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

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INTRODUCTION

The rich-burn quick-quench lean-burn (RQL or RBQQ) combustor is one potential concept being considered for the next generation high speed civil transport (HSCT) aircraft (ref.1). The rationale for developing this and other alternate combustor concepts derives primarily from NO\textsubscript{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\textsubscript{3}N\textsubscript{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 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
exhaust valve. The exhaust orifice is a water cooled plate with a 5 cm (2 in) diameter orifice in its center. The purpose of this orifice is maintain a higher pressure in the test section than in the quench section and thereby prevent water vapor from entering the test section. The quench ring is a 10.1 cm (4 in) long water cooled cylinder with holes in its interior periphery and a spray nozzle in the center on its inside diameter. Cooling water sprays through the holes and nozzle to cool the combustion product gas flow. Typically a water flow rate of 38 l/min (10 gpm) is used to cool the gas to below 120°C (250°F) by the time it reaches the end of the 15.2 cm (6 in) diameter by 0.92 m (3 ft) long quench pipe.

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

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

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

The sample holder is welded to the end of a 2.5 cm (1.0 in) diameter shaft which carries the supply and return water for the holder. This shaft passes through two bearings and is attached to a pair of air-operated cylinders which allow translation (by remote control) of the holder to the center line of the test section flow path. Between the two bearings the shaft can be broken for ease of assembly and maintenance. The air cylinders and flexible water feed and return lines are contained in the pressure containment vessel.
This vessel is pressurized with nitrogen to assure that no combustion product gases enter the vessel through the slight leakage associated with clearances in the final bearing. The use of nitrogen is required because of the fuel-rich environment. A differential pressure transducer and automatic valve are used to maintain the pressure in the vessel 150 kPa (25 psi) greater than that in the test section.

The sample holder is thermal barrier coated (Y₂O₃-ZrO₂) 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 (mₐ) and fixed system pressure (Pₛ). Both the resultant gas temperature (Tₘ) and sample temperature (Tₛ) is thus fixed by the selected f/a, mₐ and Pₛ. The rig typically operates with mₐ=0.45 kg/sec (1 lbm/sec). This flow rate was selected to provide adequate cooling to the combustor liner over the entire operating range of the combustor which has broad stability limits. Combustion can be initiated and maintained at equivalence ratios (ϕ) of 0.4 to 2.0 (f/a of 0.025 to 0.135), however
the region around stoichiometric ($f/a=0.06-0.1$, $\phi=0.9-1.5$) is avoided to minimize rig component durability problems. If the $f/a$ selected is such that moderate combustion temperatures are attained, the rig can be run with $m_e$ 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 modeling 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 (Tg=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.
! PROGRAM "X6 SHORT"
! HIGH PRESSURE BURNER RIG - DATA ACQUISITION AND CONTROL
! LAST REVISION 10/93 ; C.ROBINSON ; X-5547

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 Specimens$(2)[15], Install$(2)[15], Spec_info$(2)[80]
DIM Ans$(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 Li$[1], L4$[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 Volt(30), Dval(40), Rref(13), R(13), Hi_lim(40), Low_lim(40)
DIM P(7, 5), Amt(5), P_prop(5), Ignite_sp(4), Stor_buf(13, 500), Array(13, 500)
DIM 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
DIM REAL Ts, Trun, Tcomb, Tinsert, Tretract, Tloop, Quench_sp, Back_sp

INT INTEGER I, J, N, X, Y, Data pts, Pid, Pnt int

INTEGER Print_order(11), Cycles(6), Life_cycles, Control_ind(3), Flag(10)
INTEGER Airout, Backout, Quenchout, Fuelout

PRINTER 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); DATES(TIME(date)) & "..." & TIME(date)
LINPUT "IS THIS THE CORRECT TIME AND DATE? (Y/N)", Ans$
PRINT TABXY(1, 27); ""
IF Ans$="Y" OR Ans$="y" THEN GOTO 300
LINPUT "ENTER TODAY'S DATE & TIME (08 JUL 1991 09:45:30)", Ans$
SET TIME_DATE(DATE(Ans$[1, 11]) + TIME(Ans$[13, 20]))

Main_menu_keys: 
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 " 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"
PRINT " OPTION MENU "
PRINT " F1: DATA ACQ. AND CONTROL PGM "
PRINT " F3: EDIT TEST SETUP "
PRINT " F5: CREATE DOS FILE (from BDAT) FOR "
PRINT " F7: PRINT CONTENTS OF A DATA FILE "
PRINT " F8: PLOTTING ROUTINE "
PRINT " 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 "ASCl2DOS",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  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$(X)&",";Xmin
1990  LABEL L5$s[1,5]
2000  FOR I=1 TO 5
2010    MOVE 10+I*20,15
2020    OUTPUT L5$ USING Display_format$(X)&",";Xmin+Xdelta*2*I
2030  LABEL L5$s[1,5]
2040  NEXT I
2050  ! SCALE Y AXIS
2060  MOVE 6,19
2070  OUTPUT L5$ USING Display_format$(Y)&",";Ymin
2080  LABEL L5$s[1,5]
2090  FOR I=1 TO 7
2100    MOVE 6,I*10+19
2110    OUTPUT L5$ USING Display_format$(Y)&",";Ymin+Ydelta*I
2120  LABEL L5$s[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$," : ",Ans$s[1,50]
2250  MOVE 0,7.5
2260  CSIZE 2.0
2270  OUTPUT L8$ USING "DDDD.DD,#";Xdelta
2280  LABEL USING "7A,8A";"XDELTA=",L8$
2290  MOVE 20,7.5
2300  OUTPUT L8$ USING "DDDD.DD,#";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
  
27
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$(1)
2680 INPUT "ENTER NEW P/A RATIO TARGET",Parm$(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
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$=""
3360 Data_pts=0
3370 Trun=0.
3380 Tinsert=0.
3390 Tretract=0.
3400 Fuel_lbs=0.
3410 MAT_Flag= (0.)
3420 MAT_Control_ind= (0.)
3430 MAT_Volt= (0.)
3440 MAT_Dval= (0.)
3450 MAT_Stor_buf= (0.)
3460 MAT_Cox= (0.)
3470 MAT_Stat= (0.)
3480 Soft_keys: !
3490 CLEAR SCREEN
3500 ON KEY 1 LABEL " FORCED SHUTDOWN", 10 GOTO Shutdown
3510 ON KEY 5 LABEL " % AIR VALVE", 10 GOTO Air_out_sp
3520 ON KEY 3 LABEL "GRAPHIC DISPLAY", 10 GOTO Set_display
3530 ON KEY 4 LABEL " MANUAL DATA ", 10 GOSUB Man_prt_stor
3540 ON KEY 6 LABEL "PREVIOUSLIGHTOFF", 10 GOSUB Ignite_sp
3550  ON KEY 9 LABEL "","10 GOSUB Invalid
3560  ON KEY 7 LABEL "% BACK VALUE","10 GOTO Back_out_sp
3570  ON KEY 8 LABEL "% H2O VALUE","10 GOTO Quench_out_sp
3580  ON KEY 2 LABEL "CONTROL SETUP","10 GOTO Control_setup
3590  ON KEY 10 LABEL "","10 GOSUB Invalid
3600  ON KEY 11 LABEL "","10 GOSUB Invalid
3610  ON KEY 12 LABEL "INTERVAL","10 GOTO Set_prt_int
3620  ON KEY 13 LABEL "","10 GOSUB Invalid
3630  ON KEY 14 LABEL "","10 GOSUB Invalid
3640  ON KEY 15 LABEL "","10 GOSUB Invalid
3650  ON KEY 16 LABEL "","10 GOSUB Invalid
3660 Init_scanner: !
3670  OUTPUT 709;"AF8AL30AC8VT4VN23VA0VS1VD5SD0AE1"
3680  OUTPUT 709;"VT3"
3690  Tstart(3)=TIMEDATE
3700  Ts=TIMEDATE
3710 Scan: !
3720  Tloop=TIMEDATE-Ts
3730  Ts=TIMEDATE
3740  OUTPUT 709;"VT3"
3750  SYSTEM PRIORITY 15
3760  FOR I=1 TO 23
3770  ENTER 709 USING "#,K";Volt(I)
3780  NEXT I
3790  SYSTEM PRIORITY 9
3800  OUTPUT 709;"VT3"
3810  GOSUB Convert
3820  GOSUB Calculate
3830  GOSUB Check
3840  GOSUB Control
3850  GOSUB Status
3860  GOSUB Display
3870  OUTPUT 709;"AO3,0,"&VAL$(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 (c.coximeter) : 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
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: 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
END IF
GOSUB Illustrate
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 55,60 J=3 GOSUB Read_draw_xy MOVE 25,50 J=3 GOSUB Read_draw_xy MOVE 17.5,42.5 J=6 GOSUB Read_draw_xy MOVE 105,40 J=6 GOSUB Read_draw_xy MOVE 100,50 J=2 GOSUB Move_draw_xy DATA 105,45,110,54,115,54,115,51,110,51,110,40 ! TURBULATOR DATA 100,65,100,55,100,50,100,40 ! SPECIMEN AREA PEN 2
5940    MOVE 78.5,0
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"
6510    return
6520    overlay_num:    !
6530  RESTORE 6590
6540  FOR I = 1 TO 17
6550    READ J, X, Y
6560    OUTPUT LS$ USING Display_format$(J)"",#";Dval(J)
6570    PRINT TABXY(X, Y); LS$
6580  NEXT I
6590  DATA 15, 10, 8, 3, 10, 9, 18, 15, 25, 6, 26, 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
control loop: 

SELECT J

CASE 24  ! F/A RATIO
Err=Dval(30)-Dval(24)
Pid=1
Sp_fraction=Fuel_sp/100
GOSUB Pid
Fuel_sp=Out*100

CASE 15  ! AIR MASS FLOW
Err=Dval(31)-Dval(15)
Pid=2
Sp_fraction=Air_sp/100
GOSUB Pid
Air_sp=Out*100

CASE 23  ! SYS. PSI - REVERSED CONTROL
Err=Dval(32)-Dval(23)
Pid=3
Sp_fraction=Back_sp/100
GOSUB Pid
Out=Sp_fraction+(Sp_fraction-Out)
Back_sp=Out*100
END SELECT
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 11
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: !
8020  PRINT "PRINT OUT OF TEST DATA"
8030  PRINT "* THESE ARE THE PARAMETERS TO BE PRINTED OUT"
8040  FOR I=1 TO 11
8050    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 ",",Sensor$(Print_order(I))," = ",Chan_label$(Print_order(I))
8180  IMAGE 2D,A,2X,5A,3A,16A
8200  FOR I=1 TO 11
8210    PRINT USING ",",Sensor$(Print_order(I))
8260  NEXT I
8270  PRINT
8280  PRINTER IS 1
8290 RETURN
8300 Man_prt_stor: !
8310 GOSUB Print_data
8320 GOSUB Store_data
8330 RETURN
8340 Print_data: !
8350 PRINTER IS 701
8360 GOSUB Check
8370 PRINT USING "8A,2X,#";TIME$(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 Fa_ratio_sp=-.999
8600 Fuel_sp=0.
8610 ON KEY 6 LABEL "RESTART ",10 GOTO Rig_restart
8620 Sys_psi_sp=-999.
8630 Back_sp=80.
8640 ON KEY 7 LABEL " % BACK VALVE",10 GOTO Back_out_sp
8650 Air_flow_sp=-9.99
8660 Air_sp=60.
8670 ON KEY 5 LABEL " % AIR VALVE",10 GOTO Air_out_sp
8680 Quench_sp=0.
8690 GOSUB Update_valves
8700 ON KEY 1 LABEL " STOP SCAN",10 GOTO Pgm_stop
8710 PRINT USING 8800;"SHUTDOWN SEQUENCE IS BEING INITIATED."
8720 PRINT USING 8790;"NEW AIR VALVE SETPOINT IS ",Air_sp,"%.
8730 PRINT USING 8790;"NEW FUEL VALVE SETPOINT IS ",Fuel_sp,"%.
8740 PRINT USING 8790;"NEW BACK VALVE SETPOINT IS ",Back_sp,"%.
8750 PRINT USING 8790;"NEW H2O VALVE SETPOINT IS ",Quench_sp,"%.
8760 PRINT USING 8800;"AUTO PRINT/STORE INTERVAL TURNED OFF."
8770 IMAGE 10X,27A,3D.D,2A
8780 IMAGE 10X,37A
8790 PRINTER IS 1
8800 RETURN
8810 Ignite_sp: !
8820 Fuel_sp=Ignite_sp(1)
8830 ON KEY 6 LABEL " % FUEL VALVE",10 GOTO Fuel_out_sp
8840 Air_sp=Ignite_sp(2)
8850 Back_sp=Ignite_sp(3)
8860 Quench_sp=Ignite_sp(4)
8890  GOSUB Update valves
8900  PRINTER IS 701
8910  PRINT USING 8920;TIME$(TIMEDATE),"PREVIOUS LIGHT OFF CONDITIONS HAVE BEEN
9000  RECALLED."
8920  IMAGE 8A,2X,49A
8930  PRINT USING 8970;"NEW FUEL VALVE SETPOINT IS ",Fuel_sp,"%.
8940  PRINT USING 8970;"NEW AIR   VALVE SETPOINT IS ",Air_sp,"%.
8950  PRINT USING 8970;"NEW BACK VALVE SETPOINT IS ",Back_sp,"%.
8960  PRINT USING 8970;"NEW H2O   VALVE SETPOINT IS ",Quench_sp,"%.
8970  IMAGE 10X,27A,3D.D,2A
8980  PRINTER IS 1
8990  RETURN
9000  Light_off:!
9010  Flag(1)=1
9020  Tstart(1)=TIMEDATE
9030  IF Dval(24)<.070 THEN Flag(5)=0
9040  IF Dval(24)>0.70 THEN Flag(5)=1
9050  Ignite_sp(1)=Fuel_sp
9060  Ignite_sp(2)=Air_sp
9070  Ignite_sp(3)=Back_sp
9080  Ignite_sp(4)=Quench_sp
9090  Quench_sp=60.
9100  GOSUB Update_valves
9110  FOR I=1 TO 2
9120  IF Specimen$(I)="EMPTY" THEN GOTO 9150
9130  Cycles(I)=Cycles(I)+1
9140  NEXT I
9150  NEXT I
9160  PRINTER IS 701
9170  PRINT USING "8A,2X,43A";TIME$(TIMEDATE),"RIG HAS BEEN IGNITED!"
9180  PRINT USING 9190;"NEW H2O   VALVE SETPOINT IS ",Quench_sp,"%.
9190  IMAGE 10X,27A,3D.D,2A
9200  PRINTER IS 1
9210  RETURN
9220  Quench_out_sp:!
9230  PRINT TABXY(1,27);"PRESENT %OUTPUT OF H2O VALVE IS ";DROUND(Quench_sp,4);
9240  "%.
9250  INPUT "ENTER NEW %OUTPUT OF H2O VALVE",Quench_sp
9260  Setpoint=Quench_sp
9270  J=28
9280  GOSUB Confirm_sp
9290  Quench_sp=Setpoint
9300  GOSUB Update_valves
9310  PRINT USING 9320;TIME$(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

39
PRINT USING 9460; TIME$(TIMEDATE), "NEW AIR VALVE SETPOINT IS ", Air_sp, ": %.
IMAGE 8A, 2X, 26A, 3D.D, 2A
PRINTER IS 1
GOTO Restart
PRINT TABXY(1, 27); "PRESENT AIR FLOW SETPOINT IS "; Air_flow_sp; " LBM/SEC."
INPUT "ENTER NEW AIR FLOW SETPOINT VALUE", Air_flow_sp
Setpoint=Air_flow_sp
J=31
GOSUB Confirm_sp
Air_flow_sp=Setpoint
Control_ind(1)=1
PRINT USING 9580; TIME$(TIMEDATE), "NEW AIR FLOW SETPOINT IS ", Air_flow_sp, " LBM/HR."
IMAGE 8A, 2X, 25A, 2D.2D, 8A
PRINTER IS 1
GOTO Restart
Back_out_sp: !
PRINT 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$(TIMEDATE), "NEW BACK PSI VALVE SETPOINT IS ", Back_sp, " ."
IMAGE 8A, 2X, 31A, 3D.D, 2A
PRINTER IS 1
GOTO Restart
Sys_psi_sp: !
PRINT TABXY(1, 27); "PRESENT SYS. PSI SETPOINT IS "; Sys_psi_sp; " ."
INPUT "ENTER NEW SYS. PSI SETPOINT VALUE", Sys_psi_sp
Setpoint=Sys_psi_sp
J=32
GOSUB Confirm_sp
Sys_psi_sp=Setpoint
Control_ind(3)=1
PRINT USING 9840; TIME$(TIMEDATE), "NEW SYS. PSI SETPOINT IS ", Sys_psi_sp, " ."
IMAGE 8A, 2X, 25A, DDD.D, 2A
PRINTER IS 1
GOTO Restart
Fuel_out_sp: !
PRINT 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_sp,
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$(TIMEDATE),"AUTO PRINT/STORE INTERVAL HAS BEEN TURNED OFF!"
11010 \ IMAGE 8A,2X,46A
11020 ELSE
11030 \ PRINT USING 11040;TIME$(TIMEDATE),"AUTO PRINT/STORE INTERVAL SET AT ",Prt_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$(TIMEDATE),"SPECIMEN HAS BEEN INSERTED !"
11140 \ IMAGE 8A,2X,28A
11150 \ PRINTER IS 1
11160 RETURN
11170 Retract: !
11180 Flg(4)=0
11190 Retract=Tinsert
11200 PRINTER IS 701
11210 PRINT USING 11140;TIME$(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$(TIMEDATE)
11430 PRINT "
11440 PRINT "  .....................FACILITY NOTES...................."
11450 PRINT "
11460 PRINT USING "25A,DDD.D";"TOTAL # COMBUSTOR HOURS: ",Tcomb
11470 PRINT USING "25A,DDD.D";"TOTAL # COMBUSTOR CYCS.: ",Life_cycles
11480 PRINT "
11490 PRINT USING "19A,DD.D";"TODAY'S RUN (HRS): ",Trun/3600
11500 PRINT USING "19A,DD.D";"INSERT TIME (HRS): ",Tinsert/3600
11510 PRINT USING "19A,DD.D";"FUEL BURNED (GAL): ",Fuel_lbs/6.74
11520 PRINT USING "19A,DD.D";"STORAGE FILENAME: ",File_name$
11530 PRINT USING "19A,DD.D";"# DATA PTS: ",Data_pts
11540 PRINT "
11550 PRINT "  ................TEST STATISTICS...................."
11560 PRINT "
11570 PRINT USING 11580;"PARAMETER","TARGET","AVERAGE","MINIMUM","MAXIMUM","STD
11580 .DEV."
11590 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$(I),Stat(1,I),Stat(2,I),Stat(3,I),Stat(4,I)
11640 NEXT I
11650 DATA "AIR FLOW","8A,6X,10A,7X,DD.DD,9X,DD.DD,9X,DD.DD,9X,DD.DD"
11660 DATA "FA RATIO","8A,6X,10A,7X,DD.DD,9X,DD.DD,9X,DD.DD,9X,DD.DD"
11670 DATA "PRESSURE","8A,6X,10A,7X,DD.DD,9X,DD.DD,9X,DD.DD,9X,DD.DD"
11680 DATA "VELOCITY","8A,6X,10A,7X,DD.DD,9X,DD.DD,9X,DD.DD,9X,DD.DD"
11690 DATA "GAS TEMP","8A,6X,10A,7X,DD.DD,9X,DD.DD,9X,DD.DD,9X,DD.DD"
11700 DATA "SRF TEMP","8A,6X,10A,7X,DD.DD,9X,DD.DD,9X,DD.DD,9X,DD.DD"
11710 DATA "TC AC021","8A,6X,10A,7X,DD.DD,9X,DD.DD,9X,DD.DD,9X,DD.DD"
11720 DATA "TC AC024","8A,6X,10A,7X,DD.DD,9X,DD.DD,9X,DD.DD,9X,DD.DD"
11730 DATA "TC AC026","8A,6X,10A,7X,DD.DD,9X,DD.DD,9X,DD.DD,9X,DD.DD"
11740   PRINT  
11750   GOSUB Spec_info  
11760   PRINT  
11770   PRINT  "   ....................COMMENTS...................."  
11780   PRINT CHR$(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  "   OTHER SETUP OPTIONS"  
11970   PRINT  
11980   PRINT "8) EDIT/REVIEW PID PARAMETERS"  
11990   PRINT  
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 \text{l4$} = \text{"}\quad \text{"}
12350 \text{FOR I=1 TO 15}
12360 \quad \text{N=Screen(I,1)}
12370 \quad \text{IF N=40 THEN}
12380 \quad \quad \text{Part1 Disp$} = \text{"}
12390 \quad \quad \text{ELSE}
12400 \quad \quad \quad \text{OUTPUT L5$ USING Display_format$(N)$&",";Dval(N)}
12410 \quad \quad \quad \text{LTE} = \text{"......"}
12420 \quad \quad \quad \text{Part1 Disp$=\text{Chan_label$(N)[1,16]\&L6$[1,6]\&L5$[1,5]\&L1$[1,1]\&Unit$(N)[1,4]\}}
12430 \quad \quad \quad \text{END IF}
12440 \quad \quad \text{N=Screen(I,2)}
12450 \quad \quad \text{IF N=40 THEN}
12460 \quad \quad \quad \text{Part2 Disp$ = \text{"}}
12470 \quad \quad \quad \quad \text{ELSE}
12480 \quad \quad \quad \quad \quad \text{OUTPUT L5$ USING Display_format$(N)$&",";Dval(N)}
12490 \quad \quad \quad \quad \quad \quad \text{L6$} = \text{"......"}
12500 \quad \quad \quad \quad \quad \quad \text{Part2 Disp$=\text{Chan_label$(N)[1,16]\&L6$[1,6]\&L5$[1,5]\&L1$[1,1]\&Unit$(N)[1,4]\}}
12510 \quad \quad \quad \quad \quad \quad \quad \text{END IF}
12520 \quad \quad \quad \quad \quad \quad \quad \text{Disp$(I)=Part1 Disp$[1,32]\&L4$[1,4]\&Part2 Disp$[1,32]}
12530 \quad \text{NEXT I}
12540 \text{RETURN}
12550 \text{Modify string: !}
12560 \text{FOR I=1 TO 15}
12570 \quad \text{N=Screen(I,1)}
12580 \quad \text{IF N=40 THEN}
12590 \quad \quad \text{GOTO 12640}
12600 \quad \text{ELSE}
12610 \quad \quad \quad \text{OUTPUT L5$ USING Display_format$(N)$&",";Dval(N)}
12620 \quad \quad \quad \quad \text{END IF}
12630 \quad \quad \text{Disp$(I)[23,27]=L5$[1,5]}
12640 \quad \quad \text{N=Screen(I,2)}
12650 \quad \quad \text{IF N=40 THEN}
12660 \quad \quad \quad \text{GOTO 12710}
12670 \quad \quad \text{ELSE}
12680 \quad \quad \quad \quad \quad \text{OUTPUT L5$ USING Display_format$(N)$&",";Dval(N)}
12690 \quad \quad \quad \quad \quad \quad \text{END IF}
12700 \quad \quad \quad \quad \quad \quad \text{Disp$(I)[59,63]=L5$[1,5]}
12710 \quad \text{NEXT I}
12720 \text{RETURN}
12730 \text{Read coef: !}
12740 \text{RESTORE 12790}
12750 \text{FOR I=1 TO 13}
12760 \quad \text{READ Kref(I)}
12770 \quad \text{NEXT I}
12780 \quad \text{! TYPE K POLYNOMIAL CONVERSION AND REFERENCE COEFFICIENTS}
12790 \quad \text{DATA } -8.16774E-7,3.964E-4,1.6E-8
12800 \quad \text{DATA } -5.1E-2,2.48503E4,-3.82662E5,9.9661057E7,-1.0820624E10,6.039285E11
12810 \quad \text{DATA } -1.9109E13,3.4782347E14,-3.3991028E15,1.3828514E16
12820 \quad \text{FOR I=1 TO 13}
12830 \quad \text{READ Rref(I)}
12840 \quad \text{NEXT I}
12850 \quad \text{! TYPE R POLYNOMIAL CONVERSION AND REFERENCE COEFFICIENTS}
12860 \quad \text{DATA } -2.11284E-7,5.334E-5,1.2E-8
12870 \quad \text{DATA } 4.8343651E1,1.109827E-1,-2.435389E-6,4.5164488E-11,1.8172612E-16,0,0,0,0
12880 \quad \text{RETURN}
12890 \text{Read suffix: !}
12900 \text{RESTORE 12940}
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 !!!!rrriiiiiiiiiirirrrriiirirrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrr
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 REQUESTED!"
13800 GOSUB Cooldown
13810 IF Flag(4)=1 THEN GOSUB Retract
13820 GOTO Restart
13830 ELSE
13840 GOTO Restart
13850 END IF
13860 Log: !
13870 GOSUB Spec_update
13880 GOSUB Write_common
13890 IF Trun<60 THEN GOTO 13960
13900 IF Data_pts=0 THEN
13910 File_name$="No data!"
13920 ELSE
13930 J=1
13940 GOSUB Write_data
13950 GOSUB Statistics
13960 END IF
13970 GOSUB Summary
13980 RETURN
13990 Pgm_stop: !
14000 GOSUB Log
14010 DISP "PROGRAM ENDS"
14020 BEEP 500,3
14030 WAIT 3
14040 CLEAR SCREEN
14050 GOTO Main_menu_keys
14060 STOP
14070 END
Figure 1.—Schematic of the burner rig configuration.

Figure 2.—Test cell layout including rig and supporting 400 horsepower, high-pressure compressor air supply.
Figure 3.—Photograph of burner rig and test cell.

Figure 4.—Cross section of combustor.
Figure 5.—Combustor liner, swirl plate, and fuel nozzle assembly.

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.
50 HR FUEL RICH TEST OF DuPONT C/SIC COMPOSITES

INLET N2 TEMP...... 44. F
INLET AIR TEMP...... 187. F
PREHEAT AIR TEMP...... 318. F
INSTR RING TEMP...... 2423. F
TEST SECT TEMP...... 2669. F
SPECIMEN TEMP...... 2502. F
EXHAUST GAS TEMP...... 2582. F
AIR SYSTEM
1.00 LB/SEC
188. F
88. PSIG
319. F
F/A: .113
Phi: 1.69
FUEL SYSTEM
486. LB/HR
88. PSIG
2426. F
61. FT/S
2664. F
88. PSIG
H2O SYSTEM
9.94 GPM
PYRO: 2498. F
78. PSIG
253. F

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

User 1 Caps Command

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    0.0012    .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.

\[ Ts = 0.828\times Tg + 290 \]

where \( Ts \) is sample temp (F)
\( Tg \) is gas temp (F)
Figure 13.—Range of combustion gas temperatures available as compared to adiabatic conditions.

Lean–Burn Condition: f/a = 0.063

Gas Temperature = 2788 +/- 14°F (1531 +/- 8°C)
® 95% confidence

Sample Temperature = 2473 +/- 9°F (1356 +/- 5°C)
® 95% confidence

Figure 14.—Variation of gas temperature at fixed f/a ratio.
Figure 15.—Sample temperatures calculated using the lean-burn correlation during rich-burn testing.
NASA Lewis Research Center Lean-, Rich-Burn Materials Test Burner Rig

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Unclassified - Unlimited
Subject Categories 09 and 24

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.