pressure levels from 6 to 14 percent above the nominal nonspin pressure levels. A second X-258 motor (s/n RH46), which was removed from a NASA Scout Vehicle on the launch pad, was tested under identical conditions to verify the results of the previous test. The motor had an effective burning time of 22.25 seconds and operated at pressure levels similar to s/n RH50. The motor chamber was heated by afterburning and at 15 to 20 seconds after web-burn time the chamber failed as shown in figure 9. To reduce the propellant sliver in the headend of the X-258 rocket motor and thus reduce the afterburning, the length of the inhibitor boot on the forward internal cylindrical propellant surface was shortened  $\approx 0.6$  inch. The modified X-258 (s/n RH49) was fired while spinning at 200 rpm. The motor had an effective burning time of 22.7 seconds. A discolored band, shown in figure 10, indicated case heating during tail-off; however, the structural integrity of the chamber was not destroyed. In figure 11 representative pressure histories of the X-258 motors are compared. Note the decrease in web-burn time for increasing spin rates and corresponding increases in chamber pressure levels particularly during latter half of motor burning. For additional spin-test information at simulated altitude, see AEDC reports (refs. 10 and 11). The X-258 motor has been flight tested on the NASA Scout Vehicle.

A further modification of an X-258 (s/n RH63) was made in conjunction with NASA-Goddard's Thor Delta Program to reduce tail-off characteristics of the motor. A spin test was performed at sea level, ambient temperature, and 100 rpm using a motor with an additional 0.46 inch of inhibitor removed from the forward internal cylindrical propellant surface. The motor had a web-burn time of 20 seconds and a pressure history as shown in figure 12. No zero spin performance data are available for this exact modification of the X-258 rocket motor.

### III. ABL X-248 Static Spin Test

The marginal structural condition of the ABL X-258 motor following the 200 rpm spin test, even in the modified version, left considerable doubt as to the acceptability of this motor for flight use. The X-258 motor was designed for use as a higher performance replacement for the X-248 motor which had been used successfully on the Scout and Thor-Delta Vehicles for several years at

spin rates of approximately 200 rpm. In order to get a better feel for the structural condition required for flight use, it was decided to spin test an X-248 motor at 250 rpm to determine the physical case integrity.

Motor description.- The ABL X-248 motor is 18 inches in diameter, 59.4 inches in overall length, contains 455 pounds of ABL BUJ cast double-base propellant with a partially submerged graphite nozzle and a finocyl grain configuration as shown in figure 13. The propellant contains approximately 3 percent of Alcoa 101 aluminum powder with an average particle size of 15 microns.

Test conditions.- The motor was fired at sea level, ambient temperature and at 250 rpm.

Test results.- Previous tests conducted and reported by ABL in 1959 (ref. 1), showed drastic ballistic changes at spin rates of 450 and 720 rpm. Figure 1 shows these results in a thrust history as compared to a nominal non-spin test. Further verification of these data is shown in figure 2 which is NASA in-flight data from Trailblazer II Vehicles. Test results from the LRC static spin test at 250 rpm showed no significant ballistic change as illustrated in figure 2. Chamber temperatures recorded were slightly higher (approximately 100° F) and discoloration of the chamber is shown in figure 14.

#### IV. CYGNUS-15 - LRC Produced

A total of seven LRC produced CYGNUS-15 rocket motors have been spin tested to date. These tests were conducted to qualify the motor for use as the fourth stage of the NASA Trailblazer II Vehicle.

Motor description.- The CYGNUS-15 motor is essentially a 15-inch-diameter spherical rocket motor, 16 inches in diameter which includes the mounting tabs at the equator, 21.5 inches in overall length, containing 101 pounds of LRC BF-117b polysulfide propellant, with a partially submerged graphite nozzle and a seven-point-star grain configuration as shown in figure 15. The propellant contains 0.9 percent Reynolds 400 aluminum powder with an average particle size of 6 microns. The propellant also contains 56.5 percent of unground ammonium perchlorate of 225 microns average size and 24.2 percent of ground ammonium perchlorate of 20 microns average size.

Test conditions.- The seven LRC produced CYGNUS-15 motors were tested at ambient temperature, sea level, and simulated altitude (120 K feet) and at approximately 900 rpm. Motor chambers of heavy-walled and flight-weight construction were tested.

Test results.- No ballistic changes were noted (fig. 16) in this motor due to the spinning environment. There were no abnormal temperatures measured during these tests. Representative flight-test data verified the static spin data as shown in figure 17. It should be noted in figure 17 that the motor used on Trailblazer II-f had additional surface because of a propellant grain crack which resulted in premature burn-through of the unit. Test results for the simulated altitude firing are presented in reference 12.

## V. CYGNUS-15 - Aerojet General Produced

A total of four AGC produced CYGNUS-15 rocket motors have been spin tested. This work was done in support of the NASA Trailblazer II Vehicle in order to spin qualify the motor at 900 rpm for flight use.

Motor description.- The motor is identical to the LRC produced CYGNUS-15 (fig. 15) with the exception of the propellant formulation. The AGC version incorporates ANP-2986 polyurethane propellant containing 17.2 percent Reynolds 140 aluminum powder. The propellant also contains 47.6 percent unground +48 ammonium perchlorate and 20.4 percent of ground ammonium perchlorate.

Test conditions.- The four AGC produced motors were tested at sea-level, ambient conditions, at approximately 900 rpm. Motor chambers of heavy-walled and flight-weight construction were used.

Test results.- The first spin test was inconclusive as a pressure line failed on the static weight case resulting in pressure probe and chamber failure. All spin results of the AGC produced motor are presented in figure 18. The second and third tests used flight-weight chambers and resulted in thermal failures at 1.03 and 1.08 seconds after web burn-through; these are more clearly illustrated in figure 19. Examination of this figure (19) clearly shows that spinning increases the chamber pressure during the latter half of burning and shortens web burn-time. Figures 20 and 21 show typical pre-fire and post-fire pictures of the flight-weight case showing the results of the thermal failure. Highest temperature recorded was in excess of 1200° F at time of failure.

The fourth motor fired used a heavy-walled test-weight case which did perform successfully; this motor history is presented as figure 22. Upon completion of this test, the interior of the chamber was examined and found to contain approximately 1.5 pounds of aluminum residue; this was later analyzed by AGC and found to be primarily aluminum oxide. Although chamber temperatures were not recorded on this test, it was quite apparent from the completely charred condition of the insulator and discoloration of the heavy-walled chamber that the temperatures resulting from the spin environment were excessive. One phenomenon which seems to be present from these tests is the difference in trace shape between the flight-weight and heavy-weight test cases. In both instances, these trace shapes were reproduced and therefore it is believed that additional effects due to propellant strain are present. The strain in this case is due primarily to the difference in expansion between the flight-weight and test-weight chambers. Further discussion of this phenomenon is beyond the scope of this paper.

## VI. CETUS-17 Static Spin Tests

A total of six CETUS-17 rocket motors have been spin tested. This work has been performed in support of the NASA Scout Program to spin qualify the motor for flight use.

Motor description.- The CETUS-17 rocket motor, more commonly known as the NOTS-100 or 17-inch-diameter spherical rocket motor is 17.16 inches in diameter, 17.35 inches in overall length, containing 138 pounds of B. F. Goodrich E-107 polyurethane propellant, with a fully submerged graphite nozzle and a seven-point-star grain configuration as shown in figure 23. The propellant contains 17.7 percent Alcoa 123 aluminum powder with an average particle size of 29 microns. The propellant also contains 57.3 percent ammonium perchlorate with an average particle size of 200 microns.

Test conditions.- The six CETUS-17 motors were tested at ambient temperatures, sea-level, and simulated altitude (110 K feet), and at 200 rpm. Several modifications were tested and these included additional chamber insulation and an extended nozzle.

Test results.- The first motor (s/n 55) was tested under simulated altitude conditions and it performed successfully. Several important differences were noted, the first is illustrated in figure 24. An increase in vacuum thrust was noted as beginning at 16 seconds and resulting in an increase of approximately 7 percent over a nonspinning motor. The effective web burn-through is enhanced in the spinning environment but the tail-off characteristics degradate. Extreme case heating was observed at the motor equator but no thermocouples were located at this position. Aluminum residue (figs. 25, 26, and 27) was found at the motor equator and this amounted to slightly more than 2.9 pounds of a material later analyzed as a combination of aluminum oxide, aluminum carbide, and more than 60 percent metallic aluminum. Inspection of the nozzle also revealed the buildup of an aluminum carbide bead as well as a 1/16-inch film over the rest of the nozzle surface (fig. 28). A second motor (s/n 49) fired immediately following the first test to confirm the spin data failed due to a pressure probe leak. Both these motor tests are described in AEDC report of reference 3. A third firing was performed at LRC (s/n 20) to verify the results of the altitude tests and again the increase in thrust of approximately 6 percent occurred at approximately 15 seconds. The higher thrust level observed in motor s/n 20 (fig. 24) is believed due to the age of the motor, it was approximately 13 months old at the time of the test whereas s/n 55 was approximately 6 months old. Recommended shelf life of this motor is 6 months. Severe case heating was measured at the motor equator in excess of 1800° F but the chamber remained intact. A total of 3.6 pounds of aluminum residue was also found in this chamber, similar in amount to that in s/n 55. The appearance of the aluminum residue on the nozzle used in s/n 20 was also noted (fig. 28).

Two more tests of the CETUS-17 motor were performed to qualify the motor modified with additional insulation to reduce case heating. Although these latter motors were tested under identical conditions as s/n 20, had essentially the same grain configuration, and were made to the same propellant formulation but a different batch, the trace shapes were greatly altered (fig. 29). The exact cause of this alteration in trace shape is not clearly understood; however, it is possible that a slight change in aluminum powder particle size may have occurred or that aging of the propellant plays an important part in the ballistic characteristics of this motor. As will be noted in figure 29, a shift in the thrust trace slope did occur at approximately 16 seconds for s/n 53 and at approximately 10 seconds for s/n 54. The aluminum residue

remaining in both s/n 53 and 54 amounted to approximately 2.0 pounds which is about 60 percent of that found in previous tests. This reduction in aluminum residue weight lends support to the premise that some change was made in the propellant formulation. All chamber temperatures remained below 300° F throughout the tests.

The sixth motor was fired at simulated altitude November 5, 1964, on the AEDC spin-test apparatus and will not be discussed in this paper.

### VII. ARC XM-85 Static Spin Tests

A total of three XM-85 static spin tests have been performed to date, two on the LRC spin-test apparatus and one as late as November 10, 1964, on the AEDC spin apparatus. The purpose of these tests was to assist the Air Force in determining the spin effects on the XM-85 for use on the Blue Scout Jr. Vehicle.

Motor description.- The motor is identical in size and configuration to CETUS-17 (fig. 23) with the exception of propellant formulation. It is an ARC Arcane 35H metal "X" polyurethane formulation containing approximately 12 percent metal "X."

Test conditions.- The test conditions for these motors were ambient temperature, simulated altitude (110 K feet), and spin rate of 200 rpm.

Test results.- In both tests performed on the LRC spin-test apparatus, the nozzles blew out of both motors at ignition and the propellant extinguished, see reference 4. The third motor, as previously mentioned, was tested on the AEDC apparatus; however, it should be noted that, based on the CETUS-17 results, LRC predicted a motor thermal failure which did in fact occur on the third spin test. Preliminary data from ARC indicate the curve trace was approximately 11 percent higher than anticipated and chamber burn-through occurred between 26 and 28 seconds; visual inspection of the nozzle showed that slotting of the graphite, which normally occurs in the nonspin tests did not occur in the spin test.

### VIII. AGC ALCOR IA Static Spin Tests

Two ALCOR IA (23 KS 11,000) rocket motors manufactured by the Aerojet General Corporation - Solid Rocket Plant were test fired on the NASA-LRC spin-test apparatus as part of the development of this motor by AGC for the Air Force Athena Program. Spin tests at 300 and 480 rpm were accomplished at the AGC - SRP, Sacramento, California.

Motor description.- The ALCOR IA rocket motor as shown in figure 30 is approximately 20 inches in diameter, 76 inches in overall length, and contains 915 pounds of an AGC polybutadiene propellant. The propellant composition includes 16 percent aluminum powder. The grain configuration is a six-point-star perforation. The nozzle is a conventional converging-diverging deLaval type.

Test conditions.- The motors were tested at sea-level, ambient pressure, an 80° F temperature, and at the cited 300 and 480 rpm rates.

Test results.- The spinning environment induced only slight changes in the motor ballistics as shown in figures 31 and 32. Due to the batch-to-batch burning rate variation, the measured spin pressure history is compared with that predicted for each spin firing. Figure 31 presents the pressure history for the 300 rpm firing and figure 32 for the 480 rpm test. During the 300 rpm firing, slight motor case heating was experienced in line with the six star points. During tail-off of the 480 rpm test, a case burn-through occurred in one of these areas and the entire chamber experienced considerable heating. Figure 33 is a pre-fire photograph of the 300 rpm test and figure 34 shows the post-fire condition of the 480 rpm firing. Additional test information is presented in AGC references 5, 6, and 7.

#### IX. United Technology Center TM-3 Static Spin Tests; Two-Segment Motor

In support of the Air Force SSD development of the FW-4S (new fourth-stage Scout motor), the NASA-LRC conducted a static and two spinning tests of the UTC TM-3 two-segment motor.

Motor description.- The TM-3 two-segment motor was 18 inches in diameter, 77 inches in overall length, and contained approximately 600 pounds of UTC UTP-3096 PBAN propellant. The TM-3 motor has a partially submerged nozzle. The two-segment TM-3 grain configuration is shown in figure 35. The two segments were used to simulate the mass flow conditions of the FW-4S motor.

Test conditions.- The motors were tested at sea-level, ambient pressure, ambient temperature, and at spin rates of 0, 200, and 400 rpm.

Test results.- Figure 36 compares the pressure time histories of the TM-3 motors at 0, 200, and 400 rpm spin rates. Table 2 lists the amounts and locations of the deposits of residue remaining in the case for each of the three TM-3 motor firings of the two-segmented motor. The deposits contained 99 percent aluminum oxide and 1 percent aluminum metal. The post-fire heat soak on the chamber insulation due to the retained aluminum oxide residue increased insulation loss at increasing spin rates. A detailed discussion of these tests can be found in the UTC report (ref. 8).

#### UTC TM-3 Static Spin Test; One-Segment Motor

In continued support of the Air Force SSC development of the FW-4S motor, NASA-LRC spin tested a single-segment TM-3 motor at a spin rate of 200 rpm. Several modifications had been made to this motor.

Motor description.- The TM-3 single-segment motor was 18 inches in diameter, 50 inches in length, and contained 471 pounds of UTC UTP-3096 PBAN propellant. The TM-3 motor has a partially submerged nozzle. The single-segment TM-3 grain configuration is shown in figure 37.

Test results.- The TM-3 single-segment motor was tested at an ambient temperature of 70° F, sea-level conditions, and a spin rate of 200 rpm. In figure 38, the pressure history of the spinning motor is compared to the predicted pressure history for this configuration. Approximately 0.75 pound of residue remained in the motor chamber following spin testing. Most of the deposit was in the aft end of the chamber. Additional test information is presented in reference 9.

#### X. Lockheed Propulsion Co. HYDAC Static Spin Test

One HYDAC rocket motor as manufactured by the Lockheed Propulsion Company was test fired by NASA-LRC for the U.S. Naval Missile Center in support of the development of the TERRIER/HYDAC probe vehicle. The test spin rate was 900 rpm.

Motor description.- The HYDAC rocket motor is 9 inches in diameter, 147 inches in length, and contains 410 pounds of PBAA propellant. The propellant composition contains 16 percent aluminum with an average particle size of 6 microns, 60 percent of coarse ammonium perchlorate with an average particle size of 200 microns, and 8 percent of fine ammonium perchlorate with an average particle size of 8 microns. The HYDAC internal configuration is shown in figure 39. The forward portion is a single perforation cylinder; the aft portion is a six-point star. The HYDAC has a conventional deLaval nozzle.

Test conditions.- The HYDAC was fired at sea-level, ambient pressure, at 80° F temperature, at a spin rate of 900 rpm.

Test results.- Figure 40 compares the pressure histories for the HYDAC in the nonspin and 900 rpm spin environments. The HYDAC experienced severe case heating after motor tail-off but no failure occurred. Figures 4 and 41, respectively, show the pre-fire and post-fire conditions of the HYDAC motor. Approximately 19 pounds of residue material remained within the motor chamber.

#### XI. NOTS 551 Static Spin Test

One NOTS 551 rocket motor as manufactured by the Naval Ordnance Test Station was test fired by NASA-LRC in support of the Navy Bureau of Weapons. The test spin rate was 480 rpm.

Motor description.- The NOTS 551 rocket motor is 13 inches in diameter, 120 inches in length, and contains 700 pounds of E-107M polyurethane propellant, figure 42. The propellant composition contains 17.7 percent of Alcoa 123 aluminum with an average particle size of 20 microns, and 57 percent ammonium perchlorate with an average particle size of 200 microns. Figure 42 shows the motor assembly and the six-point-star internal configuration.

Test conditions.- The test conditions for the NOTS 551 motor were sea-level pressure, 80° F temperature, and a spin rate of 480 rpm.

Test results.- Figure 43 is an expanded plot of the pressure histories of a static nonspin test and the 480 rpm spin test for the NOTS 551 rocket motor.

At 4.98 seconds the graphite nozzle insert was ejected from the motor. Chamber pressure at this time was about 1400 psi. Figure 44 compares the pressure histories of the spin and full duration nonspin tests. Following the loss of the insert, the motor burned at a pressure level of about 180 psig until 18 seconds. At this time the case experienced a burn-through and irregular combustion was experienced until 34 seconds.

Figures 45 and 46 show the respective pre-fire and post-fire conditions of the NOTS 551 motor. Residue removed from the chamber weighed 33.5 pounds. The deposit within the chamber was about 1/2 inch thick at the nozzle end and tapered down to approximately 1/16 inch thick at the head end.

## CONCLUSIONS

The performance characteristics of some solid-propellant rocket motors have been shown in both free-flight and ground testing to be appreciably affected by the dynamic environment encountered during their thrusting period. Within the range of full-scale units tested by NASA Langley Research Center the principal effects noted are (1) ballistic, associated with alterations to the fundamental propellant combustion and flow processes, and (2) thermal, resulting from deposition of hot combustion residue within the motor chamber. Testing has shown that either of these effects may degrade a rocket motor previously fully qualified in a nonspin environment to a level totally unacceptable for use in a dynamic spin environment. Results indicate a high degree of ballistic sensitivity with severe thermal degradation in some types of motors tested ranging down to essentially no effect in other units tested.

The drawing of firm engineering conclusions as to the cause of "spin sensitivity" and the possible mechanisms associated with these phenomena is not possible at this time from the wide range of test results obtained with no systematic investigation of the parameters involved. It has been shown that certain highly aluminized propellants, when employed in certain grain configurations and exposed to given dynamic environments produce solid rocket motor performance characteristics which deviate widely from the performance of that motor obtained in a static condition. These deviations in ballistic and thermal performance clearly shown by the test results reported herein impose new design considerations for solid rockets which must function satisfactorily in these dynamic environments. The value of ground spin testing as early as possible in the development of new rocket systems designed for spin operation has been clearly demonstrated.

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9. Fourth-Stage Scout Rocket Motor Program Test Evaluation Report - Component Development Static Firing Spin Tests, Fourth Test; Single-Segment TM-3A Motor - UTC 2100 Ter1. Prepared Under Contract No. AF 04(695)-588 for SSD, USAFSC, November 9, 1964.
10. Nelius, M. A.; and White, D. W.: Results of Testing the HPC-ABL-X-258-B1 (s/n RH47) Solid-Propellant Rocket Motor Under the Combined Effects of Simulated Altitude and Rotational Spin. Tech. Documentary Report AEDC-TDR-64-41, AFSC Program Area 627A, Mar. 1964.
11. White, D. W.; and Nelius, M. A.: Results of Testing Two HPC-ABL-X-258 (s/n RH56, 58) Solid-Propellant Rocket Motor Under the Combined Effects of Simulated Altitude and Rotational Spin. Tech. Documentary 64-97, Program Area 921E, May 1964.

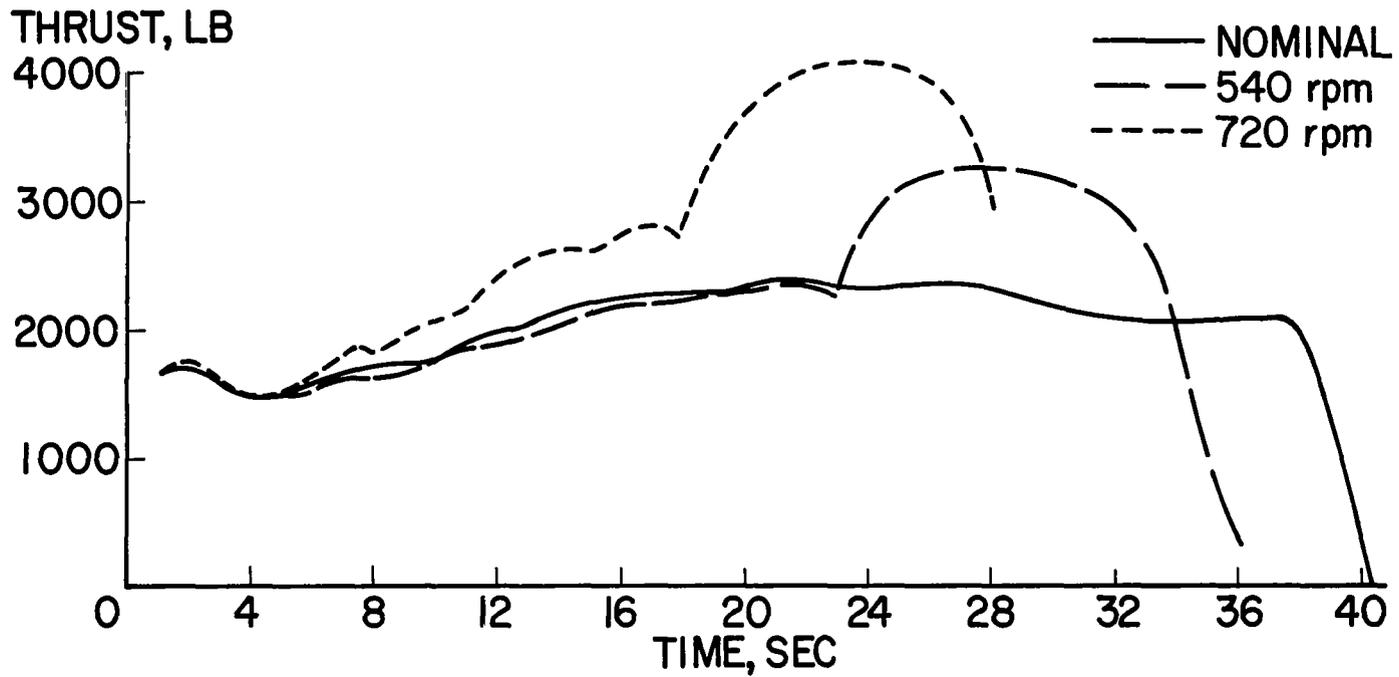
12. Lee, B. J.: An Investigation of the NASA CYGNUS-15 Solid-Propellant Rocket Motor Under the Combined Effects of Simulated Altitude and Rotational Spin. Tech. Documentary 64-78, Program Element 62503015/4979, April 1964.
13. Hercules Powder Co. - Chemical Propulsion Handbook.

TABLE 1.- SUMMARY OF TESTS CONDUCTED ON LRC ROCKET SPIN-TEST APPARATUS

Type motor	Manufacturer	Number tested	Spin rate, rpm	Approximate propellant weight, lb	Exhaust altitude, ft
X259	Hercules-ABL	2	200, 300	2500	Sea level
X258	Hercules-ABL	7	100, 200, 250	500	Sea level and 110 K
X248	Naval Prop. Plant	1	250	450	Sea level
CYGNUS-15 (spherical)	NASA-LRC	7	900	100	Sea level and 120 K
CYGNUS-15 (spherical)	Aerojet General	4	900	100	Sea level
CETUS-17 (spherical)	Naval Prop. Plant	5	200	135	Sea level and 110 K
XM-85	Atlantic Research	2	200	130	110 K
ALCOR IA	Aerojet General	2	300, 480	900	Sea level
TM-3	United Technology	4	0, 200, 400	600	Sea level
HYDAC	Lockheed Propulsion	1	900	410	Sea level
NOTS 551	Naval Ordnance Testing Station	1	480	700	Sea level

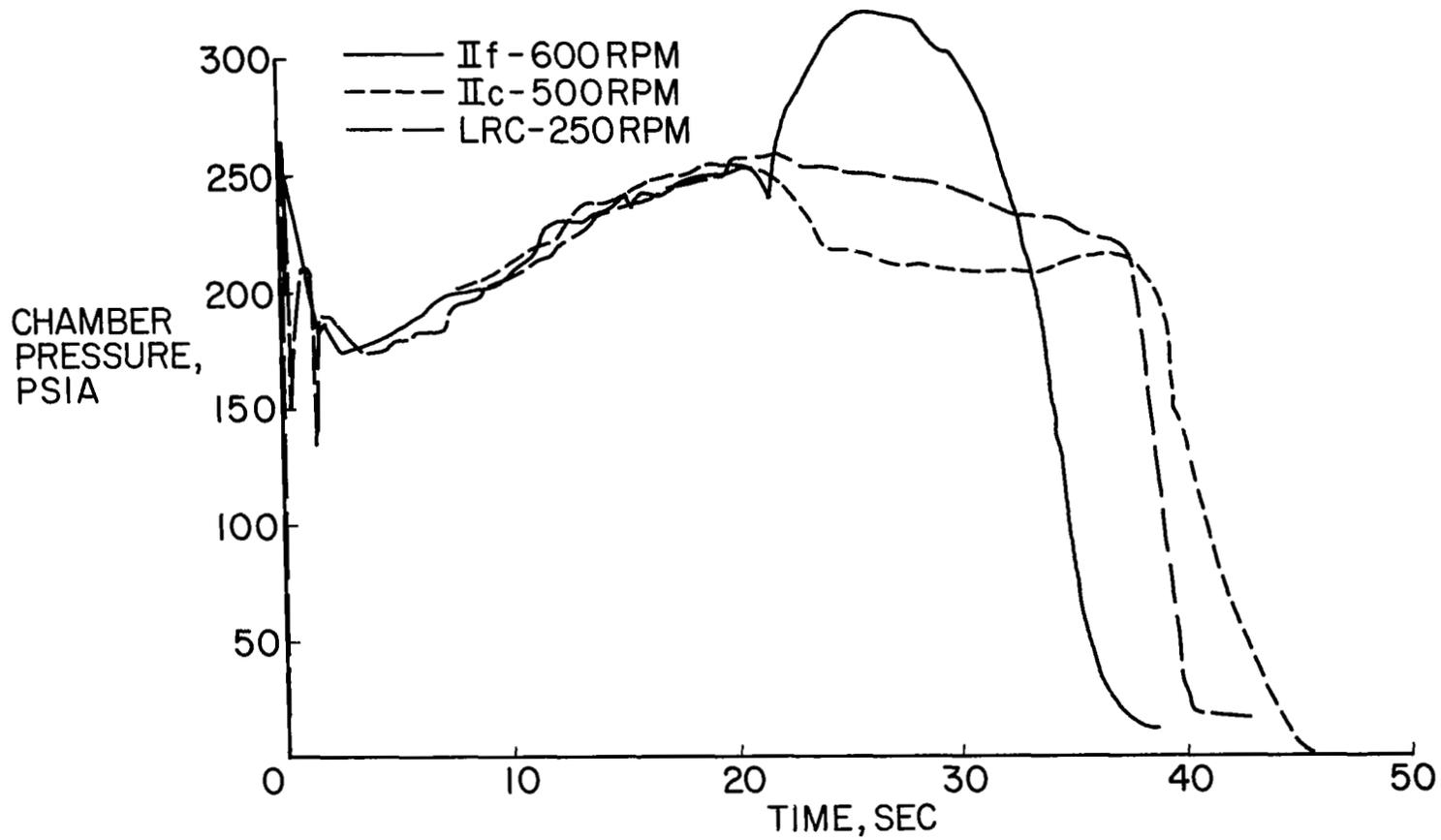
TABLE 2.- AMOUNT AND LOCATION OF ALUMINUM RESIDUE  
FROM UTC TM-3 TWO-SEGMENT MOTORS

Test, rpm	Weight in fwd end, lb	Weight in aft end, lb	Total residue weight, lb
0	4	1.5	5.5
200	10	5.0	15.0
400	16	15.0	31.0



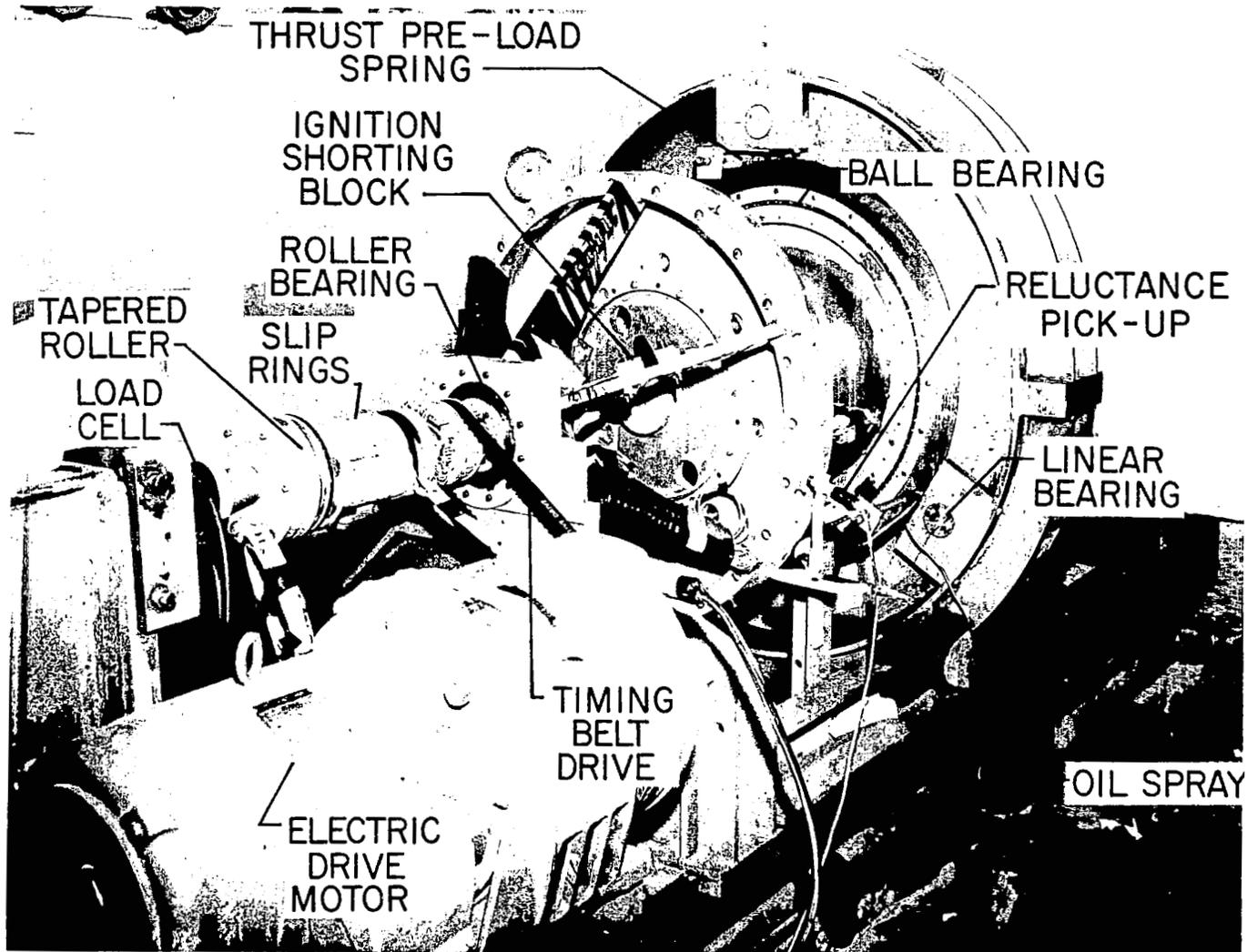
NASA

Figure 1.- ABL X248 longitudinal spin-fire data sea-level thrust versus time.



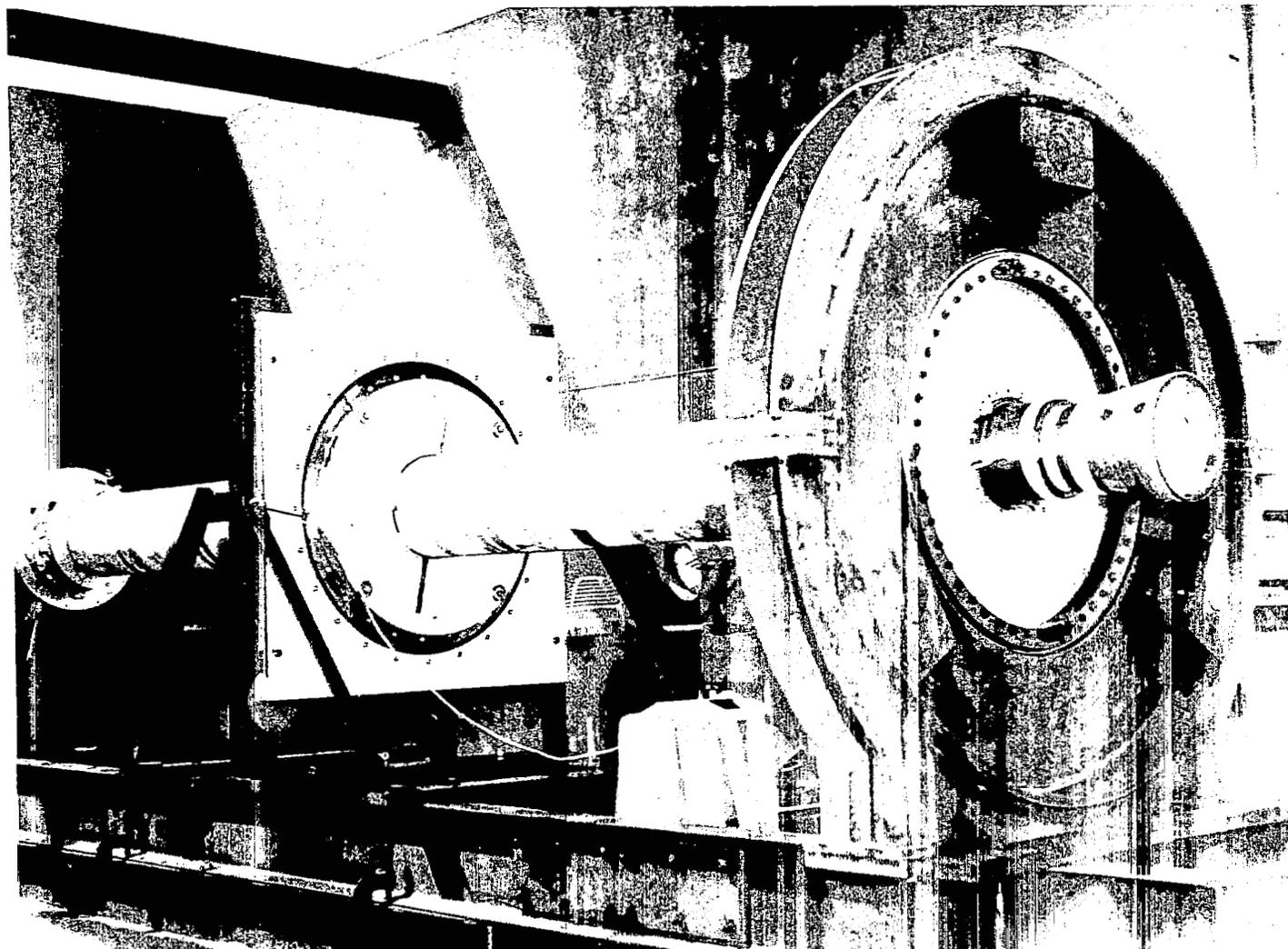
NASA

Figure 2.- X248 flight and static spin-test data.



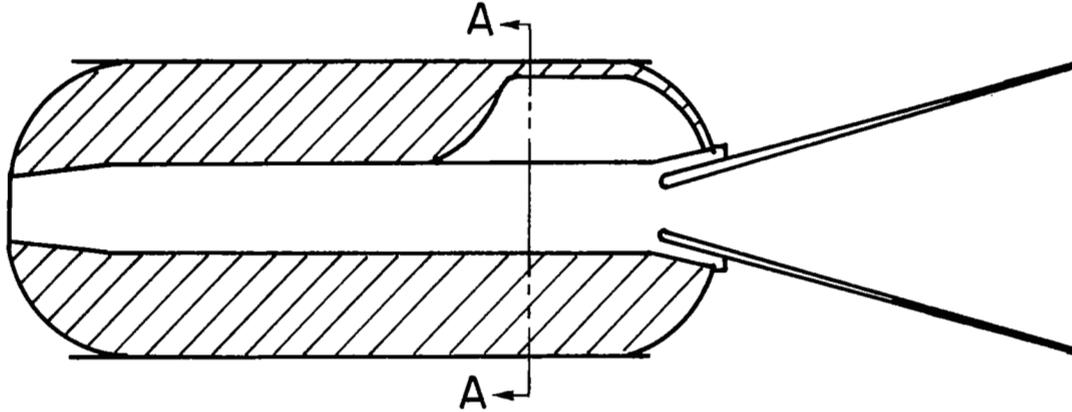
NASA

Figure 3.- Spin-test apparatus - overall view.

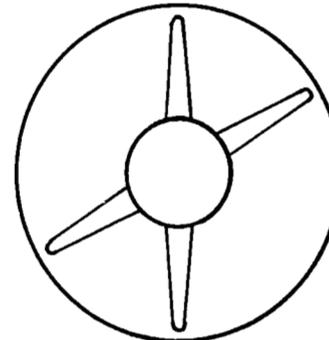


NASA

Figure 4.- Detail of aft ball-bearing spin-test apparatus.



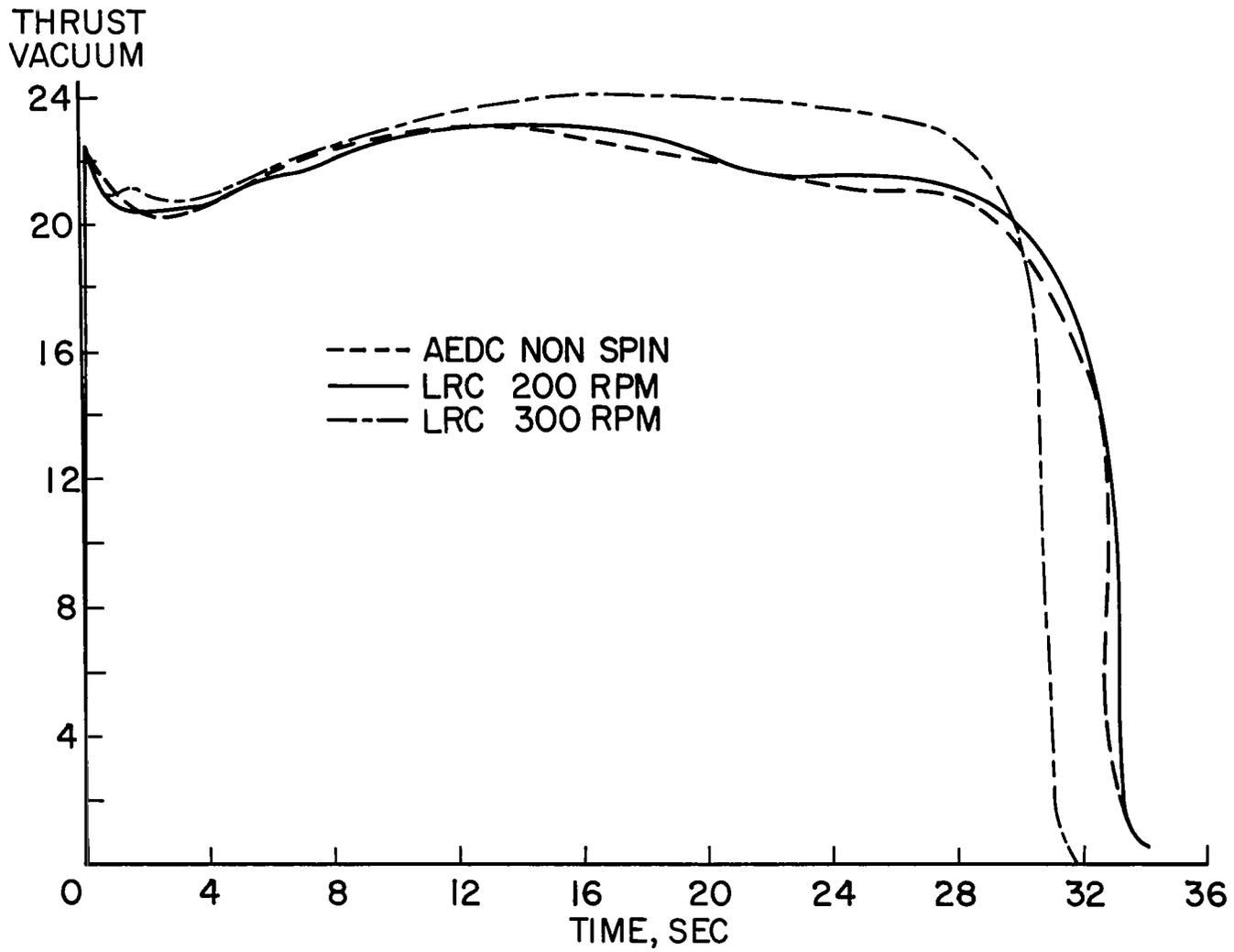
CYI 75 PROPELLANT  
APPROXIMATELY 20% AL



SECTION A-A

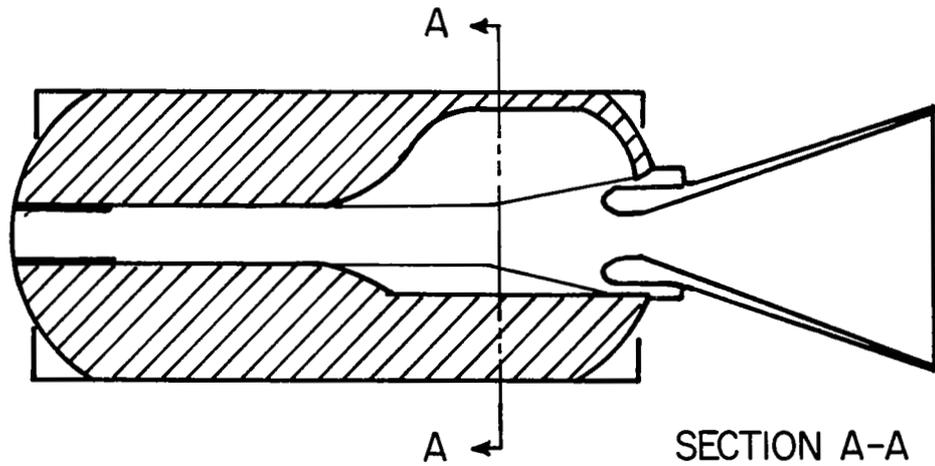
NASA

Figure 5.- ABL X259 rocket motor.

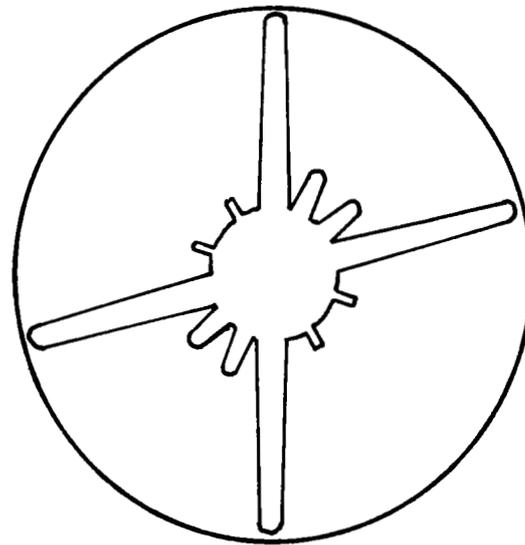


NASA

Figure 6.- Performance curves for X259.



CYI - 75 PROPELLANT  
APPROXIMATELY 20% AL



NASA

Figure 7.- ABL X258 rocket motor.



(RH-50)

Figure 8.- Aft portion remains of X258.

NASA



NASA

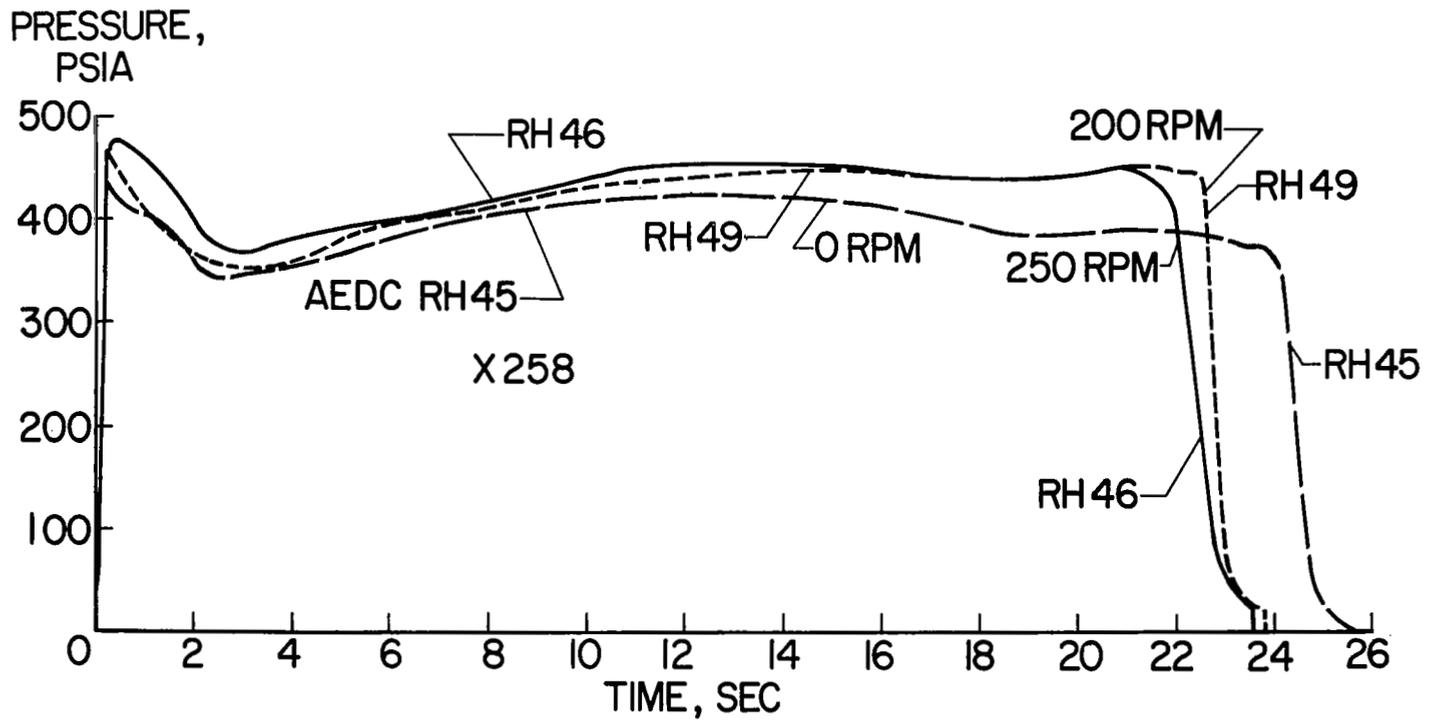
Figure 9.- Post-fire condition X258 - Spin-test apparatus.



(RH - 49)

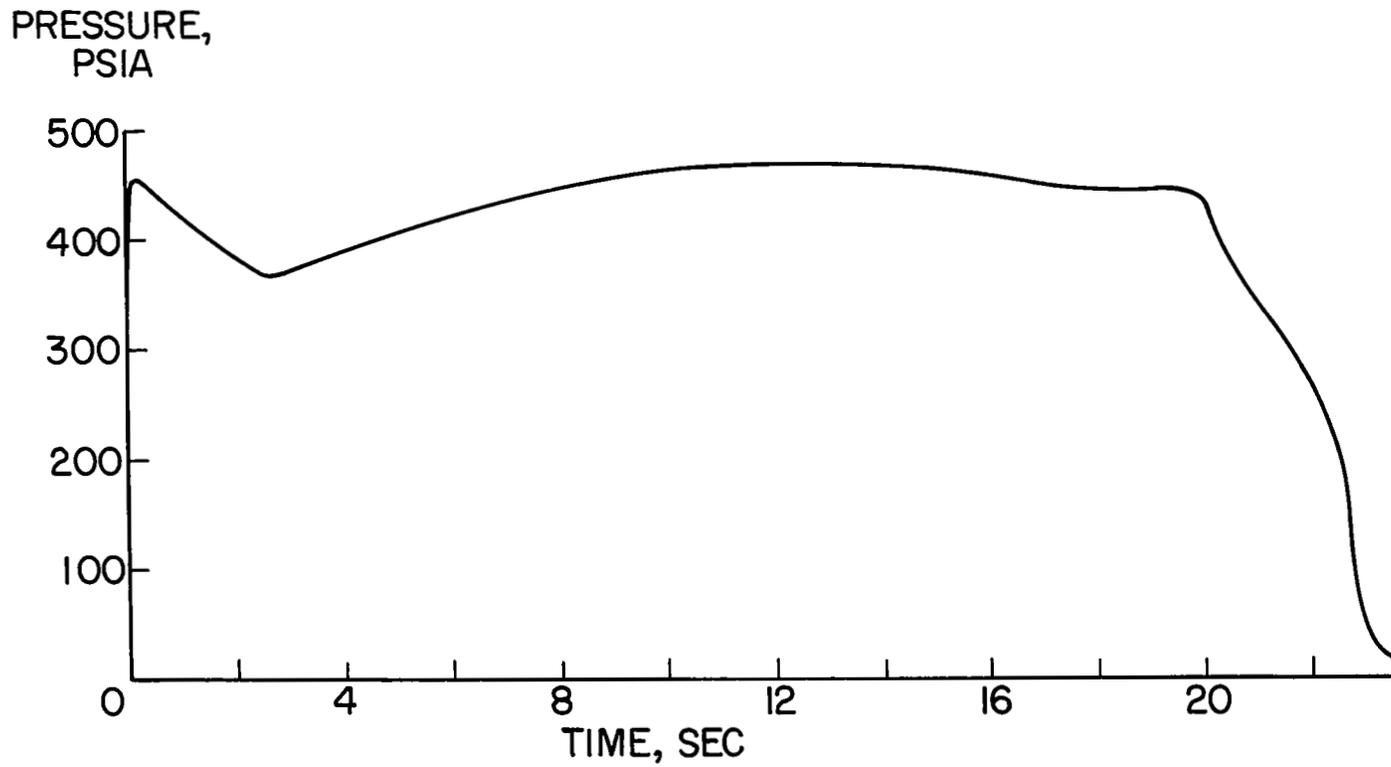
NASA

Figure 10.- Charred region on X258.



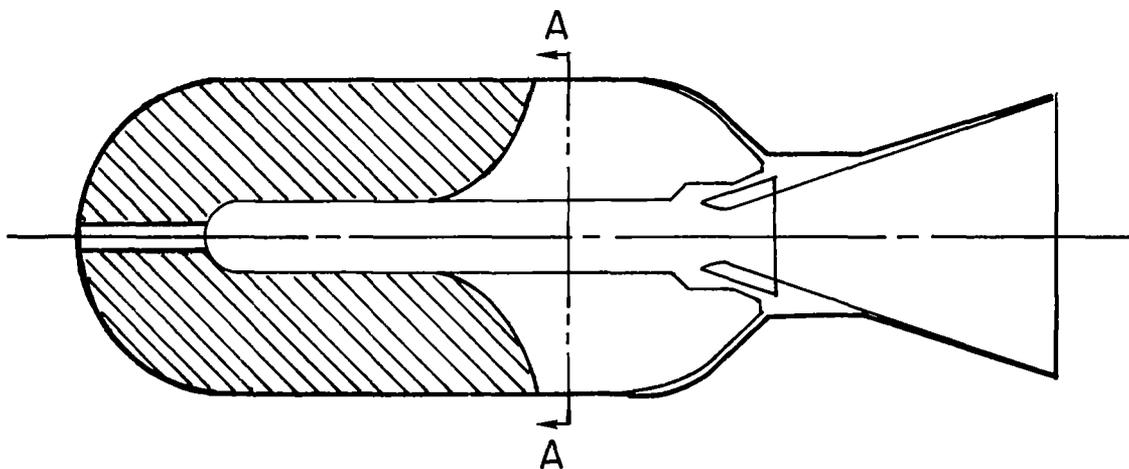
NASA

Figure 11.- Pressure time history of X258 rocket motor in spin and nonspin environment.



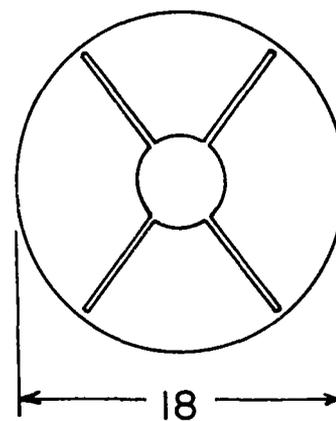
NASA

Figure 12.- Pressure time history of modified X258 rocket motor RH63 at 100-rpm spin environment.



SECTION A-A

58" OVERALL LENGTH  
Buu PROPELLANT  $\approx$  3% AL  
PARTIALLY SUBMERGED NOZZLE



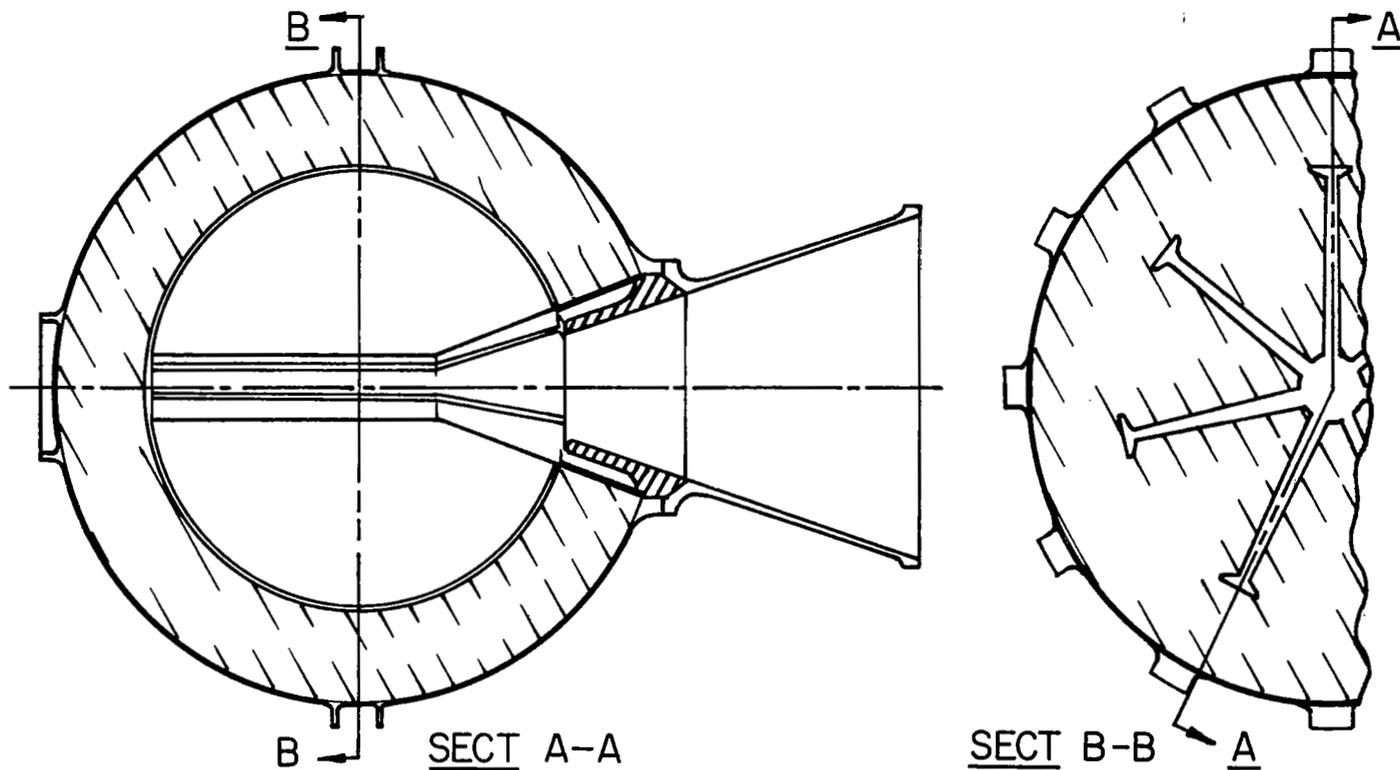
NASA

Figure 13.- ABL X248 rocket motor.



Figure 14.- X248 firing (post fire) - spin-test apparatus.

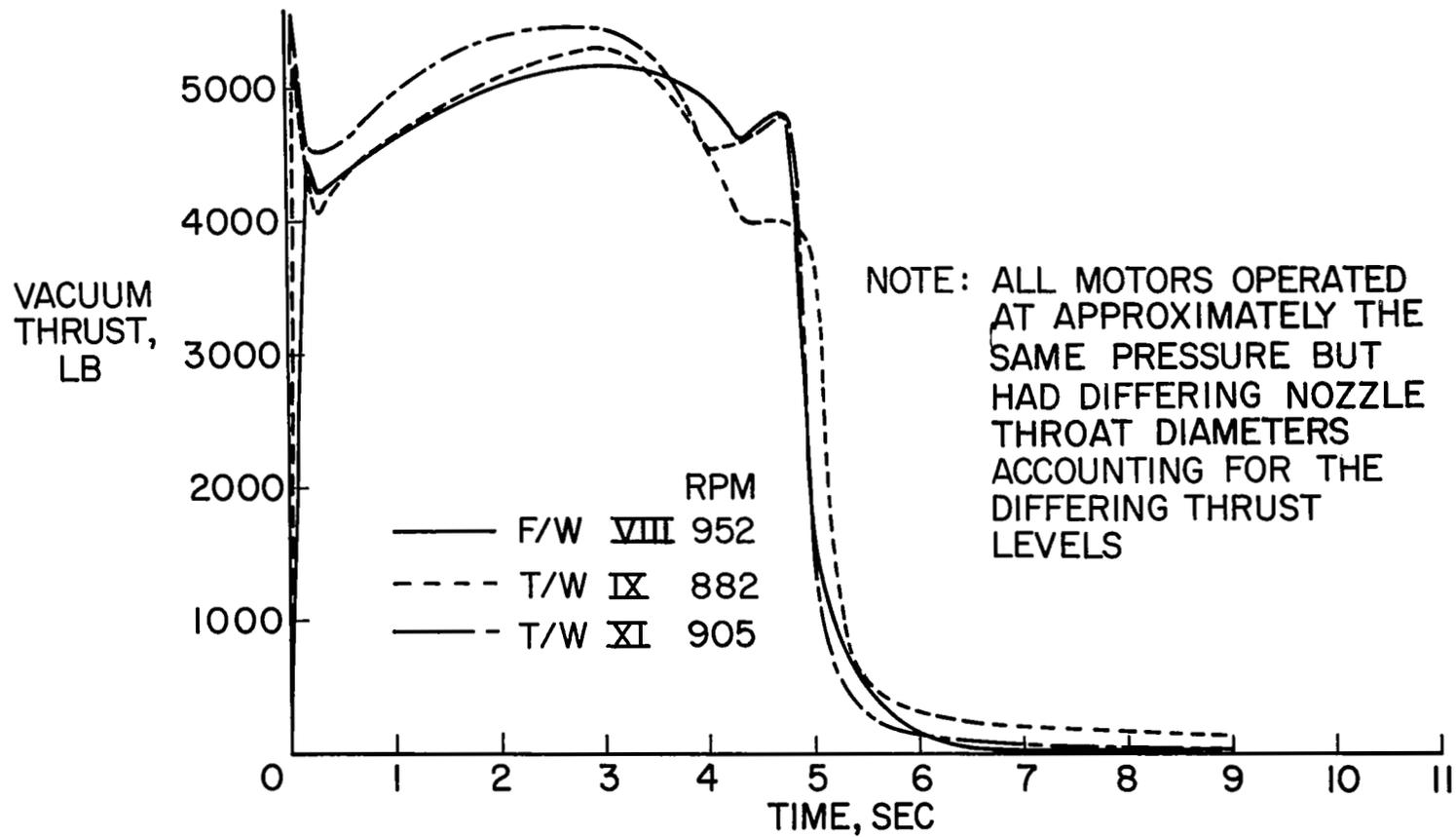
NASA



CASE: .018 TO .020 4340 AND 6Al4V  
 INSULATION: .030 V-44; NOZZLE; PARTIALLY SUBMERGED  
 ATJ GRAPHITE  
 PROPELLANT: BF-117b POLYSULFIDE (.5%  $\text{Fe}_2\text{O}_3$ , .9% AL);  
 ANP-2986 POLURETHANE (17.16% AL)

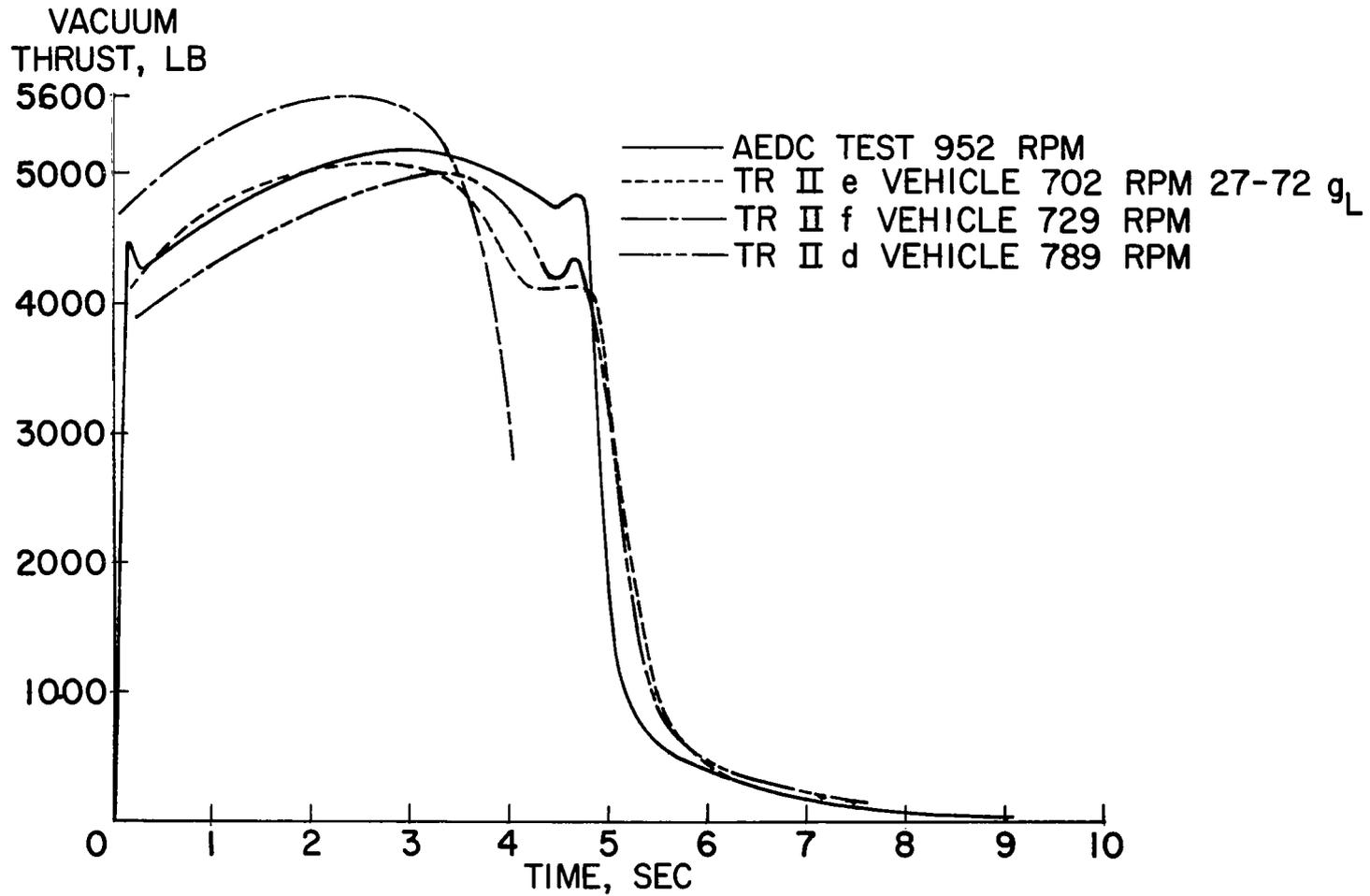
NASA

Figure 15.- CYGNUS-15 LRC and AGC produced.



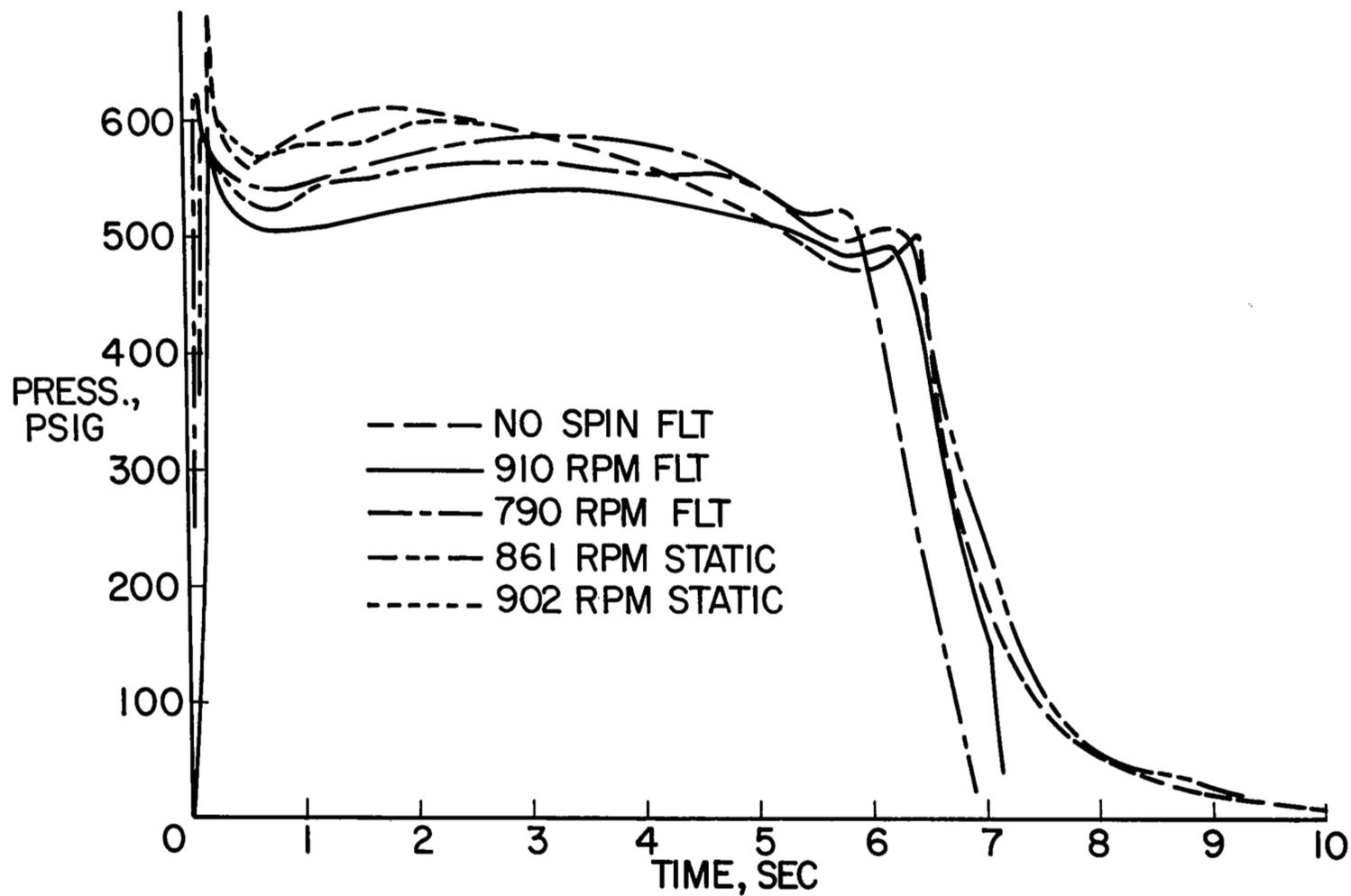
NASA

Figure 16.- Cygnus-15 LRC produced-static spin tests.



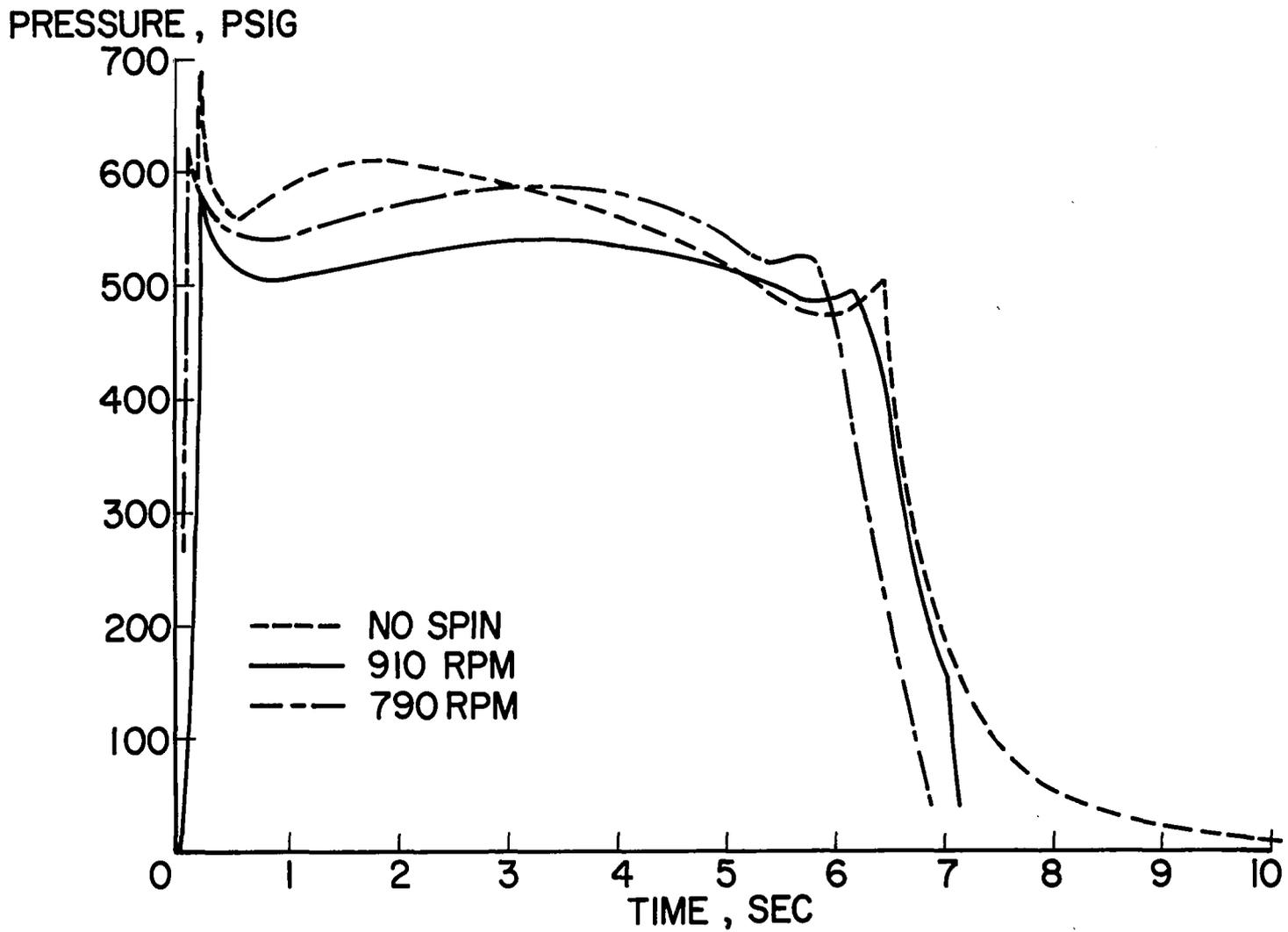
NASA

Figure 17.- CYGNUS-15 LRC produced spin results.



NASA

Figure 18.- Aerojet produced CYGNUS-15 spherical rocket motor spin test.



NASA

Figure 19.- Aerojet produced CYGNUS-15 spherical rocket motor flight weight cases spin test.



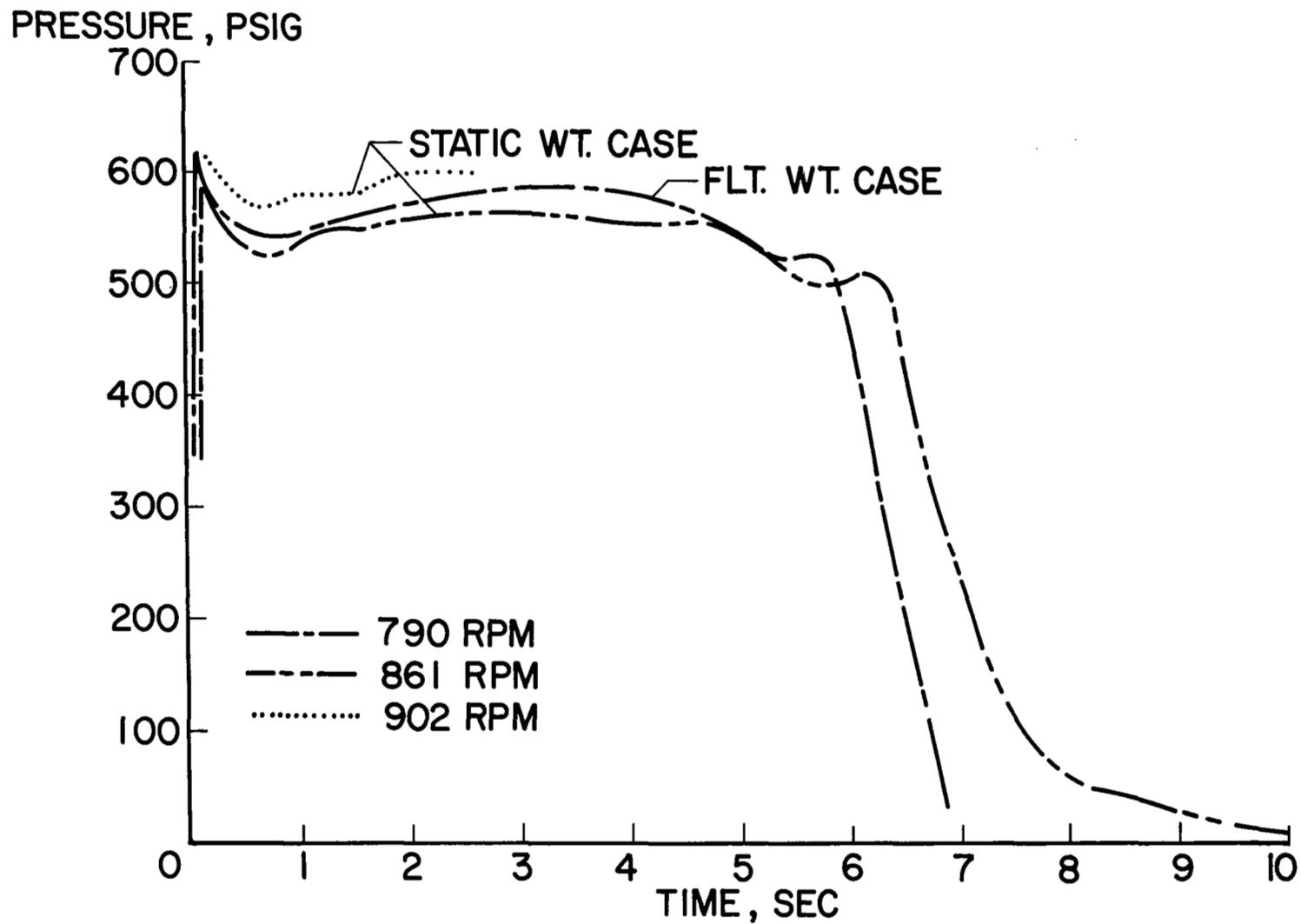
NASA

Figure 20.- Pre-fire condition of AGC CYGNUS-15 - spin-test apparatus.



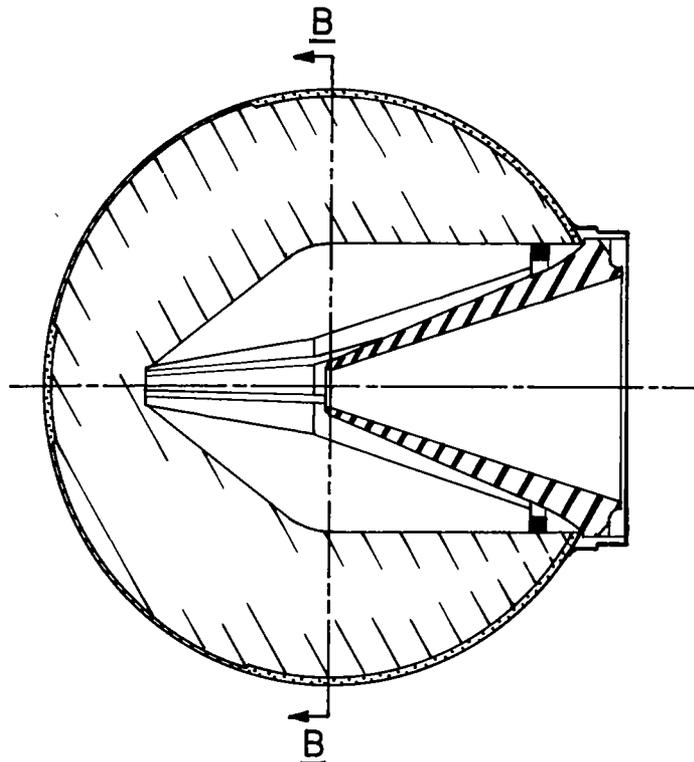
NASA

Figure 21.- Post-fire condition of AGC CYGNUS-15 - spin-test apparatus.



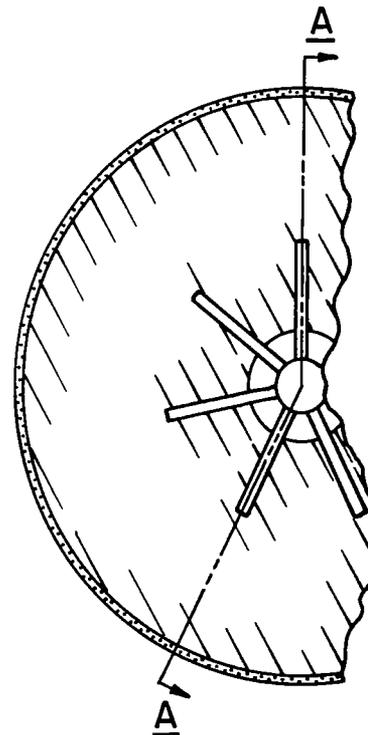
NASA

Figure 22.- Aerojet produced CYGNUS-15 spherical rocket motor spin test.



SECT A-A

CASE; 17-7 PH STAINLESS STEEL  
 NOZZLE; FULLY SUBMERGED ATJ GRAPHITE  
 INSULATION; V-44, .090 TO .150 INCHES THICK  
 (BOOT-FLAP SYSTEM)  
 PROPELLANT; E-107, POLYURETHANE TYPE,  
 17.7% ALUMINUM

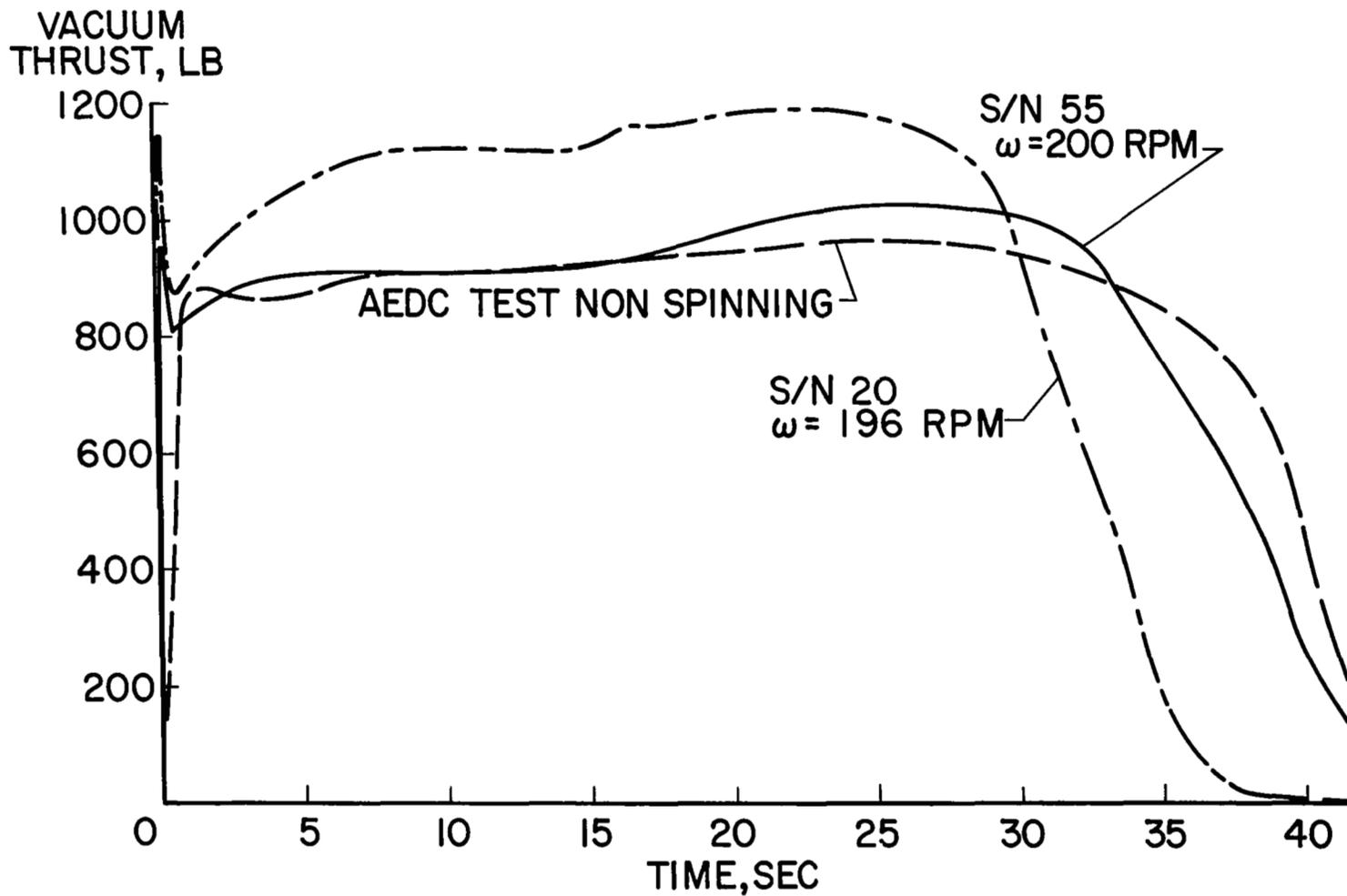


SECT B-B

PRODUCED BY:  
 NOTS  
 NPP

NASA

Figure 23.- CETUS-17 (NOTS 100) spherical rocket motor design.



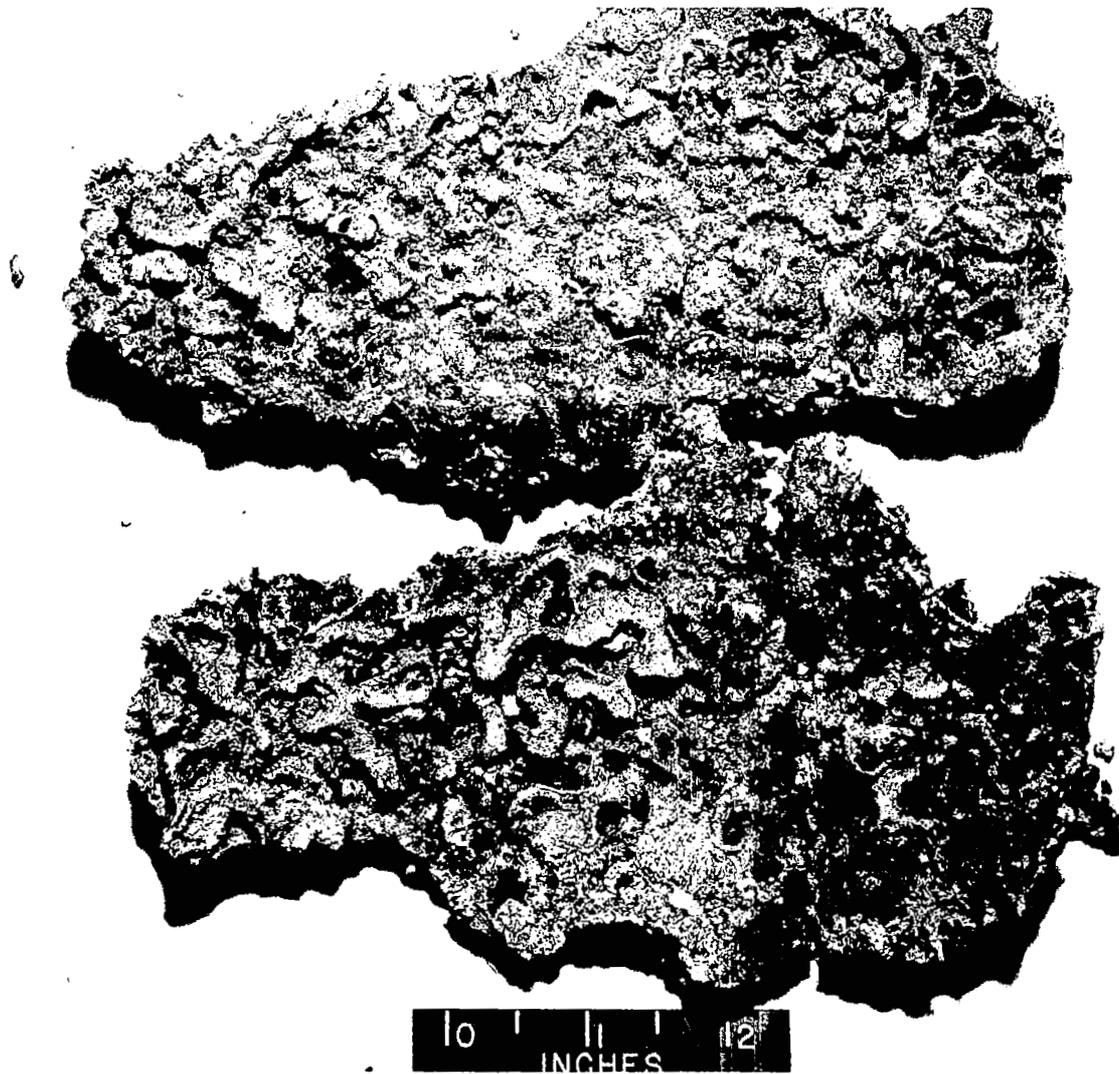
NASA

Figure 24.- Early NOTS 100B spin tests.



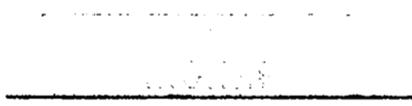
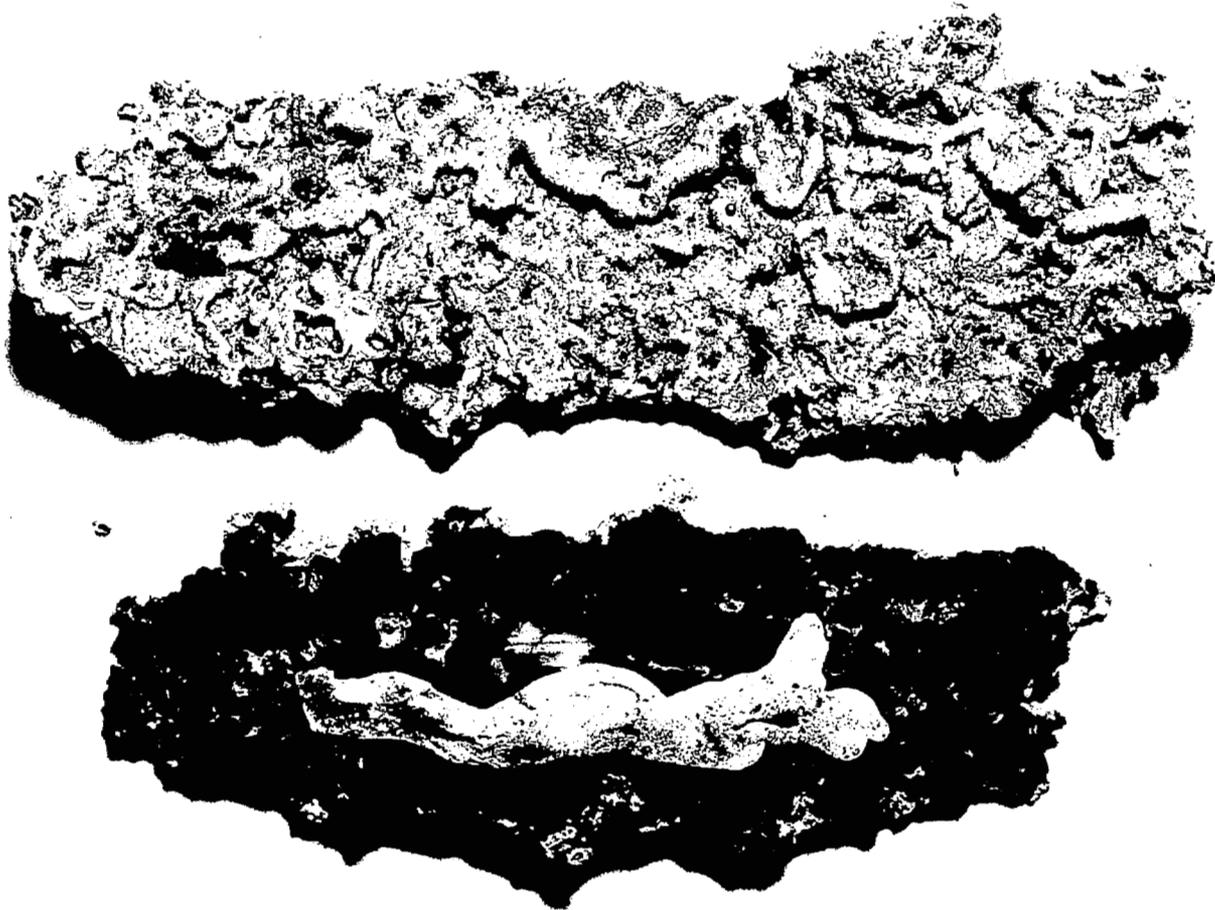
NASA

Figure 25.- CETUS-17 post-fire spin test - interior view.



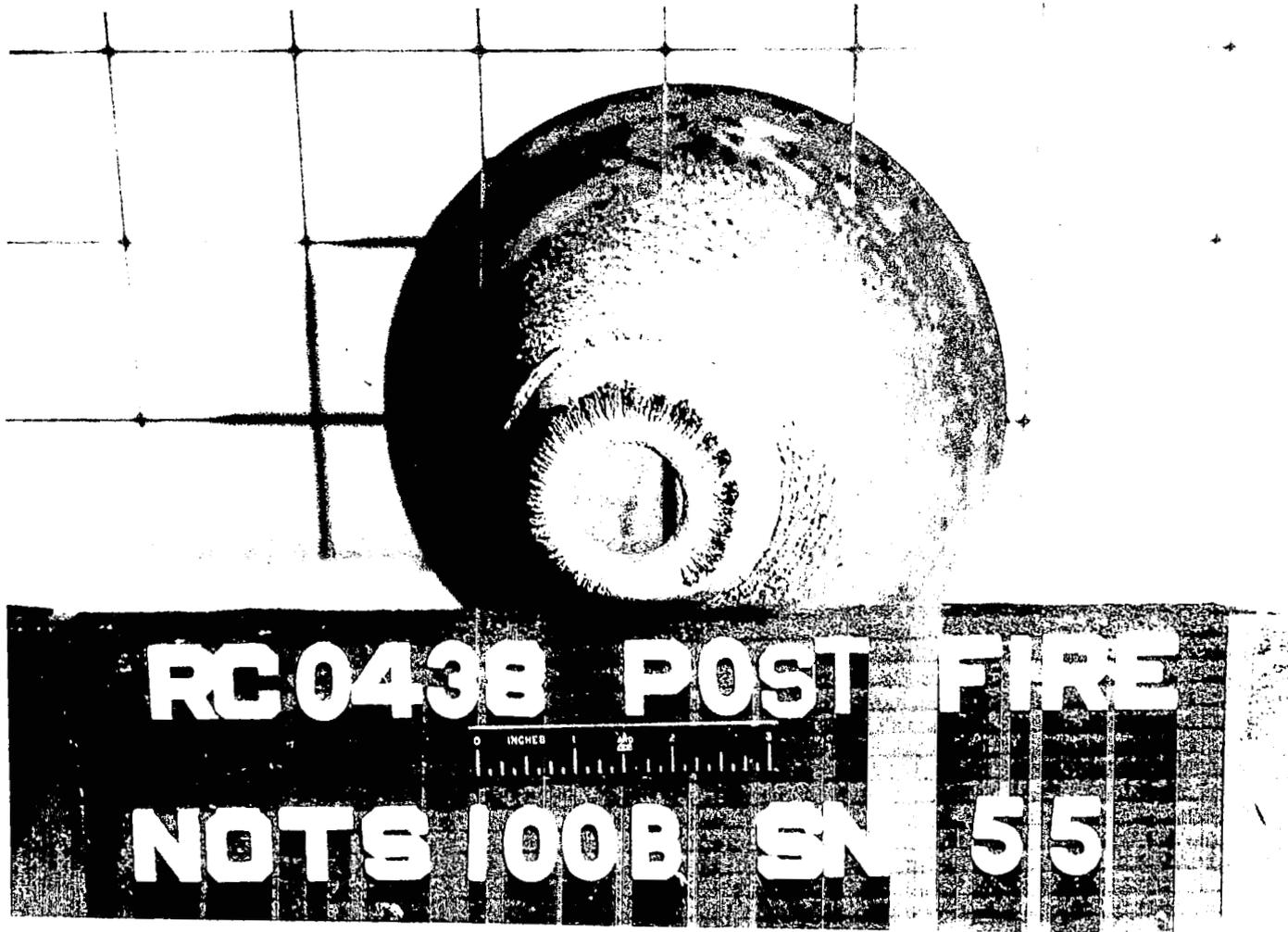
NASA

Figure 26.- CETUS-17 post-fire spin test - aluminum residue.



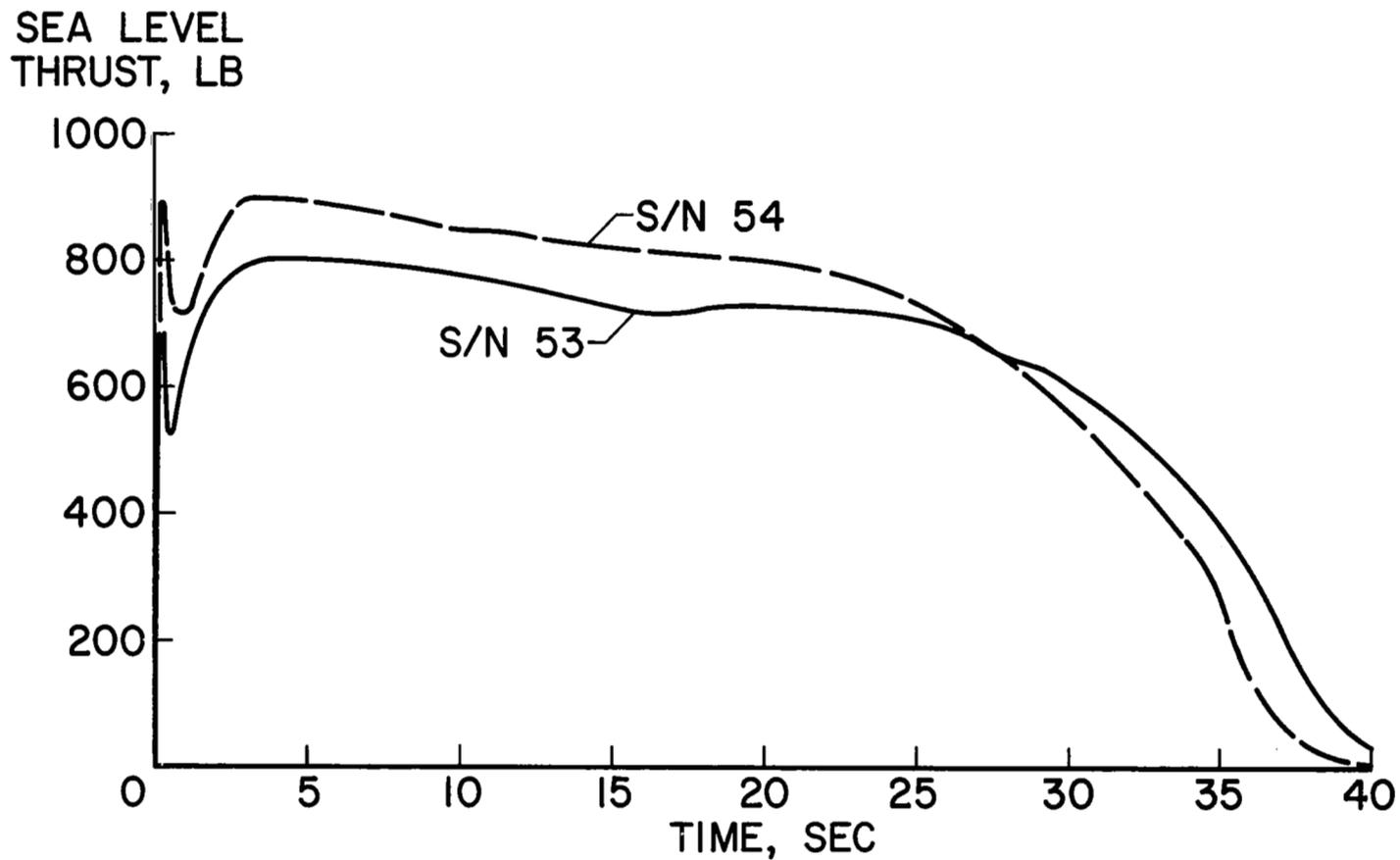
NASA

Figure 27.- CETUS-17 post-fire spin test - aluminum residue.



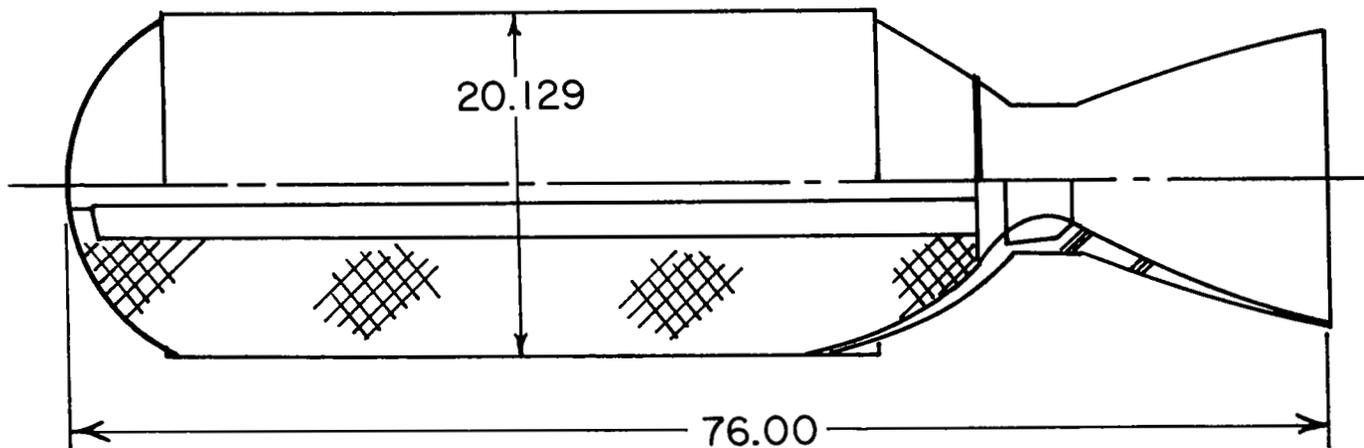
NASA

Figure 28.- CETUS-17 post-fire spin test - nozzle view.



NASA

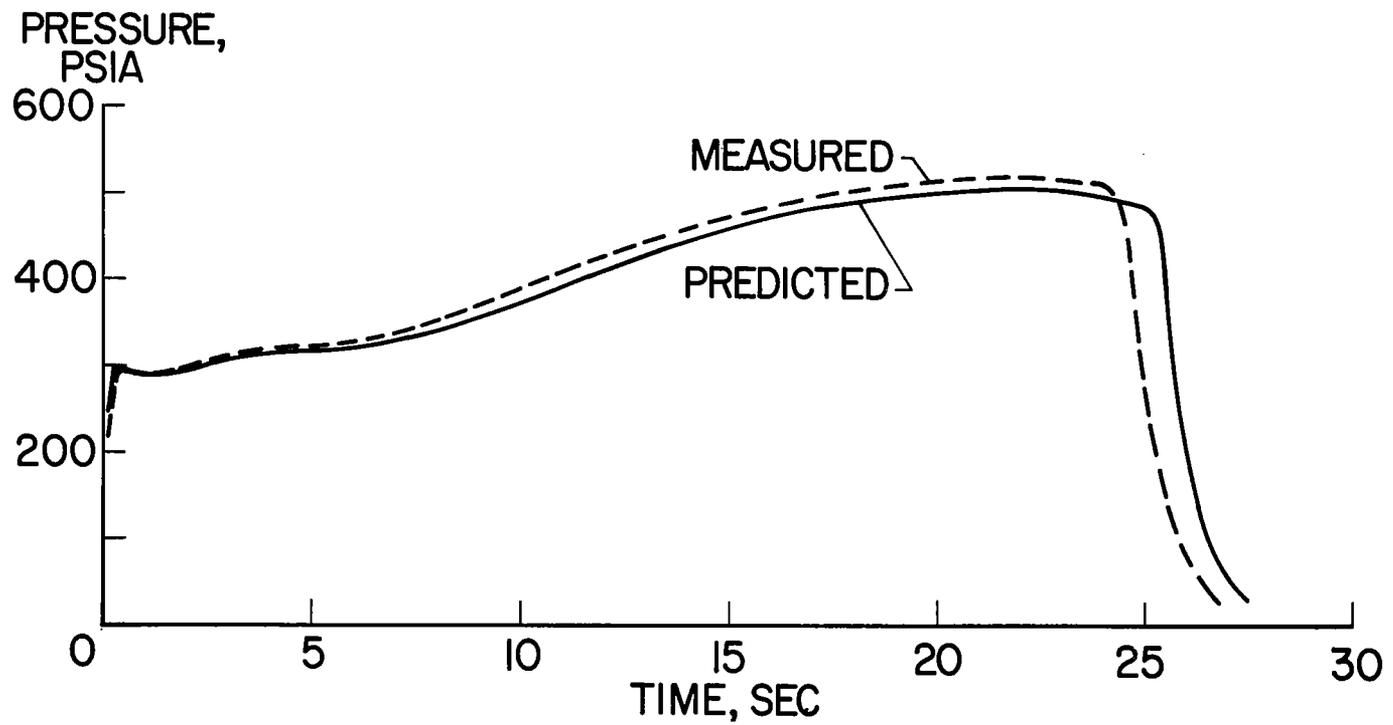
Figure 29.- NPP produced NOTS 100B spin test,  $\omega = 200$  rpm.



SIX (6) POINT STAR  
AEROWRAP CASE  
PBD PROPELLANT  $\approx$  16% AL  
AEROJET GENERAL CORP.

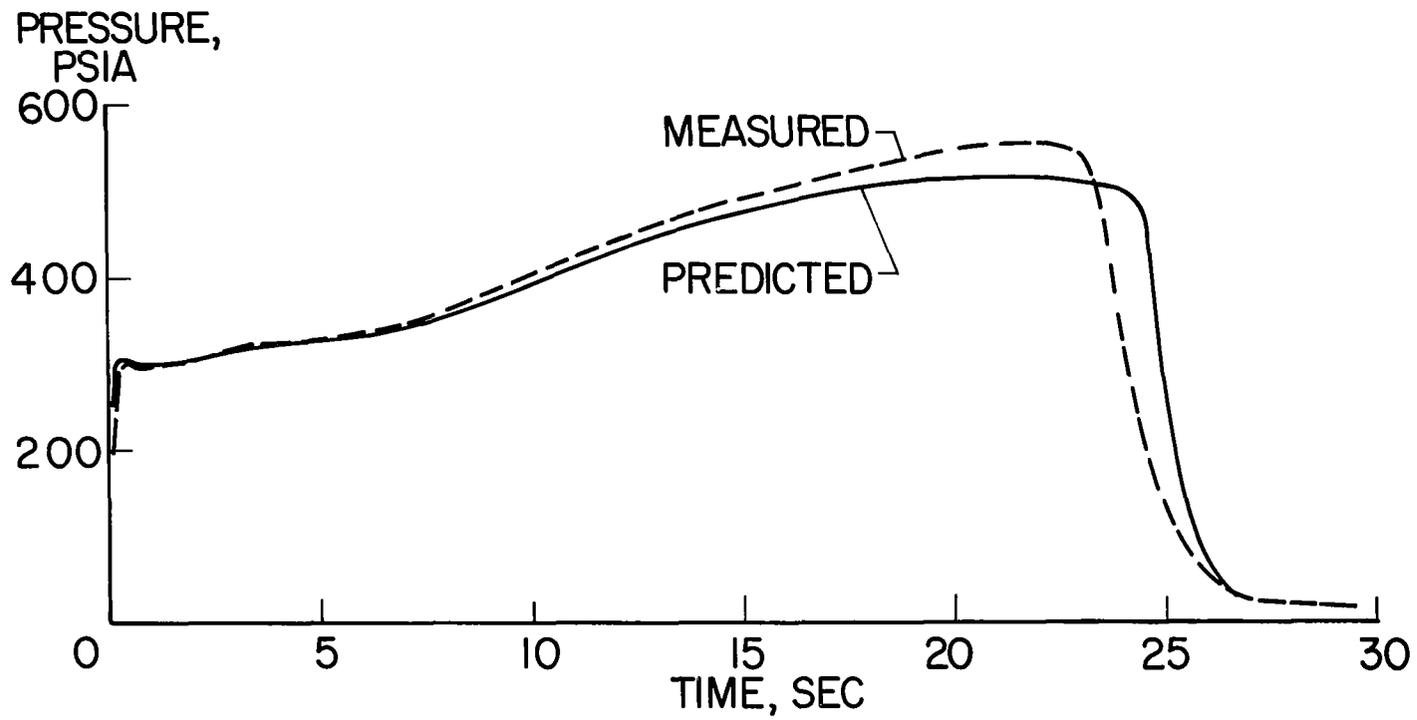
NASA

Figure 30.- ALCOR 1A configuration (23 KS 11,000).



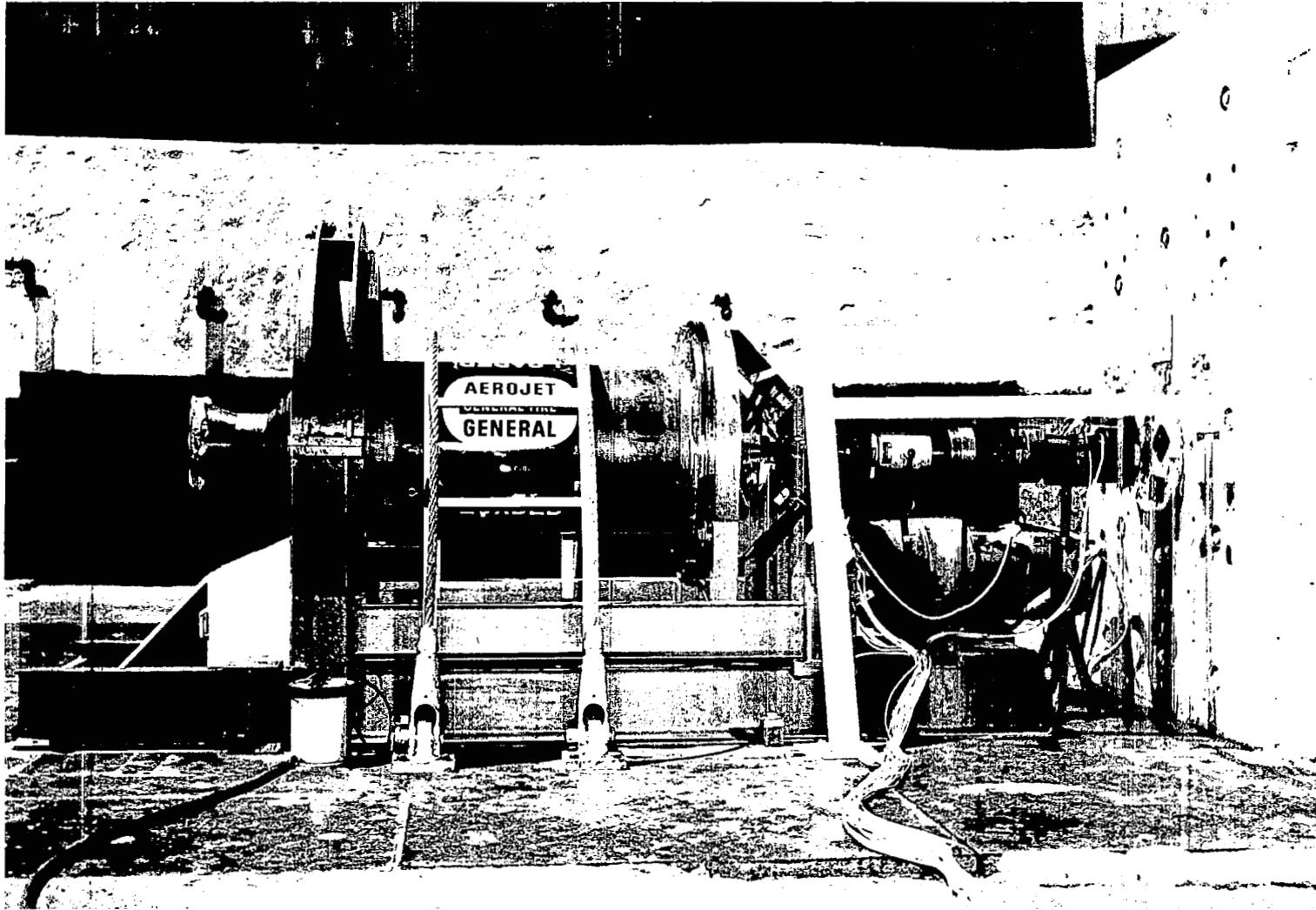
NASA

Figure 31.- ALCOR 1A (23 KS 11,000). Predicted pressure - 0 rpm; measured pressure - 300 rpm.



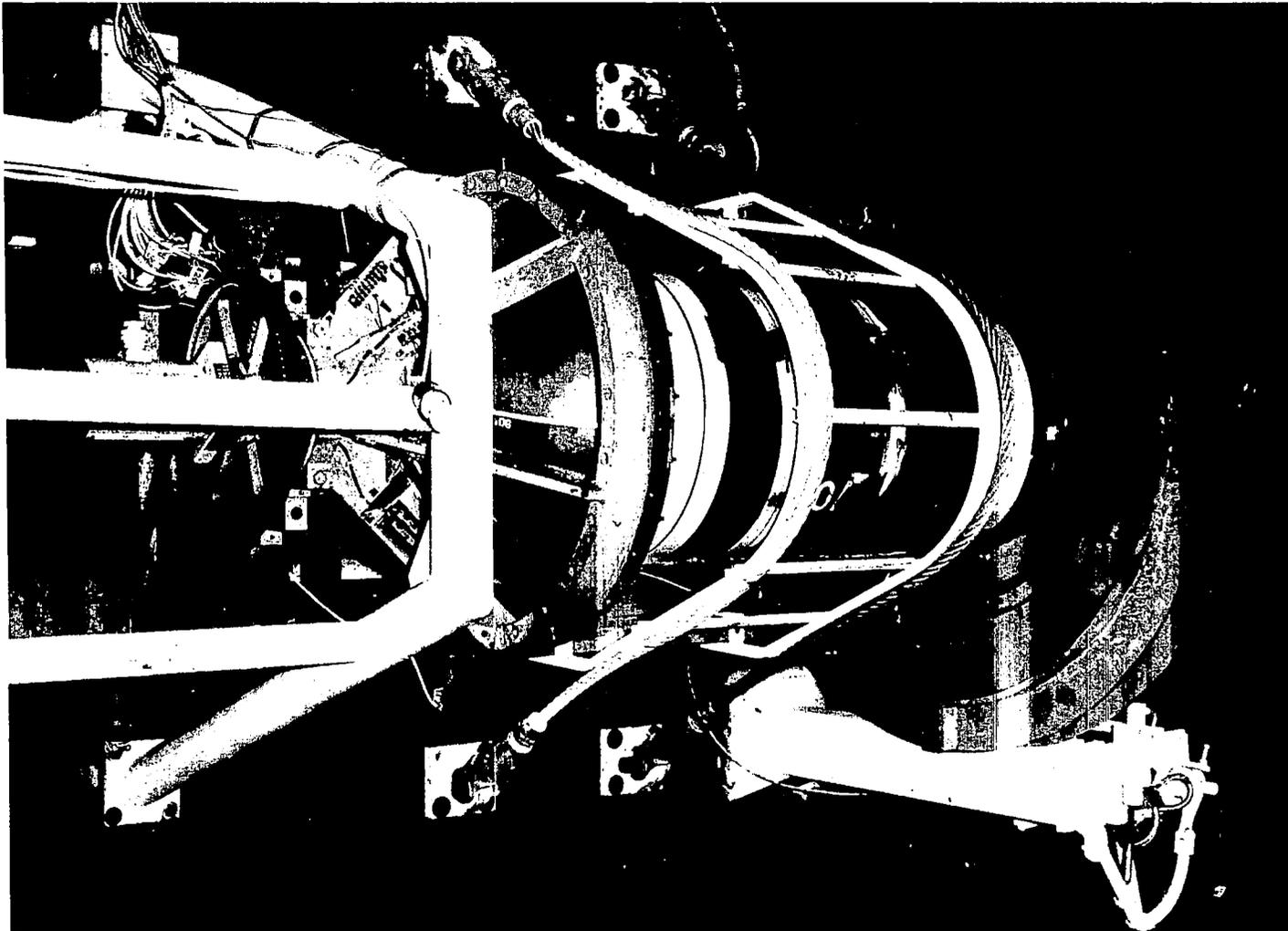
NASA

Figure 32.- ALCOR 1A (23 KS 11,000). Predicted pressure - 0 rpm; measured pressure - 480 rpm.



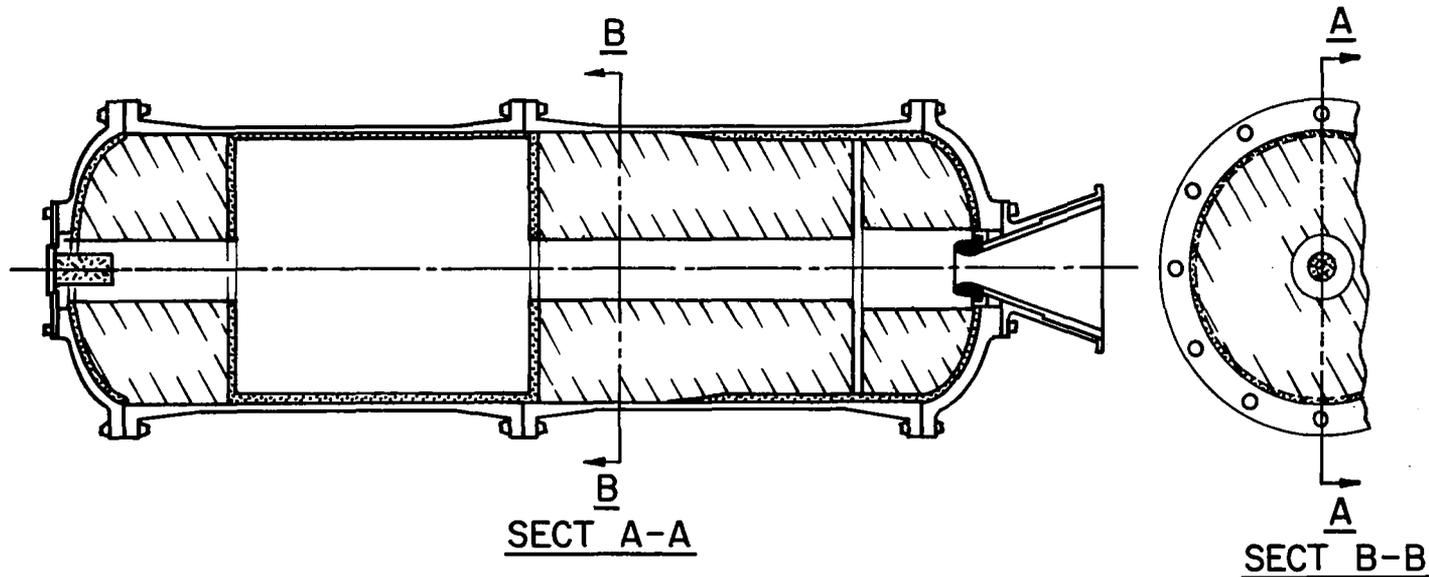
NASA

Figure 33.- ALCOR 1A firing (pre-fire) - spin-test apparatus.



NASA

Figure 34.- ALCOR 1A post-fire condition - 480 rpm.

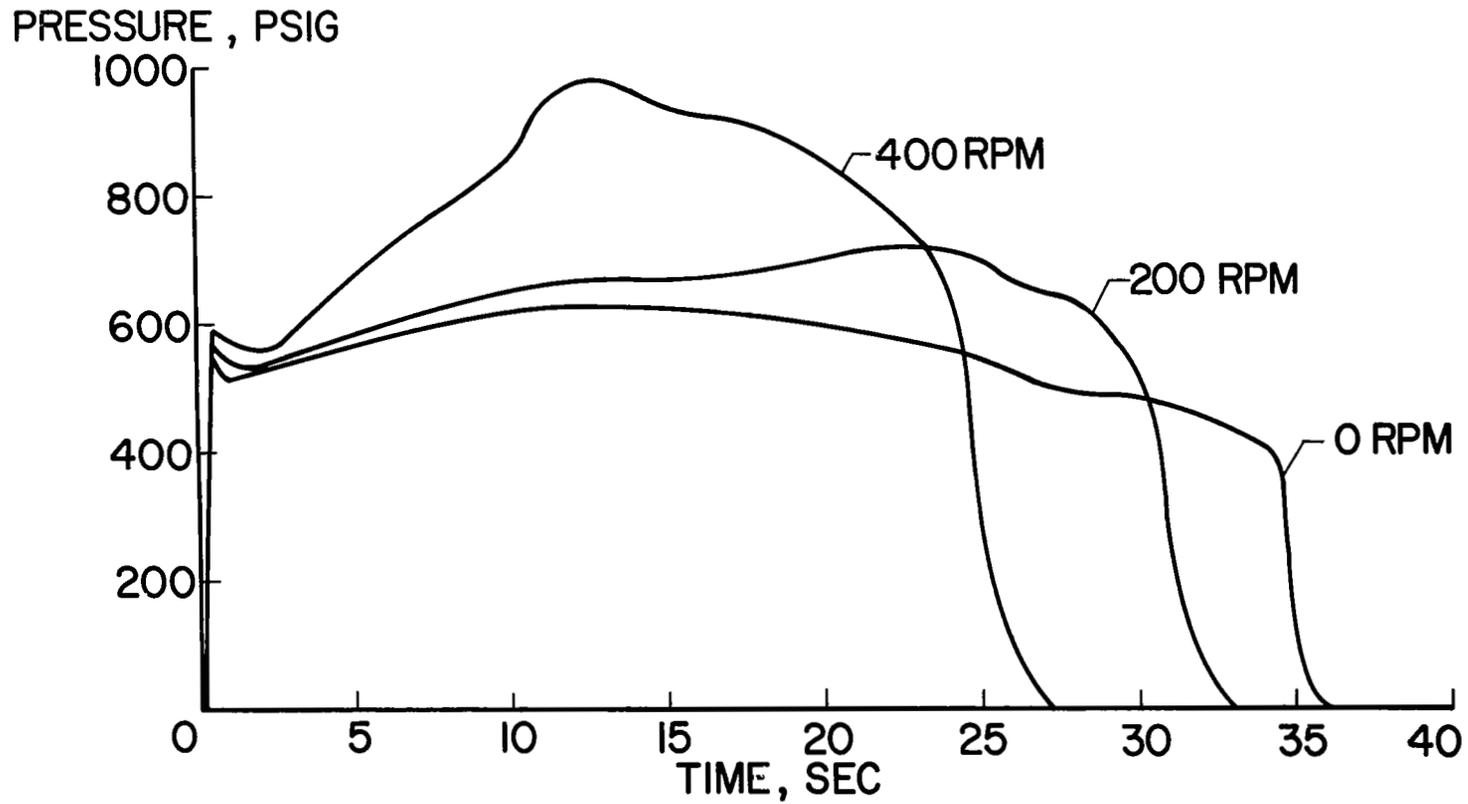


CASE; MILD STEEL, HEAVY WALL  
 NOZZLE; PARTIALLY SUBMERGED ATJ GRAPHITE  
 INSULATION; SILICA-LOADED BUNA-N RUBBER  
 PROPELLANT; UTP 3096, PBAA,  $\approx$  16% ALUMINUM

PRODUCED BY:  
 UTC

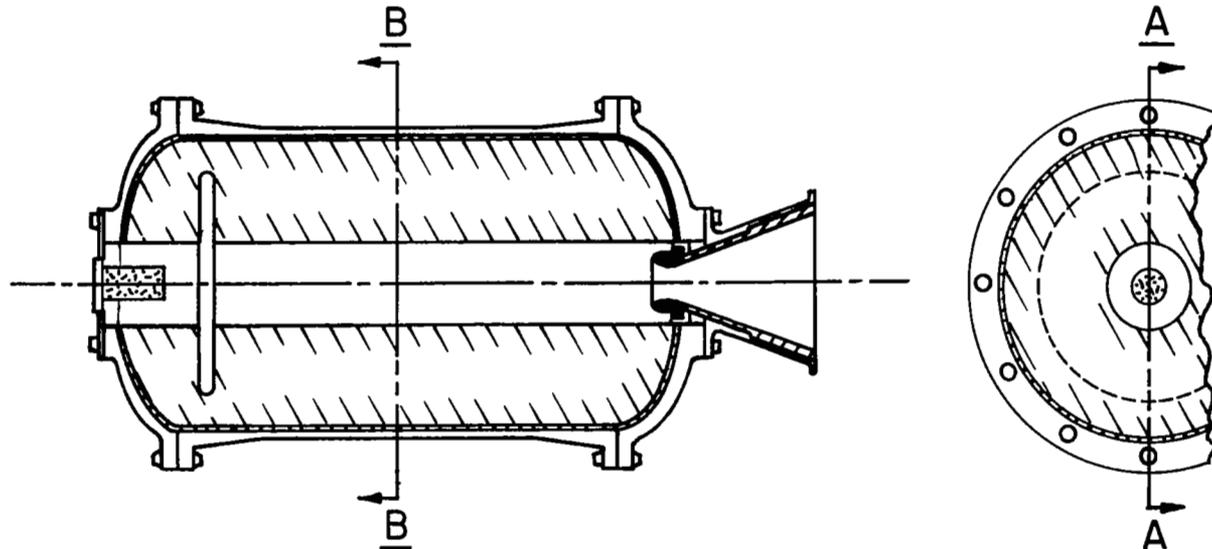
NASA

Figure 35.- UTC TM-3 rocket motor - series I.



NASA

Figure 36.- UTC TM-3 spin test.



SECT A-A

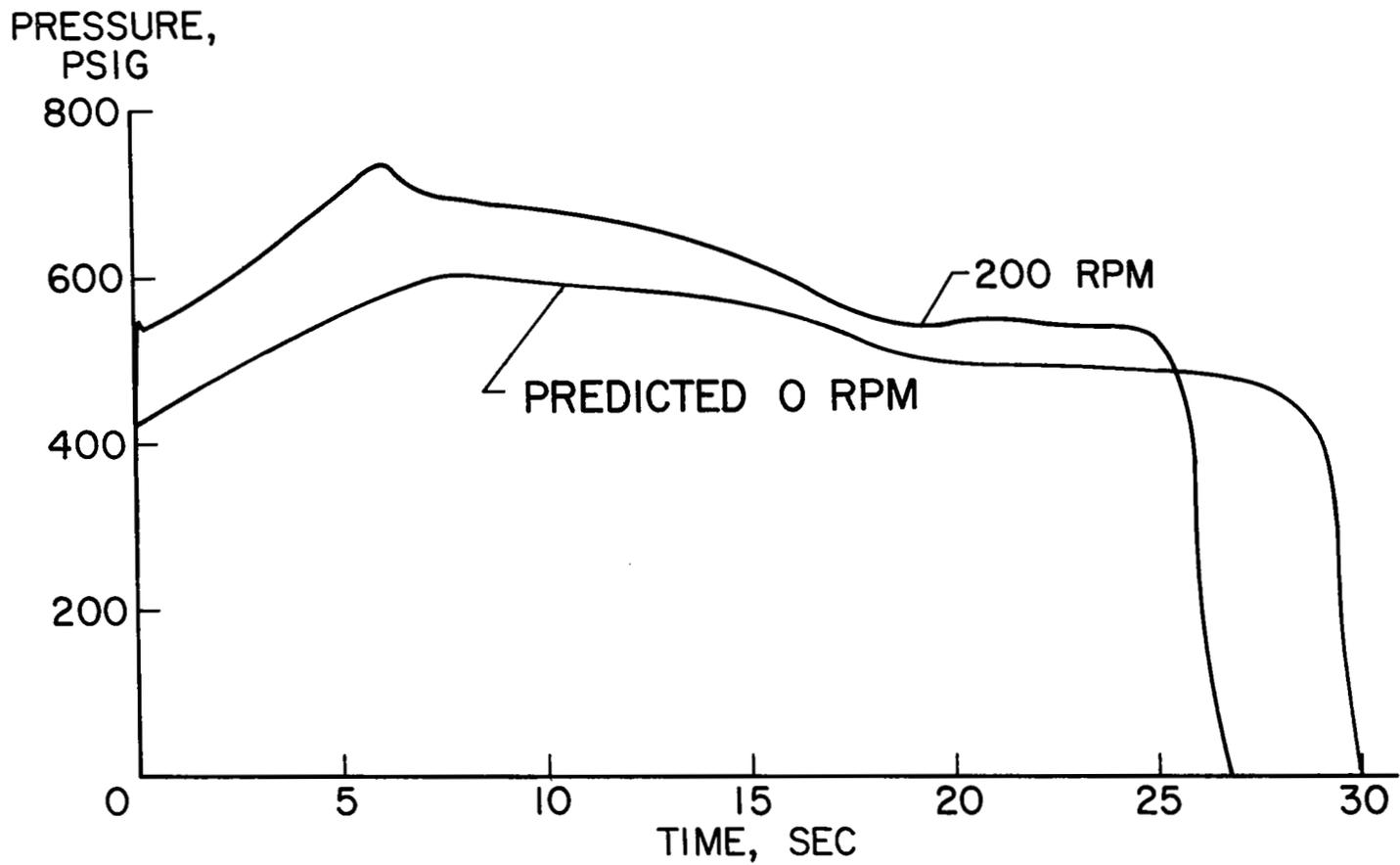
SECT B-B

PRODUCED BY:  
UTC

CASE; MILD STEEL, HEAVY WALLED  
 NOZZLE; PARTIALLY SUBMERGED ATJ GRAPHITE  
 INSULATION; GENGARD V 3050, .50 INCHES THICK  
 PROPELLANT; UTP 3096, PBAA,  $\approx$  16% ALUMINUM

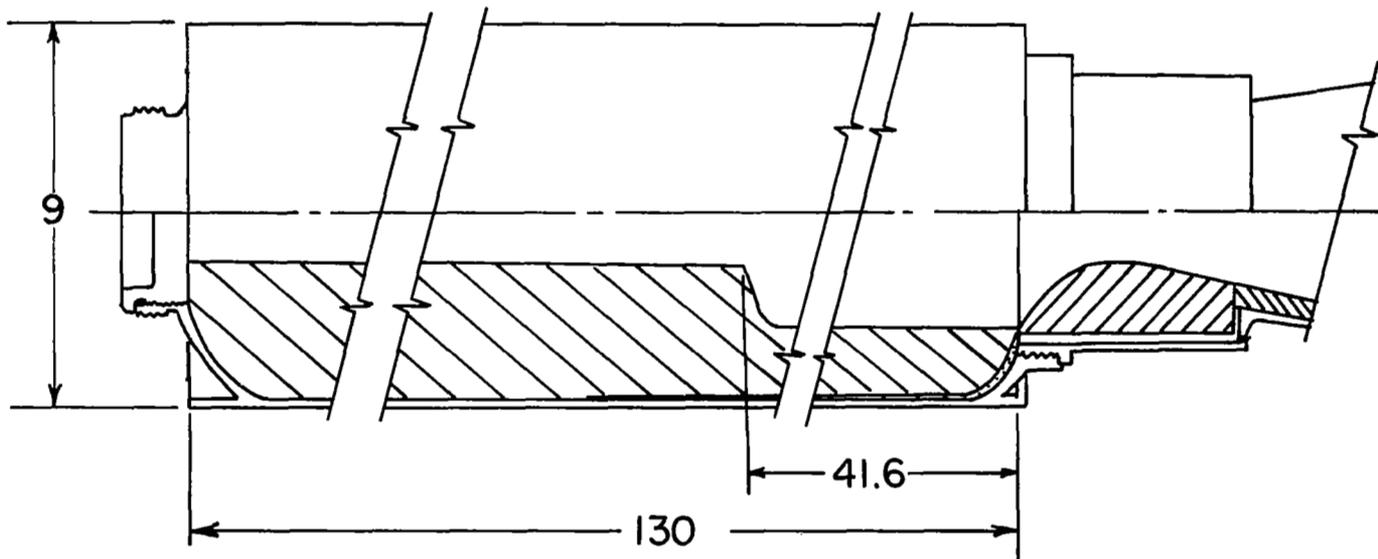
NASA

Figure 37.- UTC TM-3 rocket motor - series II.



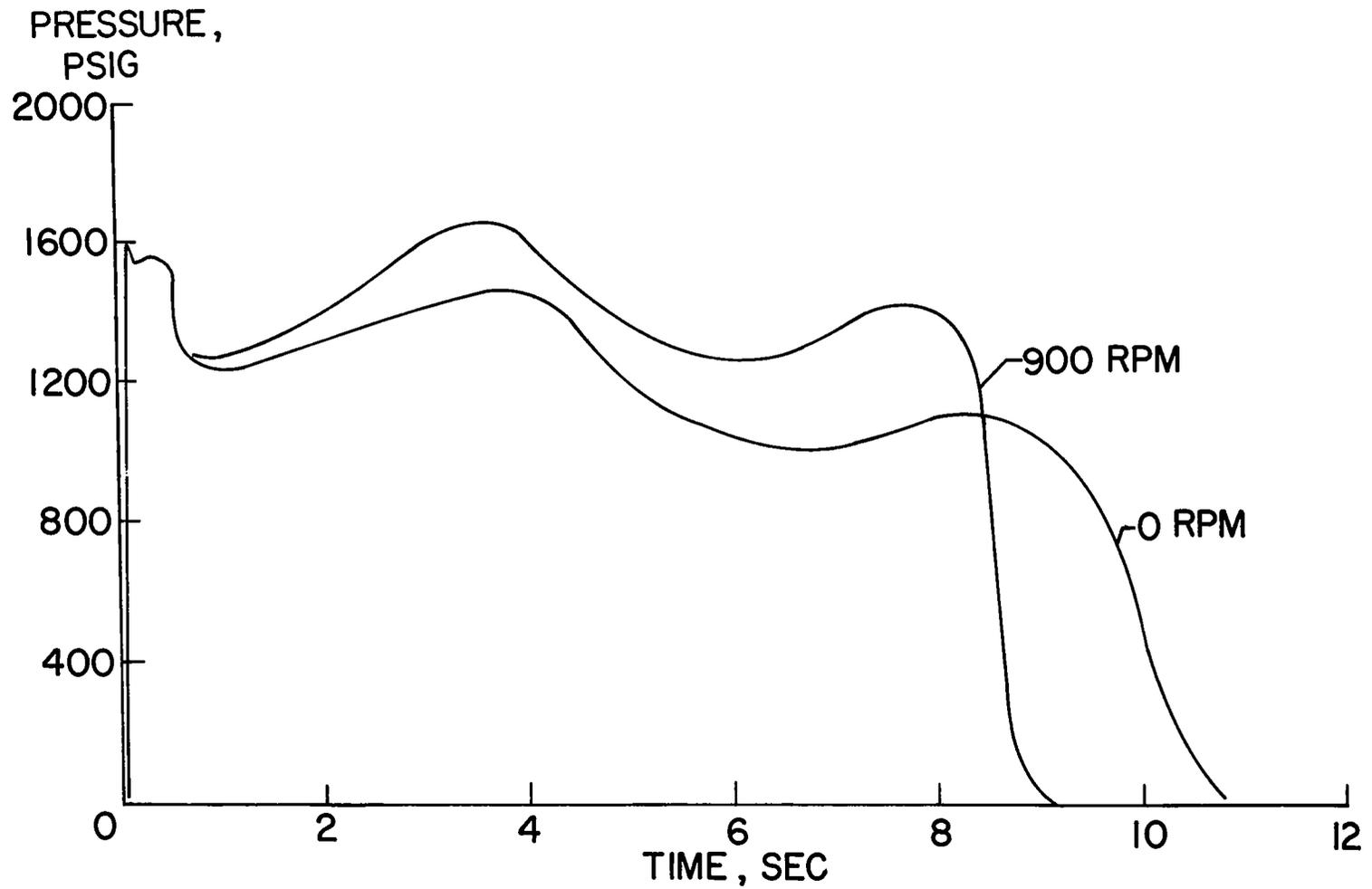
NASA

Figure 38.- UTC TM-3 spin-test 4.



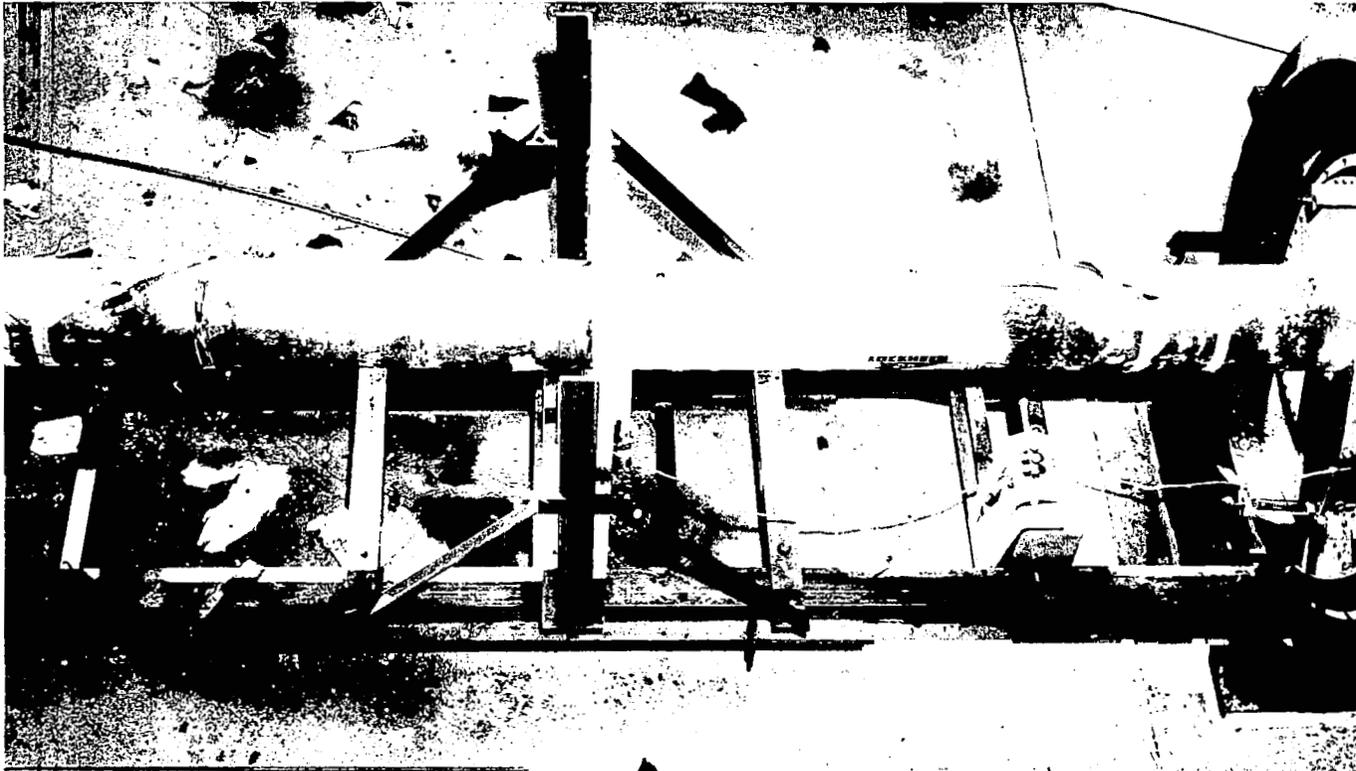
NASA

Figure 39.- HYDAC rocket motor.



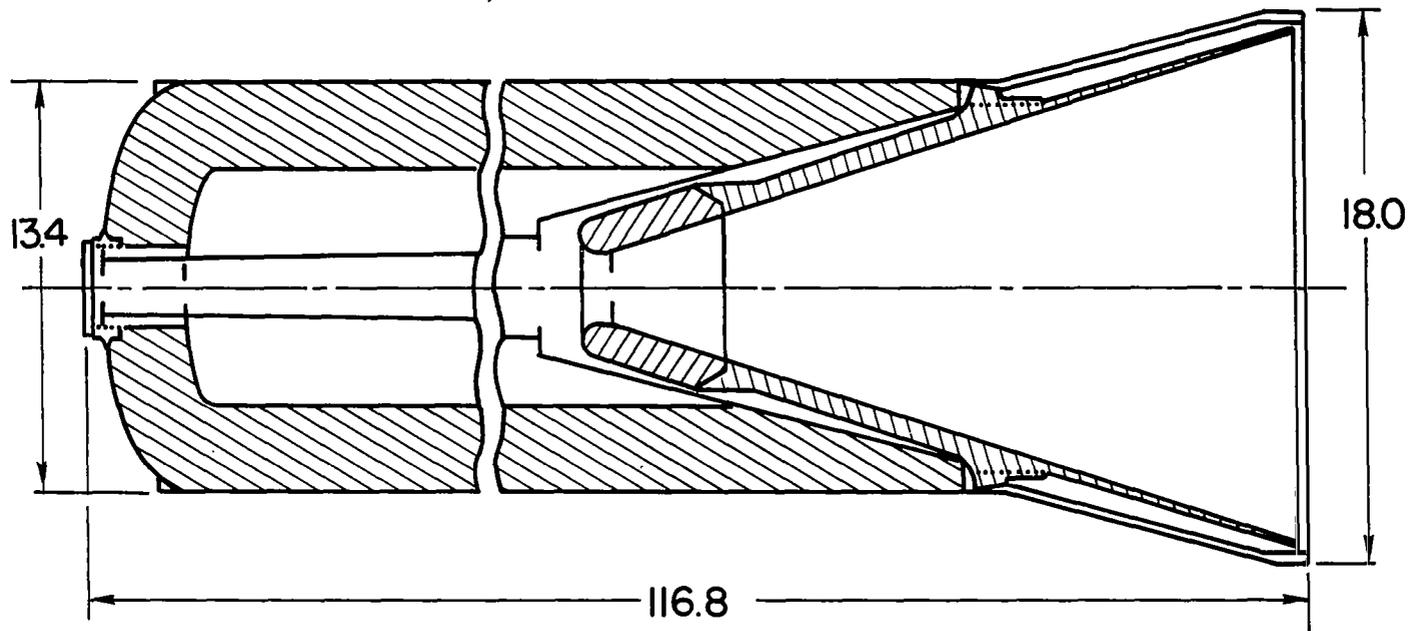
NASA

Figure 40.- Lockheed HYDAC spin test.



NASA

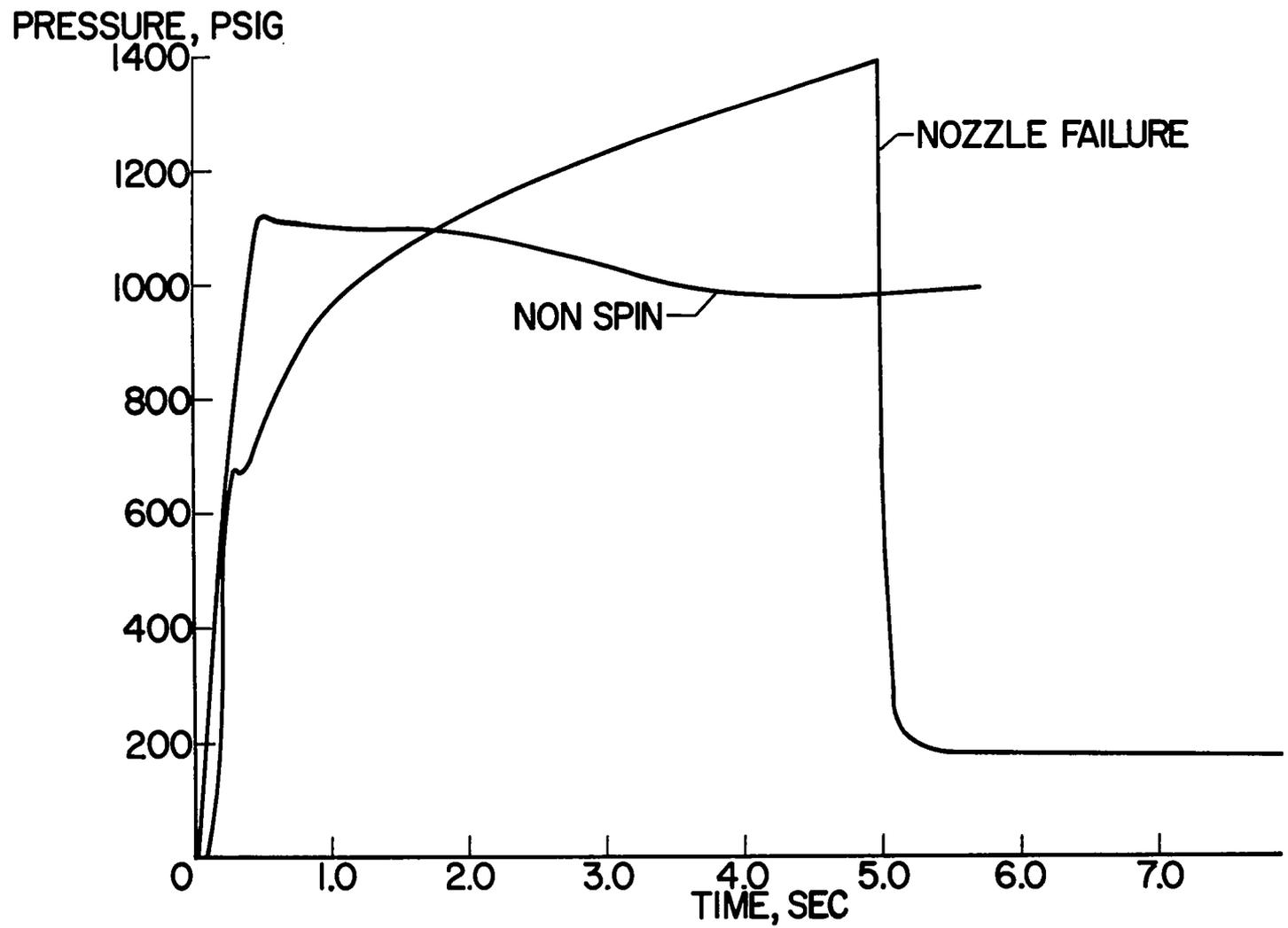
Figure 41.- Post-fire condition of HYDAC - 900 rpm - spin-test apparatus.



CASE : 4130 STEEL  
NOZZLE : PARTIALLY SUBMERGED : ATJ GRAPHITE  
INSULATION : EXTREME AFT END OF CHAMBER  
PROPELLANT : E-107M POLYURETHANE TYPE, 17.7% ALUMINUM

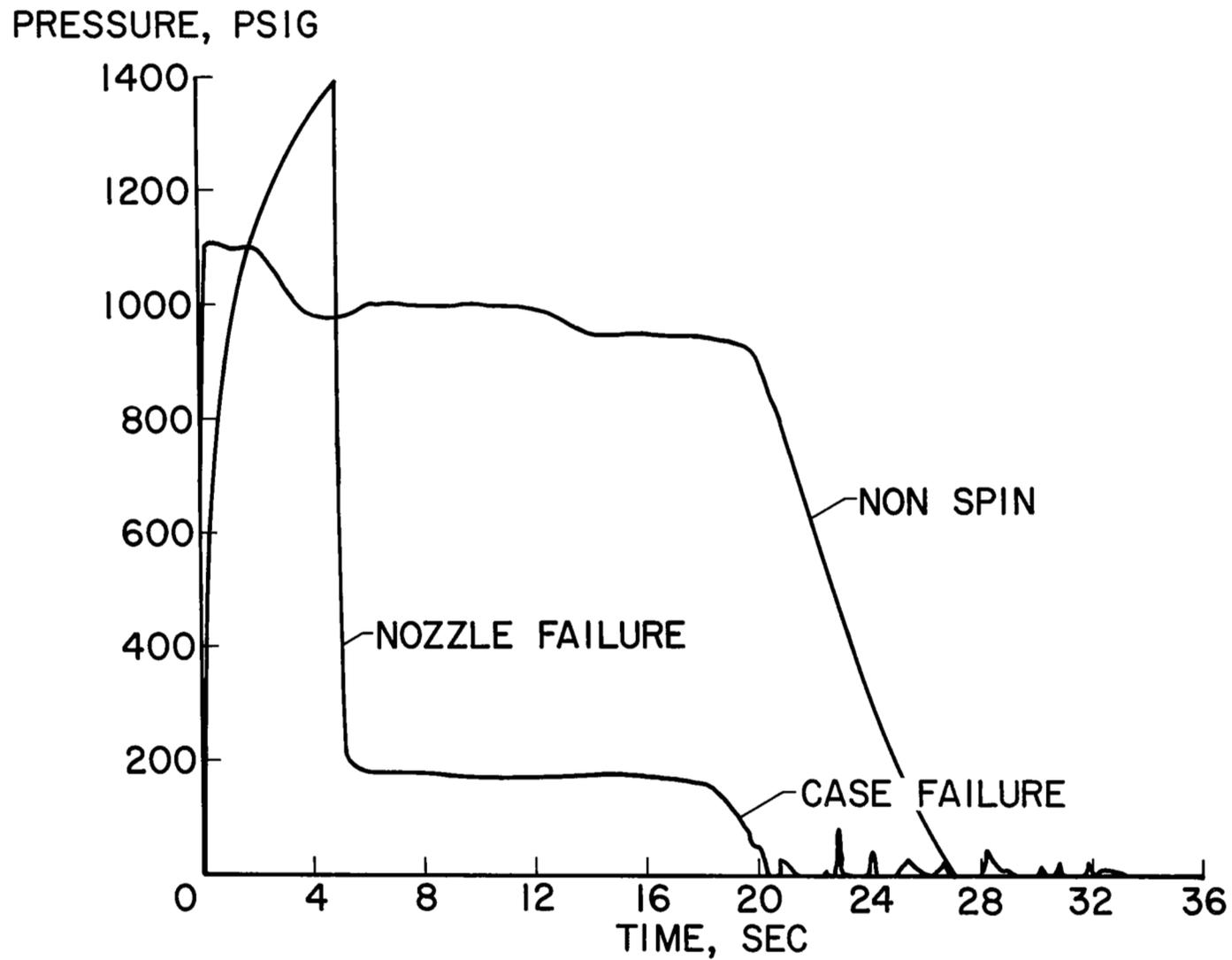
NASA

Figure 42.- NOTS - 551A rocket motor.



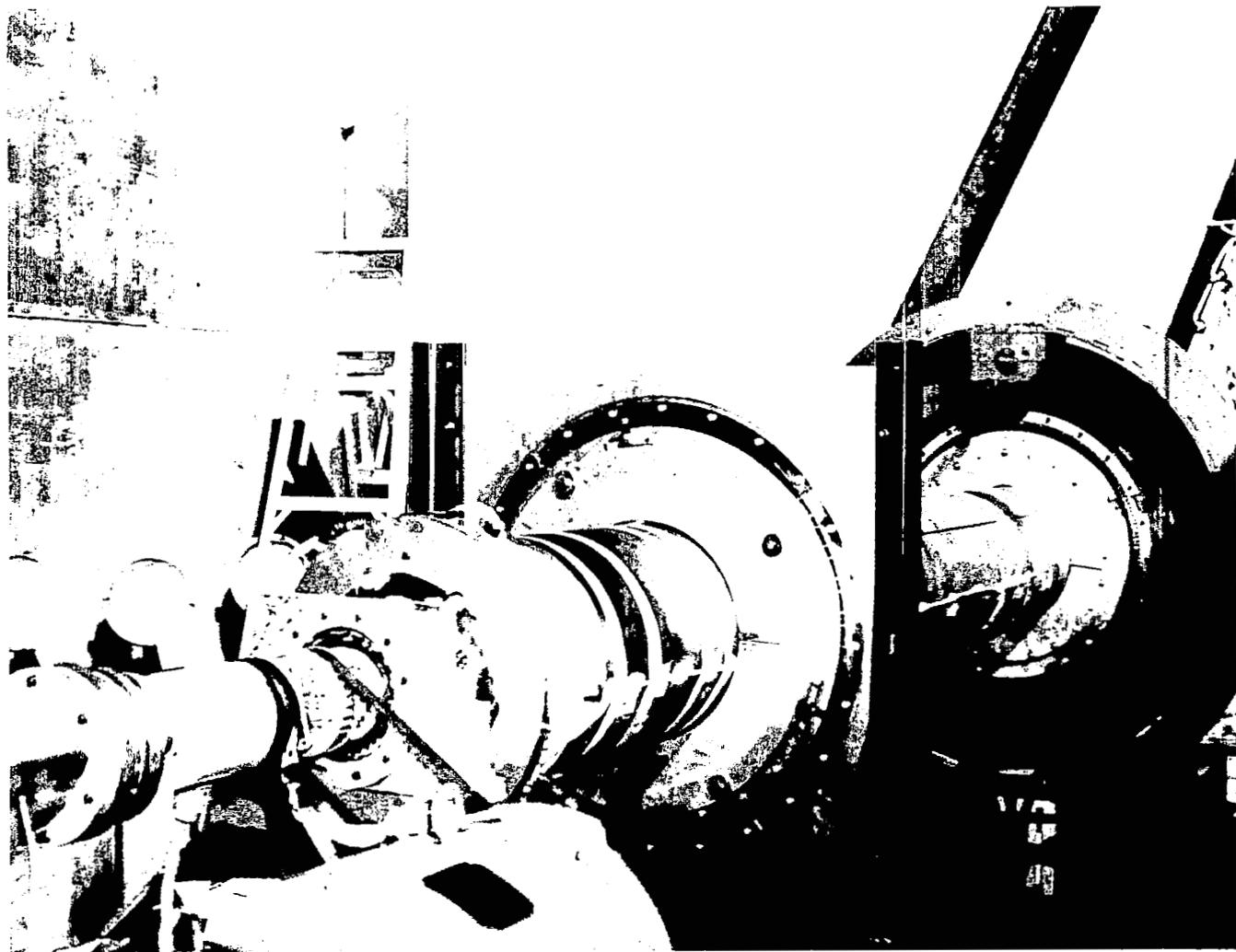
NASA

Figure 43.- NOTS 551 spin test at 480 rpm.



NASA

Figure 44.- NOTS 551 spin test at 480 rpm.



NASA

Figure 45.- Pre-fire condition of NOTS 551 - spin-test apparatus.

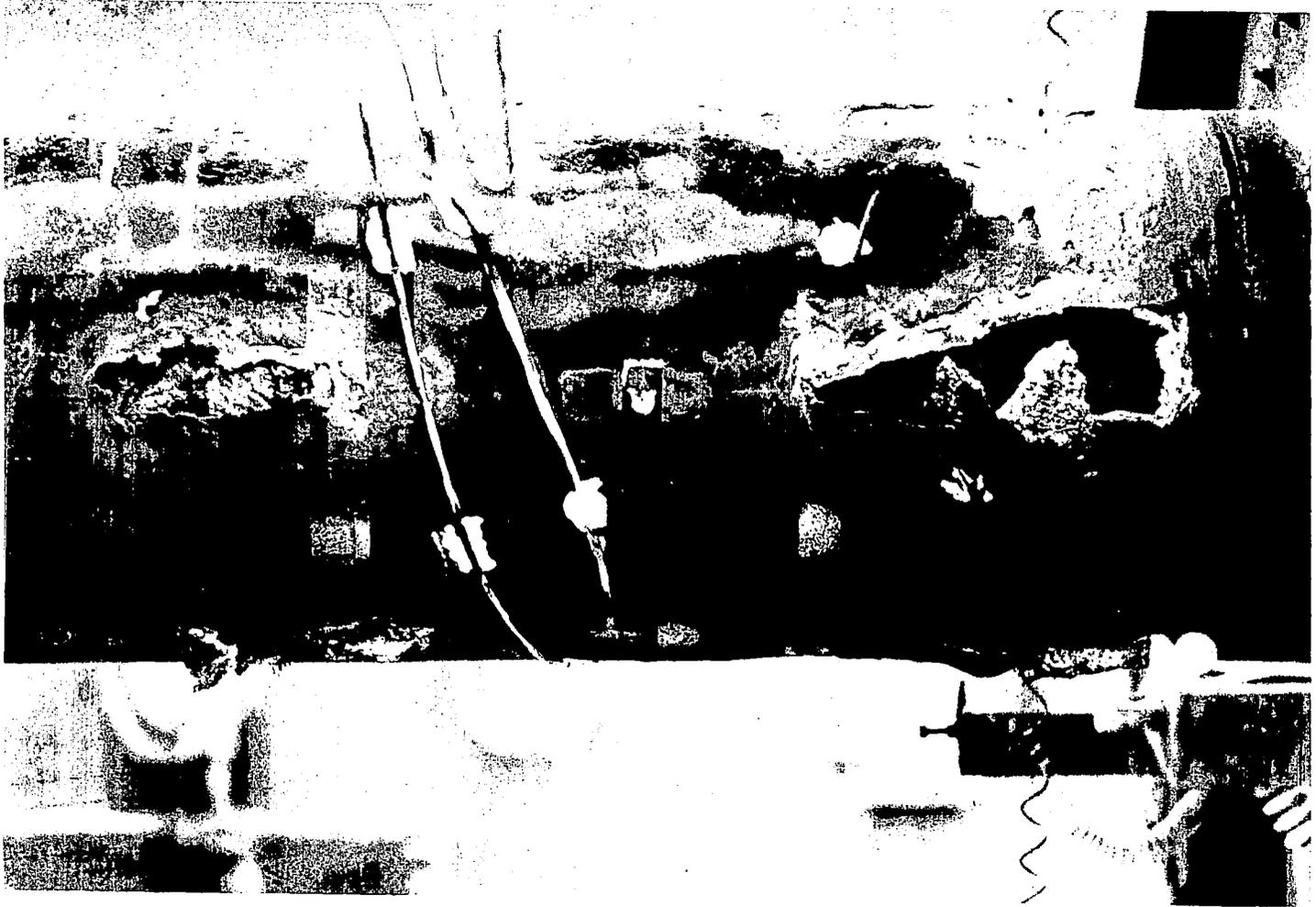


Figure 46.- NOTS 551 post-fire condition - 480 rpm.

NASA