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

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National Aeronautics and
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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

4

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

5

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 H_2S 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.

9

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

13

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

14

the region around stoichiometric (f/a=0.06-0.1, ϕ=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.

15

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 loose 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 in $\underline{not}$ 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 SiO_2 scale (at least under lean-burn conditions). This scale changes the emissivity of the sample and we have evidence that the emissivity of SiO_2 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

<u>TESTING</u> Combustion gas temperatures measured with the thermocouple are

18

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°C ($\pm$ 14°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°C ($\pm$ 9°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°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 ± 16°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°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 (ϕ=0.4 to 0.9) for lean-burn operation and 0.100 to 0.135 (ϕ=1.5 to 2.0) for rich-burn operation. Fuel-to-air ratios in the high temperature region (ϕ=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 (ϕ=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.

ACKNOWLEDGEMENTS

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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 "ASCI2DOS",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)
```

25

```
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
```

```
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
```

28

```
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
```

```
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 " %  H20   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;"AF8AL30AC8VT4VN23VA0VS1VD5SD0AE1"
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
```

```
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 HEXALOY 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
```

```
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$(TIMEDATE),"FLAMEOUT DETECTED FROM COMB TEMP!"
5040         IMAGE 8A,2X,33A
5050         GOSUB Cooldown
5060         IF Flag(4)=1 THEN GOSUB Retract
5070       END IF
5080    END IF
5090    RETURN
5100 Run_time:  !
5110    Trun=TIMEDATE-Tstart(1)
5120    IF Volt(13)>12. THEN
5130       SELECT Flag(4)
5140       CASE 0
5150         GOSUB Insert
5160       CASE 1
5170         Tinsert=Tretract+(TIMEDATE-Tstart(2))
5180       END SELECT
5190    ELSE
5200       IF Flag(4)=1 THEN GOSUB Retract
5210    END IF
5220    RETURN
5230 Display:  !
5240    IF Flag(6)=0 THEN
5250       GOSUB Modify_string
5260       IF Flag(2)=0 THEN
5270         CLEAR SCREEN
5280         PRINT "          HIGH PRESSURE RICH/LEAN BURN MATERIALS TEST BURNER
RIG          "
5290         PRINT
5300         PRINT USING "30X,11A";DATE$(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
```

```
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
```

```
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)
```

```
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
```

```
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
```

```
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;TIME$(TIMEDATE),"NEW F/A RATIO SETPOINT IS ",Fa_ratio_s
p,"."
10100   IMAGE 8A,2X,26A,.DDD,A
10110   PRINTER IS 1
10120   GOTO Restart
10130 Update_valves:  !
10140   Airout=INT((100-Air_sp)*100)
10150   OUTPUT 709;"AO2,1,"&VAL$(Airout)
10160   Fuelout=INT(Fuel_sp*100)
10170   OUTPUT 709;"AO3,1,"&VAL$(Fuelout)
10180   Backout=INT(Back_sp*100)
10190   OUTPUT 709;"AO2,0,"&VAL$(Backout)
10200   Quenchout=INT(Quench_sp*100)
10210   OUTPUT 709;"AO4,0,"&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)
```

```
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
```

```
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","ACO24","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         ! 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
```
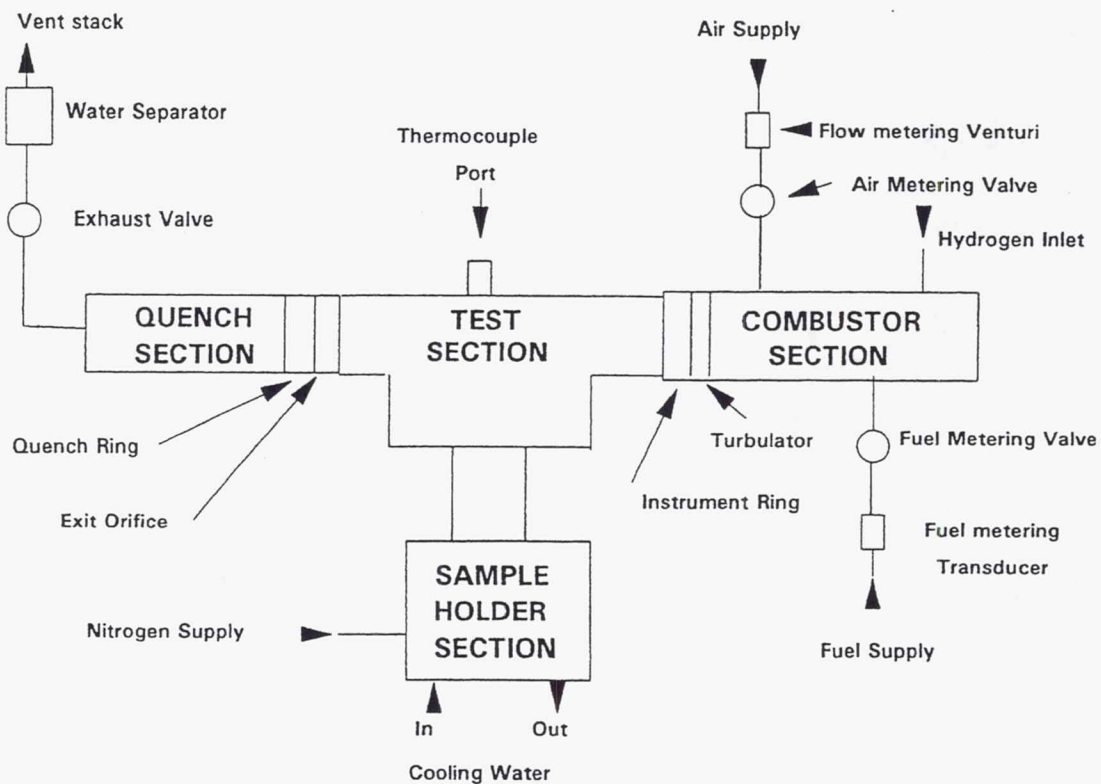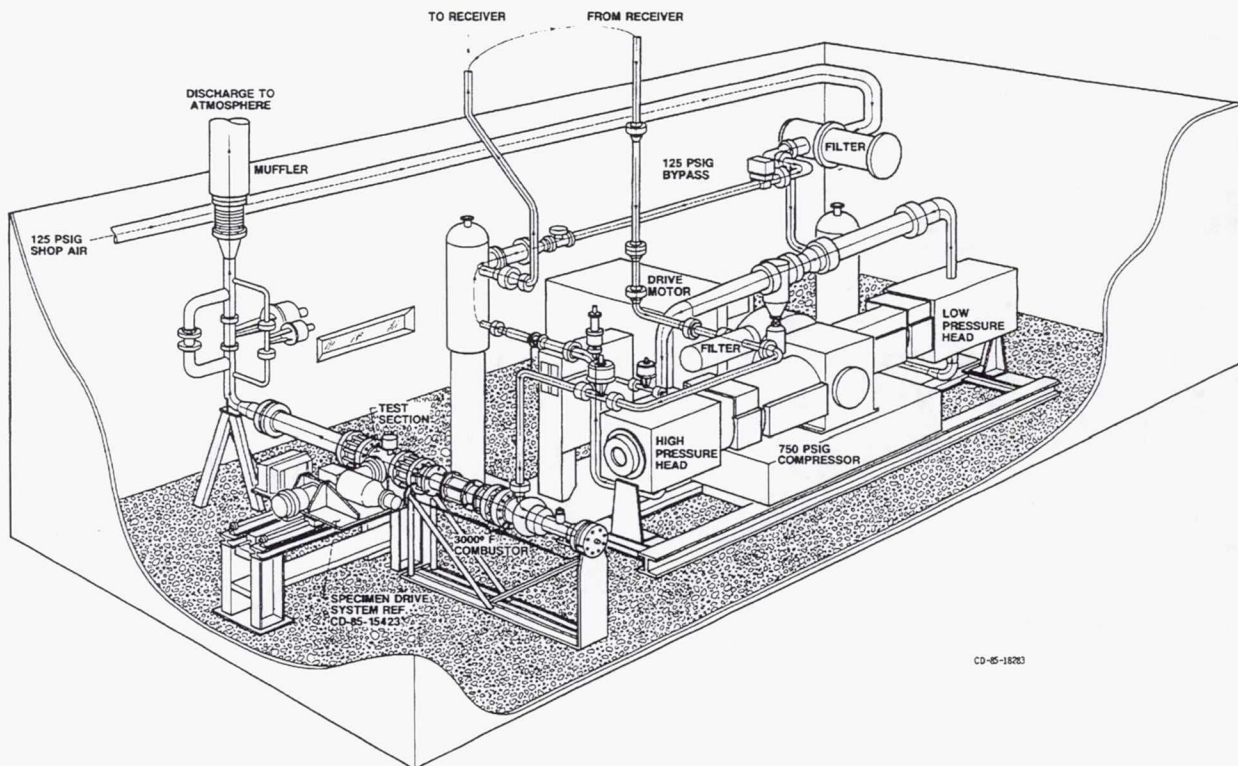
Figure 1.—Schematic of the burner rig configuration.

Figure 2.—Test cell layout including rig and supporting 400 horsepower, high-pressure compressor air supply.
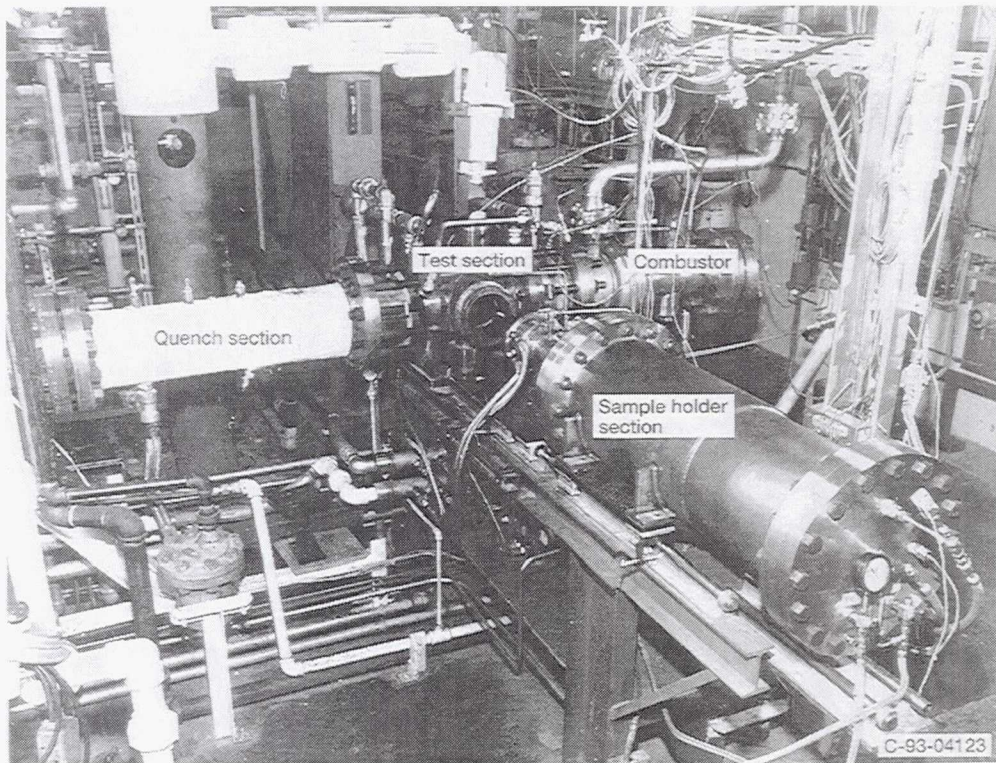
48

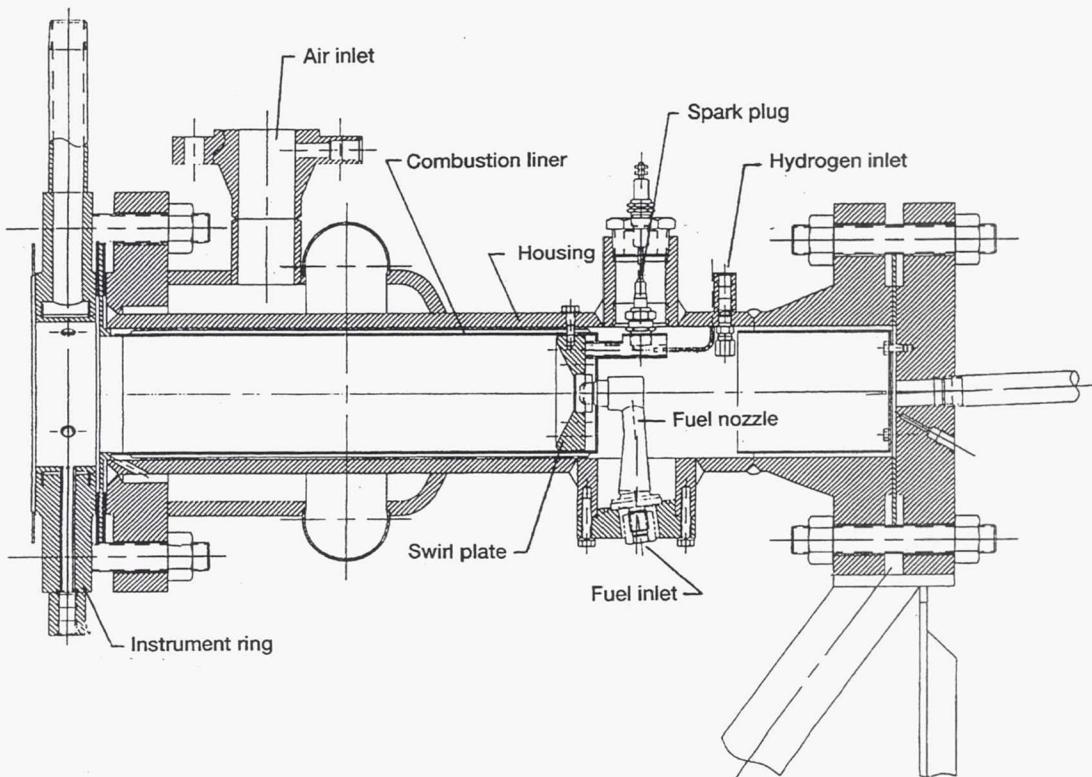Figure 3.—Photograph of burner rig and test cell.

Figure 4.—Cross section of combustor.

Overall length = 43 cm (17 in.)

C-93-04129

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

Diameter = 10 cm (4 in.)

C-93-04128

Figure 6.—Swirl plate showing inlet air swirl angle and conical expansion dome configuration.
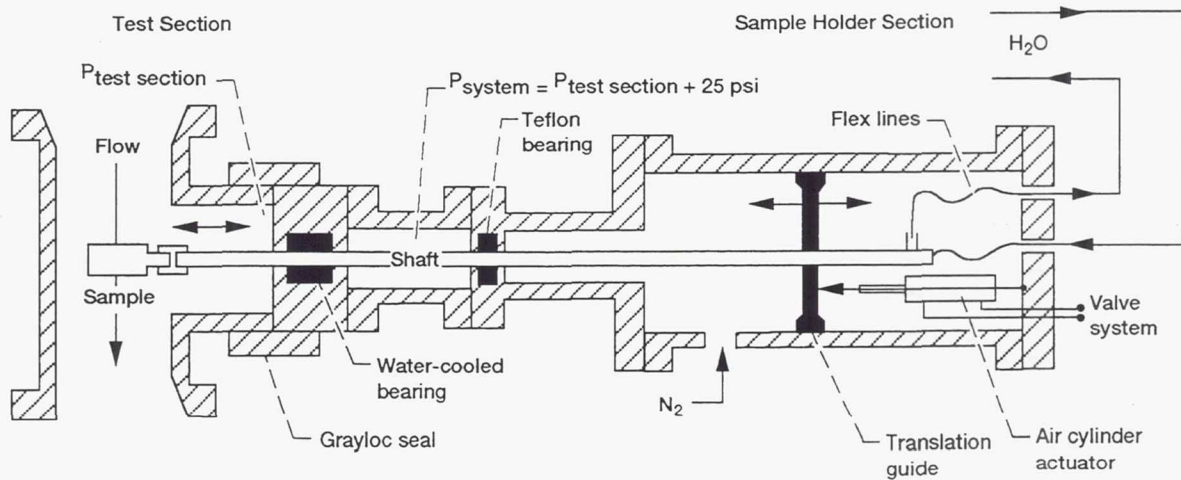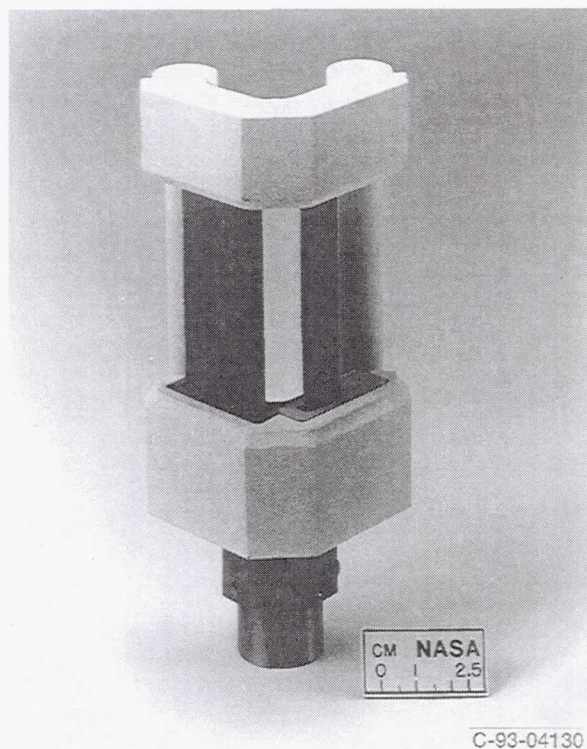
Figure 7.—Cross section of sample holder section.

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 ACFM
     GAS     VELOCITY......  61. FT/S
                                       Air  Valve %    ...... 58.3 %
     Mair  Setpoint  ..... 1.00 #SEC   Fuel Valve %    ...... 35.3 %
     F/A   Setpoint  ...... .113       Back Valve %    ...... 82.0 %
     Ptest Setpoint  ......  80. PSIG  H2O  Valve %    ...... 45.0 %


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


                                       User 1    Caps    Command
  FORCED  CONTROL GRAPHIC  MANUAL    AIR    F/A    SYS. PSI  % H2O
 SHUTDOWN SETUP   DISPLAY  DATA     FLOW   RATIO            VALVE   *
```
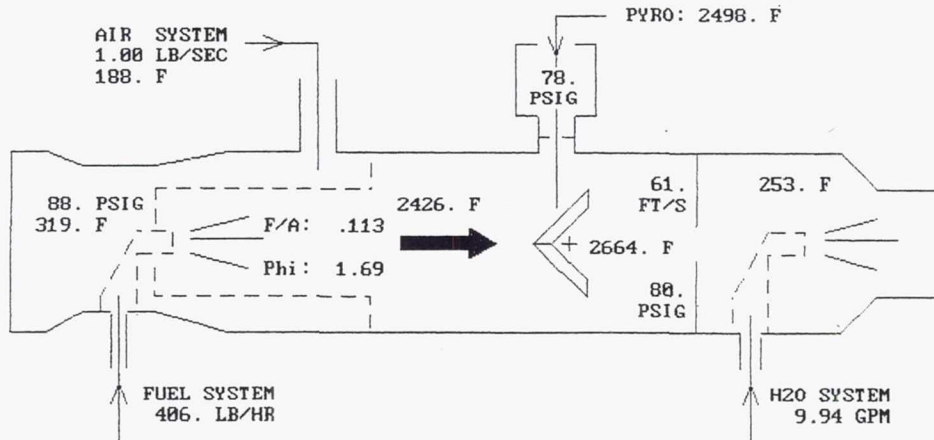


```
HIGH PRESSURE RICH/LEAN BURN MATERIALS TEST BURNER RIG

                        24 Mar 1993


                                          PYRO: 2498. F

         AIR  SYSTEM →
         1.00 LB/SEC
         188. F                         78.
                                        PSIG

                                              61.      253. F
         88. PSIG              2426. F        FT/S
         319. F      F/A:  .113         ←  2664. F

                     Phi:  1.69                80.
                                               PSIG


          FUEL SYSTEM                     H2O SYSTEM
          406. LB/HR                      9.94 GPM


                                       User 1    Caps    Command
  FORCED  CONTROL TABULAR  MANUAL    AIR    F/A    SYS. PSI  % H2O
 SHUTDOWN SETUP   DISPLAY  DATA     FLOW   RATIO            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
```
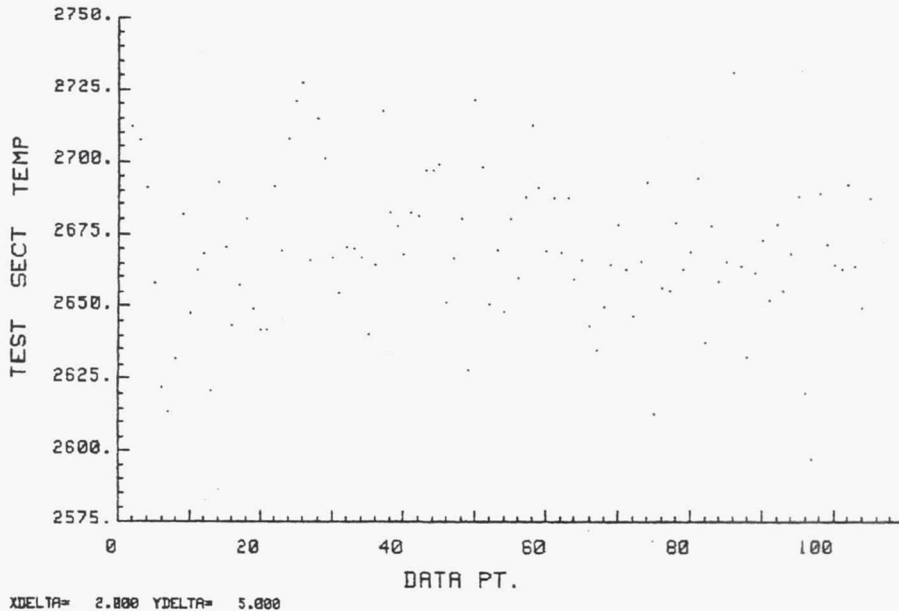

Figure 10.—Electronic test log and run summary printout including statistics and graphical data processing.
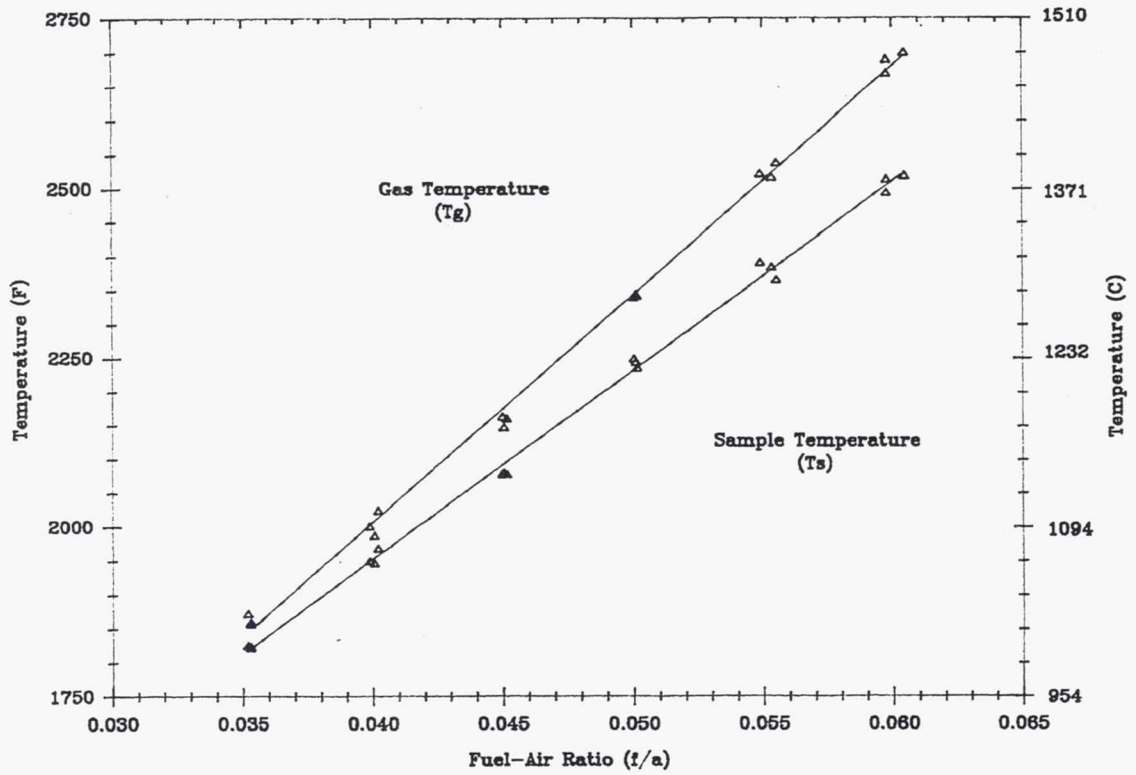
Figure 11.—Gas and test sample temperatures as a function of f/a ratio under lean-burn conditions.
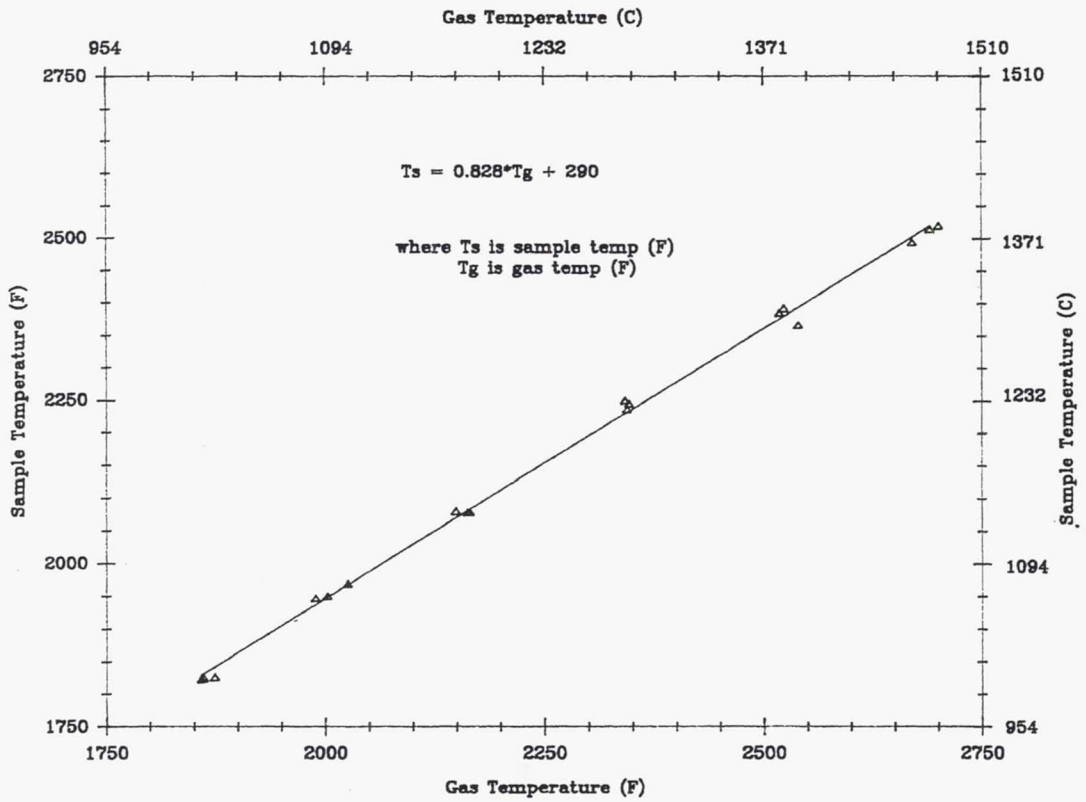

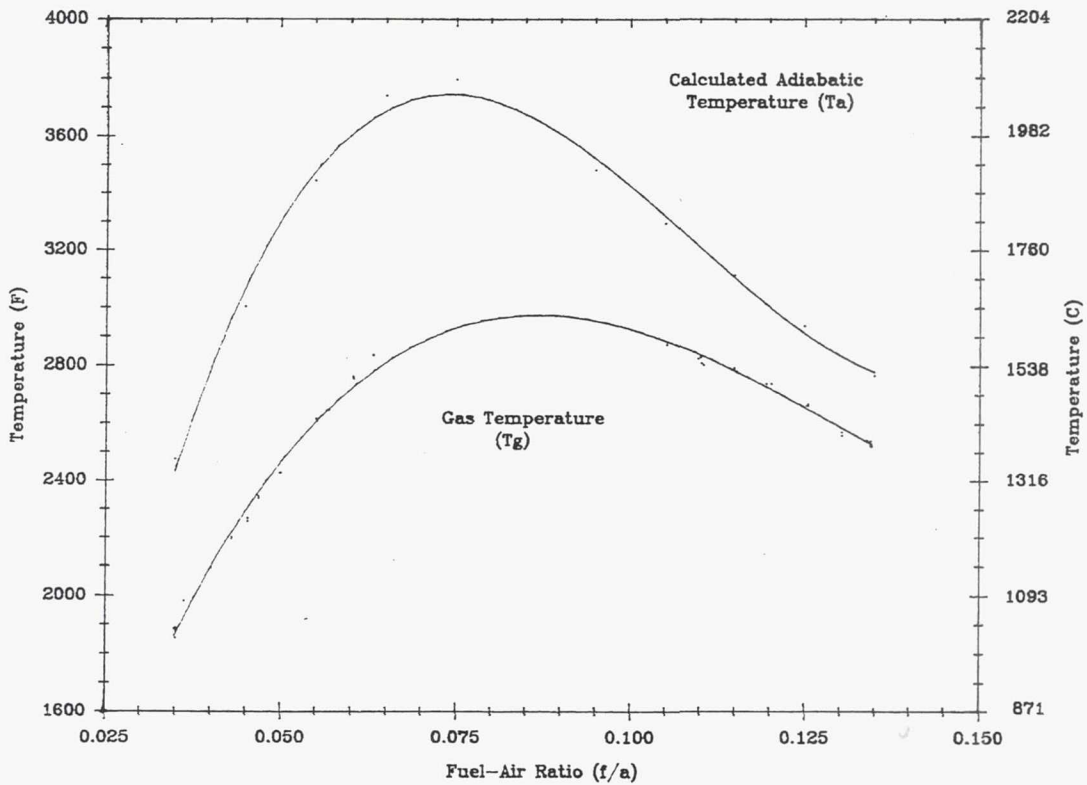Figure 12.—Relationship between sample temperature and gas temperature.

54

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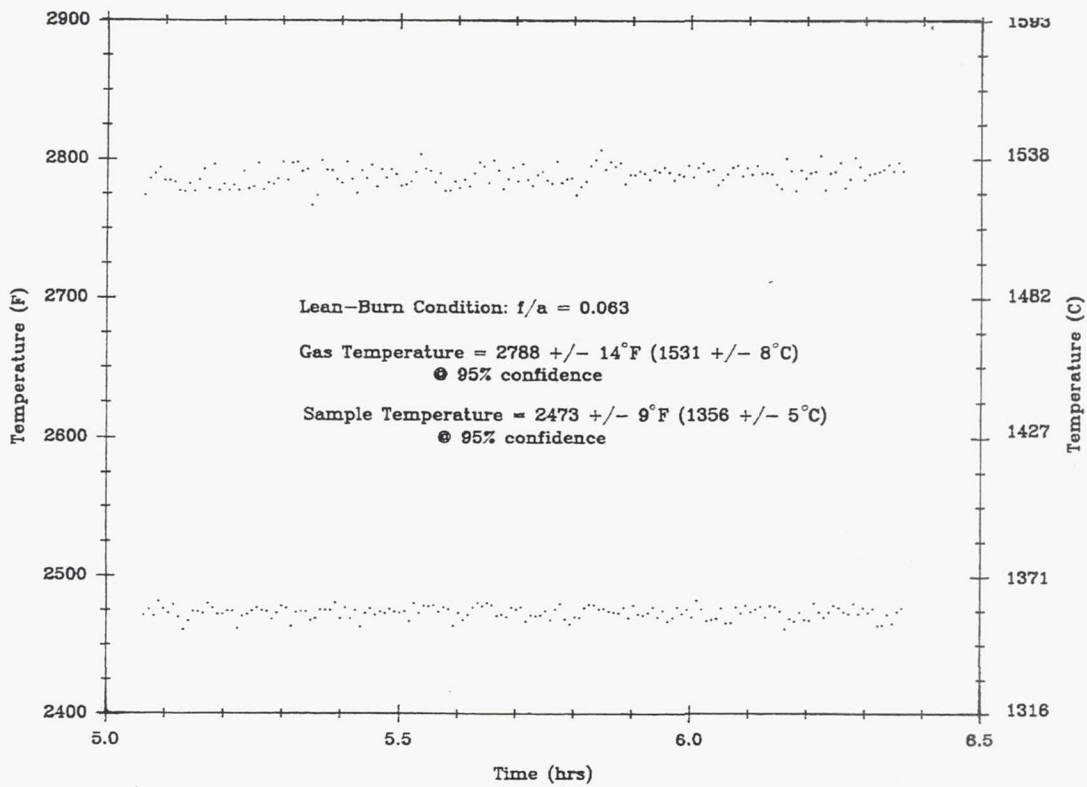

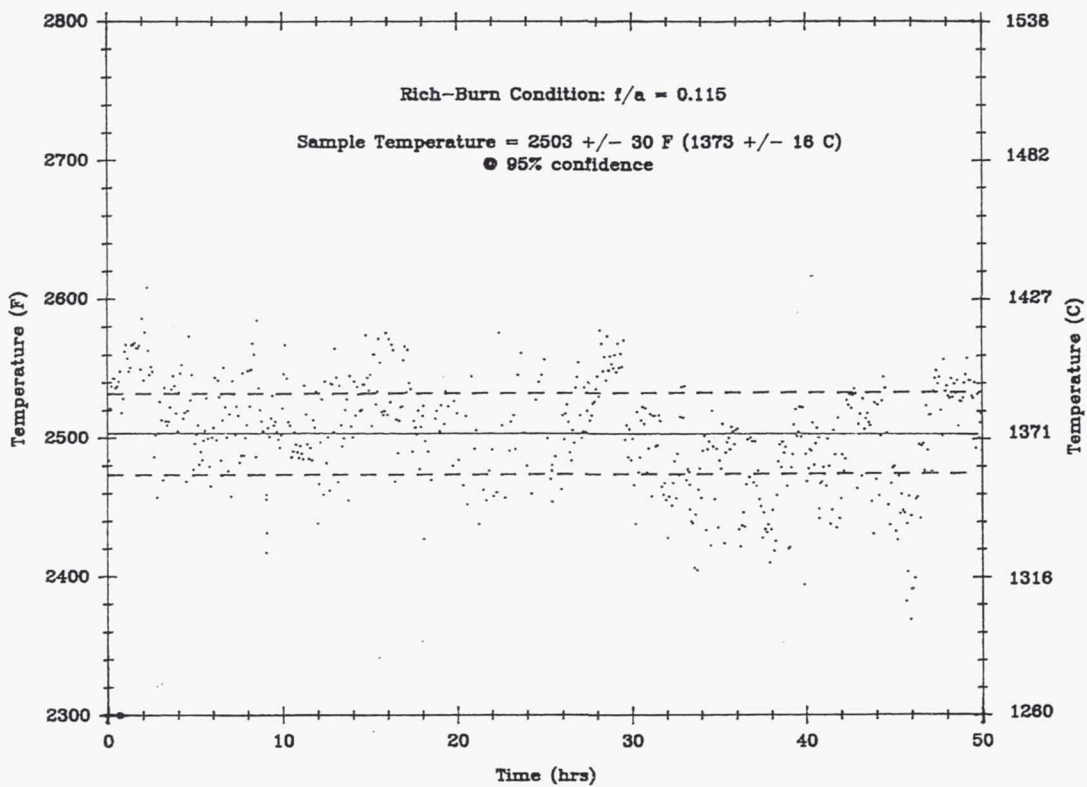Figure 14.—Variation of gas temperature at fixed f/a ratio.

55

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

REPORT DOCUMENTATION PAGE

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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.

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