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THE 0.040-SCALE SPACE SHUTTLE ORBITER BASE HEATING MODEL TESTS IN THE LEWIS RESEARCH CENTER SPACE POWER FACILITY

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THE 0.040-SCALE SPACE SHUTTLE ORBITER
BASE HEATING MODEL TESTS IN THE LEWIS RESEARCH
CENTER SPACE POWER FACILITY

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Abstract
Space Shuttle Base Heating Tests were conducted using a 0.040-scale model in the Plum Brook Space Power Facility of The NASA Lewis Research Center. The tests measured heat transfer rates, pressure distributions, and gas recovery temperatures on the orbiter vehicle 2A base configuration resulting from engine plume impingement. One hundred and sixty-eight hydrogen-oxygen engine firings were made at simulated flight altitudes ranging from 120 000 to 360 000 feet.

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SUMMARY

Space Shuttle Base Heating Tests Number OH64 were conducted using a 0.040-scale model in the Plum Brook Space Power Facility of The NASA Lewis Research Center from April through June 1975. The purpose of the tests was to measure heat transfer rates, pressure distributions, and gas recovery temperatures on the orbiter vehicle 2A base configuration resulting from engine plume recirculation and direct plume impingement. One hundred sixty-eight hydrogen-oxygen engine firings were made at simulated altitudes ranging from 120,000 to 360,000 feet. Steady-state data were achieved with the impulse type hot firings into the large volume vacuum chamber. Testing methods, an index of run conditions, and some typical results are presented.

INTRODUCTION

As part of the Space Shuttle Program, the aerothermodynamics group at Rockwell Space Division has the responsibility for defining the Space Shuttle ascent aeroheating design requirements. This task requires simulation of as much of the flight regimes as possible in evaluating the Space Shuttle integrated vehicle.

In previous tests at other space simulation chambers, the small size of the vacuum chamber has limited the data gathering period to 9 milliseconds due to shockwave return to the model and required three test runs per test setup to obtain 200 channels of data. When model firings are
accomplished without engine throats plugged during the engine start transients, operating conditions may not be achieved for 25 milliseconds or longer.

The Plum Brook Space Power Facility was selected for follow-on tests since its size permitted run times in excess of those required to reach steady-state flow for acquisition of valid recovery temperature and pressure data at simulated altitudes above 120,000 feet. This report contains a detailed description of these tests.

**TEST CONFIGURATION**

**General**

The Plum Brook Space Power Facility of the NASA Lewis Research Center consists of a 100-feet diameter by 121-feet high aluminum, high-vacuum chamber enclosed in a low-vacuum concrete chamber 130-feet in diameter by 150-feet high. The interior volumes of the aluminum chamber and the annulus between the two chambers is approximately 800,000 cubic feet each. Vacuum capability of the inner chamber is $1 \times 10^{-7}$ torr with the outer chamber at 25 torr.

The 0.040-scale model of the Space Shuttle orbiter vehicle was mounted in the center of the vacuum chamber at floor level with the engines firing vertically upward.

**TEST HARDWARE**

The impulse-type hot firing 0.040-scale model used for these tests simulates the model lines of the vehicle 2A Space Shuttle orbiter, aft of full-scale station 1400. The model base assembly simulating the external orbiter lines is seismically suspended from the structure housing the propulsion simulation system. The scale components included are the body flap, the orbital maneuvering system (OMS) pods, OMS engine nozzles, vertical tail, base heat shield, and the space shuttle main engine (SSME) nozzles. The engine nozzles (both SSME and OMS) throat diameters, internal contours, exit diameters, and lengths are scaled.
and are capable of gimbal angle changes. The vertical tail is accurate as to planform and location but simulates the undeflected rudder condition only. The body flap could be removed or positioned in the nominal zero degree position or deflected 20 degree (see fig. 1).

Within the propulsion simulation system, to which all other components attach, each propellant gas flows through a metering venturi which remains choked under normal operating conditions. Two sets of metering venturis were used for the tests, the full flow set for the three SSME firings and the three SSME plus OMS firings, while the two-thirds flow set was used for one SSME out plus OMS operation. For OMS alone operation, the venturis are unchoked and precise measurement of propellant gas flows is not possible.

The propellant gases are controlled within the propulsion simulation system through a bipropellant autovalve. The autovalve contains two propellant control valves which are yoked together to admit the hydrogen and oxygen at pressures up to 3000 psi. Energy for actuation of the control valves was supplied by a regulated source of gaseous nitrogen at 3000 psi through a solenoid-operated valve.

Downstream of the venturis, gas flows are divided; part of the gases flow through a mixing injector to a collector chamber while the remaining portion flows directly to the individual injectors for each of the three SSME combustion chambers. Ignition occurs in the collector which utilizes an automotive-type sparkplug. Internal passages connect the collector to each SSME combustion chamber and provide for diversion of a small percentage of the mass flow to the OMS engines when required.

FACILITY EQUIPMENT

The hydrogen and oxygen were loaded into type-304 stainless steel pipes called "charge tubes" which were flanged to the autovalve. The oxygen charge tube was fabricated from 1-inch schedule 80 pipe and the hydrogen charge tube from \( \frac{1}{4} \)-inch schedule 80 pipe. The charge tubes were of welded construction and "folded" for rack-mounting to provide a package approximately 39-feet long by 2-feet wide by \( \frac{3}{4} \)-feet high.
(see fig. 2). The charge tube lengths were sized for an expansion wave reflection time of at least 80 milliseconds. This wavetime was achieved for oxygen and hydrogen with 50 and 200 foot lengths, respectively. On site storage of gaseous oxygen utilized a 38-bottle, 50 000 standard cubic foot roadable trailer rated at 2400 psi working pressure (see fig. 3). Charge tube loading for oxygen was accomplished by cascading to available pressure and then pumping with a nitrogen-driven oxygen pressure intensifier to desired pressure. On-site storage of gaseous hydrogen was accomplished using 6000 psi cylinders charged to 5000 psi with 99.995 percent pure hydrogen gas. Cylinders of hydrogen being used were mounted in an eight-cylinder rack. Loading of the hydrogen charge tube was by cascading from the lowest pressure cylinders first and proceeding to desired pressure using the high pressure cylinders.

The helium used for ignition testing and leak-checking was stored on-site in a 50 000 standard cubic foot roadable trailer rated at 2400 psi working pressure.

The gaseous nitrogen required for autovalve operation and checkout runs was stored on-site in a 70 000 standard cubic foot roadable trailer rated at 2400 psi working pressure and 6000 psi cylinders charged to 5000 psi with 99.998 percent pure water-pumped nitrogen gas. The high pressure gaseous nitrogen cylinders were mounted in a four-cylinder rack and cascaded to achieve the desired pressures. Suitable valving was incorporated in the systems to allow loading the hydrogen charge tube with gaseous nitrogen, hydrogen or helium and the oxygen charge tube with gaseous oxygen or nitrogen. NASA requested, prior to delivery of the model, that the BUNA-N (nitrile) O-rings used throughout the model be replaced with Viton-A O-rings because of oxygen service to 3000 psi. The Viton-A O-rings were used for the entire test. The systems components were cleaned to meet or exceed the NASA Lewis Research Center Plum Brook Station specification RDL-003 for liquid oxygen and gaseous oxygen components.

All gases used for this test were stored outdoors. Transfer of gases from storage locations to the charge tubes or autovalve was accomplished manually from a panel with appropriate hand valves, check valves, pressure regulators, relief valves, etc., to prevent a temperature rise from rapid pressure buildup. All tubing and valves used were
1/4 inch. All lines entering the vacuum chamber were welded with a minimum amount of fittings used in any system to prevent leakage. All lines venting to atmosphere terminated with check valves and bug screens to prevent contamination of any system. Hydrogen vent lines were manifolded together to an elevated, nitrogen-purged, vent stack in a safe location.

All oxygen vents were evaluated to discharge in a safe location. Systems were pressure-checked prior to use to $1 \frac{1}{2}$ times the working pressure if hydrostatic tests were performed or $1 \frac{3}{4}$ times the working pressure if pneumatic testing was performed. All systems were leak-checked at their working pressures prior to use, using helium mass spectrometer techniques, and thereafter at any time an engine gimbal change was made or the model worked on. Initial requirements for leak-checking called for using pressure decay and bubble-check methods. The pressure decay and bubble-check methods were discarded as they proved inadequate in locating specific leak points. The soap solutions around the model would wet the gaging and model construction made pinpointing a leak virtually impossible.

Prior to initiation of the test program a detailed safety analysis of the proposed program was conducted. The maximum credible accident was determined to be simultaneous rupture and ignition of the oxygen and hydrogen charge tube gases. This failure would result in an increase of pressure in the chamber of 4.12 torr. If only the hydrogen charge tube ruptured, a rise of 0.345 torr in pressure would result and for the oxygen tube a rise of 0.048 torr. In case of the hydrogen charge tube rupturing without burning, the method of dilution would be to open the 20-inch equalizing valve between the chamber and annulus which would raise the pressure to 15 torr and provide a mixture below the lower limits for combustion of hydrogen in air.

A redundant closing signal and solenoid valve were incorporated in the model as a safety measure, to insure that engine damage would not result from a single failure mode in the closing sequence.

The hydrogen charge tube was inerted prior to the start of each pump-down of the vacuum chamber for a series of runs. Inertion of the hydrogen
system was accomplished by using a vacuum pump to lower the system pressure to about 25 torr and then backfilling with nitrogen to ambient pressure to reduce the oxygen content in the air. The system was then evacuated again to 25 torr and backfilled with hydrogen.

The design of the system, line sizes, pressures, and timing of events were important in providing uncontaminated hydrogen to the autovalve. The inertion procedure would leave the system with a slug of nitrogen at the autovalve backed up by hydrogen, this step was then followed by opening the autovalve to the vacuum chamber as evacuation of the chamber was started. Timing of events was important to prevent diffusion of the nitrogen into the hydrogen. At a chamber pressure of 200 torr, the autovalve was closed and the charge tubes loaded to the desired pressures with oxygen and hydrogen, respectively, and the system was ready for firing. At the conclusion of a day's testing, the high pressure oxygen and hydrogen were vented outdoors to atmospheric pressure and the autovalve opened to the vacuum chamber for 20 minutes. The autovalve was then closed and the hydrogen and oxygen charge tubes inerted with nitrogen.

Instrumentation leads from the model were brought to three connector terminal units (CTU's) mounted on the support structure for the model, to allow sensor connections to be made within 3 to 5 feet of the model. Approximately 200 separate channels of data were provided.

Three pressurizable containers were located in the vacuum chamber within 8 feet of the model to provide an atmospheric environment for the spark coil, autovalve sequencer, and the charge amplifiers for the pressure transducers.

Two additional pressurized containers were provided in the vacuum chamber for the high-speed motion picture cameras, used to record "plug" ejection from the nozzles, and engine plume shape. These cameras were run at 500 and 200 frames-per-second, respectively.

A special calibration stand was fabricated for calibration of the differential pressure transducers while installed on the model. The calibration stand consisted of a 48-inch inclined water manometer with 1000-scale divisions. Full-scale value was setup to equal 0.1 psi nega-
Live pressure relative to atmospheric pressure or one division was equal to 0.0001 psi with an absolute accuracy of 0.4 percent. Negative pressure was obtained with a syringe bulb and micrometer valve.

TEST DESCRIPTION

Prior to any runday, an engineering work order would be issued defining any changes to be made to the model or facility systems and any leak check or pressure check necessary because of these changes. The body flap, engine gimbal angles, and vertical tail would be positioned to agree with the day's test plan configuration as called for in the engineering work order. After all items had been signed off on the engineering work order, checkout runs were made with nitrogen or helium gases in the charge tubes to determine charge tube pressures and sequencer timing settings for the required oxygen-to-fuel ratio at the desired engine chamber pressure. A test plan for each day's operations was completed defining the test objectives, part numbers for the model configuration, engine gimbal angles, body flap position, charge tube pressures, timer settings, autovalve opening, closing, and holding pressures, and the simulated altitudes to be used. The cameras were then loaded and focused, lights positioned, and checked. For some tests, wooden engine plugs were installed in the throats of the three SSME engines. These plugs were attached to lanyards of linearly increasing weight with length, so that when they were expelled from the engines they would travel in predetermined arcs and fall in defined areas. The wooden plugs were used to cause the engine chamber pressures to reach steady state values earlier and provide additional milliseconds of steady state data. Use of the plugs were limited to the first run of each day. The timers were then set and locked in position, the atmospheric containers closed and leak checked, and the vacuum chamber pumpdown sequence started.

The vacuum chamber was pumped down to the maximum altitude desired for that day's testing and held at altitude by matching the bleed rate of gaseous nitrogen into the chamber to the pumping speed of the
chamber at the desired pressure. To decrease altitude for the follow
-on runs, the gaseous nitrogen bleed rate into the chamber would be in-
creased. When all checksheets were complete and the chamber was at
proper altitude, the autovalve closing, holding, opening, oxygen, and
hydrogen pressures would be adjusted or verified and the tests were
started.

To start a test all manual switches were placed in their proper po-
sitions. Calibrations were taken on the FM tapes, and the FM tapes
started for run data. When the fire button was pushed, a timed controlled
sequence was started. At T-2.5 seconds the camera lights and timing
signals were turned on, at T-1 second the visicorder was started and at
timeout the valve sequence was started. The valve sequence at timeout
consisted of applying power to the relays in the circuits and a main
timer set for nominally 0.5 second to allow contact closures to make
following application of actuating voltage. When the main timer timed
out, it activated the autovalve opening and redundant closing timers, and
"froze" and displayed the exact time used to define T-0. At nominally
19 milliseconds from T-0 the opening timer started propellant gas flows.
When the propellant valve spools, which were mechanically yoked to-
gether, reached the full open position (approximately 22 msec from the
open signal) two limit switches were activated which started the normal
autovalve closing timer and the spark timer.

The spark timer timed out at nominally 3 milliseconds and the nor-
mal closing timer at nominally 65 milliseconds. At one second after
the opening signal, the number two camera and lights were turned off
and the visicorder stopped. At $3\frac{1}{2}$ seconds after the opening signal, the
number one camera and lights were turned off and the timing signals
stopped, which ended the automatic sequence. The FM data tapes were
then turned off manually and the frozen timing display recorded as the
T-0 time for that run for data retrieval purposes. See figure 4 for a
representative sequence of valve operations. Visicorder traces were
then scrutinized for proper valve operation and verification that de-
sired parameters had been met prior to proceeding to the next lower
simulated altitude. Approximately 20 to 30 minutes were allowed after
each test to allow the heat transfer gages to cool down after which a resistance check was made of each of the 144 channels to determine if any were malfunctioning.

A day's testing would consist of from two to nine simulated altitudes for a given configuration. The tests were run using three shifts of eight hours each on a five day basis. From the start of pumpdown until the vacuum chamber door was opened consumed approximately 12 hours of time with 12 hours of additional time required for model configuration changes, cold flow timing checks, and leak checks.

At the end of a series of runs or a test day, the vacuum chamber was returned to atmospheric pressure and selected data from the FM tapes for each run reduced to engineering units and tabulated each half-millisecond for approximately 100 milliseconds of run time. The data was then reviewed to insure that gages had not saturated or malfunctioned and that test conditions had been those selected. The model changes desired for the next test sequence were then started and the procedures repeated. A short run report was then prepared containing the tape reel numbers, run numbers, run description, T-0 time, vacuum chamber pressures, and any discrepancies that may have been encountered. The run report and instrument data flowsheet for that day were then filed for data retrieval purposes.

Table I is a detailed listing of all hot firing tests performed at the Space Power Facility for this model.

Table II is a listing of vacuum chamber pressures required at various engine chamber pressures, to simulate the requested altitudes.
Table III is the key code used for a test description number.
Table IV defines the SSME gimbal angle key.

All tests were conducted using detailed checksheet procedures, controlled by a Test Conductor, using a Master Checksheet.

**MODEL PERFORMANCE OBSERVATIONS**

During the first checkout runs, operation of the autovalve was inconsistent. To improve the closing characteristics, the closing pres-
sure piping was replumbed and the existing nitrogen accumulator replaced with one of larger volume (see fig. 5). To eliminate spurious electrical signals on timers, the wiring was replaced with shielded wire.

The auto-valve position indicator (rotary potentiometer) and its associated linkage failed six times during 88 firings and on one occasion was the cause of failure of the valve to open on command. The rotary potentiometer and its associated linkage was replaced with an available linear potentiometer. The linear potentiometer failed three times during the next 30 runs (lost position trace) but did not affect valve performance. Since all of the valve dynamics were recorded the linear potentiometer was replaced with a proximity switch for full open position and used in this manner until the conclusion of testing.

After the first week's testing, motion picture film data were reviewed and indicated motion of the seismic mount during firing. While not affecting data, a decision was made to stiffen the thrust support mount with the addition of two vertical supports which in essence eliminated the need for the seismic mount.

After run number 34, data analysis indicated a problem in the autovalve (low chamber pressure). A subsequent leak check, followed by teardown, revealed a 1/4-inch-wide by 1/8-inch-deep-burnout of metal in the "O"-ring groove between the injector and chamber. A review of movie camera data revealed the burnout took place during run number 32. The parts were welded, machined, cleaned, reassembled, and operations resumed in 2 days.

After run number 70, model inspection revealed a blowout of solder from the lower side of SSME number 1. This instrumented nozzle was replaced with an uninstrumented nozzle until run number 103 at which time repairs had been made and the instrumented nozzle replaced. During the test program, "O"-rings were replaced when leakage was noted. All "O"-rings would be replaced in the section where the leak was detected as a matter of routine.

The automotive-type spark plug used for ignition was replaced in the autovalve for each pumpdown or series of runs; both the electrode and base of the plugs continually burned away.
Late auto-ignition occurred approximately four times during the test series. The exact cause was never pinpointed. No damage to the model or abnormal operation was experienced during these occurrences.

The nozzle plugs used during the tests were intended to increase data time by causing the combustion chamber, to fill more rapidly. The plugs used varied from 90 to 150 grams in weight. The use of the nozzle plugs reduced the time required to reach stabilized flow by about 10 percent (about 3.4 msec). The return of the reflected shockwave to the model did not occur, or was not observed, during firing at the lower altitudes. At the higher altitudes or pressure in the $3 \times 10^{-5}$ range when using plugs, a reflected wave was noticed which decreased the overall data window. This wave could have been a reflection from a wall or obstruction as the discrepancy occurred at the maximum pitch angle that was run. During this same period, arc-over in a camera connection may have contributed to the observed phenomena.

For runs numbered 53 through 86, additional instrumentation was installed and the runs collectively referred to as a gas recovery temperature probe survey. Five gas temperature probes were installed to prove the validity of calculation of the gas recovery temperature at the probe location, by analysis of the resistance changes of the two wires during the short steady-state operating time. Each probe consisted of a pair of hot-wire anemometer-type thermometers of platinum-10% rhodium wire supported on the tips of hollow steel needles. The wires were parallel to the model surface and 0.00254 millimeter in diameter. Their lengths differed by a factor of 2 (approximately 1 and 2 mm, respectively). Anticipated breakage or other problems in using the "fine" wires did not occur. The only problem occurred when "solder splatter" apparently hit the wires during the blowout of SSME nozzle number 1 during run number 70. The wires were placed approximately 1/2 inch from the instrumented surface. A series of runs were made with "long" probes which placed the wires either 3/4 or $1\frac{1}{4}$ inches from the surface.
The total heat transfer gage consists of a thin-film of platinum fused to a pyrex substrate and insulated by a thin dielectric coating of magnesium fluoride. Pressure levels less than 15 psia were measured with Hidyne variable reluctance transducers and those greater than 15 psia were measured with Kistler piezo-electric transducers. The Hidyne variable reluctance transducers were not acceleration compensated, making the seismic mount necessary. The quick-look visicorder data was the most reliable method of determining, after each run, whether or not problems were developing within the test article. If a problem was indicated, testing for the day would be terminated and the problem investigated before any major damage could occur. Television coverage of the runs was available and used during testing but because of the short time duration for a given test, could only show that the engines had fired.

The high-speed motion picture data could not be used immediately as film processing time was involved. The practice of verifying the integrity of all gages and transducers after each run eliminated the possibility of making a run and not recording critical parameters. By reducing the data to engineering units at the conclusion of a day's testing, trends could be established, noise eliminated, and gains revised for follow-on runs to avoid signal saturation, or insensitivity of a data channel, thus providing a "clean" data tape for computer reduction. Data reduction from the FM tape could be started at a precise millisecond from the defined time T-0. Firing of the engines at an exact pressure altitude was a simple problem in a vacuum chamber of this large a volume, but recording the pressure changes during a firing at the higher altitudes (3.0×10⁻⁵ pressure range) was questionable. The response of the vacuum gauging is not fast enough, nor was the instrumentation sufficient to show the pressure differentials throughout the vacuum chamber while the engines are causing the rapid pressure rise.
HEATING RATE TEST RESULTS

The data tapes, instrument flowsheets, and run report for each run were delivered to NASA Lewis Research Center, Cleveland, Ohio, for computer reduction and delivery to the Space Division/Rockwell International for analysis. The data that was reduced on a daily basis to engineering units, and the visicorder traces from each run were delivered to the Space Division/Rockwell International at the conclusion of the tests.

The data reduced at Lewis Cleveland and furnished to Rockwell International consisted of approximately 150 pages of calculated data and averages for 100 milliseconds of run data for each run, and microfilm of each of the graphical plots requested. A Dataman tape for the entire series of runs was also provided.

Figures 7 through 11 are typical plots of the data being provided. Figures 7 and 9 are typical plots showing the pressure raise x1000 at the base of the model during an engine firing, against time in milliseconds. Figures 8, 10, and 11 are typical plots for various points at the base of the model and show (delta-T)/2 in degrees Fahrenheit and the variable and constant heating rates in Btu/ft²-sec against time in milliseconds during an engine firing.

A total of 168 hot firings were made requiring 40 vacuum chamber pumpdowns during 44 working days. A total of 78 cold flow tests were accomplished with nitrogen and/or helium to establish valve timing and operational characteristics prior to and during these tests. The data from 154 of the 168 hot firing runs was reduced; the remainder of the runs being those that were repeated due to improper O/F ratio, or for some other nonsatisfactory condition.

CONCLUDING REMARKS

For any follow-on tests requiring updating of the existing model, the following recommendations are made:
1. Purge or inertion ports should be provided on the autovalve for the hydrogen and oxygen systems, to allow complete blowdown type purges from the hydrogen and oxygen sources through the autovalve and out to atmosphere, eliminating dead legs. This would eliminate the need for vacuum type inertions.

2. Replace the automotive type spark plug with one more compatible with the severe conditions encountered. Shield the inner electrode and porcelain and eliminate the base electrode so that the plug fires to the outer ring.

3. Replace the variable reluctance transducers used for these tests with acceleration compensated transducers and eliminate the seismic mount.

4. Minimize internal flow passage volumes in the model to reduce fill time and achieve steady state conditions more rapidly.

5. Provide a separate hydrogen and oxygen flow system and metering venturis for the OMS engines to enable precise flow measurements through these systems.

6. Eliminate the valve position rotary potentiometer and its' associated linkage and replace this system with proximity switches for fully open and fully closed indications.

REFERENCES


<table>
<thead>
<tr>
<th>Date</th>
<th>Sequence run number</th>
<th>Test description</th>
<th>Test objective</th>
<th>Engine pressure $P_e$</th>
<th>Simulated altitude (K-ft)</th>
<th>Altitude pressure (torr)</th>
<th>Remarks</th>
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<td>4-21-75</td>
<td>001</td>
<td>NHA 0500 +</td>
<td>Hot firing check run</td>
<td>750</td>
<td>Not critical</td>
<td>$1.7 \times 10^{-2}$</td>
<td>Valve opening time slightly long.</td>
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<td>002</td>
<td>NHA 0500</td>
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<td>750</td>
<td>1.2 $\times 10^{-2}$</td>
<td>Repeat run # 001</td>
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<td>NFA 0508 +</td>
<td>S.S.M.E. Gimbal survey</td>
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<td>240</td>
<td>$1.27 \times 10^{-2}$</td>
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<td>Valve failed to open, FM system not started.</td>
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<td>750</td>
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<td>NFA 0208 +</td>
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<td>1500</td>
<td>240</td>
<td>$1.27 \times 10^{-2}$</td>
<td>Auto-ignition, after spark.</td>
</tr>
<tr>
<td>Date</td>
<td>Sequence run number</td>
<td>Test description</td>
<td>Test objective</td>
<td>Engine pressure P₀</td>
<td>Simulated altitude (K-ft)</td>
<td>Altitude pressure torr</td>
<td>Remarks</td>
</tr>
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<tr>
<td>4-28-75</td>
<td>021</td>
<td>NFA 0208</td>
<td>S.S.M.E. Gimbal survey</td>
<td>1500</td>
<td>240</td>
<td>1.27x10⁻²</td>
<td>I.R.I.G. stopped at 3 seconds - normal 4</td>
</tr>
<tr>
<td>4-29-75</td>
<td>022</td>
<td>NFA 0204, 0108</td>
<td></td>
<td>150</td>
<td>240</td>
<td>5.6x10⁻¹</td>
<td>Normal operation.</td>
</tr>
<tr>
<td></td>
<td>023</td>
<td>NFA 0108 +</td>
<td></td>
<td>150</td>
<td>240</td>
<td>1.27x10⁻²</td>
<td>Normal operation.</td>
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<tr>
<td></td>
<td>024</td>
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<td>025</td>
<td>NFA 0104</td>
<td></td>
<td>240</td>
<td>360</td>
<td>3.01x10⁻⁵</td>
<td>A/V open too long, redundant signal closed.</td>
</tr>
<tr>
<td>4-30-75</td>
<td>026</td>
<td>NFA 0609</td>
<td>A/V elect. check.</td>
<td>N/A</td>
<td>Not critical</td>
<td>3.01x10⁻⁵</td>
<td>Charge tube pressure 100 psi. Checked good.</td>
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<tr>
<td></td>
<td>027</td>
<td>NFA 0609</td>
<td>S.S.M.E. Gimbal survey</td>
<td>1500</td>
<td>360</td>
<td>3.01x10⁻⁵</td>
<td>Arcing in vacuum chamber.</td>
</tr>
<tr>
<td></td>
<td>028</td>
<td>NFA 0609</td>
<td></td>
<td>150</td>
<td>240</td>
<td>1.27x10⁻²</td>
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</tr>
<tr>
<td></td>
<td>029</td>
<td>NFA 0608</td>
<td>Thrust structure compliance</td>
<td>240</td>
<td>240</td>
<td>5.6x10⁻¹</td>
<td>Normal operation.</td>
</tr>
<tr>
<td>5-1-75</td>
<td>030</td>
<td>NFA 0604, 0408</td>
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<td>150</td>
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<td>5.6x10⁻¹</td>
<td>Normal operation.</td>
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<td>031</td>
<td>NFA 0A08</td>
<td>I.B.F.F. Comparison</td>
<td>750</td>
<td>240</td>
<td>1.27x10⁻²</td>
<td>&quot;O&quot; Ring burnout.</td>
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<td>032</td>
<td>NFA 0A08</td>
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<td>NFA 0A07</td>
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<td>5-5-75</td>
<td>035</td>
<td>NFA 0908 +</td>
<td>I.B.F.F. Comparison</td>
<td>240</td>
<td>240</td>
<td>6.4x10⁻³</td>
<td>Normal operation.</td>
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<td>5-6-75</td>
<td>036</td>
<td>NHA 0908</td>
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<td>750</td>
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<td>6.4x10⁻³</td>
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<td>037</td>
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<td>240</td>
<td>240</td>
<td>6.4x10⁻³</td>
<td>Normal operation.</td>
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<td></td>
<td>038</td>
<td>NHA 0808</td>
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<td>150</td>
<td>240</td>
<td>2.72x10⁻¹</td>
<td>O/F off, lost FM 403</td>
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<td>039</td>
<td>NHA 0808</td>
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<td>150</td>
<td>240</td>
<td>2.72x10⁻¹</td>
<td>Run of 039, O/F still off</td>
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<tr>
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<td>040</td>
<td>NHA 0804</td>
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<td>140</td>
<td>240</td>
<td>4.07x10⁻¹</td>
<td>Position pot failed.</td>
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<tr>
<td></td>
<td>041</td>
<td>NHA 0803</td>
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<td>130</td>
<td>240</td>
<td>6.05x10⁻¹</td>
<td>No ignition - cold flow, early timing.</td>
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<td>042</td>
<td>NHA 0802</td>
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<td>130</td>
<td>240</td>
<td>6.05x10⁻¹</td>
<td></td>
</tr>
<tr>
<td>Date</td>
<td>Sequence run number</td>
<td>Test description</td>
<td>Test objective</td>
<td>Engine pressure ( P_e )</td>
<td>Simulated altitude (K-ft)</td>
<td>Altitude pressure torr</td>
<td>Remarks</td>
</tr>
<tr>
<td>--------</td>
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<tr>
<td>5-6-75</td>
<td>043</td>
<td>NHA 0802</td>
<td>I.B.F.F. Comparison</td>
<td>750</td>
<td>130</td>
<td>6.05x10^-1</td>
<td>O/F off.</td>
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<td>NHA 0801</td>
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<td>9.15x10^-1</td>
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<td>NHA 0808 +</td>
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<td>750</td>
<td>240</td>
<td>6.4x10^-3</td>
<td>Non fire - cold flow, repeat of 5-6 run for O/F = 6</td>
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<tr>
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<td>046</td>
<td>NHA 0809</td>
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<td>NHA 0804.</td>
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<tr>
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<td>NHA 0803.</td>
<td></td>
<td>130</td>
<td>6.05x10^-1</td>
<td>Normal operation.</td>
<td></td>
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<tr>
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<td>NHA 0801.</td>
<td></td>
<td>240</td>
<td>6.4x10^-3</td>
<td>Normal operation.</td>
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<td>051</td>
<td>NHA 0808 +</td>
<td></td>
<td>240</td>
<td>6.4x10^-3</td>
<td>Normal operation.</td>
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<tr>
<td>5-12-75</td>
<td>052</td>
<td>NHA 0808</td>
<td></td>
<td>240</td>
<td>1.27x10^-2</td>
<td>A/V failed to open.</td>
<td></td>
</tr>
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<td>5-12-75</td>
<td>053</td>
<td>NFA 0508 X</td>
<td>Temperature probe survey</td>
<td>1500</td>
<td>240</td>
<td>1.27x10^-2</td>
<td>A/V failed to open.</td>
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<td>054</td>
<td>NFA 0508 X</td>
<td></td>
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<td>Auto - ignition, no spark signal.</td>
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<td>055</td>
<td>NFA 0508 X</td>
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<td>Position pot failed.</td>
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<td>056</td>
<td>NFA 0508 X</td>
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<tr>
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<td>057</td>
<td>NFA 0504 X</td>
<td></td>
<td>150</td>
<td>5.44x10^-1</td>
<td>Normal operation.</td>
<td></td>
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<tr>
<td>5-14-75</td>
<td>058</td>
<td>NFA 0504 X</td>
<td></td>
<td>240</td>
<td>1.27x10^-2</td>
<td>Normal operation.</td>
<td></td>
</tr>
<tr>
<td>5-14-75</td>
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<td>NFA 0608 X</td>
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<td>150</td>
<td>5.44x10^-1</td>
<td>Normal operation.</td>
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<td>5-15-75</td>
<td>060</td>
<td>NFA 0604 X</td>
<td></td>
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<td>P_e -2 trace lost.</td>
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<tr>
<td>5-15-75</td>
<td>061</td>
<td>NFA 0604 X</td>
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<td>P_e -2 still out.</td>
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<td>NFA 0008 X</td>
<td></td>
<td>240</td>
<td>1.27x10^-2</td>
<td>Normal operation.</td>
<td></td>
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<td>064</td>
<td>NFA 0007 X</td>
<td></td>
<td>200</td>
<td>7.71x10^-2</td>
<td>Normal operation.</td>
<td></td>
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<td>5-15-75</td>
<td>065</td>
<td>NFA 0006 X</td>
<td></td>
<td>180</td>
<td>1.73x10^-1</td>
<td>Normal operation.</td>
<td></td>
</tr>
<tr>
<td>5-15-75</td>
<td>066</td>
<td>NFA 0005 X</td>
<td></td>
<td>160</td>
<td>3.72x10^-1</td>
<td>Normal operation.</td>
<td></td>
</tr>
<tr>
<td>5-15-75</td>
<td>067</td>
<td>NFA 0004 X</td>
<td></td>
<td>150</td>
<td>5.44x10^-1</td>
<td>Normal operation.</td>
<td></td>
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<tr>
<td>5-15-75</td>
<td>068</td>
<td>NFA 0003 X</td>
<td></td>
<td>140</td>
<td>8.00x10^-1</td>
<td>Normal operation.</td>
<td></td>
</tr>
<tr>
<td>Date</td>
<td>Sequence run number</td>
<td>Test description</td>
<td>Test objective</td>
<td>Engine pressure $P_e$</td>
<td>Simulated Altitude (K-ft)</td>
<td>Altitude pressure torr</td>
<td>Remarks</td>
</tr>
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<td>5-15-75</td>
<td>069</td>
<td>NFA 0002 X</td>
<td>Temperature probe survey</td>
<td>1500</td>
<td>130</td>
<td>1.191x10^0</td>
<td>Normal operation.</td>
</tr>
<tr>
<td>5-16-75</td>
<td>070</td>
<td>NFA 0001 X</td>
<td>Temperature long probe survey</td>
<td>1500</td>
<td>120</td>
<td>1.796x10^0</td>
<td>Normal operation.</td>
</tr>
<tr>
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<td>071</td>
<td>NFA 0008 XL</td>
<td>Temperature long probe survey</td>
<td>1500</td>
<td>240</td>
<td>1.27x10^-2</td>
<td>Normal operation.</td>
</tr>
<tr>
<td>5-16-75</td>
<td>072</td>
<td>NFA 0009 XL</td>
<td>Temperature long probe survey</td>
<td>200</td>
<td>7.71x10^-2</td>
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<td>Normal operation.</td>
</tr>
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<td>NFA 0004 XL</td>
<td>Temperature long probe survey</td>
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<td>5.34x10^-2</td>
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</tr>
<tr>
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<td>NFA 0005 X</td>
<td>Temperature long probe survey</td>
<td>140</td>
<td>8.00x10^-2</td>
<td></td>
<td>Normal operation.</td>
</tr>
<tr>
<td>5-17-75</td>
<td>075</td>
<td>NFA 0002 X</td>
<td>Temperature long probe survey</td>
<td>130</td>
<td>1.191x10^-0</td>
<td></td>
<td>Normal operation.</td>
</tr>
<tr>
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<td>Temperature long probe survey</td>
<td>120</td>
<td>1.796x10^-0</td>
<td></td>
<td>Normal operation.</td>
</tr>
<tr>
<td>5-19-75</td>
<td>077</td>
<td>NFA 0008 X</td>
<td>Temperature long probe survey</td>
<td>1500</td>
<td>240</td>
<td>1.27x10^-2</td>
<td>Valve failed to open.</td>
</tr>
<tr>
<td>5-19-75</td>
<td>078</td>
<td>NFA 0008 X</td>
<td>Temperature long probe survey</td>
<td>240</td>
<td>1.27x10^-2</td>
<td></td>
<td>Valve opened, increased opening press. (100psi): Normal operation.</td>
</tr>
<tr>
<td>5-19-75</td>
<td>079</td>
<td>NFA 0007 X</td>
<td>Temperature long probe survey</td>
<td>200</td>
<td>7.71x10^-2</td>
<td></td>
<td>Normal operation.</td>
</tr>
<tr>
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<td>080</td>
<td>NFA 0006 X</td>
<td>Temperature long probe survey</td>
<td>180</td>
<td>1.73x10^-1</td>
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<td>Normal operation.</td>
</tr>
<tr>
<td>5-19-75</td>
<td>081</td>
<td>NFA 0005 X</td>
<td>Temperature long probe survey</td>
<td>160</td>
<td>3.72x10^-1</td>
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<td>Normal operation.</td>
</tr>
<tr>
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<td>082</td>
<td>NFA 0004 X</td>
<td>Temperature long probe survey</td>
<td>150</td>
<td>5.44x10^-1</td>
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<td>Normal operation.</td>
</tr>
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<td>NFA 0003 X</td>
<td>Temperature long probe survey</td>
<td>140</td>
<td>8.00x10^-1</td>
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<td>Normal operation.</td>
</tr>
<tr>
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<td>NFA 0002 X</td>
<td>Temperature long probe survey</td>
<td>130</td>
<td>1.19x10^-0</td>
<td></td>
<td>Normal operation.</td>
</tr>
<tr>
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<td>NFA 0001 X</td>
<td>Temperature long probe survey</td>
<td>120</td>
<td>1.79x10^-0</td>
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<td>Normal operation.</td>
</tr>
<tr>
<td>5-20-75</td>
<td>086</td>
<td>OFA 0004 +</td>
<td>Flap effect</td>
<td>1500</td>
<td>150</td>
<td>5.44x10^-1</td>
<td>Lost position pot. auto-ignition, valve slow. Normal operation.</td>
</tr>
<tr>
<td>5-20-75</td>
<td>087</td>
<td>OFA 0004</td>
<td>Flap effect</td>
<td>240</td>
<td>5.44x10^-1</td>
<td></td>
<td>Traces indicate trouble. No ignition.</td>
</tr>
<tr>
<td>5-20-75</td>
<td>088</td>
<td>OFA 0008</td>
<td>Flap effect</td>
<td>150</td>
<td>5.44x10^-1</td>
<td></td>
<td>Normal operation.</td>
</tr>
<tr>
<td>5-20-75</td>
<td>089</td>
<td>OFA 0008</td>
<td>Flap effect</td>
<td>240</td>
<td>1.27x10^-2</td>
<td></td>
<td>Normal operation.</td>
</tr>
<tr>
<td>5-20-75</td>
<td>090</td>
<td>OFA 0004</td>
<td>Flap effect</td>
<td>150</td>
<td>5.44x10^-1</td>
<td></td>
<td>Normal operation.</td>
</tr>
<tr>
<td>Date</td>
<td>Sequence number</td>
<td>Test description</td>
<td>Test objective</td>
<td>Engine pressure P_c</td>
<td>Simulated Altitude (K-ft)</td>
<td>Altitude pressure torr</td>
<td>Remarks</td>
</tr>
<tr>
<td>----------</td>
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<tr>
<td>5-28-75</td>
<td>091</td>
<td>DFA 0008</td>
<td>Body flap effect</td>
<td>1500</td>
<td>240</td>
<td>1.27x10^-2</td>
<td>Timer 2 fired prematurely.</td>
</tr>
<tr>
<td></td>
<td>092</td>
<td>DFA 0008</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Lost spark trace. Good run.</td>
</tr>
<tr>
<td></td>
<td>093</td>
<td>DFA 0004</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>No spark trace, good data.</td>
</tr>
<tr>
<td>5-29-75</td>
<td>094</td>
<td>NFA 0009</td>
<td>Altitude survey</td>
<td>1500</td>
<td>150</td>
<td>5.44x10^-1</td>
<td>Normal operation.</td>
</tr>
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<td></td>
<td>095</td>
<td>NFA 0008</td>
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<td></td>
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<td>Normal operation.</td>
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<td>096</td>
<td>NFA 0007</td>
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<td></td>
<td>Normal operation.</td>
</tr>
<tr>
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<td>097</td>
<td>NFA 0006</td>
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<td></td>
<td>Normal operation.</td>
</tr>
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<tr>
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<td>099</td>
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<td>103</td>
<td>NQA 0008</td>
<td>Reynolds no. effect</td>
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<td>107</td>
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<td>108</td>
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<td>113</td>
<td>NFA 0704</td>
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<td>O2 injector trace bad.</td>
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<tr>
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<td>114</td>
<td>NFA 0P08</td>
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<td>240</td>
<td>1.27x10^-2</td>
<td>No spark trace, O/F high.</td>
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<tr>
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<td>115</td>
<td>NFA 0P08</td>
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<td>116</td>
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<td>No spark trace, O/F high.</td>
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</tbody>
</table>
### TABLE I - Continued. SHUTTLE BASE HEATING TESTS
(Space Power Facility, Plum Brook Station, Sandusky, Ohio)

<table>
<thead>
<tr>
<th>Date</th>
<th>Sequence run number</th>
<th>Test description</th>
<th>Test objective</th>
<th>Engine pressure $P_e$ (lbf/sq in)</th>
<th>Simulated Altitude (K-ft)</th>
<th>Altitude pressure (torr)</th>
<th>Remarks</th>
</tr>
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<tbody>
<tr>
<td>6-5-75</td>
<td>117</td>
<td>NFA OFO8</td>
<td>Combined gimbal</td>
<td>1500</td>
<td>240</td>
<td>$1.27 \times 10^{-2}$</td>
<td>No spark trace, H, venturi press. low.</td>
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<tr>
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<td>118</td>
<td>NFA OFO4</td>
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<td>150</td>
<td>$5.44 \times 10^{-1}$</td>
<td>H$_2$ still low.</td>
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<td>119</td>
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<tr>
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<td>120</td>
<td>NFA OEO4</td>
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<td>$5.44 \times 10^{-1}$</td>
<td>O/F off was visicorder calibration error.</td>
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<tr>
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<td>121</td>
<td>NFA OAO8</td>
<td>Structure compliance</td>
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<td>No problem with visicorder.</td>
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<td>NFA OEO8</td>
<td>Combined gimbal</td>
<td>1500</td>
<td>240</td>
<td>$6.7 \times 10^{-1}$</td>
<td>Repeat of # 119 Normal.</td>
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<td>Normal operation.</td>
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<td>131</td>
<td>NFA OBO8</td>
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<td>6-11-75</td>
<td>132</td>
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<td>133</td>
<td>NFA OBO7</td>
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<td>134</td>
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<tr>
<td>6-12-75</td>
<td>138</td>
<td>NHA OBO8</td>
<td>I.B.F.F. Comparison</td>
<td>750</td>
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<td>$6.4 \times 10^{-3}$</td>
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<td>139</td>
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<td>Repeat of # 138.</td>
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<tr>
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<td>140</td>
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<td>141</td>
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<td>Repeat of # 140, Normal.</td>
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</table>
### TABLE I. – Continued. SHUTTLE BASE HEATING TESTS
(Space Power Facility, Plumbook Station, Sandusky, Ohio)

<table>
<thead>
<tr>
<th>Date</th>
<th>Sequence run number</th>
<th>Test description</th>
<th>Test objective</th>
<th>Engine pressure $P_c$</th>
<th>Simulated altitude (K-ft)</th>
<th>Altitude pressure (torr)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>6-12-75</td>
<td>142</td>
<td>NHA 0804</td>
<td>I.B.P.F.</td>
<td>750</td>
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<td>Comparison</td>
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<td>NHA 0802</td>
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<td>145</td>
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<td>Gimbal survey</td>
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<td>OMS alone</td>
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<td>2.53 x 10^-1</td>
<td>Normal operation.</td>
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<tr>
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<td>151</td>
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<td>240</td>
<td>2.53 x 10^-1</td>
<td>Normal operation.</td>
</tr>
<tr>
<td></td>
<td>152</td>
<td>NO4, F839</td>
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<td></td>
<td>360</td>
<td>6.01 x 10^-5</td>
<td>Normal operation.</td>
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<tr>
<td></td>
<td>153</td>
<td>NO4, F839</td>
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<td></td>
<td>240</td>
<td>6.01 x 10^-5</td>
<td>Normal operation.</td>
</tr>
<tr>
<td></td>
<td>154</td>
<td>NO4, F838</td>
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<td></td>
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<td>2.53 x 10^-2</td>
<td>Normal operation.</td>
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<tr>
<td></td>
<td>155</td>
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<td>600</td>
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<td>6-17-75</td>
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<td>NO4, F818</td>
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<td>161</td>
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<td>Abort # 2, with OMS</td>
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<tr>
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<td>162</td>
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<tr>
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<td>164</td>
<td>NO4, F828</td>
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<td></td>
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<td>Normal operation. Camera on, with lights.</td>
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<tr>
<td>6-19-75</td>
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<td>NFX2 HCO4</td>
<td>Abort # 2, with OMS</td>
<td>1500</td>
<td>150</td>
<td>5.44 x 10^-1</td>
<td>Normal operation. Camera on, with lights.</td>
</tr>
</tbody>
</table>
TABLE I. - Concluded. SHUTTLE BASE HEATING TESTS
(Space Power Facility, Plumbrook Station, Sandusky, Ohio)

<table>
<thead>
<tr>
<th>Date</th>
<th>Sequence run number</th>
<th>Test description</th>
<th>Test objective</th>
<th>Engine pressure $P_c$</th>
<th>Simulated altitude (K-ft)</th>
<th>Altitude pressure (torr)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
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<td>NF2 HCO9</td>
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<td>Normal operation.</td>
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</table>
Table 2. SIMULATED ALTITUDE VS. VACUUM CHAMBER PRESSURE

SSME ENGINE CHAMBER PRESSURE = 1500 psia

<table>
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<tr>
<th>ALTITUDE FEET</th>
<th>VACUUM CHAMBER PRESSURE TORR</th>
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<tr>
<td>760</td>
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</tr>
<tr>
<td>120,000</td>
<td>1.796</td>
</tr>
<tr>
<td>130,000</td>
<td>1.1909</td>
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<tr>
<td>140,000</td>
<td>8.0000×10⁻¹</td>
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<tr>
<td>150,000</td>
<td>5.4365×10⁻¹</td>
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<tr>
<td>160,000</td>
<td>3.7208×10⁻¹</td>
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<tr>
<td>180,000</td>
<td>1.7312×10⁻¹</td>
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<tr>
<td>200,000</td>
<td>7.7143×10⁻²</td>
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<tr>
<td>240,000</td>
<td>1.2669×10⁻²</td>
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<tr>
<td>360,000</td>
<td>3.0066×10⁻³</td>
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</table>

SSME ENGINE CHAMBER PRESSURE = 750 psia

<table>
<thead>
<tr>
<th>ALTITUDE FEET</th>
<th>VACUUM CHAMBER PRESSURE TORR</th>
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<tbody>
<tr>
<td>760</td>
<td>760</td>
</tr>
<tr>
<td>120,000</td>
<td>8.9773×10⁻¹</td>
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<tr>
<td>130,000</td>
<td>2.7182×10⁻²</td>
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<tr>
<td>140,000</td>
<td>6.3345×10⁻³</td>
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</tbody>
</table>

OMS ENGINE CHAMBER PRESSURE = 125 psia

<table>
<thead>
<tr>
<th>ALTITUDE FEET</th>
<th>VACUUM CHAMBER PRESSURE TORR</th>
</tr>
</thead>
<tbody>
<tr>
<td>760</td>
<td>760</td>
</tr>
<tr>
<td>240,000</td>
<td>2.5339×10⁻²</td>
</tr>
<tr>
<td>360,000</td>
<td>0.0131×10⁻⁵</td>
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</tbody>
</table>

Vacuum chamber pressure for a simulated altitude were derived from the following formulas to hold proper nozzle pressure ratio.

For SSME firings (with or without OMS):

\[ P_{\text{vacuum chamber}} = \frac{P_{\text{engine chamber}} \text{ SSME}}{3000} \times P_{\text{altitude}} \]

For OMS alone firings:

\[ P_{\text{vacuum chamber}} = \frac{P_{\text{engine chamber}} \text{ OMS}}{125} \times P_{\text{altitude}} \]
### TEST DESCRIPTION KEY CODE

#### CHARACTER NUMBERS

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<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
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<td>Deflected = 20°</td>
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</table>

#### SSME CHAMBER PRESSURE

<table>
<thead>
<tr>
<th>Full = 1500 psi</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Half = 750 psi</td>
<td>H</td>
</tr>
<tr>
<td>Off</td>
<td>0</td>
</tr>
</tbody>
</table>

#### SSME OPERATING

<table>
<thead>
<tr>
<th>All Operating</th>
<th>A</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. 1 Engine Out 1</td>
<td>1</td>
</tr>
<tr>
<td>No. 2 Engine Out 2</td>
<td>2</td>
</tr>
<tr>
<td>No. 3 Engine Out 3</td>
<td>3</td>
</tr>
<tr>
<td>No Engines</td>
<td>4</td>
</tr>
</tbody>
</table>

#### CMS CHAMBER PRESS

<table>
<thead>
<tr>
<th>Double = 250 psi</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full = 125 psi</td>
<td>F</td>
</tr>
<tr>
<td>Half = 63 psi</td>
<td>H</td>
</tr>
<tr>
<td>Off</td>
<td>0</td>
</tr>
</tbody>
</table>

#### SSME GIMBAL ANGLE

<table>
<thead>
<tr>
<th>Parallel burn null</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parallel burn -11 Pitch</td>
<td>1</td>
</tr>
<tr>
<td>Parallel burn -5 pitch</td>
<td>2</td>
</tr>
<tr>
<td>Parallel burn -2 pitch</td>
<td>3</td>
</tr>
<tr>
<td>Parallel burn+2 pitch</td>
<td>4</td>
</tr>
<tr>
<td>Parallel burn+5 pitch</td>
<td>5</td>
</tr>
<tr>
<td>Parallel burn+11 pitch</td>
<td>6</td>
</tr>
<tr>
<td>Parallel burn-2 yaw</td>
<td>7</td>
</tr>
<tr>
<td>Static null</td>
<td>8</td>
</tr>
<tr>
<td>+4 pitch</td>
<td>9</td>
</tr>
</tbody>
</table>

#### PLUG PROBE

- Engine plugs used
- X Gas probes installed
- XL Long probes installed

#### SIMULATED ALTITUDE

<table>
<thead>
<tr>
<th>Atmospheric</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>120,000 feet</td>
<td>1</td>
</tr>
<tr>
<td>130,000 feet</td>
<td>2</td>
</tr>
<tr>
<td>140,000 feet</td>
<td>3</td>
</tr>
<tr>
<td>150,000 feet</td>
<td>4</td>
</tr>
<tr>
<td>160,000 feet</td>
<td>5</td>
</tr>
<tr>
<td>180,000 feet</td>
<td>6</td>
</tr>
<tr>
<td>200,000 feet</td>
<td>7</td>
</tr>
<tr>
<td>240,000 feet</td>
<td>8</td>
</tr>
<tr>
<td>360,000 feet</td>
<td>9</td>
</tr>
</tbody>
</table>

#### CMS GIMBAL ANGLES

<table>
<thead>
<tr>
<th>PITCH</th>
<th>DEGREES</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>3</td>
</tr>
</tbody>
</table>

See Table 4 for actual gimbal angles

| Table 3 |
### Table 4

<table>
<thead>
<tr>
<th>Character</th>
<th>Degrees</th>
</tr>
</thead>
<tbody>
<tr>
<td>#0 &quot;KEY&quot;</td>
<td>Pitch: Yaw</td>
</tr>
<tr>
<td>0</td>
<td>#1 0:0</td>
</tr>
<tr>
<td>Parallel burn</td>
<td>#2 0:3.5</td>
</tr>
<tr>
<td>&quot;Null&quot;</td>
<td>#3 0:3.5</td>
</tr>
<tr>
<td>1</td>
<td>Parallel burn</td>
</tr>
<tr>
<td></td>
<td>-11 Pitch</td>
</tr>
<tr>
<td></td>
<td>+3.5 Pitch</td>
</tr>
<tr>
<td>2</td>
<td>#1 -5 0</td>
</tr>
<tr>
<td></td>
<td>-5 Pitch</td>
</tr>
<tr>
<td></td>
<td>+3.5 Pitch</td>
</tr>
<tr>
<td>3</td>
<td>#1 -2 0</td>
</tr>
<tr>
<td></td>
<td>-2 Pitch</td>
</tr>
<tr>
<td></td>
<td>+3.5 Pitch</td>
</tr>
<tr>
<td>4</td>
<td>#1 +2 0</td>
</tr>
<tr>
<td></td>
<td>+2 Pitch</td>
</tr>
<tr>
<td></td>
<td>+3.5 Pitch</td>
</tr>
<tr>
<td>5</td>
<td>#1 +5 0</td>
</tr>
<tr>
<td></td>
<td>+5 Pitch</td>
</tr>
<tr>
<td></td>
<td>+3.5 Pitch</td>
</tr>
<tr>
<td>6</td>
<td>#1 +11 0</td>
</tr>
<tr>
<td></td>
<td>+11 Pitch</td>
</tr>
<tr>
<td></td>
<td>+3.5 Pitch</td>
</tr>
<tr>
<td>7</td>
<td>#1 0 -2</td>
</tr>
<tr>
<td></td>
<td>-2 Yaw</td>
</tr>
<tr>
<td></td>
<td>+1.5 Yaw</td>
</tr>
<tr>
<td>8</td>
<td>#1 0 0</td>
</tr>
<tr>
<td>Static null</td>
<td>#2 0 0</td>
</tr>
<tr>
<td></td>
<td>#3 0 0</td>
</tr>
<tr>
<td>9</td>
<td>#1 +4 0</td>
</tr>
<tr>
<td></td>
<td>+4 Pitch</td>
</tr>
<tr>
<td></td>
<td>#3 +4 0</td>
</tr>
</tbody>
</table>

#### SSME Gimbal angles

Positioning of SSME B6.12 gimbal angles with respect to the L.H. CMS and R.H. CMS.

**Table 4**
Figure 4. SHUTTLE HASE HEATING TESTS
Representative values and sequence for a typical hot firing.

- Spark plug fires and ignites.
- T₁ & T₂ timers start.
- Micro-switch starts T₃ & T₄ timers.
- Opening signal.
- Valve full open.
- Redundant closing signal.
- Normal closing signal.
- Shock wave return from charge tube.

45-50 milliseconds of steady state data.

Time-Milliseconds

- T₁ timer = Valve opening signal set for 18-19 milliseconds.
- T₂ timer = Redundant closing signal set for 80 milliseconds.
- T₃ timer = Normal closing signal set for 65 milliseconds.
- T₄ timer = Spark signal set for 3 milliseconds.
PLUMBING MODIFICATIONS

BEFORE

AFTER

FIGURE 5
SSME #1 BLOWOUT

SOLDER SPLATTER

FIGURE 6
FIGURE 7

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR
PLUMMOND SPACE POWER FACILITY RUN DATE 4/12/73 RUN 135 TEST SHEET 23-1

FIGURE 5
P. J. H. SPACE POWER FACILITY
RUN DATE 11/13/73 RUN 139 TEST SHAKES MODEL 38-9

FIGURE 10