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ALTITUDE DEVELOPMENTAL TESTING OF THE J-2 ROCKET ENGINE IN PROPULSION ENGINE TEST CELL (J-4) (TESTS J4-1801-37 AND 38)

C. E. Pillow
ARO, Inc.

October 1968

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LARGE ROCKET FACILITY

ARNOLD ENGINEERING DEVELOPMENT CENTER
AIR FORCE SYSTEMS COMMAND
ARNOLD AIR FORCE STATION, TENNESSEE
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ALTITUDE DEVELOPMENTAL TESTING OF THE
J-2 ROCKET ENGINE IN PROPULSION ENGINE
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C. E. Pillow
ARO, Inc.
FOREWORD

The work reported herein was sponsored by the National Aeronautics and Space Administration (NASA), Marshall Space Flight Center (MSFC) (I-E-J), under System 921E, Project 9194.

The results of the tests presented 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. Program direction was provided by NASA/MSFC; engineering liaison was provided by North American Rockwell Corp., Rocketdyne Division, manufacturer of the J-2 rocket engine and McDonnell Douglas Corp., Douglas Aircraft Company, Missile and Space Systems Division, manufacturer of the S-IVB stage. The testing reported herein was conducted April 16 and 23, 1968, in Propulsion Engine Test Cell (J-4) of the Large Rocket Facility (LRF) under ARO Project No. KA1801. The manuscript was submitted for publication on August 16, 1968.

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This technical report has been reviewed and is approved.

Edgar D. Smith
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Director of Test
ABSTRACT

Eight firings and two partial transition tests of the J-2 rocket engine were accomplished during test periods J4-1801-37 and 38. These tests periods were conducted on April 16 and 23, 1968, respectively. Each of these firings was in support of the S-V/S-IVB stage engine to investigate engine start transients for first burn and restart simulations. The partial transition tests were to evaluate thrust chamber temperature effects on the engine start transients. All objectives were successfully met with a total accumulated firing duration of 156.6 sec.

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NOMENCLATURE

A Area, in.²
ASI Augmented spark igniter
ES Engine start, designated as the time that helium control and ignition phase solenoids are energized
GG Gas generator
MOV Main oxidizer valve
NPSH Net positive suction head, ft
STDV Start tank discharge valve
\( t_0 \) Defined as the time at which the opening signal is applied to the start tank discharge valve solenoid
VSC  Vibration safety counts, defined as the time at which engine vibration was in excess of 150 g rms in a 960-to 6000-Hz frequency range

SUBSCRIPTS

f  Force
m  Mass
t  Throat
SECTION I
INTRODUCTION

Testing of the Rocketdyne J-2 rocket engine using an S-IVB battleship stage has been in progress since July, 1966, at AEDC in support of the J-2 engine application on the Saturn IB and Saturn V launch vehicles for the NASA Apollo Program. The eight firings and two partial transition tests reported herein were conducted during test periods J4-1801-37 and 38 on April 16 and 23, 1968, respectively, in Propulsion Engine Test Cell (J-4) (Figs. 1 and 2, Appendix I) of the Large Rocket Facility (LRF). These tests were conducted at pressure altitudes ranging from 75,000 to 110,000 ft (geometric pressure altitude, Z, Ref. 1) at engine start to investigate engine first burn and restart transients. Selected engine components were conditioned to predicted flight conditions.

Data collected to accomplish the test objectives are presented herein. The results of the previous test period are presented in Ref. 2.

SECTION II
APPARATUS

2.1 TEST ARTICLE

The test article was a J-2 rocket engine (Fig. 3) designed and developed by Rocketdyne Division of North American Rockwell Corporation. The engine uses liquid oxygen and liquid hydrogen as propellants and has a thrust rating of 230,000 lb at an oxidizer-to-fuel mixture ratio of 5.5. An S-IVB battleship stage, with flight-type S-IVB stage propellant supply ducts, was used to supply propellants to the engine. A schematic of the battleship stage is presented in Fig. 4.

Listings of major engine components and engine orifices for this test period are presented in Tables I and II, respectively (Appendix II). All engine modifications and component replacements performed since the previous test period are presented in Tables III and IV, respectively.
2.1.1 J-2 Rocket Engine

The J-2 rocket engine (Figs. 3 and 5, Ref. 3) features the following major components:

1. Thrust Chamber - The tubular-walled, bell-shaped thrust chamber consists of an 18.6-inch-diam combustion chamber (8.0 in. long from the injector mounting to the throat inlet) with a characteristic length ($L^*$) of 24.6 in., a 170.4-in.$^2$ throat area, and a divergent nozzle with an expansion ratio of 27.1. Thrust chamber length (from the injector flange to the nozzle exit) is 107 in. Cooling is accomplished by the circulation of engine fuel flow downward from the fuel manifold through 180 tubes and then upward through 360 tubes to the injector.

2. Thrust Chamber Injector - The injector is a concentric-orificed (concentric fuel orifices around the oxidizer post orifices), porous-faced injector. Fuel and oxidizer injector orifice areas are 25.0 and 16.0 $in.^2$, respectively. The porous material, forming the injector face, allows approximately 3.5 percent of total fuel flow to transpiration cool the face of the injector.

3. Augmented Spark Igniter - The augmented spark igniter unit is mounted on the thrust chamber injector and supplies the initial energy source to ignite propellants in the main combustion chamber. The augmented spark igniter chamber is an integral part of the thrust chamber injector. Fuel and oxidizer are ignited in the combustion area by two spark plugs.

4. Fuel Turbopump - The turbopump is composed of a two-stage turbine-stator assembly, an inducer, and a seven-stage axial-flow pump. The pump is self lubricated and nominally produces, at rated conditions, a head rise of 38,215 ft (1248 psia) of liquid hydrogen at a flow rate of 8585 gpm for a rotor speed of 27,265 rpm.

5. Oxidizer Turbopump - The turbopump is composed of a two-stage turbine-stator assembly and a single-stage centrifugal pump. The pump is self lubricated and nominally produces, at rated conditions, a head rise of 2170 ft (1107 psia) of liquid oxygen at a flow rate of 2965 gpm for a rotor speed of 8688 rpm.

6. Gas Generator - The gas generator consists of a combustion chamber containing two spark plugs, a pneumatically operated control valve containing oxidizer and fuel poppets, and an injector assembly. The oxidizer and fuel poppets provide a fuel lead to the gas generator combustion chamber. The high energy gases produced by the gas generator are directed to the fuel.
turbine and then to the oxidizer turbine (through the turbine crossover duct) before being exhausted into the thrust chamber at an area ratio \((A/A_t)\) of approximately 11.

7. **Propellant Utilization Valve** - The motor-driven propellant utilization valve is mounted on the oxidizer turbopump and bypasses liquid oxygen from the discharge to the inlet side of the pump to vary engine mixture ratio.

8. **Propellant Bleed Valves** - The pneumatically operated fuel and oxidizer bleed valves provide pressure relief for the boiloff of propellants trapped between the battleship stage prevalves and main propellant valves at engine shutdown.

9. **Integral Hydrogen Start Tank and Helium Tank** - The integral tanks consist of a 7258-in.\(^3\) sphere for hydrogen with a 1000-in.\(^3\) sphere for helium located within it. Pressurized gaseous hydrogen in the start tank provides the initial energy source for spinning the propellant turbopumps during engine start. The helium tank provides a helium pressure supply to the engine pneumatic control system.

10. **Oxidizer Turbine Bypass Valve** - The pneumatically actuated oxidizer turbine bypass valve provides control of the fuel turbine exhaust gases directed to the oxidizer turbine in order to control the oxidizer-to-fuel turbine spinup relationship. The fuel turbine exhaust gases which bypass the oxidizer turbine are discharged into the thrust chamber.

11. **Main Oxidizer Valve** - The main oxidizer valve is a pneumatically actuated, two-stage, butterfly-type valve located in the oxidizer high pressure duct between the turbopump and the main injector. The first-stage actuator positions the main oxidizer valve at the 14-deg position to obtain initial thrust chamber ignition; the second-stage actuator ramps the main oxidizer valve full open to accelerate the engine to main-stage operation.

12. **Main Fuel Valve** - The main fuel valve is a pneumatically actuated butterfly-type valve located in the fuel high pressure duct between the turbopump and the fuel manifold.

13. **Pneumatic Control Package** - The pneumatic control package controls all pneumatically operated engine valves and purges.

14. **Electrical Control Assembly** - The electrical control assembly provides the electrical logic required for proper sequencing of engine components during operation.
15. Primary and Auxiliary Flight Instrumentation Packages - The instrumentation packages contain sensors required to monitor critical engine parameters. The packages provide environmental control for the sensors.

2.1.2 S-IVB Battleship Stage

The S-IVB battleship stage is approximately 22 ft in diameter and 49 ft long and has a maximum propellant capacity of 46,000 lb of liquid hydrogen and 199,000 lb of liquid oxygen. The propellant tanks, fuel above oxidizer, are separated by a common bulkhead. Propellant pre-valves, in the low pressure ducts (external to the tanks) interfacing the stage and the engine, retain propellant in the stage until being admitted into the engine to the main propellant valves and serve as emergency engine shutoff valves. Propellant recirculation pumps in both fuel and oxidizer tanks are utilized to circulate propellants through the low pressure ducts and turbopumps before engine start to stabilize hardware temperatures near normal operating levels and to prevent propellant temperature stratification. Vent and relief valve systems are provided for both propellant tanks.

Pressurization of the fuel and oxidizer tanks was accomplished by facility systems using hydrogen and helium, respectively, as the pressurizing gases. The engine-supplied gaseous hydrogen for fuel tank pressurization during S-IVB flight was routed to the facility vent system.

2.2 TEST CELL

Test cell J-4, Fig. 2, is a vertically oriented test unit designed for static testing of liquid-propellant rocket engines and propulsion systems at pressure altitudes of 100,000 ft. The basic cell construction provides a 1.5-million-lbf-thrust capacity. The cell consists of four major components (1) test capsule, 48 ft in diameter and 82 ft in height, situated at grade level and containing the test article; (2) spray chamber, 100 ft in diameter and 250 ft in depth, located directly beneath the test capsule to provide exhaust gas cooling and dehumidification; (3) coolant water, steam, nitrogen (gaseous and liquid), hydrogen (gaseous and liquid), and liquid oxygen and gaseous helium storage and delivery systems for operation of the cell and test article; and (4) control building, containing test article controls, test cell controls, and data acquisition equipment. Exhaust machinery is connected with the spray chamber and maintains a minimum test cell pressure before and after the engine firing and exhausts the products of combustion from the engine firing. Before
a firing, the facility steam ejector, in series with the exhaust machinery, provides a pressure altitude of 100,000 ft in the test capsule. A detailed description of the test cell is presented in Ref. 4.

The battleship stage and the J-2 engine were oriented vertically downward on the centerline of the diffuser-steam ejector assembly. This assembly consisted of a diffuser duct (20 ft in diameter by 150 ft in length), a centerbody steam ejector within the diffuser duct, a diffuser insert (13.5 ft in diameter by 30 ft in length) at the inlet to the diffuser duct, and a gaseous nitrogen annular ejector above the diffuser insert. The diffuser insert was provided for dynamic pressure recovery of the engine exhaust gases and to maintain engine ambient pressure altitude (attained by the steam ejector) during the engine firing. The annular ejector was provided to suppress steam recirculation into the test capsule during steam ejector shutdown. The test cell was also equipped with (1) a gaseous nitrogen purge system for continuously inerting the normal air in-leakage of the cell; (2) a gaseous nitrogen repressurization system for raising test cell pressure, after engine cutoff, to a level equal to spray chamber pressure and for rapid emergency inerting of the capsule; and (3) a spray chamber liquid nitrogen supply and distribution manifold for initially inerting the spray chamber and exhaust ducting and for increasing the molecular weight of the hydrogen-rich exhaust products.

An engine component conditioning system was provided for temperature conditioning engine components. The conditioning system utilized a liquid hydrogen-helium heat exchanger to provide cold helium gas for component conditioning. Engine components requiring temperature conditioning were the thrust chamber, crossover duct, and main oxidizer valve second-stage actuator. Helium was routed internally through the crossover duct and tubular-walled thrust chamber and externally over the main oxidizer valve second-stage actuator.

2.3 INSTRUMENTATION

Instrumentation systems were provided to measure engine, stage, and facility parameters. The engine instrumentation was comprised of (1) flight instrumentation for the measurement of critical engine parameters and (2) facility instrumentation which was provided to verify the flight instrumentation and to measure additional engine parameters. The flight instrumentation was provided and calibrated by the engine manufacturer; facility instrumentation was initially calibrated and periodically recalibrated at AEDC. Appendix III contains a list of all measured test parameters and the locations of selected sensing points.
Pressure measurements were made using strain-gage-type pressure transducers. Temperature measurements were made using resistance temperature transducers and thermocouples. Oxidizer and fuel turbopump shaft speeds were sensed by magnetic pickup. Fuel and oxidizer flow rates to the engine were measured by turbine-type flowmeters which are an integral part of the engine. The propellant recirculation flow rates were also monitored with turbine-type flowmeters. Vibrations were measured by accelerometers mounted on the oxidizer injector dome and on the turbopumps. Primary engine and stage valves were instrumented with linear potentiometers and limit switches.

The data acquisition systems were calibrated by (1) precision electrical shunt resistance substitution for the pressure transducers and resistance temperature transducer units; (2) voltage substitution for the thermocouples; (3) frequency substitution for shaft speeds and flowmeters; and (4) frequency-voltage substitution for accelerometers.

The types of data acquisition and recording systems used during this test period were (1) a multiple-input digital data acquisition system (MicroSADIC®) scanning each parameter at 40 samples per second and recording on magnetic tape; (2) single-input, continuous-recording FM systems recording on magnetic tape; (3) photographically recording galvanometer oscillographs; (4) direct-inking, null-balance potentiometer-type X-Y plotters and strip charts; and (5) optical data recorders. Applicable systems were calibrated before each test (atmospheric and altitude calibrations). Television cameras, in conjunction with video tape recorders, were used to provide visual coverage during an engine firing, as well as for replay capability for immediate examination of unexpected events.

2.4 CONTROLS

Control of the J-2 engine, battleship stage, and test cell systems during the terminal countdown was provided from the test cell control room. A facility control logic network was provided to interconnect the engine control system, major stage systems, the engine safety cutoff system, the observer cutoff circuits, and the countdown sequencer. A schematic of the engine start control logic is presented in Fig. 6. The sequence of engine events for a normal start and shutdown is presented in Figs. 7a and b. Two control logics for sequencing the stage pre-valves and recirculation systems with engine start for simulating engine flight start sequences are presented in Figs. 7c and d.
SECTION III
PROCEDURE

Preoperational procedures were begun several hours before the test period. All consumable storage systems were replenished, and engine inspections, leak checks, and drying procedures were conducted. Propellant tank pressurants and engine pneumatic and purge gas samples were taken to ensure that specification requirements were met. Chemical analysis of propellants was provided by the propellant suppliers. Facility sequence, engine sequence, and engine abort checks were conducted within a 24-hr time period before an engine firing to verify the proper sequence of events. Facility and engine sequence checks consisted of verifying the timing of valves and events to be within specified limits; the abort checks consisted of electrically simulating engine malfunctions to verify the occurrence of an automatic engine cutoff signal. A final engine sequence check was conducted immediately preceding the test period.

Oxidizer dome, gas generator oxidizer injector, and thrust chamber jacket purges were initiated before evacuating the test cell. After completion of instrumentation calibrations at atmospheric conditions, the test cell was evacuated to approximately 0.5 psia with the exhaust machinery, and instrumentation calibrations at altitude conditions were conducted. Immediately before loading propellants on board the vehicle, the cell and exhaust-ducting atmosphere was inerted. At this same time, the cell nitrogen purge was initiated for the duration of the test period, except for the engine firing. The vehicle propellant tanks were then loaded, and the remainder of the terminal countdown was conducted. Temperature conditioning of the various engine components was accomplished as required, using the facility-supplied engine component conditioning system. Engine components which required temperature conditioning were the thrust chamber, the crossover duct, and main oxidizer valve second-stage actuator. Table V presents the engine purges and thermal conditioning operations during the terminal countdown and immediately following the engine firing.
SECTION IV
RESULTS AND DISCUSSION

4.1 TEST SUMMARY

Eight firings and two partial transition tests were accomplished during test periods J4-1801-37 and J4-1801-38 which were conducted on April 16 and 23, 1968, respectively. Each of these firings was in support of the S-V/S-IVB stage engine to investigate start transients for first burn, two orbit restarts, 80-min orbital coast restart, and 6-hr orbital coast restart simulation. The partial transition tests were to evaluate thrust chamber thermal conditioning on engine start transient. The accumulated firing duration for these test periods was 156.6 sec.

Each of the first burn firings was conducted with a propellant utilization valve excursion from the null to the closed position approximately 10 sec after start tank discharge, which resulted in a change in mixture ratio from approximately 5.0 to 5.5. The restart after the simulated 6-hr orbital coast included a propellant utilization valve excursion from the open to closed position at about 14 sec after start tank discharge. This resulted in a change in mixture ratio from approximately 4.5 to 5.5. Each of the 80-min restart simulations was conducted with the propellant utilization valve in the open position. The partial transition tests were conducted with the propellant utilization valve in the null position.

Firing 38B was prematurely terminated at $t_0 + 1.242$ sec as the result of a momentary loss of the oxidizer pre valve "open" limit switch feedback signal. However, the duration was sufficient enough that the test objectives were met.

The thrust chamber, crossover duct, and the main oxidizer valve second-stage actuator were thermally conditioned to targets predicted for S-IVB flight conditions. A summary of test requirements and results is presented in Table VI. Engine start conditions for the pump inlets, start tank, and helium tank are shown in Fig. 8. Component thermal conditioning histories and engine start and shutdown transients for tests J4-1801-37 and J4-1801-38 are shown in Figs. 9 through 48. Selected engine valve timings are tabulated in Table VII for the engine start and shutdown transients. Calculated engine performance (Appendix IV) for the four 32.5-sec duration firings is presented in Table VIII. Specific test objectives and a brief summary of results obtained from each firing are presented as follows:
<table>
<thead>
<tr>
<th>Firing</th>
<th>Test Objective</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>37A</td>
<td>S-IVB first burn simulation to evaluate engine start transients at minimum start energy</td>
<td>A successful 32.6-sec firing was achieved. Thrust chamber ignition (chamber pressure = 100 psia) was recorded at $t_0 + 1.047$ sec with main-stage operation (chamber pressure = 550 psia) recorded at $t_0 + 2.117$ sec. Excessive engine vibration (VSC) was recorded for 38 msec beginning at $t_0 + 1.045$ sec. The gas generator temperature peak was 1270°F. Minimum fuel pump stall margin was approximately 400 gpm at about 18,000 rpm.</td>
</tr>
<tr>
<td>37B</td>
<td>S-IVB 80-min restart simulation to evaluate engine start transients with narrow band start tank relief valve conditions of 1200 psia and -260°F and coldest (-200°F) expected thrust chamber conditions</td>
<td>A 7.6-sec firing was successfully accomplished. Thrust chamber ignition was recorded at $t_0 + 0.987$ sec with main-stage operation occurring at $t_0 + 2.050$ sec. The gas generator temperature peak was 1850°F. Engine vibration (VSC) was recorded for 15 msec beginning at $t_0 + 0.994$ sec.</td>
</tr>
<tr>
<td>37C</td>
<td>S-IVB restart simulation, with low starting energy and -100°F crossover duct after a simulated 6-hr orbital coast</td>
<td>A 32.6-sec firing was successfully achieved. Thrust chamber ignition was recorded at $t_0 + 1.090$ sec. Main-stage operation occurred at $t_0 + 2.800$ sec. Excessive engine vibration (VSC) was recorded for 55 msec beginning at $t_0 + 1.087$ sec. The initial gas generator outlet temperature peak was 890°F.</td>
</tr>
<tr>
<td>37D</td>
<td>S-IVB 80-min restart simulation to evaluate engine start transients with</td>
<td>A successful 7.6-sec firing was accomplished. Thrust chamber ignition was recorded at</td>
</tr>
<tr>
<td>Firing</td>
<td>Test Objectives</td>
<td>Results</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>37D (con’t)</td>
<td>narrow band start tank relief valve conditions of 1300 psia and -265°F, coldest (-200°F) expected thrust chamber conditions, and high fuel pump inlet pressure (41 psia)</td>
<td>t₀ + 0.954 sec. Main-stage operation was attained at t₀ + 1.625 sec. Excessive engine vibration (VSC) was recorded for 66 msec beginning at t₀ + 0.935 sec. The initial gas generator outlet temperature peak was 1585°F with a second peak of 1490°F. Programmed cutoff occurred 700 msec after main-stage signal. Thrust chamber ignition occurred at t₀ + 0.967 sec. A minimum fuel pump stall margin of approximately 1000 gpm occurred at about 12,400 rpm during start tank discharge. The maximum gas generator outlet temperature before cutoff was 1295°F. A successful 32.6-sec firing was conducted. Thrust chamber ignition was recorded at t₀ + 1.020 sec. Excessive engine vibration (VSC) was recorded for 31 msec beginning at t₀ + 1.018 sec. Main-stage operation was achieved at t₀ + 2.017 sec. The maximum gas generator outlet temperature was 1645°F. This firing was prematurely terminated at t₀ + 1.24 sec as the result of a momentary loss of the oxidizer prevalve open limit switch feedback signal. Thrust chamber ignition was recorded at t₀ + 1.010 sec. Excessive engine vibration</td>
</tr>
<tr>
<td>37E</td>
<td>S-IVB partial transition firing to evaluate thrust chamber temperature (25 ± 15°F) effects on engine start transient and relief of launch restraints</td>
<td></td>
</tr>
<tr>
<td>38A</td>
<td>S-IVB first burn simulation to evaluate engine start transients at AS-502 flight conditions</td>
<td></td>
</tr>
<tr>
<td>38B</td>
<td>S-IVB two-orbit restart simulation to evaluate expected engine start transient at AS-502 flight conditions</td>
<td></td>
</tr>
</tbody>
</table>
Firing | Test Objectives | Results
--- | --- | ---
38B (cont'd) | | (VSC) was recorded for 51 msec beginning at \( t_0 + 1.010 \) sec. The maximum gas generator outlet temperature was 1235°F before engine cutoff signal.
38C | S-IVB first burn simulation to evaluate augmented spark igniter and gas generator temperatures at maximum starting energy and fuel inlet pressure and the warmest (-80°F) expected thrust chamber | A 32.6-sec firing was successfully accomplished. The initial gas generator outlet temperature peak was 1580°F with a second peak of 1545°F. No apparent erosion of the augmented spark igniter chamber was detected. Thrust chamber ignition was recorded at \( t_0 + 0.968 \) sec. Excessive engine vibration (VSC) was recorded for 15 msec beginning at \( t_0 + 0.970 \) sec. Main-stage operation was achieved at \( t_0 + 1.858 \) sec.
38D | S-IVB 80-min restart simulation with narrow band relief valve limits on start energy (1300 psia and -265°F) and maximum fuel inlet pressure | A successful 7.6-sec firing was accomplished. Thrust chamber ignition was recorded at \( t_0 + 0.955 \) sec. Excessive engine vibration (VSC) was recorded for 10 msec beginning at \( t_0 + 0.955 \) sec. Main-stage operation was achieved at \( t_0 + 2.016 \) sec. The initial gas generator outlet temperature peak was 1555°F with a second peak of 1825°F.
38E | S-IVB partial transition firing to evaluate thrust chamber temperature (50 ± 15°F) effect on engine start transient | A programmed cutoff occurred 700 msec after main-stage signal. Thrust chamber ignition was recorded at \( t_0 + 0.972 \) sec. A minimum fuel pump stall margin of approximately 600 gpm was
The following sections will consist of discussions and analyses of selected firings. The data presented will be those recorded on the digital data acquisition system, except as noted.

### 4.2 S-IVB First Burn Simulation

Comparison of firings 37E and 38E to firing 36E (Ref. 2) showed the effect of thrust chamber thermal conditioning on fuel pump and gas generator start transients, as discussed in subsequent sections. Each of these firings was conducted at similar conditions as shown below:

<table>
<thead>
<tr>
<th>Firing</th>
<th>36E</th>
<th>37E</th>
<th>38E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel Lead, sec</td>
<td>3.001</td>
<td>3.020</td>
<td>3.001</td>
</tr>
<tr>
<td>Fuel Pump Inlet Pressure, psia, at Engine Start</td>
<td>27.9</td>
<td>28.6</td>
<td>27.9</td>
</tr>
<tr>
<td>Fuel Pump Inlet Temperature, °F, at Engine Start</td>
<td>-420.9</td>
<td>-421.4</td>
<td>-420.9</td>
</tr>
<tr>
<td>Oxidizer Pump Inlet Pressure, psia, at Engine Start</td>
<td>44.4</td>
<td>45.5</td>
<td>45.3</td>
</tr>
<tr>
<td>Oxidizer Pump Inlet Temperature, °F, at Engine Start</td>
<td>-294.3</td>
<td>-294.8</td>
<td>-294.4</td>
</tr>
<tr>
<td>Start Tank Pressure, psia, at Engine Start</td>
<td>1388</td>
<td>1380</td>
<td>1394</td>
</tr>
<tr>
<td>Start Tank Temperature, °F, at Engine Start</td>
<td>-199</td>
<td>-207</td>
<td>-203</td>
</tr>
<tr>
<td>Average Thrust Chamber Temperature, °F, at Engine Start/at t0</td>
<td>-14/-91</td>
<td>19/-66</td>
<td>51/-30</td>
</tr>
<tr>
<td>Average Crossover Duct Temperature, °F, at Engine Start</td>
<td>22</td>
<td>22</td>
<td>20</td>
</tr>
</tbody>
</table>

Each of these firings was a partial transition test with a programmed cutoff occurring at approximately 700 msec after the main-stage solenoid was energized.
4.2.1 Thrust Chamber Thermal Conditioning Effects on Fuel Pump Operation

The operation of the fuel pump was directly affected during start tank discharge by thrust chamber thermal conditioning. This resulted from thrust chamber temperature directly affecting the resistance to fuel flow through the thrust chamber. The warmest conditioned thrust chamber provided the greatest resistance to fuel flow, as evidenced by the sharp reduction in fuel pump flow coefficient (Fig. 49) during start tank discharge. This reduction occurred earliest with the warmest conditioned thrust chamber. The reduction in fuel flow resulted in an increase in fuel pump discharge pressure, which is shown by the increase in fuel pump head rise coefficient (Fig. 50). The resulting effect of thrust chamber thermal conditioning on fuel pump operation was to reduce the minimum stall margin during start tank discharge (Fig. 51); the warmest thrust chamber resulted in a stall margin of about 600 rpm at approximately 12,300 rpm.

4.2.2 Thrust Chamber Thermal Conditioning Effects on Gas Generator Operation

Gas generator operation during start tank discharge was directly affected by thrust chamber thermal conditioning. This was true since the fuel injection pressure into the gas generator was directly related to the fuel pump discharge pressure. The previous section (Section 4.2.1) showed that the pump discharge pressure increased with increases in thrust chamber conditioning temperature. This resulted in increased fuel injection pressure (Fig. 52) into the gas generator during start tank discharge as the thrust chamber conditioning temperature was increased. This, in effect, provided better quality fuel in the gas generator which reduced the mixture ratio. This was reflected in the reduction of the initial gas generator outlet temperature peak from 1585 to 1255°F (Fig. 53). Thus, an increase in thrust chamber conditioning temperature from -14 to 50°F reduced the initial gas generator outlet temperature peak about 330°F.

4.3 S-IVB 80-MIN ORBITAL COAST RESTART SIMULATION

Comparison of firing 37D to 38D showed the effect of thrust chamber thermal conditioning effects on fuel pump and gas generator start transients, as discussed in subsequent sections. Both of these firings were conducted at conditions predicted for an 80-min orbital coast restart as shown:
<table>
<thead>
<tr>
<th>Firing</th>
<th>36D</th>
<th>37D</th>
<th>38D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel Lead, sec</td>
<td>7.92</td>
<td>7.92</td>
<td>7.92</td>
</tr>
<tr>
<td>Fuel Pump Inlet Pressure, psia, at Engine Start</td>
<td>26.6</td>
<td>41.0</td>
<td>41.0</td>
</tr>
<tr>
<td>Fuel Pump Inlet Temperature, °F, at Engine Start</td>
<td>-420.6</td>
<td>-420.6</td>
<td>-421.1</td>
</tr>
<tr>
<td>Oxidizer Pump Inlet Pressure, psia, at Engine Start</td>
<td>45.0</td>
<td>45.0</td>
<td>45.1</td>
</tr>
<tr>
<td>Oxidizer Pump Inlet Temperature, °F, at Engine Start</td>
<td>-294.8</td>
<td>-294.7</td>
<td>-294.3</td>
</tr>
<tr>
<td>Start Tank Pressure, psia, at Engine Start</td>
<td>1298</td>
<td>1296</td>
<td>1295</td>
</tr>
<tr>
<td>Start Tank Temperature, °F, at Engine Start</td>
<td>-266</td>
<td>-276</td>
<td>-269</td>
</tr>
<tr>
<td>Average Thrust Chamber Temperature, °F, at Engine Start/ at t₀</td>
<td>-210/-362</td>
<td>-228/-366</td>
<td>36/-286</td>
</tr>
<tr>
<td>Crossover Duct Temperature, °F, at Engine Start (TFTD-2/-3/-8)</td>
<td>450/174/408</td>
<td>409/171/384</td>
<td>438/173/396</td>
</tr>
</tbody>
</table>

### 4.3.1 Thrust Chamber Thermal Conditioning Effects on Fuel Pump Operation

The initial resistance to fuel flow through the thrust chamber by the warmer conditioned chamber was greatly reduced by the 8-sec fuel lead. The average thrust chamber temperatures after the fuel lead (t₀) were -366 and -286°F for firings 37D and 38D, respectively. The resistance to fuel flow was essentially equal for both firings, as shown in Fig. 54. However, the warmer conditioned (-286°F) thrust chamber resulted in the higher fuel pump head rise coefficient during start tank discharge (Fig. 55). The net result was to reduce the minimum fuel pump stall margin from about 2360 to 2160 gpm at approximately 13,500 rpm during start tank discharge, Fig. 56.
4.3.2 Thrust Chamber Thermal Conditioning Effects on Gas Generator Operation

Both firings 37D and 38D were conducted with a fuel pump inlet pressure of 41.0 psia at engine start. This resulted in high gas generator fuel injection pressure and better quality fuel in the gas generator chamber. Ignition in the chamber occurred at \( t_0 + 0.660 \) sec for firing 38D. Ignition during firing 37D was characterized by apparent low energy combustion from \( t_0 + 0.670 \) sec to \( t_0 + 0.740 \) sec, as shown by gas generator chamber pressure in Fig. 57.

Thrust chamber ignition, which provides the mechanism for terminating the initial gas generator outlet temperature peak, occurred at \( t_0 + 0.955 \) sec for both firings. The initial gas generator outlet temperature peak for firing 37D (1585°F) was about 30°F hotter than for firing 38D (1555°F). This is shown in Fig. 58. Therefore, an increase in thrust chamber conditioning temperature from -366°F to -286°F resulted in a 30°F decrease in the initial gas generator outlet temperature peak.

4.3.3 Fuel Pump Inlet Pressure Effect on Fuel Pump Operation

The effect of fuel inlet pressure on fuel pump operation during start tank discharge could be seen by a comparison of firing 36D to 37D. From the data tabulated in Section 4.3, all starting conditions were essentially equal with the exception of fuel pump inlet pressure at engine start. The inlet pressure was 26.5 and 41.0 psia for firings 36D and 37D, respectively.

Oxidizer pump operation was the same for both firings; the peak turbine speed was approximately 3850 rpm at \( t_0 + 0.560 \) sec during start tank discharge. The average oxidizer pump discharge pressure (data from FM system) at \( t_0 + 0.560 \) was 305 psia for both firings.

The fuel pump speed at \( t_0 + 0.560 \) sec was about 660 rpm higher for firing 37D (13,565 rpm) than for firing 36D. This resulted in an average pump discharge pressure (data from FM system) of 100 psia at \( t_0 + 0.560 \) sec for firing 37D; this was about 40 psi greater than for firing 36D. Fuel pump head rise coefficient was lower for firing 37D during start tank discharge, as shown in Fig. 59. The flow coefficient (Fig. 60) was correspondingly higher for 37D at this same time period. The net effect of the increase from 26.5 to 41.0 psia fuel pump inlet pressure was to increase the minimum stall margin during start tank discharge from 1720 to 2000 gpm, as shown in Fig. 61.
4.3.4 Fuel Pump Inlet Pressure Effect on Gas Generator Operation

Higher fuel pump inlet pressure for firing 37D resulted in a higher fuel injection pressure into the gas generator than for firing 36D, as shown in Fig. 62. This provided a better quality fuel in the gas generator for firing 37D. With oxidizer injection pressure equal for both firings, the result was a lower mixture ratio in the gas generator chamber during firing 37D. Both firings were characterized by apparent low energy combustion; firing 37D from \( t_0 + 0.670 \) to 0.740 sec and firing 36D from \( t_0 + 0.650 \) to 0.750 sec. This was reflected in the gas generator chamber pressure as shown in Fig. 63.

Thrust chamber ignition occurred at \( t_0 + 0.955 \) sec for both firings. This provided the mechanism for terminating the initial gas generator outlet temperature (Fig. 64) at 1585°F for firing 37D about 575°F colder than for firing 36D. Therefore, an increase in fuel pump inlet conditioning pressure at engine start from 26.5 to 41.0 psia resulted in a decrease in the initial gas generator outlet temperature of 575°F.

4.4 S-IVB 6-HR ORBITAL COAST RESTART

Simulated restart conditions expected for the S-IVB stage engine after a 6-hr orbital coast are characterized by low starting energy. Both firings 37C and 36A (Ref. 2) were S-IVB 6-hr orbital coast restart simulations and were conducted at essentially the same starting conditions as shown below:

<table>
<thead>
<tr>
<th>Firing</th>
<th>36A</th>
<th>37C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel Lead, sec</td>
<td>7.92</td>
<td>7.92</td>
</tr>
<tr>
<td>Fuel Pump Inlet Pressure, psia, at Engine Start</td>
<td>26.8</td>
<td>27.0</td>
</tr>
<tr>
<td>Fuel Pump Inlet Temperature, °F, at Engine Start</td>
<td>-421.4</td>
<td>-421.2</td>
</tr>
<tr>
<td>Oxidizer Pump Inlet Pressure, psia, at Engine Start</td>
<td>33.6</td>
<td>33.5</td>
</tr>
<tr>
<td>Oxidizer Pump Inlet Temperature, °F, at Engine Start</td>
<td>-294.6</td>
<td>-294.8</td>
</tr>
<tr>
<td>Start Tank Pressure, psia, at Engine Start</td>
<td>1250</td>
<td>1237</td>
</tr>
<tr>
<td>Start Tank Temperature, °F, at Engine Start</td>
<td>-139</td>
<td>-146</td>
</tr>
</tbody>
</table>
Average Thrust Chamber Temperature, °F, at Engine Start/at t₀  
Firing  
36A  37C  
-182/-356  -231/-367

Average Crossover Duct Temperature, °F, at Engine Start  
-93  -99

Thrust chamber ignition occurred at t₀ + 1.090 sec for firing 37C and at t₀ + 1.079 sec for firing 36A. When compared with ignition time for first burn and 80-min orbital coast restart simulations, the 6-hr orbital coast ignition time was delayed about 90 msec. Thrust chamber pressure attained 550 psia at t₀ + 2800 sec for firings 37C and 36A, which is slow when compared with first burn and 80-min orbital coast restart simulations.

The initial gas generator outlet temperature peak was 890°F for firing 37C (Fig. 18f). This was about 10°F warmer than recorded for firing 36A. The 10°F difference resulted from lower resistance to fuel flow through the thrust chamber by the colder (-367°F) conditioned thrust chamber (firing 37C). This decreased the fuel available to the gas generator and thereby increased the mixture ratio in the gas generator.

The 10°F difference in the thrust chamber conditioning temperatures at t₀ did not significantly affect fuel pump operation. Thus firing 37C (Fig. 19) is representative of fuel pump start transient performance for firing 36A. The engine start transients for firing 37C (Fig. 18) are also representative of the start transients which existed for firing 36A.

4.5 POST-TEST INSPECTION

Inspection after the completion of tests J4-1801-37 and 38 revealed no apparent engine component damage.

SECTION V
SUMMARY OF RESULTS

The results of testing the J-2 rocket engine in Test Cell J-4 during tests J4-1801-37 and 38 conducted on April 16 and 23, 1968, respectively, are summarized as follows:

1. The engine started with the thrust chamber conditioned to +50°F at engine start (firing 38E), in conjunction with a
3-sec fuel lead for an S-IVB first burn mission. The minimum fuel pump stall margin was about 600 gpm at approximately 12,300 rpm.

2. An increase in average thrust chamber conditioning temperature at engine start from -14°F (firing 36E) to 50°F (firing 38E) for an S-IVB first burn reduced the initial gas generator outlet temperature peak about 330°F.

3. An increase in average thrust chamber conditioning temperature at engine start from -366°F (firing 37D) to -286°F (firing 38D) for an S-IVB 80-min orbital coast simulation resulted in a 30°F decrease in the initial gas generator outlet temperature peak.

4. A change in the fuel pump inlet conditioning pressure at engine start from 26.6 psia (firing 36D) to 41.0 psia (firing 37D) reduced the initial gas generator outlet temperature peak 575°F.

5. A minimum starting energy S-IVB 6-hr orbital coast restart (firing 37C) simulation was satisfactorily accomplished. The initial gas generator outlet temperature peak was 890°F.

6. An S-IVB first burn simulation (firing 37A) with minimum starting energy resulted in a minimum fuel pump stall margin of 400 gpm at about 18,000 rpm.

REFERENCES


APPENDIXES

I. ILLUSTRATIONS
II. TABLES
III. INSTRUMENTATION
IV. METHODS OF CALCULATION (PERFORMANCE PROGRAM)
Fig. 1 Test Cell J-4 Complex
Fig. 2 Test Cell J-4, Artist's Conception
Fig. 3 Engine Details
To Fuel Flare Stack
Fuel Tank Pressurization

Fuel Fill and Drain Line

Oxidizer Fill and Dump Line

Fuel Recirculation Pump

Fuel Prevalve

Fuel Recirculation Valve

Fuel Bleed Valve

Main Oxidizer Valve

Engine Fuel Valve

Oxidizer Turbine Bypass Valve

Combustion Products
- Liquid Hydrogen
- Gaseous Hydrogen
- Liquid Oxygen
- Gaseous Oxygen
- Gaseous Helium

Fig. 4 S-IVB Battleship Stage/J-2 Engine Schematic
Fig. 5 Engine Schematic
Engine Start
Bleed Valves Close
Oxidizer Dome and GG
Oxidizer Purge Flow
Main Fuel and ASI
Propellant Flow
Fuel Temperature OK Signal
Ignition-Phase Timer Ener-
gized 0.450 ± 0.030 sec
Pump Buildup
Ignition-Phase Timer Expires
Main-Stage Signal
Purge Control Valve Closed
Main Oxidizer Flow
GG Propellant Flow
Oxidizer Turbine Bypass Valve Closed
Main-Stage OK Signal
ASI and GG Sparks De-Energized

a. Start Sequence

Signal Time, sec  0  0.1  0.2  0.3  0.4  0.5  0.6  0.7  0.8  0.9  1.0

Cutoff Signal
GG Valve Close (Oxidizer)
GG Valve Close (Fuel)
ASI Oxidizer Valve Close
MOV Close
Main Fuel Valve Close
Oxidizer Dome Purge and GG
Oxidizer Purge on
He Control Solenoid
De-Energizes
Bleed Valves Open

b. Shutdown Sequence

Fig. 7 Engine Start and Shutdown Sequence
### Time Index Lines, 1-sec Intervals

<table>
<thead>
<tr>
<th>Event</th>
<th>Time Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fire Command</td>
<td></td>
</tr>
<tr>
<td>Prevalves Open Signal</td>
<td></td>
</tr>
<tr>
<td>Recirculation Pumps Off Signal</td>
<td>1</td>
</tr>
<tr>
<td>Recirculation Valves Close Signal</td>
<td></td>
</tr>
<tr>
<td>Engine Start Signal</td>
<td>1</td>
</tr>
<tr>
<td>Start Tank Discharge Valve Open Signal</td>
<td></td>
</tr>
</tbody>
</table>

1. Nominal Occurrence Time (Function of Prevalves Opening Time)
2. One-sec Fuel Lead (S-II/S-V and S-IVB/S-IB)
3. Eight-sec Fuel Lead (S-IVB/S-V and S-IB Orbital Restart)

c. Normal Logic Start Sequence

### Time Index Lines, 1-sec Intervals

<table>
<thead>
<tr>
<th>Event</th>
<th>Time Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fire Command</td>
<td></td>
</tr>
<tr>
<td>Prevalves Open Signal</td>
<td></td>
</tr>
<tr>
<td>Engine Start Signal</td>
<td></td>
</tr>
<tr>
<td>Oxidizer Recirculation Pump Off Signal</td>
<td></td>
</tr>
<tr>
<td>Fuel Recirculation Pump Off Signal</td>
<td></td>
</tr>
<tr>
<td>Recirculation Valves Close Signal</td>
<td></td>
</tr>
<tr>
<td>Start Tank Discharge Valve Open Signal</td>
<td>1</td>
</tr>
</tbody>
</table>

1. Three-sec Fuel Lead (S-IVB/S-V First Burn)

d. Auxiliary Logic Start Sequence

Fig. 7 Concluded
Fig. 8 Engine Start Conditions for the Pump Inlets, Start Tank, and Helium Tank
CONSTANT ENERGY LINE* CALCULATED FROM "TABLE OF THERMAL PROPERTIES OF GASES" NATIONAL BUREAU OF STANDARDS CIRCULAR 564, NOVEMBER 1965.

Fig. 8 Concluded
a. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

b. Crossover Duct, TFTD

c. Thrust Chamber Throat, TTC-1P

Fig. 9 Thermal Conditioning History of Engine Components, Firing 37A
a. Thrust Chamber Fuel System, Start

b. Thrust Chamber Oxidizer System, Start

Fig. 10 Engine Transient Operation, Firing 37A
c. Thrust Chamber Fuel System, Shutdown

---

d. Thrust Chamber Oxidizer System, Shutdown

Fig. 10 Continued
e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

f. Gas Generator Chamber Pressure and Temperature, Start

Fig. 10 Continued
g. Gas Generator Injector Pressures, Shutdown

h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 10 Concluded
NOTE: STALL INCEPTION LINE IS BASED ON TOTAL HEAD RISE ACROSS THE PUMP. THE DATA PLOTTED ARE PUMP DISCHARGE STATIC PRESSURE CONVERTED TO HEAD. DATA ARE FROM FM SYSTEM.

Fig. 11 Fuel Pump Start Transient Performance, Firing 37A
Fig. 12 Engine Ambient and Combustion Chamber Pressures, Firing 37A
a. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

b. Crossover Duct, TFTD

c. Thrust Chamber Throat, TTC-1P

Fig. 13 Thermal Conditioning History of Engine Components, Firing 37B
Fig. 14 Engine Transient Operation, Firing 37B

a. Thrust Chamber Fuel System, Start

b. Thrust Chamber Oxidizer System, Start
c. Thrust Chamber Fuel System, Shutdown

d. Thrust Chamber Oxidizer System, Shutdown

Fig. 14 Continued
e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

f. Gas Generator Chamber Pressure and Temperature, Start

Fig. 14 Continued
g. Gas Generator Injector Pressures, Shutdown

h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 14 Concluded
NOTE: STALL INCEPTION LINE IS BASED ON TOTAL HEAD RISE ACROSS THE PUMP. THE DATA PLOTTED ARE PUMP DISCHARGE STATIC PRESSURE CONVERTED TO HEAD. DATA ARE FROM FM SYSTEM.

Fig. 15 Fuel Pump Start Transient Performance, Firing 37B
Fig. 16 Engine Ambient and Combustion Chamber Pressures, Firing 37B
Fig. 17 Thermal Conditioning History of Engine Components, Firing 37C
a. Thrust Chamber Fuel System, Start

b. Thrust Chamber Oxidizer System, Start

Fig. 18 Engine Transient Operation, Firing 37C
c. Thrust Chamber Fuel System, Shutdown

d. Thrust Chamber Oxidizer System, Shutdown

Fig. 18 Continued
e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

f. Gas Generator Chamber Pressure and Temperature, Start

Fig. 18 Continued
g. Gas Generator Injector Pressures, Shutdown

h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 18 Concluded
NOTE: STALL INCISION LINE IS BASED ON TOTAL HEAD RISE ACROSS THE PUMP. THE DATA PLOTTED ARE PUMP DISCHARGE STATIC PRESSURE CONVERTED TO HEAD. DATA ARE FROM FM SYSTEM.

Fig. 19 Fuel Pump Start Transient Performance, Firing 37C
Fig. 20 Engine Ambient and Combustion Chamber Pressures, Firing 37C
Fig. 21 Thermal Conditioning History of Engine Components, Firing 37D
Fig. 22 Engine Transient Operation, Firing 37D
c. Thrust Chamber Fuel System, Shutdown

---

d. Thrust Chamber Oxidizer System, Shutdown

Fig. 22 Continued
e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

f. Gas Generator Chamber Pressure and Temperature, Start

Fig. 22 Continued
g. Gas Generator Injector Pressures, Shutdown

h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 22 Concluded
NOTE: STALL INCEPTION LINE IS BASED ON TOTAL HEAD RISE ACROSS THE PUMP. THE DATA PLOTTED ARE PUMP DISCHARGE STATIC PRESSURE CONVERTED TO HEAD. DATA ARE FROM FM SYSTEM.

Fig. 23 Fuel Pump Start Transient Performance, Firing 37D
Fig. 24 Engine Ambient and Combustion Chamber Pressures, Firing 37D
a. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

b. Crossover Duct, TFTD

c. Thrust Chamber Throat, TTC-1P

Fig. 25 Thermal Conditioning History of Engine Components, Firing 37E
a. Thrust Chamber Fuel System, Start

b. Thrust Chamber Oxidizer System, Start

Fig. 26 Engine Transient Operation, Firing 37E
c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

---

d. Gas Generator Chamber Pressure and Temperature, Start

*Fig. 26 Concluded*
NOTE: STALL INCEPTION LINE IS BASED ON TOTAL HEAD RISE ACROSS THE PUMP. THE DATA PLOTTED ARE PUMP DISCHARGE STATIC PRESSURE CONVERTED TO HEAD. DATA ARE FROM FM SYSTEM.
Fig. 28 Engine Ambient and Combustion Chamber Pressures, Firing 37E
Fig. 29 Thermal Conditioning History of Engine Components, Firing 38A
a. Thrust Chamber Fuel System, Start

b. Thrust Chamber Oxidizer System, Start

Fig. 30 Engine Transient Operation, Firing 38A
c. Thrust Chamber Fuel System, Shutdown

Fig. 30 Continued

d. Thrust Chamber Oxidizer System, Shutdown
e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

f. Gas Generator Chamber Pressure and Temperature, Start

Fig. 30 Continued
g. Gas Generator Injector Pressures, Shutdown

h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 30 Concluded
Fig. 31 Fuel Pump Start Transient Performance, Firing 38A

NOTE: STALL INCEPTION LINE IS BASED ON TOTAL HEAD RISE ACROSS THE PUMP. THE DATA PLOTTED ARE PUMP DISCHARGE STATIC PRESSURE CONVERTED TO HEAD. DATA ARE FROM FM SYSTEM.
Fig. 32 Engine Ambient and Combustion Chamber Pressures, Firing 38A
Fig. 33 Thermal Conditioning History of Engine Components, Firing 38B

a. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

b. Crossover Duct, TFTD

c. Thrust Chamber Throat, TTC-1P
a. Thrust Chamber Fuel System, Start

b. Thrust Chamber Oxidizer System, Start

Fig. 34 Engine Transient Operation, Firing 38B
c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

d. Gas Generator Chamber Pressure and Temperature; Start

Fig. 34 Concluded
NOTE: STALL INCEPTION LINE IS BASED ON TOTAL HEAD RISE ACROSS THE PUMP. THE DATA PLOTTED ARE PUMP DISCHARGE STATIC PRESSURE CONVERTED TO HEAD. DATA ARE FROM FM SYSTEM.
Fig. 36 Engine Ambient and Combustion Chamber Pressures, Firing 38B
a. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

b. Crossover Duct, TFTD

c. Thrust Chamber Throat, TTC-1P

Fig. 37 Thermal Conditioning History of Engine Components, Firing 38C
Fig. 38: Engine Transient Operation, Firing 38C

a. Thrust Chamber Fuel System, Start

b. Thrust Chamber Oxidizer System, Start
c. Thrust Chamber Fuel System, Shutdown

d. Thrust Chamber Oxidizer System, Shutdown

Fig. 38 Continued
e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

f. Gas Generator Chamber Pressure and Temperature, Start

Fig. 38 Continued
g. Gas Generator Injector Pressures, Shutdown

h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 38 Concluded
NOTE: STALL INCEPTION LINE IS BASED ON TOTAL HEAD RISE ACROSS THE PUMP. THE DATA PLOTTED ARE PUMP DISCHARGE STATIC PRESSURE CONVERTED TO HEAD. DATA ARE FROM FM SYSTEM.

Fig. 39 Fuel Pump Start Transient Performance, Firing 38C
Fig. 40  Engine Ambient and Combustion Chamber Pressures, Firing 38C
Fig. 41 Thermal Conditioning History of Engine Components, Firing 38D
Fig. 42 Engine Transient Operation, Firing 38D
c. Thrust Chamber Fuel System, Shutdown

d. Thrust Chamber Oxidizer System, Shutdown

Fig. 42 Continued
e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

f. Gas Generator Chamber Pressure and Temperature, Start

Fig. 42 Continued
g. Gas Generator Injector Pressures, Shutdown

h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 42 Concluded
NOTE: STALL INCEPTION LINE IS BASED ON TOTAL HEAD RISE ACROSS THE PUMP. THE DATA PLOTTED ARE PUMP DISCHARGE STATIC PRESSURE CONVERTED TO HEAD. DATA ARE FROM FM SYSTEM.

Fig. 43 Fuel Pump Start Transient Performance, Firing 38D
Fig. 44 Engine Ambient and Combustion Chamber Pressures, Firing 38D
a. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

b. Crossover Duct, TFTD

c. Thrust Chamber Throat, TTC-1P

Fig. 45 Thermal Conditioning History of Engine Components, Firing 38E
Fig. 46  Engine Transient Operation, Firing 38E
c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

![Graph showing pressure and position over time]

**Fig. 46 Concluded**

---

d. Gas Generator Chamber Pressure and Temperature, Start

![Graph showing pressure and temperature over time]

**Fig. 46 Concluded**
NOTE: STALL INCEPTION LINE IS BASED ON TOTAL HEAD RISE ACROSS THE PUMP. THE DATA PLOTTED ARE PUMP DISCHARGE STATIC PRESSURE CONVERTED TO HEAD. DATA ARE FROM FM SYSTEM.

Fig. 47 Fuel Pump Start Transient Performance, Firing 38E
Fig. 48 Engine Ambient and Combustion Chamber Pressures, Firing 38E
Fig. 49 Thrust Chamber Temperature Conditioning Effects on Fuel Pump Flow Coefficient, Firings 36E, 37E, and 38E
Fig. 50 Thrust Chamber Temperature Conditioning Effects on Fuel Pump Head Rise Coefficient, Firings 36E, 37E, and 38E
Fig. 51 Thrust Chamber Temperature Conditioning Effects on Fuel Pump Start Transient Performance, Firings 36E, 37E, and 38E
Fig. 52  Thrust Chamber Temperature Conditioning Effects on Gas Generator Fuel Injector Pressure, Firings 36E, 37E, and 38E
Fig. 53 Thrust Chamber Temperature Conditioning Effects on Gas Generator Outlet Temperature Transient, Firings 36E, 37E, and 38E
Fig. 54 Thrust Chamber Temperature Conditioning Effects on Fuel Pump Flow Coefficient, Firings 37D and 38D
Fig. 55 Thrust Chamber Temperature Conditioning Effects of Fuel Pump
Head Rise Coefficient, Firings 37D and 38D
Fig. 56  Thrust Chamber Temperature Conditioning Effects on Fuel Pump Start Transient Performance, Firings 37D and 38D
Fig. 57 Thrust Chamber Temperature Conditioning Effects on Gas Generator Chamber Pressure Transients, Firings 37D and 38D

TSC$_{AVG}$ = -286°F (FIRING 38D)

TSC$_{AVG}$ = -366°F (FIRING 37D)
Fig. 58 Thrust Chamber Temperature Conditioning Effects on Gas Generator Outlet Temperature Transient, Firings 37D and 38D
Fig. 59 Fuel Pump Inlet Pressure Effect on Fuel Pump Head Rise Coefficient, Firings 36D and 37D

PFPI = 26.6 PSIA (FIRING 36D)

PFPI = 41 PSIA (FIRING 37D)

DATA FROM FM SYSTEM
Fig. 60 Fuel Pump Inlet Pressure Effect on Fuel Pump Flow Coefficient, Firings 36D and 37D
NOTE: STALL INCEPTION LINE IS BASED ON TOTAL HEAD RISE ACROSS THE PUMP. THE DATA PLOTTED ARE PUMP DISCHARGE PRESSURE CONVERTED TO HEAD. DATA ARE FROM FM SYSTEM.

Fig. 61 Fuel Pump Inlet Pressure Effect on Fuel Pump Start Transient Performance, Firings 36D and 37D
Fig. 62  Fuel Pump Inlet Pressure Effect on Gas Generator Fuel Injector Pressure, Firings 36D and 37D
Fig. 63  Fuel Pump Inlet Pressure Effect on Gas Generator Chamber
Pressure Transients, Firings 36D and 37D
Fig. 64 Fuel Pump Inlet Pressure Effect on Gas Generator Outlet Temperature Transients, Firings 36D and 37D
<table>
<thead>
<tr>
<th>Part Name</th>
<th>P/N</th>
<th>S/N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thrust Chamber Body</td>
<td>206600-31</td>
<td>4072755</td>
</tr>
<tr>
<td>Thrust Chamber Injector Assembly</td>
<td>208021-11</td>
<td>4071421</td>
</tr>
<tr>
<td>Fuel Turbopump Assembly</td>
<td>460160-31</td>
<td>4072328</td>
</tr>
<tr>
<td>Oxidizer Turbopump Assembly</td>
<td>458175-81</td>
<td>6645876</td>
</tr>
<tr>
<td>Start Tank</td>
<td>303439</td>
<td>0038</td>
</tr>
<tr>
<td>Augmented Spark Igniter</td>
<td>20828-81</td>
<td>4078806</td>
</tr>
<tr>
<td>Gas Generator Fuel Injector and Combustor</td>
<td>308360-11</td>
<td>4088543</td>
</tr>
<tr>
<td>Gas Generator Oxidizer Injector and Poppet Assembly</td>
<td>303323</td>
<td>4091740</td>
</tr>
<tr>
<td>Helium Regulator Assembly</td>
<td>4072892</td>
<td>558130-111</td>
</tr>
<tr>
<td>Electrical Control Package</td>
<td>502670-51</td>
<td>4087776</td>
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<tr>
<td>Primary Flight Instrumentation Package</td>
<td>703685</td>
<td>4077391</td>
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<tr>
<td>Auxiliary Flight Instrumentation Package</td>
<td>703680</td>
<td>4077313</td>
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<tr>
<td>Main Fuel Valve</td>
<td>409120</td>
<td>4062181</td>
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<td>Main Oxidizer Valve</td>
<td>411031</td>
<td>4085563</td>
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<tr>
<td>Gas Generator Control Valve</td>
<td>309040-31</td>
<td>4062168</td>
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<tr>
<td>Start Tank Discharge Valve</td>
<td>304386</td>
<td>40853957</td>
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<tr>
<td>Oxidizer Turbine Bypass Valve</td>
<td>409940</td>
<td>4062266</td>
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<tr>
<td>Propellant Utilization Valve</td>
<td>251351-11</td>
<td>4068732</td>
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<tr>
<td>Main-Stage Control Valve</td>
<td>558065</td>
<td>8275908</td>
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<tr>
<td>Ignition Phase Control Valve</td>
<td>558065</td>
<td>8313742</td>
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<tr>
<td>Helium Control Valve</td>
<td>NA5-27273</td>
<td>340910</td>
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<tr>
<td>Start Tank Vent and Relief Valve</td>
<td>558325</td>
<td>8358552</td>
</tr>
<tr>
<td>Helium Tank Vent Valve</td>
<td>NA5-27273</td>
<td>328191</td>
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<tr>
<td>Fuel Bleed Valve</td>
<td>309034</td>
<td>4077233</td>
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<tr>
<td>Oxidizer Bleed Valve</td>
<td>309029</td>
<td>4076750</td>
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<tr>
<td>Augmented Spark Igniter Oxidizer Valve</td>
<td>308880</td>
<td>4089946</td>
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<tr>
<td>Pressure-Actuated Shutdown Valve Assembly</td>
<td>558127-11</td>
<td>4087861</td>
</tr>
<tr>
<td>Pressure-Actuated Purge Control Valve</td>
<td>558126</td>
<td>4089662</td>
</tr>
<tr>
<td>Start Tank Fill/Refill Valve</td>
<td>558000</td>
<td>4072899</td>
</tr>
<tr>
<td>Fuel Flowmeter</td>
<td>251225</td>
<td>4075564</td>
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<tr>
<td>Oxidizer Flowmeter</td>
<td>251216</td>
<td>4077137</td>
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<tr>
<td>Fuel Injector Temperature Transducer</td>
<td>NA5-27441</td>
<td>12350</td>
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<tr>
<td>Restartable Ignition Detect Probe</td>
<td>NA5-27298T2</td>
<td>102</td>
</tr>
</tbody>
</table>
### TABLE II
**SUMMARY OF ENGINE ORIFICES**

<table>
<thead>
<tr>
<th>Orifice Name</th>
<th>Part Number</th>
<th>Diameter</th>
<th>Date Effective</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas Generator Fuel Supply Line</td>
<td>RD251-4107</td>
<td>0.508 in.</td>
<td>March 25, 1968</td>
<td></td>
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<tr>
<td>Gas Generator Oxidizer Supply Line</td>
<td>RD251-4106</td>
<td>0.288 in.</td>
<td>March 25, 1968</td>
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</tr>
<tr>
<td>Main Oxidizer Valve Closing Control</td>
<td>410437-084</td>
<td>8.45 scfm</td>
<td>April 17, 1968</td>
<td>Thermostatic Orifice</td>
</tr>
<tr>
<td>Oxidizer Turbine Exhaust Manifold</td>
<td>RD251-9004</td>
<td>10.0 in.</td>
<td>January 18, 1966</td>
<td>Installed on Engine before Shipment to AEDC</td>
</tr>
<tr>
<td>Augmented Spark Igniter Oxidizer Supply Line</td>
<td>406361-3</td>
<td>0.125 in., 0.137 in.</td>
<td>March 21, 1968</td>
<td>Gives an Effective Diameter of 0.110 in.</td>
</tr>
<tr>
<td>Modification</td>
<td>Completion Date</td>
<td>Description of Modification</td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------------</td>
<td>------------------</td>
<td>-----------------------------------------------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Test J4-1801-36</td>
<td>4/10/68</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>RFD 19-68</td>
<td>April 11, 1968</td>
<td>Retimed Main Oxidizer Valve</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Second-Stage Opening Time to</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$+10$</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$1650 -20$ m sec</td>
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<tr>
<td>RFD 65-1-67</td>
<td>April 12, 1968</td>
<td>Removal of the Gas Generator Oxidizer Supply Line Conditioning</td>
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<tr>
<td></td>
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<td>Sleeve</td>
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<tr>
<td>Test J4-1801-37</td>
<td>4/16/68</td>
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<tr>
<td>RFD 12-68</td>
<td>April 17, 1968</td>
<td>Retimed Main Oxidizer Valve</td>
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<td></td>
<td></td>
<td>Second-Stage Opening Time to</td>
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<tr>
<td></td>
<td></td>
<td>$+30$</td>
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<tr>
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<td></td>
<td>$1700 -0$ m sec</td>
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<tr>
<td>Test J4-1801-38</td>
<td>4/23/68</td>
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1RFD - Rocketdyne Field Directive
TABLE IV  
ENGINE COMPONENT REPLACEMENTS 
(BETWEEN TESTS J4-1801-36 AND J4-1801-38)

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<thead>
<tr>
<th>Replacement</th>
<th>Completion Date</th>
<th>Component Replaced</th>
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<tbody>
<tr>
<td>Test J4-1801-36</td>
<td>4/10/68</td>
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</tr>
<tr>
<td>UCR1-007391</td>
<td>April 11, 1968</td>
<td>Fuel Turbopump Intermediate Shaft Seal P/N NA5-260115</td>
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<tr>
<td></td>
<td></td>
<td>S/N CR138</td>
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<tr>
<td>UCR-007391</td>
<td>April 11, 1968</td>
<td>Fuel Turbopump Turbine Shaft Seal P/N NA5-26628</td>
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<tr>
<td></td>
<td></td>
<td>S/N P112</td>
</tr>
<tr>
<td>Test J4-1801-37</td>
<td>4/16/68</td>
<td></td>
</tr>
<tr>
<td>UCR-005113</td>
<td>April 18, 1968</td>
<td>Fuel Turbopump Interstage Pressure Transducer (PF6)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>P/N NA5-27412T-2T</td>
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<tr>
<td></td>
<td></td>
<td>S/N 7904A</td>
</tr>
<tr>
<td>Test J4-1801-38</td>
<td>4/23/68</td>
<td></td>
</tr>
</tbody>
</table>

¹UCR - Unsatisfactory Condition Report
# TABLE V

## ENGINE PURGE AND COMPONENT CONDITIONING SEQUENCE

<table>
<thead>
<tr>
<th>Time, min</th>
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<th></th>
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<th></th>
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</thead>
<tbody>
<tr>
<td>10</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2-min Minimum Following Recirculation, 1 to 3 min</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 sec (Supplied by Engine Helium Tank during Start and Cutoff Transients)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Process Description</th>
<th>Helium, psig</th>
<th>Nitrogen, psig</th>
<th>Oxygen, psig</th>
<th>Hydrogen, psig</th>
<th>Other, psig</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Turbopump and Gas Generator Purge (Purge Manifold System)</strong></td>
<td>82 - 125 psig at Customer Connect</td>
<td>175 - 230 scfm</td>
<td>415 - 675 psig</td>
<td>1200 to 1400 psia</td>
<td>1400 psig</td>
</tr>
<tr>
<td><strong>Oxidizer Dome and Gas Generator Liquid Oxygen Injector (Engine Pneumatic System)</strong></td>
<td>1400 psig</td>
<td>100 - 200°F</td>
<td>1400 psig</td>
<td>-300 to -140°F</td>
<td>1700 to 3250 psia</td>
</tr>
<tr>
<td><strong>Oxidizer Dome (Facility Line to Port CO3A)</strong></td>
<td>415 - 675 psig</td>
<td>100 - 200°F</td>
<td>1400 psig</td>
<td>-300 to -140°F</td>
<td>1700 to 3250 psia</td>
</tr>
<tr>
<td><strong>Oxidizer Turbopump Intermediate Seal Cavity (Engine Pneumatic System)</strong></td>
<td>1000 psig</td>
<td>100 - 200°F</td>
<td>1400 psig</td>
<td>-300 to -140°F</td>
<td>1700 to 3250 psia</td>
</tr>
<tr>
<td><strong>Thrust Chamber Jacket (Customer Connect) Panel</strong></td>
<td>55 - 200 psig</td>
<td>100 - 200°F</td>
<td>1400 psig</td>
<td>-300 to -140°F</td>
<td>1700 to 3250 psia</td>
</tr>
<tr>
<td><strong>Thrust Chamber Temperature Conditioning</strong></td>
<td>1000 psig</td>
<td>100 - 200°F</td>
<td>1400 psig</td>
<td>-300 to -140°F</td>
<td>1700 to 3250 psia</td>
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<tr>
<td><strong>Pump Inlet Pressure and Temperature Conditioning</strong></td>
<td>Oxidizer: 35 to 48 psia</td>
<td>28 to 46 psia</td>
<td>Hydrogen: 1200 to 1400 psia</td>
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<td>1700 to 3250 psia</td>
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<td>-300 to -140°F</td>
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1. Conditioning temperature to be maintained for the last 15 min of pre-fire.
### TABLE VI

**SUMMARY OF TEST REQUIREMENTS AND RESULTS**

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<th>Time of Day, hr/Day</th>
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<th>37C</th>
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<td>0.98 ± 0.07</td>
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| Notes: ^1Data reduced from simulation. ^2Component conditioning to be maintained within limits for last 15 min before engine start. ^3Component conditioning to be maintained within limits for last 30 min before engine start or coast duration, whichever is longer.
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<tr>
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Notes:  
1. Data from oscillogram.  
2. Component conditioning to be maintained within limits for last 15 min before engine start.  
3. Component conditioning to be maintained within limits for last 30 min before engine start or coast duration, whichever is longer.
**TABLE VII**

**ENGINE VALVE TIMINGS**

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<tr>
<th>Firing Number</th>
<th>Start Tank Discharge Valve</th>
<th>Main Fuel Valve</th>
<th>Main Oxidizer Valve</th>
<th>Main Oxidizer Valve</th>
<th>Gas Generator Oxidizer Poppet</th>
<th>Gas Generator Fuel Poppet</th>
<th>Oxidizer Turbine Bypass Valve</th>
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<td>0.124</td>
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Notes: 1. All valve signal times are referenced to the time when the main oxidizer valves open at 32.575 sec.
2. Valve delay time is the time required for initial valve movement after the valve "open" or "closed" solenoid has been energized.
3. Final sequence sheet is conducted without propellants and within 12 hr before testing.
4. Data reduced from oscillogram.
### TABLE VII (Concluded)

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<th>Firing Number</th>
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<th>Main Oxidizer Valve Second Stage</th>
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<th>Oxidizer Turbine Bypass Valve</th>
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<td>Valve Opening Time, sec</td>
<td>Time of Valve Closing, sec</td>
<td>Time of Valve Delay, sec</td>
<td>Valve Opening Time, sec</td>
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<td>0.015</td>
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### Shutdown

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**Notes:**
1. All valve signal times are referenced to t₀.
2. Valve delay time is the time required for initial valve movement after the valve "open" or 'closed" solenoid has been energized.
3. Final sequence check is conducted without propellants and within 12 hr before testing.
4. Data reduced from oscillogram.
## ENGINE PERFORMANCE SUMMARY

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<th>37C</th>
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**Note:**
1. Site data are calculated from test data.
2. Normalized data are corrected to standard pump inlet and engine ambient pressure conditions.
3. Input data are test data averaged from 29 to 30 sec, except as noted.
4. Site and normalized data were computed using the Rocketdyne PAST 640 modification zero computer program.
The instrumentation for AEDC tests J4-1801-37 and J4-1801-38 is tabulated in Table III-1. The location of selected major engine instrumentation is shown in Fig. III.1.
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<th>AEDC Code</th>
<th>Parameter</th>
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<tr>
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<td>PFFA</td>
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**TABLE III-1
INSTRUMENTATION LIST**
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### Speeds (rpm)

| NFP-1P | Fuel Pump | 0 to 30,000 | x | x | x |
| NFRP   | Fuel Recirculation Pump | 0 to 15,000 | x |   |   |
| NOP-1P | Oxidizer Pump | 0 to 12,000 | x | x | x |
### TABLE III-1 (Continued)

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Temperatures
- NORP Oxidizer Recirculation Pump Temperatures: 0 to 15,000 °F
- TA1 Test Cell (North) Temperatures: -50 to +800 °F
- TA2 Test Cell (East) Temperatures: -50 to +800 °F
- TA3 Test Cell (South) Temperatures: -50 to +800 °F
- TA4 Test Cell (West) Temperatures: -50 to +800 °F
- TAIP-1A Auxiliary Instrument Package Temperatures: -300 to +200 °F
- TBPM Bypass Manifold Temperatures: -325 to +200 °F
- TBSC Oxidizer Bootstrap Conditioning Temperatures: -350 to +150 °F
- TECP-1P Electrical Controls Package NST1A Temperatures: -300 to +200 °F
- TFASU Augmented Spark Igniter Fuel Injection Temperatures: -425 to +100 °F
- TFASIL-1 Augmented Spark Igniter Line Temperatures: -300 to +200 °F
- TFASIL-2 Augmented Spark Igniter Line Temperatures: -300 to +300 °F
- TFBV-1A Fuel Bleed Valve Temperature: GFT1 -425 to -375 °F
- TFD-1 Fire Detection Temperature: 0 to 1000 °F
- TFJ-1P Main Fuel Injection Temperature: CFT2 -425 to +250 °F
- TFPD-1P Fuel Pump Discharge Temperature: PFT1 -425 to -400 °F
- TFPD-2 Fuel Pump Discharge Temperature: PFT1 -425 to -400 °F
- TFPPD Fuel Pump Discharge Duct Temperature: -320 to +300 °F
- TFPI-1 Fuel Pump Inlet Temperature: -425 to -400 °F
- TFPI-2 Fuel Pump Inlet Temperature: -425 to -400 °F
- TFPPSD-1 Fuel Pump Primary Seal Drain Temperature: -425 to +100 °F
- TFPPSP-1 Fuel Pump Seal Purge Temperature: -425 to +100 °F
- TFRPO Fuel Recirculation Pump Outlet Temperature: -425 to -410 °F
- TFRPR Fuel Recirculation Pump Return Line Temperature: -425 to -250 °F
- TFRT-1 Fuel Tank Temperature: -425 to -410 °F
- TFRT-3 Fuel Tank Temperature: -425 to -410 °F
- TFST-1P Fuel Start Tank Temperature: TFT1 -350 to +100 °F
- TFST-2 Fuel Start Tank Temperature: TFT1 -350 to +100 °F
- TFD-1 Fuel Turbine Discharge Duct Temperature: -200 to +800 °F
- TFD-2 Fuel Turbine Discharge Duct Temperature: -200 to +1000 °F
- TFD-3 Fuel Turbine Discharge Duct Temperature: -200 to +1000 °F
- TFD-4 Fuel Turbine Discharge Duct Temperature: -200 to +1000 °F
- TFD-5 Fuel Turbine Discharge Duct Temperature: -200 to +1400 °F
- TFD-6 Fuel Turbine Discharge Duct Temperature: -200 to +1400 °F
- TFD-7 Fuel Turbine Discharge Duct Temperature: -200 to +1400 °F
- TFD-8 Fuel Turbine Discharge Duct Temperature: -200 to +1400 °F
- TFFO Fuel Turbine Outlet Temperature: TFT2 0 to 1800 °F
### TABLE III-1 (Continued)

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a. Engine Pressure Tap Locations
Fig. III-1 Instrumentation Locations
b. Engine Temperature, Flow, and Speed Instrumentation Locations

Fig. III-1 Continued
Sequence Outlet

Port

Opening Port

Balance Pressure Port

Closing Port

Opening Port

c. Main Oxidizer Valve
Fig. III-1 Continued
d. Start Tank Discharge Valve
Fig. III-1 Continued
VIEW LOOKING AFT

e. Thrust Chamber

Fig. III-1 Concluded
APPENDIX IV
METHOD OF CALCULATION (PERFORMANCE PROGRAM)

TABLE IV-1
PERFORMANCE PROGRAM DATA INPUTS

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<thead>
<tr>
<th>Item No.</th>
<th>Parameter</th>
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<tbody>
<tr>
<td>1</td>
<td>Thrust Chamber (Injector Face) Pressure, psia</td>
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<td>2</td>
<td>Thrust Chamber Fuel and Oxidizer Injection Pressures, psia</td>
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<tr>
<td>3</td>
<td>Thrust Chamber Fuel Injection Temperature, °F</td>
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<tr>
<td>4</td>
<td>Fuel and Oxidizer Flowmeter Speeds, Hz</td>
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<tr>
<td>5</td>
<td>Fuel and Oxidizer Engine Inlet Pressures, psia</td>
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<tr>
<td>6</td>
<td>Fuel and Oxidizer Pump Discharge Pressures, psia</td>
</tr>
<tr>
<td>7</td>
<td>Fuel and Oxidizer Engine Inlet Temperatures, °F</td>
</tr>
<tr>
<td>8</td>
<td>Fuel and Oxidizer (Main Valves) Temperatures, °F</td>
</tr>
<tr>
<td>9</td>
<td>Propellant Utilization Valve Center Tap Voltage, volts</td>
</tr>
<tr>
<td>10</td>
<td>Propellant Utilization Valve Position, volts</td>
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<tr>
<td>11</td>
<td>Fuel and Oxidizer Pump Speeds, rpm</td>
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<tr>
<td>12</td>
<td>Gas Generator Chamber Pressure, psia</td>
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<tr>
<td>13</td>
<td>Gas Generator (Bootstrap Line at Bleed Valve) Temperature, °F</td>
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<tr>
<td>14</td>
<td>Fuel* and Oxidizer Turbine Inlet Pressure, · psia</td>
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<tr>
<td>15</td>
<td>Oxidizer Turbine Discharge Pressure, psia</td>
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<tr>
<td>16</td>
<td>Fuel and Oxidizer Turbine Inlet Temperature, °F</td>
</tr>
<tr>
<td>17</td>
<td>Oxidizer Turbine Discharge Temperature, °F</td>
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</tbody>
</table>

*At AEDC, fuel turbine inlet pressure is calculated from gas generator chamber pressure.
NOMENCLATURE

A  Area, in.²
B  Horsepower, hp
C* Characteristic velocity, ft/sec
Cp Specific heat at constant pressure, Btu/lb/°F
D  Diameter, in.
H  Head, ft
h  Enthalpy, Btu/lbₘ
M  Molecular weight
N  Speed, rpm
P  Pressure, psia
Q  Flow rate, gpm
R  Resistance, sec²/ft³-in.²
r  Mixture ratio
T  Temperature, °F
TC* Theoretical characteristic velocity, ft/sec
W  Weight flow, lb/sec
Z  Pressure drop, psi
β  Ratio
γ  Ratio of specific heats
η  Efficiency
θ  Degrees
ρ  Density, lb/ft³

SUBSCRIPTS

A  Ambient
AA Ambient at thrust chamber exit
B  Bypass nozzle

134
<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
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<tr>
<td>BIR</td>
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<td>BNI</td>
<td>Bypass nozzle inlet (total)</td>
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<td>CV</td>
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<td>em</td>
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<td>Isentropic turbine oxidizer</td>
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<td>Nozzle</td>
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<td>Bypass nozzle (throat)</td>
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<td>Abbreviation</td>
<td>Definition</td>
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<td>Turbine inlet fuel isentropic</td>
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<td>TIO</td>
<td>Turbine inlet oxidizer</td>
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<td>V</td>
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<tr>
<td>XO</td>
<td>Oxidizer tank repressurant</td>
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</tbody>
</table>
PERFORMANCE PROGRAM EQUATIONS

MIXTURE RATIO

Engine

\[ r_E = \frac{W_{EO}}{W_{EF}} \]

\[ W_{EO} = W_{OM} - W_{xo} \]

\[ W_{EF} = W_{FM} - W_{XF} \]

\[ W_E = W_{EO} + W_{EF} \]

Thrust Chamber

\[ r_C = \frac{W_{CO}}{W_{CF}} \]

\[ W_{CO} = W_{OM} - W_{xo} - W_{GO} \]

\[ W_{CF} = W_{FM} - W_{XF} - W_{GF} \]

\[ W_{xo} = 0.8 \text{ lb/sec} \]

\[ W_{XF} = 1.8 \text{ lb/sec} \]

\[ W_{GO} = W_T - W_{GF} \]

\[ W_{CF} = \frac{W_T}{1 + r_G} \]

\[ W_T = \frac{P_{TIF} A_{TIF} K_7}{T_C T_{IF}} \]

\[ K_7 = 32.174 \]

\[ W_C = W_{CO} + W_{CF} \]

CHARACTERISTIC VELOCITY

Thrust Chamber

\[ C^* = \frac{K_7 P_e A_t}{W_C} \]

\[ K_7 = 32.174 \]
DEVELOPED PUMP HEAD

Flows are normalized by using the following inlet pressures, temperatures, and densities.

\[ P_{10} = 39 \text{ psia} \]
\[ P_{1F} = 30 \text{ psia} \]
\[ \rho_{10} = 70.79 \text{ lb/ft}^3 \]
\[ \rho_{1F} = 4.40 \text{ lb/ft}^3 \]
\[ T_{10} = -295.212 \text{°F} \]
\[ T_{1F} = -422.547 \text{°F} \]

Oxidizer

\[ H_O = K_4 \left( \frac{P_{0O}}{P_{1O}} - \frac{P_{1O}}{P_{1O}} \right) \]
\[ K_4 = 144 \]
\[ \rho = \text{National Bureau of Standards Values } f(P,T) \]

Fuel

\[ h_f = 778.16 \Delta h_{OFS} \]
\[ \Delta h_{OFS} = h_{OFS} - h_{1F} \]
\[ h_{OFS} = f(P,T) \]
\[ h_{1F} = f(P,T) \]

PUMP EFFICIENCIES

Fuel, Isentropic

\[ \eta_f = \frac{h_{OFS} - h_{1F}}{h_{OF} - h_{1F}} \]
\[ h_{OF} = f(P_{OF}, T_{OF}) \]

Oxidizer, Isentropic

\[ \eta_O = \eta_{OC} \cdot Y_O \]
\[ \eta_{OC} = K_{40} \left( \frac{Q_{PO}}{N_O} \right)^2 + K_{50} \left( \frac{Q_{PO}}{N_O} \right) + K_{60} \]
\[ K_{40} = 5.0526 \]
\[ K_{50} = 3.8611 \]
\[ K_{60} = 0.0733 \]
\[ Y_O = 1.000 \]
TURBINES

Oxidizer, Efficiency

\[ \eta_{TO} = \frac{B_{TO}}{B_{ITO}} \]

\[ B_{TO} = K_5 \frac{W_{PO} H_0}{\eta_0} \]

\[ K_5 = 0.001818 \]

\[ W_{PO} = W_{OM} + W_{PUVO} \]

\[ W_{PUVO} = \frac{Z_{PUVO} P_{OO}}{R_v} \]

\[ Z_{PUVO} = A + B (P_{OO}) \]

\[ A = -1.597 \]

\[ B = 2.3828 \]

If \( P_{OO} \geq 1010 \) Set \( P_{OO} = 1010 \)

\[ \ln R = A_3 + B_3 (\theta_{PUVO}) - C (\theta_{PUVO})^3 + D_3 (\theta_{PUVO})^5 \]

\[ + \frac{E_3 (\theta_{PUVO})}{(\theta_{PUVO})^7} + \frac{F_3}{(\theta_{PUVO})^7} \]

\[ A_3 = 5.5659 \times 10^{-1} \]

\[ B_3 = 1.4997 \times 10^{-2} \]

\[ C_3 = 7.9413 \times 10^{-6} \]

\[ D_3 = 1.2343 \]

\[ E_3 = -7.2554 \times 10^{-2} \]

\[ F_3 = 5.0691 \times 10^{-2} \]

Fuel, Efficiency

\[ \eta_{TF} = \frac{B_{TF}}{B_{ITF}} \]

\[ B_{ITF} = K_{10} \Delta h_f W_T \]

\[ \Delta h_f = h_{TIF} - h_{TEF} \]

\[ B_{TF} = B_{PF} = K_5 \left( \frac{W_{PF} H_f}{\eta_f} \right) \]

\[ W_{PF} = W_{FM} \]

\[ K_{10} = 1.4148 \]

\[ K_5 = 0.001818 \]
Oxidizer, Developed Horsepower

\[ B_{TO} = B_{PO} - K_{56} \]
\[ B_{PO} = K_5 \frac{W_{PO} H_0}{\eta_0} \]
\[ K_{56} = -15 \]

Fuel, Developed Horsepower

\[ B_{TF} = B_{PF} \]
\[ B_{PF} = K_5 \frac{W_{PF} H_f}{\eta_f} \]
\[ W_{PF} = W_{FM} \]

Fuel, Weight Flow

\[ W_{TF} = W_T \]

Oxidizer Weight Flow

\[ W_{TO} = W_T - W_B \]
\[ W_R = \left[ \frac{2K_7 H_2}{\gamma_{H_2} - 1} \right] \left[ \frac{1}{P_{RNC}} \right] \left[ 1 - \frac{\gamma_{H_2} - 1}{\gamma_{H_2}} \right]^{\frac{\gamma_{H_2}}{\gamma_{H_2} - 1}} \left[ \frac{A_N B}{P_{BIN}} \right] \left[ \frac{R_{H_2} T_{BIR}}{(R_{H_2} T_{F_2})} \right]^{\frac{1}{2}} \]

\[ P_{RNC} = f(\beta_N B, \gamma_{H_2}) \]
\[ \beta_N B = \frac{D_{NB}}{D_B} \]
\[ \gamma_{H_2}, M_{H_2} = f(T_{H_2 R}, R_C) \]
\[ A_N B = K_{13} D_{NB} \]
\[ K_{13} = 0.7854 \]
\[ T_{BIR} = T_{TIO} + 460 \]
\[ P_{BIN} = P_{TEFS} \]

\[ P_{TEFS} = \text{Iteration of } P_{TEF} \]
\[ P_{TEF} = P_{TEFS} \left[ 1 - K_8 \left( \frac{W_T}{P_{TEFS}} \right)^{2} \frac{T_{H_2 R}}{D_{TEF} M_{H_2}} \left( \frac{\gamma_{H_2} - 1}{\gamma_{H_2}} \right) \right]^{\frac{\gamma_{H_2}}{\gamma_{H_2} - 1}} \]
\[ K_8 = 38.8983 \]
GAS GENERATOR

Mixture Ratio

\[
\eta_G = D_1 (T_{HI})^3 + C_1 (T_{HI})^2 + B_1 (T_{HI}) + A_1
\]

\[
A_1 = 0.2575
\]

\[
B_1 = 5.586 \times 10^{-4}
\]

\[
C_1 = -5.332 \times 10^{-9}
\]

\[
D_1 = 1.1312 \times 10^{-11}
\]

\[
T_{HI} = T_{TIFS}
\]

Flows

\[
T_{C,TIFS} = D_2 (T_{HI})^3 + C_2 (T_{HI})^2 + B_2 (T_{HI}) + A_2
\]

\[
A_2 = 4.4226 \times 10^3
\]

\[
B_2 = 3.2267
\]

\[
C_2 = -1.3790 \times 10^{-3}
\]

\[
D_2 = 2.6212 \times 10^{-7}
\]

\[
P_{TIFS} = P_{TIFS} \left[ 1 + K_8 \left( \frac{W_T}{P_{TIFS}} \right)^2 - \frac{T_{HIR}}{D_{TIFS} H_1} \frac{Y_{H_1} - 1}{Y_{H_1}} \right]^{Y_{H_1}}
\]

\[
K_8 = 38.8983
\]

Note: \( P_{TIFS} \) is determined by iteration.

\[
T_{HIR} = T_{TIFS}
\]

\[
M_{H_1}, Y_{H_1}, C_p, r_{H_1} = f (T_{HIR}, \eta_G)
\]
**Abstract**

Eight firings and two partial transition tests of the J-2 rocket engine were accomplished during test periods J4-1801-37 and 38. These tests periods were conducted on April 16 and 23, 1968, respectively. Each of these firings was in support of the S-V/S-IVB stage engine to investigate engine start transients for first burn and restart simulations. The partial transition tests were to evaluate thrust chamber temperature effects on the engine start transients. All objectives were successfully met with a total accumulated firing duration of 156.6 sec.

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[Signature]

July 12, 1968

[Signature]
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<th>LINK C</th>
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1. Rocket motors -- J-2
2. Performance
3. Ignition
4. Restarting
5. 16-3