Hot Corrosion Test Facility at the NASA Lewis Special Projects Laboratory

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SUMMARY

The hot corrosion test facility (HCTF) at the NASA Lewis Special Projects Laboratory (SPL) is a high-velocity, pressurized burner rig currently used to evaluate the environmental durability of advanced ceramic materials such as SiC and Si₃N₄. The HCTF uses laboratory service air which is preheated, mixed with jet fuel, and ignited to simulate the conditions of a gas turbine engine. Air, fuel, and water systems are computer-controlled to maintain test conditions which include maximum air flows of 250 kg/hr (550lbm/hr), pressures of 100-600 kPa (1-6 atm), and gas temperatures exceeding 1500°C (2732°F).

The HCTF provides a relatively inexpensive, yet sophisticated means for researchers to study the high-temperature oxidation of advanced materials, and the injection of a salt solution provides the added capability of conducting hot corrosion studies.

INTRODUCTION

Future jet engines will provide more thrust at greater engine efficiency by operating at higher temperatures and using more advanced,
lightweight materials such as SiC and Si₃N₄ for hot-section engine components. The environmental durability of such candidates must be considered and is best evaluated if testing is conducted under realistic conditions, where the materials are subjected to the high temperatures and harsh environments encountered in a gas turbine engine. If operating in a corrosive environments, the high-temperature corrosion of hot-section components then becomes a concern. This process occurs when sodium, either as a fuel impurity or an airborne contaminant, combines with sulfur impurities in the fuel to form sodium sulfate (Na₂SO₄). Molten Na₂SO₄ can condense on hot engine components leading to accelerated oxidation and severe corrosion.Degradation by this salt is termed "hot corrosion."

Hot corrosion has been studied by immersion tests, thin salt film tests, and burner rig studies.¹ Burner rig tests more closely model the harsh, corrosive environments in a gas turbine engine while providing a continuous deposition of salt, opposed to the one-time deposition used in furnace testing. Two examples of previous studies at NASA Lewis involve the effect of hot corrosion on the room temperature four-point bend strength of sintered α-SiC.²³ In those experiments, test variables included 1000°C (1832°F) specimen temperature, 4 atm system pressure, 2 ppm added sodium (as NaCl), and 40 hours of exposure time. A detailed view of the product layer formed on one sample is shown in Fig. 1, where portions of this product were chipped away to examine the interior of the layer. Removing the products by HF dissolution revealed a dramatic pitting attack of the SiC substrate, shown in Fig. 2. A correlation was found between fracture strength and corrosion pit dimensions, and the
strength decreased by as much as 25-35% due to the formation of deep pits in the SiC.

Studies like this make rigs such as the HCTF and other 1 atm, mach 0.3 burner rigs at NASA LeRC very valuable in the development of advanced aerospace materials. The purpose of this report is to promote awareness of the HCTF, provide corporate documentation of both the hardware and software being used, and describe the operation and capabilities of the test facility with emphasis on corrosion testing.

CORROSION TESTING REQUIREMENTS

At this point, it is helpful to discuss both the factors that influence hot corrosion and the significance of the HCTF in such studies. The deposition of Na₂SO₄ and subsequent corrosion is a function of temperature and pressure, therefore a burner rig used to study hot corrosion must satisfy certain requirements. The HCTF’s operating range was specifically chosen such that deposition of the salt is predicted to occur on the test specimens.

As stated, hot corrosion occurs when sodium combines with sulfur impurities in the fuel to form Na₂SO₄. Deposition of Na₂SO₄ occurs in a temperature window bordered by the melting point of the salt (884°C or 1623°F) and the dew point which is pressure dependent. The dew point is the highest temperature at which the condensed phase of the salt can form. A test temperature of 1000°C (1832°F) was targeted because furnace tests have shown rapid kinetics to occur at this temperature. The dew point was calculated (see Table I) for various sodium and sulfur combinations (jet fuel is typically 0.05% S) at a test pressure of 100
kPa (1 atm). The dew point ranged between 920-970°C (1688-1778°F) for 0.5-4.0 ppm of Na, respectively. Higher operating pressures will raise the dew point and allow deposition to occur at higher temperatures. As a result, testing at higher pressures will more accurately model conditions in the engine, and since it raises the dew point, test temperatures of 1000°C (1832°F) can be obtained. Given a test pressure of 400 kPa (4 atm), dew points are on the order of 981-1038°C (1798-1900°F), therefore deposition should occur for sodium concentrations above 2.0 ppm, as indicated by Table I.

In summary, the HCTF allows testing at temperatures of 1000°C (1832°F) or above, but more importantly the capability of being pressurized to 4 atm assures Na2SO4 deposition.

TEST FACILITY SYSTEMS

The HCTF pictured in Fig. 3 has a number of critical systems which must work together to attain desired test conditions. These systems include the air, fuel, water, and salt systems which are shown schematically in Fig. 4. The combustion process occurs as preheated air is mixed with jet fuel and ignited in the combustor. After ignition, a salt solution is introduced into the gas stream. The hot gases flow downstream passing over the test specimens located in the test section, where temperature and pressure is maintained by automated control. Before exiting, the hot exhaust gases are quenched with cooling water to desired temperature levels.

AIR SYSTEM The HCTF uses 800 kPa (120 psig) pressurized air supplied by the laboratory central air system. The pressurized air is filtered
through a filter assembly and then passes through a venturi flowmeter. The mass flow rate is calculated from the pressures, temperature, and flow coefficients associated with the venturi. Air flow, which is controlled using valve A, can be supplied at rates of 50-250 kg/hr (100-550 lbm/hr), with a typical corrosion test operating at a mass flow rate of 150 kg/hr (325 lbm/hr). The air flow is directed into a preheater which increases the air temperature to 260°C (500°F) prior to entering the combustor. Preheating allows combustion to occur more efficiently, resulting in less soot development and buildup in the combustor.

The rig is pressurized to higher pressures by closing down exhaust valve B. As mentioned, test pressures can be varied between 100-600 kPa (1-6 atm), depending on mass air flow rates. Maximum air flows are available only at lower pressures. As discussed, hot corrosion tests are typically conducted at 4 atm to raise the dew point of Na₂SO₄ above 1000°C (1832°F).

**FUEL SYSTEM** The HCTF can burn Jet-A, JP-4, or JP-5 jet fuel, as well as diesel fuel. The jet fuels are supplied from a 19,000 liter (5000 gal) underground storage tank while the diesel fuel is supplied from a smaller surface tank. Each storage tank is equipped with a low-pressure fuel pump and 25-micron filter for delivering fuel to the facility. The fuel then passes through a high-pressure pump (1.7 MPa or 250 psig max.) in the test cell before being filtered through a second, 10-micron assembly and injected into the combustor.

The amount of fuel burned depends on the desired test temperature. Fuel flow is controlled with valve C, which schedules the fuel-to-air ratio required to produce the desired temperature. Flow rates, which are
measured with a turbine flowmeter, are relatively low with a maximum of 0.1 l/min (.025 gpm). A fuel nozzle (80°swirl) sprays atomized fuel into the combustor where it is mixed with the combustion air and ignited. The available range of fuel-to-air ratios and resulting gas temperatures are given in Fig. 5, suggesting only minimal heat loss when compared to calculated adiabatic temperatures. As an example, the standard hot corrosion test temperature of 1000°C (1832°F) would require a fuel-to-air ratio of approximately 0.024. This corresponds to a fuel flow near 0.073 l/min (.019 gpm) for the standard mass air flow of 150 kg/hr (325 lbm/hr).

WATER SYSTEM City water (400 kPa or 60 psig) is used to quench the combustion air exiting the test section. The hot gases expelled from the combustor, noted to reach as high as 1500°C (2732°F), must be cooled to protect the exhaust valve from thermal failure. The water pressure is initially boosted using a high-pressure pump (10 MPa or 160 psig max) before being filtered through a 25-micron filter. Water flow rates, also measured with a turbine flowmeter, are regulated with valve D as the cooling water is directed through a spray ring and water jet nozzles located before the exhaust valve. A Chromel-Alumel thermocouple (type K) monitors the exit temperature used to control the water flow. Only a flow of 2.0 l/min (.5 gpm) is required to cool the exhaust below 100°C (200°F).

SALT SYSTEM Salt solutions are injected into the hot gases leaving the combustor with an aspirating probe. The salt solution typically consists of 2-4 ppm NaCl in distilled water and is supplied from a 20 liter teflon tank located in the test cell. Salt flow is controlled with an
adjustable pump, capable of delivering a maximum steady flow of 2.0 l/hr. Current hot corrosion tests operate at a flow near 0.25 l/hr. Salt flow is indicated by a load cell which monitors the weight change of the salt tank. The salt solution is atomized within the aspirator probe and injected into the combustor.

TEST FACILITY CONFIGURATIONS

For discussion purposes, the HCTF has two primary areas of concern, the combustor and the test section (Fig. 6). Maintenance is often required in these areas due to their high-temperature nature and typically involves the replacement of certain components or the installation of test specimens. This section of the report focusses on the configuration of these two areas, discussing both the components and instrumentation which are an integral part of each area.

In Fig. 7, preheated air enters the combustor through a 1.9 cm (3/4 in) inlet. Here, a thermocouple (type K) monitors the inlet temperature used to control the preheater. Combustion pressure is also monitored. The air is forced through a swirler and mixed with the atomized fuel in the combustor liner. The fuel is sprayed from a fuel nozzle found in the center of the co-rotating swirler. Gases in the primary zone are ignited with a spark generated from an ignitor which extends through an opening in the liner. The liner, fabricated from Inconnel 601 material, is cooled with bypass air flowing down the outside diameter. This cooling air eventually dumps into the secondary zone through perforations in the liner and is added to the combustion process. The salt aspirator and a platinum-platinum/(13%)rhodium
thermocouple (type R) also extend through an opening into the liner. The combustion thermocouple monitors the flame temperature inside the liner and is used to detect a flameout condition.

As the combustor transitions into the test section, the hot gases accelerate through a nozzle and into the flame tube. Gas velocities typically reach 45-60 m/s (150-200 ft/sec) but can exceed 300 m/s (1000 ft/sec). Two test specimens (2.54 cm x 0.64 cm x 0.32 cm) are loaded horizontally through openings in the flame tube. The two specimens are held by a set of lava grips which are positioned by a lava specimen holder clamped to the flame tube. A cross section of this arrangement is shown in Fig. 8. A thermocouple (type R) is positioned on center between the two test specimens to monitor the test temperature and to control fuel flow. A flange on either side can be removed to gain easy access to the test section, which along with the transition section is packed with ceramic fiber insulation to minimize heat losses. A second set of test specimens can be assembled downstream in the test section (see Fig. 6). Here, the thermocouple is for information purposes only and temperatures are reduced approximately 25°C (50°F) due to heat losses.

DATA ACQUISITION AND CONTROL SYSTEM

The HCTF is equipped with an automated data acquisition and control system which is responsible for collecting data and modulating the control valves of the air, fuel, and water supplies. The rig is operated from the control room (Fig. 9), containing both the computer system and control panel. The computer system is integrated with the manual controls which include all the "hard-wired" permissives and
safety interlocks which must be satisfied before computer operation of
the control valves is permitted.

The computer interfaces with a data acquisition and control unit
to manage data flowing between the test facility and control room. An
internal voltmeter collects data from pressure, temperature, and flow
sensors. The data is processed by software and displayed as shown in
Fig. 10, along with test parameter setpoints and valve positions. As
setpoints are changed with the special function keys, control
subroutines compare the data with corresponding setpoints and
automatically make any necessary corrections to valve positions. Data
scanning and setpoint control occurs at 0.5-1.0 Hz. The test parameters
available for such closed-loop feedback and control include mass air
flow, specimen temperature, and system pressure.

The software was developed internally at NASA LeRC and is listed
in Appendix A for documentation purposes. In addition to data
acquisition and control, the software also provides automated
documentation. Data may be printed out or stored on a hard disk at user-
defined intervals. Furthermore, a test log (Fig. 11) is used to store
the test conditions and specimen data of individual test runs. These
test conditions include a programmable "real-time" clock which adds the
capability of unattended operation.

SAFEETY FEATURES

The HCTF was designed with safety interlocks which prevent the rig
from reaching a potentially unsafe or destructive mode. The HCTF’s
control logic will initiate a shutdown to safely handle any critical
situation. As mentioned, the computer works together with these "hard-wired" features, requiring that certain permissives are satisfied before computer operation of the control valves is permitted.

The most important parameters monitored are temperature and pressure. As previously mentioned, the HCTF was designed with a preheater which can only be operated if sufficient air flow is indicated by a pressure switch located at the venturi meter. Even as sufficient air flow is present, ignition is permitted only when the preheated air temperature is between assigned low and high limits. Other critical parameters which either must be within limits before ignition or during operation include combustor temperature, exit temperature, and system pressure. The upper and lower limits are given in Table II.

In the event that any critical limits are exceeded, an appropriate meter relay will automatically close the fuel supply solenoid valve and disable computer control of the fuel. Indicator lights in the control panel are used to provide diagnostic information. Therefore, any loss of air flow, mechanical malfunction, or operator control error will result in shutdown of the rig.

Although having a secondary logic priority, the computer will also initiate the shutdown of the facility under certain circumstances. If sensor data is not within software-defined limits, closed loop control of the setpoints is no longer possible. Therefore, the control valve to the fuel is closed, triggering the "hard-wired" shutdown. A diagnostic message is printed to indicate which parameter caused the shutdown.
CONCLUSIONS

The SPL hot corrosion test facility at NASA Lewis is a relatively simple, easy-to-operate resource for providing researchers with valuable information on advanced, high-temperature materials. Low maintenance and fuel costs make the facility attractive economically, and the rig's flexibility makes it useful for both oxidation and corrosion studies. The HCTF has been helpful in numerous programs, evaluating materials for aerospace, automotive, and other applications. Researchers interested in using the HCTF should contact the Facility Manager, Environmental Durability Branch, or the Materials Division.

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REFERENCES


APPENDIX A

The software listed on the following pages has been included to serve as documentation for the control and operational procedures used in this facility. As seen before, test facilities can experience periods of dormancy due to programmatic or personnel changes. In such a case, this record could prove critical in attempts to renew operations of the facility after any such period.
10 ! PROGRAM "X1PGM"
20 ! 4.0 ATMOSHERES, HOT CORROSION BURNER RIG
30 ! CELL #1-BLDG. 24
40  OPTION BASE 1
50  MASS STORAGE IS ":CS80,805"
60  PRINTER IS 1
70  SYSTEM PRIORITY 9
80  GOSUB Clearscreen
90  PRINT TABXY(1,5)
100  PRINT "x
110  PRINT "x
120  PRINT "x X1PGM - SPL HCTF DATA ACQ.
130  PRINT "LATEST REVISION: 1/93
140  PRINT "x
150  PRINT "x THIS PROGRAM IS THE PROPERTY OF
160  PRINT "x THE NASA ENVIROMENTAL DURABILITY
170  PRINT "x BRANCH. MAINTENANCE BY UNAUTHOR-
180  PRINT "xIZED PERSONNEL IS PROHIBITED.
190  PRINT "x
200  PRINT "x CONTACT: C. ROBINSON X-5547
210  PRINT 
x
220  WAIT 4
230  DIM Chan_label $(40) [14], Display_format$(40) [5], Sensor$(40) [5]
240  DIM Unit$(40) [5], Disp$(12) [80], L$(10), A$(5), B$(5), Title$(9), Fuel$(6)
250  DIM Ans$(25), Run_time$(11), Target_time$(15), Elap_time$(15)
260  DIM Air_control$(6), Back_control$(6), Fuel_control$(6), Blank$(80)
270  DIM Specimen$(4)[15], Install$(4)[15], Tot_time$(4)[15]
280  DIM Volt(30), Dval(40), K(13), R(13), Hi_lim(40), Low_lim(40)
290  DIM P(7,5), Amt(5), P_prop(5)
300  REAL Vref, Volt_comp, Vt, Temp, Err, Out, Prop, Sp_fraction
310  REAL Ts, Trun, Trun_start, Prev_ts, Fuel_gal, Target_temp
320  REAL Fuel_sp, Quench_sp, Air_sp, Back_sp, Setpoint
330  REAL Spec_temp_sp, Quench_temp_sp, Air_flow_sp, Back_psi_sp
340  REAL C, F, Tair, Roe, Wair_cuf, Mu, Re_cuf, Cf
350  INTEGER I, J, N, X, Z, Y, Print_order(15), Ignite_ind, Screen(12,2), Ans, Pid_ind
360  INTEGER Nlines, Nlines_page, Hot_ind, Prt_int, Out_lim_ind, Ctrl_ind, Pid
370  INTEGER Hours, Minutes, Tot_hours, Tot_minutes, Target_minutes
380  INTEGER Airout, Backout, Quenchout, Fuelout
390  Main menu_keys: !
400  PRINTER IS 1
410  OFF KEY
420  ON KEY 0 LABEL " RUN RIG ",10 GOTO Main
430  ON KEY 2 LABEL " TEST SETUP ",10 GOTO Setup
440  Menu display: !
450  GOSUB Clearscreen
460  PRINT TABXY(1,5);" MAIN MENU"
470  PRINT TABXY(1,8);" CHOOSE DESIRED OPTION"
480  PRINT TABXY(1,10);" K0: DATA ACQUISITION "
490  PRINT TABXY(1,12);" K2: TEST SETUP"
500  Echo: !
510  GOTO Echo
520  !!!!!!!!!!!!!!!!!!!!!! TEST SETUP SUBPROGRAM !!!!!!!!!!!!!!!!!!!!!!!!
530  Setup: 
540  Blank$="

550  GOSUB Read_common
560  GOSUB Clearscreen
570  GOSUB Test_info
580  PRINT TABXY(1,18);"ENTER INDEX OF INFORMATION TO BE CHANGED"
590  INPUT ",(1=TEST PARAMETERS  2=SPECIMEN DATA  0=EXIT)",N
SELECT N
CASE 1
   PRINT TABXY(1,18);Blank$
   INPUT "ENTER INDEX FOR TYPE OF TEST (1=OXIDATION  2=CORROSION)",I
   IF I=1 THEN Title$="OXIDATION"
   IF I=2 THEN Title$="CORROSION"
   INPUT "ENTER INDEX FOR FUEL TYPE (1=JET A  2= DIESEL)",I
   IF I=1 THEN Fuel$="JET A"
   IF I=2 THEN Fuel$="DIESEL"
   INPUT "ENTER TARGET TEMP IN DEG F",Target_temp
   LINPUT "ENTER TEST DURATION (xxHRS,xxMIN)",Target_time$
   LINPUT "ENTER TIME ELAPSED (xxHRS,xxMIN)",Elap_time$
   GOTO 560
CASE 2
   PRINT TABXY(1,18);Blank$
   INPUT "ENTER POSITION NO. OF SPECIMEN TO BE CHANGED",I
   GOSUB Spec_change
   GOTO 560
CASE 0
   GOSUB Write_common
   GOTO Main_menu_keys
CASE ELSE
   BEEP
   GOTO 580
END SELECT
Spec_change:
   LINPUT "ENTER 8 CHARACTER PART NO. OR -1=NO CHANGE -2=EMPTY",Ans$
   IF Ans$="-2" THEN
      Specimen$(I)="EMPTY"
      Install$(I)=""
      Tot time$(I)="0 HRS,0 MIN"
      GOTO 1050
   END IF
   IF Ans$="-1" THEN
      GOTO 980
   ELSE
      Specimen$(I)=Ans$
      END IF
   LINPUT "ENTER DATE INSTALLED (DD MMM YYY) OR -1=NO CHANGE",Ans$
   IF Ans$="-1" THEN
      GOTO 1040
   ELSE
      Install$(I)=Ans$
      END IF
   LINPUT "ENTER TEST TIME TO DATE (xxHRS,xxMIN)",Tot_time$(I)
   1050 RETURN
Test_info:
   PRINT "SPL HOT CORROSION TEST FACILITY - CURRENT TEST SETUP"
   PRINT "TEST TYPE: "&Title$
   PRINT "FUEL TYPE: "&Fuel$
   PRINT "TARGET TEMP IN DEG F: "&VAL$(Target_temp)
   PRINT "CURRENT TEST TIME REQUEST: "&Target_time$
   PRINT " TIME ELAPSED: "&Elap_time$
   PRINT " POSITION #1  POSITION #2  POSITION #3  POSITION #4"
   PRINT USING 1210;"SPEC NAME: ",Specimen$(1),Specimen$(2),Specimen$(3),Spe
PRINT USING 1220; "INSTALLED: ", Install$(1), Install$(2), Install$(3), Install$(4)
PRINT USING 1220; "TEST TIME: ", Tot_time$(1), Tot_time$(2), Tot_time$(3), Tot_time$(4)
IMAGE 11A, 4X, 8A, 10X, 11A, 7X, 11A, 7X, 11A
IMAGE 11A, 4X, 11A, 7X, 11A, 7X, 11A, 7X, 11A
RETURN

Cimen$(4)
PRINT USING 2200; "INSTALLED: ", Install$(1), Install$(2), Install$(3), Install$(4)
PRINT USING 2200; "TEST TIME: ", Tot_time$(1), Tot_time$(2), Tot_time$(3), Tot_time$(4)
IMAGE 11A, 4X, 8A, 10X, 11A, 7X, 11A, 7X, 11A
IMAGE 11A, 4X, 11A, 7X, 11A, 7X, 11A, 7X, 11A
RETURN

!!! MAIN SUBPROGRAM !!!!!!!!!!!!!!!!!!!!!!!!

Main:
CLEAR 705
GOSUB Read_coef
GOSUB Read-label_lim
GOSUB Read-common
GOSUB Read_id_val
GO SUB Screen_setup
GOSUB Build_string
RESTORE 1370
FOR I=1 TO 12
READ Print_order(I)
NEXT I
DATA 24, 23, 31, 32, 25, 26, 2, 8, 6, 7, 11, 29
Reset:
LINPUT "ENTER TODAY'S DATE AND TIME (DD MMM YYYY HH:MM:SS) ", Ans$
SET TIMEDATE DATE(Ans$(1, 11)) + TIME(Ans$(13, 20))
PRINTER IS 701
PRINT CHR$(12)
Nlines=0
GOSUB Print_header_1
PRINTER IS 701
Init variables:
Target minutes= VAL(Target time$(1, 2)) * 60 + VAL(Target time$(7, 8)) - VAL(Elap_time$(1, 2)) * 60 - VAL(Elap_time$(7, 8))
Prt int=300
Fuel_sp=0.
Quench_sp=50.
Air_sp=50.
Back_sp=50.
GOSUB Air_out
GOSUB Back_out
GOSUB Quench_out
Spec temp_sp=-999.
Air flow_sp=-99.9
Quench temp_sp=200.
Back psi sp=-99.9
Fuel_control$="OPEN"
Air_control$="OPEN"
Back control$="OPEN"
Blank$=""

Hours=0
Minutes=0
Tot hours=0
Tot minutes=0
Hot_ind=2
Ignite_ind=2
Out lim ind=0
Run time$="0 HRS, 0 MIN"
Nlines page=60
1740 Fuel gal=0.
1750 MAT Volt= (0.)
1760 MAT Dval= (0.)
1770 Soft keys: 
1780 GO SUB Clear screen
1790 ON KEY 0 LABEL " SHUT_DOWN ",10 GOTO Shutdown
1800 ON KEY 1 LABEL " START FUEL ",10 GOSUB Start fuel
1810 ON KEY 2 LABEL " % AIR VALVE",10 GOTO Air out sp
1820 ON KEY 3 LABEL " % BACK VALVE",10 GOTO Back out sp
1830 ON KEY 4 LABEL " % H20 VALVE",10 GOTO Quench out sp
1840 ON KEY 5 LABEL " SET INTERVALS",10 GOTO Set prt int
1850 ON KEY 6 LABEL " ",10 GOSUB Invalid
1860 ON KEY 7 LABEL " SET PID ",10 GOTO Pid parm
1870 ON KEY 8 LABEL " SET CONTROL ",10 GOTO Control setup
1880 ON KEY 9 LABEL " PRINT DUMP ",10 GOSUB Print data
1890 Init scanner: 
1900 OUTPUT 705;"AF0AL29AC0VT4VN30VA0VS1VD5SD0AE1"
1910 OUTPUT 705;"VT3"
1920 Tp=TIMEDATE
1930 Ts=TIMEDATE
1940 "!!!!!!!!!!!!!!!!!!!! MAIN PROGRAM LOOP !!!!!!!!!!!!!!!!!!!!!!!
1950 Scan: 
1960 Prev ts=Ts
1970 Ts=TIMEDATE
1980 OUTPUT 705;"VS"
1990 SYSTEM PRIORITY 15
2000 FOR I=1 TO 30
2010 ENTER 705 USING ";K";Volt(I)
2020 NEXT I
2030 SYSTEM PRIORITY 9
2040 OUTPUT 705;"VT3"
2050 GOSUB Convert
2060 GOSUB Calculate
2070 GOSUB Check
2080 GOSUB Control
2090 GOSUB Status
2100 GOSUB Display
2110 IF Prt_int=-3 THEN GOTO 2160
2120 IF Ts-Tp>Prt_int THEN
2130 Tp=Ts
2140 GOSUB Print data
2150 END IF
2160 GOSUB Fuel_count
2170 GOTO Scan
2180 "!!!!!!!!!!!!!!!!!!!! PRIMARY SUBROUTINES !!!!!!!!!!!!!!!!!!!!!!!!
2190 Convert: 
2200 HP 3497 ANALOG INPUT CHANNELS/SLOT #0
2210 Vref=Volt(20)
2220 FOR I=1 TO 4 ! CHAN A0-A3
2230 GOSUB Type_k
2240 NEXT I
2250 FOR I=5 TO 8 ! CHAN A4-A7
2260 GOSUB Type_r
2270 NEXT I
2280 I=11 ! CHAN B0
2290 GOSUB Type k
2300 HP 3497 ANALOG INPUT CHANNELS/SLOT #1
2310 Dval(21)=6.689*Volt(21)*1000-.428 ! CHAN A0 - VENTURI PSI
2320 Dval(22)=.318*Volt(22)*1000-.010 ! CHAN A1 - VENTURI DP
2330 ! CHAN A2 - FUEL FLOW
Dval(23) = Volt(23) * 160

! IF Dval(23) < 10 THEN! MUST ZERO CALCULATED VALUE TO TO Y-INTERCEPT
Dval(23) = 0.
GOTO 2400

! END IF

Dval(23) = (9.13E-9 * Dval(23)^2 + 4.41E-5 * Dval(23) + .0090356) * 60

! Hz to GPH
Dval(24) = 16.378 * Volt(24) * 1000 - 4.569

! CHAN A3 - FUEL PRESS

! CHAN A4 - COMB PRESS
Dval(26) = (4.007 * Volt(26) * 1000 + .008) + 14.7

! CHAN A5 - TEST PRESS
Dval(27) = 7.975 * Volt(27) * 1000 - 1.412

! CHAN A6 - H2O PRESS
Dval(28) = Volt(28) * 320

! CHAN A7 - H2O FLOW
Dval(29) = .000517 * Dval(28) + .003

RETURN

Type k:

Volt_comp = K(1) + Vref * (K(2) + Vref * K(3))
Vt = Volt_comp + Volt(I)
Temp = K(8) + Vt * (K(9) + Vt * (K(10) + Vt * (K(11) + Vt * (K(12) + Vt * (K(13) + Vt * (K(13)))))))
Dval(I) = Temp * 1.8 + 32
RETURN

Type r:

Volt_comp = R(1) + Vref * (R(2) + Vref * R(3))
Vt = Volt_comp + Volt(I)
Vt = Vt * 1E+6
Temp = R(8) + Vt * (R(9) + Vt * (R(10) + Vt * (R(11) + Vt * (R(12) + Vt * (R(13) + Vt * (R(13)))))))
Dval(I) = Temp * 1.8 + 32
RETURN

Check:

FOR Z = 1 TO 11
IF Dval(Z) < 0. THEN Dval(Z) = 0.
IF Dval(Z) > 9999. THEN Dval(Z) = 9999.
NEXT Z

FOR Z = 21 TO 32
IF Dval(Z) < 0. THEN Dval(Z) = 0.
SELECT Display_format$(Z)
CASE "DDD.D"
IF Dval(Z) > 999.9 THEN Dval(Z) = 999.9
CASE "DD.DD"
IF Dval(Z) > 99.99 THEN Dval(Z) = 99.99
CASE "D.DDD"
IF Dval(Z) > 9.999 THEN Dval(Z) = 9.999
END SELECT
NEXT Z
RETURN

Limits:

IF Dval(J) < Low_lim(J) OR Dval(J) > Hi_lim(J) THEN
GOSUB Print_Data
PRINTER IS 701
X = 2
GOSUB Turn_page
PRINT USING "8A,2X,14A,34A"; TIME$(TIMEDATE), Chan_label$(J), " DATA HAS BEEN XCEED A HI/LOW LIMIT!"
PRINT
Nlines = Nlines + 2
PRINTER IS 1
Out_lim_ind = Out_lim_ind + 1
IF Out_lim_ind > 4 THEN
PRINTER IS 701
X=3
GOSUB Turn page
PRINT USING "8A,2X,21A";TIME$(TIMEDATE),"5 CLOSED LOOP ERRORS!"
GOSUB End_sequence
GOTO Restart

ELSE
GOTO Restart
END IF
END IF
RETURN

Calculate:

COMB AIR MASS FLOW RATE
C=1-(Dval(22)/(Dval(21)+14.7))
Tair=Dval(1)+459.7
Mu=32.1741*(2.270E-8*(Tair^1.5/(Tair+198.6)))
Roe=144*Dval(21)/(53.35*Tair)
IF C=1 OR Mu=0. OR Roe=0. OR Dval(22)<0. THEN
Dval(31)=0.
GOTO 3230
END IF
F=(C^1.42857*3.5*((1-C^0.28571)/(1-C))*(.79241/(1-.20759*C^1.42857)))^0.5
Wair Cf=.52502*F*.675^2*(Roe*Dval(22)^0.5
Re Cf=(48*Wair Cf/(3.14*.675*Mu))/100000
IF Re Cf>1.73 THEN
Cf=1.07594+.0021752*Re Cf
ELSE
Cf=1.12381-.05719*Re Cf+.017205*Re Cf^2
END IF
Dval(31)=3600*Cf*Wair Cf
FUEL/AIR RATIO
IF Dval(31)=0. THEN
Dval(32)=0.
ELSE
Dval(32)=Dval(23)*6.74/Dval(31)
END IF
SETPOINTS
Dval(33)=Air_flow_sp
Dval(34)=Spec_temp_sp
Dval(35)=Back_psi_sp
Dval(36)=Quench_temp_sp
Dval(37)=Air_sp
Dval(38)=Fuel_sp
Dval(39)=Back_sp
Dval(40)=Quench_sp
RETURN
Fuel count:
IF Ignite_ind=0 THEN GOTO 3440
IF Dval(23)<0 THEN Dval(23)=0.
IF Dval(23)<Hi lim(23) THEN Dval(23)=0.
Fuel gal=Fuel gal+Dval(23)*(Ts-Prev ts)/3600
RETURN
Status:
IF Dval(6)>Target_temp-50. AND Ignite_ind=1 THEN
SELECT Hot_ind
CASE 0
Hot_ind=1
Trun start=TIMEDATE
GOSUB Print_data
CASE 1
3530 Trun=Trun+(TIMEDATE-Trun_start)
3540 Trun_start=TIMEDATE
3550 Minutes=Trun DIV 60
3560 Hours=Minutes DIV 60
3570 Minutes=Minutes MOD 60
3580 Run_time$[1,2]=VAL$(Hours)
3590 Run_time$[7,8]=VAL$(Minutes)
3600 IF Trun DIV 60=Target_minutes THEN
3610 PRINT USING "8A,2X,15A";TIME$(TIMEDATE);"TEST COMPLETED!"
3620 GOSUB End_sequence
3630 END IF
3670 CASE 2
3680 PRINT USING "8A,2X,15A";TIME$(TIMEDATE);"STATUS ERRORS!"
3690 GOSUB End_sequence
3700 END SELECT
3740 ELSE
3750 IF Dval(8)>500 THEN
3760 SELECT Ignite_ind
3770 CASE 0
3780 Ignite_ind=1
3790 Hot_ind=0
3800 Quench_sp=95.
3810 GOSUB Quench_out
3820 PRINT USING "8A,2X,15A";TIME$(TIMEDATE);"RIG HAS BEEN IGNITED!"
3830 PRINT USING "10X,31A";"NEW H2O VALVE SETPOINT IS 95 %.
3840 GOSUB Print_data
3850 GOSUB Turn_page
3880 Nlines=Nlines+3
3890 GOSUB Print_data
3900 CASE 1
3910 IF Hot_ind=1 THEN
3930 Hot_ind=0
3940 GOSUB Print_data
3950 END IF
3960 CASE ELSE
3970 GOTO 4110
3980 END SELECT
3990 ELSE
4000 IF Ignite_ind=1 THEN
4010 PRINT USING "8A,2X,15A";TIME$(TIMEDATE);"FLAMEOUT DETECTED!"
4020 GOSUB End_sequence
4030 END IF
4040 RETURN
4100 END IF
4070 GOTO 4110
4080 END IF
4090 END IF
4110 RETURN
4120 Display: !
4130 GOSUB Build_string
4140 PRINT TABXY(26,1);"SPL HOT CORROSION TEST FACILITY"
4150 PRINT TABXY(1,2);Blank$
4160 PRINT "                        ** RIG PARAMETERS **
4170 FOR I=1 TO 8
4180   PRINT Disp$(I)
4190 NEXT I
4200 PRINT TABXY(1,12);Blank$
4210 PRINT "                        ** CONTROL SECTION **
4220 FOR I=9 TO 12
4230   PRINT Disp$(I)
4240 NEXT I
4250 PRINT TABXY(1,18);Blank$
4260 DISP USING "8A,5X,6A,DD.DD";TIME$(TIMEDATE),"CYCLE=",Ts-Prev_ts
4270 OUTPUT 705;"A04,0,"&VAL$(INT(Dval(32)*2000))
4280 RETURN
4290 !!!!!!!!!!!!!!!!!!!!!!!!! CLOSED LOOP CONTROL !!!!!!!!!!!!!!!!!!!!
4300 Control: !
4310 IF Fuel_control$="TEMP" THEN
4320   J=6
4330   GOSUB Limits
4340   GOSUB Control_loop
4350   GOSUB Fuel_out
4360 END IF
4370 IF Air_control$="FLOW" THEN
4380   J=31
4390   GOSUB Limits
4400   GOSUB Control_loop
4410   GOSUB Air_out
4420 END IF
4430 IF Back_control$="PRESS" THEN
4440   J=26
4450   GOSUB Limits
4460   GOSUB Control_loop
4470   GOSUB Back_out
4480 END IF
4490 RETURN
4500 Control_loop: !
4510 SELECT J
4520 CASE 6 ! SPEC TEMP
4530   Err=Dval(34)-Dval(6)
4540   Pid=1
4550   Sp_fraction=Fuel_sp/100
4560   GOSUB Pid
4570   IF Out<Low_lim(38)/100. THEN
4580     Out=Low_lim(38)/100.
4590   END IF
4600   Fuel_sp=Out*100
4610   IF Fuel_sp>Hi_lim(38) THEN Fuel_sp=Hi_lim(38)
4620 CASE 31 ! AIR MASS FLOW
4630   Err=Dval(33)-Dval(31)
4640   Pid=2
4650   Sp_fraction=Air_sp/100
4660   GOSUB Pid
4670   IF Out<Low_lim(37)/100. THEN
4680     Out=Low_lim(37)/100.
4690   END IF
4700   Air_sp=Out*100
4710   IF Air_sp>Hi_lim(37) THEN Air_sp=Hi_lim(37)
4720 CASE 26 ! TEST PRESS
Err=Dval(35)-Dval(26)
Pid=3
Sp_fraction=Back_sp/100
GOSUB Pid
Out=Sp_fraction+(Sp_fraction-Out)
IF Out<Low_lim(39)/100 THEN
Out=Low_lim(39)/100
END IF
Back_sp=Out*100
IF Back_sp>Hi_lim(39) THEN Back_sp=Hi_lim(39)
END SELECT
RETURN

PID:  

IF Err<=-P(3,Pid) THEN
  Prop=(Err+P(3,Pid))*P(4,Pid)-P(3,Pid)*P(2,Pid)
ELSE
  IF Err<P(3,Pid) THEN
    Prop=Err*P(2,Pid)
  ELSE
    Prop=(Err-P(3,Pid))*P(5,Pid)+P(3,Pid)*P(2,Pid)
  END IF
END IF

Amt(Pid)=Sp_fraction+prop*(Ts-prev_ts)*P(7,Pid)
IF Amt(Pid)>P(1,Pid) THEN Amt(Pid)=P(1,Pid)
IF Amt(Pid)<-P(1,Pid) THEN Amt(Pid)=-P(1,Pid)
Out=Prop+Amt(Pid)+((Prop-P_prop(Pid))/(Ts-Prev_ts))*P(6,Pid)
IF Out>1 THEN Out=1.
P_prop(Pid)=Prop
RETURN

P.I.D. VALUES !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!

PID parm:  

GOSUB Clearscreen
PRINT
PRINT "CURRENT CLOSED LOOP PARAMETERS"
PRINT "1. SPECIMEN TEMP CONTROL OF FUEL VALVE"
PRINT "2. MASS AIR FLOW CONTROL OF AIR VALVE"
PRINT "3. SYSTEM PRESS CONTROL OF BACK PSI VALVE"
INPUT "ENTER INDEX OF PARAMETER (0 TO QUIT)",Index
IF Index=0 THEN GOTO Restart
SELECT Index
CASE 1 SPECIMEN TEMP
  Pid_ind=1
  GOSUB Pid_val_input
CASE 2  AIR FLOW
  Pid_ind=2
  GOSUB Pid_val_input
CASE 3 SYSTEM PRESS
  Pid_ind=3
  GOSUB Pid_val_input
END SELECT
GOTO Restart

Pid_val_input:  

GOSUB Clearscreen
PRINT
PRINT TABXY(3,1);"SPECIMEN TEMPERATURE ";
CASE 2
PRINT TABXY(3,1);"MASS AIR FLOW ";
CASE 3
PRINT TABXY(3,1);"SYSTEM PRESSURE ";
END SELECT
PRINT "CONTROL LOOP PARAMETERS"
PRINT
PRINT "1) RESET LIMIT";P(1,Pid_ind)
PRINT "2) MID-BAND GAIN";P(2,Pid_ind)
PRINT "3) 1/2 MID-BAND WIDTH";P(3,Pid_ind)
PRINT "4) LOW BAND GAIN";P(4,Pid_ind)
PRINT "5) HI BAND GAIN";P(5,Pid_ind)
PRINT "6) RATE CONSTANT";P(6,Pid_ind)
PRINT "7) RESET CONSTANT";P(7,Pid_ind)
PRINT
PRINT TABXY(1,18);"ENTER INDEX OF PARAMETER TO BE CHANGED"
INPUT "(0 TO QUIT, OR -1 TO RECALL LAST STORED SET)",Index
IF Index>0 THEN
  INPUT "ENTER NEW VALUE",P(Index,Pid_ind)
  GOTO pid_val_input
END IF
IF Index=-1 THEN
  GOSUB Read_pid_val
  GOTO pid_val_input
ELSE
  PRINT TABXY(1,18);Blank$
END IF
GOSUB write_pid_val
RETURN

PRINT "* THESE ARE THE PARAMETERS TO BE PRINTED OUT"
FOR I=1 TO 12
  PRINT USING "5X,2D,A,2X,16A";I,",",Chan_label$(Print_order(I))
NEXT I
PRINT
5930 Nlines=Nlines+32
5940 GOSUB Print_header_2
5950 RETURN
5960 Print_data: !
5970 PRINTER IS 701
5980 GOSUB Check
5990 X=2
6000 GOSUB Turn_page
6010 PRINT USING "8A,X,#";TIME$(TIMEDATE)
6020 FOR Z=1 TO 12
6030 PRINT USING Display_format$(Print_order(Z));X,#"Dval(Print_order(Z))
6040 NEXT Z
6050 PRINT
6060 PRINT
6070 Nlines=Nlines+2
6080 PRINTER IS 1
6090 RETURN
6100 Turn_page: !
6110 IF Nlines+X>Nlines_page THEN
6120 PRINT CHR$(12)
6130 Nlines=0
6140 GOSUB Print_header_2
6150 END IF
6160 RETURN
6170 !!!!!!!!!!!!!!!!!!!!!!!!!!!! SETPOINT SECTION !!!!!!!!!!!!!!!!!!!!!!!!!!!!
6180 Cooldown: !
6190 Ignite_ind=2 ! RIG CANNOT RE-IGNITE THUS ELIMINATING ERRONEOUS MESSAGES
6200 Hot_ind=2 ! DUE TO TC DRIFT
6210 Prt_int=-3
6220 Quench_sp=50.
6230 GOSUB Quench_out
6240 Fuel_control$="OPEN"
6250 Spec_temp_sp=-999.
6260 Fuel_sp=0.
6270 GOSUB Fuel_out
6280 ON KEY 1 LABEL " RIG RESTART ",10 GOTO Rig_restart
6290 Back_control$="OPEN"
6300 Back_psi_sp=-99.9
6310 Back_sp=50.
6320 GOSUB Back_out
6330 ON KEY 3 LABEL " % BACK VALVE",10 GOTO Back_out_sp
6340 Air_control$="OPEN"
6350 Air_flow_sp=-99.9
6360 Air_sp=60.
6370 GOSUB Air_out
6380 ON KEY 2 LABEL " % AIR VALVE",10 GOTO Air_out_sp
6390 ON KEY 0 LABEL " PROGRAM END ",10 GOTO Pgm_stop
6400 PRINTER IS 701
6410 X=5
6420 GOSUB Turn_page
6430 PRINT USING "10X,25A,3D.D,23A";"NEW AIR VALVE SETPOINT IS",Air_sp,"% IN OPEN LOOP CONTROL!"
6440 PRINT USING "10X,26A,3D.D,23A";"NEW FUEL VALVE SETPOINT IS",Fuel_sp,"% IN OPEN LOOP CONTROL!"
6450 PRINT USING "10X,27A,3D.D,23A";"NEW BACK VALVE SETPOINT IS ",Back_sp,"% IN OPEN LOOP CONTROL!"
6460 PRINT USING "10X,28A,3D.D,23A";"NEW H2O VALVE SETPOINT IS",Quench_sp,"% IN OPEN LOOP CONTROL!"
6470 PRINT
6480 Nlines=Nlines+5
6490 PRINTER IS 1
6500 RETURN
6510 Quench out_sp: !
6520 PRINT TABXY(1,18);Blank$
6530 PRINT TABXY(1,18);"PRESENT %OUTPUT OF H2O VALVE IS ";DROUND(Quench_sp,4);
6540 INPUT "ENTER NEW %OUTPUT OF H2O VALVE",Quench_sp
6550 Setpoint=Quench_sp
6560 J=40
6570 GOSUB Confirm_sp
6580 GOSUB Quench_out
6590 PRINT USING "8A,2X,25A,3D.D,23A";TIME$(TIMEDATE),"NEW H2O VALVE SETPOINT IS",Quench_sp,"% IN OPEN LOOP CONTROL!"
6600 PRINT
6610 PRINTER IS 1
6620 GOTO Restart
6630 Quench_out: !
6640 Quenchout=INT(Quench_sp*100)
6650 OUTPUT 705;"AO3,1,"&VAL$(Quenchout)
6660 RETURN
6670 Air out_sp: !
6680 PRINT-TABXY(1,18);Blank$
6690 PRINT TABXY(1,18);"PRESENT %OUTPUT OF AIR VALVE IS ";DROUND(Air_sp,4);"%.
6700 INPUT "ENTER NEW %OUTPUT OF AIR VALVE",Air_sp
6710 Setpoint=Air_sp
6720 J=37
6730 GOSUB Confirm_sp
6740 Air control$="OPEN"
6750 Air flow_sp=-99.9
6760 GOSUB Air_out
6770 PRINT USING "8A,2X,25A,3D.D,23A";TIME$(TIMEDATE),"NEW AIR VALVE SETPOINT IS",Air_sp,"% IN OPEN LOOP CONTROL!"
6780 PRINT
6790 PRINTER IS 1
6800 GOTO Restart
6810 Air flow_sp: !
6820 PRINT TABXY(1,18);Blank$
6830 PRINT TABXY(1,18);"PRESENT AIR FLOW SETPOINT IS ";Air_flow_sp;" LBM/HR."
6840 INPUT "ENTER NEW AIR FLOW SETPOINT VALUE",Air_flow_sp
6850 Setpoint=Air_flow_sp
6860 J=33
6870 GOSUB Confirm_sp
6880 Air_control$="FLOW"
6890 PRINT USING "8A,2X,25A,3D.D,31A";TIME$(TIMEDATE),"NEW AIR FLOW SETPOINT IS ",Air_flow_sp," LBM/HR IN CLOSED LOOP CONTROL!"
6900 PRINT
6910 PRINTER IS 1
6920 GOTO Restart
6930 Air out: !
6940 Airout=INT(Air_sp*100)
6950 OUTPUT 705;"AO2,0,"&VAL$(Airout)
6960 RETURN
6970 Back out_sp: !
6980 PRINT TABXY(1,18);Blank$
6990 PRINT TABXY(1,18);"PRESENT %OUTPUT OF BACK PSI VALVE IS ";DROUND(Back_sp,4);"%.
7000 INPUT "ENTER NEW %OUTPUT OF BACK PSI VALVE",Back_sp
7010 Setpoint=Back_sp
7020 J=39
GOSUB Confirm_sp
Back_control$="OPEN"
Back_psi_sp=-99.9
GOSUB Back_out
PRINT USING "8A,2X,30A,3D.D,23A";TIME$(TIMEDATE),"NEW BACK PSI VALVE SETPOINT IS",Back_sp,"% IN OPEN LOOP CONTROL!"
PRINT
PRINTER IS 1
GOTO Restart
Back_psi_sp:!
PRINT TABXY(1,18);Blank$
PRINT TABXY(1,18);"PRESENT SYSTEM PRESS SETPOINT IS ";Back_psi_sp," PSIA."
INPUT "ENTER NEW SYSTEM PRESS SETPOINT VALUE",Back_psi_sp
Setpoint=Back_psi_sp
J=35
GOSUB Confirm_sp
Back_control$="PRESS"
PRINT USING "8A,2X,29A,3D.D,29A";TIME$(TIMEDATE),"NEW SYSTEM PRESS SETPOINT IS ";Back_psi_sp," PSIA IN CLOSED LOOP CONTROL!"
PRINT-
PRINTER IS 1
GOTO Restart
Back_out:!
Backout=INT((100-Back_sp)*100) NORMALLY OPEN (20mA FOR 0%=CLOSE)
OUTPUT 705;"A03,0,"&VAL$(Backout)
RETURN
Start_fuel:!
Ignite_ind=0
Fuel_sp=15.
GOSUB Fuel_out
ON KEY 1 LABEL " % FUEL VALVE", 10 GOTO Fuel_out_sp
PRINTER IS 701
X=3
GOSUB Turn_page
PRINT USING "8A,2X,54A";TIME$(TIMEDATE),"RIG IS READY FOR IGNITION. CURRENT VALVE SETTINGS ARE:"
PRINT USING 7370;"AIR=";Air_sp,"%","FUEL=";Fuel_sp,"%","BACK=";Back_sp,"%","H2O=";Quench_sp,"%"
IMAGE 10X,4A,3D.D,A,5X,5A,3D.D,A,5X,5A,3D.D,A,5X,4A,3D.D,A
PRINT
Nlines=Nlines+3
GOSUB Print_data
PRINTER IS 1
RETURN
Fuel_out_sp:!
PRINT TABXY(1,18);Blank$
PRINT TABXY(1,18);"PRESENT %OUTPUT OF FUEL VALVE IS ";DROUND(Fuel_sp,4);"% ."
INPUT "ENTER NEW %OUTPUT OF FUEL VALVE",Fuel_sp
Setpoint=Fuel_sp
J=38
GOSUB Confirm_sp
Fuel_control$="OPEN"
Spec_temp_sp=-999.
GOSUB Fuel_out
PRINT USING "8A,2X,26A,3D.D,23A";TIME$(TIMEDATE),"NEW FUEL VALVE SETPOINT IS ";Fuel_sp,"% IN OPEN LOOP CONTROL!"
PRINT
PRINTER IS 1
7560   GOTO Restart
7570   Spec_temp_sp:   !
7580   PRINT TABXY(1,18);Blank$
7590   PRINT TABXY(1,18);"PRESENT SPEC. TEMP SETPOINT IS ",Spec_temp_sp;" DEG F.
7600   INPUT "ENTER NEW SPEC. TEMP SETPOINT VALUE",Spec_temp_sp
7610   Setpoint=Spec_temp_sp
7620   J=34
7630   GOSUB Confirm_sp
7640   Fuel_control$="TEMP"
7650   PRINT USING "8A,2X,27A,4D,26A";TIME$(TIMEDATE),"NEW FLAME TEMP SETPOINT IS ",Spec_temp_sp," F IN CLOSED LOOP CONTROL!"
7660   PRINT
7670   PRINTER IS 1
7680   GOTO Restart
7690   Fuel_out:   !
7700   Fuelout=INT(Fuel_sp*100)
7710   OUTPUT 705;"A02,1,"&VAL$(Fuelout)
7720   RETURN
7730   Confirm_sp:   !
7740   IF Setpoint>Hi lim(J) THEN Setpoint=Hi lim(J)
7750   IF Setpoint<Low lim(J) THEN Setpoint=Low_lim(J)
7760   PRINT TABXY(1,18);Blank$
7770   PRINTER IS 701
7780   X=2
7790   GOSUB Turn_page
7800   Nlines=Nlines+2
7810   RETURN
7820   !!!!!!!!!!!!!!!!!!!!!!!!!!!!! MISC SUBROUTINES !!!!!!!!!!!!!!!!!!!!!!!!!!!!!
7830   Read_pid_val:   !
7840   ASSIGN @Pid TO "PID PARM"
7850   ENTER @Pid;P(*)
7860   ASSIGN @Pid TO *
7870   RETURN
7880   Write_pid_val:   !
7890   ASSIGN @Pid TO "PID PARM"
7900   OUTPUT @Pid;P(*)
7910   ASSIGN @Pid TO *
7920   RETURN
7930   Read_common:   !
7940   ASSIGN @Path_1 TO "TEST_LOG"
7950   ENTER @Path_1;Title$,Fuel$,Target_temp,Target_time$,Elap_time$
7960   ENTER @Path_1;Specimen$(*),Install$(*),Tot_time$(*)
7970   ASSIGN @Path_1 TO *
7980   RETURN
7990   Write_common:   !
8000   ASSIGN @Path_1 TO "TEST_LOG"
8010   OUTPUT @Path_1;Title$,Fuel$,Target_temp,Target_time$,Elap_time$
8020   OUTPUT @Path_1;Specimen$(*),Install$(*),Tot_time$(*)
8030   ASSIGN @Path_1 TO *
8040   RETURN
8050   Set_prt_int:   !
8060   INPUT "ENTER NEW PRINT INTERVAL IN SECONDS (-1=15min, -2=30min, OR -3=OFF ")",Prt_int
8070   IF Prt_int=-1 THEN Prt_int=900
8080   IF Prt_int=-2 THEN Prt_int=1800
8090   GOTO Restart
8100   Spec_update:   !
8110   FOR I=1 TO 4
8120   IF Specimen$(I)="EMPTY" THEN GOTO 8180

27
Minutes=(VAL(Tot_time$(I)[1,2])+VAL(Run_time$[1,2])*60+VAL(Tot_time$(I)[7,8])+VAL(Run_time$[7,8]))

Minutes=Minutes DIV 60

Tot_time$(I)[1,2]=VAL(Hours)

Tot_time$(I)[7,8]=VAL(Minutes)

NEXT I

Minutes=(VAL(Elap_time$[1,2])+VAL(Run_time$[1,2])*60+VAL(Elap_time$[7,8])+VAL(Run_time$[7,8]))

Minutes=Minutes MOD 60

Elap_time$[1,2]=VAL(Hours)

Elap_time$[7,8]=VAL(Minutes)

RETURN

Summary: !

PRINT CHR$(12)
PRINT
PRINT "* * * * * * * * * * * * * * * * *
RUN SUMMARY * * * * * * * * *
* * * * * * * * * * * * * * * * * * *
PRINT "SPL HOT CORROSION TEST FACILITY"
PRINT
PRINT DATE$(TIMEDATE)
PRINT "CURRENT TEST: ",Title$
PRINT "FUEL TYPE: ",Fuel$
PRINT "TARGET TEMP IN DEG F: ",VAL$(Target temp)
PRINT "TOTAL TIME REQUESTED: ",Target_time$
PRINT "TIME COMPLETED: ",Elap_time$
PRINT
PRINT USING "12A,11A","TODAYS RUN: ",Run_time$
PRINT USING "12A,3D.D,8A","FUEL USAGE: ",Fuel_gal," GALLONS"
PRINT
PRINT "AS OF TODAYS RUN:"
PRINT
GOSUB 1160
PRINT
PRINT "CURRENT VALVE CONTROL OPTIONS:"
PRINT
PRINT "1) FUEL- MANUAL CONTROL OF VALVE OUTPUT"
PRINT "2) FUEL- CLOSED LOOP WITH SPECIMEN TEMP"
PRINT "3) AIR- MANUAL CONTROL OF VALVE OUTPUT"
PRINT "4) AIR- CLOSED LOOP WITH AIR FLOW RATE"
PRINT "5) BACK PSI- MANUAL CNTRL OF VALVE OUTPUT"
PRINT "6) BACK PSI- CLOSED LOOP W/ SYSTEM PRESS"
PRINT "7) WATER- MANUAL CONTROL OF VALVE OUTPUT"
PRINT "8) WATER- CLOSED LOOP WITH EXIT AIR TEMP"
PRINT "ENTER (0) TO RETURN"

!
8700 INPUT "ENTER YOUR CHOICE", Cntrl_ind
8710 SELECT Cntrl_ind
8720 CASE 0
8730   GOTO Restart
8740 CASE 1
8750   IF Ignite_ind=2 THEN
8760     BEEP
8770     DISP "FUEL CONTROL CURRENTLY NOT AVAILABLE"
8780     WAIT 1
8790     GOTO Control_setup
8800   END IF
8810   ON KEY 1 LABEL " % FUEL VALVE", 10 GOTO Fuel_out_sp
8820   GOTO Fuel_out_sp
8830 CASE 2
8840   IF Ignite_ind=2 THEN
8850     BEEP
8860     DISP "FUEL CONTROL CURRENTLY NOT AVAILABLE"
8870     WAIT 1
8880     GOTO Control_setup
8890   END IF
8900   ON KEY 1 LABEL " SPEC_TEMP_SP", 10 GOTO Spec_temp_sp
8910   GOTO Spec_temp_sp
8920 CASE 3
8930   ON KEY 2 LABEL " % AIR VALVE", 10 GOTO Air_out_sp
8940   GOTO Air_out_sp
8950 CASE 4
8960   ON KEY 2 LABEL "AIR FLOW SP ", 10 GOTO Air_flow_sp
8970   GOTO Air_flow_sp
8980 CASE 7
8990   GOTO Quench_out_sp
9000 CASE 8
9010   BEEP
9020   DISP "OPTION CURRENTLY NOT PROGRAMMED"
9030   WAIT 1
9040   GOTO Control_setup
9050 CASE 5
9060   ON KEY 3 LABEL " % BACK VALVE", 10 GOTO Back_out_sp
9070   GOTO Back_out_sp
9080 CASE 6
9090   ON KEY 3 LABEL " SYS_PSI_SP " , 10 GOTO Back_psi_sp
9100   GOTO Back_psi_sp
9110 CASE ELSE
9120   GOTO Control_setup
9130 END SELECT
9140 !!!!!!!!!!!!!!!!!!!!!! SETUP STRINGS & ARRAYS !!!!!!!!!!!!!!!!!!!!!!
9150 Build_string: !
9160  LS=" "
9170  FOR I=1 TO 12
9180    N=Screen(I,1)
9190    J=Screen(I,2)
9200    OUTPUT A$ USING Display_format$(N)"",";Dval(N)
9210    OUTPUT B$ USING Display_format$(J)"",";Dval(J)
9220    Disp$(I)=Chan_label$(N)[1,14]&LS[1,10]&A$(1,5)&LS[1,3]&Unit$(N)[1,5]&LS[1,6]&Chan_label$(J)[1,14]&LS[1,10]&B$(1,5)&LS[1,3]&Unit$(J)[1,5]
9230  NEXT I
9240  RETURN
9250 Read_coef: !
9260  RESTORE 9300
9270  FOR I=1 TO 13
9280  READ K(I)
9290 NEXT I
9300 DATA -8.16774E-7, 3.964E-4, 1.6E-8!
9310 DATA -5.1E-2, 2.48503E4, -3.82662E5, 9.9661057E7, -1.0820624E10
9320 DATA 6.0392855E11, -1.9109E13, 3.4782347E14, -3.3991028E15, 1.3828514E16
9330 FOR I=1 TO 13
9340 READ R(I)
9350 NEXT I
9360 DATA -2.11284E-7, 5.334E-5, 1.2E-8, 4.8343651E1
9370 DATA 1.109827E-1, -2.435389E-6, 4.5164488E-11, 1.8172612E-16, 0, 0, 0, 0, 0
9380 RETURN
9390 Read label lim: !
9400 RESTORE 9450
9410 FOR I=1 TO 40
9420 READ Chan_label$(I), Unit$(I), Display_format$(I), Sensor$(I)
9430 \ READ Hi_limm(I), Low_limm(I)
9440 NEXT I
9450 DATA "INLET AIR TEMP","DEG F","DDDD.","AS112",500,0     ! SLOT #0
9460 DATA "PREHEATER-WEST","DEG F","DDDD.","TP1",650,250
9470 DATA "EXIT TEMP" , "DEG F" , "DDDD." , "TP130" , 400 , 0
9480 DATA "PREHEATER- API" , "DEG F" , "DDDD." , "K-4" , 650 , 250!
9490 DATA "COMBUSTOR TEMP" , "DEG F" , "DDDD." , "TP136" , 2200 , 500 ! R
9500 DATA "SPEC. TEMP #1" , "DEG F" , "DDDD." , "TP100" , 2500 , 500 ! R
9510 DATA "SPEC. TEMP #2" , "DEG F" , "DDDD." , "TP2" , 2500 , 0 ! R
9520 DATA "COMB TEMP- API" , "DEG F" , "DDDD." , "R-4" , 2500 , 500 ! R
9530 DATA "SPARE TYPE R" , "DEG F" , "DDDD." , "R-5" , 3200 , 0 ! R
9540 DATA "SPARE TYPE R" , "DEG F" , "DDDD." , "R-6" , 3200 , 0 ! R
9550 DATA "EXIT TEMP- API" , "DEG F" , "DDDD." , "K-5" , 400 , 0
9560 DATA "", "", "", "", "", 3200 , 0
9570 DATA "", "", "", "", "", "", 3200 , 0
9580 DATA "", "", "", "", "", "", 3200 , 0
9590 DATA "", "", "", "", "", "", 3200 , 0
9600 DATA "", "", "", "", "", "", 3200 , 0
9610 DATA "", "", "", "", "", "", 3200 , 0
9620 DATA "", "", "", "", "", "", 3200 , 0
9630 DATA "", "", "", "", "", "", 3200 , 0
9640 DATA "TC REF. VOLT" , "", "DDDD." , "REF" , 3200 , 0
9650 DATA "INLET PRESSURE" , "PSIA" , "DDDD.\" , "AS114" , 200 , 0     ! SLOT #1
9660 DATA "VENTURI DP" , "PSID" , "DD.DD" , "AS116" , 5 , 0
9670 DATA "FUEL FLOW RATE" , "GPH" , "DD.DD" , "FC105" , 6 , 6
9680 DATA "FUEL PRESSURE" , "PSIG" , "DD.DD" , "FC107" , 500 , 0
9690 DATA "COMB PRESSURE" , "PSIA" , "DD.DD" , "TP137" , 120 , 0
9700 DATA "SYS. PRESSURE" , "PSIA" , "DD.DD" , "TP104" , 120 , 0
9710 DATA "H2O PRESSURE" , "PSIG" , "DD.DD" , "WD107" , 200 , 0
9720 DATA "H2O FLOW RATE" , "GPM" , "DD.DD" , "WD112" , 75 , 0.02
9730 DATA "SALT LOAD CELL" , "VOLT" , "D.DDD" , "SALT " , 10 , 0
9740 DATA "" , "" , "" , "DD.DD" , "" , 100 , 0
9750 DATA "A IR FLOW RATE" , "LB/HR" , "DD.DD" , "Mair",800,50     ! CALCULATED
9760 DATA "F/A RATIO" , "" , "D.DDD" , "F/A",2,0
9770 DATA "AIR FLOW SP" , "LB/HR" , "DD.DD" , "SP #1",800,50
9780 DATA "SPEC. TEMP SP" , "DEG F" , "DD.DD" , "SP #2",3000,100
9790 DATA "SYSTEM PSI SP" , "PSIA" , "DD.DD" , "SP #3",120,0
9800 DATA "EXIT TEMP SP" , "DEG F" , "DD.DD" , "SP #4",350,0
9810 DATA "% AIR VALVE" , "%" , "DD.DD" , "AS111",100,0
9820 DATA "% FUEL VALVE" , "%" , "DD.DD" , "FC104",100,0
9830 DATA "% BACK VALVE" , "%" , "DD.DD" , "TP113",100,0
9840 DATA "% H2O VALVE" , "%" , "DD.DD" , "WD109",100,0
9850 RETURN
9860 Screen_setup: !
9870 RESTORE 9930
9880 FOR I=1 TO 12
30
FOR J=1 TO 2
READ Screen(I,J)
NEXT J
DATA 21,22,31,1,24,2,23,8,32,6,25,7,26,11,27,28,33,37,34,38,35,39,36,40
RETURN

UTILITY SUBROUTINES

Print using "10X,28A";'SHUTDOWN SEQUENCE INITIATED.'
PRINT
Nlines=Nlines+3
PRINTER IS 1
GOSUB Cooldown
GOSUB Print_data
GOSUB Spec_update
GOSUB Write_common
GOSUB Summary
RETURN

Restart: !
GOSUB Fuel_count
OUTPUT 705;'VS1'
OUTPUT 705;'VT3'
GOTO Scan

Rig_restart: !
PRINTER IS 701
PRINT CHR$(12)
Nlines=0
GOSUB Print_header
GOTO Init_variables

Clearscreen: !
OUTPUT 2 USING "#,B";255,75
RETURN

Invalid: !
BEEP
DISP Blank$
DrSp "NOT VALID KEY"
WAIT .5
RETURN

Shutdown:
BEEP
LINPUT "DO YOU REALLY WISH TO SHUTDOWN?(Y/N)",Ans$
IF Ans$="Y" THEN
PRINTER IS 701
X=3
GOSUB Turn_page
PRINT USING "8A,2X,17A";TIME$(TIMEDATE),"OPERATOR REQUEST!"
GOSUB End_sequence
GOTO Restart
ELSE
GOTO Restart
END IF

Pgm stop: !
BEEP
GOSUB Clearscreen
PRINT "THIS WILL RETURN YOU TO THE MAIN MENU."
PRINT
PRINT "RIG SHOULD BE COOLED DOWN BEFORE PROCEEDING!"
LINPUT "DO YOU WISH TO CONTINUE? (Y/N)",Ans$
IF Ans$="Y" THEN
Table I. - Dew Point of Na₂SO₄ for Given Sodium Concentrations

<table>
<thead>
<tr>
<th>Na (ppm)</th>
<th>1 atm Dew Pt.</th>
<th>4 atm Dew Pt.</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>920°C (1688°F)</td>
<td>981°C (1798°F)</td>
</tr>
<tr>
<td>1.0</td>
<td>938°C (1720°F)</td>
<td>1001°C (1834°F)</td>
</tr>
<tr>
<td>2.0</td>
<td>954°C (1749°F)</td>
<td>1020°C (1868°F)</td>
</tr>
<tr>
<td>4.0</td>
<td>970°C (1778°F)</td>
<td>1038°C (1900°F)</td>
</tr>
</tbody>
</table>

Table II. - Safety Upper/Lower Limits on Critical Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Upper limit</th>
<th>Lower limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preheated temperature</td>
<td>370°C (700°F)</td>
<td>120°C (250°F)</td>
</tr>
<tr>
<td>Combustor temperature</td>
<td>1400°C (2550°F)</td>
<td>420°C (800°F)</td>
</tr>
<tr>
<td>Exhaust temperature</td>
<td>200°C (400°F)</td>
<td>none</td>
</tr>
<tr>
<td>System pressure</td>
<td>600 kPa</td>
<td>none</td>
</tr>
</tbody>
</table>
Figure 1.—SEM views of glassy products on SiC burner rig sample; (a) the entire sample (bar = 1 mm), (b) an enlargement of products near surface (bar = 100 μm); and (c) the underside of a spalled section (bar = 100 μm).

Figure 2.—Surface views of corroded SiC (products removed by HF); (a) the entire sample (bar = 100 μm), (b) enlargement of leading edge region (bar = 100 μm), (c) enlargement of trailing edge region (bar = 100 μm).
Figure 3.—Hot corrosion test facility at the NASA Lewis Research Center.

Figure 4.—Schematic of HCTF’s components and support systems.
Figure 5.—Fuel-to-air ratio versus operating temperature.

Figure 6.—HCTF combustor and test section.
Figure 7.—Components of combustor and test section.

Figure 8.—Assembly of test specimens, lava holder, and flame tubes.

Figure 9.—HCTF control room with safety interlocks, computer and printer.
SPL HOT CORROSION TEST FACILITY

****** RIG PARAMETERS ******

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value 1</th>
<th>Value 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>INLET PRESSURE</td>
<td>78.7 PSIA</td>
<td>VENTURI DP</td>
</tr>
<tr>
<td>AIR FLOW RATE</td>
<td>223.2 LB/HR</td>
<td>INLET AIR TEMP</td>
</tr>
<tr>
<td>FUEL PRESSURE</td>
<td>171.7 PSIG</td>
<td>PREHEATER-WEST</td>
</tr>
<tr>
<td>FUEL FLOW RATE</td>
<td>1.25 GPH</td>
<td>COMB TEMP- API</td>
</tr>
<tr>
<td>F/A RATIO</td>
<td>.025</td>
<td>SPEC. TEMP #1</td>
</tr>
<tr>
<td>COMB PRESSURE</td>
<td>60.0 PSIA</td>
<td>SPEC. TEMP #2</td>
</tr>
<tr>
<td>SYS. PRESSURE</td>
<td>60.1 PSIA</td>
<td>EXIT TEMP- API</td>
</tr>
<tr>
<td>H2O PRESSURE</td>
<td>108.5 PSIG</td>
<td>H2O FLOW RATE</td>
</tr>
</tbody>
</table>

****** CONTROL SECTION ******

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value 1</th>
<th>Value 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>AIR FLOW SP</td>
<td>325.0 LB/HR</td>
<td>% AIR VALVE</td>
</tr>
<tr>
<td>SPEC. TEMP SP</td>
<td>1002. DEG F</td>
<td>% FUEL VALVE</td>
</tr>
<tr>
<td>SYSTEM PSI SP</td>
<td>60.0 PSI</td>
<td>% BACK VALVE</td>
</tr>
<tr>
<td>EXIT TEMP SP</td>
<td>-998. DEG F</td>
<td>% H2O VALVE</td>
</tr>
</tbody>
</table>

15:03:57 CYCLE= 2.22

Figure 10.—Computer's data acquisition and control display screen.

SPL HOT CORROSION TEST FACILITY - CURRENT TEST SETUP

TEST TYPE: CORROSION
FUEL TYPE: JET A
TARGET TEMP IN DEG F: 1832
CURRENT TEST TIME REQUEST: 40HRS,0 MIN
TIME ELAPSED: 25HRS,30MIN

<table>
<thead>
<tr>
<th>Position #1</th>
<th>Position #2</th>
<th>Position #3</th>
<th>Position #4</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPEC NAME:</td>
<td>SPEC. #1</td>
<td>SPEC. #2</td>
<td>SPEC. #3</td>
</tr>
<tr>
<td>TEST TIME:</td>
<td>25HRS,30MIN</td>
<td>25HRS,30MIN</td>
<td>65HRS,30MIN</td>
</tr>
</tbody>
</table>

ENTER INDEX OF INFORMATION TO BE CHANGED
(1=TEST PARAMETERS  2=SPECIMEN DATA  0=EXIT)

Figure 11.—Test setup and documentation utility.
# Report Title
Hot Corrosion Test Facility at the NASA Lewis Special Projects Laboratory

## Report Details

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**Report Type:** Final Contractor Report

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Sverdrup Technology, Inc.  
Lewis Research Center Group  
2001 Aerospace Parkway  
Brook Park, Ohio 44142

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**Sponsoring Agency:**
National Aeronautics and Space Administration  
Lewis Research Center  
Cleveland, Ohio 44135-3191

## Abstract
The hot corrosion test facility (HCTF) at the NASA Lewis Special Projects Laboratory (SPL) is a high-velocity, pressurized burner rig currently used to evaluate the environmental durability of advanced ceramic materials such as SiC and Si3N4. The HCTF uses laboratory service air which is preheated, mixed with jet fuel, and ignited to simulate the conditions of a gas turbine engine. Air, fuel, and water systems are computer-controlled to maintain test conditions which include maximum airflow rates of 250 kg/hr (550 lbm/hr), pressures of 100-600 kPa (1-6 atm), and gas temperatures exceeding 1500°C (2732°F). The HCTF offers a relatively inexpensive, yet sophisticated means for researchers to study the high-temperature oxidation of advanced materials, and the injection of a salt solution provides the added capability of conducting hot corrosion studies.

## Subject Terms
Burner rig; Corrosion; Materials testing

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### Security Classification

- **Of Report:** Unclassified  
- **Of This Page:** Unclassified  
- **Of Abstract:** Unclassified

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### Distribution/Availability Statement
Unclassified - Unlimited  
Subject Categories 9 and 24

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### Limitation of Abstract

Unclassified

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