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 NOx 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 Si3N4) 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.
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 Y₂O₃-ZrO₂ (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
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
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 to 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 (\( \phi \)) 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 \( m_e \) 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 $m_e$ 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 ± 8°C (± 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 ± 5°C (± 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 ± 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 ($\phi=0.4$ 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.
ACKNOWLEDGEMENTS

It is a pleasure to acknowledge the considerable design consultation and implementation contributed by Mr. Brian Fraser. Likewise, Mr. Leonard Bunyak’s contributions to the construction and operation of the facility have been invaluable.

REFERENCES

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.
OPTION BASE 1
DIM Chan_label$(40)[16], Display_format$(40)[5], Sensor$(40)[5], Test$(15)
DIM Unit$(40)[4], Suffix$(10)[1], Disp$(15)[68], Parm$(10)[15]
DIM Specimen$(2)[15], Install$(2)[15], Spec_info$(2)[80]
DIM Ll[1], L4[4], L5[5], L6[6], L8[8], Part1 disp$(32], Part2 disp$(32]
DIM Ans$[80], Blank$[80], File_name$[15], Image$[80], Template$[15]
DIM Screen(15,2), Cox(5), Tstart(3), Trich(2), Tlean(2), Stat(4,10)
DIM Vol(30), Dval(40), Kref(13), Rref(13), R(13), Hi_lim(40), Low_lim(40)
P(7,5), Amt(5), P_prop(5), Ignite_sp(4), Stor buf(13,500), Array(13,500)
REAL Vref, Volt comp, Vt, Temp, Err, Out, Prop, Sp_fraction, Bytes, Fuel_lbs
REAL Air_flow_sp, Fa_ratio_sp, Sys psi_sp, Setpoint, Fuel_sp, Air_sp
REAL Ts, Trun, Tcomb, Tinsert, Tretract, Tloop, Quench_sp, Back_sp
 INTEGER I, J, N, X, Y, Data_pts, Pid, Prt_int
INTEGER Print_order(11), Cycles(6), Life_cycles, Control_ind(3), Flag(10)
INTEGER Airout, Backout, Quenchout, Fuelout
IDENT IS 1
DUMP DEVICE IS 26
CLEAR SCREEN
PLOTTER IS CRT, "INTERNAL"; COLOR MAP
SET PEN 0 INTENSITY 0, 0, .45
PRINT TABXY(1, 27); "\"DATE$(TIMEDATE) & "\"DATE$(TIME$(TIMEDATE)) & \"; \"TIME$(TIMEDATE)
PRINT "IS THIS THE CORRECT TIME AND DATE? (Y/N)", Ans$
PRINT TABXY(1, 27); "\" Ans$
PRINT "TABXY(1, 27); "\"
IF Ans$ = "Y" OR Ans$ = "y" THEN GOTO 300
PRINT "ENTER TODAY'S DATE & TIME (08 JUL 1991 09:45:30)", Ans$
SET TIMEDATE DATE(Ans$[1, 11]) + TIME(Ans$[13, 20])
ON KEY 1 LABEL "RUN RIG ", 10 GOTO Main
ON KEY 2 LABEL "TEST ", 10 GOSUB Invalid
ON KEY 3 LABEL " SETUP ", 10 GOTO Setup
ON KEY 4 LABEL " ", 10 GOSUB Invalid
ON KEY 5 LABEL " CREATE DOS ", 10 GOTO Create_ascii
ON KEY 6 LABEL " ", 10 GOSUB Invalid
ON KEY 7 LABEL " PRINTOUT ", 10 GOTO Printout
ON KEY 8 LABEL " PLOT ", 10 GOTO Plot
Menu display: !
PRINT TABXY(2, 1)
PRINT "HIGH PRESSURE RICH/LEAN BURN MATERIALS TEST BURNER RIG"
OPTION MENU
F1: DATA ACQ. AND CONTROL PGM
F3: EDIT TEST SETUP
F5: CREATE DOS FILE (from BDAT) FOR MATLAB, SIGMAPLOT, & OTHER USES
F7: PRINT CONTENTS OF A DATA FILE
F8: PLOTTING ROUTINE
DISP "CHOOSE OPTION USING FUNCTION KEYS"
KEY LABELS ON
Echo: !
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 PRINT "DATA RETRIEVED FROM FILE: \BLP\X6_BDATS",File_name$","DOS,C"
1030 PRINT "TOTAL DATA PTS: ",Data_pts
1040 PRINT
1050 PRINT
1060 FOR I=1 TO 13
1070 PRINT USING "2D,2A,16A";I,". ",Chan_label$(I)
1080 NEXT I
1090 PRINT
1100 PRINT " 1  2  3  4  5  6  7  8  9  10  11  12  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 PRINT \r
1200 RETURN \r
1210 Plot: ! \r
1220 MASS STORAGE IS "\BLP\X6_BDATS:DOS,C" \r
1230 PLOTTER IS CRT,"INTERNAL";COLOR MAP \r
1240 SET PEN 0 INTENSITY 0,0,.45 \r
1250 CLEAR SCREEN \r
1260 CAT;NAMES \r
1270 LINPUT "ENTER FILENAME OF DATA TO BE PLOTTED",File_name$ \r
1280 GOSUB Read_bdat \r
1290 GOSUB X_parm \r
1300 GOSUB Y_parm \r
1310 GOSUB Create_plot \r
1320 ON KEY 1 LABEL " CHANGE X-PARM ";10 GOSUB X_parm \r
1330 ON KEY 2 LABEL " CHANGE Y-PARM ";10 GOSUB Y_parm \r
1340 ON KEY 3 LABEL "SCALE XY",10 GOSUB Scale_xy \r
1350 ON KEY 4 LABEL " PLOT ",10 GOSUB Create_plot \r
1360 ON KEY 5 LABEL "NEW DATA",10 GOTO Plot \r
1370 ON KEY 6 LABEL " TITLE ",10 GOSUB Plot_label \r
1380 ON KEY 7 LABEL " DUMP ",10 GOSUB Dump \r
1390 ON KEY 8 LABEL " EXIT ",10 GOTO Review \r
1400 Hold: ! \r
1410 GOTO Hold \r
1420 Dump: ! \r
1430 DUMP GRAPHICS \r
1440 PRINT \r
1450 INPUT "ENTER NEW PLOT TITLE (50 CHARACTERS MAX)",Ans$ \r
1460 GOSUB Create_plot \r
1470 RETURN \r
1480 Plot label: ! \r
1490 X_parm: ! \r
1500 GOSUB Plot_variables \r
1510 RETURN \r
1520 SCALE XY: ! \r
1530 INPUT "SCALE X OR Y?",Ans$ \r
1540 DISP Blank$ \r
1550 IF Ans$="X" THEN \r
1560 INPUT "ENTER XMIN",Xmin \r
1570 INPUT "ENTER XDELTA",Xdelta \r
1580 END IF \r
1590 IF Ans$="Y" THEN \r
1600 INPUT "ENTER YMIN",Ymin \r
1610 INPUT "ENTER YDELTA",Ydelta \r
1620 END IF \r
1630 RETURN \r
1640 Y_parm: ! \r
1650 GOSUB Plot_variables \r
1660 INPUT "ENTER INDEX OF Y PARAMETER",Y \r
1670 INPUT "ENTER YMIN",Ymin \r
1680 INPUT "ENTER YDELTA",Ydelta \r
1690 RETURN \r
1700 Ydelta=(Ymax-Ymin)/7
DISP "CHOOSE NEXT OPTION USING FUNCTION KEYS"
RETURN
Plot variables:
CLEAR SCREEN
PRINT "CHOOSE PLOT PARAMETERS"
PRINT
FOR I=1 TO 13
PRINT USING "DD,2A,16A";I," ",Chan_label$(I)
NEXT I
RETURN
Create_plot:
CLEAR SCREEN
GINIT
CLIP 15,125,20,90
AXES 2,2,15,20,5,5,3
CLIP OFF
CSIZE 2.8
SCALE X AXIS
MOVE 10,15
OUTPUT L5$ USING Display_format$(X)&",";Xmin
LABEL L5$[1,5]
FOR I=1 TO 5
MOVE 10+I*20,15
OUTPUT L5$ USING Display_format$(X)&",";Xmin+Xdelta*2*I
LABEL L5$[1,5]
NEXT I
SCALE Y AXIS
MOVE 6,19
OUTPUT L5$ USING Display_format$(Y)&",";Ymin
LABEL L5$[1,5]
FOR I=1 TO 7
MOVE 6,I*10+19
OUTPUT L5$ USING Display_format$(Y)&",";Ymin+Ydelta*I
LABEL L5$[1,5]
NEXT I
LABEL X-Y AXIS
MOVE 55,10
CSIZE 3.5
LABEL Chan_label$(X)
MOVE 3,40
LDIR 89.53
LABEL Chan_label$(Y)
! TITLE & FOOTNOTES
LDIR 0
MOVE 10,97
LABEL USING "8A,3A,50A";File_name$," ",Ans$[1,50]
MOVE 0,7.5
CSIZE 2.0
OUTPUT L8$ USING "DDDD.DDD,#";Xdelta
LABEL USING "7A,8A";"XDELTA=";L8$
MOVE 20,7.5
OUTPUT L8$ USING "DDDD.DDD,#";Ydelta
LABEL USING "7A,8A";"YDELTA=";L8$
DATA POINTS
VIEWPORT 15,125,20,90
WINDOW Xmin,Xmin+Xdelta*11,Ymin,Ymin+Ydelta*7
FOR I=1 TO Data_pts
MOVE Array(X,I),Array(Y,I)
PLOT Array(X,I),Array(Y,I)
NEXT I
Setup: !
MASS STORAGE IS "\BLP\PGMS:DOS,C"
GOSUB Read_common
KEY LABELS OFF
CLEAR SCREEN
PRINT "TEST: ",Test$
PRINT USING 2490;"Time on combustor (hrs):",Tcomb
PRINT USING 2490;"Total number of cycles:",Life_cycles
IMAGE 24A,4D.D
PRINT
PRINT "AIR FLOW : ",&Parm$(1)
PRINT "FA RATIO : ",&Parm$(2)
PRINT "PRESSURE : ",&Parm$(3)
PRINT "VELOCITY : ",&Parm$(4)
PRINT "GAS TEMP : ",&Parm$(5)
PRINT "SRF TEMP : ",&Parm$(6)
PRINT
GOSUB Spec_info
INPUT "ENTER INDEX: (1=HRS/CYC 2=TEST DATA 3=SPEC DATA 0=QUIT)",I
SELECT I
CASE 1
INPUT "ENTER NEW COMBUSTOR TIME ",Tcomb
INPUT "ENTER NEW TOTAL # CYCLES ",Life_cycles
GOTO 2440
CASE 2
INPUT "ENTER NEW TEST ",Test$
INPUT "ENTER NEW AIR FLOW TARGET",Parm$(1)
INPUT "ENTER NEW F/A RATIO TARGET",Parm$(2)
INPUT "ENTER NEW PRESSURE TARGET",Parm$(3)
INPUT "ENTER NEW GAS VELOCITY TARGET",Parm$(4)
INPUT "ENTER NEW GAS TEMPERATURE",Parm$(5)
INPUT "ENTER NEW SRF TEMPERATURE",Parm$(6)
GOTO 2440
CASE 3
INPUT "ENTER POSITION TO BE EDITED (1=TOP,2=BOT)",J
LINPUT "ENTER SPECIMEN ID (8 CHARACTERS MAX) OR -1 FOR NO CHANGE",Ans$
IF Ans$="-1" THEN GOTO 2790
Specimen$(J)=Ans$
LINPUT "ENTER DATE INSTALLED (DD MMM YYYY) OR -1 FOR NO CHANGE",Ans$
IF Ans$="-1" THEN GOTO 2820
Install$(J)=Ans$
INPUT "ENTER NUMBER OF CYCLES COMPLETE",Cycles(J)
INPUT "ENTER LEAN TIME (HRS) TO DATE",Tlean(J)
INPUT "ENTER RICH TIME (HRS) TO DATE",Trich(J)
LINPUT "ENTER SPECIMEN NOTES (1 line max) OR -1 FOR NO CHANGE",Ans$
IF Ans$="-1" THEN GOTO 2440
Spec_info$(J)=Ans$
GOTO 2440
CASE 0
GOSUB Write_common
CLEAR SCREEN
GOTO Main_menu_keys
CASE ELSE
GOTO 2440
END SELECT
Spec_info: !
PRINT "..................SPECIMEN HISTORY.................."
PRINT
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$=""
3360 Data_pts=0
3370 Trun=0.
3380 Tinsert=0.
3390 Tretract=0.
3400 Fuel_lbs=0.
3410 MAT Flag= (0.)
3420 MAT Control_ind= (0.)
3430 MAT Volt= (0.)
3440 MAT Dval= (0.)
3450 MAT Stor_buf= (0.)
3460 MAT Cox= (0.)
3470 MAT Stat= (0.)
3480 Soft_keys: !
3490 CLEAR SCREEN
3500 ON KEY 1 LABEL " FORCED SHUTDOWN", 10 GOTO Shutdown
3510 ON KEY 5 LABEL " % AIR VALVE", 10 GOTO Air_out_sp
3520 ON KEY 3 LABEL "GRAPHIC DISPLAY", 10 GOTO Set_display
3530 ON KEY 4 LABEL " MANUAL DATA ", 10 GOSUB Man_prt_stor
3540 ON KEY 6 LABEL "PREVIOUSLIGHTOFF", 10 GOSUB Ignite_sp
3550  ON KEY 9 LABEL " ,10 GOSUB Invalid
3560  ON KEY 7 LABEL " % BACK VALVE",10 GOTO Back_out_sp
3570  ON KEY 8 LABEL " % H2O VALVE",10 GOTO Quench_out_sp
3580  ON KEY 2 LABEL "CONTROL SETUP",10 GOTO Control_setup
3590  ON KEY 10 LABEL " ,10 GOSUB Invalid
3600  ON KEY 11 LABEL " ,10 GOSUB Invalid
3610  ON KEY 12 LABEL "INTERVAL",10 GOTO Set_prt_int
3620  ON KEY 13 LABEL " ,10 GOSUB Invalid
3630  ON KEY 14 LABEL " ,10 GOSUB Invalid
3640  ON KEY 15 LABEL " ,10 GOSUB Invalid
3650  ON KEY 16 LABEL " ,10 GOSUB Invalid
3660  Init_scanner: !
3670  OUTPUT 709;"AF8AL30AC8VT4VN23VA0VS1VD5SD0AE1"
3680  OUTPUT 709;"VT3"
3690  Tstart(3)=TIMEDATE
3700  Ts=TIMEDATE
3710  Scan: !
3720  Tloop=TIMEDATE-Ts
3730  Ts=TIMEDATE
3740  OUTPUT 709;"VS"
3750  SYSTEM PRIORITY 15
3760  FOR I=1 TO 23
3770    ENTER 709 USING ",K";Volt(I)
3780  NEXT I
3790  SYSTEM PRIORITY 9
3800  OUTPUT 709;"VT3"
3810  GOSUB Convert
3820  GOSUB Calculate
3830  GOSUB Check
3840  GOSUB Control
3850  GOSUB Status
3860  GOSUB Display
3870  OUTPUT 709;"AO3,0,"&VAL$(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  END IF
3940  GOSUB Man_prt_stor
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
Volts_comp=R(1)+Vref*(R(2)+Vref*R(3))

FOR I=6 TO 9
VT=Volts_comp+Volts(I)
VT=VT*1.E+6
GOSUB Temp_calc
NEXT I

! AC051 - Pyrometer : 0-5 volts = 1800-3200 F
Dval(14)=(Volts(14)*14000+1800)

! AC051 - Pyrometer correlation with TC probe
Dval(14)=Dval(8)*.826+298.2 ! FOR HEXALOY IN LAVA
Dval(14)=Dval(8)*.864+153.7 ! FOR BF GOODRICH SiC/SiC IN LAVA

! AC008 - Daniels Airflow : 0-5 volts = 0-2 pps
Dval(15)=Volts(15)*.40

! FC227 - Fuel Flow (coxmeter) : 0-1200 Hz = 0-2.5 GPM
Dval(16)=Volts(16)*400/2.5 ! (DC to Hz, 800 Hz fs, cal=50%)
Dval(16)=Dval(16)*.0020261-.0001078 ! (Hz to GPM)
Dval(16)=Dval(16)*60*6.74 ! (GPM to#/HR)

FOR I=1 TO 4
Cox(I)=Cox(I+1)
NEXT I
Cox(5)=Dval(16)

Dval(16)=(Cox(1)+Cox(2)+Cox(3)+Cox(4)+Cox(5))/5

! WS075 - H2O Flow
Dval(17)=Volts(17)*400/2.5 ! (DC to Hz, 800 Hz fs, CAL=50%)
Dval(17)=Dval(17)*.02565-.023895 ! (Hz to GPM)

! FC219 - Fuel Flow
Dval(18)=Volts(18)*125.-125.

! AC040 - Nitrogen Press
Dval(19)=Volts(19)*1000./5.

! FC223 - Fuel Press
Dval(20)=(-.026+20.0*Volts(20))*1000./100.

! AC090 - Preheat Press
Dval(21)=Volts(21)*1000./5.0

! AC050 - Viewport Press
Dval(22)=Volts(22)*836.0/4.186

! AC091 - Test Sect Press
Dval(23)=Volts(23)*831.2/4.1643

RETURN

Temp_calc:
Temp=R(8)+VT*(R(9)+VT*(R(10)+VT*(R(11)+VT*(R(12)+VT*(R(13))))))
Temp=R(4)+VT*(R(5)+VT*(R(6)+VT*(R(7)+VT*Temp)))
Dval(I)=Temp*1.8+32
RETURN

Check:
FOR I=1 TO 33
IF Dval(I)<Low_limit(I) THEN Dval(I)=Low_limit(I)
IF Dval(I)>Hi_limit(I) THEN
SELECT Display_format$(I)
CASE "DDD.D"
Dval(I)=999.9
CASE "DD.DD"
Dval(I)=99.99
CASE ELSE
Dval(I)=9999.
END SELECT
END IF
GOTO 4730
NEXT I
RETURN
4750 Calculate:
4760 IF Dval(15)=0. THEN
4770 Dval(24)=0.
4780 ELSE
4790 Dval(24)=Dval(16)/(Dval(15)*3600)
4800 END IF
4810 Dval(25)=1.85*Dval(15)*(Dval(8)+460)/(Dval(23)+14.7)
4820 Dval(26)=Fuel_sp
4830 Dval(27)=Air_sp
4840 Dval(28)=Quench_sp
4850 Dval(29)=Back_sp
4860 Dval(30)=Fa_ratio_sp
4870 Dval(31)=Air_flow_sp
4880 Dval(32)=Sys_psi_sp
4890 Dval(33)=Dval(24)/.067
4900 Status:
4910 IF Dval(8)>800 OR Dval(6)>800 THEN
4920 SELECT Flag(1)
4930 CASE 0
4940 GOSUB Light_off
4950 CASE 1
4960 GOSUB Run_time
4970 CASE ELSE
4980 GOTO 5080
4990 END SELECT
5000 ELSE
5010 IF Flag(1)=1 THEN
5020 PRINTER IS 701
5030 PRINT USING 5040;TIME$(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 RETURN
5090 Run_time:
5110 IF Volt(13)>12. THEN
5120 SELECT Flag(4)
5130 CASE 0
5140 GOSUB Insert
5150 CASE 1
5160 GOSUB Retract
5170 Tinset=Tinset+(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]
PRINT TABXY(43,I+7);Disp$(I)
NEXT I
Flag(2)=1
KEY LABELS ON
ELSE
FOR I=1 TO 15
PRINT TABXY(29,I+7);Disp$(I)
PRINT TABXY(65,I+7);Disp$(I)
NEXT I
END IF
ELSE
GOSUB Illustrate
END IF
IF Flag(1)=1 THEN
DISP USING "9A,DD.D";"RUN TIME:";Trun/3600
END IF
RETURN
Illustrate: !
IF Flag(3)=0 THEN
CLEAR SCREEN
PEN 1
LINE TYPE 1
! MAIN OUTLINE
MOVE 5,65
RESTORE 5660
J=6
GOSUB Read_draw_xy
MOVE 50,75
J=17
GOSUB Read_draw_xy
MOVE 75,70
RECTANGLE 11,10
DATA 10,65,15,62.5,25,62.5,35,65,45,65,45,65,70
DATA 50,65,77.5,65,77.5,70,82.5,70,82.5,65,120,65,125,60
DATA 140,60,140,45,125,45,120,40,35,40,25,42.5,15,42.5,10,40,5,40,5,65
! BURNER CAN
LINE TYPE 5
MOVE 55,65
J=3
GOSUB Read_draw_xy
MOVE 25,50
J=3
GOSUB Read_draw_xy
DATA 55,60,25,60,25,55,25,45,55,45,55,40
! FUEL NOZZLE
MOVE 17.5,42.5
J=6
GOSUB Read_draw_xy
DATA 17.5,45,22.5,54,27.5,54,27.5,51,22.5,51,22.5,42.5
! H2O NOZZLE
MOVE 105,40
J=6
GOSUB Read_draw_xy
DATA 105,45,110,54,115,54,115,51,110,51,110,40
! TURBULATOR
J=2
GOSUB Move_draw_xy
DATA 100,65,100,55,100,50,100,40
! SPECIMEN
AREA PEN 2
MOVE 78.50
RECTANGLE 5.5,FILL
! AIR SYSTEM
PEN 5
MOVE 37.5,80
DRAW 47.5,80
DRAW 47.5,62.5
! H2O SYSTEM
J=4
GOSUB Move_draw_xy
DATA 107.5,42.5,107.5,25,117.5,51,125,49,117.5,52.5,127.5,52.5,117.5,54.125,56
! FUEL SYSTEM
J=4
GOSUB Move_draw_xy
DATA 20,45,20,25,30,51,37.5,49,30,52.5,40,52.5,30,54,37.5,56
! PYROMETER
MOVE 87.5,84
DRAW 80.5,84
DRAW 80.5,57.5
GOSUB Template
GOSUB Overlay_num
Flag(3)=1
KEY LABELS ON
ELSE
GOSUB Overlay_num
END IF
RETURN
Read_draw_xy: !
FOR I=1 TO J
READ X,Y
DRAW X,Y
NEXT I
RETURN
Move_draw_xy: !
FOR I=1 TO J
READ X,Y
MOVE X,Y
READ X,Y
DRAW X,Y
NEXT I
RETURN
Template: !
PRINT "HIGH PRESSURE RICH/LEAN BURN MATERIALS TEST BURNER RIG"
PRINT USING "30X,11A";DATE$(TIMEDATE)
RESTORE
FOR I=1 TO 20
READ X,Y,Template$
PRINT TABXY(X,Y);Template$
NEXT I
PRINT TABXY(X,Y);Template$
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  END IF
6920  Setpoint=Air_sp
6930    J=27
6940    GOSUB Confirm_sp
6950    Air_sp=Setpoint
6960    PRINTER IS 1
6970 GOSUB Control_loop
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 "CURRENT CLOSED LOOP PARAMETERS"
7610  PRINT "1. F/A RATIO"
7620  PRINT "2. MASS AIR FLOW"
7630  PRINT "3. SYSTEM PRESSURE"
7640  PRINT "4. COMBUSTOR TEMP"
7650  PRINT "5. QUENCH TEMP"
7660  INPUT "ENTER INDEX OF PARAMETER (0 TO QUIT)",Index
7670  IF Index=0 THEN GOTO Restart
7680
7700  GO SUB 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  GO SUB Read_pid_val
7930  GOTO Pid_val_input
7940  CASE 0
7950  GO SUB 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:  !
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 Ratio_sp=−.999  
8600 Fuel_sp=0.  
8610 FOR I=1 TO 11  
8620 Fuel_sp=Ignite_sp(I)  
8630 ON KEY 6 LABEL "% FUEL VALVE",10 GOTO Fuel_out_sp  
8640 ON KEY 7 LABEL "% BACK VALVE",10 GOTO Back_out_sp  
8650 ON KEY 8 LABEL "% AIR VALVE",10 GOTO Air_out_sp  
8660 ON KEY 9 LABEL "% H2O VALVE",10 GOTO Quench_out_sp  
8670 PRINT USING 8800; "STOP SCAN",10 GOTO Pgm_stop  
8680 IMAGE 10X,27A,3D.D,2A  
8690 RETURN  
8700 Ignite_sp:  !
8710 MAT Control_ind= (0.)  
8720 MAT Flag= (0.)  
8730 PRINT USING 8790;"NEW AIR VALVE SETPOINT IS ",Air_sp,"%."  
8740 PRINT USING 8790;"NEW FUEL VALVE SETPOINT IS ",Fuel_sp,"%."  
8750 PRINT USING 8790;"NEW BACK VALVE SETPOINT IS ",Back_sp,"%."  
8760 PRINT USING 8790;"NEW H2O VALVE SETPOINT IS ",Quench_sp,"%."  
8770 PRINT USING 8800;"AUTO PRINT/STORE INTERVAL TURNED OFF."  
8780 IMAGE 10X,27A,3D.D,2A  
8800 RETURN  
8810 Image 10X,37A  
8820 RETURN  
8830 Image 10X,27A,3D.D,2A  
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$(TIMEDATE),"NEW H2O VALVE SETPOINT IS ",Quench_sp,"%.
9320  IMAGE 8A,2X,26A,3D.D,2A
9330  PRINTER IS 1
9340  GOTO Restart
9350  Air_out_sp: !
9360  PRINT TABXY(1,27);"PRESENT %OUTPUT OF AIR VALVE IS ";DROUND(Air_sp,4);"%.
9370  INPUT "ENTER NEW %OUTPUT OF AIR VALVE",Air_sp
9380  Setpoint=Air_sp
9390  J=27
9400  GOSUB Confirm_sp
9410  Air_sp=Setpoint
9420  Control_ind(1)=0
9430  Air_flow_sp=-9.99
9440  GOSUB Update valves
PRINT USING 9460;TIME$(TIMEDATE),"NEW AIR VALVE SETPOINT IS ",Air_sp,"%.
IMAGE 8A,2X,26A,3D.D,2A
PRINTER IS 1
GOTO Restart

PRINT \(\text{TABXY}(1,27)\);"PRESENT AIR FLOW SETPOINT IS ";Air_flow_sp;" LBM/SEC."
INPUT "ENTER NEW AIR FLOW SETPOINT VALUE",Air_flow_sp
Setpoint=Air_flow_sp
J=31
GOSUB Confirm_sp
Air_flow_sp=Setpoint
Control_ind(1)=1
PRINT USING 9580;TIME$(TIMEDATE),"NEW AIR FLOW SETPOINT IS ",Air_flow_sp,
" LBM/HR."
IMAGE 8A,2X,25A,2D.2D,8A
PRINTER IS 1
GOTO Restart

PRINT \(\text{TABXY}(1,27)\);"PRESENT %OUTPUT OF BACK PSI VALVE IS ";DROUND(Back_sp,4);
"%.
INPUT "ENTER NEW %OUTPUT OF BACK PSI VALVE",Back_sp
Setpoint=Back_sp
J=29
GOSUB Confirm_sp
Back_sp=Setpoint
Control_ind(3)=0
Sys_psi_sp=-999.
GOSUB Update_valves
PRINT USING 9720;TIME$(TIMEDATE),"NEW BACK PSI VALVE SETPOINT IS ",Back_sp,
"%.
IMAGE 8A,2X,31A,3D.D,2A
PRINTER IS 1
GOTO Restart

PRINT \(\text{TABXY}(1,27)\);"PRESENT SYS. PSI SETPOINT IS ";Sys_psi_sp;" ." INPUT "ENTER NEW SYS. PSI SETPOINT VALUE",Sys_psi_sp
Setpoint=Sys_psi_sp
J=32
GOSUB Confirm_sp
Sys_psi_sp=Setpoint
Control_ind(3)=1
PRINT USING 9840;TIME$(TIMEDATE),"NEW SYS. PSI SETPOINT IS ",Sys_psi_sp,
".
IMAGE 8A,2X,25A,DDD.D,2A
PRINTER IS 1
GOTO Restart

PRINT \(\text{TABXY}(1,27)\);"PRESENT %OUTPUT OF FUEL VALVE IS ";DROUND(Fuel_sp,4);
"%.
INPUT "ENTER NEW %OUTPUT OF FUEL VALVE",Fuel_sp
Setpoint=Fuel_sp
J=26
GOSUB Confirm_sp
Fuel_sp=Setpoint
Control_ind(2)=0
Fa_ratio_sp=-.999
GOSUB Update_valves
PRINT USING 5980;TIME$(TIMEDATE),"NEW FUEL VALVE SETPOINT IS ",Fuel_sp,"%
IMAGE 8A,2X,27A,3D.D,2A
9990 PRINTER IS 1
10000 GOTO Restart
10010 Fa_ratio_sp: !
10020 PRINT TABXY(1,27);"PRESENT F/A RATIO SETPOINT IS ";Fa_ratio_sp;" ."
10030 INPUT "ENTER NEW F/A RATIO SETPOINT VALUE",Fa_ratio_sp
10040 Setpoint=Fa_ratio_sp
10050 J=27
10060 GOSUB Confirm_sp
10070 Fa_ratio_sp=Setpoint
10080 Control ind(2)=1
10090 PRINT USING 10100;TIME$(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;"AO3,0,"&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)11,Prt_int
10970 Tstart(3)=TIMEDATE
10980 PRINTER IS 701
10990 IF Prt_int=-1 THEN
11000	 PRINT USING 11010;TIME$(TIMEDATE),"AUTO PRINT/STORE INTERVAL HAS BEEN T
11010	 IMAGE 8A,2X,46A
11020 ELSE
11030	 PRINT USING 11040;TIME$(TIMEDATE),"AUTO PRINT/STORE INTERVAL SET AT ",P
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
RETURN

1170 Retract: !
1180 Flag(4)=0
1190 Tinsert=Tinsert
1200 PRINT IS 701
1210 PRINT USING 11140; TIME$(TIMEDATE), "SPECIMEN HAS BEEN RETRACTED!"
1220 PRINT IS 1
1230 RETURN

1240 Statistics: !
1250 FOR J=3 TO 11
1260 Stat(2,J-2)=Array(J,1)
1270 Stat(3,J-2)=Array(J,1)
1280 FOR I=1 TO Data_pts
1290 Stat(1,J-2)=Stat(1,J-2)+Array(J,I)
1300 IF Array(J,I)<Stat(2,J-2) THEN Stat(2,J-2)=Array(J,I)
1310 IF Array(J,I)>Stat(3,J-2) THEN Stat(3,J-2)=Array(J,I)
1320 NEXT I
1330 Stat(4,J-2)=Stat(4,J-2)/Data_pts
1340 FOR I=1 TO Data_pts
1350 Stat(4,J-2)=Stat(4,J-2)+(Array(J,I)-Stat(1,J-2))^2
1360 NEXT I
1370 Stat(4,J-2)=(Stat(4,J-2)/(Data_pts-1))^.5
1380 NEXT J
1390 RETURN

1400 Summary: !
1410 PRINT IS 26
1420 PRINT USING "13A,11A"; "RUN SUMMARY: ", DATE$(TIMEDATE)
1430 PRINT
1440 PRINT " ..................FACILITY NOTES..............."
1450 PRINT
1460 PRINT USING "25A,DDD.D"; "TOTAL # COMBUSTOR HOURS: ", Tcomb
1470 PRINT USING "25A,DDD.D"; "TOTAL # COMBUSTOR CYCS.: ", Life_cycles
1480 PRINT
1490 PRINT USING "19A,DDD.D"; "TODAY'S RUN (HRS): ", Trun/3600
1500 PRINT USING "19A,DDD.D"; "INSERT TIME (HRS): ", Tinsert/3600
1510 PRINT USING "19A,DDD.D"; "FUEL BURNED (GAL): ", Fuel_lbs/6.74
1520 PRINT USING "19A,8A"; "STORAGE FILENAME: ", File_name$
1530 PRINT USING "19A,DDD."; " # DATA PTS: ", Data_pts
1540 PRINT
1550 PRINT "  ................TEST  STATISTICS................"
1560 PRINT
1570 PRINT USING 11580; "PARAMETER", "TARGET", "AVERAGE", "MINIMUM", "MAXIMUM", "STD .DEV.".
1580 IMAGE 9A,5X,6A,10X,7A,7X,7A,7A,6X,8A
1590 PRINT
1600 RESTORE 11650
1610 FOR I=1 TO 9
1620 READ Ans$, Image$
1630 PRINT USING Image$; Ans$, Parm$(I), Stat(1,I), Stat(2,I), Stat(3,I), Stat(4,I )
1640 NEXT I
1650 DATA "AIR FLOW", "8A,6X,10A,7X,DD.DD,9X,DD.DD,9X,DD.DD,9X,DD.DD"
1660 DATA "FA RATIO", "8A,6X,10A,7X,DD.DD,9X,DD.DD,9X,DD.DD,9X,DD.DD"
1670 DATA "PRESSURE", "8A,6X,10A,7X,DD.DD,9X,DD.DD,9X,DD.DD,9X,DD.DD"
1680 DATA "VELOCITY", "8A,6X,10A,7X,DD.DD,9X,DD.DD,9X,DD.DD,9X,DD.DD"
1690 DATA "GAS TEMP", "8A,6X,10A,7X,DD.DD,9X,DD.DD,9X,DD.DD,9X,DD.DD"
1700 DATA "SRF TEMP", "8A,6X,10A,7X,DD.DD,9X,DD.DD,9X,DD.DD,9X,DD.DD"
1710 DATA "TC AC021", "8A,6X,10A,7X,DD.DD,9X,DD.DD,9X,DD.DD,9X,DD.DD"
1720 DATA "TC AC024", "8A,6X,10A,7X,DD.DD,9X,DD.DD,9X,DD.DD,9X,DD.DD"
1730 DATA "TC AC026", "8A,6X,10A,7X,DD.DD,9X,DD.DD,9X,DD.DD,9X,DD.DD"
PRINT
GOSUB Spec_info
PRINT
PRINT "....................COMMENTS...................."
PRINT CHR$(12)
PRINTER IS 1
RETURN
Control_setup: !
CLEAR SCREEN
Flag(2)=0
Flag(3)=0
PRINT
PRINT "RIG CONTROL OPTIONS"
PRINT
PRINT 1) FUEL VALVE: MANUAL CONTROL OF % OPEN/CLOSE"
PRINT
PRINT 2) FUEL VALVE: CLOSED LOOP CONTROL OF F/A RATIO"
PRINT
PRINT 3) AIR VALVE: MANUAL CONTROL OF % OPEN/CLOSE"
PRINT
PRINT 4) AIR VALVE: CLOSED LOOP CONTROL OF AIR FLOW"
PRINT
PRINT 5) H2O VALVE: MANUAL CONTROL OF % OPEN/CLOSE"
PRINT
PRINT 6) BACK VALVE: MANUAL CONTROL OF % OPEN/CLOSE"
PRINT
PRINT 7) BACK VALVE: CLOSED LOOP CONTROL OF SYS. PSI"
PRINT
PRINT
PRINT "OTHER SETUP OPTIONS"
PRINT
PRINT 8) EDIT/REVIEW PID PARAMETERS"
PRINT
INPUT "ENTER YOUR CHOICE OR (0) TO RETURN",Index
SELECT Index
CASE 0
GOTO Restart
CASE 1
ON KEY 6 LABEL " % FUEL VALVE",10 GOTO Fuel_out_sp
CASE 2
ON KEY 6 LABEL " F/A RATIO",10 GOTO Fa_ratio_sp
CASE 3
ON KEY 5 LABEL " % AIR VALVE",10 GOTO Air_out_sp
CASE 4
ON KEY 5 LABEL " AIR FLOW",10 GOTO Air_flow_sp
CASE 5
ON KEY 8 LABEL " % H2O VALVE",10 GOTO Quench_out_sp
CASE 6
ON KEY 7 LABEL " % BACK VALVE",10 GOTO Back_out_sp
CASE 7
ON KEY 7 LABEL "SYS. PSI",10 GOTO Sys_psi_sp
CASE ELSE
GOTO Control_setup
END SELECT
Build string: !
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
12880  RETURN
12890  Read_suffix:  !
12900  RESTORE 12940

45
12910 FOR I=1 TO 10
12920 READ Suffix$(I)
12930 NEXT I
12940 DATA "Any", "^nCn^nDrr^nEn^"F", "^nGu^"Hn^uln^nJu
12950 RETURN
12960 Read_label_lim: !
12970 RESTORE 13050
12980 FOR I=1 TO 34
12990 READ Chan_label$(I),Sensor$(I),Display_format$(I),Unit$(I)
13000 READ Hi_lim(I),Low_lim(I)
13010 NEXT I
13020 HP3497, SLOT# 0 - 20 CHANNEL MVX (A8-B9)
13030 HP3497, SLOT# 1 - 20 CHANNEL MVX (A0-B0)
13040 DATA "EXHAUST GAS TEMP", "AC067", "DDDD.", "F", 2500, 0
13050 DATA "VENTURI AIR TEMP", "AC013", "DDDD.", "F", 2500, 0
13060 DATA "INLET AIR TEMP", "AC024", "DDDD.", "F", 2500, 0
13070 DATA "INLET N2 TEMP", "AC039", "DDDD.", "F", 2500, 0
13080 DATA "PREHEAT AIR TEMP", "AC012", "DDDD.", "F", 3200, 0
13090 DATA "INSTR RING1 TEMP", "AC021", "DDDD.", "F", 3200, 0
13100 DATA "INSTR RING4 TEMP", "AC024", "DDDD.", "F", 3200, 0
13110 DATA "INSTR RING6 TEMP", "AC026", "DDDD.", "F", 3200, 0
13120 DATA "INSTR RING9 TEMP", "AC026", "DDDD.", "F", 3200, 0
13130 DATA "SPARE - TYPE K -", "KTC-7", "DDDD.", "F", 2500, 0
13140 DATA "SPARE - TYPE K -", "KTC-8", "DDDD.", "F", 2500, 0
13150 DATA "TC REF. VOLTAGE", "REF", "DDDD.", "MV", 2500, 0
13160 DATA "INSERT VOLTAGE", "", "DDDD.", "", 1000, 0
13170 DATA "SPECIMEN TEMP", "AC051", "DDDD.", "F", 3200, 1750
13180 DATA "AIR FLOW", "AC008", "DD.DD.", "#/SEC", 2.00, 0
13190 DATA "H2O-Quench FLOW", "WS075", "DD.DD.", "GPM", 50.0, 0
13200 DATA "FUEL FLOW", "FC227", "DDDD.", "#/HR", 500.0, 0
13210 DATA "NITROGEN PRESS", "AC040", "DDDD.", "PSIG", 1000, 0
13220 DATA "FUEL PRESS", "FC223", "DDDD.", "PSIG", 1000, 0
13230 DATA "PREHEATED PRESS", "AC090", "DDDD.", "PSIG", 1000, 0
13240 DATA "VIEWPORT PRESS", "AC050", "DDDD.", "PSIG", 1000, 0
13250 DATA "TEST SECT PRESS", "AC091", "DDDD.", "PSIG", 1000, 0
13260 DATA "FUEL/AIR RATIO", "F/A", "D.DD.", ",.150, 0
13270 DATA "GAS VELOCITY", "VGAS", "DDDD.", "FT/S", 3000, 0
13280 DATA "Fuel Valve %", "FUEL", "DDD.D", ",100.0, 0
13290 DATA "Air Valve %", "AIR", "DDD.D", ",100.0, 0
13300 DATA "H2O Valve %", "WATER", "DDD.D", ",100.0, 0
13310 DATA "Back Valve %", "BACK", "DDD.D", ",100.0, 0
13320 DATA "F/A Setpoint", "FA_SP", "D.DD.", ",.150, 0
13330 DATA "Mair Setpoint", "AF_SP", "DD.DD.", "#/SEC", 2.00, 0
13340 DATA "Ptest Setpoint", "SP_SP", "DDDD.", "PSIG", 1000, 0
13350 DATA "EQUIVALENT RATIO", "PHI", "DD.DD.", ",.2.00, 0
13360 DATA "SPARE", "", "DDDD.", ",1000, 0
13370 RETURN
13450 Screen_setup: !
13470 RESTORE 13550
13480 FOR I=1 TO 15
13490 READ Screen(I,1)
13500 READ Screen(I,2)
NEXT I
FOR I=1 TO 11
READ Print_order(I)
NEXT I
DATA 4,19,3,20,5,22,7,21,8,23,14,40,1,15,40,18,24,15,24,23,25,8,14,6,7,9,3,5
RETURN
!!!!!!!!!!!!!!!!!!!!!!! UTILITY SUBROUTINES !!!!!!!!!!!!!!!!!!!!!!!!
Restart:
IF Flag(1)=1 THEN Fuel_lbs=Fuel_lbs+Dval(16)*Tloop/3600
OUTPUT 709;"VS1"
OUTPUT 709;"VT3"
GOTO Scan
Rig_restart:
GOSUB Log
GOSUB Print_header_1
GOTO Init_variables
Invalid:
BEEP
DISP "NOT VALID KEY"
WAIT 1
DISP ""
RETURN
Shutdown:
BEEP
LINPUT "DO YOU REALLY WISH TO SHUTDOWN? (Y/N)",Ans$
IF Ans$="Y" THEN
PRINTER IS 701
PRINT USING "8A,2X,38A";TIME$(TIMEDATE),"EMERGENCY SHUTDOWN HAS BEEN REQUESTED!"
GOSUB Cooldown
GOTO Restart
ELSE
GOTO Restart
END IF
Log:
GOSUB Spec_update
GOSUB Write_common
IF Trun<60 THEN GOTO 13960
IF Data_pts=0 THEN
File_name$="No data!"
ELSE
J=1
GOSUB Write_data
GOSUB Statistics
END IF
GOSUB Summary
RETURN
Pgm_stop:
GOSUB Log
DISP "PROGRAM ENDS"
BEEP 500,3
WAIT 3
CLEAR SCREEN
GOTO Main_menu_keys
STOP
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.
Figure 5.—Combustor liner, swirl plate, and fuel nozzle assembly.

Overall length = 43 cm (17 in.)

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

Diameter = 10 cm (4 in.)
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**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>INLET N₂ TEMP</td>
<td>44. F</td>
</tr>
<tr>
<td>INLET AIR TEMP</td>
<td>187. F</td>
</tr>
<tr>
<td>PREHEAT AIR TEMP</td>
<td>318. F</td>
</tr>
<tr>
<td>INSTR RING TEMP</td>
<td>2423. F</td>
</tr>
<tr>
<td>TEST SECT TEMP</td>
<td>2569. F</td>
</tr>
<tr>
<td>SPECIMEN TEMP</td>
<td>2502. F</td>
</tr>
<tr>
<td>EXHAUST GAS TEMP</td>
<td>253. F</td>
</tr>
<tr>
<td>FUEL/AIR RATIO</td>
<td>.113</td>
</tr>
<tr>
<td>EQUIVALENT RATIO</td>
<td>1.69</td>
</tr>
<tr>
<td>GAS VELOCITY</td>
<td>61. FT/S</td>
</tr>
<tr>
<td>Mair Setpoint</td>
<td>1.00 USEC</td>
</tr>
<tr>
<td>F/A Setpoint</td>
<td>.113</td>
</tr>
<tr>
<td>Ptest Setpoint</td>
<td>80. PSIG</td>
</tr>
<tr>
<td>NITROGEN PRESS</td>
<td>557. PSIG</td>
</tr>
<tr>
<td>FUEL PRESS</td>
<td>236. PSIG</td>
</tr>
<tr>
<td>VIEWPORT PRESS</td>
<td>78. PSIG</td>
</tr>
<tr>
<td>PREHEATED PRESS</td>
<td>80. PSIG</td>
</tr>
<tr>
<td>TEST SECT PRESS</td>
<td>80. PSIG</td>
</tr>
<tr>
<td>AIR FLOW</td>
<td>1.00 #SEC</td>
</tr>
<tr>
<td>FUEL FLOW</td>
<td>487. #HR</td>
</tr>
<tr>
<td>H₂O-Quench FLOW</td>
<td>9.93 GPM</td>
</tr>
<tr>
<td>M₂-Viewport FLOW</td>
<td>1.50 ACFM</td>
</tr>
<tr>
<td>Air Valve x</td>
<td>58.3 x</td>
</tr>
<tr>
<td>Fuel Valve x</td>
<td>35.3 x</td>
</tr>
<tr>
<td>Back Valve x</td>
<td>82.0 x</td>
</tr>
<tr>
<td>H₂O Valve x</td>
<td>45.0 x</td>
</tr>
</tbody>
</table>

**RUN TIME:** 0 HRS, 47MIN  **TEST TIME:** 34.8 HRS

---

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

---

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

.................FACILITY NOTES.................
COMBUSTOR TIME LOGGED : 8 HRS, 50MIN
INSERTED LEAN-BURN TIME : 0 HRS, 0 MIN
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.................

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>TARGET</th>
<th>AVERAGE</th>
<th>STD.DEV.</th>
<th>MIN</th>
<th>MAX</th>
</tr>
</thead>
<tbody>
<tr>
<td>AIR FLOW (LB/SEC)</td>
<td>1.0</td>
<td>0.999</td>
<td>0.0012</td>
<td>0.9967</td>
<td>1.0044</td>
</tr>
<tr>
<td>FA RATIO</td>
<td>0.121</td>
<td>0.121</td>
<td>0.0003</td>
<td>0.1201</td>
<td>0.1215</td>
</tr>
<tr>
<td>PRESSURE (PSIG)</td>
<td>80</td>
<td>80.00</td>
<td>2.988</td>
<td>79.25</td>
<td>80.68</td>
</tr>
<tr>
<td>VELOCITY (FT/SEC)</td>
<td>60</td>
<td>61.13</td>
<td>0.552</td>
<td>59.27</td>
<td>62.59</td>
</tr>
<tr>
<td>GAS TEMP (F)</td>
<td>2675</td>
<td>2670</td>
<td>27.01</td>
<td>2597</td>
<td>2751</td>
</tr>
<tr>
<td>SRF TEMP (F)</td>
<td>2450</td>
<td>2461</td>
<td>23.33</td>
<td>2397</td>
<td>2530</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>POSITION</th>
<th>SPECIMEN</th>
<th>INSTALLED CYCLES</th>
<th>FUEL LEAN</th>
<th>FUEL RICH</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>HPBR-4</td>
<td>28 APR 1993</td>
<td>6</td>
<td>1 HRS, 3 MIN</td>
</tr>
<tr>
<td>#2</td>
<td>EMPTY</td>
<td>0</td>
<td>0</td>
<td>0 HRS, 0 MIN</td>
</tr>
</tbody>
</table>

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.

\[ T_s = 0.828 \times T_g + 290 \]

where \( T_s \) is sample temp (F)

\( T_g \) is gas temp (F)

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.
Rich–Burn Condition: \( t/a = 0.115 \)

Sample Temperature = 2503 +/- 20 F (1373 +/- 16 C)

○ 95% confidence

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

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.

## Subject Terms

Burner rig; Materials testing

## Security Classification

Unclassified

## Number of Pages

58

## Price Code

A04