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NASA Lewis Research Center Lean-, Rich-Burn Materials Test Burner Rig

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INTRODUCTION

The rich-burn quick-quench lean-burn (RQL or RBQQ) combustor is one potential concept being considered for the next generation high speed civil transport (HSCT) aircraft (ref.1). The rationale for developing this and other alternate combustor concepts derives primarily from NO_x emission considerations (ref.1-3). Ceramic matrix composites (CMC's) are being pursued as candidate construction materials for the RQL combustor. Based mainly on temperature capability, thermal conductivity and density considerations, silicon based CMC's (fiber reinforced SiC and Si_3N_4) are at this time prime candidates. How such silicon based materials will behave in the quasi reducing environment (ref.4) of the rich-burn section of the RQL is of fundamental importance to materials development. As part of NASA's Enabling Propulsion Materials (EPM) program, efforts are underway at Lewis Research Center (LeRC) to answer this question. In addition to

theoretical chemical analyses and laboratory type studies (ref.4-5 and references cited therein), the EPM program mandated that a test rig be developed in which sample materials could be subjected to the rich-burn environment (equivalence ratio, temperatures and flow velocities) projected for the RQL burning jet fuel. The high pressure burner rig in existence at LeRC was proposed as a possible facility. If this rig could be adapted to the needs at hand, it would expedite the onset of materials testing and be more economical than development of a new rig.

Initial experiments demonstrated the feasibility of rich-burn operation. However, subsequent studies concluded that (1) the fuel-air mixing was not satisfactory, (2) sufficiently low flow velocities could not be achieved, (3) combustor durability was not satisfactory, (4) a water cooled sample holder would be necessary and (5) the by-products of rich-burn operation must be environmentally safe. At this point it was presumed that the rig could be relatively easily modified to meet the program required test conditions. This report is intended mainly for the EPM community and its purpose is to describe and document the modified rig and present the range of operational parameters available.

Modifying the existing facility to meet EPM test requirements was a more formidable task than originally anticipated. Key efforts included the implementation of a state-of-the-art air blast fuel nozzle, the installation of a stack burner for the removal of environmentally hazardous emissions, and the use of an inert gas to cool observation windows. Materials durability was another major

hurdle in that rig components were required to have the same durability that forms the basis for developing new combustor materials. Fortunately, weight constraints (which are a major driver in the HSCT program) do not apply to rig testing. In addition, the rig could use cooling approaches unavailable in flight hardware. Lastly, computer control was added to ensure quality and repeatability of test conditions. After nearly a two year intensive effort, the rig has been brought to the point where it satisfactorily meets EPM testing requirements and the materials test program has been initiated.

RIG HARDWARE & TEST FACILITY SYSTEMS

A schematic representation of the burner rig configuration is shown in Figure 1. The combustor burns jet fuel and air in controlled ratios, the combustion products flow downstream and impinge on samples supported in a water cooled holder in the test section. After passage through the test section the combustion gases pass through a water cooled orifice plate and into a quench section where they are cooled by a water spray before being vented to the atmosphere. The rig is constructed such that it can be operated to pressures above 5 MPa (800 psig). In addition to the combustor rig the test cell houses an associated 400 hp compressor which delivers combustion air to the rig. The test cell layout is shown in Figure 2, and a photograph of the rig is shown in Figure 3. Description of the rig's various components and systems is best accomplished by considering them individually.

COMBUSTOR SECTION The combustor section consists of a housing, combustion liner, fuel injection nozzle, air swirl plate, turbulator and instrument ring. The combustor section (less the turbulator) is shown in cross-section in Figure 4. Air enters the housing through a 5 cm (2 in) diameter pipe, passes through the annulus between the housing and the outside diameter of the combustion liner. A distribution system assures uniform air flow over the outside diameter of the liner. The combustion liner is thus cooled by the inlet air which typically enters the housing at 100°C (200°F). After passing over the liner, the air enters the interior of the combustion liner through the swirl plate and swirl section of the fuel nozzle. The air temperature is increased by heat picked up as the air flows over the liner. The temperature rise depends on the combustor temperature (fuel-to-air ratio) and air mass flow rate. With a mass flow rate of 0.45 kg/sec (1 lbm/sec) and the range of temperatures produced by combustion, the air actually enters the combustion liner between 150 and 200°C (300-400°F). The combustor housing is constructed of stainless steel while the liner and swirl plate are fabricated from Inconel 601 and 600, respectively. A photograph of the liner, swirl plate, and fuel nozzle assembly is shown in Figure 5. The liner has an inside diameter of 10 cm (4 in) and is 43 cm (17 in) overall in length. The liner has a wall thickness of 0.02 cm (0.08 in) and ribs (cooling fins) which are 0.28 cm (0.11 in) high by 0.25 cm (0.10 in) wide. There are forty ribs on the liner. A $Y_2O_3-ZrO_2$ (yttria-stabilized zirconia) thermal barrier coating, 0.038 cm (0.015 in) thick, is plasma sprayed over a 0.013 cm (0.005 in) NiCrAlY bond coat on the

interior of the liner.

The swirl plate is fixed in position and supported in the housing at three points by pins. The liner is fixed in position and supported at the downstream flanges of the housing. The inside diameter of the liner fits around the swirl plate and has three slots which allow it to grow in length (over the swirl plate and beyond the pins) as it is heated. As shown in Figure 6, the swirl plate has a single row of radial holes to produce air swirl (approx. 60°) with the same rotation as that produced by the air-blast fuel nozzle. In addition to the swirl angle, the geometry of the dome (conical expansion configuration) is critical in achieving the proper fuel-air mixing (ref. 6). The structure appended to the swirl plate accommodates the spark plug and hydrogen pilot inlet used for ignition.

The air-blast fuel nozzle is supported in a port on the housing and seats in the center of the swirl plate. This nozzle, graciously supplied by Textron Fuel Systems Inc., is the type used in Pratt and Whitney's 2037 turbine engine and it is considered to be a state-of-the-art nozzle with respect to fuel atomization. Injected fuel is mixed with air in the nozzle and sheared through a nozzle passage before mixing with additional air through swirl vanes in the nozzle. Additional combustion air is added to the combustor through the swirl plate and via the small clearance between the swirl plate outside diameter and liner inner diameter. Under cold flow conditions with 0.45 kg/sec (1 lbm/sec) air flow, the pressure drop across the combustor liner inlet is about 40 kPa (6 psi).

The turbulator, a pressure constrictor with an orifice diameter

of 6.35 cm (2.5 in), is located at the exit end of the combustor liner. This orifice is water cooled and also protected with a thermal barrier coating, and its function is to provide more uniform burning. Immediately downstream of the turbulator is a 10.2 cm (4 in) long by 15.2 cm (6 in) inside diameter water-cooled instrument ring which is also protected with a thermal barrier coating. This ring has four 1.27 cm (0.5 in) diameter ports equally spaced circumferentially and radially directed. These ports provide access for thermocouples and pressure taps. Three Pt-Pt13Rh thermocouples in closed end Pt10Rh tubes located in this instrument ring are used for rig monitoring purposes. These couples do not penetrate to the center of the gas path; rather they protrude only slightly beyond the interior wall and thus they only provide relative temperatures. This arrangement was found to be necessary to provide reasonable thermocouple life.

TEST SECTION The test section consists of a stainless steel water cooled tee with an inside diameter of 15.2 cm (6 in). The straight through ends of the tee are flanged (6 in, 800 pound ASA flanges) to mate with the combustor housing (with the turbulator and instrument ring contained between) and quench section respectively. The side arm of the tee is a 15.2 cm (6 in) inside diameter port that mates with the sample holder housing section through a Grayloc hub flange. The wall of the tee opposite the side arm has a 0.159 cm (0.625 in) inside diameter port to accept a water cooled thermocouple probe. The water cooled section of this probe is 0.127 cm (0.5 in) in diameter and extending beyond this is a 7.62 cm (3 in) length of Pt10Rh tube.

Inside this tube is a double bore alumina tube which carries a Pt-Pt13Rh thermocouple. The alumina tube extends 0.64 cm (0.25 in) beyond the Pt10Rh tube and the thermocouple bead is exposed at the end of the alumina tube. This thermocouple is positioned such that the junction is located on the centerline of the test section, thus in the center of the combustion product flow path and directly behind the samples when the sample holder is inserted.

On the top centerline of the tee straight section (90 degrees circumferentially from the side arm) is a nominal 3.8 cm (1.5 in) diameter by 7.6 cm (3 in) long tube attached to a viewport assembly. This tube is 3.8 cm (1.5 in) forward of the tee side arm centerline and centered with respect to the gas flow path. The viewport assembly consists of a housing containing a 5.08 cm (2 in) diameter by 5.08 cm (2 in) thick quartz window with appropriate pressure seals. There is a 1.27 cm (0.5 in) diameter side port in the tube below the window. A plate with a 1.27 cm (0.5 in) diameter hole is located in the tube a short distance below the side port. The section between the window and plate is pressurized by flowing nitrogen (1.5 ACFM @ 4MPa (550 psig)) through the side port. The nitrogen flow maintains a positive pressure in the enclosure which in turn keeps the window cool and clean. The viewport is used for observing a sample under test with a two-color optical pyrometer and video camera.

QUENCH AND EXHAUST SYSTEM The quench section attached to the downstream end of the test section consists of an exhaust orifice, a quench ring, a quench pipe and transition piping to the back pressure

exhaust valve. The exhaust orifice is a water cooled plate with a 5 cm (2 in) diameter orifice in its center. The purpose of this orifice is maintain a higher pressure in the test section than in the quench section and thereby prevent water vapor from entering the test section. The quench ring is a 10.1 cm (4 in) long water cooled cylinder with holes in its interior periphery and a spray nozzle in the center on its inside diameter. Cooling water sprays through the holes and nozzle to cool the combustion product gas flow. Typically a water flow rate of 38 l/min (10 gpm) is used to cool the gas to below 120°C (250°F) by the time it reaches the end of the 15.2 cm (6 in) diameter by 0.92 m (3 ft) long quench pipe.

Gas flow from the quench pipe is diverted from the horizontal to a vertical flow path by transition piping and carried to the exhaust valve. This air operated automatic valve is used to control the pressure in the test section, as measured by a pressure transducer connected to the test section.

Downstream of the exhaust valve the cooled combustion product gas flows through a water separator to remove the excess water not converted to steam. The water (and any soot contained within as a result of fuel-rich operation) is pumped into an appropriate sewer. The gases exiting the water separator pass through the cell ceiling and enter a natural gas fired stack burner rising 7.3 m (24 feet) above the roof. The rig combustion gases are diluted with air and the combustible components are ignited by the 788°C (1450°F) natural gas flame. Thus the CO and small quantities of H₂S found in the combustion products during fuel-rich operation are reduced to levels which meet

or exceed environmental discharge standards.

SAMPLE HOLDER SECTION The sample holder section, shown schematically in Figure 7, consists of the sample holder, its support shaft, the translation mechanism, and the pressure containment vessel. Figure 8 is a photograph of the thermal barrier coated, water-cooled sample holder with two samples in place. The samples are held in the holder with lava or superalloy blocks which have slots appropriately sized to the sample width and thickness. The lava blocks are preferred, because they provide some thermal insulation of the sample from the water cooled holder, but in some instances are subject to cracking. In such circumstances we have used superalloy (Haynes 214) blocks and found the heat loss to be acceptable. The required sample length is 7.5 cm (3 in) and any combination of sample widths can be accommodated to a maximum width of about 3.0 cm (1.2 in). Sample thickness should be in the nominal range from 0.25 to 0.50 cm (0.1 to 0.2 in). The samples extend into the lava blocks approximately 0.64 cm (0.25 in) on each end.

The sample holder is welded to the end of a 2.5 cm (1.0 in) diameter shaft which carries the supply and return water for the holder. This shaft passes through two bearings and is attached to a pair of air-operated cylinders which allow translation (by remote control) of the holder to the center line of the test section flow path. Between the two bearings the shaft can be broken for ease of assembly and maintenance. The air cylinders and flexible water feed and return lines are contained in the pressure containment vessel.

This vessel is pressurized with nitrogen to assure that no combustion product gases enter the vessel through the slight leakage associated with clearances in the final bearing. The use of nitrogen is required because of the fuel-rich environment. A differential pressure transducer and automatic valve are used to maintain the pressure in the vessel 150 kPa (25 psi) greater than that in the test section.

The sample holder is thermal barrier coated ($Y_2O_3-ZrO_2$) everywhere except in the recesses for the lava blocks and in the area of the attachment screws. Room temperature, deionized water is supplied to the holder by a closed loop water system with high pressure pump. The return leg of the water system passes through a heat exchanger before being returned to the 380 liter (100 gallon) supply reservoir. The temperature of the return water is monitored immediately after it exits the pressure vessel to assure proper cooling of the sample holder. With a water flow rate of 9.5 l/min (2.5 gpm) through the sample holder and a gas temperature as high as 1550°C (2825°F), the temperature rise of the water after passing through the holder is only about 25°C (50°F).

It should be noted that when the sample holder is in the retracted position the samples are out of the flow path but still in a high temperature environment.

AIR AND FUEL SUPPLY SYSTEMS A compressor, capable of delivering 4.4 kg/sec (2 lbm/sec) of air at 7 MPa (1000 psig), delivers air to a large roof mounted ballast reservoir which automatically vents to atmosphere to maintain the pressure near 5 MPa (800 psig). Filtered

laboratory service air at 850 kPa (125 psig) supplies the compressor. Air from the reservoir is piped to the rig inlet through a filter, flow measuring Venturi and automatic valve.

Fuel is supplied from a 6000 gallon underground tank. Low and high pressure fuel pumps in series deliver fuel to the rig through filters, an automatic valve and flow rate transducer. The fuel system is plumbed with return lines so excess fuel delivered by the pumps can be returned to the tank. The low pressure pump is located outside the building at the fuel tank and the high pressure pump, automatic valve and flow transducer are located in the test cell.

IGNITION SYSTEM The ignition system consists of a spark plug, high voltage source and hydrogen supply. The spark plug is attached to the appendage on the swirl plate and is contained inside the combustor housing. Connected (via a spring) to a high voltage feedthrough in the top of the combustor housing, the spark plug is wired to a high voltage transformer. Bottled hydrogen is routed into the combustor housing where a 0.32 cm (0.125 in) diameter stainless tube delivers it into the spark plug appendage. The fuel is ignited by a depressing a control switch which activates a time sequence spark plug firing, hydrogen supply and fuel supply. If ignition is not achieved, the fuel and hydrogen valves are closed, the fuel line is automatically purged with nitrogen, and a time delay is initiated before a permissive is satisfied allowing another ignition sequence attempt. Usually the combustor ignites on the first attempt.

CONTROL AND MONITORING SYSTEMS

All transducers, thermocouples and automatic valve controls are wired from their rig locations to a console located in a control room adjacent to the test cell. All systems are monitored by a programmable controller (Modicon) which sequences required permissives through appropriate relay networks (relay ladder logic networks). There are two operating modes to control air flow, fuel flow, system pressure, and quench water flow. They include 1) analog control from the control panel, and 2) digital control from a personal computer. Analog control is used for system checkouts while all test runs are made under computer control.

Critical system permissives are additionally wired to an annunciator panel with visual indication and audio alarm. All system parameters are monitored with analog devices and selected parameters are also monitored and recorded with the computer.

ANALOG CONTROL AND MONITORING Proportional controllers with rate and reset are used to control air flow, fuel flow, system pressure, nitrogen differential pressure and quench water flow. Each of these controllers can be operated in either manual valve control or automatic setpoint control. Manual control involves direct positioning of supply valves. In the automatic mode, a supply valve is regulated such that an input signal (feedback) is matched to a setpoint. Input for the air flow controller is provided by a mass flow rate computer whose inputs are pressure, temperature and differential pressure

across the air line venturi. The fuel flow controller receives input from a mass flow rate indicator coupled with a flow transmitter and temperature sensor. The system pressure, quench water flow, and nitrogen flow controllers receive inputs from a pressure transducer, thermocouple, and differential pressure transducer, respectively.

Analog monitoring is accomplished with analog or digital meters, a two color optical pyrometer, and a video camera, all of which are mounted in the control room console.

COMPUTER CONTROL, MONITORING & DATA ACQUISITION A personal computer is interfaced with a data acquisition and control unit containing both analog input and analog output cards. Critical instrumentation is wired to the analog input cards. Directed by the computer, an internal voltmeter scans the input cards to monitor temperature, pressure, and mass flow rate inputs. Using calibration coefficients, the software converts the input signals and displays the data in either tabular or graphics format as shown in Figures 9a and 9b, respectively. Information such as valve positions, setpoints, and other calculated values (fuel-air ratio, velocity, time) is also displayed on the computer screen.

Control of air flow, fuel flow, quench water flow, and system pressure is maintained with analog output cards which are wired to corresponding electro-pneumatic control valves. Two modes of computer control (direct control of valve position and closed loop control of a specified setpoint) are available for each valve. Valve positions and setpoints may be changed using special function keys defined by

the mode selected. Air mass flow rate, fuel-to-air ratio, system pressure, and exit temperature are the parameters available for closed loop control. When selected, rate and reset (PID) subroutines compare the actual data to the setpoint, modifying the valve positions until the setpoint is converged upon. In addition to data monitoring and control, the computer provides automated data acquisition and an electronic logbook. Internal clocks provide "real-time" stamping of data which can be printed and/or stored on a hard disk at user-defined intervals. A run summary (shown in Figure 10) is generated to document simple statistics on test parameters in addition to logged combustion time, fuel usage, and specimen test history. The software (developed by the authors and listed in Appendix A for documentation purposes) also includes subroutines for data plotting.

OPERATIONS

OPERATIONAL MODES The standard mode of operation is to control the fuel-to-air-ratio (f/a) for a fixed air flow rate (m_a) and fixed system pressure (P_s). Both the resultant gas temperature (T_g) and sample temperature (T_s) is thus fixed by the selected f/a , m_a and P_s . The rig typically operates with $m_a=0.45$ kg/sec (1 lbm/sec). This flow rate was selected to provide adequate cooling to the combustor liner over the entire operating range of the combustor which has broad stability limits. Combustion can be initiated and maintained at equivalence ratios (ϕ) of 0.4 to 2.0 (f/a of 0.025 to 0.135), however

the region around stoichiometric ($f/a=0.06-0.1$, $\phi=0.9-1.5$) is avoided to minimize rig component durability problems. If the f/a selected is such that moderate combustion temperatures are attained, the rig can be run with m_a as low as 0.23 kg/sec (0.5 lb/sec) and still have sufficient cooling for the combustor liner. The system pressure is selected on the basis of the desired combustion product flow velocity in the test section. Stable operation has been achieved for system pressures of 5 to 25 atmospheres (60 to 350 psig) for the range of f/a of interest to the materials test program.

If lower sample temperatures are desired at a selected f/a , an option is available to add a water-cooled transition section between the combustor and test section. (The interior of this section is thermal barrier coated.) With this section in place the associated heat loss results in lowering both the gas and sample temperatures between 200 and 300°C (400-600°F) depending on the particular f/a . By appropriately controlling the cooling water flow through the transition section it may be possible control the heat loss and thus the temperature drop.

HEAT TRANSPORT MECHANISMS The samples under test are heated mainly by convection from the flowing gas but there is also some heating by radiation from the combustor. Radiation heating has been observed by monitoring the test section thermocouple with the samples both withdrawn and inserted. When the samples are inserted the thermocouple yields a lower temperature, possibly because the samples (i.e., 2.5 cm wide samples) block some/all of the radiation from the combustor.

The observed temperature difference depends on the f/a ratio and resultant combustor temperature (at $f/a=.06$ the temperature drop is about 50°C or 100°F). The samples lose heat by conduction to the holder and by radiation to the relatively cold test section walls. However, under rich-burn conditions the gas is extremely luminous, therefore heat loss by radiation from the samples is assumed to be negligible.

The rig configuration is too complex to reasonably calculate heat transfer coefficients, etc. In addition, the inability to account for radiation heating, radiation cooling, and conductive heat losses make analytical modelling of sample temperatures difficult. As a result, we rely on thermocouple and optical pyrometry measurements to ascertain gas and sample temperatures.

TEMPERATURE MEASUREMENT As noted, a two color optical pyrometer can be sighted through the viewport onto the sample and a video camera can also be sighted on the sample through the pyrometer. When operating in the lean-burn mode the sample's leading edge can readily be seen and its apparent temperature measured with the pyrometer. In the rich-burn mode the sample is not visible because of the intense luminosity of the combustion product gas and therefore sample temperature cannot be measured directly. To circumvent this problem the sample temperature (T_s) is measured via pyrometer, as a function of f/a , in the lean-burn mode, and correlated with the gas temperature (T_g) measured by the test section thermocouple located directly behind the samples. A plot of the respective temperatures versus f/a is shown in

Figure 11 for a Hexoloy (hot-pressed SiC monolithic) sample. The resulting correlation between the pyrometer measured sample temperature and the gas temperature is shown in Figure 12, where a least squares fit of the data was used to obtain an equation relating sample temperature to gas temperature.

This correlation is used to estimate the sample temperature in the rich-burn mode. To deduce sample temperature in the rich-burn mode, it is assumed that the relationship between the sample temperature and the gas temperature, measured in the lean-burn mode, still holds. By measuring the gas temperature in the rich-burn mode the sample temperature can be calculated. Assumptions made in this procedure have not been validated experimentally but appear reasonable since the air mass flow is held constant and the fuel flow is only a small fraction (13.4% at $\phi = 2.0$) of the 0.45 kg/sec (1 lbm/sec) air mass flow. The difference in the combustion products composition between the lean and rich modes is expected to make little difference in the heat transfer to the sample except possibly when heavy sooting occurs. Not surprisingly, the calibration curve depends on the sample material and size as well as on the sample holder material (insulator vs superalloy). Therefore a separate calibration curve is determined for each material tested.

At this point, it is helpful to discuss both the factors which influence temperature measurement with a two color optical pyrometer and the errors which may be present in the data collected. When measuring sample temperatures one must be aware that sample emissivity is still a dominant factor to be considered! The pyrometer sensor

operates by comparing the radiation detected at two wavelengths and computing the ratio. If the sample's emissivity characteristics are independent of wavelength, for the two wavelengths measured, then the measured temperature is correct. However, if there is a wavelength dependence of emissivity the ratio of the two detected signals would be weighted incorrectly and a temperature error would result. The two color pyrometer has a slope adjustment to compensate for the slope in the emissivity versus wavelength curve. If the sample temperature is independently known the proper slope setting can be ascertained and set to yield correct temperatures.

In our situation the sample temperature is not independently known. In practice we set the slope adjustment to the greybody position which is correct for clean unoxidized SiC. In reality though the SiC sample grows a SiO₂ scale (at least under lean-burn conditions). This scale changes the emissivity of the sample and we have evidence that the emissivity of SiO₂ is not wavelength independent over the range of wavelengths used by the pyrometer. Thus the greybody slope setting is no longer valid; the pyrometer temperatures we record have an uncertainty associated with them. The magnitude of this uncertainty is at present unknown and we are still addressing this problem.

PERFORMANCE

TESTING Combustion gas temperatures measured with the thermocouple are

shown as a function of f/a in Figure 13 for both the lean and rich-burn modes together with the calculated adiabatic temperature. This data was obtained by varying the f/a for a fixed m_a and P_s . The gas temperature curve excludes data within stoichiometric range and is expected to have a higher apex. As noted, operation in this range of higher temperatures is avoided for rig component durability reasons. At any fixed f/a the gas temperature variation with time for short time intervals, e.g. 1.5 hrs, is only near $\pm 8^\circ\text{C}$ ($\pm 14^\circ\text{F}$) as shown in Figure 14. Note, the corresponding sample temperature variation measured directly from a C/SiC (carbon reinforced silicon carbide) composite during lean-burn operation is even less at $\pm 5^\circ\text{C}$ ($\pm 9^\circ\text{F}$). However, on the basis of the limited data now available it has been observed that during time intervals of 50-100 hrs, at fixed f/a , the temperature gradually drifts and the variation increases. Many variables (test cell temperature, compressor discharge temperature, metal temperatures) are different at startup as opposed to extended running and may in part account for the drift.

Figure 15 shows some typical data obtained during the rich-burn testing of the C/SiC composite samples. The x-axis is time and the y-axis is the sample temperature as calculated from the gas temperature correlation data. Here, the temperature varies about $\pm 22^\circ\text{C}$ (40°F) suggesting that the gas temperature variation increases slightly during rich-burn operation. The long term drift also contributes to the increased variation. However, it is believed that the sample temperature does not actually vary this much (Figure 14) because its thermal mass is much greater than that of the gas temperature

measurement thermocouple. From Figure 15 one obtains an average temperature of 1373°C (2503°F) that represents the sample exposure test conditions to an estimated $\pm 16^\circ\text{C}$ (30°F).

RIG DURABILITY The combustor components have shown excellent durability over the first 300 hours of operation with over 150 ignition cycles. No distortion of the liner has been observed and the thermal barrier coating on its interior has remained perfectly intact. At 4 inspection intervals in the 300 hours some very slight soot accumulation in the combustor liner has been noted. The accumulation is very friable and easily brushed away. No clogging of the fuel nozzle has been observed and the swirller is almost pristine. Thermocouple life had proven to be a major durability problem, but through experience has lead to improved designs and a systematic change schedule has been established. The sample holder shows no distress after 300 hours. The lava sample support blocks have shown some degradation, however they did function satisfactorily during 50 hrs of exposure ($T_g=1500^\circ\text{C}$ or 2725°F) of rich-burn ($f/a=1.8$) operation using Hexoloy samples. In a 50 hr test with the C/SiC samples the lava blocks had undergone such severe degradation that they had to be changed several times. It is believed that with these samples the heat transfer to the lava blocks was sufficiently increased to account for the degradation. Substituting superalloy blocks for the lava has proven to be a viable alternative.

CONCLUDING REMARKS

The high pressure burner rig at Lewis Research Center has been successfully modified to be a lean- or rich-burn materials test facility. The preferred range of fuel-to-air ratios is from 0.025 to 0.060 ($\phi=0.4$ to 0.9) for lean-burn operation and 0.100 to 0.135 ($\phi=1.5$ to 2.0) for rich-burn operation. Fuel-to-air ratios in the high temperature region ($\phi=0.9$ to 1.5) near stoichiometric are avoided so as not to exacerbate rig component durability problems. Apparent sample temperatures as high as 1550°C (2800°F) can be obtained while still avoiding the stoichiometric region.

Three sample materials (Hexoloy, Carbon reinforced SiC, and SiC reinforced SiC) have been successfully tested for 50 hr. each in a rich-burn ($\phi=1.8$) combustion environment.

Accurate determination of true sample temperatures in the test rig is still a formidable problem and the subject of ongoing efforts. However we feel that the temperatures we report are sufficiently accurate for materials test purposes and the temperature variability certainly is within the limits expected for aero engine combustors.

While the rig has demonstrated satisfactory durability, opportunities for improvement continually present themselves and these are being pursued iteratively while conducting the materials test program.

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APPENDIX A

The software listed on the following pages has been included to serve as documentation of the control and operational procedures used in this facility. As seen before, facilities such as these may experience periods of dormancy due to programmatic or personnel changes. In such a case, this record could prove critical in attempts to renew operations to the facility after any such period.

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10 ! PROGRAM "X6 SHORT"
20 ! HIGH PRESSURE BURNER RIG - DATA AQUISITION AND CONTROL
30 ! LAST REVISION 10/93 ; C.ROBINSON ; X-5547
40 OPTION BASE 1
50 DIM Chan_label$(40)[16],Display_format$(40)[5],Sensor$(40)[5],Test$(15)
60 DIM Unit$(40)[4],Suffix$(10)[1],Disp$(15)[68],Parm$(10)[15]
70 DIM Specimen$(2)[15],Install$(2)[15],Spec_info$(2)[80]
80 DIM L1$(1),L4$(4),L5$(5),L6$(6),L8$(8),Part1_disp$(32),Part2_disp$(32)
90 DIM Ans$(80),Blank$(80),File_name$(15),Image$(80),Template$(15)
100 DIM Screen(15,2),Cox(5),Tstart(3),Trich(2),Tlean(2),Stat(4,10)
110 DIM Volt(30),Dval(40),Kref(13),Rref(13),R(13),Hi_lim(40),Low_lim(40)
120 DIM P(7,5),Amt(5),P_prop(5),Ignite_sp(4),Stor_buf(13,500),Array(13,500)
130 REAL Vref,Volt_comp,Vt,Temp,Err,Out,Prop,Sp_fraction,Bytes,Fuel_lbs
140 REAL Air_flow_sp,Fa_ratio_sp,Sys_psi_sp,Setpoint,Fuel_sp,Air_sp
150 REAL Ts,Trun,Tcomb,Tinsert,Tretract,Tloop,Quench_sp,Back_sp
160 INTEGER I,J,N,X,Y,Data_pts,Pid,Prt_int
170 INTEGER Print_order(11),Cycles(6),Life_cycles,Control_ind(3),Flag(10)
180 INTEGER Airout,Backout,Quenchout,Fuelout
190 PRINTER IS 1
200 DUMP DEVICE IS 26
210 CLEAR SCREEN
220 PLOTTER IS CRT,"INTERNAL";COLOR MAP
230 SET PEN 0 INTENSITY 0,0,.45
240 PRINT TABXY(1,27);DATE$(TIMEDATE)&"...."&TIME$(TIMEDATE)
250 LINPUT "IS THIS THE CORRECT TIME AND DATE? (Y/N)",Ans$
260 PRINT TABXY(1,27);" "
270 IF Ans$="Y" OR Ans$="y" THEN GOTO 300
280 LINPUT "ENTER TODAY'S DATE & TIME (08 JUL 1991 09:45:30)",Ans$
290 SET TIMEDATE DATE(Ans$[1,11])+TIME(Ans$[13,20])
300 Main_menu_keys: !
310 ON KEY 1 LABEL "RUN RIG ",10 GOTO Main
320 ON KEY 2 LABEL " ",10 GOSUB Invalid
330 ON KEY 3 LABEL " TEST SETUP ",10 GOTO Setup
340 ON KEY 4 LABEL " ",10 GOSUB Invalid
350 ON KEY 5 LABEL " CREATE DOS ",10 GOTO Create_ascii
360 ON KEY 6 LABEL " ",10 GOSUB Invalid
370 ON KEY 7 LABEL "PRINTOUT",10 GOTO Printout
380 ON KEY 8 LABEL " PLOT ",10 GOTO Plot
390 Menu_display: !
400 PRINT TABXY(2,1)
410 PRINT " HIGH PRESSURE RICH/LEAN BURN MATERIALS TEST BURNER RIG"
420 PRINT
430 PRINT
440 PRINT " OPTION MENU "
450 PRINT
460 PRINT " F1: DATA ACQ. AND CONTROL PGM "
470 PRINT
480 PRINT " F3: EDIT TEST SETUP "
490 PRINT
500 PRINT " F5: CREATE DOS FILE (from BDAT) FOR "
510 PRINT " MATLAB, SIGMAPLOT, & OTHER USES "
520 PRINT
530 PRINT " F7: PRINT CONTENTS OF A DATA FILE "
540 PRINT
550 PRINT " F8: PLOTTING ROUTINE "
560 DISP "CHOOSE OPTION USING FUNCTION KEYS"
570 KEY LABELS ON
580 Echo: !
590 GOTO Echo

```

```

600 Printout: !
610 MASS STORAGE IS "\BLP\X6_BDATS:DOS,C"
620 CLEAR SCREEN
630 CAT;NAMES
640 LINPUT "ENTER FILENAME TO PRINT OR 0=QUIT",File_name$
650 IF File_name$="0" THEN
660 CLEAR SCREEN
670 GOTO Menu_display
680 ELSE
690 GOSUB Read_bdat
700 GOSUB Tabulate
710 GOTO 640
720 END IF
730 Read_bdat: !
740 ASSIGN @Path_1 TO File_name$
750 ENTER @Path_1;File_name$,Data_pts
760 FOR I=3 TO 13
770 ENTER @Path_1;Chan_label$(I),Display_format$(I)
780 NEXT I
790 MAT Array= Stor_buf(1:13,1:Data_pts)
800 ENTER @Path_1;Array(*)
810 ASSIGN @Path_1 TO *
820 Chan_label$(1)="DATA PT. "
830 Chan_label$(2)="TIME (HRS) "
840 Display_format$(1)="DDD"
850 Display_format$(2)="DD.DD"
860 RETURN
870 Create ascii: !
880 CLEAR SCREEN
890 MASS STORAGE IS "\BLP\X6_BDATS:DOS,C"
900 CAT;NAMES
910 LINPUT "ENTER FILENAME OF DATA TO BE CONVERTED TO DOS",File_name$
920 GOSUB Read_bdat
930 Bytes=8*Data_pts+20*Data_pts+10*11*Data_pts
940 Bytes=INT(Bytes/256)+1
950 MASS STORAGE IS "\BLP\PGMS:DOS,C"
960 CREATE ASCII "XXXXXXXX",Bytes
970 ASSIGN @Path_1 TO "XXXXXXXX"
980 OUTPUT @Path_1;Array(*)
990 ASSIGN @Path_1 TO *
1000 LOAD "ASCII2DOS",10
1010 Tabulate: !
1020 PRINTER IS 26
1030 PRINT "DATA RETRIEVED FROM FILE: \BLP\X6_BDATS\",File_name$,":DOS,C"
1040 PRINT "TOTAL DATA PTS: ",Data_pts
1050 PRINT
1060 FOR I=1 TO 13
1070 PRINT USING "2D,2A,16A";I,". ",Chan_label$(I)
1080 NEXT I
1090 PRINT
1100 PRINT " 1 2 3 4 5 6 7 8 9 10 11 1
2 13 "
1110 PRINT
1120 FOR J=1 TO Data_pts
1130 FOR I=1 TO 13
1140 PRINT USING Display_format$(I)&"X,#";Array(I,J)
1150 NEXT I
1160 PRINT
1170 NEXT J
1180 PRINT CHR$(12)

```

```

1190  PRINTER IS 1
1200  RETURN
1210  Plot: !
1220  MASS STORAGE IS "\BLP\X6_BDATS:DOS,C"
1230  PLOTTER IS CRT,"INTERNAL";COLOR MAP
1240  SET PEN 0 INTENSITY 0,0,.45
1250  CLEAR SCREEN
1260  CAT;NAMES
1270  LINPUT "ENTER FILENAME OF DATA TO BE PLOTTED",File_name$
1280  GOSUB Read_bdat
1290  GOSUB X_parm
1300  GOSUB Y_parm
1310  GOSUB Create_plot
1320  ON KEY 1 LABEL " CHANGE X-PARM ",10 GOSUB X_parm
1330  ON KEY 2 LABEL " CHANGE Y-PARM ",10 GOSUB Y_parm
1340  ON KEY 3 LABEL "SCALE XY",10 GOSUB Scale_xy
1350  ON KEY 4 LABEL " PLOT ",10 GOSUB Create_plot
1360  ON KEY 5 LABEL "NEW DATA",10 GOTO Plot
1370  ON KEY 6 LABEL " TITLE ",10 GOSUB Plot_label
1380  ON KEY 7 LABEL " DUMP ",10 GOSUB Dump
1390  ON KEY 8 LABEL " EXIT ",10 GOTO Review
1400  Hold: !
1410  GOTO Hold
1420  Dump: !
1430  DUMP GRAPHICS
1440  PRINTER IS 26
1450  PRINT CHR$(12)
1460  PRINTER IS 1
1470  RETURN
1480  Plot_label: !
1490  LINPUT "ENTER NEW PLOT TITLE (50 CHARACTERS MAX)",Ans$
1500  GOSUB Create_plot
1510  RETURN
1520  X_parm: !
1530  GOSUB Plot_variables
1540  INPUT "ENTER INDEX OF X PARAMETER",X
1550  INPUT "ENTER XMIN",Xmin
1560  INPUT "ENTER XMAX",Xmax
1570  Xdelta=(Xmax-Xmin)/11
1580  DISP "CHOOSE NEXT OPTION USING FUNCTION KEYS"
1590  RETURN
1600  Scale_xy: !
1610  LINPUT "SCALE X OR Y?",Ans$
1620  DISP Blank$
1630  IF Ans$="X" THEN
1640     INPUT "ENTER XMIN",Xmin
1650     INPUT "ENTER XDELTA",Xdelta
1660  END IF
1670  IF Ans$="Y" THEN
1680     INPUT "ENTER YMIN",Ymin
1690     INPUT "ENTER YDELTA",Ydelta
1700  END IF
1710  GOSUB Create_plot
1720  RETURN
1730  Y_parm: !
1740  GOSUB Plot_variables
1750  INPUT "ENTER INDEX OF Y PARAMETER",Y
1760  INPUT "ENTER YMIN",Ymin
1770  INPUT "ENTER YMAX",Ymax
1780  Ydelta=(Ymax-Ymin)/7

```

```

1790 DISP "CHOOSE NEXT OPTION USING FUNCTION KEYS"
1800 RETURN
1810 Plot_variables: !
1820 CLEAR SCREEN
1830 PRINT "CHOOSE PLOT PARAMETERS"
1840 PRINT
1850 FOR I=1 TO 13
1860 PRINT USING "DD,2A,16A";I,". ",Chan_label$(I)
1870 NEXT I
1880 RETURN
1890 Create_plot: !
1900 CLEAR SCREEN
1910 GINIT
1920 CLIP 15,125,20,90
1930 AXES 2,2,15,20,5,5,3
1940 CLIP OFF
1950 CSIZE 2.8
1960 ! SCALE X AXIS
1970 MOVE 10,15
1980 OUTPUT L5$ USING Display_format$(X)&","#";Xmin
1990 LABEL L5$[1,5]
2000 FOR I=1 TO 5
2010 MOVE 10+I*20,15
2020 OUTPUT L5$ USING Display_format$(X)&","#";Xmin+Xdelta*2*I
2030 LABEL L5$[1,5]
2040 NEXT I
2050 ! SCALE Y AXIS
2060 MOVE 6,19
2070 OUTPUT L5$ USING Display_format$(Y)&","#";Ymin
2080 LABEL L5$[1,5]
2090 FOR I=1 TO 7
2100 MOVE 6,I*10+19
2110 OUTPUT L5$ USING Display_format$(Y)&","#";Ymin+Ydelta*I
2120 LABEL L5$[1,5]
2130 NEXT I
2140 ! LABEL X-Y AXIS
2150 MOVE 55,10
2160 CSIZE 3.5
2170 LABEL Chan_label$(X)
2180 MOVE 3,40
2190 LDIR 89.53
2200 LABEL Chan_label$(Y)
2210 ! TITLE & FOOTNOTES
2220 LDIR 0
2230 MOVE 10,97
2240 LABEL USING "8A,3A,50A";File_name$," : ",Ans$[1,50]
2250 MOVE 0,7.5
2260 CSIZE 2.0
2270 OUTPUT L8$ USING "DDDD.DDD,#";Xdelta
2280 LABEL USING "7A,8A";"XDELTA=",L8$
2290 MOVE 20,7.5
2300 OUTPUT L8$ USING "DDDD.DDD,#";Ydelta
2310 LABEL USING "7A,8A";"YDELTA=",L8$
2320 ! DATA POINTS
2330 VIEWPORT 15,125,20,90
2340 WINDOW Xmin,Xmin+Xdelta*11,Ymin,Ymin+Ydelta*7
2350 FOR I=1 TO Data_pts
2360 MOVE Array(X,I),Array(Y,I)
2370 PLOT Array(X,I),Array(Y,I)
2380 NEXT I

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2390 RETURN
2400 Setup: !
2410 MASS STORAGE IS "\BLP\PGMS:DOS,C"
2420 GOSUB Read_common
2430 KEY LABELS OFF
2440 CLEAR SCREEN
2450 PRINT "TEST: ",Test$
2460 PRINT
2470 PRINT USING 2490;"Time on combustor (hrs):",Tcomb
2480 PRINT USING 2490;"Total number of cycles:",Life_cycles
2490 IMAGE 24A,4D.D
2500 PRINT
2510 PRINT "AIR FLOW : "&Parm$(1)
2520 PRINT "FA RATIO : "&Parm$(2)
2530 PRINT "PRESSURE : "&Parm$(3)
2540 PRINT "VELOCITY : "&Parm$(4)
2550 PRINT "GAS TEMP : "&Parm$(5)
2560 PRINT "SRF TEMP : "&Parm$(6)
2570 PRINT
2580 GOSUB Spec_info
2590 INPUT "ENTER INDEX: (1=HRS/CYC 2=TEST DATA 3=SPEC DATA 0=QUIT)",I
2600 SELECT I
2610 CASE 1
2620 INPUT "ENTER NEW COMBUSTOR TIME ",Tcomb
2630 INPUT "ENTER NEW TOTAL # CYCLES ",Life_cycles
2640 GOTO 2440
2650 CASE 2
2660 INPUT "ENTER NEW TEST #",Test$
2670 INPUT "ENTER NEW AIR FLOW TARGET",Parm$(1)
2680 INPUT "ENTER NEW F/A RATIO TARGET",Parm$(2)
2690 INPUT "ENTER NEW PRESSURE TARGET",Parm$(3)
2700 INPUT "ENTER NEW GAS VELOCITY TARGET",Parm$(4)
2710 INPUT "ENTER NEW GAS TEMPERATURE",Parm$(5)
2720 INPUT "ENTER NEW SRF TEMPERATURE",Parm$(6)
2730 GOTO 2440
2740 CASE 3
2750 INPUT "ENTER POSITION TO BE EDITED (1=TOP,2=BOT)",J
2760 LINPUT "ENTER SPECIMEN ID (8 CHARACTERS MAX) OR -1 FOR NO CHANGE",Ans$
2770 IF Ans$="-1" THEN GOTO 2790
2780 Specimen$(J)=Ans$
2790 LINPUT "ENTER DATE INSTALLED (DD MMM YYYY) OR -1 FOR NO CHANGE",Ans$
2800 IF Ans$="-1" THEN GOTO 2820
2810 Install$(J)=Ans$
2820 INPUT "ENTER NUMBER OF CYCLES COMPLETE",Cycles(J)
2830 INPUT "ENTER LEAN TIME (HRS) TO DATE",Tlean(J)
2840 INPUT "ENTER RICH TIME (HRS) TO DATE",Trich(J)
2850 LINPUT "ENTER SPECIMEN NOTES (1 line max) OR -1 FOR NO CHANGE",Ans$
2860 IF Ans$="-1" THEN GOTO 2440
2870 Spec_info$(J)=Ans$
2880 GOTO 2440
2890 CASE 0
2900 GOSUB Write_common
2910 CLEAR SCREEN
2920 GOTO Main_menu_keys
2930 CASE ELSE
2940 GOTO 2440
2950 END SELECT
2960 Spec_info: !
2970 PRINT " .....SPECIMEN HISTORY....."
2980 PRINT

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2990 PRINT USING 3020;"POSITION","SPECIMEN","INSTALLED","CYCLES","LEAN HRS.,""
RICH HRS."
3000 PRINT USING 3030;"TOP",Specimen$(1),Install$(1),Cycles(1),Tlean(1),Trich(
1)
3010 PRINT USING 3030;"BOT",Specimen$(2),Install$(2),Cycles(2),Tlean(2),Trich(
2)
3020 IMAGE 8A,5X,8A,5X,9A,5X,6A,5X,9A,5X,9A
3030 IMAGE 2X,3A,8X,10A,2X,11A,6X,3D,6X,3D.D,10X,3D.D
3040 PRINT
3050 PRINT "TOP: "&Spec_info$(1)
3060 PRINT "BOT: "&Spec_info$(2)
3070 RETURN
3080 Spec_update:! UPDATE ACCUMULATIVE HOT TIMES
3090 Tcomb=Tcomb+Trun/3600
3100 IF Flag(5)=0 THEN
3110 Tlean(1)=Tlean(1)+Tinsert/3600
3120 Tlean(2)=Tlean(2)+Tinsert/3600
3130 ELSE
3140 Trich(1)=Trich(1)+Tinsert/3600
3150 Trich(2)=Trich(2)+Tinsert/3600
3160 END IF
3170 RETURN
3180 Main: !
3190 MASS STORAGE IS "\BLP\PGMS:DOS,C"
3200 KEY LABELS OFF
3210 GOSUB Read_coef
3220 GOSUB Read_label_lim
3230 GOSUB Read_common
3240 GOSUB Read_pid_val
3250 GOSUB Read_suffix
3260 GOSUB Screen_setup
3270 GOSUB Build_string
3280 GOSUB Print_header_1
3290 Init_variables: !
3300 CLEAR SCREEN
3310 Prt_int=-1
3320 Fa_ratio_sp=-.999
3330 Air_flow_sp=-9.99
3340 Sys_psi_sp=-999.
3350 Blank$=""
"
3360 Data_pts=0
3370 Trun=0.
3380 Tinsert=0.
3390 Tretract=0.
3400 Fuel_lbs=0.
3410 MAT Flag= (0.)
3420 MAT Control_ind= (0.)
3430 MAT Volt= (0.)
3440 MAT Dval= (0.)
3450 MAT Stor_buf= (0.)
3460 MAT Cox= (0.)
3470 MAT Stat= (0.)
3480 Soft_keys: !
3490 CLEAR SCREEN
3500 ON KEY 1 LABEL " FORCED SHUTDOWN",10 GOTO Shutdown
3510 ON KEY 5 LABEL " % AIR VALVE",10 GOTO Air_out_sp
3520 ON KEY 3 LABEL "GRAPHIC DISPLAY",10 GOTO Set_display
3530 ON KEY 4 LABEL " MANUAL DATA ",10 GOSUB Man_prt_stor
3540 ON KEY 6 LABEL "PREVIOUSLIGHTOFF",10 GOSUB Ignite_sp

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3550 ON KEY 9 LABEL " " ",10 GOSUB Invalid
3560 ON KEY 7 LABEL " % BACK VALVE",10 GOTO Back_out_sp
3570 ON KEY 8 LABEL " % H2O VALVE",10 GOTO Quench_out_sp
3580 ON KEY 2 LABEL "CONTROL SETUP",10 GOTO Control_setup
3590 ON KEY 10 LABEL " " ",10 GOSUB Invalid
3600 ON KEY 11 LABEL " " ",10 GOSUB Invalid
3610 ON KEY 12 LABEL "INTERVAL",10 GOTO Set_prt_int
3620 ON KEY 13 LABEL " " ",10 GOSUB Invalid
3630 ON KEY 14 LABEL " " ",10 GOSUB Invalid
3640 ON KEY 15 LABEL " " ",10 GOSUB Invalid
3650 ON KEY 16 LABEL " " ",10 GOSUB Invalid
3660 Init_scanner: !
3670 OUTPUT 709;"AF8AL30AC8VT4VN23VA0VS1VD5SDOAE1"
3680 OUTPUT 709;"VT3"
3690 Tstart(3)=TIMEDATE
3700 Ts=TIMEDATE
3710 Scan: !
3720 Tloop=TIMEDATE-Ts
3730 Ts=TIMEDATE
3740 OUTPUT 709;"VS"
3750 SYSTEM PRIORITY 15
3760 FOR I=1 TO 23
3770 ENTER 709 USING "#,K";Volt(I)
3780 NEXT I
3790 SYSTEM PRIORITY 9
3800 OUTPUT 709;"VT3"
3810 GOSUB Convert
3820 GOSUB Calculate
3830 GOSUB Check
3840 GOSUB Control
3850 GOSUB Status
3860 GOSUB Display
3870 OUTPUT 709;"AO3,0,"&VAL$(INT(Dval(24)*2000))
3880 OUTPUT 709;"AO4,1,"&VAL$(INT(Dval(25)/1000*2000))
3890 IF Flag(1)=1 THEN Fuel_lbs=Fuel_lbs+Dval(16)*Tloop/3600
3900 IF Prt_int=-1 THEN GOTO 3950
3910 IF TIMEDATE-Tstart(3)>Prt_int THEN
3920 Tstart(3)=TIMEDATE
3930 GOSUB Man_prt_stor
3940 END IF
3950 GOTO Scan
3960 Convert: !
3970 Vref=Volt(12)
3980 Type_k: !
3990 FOR J=1 TO 13
4000 R(J)=Kref(J)
4010 NEXT J
4020 Volt_comp=R(1)+Vref*(R(2)+Vref*R(3))
4030 FOR I=1 TO 5
4040 Vt=Volt_comp+Volt(I)
4050 GOSUB Temp_calc
4060 NEXT I
4070 FOR I=10 TO 11
4080 Vt=Volt_comp+Volt(I)
4090 GOSUB Temp_calc
4100 NEXT I
4110 Type_r: !
4120 FOR J=1 TO 13
4130 R(J)=Rref(J)
4140 NEXT J

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4150 Volt_comp=R(1)+Vref*(R(2)+Vref*R(3))
4160 FOR I=6 TO 9
4170   Vt=Volt_comp+Volt(I)
4180   Vt=Vt*1.E+6
4190   GOSUB Temp_calc
4200 NEXT I
4210 ! AC051 - Pyrometer : 0-5 volts = 1800-3200 F
4220! Dval(14)=(Volt(14)*14000+1800)
4230 ! AC051 - Pyrometer correlation with TC probe
4240! Dval(14)=Dval(8)*.826+298.2 ! FOR HEXALLOY IN LAVA
4250 Dval(14)=Dval(8)*.864+153.7 ! FOR BF GOODRICH SiC/SiC IN LAVA
4260 ! AC008 - Daniels Airflow : 0-5 volts = 0-2 pps
4270 Dval(15)=Volt(15)*.40
4280 ! FC227 - Fuel Flow (coxmeter) : 0-1200 Hz = 0-2.5 GPM
4290 Dval(16)=Volt(16)*400/2.5 ! (DC to Hz, 800 Hz fs, cal=50%)
4300 Dval(16)=Dval(16)*.0020261-.0001078 ! (Hz to GPM)
4310 Dval(16)=Dval(16)*60*6.74 ! (GPM to #/HR)
4320 FOR I=1 TO 4
4330   Cox(I)=Cox(I+1)
4340 NEXT I
4350 Cox(5)=Dval(16)
4360 Dval(16)=(Cox(1)+Cox(2)+Cox(3)+Cox(4)+Cox(5))/5
4370 ! WS075 - H2O Flow
4380 Dval(17)=Volt(17)*400/2.5 ! (DC TO Hz, 800 Hz fs, CAL=50%)
4390 Dval(17)=Dval(17)*.02565-.023895 ! (Hz TO GPM)
4400 ! FC219 - Fuel Flow
4410 Dval(18)=Volt(18)*125.-125.
4420 ! AC040 - Nitrogen Press
4430 Dval(19)=Volt(19)*1000./5.
4440 ! FC223 - Fuel Press
4450 Dval(20)=(-.026+20.0*Volt(20))*1000./100.
4460 ! AC090 - Preheat Press
4470 Dval(21)=Volt(21)*1000./5.0
4480 ! AC050 - Viewport Press
4490 Dval(22)=Volt(22)*836.0/4.186
4500 ! AC091 - Test Sect Press
4510 Dval(23)=Volt(23)*831.2/4.1643
4520 RETURN
4530 Temp_calc: !
4540 Temp=R(8)+Vt*(R(9)+Vt*(R(10)+Vt*(R(11)+Vt*(R(12)+Vt*(R(13))))))
4550 Temp=R(4)+Vt*(R(5)+Vt*(R(6)+Vt*(R(7)+Vt*Temp)))
4560 Dval(I)=Temp*1.8+32
4570 RETURN
4580 Check: !
4590 FOR I=1 TO 33
4600 IF Dval(I)<Low_lim(I) THEN Dval(I)=Low_lim(I)
4610 IF Dval(I)>Hi_lim(I) THEN
4620 SELECT Display_format$(I)
4630 CASE "DDD.D"
4640 Dval(I)=999.9
4650 CASE "DD.DD"
4660 Dval(I)=99.99
4670 CASE ELSE
4680 Dval(I)=9999.
4690 END SELECT
4700 ELSE
4710 GOTO 4730
4720 END IF
4730 NEXT I
4740 RETURN

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4750 Calculate: !
4760 IF Dval(15)=0. THEN
4770     Dval(24)=0.
4780 ELSE
4790     Dval(24)=Dval(16)/(Dval(15)*3600)
4800 END IF
4810 Dval(25)=1.85*Dval(15)*(Dval(8)+460)/(Dval(23)+14.7)
4820 Dval(26)=Fuel_sp
4830 Dval(27)=Air_sp
4840 Dval(28)=Quench_sp
4850 Dval(29)=Back_sp
4860 Dval(30)=Fa_ratio_sp
4870 Dval(31)=Air_flow_sp
4880 Dval(32)=Sys_psi_sp
4890 Dval(33)=Dval(24)/.067
4900 Status: !
4910 IF Dval(8)>800 OR Dval(6)>800 THEN
4920     SELECT Flag(1)
4930     CASE 0
4940         GOSUB Light_off
4950     CASE 1
4960         GOSUB Run_time
4970     CASE ELSE
4980         GOTO 5080
4990     END SELECT
5000 ELSE
5010     IF Flag(1)=1 THEN
5020         PRINTER IS 701
5030         PRINT USING 5040;TIME$(TIMEDATE),"FLAMEOUT DETECTED FROM COMB TEMP!"
5040         IMAGE 8A,2X,33A
5050         GOSUB Cooldown
5060         IF Flag(4)=1 THEN GOSUB Retract
5070     END IF
5080 END IF
5090 RETURN
5100 Run_time: !
5110 Trun=TIMEDATE-Tstart(1)
5120 IF Volt(13)>12. THEN
5130     SELECT Flag(4)
5140     CASE 0
5150         GOSUB Insert
5160     CASE 1
5170         Tinsert=Trertract+(TIMEDATE-Tstart(2))
5180     END SELECT
5190 ELSE
5200     IF Flag(4)=1 THEN GOSUB Retract
5210 END IF
5220 RETURN
5230 Display: !
5240 IF Flag(6)=0 THEN
5250     GOSUB Modify_string
5260     IF Flag(2)=0 THEN
5270         CLEAR SCREEN
5280         PRINT "                HIGH PRESSURE RICH/LEAN BURN MATERIALS TEST BURNER
RIG                "
5290         PRINT
5300         PRINT USING "30X,11A";DATE$(TIMEDATE)
5310         PRINT
5320         FOR I=1 TO 15
5330             PRINT TABXY(7,I+7);Disp$(I)[1,32]

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5340     PRINT TABXY(43,I+7);Disp$(I)[37,68]
5350     NEXT I
5360     Flag(2)=1
5370     KEY LABELS ON
5380     ELSE
5390     FOR I=1 TO 15
5400     PRINT TABXY(29,I+7);Disp$(I)[23,27]
5410     PRINT TABXY(65,I+7);Disp$(I)[59,63]
5420     NEXT I
5430     END IF
5440     ELSE
5450     GOSUB Illustrate
5460     END IF
5470     IF Flag(1)=1 THEN
5480     DISP USING "9A,DD.D";"RUN TIME:",Trun/3600
5490     END IF
5500     RETURN
5510 Illustrate: !
5520     IF Flag(3)=0 THEN
5530     CLEAR SCREEN
5540     PEN 1
5550     LINE TYPE 1
5560     ! MAIN OUTLINE
5570     MOVE 5,65
5580     RESTORE 5660
5590     J=6
5600     GOSUB Read_draw_xy
5610     MOVE 50,75
5620     J=17
5630     GOSUB Read_draw_xy
5640     MOVE 75,70
5650     RECTANGLE 11,10
5660     DATA 10,65,15,62.5,25,62.5,35,65,45,65,45,75
5670     DATA 50,65,77.5,65,77.5,70,82.5,70,82.5,65,120,65,125,60
5680     DATA 140,60,140,45,125,45,120,40,35,40,25,42.5,15,42.5,10,40,5,40,5,65
5690     ! BURNER CAN
5700     LINE TYPE 5
5710     MOVE 55,65
5720     J=3
5730     GOSUB Read_draw_xy
5740     MOVE 25,50
5750     J=3
5760     GOSUB Read_draw_xy
5770     DATA 55,60,25,60,25,55,25,45,55,45,55,40
5780     ! FUEL NOZZLE
5790     MOVE 17.5,42.5
5800     J=6
5810     GOSUB Read_draw_xy
5820     DATA 17.5,45,22.5,54,27.5,54,27.5,51,22.5,51,22.5,42.5
5830     ! H2O NOZZLE
5840     MOVE 105,40
5850     J=6
5860     GOSUB Read_draw_xy
5870     DATA 105,45,110,54,115,54,115,51,110,51,110,40
5880     ! TURBULATOR
5890     J=2
5900     GOSUB Move_draw_xy
5910     DATA 100,65,100,55,100,50,100,40
5920     ! SPECIMEN
5930     AREA PEN 2

```

```

5940     MOVE 78,50
5950     RECTANGLE 5,5,FILL
5960     ! AIR SYSTEM
5970     PEN 5
5980     MOVE 37.5,80
5990     DRAW 47.5,80
6000     DRAW 47.5,62.5
6010     ! H2O SYSTEM
6020     J=4
6030     GOSUB Move_draw_xy
6040     DATA 107.5,42.5,107.5,25,117.5,51,125,49,117.5,52.5,127.5,52.5,117.5,54
,125,56
6050     ! FUEL SYSTEM
6060     PEN 2
6070     J=4
6080     GOSUB Move_draw_xy
6090     DATA 20,45,20,25,30,51,37.5,49,30,52.5,40,52.5,30,54,37.5,56
6100     ! PYROMETER
6110     MOVE 87.5,84
6120     DRAW 80.5,84
6130     DRAW 80.5,57.5
6140     GOSUB Template
6150     GOSUB Overlay_num
6160     Flag(3)=1
6170     KEY LABELS ON
6180     ELSE
6190     GOSUB Overlay_num
6200     END IF
6210     RETURN
6220 Read_draw_xy: !
6230     FOR I=1 TO J
6240         READ X,Y
6250         DRAW X,Y
6260     NEXT I
6270     RETURN
6280 Move_draw_xy: !
6290     FOR I=1 TO J
6300         READ X,Y
6310         MOVE X,Y
6320         READ X,Y
6330         DRAW X,Y
6340     NEXT I
6350     RETURN
6360 Template: !
6370     PRINT "                HIGH PRESSURE RICH/LEAN BURN MATERIALS TEST BURNER RIG"
6380     PRINT
6390     PRINT USING "30X,11A";DATE$(TIMEDATE)
6400     RESTORE 6450
6410     FOR I=1 TO 20
6420         READ X,Y,Template$
6430         PRINT TABXY(X,Y);Template$
6440     NEXT I
6450     DATA 55,6,"PYRO:           F",52,17,"           F",10,7," AIR SYSTEM"
6460     DATA 10,8,"           LB/SEC",10,9,"           F",5,15,"           PSIG"
6470     DATA 5,16,"           F",25,16,"F/A:",25,18,"Phi:",36,15,"           F"
6480     DATA 36,17,"           F",65,14,"           F",47,10,"PSIG",56,15,"FT/S"
6490     DATA 56,20,"PSIG",15,24,"FUEL SYSTEM",15,25,"           LB/HR"
6500     DATA 67,24,"H2O SYSTEM",67,25,"           GPM",36,19,"           F"
6510     RETURN
6520 Overlay_num: !

```

```

6530  RESTORE 6590
6540  FOR I=1 TO 17
6550    READ J,X,Y
6560    OUTPUT L5$ USING Display_format$(J)&" ,#" ;Dval(J)
6570    PRINT TABXY(X,Y);L5$
6580  NEXT I
6590  DATA 15,10,8,3,10,9,18,15,25,6,36,15,7,36,17,23,55,19,33,30,18
6600  DATA 25,55,14,1,65,14,21,5,15,24,30,16,14,61,6,17,68,25,22,46,9
6610  DATA 8,52,17,5,5,16,9,36,19
6620  RETURN
6630 Control:  !
6640 Fuel:  !
6650  IF Control_ind(2)=0 THEN GOTO Air
6660  IF Dval(24)=0. OR Dval(24)=9.999 THEN
6670    PRINTER IS 701
6680    PRINT USING "8A,2X,56A";TIME$(TIMEDATE), "F/A RATIO DATA FOR CLOSED LOOP
CONTROL IS OUT OF LIMITS!"
6690    GOSUB Cooldown
6700    GOSUB Print_data
6710    GOTO Restart
6720  ELSE
6730    J=24
6740    GOSUB Control_loop
6750  END IF
6760  Setpoint=Fuel_sp
6770  J=26
6780  GOSUB Confirm_sp
6790  Fuel_sp=Setpoint
6800  PRINTER IS 1
6810 Air:  !
6820  IF Control_ind(1)=0 THEN GOTO Back
6830  IF Dval(15)=0. OR Dval(15)=99.99 THEN
6840    PRINTER IS 701
6850    PRINT USING "8A,2X,55A";TIME$(TIMEDATE), "AIR FLOW DATA FOR CLOSED LOOP
CONTROL IS OUT OF LIMITS!"
6860    GOSUB Print_data
6870    GOSUB Cooldown
6880    GOTO Restart
6890  ELSE
6900    J=15
6910    GOSUB Control_loop
6920  END IF
6930  Setpoint=Air_sp
6940  J=27
6950  GOSUB Confirm_sp
6960  Air_sp=Setpoint
6970  PRINTER IS 1
6980 Back:  !
6990  IF Control_ind(3)=0 THEN GOTO 7150
7000  IF Dval(23)=0. OR Dval(23)=9999. THEN
7010    PRINTER IS 701
7020    PRINT USING "8A,2X,55A";"SYS. PSI DATA FOR CLOSED LOOP CONTROL IS OUT O
F LIMITS!"
7030    GOSUB Cooldown
7040    GOSUB Print_data
7050    GOTO Restart
7060  ELSE
7070    J=23
7080    GOSUB Control_loop
7090  END IF

```

```

7100 Setpoint=Back_sp
7110 J=29
7120 GOSUB Confirm_sp
7130 Back_sp=Setpoint
7140 PRINTER IS 1
7150 GOSUB Update_valves
7160 RETURN
7170 Control_loop: !
7180 SELECT J
7190 CASE 24 ! F/A RATIO
7200 Err=Dval(30)-Dval(24)
7210 Pid=1
7220 Sp_fraction=Fuel_sp/100
7230 GOSUB Pid
7240 Fuel_sp=Out*100
7250 CASE 15 ! AIR MASS FLOW
7260 Err=Dval(31)-Dval(15)
7270 Pid=2
7280 Sp_fraction=Air_sp/100
7290 GOSUB Pid
7300 Air_sp=Out*100
7310 CASE 23 ! SYS. PSI - REVERSED CONTROL
7320 Err=Dval(32)-Dval(23)
7330 Pid=3
7340 Sp_fraction=Back_sp/100
7350 GOSUB Pid
7360 Out=Sp_fraction+(Sp_fraction-Out)
7370 Back_sp=Out*100
7380 END SELECT
7390 RETURN
7400 Pid: !
7410 IF Err<=-P(3,Pid) THEN
7420 Prop=(Err+P(3,Pid))*P(4,Pid)-P(3,Pid)*P(2,Pid)
7430 ELSE
7440 IF Err<P(3,Pid) THEN
7450 Prop=Err*P(2,Pid)
7460 ELSE
7470 Prop=(Err-P(3,Pid))*P(5,Pid)+P(3,Pid)*P(2,Pid)
7480 END IF
7490 END IF
7500 Amt(Pid)=Sp_fraction+Prop*(Tloop)*P(7,Pid)
7510 IF Amt(Pid)>P(1,Pid) THEN Amt(Pid)=P(1,Pid)
7520 IF Amt(Pid)<P(1,Pid) THEN Amt(Pid)=-P(1,Pid)
7530 Out=Prop+Amt(Pid)+((Prop-P_prop(Pid))/(Tloop))*P(6,Pid)
7540 IF Out>1 THEN Out=1.
7550 P_prop(Pid)=Prop
7560 RETURN
7570 Pid_parm: !
7580 CLEAR SCREEN
7590 PRINT
7600 PRINT
7610 PRINT "CURRENT CLOSED LOOP PARAMETERS"
7620 PRINT
7630 PRINT "1. F/A RATIO"
7640 PRINT "2. MASS AIR FLOW"
7650 PRINT "3. SYSTEM PRESSURE"
7660 PRINT "4. COMBUSTOR TEMP"
7670 PRINT "5. QUENCH TEMP"
7680 INPUT "ENTER INDEX OF PARAMETER (0 TO QUIT)",Index
7690 IF Index=0 THEN GOTO Restart

```

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7700  GOSUB Pid_val_input
7710  GOTO Restart
7720  Pid_val_input:  !
7730  CLEAR SCREEN
7740  IF Index=1 THEN PRINT "FUEL / AIR RATIO"
7750  IF Index=2 THEN PRINT "MASS AIR FLOW"
7760  IF Index=3 THEN PRINT "SYSTEM PRESSURE"
7770  IF Index=4 THEN PRINT "COMB TEMPERATURE"
7780  IF Index=5 THEN PRINT "QUENCH TEMPERATURE"
7790  PRINT "CONTROL LOOP PARAMETERS"
7800  PRINT
7810  PRINT "1) RESET LIMIT=";P(1,Index)
7820  PRINT "2) MID-BAND GAIN=";P(2,Index)
7830  PRINT "3) 1/2 MID-BAND WIDTH=";P(3,Index)
7840  PRINT "4) LOW BAND GAIN=";P(4,Index)
7850  PRINT "5) HI BAND GAIN=";P(5,Index)
7860  PRINT "6) RATE CONSTANT=";P(6,Index)
7870  PRINT "7) RESET CONSTANT=";P(7,Index)
7880  PRINT
7890  INPUT "ENTER # TO EDIT, 0 TO QUIT, OR -1 TO RECALL LAST STORED SET",J
7900  SELECT J
7910  CASE -1
7920      GOSUB Read_pid_val
7930      GOTO Pid_val_input
7940  CASE 0
7950      GOSUB Write_pid_val
7960  CASE ELSE
7970      INPUT "ENTER NEW VALUE",P(J,Index)
7980      GOTO Pid_val_input
7990  END SELECT
8000  RETURN
8010  Print_header_1:  !
8020  PRINTER IS 701
8030  PRINT CHR$(12)
8040  PRINT DATE$(TIMEDATE), "          PRINTOUT OF TEST DATA"
8050  PRINT
8060  PRINT
8070  PRINT "* THESE ARE THE PARAMETERS TO BE PRINTED OUT"
8080  FOR I=1 TO 11
8090      PRINT USING 8100;I,".",Sensor$(Print_order(I))," = ",Chan_label$(Print_
order(I))
8100      IMAGE 2D,A,2X,5A,3A,16A
8110  NEXT I
8120  PRINT
8130  PRINT USING "#,8X"
8140  FOR I=1 TO 11
8150      PRINT USING "#,XXX,DD,X";I
8160  NEXT I
8170  PRINT
8180  PRINT USING "#,10A";" TIME      "
8190  FOR I=1 TO 11
8200      PRINT USING "#,5A,X";Sensor$(Print_order(I))
8210  NEXT I
8220  PRINT
8230  PRINT USING "#,10X"
8240  FOR I=1 TO 11
8250      PRINT USING "#,4A,2X";Unit$(Print_order(I))
8260  NEXT I
8270  PRINT
8280  PRINTER IS 1

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8290 RETURN
8300 Man_prt_stor: !
8310 GOSUB Print_data
8320 GOSUB Store_data
8330 RETURN
8340 Print_data: !
8350 PRINTER IS 701
8360 GOSUB Check
8370 PRINT USING "8A,2X,#";TIME$(TIMEDATE)
8380 FOR I=1 TO 11
8390 PRINT USING Display_format$(Print_order(I))&"X,#";Dval(Print_order(I))
8400 NEXT I
8410 PRINT
8420 PRINTER IS 1
8430 RETURN
8440 Store_data: ! !!! Store data temporarily in buffer
8450 IF Data_pts=500 THEN
8460 GOSUB Write_data
8470 END IF
8480 Data_pts=Data_pts+1
8490 Stor_buf(1,Data_pts)=Data_pts
8500 Stor_buf(2,Data_pts)=Trun/3600
8510 FOR I=1 TO 11
8520 Stor_buf(2+I,Data_pts)=Dval(Print_order(I))
8530 NEXT I
8540 RETURN
8550 Cooldown: !
8560 Flag(6)=0
8570 MAT Control_ind= (0.)
8580 MAT Flag= (0.)
8590 Flag(1)=2
8600 Prt_int=-1
8610 Fa_ratio_sp=-.999
8620 Fuel_sp=0.
8630 ON KEY 6 LABEL "RESTART ",10 GOTO Rig_restart
8640 Sys_psi_sp=-999.
8650 Back_sp=80.
8660 ON KEY 7 LABEL " % BACK VALVE",10 GOTO Back_out_sp
8670 Air_flow_sp=-9.99
8680 Air_sp=60.
8690 ON KEY 5 LABEL " % AIR VALVE",10 GOTO Air_out_sp
8700 Quench_sp=0.
8710 GOSUB Update_valves
8720 ON KEY 1 LABEL " STOP SCAN",10 GOTO Pgm_stop
8730 PRINT USING 8800;"SHUTDOWN SEQUENCE IS BEING INITIATED."
8740 PRINT USING 8790;"NEW AIR VALVE SETPOINT IS ",Air_sp,"%."
8750 PRINT USING 8790;"NEW FUEL VALVE SETPOINT IS ",Fuel_sp,"%."
8760 PRINT USING 8790;"NEW BACK VALVE SETPOINT IS ",Back_sp,"%."
8770 PRINT USING 8790;"NEW H2O VALVE SETPOINT IS ",Quench_sp,"%."
8780 PRINT USING 8800;"AUTO PRINT/STORE INTERVAL TURNED OFF."
8790 IMAGE 10X,27A,3D.D,2A
8800 IMAGE 10X,37A
8810 PRINTER IS 1
8820 RETURN
8830 Ignite_sp: !
8840 Fuel_sp=Ignite_sp(1)
8850 ON KEY 6 LABEL " % FUEL VALVE",10 GOTO Fuel_out_sp
8860 Air_sp=Ignite_sp(2)
8870 Back_sp=Ignite_sp(3)
8880 Quench_sp=Ignite_sp(4)

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```

8890 GOSUB Update_valves
8900 PRINTER IS 701
8910 PRINT USING 8920;TIME$(TIMEDATE),"PREVIOUS LIGHT OFF CONDITIONS HAVE BEEN
RECALLED."
8920 IMAGE 8A,2X,49A
8930 PRINT USING 8970;"NEW FUEL VALVE SETPOINT IS ",Fuel_sp,"%."
8940 PRINT USING 8970;"NEW AIR VALVE SETPOINT IS ",Air_sp,"%."
8950 PRINT USING 8970;"NEW BACK VALVE SETPOINT IS ",Back_sp,"%."
8960 PRINT USING 8970;"NEW H2O VALVE SETPOINT IS ",Quench_sp,"%."
8970 IMAGE 10X,27A,3D.D,2A
8980 PRINTER IS 1
8990 RETURN
9000 Light_off: !
9010 Flag(1)=1
9020 Tstart(1)=TIMEDATE
9030 IF Dval(24)<.070 THEN Flag(5)=0
9040 IF Dval(24)>.070 THEN Flag(5)=1
9050 Ignite_sp(1)=Fuel_sp
9060 Ignite_sp(2)=Air_sp
9070 Ignite_sp(3)=Back_sp
9080 Ignite_sp(4)=Quench_sp
9090 Quench_sp=60.
9100 GOSUB Update_valves
9110 Life_cycles=Life_cycles+1
9120 FOR I=1 TO 2
9130 IF Specimen$(I)="EMPTY" THEN GOTO 9150
9140 Cycles(I)=Cycles(I)+1
9150 NEXT I
9160 PRINTER IS 701
9170 PRINT USING "8A,2X,43A";TIME$(TIMEDATE),"RIG HAS BEEN IGNITED!"
9180 PRINT USING 9190;"NEW H2O VALVE SETPOINT IS ",Quench_sp,"%."
9190 IMAGE 10X,27A,3D.D,2A
9200 PRINTER IS 1
9210 RETURN
9220 Quench_out_sp: !
9230 PRINT TABXY(1,27);"PRESENT %OUTPUT OF H2O VALVE IS ";DROUND(Quench_sp,4);
"%."
9240 INPUT "ENTER NEW %OUTPUT OF H2O VALVE",Quench_sp
9250 Setpoint=Quench_sp
9260 J=28
9270 GOSUB Confirm_sp
9280 Quench_sp=Setpoint
9290 Quench_control$="OPEN"
9300 GOSUB Update_valves
9310 PRINT USING 9320;TIME$(TIMEDATE),"NEW H2O VALVE SETPOINT IS ",Quench_sp,"
%."
9320 IMAGE 8A,2X,26A,3D.D,2A
9330 PRINTER IS 1
9340 GOTO Restart
9350 Air_out_sp: !
9360 PRINT TABXY(1,27);"PRESENT %OUTPUT OF AIR VALVE IS ";DROUND(Air_sp,4);"%."
"
9370 INPUT "ENTER NEW %OUTPUT OF AIR VALVE",Air_sp
9380 Setpoint=Air_sp
9390 J=27
9400 GOSUB Confirm_sp
9410 Air_sp=Setpoint
9420 Control_ind(1)=0
9430 Air_flow_sp=-9.99
9440 GOSUB Update_valves

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9450 PRINT USING 9460;TIME$(TIMEDATE), "NEW AIR VALVE SETPOINT IS ",Air_sp,"%."
9460 IMAGE 8A,2X,26A,3D.D,2A
9470 PRINTER IS 1
9480 GOTO Restart
9490 Air_flow_sp: !
9500 PRINT TABXY(1,27);"PRESENT AIR FLOW SETPOINT IS ";Air_flow_sp;" LBM/SEC."
9510 INPUT "ENTER NEW AIR FLOW SETPOINT VALUE",Air_flow_sp
9520 Setpoint=Air_flow_sp
9530 J=31
9540 GOSUB Confirm_sp
9550 Air_flow_sp=Setpoint
9560 Control_ind(1)=1
9570 PRINT USING 9580;TIME$(TIMEDATE), "NEW AIR FLOW SETPOINT IS ",Air_flow_sp,
" LBM/HR."
9580 IMAGE 8A,2X,25A,2D.2D,8A
9590 PRINTER IS 1
9600 GOTO Restart
9610 Back_out_sp: !
9620 PRINT TABXY(1,27);"PRESENT %OUTPUT OF BACK PSI VALVE IS ";DROUND(Back_sp,
4);"%."
9630 INPUT "ENTER NEW %OUTPUT OF BACK PSI VALVE",Back_sp
9640 Setpoint=Back_sp
9650 J=29
9660 GOSUB Confirm_sp
9670 Back_sp=Setpoint
9680 Control_ind(3)=0
9690 Sys_psi_sp=-999.
9700 GOSUB Update_valves
9710 PRINT USING 9720;TIME$(TIMEDATE), "NEW BACK PSI VALVE SETPOINT IS ",Back_s
p,"%."
9720 IMAGE 8A,2X,31A,3D.D,2A
9730 PRINTER IS 1
9740 GOTO Restart
9750 Sys_psi_sp: !
9760 PRINT TABXY(1,27);"PRESENT SYS. PSI SETPOINT IS ";Sys_psi_sp;" ."
9770 INPUT "ENTER NEW SYS. PSI SETPOINT VALUE",Sys_psi_sp
9780 Setpoint=Sys_psi_sp
9790 J=32
9800 GOSUB Confirm_sp
9810 Sys_psi_sp=Setpoint
9820 Control_ind(3)=1
9830 PRINT USING 9840;TIME$(TIMEDATE), "NEW SYS. PSI SETPOINT IS ",Sys_psi_sp,"
."
9840 IMAGE 8A,2X,25A,DDD.D,2A
9850 PRINTER IS 1
9860 GOTO Restart
9870 Fuel_out_sp: !
9880 PRINT TABXY(1,27);"PRESENT %OUTPUT OF FUEL VALVE IS ";DROUND(Fuel_sp,4);"
%."
9890 INPUT "ENTER NEW %OUTPUT OF FUEL VALVE",Fuel_sp
9900 Setpoint=Fuel_sp
9910 J=26
9920 GOSUB Confirm_sp
9930 Fuel_sp=Setpoint
9940 Control_ind(2)=0
9950 Fa_ratio_sp=-.999
9960 GOSUB Update_valves
9970 PRINT USING 9980;TIME$(TIMEDATE), "NEW FUEL VALVE SETPOINT IS ",Fuel_sp,"%
."
9980 IMAGE 8A,2X,27A,3D.D,2A

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9990  PRINTER IS 1
10000 GOTO Restart
10010 Fa_ratio_sp: !
10020 PRINT TABXY(1,27);"PRESENT F/A RATIO SETPOINT IS ";Fa_ratio_sp;" ."
10030 INPUT "ENTER NEW F/A RATIO SETPOINT VALUE",Fa_ratio_sp
10040 Setpoint=Fa_ratio_sp
10050 J=27
10060 GOSUB Confirm_sp
10070 Fa_ratio_sp=Setpoint
10080 Control_ind(2)=1
10090 PRINT USING 10100;TIMES$(TIMEDATE),"NEW F/A RATIO SETPOINT IS ",Fa_ratio_s
p, "."
10100 IMAGE 8A,2X,26A,.DDD,A
10110 PRINTER IS 1
10120 GOTO Restart
10130 Update_valves: !
10140 Airout=INT((100-Air_sp)*100)
10150 OUTPUT 709;"A02,1,"&VAL$(Airout)
10160 Fuelout=INT(Fuel_sp*100)
10170 OUTPUT 709;"A03,1,"&VAL$(Fuelout)
10180 Backout=INT(Back_sp*100)
10190 OUTPUT 709;"A02,0,"&VAL$(Backout)
10200 Quenchout=INT(Quench_sp*100)
10210 OUTPUT 709;"A04,0,"&VAL$(Quenchout)
10220 RETURN
10230 Confirm_sp: !
10240 IF Setpoint>Hi_lim(J) THEN Setpoint=Hi_lim(J)
10250 IF Setpoint<Low_lim(J) THEN Setpoint=Low_lim(J)
10260 PRINT TABXY(1,27);Blank$
10270 PRINTER IS 701
10280 RETURN
10290 Read_pid_val: !
10300 ASSIGN @Pid TO "X6PID_5"
10310 ENTER @Pid;P(*)
10320 ASSIGN @Pid TO *
10330 RETURN
10340 Write_pid_val: !
10350 ASSIGN @Pid TO "X6PID_5"
10360 OUTPUT @Pid;P(*)
10370 ASSIGN @Pid TO *
10380 RETURN
10390 Read_common: !
10400 ASSIGN @Path_1 TO "X6_LOG"
10410 ENTER @Path_1;Tcomb,Life_cycles
10420 ENTER @Path_1;Test$,Parm$(*)
10430 ENTER @Path_1;Specimen$(*),Install$(*),Cycles$(*),Tlean$(*),Trich(*)
10440 ENTER @Path_1;Ignite_sp$(*),Spec_info$(*)
10450 ASSIGN @Path_1 TO *
10460 RETURN
10470 Write_common: !
10480 ASSIGN @Path_1 TO "\BLP\PGMS\X6_LOG:DOS,C"
10490 OUTPUT @Path_1;Tcomb,Life_cycles
10500 OUTPUT @Path_1;Test$,Parm$(*)
10510 OUTPUT @Path_1;Specimen$(*),Install$(*),Cycles$(*),Tlean$(*),Trich(*)
10520 OUTPUT @Path_1;Ignite_sp$(*),Spec_info$(*)
10530 ASSIGN @Path_1 TO *
10540 RETURN
10550 Write_data: !
10560 MASS_STORAGE IS "\BLP\X6_BDATS:DOS,C"
10570 Ans$=DATE$(TIMEDATE)

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10580 Bytes=16+30*11+(11+2)*Data_pts*8
10590 Bytes=INT(Bytes/256+1)
10600 File_name$=Ans$(10,11)&Ans$(4,6)&Ans$(1,2)&Suffix$(J)[1,1]
10610 ON ERROR GOTO Off_error
10620 CREATE BDAT File_name$,Bytes
10630 ASSIGN @Path_1 TO File_name$
10640 OUTPUT @Path_1;File_name$,Data_pts
10650 FOR I=1 TO 11
10660     OUTPUT @Path_1;Chan_label$(Print_order(I))
10670     OUTPUT @Path_1;Display_format$(Print_order(I))
10680 NEXT I
10690 MAT Array= Stor_buf(1:13,1:Data_pts)
10700 OUTPUT @Path_1;Array(*)
10710 ASSIGN @Path_1 TO *
10720 MASS STORAGE IS "\BLP\PGMS:DOS,C"
10730 MAT Stor_buf= (0.)
10740 RETURN
10750 Off_error: !
10760 OFF ERROR
10770 IF ERRN=54 THEN
10780     J=J+1
10790     GOTO 10600
10800 ELSE
10810     DISP ERRM$
10820     PAUSE
10830 END IF
10840 Set_display: !
10850 IF Flag(6)=0 THEN
10860     Flag(6)=1
10870     Flag(2)=0
10880     ON KEY 3 LABEL "TABULAR DISPLAY",10 GOTO Set_display
10890 ELSE
10900     Flag(6)=0
10910     Flag(3)=0
10920     ON KEY 3 LABEL "GRAPHIC DISPLAY",10 GOTO Set_display
10930 END IF
10940 GOTO Restart
10950 Set_prt_int: !
10960 INPUT "ENTER NEW INTERVAL IN SECONDS (-1=OFF)",Prt_int
10970 Tstart(3)=TIMEDATE
10980 PRINTER IS 701
10990 IF Prt_int=-1 THEN
11000     PRINT USING 11010;TIME$(TIMEDATE),"AUTO PRINT/STORE INTERVAL HAS BEEN T
URNED OFF!"
11010     IMAGE 8A,2X,46A
11020 ELSE
11030     PRINT USING 11040;TIME$(TIMEDATE),"AUTO PRINT/STORE INTERVAL SET AT ",P
rt_int/60.," MINUTES."
11040     IMAGE 8A,2X,33A,2D.D,9A
11050     GOSUB Man_prt_stor
11060 END IF
11070 PRINTER IS 1
11080 GOTO Restart
11090 Insert: !
11100 Flag(4)=1
11110 Tstart(2)=TIMEDATE
11120 PRINTER IS 701
11130 PRINT USING 11140;TIME$(TIMEDATE),"SPECIMEN HAS BEEN INSERTED !"
11140 IMAGE 8A,2X,28A
11150 PRINTER IS 1

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11160 RETURN
11170 Retract: !
11180 Flag(4)=0
11190 Tretract=Tinsert
11200 PRINTER IS 701
11210 PRINT USING 11140;TIME$(TIMEDATE),"SPECIMEN HAS BEEN RETRACTED!"
11220 PRINTER IS 1
11230 RETURN
11240 Statistics: !
11250 FOR J=3 TO 11
11260   Stat(2,J-2)=Array(J,1)
11270   Stat(3,J-2)=Array(J,1)
11280   FOR I=1 TO Data_pts
11290     Stat(1,J-2)=Stat(1,J-2)+Array(J,I)
11300     IF Array(J,I)<Stat(2,J-2) THEN Stat(2,J-2)=Array(J,I)
11310     IF Array(J,I)>Stat(3,J-2) THEN Stat(3,J-2)=Array(J,I)
11320   NEXT I
11330   Stat(1,J-2)=Stat(1,J-2)/Data_pts
11340   FOR I=1 TO Data_pts
11350     Stat(4,J-2)=Stat(4,J-2)+(Array(J,I)-Stat(1,J-2))^2
11360   NEXT I
11370   Stat(4,J-2)=(Stat(4,J-2)/(Data_pts-1))^.5
11380 NEXT J
11390 RETURN
11400 Summary: !
11410 PRINTER IS 26
11420 PRINT USING "13A,11A";"RUN SUMMARY: ",DATE$(TIMEDATE)
11430 PRINT
11440 PRINT "          .....FACILITY NOTES....."
11450 PRINT
11460 PRINT USING "25A,DDD.D";"TOTAL # COMBUSTOR HOURS: ",Tcomb
11470 PRINT USING "25A,DDD.D";"TOTAL # COMBUSTOR CYCS.: ",Life_cycles
11480 PRINT
11490 PRINT USING "19A,DD.D";"TODAY'S RUN (HRS): ",Trun/3600
11500 PRINT USING "19A,DD.D";"INSERT TIME (HRS): ",Tinsert/3600
11510 PRINT USING "19A,DDD."; "FUEL BURNED (GAL): ",Fuel_lbs/6.74
11520 PRINT USING "19A,8A";"STORAGE FILENAME: ",File_name$
11530 PRINT USING "19A,DDD."; "      # DATA PTS: ",Data_pts
11540 PRINT
11550 PRINT "          .....TEST STATISTICS....."
11560 PRINT
11570 PRINT USING 11580;"PARAMETER","TARGET","AVERAGE","MINIMUM","MAXIMUM","STD
.DEV."
11580 IMAGE 9A,5X,6A,10X,7A,7X,7A,7X,7A,6X,8A
11590 PRINT
11600 RESTORE 11650
11610 FOR I=1 TO 9
11620   READ Ans$,Image$
11630   PRINT USING Image$;Ans$,Parm$(I),Stat(1,I),Stat(2,I),Stat(3,I),Stat(4,I
)
11640 NEXT I
11650 DATA "AIR FLOW","8A,6X,10A,7X,DD.DD,9X,DD.DD,9X,DD.DD,9X,DD.DD"
11660 DATA "FA RATIO","8A,6X,10A,7X,.DDDD,9X,.DDDD,9X,.DDDD,9X,.DDDD"
11670 DATA "PRESSURE","8A,6X,10A,7X,DDD.D,9X,DDD.D,9X,DDD.D,9X,DDD.D"
11680 DATA "VELOCITY","8A,6X,10A,7X,DDD.D,9X,DDD.D,9X,DDD.D,9X,DDD.D"
11690 DATA "GAS TEMP","8A,6X,10A,7X,DDDD.,9X,DDDD.,9X,DDDD.,9X,DDDD."
11700 DATA "SRF TEMP","8A,6X,10A,7X,DDDD.,9X,DDDD.,9X,DDDD.,9X,DDDD."
11710 DATA "TC AC021","8A,6X,10A,7X,DDDD.,9X,DDDD.,9X,DDDD.,9X,DDDD."
11720 DATA "TC AC024","8A,6X,10A,7X,DDDD.,9X,DDDD.,9X,DDDD.,9X,DDDD."
11730 DATA "TC AC026","8A,6X,10A,7X,DDDD.,9X,DDDD.,9X,DDDD.,9X,DDDD."

```

```

11740 PRINT
11750 GOSUB Spec_info
11760 PRINT
11770 PRINT " .....COMMENTS....."
11780 PRINT CHR$(12)
11790 PRINTER IS 1
11800 RETURN
11810 Control_setup: !
11820 CLEAR SCREEN
11830 Flag(2)=0
11840 Flag(3)=0
11850 PRINT
11860 PRINT "          RIG CONTROL OPTIONS"
11870 PRINT
11880 PRINT "1) FUEL VALVE: MANUAL CONTROL OF % OPEN/CLOSE"
11890 PRINT "2) FUEL VALVE: CLOSED LOOP CONTROL OF F/A RATIO"
11900 PRINT "3) AIR VALVE: MANUAL CONTROL OF % OPEN/CLOSE"
11910 PRINT "4) AIR VALVE: CLOSED LOOP CONTROL OF AIR FLOW"
11920 PRINT "5) H2O VALVE: MANUAL CONTROL OF % OPEN/CLOSE"
11930 PRINT "6) BACK VALVE: MANUAL CONTROL OF % OPEN/CLOSE"
11940 PRINT "7) BACK VALVE: CLOSED LOOP CONTROL OF SYS. PSI"
11950 PRINT
11960 PRINT
11970 PRINT "          OTHER SETUP OPTIONS"
11980 PRINT
11990 PRINT "8) EDIT/REVIEW PID PARAMETERS      "
12000 PRINT
12010 PRINT
12020 INPUT "ENTER YOUR CHOICE OR (0) TO RETURN",Index
12030 SELECT Index
12040 CASE 0
12050     GOTO Restart
12060 CASE 1
12070     ON KEY 6 LABEL " % FUEL VALVE",10 GOTO Fuel_out_sp
12080     GOTO Fuel_out_sp
12090 CASE 2
12100     ON KEY 6 LABEL " F/A RATIO",10 GOTO Fa_ratio_sp
12110     GOTO Fa_ratio_sp
12120 CASE 3
12130     ON KEY 5 LABEL " % AIR VALVE",10 GOTO Air_out_sp
12140     GOTO Air_out_sp
12150 CASE 4
12160     ON KEY 5 LABEL " AIR FLOW",10 GOTO Air_flow_sp
12170     GOTO Air_flow_sp
12180 CASE 5
12190     ON KEY 8 LABEL " % H2O VALVE",10 GOTO Quench_out_sp
12200     GOTO Quench_out_sp
12210 CASE 6
12220     ON KEY 7 LABEL " % BACK VALVE",10 GOTO Back_out_sp
12230     GOTO Back_out_sp
12240 CASE 7
12250     ON KEY 7 LABEL "SYS. PSI",10 GOTO Sys_psi_sp
12260     GOTO Sys_psi_sp
12270 CASE 8
12280     GOTO Pid_parm
12290 CASE ELSE
12300     GOTO Control_setup
12310 END SELECT
12320 Build_string: !
12330 L1$=" "

```

```

12340 L4$="      "
12350 FOR I=1 TO 15
12360   N=Screen(I,1)
12370   IF N=40 THEN
12380     Part1_disp$="      "
12390   ELSE
12400     OUTPUT L5$ USING Display_format$(N) &" ,#";Dval(N)
12410     L6$="....."
12420     Part1_disp$=Chan_label$(N) [1,16]&L6$[1,6]&L5$[1,5]&L1$[1,1]&Unit$(N) [
1,4]
12430   END IF
12440   N=Screen(I,2)
12450   IF N=40 THEN
12460     Part2_disp$="      "
12470   ELSE
12480     OUTPUT L5$ USING Display_format$(N) &" ,#";Dval(N)
12490     L6$="....."
12500     Part2_disp$=Chan_label$(N) [1,16]&L6$[1,6]&L5$[1,5]&L1$[1,1]&Unit$(N) [
1,4]
12510   END IF
12520   Disp$(I)=Part1_disp$[1,32]&L4$[1,4]&Part2_disp$[1,32]
12530 NEXT I
12540 RETURN
12550 Modify_string: !
12560 FOR I=1 TO 15
12570   N=Screen(I,1)
12580   IF N=40 THEN
12590     GOTO 12640
12600   ELSE
12610     OUTPUT L5$ USING Display_format$(N) &" ,#";Dval(N)
12620   END IF
12630   Disp$(I) [23,27]=L5$[1,5]
12640   N=Screen(I,2)
12650   IF N=40 THEN
12660     GOTO 12710
12670   ELSE
12680     OUTPUT L5$ USING Display_format$(N) &" ,#";Dval(N)
12690   END IF
12700   Disp$(I) [59,63]=L5$[1,5]
12710 NEXT I
12720 RETURN
12730 Read_coef: !
12740 RESTORE 12790
12750 FOR I=1 TO 13
12760   READ Kref(I)
12770 NEXT I
12780 ! TYPE K POLYNOMIAL CONVERSION AND REFERENCE COEFFICIENTS
12790 DATA -8.16774E-7,3.964E-4,1.6E-8
12800 DATA -5.1E-2,2.48503E4,-3.82662E5,9.9661057E7,-1.0820624E10,6.0392855E11
12810 DATA -1.9109E13,3.4782347E14,-3.3991028E15,1.3828514E16
12820 FOR I=1 TO 13
12830   READ Rref(I)
12840 NEXT I
12850 ! TYPE R POLYNOMIAL CONVERSION AND REFERENCE COEFFICIENTS
12860 DATA -2.11284E-7,5.334E-5,1.2E-8
12870 DATA 4.8343651E1,1.109827E-1,-2.435389E-6,4.5164488E-11,1.8172612E-16,0,0
,0,0,0
12880 RETURN
12890 Read_suffix: !
12900 RESTORE 12940

```

```

12910 FOR I=1 TO 10
12920   READ Suffix$(I)
12930 NEXT I
12940 DATA "A","B","C","D","E","F","G","H","I","J"
12950 RETURN
12960 Read_label_lim: !
12970 RESTORE 13050
12980 FOR I=1 TO 34
12990   READ Chan_label$(I),Sensor$(I),Display_format$(I),Unit$(I)
13000   READ Hi_lim(I),Low_lim(I)
13010 NEXT I
13020 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
13030 !!!!   HP3497, SLOT# 0 - 20 CHANNEL MVX (A8-B9)                               ! Dval(I),Volt(I)
13040 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
13050 DATA "EXHAUST GAS TEMP","AC067","DDDD.," " F ",2500,0                       ! 1
13060 DATA "VENTURI AIR TEMP","AC013","DDDD.," " F ",2500,0                       ! 2
13070 DATA "INLET AIR TEMP","AC024","DDDD.," " F ",2500,0                       ! 3
13080 DATA "INLET N2 TEMP","AC039","DDDD.," " F ",2500,0                       ! 4
13090 DATA "PREHEAT AIR TEMP","AC012","DDDD.," " F ",2500,0                       ! 5
13100 DATA "INSTR RING1 TEMP","AC021","DDDD.," " F ",3200,0                       ! 6
13110 DATA "INSTR RING4 TEMP","AC024","DDDD.," " F ",3200,0                       ! 7
13120 DATA "GAS STREAM TEMP","AC046","DDDD.," " F ",3200,0                       ! 8
13130 DATA "INSTR RING6 TEMP","AC026","DDDD.," " F ",3200,0                       ! 9
13140 DATA "SPARE -TYPE K-","KTC-7","DDDD.," " F ",2500,0                       ! 10
13150 DATA "SPARE -TYPE K-","KTC-8","DDDD.," " F ",2500,0                       ! 11
13160 DATA "TC REF. VOLTAGE"," REF ", "DDDD.," "MV ",2500,0                       ! 12
13170 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
13180 !!!!   HP3497, SLOT# 1 - 20 CHANNEL MVX (A0-B0)
13190 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
13200 DATA "INSERT VOLTAGE", " ", "DDDD.," " ",1000,0                               ! 13
13210 DATA "SPECIMEN TEMP","AC051","DDDD.," " F ",3200,1750                       ! 14
13220 DATA "AIR FLOW","AC008","DD.DD",""#SEC",2.00,0                               ! 15
13230 DATA "FUEL (Cox) FLOW","FC227","DDDD.," " #/HR",500.0,0                     ! 16
13240 DATA "H2O-Quench FLOW","WS075","DD.DD",""GPM ",50.0,0                     ! 17
13250 DATA "FUEL FLOW","FC219","DDDD.," " #/HR",500.0,0                         ! 18
13260 DATA "NITROGEN PRESS","AC040","DDDD.," "PSIG",1000,0                       ! 19
13270 DATA "FUEL PRESS","FC223","DDDD.," "PSIG",1000,0                         ! 20
13280 DATA "PREHEATED PRESS","AC090","DDDD.," "PSIG",1000,0                       ! 21
13290 DATA "VIEWPORT PRESS","AC050","DDDD.," "PSIG",1000,0                       ! 22
13300 DATA "TEST SECT PRESS","AC091","DDDD.," "PSIG",1000,0                       ! 23
13310 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
13320 !!!!   CALCULATED VALUES
13330 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
13340 DATA "FUEL/AIR RATIO"," F/A ", "D.DDD", " ",.150,0                           ! 24
13350 DATA "GAS VELOCITY","VGAS ", "DDDD.," "FT/S",3000,0                       ! 25
13360 DATA "Fuel Valve %", "FUEL ", "DDD.D", "% ",100.,0                           ! 26
13370 DATA "Air Valve %", " AIR ", "DDD.D", "% ",100.,0                           ! 27
13380 DATA "H2O Valve %", "WATER", "DDD.D", "% ",100.,0                           ! 28
13390 DATA "Back Valve %", "BACK ", "DDD.D", "% ",100.,0                           ! 29
13400 DATA "F/A Setpoint", "FA_SP", "D.DDD", " ",.150,0                           ! 30
13410 DATA "Mair Setpoint", "AF_SP", "DD.DD", "#SEC",2.00,0                       ! 31
13420 DATA "Ptest Setpoint", "SP_SP", "DDDD.," "PSIG",1000,0                       ! 32
13430 DATA "EQUIVALENT RATIO", " PHI ", "DD.DD", " ",3.00,0                       ! 33
13440 DATA "SPARE", " ", "DDDD.," " ",1000,0                                     ! 34
13450 RETURN
13460 Screen_setup: !
13470 RESTORE 13550
13480 FOR I=1 TO 15
13490   READ Screen(I,1)
13500   READ Screen(I,2)

```

```

13510 NEXT I
13520 FOR I=1 TO 11
13530   READ Print_order(I)
13540 NEXT I
13550 DATA 4,19,3,20,5,22,7,21,8,23,14,40,1,15,40,18,24,16,33,17,25,40
13560 DATA 40,27,31,26,30,29,32,28,15,24,23,25,8,14,6,7,9,3,5
13570 RETURN
13580 !!!!!!!!!!!!!!!!!!!!!!! UTILITY SUBROUTINES !!!!!!!!!!!!!!!!!!!!!!!
13590 Restart: !
13600 IF Flag(1)=1 THEN Fuel_lbs=Fuel_lbs+Dval(16)*Tloop/3600
13610 OUTPUT 709;"VS1"
13620 OUTPUT 709;"VT3"
13630 GOTO Scan
13640 Rig_restart: !
13650 GOSUB Log
13660 GOSUB Print_header_1
13670 GOTO Init_variables
13680 Invalid: !
13690 BEEP
13700 DISP "NOT VALID KEY"
13710 WAIT 1
13720 DISP "          "
13730 RETURN
13740 Shutdown: !
13750 BEEP
13760 LINPUT "DO YOU REALLY WISH TO SHUTDOWN? (Y/N)",Ans$
13770 IF Ans$="Y" THEN
13780   PRINTER IS 701
13790   PRINT USING "8A,2X,38A";TIME$(TIMEDATE),"EMERGENCY SHUTDOWN HAS BEEN RE
QUESTED!"
13800   GOSUB Cooldown
13810   IF Flag(4)=1 THEN GOSUB Retract
13820   GOTO Restart
13830 ELSE
13840   GOTO Restart
13850 END IF
13860 Log: !
13870 GOSUB Spec_update
13880 GOSUB Write_common
13890! IF Trun<60 THEN GOTO 13960
13900 IF Data_pts=0 THEN
13910   File_name$="No data!"
13920 ELSE
13930   J=1
13940   GOSUB Write_data
13950   GOSUB Statistics
13960 END IF
13970 GOSUB Summary
13980 RETURN
13990 Pgm_stop: !
14000 GOSUB Log
14010 DISP "PROGRAM ENDS"
14020 BEEP 500,3
14030 WAIT 3
14040 CLEAR SCREEN
14050 GOTO Main_menu_keys
14060 STOP
14070 END

```

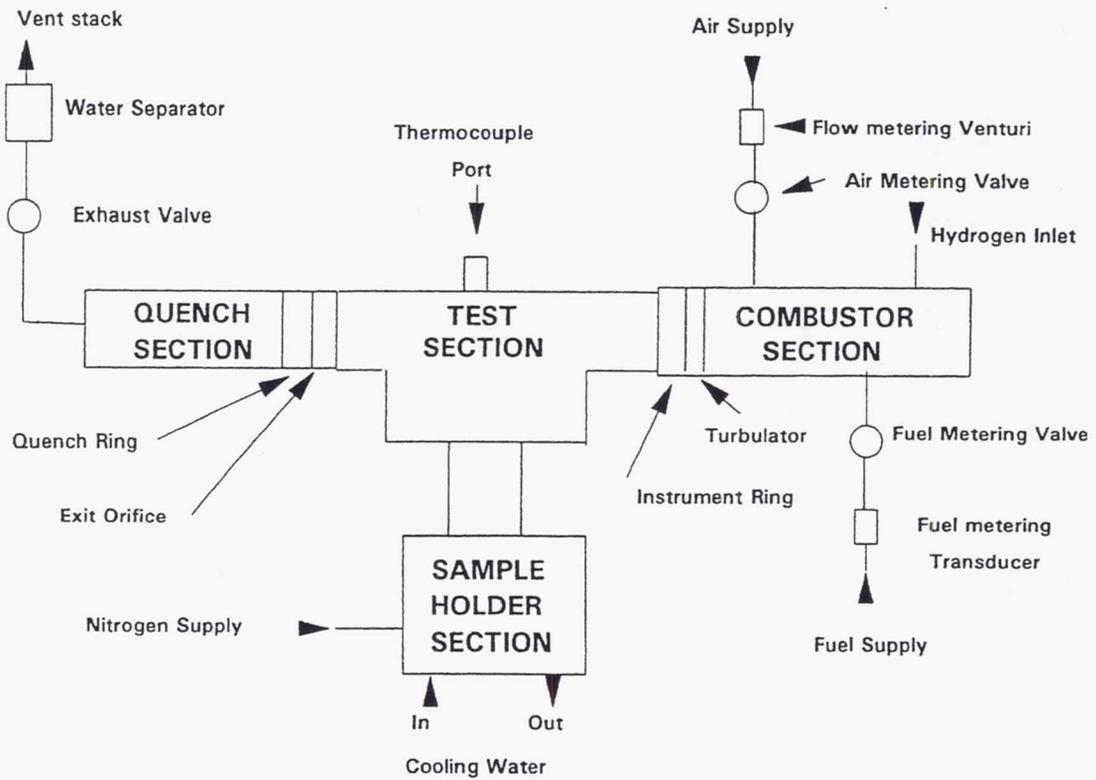


Figure 1.—Schematic of the burner rig configuration.

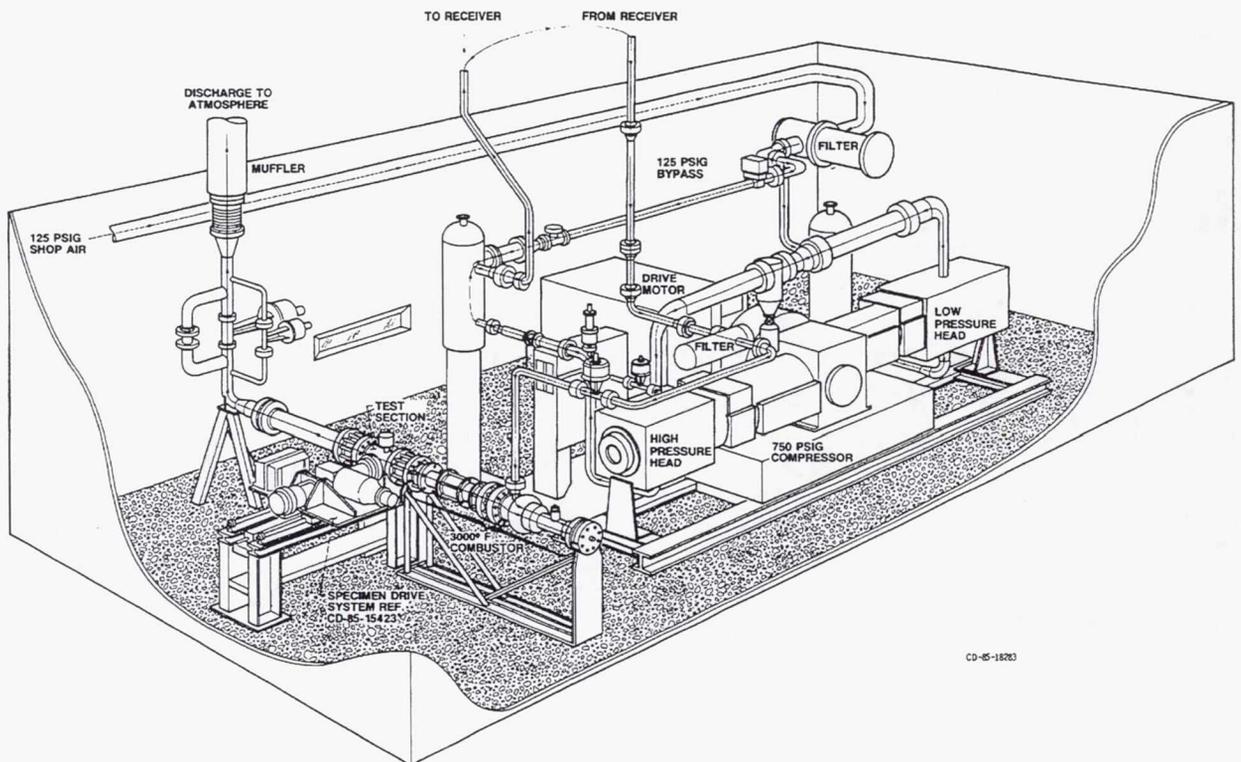


Figure 2.—Test cell layout including rig and supporting 400 horsepower, high-pressure compressor air supply.

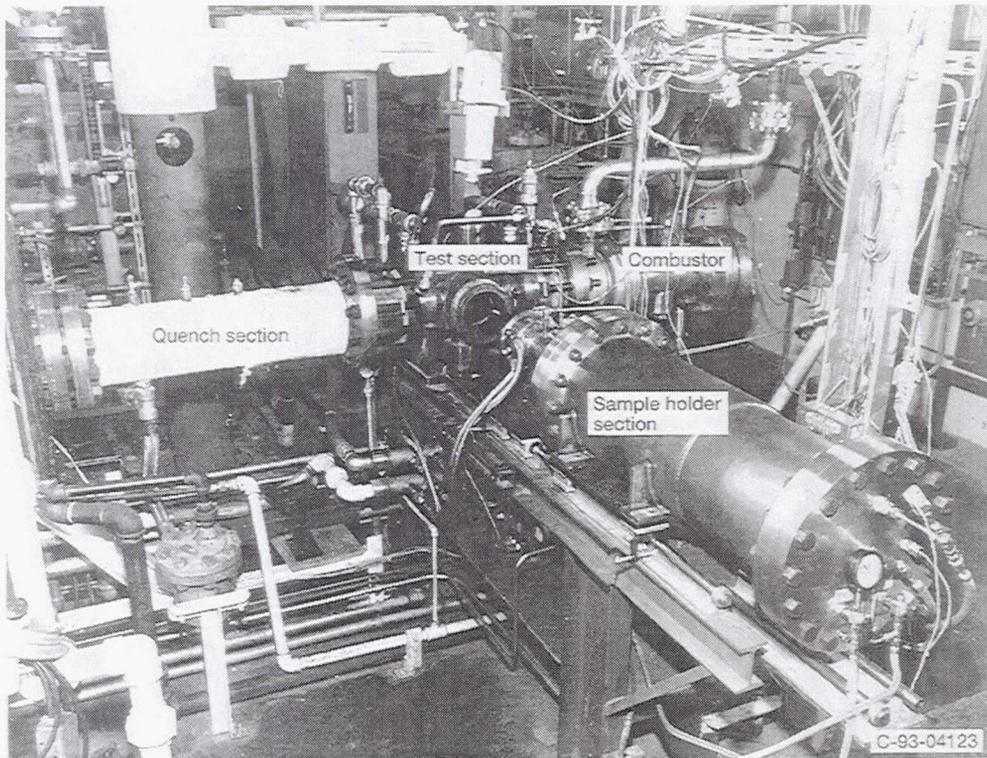


Figure 3.—Photograph of burner rig and test cell.

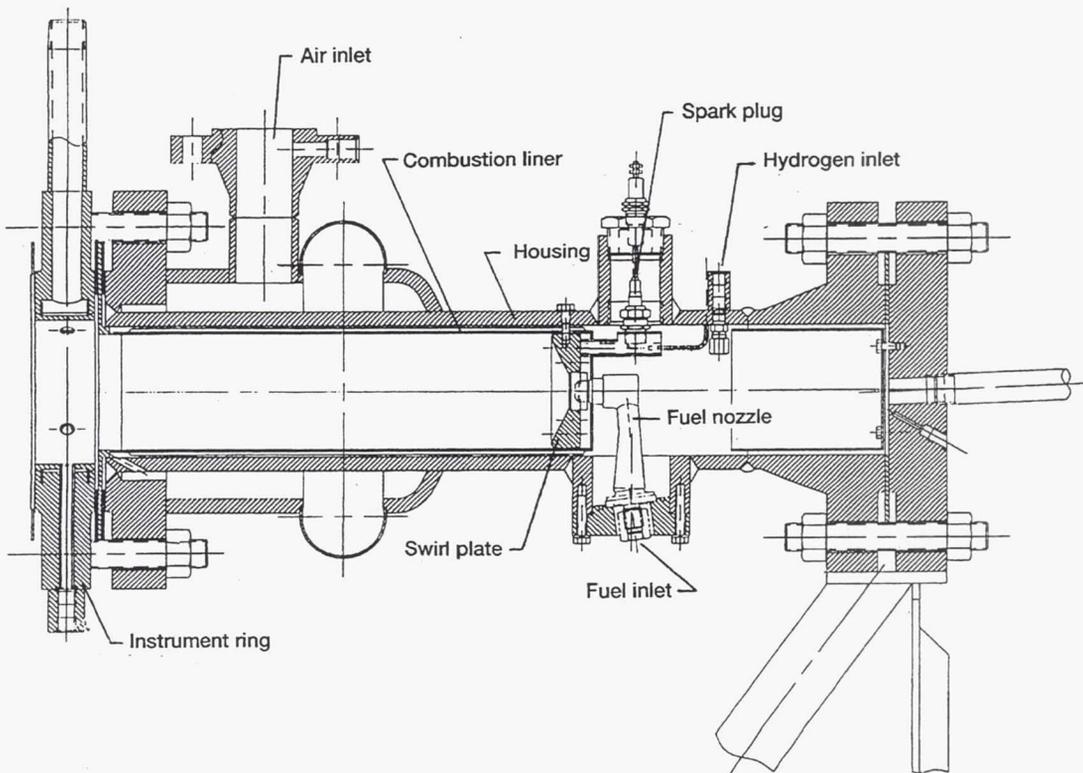


Figure 4.—Cross section of combustor.



C-93-04129

Figure 5.—Combustor liner, swirl plate, and fuel nozzle assembly.



C-93-04128

Figure 6.—Swirl plate showing inlet air swirl angle and conical expansion dome configuration.

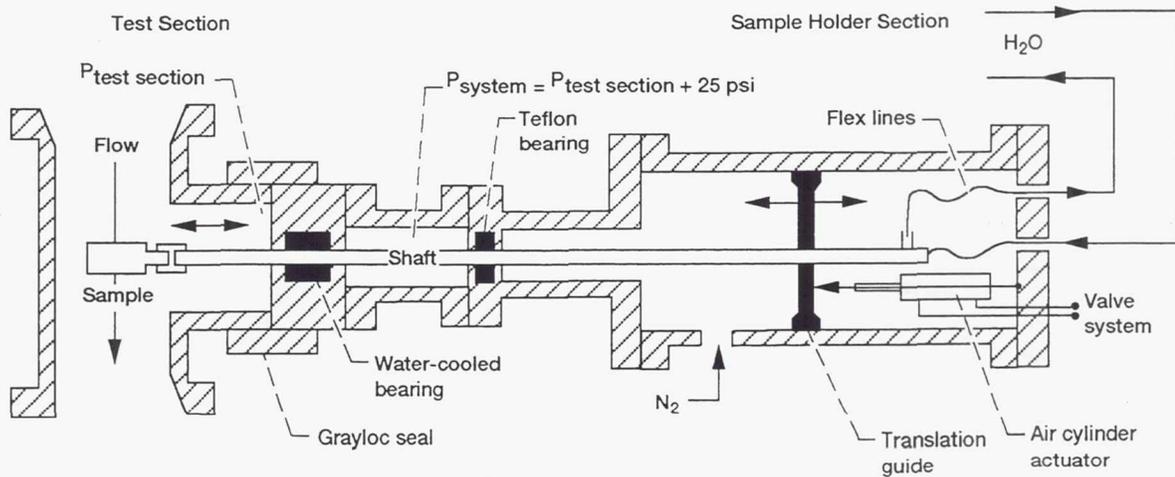


Figure 7.—Cross section of sample holder section.

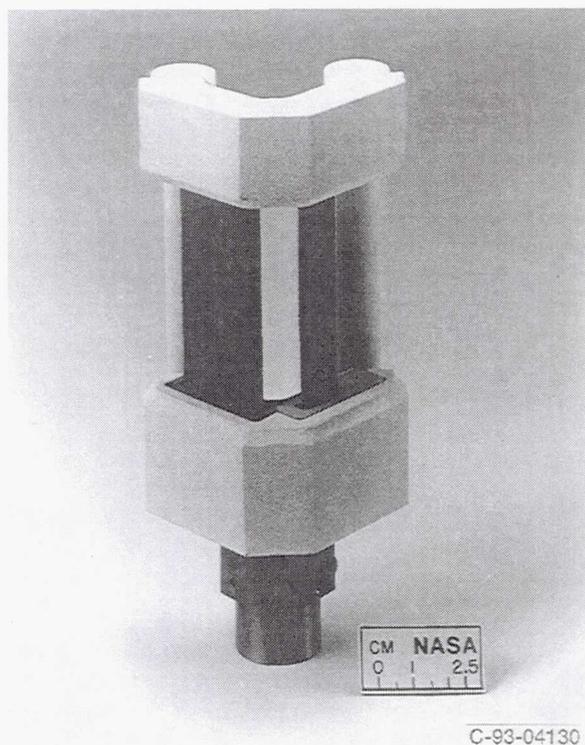


Figure 8.—Thermal barrier coated sample holder assembled with blocks (lava & superalloy) and various size samples.

HIGH PRESSURE RICH/LEAN BURN MATERIALS TEST BURNER RIG

24 Mar 1993

50 HR FUEL RICH TEST OF DuPONT C/SiC COMPOSITES

INLET N2 TEMP..... 44. F	NITROGEN PRESS..... 557. PSIG
INLET AIR TEMP..... 187. F	FUEL PRESS..... 236. PSIG
PREHEAT AIR TEMP..... 318. F	VIEWPORT PRESS..... 78. PSIG
INSTR RING TEMP.....2423. F	PREHEATED PRESS..... 88. PSIG
TEST SECT TEMP.....2669. F	TEST SECT PRESS..... 80. PSIG
SPECIMEN TEMP.....2502. F	
EXHAUST GAS TEMP..... 253. F	AIR FLOW..... 1.00 #SEC
	FUEL FLOW..... 407. #HR
FUEL/AIR RATIO..... .113	H2O-Quench FLOW..... 9.93 GPM
EQUIVALENT RATIO..... 1.69	N2-Viewport FLOW..... 1.50 ACMF
GAS VELOCITY..... 61. FT/S	
Mair Setpoint 1.00 #SEC	Air Valve % 58.3 %
F/A Setpoint113	Fuel Valve % 35.3 %
Ptest Setpoint 80. PSIG	Back Valve % 82.0 %
	H2O Valve % 45.0 %

RUN TIME: 0 HRS,47MIN TEST TIME: 34.0 HRS

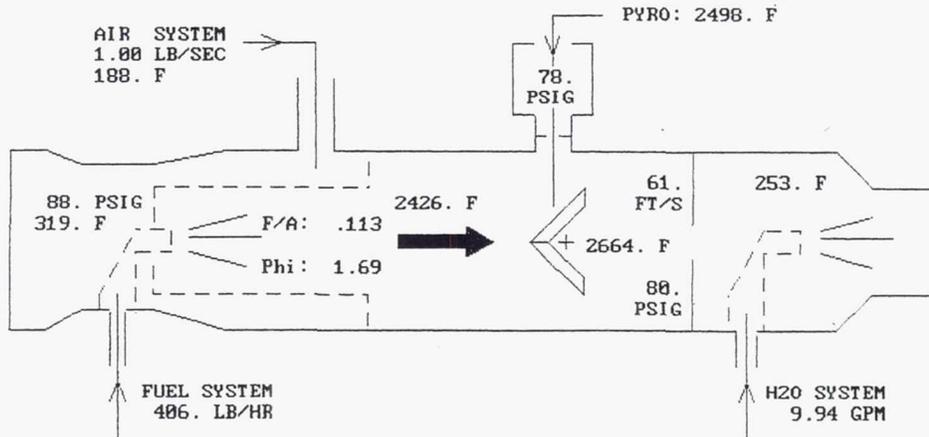
FORCED SHUTDOWN CONTROL SETUP GRAPHIC DISPLAY MANUAL DATA

User 1 Caps Command

AIR FLOW F/A RATIO SYS. PSI % H2O VALVE *

HIGH PRESSURE RICH/LEAN BURN MATERIALS TEST BURNER RIG

24 Mar 1993



FORCED SHUTDOWN CONTROL SETUP TABULAR DISPLAY MANUAL DATA

User 1 Caps Command

AIR FLOW F/A RATIO SYS. PSI % H2O VALVE *

Figure 9.—Screen dumps of (a) tabular display and (b) graphics display including special function control keys.

RUN SUMMARY: 30 Apr 1993
 B.F. GOODRICH Sic/Sic COMPOSITE - 50 HR RICH-BURN TEST

.....FACILITY NOTES.....
 COMBUSTOR TIME LOGGED : 8 HRS,50MIN TOTAL # COMBUSTOR HOURS : 176.5
 INSERTED LEAN-BURN TIME : 0 HRS,0 MIN TOTAL # COMBUSTOR CYCS. : 138
 INSERTED RICH-BURN TIME : 8 HRS,43MIN
 GALLONS OF FUEL BURNED : 566.7
 FILENAME OF DATA FILE : 93APR30A
 NO. OF DATA PTS : 105

.....TEST PARAMETERS.....

PARAMETER	TARGET	AVERAGE	STD.DEV.	MIN	MAX
AIR FLOW	1.0 LB/SEC	0.999	.0012	.9967	1.0044
FA RATIO	0.121	0.121	.0003	.1201	.1215
PRESSURE	80 PSIG	80.00	.2988	79.25	80.68
VELOCITY	60 FT/SEC	61.13	.552	59.27	62.59
GAS TEMP	2675 F	2670.	27.01	2597.	2751.
SRF TEMP	2450 F	2461.	23.33	2397.	2530.

.....SPECIMEN HISTORY.....

POSITION	SPECIMEN	INSTALLED	CYCLES	FUEL LEAN	FUEL RICH
#1	HPBR-4	28 APR 1993	6	1 HRS,3 MIN	16HRS,50MIN
#2	EMPTY		0	0 HRS,0 MIN	0 HRS,0 MIN

POS #1 (TOP): 1/2" BF GOODRICH Sic/Sic COMPOSITE (initial wt = 7.355 gm)
 POS #2 (BOT): EMPTY

.....COMMENTS.....

TITLE: APRIL 30TH.....BF GOODRICH HPBR-4

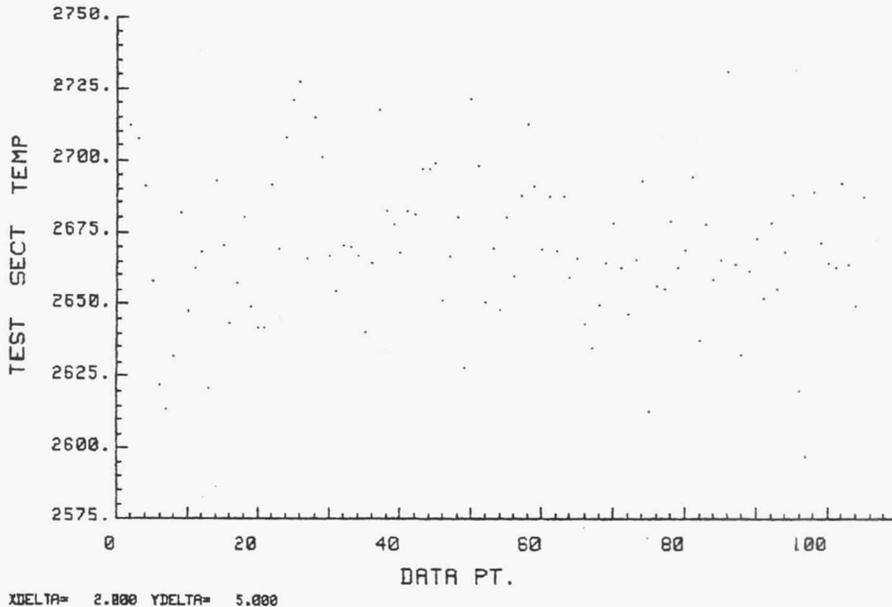


Figure 10.—Electronic test log and run summary printout including statistics and graphical data processing.

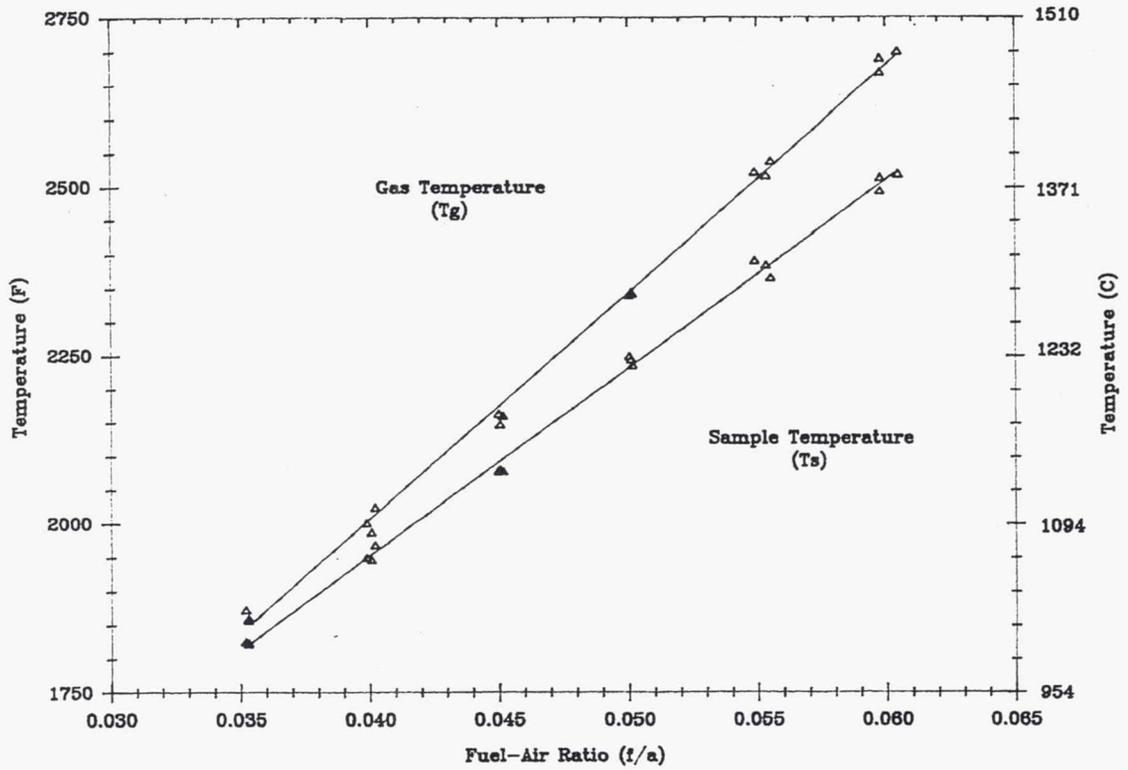


Figure 11.—Gas and test sample temperatures as a function of f/a ratio under lean-burn conditions.

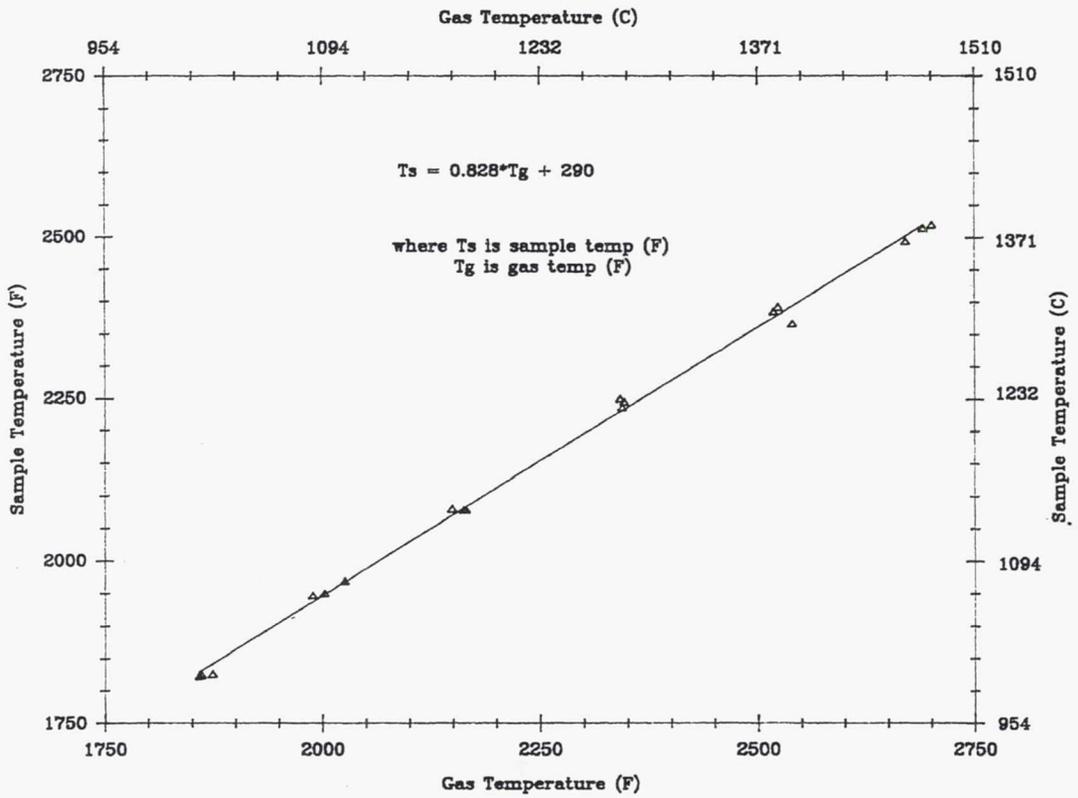


Figure 12.—Relationship between sample temperature and gas temperature.

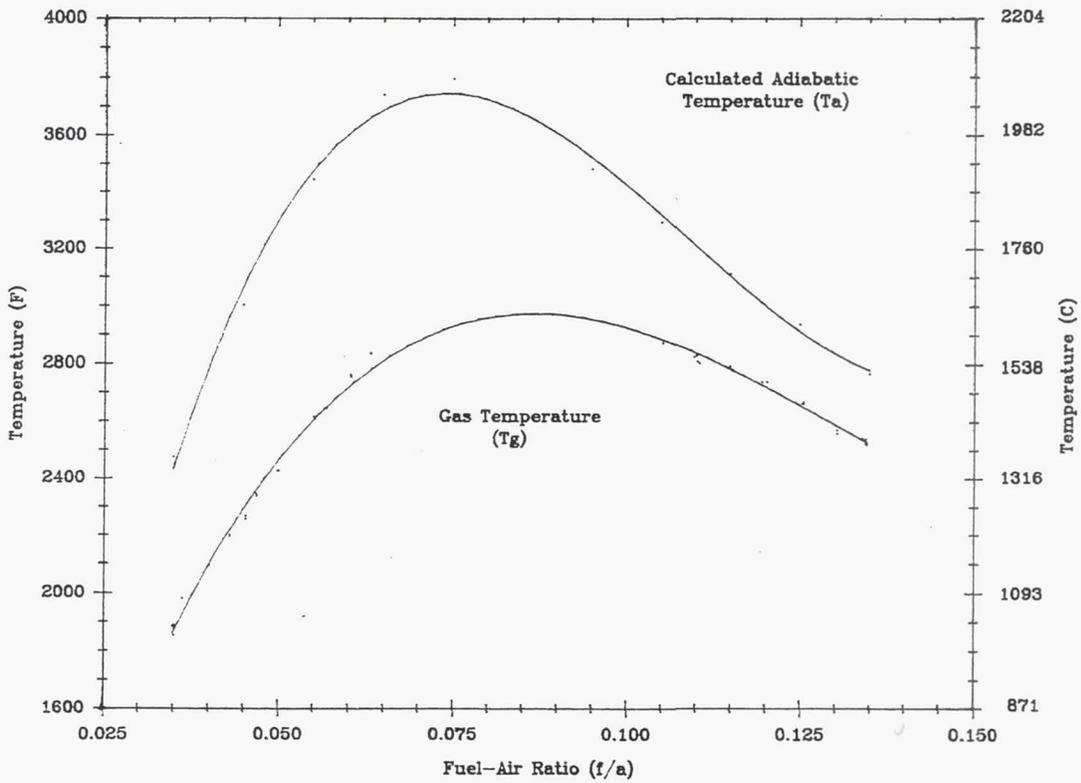


Figure 13.—Range of combustion gas temperatures available as compared to adiabatic conditions.

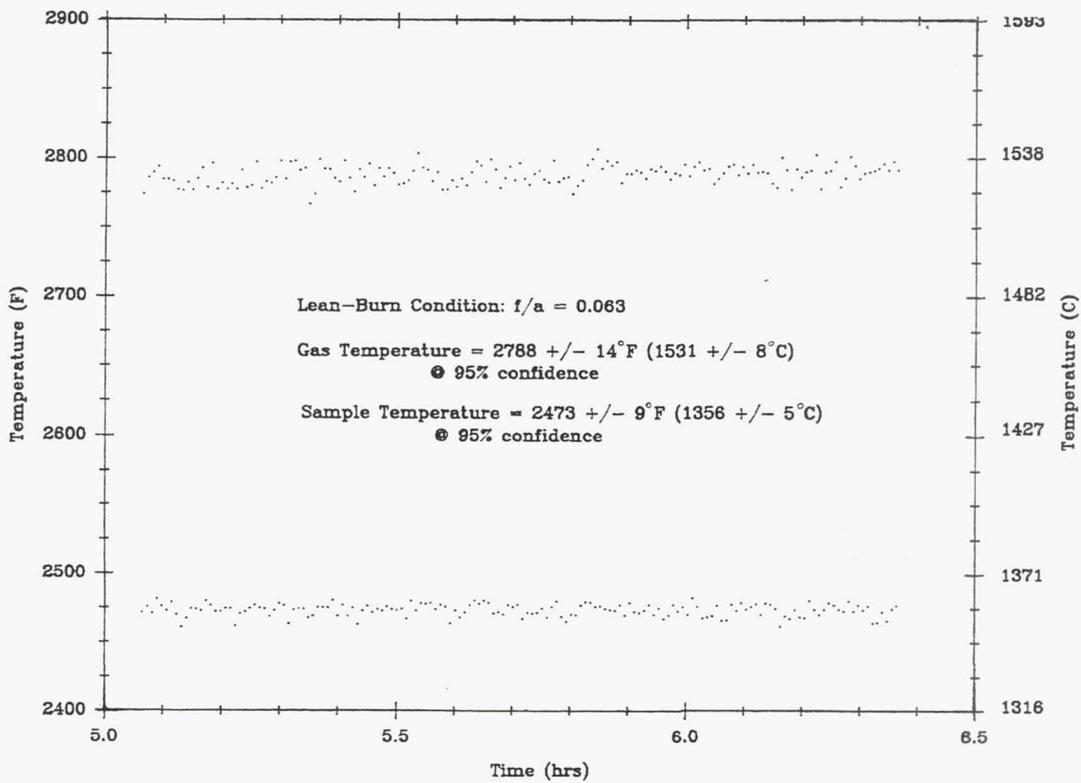


Figure 14.—Variation of gas temperature at fixed f/a ratio.

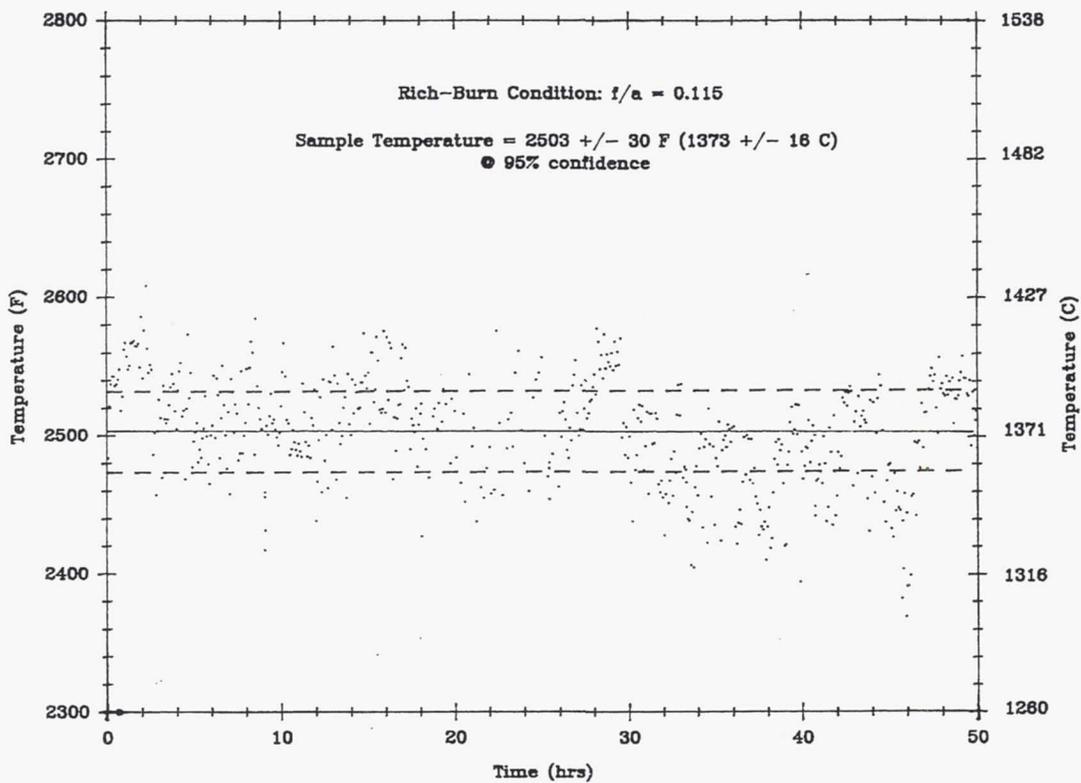


Figure 15.—Sample temperatures calculated using the lean-burn correlation during rich-burn testing.

REPORT DOCUMENTATION PAGE

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6. AUTHOR(S) C.A. Stearns and R.C. Robinson				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Sverdrup Technology, Inc. Lewis Research Center Group 2001 Aerospace Parkway Brook Park, Ohio 44142			8. PERFORMING ORGANIZATION REPORT NUMBER E-8285	
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13. ABSTRACT (Maximum 200 words) <p>The lean-, rich-burn materials test burner rig at NASA LeRC is used to evaluate the high temperature environmental durability of aerospace materials. The rig burns jet fuel and pressurized air, and sample materials can be subjected to both lean-burn and rich-burn environments. As part of NASA's Enabling Propulsion Materials (EPM) program, an existing rig was adapted to simulate the rich-burn quick-quench lean-burn (RQL) combustor concept which is being considered for the HSCT (high speed civil transport) aircraft. RQL materials requirements exceed that of current superalloys, thus ceramic matrix composites (CMC's) have emerged as the leading candidate materials. The performance of these materials in the quasi reducing environment of the rich-burn section of the RQL is of fundamental importance to materials development. This rig was developed to conduct such studies, and this report describes its operation and capabilities.</p>				
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