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RESULTS OF TESTING UTC XSR 57-UT-1 SOLID-PROPELLANT ROCKET MOTORS UNDER THE COMBINED EFFECTS OF SIMULATED ALTITUDE AND ROTATIONAL SPIN (PRELIMINARY FLIGHT RATING TEST)

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ARO, Inc.

March 1965

ROCKET TEST FACILITY
ARNOLD ENGINEERING DEVELOPMENT CENTER
AIR FORCE SYSTEMS COMMAND
ARNOLD AIR FORCE STATION, TENNESSEE

NOTICES

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FOREWORD

The test program reported herein was conducted at the request of the Air Force Rocket Propulsion Laboratory (AFRPL) (RPMMS), Air Force Systems Command (AFSC), for the United Technology Center (UTC) under Program Element 62405184/3059.

The results of tests were obtained by ARO, Inc. (a subsidiary of Sverdrup and Parcel, Inc.), contract operator of the Arnold Engineering Development Center (AEDC), AFSC, Arnold Air Force Station, Tennessee, under Contract AF 40(600)-1000. The test was conducted in Propulsion Engine Test Cell (T-3) of the Rocket Test Facility (RTF) from December 8 to 15, 1964, under ARO Project No. RC0510, and the report was submitted by the author on February 11, 1965.

This technical report has been reviewed and is approved.

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ABSTRACT

Two UTC XSR 57-UT-1 solid-propellant rocket motors (S/N's 20002 and 20003) were fired at simulated altitude conditions while mounted in a spin fixture which rotated the motors about their axial centerlines at approximately 200 rpm. A third motor (S/N 20004) was fired in the no-spin mode after having been temperature-cycled between 35 and 105°F. This firing resulted in failure in the aft dome region 2.3 sec after ignition. The major program objectives were to determine motor ballistic performance and structural integrity. Vacuum specific impulse based on the manufacturer's stated propellant weight was 284.35 (S/N 20002) and 284.98 (S/N 20003) lb_f-sec/lb_m. Post-fire motor examination of motors S/N 20002 and S/N 20003 revealed that the uninsulated portion of each cylindrical chamber was charred, and the fiber glass filaments were essentially unbonded.

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SECTION I
INTRODUCTION

The United Technology Center (UTC) XSR 57-UT-1 rocket motor is being developed as the propulsion unit for the fourth stage of the Scout Launch Vehicle. Six Preliminary Flight Rating Tests (PFRT) of the XSR 57-UT-1 rocket motor were planned. The test series consisted of two sea-level, non-spin firings and one sea-level, 200-rpm spin firing at UTC plus one non-spin and two 200-rpm spin tests at AEDC. The AEDC testing was performed under simulated altitude conditions, and the test results are reported herein.

The primary objectives of the first two motor firings reported herein were to determine ballistic performance and structural integrity of the XSR 57-UT-1 motor under the combined effects of rotational spin and near vacuum environment. Similar objectives were established for a third firing which was conducted in the no-spin mode following temperature cycling between 35 and 105 ± 5°F. Secondary objectives were to measure thrust misalignment of the motors tested in the spin mode and to evaluate ignition characteristics for each motor under simulated altitude conditions.

The first two motors (S/N's 20002 and 20003) were fired at an average pressure altitude in excess of 97,000 ft while spinning at approximately 200 rpm about the motor axial centerline. The third motor (S/N 20004) was fired following temperature cycling in the no-spin mode at an initial pressure altitude of 111,000 ft.

SECTION II
APPARATUS

2.1 TEST ARTICLE

The UTC XSR 57-UT-1 flightweight solid-propellant rocket motor (Fig. 1) is 19.60 in. in outside diameter and 58.45 in. in overall length. The 40.38-in.-long chamber is a filament-wound glass fiber and epoxy resin structure with ovaloid forward and aft domes which incorporate integrally wound forward and aft adapters of high-strength aluminum. The domes terminate in aluminum polar bosses for igniter and nozzle installation. The chamber is filament-wound directly over a semi-destructible mandrel which supports forward and aft insulation of silica-loaded Buna-N rubber. The insulator is so constructed that the thickness in any particular region is proportional to the time that the insulator is exposed to propellant gases. The cylindrical section of the chamber is approximately 27 in. long and nominally 0.080-in. thick.

The nozzle assembly (Fig. 1a) consists of an ATJ graphite throat insert (area 4.086 in.^{2}) and an expansion cone comprised of high-silica phenolic backed with a steel shell to provide structural rigidity. A graphite cloth is bonded to the silica-phenolic covering an area from the graphite throat insert to an expansion ratio of 9:1. The nominal expansion ratio is 52.8:1, and the expansion cone half-angle is 20 deg. The nozzle assembly is attached to the motor case by mating flanges; the nozzle thrust axis is aligned with the motor centerline with a tolerance of 0.02 deg, nominal.

The loaded motor weighs approximately 650 lb_m, of which 600 lb_m is propellant. The composite propellant grain (UTP 309a) is a case-bonded, transversely slotted tube configuration (Fig. 1a). The grain configuration has a nominal port diameter of 4.1 in. forward of the transverse slot and a nominal port diameter of 4.2 in. aft of the slot. Nominal motor performance is: thrust 6000 lb_f, chamber pressure 720 psia, vacuum specific impulse 285 lb_f-sec/lb_m, and action time 31 sec.

Ignition was accomplished by an igniter (Fig. 2), which contained 0.16 lb_m of UTP 1095 propellant. The igniter incorporated one double-bridge wire SD60A-0, nominal 6-sec-delay squib which was used to ignite a 5.0-gm boron-potassium nitrate ($BKNO_3$) pellet charge, which in turn initiated burning within the igniter. The $BKNO_3$ pellets are held in position by a pellet retainer. Two squib ports were available; however, one port was used as an igniter pressure port. The igniter also contains two chamber pressure ports.

The motor did not contain a nozzle closure. Therefore, motor chamber pressure was equal to simulated altitude pressure at ignition.

2.2 INSTALLATION

The motors were installed in Propulsion Engine Test Cell (T-3)[1] in a spin fixture assembly mounted on a thrust cradle which was supported from the cradle support stand by three vertical and two horizontal double-flexure columns (Fig. 3). The spin fixture assembly consisted of a 10-hp

[1] Test Facilities Handbook, (5th Edition). "Rocket Test Facility, Vol. 2." Arnold Engineering Development Center, July 1963.

squirrel-cage-type drive motor, a forward thrust bearing assembly, a drive shaft and thrust pylon, and an aft bearing assembly. The spin fixture was locked in place for the test of motor S/N 20004 in the non-spin mode. Electrical leads to and from the igniter, pressure transducers, and thermocouples on the rotating motors (S/N's 20002 and 20003) were provided through two 52-channel, slip-ring assemblies mounted on the drive shaft. Axial thrust was transmitted through the drive shaft-thrust bearing assembly to two double-bridge load cells mounted just forward of the thrust bearing.

Pre-ignition pressure altitude conditions were maintained in the test cell by a steam ejector operating in series with the RTF exhaust compressors. During a motor firing, the motor exhaust gases were used as the driving gas for the 35.0-in.-diam, ejector-diffuser system to maintain test cell pressure at an acceptable level.

2.3 INSTRUMENTATION

Instrumentation was provided to measure axial thrust, test cell pressure, motor chamber pressure, igniter pressure, and motor case and nozzle temperatures. For motors S/N 20002 and 20003 which were fired in the spin mode, side force and motor rotational speed were also measured. Table I presents instrument ranges, recording methods, and system accuracies for all measured parameters.

The axial thrust measuring systems consisted of two double-bridge, strain-gage-type load cells mounted in the axial double-flexure column forward of the thrust bearing on the rocket motor centerline. The side force measuring system consisted of forward and aft double-bridge, strain-gage-type load cells installed between the flexure-mounted cradle and the cradle support stand normal to the rocket motor axial centerline and in the motor horizontal plane (Fig. 4). Unbonded strain-gage-type transducers were used to measure test cell pressure and low range (0 to 2 psia) chamber pressure (S/N 20002 only). Bonded strain-gage-type transducers in ranges of 0 to 100, 0 to 1000, and 0 to 3000 psi were used to measure motor chamber and igniter pressures. Iron-constantan (IC) thermocouples were bonded to the motor case and nozzle (Fig. 5) to measure outer surface temperatures during and after the motor burn time. Rotational speed of the motor and spin rig assembly was determined from the output of a magnetic pickup.

The output signal of each measuring device was recorded on independent instrumentation channels. Primary data were obtained from four axial thrust channels, two test cell pressure channels, one igniter pressure channel, and three motor chamber pressure channels (four channels for S/N 20002). These data were recorded as follows: Each instrument output signal was indicated in totalized digital form on a visual readout of a millivolt-to-frequency converter. A magnetic tape system, recording in frequency form, stored the signal from the converter for reduction at a later time by an electronic digital computer. The computer provided a tabulation of average absolute values for each 0.10-sec time increment and total integrals over the cumulative time increments.

The output signal from the magnetic rotational speed pickup was recorded in the following manner: A frequency-to-analog converter was triggered by the pulse output from the magnetic pickup and in turn supplied a square wave of constant amplitude to the electronic counter, magnetic tape, and oscillograph recorders. The scan sequence of the electronic counter was adjusted so that it displayed directly the motor spin rate in revolutions per minute.

The millivolt outputs of the thermocouples were recorded on magnetic tape from a multi-input, high-speed, analog-to-digital converter at a sampling rate for each thermocouple of 6.66 samples per second. The millivolt outputs of the side force load cells were recorded on magnetic tape from a multi-input, ultra-high-speed, analog-to-digital converter at a sampling rate for each thrust channel of 2400 samples per second.

A photographically recording, galvanometer-type oscillograph provided an independent backup of all operating instrumentation channels. Selected channels of thrust, pressures, and temperatures were recorded on null-balance, potentiometer-type strip charts for analysis immediately following a motor firing. Visual observation of the firing was provided by a closed-circuit television monitor. High-speed, motion-picture cameras provided a permanent visual record of the firings.

2.4 CALIBRATION

The thrust calibrator weights, thrust load cells, and pressure transducers were laboratory calibrated prior to usage in this test. After installation of the measuring devices in the test cell, all systems were again calibrated at sea-level ambient conditions. After 200-rpm rotative speed was attained for motors S/N 20002 and 20003 and just before each motor firing, all systems were again calibrated.

The pressure systems were calibrated by an electrical, four-step calibration, using resistances in the transducer circuits to simulate pressure levels. Thermocouples were calibrated by using known millivolt levels to simulate thermocouple outputs of 150, 640, and 965°F.

The axial thrust instrumentation systems were calibrated by applying to the thrust cradle known forces which were produced by the deadweights acting through a bell crank. The calibrator is hydraulically actuated and remotely operated from the control room. The side force instrumentation systems were calibrated by an electrical, four-step calibration, using resistances in the load cell circuits to simulate selected force levels.

After each motor firing, with the test cell still at simulated altitude pressure, the systems were again recalibrated to determine any shift in the systems.

SECTION III
PROCEDURE

The UTC XSR 57-UT-1 rocket motors arrived at AEDC on November 24 (two motors) and December 4, 1964 (one motor). The motors were visually inspected for possible shipping damage and radiographically inspected for grain cracks, voids, or separation and found to meet criteria provided by the manufacturer. During storage in an area temperature-conditioned at 75 ± 10°F, the motors were checked to ensure correct fit of mating hardware, the electrical resistance of the igniters was measured, the nozzle throat and exit diameters were obtained, thermocouples were bonded to the nozzle and motor case, and the entire motor assembly was weighed. Before installation in the test cell, motors S/N's 20002 and 20003 were temperature-conditioned at 75 ± 5°F for a minimum of 40 hr; motor S/N 20004 was temperature-conditioned at 35, 105, and 35 ± 5°F for a period of 40 hr at each temperature. The test cell temperature was maintained at 75 ± 5°F from the time of motor installation until ignition for motors S/N's 20002 and 20003; for motor S/N 20004, the test cell temperature was maintained at approximately 40°F. The time after removal of motor S/N 20004 from the temperature-conditioning unit until the motor was fired was 6 hr and 50 min.

After installation of the spin motors (S/N's 20002 and 20003) in the test cell, the motor centerlines were axially aligned with the thrust column centerline, the motors were balanced while spinning at 200 rpm (see Appendix), the initiators were installed in the igniters, and a continuity check of all electrical systems was performed. Like procedures, except motor balancing, were followed for the no-spin motor S/N 20004. Pre-fire, sea-level calibrations were completed, and the test cell pressure was reduced to the desired altitude condition. Altitude calibrations were taken at this time for motor S/N 20004. Spinning of units S/N's 20002 and 20003 was started, and after spinning had stabilized at 200 rpm, a complete set of altitude calibrations was taken.

The final operation prior to firing a motor was the adjustment of the circuit resistance and voltage to provide the desired current to the igniter squib. The entire instrumentation measuring-recording complex was activated, and the motors were fired, S/N's 20002 and 20003 spinning (under power) at 200 rpm and S/N 20004 in the no-spin mode. After motor burnout, the 200-rpm spin rate was continued for approximately 5 and 3 min for S/N's 20002 and 20003, respectively. Each spin unit was then decelerated slowly until rotation had stopped, and a complete set of calibrations was taken. Motor S/N 20004 failed during firing, which precluded the taking of post-fire calibrations for this unit. The test cell pressure was returned to ambient conditions, and the motors were inspected, photographed, and removed to the storage area. Post-fire inspections at the storage area consisted of measuring the throat and exit diameters of the nozzles, weighing the motors, and photographically recording the post-fire condition of the motors.

SECTION IV
RESULTS AND DISCUSSION

Two UTC XSR 57-UT-1 solid-propellant rocket motors (S/N's 20002 and 20003) were tested at simulated altitude conditions while rotating about their axial centerlines at average rotational speeds of 201 (S/N 20002) and 200 (S/N 20003) rpm. The primary test objectives were to determine ballistic performance and structural integrity of the XSR 57-UT-1 motor under the combined effects of rotational spin and near-vacuum environment. Secondary objectives were to determine extraneous thrust vector data and ignition characteristics under simulated altitude conditions.

One UTC XSR 57-UT-1 solid-propellant rocket motor (S/N 20004) was tested at simulated altitude conditions in the no-spin mode following temperature cycling between 35 and 105 ± 5°F. The test objective was to determine ballistic performance and structural integrity at near-vacuum conditions. The motor ignited and burned normally for 2.3 sec, at which time the motor case failed in the aft dome region near the nozzle.

Altitude ignition characteristics and structural integrity of the three motors are discussed. Altitude ballistic performance and extraneous thrust vector data from the two spin motors are discussed. Motor performance data are summarized in Table II. When more than one instrumentation channel was used to obtain values of a single parameter, the average value is discussed and used to calculate the data presented. Pre- and post-fire physical dimensions are summarized in Table III.

4.1 ALTITUDE IGNITION CHARACTERISTICS

The motors ignited at pressure altitudes in excess of 100,000 ft. An analog trace of a typical ignition event is shown in Fig. 6. Ignition delay times, defined as the time interval from application of ignition voltage to the time when chamber pressure had risen to 10 percent of maximum, were 6.14 (S/N 20002), 5.96 (S/N 20003), and 5.80 (S/N 20004) sec. The igniters contained only one nominal 6-sec-delay squib. Ignition rise times, defined as the time required for the chamber pressure to rise from 10 to 75 percent of maximum, were 0.04 sec for S/N 20002 and 0.05 sec for S/N 20003 and S/N 20004.

4.2 ALTITUDE BALLISTIC PERFORMANCE FOR MOTORS S/N's 20002 AND 20003 SPINNING AT 200 rpm

The variations of thrust, chamber pressure, and test cell pressure for each motor fired while spinning at 200 rpm are shown in Fig. 7. Action times (t_a), defined as beginning when chamber pressure has risen to 10 percent of maximum and ending when the pressure has fallen to 10 percent of maximum, were 31.0 (S/N 20002) and 31.3 (S/N 20003) sec. Maximum values of chamber pressure were 757 and 751 psia occurring at 9.8 and 10.1 sec following ignition for motors S/N's 20002 and 20003, respectively. Corresponding values of thrust at these times were 5933 and 5889 lb_f. Maximum values of thrust were 6053 and 5991 lb_f, occurring at 13.0 and 12.9 sec following ignition for motors S/N's 20002 and 20003, respectively. Corresponding values of chamber pressure at these times were 747 and 736 psia. This period of increasing thrust and decreasing chamber pressure is considered to have been caused by the excessive throat erosion (Table III) discussed in section 4.3. By comparing the slopes of the thrust and chamber pressure curves in Fig. 7, it is apparent that throat erosion continued beyond the above time periods to approximately 24 (S/N 20002) and 26 (S/N 20003) sec after ignition.

The variations of chamber pressure, measured with a 0- to 2-psia transducer, and test cell pressure during extended portion of tailoff for motor S/N 20002 are presented in Fig. 8a. Total burn time (t_s), defined as the time beginning when chamber pressure starts to rise and ending when chamber pressure becomes equal to test cell pressure, was 221 sec.

Since chamber pressure data measured with a 0- to 2-psia transducer were not obtained from motor S/N 20003, the following data analysis and comparison are made using low-range chamber pressure data obtained from 0- to 100-psia transducers. The variations of chamber pressure and cell pressure during tailoff for motors S/N's 20002 and 20003 are presented in Figs. 8b and c. Total burn times (t_s), were 65.0 (S/N 20002) and 66.2 (S/N 20003) sec.

Since the nozzle does not operate fully expanded at the low chamber pressure encountered during tailoff burning, the measured total impulse data during this period cannot be corrected to vacuum conditions by adding the product of cell pressure integral and nozzle exit area. Therefore, total burn time (t_s) was segmented (as shown in Fig. 9), and the method of determining vacuum impulse is described as follows: The time of exhaust nozzle flow breakdown (t_{bd}) was considered to have occurred simultaneously with the time of exhaust diffuser flow breakdown (as indicated by an increase in cell pressure). After this time, flow at the nozzle throat was considered to be at sonic velocity until the time at which the ratio of motor chamber pressure to cell pressure had decreased to a value of 1.3 (t_u, Fig. 9). Vacuum corrected total impulse data were then calculated from

$$I_{vac} = \int_0^{t_{bd}} F\,dt + A_{ex_{avg}} \int_0^{t_{bd}} P_{cell}\,dt + c_F\, A_{t_{post\text{-}fire}} \int_{t_{bd}}^{t_u} P_{ch}\,dt$$

where

F = measured thrust, lb_f

$A_{ex_{avg}}$ = average of pre- and post-fire nozzle exit area, in.^{2}

P_{cell} = measured cell pressure, psia

$A_{t_{post\text{-}fire}}$ = post-fire nozzle throat area, in.^{2}

P_{ch} = measured chamber pressure, psia

and

$$c_F = A_{t_{post\text{-}fire}} \frac{\int_{t_1}^{t_2} F\,dt}{\int_{t_1}^{t_2} P_{ch}\,dt}$$

where the time interval t_1 to t_2 is a one-second interval just prior to decrease in chamber pressure (27 to 28 sec, Fig. 6). The impulse accumulated between the time that the nozzle throat flow becomes subsonic (t_u) and the end of burn time (t_s) is considered negligible.

Vacuum-corrected total impulse calculated in the foregoing manner was 170,790 lb_f-sec for S/N 20002 and 170,680 lb_f-sec for S/N 20003.

Vacuum specific impulse, action time (t_a), time that nozzle flow becomes subsonic (t_u), and thrust coefficient for S/N's 20002 and 20003 are compared below. Identical methods of calculation were used to determine these values.

	Motor S/N 20002	Motor S/N 20003
Time after ignition that nozzle flow becomes subsonic (t_u), sec	62	61
Approximate altitude at which t_u occurs, ft	127,000	115,000
Vacuum specific impulse, lb_f-sec/lb_m (based on t_u and the manufacturer's stated propellant weight, w_p)	284.35	284.98
Action time (t_a), sec	31.0	31.3
Vacuum specific impulse, lb_f-sec/lb_m (based on t_a and w_p)	283.32	283.44
Thrust coefficient (based on t_a)	1.815	1.816

Post-fire examination of the internal motor cases showed deposits of products of combustion distributed around the cylindrical section. The products of combustion were removed and separated into what was apparently charred insulation and Al_2O_3. The Al_2O_3 was weighed, and it was determined that motor S/N 20002 had contained 2.16 lb_m and that motor S/N 20003 had contained 2.26 lb_m.

4.3 STRUCTURAL INTEGRITY OF MOTORS S/N's 20002 AND 20003

Motors S/N's 20002 and 20003 were tested while spinning at approximately 200 rpm. Both motors operated without incident for the entire burn time, withstanding maximum chamber pressures of 757 (S/N 20002) and 751 (S/N 20003) psia. The 200-rpm rotational speed was maintained for approximately 5 min (S/N 20002) and 3 min (S/N 20003) following burnout. Post-fire examination of the motors revealed that the uninsulated portion of each cylindrical chamber was charred externally and the fiber glass filaments were essentially unbonded (Fig. 10). The area of greatest thermal concentration appeared to be a 4-in.-wide band around the chamber extending from 21 to 25 in. aft of the forward adapter flange.

Motor case temperature variations at 0 and 270 deg (Fig. 5) are presented in Fig. 11. The maximum case temperatures, recorded on thermocouple T15 in the 0-deg position, were 548°F (S/N 20002) and 600°F (S/N 20003); these maximums occurred 210 sec after ignition for both motors. Thermocouple T15 was located 8.1 in. forward of the aft adapter flange on a portion of the motor case that was insulated by the aft insulator (Fig. 6).

Post-fire photographs of the nozzle expansion cones are shown in Fig. 12. The graphite nozzle throat inserts became unbonded and fell into the motor chamber during spinning following motor burnout (this also occurred during the sea-level spin firing at UTC). The graphite throat inserts were recovered, inspected, and both were found to have eroded (increased in area) approximately 22.5 percent from the pre-fire area (Table III). Temperature variations along the outer surface of the nozzle expansion cones are presented in Fig. 13. The maximum temperatures recorded on the nozzles were 890°F (S/N 20002) and 785°F (S/N 20003) and occurred approximately 110 and 140 sec, respectively, after ignition.

4.4 ALTITUDE IGNITION CHARACTERISTICS AND STRUCTURAL INTEGRITY FOR MOTOR S/N 20004

Motor S/N 20004 was subjected to a 1000-mile secondary road test enroute to AEDC from UTC. Upon receipt of the motor at AEDC, it was X-rayed and no discontinuities or separations were evident. The motor was then temperature-cycled at 35, 105, and 35 ±5°F for periods of 40 hr at each temperature. The motor was not X-rayed following temperature cycling. The motor was removed from the temperature-conditioning unit and tested in a temperature environment of approximately 40°F.

The motor ignited at a pressure altitude of 110,000 ft and burned normally for 2.3 sec, at which time the motor case failed in the aft dome region near the nozzle, thereby terminating propellant burning. The variations of thrust, chamber pressure, and test cell pressure during motor operation are shown in Fig. 14. The values of thrust and chamber pressure at the time of case failure were 5043 lb_f and 666 psia, respectively. These values were 0.2 percent lower (thrust) and 2 percent lower (chamber pressure) than the average thrust and chamber pressure of motors S/N's 20002 and 20003, at the same time in the firing cycle. Temperature data did not indicate any rise in surface temperature in the area where the failure occurred.

The motor reignited 6.9 sec after the initial ignition event and burned at low pressure (approximately 3 psia) for about 0.9 sec. Reignition occurred again at 16.9 sec after the initial ignition event, and the motor burned at a chamber pressure of approximately 2 psia for 4.3 sec, at which time chamber pressure suddenly increased to a level of 47 psia. Burning continued at a decreasing pressure level as the aft dome burned away until, at 212 sec from initial ignition, burning was extinguished with a water spray to prevent damage to the test cell. Post-fire examination of the motor showed that approximately 80 lb_m of unburned propellant remained in the case. A post-fire photograph of the motor is shown in Fig. 15.

4.5 EXTRANEOUS THRUST VECTOR MEASUREMENTS FOR MOTORS S/N's 20002 AND 20003

A secondary test objective for the two spin motors (S/N's 20002 and 20003) was to measure motor thrust misalignment. This objective was accomplished by measuring the total side force of the rotating motor as well as the axial thrust. The recorded side force data were treated to eliminate or correct for all test installation and/or electronic effects as outlined in the Appendix. The resultant data are presented in Fig. 16 as variations in the magnitude and angular direction of the extraneous thrust vector. Axial thrust and the angles (α) formed by the extraneous thrust vector and the axial thrust are also presented.

Maximum extraneous side thrust magnitudes of 17 lb_f (α = 10.4') and 23 lb_f (α = 15') occurred just prior to web burnout for S/N 20002 and S/N 20003, respectively. These data are considered to be accurate within ±2 lb_f. The angular positions of the thrust vectors were approximately 350 (S/N 20002) and 150 deg (S/N 20003) from motor top dead center, measured clockwise looking upstream.

SECTION V. SUMMARY OF RESULTS

Two UTC XSR 57-UT-1 solid-propellant rocket motors (S/N's 20002 and 20003) were tested to determine ballistic performance and structural integrity under the combined effects of rotational speed and near-vacuum environment. A secondary objective was to measure thrust misalignment. One UTC XSR 57-UT-1 motor (S/N 20004) was tested in the no-spin mode following temperature cycling to determine ballistic performance and structural integrity at near-vacuum conditions. Results are summarized as follows:

1. Motors S/N's 20002 and 20003 having been temperature-conditioned at 75 ± 5°F operated without incident (while spinning at 200 rpm), successfully withstanding maximum chamber pressures of 757 and 751 psia. Post-fire examination revealed that the uninsulated portion of each cylindrical chamber was charred and the fiber glass filaments were essentially unbonded. The area of greatest thermal concentration was a 4-in.-wide band around the chamber extending from 21 to 25 in. aft of the forward adapter flange.

2. Motor S/N 20004 was temperature-conditioned at 35, 105, and 35 ± 5°F for periods of 40 hr and fired in the no-spin mode at 35°F. The motor ignited and burned normally for 2.3 sec, at which time the motor case failed in the aft dome region near the nozzle, thereby terminating propellant burning. Values of thrust and chamber pressure at the time of failure were 5043 lb_f and 666 psia. Temperature data did not indicate any rise in surface temperature in the area where the failure occurred. Reignition occurred at 16.9 sec after initial ignition, and the motor was allowed to burn until 212 sec following initial ignition when burning was stopped by quenching with a water spray. Post-fire examination revealed that approximately 80 lb_m of unburned propellant remained in the case and that the aft dome area was burned away.

3. Performance characteristics for S/N 20002 and S/N 20003, respectively, are:

   a. Action times were 31.0 and 31.3 sec. Total burn times (zero to zero thrust) were approximately 65 and 66 sec.

   b. Vacuum total impulse values were 170,790 and 170,680 lb_f-sec. Vacuum specific impulse values based on the manufacturer's stated propellant weight were 284.35 and 284.98 lb_f-sec/lb_m.

   c. Thrust coefficients based on action time and average pre- and post-fire throat areas were 1.815 and 1.816.

4. Ignition characteristics for S/N 20002, S/N 20003, and S/N 20004, respectively, are:

   a. Time intervals from application of ignition voltage to the time when chamber pressure has risen to 10 percent of maximum were 6.14, 5.96, and 5.80 sec.

   b. The times required for chamber pressure to rise from 10 to 75 percent of maximum were 0.04, 0.05, and 0.05 sec.

5. The maximum motor case temperatures recorded were 548°F (S/N 20002) and 600°F (S/N 20003); both maxima occurring 210 sec after ignition.

6. The nozzle throat inserts eroded from a pre-fire area of 4.086 in.^{2} to post-fire area of 5.007 (S/N 20002) and 5.003 (S/N 20003) in.^{2}, increases of 22.54 and 22.44 percent, respectively.

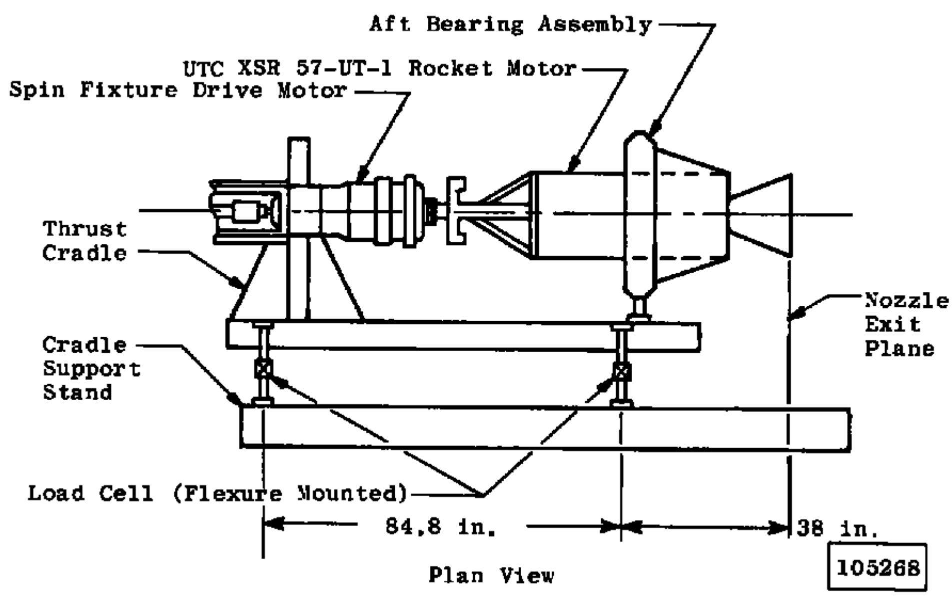
7. Maximum extraneous thrust magnitudes of 17 lb_f (S/N 20002) and 23 lb_f (S/N 20003) occurred just prior to web burnout. The angular positions of the thrust vectors were approximately 350 and 150 deg from motor top dead center, measured clockwise looking upstream. The angles formed by the axial thrust and the extraneous thrust vector, when the extraneous thrust magnitudes were maximum, were 10.4 and 15.0 min for motors S/N 20002 and S/N 20003, respectively.

APPENDIX
EXTRANEOUS THRUST VECTOR DATA ACQUISITION AND REDUCTION

Determination of non-axial components of solid-propellant rocket motor thrust vectors has, in the past, been accomplished with a six-component thrust stand. The complexities inherent in this system (motor weight change, thrust stand interactions, motor CG changes, test cell vibration) make it difficult to obtain an accurate determination of non-axial thrust vector. Consequently, a method has been devised whereby the magnitude and angular location of an extraneous thrust vector can be determined by measuring only forward and aft side forces in the motor horizontal plane while rotating the test motor about the axial centerline. Such a method allows determination of the extraneous thrust vector independent of motor gravitational effects and thrust stand interaction effects. This method is described in the following sections.

INSTALLATION AND INSTRUMENTATION

The motor spin fixture was mounted on the thrust cradle with the spin axis axially aligned with the axial thrust column centerline. Forward and aft side load cells (0 to 200 lb_f) were mounted in the plane of the spin fixture horizontal centerline, as shown below:



The motor was installed in the spin fixture and motor centerline eccentricity determined by measuring the runout of the forward and aft motor mounting adapters. The motor centerline was defined as the line passing through the center of the forward and aft mounting flanges which were designed for concentricity within ±0. 001 in. The motor mounting adapters were press-fit onto the mounting flanges and also designed for concentricity within ±0. 001 in. Centerline eccentricity was determined to be 0. 007 in. A calculated error resulting from this eccentricity and assuming a 6000 lb_f axial thrust load was ±0. 5 lb_f.

After motor alignment, the motor was balanced to a degree where total side force produced by motor unbalance, while spinning at 200 rpm, was less than 5 lb_f.

CALIBRATION AND DATA REDUCTION

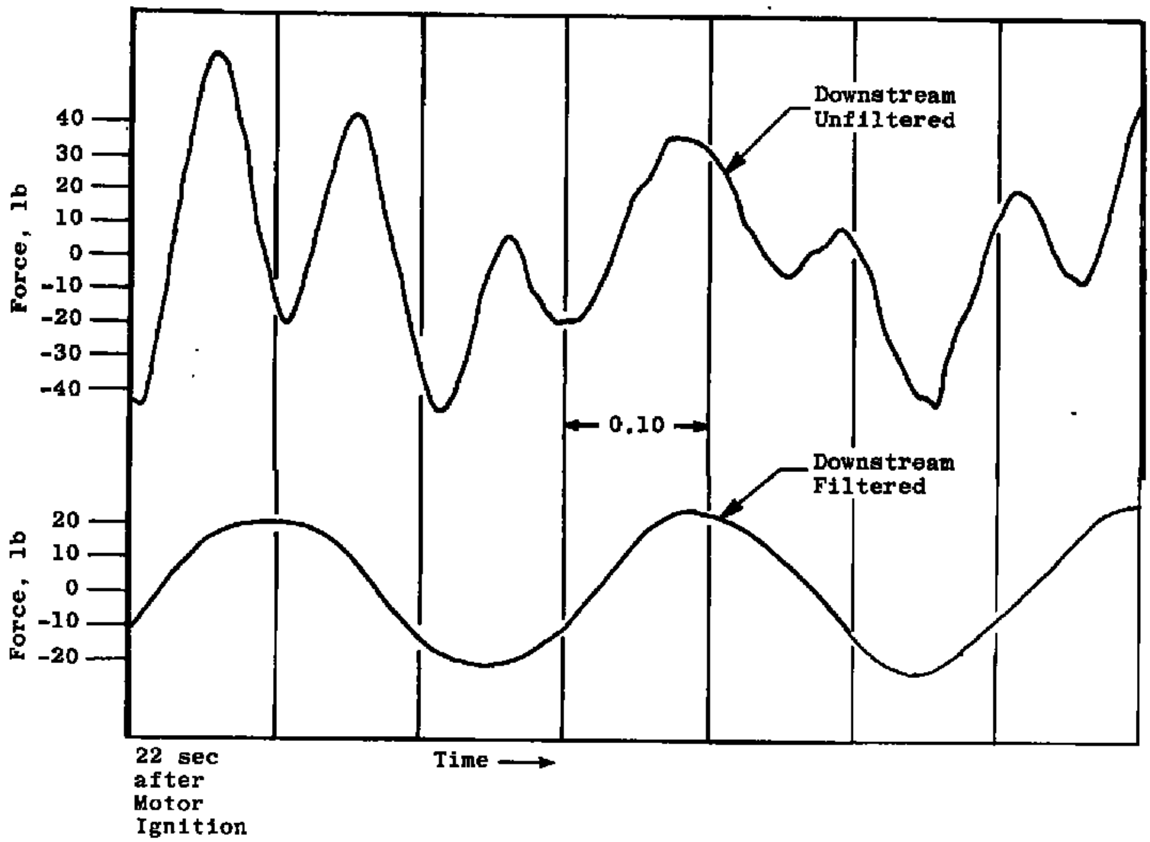
A pre-test calibration of the side force measuring system was conducted at sea-level conditions by applying known side forces to the thrust cradle perpendicular to the axial thrust column with and without an axial load of 4800 lb_f applied to the cradle. The sum of the measured side loads deviated less than 1. 2 lb_f from the applied side force (in the range of interest), and the side force data measured during motor test were corrected accordingly. An electrical resistance calibration of the side load cells was accomplished at simulated altitude conditions prior to motor firing.

The outputs of the side load cells were recorded before, during, and after the motor firing, with the motor spinning at 200 rpm. The resultant extraneous thrust vector produced by the motor firing approximated a sine wave composed of the following vectors:

1. Force resulting from the eccentricity of the motor centerline.
2. Centrifugal force produced by unbalance of the spinning mass.
3. Force produced by basic motor thrust misalignment.

Superimposed on these data were cell vibrations at frequencies above the rotational frequency.

During the pre- and post-fire spin periods, only item 2 produced the sine wave output of the side force system. The side force data were electronically filtered to remove all frequencies above the rotational frequency and recorded on magnetic tape in frequency modulated form and also on an oscillograph. A typical oscillograph recording of filtered and unfiltered side force data is presented in the following figure.



Filtered and Unfiltered Side Force Data

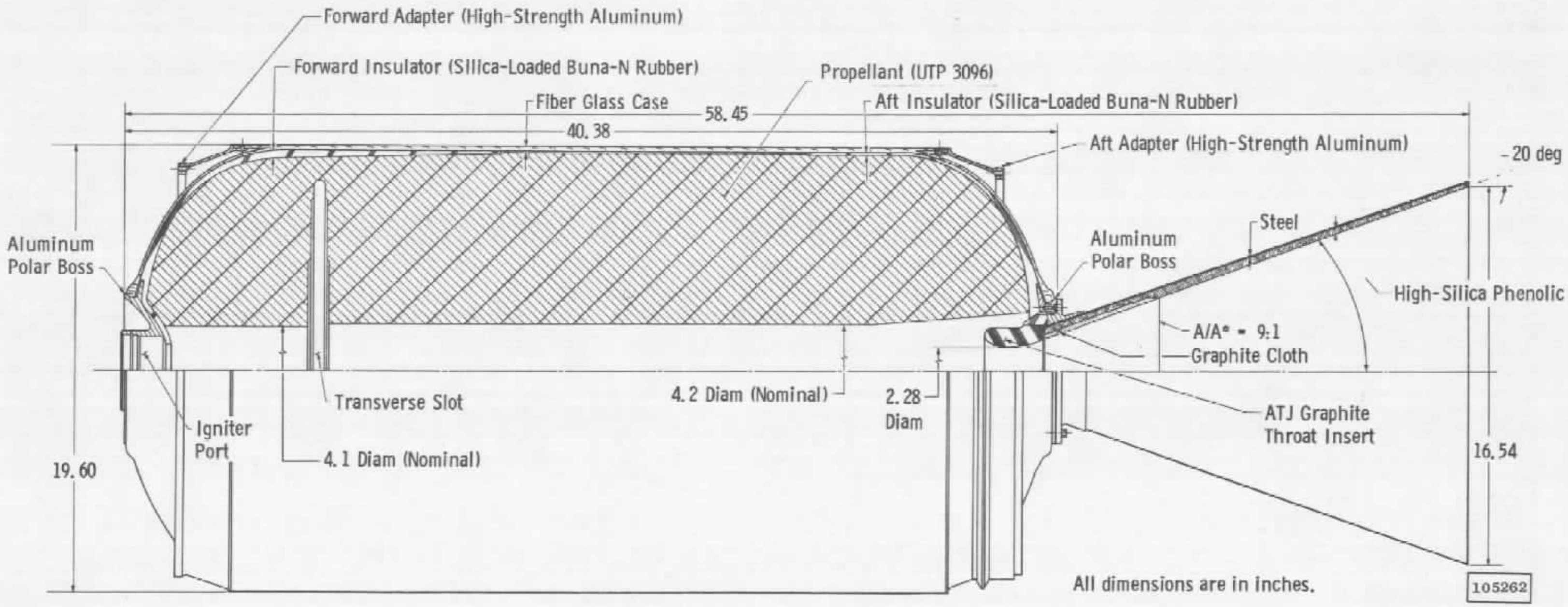
The magnetic tape data were reduced on a time-correlated basis by an electronic digital computer. The reduced data presented in Fig. 16 of this report were corrected for the following:

1. Amplitude ratio and phase lag, which were determined by comparing a filtered and unfiltered sinusoidal signal (3.33 cps) produced by an oscillator.

2. The forced vibration magnification factor of the thrust stand- load cell system which was determined during pre-fire calibrations by applying a known unbalance to the installation, calculating the centrifugal force which would be produced by this unbalance at 200 rpm, and dividing this force by the measured force.

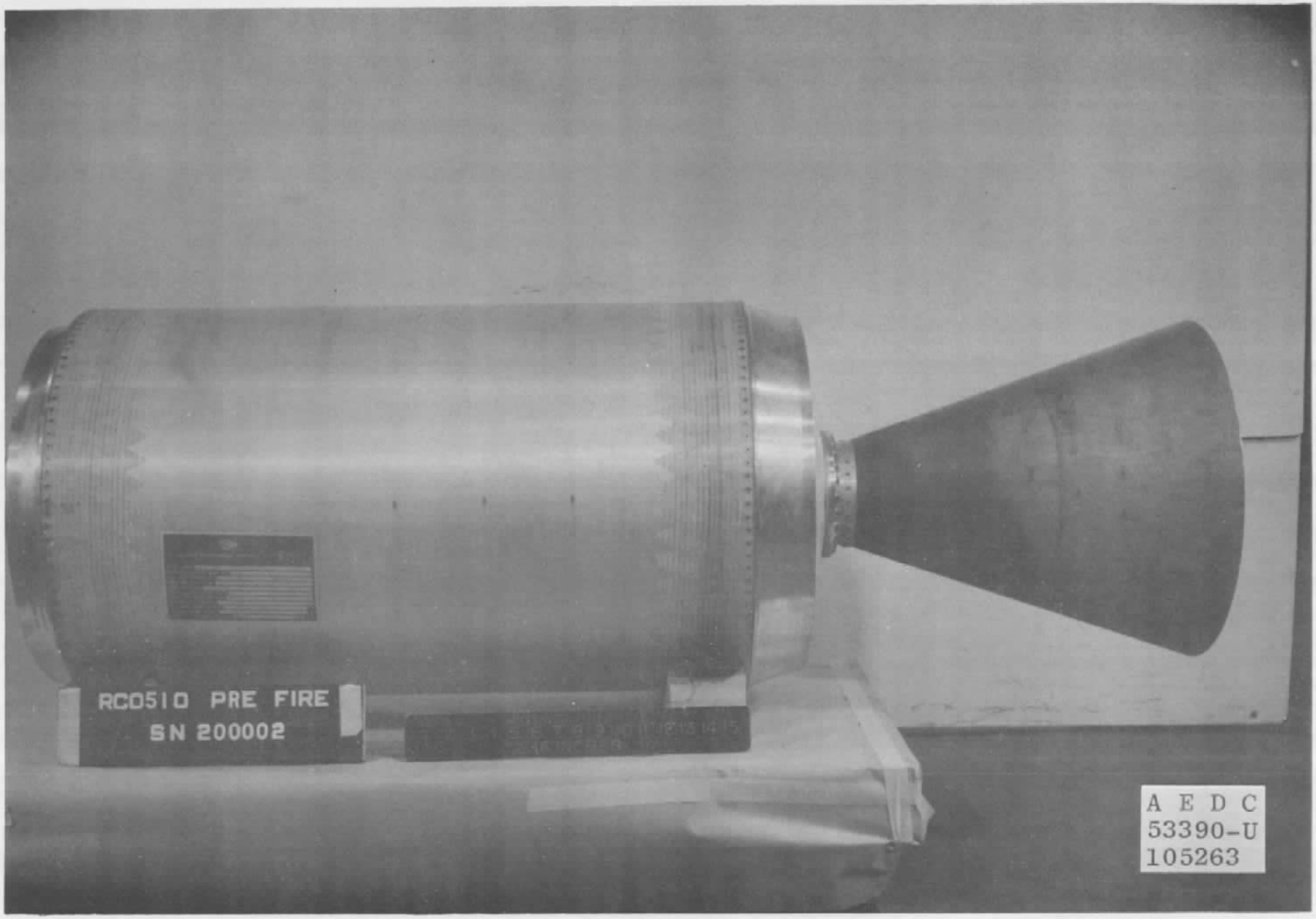
3. Tare of the thrust stand, which was determined as a ratio of force applied to the thrust cradle perpendicular to the axial thrust column to the algebraic sum of the forces measured by the two side load cells.

4. The centrifugal force, which was produced by motor and system unbalance. Measured side forces during firing were corrected by assuming that the magnitude and direction of the unbalance vector varied linearly with time.



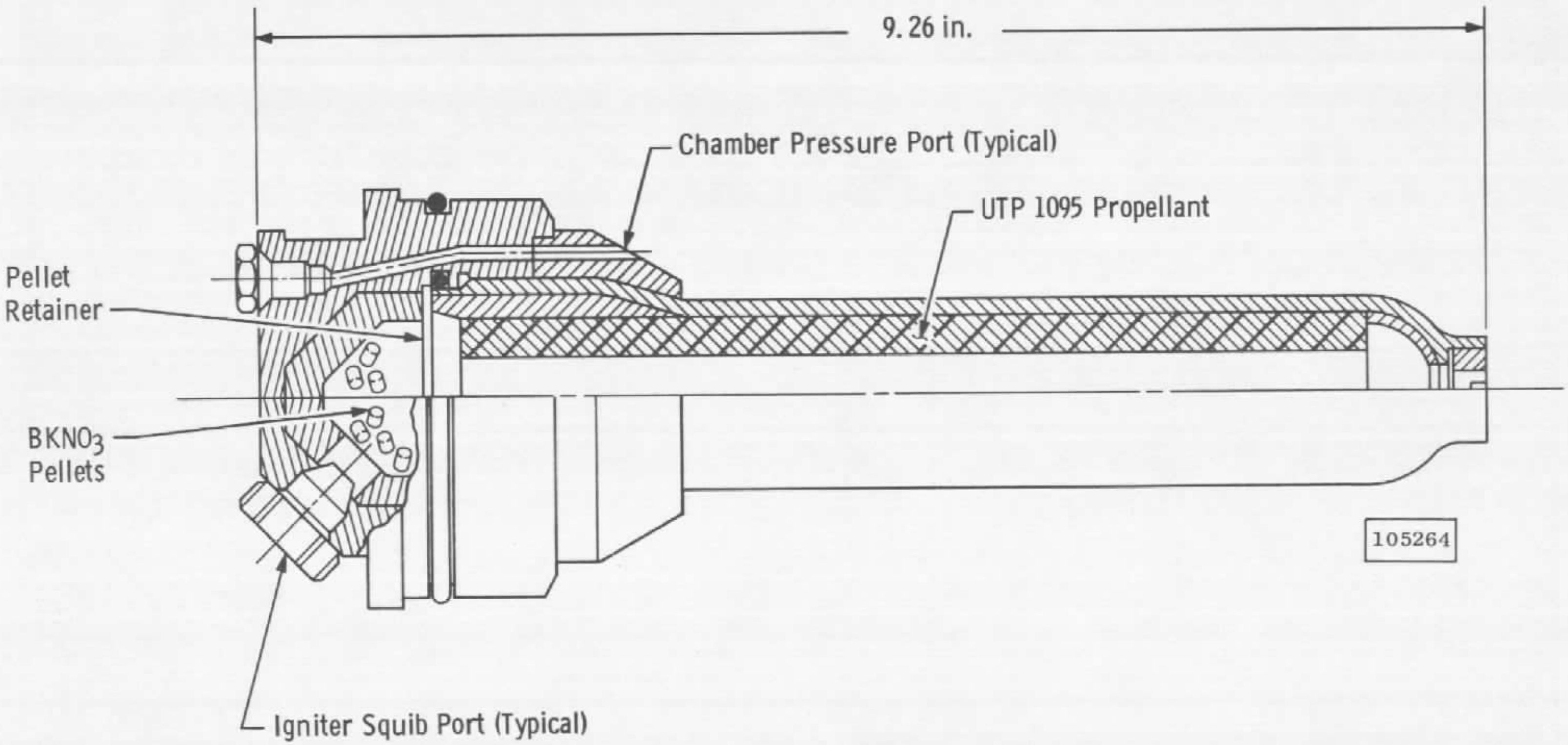
a. Schematic

Fig. 1 United Technology Center XSR 57-UT-1 Rocket Motor



b. Photograph

Fig. 1 Concluded

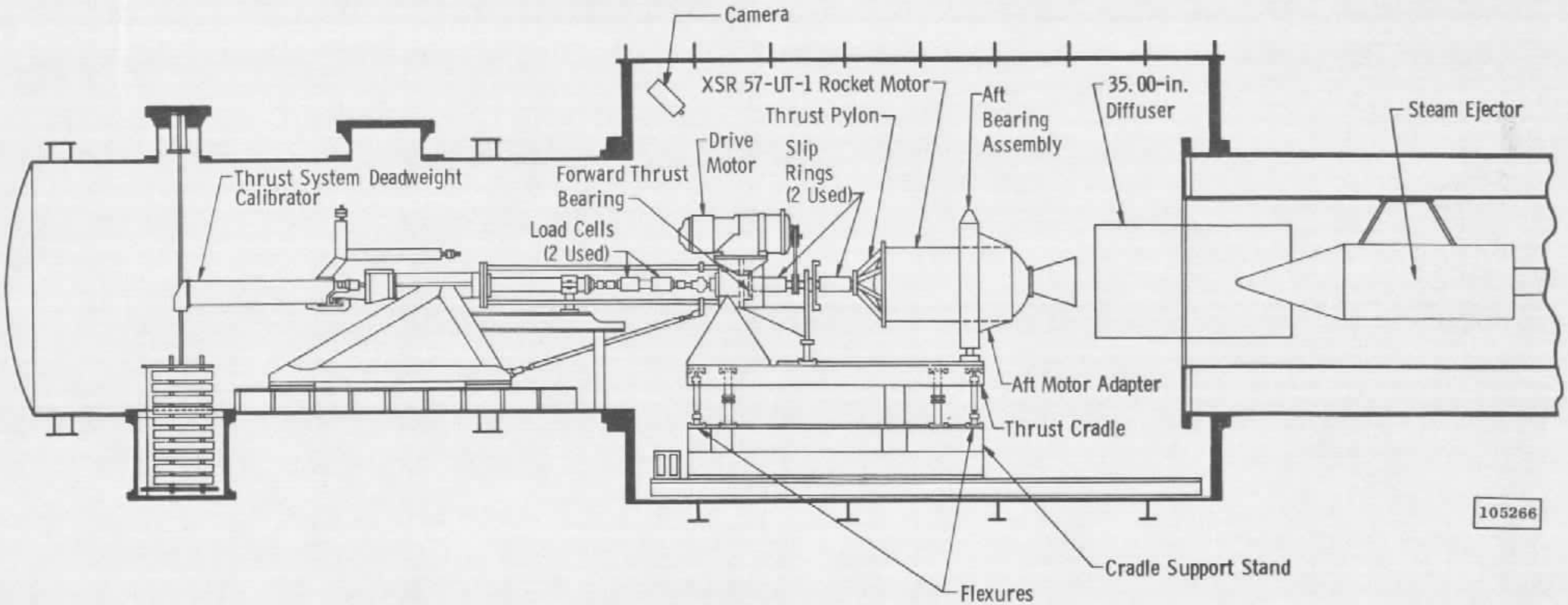


a. Schematic

Fig. 2 XSR 57-UT-1 Igniter

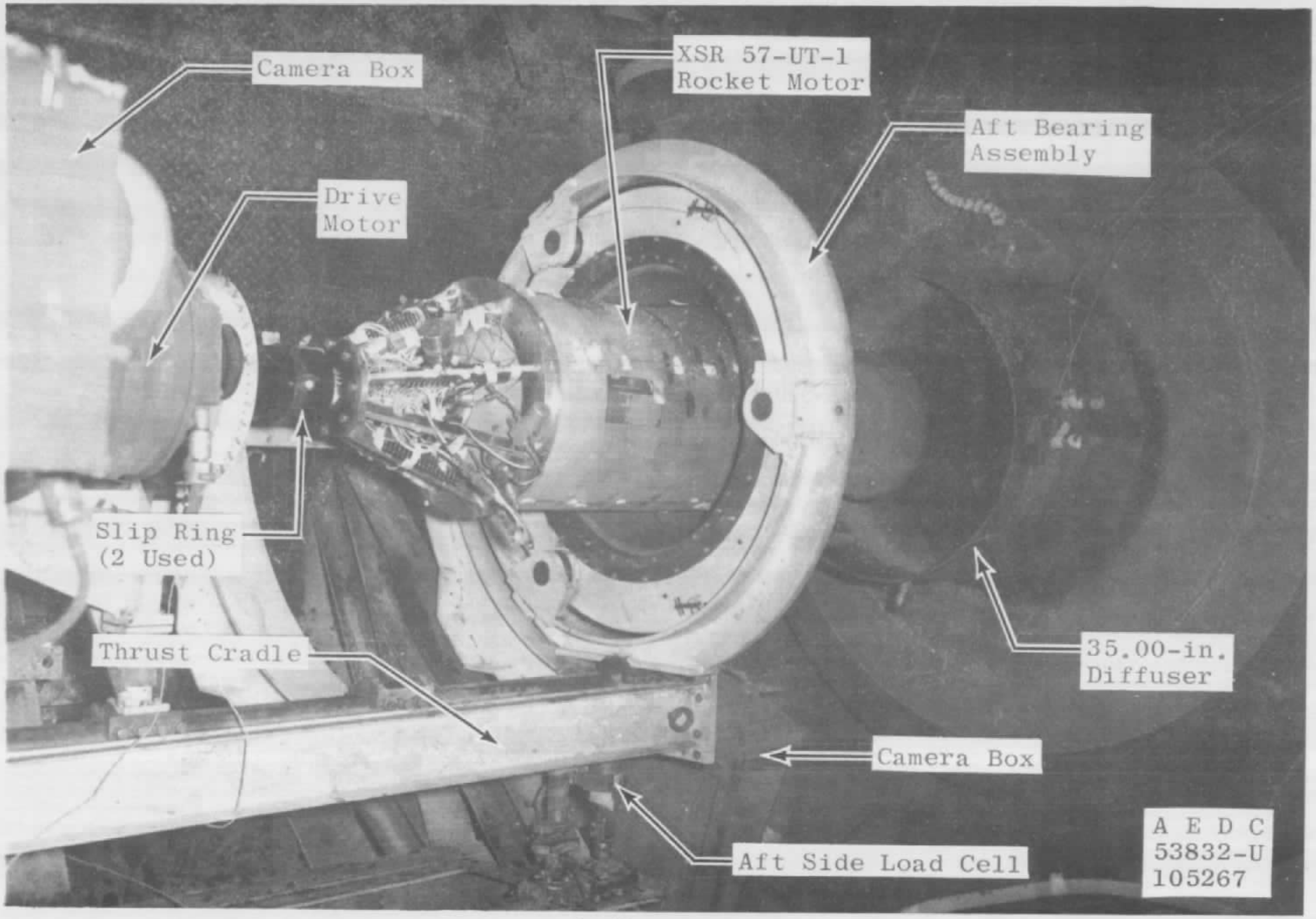
b. Photograph

Fig. 2 Concluded



a. Schematic

Fig. 3 Installation of XSR 57-UT-1 Motor and Spin Assembly in Propulsion Engine Test Cell (T-3)



b. Photograph

Fig. 3 Concluded

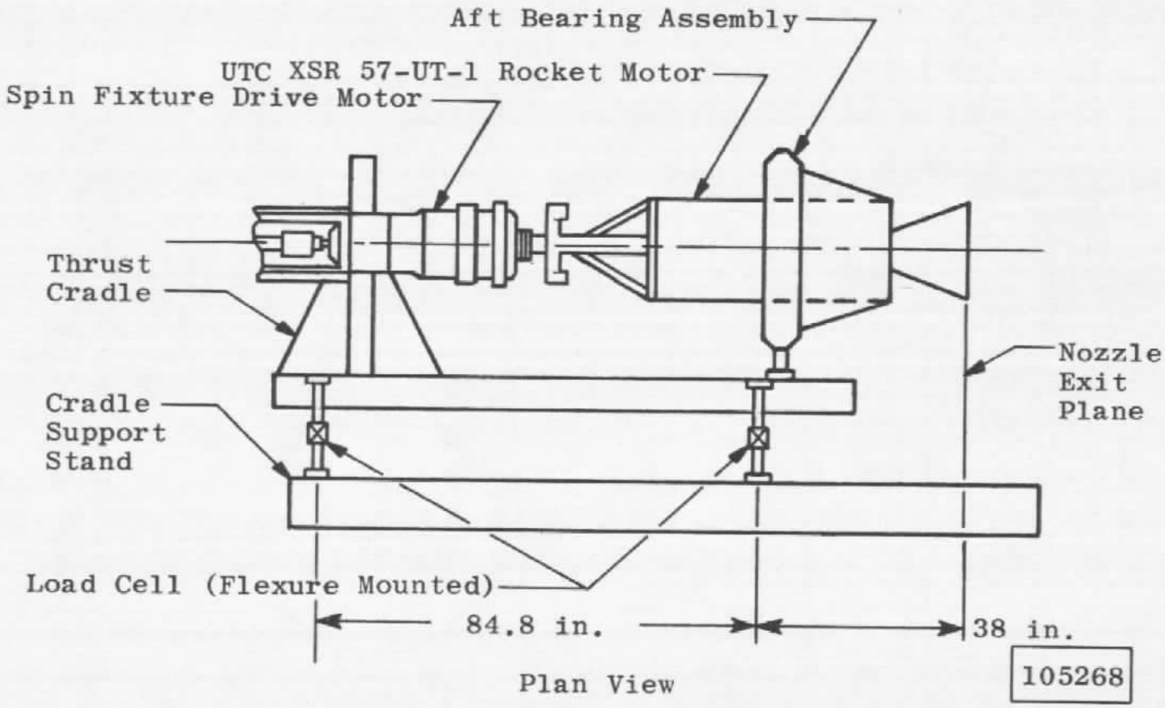


Fig. 4 Schematic Showing Side Force Measuring System

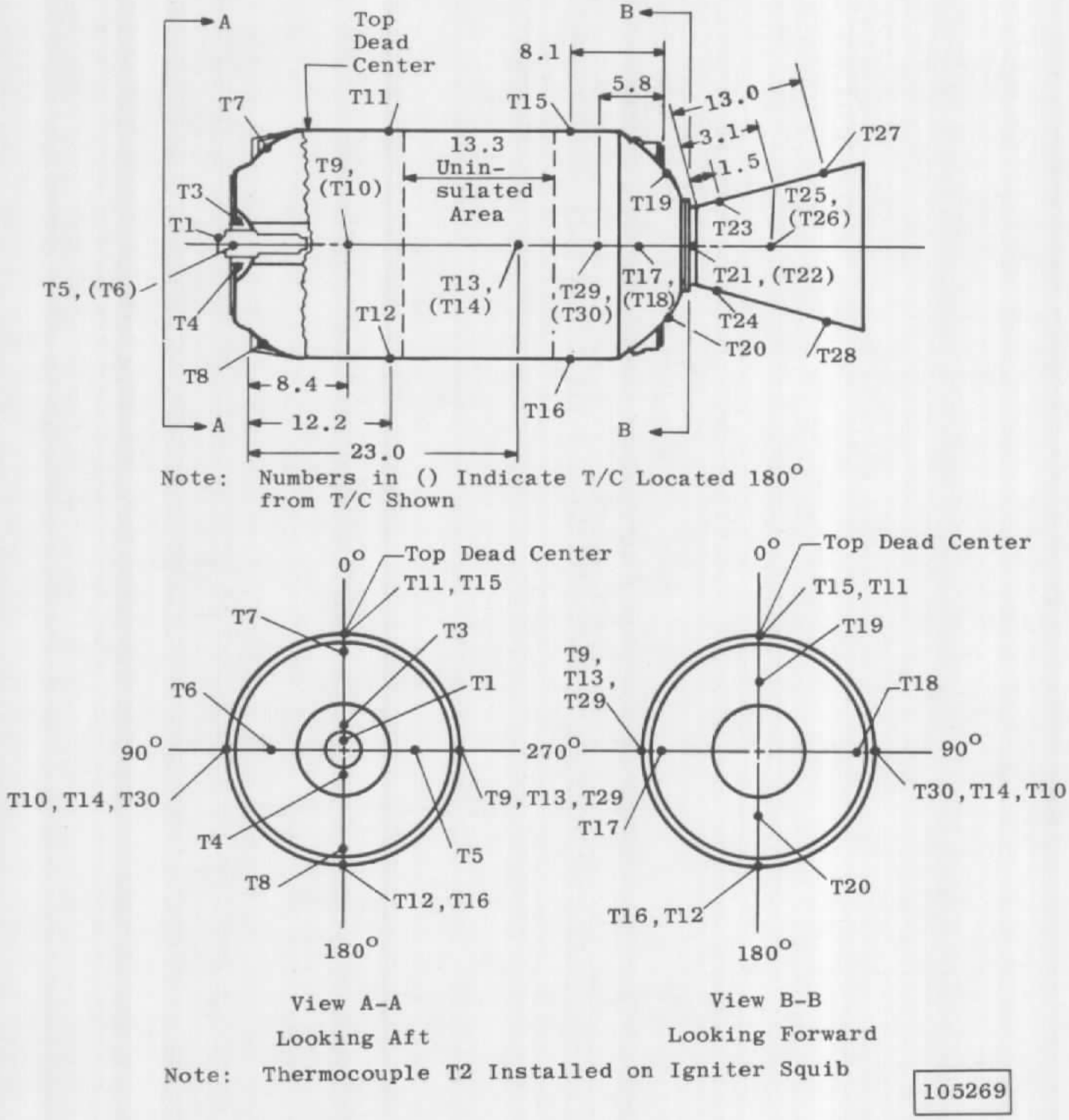
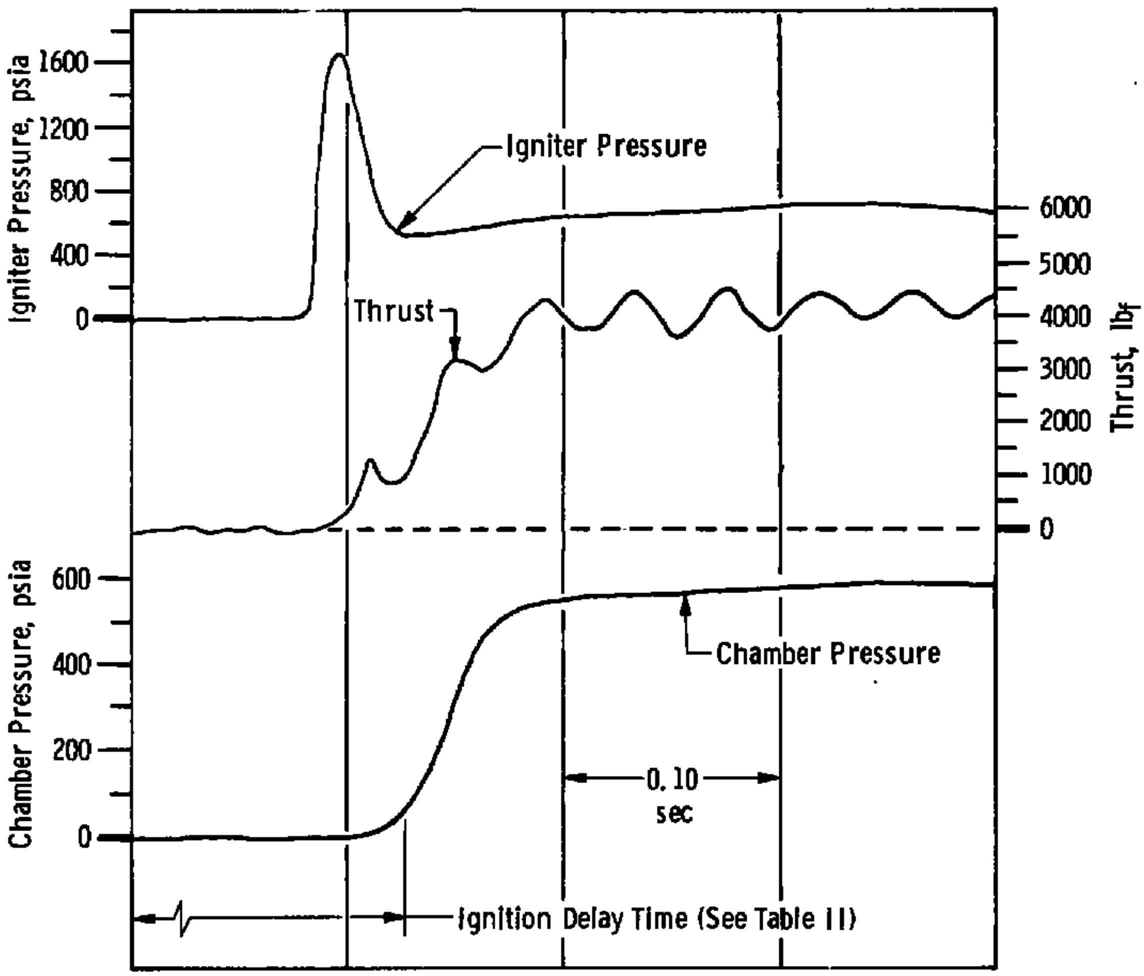


Fig. 5 Schematic Showing Thermocouple Locations



Note: Ignition delay time is measured from application of ignition current.

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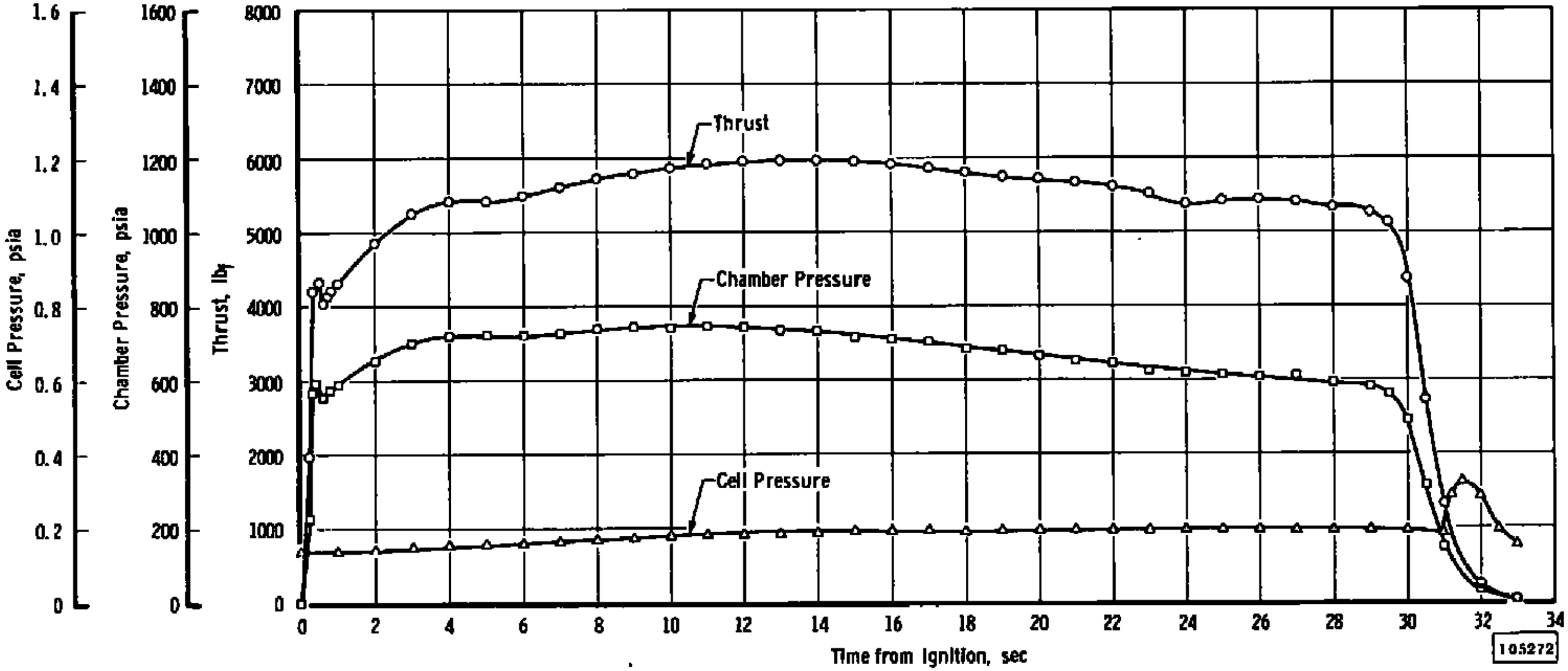
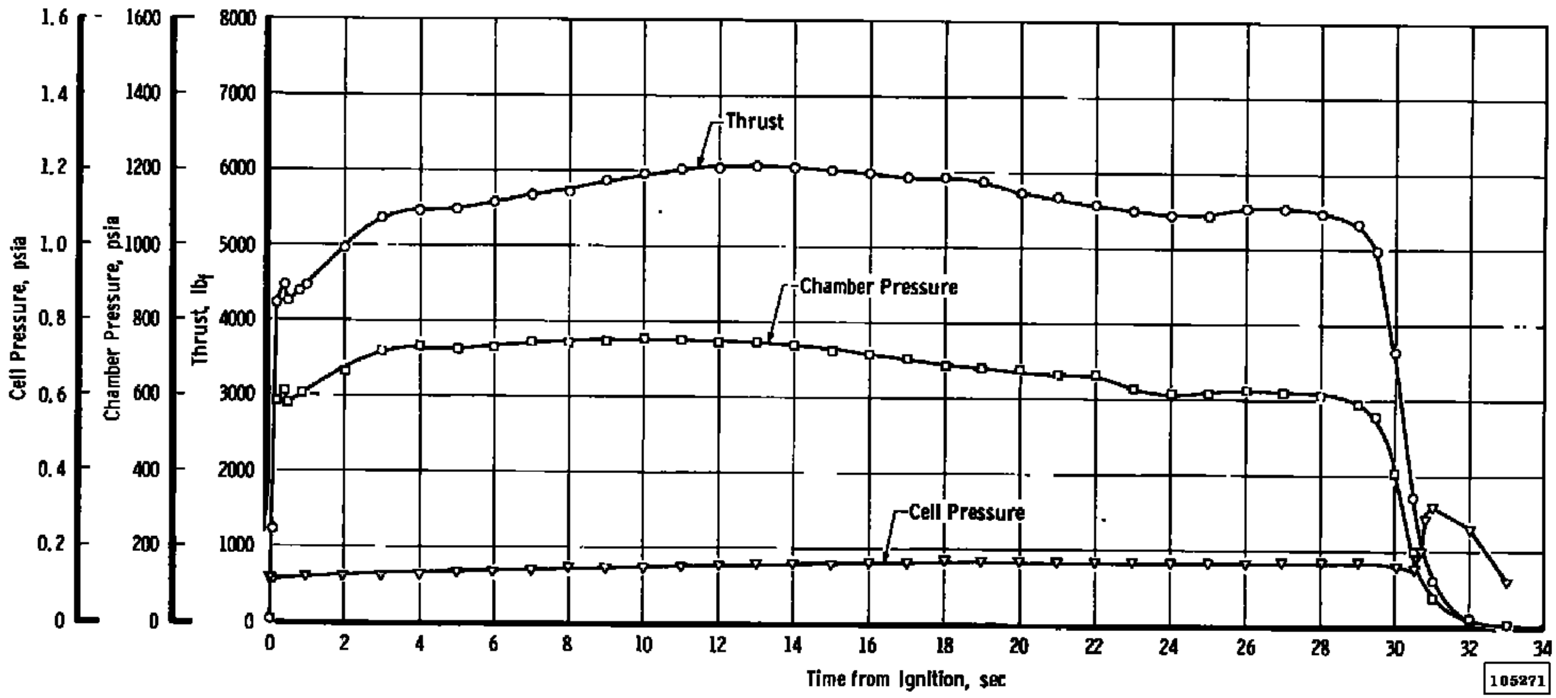
Fig. 6 Analog Trace of Typical Ignition Event for UTC XSR 57-UT-1 Motor



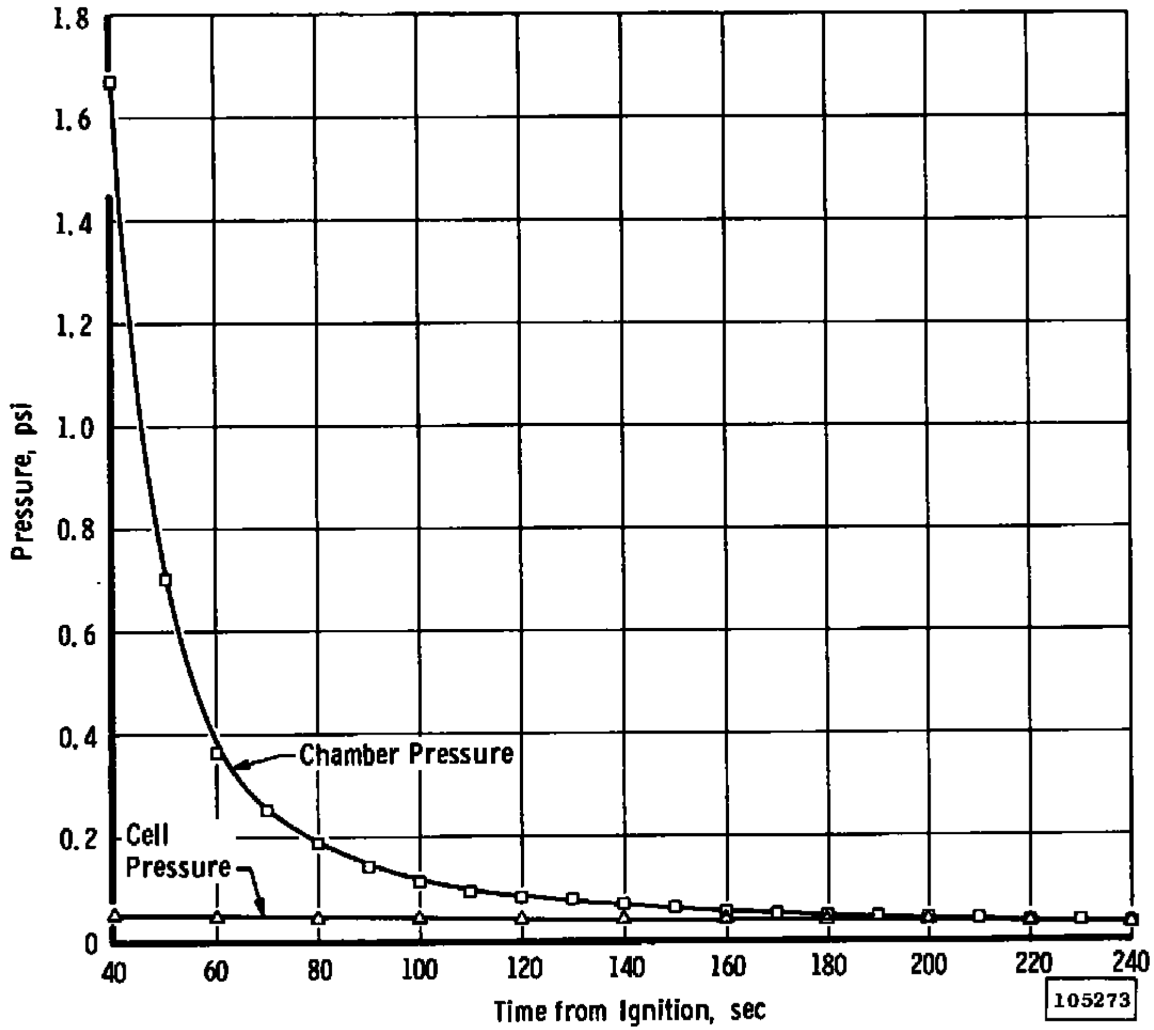
a. Motor S/N 20002

Fig. 7 Variation in Thrust, Chamber Pressure, and Cell Pressure during Firing



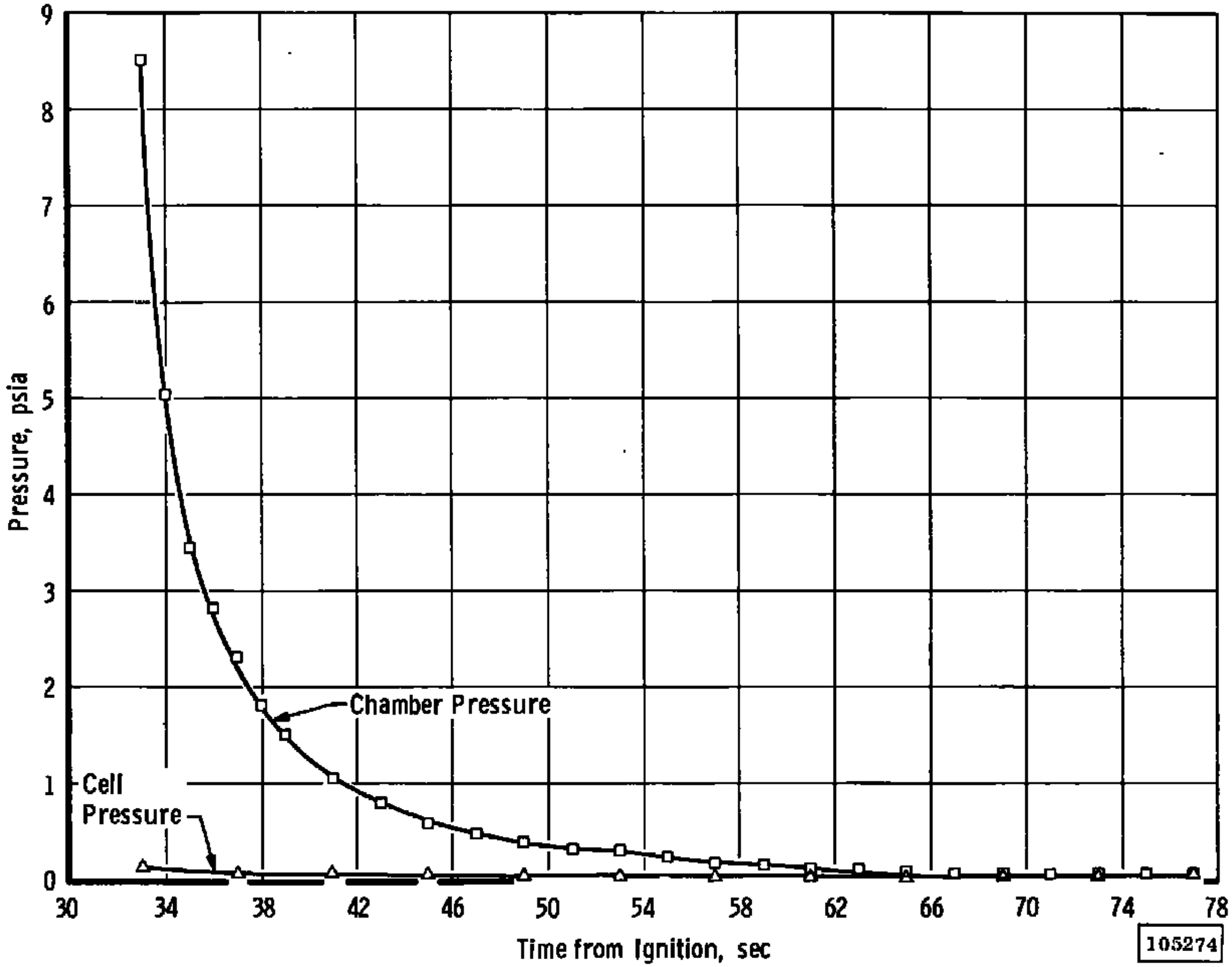
b. Motor S/N 20003

Fig. 7 Concluded



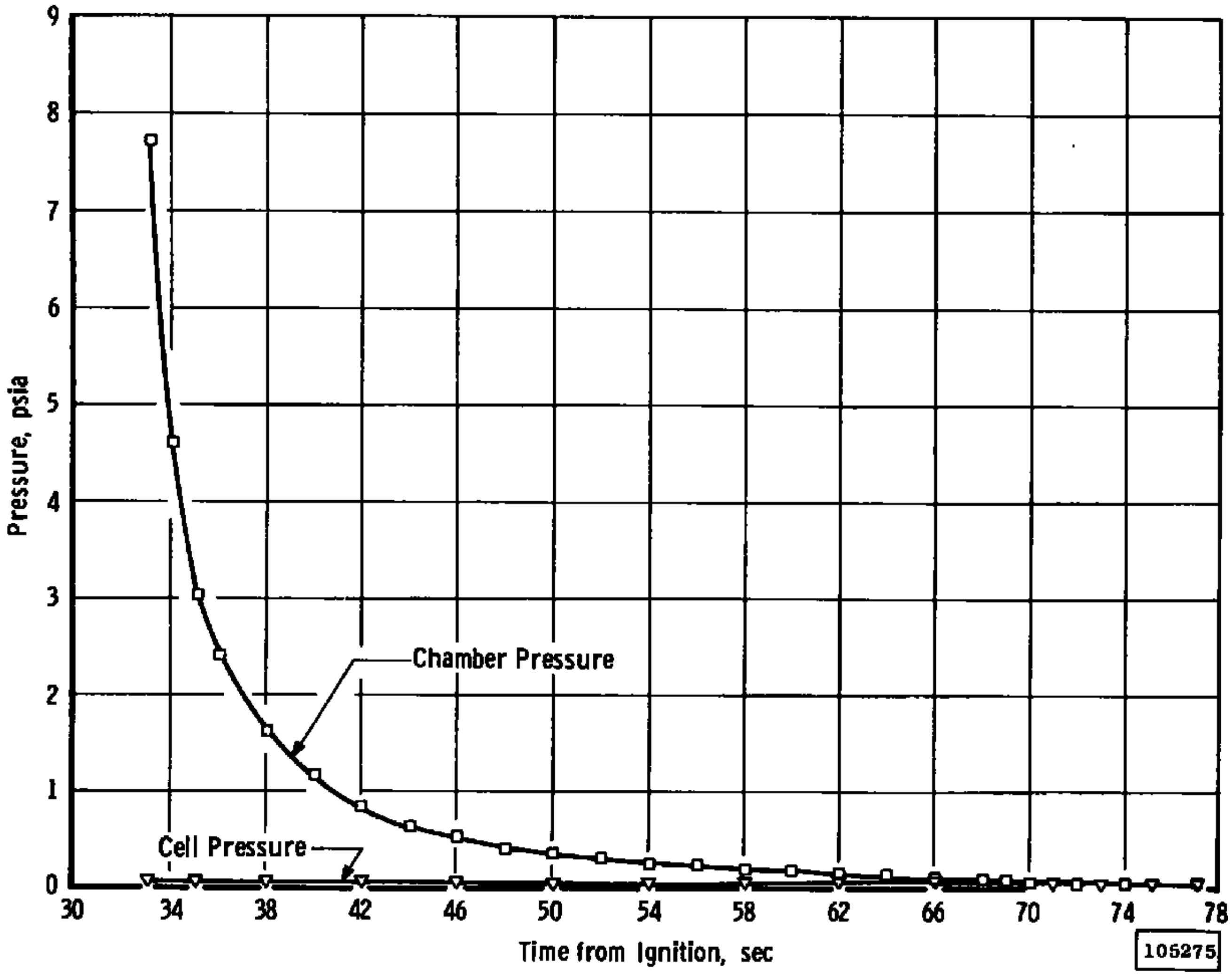
a. Motor S/N 20002 (Chamber Pressure Measured with 0- to 2-psia Transducer)

Fig. 8 Chamber Pressure and Cell Pressure Variations during Motor Tailoff



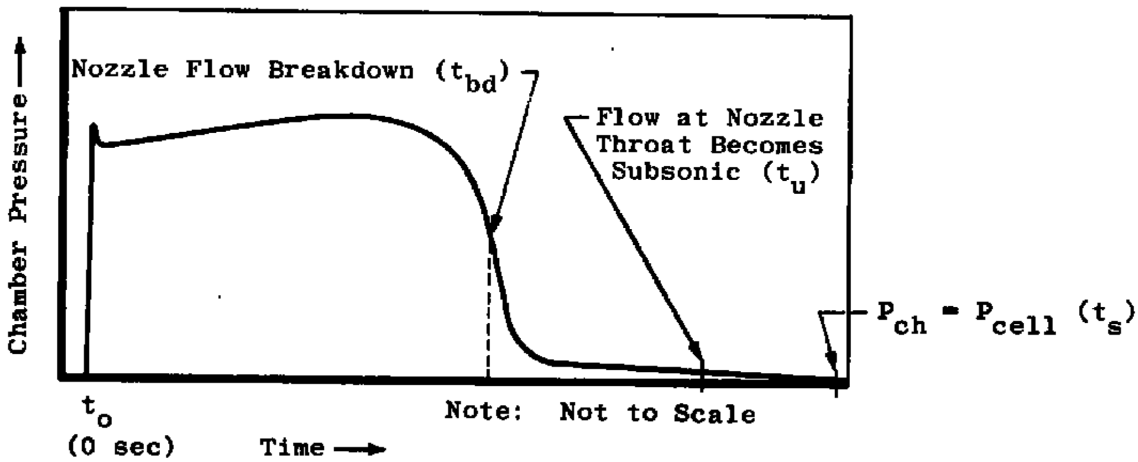
b. Motor S/N 20002 (Chamber Pressure Measured with 0- to 100-psia Transducer)

Fig. 8 Continued



c. Motor S/N 20003 (Chamber Pressure Measured with 0- to 100-psia Transducer)

Fig. 8 Concluded



$$\int_0^{t_{bd}} F dt = \begin{matrix} \text{S/N 20002 - 168,910 lb}_f\text{-sec} \\ \text{S/N 20003 - 168,480 lb}_f\text{-sec} \end{matrix}$$

$$\int_0^{t_{bd}} P_{cell} dt = \begin{matrix} \text{S/N 20002 - 4.706 psi-sec} \\ \text{S/N 20003 - 5.780 psi-sec} \end{matrix}$$

$$\int_{t_{bd}}^{t_u} P_{ch} dt = \begin{matrix} \text{S/N 20002 - 96.0 psi-sec} \\ \text{S/N 20003 - 106.8 psi-sec} \end{matrix}$$

Where:

F = Measured Thrust

P_{ch} = Measured Chamber Pressure

P_{cell} = Measured Cell Pressure

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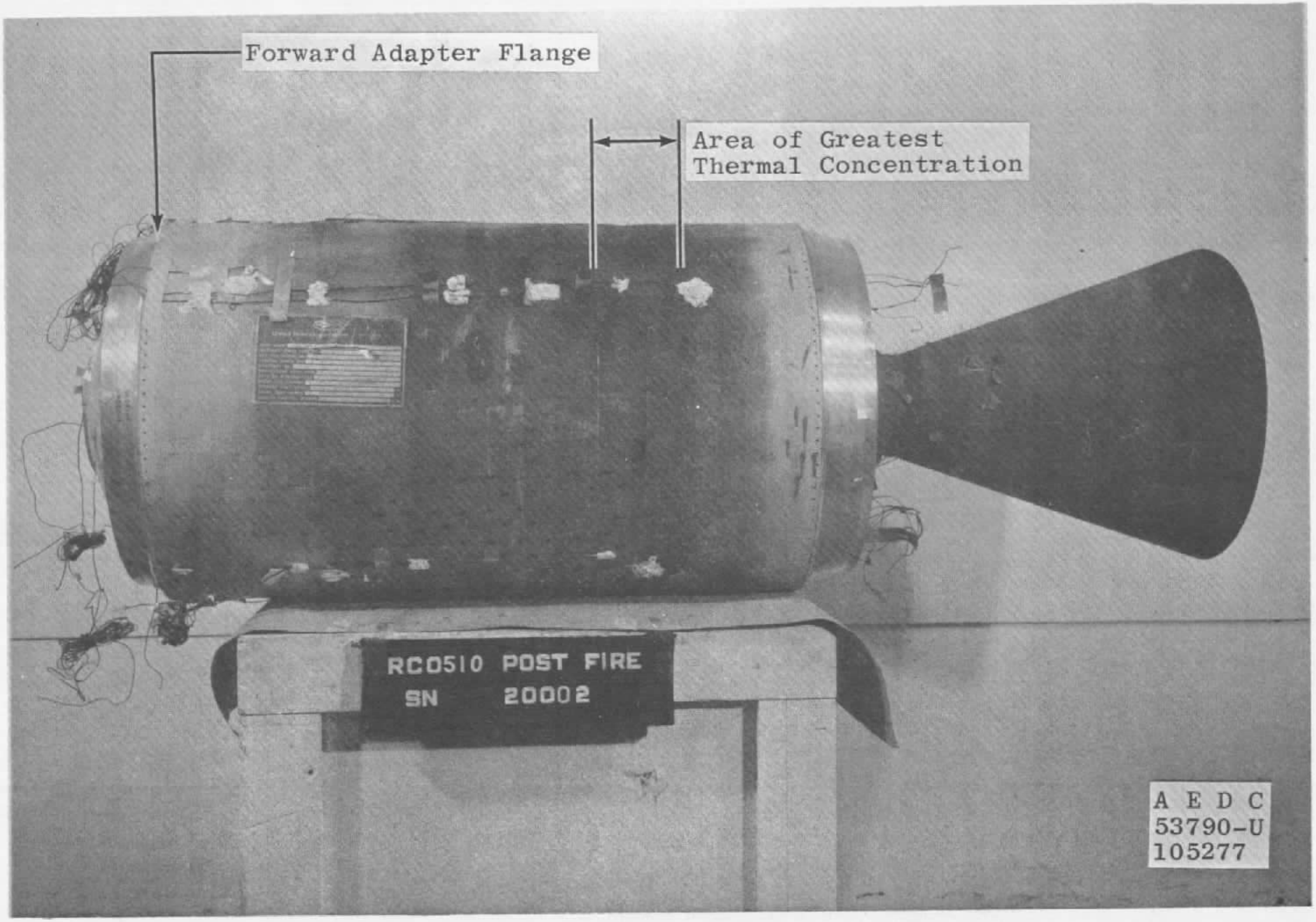
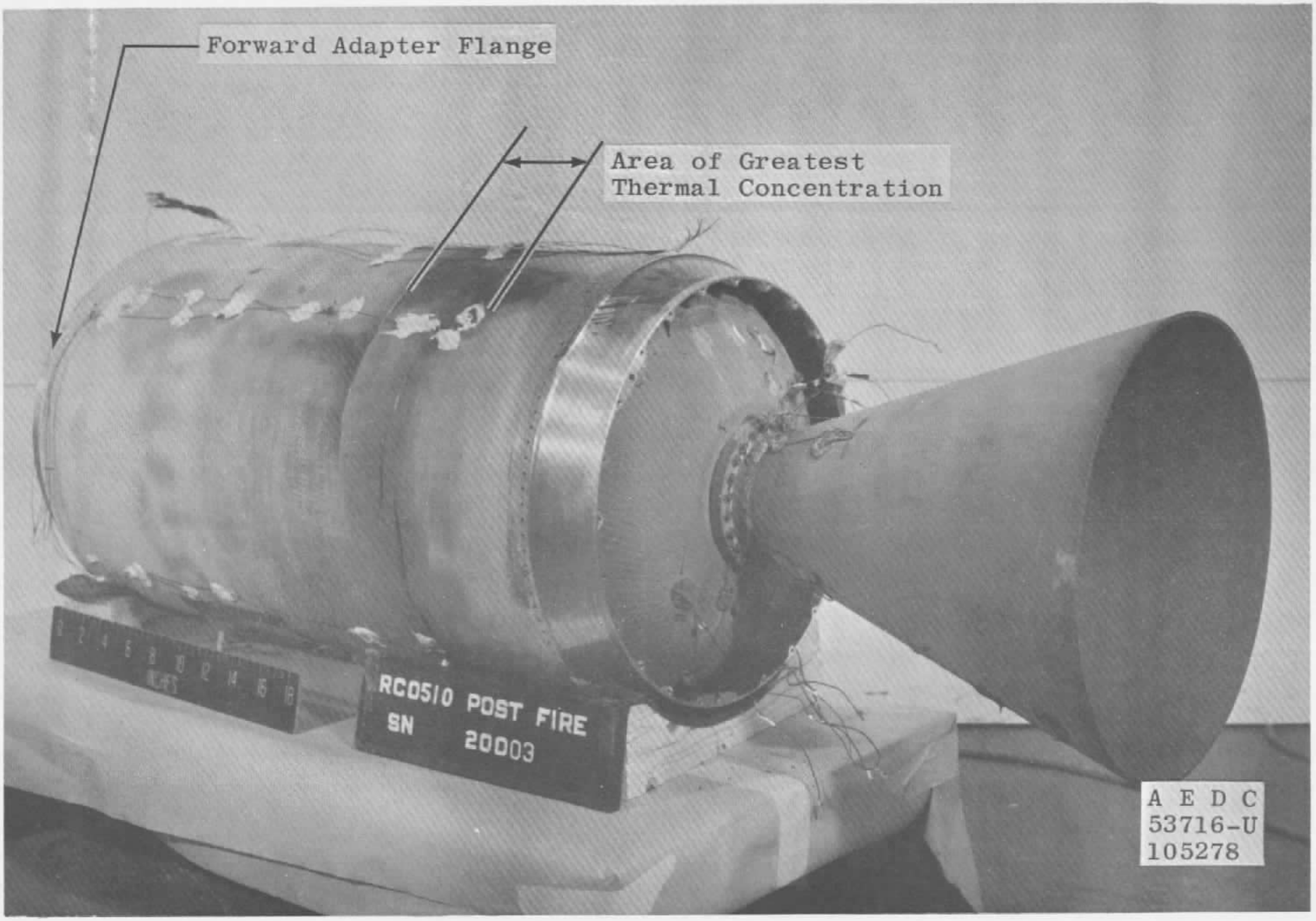
Fig. 9 Schematic of Chamber Pressure-Time Variation Defining Characteristic Events

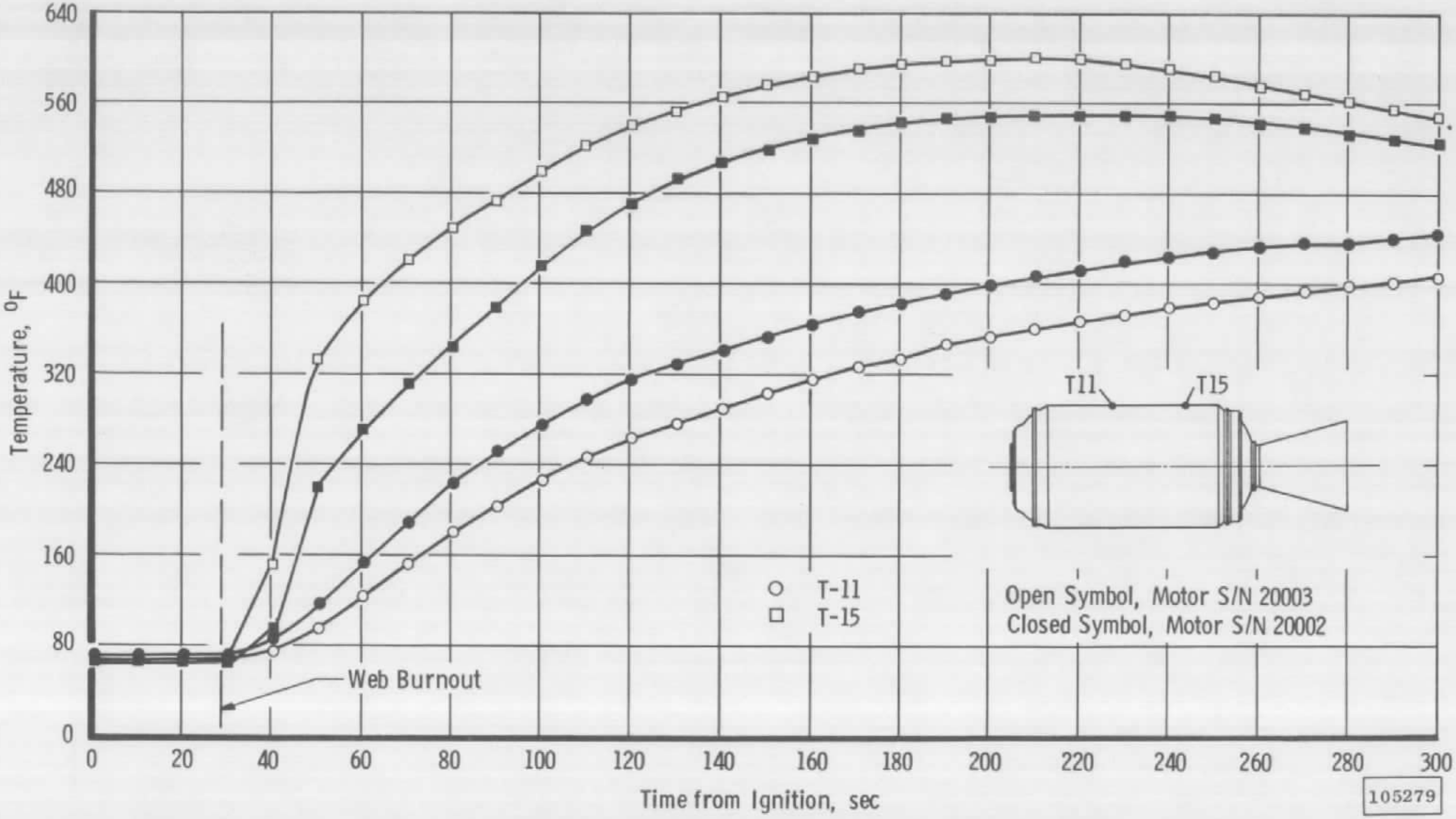


a. Motor S/N 20002

Fig. 10 Post-Fire Photographs of XSR 57-UT-1 Motors

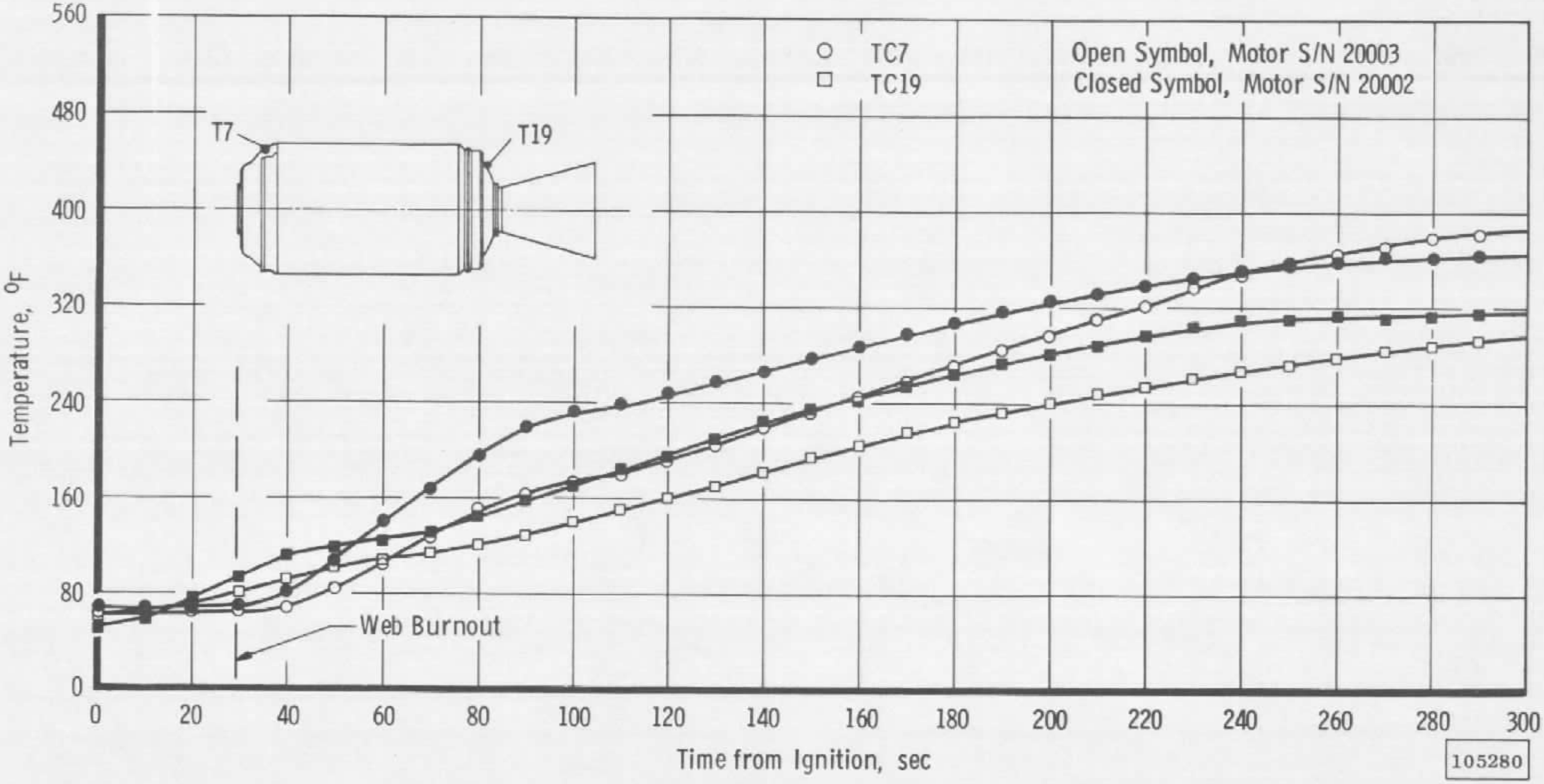


b. Motor S/N 20003
Fig. 10 Concluded



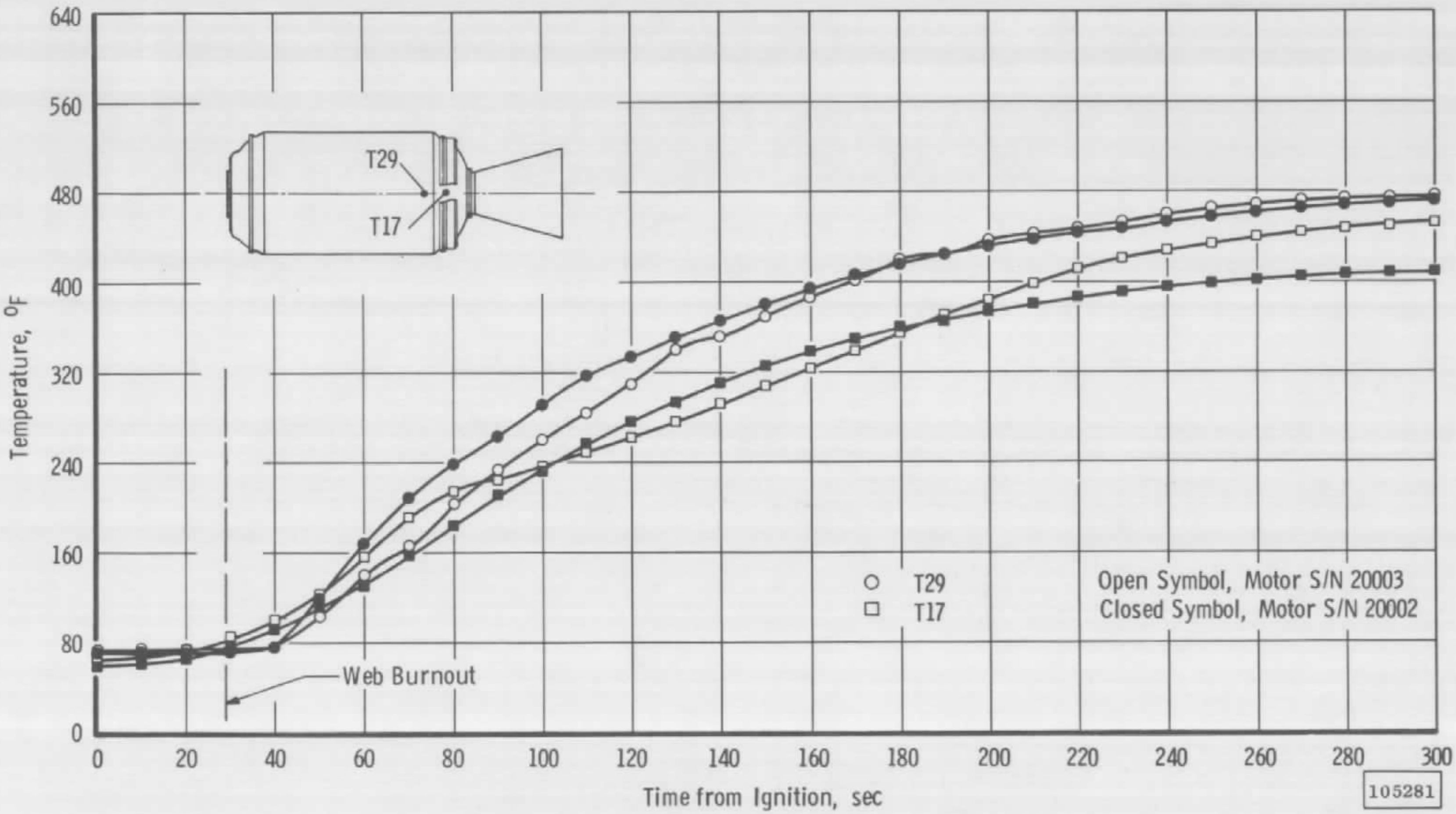
a. T11 and T15 along Top Dead Center (0-deg Position)

Fig. 11 Motor Case Temperature Variations for Motor S/N's 20002 and 20003



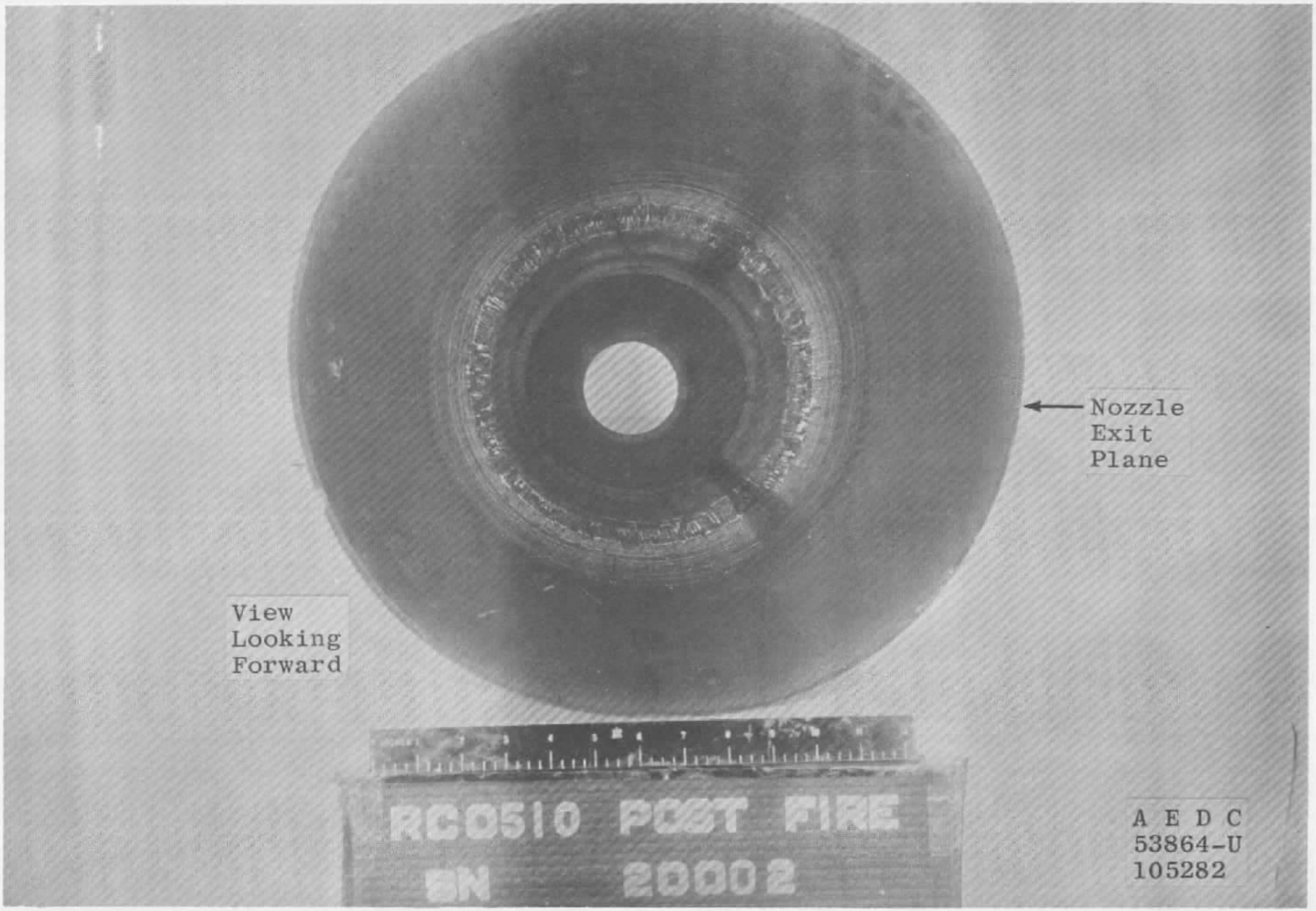
b. T7 and T19 along Top Dead Center (0-deg Position)

Fig. 11 Continued



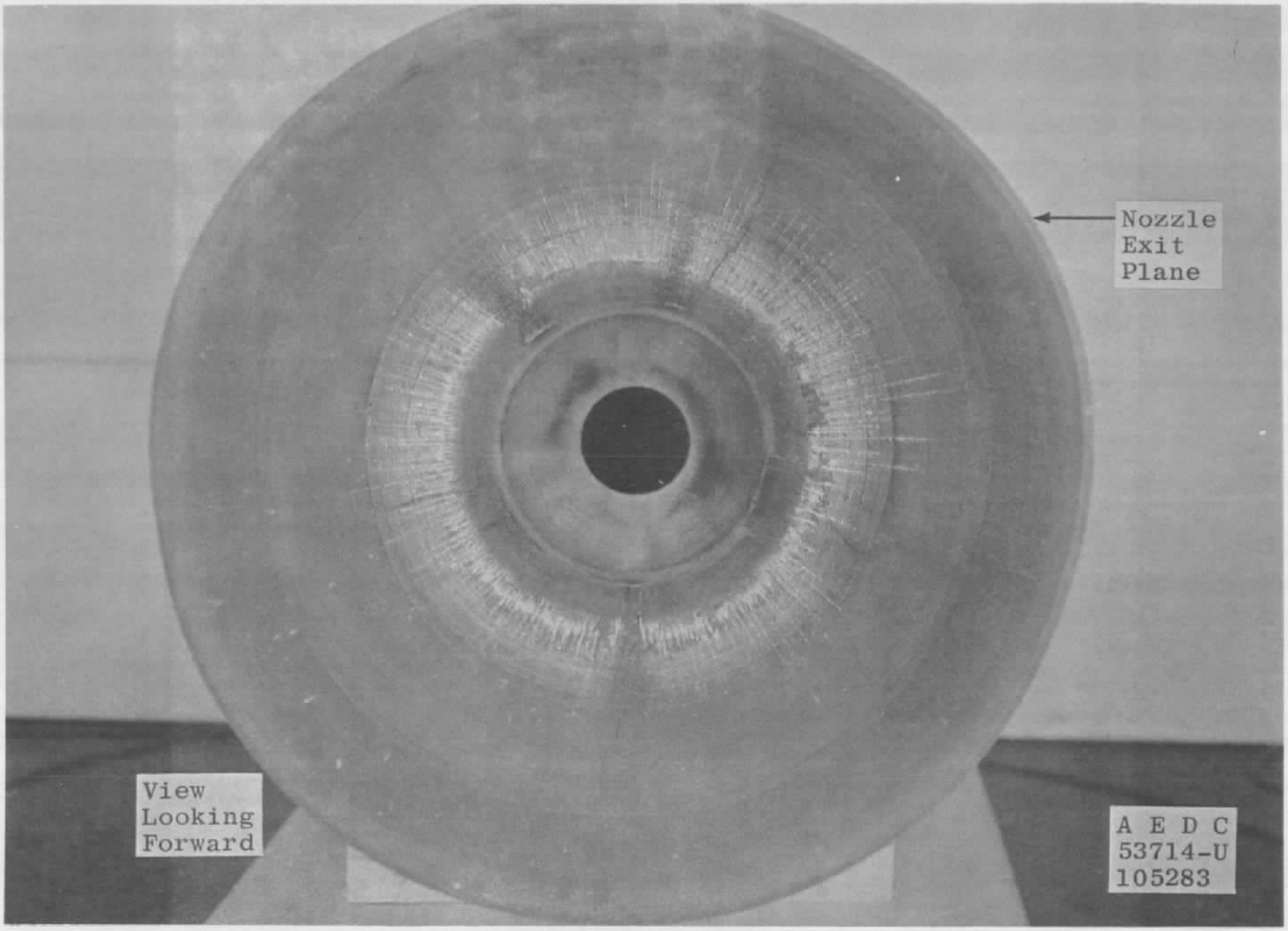
c. T17 and T29 along 270-deg Position

Fig. 11 Concluded



a. For Motor S/N 20002

Fig. 12 Post-Fire Photographs of Nozzle Expansion Cones



b. For Motor S/N 20003

Fig. 12 Concluded

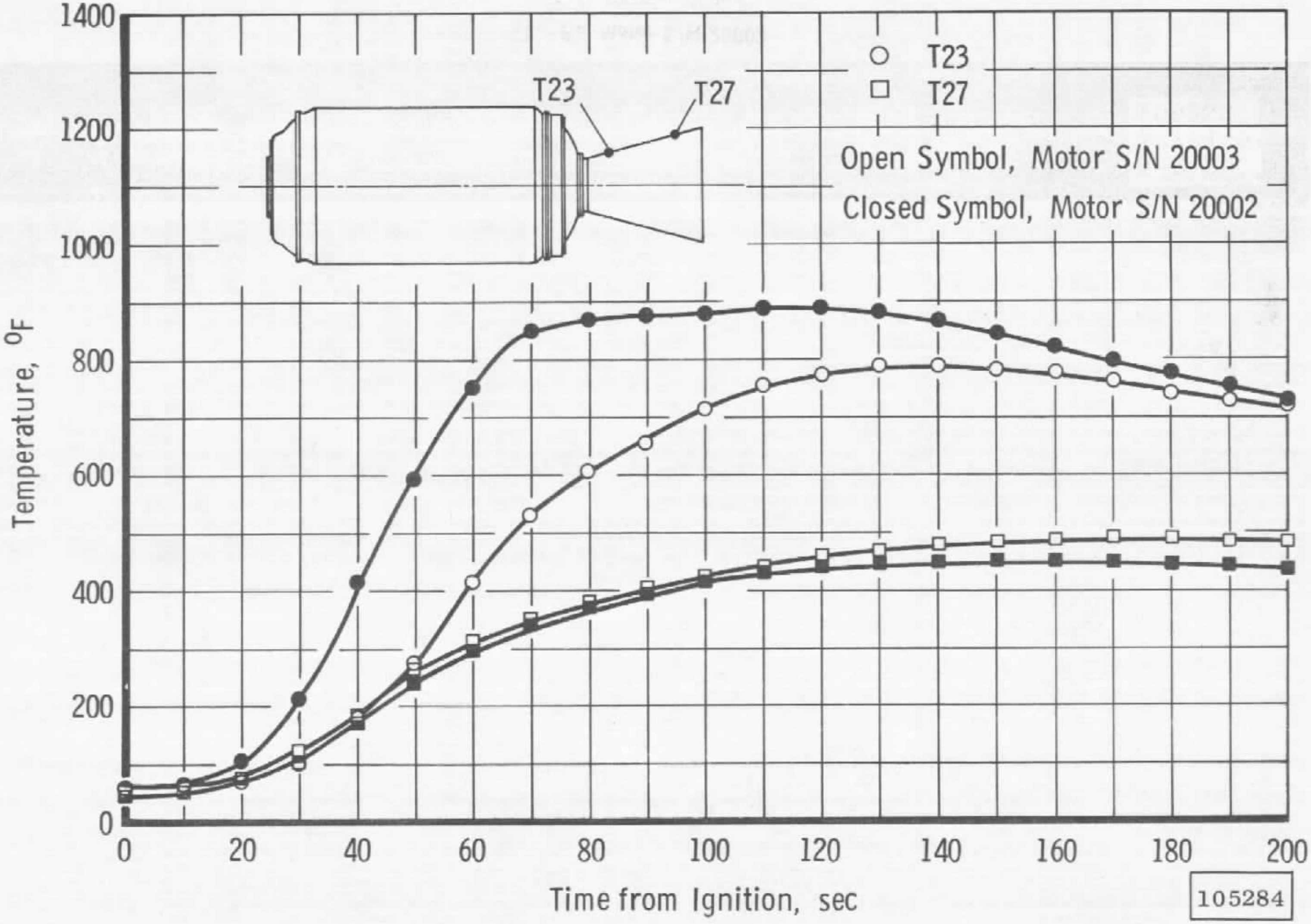


Fig. 13 Temperature Variations along Nozzle Expansion Cones for S/N's 20002 and 20003

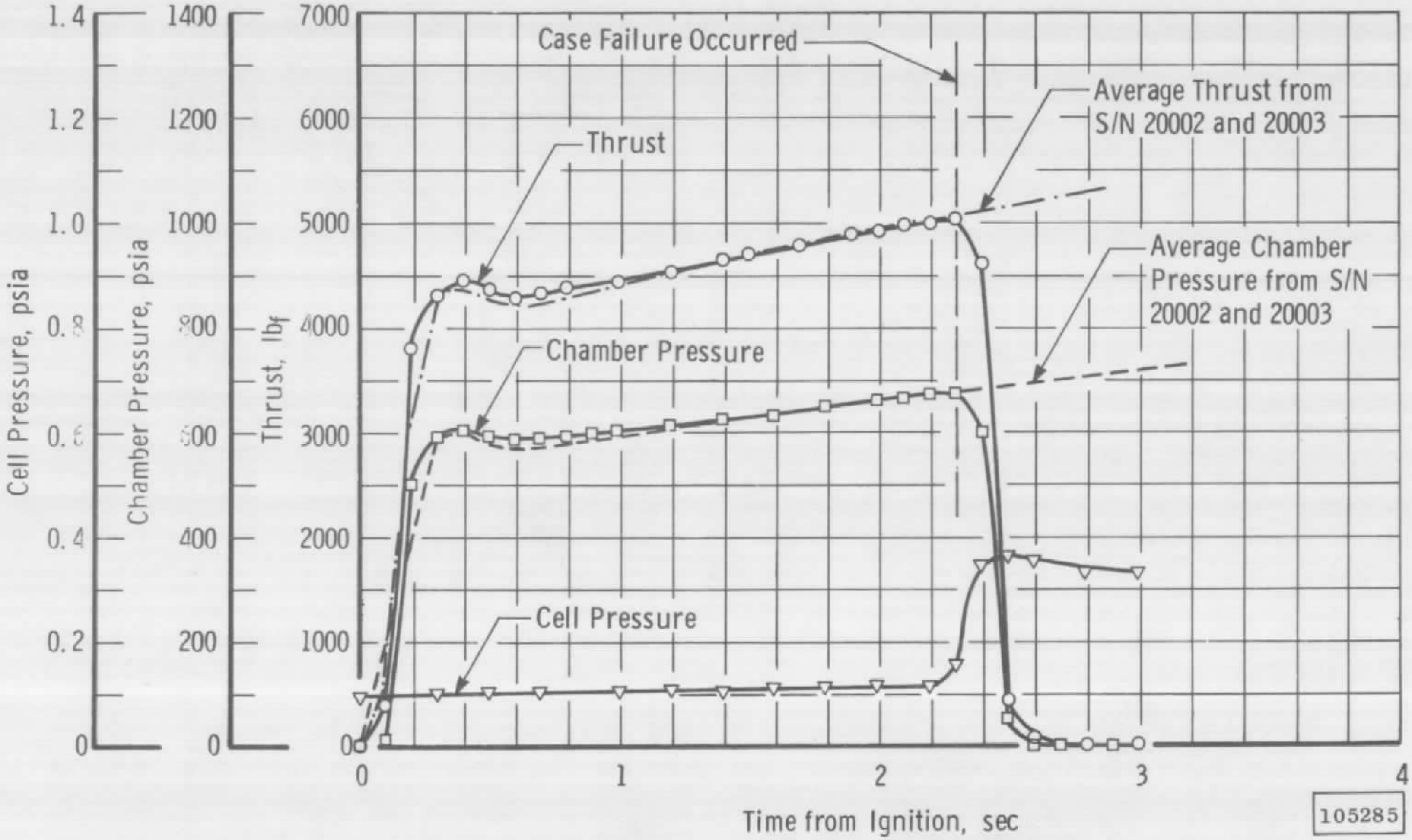


Fig. 14 Variation in Thrust, Chamber Pressure, and Cell Pressure during Operation of Motor S/N 20004

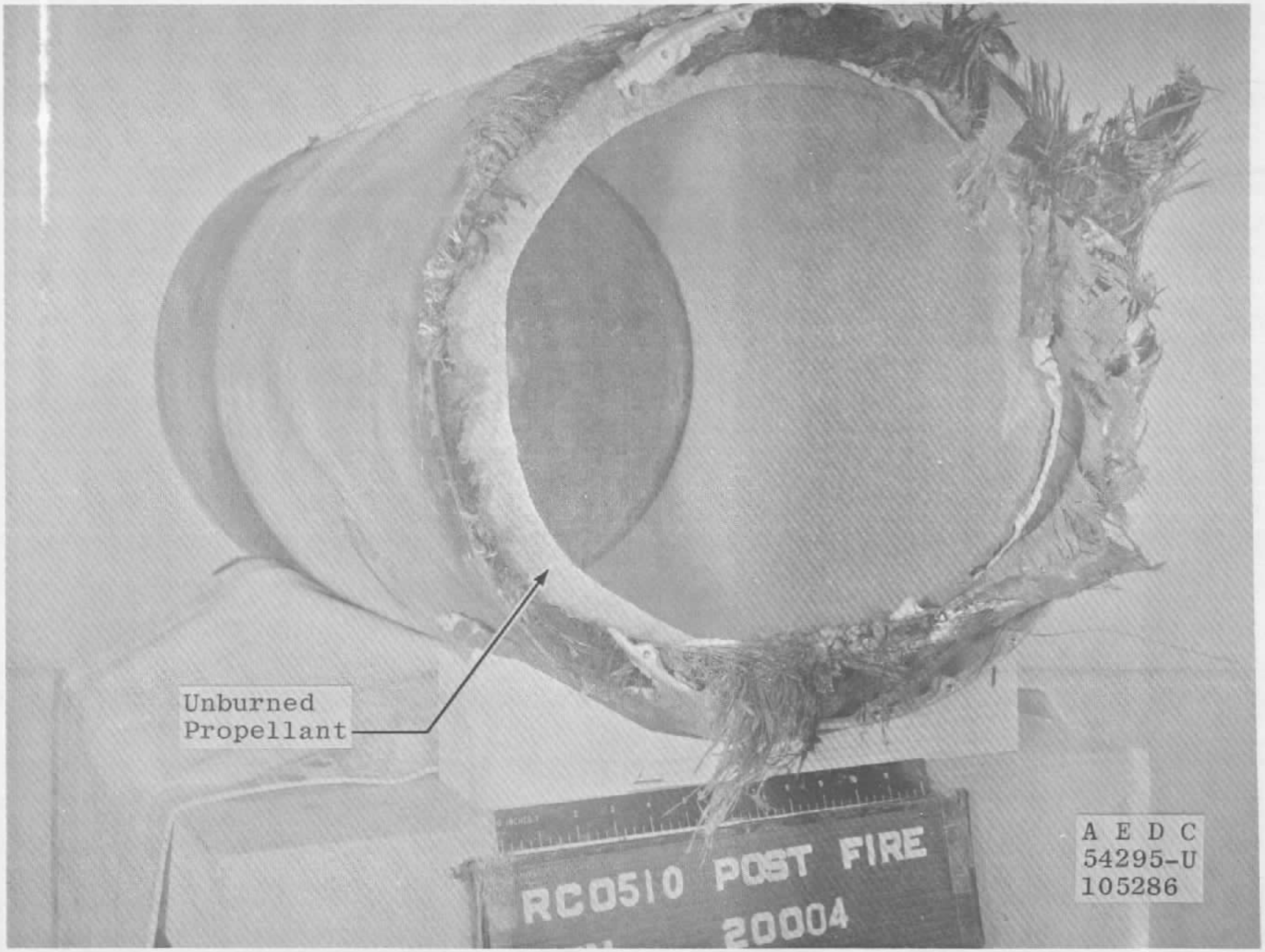
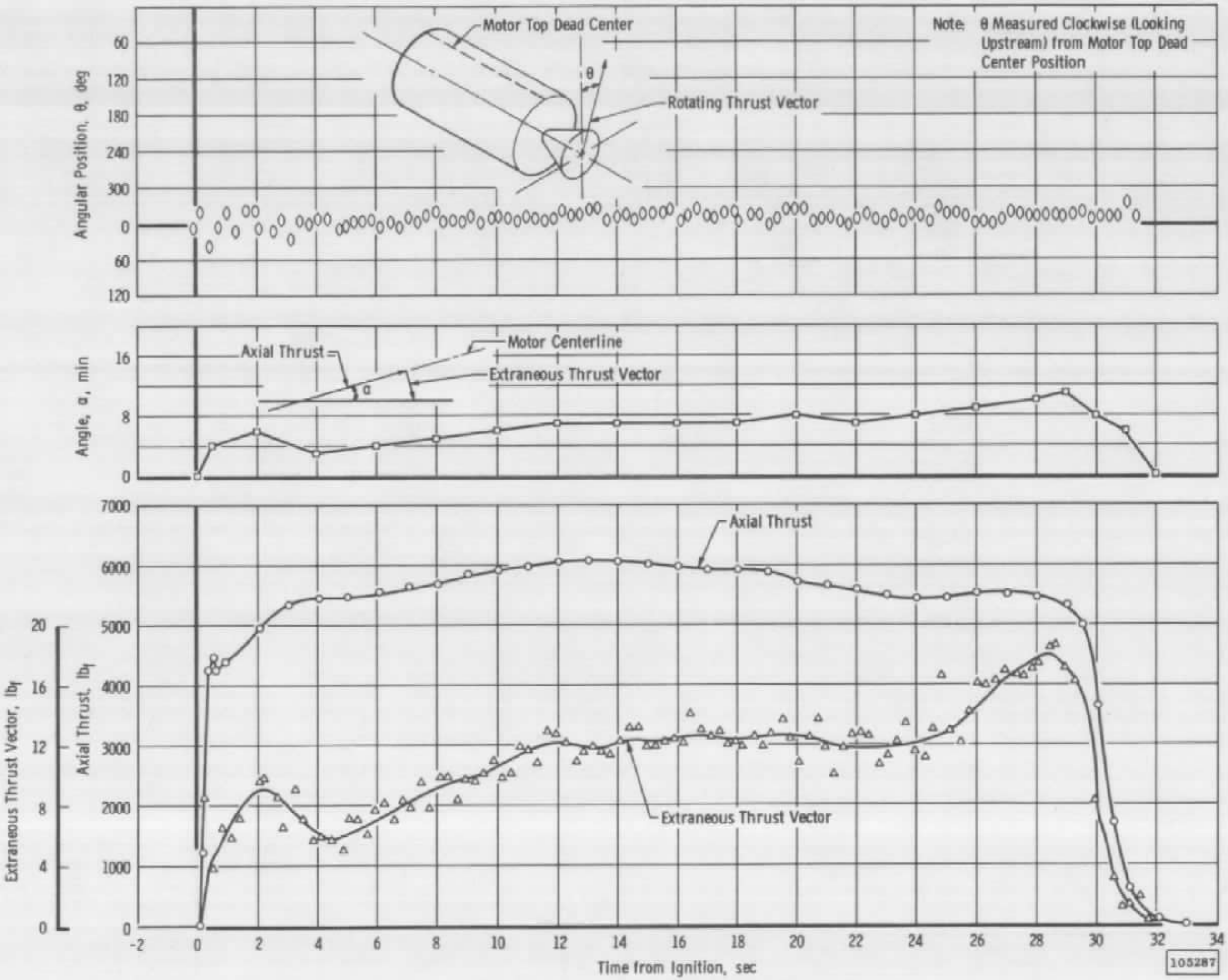
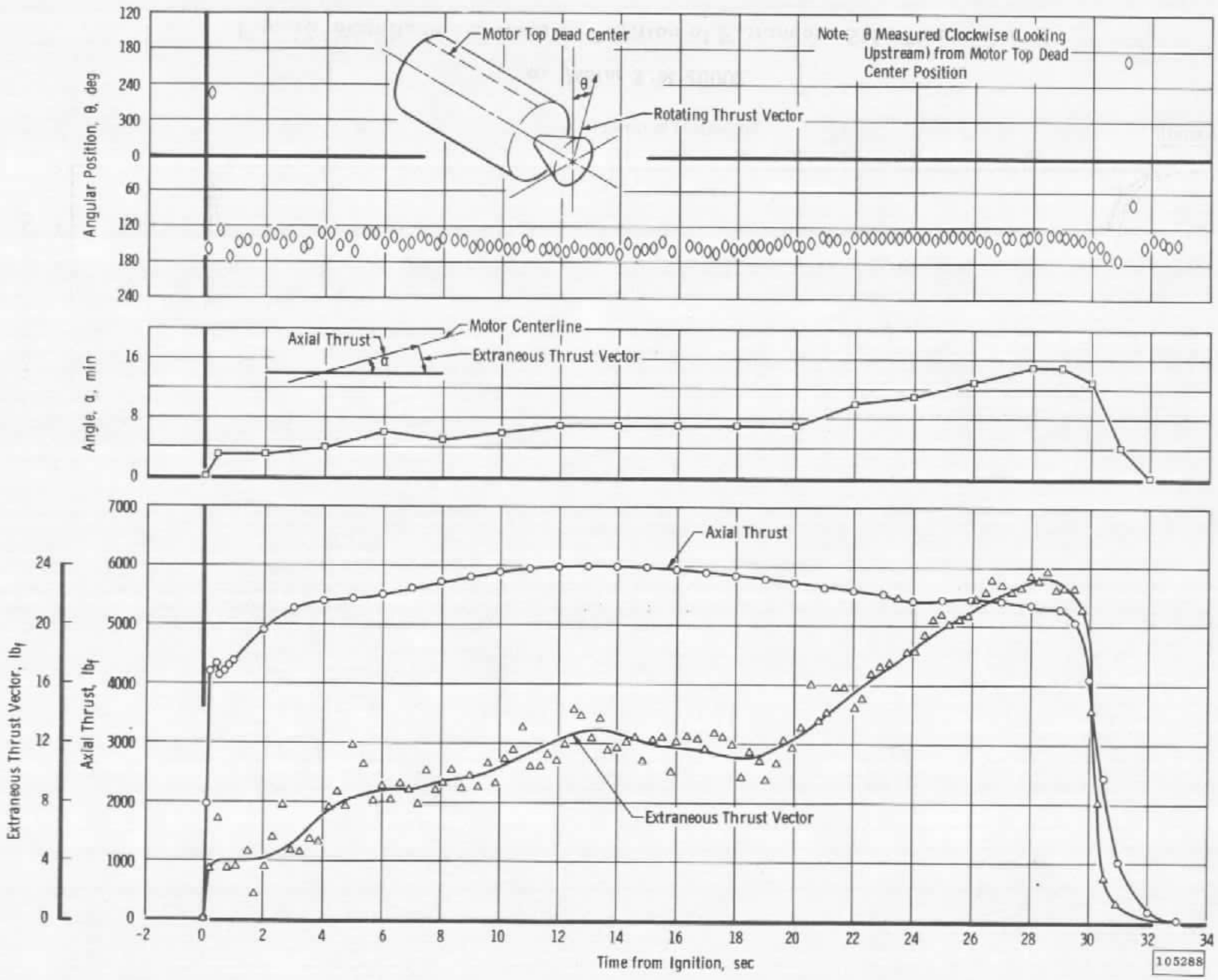


Fig. 15 Post-Fire Photograph of Motor S/N 20004



a. Motor S/N 20002

Fig. 16 Magnitude and Angular Position of Extraneous Side Thrust Vector



b. Motor S/N 20003

Fig. 16 Concluded

TABLE I
INSTRUMENTATION

Parameter	Estimated System Accuracy: Assumes Steady-State Signal at Operating Level	Estimated System Accuracy: Integral	Measuring Device	Range of Measuring Device	Recording Device	Method of System Calibration
Axial Force, lb_f (Full Range)	±0.40%	–	Bonded Strain-Gage-Type Load Cell (2 Used)	0-10,000 lb_f	Millivolt-to-Frequency Converter onto Magnetic Tape	Deadweight
Total Impulse, lb_f-sec	–	±0.35%				
Motor Chamber Pressure, psia	±0.85%[(1)]	–	Bonded Strain-Gage-Type Transducers	0-1000 psia 0-100 0-2	"	Electrical Calibration
Chamber Pressure Integral, psia-sec	–	±0.75%[(1)]				
Test Cell Pressure, psia	±2.35%	–	Unbonded Strain-Gage-Type Transducers	0-0.5 psia	"	Electrical Calibration
Cell Pressure Integral, psia-sec	–	±2.30%				
Time Intervals, msec	±5 msec	–	Synchronous Timing Line Generator	–	Photographically Recording, Galvanometer-Type Oscillograph	Compare with 60 cps
Temperature, °F	±5	–	Iron-Constantan Thermocouples	0-1200 °F	Digital Millivolt-Meter onto Magnetic Tape	Known Millivolt Source and N.B.S. Temperature Tables
Weight, lb_m	±0.03 lb_m	–	Beam Balance Scales	0-3000 lb_m	Visual Readout	Periodic Deadweight Calibration

(1) Applies only to 0- to 1000-psia transducer

TABLE II
SUMMARY OF MOTOR PERFORMANCE

Motor S/N	20003	20002	20004
Test Number RC0510	01	02	03
Test Date	12-8-64	12-10-64	12-15-64
Simulated Altitude at Ignition, ft	104,000	107,000	110,000
(1)Ignition Delay Time, sec	5.96	6.14	5.80
(1)Ignition Rise Time, sec	0.05	0.04	0.05
(2)Burn Time (t_s), sec	66.2	65.0	*
Action Time (t_a), sec	31.3	31.0	*
Average Rotational Speed during Firing, rpm	200	201	0
Total Measured Impulse (based on t_a), lb_f-sec			
System 1	168,690	169,100	*
System 2	168,700	169,120	*
System 3	168,750	169,180	*
System 4	---	169,130	*
Average	168,710	169,130	*
Maximum Deviation from Average, percent	0.023	0.029	*
Chamber Pressure Integral (based on t_a), psia-sec			
System 1	20,550	20,624	*
System 2	20,640	20,622	*
Average	20,595	20,623	*
Maximum Deviation from Average, percent	0.218	0.004	*
Cell Pressure Integral (based on t_a), psia-sec			
System 1	5.7804	4.7485	*
System 2	5.9189	4.8506	*
Average	5.8497	4.8000	*
Maximum Deviation from Average, percent	1.184	1.072	*
Average Simulated Altitude (based on t_a), ft	97,000	101,000	*
(3)Vacuum Total Impulse (based on t_a), lb_f-sec	170,680	170,790	*
Vacuum Specific Impulse, lb_f-sec/lb_m			
Based on the Manufacturer's Propellant Weight	284.98	284.35	*
Based on Expended Mass (AEDC)	282.91	282.13	*
Average Vacuum Thrust Coefficient, $\bar{C}_F$			
Based on t_a and Average Pre- and Post-Fire Throat Area (A_t)	1.816	1.815	*

(1)Reference section 4.1

(2)Based on time chamber pressure (P_{ch}) was greater than cell pressure (P_{cell}) where P_{ch} was measured with a 0- to 900-psia transducer

(3)Reference section 4.2

* Motor S/N 20004 failed 2.3 sec after ignition

TABLE III
SUMMARY OF MOTOR PHYSICAL DIMENSIONS

Motor Serial Number	20003	20002	20004(1)
Test Number RC0510	01	02	03
Test Date	12-8-64	12-10-64	12-15-64
Expended Mass, lb_m	603.28	605.33	---
Manufacturer's Stated Propellant Weight (W_p), lb_m	598.90	600.60	598.75
Nozzle Throat Area, in.^{2}			
Pre-Fire	4.086	4.086	4.086
Post-Fire	5.003	5.007	---
Percent Change from Pre-Fire Pre-Fire	+22.44	+22.54	---
Average	4.545	4.547	---
Nozzle Exit Area, in.^{2}			
Pre-Fire	215.019	214.993	215.097
Post-Fire(2)	216.109	215.721	---
Percent Change from Pre-Fire	+0.51	+0.34	---
Average	215.564	215.357	---
Nozzle Area Ratio			
Pre-Fire	52.623	52.617	52.642
Post-Fire	43.196	43.084	---
Average	47.429	47.362	---

Note: (1)Motor serial No. 20004 failed at 2.3 sec after motor ignition.

(2)Exhaust products not removed prior to measurement

UNCLASSIFIED

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4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

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5 AUTHOR(S) (Last name, first name, initial)

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13 ABSTRACT

Two UTC XSR 57-UT-1 solid-propellant rocket motors (S/N's 20002 and 20003) were fired at simulated altitude conditions while mounted in a spin fixture which rotated the motors about their axial centerlines at approximately 200 rpm. A third motor (S/N 20004) was fired in the no-spin mode after having been temperature-cycled between 35 and 105°F. This firing resulted in failure in the aft dome region 2.3 sec after ignition. The major program objectives were to determine motor ballistic performance and structural integrity. Vacuum specific impulse based on the manufacturer's stated propellant weight was 284.35 (S/N 20002) and 284.98 (S/N 20003) lb_f-sec/lb_m. Post-fire motor examination of motors S/N 20002 and S/N 20003 revealed that the uninsulated portion of each cylindrical chamber was charred, and the fiber glass filaments were essentially unbonded.

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Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
rocket motors						
solid propellants						
simulated altitude						
rotational spin						
ballistic performance						
structural integrity						

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