DESIGN ASSURANCE TEST OF THE THIOKOL TE-M-521-5
APOGEE KICK MOTOR TESTED IN THE SPIN MODE
AT SIMULATED ALTITUDE CONDITIONS

A. A. Cimino
ARO, Inc.

March 1973

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ARNOLD ENGINEERING DEVELOPMENT CENTER
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FOREWORD

The test program reported herein was conducted at the Arnold Engineering Development Center 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 921E3...

The results of the test were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of the AEDC, Air Force Systems Command (AFSC), Arnold Air Force Station, Tennessee. The test was conducted in Propulsion Development Test Cell (T-3) of the Engine Test Facility (ETF) on July 28, 1972; under ARO Project No. RA182, and the manuscript was submitted for publication on October 31, 1972.

This technical report has been reviewed and is approved.

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Colonel, USAF 
Director of Test
ABSTRACT

One Thiokol Chemical Corporation TE-M-521-5 solid-propellant apogee rocket motor was successfully fired at an average simulated altitude of about 108,000 ft while spinning at 46 rpm. The general program objectives were to verify compliance of motor performance with the manufacturer's specifications. Specific primary objectives were to determine vacuum ballistic performance of the motor after prefire vibration conditioning and temperature conditioning at 40°F, altitude ignition characteristics, motor structural integrity, and motor temperature-time history during and after motor operation. Additional objectives were to measure the lateral (nonaxial) thrust component during motor operation and to measure radiation heat flux in the vicinity of the nozzle exit plane.
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NOMENCLATURE

Aex  
Nozzle exit area, in.²  

At  
Nozzle throat area, in.²  

\( \bar{c}_f \)  
Average vacuum thrust coefficient over a selected 1-sec interval of motor operation just prior to tailoff  

F  
Measured axial thrust, lbf  

\( I_{vac,action} \)  
Vacuum impulse based on action time \( (t_a) \), lbf-sec  

\( I_{vac,total} \)  
Vacuum impulse based on total burn time \( (t_{bd}) \), lbf-sec  

Pcell  
Measured cell pressure, psia  

Pch  
Measured chamber pressure, psia  

\( t_a \)  
Action time, time interval from 10 percent of maximum chamber pressure at ignition to 10 percent of maximum chamber pressure at tailoff, sec  

\( t_{bd} \)  
Time of nozzle flow breakdown, sec  

\( t_{ts} \)  
Total burn time, time interval between the application of ignition voltage and the time at which the ratio of \( P_{ch} \) to \( P_{cell} \) has decreased to 1.3 during tailoff, sec
\[ t_g \] Ignition lag time, time interval from application of ignition voltage to the first perceptible rise in chamber pressure, sec

\[ t_o \] Zero time, time of application of voltage to the igniter, sec
SECTION I
INTRODUCTION

The Thiokol Chemical Corporation (TCC) TE-M-521-5 solid-propellant rocket motor is to be used as the apogee kick motor for the Interplanetary Monitoring Platform (IMP)-H and IMP-J spacecraft (Ref. 1). The kick motor will impart sufficient velocity to inject the spacecraft into a circular orbit at the apogee of its ascent transfer ellipse. The apogee motor is contained within the spacecraft, which is internally insulated with a material designed to protect the communications package from the high temperatures attributable to apogee motor heat soakback (Ref. 1).

The test reported herein was a continuation of the design assurance test program for the TE-M-521-5 motor. An earlier test was conducted at the AEDC on a TE-M-521-5 motor, that had undergone nondestructive vibrational tests at the manufacturer's facilities, which duplicated launch vehicle accelerations (Ref. 2). A subsequent change in the launch vehicle configuration established new requirements for nondestructive vibration tests; these new tests were performed on the motor prior to the motor firing at simulated altitude, reported herein.

The TE-M-521-5 motor is ballistically identical to the earlier models of the TE-M-521 apogee kick motor, used for the Interim Defense Communication Satellite Program (IDCSP/A) spacecraft (Refs. 3 and 4); however, the TE-M-521-5 has a greater minimum wall thickness specification (0.038 in. instead of 0.032 in.) in the forward and aft hemispheres, the nozzle exit cone is fabricated with an additional 0.050-in. phenolic glass cloth overwrap extending 5 in. downstream from the throat, and the Gengard V-44 rubber asbestos propellant-to-case insulation has been replaced with TIR-300 asbestos-polyisoprene.

The general objective of the program reported herein was to verify compliance of motor performance to the manufacturer's specification (Ref. 5). Specific objectives were to determine: (1) the altitude ballistic performance of the TE-M-521-5 rocket motor while spinning about its axial centerline at 46 rpm, after prefire vibration conditioning and temperature conditioning at 40 ± 5°F for a minimum of 24 hr, (2) altitude ignition characteristics, (3) motor structural integrity, and (4) motor temperature-time history during and after motor operation. Additional objectives were to measure the lateral (nonaxial) thrust component during motor operation and to measure radiation heat flux in the vicinity of the nozzle exit plane.

Motor altitude ballistic performance, ignition characteristics, structural integrity, motor temperature, exhaust plume heat flux, and motor lateral (nonaxial) thrust are presented and discussed.
SECTION II
APPARATUS

2.1 TEST ARTICLE

The Thiokol Chemical Corporation (TCC) TE-M-521-5 solid-propellant rocket motor
(Fig. 1, Appendix I) is a full-scale, flightweight motor having the following nominal
dimensions and burning characteristics at 40°F:

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length, in.</td>
<td>38.64</td>
</tr>
<tr>
<td>Diameter, in.</td>
<td>17.44</td>
</tr>
<tr>
<td>Loaded Weight, lbm</td>
<td>275</td>
</tr>
<tr>
<td>Propellant Weight, lbm</td>
<td>247</td>
</tr>
<tr>
<td>Maximum Thrust, lbf</td>
<td>4000</td>
</tr>
<tr>
<td>Maximum Chamber Pressure, psia</td>
<td>706</td>
</tr>
<tr>
<td>Action Time, sec</td>
<td>20.0</td>
</tr>
<tr>
<td>Throat Area, in.</td>
<td>2.788</td>
</tr>
<tr>
<td>Nozzle Area Ratio, $A_{ex}/A_t$</td>
<td>49.11</td>
</tr>
</tbody>
</table>

The elongated spherical motor case is constructed of 0.071-in. forged titanium
(6A1-4V) welded to two hemispherical sections of 0.38 in. thickness. The case is lined
internally with TCC TL-H-304 liner and insulated with TIR-300 asbestos-polyisoprene. A
stress relief boot assembly is contained in the forward end of the motor case (Fig. 1a). A
flange on the motor cylindrical section provides for attachment to the IMP spacecraft.

The contoured nozzle assembly contains a Graph-I-Tite G-90 carbon throat insert
pinned and bonded to the nozzle adapter flange. The expansion cone is constructed of
vitreous silica phenolic, externally coated with vapor-deposited aluminum. The cone is
threaded, bonded, and pinned to the aluminum nozzle adapter flange. The nozzle assembly
has a nominal 49.1:1 area ratio and a 14-deg half-angle at the exit plane. A styrofoam
closure was bonded in the nozzle expansion cone. The closure was punctured prior to
testing so that the rocket motor chamber pressure was equal to the simulated altitude
pressure at motor ignition.

The TE-M-521-5 rocket motor contains a composite propellant grain formulation
designated TP-H-3062 (ICC Class B), cast in an eight-point-star configuration. The isentropic
exponent of the propellant exhaust gases is 1.18 (assuming frozen equilibrium).

Ignition was accomplished by two TE-P-386-7 pyrogen igniters (Fig. 1a) which
incorporated Holex 4496 initiators and contained 20 BKNO₃ pellets (size 2A) used to
initiate the 0.08-lbm primary polysulphide igniter grain. Nominal ignition current was 4.5
amp for 25 msec for each of the two igniters.
2.2 INSTALLATION

The motor assembly was cantilever mounted from the spindle face of a spin-fixture assembly in Propulsion Development Test Cell (T-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. 2). The spin-fixture assembly consists of a 10-hp squirrel-cage-type drive motor, a thrust bearing assembly, a 46-in.-long spindle having a 36-in.-diam aft spindle face, and a 170-channel slip-ring assembly. The spin fixture was rotated counterclockwise, looking upstream. Electrical leads to and from the igniters, pressure transducers, and thermocouples on the rotating motor were provided through a 170-channel, slip-ring assembly mounted between the forward and aft bearing assemblies of the spindle. Axial thrust was transmitted through the spindle-thrust bearing assembly to two double-bridge load cells mounted just forward of the thrust bearing on the motor axial centerline.

Preignition pressure altitude conditions were maintained in the test cell by a steam ejector operating in series with the ETF exhaust gas compressors. During the motor firing, the motor exhaust gases were used as the driving gas for the 29-in.-diam, ejector-diffuser system to maintain test cell pressure at an acceptable level.

2.3 INSTRUMENTATION

Instrumentation was provided to measure axial force, motor chamber pressure, lateral (nonaxial) force, test cell pressure, motor case and nozzle temperatures, motor rotational speed, and heat flux from the rocket plume. Table I (Appendix II) presents instrument ranges, recording methods, and measurement uncertainty for all reported parameters.

The axial force 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 spacecraft centerline. The lateral (nonaxial) force measuring system consisted of two double-bridge, strain-gage-type load cells installed forward and aft between the flexure-mounted cradle and the cradle support stand normal to the rocket motor axial centerline and in the horizontal plane passing through the motor axial centerline (Fig. 2c).

Unbonded strain-gage-type transducers (0- to 1-psia) were used to measure test cell pressure. Bonded strain-gage-type transducers with ranges from 0 to 50 and 0 to 1000 psi were used to measure motor chamber pressure. Chromel®-Alumel®(CA) thermocouples were bonded to the motor case and nozzle (Fig. 3) to measure surface temperatures during and after motor burn time. Rotational speed of the motor-spacecraft assembly was determined from the output of a magnetic pickup. The heat flux from the rocket plume was measured by one calorimeter and five radiometers mounted as shown in Fig. 4.
The output signal of each measuring device was recorded on independent instrumentation channels. Primary data were obtained from four axial-thrust channels, three test cell pressure channels, and three motor 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 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 lateral (nonaxial) force load cells, radiometers, calorimeter, and thermocouples were recorded on magnetic tape from a multi-input, analog-to-digital converter and reduced to engineering units by an electronic computer.

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

2.4 CALIBRATION

The thrust system 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, the thrust load cells were again calibrated at sea-level, nonspin ambient conditions and also at simulated altitude while spinning at 46 rpm.

The pressure recording 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 recording instruments were calibrated by using known millivolt levels to simulate thermocouple outputs. Calibration curves for the radiometers and the calorimeter were supplied by the transducer manufacturer.

After the motor firing, with the test cell still at simulated altitude pressure, the recording systems were recalibrated to determine any shift.
Calibrations of the lateral (nonaxial) forces measuring system were conducted using the procedure outlined in Ref. 6.

SECTION III
PROCEDURE

The TCC TE-M-521-5 rocket motor (S/N PV32-248-2) and associated hardware arrived at AEDC on July 10, 1972. The motor was visually inspected for possible shipping damage and radiographically inspected for grain cracks, voids, or separations and found to meet criteria provided by the manufacturer.

After radiographic inspection, the motor was stored in an area temperature conditioned at 70 ± 5°F, where the motor was checked to ensure correct fit of mating hardware, the electrical resistances of the igniters were measured, and the nozzle exit diameter was obtained. The motor was leak checked after installation of the chamber pressure transducers. The entire assembly was weighed and photographed. Thermocouples had been bonded to the nozzle and motor case at the manufacturer's facilities. After the thrust adapter was secured to the motor case, the assembly was mounted on a spin table, and radial dimensions of the spacecraft flange and nozzle flange as a function of angular position relative to the centerline of the assembly were determined to facilitate alignment with the spin-rig spin axis during test cell installation.

After installation of the assembly in the test cell, the motor centerline was axially aligned with the spin-rig spin axis by rotating the motor assembly and measuring the deflection of the nozzle flange and the motor flange with a dial indicator and making appropriate adjustments. The instrumentation connections were made, and the motor assembly was balanced at a rotational speed of 46 rpm. Cell temperature was controlled to condition the motor assembly at 40°F for a period in excess of 24 hr. A continuity check of all electrical systems was performed, prefire ambient calibrations were completed, the test cell pressure was reduced to the desired simulated altitude, and spinning of the unit was started. After spinning had stabilized at 46 rpm, a complete set of altitude calibrations was taken.

The final operation prior to firing the motor was to adjust the firing circuit resistance to provide the desired current to the igniter squibs. The entire instrumentation measuring-recording complex was activated, and the motor was fired while spinning (under power) at 46 rpm.

Spinning of the motor was continued for approximately 70 min after burnout, during which time motor and blanket temperatures were recorded, and postfire calibrations were accomplished. The unit was decelerated slowly until rotation had stopped, and another set of calibrations was taken. The test cell pressure was then returned to ambient conditions, and the motor assembly was inspected, photographed, and removed to the storage area. Postfire inspections at the storage area consisted of measuring the throat and exit diameters of the nozzle, weighing the motor, and photographically recording the postfire condition of the motor.
SECTION IV
RESULTS AND DISCUSSION

One Thiokol Chemical Corporation TE-M-521-5 solid-propellant rocket motor (S/N PV32-248-2) was successfully fired at an average altitude of 108,000 ft. The motor was prefire vibration conditioned, and temperature conditioned at 40 ± 5°F for a period in excess of 24 hr prior to firing with the motor assembly spinning about the motor longitudinal axis at 46 rpm. The general objective of this quality assurance program was to verify compliance of motor performance with the manufacturer's specifications (Ref. 5). Specific primary objectives were to determine vacuum ballistic performance, altitude ignition characteristics, motor structural integrity, and test article temperature-time histories during and after motor operation. Additional secondary objectives were to measure the motor lateral (nonaxial) thrust component during motor operation and to measure radiation heat flux in the vicinity of the nozzle exit plane. The resulting data are presented in both tabular and graphical form.

Motor performance based on action time ($t_a$) and total burn time ($t_f$) is summarized and compared with results from previous altitude firings of the TE-M-521 in Table II. Motor physical dimensions are compared with the previous motors in Table III. Altitude ignition characteristics, rocket exhaust plume radiation heat flux, and temperature-time histories of motor case and nozzle are presented and discussed. When multiple channels of equal accuracy instrumentation were used to obtain values of a single parameter, the average values were used to calculate the data presented.

4.1 ALTITUDE IGNITION CHARACTERISTICS

The motor was ignited at a pressure altitude of 115,000 ft. The average simulated, altitude during motor action time ($t_a$) was 108,000 ft. An analog trace of thrust, chamber pressure, and test cell pressure characteristics during motor ignition are presented in Fig. 5.

Ignition time ($t_i$) was 0.11 sec and was within the manufacturer's specifications of not less than 0.025 sec or greater than 0.250 sec for a temperature range of 0 to 110°F. Ignition lag time ($t_g$) was 0.006 sec, utilizing both pyrogen igniters. The ignition lag time of motors previously tested at the AEDC which were temperature conditioned at 40°F were 0.002 sec (Ref. 2), utilizing two pyrogen igniters, and 0.006 sec (Ref. 3), and 0.008 sec (Ref. 4), utilizing two pyrogen igniters. One motor, temperature conditioned at 100°F and utilizing both pyrogen igniters had an ignition lag time of 0.002 sec (Ref. 3). Ignition lag times of all TE-M-521 motors tested at the AEDC were within the manufacturer's estimated value of 0.006 ± 0.005 sec. No effect of prefire grain temperature or number of pyrogen igniters utilized is apparent on ignition lag time.
4.2 ALTITUDE BALLISTIC PERFORMANCE

Since the nozzle does not operate fully expanded at the low chamber pressures encountered during tailoff, 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 and action time were segmented, and the method used to determine vacuum impulse is illustrated in Fig. 6. The time of exhaust nozzle flow breakdown \( t_{bd} \) was considered to have occurred simultaneously with the exhaust diffuser flow breakdown (as indicated by a rapid increase in cell pressure during tailoff). The flow at the nozzle throat was considered sonic velocity until the time \( t_i \) at which the ratio of chamber-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. 6).

Performance characteristics of the motor reported herein and the four previously fired TE-M-521 motors (Refs. 2, 3, and 4) are presented in Table II. Action time \( t_a \) for motor S/N PV32-248-2 was 20.68 sec, which was 0.56 sec less than that for the Ref. 2 motor, which was fired at the same spin rate (46 rpm), and at the same temperature (40°F) as the motor reported herein. The total burn time \( t_i \) for motor S/N PV32-248-2 was 21.63 sec or 5.84 sec less than the Ref. 2 motor. Vacuum total impulse was 71,469 lbf-sec for motor S/N PV32-248-2 and 71,671 lbf-sec for Ref. 2 motor; both motors were within the manufacturer's specifications of 71,350 ± 350 lbf-sec, 3σ deviation. Vacuum specific impulse (based on \( t_i \) and the manufacturer's stated propellant weight) was 289.08 lbf-sec/lbm for motor S/N PV32-248-2 and 289.81 lbf-sec/lbm for the Ref. 2 motor. Vacuum specific impulse based on expended mass, as determined by pre- and post-fire motor weight measurements taken at the AEDC, was 288.76 lbf-sec/lbm for the motor reported herein, compared with 286.83 lbf-sec/lbm for the Ref. 2 motor.

It was noted (Table III) that the expended mass from the motor reported herein was approximately equal to the manufacturer's stated propellant weight, whereas, for the previous four motor firings (Ref. 2 to 4), expended mass was 2 to 3 lbm greater than the manufacturer's stated propellant weight. Postfire inspection of the motor case at the AEDC revealed appreciable unburned propellant remaining in the motor case (8 slivers, each approximately 12 in. long and from 1/2 to 3/4 in. wide). This unburned propellant could account for the shorter total burn time of the motor firing reported herein (21.63 sec), as compared with the total burn time (27.47 sec) of the Ref. 2 motor. However, the vacuum specific impulse performance of the current motor (288.76 lbf-sec/lbm, based on expended mass) was almost 0.7 percent greater than the Ref. 2 motor. The improvement in performance was further evidenced by the approximate 1-percent increase in vacuum thrust coefficient. The reason for the improvement in ballistic performance has not been determined.
A comparison of thrust and chamber pressure is presented in Fig. 7 for motors fired with the same prefire temperature conditioning (40°F) but with spin rates of 46 rpm (current test and Ref. 2) and 100 rpm (Ref. 3). The thrust and chamber pressure data from the current test are approximately 1.5 percent higher than data from the Ref. 2 and 3 tests, but had a burn time \(t_a\) 3 percent shorter. The vacuum total impulse of 71,469 lbf-sec, from the current test, is 0.28 percent lower than the value measured during the previous test (Ref. 2); however, the vacuum total impulse for both motors is within the manufacturer's specifications.

4.3 STRUCTURAL INTEGRITY AND MOTOR TEMPERATURE-TIME HISTORY

External postfire examination of the motor case and nozzle assembly did not reveal any evidence of thermal damage (Fig. 8). The pinned nozzle throat section was securely in place after the test. Nozzle throat measurements indicated a throat area increase of 10.5 percent from the prefire area. The nozzle exit area had decreased approximately 1.02 percent from the prefire area.

Motor case and nozzle temperature variations with time are presented in Fig. 9. The maximum indicated case temperature (590°F) occurred approximately 450 sec after motor ignition, as indicated by the thermocouple (TC-14) located on the motor case near the nozzle closure (Fig. 9f) and was within the maximum manufacturer's limit of 600°F. The maximum case temperature recorded during the Ref. 2 motor test was 525°F, 600 sec after motor ignition. The maximum indicated nozzle temperature (560°F) occurred 150 sec after motor ignition, as indicated by the thermocouple (TN-12) located near the nozzle throat (Fig. 9f); the previous maximum nozzle temperature for Ref. 2 motor was 705°F, 245 sec after motor ignition. The Ref. 2 motor was enclosed in a lightweight thermal insulation blanket.

4.4 PLUME RADIATION

Five narrow-angle radiometers were used to obtain rocket exhaust plume radiation heat flux data. One wide-angle calorimeter was used to obtain background radiation. The instruments were positioned around the nozzle assembly as shown in Fig. 4.

The variation of radiation heat flux with time is presented in Fig. 10. The maximum radiation heat flux (prior to motor burnout and diffuser breakdown) was 18 Btu/ft\(^2\)-sec (Fig. 10f, R-5) and occurred 19 sec after ignition. The maximum measured radiation was 3 Btu/ft\(^2\)-sec higher than the maximum measured during the previous test (Ref. 2). Measured radiation heat flux increased throughout the firing.

4.5 LATERAL (NONAXIAL) THRUST VECTOR MEASUREMENT

An additional objective for this test was to measure the lateral (nonaxial) component of motor thrust. The recorded lateral thrust data were corrected for installation and/or electronic effects as described in Ref. 6.
The maximum magnitude of lateral thrust recorded during the near steady-state portion of motor operation was 2.9 lbf and occurred at approximately 2 and 14 sec after motor ignition (Fig. 11). The corresponding angular positions of the lateral thrust vector (measured clockwise looking upstream) were 50 and 45 deg.

SECTION V
SUMMARY OF RESULTS

One Thiokol Chemical Corporation TE-M-521-5 solid-propellant rocket motor was successfully fired at an average pressure altitude of about 108,000 ft, while spinning at 46 rpm about the motor axis. The motor was prefire vibration conditioned, and temperature conditioned in a controlled environment of 40 ± 5°F for a period in excess of 24 hr prior to firing. Results are summarized as follows:

1. Ignition time (t₁), the time interval from application of ignition voltage to attainment of 90 percent of peak thrust during the ignition transient, was 0.11 sec and met the manufacturer’s specifications.

2. Ignition lag time (t₂), the time interval from the time at which ignition voltage was applied to the igniter circuit to the first perceptible rise in chamber pressure, was 0.006 sec. Action time (t₃), the time interval between 10 percent of maximum chamber pressure during ignition and 10 percent of maximum chamber pressure during tailoff, was 20.68 sec.

3. Total burn time (t₄), the time interval between the application of ignition voltage to the time at which the ratio of chamber-to-cell pressure had decreased to 1.3 at tailoff, was 21.63 sec. This burn time was 5.84 sec less than the previous altitude firing of the TE-M-521-5 and is attributed to a faster propellant burn rate and incomplete propellant combustion. Eight slivers of propellant, approximately 12 in. long and 1/2 to 3/4 in. wide remained in the motor case.

4. Vacuum total impulse, based on t₄, was 71,469 lbf-sec, and was within the manufacturer’s specification of 71,350 ± 350 lbf-sec. Vacuum specific impulse, based on t₄ and expended mass, was 288.76 lbf-sec/lbm, and was almost 0.7 percent greater than the previous TE-M-521-5 motor. The improvement in motor performance was further evidenced by an approximate 1-percent increase in vacuum thrust coefficient (1.856 for the current motor, compared with 1.838 for the previous -5 motor). The reason for the improved motor ballistic performance has not been determined.

5. The nozzle throat area increased approximately 10.5 percent from the prefire area during the firing. The nozzle exit area decreased nominally 1.02 percent.
6. The maximum motor case temperature was 590°F and occurred approximately 450 sec after motor ignition. The maximum nozzle temperature was 560°F and occurred approximately 150 sec after ignition.

7. The maximum magnitude of lateral (nonaxial) thrust measured during near steady-state portion of motor operation was 2.9 lbf and occurred at approximately 2 and 14 sec after first indication of chamber pressure.

8. The maximum radiation heat flux was 18 Btu/ft²·sec at the exit plane 19 sec after ignition and was within the range measured during previous tests. Measured radiation heat flux increased throughout the firing.

REFERENCES


APPENDIXES
I. ILLUSTRATIONS
II. TABLES
a. Schematic

Fig. 1 Thiokol Chemical Corporation TE-M-521-5 Solid-Propellant Rocket Motor
b. Photograph (Less Igniters)
Fig. 1 Concluded
Fig. 2   Installation of the Thiokol TE-M-521-5 Rocket Motor in Propulsion Development Test Cell (T-3)
b. Photograph
Fig. 2 Continued
c. Details of Nonaxial Force Measuring System

Fig. 2 Concluded
Motor case and nozzle thermocouples located in line with pyrogens.

Fig. 3 Schematic of Motor Showing Thermocouple Locations
Fig. 4 Schematic of Motor Installation Showing Radiometer and Calorimeter Locations

All Dimensions in Inches
Fig. 5 Analog Trace of Motor Ignition Event
Flow at Nozzle Throat Becomes Subsonic

Flow at Nozzle Throat Becomes Subsonic

Where: \( \bar{c}_f = \frac{\int F dt + A_{ex \text{avg}} \int P_{cell} dt + \bar{c}_f A_{th \text{post}} \int P_{ch} dt}{A_t \int^t_1 P_{ch} dt} \)

Established from data during the time interval from 18.00 \( (t_1) \) to 19.00 \( (t_2) \) sec after first indication of chamber pressure.

Fig. 6 Definition of Vacuum Total and Action Impulse
Fig. 7 Variation of Thrust, Chamber Pressure, and Test Cell Pressure during Firing.
a. Motor Case and Nozzle

Fig. 8 Postfire Photographs of Motor Assembly
Fig. 9 Motor Temperature Variation with Time

a. Motor Case; TC-1, TC-2, and TC-15

b. Motor Case; TC-3, TC-4, TC-16, and TC-17
c. Motor Case; TC-5, TC-6, TC-18, and TC-19

d. Motor Case; TC-7, TC-8, TC-20, and TC-21

Fig. 9 Continued
f. Nozzle; TN-11, TN-12, TN-13, and TN-24

Fig. 9 Concluded
Fig. 10  Exhaust Plume Radiation Variations with Time

a. Calorimeter, C-1 (View Angle = 140 deg)

b. Radiometer, R-1 (View Angle = 30 deg)

c. Radiometer, R-2 (View Angle = 60 deg)
Fig. 10 Concluded

d. Radiometer, R-4 (View Angle = 90 deg)
e. Radiometer, R-5 (View Angle = 3 deg)
f. Radiometer, R-6 (View Angle = 3 deg)

Fig. 10 Concluded
Fig. 11 Space-Time Variation of Magnitude and Angular Position of Lateral (Nonaxial) Thrust Vector
<table>
<thead>
<tr>
<th>Parameter Description</th>
<th>Parameter Designation</th>
<th>Precision Index</th>
<th>Uncertainty Type</th>
<th>Method of Calibration</th>
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<tr>
<td></td>
<td></td>
<td>Percent Reading</td>
<td>Uncertainty of Reading</td>
<td>Percent Reading</td>
</tr>
</tbody>
</table>

| Axial Force, lbf      | ±0.126                | ±0.1            | ±0.35            | 2000 to 4000 lbf     |
|                       |                       |                 |                 | Bonded Strain-Gage-Type Force Transducers |
|                       |                       |                 |                 | Voltage-to-Frequency Converter onto Magnetic Tape |
|                       |                       |                 |                 | In-place Application of Deadweigths Calibrated in the Standards Laboratory |
|                       |                      |                 |                 |                       |                       |
| Total Impulse, lbf-sec| ±0.112                | ±0.1            | ±0.32            | Bonded Strain-Gage-Type Pressure Transducers |
|                       |                       |                 |                 | Resistance Shunt Based on the Standards Laboratory Determination of Transducer Applied Pressure versus Resistance Shunt Equivalent Pressure Relationship |
|                       |                       |                 |                 |                       |                       |
| Chamber Pressure, psia| ±0.084                | ±0.1            | ±1.29            | 500 to 1000 psia      |
|                       |                       |                 |                 | Bonded Strain-Gage-Type Pressure Transducers |
|                       |                       |                 |                 |                       |                       |
| Chamber Pressure Integral, psia-sec | ±0.07 | ±0.1 | ±0.24 | 4.0 to 40 psia |
| Low Range Chamber Pressure, psia | ±(0.1% + 0.002 psi) | ±0.008 psi | ±(0.2% + 0.012 psi) | 4.0 to 40 psia |
| Test Cell Pressure, psia | ±0.23 | ±1.25 | ±1.7 | 0.8 to 10 psia |
| Test Cell Pressure Integral, psia-sec | ±0.22 | ±1.25 | ±1.7 | 0.12 psia |
| Motor Temperature, °F | ±0.35°F | ±2.2°F | ±2.7°F | 0 to 60°F |
| Exhaust Plume Heat Flux, Btu/ft²-sec | ±0.77 | ±0.77 | Note 1 | 0 to 600°F |
| Time Interval, msec | ±0.25 | ±0.01 | ±0.5 | Time Pulse Generator |
| Weight, lbf | ±0.125 | ±0.02 | ±0.27 | Beam-Balance Scales |
| Lateral Thrust Vector Magnitude, lbf | ±0.12 | ±0.31 | ±0.57 | Bonded Strain-Gage-Type Force Transducers |

**Note 1:** Uncertainty estimate for this parameter does not include User-furnished calorimeter.

<table>
<thead>
<tr>
<th>Test Number</th>
<th>RA182-01</th>
<th>Ref. 2</th>
<th>Ref. 3</th>
<th>Ref. 3</th>
<th>Ref. 4</th>
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<tr>
<td>Test Date</td>
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<td>01-20-72</td>
<td>7-26-68</td>
<td>6-1-68</td>
<td>4-11-69</td>
</tr>
<tr>
<td>Average Motor Spin Rate during Firing, rpm</td>
<td>46</td>
<td>46</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Motor Case Temperature at Ignition, °F</td>
<td>40</td>
<td>40</td>
<td>40</td>
<td>40</td>
<td>40</td>
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<tr>
<td>Number of Pyrogen Igniters Utilized</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
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<tr>
<td>Ignition Lag Time ((t_l)), sec((1))</td>
<td>0.006</td>
<td>0.002</td>
<td>0.006</td>
<td>0.002</td>
<td>0.008</td>
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<tr>
<td>Ignition Time ((t_i)), sec((2))</td>
<td>0.110</td>
<td>---</td>
<td>0.002</td>
<td>---</td>
<td>0.008</td>
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<tr>
<td>Time from Ignition until Diffuser Flow Breakdown ((t_{bd})), sec((3))</td>
<td>20.20</td>
<td>21.10</td>
<td>20.30</td>
<td>18.80</td>
<td>20.20</td>
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<tr>
<td>Time Interval that Nozzle Throat Flow was Sonic ((t_{ts})), sec((4))</td>
<td>31.63</td>
<td>27.47</td>
<td>36.30</td>
<td>36.30</td>
<td>32.30</td>
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<tr>
<td>Simulated Altitude at Ignition, ft</td>
<td>115,000</td>
<td>121,000</td>
<td>111,000</td>
<td>110,000</td>
<td>113,000</td>
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<tr>
<td>Average Simulated Altitude during (t_s), ft</td>
<td>108,000</td>
<td>108,000</td>
<td>113,000</td>
<td>115,000</td>
<td>117,000</td>
</tr>
<tr>
<td>Measured Total Impulse (\text{Based on } t_{bd}), lbf-sec</td>
<td>70,831</td>
<td>70,801</td>
<td>70,015</td>
<td>70,240</td>
<td>70,443</td>
</tr>
<tr>
<td>Maximum Channel Deviation from Average, percent</td>
<td>0.040</td>
<td>0.024</td>
<td>0.059</td>
<td>0.066</td>
<td>0.033</td>
</tr>
<tr>
<td>Chamber Pressure Integral (\text{Based on } t_{bd}), psia-sec</td>
<td>13,072</td>
<td>13,214</td>
<td>13,047</td>
<td>13,071</td>
<td>13,071</td>
</tr>
<tr>
<td>Maximum Channel Deviation, percent</td>
<td>0.030</td>
<td>0.053</td>
<td>0.17</td>
<td>---</td>
<td>---</td>
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<tr>
<td>Cell Pressure Integral (\text{Based on } t_{bd}), psia-sec</td>
<td>2.3628</td>
<td>2.3038</td>
<td>1.8279</td>
<td>1.5301</td>
<td>1.5224</td>
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<tr>
<td>Average of Three Channels of Data</td>
<td>1.840</td>
<td>1.838</td>
<td>1.840</td>
<td>1.840</td>
<td>1.840</td>
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<tr>
<td>Maximum Channel Deviation, percent</td>
<td>0.40</td>
<td>3.67</td>
<td>0.18</td>
<td>0.35</td>
<td>0.645</td>
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<tr>
<td>Vacuum Total Impulse (\text{Based on } t_{td}), lbf-sec</td>
<td>71,231</td>
<td>71,254</td>
<td>71,369</td>
<td>71,513</td>
<td>71,607</td>
</tr>
<tr>
<td>Vacuum Total Impulse (\text{Based on } t_{td}), lbf-sec</td>
<td>71,469</td>
<td>71,671</td>
<td>71,600</td>
<td>71,765</td>
<td>71,879</td>
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<tr>
<td>Vacuum Total Impulse (\text{Based on } t_{td}), lbf-sec</td>
<td>288.12</td>
<td>288.19</td>
<td>288.94</td>
<td>289.53</td>
<td>289.91</td>
</tr>
</tbody>
</table>
| Vacuum Specific Impulse \(\text{Based on } t_{td}\), lbf-sec/1bm
Based on the Manufacturer's Stated Propellant Weight | 287.80 | 286.16 | 285.37 | 285.78 | 287.14 |
| Vacuum Specific Impulse \(\text{Based on } t_{td}\), lbf-sec/1bm
Based on the Manufacturer's Stated Propellant Weight | 289.08 | 289.81 | 289.88 | 290.55 | 291.01 |
| Average Vacuum Thrust Coefficient, \(C_F\)
Based on \(t_{td}\) and Average Pre- and Postfire Areas | 1.856 | 1.838 | 1.840 | 1.840 | 1.841 |

\((1)\) Defined as the time interval from application of ignition voltage to the first perceptible rise in chamber pressure.

\((2)\) Defined as the time interval from application of ignition voltage to attainment of 90 percent of peak thrust during the ignition transient.

\((3)\) Defined as the time interval beginning when chamber pressure has risen to 10 percent of maximum at ignition and ending when chamber pressure has fallen to 10 percent of maximum during tailoff.

\((4)\) 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.

\((A)\) One channel of chamber pressure utilized.

\((B)\) Chamber pressure data invalid from 3.5 to 18.0 sec after ignition.
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<tr>
<td>Motor Spin Rate, rpm</td>
<td>46</td>
<td>46</td>
<td>100</td>
<td>100</td>
<td>100</td>
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<tr>
<td>AEDC Prefire Motor Weight, lbm</td>
<td>442.340*</td>
<td>473.250</td>
<td>274.612</td>
<td>274.649</td>
<td>275.713</td>
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<tr>
<td>AEDC Postfire Motor Weight, lbm</td>
<td>194.840*</td>
<td>223.375</td>
<td>24.516</td>
<td>24.410</td>
<td>26.335</td>
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<tr>
<td>AEDC Expended Mass, lbm</td>
<td>247.500</td>
<td>249.875</td>
<td>250.096</td>
<td>250.239</td>
<td>249.378</td>
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<tr>
<td>Manufacturer's Stated Propellant Weight, lbm</td>
<td>247.2</td>
<td>247.30</td>
<td>247.0</td>
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<td>Nozzle Throat Area, in.</td>
<td>2.790**</td>
<td>2.790</td>
<td>2.7907</td>
<td>2.7847</td>
<td>2.7877</td>
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<tr>
<td>Prefire</td>
<td>3.082</td>
<td>3.076</td>
<td>3.0697</td>
<td>3.0757</td>
<td>3.1201</td>
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<td>Postfire</td>
<td>+10.5</td>
<td>+10.3</td>
<td>+9.997</td>
<td>+10.450</td>
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<td>Change from Prefire Measurement, percent</td>
<td>148.53</td>
<td>148.41</td>
<td>148.574</td>
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<td>Nozzle Exit Area, in.</td>
<td>147.02</td>
<td>147.23</td>
<td>146.858</td>
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<td>-1.02</td>
<td>-0.8</td>
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<td>-0.808</td>
<td>-0.4265</td>
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*Includes igniter weight and thrust adapter
**Supplied by motor manufacturer
**REPORT TITLE**

DESIGN ASSURANCE TEST OF THE THIOKOL TE-M-521-5 APOGEE KICK MOTOR TESTED IN THE SPIN MODE AT SIMULATED ALTITUDE CONDITIONS

**AUTHOR(S)**

A. A. Cimino, ARO, Inc.

**DESCRIPTIVE NOTES**

July 28, 1972—Final Report

**ABSTRACT**

One Thiokol Chemical Corporation TE-M-521-5 solid-propellant apogee rocket motor was successfully fired at an average simulated altitude of about 108,000 ft while spinning at 46 rpm. The general program objectives were to verify compliance of motor performance with the manufacturer's specifications. Specific primary objectives were to determine vacuum ballistic performance of the motor after prefire vibration conditioning and temperature conditioning at 40°F, altitude ignition characteristics, motor structural integrity, and motor temperature-time history during and after motor operation. Additional objectives were to measure the lateral (nonaxial) thrust component during motor operation and to measure radiation heat flux in the vicinity of the nozzle exit plane.
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