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QUALITY ASSURANCE TEST OF A THIOKOL CHEMICAL CORPORATION TE-M-364-3 SOLID-PROPELLANT ROCKET MOTOR TESTED IN THE SPIN MODE AT SIMULATED ALTITUDE CONDITIONS

H. L. Merryman and R. M. Brooksbank

ARO, Inc.

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

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FOREWORD

The test program reported herein was conducted under the sponsorship of the National Aeronautics and Space Administration (NASA), Goddard Space Flight Center (GSFC), for the Thiokol Chemical Corporation (TCC), Elkton Division, under Program Element 921E, Project 9033.

The results of the test were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), Arnold Air Force Station, Tennessee, under Contract F40600-69-C-0001. The test was conducted in Propulsion Development Test Cell (T-3) of the Engine Test Facility (ETF) on March 15, 1970, under ARO Project No. RC1067, and the manuscript was submitted for publication on April 29, 1970.

Information in this report is embargoed under the Department of State International Traffic in Arms Regulations. This report may be released to foreign governments by departments or agencies of the U. S. Government subject to approval of NASA, Goddard Space Flight Center, or higher authority. Private individuals or firms require a Department of State export.license.

This technical report has been reviewed and is approved.

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ABSTRACT

One Thiokol Chemical Corporation TE-M-364-3 solid-propellant rocket motor was fired as a quality assurance test at near vacuum conditions to determine motor structural integrity and altitude ballistic performance. The motor was fired while spinning about its axial centerline at 110 rpm. Vacuum total impulse was within the specification limits, but the motor case temperature exceeded the specification limit. A "hot spot" developed on the nozzle of the motor, beginning approximately 39 sec after ignition.

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NOMENCLATURE

A/A^*	Nozzle area ratio
$A_{ex_{pre}}$	Prefire nozzle exit area, in.^{2}
$A_{t_{post}}$	Post-fire nozzle throat area, in.^{2}
C_F	Vacuum thrust coefficient
$\bar{c}_f$	Thrust coefficient over a selected 1-sec interval
F	Measured thrust, lbf
I_{vac}	Vacuum total impulse
P_{cell}	Measured cell pressure, psia
P_{ch}	Measured chamber pressure, psia
P_{max}	Maximum chamber pressure developed during normal motor operation, excluding ignition spike, psia
t	Time

t_a Action time, time interval between 10 percent of maximum chamber pressure during ignition and 10 percent of maximum chamber pressure during tailoff, sec

t_{bd} Time of nozzle flow breakdown (indicated by increase in cell pressure), sec

t_i Time of first increase in chamber pressure at motor ignition, sec

t_{is} Time interval from time of increase in chamber pressure during ignition until the ratio of chamber pressure to test cell pressure has decreased to 1.3 during tailoff, sec

t_ℓ Ignition lag time, interval from zero time to time of increase in chamber pressure, sec

t_o Zero time, time at which firing voltage is applied to the igniter circuit, sec

t_s Nozzle throat flow goes subsonic, time at which the ratio of chamber pressure to test cell pressure has decreased to 1.3 during tailoff, sec

SECTION I
INTRODUCTION

The Thiokol Chemical Corporation (TCC) TE-M-364-3 solid-propellant rocket motor is being used as the third stage of the Improved Delta Launch Vehicle, DSV-3E (Fig. 1, Appendix I). Delta missions which either used or are scheduled to use the TE-M-364-3 motor include Radio Astronomy Explorer (RAE), Interim Defense Communications Satellite Program (IDCSP), International Tele-Communications Satellite Program (Intelsat III), and the NATO-A satellite (Ref. 1). For each of these third-stage and payload combinations, attitude control will be achieved by spin stabilization.

A qualification test program consisting of six TCC TE-M-364-3 motors was previously conducted at near vacuum conditions. The results of this phase of testing are presented in Refs. 1 and 2 and discussed in Section IV.

The primary objectives of the quality assurance test reported herein were to fire one motor in the spin mode while spinning about the motor axial centerline at 110 rpm to determine altitude ballistic performance, temperature-time history during and after motor operation, and component structural integrity. Testing was accomplished in direct support of a launch of the NATO-A Communications Satellite scheduled for March 18, 1970. The motor was prefire conditioned and fired at a temperature of 75 ± 5°F.

Motor altitude ballistic performance, temperature-time history, and structural integrity are discussed and compared with results obtained during the qualification test program.

SECTION II
APPARATUS

2.1 TEST ARTICLE

The TCC TE-M-364-3 solid-propellant rocket motor (Fig. 2) is a full-scale flightweight motor having the following nominal dimensions and burning characteristics at 75°F:

Length, in.	53
Diameter, in.	37
Loaded Weight, lbm	1580
Propellant Weight, lbm	1440
Throat Area, in.^{2}	8.50
Nozzle Area Ratio, A/A*	53:1
Maximum Thrust, lbf	10,970
Maximum Chamber Pressure, psia	650
Burn Time, sec	40

The cylindrical motor case is constructed of 0.040-in. steel. The aft hemisphere and approximately one-half of the forward hemisphere regions are insulated with V-44 asbestos-filled Buna-N® rubber. The remaining case area is uninsulated (Fig. 2a). Two 37-in.-diam thrust attachment flanges are located near the motor equator.

The contoured nozzle assembly contains a Graph-I-Tite® G-90 carbon throat insert and an expansion cone constructed of outer layers of glass cloth phenolic and inner layers of carbon cloth phenolic. The partially submerged nozzle assembly has a nominal 53:1 area ratio (A/A*) and a 15-deg half-angle at the exit plane. A carbon cloth phenolic band (Fig. 2a) is bonded to the nozzle expansion cone adjacent to the exit plane as a stiffener (support) ring (Ref. 2).

The TE-M-364-3 rocket motor contains a propellant grain formulation designated TP-H-3062 (ICC Class B), which is cast in an eight-point-star configuration (Fig. 2b). The isentropic exponent of the propellant exhaust gases is 1.18 (assuming frozen equilibrium).

Ignition was accomplished by a TE-P-358-3 Pyrogen® igniter (Fig. 3), which contained 19 gm of size 2A boron pellets used to initiate the eight-point-star igniter grain. The aft section of the igniter contained six small nozzles for distribution of the igniter propellant flame onto the motor propellant grain (Fig. 2a). The head end of the igniter contained a mechanical safe and arm device, two squib ports, and one chamber pressure port. Two Hi-Shear PC-37-03 short-delay squibs were used for the test reported herein. Nominal ignition current was 5 amp/squib and was maintained for approximately 0.1 sec.

2.2 INSTALLATION

The motor was cantilever mounted from the spindle face of a spin fixture assembly in Propulsion Development Test Cell (T-3)(Ref. 3). The spin assembly was mounted on a thrust cradle, which was supported from the cradle support stand by three vertical and two horizontal double-flexure columns (Fig. 4). The spin fixture assembly consists of a 10-hp squirrel-cage-type drive motor, a forward thrust bearing assembly, a 46-in.-long spindle having a 36-in.-diam aft spindle face, and an aft bearing assembly. The motor was secured in a mounting can which was adapted to the spindle face. During the firing, the spin fixture rotated counterclockwise, looking upstream. Electrical leads to and from the igniters, pressure transducers, thermocouples, and strain grids on the motor were provided through a 170-channel, slip-ring assembly mounted between the forward and aft bearing assemblies on the spindle. Axial thrust was transmitted through the spindle-thrust bearing assembly to two 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 gas compressors. During the motor firing, the motor exhaust gases were used as the driving gas for the 42-in.-diam, ejector-diffuser system to maintain test cell pressure at an acceptable level.

2.3 INSTRUMENTATION

Instrumentation was provided to measure axial thrust, motor chamber pressure, test cell pressure, motor case and nozzle temperatures, motor case and nozzle flange strains, and rotational speed. Table I (Appendix II) presents range of measurements, recording methods, and an estimate of measurement uncertainty for all reported parameters.

The axial thrust measuring system consisted of two double-bridge, strain-gage-type load cells mounted in the axial double-flexure column forward of the thrust bearing on the motor centerline (Fig. 4c).

Unbonded strain-gage-type transducers were used to measure test cell pressure. Bonded strain-gage-type transducers (0 to 1500 psia) were used to measure motor chamber pressure. Chromel® -Alumel® (CA) thermocouples were bonded to the motor case and nozzle (Fig. 5a) to measure outer surface temperatures during and after motor burn time. Strain grids were bonded to the motor case (4) and nozzle mounting flange (42) (Fig. 5b) to measure strain (deflection) during motor operation. Rotational speed of the motor assembly was determined from the output of a magnetic pickup.

The output signal of each measuring device was recorded on independent instrumentation channels. Ballistic data were obtained from four axial thrust channels, three test cell pressure channels, and two chamber pressure channels. 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 and oscillograph recorder. 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 and strain grids were recorded on magnetic tape from a multi-input, analog-to-digital converter at a sampling rate for each parameter of 150 samples per second.

A recording oscillograph was used to provide an independent backup of all operating instrumentation channels except for the temperature and strain systems. Selected channels of thrust and pressures were recorded on null-balance potentiometer-type strip charts for analysis immediately after the 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 firing.

The thrust calibrator weights, axial load cells, and pressure transducers were laboratory calibrated prior to usage in this program. After installation of the measuring devices in the test cell, all systems were calibrated at ambient conditions and again at simulated altitude conditions just before the motor firing.

The pressure systems were calibrated by an electrical, four-step calibration, using resistances in the transducer circuits to simulate selected pressure levels. The axial thrust instrumentation systems were calibrated by applying to the thrust cradle known forces which were produced by deadweights acting through a bell crank. The calibrator is hydraulically actuated and remotely operated from the control room. Thermocouple systems were calibrated by using known millivolt levels to simulate selected thermocouple outputs. The strain-grid systems were calibrated by using resistance in the circuits to simulate selected strain levels.

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

SECTION III
PROCEDURE

The TCC TE-M-364-3 rocket motor (S/N 00010) arrived at AEDC on March 13, 1970, was visually inspected for possible shipping damage and radiographically inspected at about 75°F for grain cracks, voids, or separations, and was found to meet criteria provided by the manufacturer. During storage in an area temperature conditioned at 75 ± 5°F, the motor was checked to ensure correct fit of mating hardware, and the electrical resistance of the igniter was measured. The nozzle throat and exit diameters were obtained, and the motor was weighed. Thermocouples were bonded to the nozzle and motor case, strain grids were bonded to the motor case and nozzle mounting flange, the pressure manifold with transducers was mounted, and the entire motor assembly was photographed and then installed in the firing can. Since the nozzle was removed for installation of the strain grids on the nozzle mounting flange, the motor was pressure checked at 75 psia (with no leaks for 15 min) after the nozzle was reinstalled to the motor case.

After installation of the motor in the test cell, instrumentation connections were made, and a continuity check of all electrical systems was performed. The motor centerline was axially aligned with the spin axis by rotating the motor and measuring the deflection of the selected motor surfaces with a dial indicator and making appropriate adjustments. The assembly was spun at a rotational speed of 110 rpm to check for the level of unbalance (balancing was not required). Prefire ambient calibrations were completed, the test cell pressure was reduced to simulate the desired altitude, and altitude calibrations were made after spinning of the motor assembly had stabilized at 110 rpm.

The final operation prior to firing the motor was to adjust the firing circuit resistance to provide the desired current (5 amp) to the igniter squibs. The entire instrumentation measuring-recording complex was activated, and the motor was fired. Simulated altitude conditions were maintained for approximately 45 min after the firing, during which time motor temperatures were recorded and postfire calibrations were completed. The test cell pressure was then returned to ambient conditions, and the motor was inspected, photographed, and removed to the storage area. Postfire inspections at the storage area consisted of measuring the nozzle throat diameter, weighing the motor, and photographically recording the postfire condition of the motor.

SECTION IV
RESULTS AND DISCUSSION

One Thiokol Chemical Corporation (TCC) TE-M-364-3 solid-propellant rocket motor (S/N 00010) was fired in Propulsion Development Test Cell (T-3) while spinning about the motor axial centerline at about 110 rpm. The primary objectives of the quality assurance test reported herein were to determine altitude ballistic performance, temperature-time history during and after motor operation, and component structural integrity. Testing was accomplished in direct support of a launch of the NATO-A Communications Satellite scheduled on March 18, 1970. However, because of a "hot spot" which occurred on the nozzle beginning approximately 39 sec after ignition, the launch was delayed until March 20, 1970, to enable review of the test results in more detail.

Data from the motor test are presented in both tabular and graphical form and are compared with previous results obtained in Refs. 1 and 2. A summary of motor physical dimensions is presented in Table II. Motor performance data, based on action time (t_a) and t_{is} are summarized in Table III. Specific impulse values are presented using both the manufacturer's stated propellant weight and the motor expended mass determined from pre- and postfire motor weights. When multiple channels of equal accuracy instrumentation data were used to obtain values of a single parameter, the average value was used to calculate the data presented.

4.1 ALTITUDE IGNITION CHARACTERISTICS

The motor was ignited at a pressure altitude of 111,000 ft. Variation of thrust and chamber pressure during the ignition event is shown in Fig. 6. Also shown (Fig. 6b) is a typical ignition event from Ref. 2. These figures are shown for comparison since the chamber pressures reported herein were measured through the Pyrogen pressure port. The igniter for the motor reported herein incorporated two Hi-Shear PC-37-03 short delay squibs. The igniters for the motors previously tested (Refs. 1 and 2) incorporated McCormick-Selph squibs (nominal 15-sec delay).

The ignition lag time (t_ℓ) for the motor reported herein was 0.001 sec. This value cannot be directly compared with the t_ℓ values presented in Refs. 1 and 2 because of the differences in squib types and location of the chamber pressure measuring ports. However, the comparison of Figs. 6a and b shows that thrust increased at about the same time after the first indication of Pyrogen pressure (chamber pressure for the motor herein), and it is, therefore, concluded that the ignition event of motor S/N 00010 agreed closely with the ignition events presented in Refs. 1 and 2.

4.2 ALTITUDE BALLISTIC PERFORMANCE

The variations of thrust, chamber pressure, and test cell pressure for the motor firing are shown in Fig. 7.

Since the nozzle does not operate fully expanded at the low chamber pressures 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, the interval during which nozzle throat flow was sonic (t_{is}) was segmented, and the method used to determine vacuum impulse is described in Fig. 8. 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 the sudden increase in cell pressure). After this time, flow at the nozzle throat was considered to be at sonic velocity until the time (t_s) at which the ratio of motor chamber pressure to cell pressure had decreased to a value of 1.3.

The time interval (t_1 to t_2) is a one-second interval of motor operation just prior to decrease in chamber pressure (Fig. 8). Performance characteristics for the motor are tabulated in Table IV along with the performance characteristics of the six previous motor firings reported in Refs. 1 and 2. The ballistic performance of the motor reported herein agrees closely with the performance of the six previous TE-M-364-3 motors tested. The average vacuum total impulse and vacuum specific impulse values for the six previously tested motors (Ref. 1 and 2) were 419,046 lbf-sec and 291.02 lbf/sec/lbm, respectively. Corresponding values for the motor reported herein were 418,954 lbf-sec and 290.95 lbf-sec/lbm. Postfire inspection of the motor case interior revealed no evidence of propellant slivers.

4.3 STRUCTURAL INTEGRITY

Examination of motion-picture film of the subject test firing revealed a pronounced "hot spot" which became visible approximately 39 sec after ignition (Fig. 9). The "hot spot" developed approximately 4 in. aft of the nozzle attachment flange at a circumferential location of about 230 deg. Slight sparking with accompanying smoke was observed, but no "torching," associated with a direct burnthrough, was noted. Examination of the nozzle in the region of the observed "hot spot" revealed a soft area externally and a large cracked area internally (Fig. 10). It is believed that cracking of the carbon cloth phenolic internal nozzle wall altered the heat loading on the wall which caused some of the nozzle insulation material to burn away and unbonding of the external fiber glass phenolic overwrap. Complete nozzle burnthrough was probably imminent at motor burnout. Postfire inspection of the nozzle showed that the fiber glass overwrap had become unbonded in several locations (Fig. 10a), and interior cracking of the carbon cloth phenolic, similar to that seen in the six TE-M-364-3 motors previously tested at the AEDC (Refs. 1 and 2), had occurred (Fig. 10b). The structural integrity of the motor case appeared satisfactory since no distortion or thermal damage to the case was observed.

Motor case and nozzle temperatures are presented in Fig. 11. The maximum case temperature was 747°F and occurred approximately 115 sec after motor ignition at thermocouple TC-9 (Fig. 11a) located at the junction of the insulated and uninsulated portion of the forward hemisphere over a propellant peak. The motor qualification specification (Ref. 4) states that the temperature of the motor case external surface shall not exceed 500°F at any time from ignition to 150 sec thereafter. However, maximum temperature was nominal for the TE-M-364-3 motors fired to date. The maximum nozzle temperature was 711°F and occurred approximately 50 sec after motor ignition at thermocouple TC-21 (Fig. 11f) located approximately 1 in. forward of the exit plane.

Motor case and nozzle flange strain data are presented in Fig. 12. The maximum strain level measured was 4500 μin./in. (tension) and occurred approximately 26 sec after motor ignition at grid SG-45 (Fig. 12o), located on the aft end of the nozzle flange at a circumferential location of 0 deg (see Fig. 5b for detailed strain-grid locations).

Two, triaxial flight-type strain grids supplied by McDonnell-Douglas were located at circumferential locations of 0 and 180 deg (Fig. 5b). Strain levels, as measured by these grids, were in good agreement with the strain levels obtained from the Thiokol-supplied (commercial-grade) tiraxial grids located at 90 and 270 deg. Analysis of the biaxial grid data revealed that the maximum hoop strain levels were relatively constant (~2600 μin. / in. tension), whereas the maximum longitudinal strain levels increased from about 1000 μin. / in. (compression) on the ID of the flange to 3500 μin. / in. at the OD. All strain grids were installed by Thiokol Representatives using Eastman 910® adhesive.

Pre- and postfire nozzle throat measurements revealed that the throat area increased 11.32 percent during the firing. Postfire measurements of the nozzle exit were not attempted because of minor damage sustained by the nozzle during removal from the motor.

SECTION V
SUMMARY OF RESULTS

One Thiokol Chemical Corporation TE-M-364-3 solid-propellant rocket motor was temperature conditioned at 75 ± 5°F for a period in excess of 48 hr and fired at an average simulated altitude of 106,000 ft while spinning about its axial centerline at 110 rpm. Results are summarized as follows:

1. A small "hot-spot" developed on the nozzle approximately 4 in. aft of the attachment flange at approximately 39 sec after motor ignition. Postfire examination of the nozzle in the region of the observed "hot-spot" revealed a soft area externally and a large cracked area internally.
2. Postfire inspection of the nozzle showed that the fiber glass overwrap had become unbonded from the nozzle in several locations, and interior cracking, similar to that seen in previous TE-M-364-3 motors tested at the AEDC, was observed. The motor case structural integrity appeared satisfactory.

3. The vacuum total impulse value during the time that the nozzle throat flow remained sonic was 418, 594 lbf-sec. The corresponding vacuum specific impulse value, based on the manufacturer's stated propellant weight, was 290. 95 lbf-sec/lbm.
4. The time interval from the time at which firing voltage was applied to the igniter circuit to the time of increase in chamber pressure was 0. 001 sec.
5. The time interval between 10 percent of maximum chamber pressure during ignition and 10 percent of maximum chamber pressure during tailoff (t_a) was 44. 5 sec.
6. The maximum measured case temperature was 747°F, occurring approximately 115 sec after ignition at an area on the forward hemisphere between the insulated and uninsulated portion of the case. This temperature exceeds the 500°F maximum specified in the motor qualification specification.
7. The maximum strain value measured on the nozzle flange was 4500 μin. / in. (tension), occurring approximately 26 sec after ignition.

REFERENCES

1. White, D. W. and Harris, J. E. "Qualification Tests of Thiokol Chemical Corporation TE-M-364-3 Solid-Propellant Rocket Motors Tested in the Spin and No-Spin Mode at Simulated Altitude Conditions (Part I - Initial Phase)." AEDC-TR-67-179 (AD821825), October 1967.
2. White, D. W. and Harris, J. E. "Qualification Tests of Thiokol Chemical Corporation TE-M-364-3 Solid-Propellant Rocket Motors Tested in the Spin and No-Spin Mode at Simulated Altitude Conditions (Part II - Final Phase)." AEDC-TR-67-256 (AD824952), January 1968.
3. <u>Test Facilities Handbook</u> (8th Edition)(AD863646). "Rocket Test Facility, Vol. 2." Arnold Engineering Development Center, December 1969.
4. Douglas Aircraft Specification Number CP00154A.

APPENDIXES
I. ILLUSTRATIONS
II. TABLES

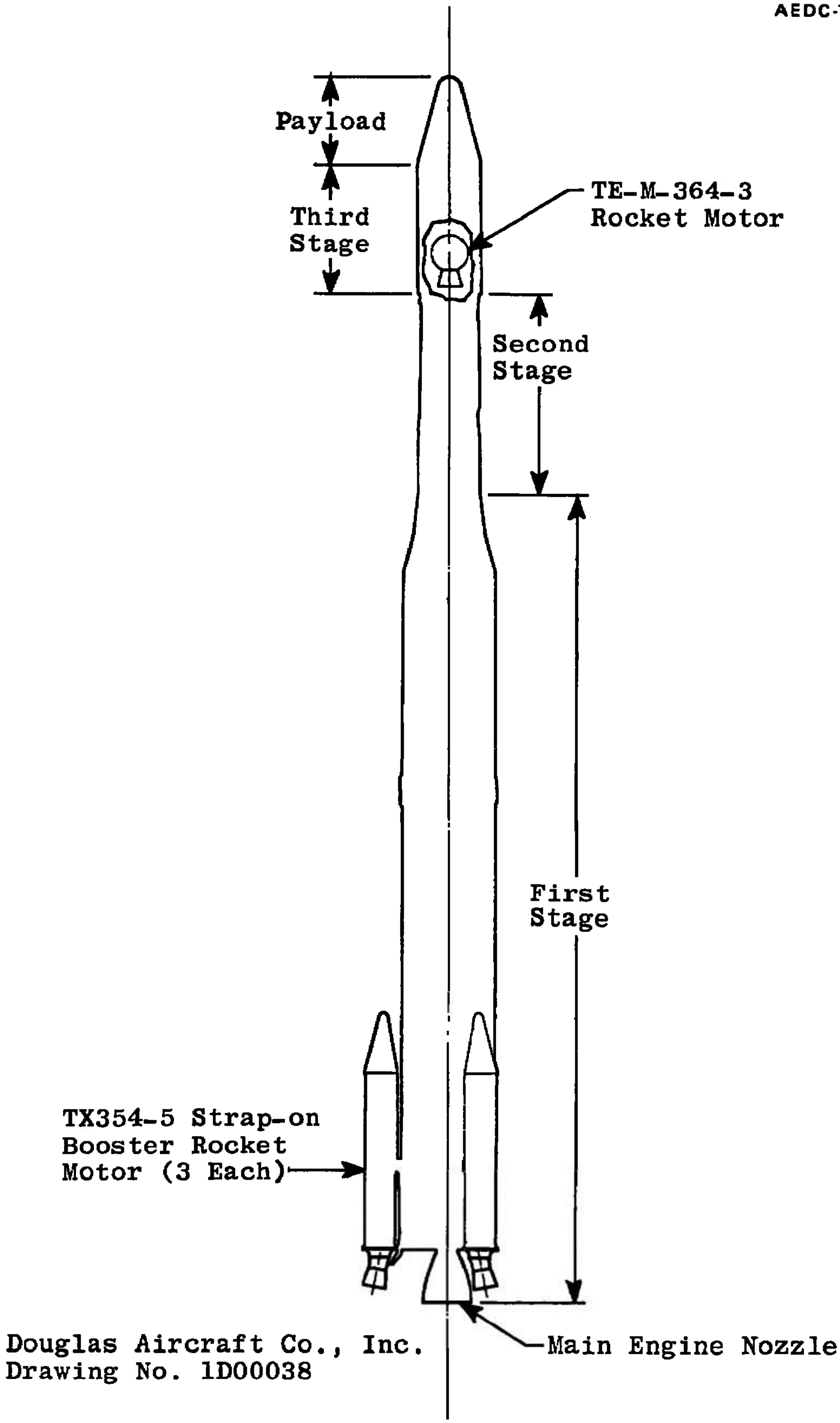
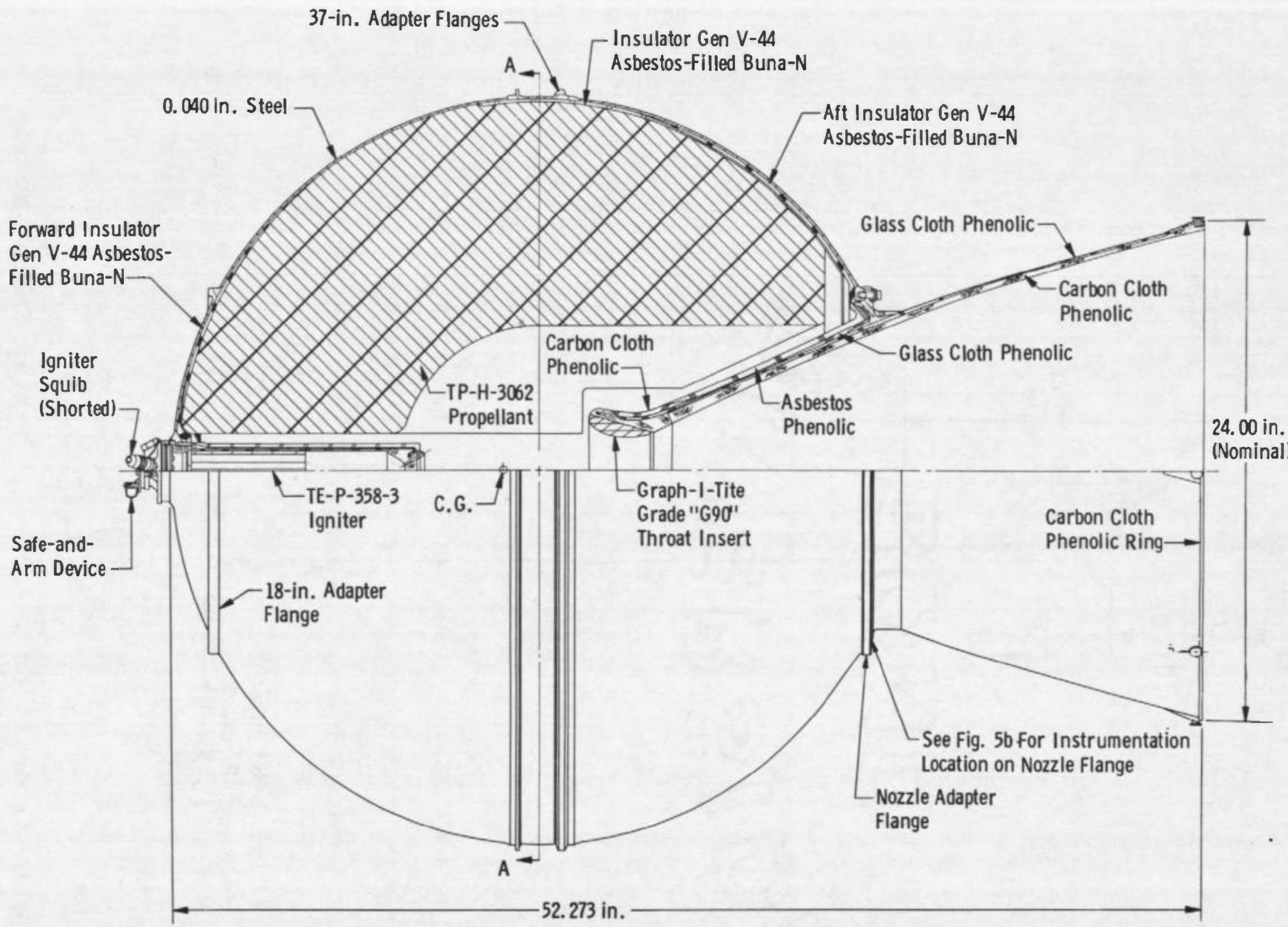
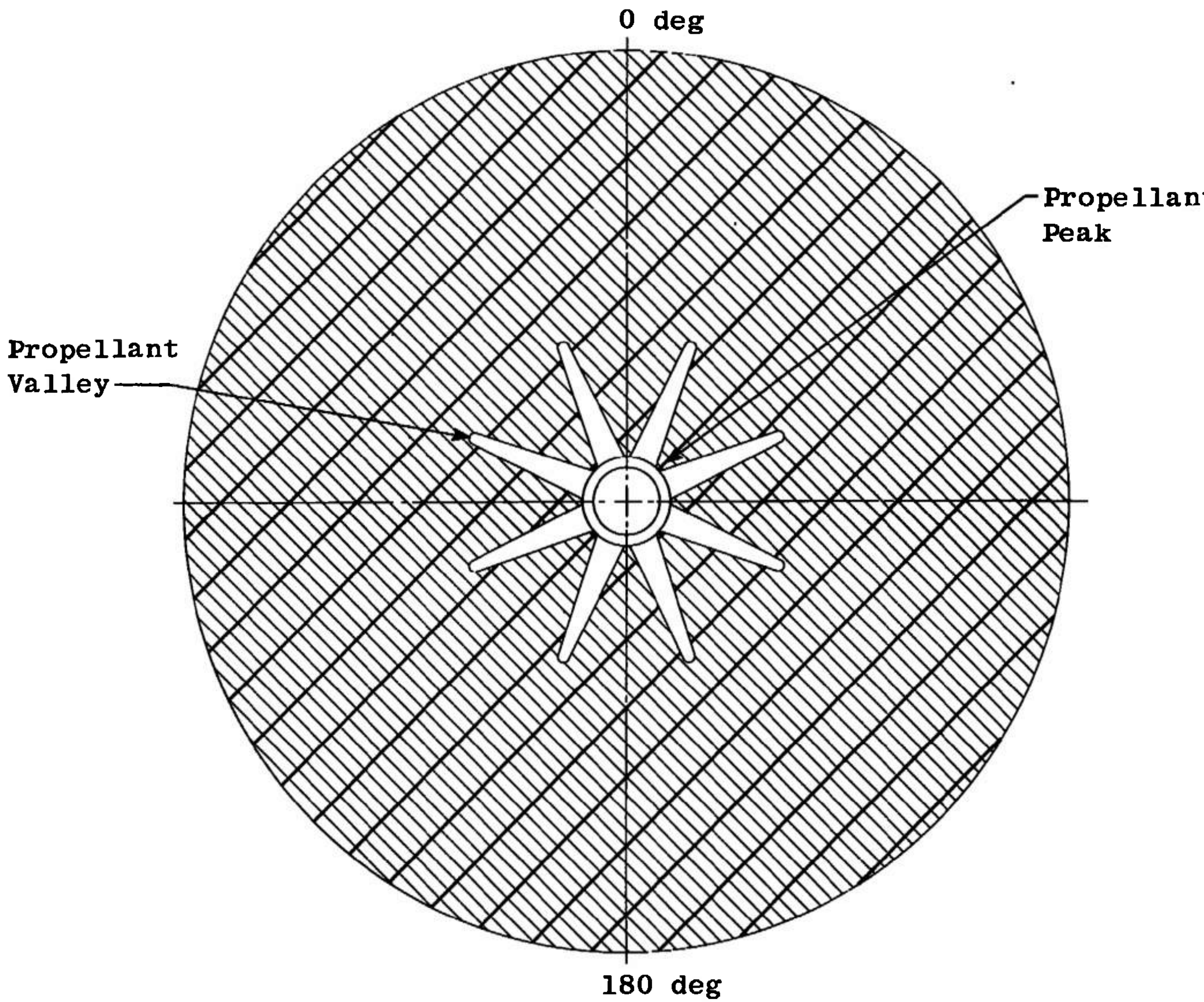


Fig. 1 Schematic of the Improved Delta Launch Vehicle DSV-3E



a. Motor Schematic
Fig. 2 TE-M-364-3 Rocket Motor



b. Propellant Schematic (Section A-A)
Fig. 2 Continued

c. Photograph (Motor Installed in Mounting Can)

Fig. 2 Concluded

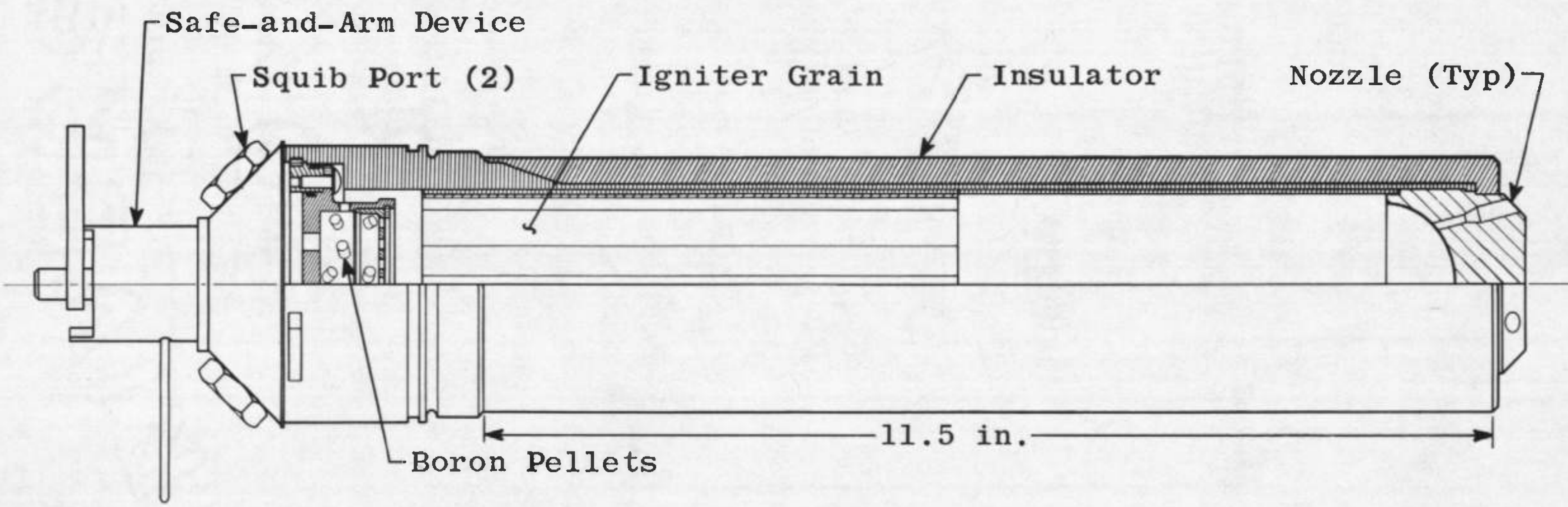
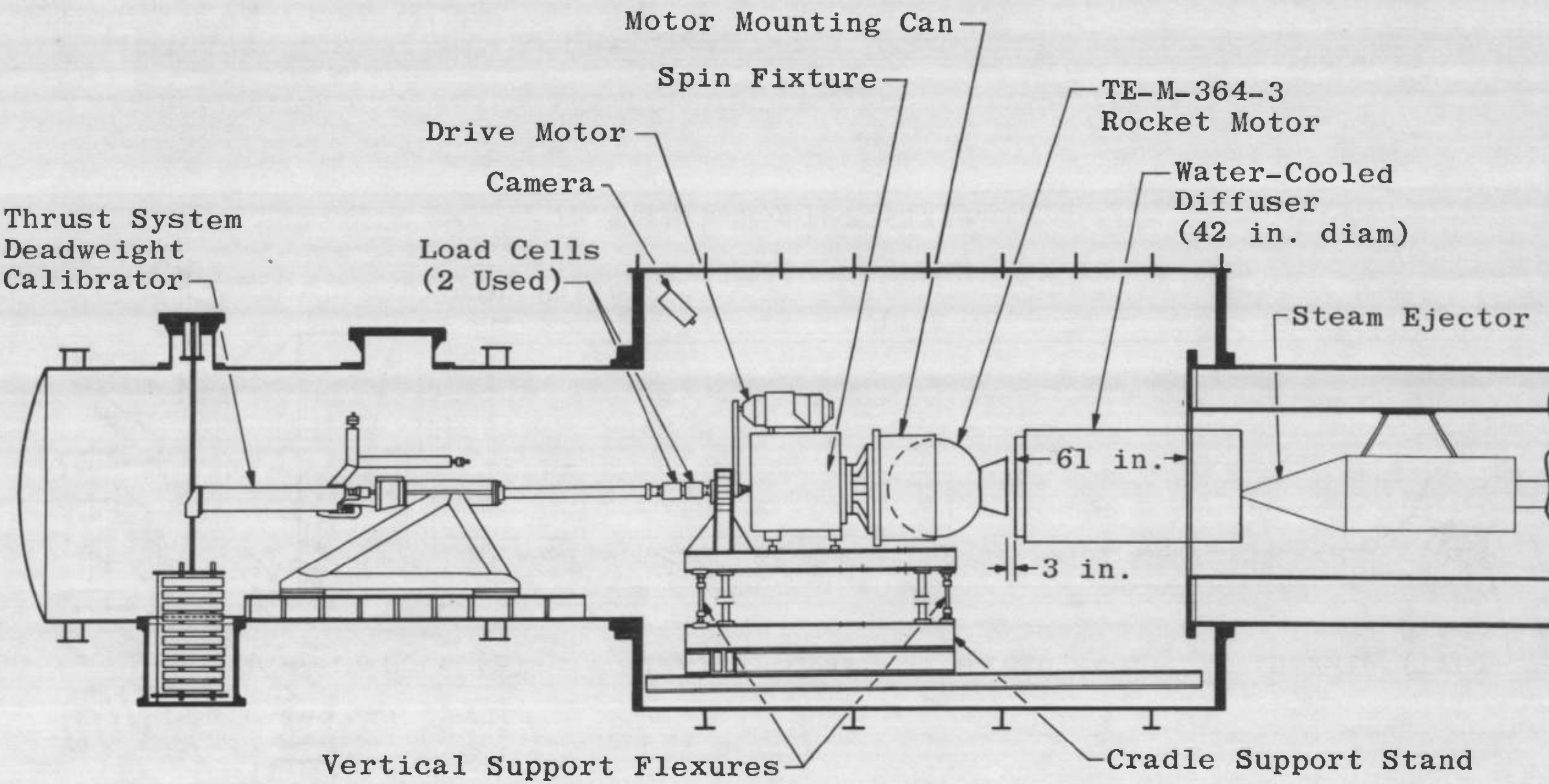
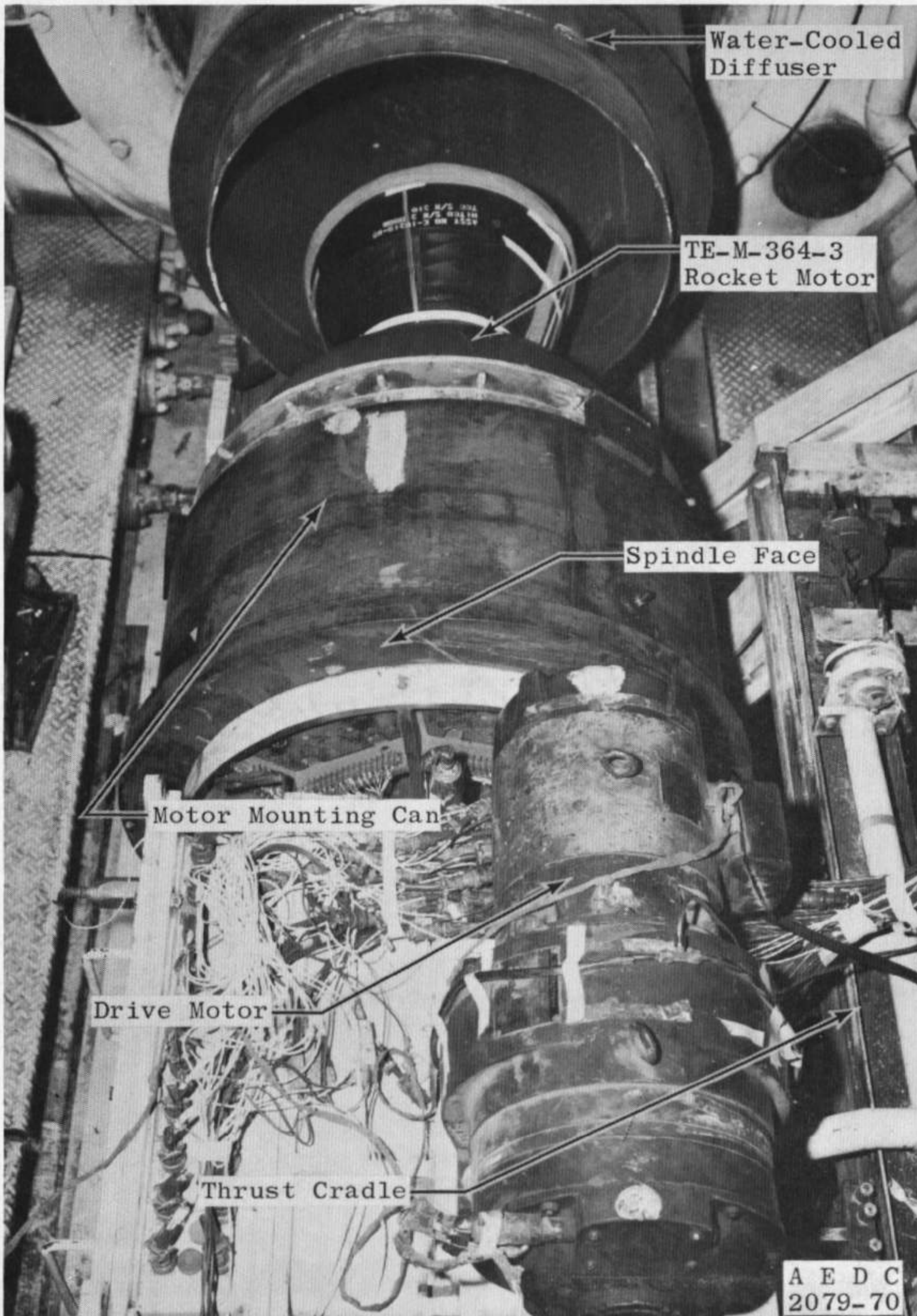


Fig. 3 Schematic of TE-P-358-3 Igniter

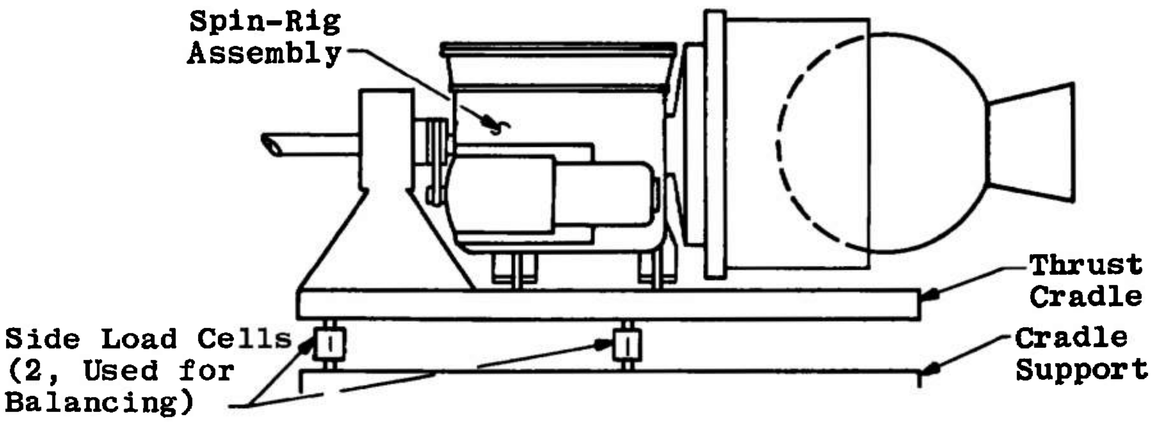


a. Schematic

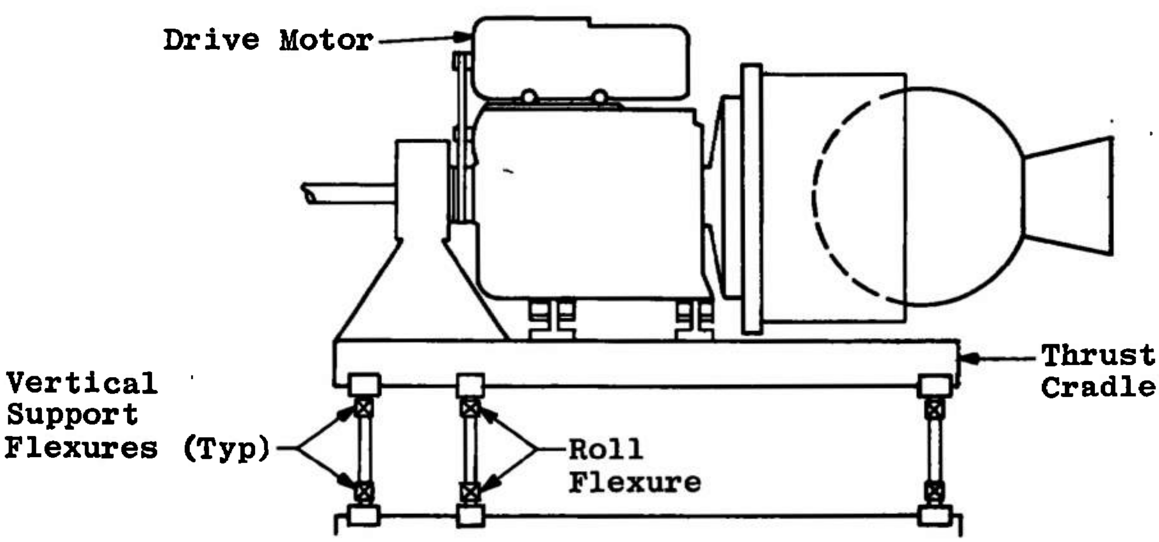
Fig. 4 Installation of the TE-M-364-3 Motor Assembly in Propulsion Development Test Cell (T-3)



b. Photograph (Looking Downstream)
Fig. 4 Continued



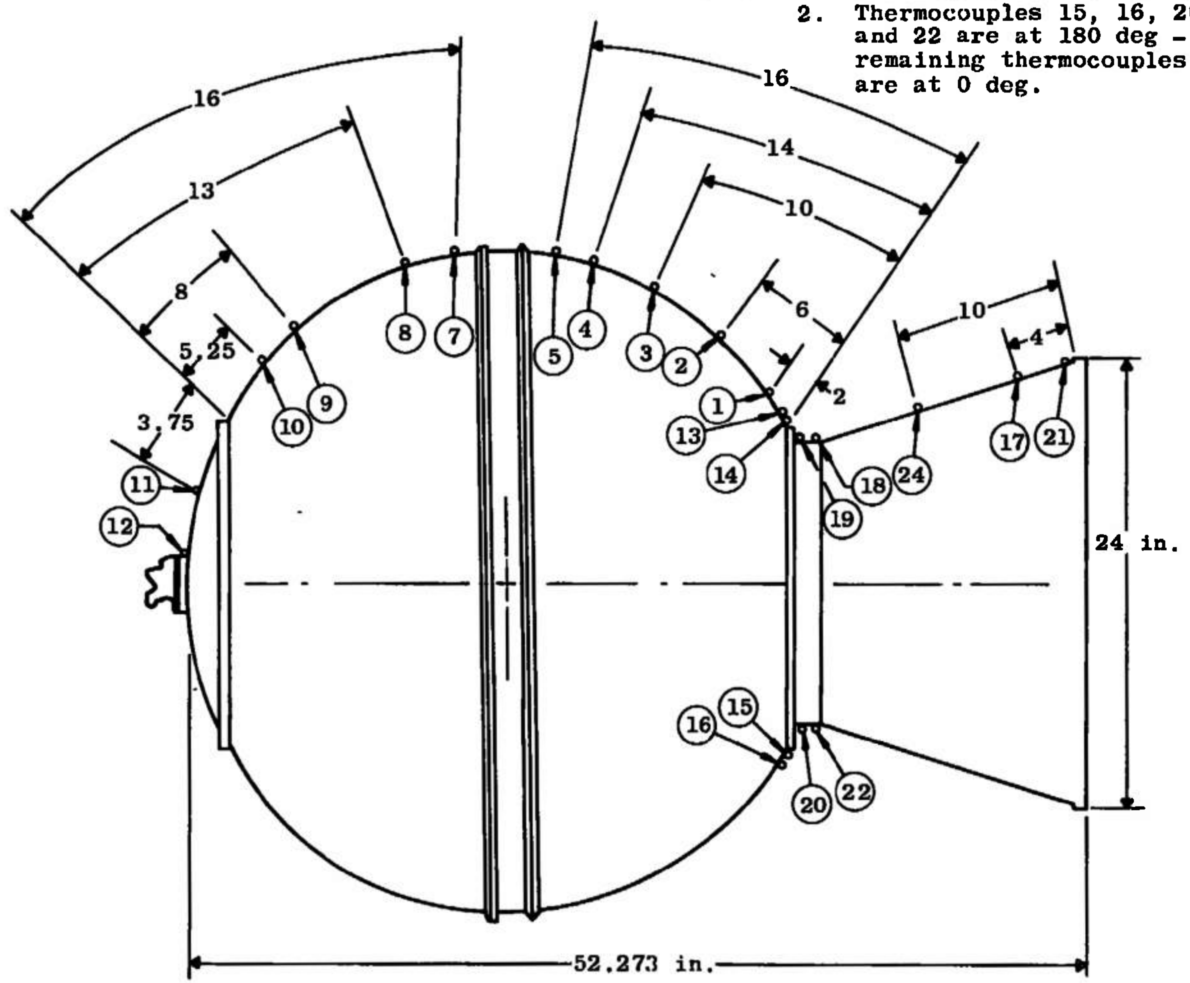
Plan View



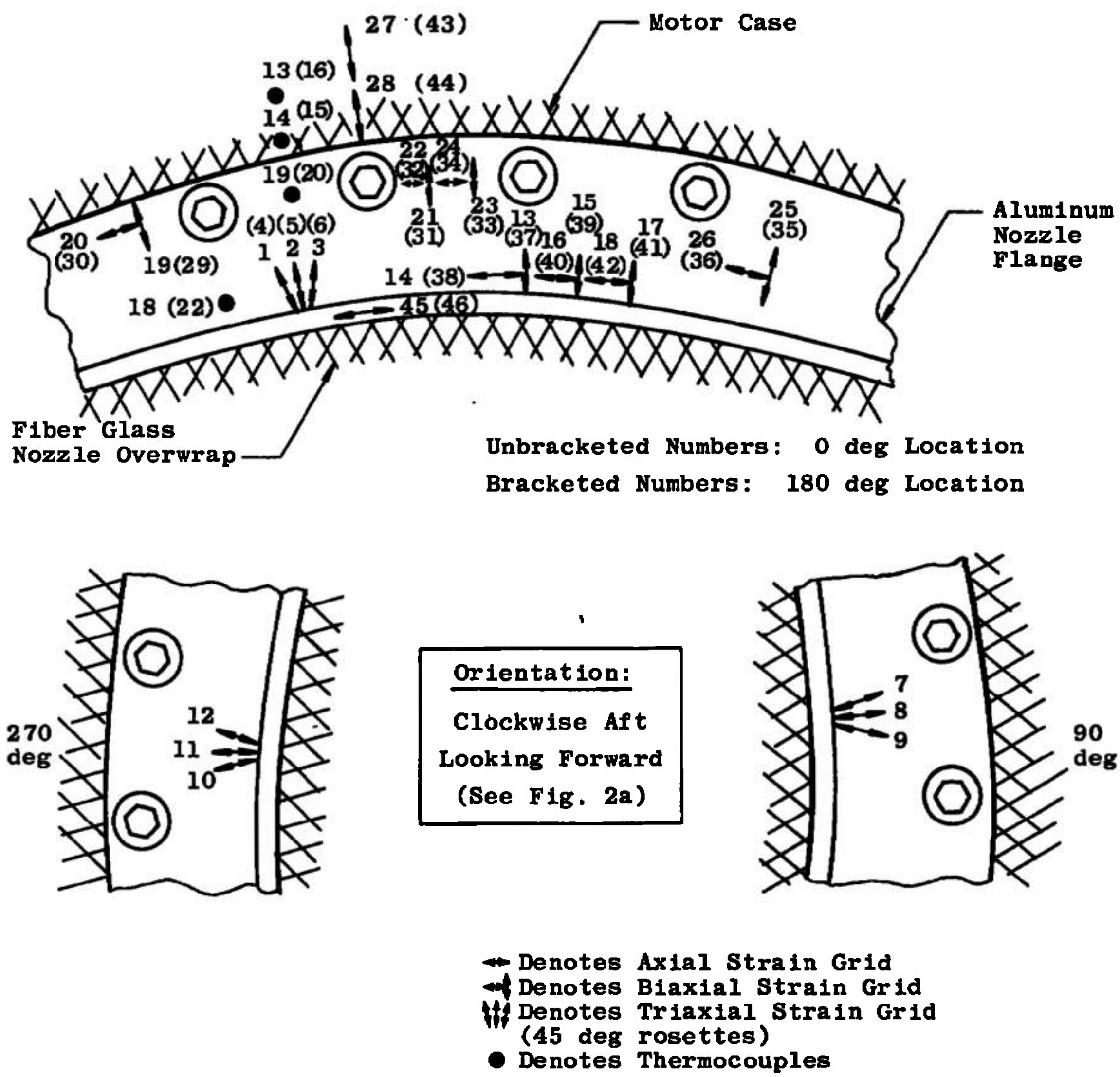
Elevation View

c. Detail
Fig. 4 Concluded

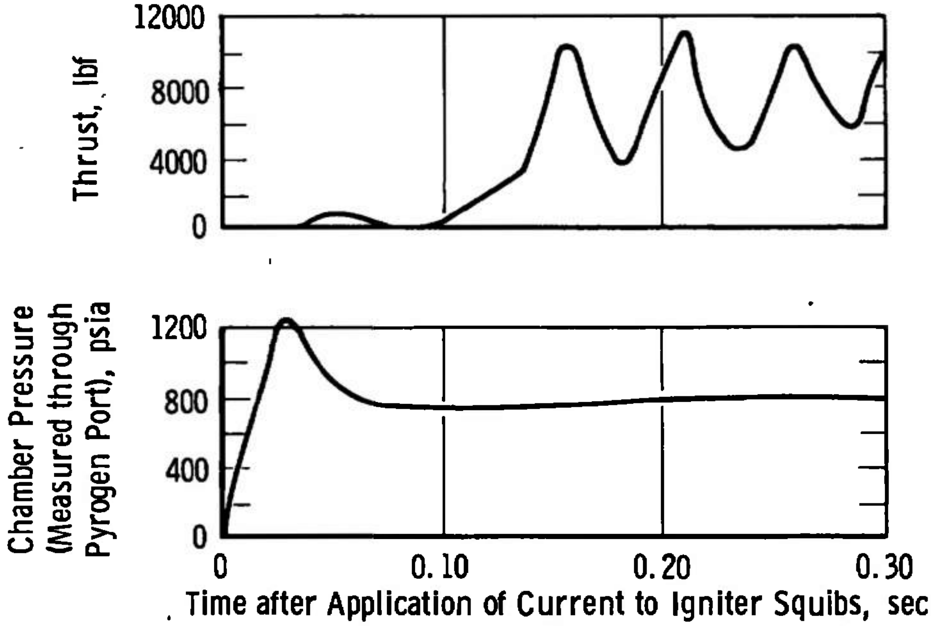
Note: 1. All Dimensions in Inches
2. Thermocouples 15, 16, 20, and 22 are at 180 deg - remaining thermocouples are at 0 deg.



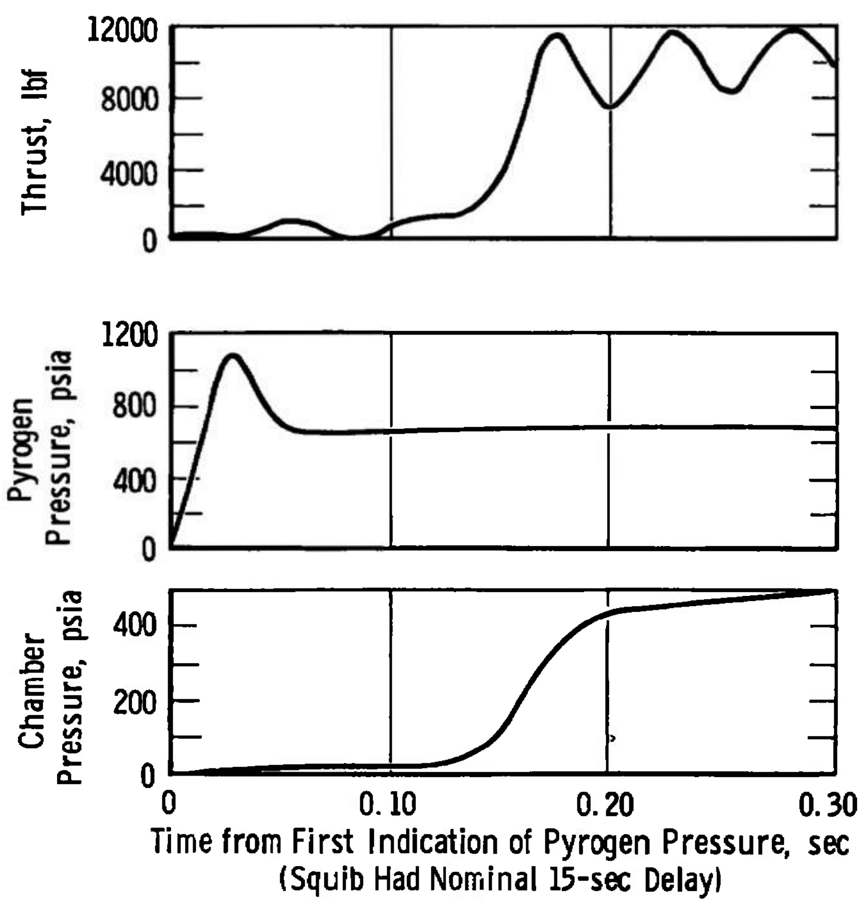
a. Thermocouples
Fig. 5 Instrumentation Locations



b. Strain Grid and Thermocouple Locations on Nozzle Flange
Fig. 5 Concluded



a. Motor S/N 00010



b. Typical Motor from Ref. 2

Fig. 6 Variation of Thrust and Chamber Pressure during the Motor Ignition Event

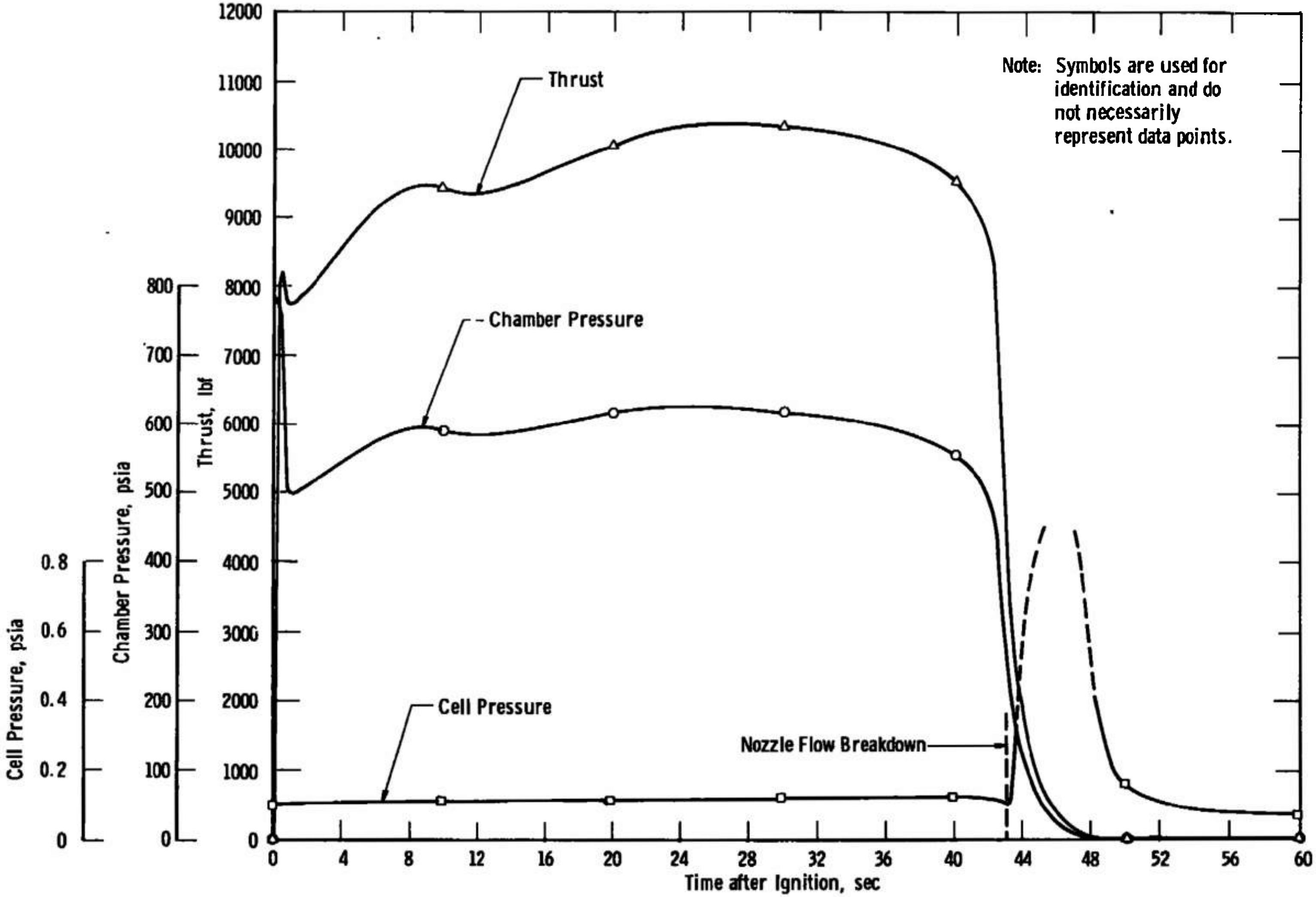
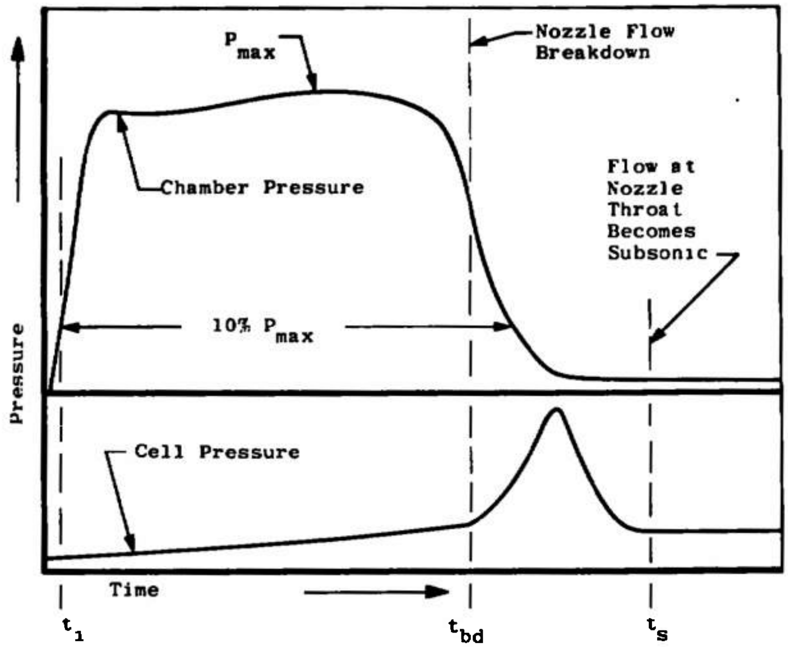


Fig. 7 Variation of Thrust, Chamber Pressure, and Test Cell Pressure during Motor Burn Time



$$I_{vac} = \int_{t_i}^{t_{bd}} F dt + A_{ex_{pre}} \int_{t_i}^{t_{bd}} P_{cell} dt + \bar{c}_f A_{t_{post}} \int_{t_{bd}}^{t_s} P_{ch} dt$$

$$\int_{t_i}^{t_{bd}} F dt = 412{,}399 \text{ lbf-sec}$$

$$\int_{t_i}^{t_{bd}} P_{cell} dt = 5.0119 \text{ psia-sec}$$

$$\int_{t_{bd}}^{t_s} P_{ch} dt = 250.00 \text{ psia-sec}$$

$$\bar{c}_f = \frac{\int_{t_1}^{t_2} F dt + A_{ex(pre)} \int_{t_1}^{t_2} P_{cell} dt}{A_{t_{post}} \int_{t_1}^{t_2} P_{ch} dt}$$

	S/N 00010
t_1 =	38.15
t_2 =	39.15
$\bar{c}_f$ =	1.854

Note: Postfire nozzle exit dimensions were not taken.

Fig. 8 Schematic of Chamber and Cell Pressure-Time Variation Defining Characteristic Events

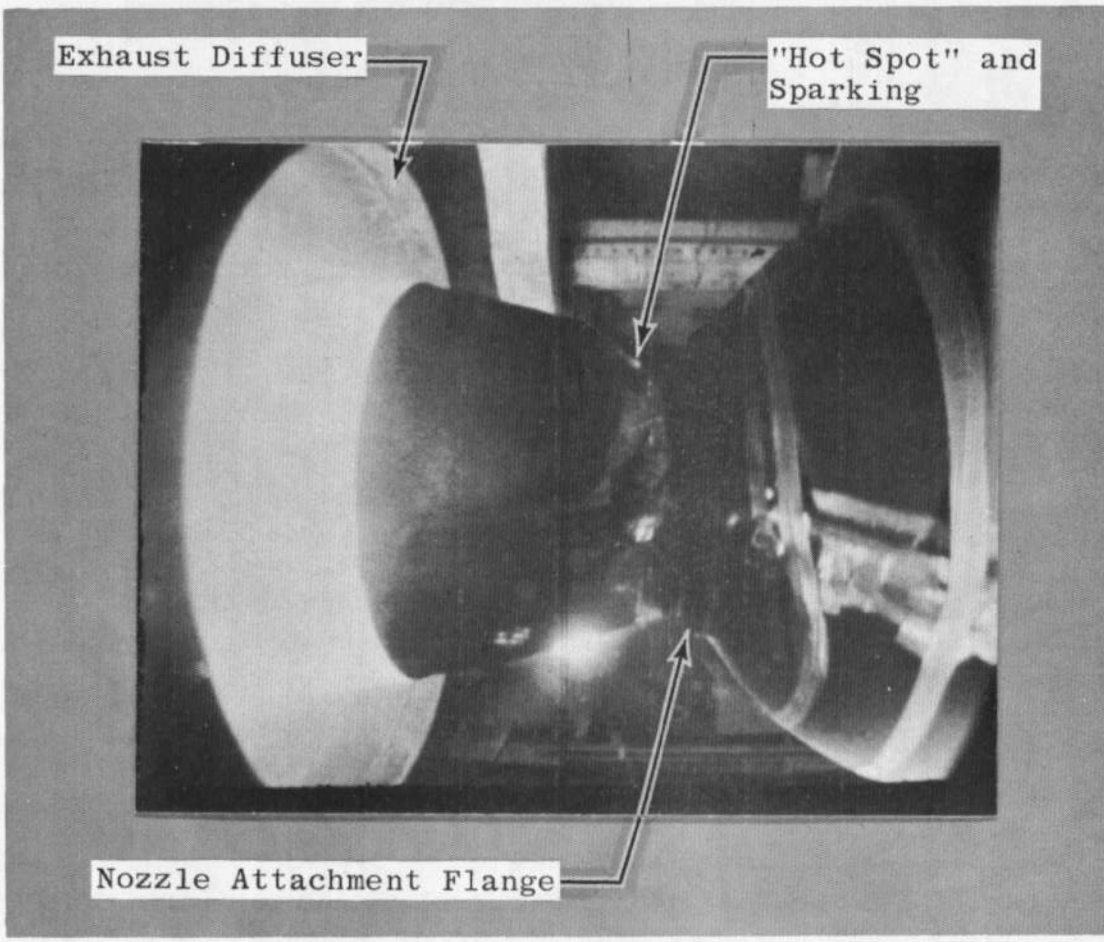
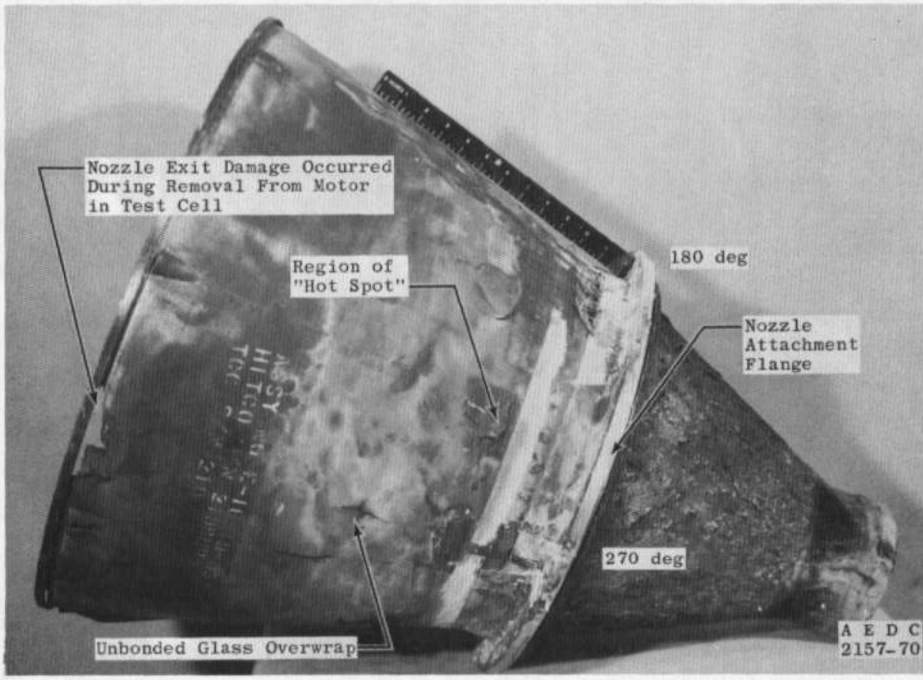


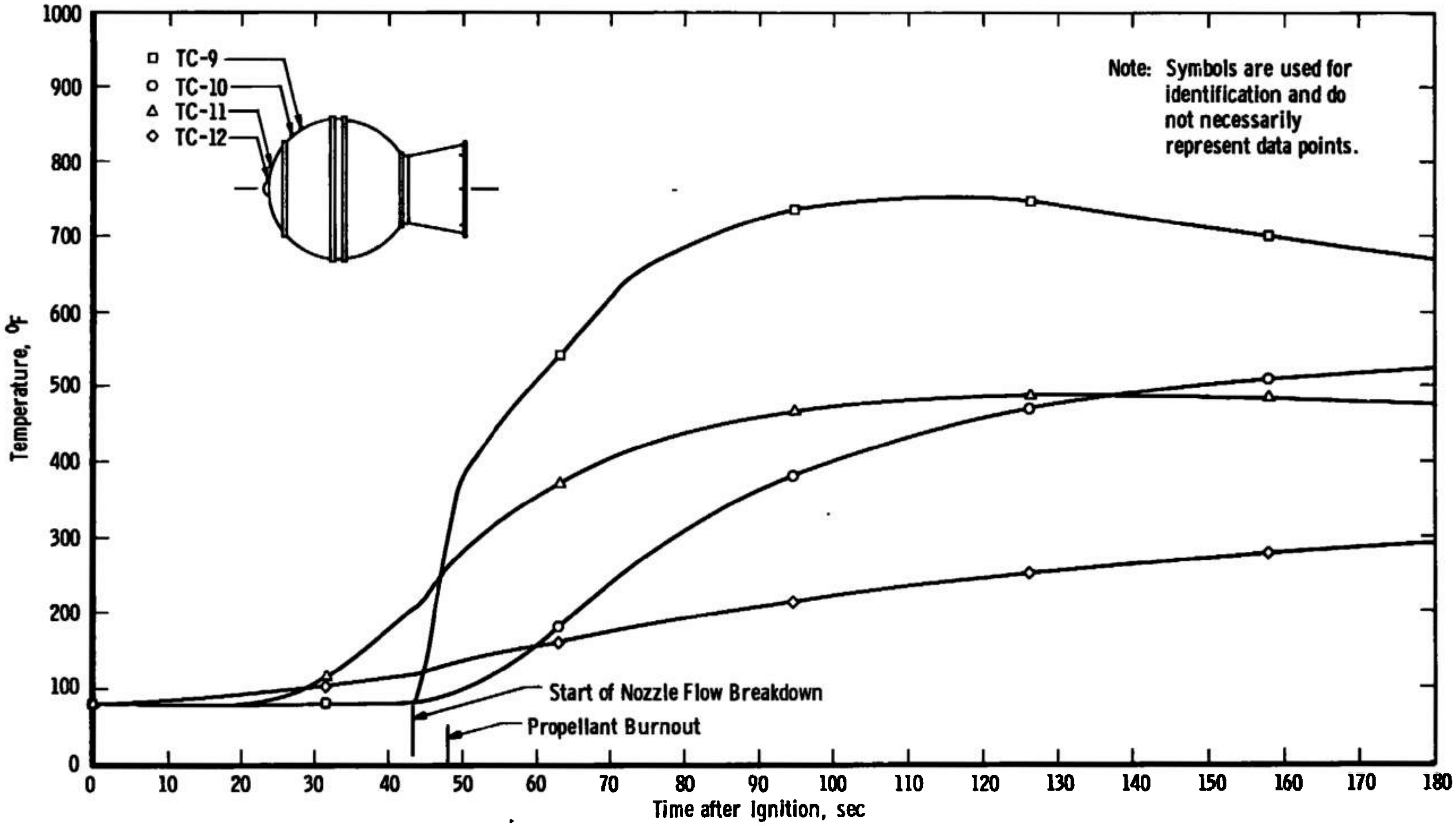
Fig. 9 Motion-Picture Frame Approximately 41 sec after Ignition Showing "Hot Spot" and Sparking



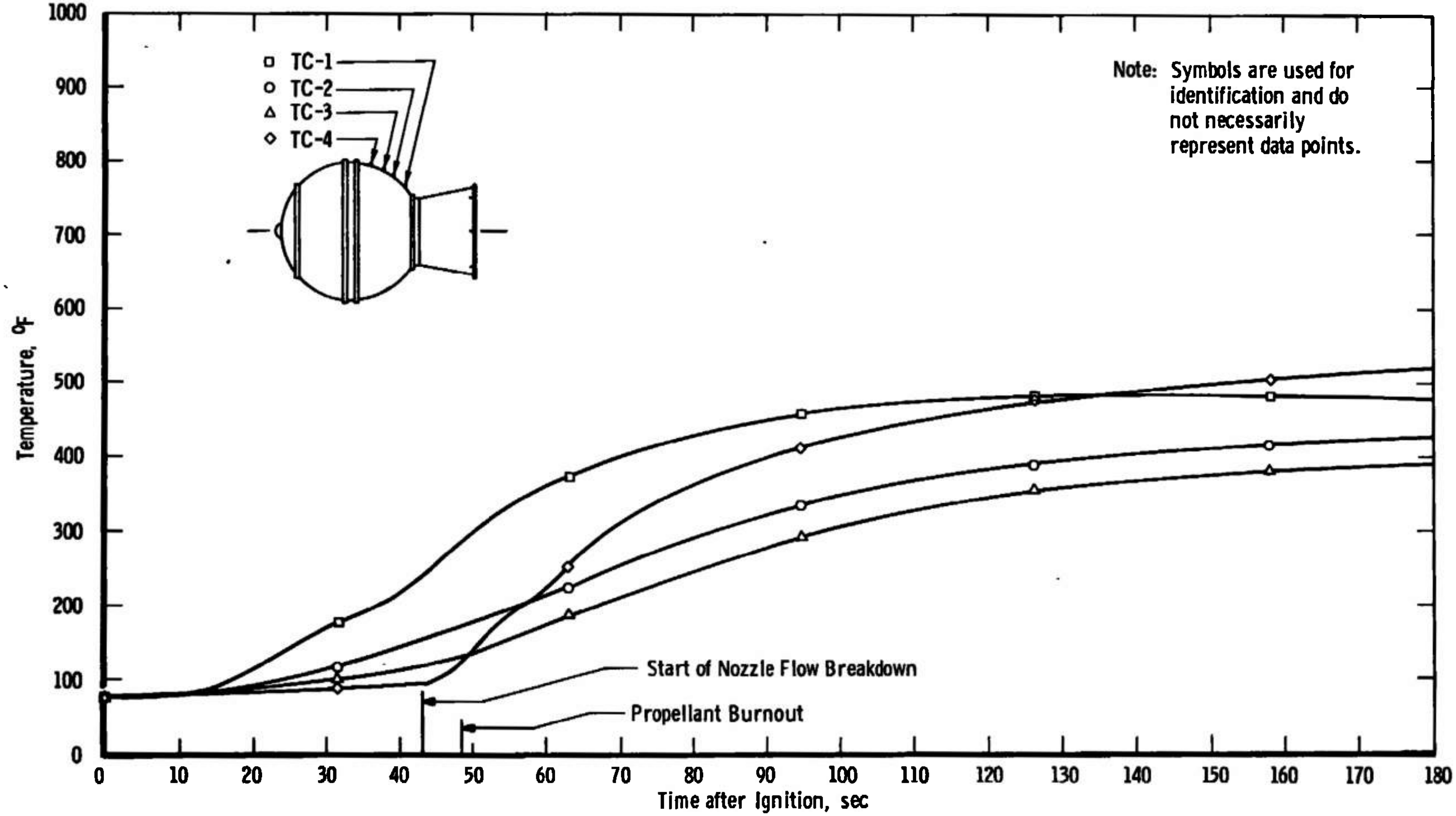
a. Exterior View

b. Interior View

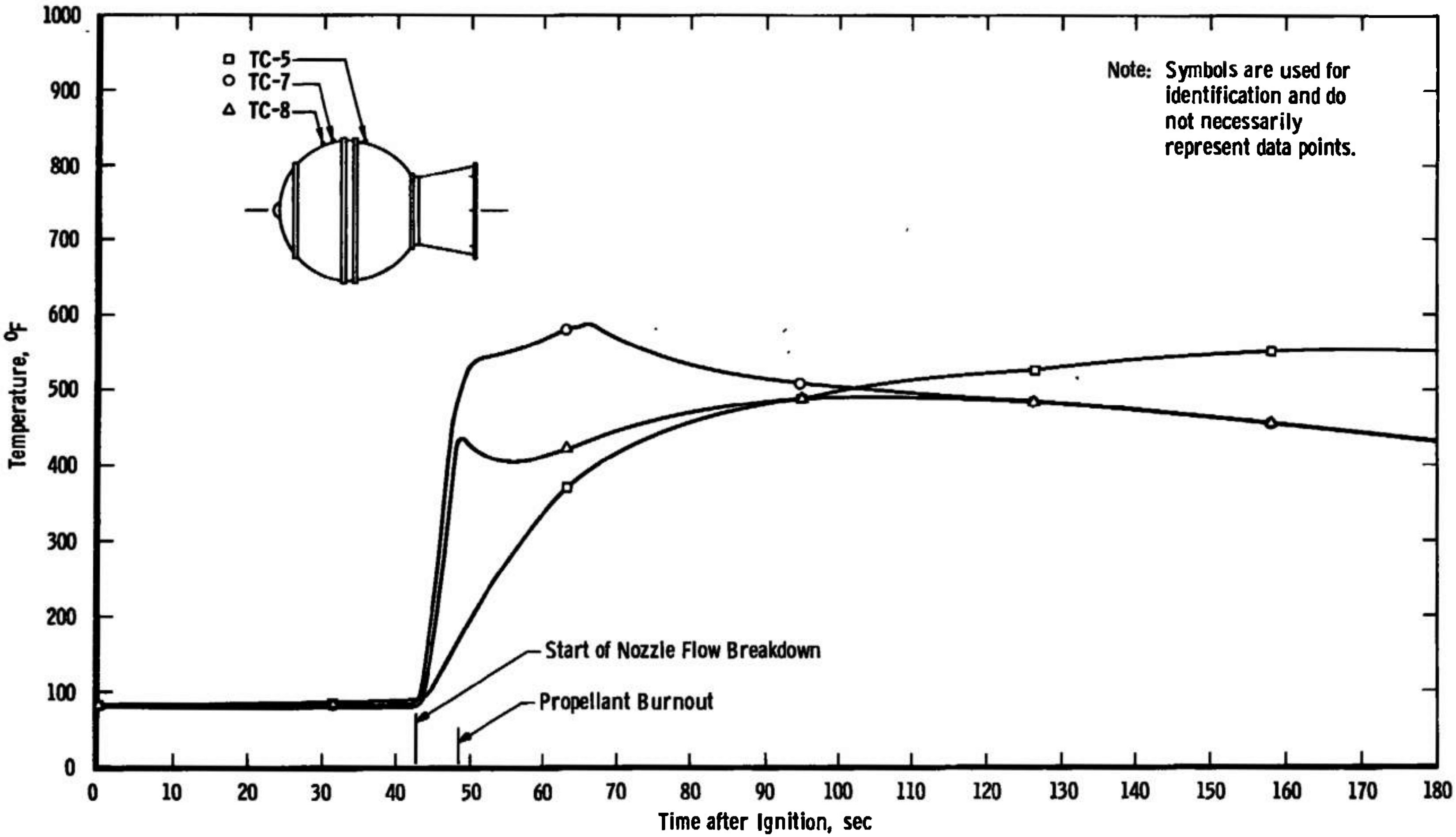
Fig. 10 Postfire Photograph of Nozzle Assembly



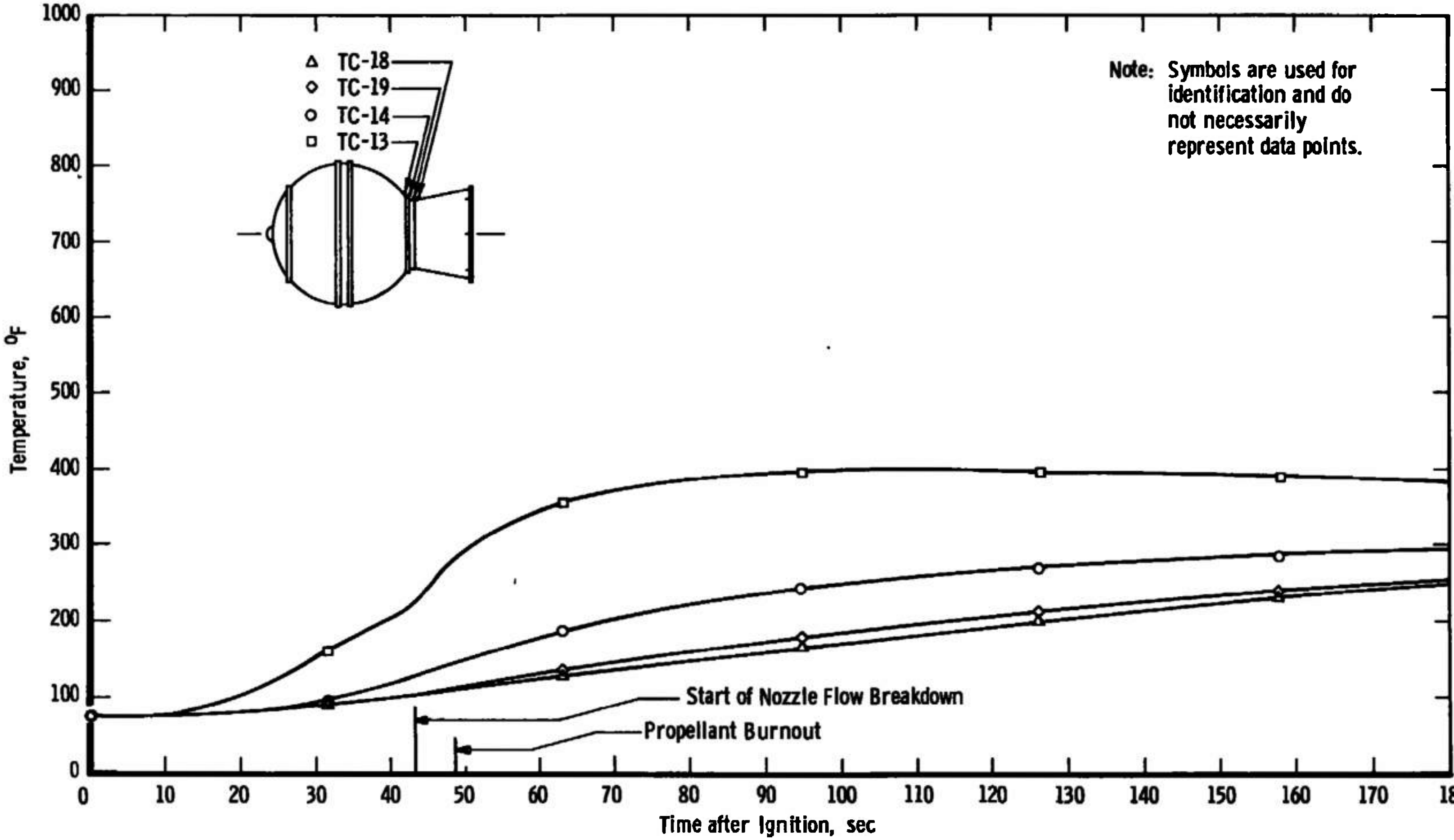
a. Forward Hemisphere (TC-9, TC-10, TC-11, TC-12)
Fig. 11 Time Variation of Motor Case Temperatures



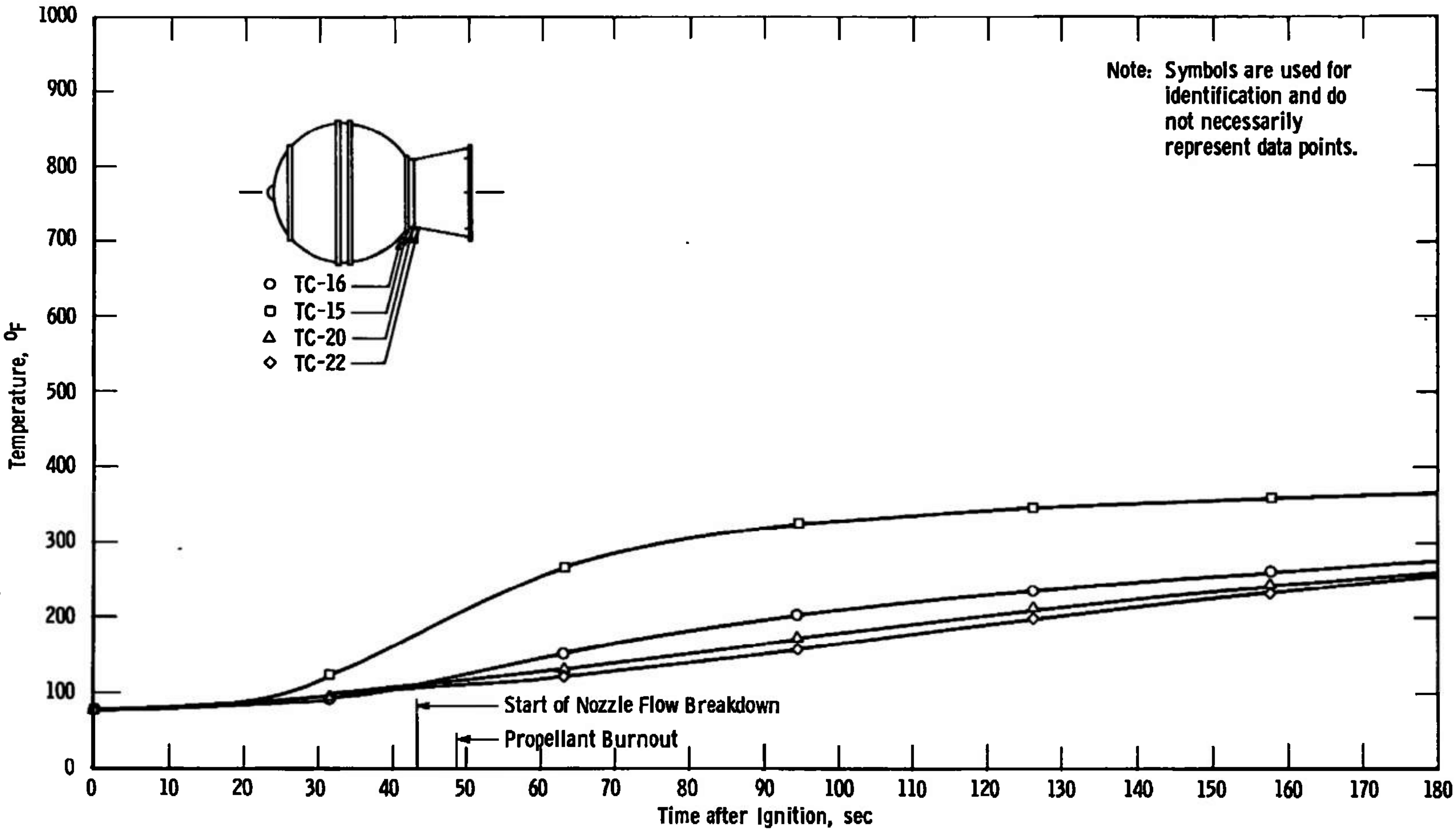
b. Aft Hemisphere (TC-1, TC-2, TC-3, TC-4)
Fig. 11 Continued



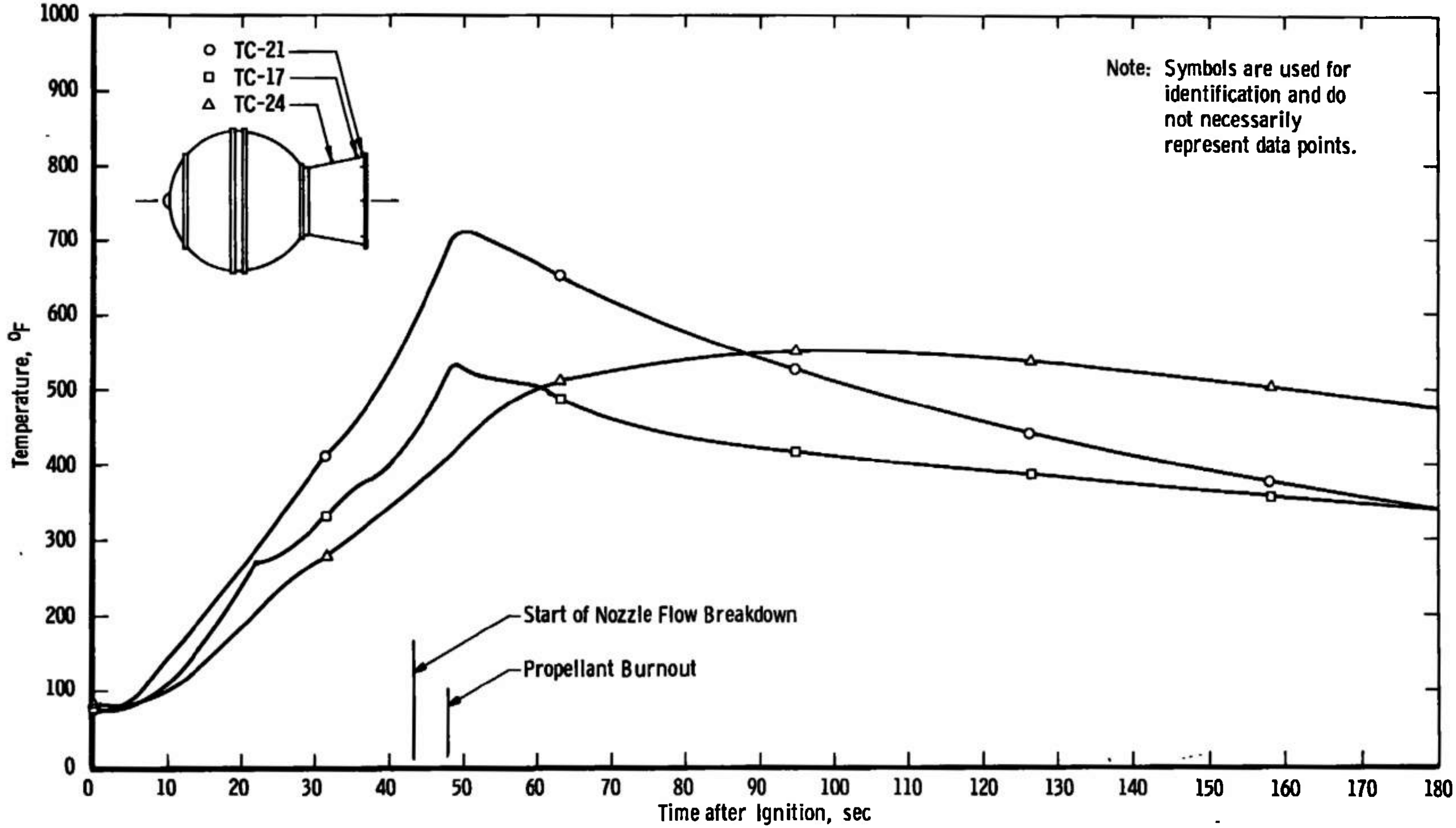
c. Midsection (TC-5, TC-7, TC-8)
Fig. 11 Continued



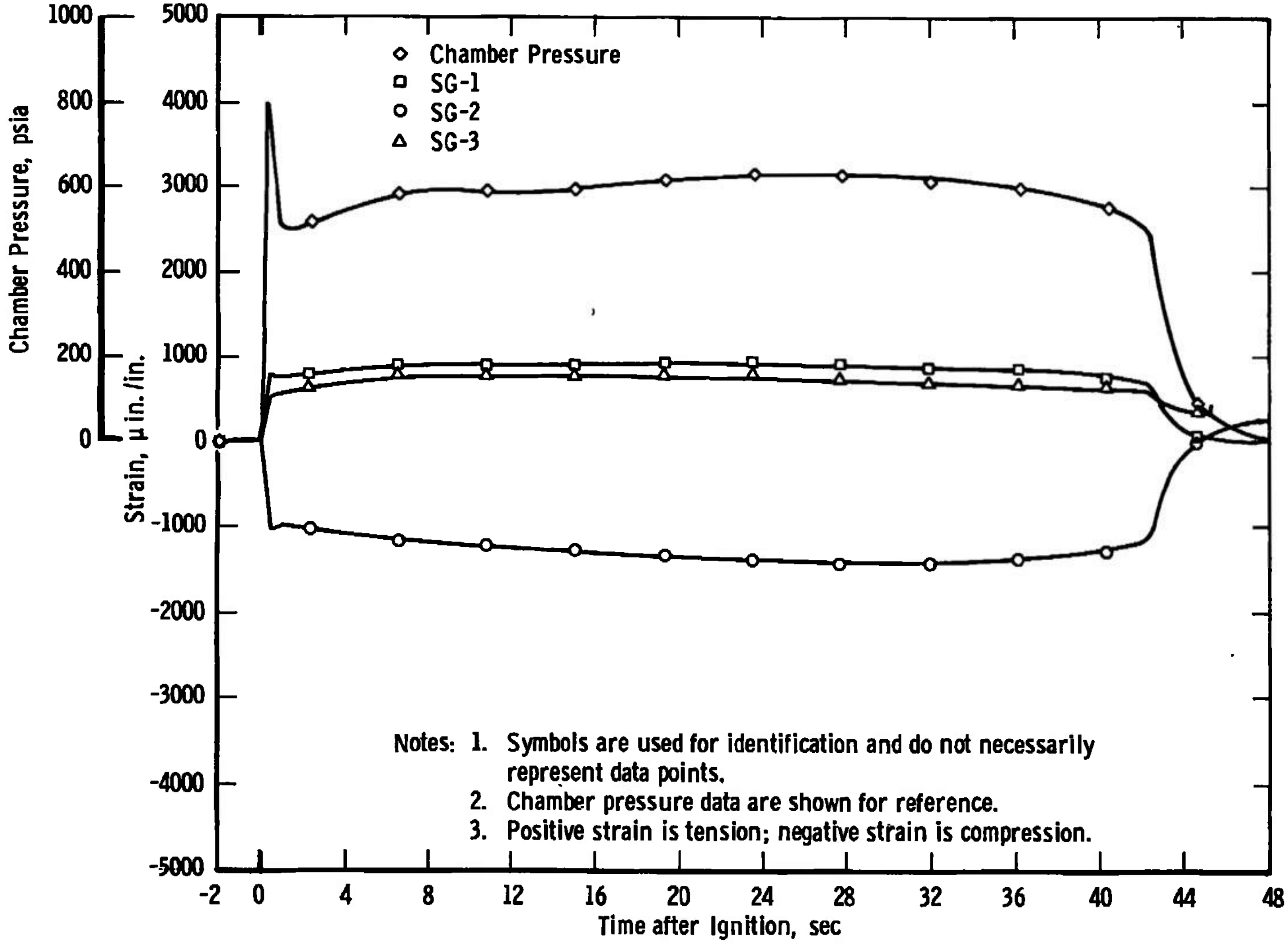
d. Nozzle Adapter Flange (0 deg) (TC-13, TC-14, TC-18, TC-19)
Fig. 11 Continued



e. Nozzle Adapter Flange (180 deg) (TC-15, TC-16, TC-20, TC-22)
Fig. 11 Continued

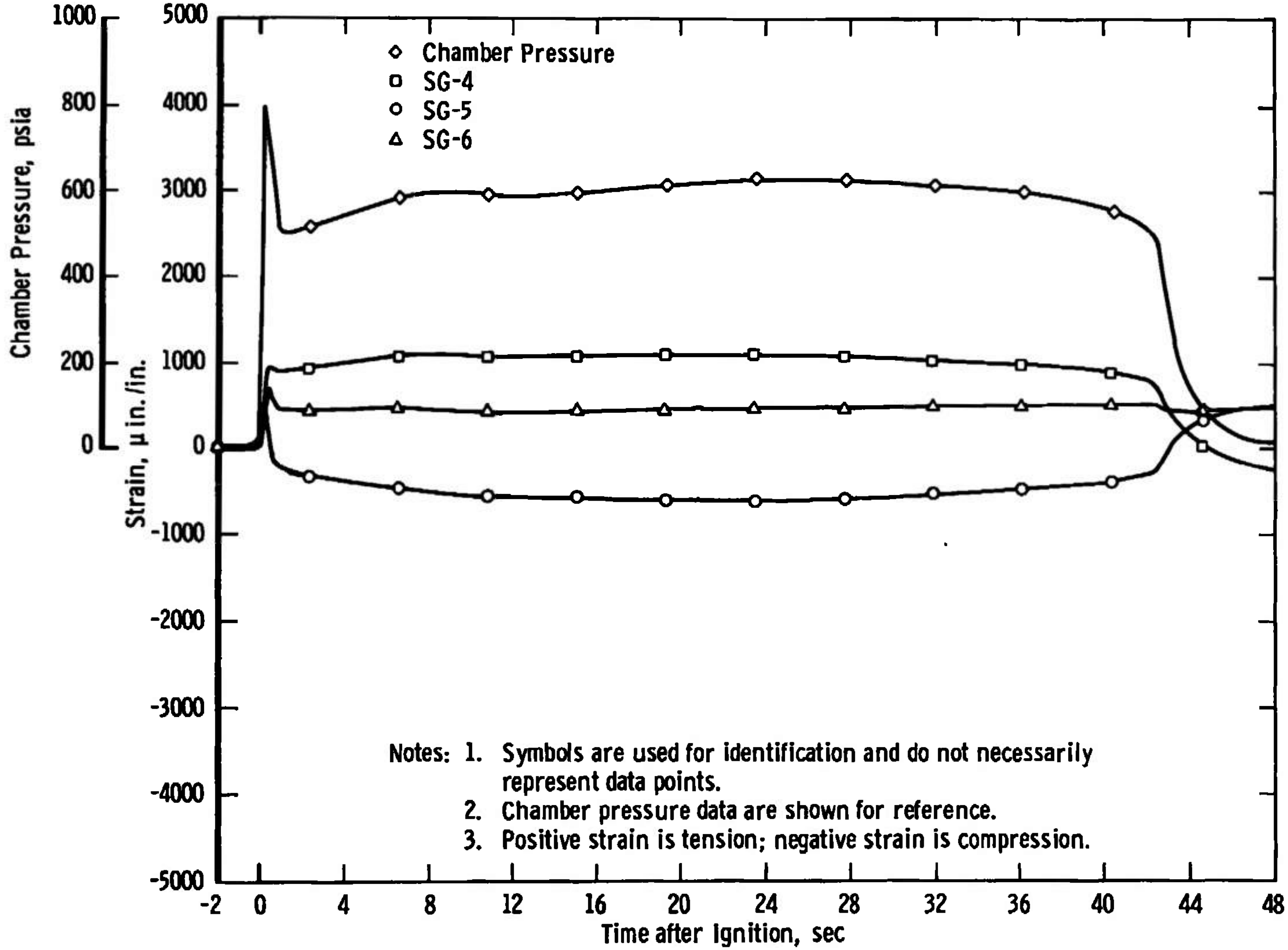


f. Nozzle (0 deg) (TC-17, TC-21, TC-24)
Fig. 11 Concluded

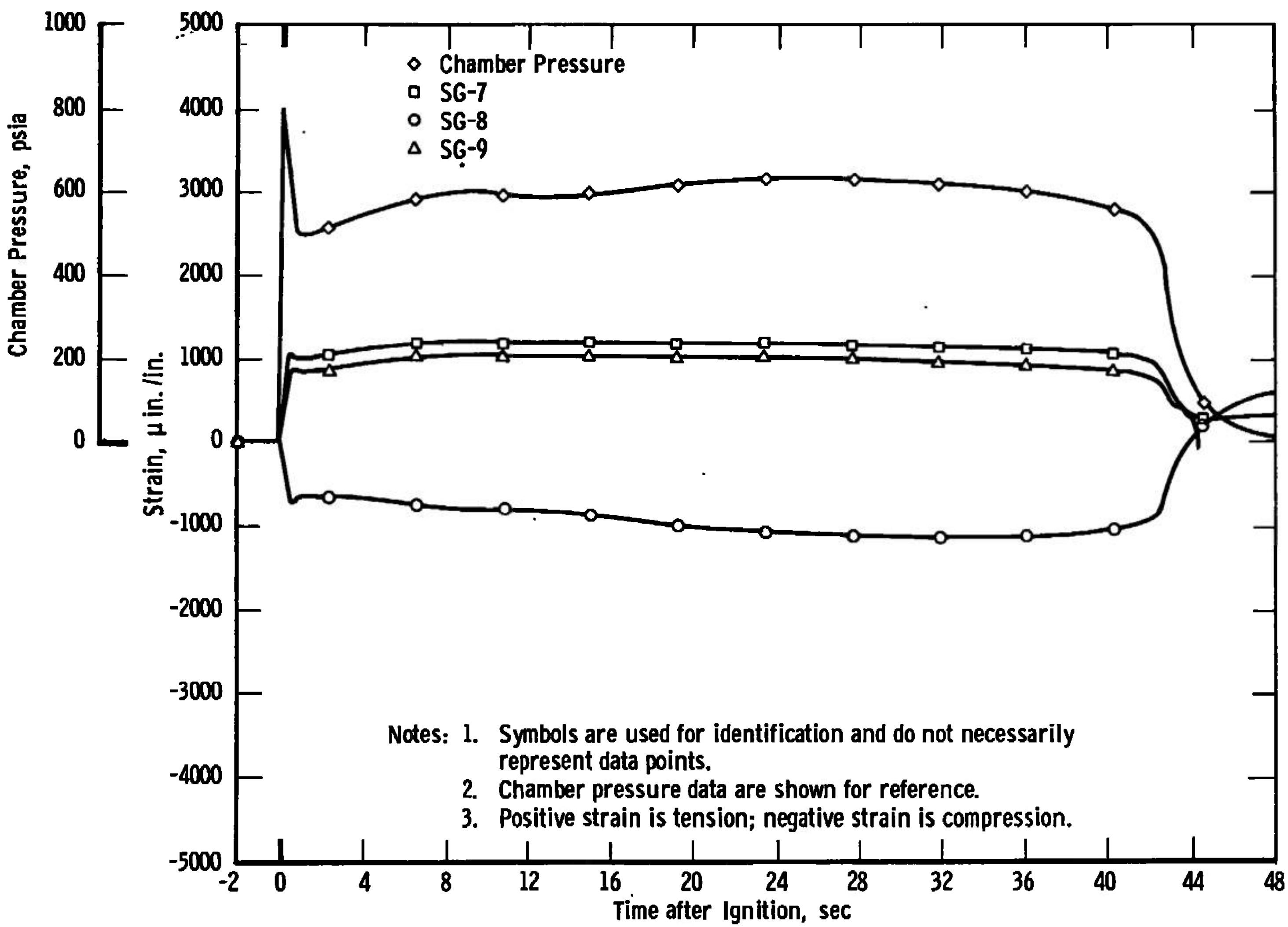


a. Flange (0 deg), Triaxial (SG-1, SG-2, SG-3)

Fig. 12 Case and Nozzle Adapter Flange Strain Variation with Time

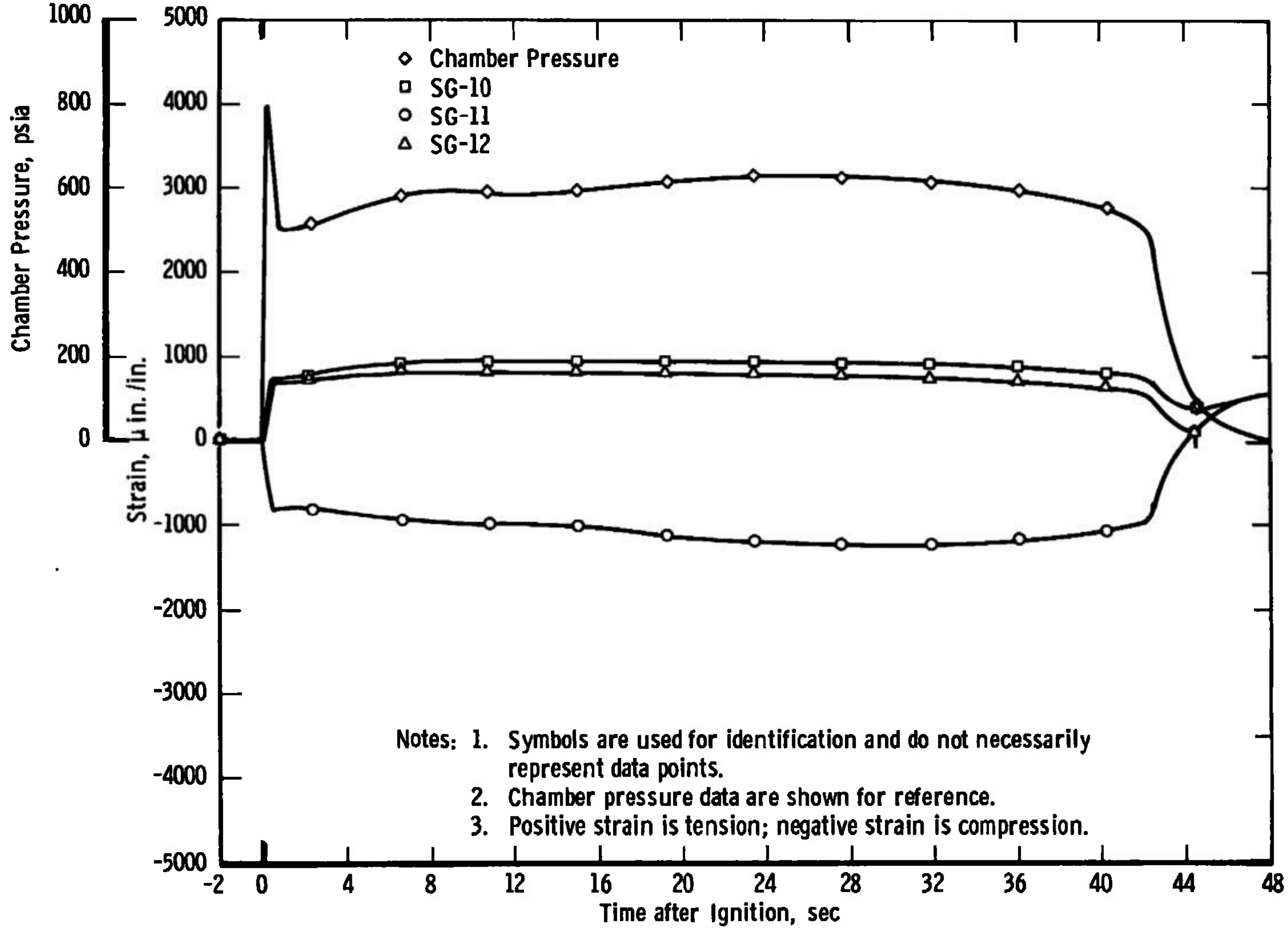


b. Flange (180 deg), Triaxial (SG-4, SG-5, SG-6)
Fig. 12 Continued

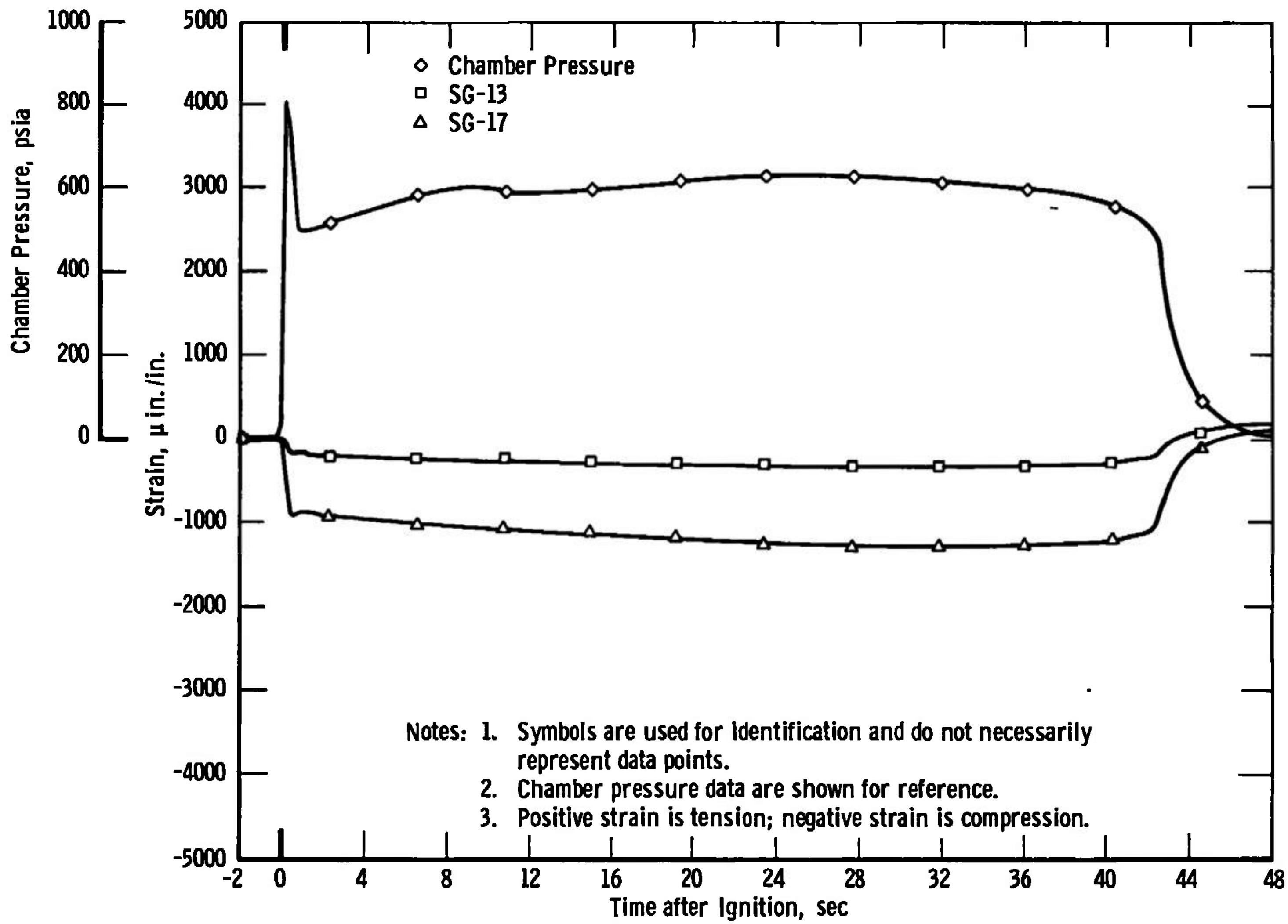


c. Flange (90 deg), Triaxial (SG-7, SG-8, SG-9)

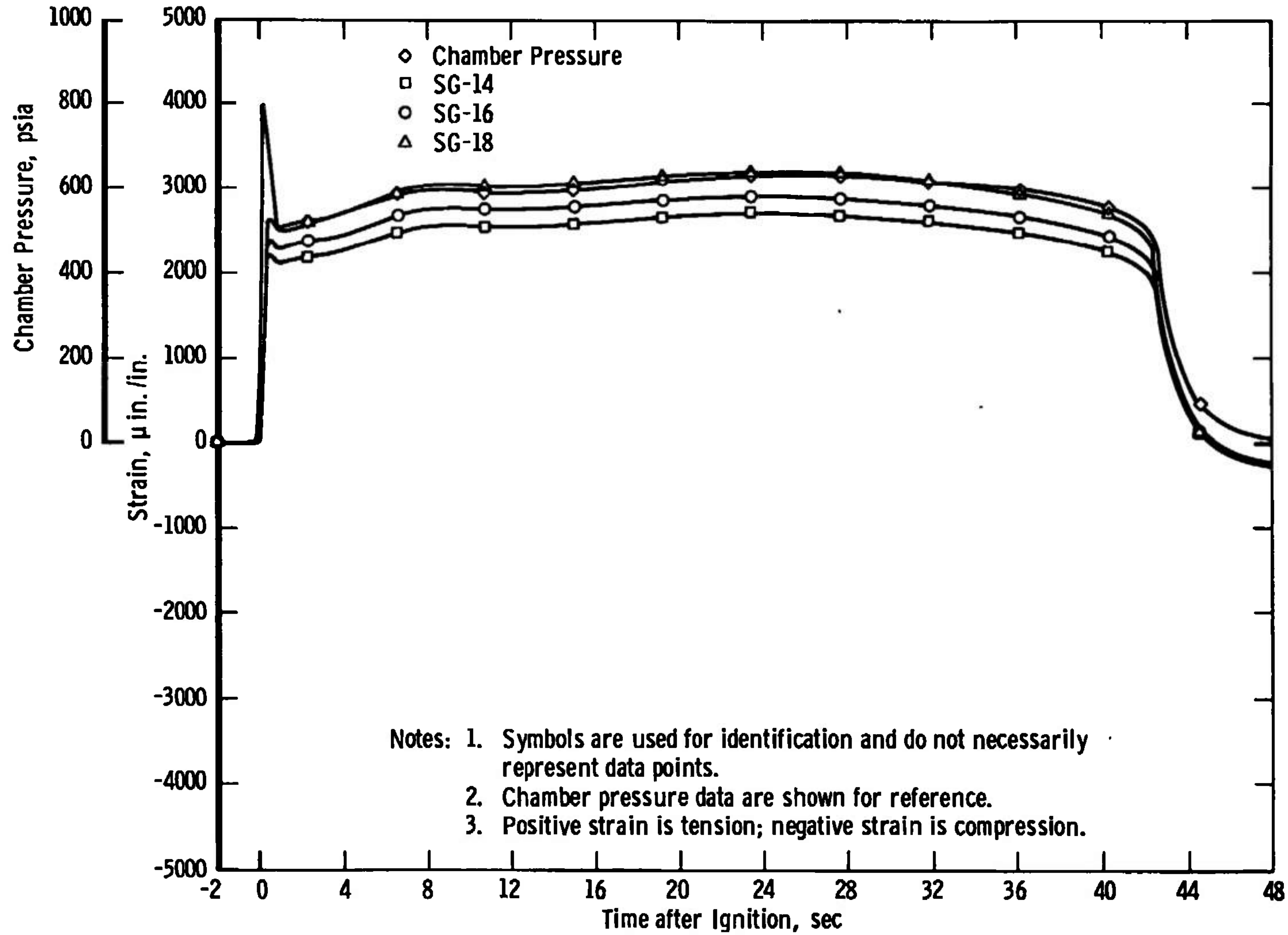
Fig. 12 Continued



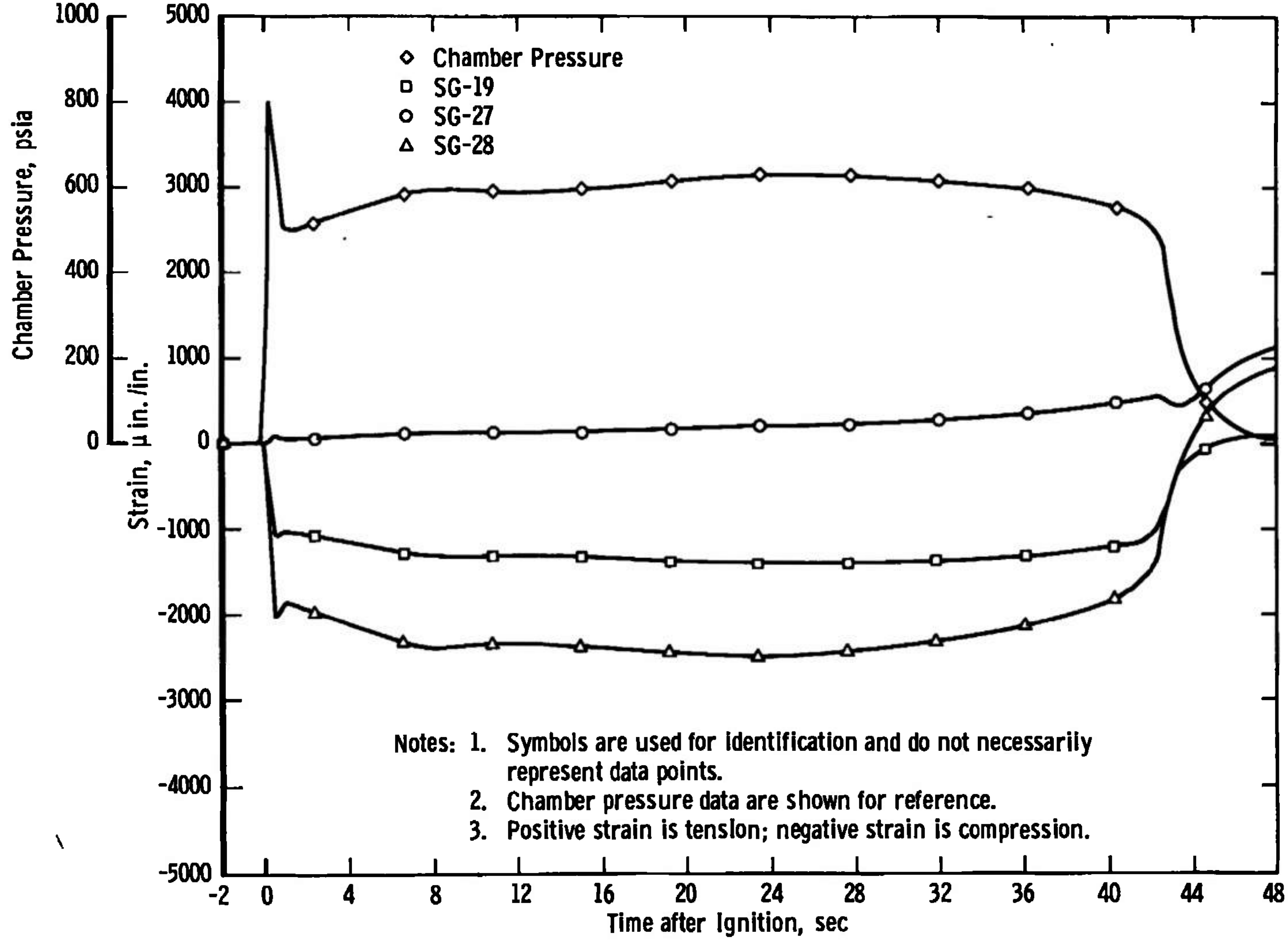
d. Flange (270 deg), Triaxial (SG-10, SG-11, SG-12)
Fig. 12 Continued



e. Flange (0 deg), Longitudinal (SG-13, SG-17)
Fig. 12 Continued

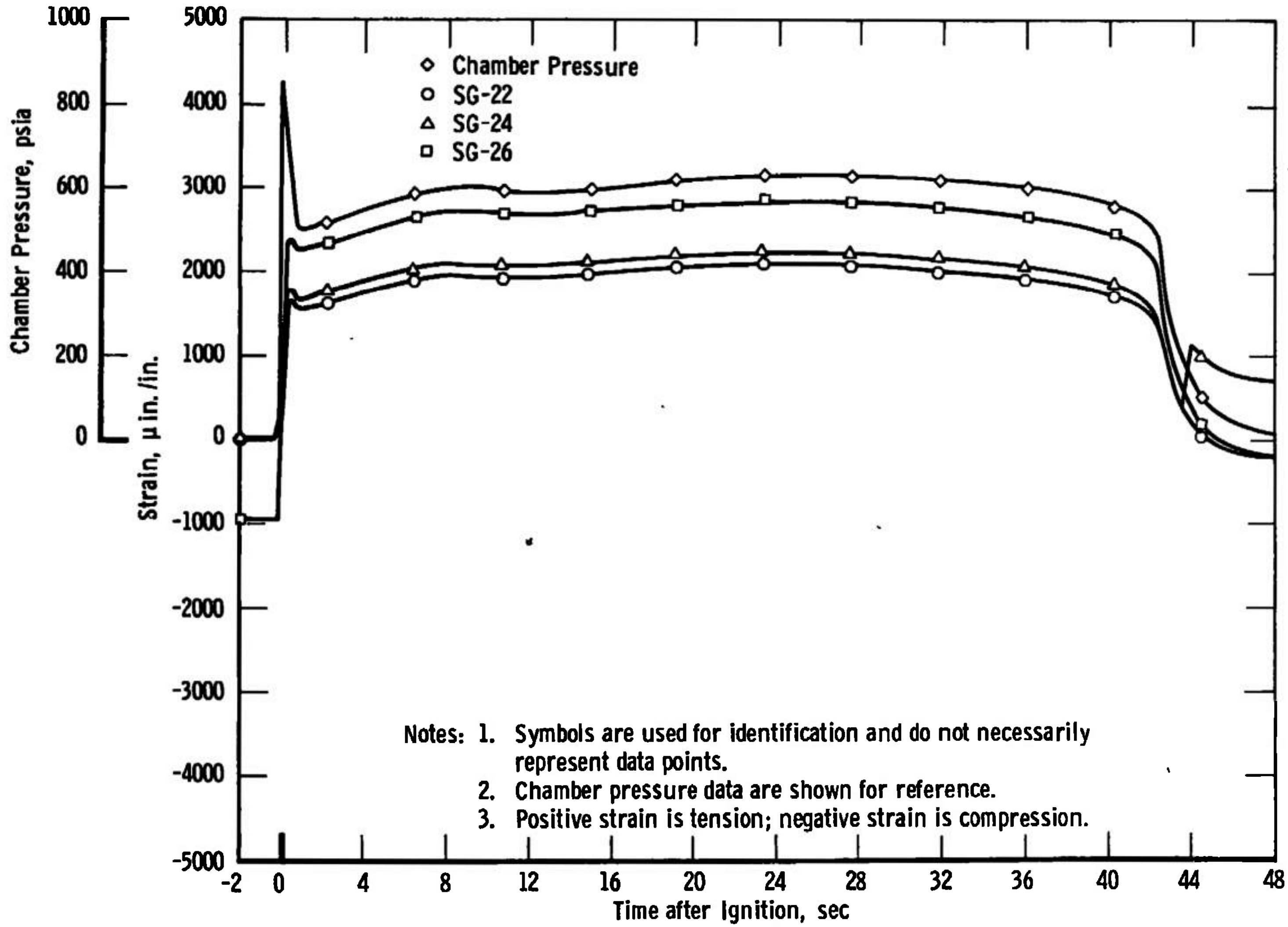


f. Flange (0 deg), Hoop (SG-14, SG-16, SG-18)
Fig. 12 Continued



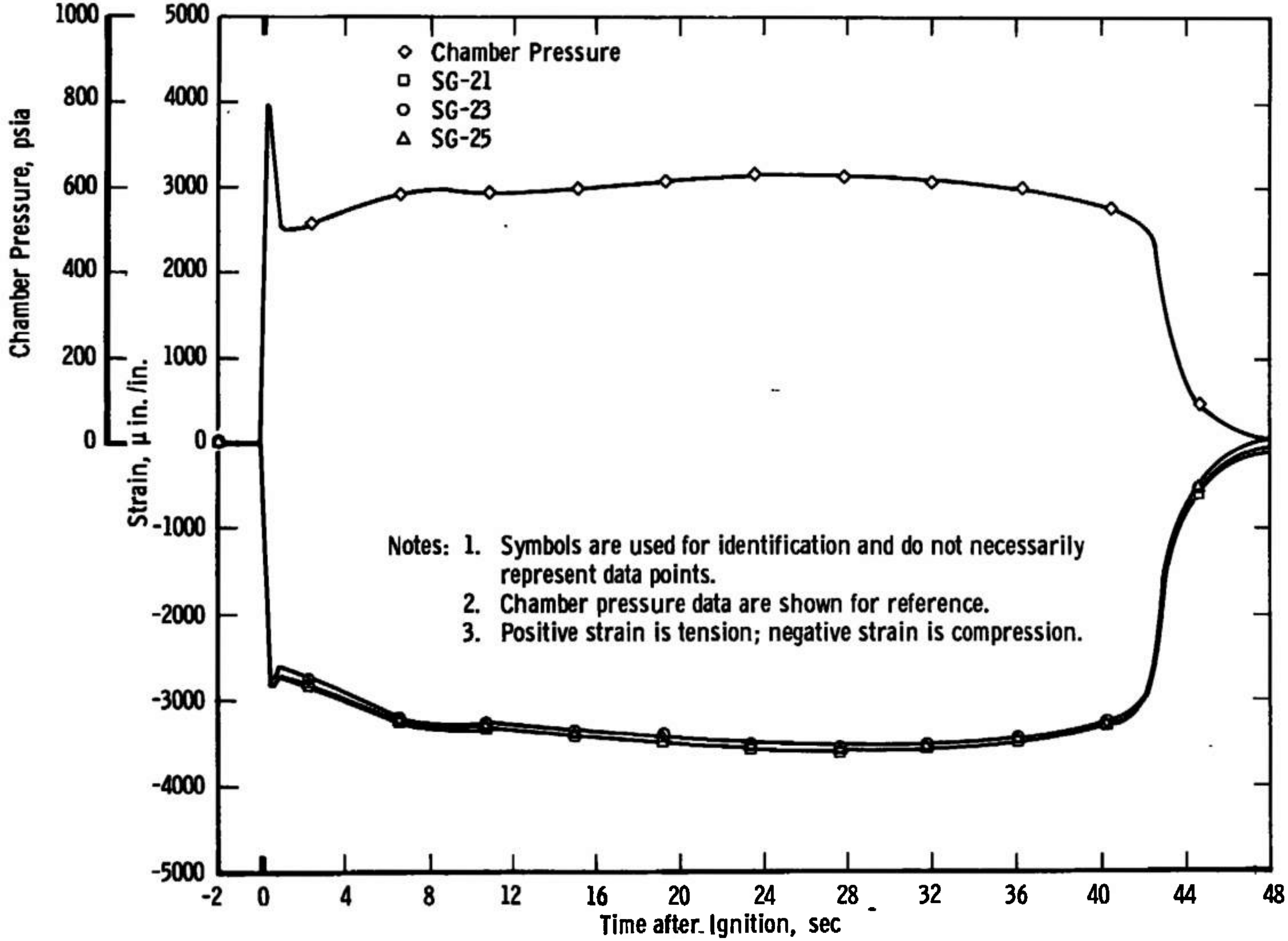
g. Flange and Case (0 deg), Longitudinal (SG-19, SG-27, SG-28)

Fig. 12 Continued

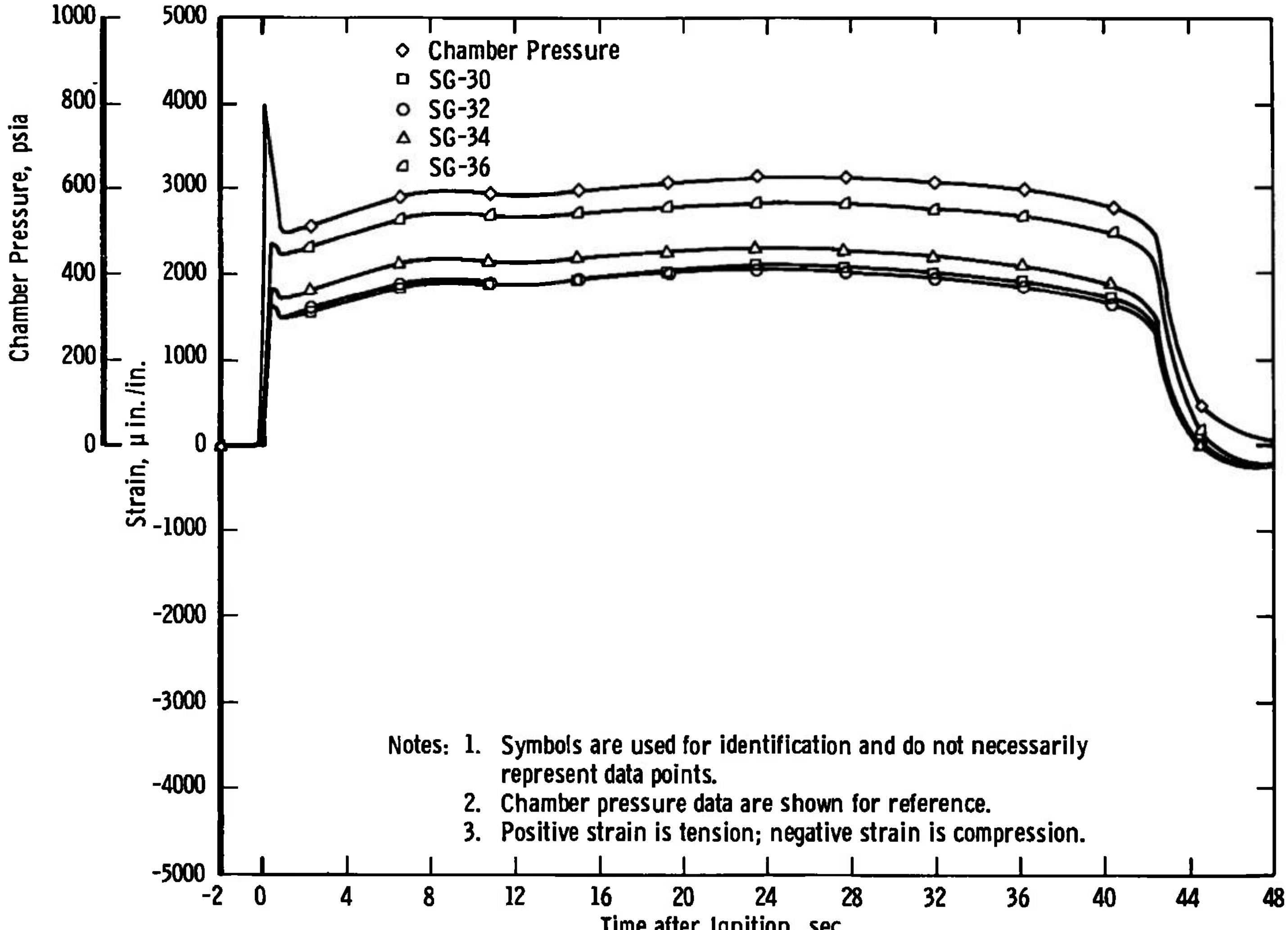


h. Flange (0 deg), Hoop (SG-22, SG-24, SG-26)

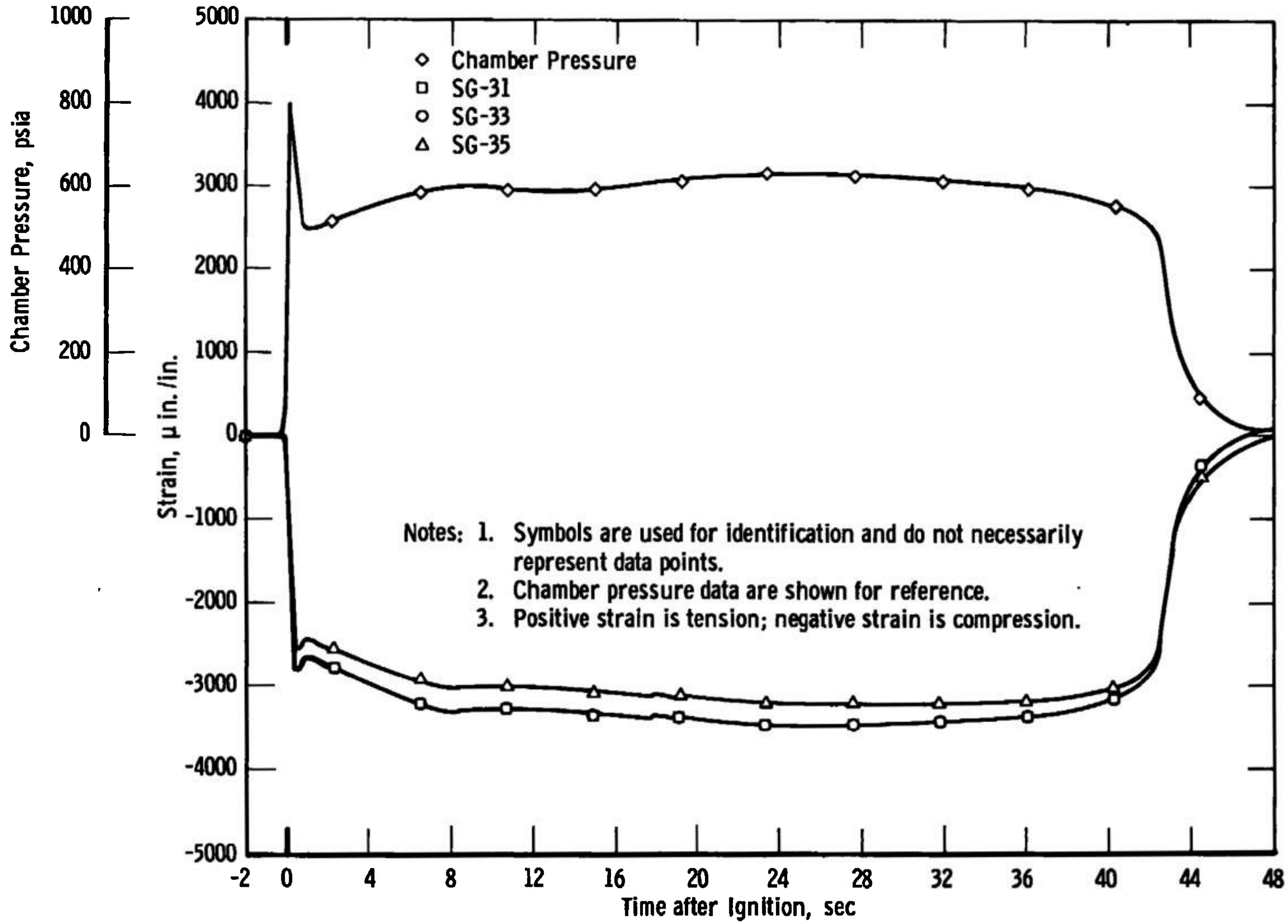
Fig. 12 Continued



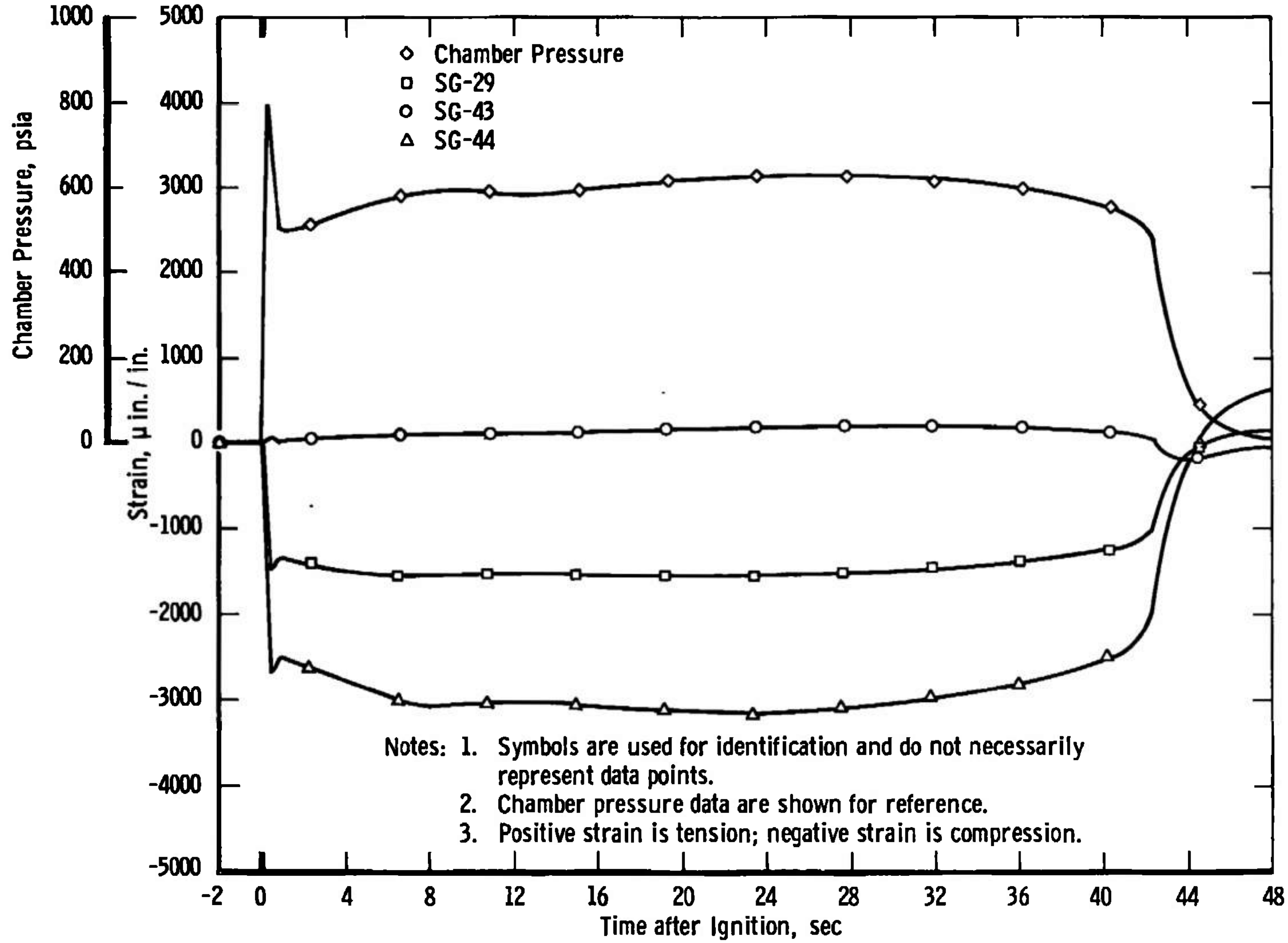
i. Flange (0 deg), Longitudinal (SG-21, SG-23, SG-25)
Fig. 12 Continued



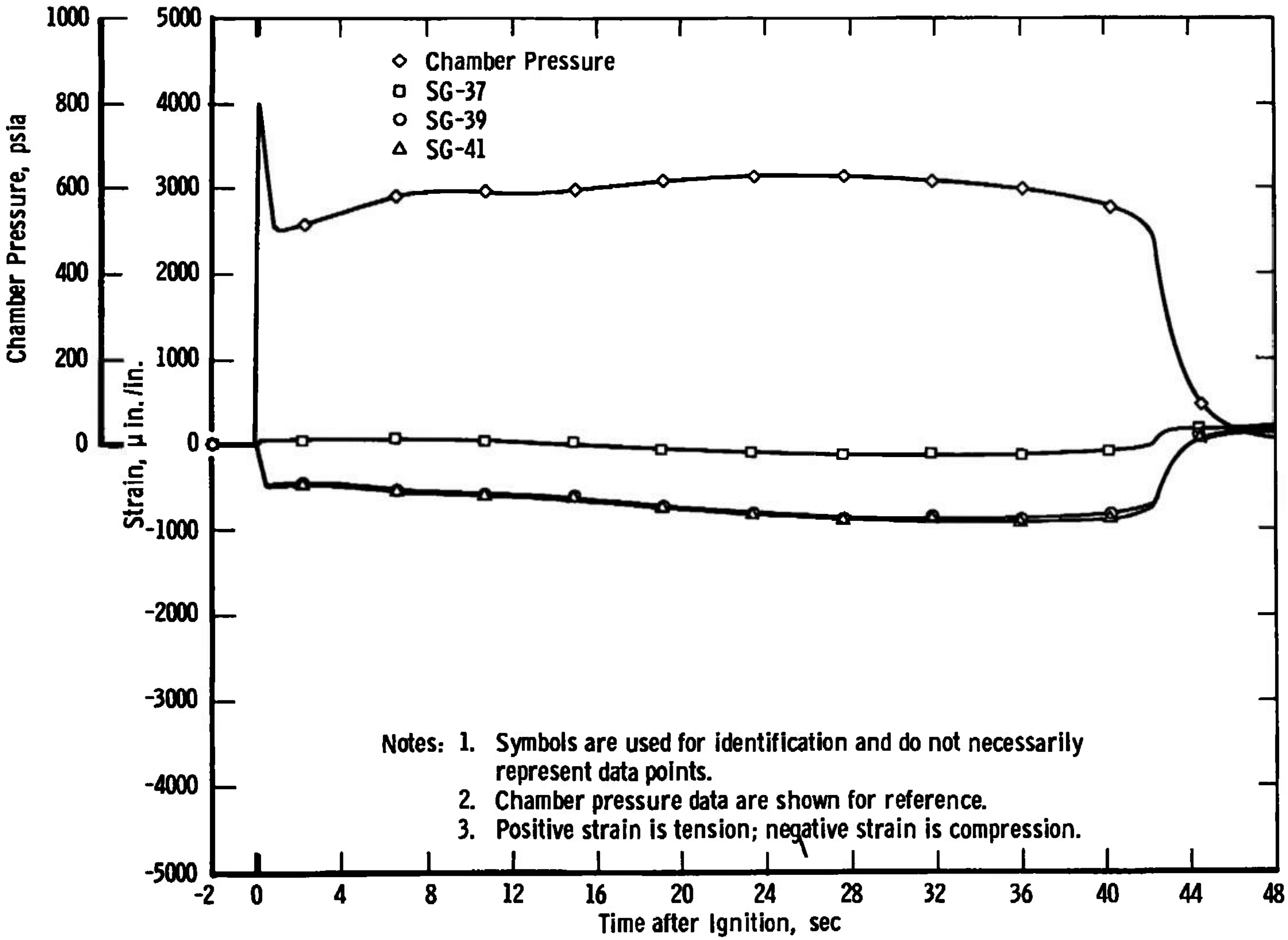
j. Flange (180 deg), Hoop (SG-30, SG-32, SG-34, SG-36)
Fig. 12 Continued



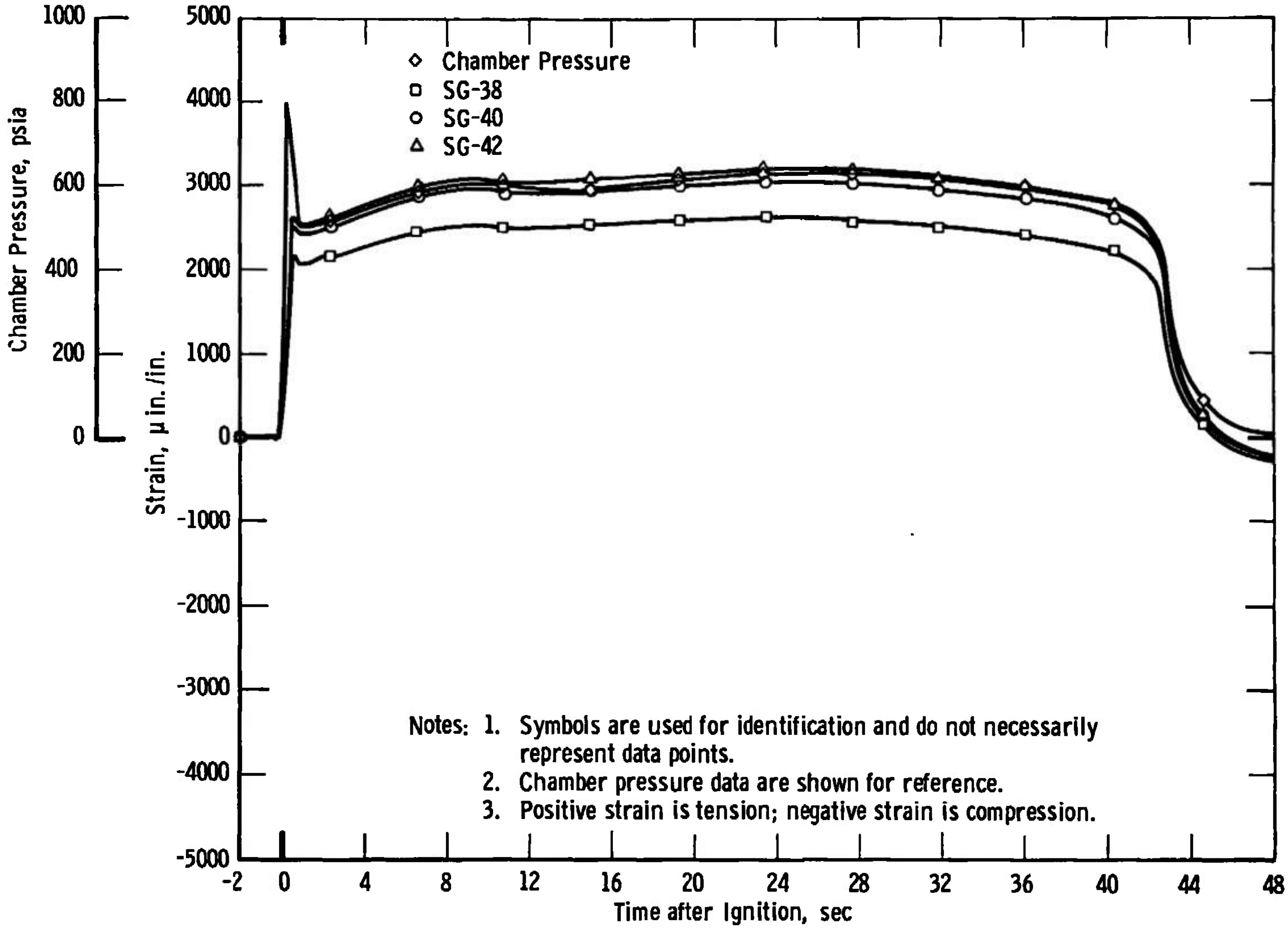
k. Flange (180 deg), Longitudinal (SG-31, SG-33, SG-35)
Fig. 12 Continued



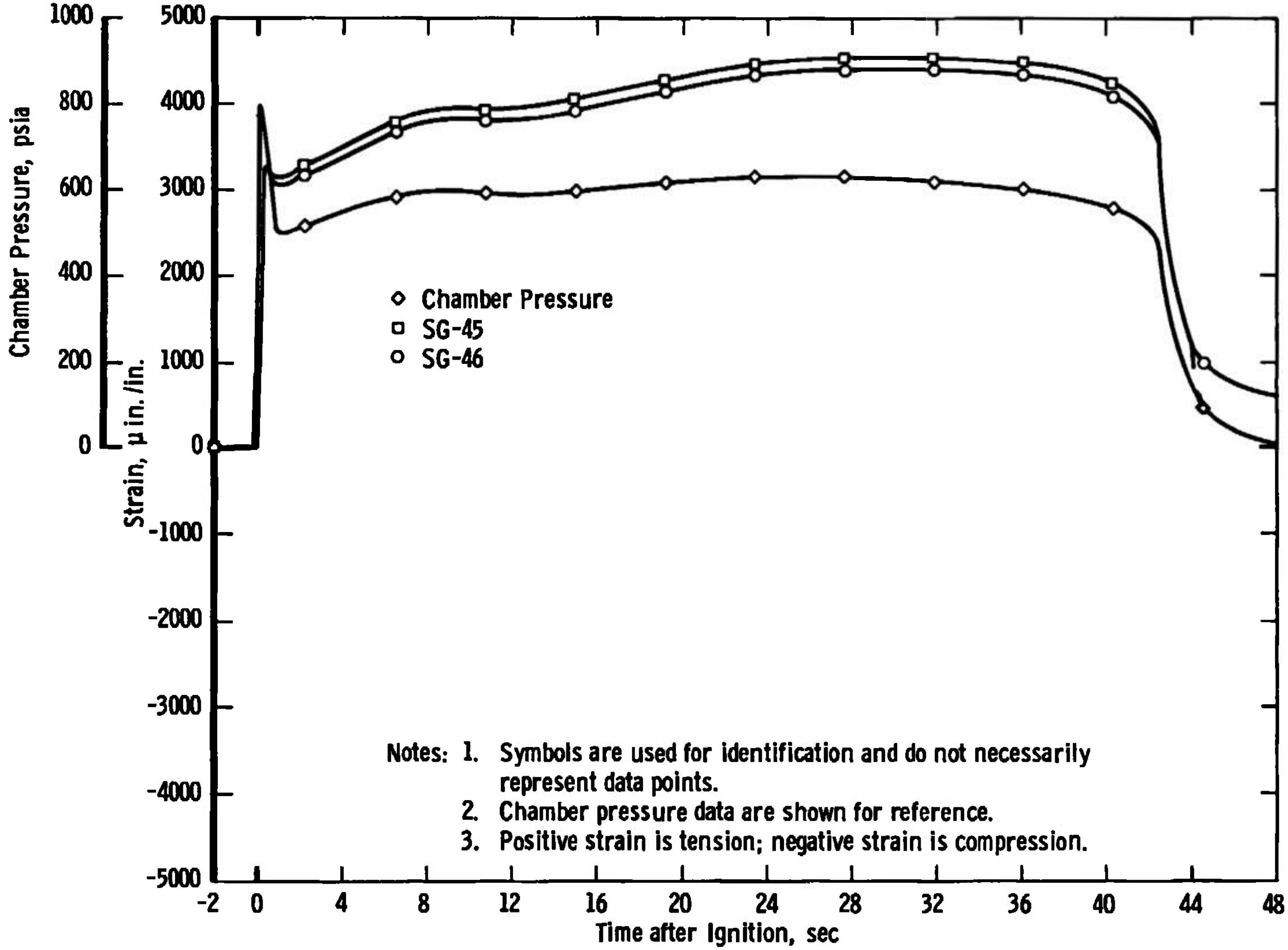
l. Flange and Case (180 deg), Longitudinal (SG-29, SG-43, SG-44)
Fig. 12 Continued



m. Flange (180 deg), Longitudinal (SG-37, SG-39, SG-41)
Fig. 12 Continued



n. Flange (180 deg), Hoop (SG-38, SG-40, SG-42)
Fig. 12 Continued



o. Flange Extension (0 and 180 deg), Hoop (SG-45, SG-46)
Fig. 12 Concluded

TABLE I
INSTRUMENTATION SUMMARY AND MEASUREMENT UNCERTAINTY

Parameter Designation	Estimated Measurement Uncertainty, 2 Sigma				Type of Measuring Device	Type of Recording Device	Method of System Calibration
	Steady State		Integral, Percentage of Reading	Range of Measurement			
	Percentage of Reading	Units of Measurement					
Axial Force, lbf	±0.28	---	---	8,000 to 10,500 lbf	Bonded Strain-Gage-Type Force Transducers (0 to 10,000 lbf load cells) Two Used	Voltage-to-Frequency Converter onto Magnetic Tape	In-Place Application of Deadweights Calibrated in the Standards Laboratory
Total Impulse, lbf-sec	---	---	±0.28	---			
Chamber Pressure, psia	±0.44	---	---	500 to 620 psi	Bonded Strain-Gage-Type Pressure Transducers (0 to 1500 psia) Two Used		Resistance Shunt Based on the Standards Laboratory Determination of Transducer Applied Pressure versus Resistance Shunt Equivalent Pressure Relationship
Chamber Pressure Integral, psia-sec	---	---	±0.39	---			
Test Cell Pressure, psia	---	±0.001208 psi	---	0.1 to 0.13 psia	Unbonded Strain-Gage-Type Pressure Transducers (0 to 1 psia) Three Used		
Test Cell Pressure Integral, psia-sec	---	---	±0.93	---			
Weight, lbm	---	±0.031 lbm	---	580 to 2040 lbm	Beam Balance Scales	Visual Readout	In-Place Application of Deadweights Calibrated in the Standards Laboratory
Time Interval, msec	---	±5.0 msec	---	---	Time Pulse Generator	Photographically Recording Galvanometer Oscillograph	Time Pulse Generator Calibrated in the Standards Laboratory
Motor Case and Nozzle Flange Strain, μin./in.	---	±112.5 μin./in.	---	0 to 1125 μin./in.	Strain Grid	Sequential Sampling, Millivolt-to-Digital Converter and Magnetic Tape Storage Data Acquistion System	Resistance Shunt Based on Manufacturer-Supplied Calibration Factor
	±10	---	---	1125 to 4500 μin./in.			
Motor Temperature, °F	---	±3°F	---	70 to 530°F	Chromel-Alumel Temperature Transducers		Millivolt Substitution Based on the NBS Temperature versus Millivolt Tables
	---	±(1.70°F + 0.25 percent of Reading)		530 to 750°F			

TABLE II
SUMMARY OF TE-M-364-3 MOTOR PERFORMANCE

Test Number RC1067	01
Motor Serial Number	00010
Test Date	3/15/70
Average Motor Spin Rate during Firing, rpm	110
Motor Case Temperature at Ignition, °F	81
Ignition Lag Time (t_ℓ)[1], sec	0.001
Action Time (t_a)[2], sec	44.533
Time Interval that Nozzle Throat Flow was Sonic (t_{is})[3], sec	49.53
Simulated Altitude at Ignition, ft	111,000
Average Simulated Altitude during t_a, ft	106,000
Measured Total Impulse (based on t_a), lbf-sec	
Average of Four Channels of Data	414,973
Maximum Channel Deviation from Average, percent	0.05
Chamber Pressure Integral (based on t_a), psia-sec	
Average of Two Channels of Data	25,464[4]
Maximum Channel Deviation from Average, percent	0.12
Cell Pressure Integral (based on t_a), psia-sec	
Average of Three Channels of Data	5.4421
Maximum Channel Deviation from Average, percent	0.15
Vacuum Total Impulse (based on t_a), lbf-sec	417,440
Vacuum Total Impulse (based of t_{is}), lbf-sec	418,954
Vacuum Specific Impulse (based on t_a), lbf-sec/lbm	
Based on Manufacturer's Stated Propellant Weight	289.90
Based on Expended Mass (AEDC)	288.69
Vacuum Specific Impulse (based on t_{is}), lbf-sec/lbm	
Based on Manufacturer's Stated Propellant Weight	290.95
Based on Expended Mass (AEDC)	289.74
Average Vacuum Thrust Coefficient, C_F	
Based on t_a and Average Pre- and Postfire Throat Areas	1.849

[1]Defined as the time interval from application of ignition voltage to the first perceptible rise in chamber pressure

[2]Defined as the time interval beginning when chamber pressure has risen to 10 percent of maximum and ending when chamber pressure has fallen to 10 percent of maximum

[3]Defined as the time interval between the first indication of chamber pressure at ignition and the time at which the ratio of chamber to cell pressure has decreased to 1.3 during tailoff

[4]Chamber pressure measured through Pyrogen pressure port

TABLE III
SUMMARY OF TE-M-364-3 MOTOR PHYSICAL DIMENSIONS

Test Number	01
Motor Serial Number	00010
Test Date	3/15/70
Motor Spin Rate, rpm	110
AEDC Prefire Motor Weight*, lbm	2032.98
AEDC Postfire Motor Weight*, lbm	587.00
AEDC Expended Mass, lbm	1445.98
Manufacturer's Stated Propellant Weight, lbm	1439.95
Nozzle Throat Area, in.^{2}	
Prefire	8.491
Postfire	9.241
Percent Change from Prefire Measurement	11.32
Prefire Nozzle Exit Area, in.^{2}	453.390
Prefire Nozzle Area Ratio	53.40

*Nozzle Assembly was removed

TABLE IV
COMPARISON OF BALLISTIC PERFORMANCE FOR THE TE-M-364-3 MOTORS TESTED TO DATE AT AEDC

Parameter	Ref. 2				Ref. 1		Reported Herein
Motor S/N	T00001	T00002	T00003	T00006	T00004	T00005	00010
Prefire Grain Temperature, °F	55 ± 5	95 ± 5	75 ± 5	50 ± 5	75 ± 3	75 ± 3	80 ± 5[2]
Motor Spin Rate, rpm	110	110	0	110	0	110	110
Action Time (t_a), sec	45. 6	43. 5	45. 0	46. 1	45. 2	44. 6	44. 5
t_{is}, sec	121. 6[1]	100. 8[1]	100. 8[1]	111. 85[1]	111. 3[1]	90. 9[1]	49. 5[3]
Vacuum Total Impulse Based on t_{is}, lbf-sec	418, 861	419, 426	419, 531	418, 133	418, 601	419, 724	418, 954
Vacuum Specific Impulse Based on t_{is} and the Manufacturer's Stated Propellant Weight, lbf-sec/lbm	291. 00	291. 53	291. 22	290. 39	290. 86	291. 14	290. 95
Vacuum Specific Impulse Based on t_{is} and Expended Mass, lbf-sec/lbm	288. 40	288. 94	288. 64	287. 90	288. 20	288. 77	289. 74
Average Vacuum Thrust Coefficient Based on t_a and the Averaged Pre- and Postfire Throat Area, C_F	1. 862	1. 859	1. 854	1. 858	---[4]	1. 859	1. 849

[1]Data obtained from chamber pressure port using 0 to 5 psi transducers

[2]Prefire motor case temperature

[3]Data obtained from pyrogen pressure port using 0 to 1500 psi transducers

[4]Average vacuum thrust coefficient not available

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13. ABSTRACT

One Thiokol Chemical Corporation TE-M-364-3 solid-propellant rocket motor was fired as a quality assurance test at near vacuum conditions to determine motor structural integrity and altitude ballistic performance. The motor was fired while spinning about its axial centerline at 110 rpm. Vacuum total impulse was within the specification limits, but the motor case temperature exceeded the specification limit. A "hot spot" developed on the nozzle of the motor, beginning approximately 39 sec after ignition.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
solid-propellant rocket motor						
TE-M-364-3						
quality assurance						
performance evaluation						
spin stabilization						
attitude control						
altitude simulation						
structural stability						
ballistics						