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Digital Temperature and Velocity Control of Mach 0.3 Atmospheric Pressure Durability Testing Burner Rigs in Long Time, Unattended Cyclic Testing

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DIGITAL TEMPERATURE AND VELOCITY CONTROL OF MACH 0.3 ATMOSPHERIC PRESSURE DURABILITY TESTING BURNER RIGS IN LONG TIME, UNATTENDED CYCLIC TESTING

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SUMMARY

Hardware and software were developed to implement the hybrid digital control of two Jet A-1 fueled Mach 0.3 burners from startup to completion of a preset number of hot corrosion flame durability cycle tests of materials at 1652 °F. This was accomplished by use of a basic language programmable microcomputer and data acquisition and control unit connected together by the IEEE-488 Bus. The absolute specimen temperature was controlled to ±3 °F by use of digital adjustment of the fuel flow using a P-I-D (Proportional-Integral-Derivative) control algorithm. The specimen temperature was within ±2 °F of the set point more than 90 percent of the time. Pressure control was achieved by digital adjustment of the combustion air flow using a proportional control algorithm. The burner pressure was controlled at 1.0±0.02 psig.

Logic schemes were incorporated into the system to protect the test specimen from abnormal test conditions in the event of a hardware or software malfunction.

INTRODUCTION

Material durability testing in dynamic flame combustion products is in common use in the gas turbine and high temperature alloys industries (refs. 1 to 3). The determination and control of the true surface temperature has been a continuing problem and source of uncertainty in the results obtained from such tests. The burner rigs used in this testing have utilized analog (electromechanical) controlling instruments which implement proportional-integral control modes. With this type of control system, a temperature signal is usually obtained from an infrared optical sensor aimed at the test specimen and compared by electronic circuitry to a set point signal. The resulting error signal is used to adjust the position of a fuel valve in such a manner as to return the temperature to the set point. This is a real time feedback control system and if the proportional and integral parameters are set properly, it yields good average temperature control. The infrared temperature sensor requires calibration to account for specimen emissivity. If the emissivity changes as the test proceeds, for example from changing scale composition, the test results may be adversely affected. The use of a two-color optical pyrometer holds some promise of minimizing this problem provided that any changes in the emissivity of the surface are independent of the wavelength. This appears to be a good assumption for most oxides formed during high temperature metal corrosion.

An absolute method of near surface temperature measurement can be attained by placing a small thermocouple in a hole located 5 to 10 mils (0.127 to 0.254 mm) beneath the surface. This has several practical drawbacks when applied to long time routine testing. First, the specimen is rotating so a slip ring must be used to bring out the signal. The slip ring assembly can require much maintenance when used in long time testing and may also introduce noise into the signal. Furthermore, a hole for the thermocouple must be drilled in each test specimen which increases their cost. Finally, small diameter thermocouple wire is fragile and may tend to rupture when changing specimens.

The setting of the proportional and integral parameters of an analog controller is tedious and requires often readjustment. Furthermore, even with the best settings, the low thermal inertia of the burner rig system causes large and rapid changes in the fuel valve throughput to quickly reduce the temperature error to zero and achieve the desired temperature control. This action causes large variations in the instantaneous fuel-to-air ratio which in turn produces a flame with a pulsating temperature and this causes excessive carbon buildup in the combustor. This latter problem can alter the flame pattern and parameters of the burner.

To control the flame velocity a second controller is required for the combustion air flow. This controller compensates for pressure changes in the combustion chamber caused by changes in the flame temperature. There is thus some interaction between the fuel and air flow controllers.

A further complication of the analog control system is imposed by the temperature cycling required in most material durability testing. At the conclusion of the heating cycle time, the flame is removed from the test specimen and its temperature falls rapidly. The specimen temperature sensor then signals the analog controller to open the fuel valve in an effort to raise the specimen temperature to the set point. If this action is not quickly arrested, the flame is blown out. The arrest of the fuel valve travel is accomplished by deviation circuitry in the analog controller which switches the controller from automatic to manual control mode. The setting of this cutoff point is critical and tedious. For example if set too high, a large temperature overshoot occurs on heatup in the next heating cycle: on the other hand if set too low, the test temperature is not reached on heat up and the controller remains in the manual mode. Furthermore, experience has demonstrated that the cutoff point setting changes with time.

Durability testing usually involves long duration tests in which the test is proceeding unattended much of the time. During these periods many changes in the environment to which the specimen is exposed may occur, such as the change in test temperature caused by a variation in the cutoff setting described above. The interpretation of test results for specimens tested under varying and sometimes questionable conditions is greatly suspect. Also, specimens become more costly as the test time increases and the prevention of nonnormal testing is a necessary goal. Experience has proven that this is not easily achieved by analog (electromechanical) technology alone. The purpose of the work reported here was to determine the feasibility of using a digital computer to control one or more burner rigs.

The approach used was to control the temperature and pressure through the use of a digital microcomputer system (refs. 4 to 9). This approach uses a programmable computer which, via a suitable interface, acquires information about the temperature, pressure, and other system parameters. The computer program then calculates appropriate feedback control signals. This type of control is really a simulation of a manual mode whereby the fuel or air valve are adjusted by small incremental steps ("tweeked") only when needed. In this way the fuel to air ratio is not varied rapidly or over a large range; it is only slowly "nudged" in the direction necessary to adjust the temperature and pressure to their respective set points. The frequency and magnitude of this fine adjustment ("nudging") can be readily obtained by software using any one or a combination of control algorithms. One of the most commonly used is a real time P-I-D feedback loop. Also, the special and difficult problem of transition from heating to cooling and back to heating, presented by cyclic testing, can be easily handled in a positive way through software by using a hardware generated burner position signal. Tests for abnormal conditions can be made through software logic and burner shutdown action can be initiated.

Satisfactory digital control of two independent burner rigs, burning Jet A-1 fuel, has been accomplished using a single computer. The absolute specimen temperature was controlled to ±3 °F. For >90 percent of the time the temperature was within ±2 °F of the set point. Burner pressure was controlled at 1.0±0.02 psig to yield flame velocity control at Mach 0.3±0.02.

HARDWARE

Figure 1 is a photograph of a burner rig used in this study and shows the layout of the major components. The burner is in position to heat the specimen. In the cooling position it rotates about the pivot so that the flame misses the test specimen and a flow of compressed air impinges on the specimen. The fiber optic cable conducts the light from the specimen to the two color optical pyrometer detector located beneath the table. A cutaway specimen rotating on its own long axis is shown. This specimen geometry is used to reduce temperature gradients and yield more meaningful test results (ref. 10). A two color optical pyrometer provides the temperature dependent control signal. This type of pyrometer compensates for emissivity.

Figure 2 is a schematic diagram of the total control system. The data acquisition and control unit is the heart of the system. It contains circuit boards for input and output of signals and is totally controllable by the computer. The level of the input voltages from the transducers are measured by a 5-1/2 digit system voltmeter. These voltages are converted to engineering units by software. The digital outputs from the computer are converted to current flows by the output boards. The boards output 0 to 20 mA in 10 000 digital steps, that is 0.002 mA per step. It was found that a change of 10 digital steps moved the fuel valve stem a distance of 1 mil (0.0254 mm) and changed the temperature of the specimen by 1 °F for the burner configuration used. It should be kept in mind that the above digital calibration of the analog system is given for reference purposes and was found to vary slightly on day-to-day basis. The data acquisition and control unit is connected to the microcomputer and printer by the standard IEEE-488 Handshake Bus.

It will be noticed that this is a hybrid system that is partly computer controlled (digital) and partly analog (electromechanically) controlled. This configuration evolved because the computer was applied to an existing system which has previously totally controlled by analog (electromechanically) systems. For example, while the combustion air preheater is turned on by computer control the air temperature is controlled by an analog-electromechanical controller. Likewise, the ignitor is turned on by the computer but it is turned off after 30 sec by a timer actuated electromechanical switch. With further effort the system could be converted to total computer control. This may result in a cost saving and surely easier programming.

SOFTWARE

Software was developed so that the computer could make observations and then adjustments in burning parameters and burner actions in conjunction with the existing system hardware. The program listing is presented in the appendix with the logic and sequencing reviewed schematically in figure 3.

The program performs three main tasks. The first is to startup the burner and then adjust the specimen temperature and burner pressure, within small ranges of their respective set points before transferring to the P-I-D fuel loop and proportional air control loop in the first cycle. The second task is the operation of the P-I-D and proportional air control loops. Task three consists of the scheme for cooling and reheating without temperature overshoot. Associated with these tasks is a certain amount of safety, record-keeping, measurement, display and calculation activity. A brief description of the operation of these main parts through the first complete cycle for a single rig (number 3) follows.

Task one is the startup and establishment of the temperature and burner pressure with subsequent transfer to the P-I-D temperature control loop. Figure 3(a) presents the steps involved. First the desired rig is selected by keyboard selection through a special function key. Screen prompts then ask for operator keyboard inputs of cycle data as number of cycles desired, number of previous cycles completed, and specimen identification. No further operator attention is needed. The combustion air valve is opened as the computer outputs a preset digital valve to the digital to analog board where it is converted to an electrical signal that actuates the air valve and the combustion air heater is turned on. Program execution then returns to the rig selection segment thus completing the first loop. On subsequent program executions through this loop a branching flag directs the execution to the next segment where the temperature of the combustion air is checked and if it has not reached 440 °F execution returns to the rig selection segment. By use of branching flags each loop is executed in succession throughout the program. Once the air temperature reaches the 440 °F set point, the fuel is turned on and ignited. Next the fuel pressure is set to 91 to 92 psig after which the cooling timer is started. During the initial cooling period of three minutes the fuel to air ratio is set to 0.025 to 0.026. From prior experience this value was known to produce a flame temperature which would not heat the specimen beyond the desired test temperature. However, a fuel pressure lower limit of 86 psig was used to prevent flame out. After the initial cooling period the burner is pivoted so the flame strikes the specimen. The specimen now enters the heatup stage and if the specimen is new and without any previous test cycles it is held for 30 min in the flame before final adjustment to the set point temperature. This procedure was found necessary because machined specimens had a highly reflective or polished surface. These surfaces produced high valued two color pyrometer readings. It was found during this initial 30 min heating period that the high apparent temperature decreases rapidly as the surface darkens and takes on a matte appearance due to oxidation and corrosion. If the test specimen was previously exposed to the flame, as in previous test cycles, no initial heating period is used and the program immediately proceeds to adjust the fuel and air flows in the proper direction so that the temperature and burner pressure closely approach their respective set points. This is achieved by stepwise incrementing or decrementing the fuel flow and proportional control of the air flow. Once the temperature is within the arbitrarily chosen range of 1648 to 1654 °F control is transferred to the P-I-D loop. If this temperature range cannot be achieved within 10 min or the fuel pressure exceeds 155 psig then the burner is shutoff. Transfer to the P-I-D loop is accomplished by setting the branching flag, control 3, to a value of 2. This causes the program to always branch to "running" at point "A" in figure 3(b). At point "A" a check of the burner position signal is made, because the burner is now in the heating position and the heatup flag, Out 3, is >2, execution enters the P-I-D loop. The first cycle startup segment is not used again.

The steps of task two include the P-I-D loop and the cooling and heatup branching tests. A schematic of the logic steps are presented in figure 3(b). The major function of this loop is the calculation of the fuel and air control digits and adjustment of the fuel and air flows. However, several other functions appropriate to this program segment, as, screen display of data, safety checks, and other housekeeping tasks are also accomplished.

The P-I-D calculation of the fuel digit is:

$$\text{Outfuel3} = \text{Outfuel3s} - (\text{Errt*Gai3}) - (\text{Sumint3*Res3}) - (\text{Rate*Rcon3}) \qquad (1)$$

where Errt is the error in temperature, that is (measured temperature - set point); Sumint is the integral of the temperature error curve versus time determined by a numerical approximation; and Rate is the temperature change per unit of time; Gai3, Res3 and Rcon3 are tuning constants. The tuning constants are used to tune the control loop to maximum control quality. Tuning constants can be determined by analytical procedures (ref. 5) or by trial. The latter method was employed here to determine the optimum constants. Outfuel3s is the bias term and takes on its value when the temperature is in a narrow range of the set point during initial setting of the temperature on heatup, and this value is retained for the cycle. The final digit is then the algebraic sum of the terms in equation (1). This digit is sent to the digital to analog hardware which converts the digit to an electrical control signal and via an electropneumatic transducer positions the fuel valve.

The proportional calculation of the air digit is:

$$\text{Air3} = \text{Air3} - (\text{Errp*Air3c}) \qquad (2)$$

where Errp is the error in the burner pressure, that is (measured pressure-set point pressure) and Air3c is a tuning constant. No bias is used, that is, the final output digit is obtained by readajusting the presently stored digit. This scheme was found to give sufficiently good control of the burner pressure and hence flame velocity so no further terms were used. The tuning constant was determined by trial. The readjustment of the fuel and air occurred 10 times per minute for each burner. While this was sufficient, with more efficient programming it is estimated that a rate of 15 to 20 times per minute may be possible.

Afterwards or concurrently with the fuel and air adjustment several other functions are performed in the P-I-D loop. For example display on the CRT screen of the burner pressure, the specimen temperature, and the fuel to air ratio as a function of time is performed. This is useful for on-line visual assessment of burner action.

Also the fuel flow digit is stored when the temperature is within a 2° band of the set point. This digit is adjusted by decreasing its value by a 1/2 percent and is used as the initial value in heatup in the next cycle. This 1/2 percent setback is actually calculated in the cooling and heatup loop to be described later. The maximum and minimum temperatures attained in each heating cycle are tracked and recorded within the P-I-D loop. A most useful bit of information is the temperature distribution in a heating cyle. This was calculated as the time spent in three temperature bands. The first is the percentage of the cycle heating time that the temperature is greater than the minimum but less than 1650 °F, the next is the percent of time the temperature is between 1650 and 1654 °F, this is ±2 °F of the set point, and lastly the portion above 1654 °F but less that the maximum temperature. An examination of these values gives the operator a means of judging the control action. Very good control was considered to show >90 percent of the time in the center band. Less than 80 percent was not accepted and the test was stopped if this occurred. This latter action is taken in the cooling and heating loop to be described later. Also, if the time distribution in each band is symmetrical then the control action is generally considered to be desirable. If the distribution is skewed then this may indicate that the control action is undesirable and operator corrective action may be called for, such as, changing the tuning constants and/or hardware.

Distributed in the program are several software checks for "out of limit" operations. Operation beyond these limits results in shutdown of the burner to prevent possible extended testing under abnormal conditions. Due to the hybrid nature of this system most of these software checks are involved with protection of the specimen because the burner hardware has several analog safety overrides to shutoff the fuel flow if certain conditions hazardous to equipment and personnel develop. The software provides some redundancy which is not undesirable from a safety standpoint. If the temperature of the combustion chamber falls below 900 °F or the fuel pressure exceeds 155 psig the fuel flow is shutoff. Also, if the ac line power to the computer fails and the failure lasts more than 1 sec then the computer switches to battery operation. The 1 sec delay allows for short term power loss before going irreversibly to the battery mode. During the one minute of battery operation the fuel flow is shutoff and the test is terminated. If the line power to the data acquisition units fails then the burner is automatically shutoff with no assist from the computer.

At the end of the present heating time a separate electromechanical timer actuates a solenoid valve which actuates an air driven piston that causes the burner to rotate so that the flame misses the specimen and the cooling cycle starts. When the burner position signal is checked by the computer it will indicate that the burner is in the cooling position. This causes the program to branch to the cooling segment which starts at point "B" in figure 3(b).

The software for task three is involved with the cooling and heatup of the specimen. A schematic of the major logical steps is presented in figure 3(c). The first step is to determine whether this is the first pass through the cooling cycle loop. When the branching flag "N" is equal to 1, the program proceeds to execute the statements of the first pass segment. These include printing a hard copy of the heating parameters and calculating the initial fuel digit for the next heating cycle. This is performed on the fuel digit stored during the heating cycle when the temperature was within ±2 °F of the set point. This latter digit is decreased by 1/2 percent (set-back). The resulting digit is output to the fuel valve so that the flame temperature is lowered to a point where it will not heat the specimen up to the set point in the next heating cycle. This allows a slow and controlled approach to the set point in the next cycle heatup and prevents temperature overshoot. Next comes incrementing the software cycle counter, setting the integral term in the P-I-D loop to zero, checking the residence time in the middle temperature band and shutting off the burner if it is less than 80 percent. Also, the initial values of T_{max} and T_{min} are reset to 1652 °F for the next cycle and two branching flags (N and Out3) are reset. A software cooling timer is also started. The second and all subsequent passes through the cooling loop until the 3 min of cooling cycle time has elapsed then go to the path where N = 2. Here several checks are made. If the cycles desired equals the cycles completed then the main power to the burner is shutoff and execution of the program is stopped. If more cycles have to be run, a check of the elapsed software cooling time is made and if more than 10 min or the fuel pressure is more than 155 psig then the burner is shutoff because of some malfunction in the analog system.

Upon the completion of the cooling cycle the burner is rotated by the electromechanical timer and pneumatic actuator to the heating position and the electromechanical heating timer is started. The burner position signal test at point "A" will now direct execution to heating and test of the heatup branching flag, Out3, will be found to be two so branching to point "C" in figure 3(c) will occur. In this loop the fuel flow is incremented in small steps until the temperature set point is nearly reached. When this is achieved the heatup flag, Out3, is set to three and further passes through the heatup branching test point will send the execution to the P-I-D control loop in figure 3(b). This completes the first heating and cooling cycle.

The program also incorporates several other functions. A special purpose key can be pressed at any time that a comparison of the transducer determined values of fuel and air flow and those read by the operator from calibrated analog rotometers is desired. The operator readings of fuel and air flow are input at the keyboard in response to a screen prompt and the fuel and air flows and the fuel to air ratio for each set of values are printed on the hard copy printer.

If an execution time error occurs, an error interrupt message sends the program execution to an error handling subroutine where the fuel flow and burner ac power are shutoff and the execution error number is hard copy printed to aid the operator in determination of the software cause of the error and its correction. At initial startup a test of the burner pivot cylinder air supply is made via the position signal to warn the operator if it is off and stop execution until this condition is operator corrected. A test is also made to determine if the peripherals (printer and data acquisition unit) attached to the IEEE-488 Bus are energized and if not to stop program execution and warn the operator. There is a special purpose key for operator use to shutoff a burner at any time.

A critical parameter in hot corrosion testing is the salt solution flow to the injector which aspirates the solution into the combustor. If this flow stops or deviates too far from an acceptable range the testing must be discontinued or erroneous results will be obtained. In our system the rate is manually hardware set by the operator and no further control is provided. Flow is monitored by continuously measuring the weight of the salt solution container supported by a load cell. If the flow, as reflected by weight change, is within preset limits, testing is allowed to continue, if not the test is stopped. This aspect of operation has been hardware implemented but the software has not as yet been developed. During actual use of the control program described here the salt solution flow monitoring is provided by another computer based monitoring system developed previously. The function of this latter system will be briefly described later.

RESULTS

Typical burner rig flame hot corrosion test parameters taken at 15 min intervals over a 14 hr period are presented in figure 4. The burner rig was operated under digital control. Examination of this data indicates that good results of the digitally maintained specimen temperature and burner pressure and thusly Mach number were obtained. The "see-saw" nature of the calculated sodium content of the flame is due to the low sensitivity of the strain gauge load cell used to weigh the salt solution container and not actual flow variations.

The data points reported in figure 4 were gathered by a separate computer based monitoring system. The data are recorded on a floppy disc for off-line printing or plotting. This system was previously developed to track certain burner parameters and shutoff the burner if any of the parameters exceeded preset limits for three consecutive measurements. The monitor system uses a separate microcomputer, program and data acquisition unit. Both the control and monitor systems derive their input signals from the same burner rig transducers for pressure and etc. The monitor system functions equally well with analog or digital burner control.

From analysis of screen plotted data during each cycle (fig. 5) it is concluded that the digital control system can maintain an absolute temperature control of ±3 °F with greater than 90 percent of the time the temperature is within ±2 °F of the set point. Also, temperature overshoot of no more than 3 °F was achieved. The burner pressure can concurrently be maintained at 1.0±0.02 psig which produces a Mach number of 0.3±0.02.

CONCLUSIONS

The digital control mode of operation of burner rigs is a viable, highly flexible, and accurate means of long time, unattended materials durability hot corrosion testing. Limits of acceptable testing can be set and easily changed. Also, test modes can be easily changed, such as ramp or other heating and cooling patterns can be programmed. Data can be collected on disk or tape and used to make calculations and correlations off-line. Also, on line hard copy and screen plotting of information is readily implemented for real time assessment of burner operation. Furthermore, the computer starts and operates the burner in a more reproducible and predictable manner than a human operator. This greatly minimizes carbon buildup and frequency of cleaning of the burner. The computer based control system starts, runs the tests and turns off the burner when finished or when the test conditions are out of preset limits. This latter mode of operation protects the test specimen from abnormal testing.

APPENDIX

A listing of the entire digital control program is presented in the following pages. This program is written in a commercial basic language. The variables and function of the various program sections are defined in REM statements. It must be emphasized that this set of instructions (program) is not a general control program for all burner rigs, rather it was written to do a specific job and experience has demonstrated that it does that job very well.

APPENDIX

```
1                            !***************************
3                             ! DIGITAL CONTROL PROGRAM
4                            !***************************
5  !
11    CLEAR 709
12    ON INTR 5 GOTO Pfail!INITIALIZE POWER FAIL INTERUPT
13    ENABLE INTR 5;1
14    CONTROL 5,5;50,4000,400
16    ON ERROR GOTO Error
17    PRINTER IS 701
20    ON TIMEOUT 7,5 GOTO 7104
21    PRINT "PRINTER ON"
23    PRINTER IS 1
24    !          ************************************************
26    !           CHECKING AIR SUPPLY TO BURNER RIG PIVOT CYLINDER
27    !          ************************************************
29    OUTPUT 709;"VC3"
30         OUTPUT 709;"AI31"
31         ENTER 709;Pos13
32         OUTPUT 709;"AI32"
33         ENTER 709;Pos14
34         IF Pos13>2. OR Pos14>2. THEN GOTO Abort
35    !^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^   ^^^^^^^
37    REAL Const(15),Qtot(50)
38    Spt=1652! TEMP SETPOINT BOTH RIGS 3&4 (DEGREES F)
39    Bpspt=1.0! BURNER PRESS. SET POINT BOTH RIGS 3&4 (psig)
40    Start3=0
41    Start4=0
42    Samp3=0
43    Samp4=0
44    Ctt=0
45    Ctt44=0
46    Control3=0
47    Control4=0
48    Tmax4=1652
49    Tmin4=1652
50    Tmax3=1652
51    Tmin3=1652
52    Mmm=0
53    Tup3=0
54    Tdn3=0
55    Tup4=0
56    Tdn4=0
57  !        *****************************
58  !          INITIAL PID LOOP CONSTANTS
59  !        *****************************
60  !                  FUEL FLOW LOOP
61  !               ^^^^^^^^^^^^^^^^^^^
62  !
63 Gai3=8 !    PROP. GAIN BURNER RIG 3 INIT. VALUES
64 Res3=3!     RESET BURNER RIG 3
65 Rcon3=10!   RATE CONSTANT BURNER RIG 3
66 Gai4=15!    PROP. GAIN BURNER RIG 4
67 Res4=3!     RESET BURNER RIG 4
68 Rcon4=20!   RATE BURNER RIG 4
69 !
70 !                ^^^^^^^^^^^^^^^^^^^
71 !                   AIR FLOW LOOP
72 !                ^^^^^^^^^^^^^^^^^^^^
73 !
74 Air3c=200!  AIR FLOW PROP. GAIN RIG 3
75 Air4c=200!  AIR FLOW PROP. GAIN RIG 4
76 !**********************************************************************
77 IMAGE AAAAAA,2X,DD,2X,DD,2X,DDD,2X,DDDD,2X,DD.D,2X,DDD.D,2X,DD.D,2X,DDDD,2X,.
DDDD,2X,D.DDD,2X,DDD
78 ALLOCATE Outfuel3s(10)
```

```
79 ALLOCATE Outfuel4s(10)
80 REAL To(10,10)
90 REAL Timer(10,10)
91 REAL Tot(50),El(50),Rater(50),Errrt(50)
92 REAL Ti(50),Bprr(50),Errrp(50)
100 First3=1
110 First4=1
130 Outc3=0
140 Outc4=0
150 Sumint3=0
160 Sumint4=0
170 Sumerrt3=0
180 Sumerrt4=0
190 Ht3=0
200 Ht4=0
210 Ctime3=0
220 Ctime4=0
250 Ct3=0
260 Ct4=0
270 ALLOCATE Rn(25)
280 N=0
290 L=0
291 Nn=0
292 Nx=0
293 Cycl3=1
294 Cycl4=1
300 Cycles3=1
310 Cycles4=1
311 Cyflag3=0
312 Cyflag4=0
320 GOSUB Clearscreen
321 Dumm=1
330 OFF KEY
331 !       ****************************************
333 !         SCREEN DISPLAY OF SPECIAL FUNCTION KEYS
334 !       ****************************************
340 ON KEY 9 LABEL "STOP" GOTO Stop
341 ON KEY 4 LABEL "SENSOR CK" GOSUB Check
350 ON KEY 0 LABEL "STR3" GOTO Str3
360 ON KEY 1 LABEL "STR4" GOTO Str4
370 ON KEY 5 LABEL "P.GAIN" GOSUB Gain
380 ON KEY 6 LABEL "RESET" GOSUB Reset
390 ON KEY 7 LABEL "RATE" GOSUB Rates
400 ON KEY 3 LABEL "AIR3C" GOSUB Airrate
401 ON KEY 8 LABEL "AIR4C" GOSUB Airrate4
410 Spin:      DISP X
420       GOTO Spin
430       !
440       OUTPUT 2 USING "#,B";255,75
441 !^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^
442 !      BRANCHING AND TIME DISPLAY
443 !^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^
450 GOSUB Control
460 OUTPUT 709;"TD"
470 ENTER 709;Time$
480 DISP Time$[7,14]
490 GOTO 450
500!           ==============================================
510!                      CLEAR SCREEN
511 !          ==============================================
530 Clearscreen:!
540             OUTPUT 2 USING "#,B";255,75
550             RETURN
560!           ==============================================
561 !                     START BURNER RIG 3
```

```
562 !          ============================================
564 Str3:!
565   PRINT TABXY(1,10);"TURN ON PRINTER"
566   Wai3=5
567   INPUT "TOTAL NO. OF HEATING CYCLES",Nocy3
568   INPUT "NO. OF PREVIOUS CYCLES",Prevcy3
569   INPUT "BAR NO.",Barno3$
570   Totcy3=Prevcy3+1
571   GOSUB Clearscreen
572   OUTPUT 709;"DO2,6"!                      TURN ON SYST. PWR.
573      Control3=1
574      Air3=5500
575      OUTPUT 709;"AO3,0,"&VAL$(Air3)!    OPEN AIR VALVE
576      WAIT 1
577      OUTPUT 709;"DC2,2"!AIR HTR 3!      START AIR PREHEATER
578      Start3=1
579      GOTO 450
580 Airtem:!
581      GOSUB Tep!       MEASURE COMBUSTION AIR AND COMB. CHAMB.TEMP
582      IF Cat3<440 THEN RETURN
583      Start3=2
584      Outfuel3=3000       ! FUEL NOZ.=1.00
585      OUTPUT 709;"AO3,1,"&VAL$(Outfuel3)!   OPEN FUEL VALVE
586      WAIT 1
587      OUTPUT 709;"DC2,0"!TURN ON IGNITOR
588      RETURN
589 Chamt:!
590      GOSUB Tep
591      IF Chamb3<800 THEN RETURN
592  !#####################################################
593    GOSUB 1760
594    !**********************************************
595    !        SET FUEL PRESSURE TO 90-92 psig
596    !^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^
598    PRINT TABXY(1,1);"FU NOZ. PR.=";Fupress
599    IF Fupress>92 THEN !          FUEL NOZ.=1.00
600         Outfuel3=Outfuel3-50
601         OUTPUT 709;"AO3,1,"&VAL$(Outfuel3)
602         END IF
603    IF Fupress<90 THEN
604         Outfuel3=Outfuel3+25
605         OUTPUT 709;"AO3,1,"&VAL$(Outfuel3)
606         END IF
607     IF Fupress>92 OR Fupress<90 THEN RETURN
608  !**********************************************************
609      Start3=3
610      OUTPUT 709;"DC2,1"! START CYCLE TIMER
611      RETURN
612 !              ====================================
613 !                         START BURNER RIG 4
614 !              ====================================
615 Str4:!
616   PRINT TABXY(27,10);"TURN ON PRINTER"
617   PRINT TABXY(27,11);"TURN ON POWER RIG 3- "
618   PRINT TABXY(27,12);"TURNS ON 2-COLOR PWR."
619   Wai4=5
620   INPUT " NO. OF HEATING CYCLES",Nocy4
621   INPUT "NO. OF PREVIOUS CYCLES",Prevcy4
622   INPUT "BAR NO",Barno4$
623   Totcy4=Prevcy4+1
624   GOSUB Clearscreen
625   OUTPUT 709;"DO2,7"!TURN ON SYST. PWR.
626      Control4=1
627      Air4=4750
628      OUTPUT 709;"AO4,0,"&VAL$(Air4)
629      WAIT 1
```

```
630      OUTPUT 709;"DC2,5"! AIR HTR 4
631      Start4=1
632      GOTO 450
633 Airtem4:!
634      GOSUB Tep
635      IF Cat4<440 THEN RETURN
636      Start4=2
637      Outfuel4=4400
638      OUTPUT 709;"AO4,1,"&VAL$(Outfuel4)
639      WAIT 3
640      OUTPUT 709;"DC2,3"!IGN 4
641      RETURN
642 Chamt4:!
643      GOSUB Tep
644      IF Chamb4<650 THEN RETURN
645      OUTPUT 709;"AO4,0,4650"!AIR
646  !#####################################################
647      GOSUB 1760
648      PRINT TABXY(27,1);"FU.NOZ.PRES.=";Fupress
649  IF Fupress>92 THEN
650      Outfuel4=Outfuel4-50
651      OUTPUT 709;"AO4,1,"&VAL$(Outfuel4)
652      PRINT TABXY(27,2);"FUEL DIG";Outfuel4
653      END IF
654  IF Fupress<90 THEN
655      Outfuel4=Outfuel4+15
656      OUTPUT 709;"AO4,1,"&VAL$(Outfuel4)
657      PRINT TABXY(27,2);"FUEL DIG";Outfuel4
658      END IF
659  IF Fupress>92 OR Fupress<90 THEN RETURN
660  !#########################################
661      Air4=4650
662      Start4=3
663      OUTPUT 709;"DC2,4"!TIMER 4
664      RETURN
665  !************************************************
666  !           MANUAL STOP OF RIGS
667  !^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^
669 Stop:!
670      INPUT "WHICH RIG",Rig
671      IF Rig=4 THEN GOTO 682
672      OUTPUT 709;"AO3,1,10"
673      Control3=0
674      OUTPUT 709;"DC2,6"
675      GOSUB Clearscreen
676      PRINTER IS 701
677      PRINT "RIG 3 STOPPED";" ";"TOTAL CYCLES=";Totcy3
678      PRINTER IS 1
679      First3=1
680   IF Control4=0 THEN GOTO 731
681      GOTO 450
682      OUTPUT 709;"AO4,1,10"
683      OUTPUT 709;"DC2,7"
684      Control4=0
690      GOSUB Clearscreen
691      PRINTER IS 701
700      PRINT "RIG 4 STOPPED";" ";"TOTAL CYCLES=";Totcy4
710      PRINTER IS 1
720      First4=1
722   IF Control3=0 THEN GOTO 731
730      GOTO 450
731      CLEAR 709
732      STOP
740 !============================================
750 Rates:!
751       INPUT "RIG NO.",Rigcon
```

```
760             INPUT "RATE",Rcon
761        IF Rigcon=3 THEN Rcon3=Rcon
762        IF Rigcon=4 THEN Rcon4=Rcon
770             RETURN
780 Gain:  !
781        INPUT "RIG NO.",Rigcon
790             INPUT "PROP. GAIN",Gai
791        IF Rigcon=3 THEN Gai3=Gai
792        IF Rigcon=4 THEN Gai4=Gai
800             RETURN
810 Reset: !
811         INPUT "RIG NO.",Rigcon
820             INPUT "RESET",Res
821         IF Rigcon=3 THEN Res3=Res
822         IF Rigcon=4 THEN Res4=Res
830             RETURN
1330       !-------------------------------------
1331 Airrate: !
1332           INPUT "AIR CONT FOR RIG 3",Air3c
1333           RETURN
1334 Airrate4:!
1335           INPUT "AIR CONT FOR RIG 4",Air4c
1336           RETURN
1338       !#############################################
1339       !               CENTRAL STEERING FOR PROGRAM FLOW
1340       !^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^
1342 Control:!
1520 FOR Rignum=3 TO 4
1521   GOSUB Tep
1530     IF Control3=0 AND Rignum=3 THEN GOTO 1730
1540     IF Control4=0 AND Rignum=4 THEN GOTO 1730
1550 !---------------------
1551     IF Control3=2 AND Rignum=3 AND Chamb3<800 THEN GOTO Shutoff3
1552     IF Control4=2 AND Rignum=4 AND Chamb4<800 THEN GOTO Shutoff4
1554 IF Rignum=3 AND Control3=2 THEN GOTO 1617
1555 IF Rignum=4 AND Control4=2 THEN GOTO 1617
1556 !------------------------
1560   IF Rignum=3 AND Control3=1 AND Start3=1 THEN
1561      GOSUB Airtem
1562      GOTO 1730
1563      END IF
1570   IF Rignum=3 AND Control3=1 AND Start3=2 THEN
1571      GOSUB Tep
1572      IF Cat3>575 THEN GOTO Shutoff3
1574      GOSUB Chamt
1575      GOTO 1730
1576      END IF
1580   IF Rignum=3 AND Control3=1 AND Start3=3 THEN
1581      GOSUB Tep
1582      IF Cat3>575 THEN GOTO Shutoff3
1590      GOSUB Heatup3
1591      GOTO 1730
1592      END IF
1593   !---------------------------------------
1595   IF Rignum=4 AND Control4=1 AND Start4=1 THEN
1596      GOSUB Airtem4
1597      GOTO 1730
1598      END IF
1599   IF Rignum=4 AND Control4=1 AND Start4=2 THEN
1600      GOSUB Tep
1601      IF Cat4>575 THEN GOTO Shutoff4
1603      GOSUB Chamt4
1604      GOTO 1730
1605      END IF
1606   IF Rignum=4 AND Control4=1 AND Start4=3 THEN
1607      GOSUB Tep
```

```
1608       IF Cat4>575 THEN GOTO Shutoff4
1610       GOSUB Heatup4
1611       GOTO 1730
1612       END IF
1613 !------------------------------------------------
1617   GOSUB Meas!     MEASUREMENT OF RIG PARAMETERS
1647 !------------------------------------------------
1720      GOSUB 1760
1730        NEXT Rignum
1740        RETURN
1750 !*****************************************
1760           IF Rignum=3 THEN Fupre=24
1770           IF Rignum=4 THEN Fupre=29
1780      OUTPUT 709;"AI"&VAL$(Fupre)
1790      ENTER 709;Fvolt
1800      Fupress=Fvolt*10000
1801   IF Rignum=3 AND Start3=2 THEN RETURN
1802   IF Rignum=4 AND Start4=2 THEN RETURN
1810   IF Rignum=3 AND Control3=1 THEN GOTO 6957
1820   IF Rignum=4 AND Control4=1 THEN GOTO 6957
2030      !-------------------------------
2040       IF Rignum=3 THEN Xp=1
2050       IF Rignum=4 THEN Xp=27
2051       IF Rignum=3 THEN Cyo=Cycles3
2052       IF Rignum=4 THEN Cyo=Cycles4
2060            PRINT TABXY(Xp,1);"BP";DROUND(Bp2,3);"FP";DROUND(Fupress,3);"CY";
Cyo
2120   IF Rignum=3 THEN PRINT TABXY(Xp,3);"PG";Gai3;"RS";Res3;"RA";Rcon3;"AC";Air
3c
2121   IF Rignum=4 THEN PRINT TABXY(Xp,3);"P.G";Gai4;"RES";Res4;"RA";Rcon4;"AC";A
ir4c
2130            IF Rignum=3 THEN Airp=Air3
2140            IF Rignum=4 THEN Airp=Air4
2150            IF Rignum=3 THEN Fuelp=Outfuel3
2160            IF Rignum=4 THEN Fuelp=Outfuel4
2170            PRINT TABXY(Xp,4);"F DIG";Fuelp;"A DIG";Airp
2180    !________________________________
2210       IF Rignum=3 THEN GOTO 2510
2220       IF Rignum=4 THEN GOTO 2940
2230            IF Rignum=3 THEN GOSUB 2280
2240            IF Rignum=4 THEN GOSUB 2390
2250            Cxxxx=0
2260            RETURN
2261 !          **********************************************
2272 !               FUEL AND AIR ADJUST FOR RIGS 3 AND 4
2273 !          ^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^
2280     Outc3=Outc3+1
2295     IF Outc3>1 THEN GOTO 2310
2300     Outfuel3s(1)=Outfuel3
2310       Outfuel3=Outfuel3s(1)-INT(Errt*Gai3)-INT(Res3*Sumint3)-INT(Rate*Rcon3)
2330            OUTPUT 709;"AO3,1,"&VAL$(Outfuel3)
2340       Air3=Air3-INT(Errp*Air3c)
2350            OUTPUT 709;"AO3,0,"&VAL$(Air3)
2351     GOSUB Tep
2352     IF Cat3>575 THEN GOTO Shutoff3
2360       PRINT TABXY(Xp,5);"S";INT(Sumint3);"FF1";DROUND(Fuelflow,2);"F/A";DROU
ND(F3,3)
2362 PRINT TABXY(Xp,6);">54";INT(Pctup3);"5054";INT(Pctmid3);"<50";INT(Pctdn3)
2363       PRINT TABXY(Xp,2);"CA";DROUND(Cat3,3);"CH";DROUND(Chamb3,4);"AF1";DROU
ND(Airflow,3)
2370            RETURN
2380    !^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^
2390    Outc4=Outc4+1
2404    IF Outc4>1 THEN GOTO 2420
2410    Outfuel4s(1)=Outfuel4
2420       Outfuel4=Outfuel4s(1)-INT(Errt*Gai4)-INT(Res4*Sumint4)-INT(Rcon4*Rate)
```

```
2440           OUTPUT 709;"A04,1,"&VAL$(Outfuel4)
2450       Air4=Air4-INT(Errp*Air4c)
2460           OUTPUT 709;"A04,0,"&VAL$(Air4)
2461     GOSUB Tep
2462     IF Cat4>575 THEN GOTO Shutoff4
2470     PRINT TABXY(Xp,5);"S";INT(Sumint4);"FF1";DROUND(Fuelflow,2);"F/A";DROUND
(F4,3)
2471     PRINT TABXY(Xp,6);">54";INT(Pctup4);"5054";INT(Pctmid4);"<50";INT(Pctdn4
)
2472     PRINT TABXY(Xp,2);"CA";DROUND(Cat4,4);"CH";DROUND(Chamb4,4);"AF1";DROUND
(Airflow,3)
2480           RETURN
2490  !           ------------------------------------
2491  !              RIG 3 PID LOOP BRANCHING CONTROL
2500  !           ------------------------------------
2510  OUTPUT 709;"AI31"
2511  ENTER 709;Pos3
2512  IF Pos3<=2. THEN GOTO 2760
2520 !-----------------------------------------
2521 !                  HEATING
2522 !^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^
2530      IF First3=1 THEN Time3=TIMEDATE
2540      First3=5
2550           N=0
2560           Timeht=TIMEDATE
2570           Ht3=(Timeht-Time3)/60
2571           IF Ht3>4 THEN Cyflag3=0
2580     !-------------------------------------
2590    PRINT TABXY(Xp,7);"HT";DROUND(Ht3,3);"TEM";DROUND(Tempt,4)
2591    IF Tempt>Tmax3 AND Ht3>.2 THEN Tmax3=Tempt
2592    IF Tempt<Tmin3 AND Ht3>2 THEN Tmin3=Tempt
2593 IF Tempt>1654 AND Tempt<=Tmax3 AND Ht3>.2 THEN Tup3=Tup3+(El(Wai)/60)
2594 IF Tempt<1650 AND Tempt>=Tmin3 AND Ht3>2 THEN Tdn3=Tdn3+(El(Wai)/60)
2595 IF Samp3=0 THEN GOTO 2602
2597 Pctup3=(Tup3/Samp3)*100
2598 Pctdn3=(Tdn3/Samp3)*100
2599 Pctmid3=100-(Pctup3+Pctdn3)
2600    PRINT TABXY(Xp,8);"TMAX";DROUND(Tmax3,4);"TMIN";DROUND(Tmin3,4)
2601    !---------------------------------------
2602    Temptc=INT((Tempt-32)*5/9)
2603           IF Temptc<=860 THEN GOTO 2735
2610           IF Temptc>=940 THEN GOTO 2735
2620      !-------------------------------------
2630           Txx=(Temptc-860)/(80/60)
2640           GOSUB 6620
2650      MOVE Ht3,Txx
2690      DRAW Ht3,Txx
2710    Bpp=45+((Bp2-.95)*150)
2720    MOVE Ht3,Bpp
2730    DRAW Ht3,Bpp
2731    Ftox=(F3-.025)*1500
2732    MOVE Ht3,Ftox
2733    DRAW Ht3,Ftox
2735    IF Fupress>165 THEN GOTO Shutoff3
2736    !-----------------------------------------
2737    IF Outc3>=1 THEN GOTO 2750
2738    !------------------------------------------
2739    IF Tempt<1636 AND Ht3<1 THEN GOTO 2250
2740         IF Tempt>1620 AND Tempt<1636 THEN
2741            Outfuel3=Outfuel3+8
2742            GOTO 2330
2743            END IF
2744         IF Tempt>1636 AND Tempt<1650 THEN
2745            Outfuel3=Outfuel3+5
2746            Sumint3=0
2747            GOTO 2330
```

```
2748            END IF
2749    !++++++++++++++++++++++++++++++++++++++++
2750                  GOTO 2230
2751 !--------------------------------------
2752 !              COOLING
2753 !^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^
2760           N=N+1
2770           IF N>=2 THEN GOTO 2880
2771       Ht3=0
2772       Samp3=0
2774       Sumint3=0
2775       Outc3=0
2776       Tup3=0
2777       Tdn3=0
2779       Outfuel3=INT(Outf3-(Outf3*.005))
2780       OUTPUT 709;"AO3,1,"&VAL$(Outfuel3)
2781   PRINTER IS 701
2782   PRINT USING 77;Barno3$,Rignum,Cycles3,Totcy3,Tmax3,Pctup3,Pctmid3,Pctdn3,T
min3,F3,Bp2,Fupress
2783         IF Pctmid3<80 AND Cycles3>1 THEN GOTO Shut3
2785   PRINTER IS 1
2786           Tmax3=1652
2787           Tmin3=1652
2788           Ct3=0
2840           Sumerrt3=0
2850           Time13=TIMEDATE
2870           GOSUB Display1
2880       Time3=TIMEDATE
2890       Ctime3=(Time3-Time13)/60
2893       IF Ctime3>=2.0 THEN GOSUB Cyclrt3
2900       PRINT TABXY(Xp,7);"CLTIM";DROUND(Ctime3,3);"TEM";DROUND(Tempt,4)
2901    !^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^
2902    IF Ctime3>10 OR Fupress>165 THEN GOTO Shutoff3!IF BURNER STICKS IN COOLIN
G POSITION
2908    !~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
2910       GOTO 2250
2920   !         ------------------------------------
2921   !            RIG 4 PID LOOP BRANCHING CONTROL
2930   !         ------------------------------------
2940      OUTPUT 709;"AI32"
2941      ENTER 709;Pos4
2942      IF Pos4<=2. THEN GOTO 3170
2950 !------------------------------------------
2951 !              HEATING
2952 !^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^
2960      IF First4=1 THEN Time4=TIMEDATE
2970      First4=5
2980           L=0
2990           Timeht=TIMEDATE
3000           Ht4=(Timeht-Time4)/60
3001           IF Ht4>4 THEN Cyflag4=0
3010           PRINT TABXY(Xp,7);"HT";DROUND(Ht4,3);"TEM";DROUND(Tempt,4)
3011        IF Tempt>Tmax4 AND Ht4>.2 THEN Tmax4=Tempt
3013        IF Tempt<Tmin4 AND Ht4>2 THEN Tmin4=Tempt
3014   IF Tempt>1654 AND Tempt<=Tmax4 AND Ht4>.2 THEN Tup4=Tup4+(El(Wai)/60)
3015   IF Tempt<1650 AND Tempt>=Tmin4 AND Ht4>2 THEN Tdn4=Tdn4+(El(Wai)/60)
3016   IF Samp4=0 THEN GOTO 3022
3018   Pctup4=(Tup4/Samp4)*100
3019   Pctdn4=(Tdn4/Samp4)*100
3020   Pctmid4=100-(Pctup4+Pctdn4)
3021        PRINT TABXY(Xp,8);"TMAX";DROUND(Tmax4,4);"TMIN";DROUND(Tmin4,4)
3022 !-----------------------------------
3023 Temptc=INT((Tempt-32)*5/9)
3024     IF Temptc<=860 THEN GOTO 3145
3030     IF Temptc>=940 THEN GOTO 3145
3031 !**************************************
```

```
3040    Txx=(Temptc-860)/(80/60)
3050    GOSUB 6800
3090 MOVE Ht4,Txx
3100 DRAW Ht4,Txx
3120  Bpp=45+((Bp2-.95)*150)
3130  MOVE Ht4,Bpp
3140  DRAW Ht4,Bpp
3141  Ftox=(F4-.025)*1500
3142  MOVE Ht4,Ftox
3143  DRAW Ht4,Ftox
3145  IF Fupress>155 THEN GOTO Shutoff4
3146  !~~~~~~~~~~~~~~~~~~~~~~~~
3147  IF Outc4>=1 THEN GOTO 3165
3148  !*************************
3149  IF Tempt<1636 AND Ht4<1 THEN GOTO 2250
3150  IF Tempt>1660 AND Tempt<1680 THEN
3151      Outfuel4=Outfuel4-8
3152      GOTO 2440
3153      END IF
3155  IF Tempt<1620 THEN
3156      Outfuel4=Outfuel4+8
3157      GOTO 2440
3158      END IF
3159  IF Tempt>1620 AND Tempt<1650 THEN
3160      Outfuel4=Outfuel4+6
3161      Sumint4=0
3162      GOTO 2440
3163      END IF
3164  !*************************
3165          GOTO 2230
3166  !----------------------------------------
3167  !                  COOLING
3168  !^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^
3170          L=L+1
3180          IF L>=2 THEN GOTO 3290
3181       Ht4=0
3182       Samp4=0
3184       Sumint4=0
3185       Outc4=0
3186       Tup4=0
3187       Tdn4=0
3189     Outfuel4=INT(Outf4-(Outf4*.005))
3191     OUTPUT 709;"AO4,1,"&VAL$(Outf4)
3192          Ct4=0
3202   PRINTER IS 701
3212   PRINT USING 77;Barno4$,Rignum,Cycles4,Totcy4,Tmax4,Pctup4,Pctmid4,Pctdn4,
Tmin4,F4,Bp2,Fupress
3213          IF Pctmid4<80 AND Cycles4>1 THEN GOTO Shut4
3222   PRINTER IS 1
3232          Tmax4=1652
3242          Tmin4=1652
3250          Sumerrt4=0
3260          Time14=TIMEDATE
3280    GOSUB Display2
3290      Time4=TIMEDATE
3300      Ctime4=(Time4-Time14)/60
3303      IF Ctime4>=2.0 THEN GOSUB Cyclrt4
3310      PRINT TABXY(Xp,7);"CLTIM";DROUND(Ctime4,3);"TEM";DROUND(Tempt,4)
3311  !^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^
3313      IF Ctime4>10 OR Fupress>155 THEN GOTO Shutoff4
3318  !------------------------------
3320      GOTO 2250
3321  !++++++++++++++++++++++++++++++++++++++++++
3322  !                 CYCLE COUNTING RIG 3
3323  !^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^
3325 Cyclrt3: !
```

```
3326       IF Cyflag3>=1 THEN GOTO 3330
3327          Cycles3=Cycles3+1
3328          Totcy3=Prevcy3+Cycles3
3329       IF Cycles3=(Nocy3+1) THEN GOTO Shutoff3
3330          Cyflag3=Cyflag3+1
3331       RETURN
3332 !----------------------------------------
3333 !                CYCLE COUNTING RIG 4
3334 !^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^
3336 Cyclrt4:!
3337       IF Cyflag4>=1 THEN GOTO 3341
3338          Cycles4=Cycles4+1
3339          Totcy4=Prevcy4+Cycles4
3340       IF Cycles4=(Nocy4+1) THEN GOTO Shutoff4
3341          Cyflag4=Cyflag4+1
3342       RETURN
3343!---------------------------------------------------
3344 !            SHUTOFF RIGS 3&4 IF TEMP. CONTROL DEGRADES
3345 !^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^
3347 Shut3:!
3348       PRINTER IS 701
3349       PRINT "RIG 3 BURNER OFF--LESS THAN 80 % IN BAND-CYCLES=";Totcy3
3350       PRINTER IS 1
3351       OUTPUT 709;"A03,1,0"!   FUEL VALVE  CLOSED
3352       WAIT 2
3353       OUTPUT 709;"DC2,6"!     POWER OFF
3354       GOTO 3387
3355 !**************************************************
3357 Shut4:!
3358       PRINTER IS 701
3359       PRINT "RIG 4 BURNER OFF---LESS THAN 80 % IN BAND-CYCLES=";Totcy4
3360       PRINTER IS 1
3361       OUTPUT 709;"A04,1,0"
3362       WAIT 2
3363       OUTPUT 709;"DC2,7"
3364       GOTO 3419
3365  !**************************************************************
3366  !          SHUTOFF RIGS 3&4 IF CYCLES COMPLETED OR A MALFUNCTION
3367  !^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^
3369 Shutoff3:!
3370          OUTPUT 709;"A03,1,10"!FUEL OFF
3371          GOSUB Clearscreen
3372        IF Cycles3=Nocy3 THEN GOTO 3380
3373    IF Cycles3<>(Nocy3+1) THEN
3374    PRINTER IS 701
3375         PRINT "BURNER RIG 3-MALFUNCTION"
3376    PRINTER IS 1
3377         OUTPUT 709;"DC2,6"!SYST. PWR OFF
3378         GOTO 3387
3379         END IF
3380          PRINT TABXY(1,5);"CYCLES COMPLETED"
3381      PRINTER IS 701
3382      PRINT "RIG 3-CYCLES COMPLETED"
3383      PRINTER IS 1
3384      OUTPUT 709;"DC2,6"
3385          Control3=0
3386          OUTPUT 709;"A03,0,10"!AIR OFF
3387          Control3=0
3388          IF Control4<>0 THEN GOTO 450
3389          CLEAR 709!OPENS ALL RELAYS
3390      GOSUB Clearscreen
3391      PRINT TABXY(3,8);"DONE"
3392          GOTO 7123!END
3393 !****************************************
3394 Shutoff4:!
3395          OUTPUT 709;"A04,1,10"
```

```
3396          GOSUB Clearscreen
3397      IF Cycles4=Nocy4 THEN GOTO 3405
3398     IF Cycles4<>(Nocy4+1) THEN
3399    PRINTER IS 701
3400        PRINT "BURNER RIG 4-MALFUNCTION"
3401    PRINTER IS 1
3402        OUTPUT 709;"DC2,7"
3403        GOTO 3419
3404        END IF
3405          PRINT TABXY(27,5);"CYCLES COMPLETED"
3406       PRINTER IS 701
3407       PRINT "RIG 4-CYCLES COMPLETED"
3408       PRINTER IS 1
3409       OUTPUT 709;"DC2,7"
3410          Control4=0
3418          OUTPUT 709;"AO4,0,10"
3419          Control4=0
3428          IF Control3<>0 THEN GOTO 450
3438          CLEAR 709
3439          GOSUB Clearscreen
3440          PRINT TABXY(29,8);"DONE"
3448          GOTO 7123!END
3458 !***************************************************************
3468 !          MEASURE COMBUSTION AIR AND COMBUSTION CHAMBER TEMP.
3478 !^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^
4360 Tep:!
4370           IF Rignum=3 THEN Cat=0
4380           IF Rignum=4 THEN Cat=2
4390           IF Rignum=3 THEN Cham=1
4400           IF Rignum=4 THEN Cham=4
4410           OUTPUT 709;"AI"&VAL$(Cat)
4420           ENTER 709;T
4430     GOSUB Tempcal
4440           OUTPUT 709;"AI"&VAL$(Cham)
4450           ENTER 709;T
4460     GOSUB Tempcal2
4470 IF Rignum=3 AND Control3=1 THEN PRINT TABXY(1,4);"CAT";DROUND(Cat3,4);"CHAM
";DROUND(Chamb3,4)
4471 IF Rignum=4 AND Control4=1 THEN PRINT TABXY(27,4);"CAT";DROUND(Cat4,4);"CHA
M";DROUND(Chamb4,4)
4480           RETURN
4500 Tempcal:!
4510         OUTPUT 709;"AI019"
4520         ENTER 709;R
4530         C=25+(R-2.5)/.1
4540         D=T+C*4.0E-5
4550   Tc=.2265+D*(24150+D*(67230+D*(2.21E+6+D*(-8.61E+8+D*4.835E+10))))
4560   Tf=Tc*1.8+32
4570   IF Rignum=3 THEN Cat3=Tf
4580   IF Rignum=4 THEN Cat4=Tf
4590     RETURN
4600 Tempcal2: !
4610          OUTPUT 709;"AI019"
4620          ENTER 709;R
4630          C=25+(R-2.5)/.1
4640          D=T+C*4.0E-5
4650   Tc=.2265+D*(24150+D*(67230+D*(2.21E+6+D*(-8.61E+8+D*4.835E+10))))
4660   Tf=Tc*1.8+32
4670   IF Rignum=3 THEN Chamb3=Tf
4680   IF Rignum=4 THEN Chamb4=Tf
4690   RETURN
4781  !****************************************
4782  !           FIRST CYCLE HEATUP RIG 3
4783  !^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^
4790 Heatup3:!
4800         OUTPUT 709;"AI"&VAL$(20)
```

```
4810         ENTER 709;Tvolts
4820         Two=(800+(Tvolts*4400))*1.8+32
4830         OUTPUT 709;"AI"&VAL$(21)
4840         ENTER 709;Prevol
4850         Pre=Prevol*1000
4851         GOTO 1760
4860   Errt3=Two-Spt
4870   Errp3=Pre-Bpspt
4880     PRINT TABXY(1,2);"TEMP";DROUND(Two,4);"B.PR.";DROUND(Pre,3)
4901   IF Prevcy3=0 AND Cycles3=1 AND Ctt<30 THEN GOTO 5020
4910   IF Two<1620 THEN GOTO 5020!COOLING
4920   IF Two>1620 THEN GOTO 5160! HEATING UP
4940     Outfuel3=Outfuel3-INT(1.5*Errt3)
4950     OUTPUT 709;"AO3,1,"&VAL$(Outfuel3)
4960     Air3=Air3-INT(700*Errp3)
4970     OUTPUT 709;"AO3,0,"&VAL$(Air3)
4980   PRINT TABXY(1,3);"FUEL";DROUND(Outfuel3,4);"AIR";DROUND(Air3,4)
4990   PRINT TABXY(1,5);"FU.FL.";DROUND(Fuelflow,3)
4991   PRINT TABXY(1,6);"F/A";DROUND(F3,3)
4992   PRINT TABXY(1,7);"FU.PR.";DROUND(Fupress,4)
4993   PRINT TABXY(1,8);"AIR FL";DROUND(Airflow,5)
5000     RETURN
5020       Nn=Nn+1
5030       IF Nn>=2 THEN GOTO 5070
5040          Cti=TIMEDATE
5060          Outfuel3=Outfuel3-(INT(.015*Outfuel3))
5070     Hti=TIMEDATE
5071  PRINT TABXY(1,7);"FU.PR.",DROUND(Fupress,4)
5072  PRINT TABXY(1,5);"FU. FL.";DROUND(Fuelflow,3)
5073  PRINT TABXY(1,6);"F/A";DROUND(F3,3)
5074  PRINT TABXY(1,8);"AIR FL";DROUND(Airflow,5)
5080     Cta=TIMEDATE
5090     Ctt=(Cta-Cti)/60
5100     PRINT TABXY(1,1);"COL T";DROUND(Ctt,3)
5101     IF Prevcy3=0 AND Cycles3=1 THEN GOTO 5104
5103   IF Ctt>10 OR Fupress>155 THEN GOTO Shutoff3
5104   IF Prevcy3=0 AND Cycles3=1 AND Ctt>30 THEN GOTO 5118
5105   IF (Ctt<3 OR Prevcy3=0) AND Fupress<86 THEN GOTO 5112!  FUEL NOZ=1.0
5106   !**************************************************
5108   IF (Ctt<3 OR Prevcy3=0) AND F3>.026 THEN
5109   Outfuel3=Outfuel3-35
5110   OUTPUT 709;"AO3,1,"&VAL$(Outfuel3)
5111       END IF
5112   IF (Ctt<3 OR Prevcy3=0) AND (F3<.025 OR Fupress<85) THEN
5113   Outfuel3=Outfuel3+25
5114   OUTPUT 709;"AO3,1,"&VAL$(Outfuel3)
5115       END IF
5116 !^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^
5117   IF Prevcy3=0 AND Cycles3=1 AND Ctt<30 THEN GOTO 4960
5118     IF Ctt>3.2 AND Two<1620 THEN
5120     Outfuel3=Outfuel3+12
5121     IF Ctt>55 THEN GOTO Shutoff3
5130     GOTO 4950
5140     END IF
5141     GOTO 4960
5150    RETURN !FROM COOLING
5151 !$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
5160    Cyt=TIMEDATE
5170    Ht=(Cyt-Hti)/60
5180    PRINT TABXY(1,1);"HT T";DROUND(Ht,3);"F/A";DROUND(F3,3)
5181    PRINT TABXY(1,8);"AIR FL";DROUND(Airflow,5)
5190    Nn=0
5300  IF Two>=1648 AND Two<=1654 THEN GOSUB End3
5301  IF Control3=2 THEN GOTO 450
5303  IF Ht>10 OR Fupress>155 THEN GOTO Shutoff3
5310    IF Two>1620 AND Two<1650 THEN
```

```
5320    Outfuel3=Outfuel3+8
5330    GOTO 4950
5340    END IF
5341    IF Two>1653 THEN
5342    Outfuel3=Outfuel3-8
5343    GOTO 4950
5344    END IF
5350    GOTO 4940
5750  !*********************************************
5760  !          FIRST CYCLE HEATUP OF RIG 4
5770  !^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^
6000 Heatup4:!
6010         OUTPUT 709;"AI"&VAL$(25)
6020         ENTER 709;Tvolts
6030         Two=(800+(Tvolts*3800))*1.8+32
6040         OUTPUT 709;"AI"&VAL$(30)
6050         ENTER 709;Prevol
6060         Pre=Prevol*1000
6061         GOTO 1760
6070   Errt4=Two-Spt
6080   Errp4=Pre-Bpspt
6090     PRINT TABXY(27,2);"TEMP";DROUND(Two,4);"PRESS";DROUND(Pre,3)
6110     !----------------------------------
6111   IF Prevcy4=0 AND Cycles4=1 AND Ctt44<30 THEN GOTO 6230
6120   IF Two<1620 THEN GOTO 6230!COOLING
6130   IF Two>1620 THEN GOTO 6370! HEATING UP
6140     !----------------------------------
6150     Outfuel4=Outfuel4-INT(1.5*Errt4)
6160     OUTPUT 709;"A04,1,"&VAL$(Outfuel4)
6170     Air4=Air4-INT(700*Errp4)
6180     OUTPUT 709;"A04,0,"&VAL$(Air4)
6190   PRINT TABXY(27,3);"FUEL";DROUND(Outfuel4,4);"AIR";DROUND(Air4,4)
6200   PRINT TABXY(27,5);"FU.FL.";DROUND(Fuelflow,3)
6201   PRINT TABXY(27,6);"F/A";DROUND(F4,3)
6202   PRINT TABXY(27,7);"FU.PR.";DROUND(Fupress,3)
6210     RETURN
6220  !---------------------------------------
6230       Nx=Nx+1
6240       IF Nx>=2 THEN GOTO 6280
6250          Cti44=TIMEDATE
6270          Outfuel4=Outfuel4-(INT(.005*Outfuel4))
6280     Hti44=TIMEDATE
6282  PRINT TABXY(27,6);"F/A";DROUND(F4,3)
6283  PRINT TABXY(27,5);"FU.FL.";DROUND(Fuelflow,3)
6284  PRINT TABXY(27,7);"FU.PR.";DROUND(Fupress,4)
6285  PRINT TABXY(27,8);"AIR FL";DROUND(Airflow,5)
6290     Cta44=TIMEDATE
6300     Ctt44=(Cta44-Cti44)/60
6310     PRINT TABXY(27,1);"COL T";DROUND(Ctt44,3)
6311   IF Prevcy4=0 AND Cycles4=1 THEN GOTO 6314
6313     IF Ctt44>10 OR Fupress>155 THEN GOTO Shutoff4
6314   IF Prevcy4=0 AND Cycles4=1 AND Ctt44>30 THEN GOTO 6329
6315  IF (Ctt44<3 OR Prevcy4=0) AND Fupress<86 THEN GOTO 6322
6316   !####################################
6318  IF (Ctt44<3 OR Prevcy4=0) AND F4>.027 THEN
6319  Outfuel4=Outfuel4-16
6320  OUTPUT 709;"A04,1,"&VAL$(Outfuel4)
6321     END IF
6322  IF (Ctt44<3 OR Prevcy4=0) AND (F4<.026 OR Fupress<85) THEN
6323  Outfuel4=Outfuel4+12
6324  OUTPUT 709;"A04,1,"&VAL$(Outfuel4)
6325      END IF
6326      !&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&
6328   IF Prevcy4=0 AND Cycles4=1 AND Ctt44<30 THEN GOTO 6170
6329     IF Ctt44>4.0 AND Two<1620 THEN
6330     Outfuel4=Outfuel4+10
```

```
6331      IF Ctt44>55 THEN GOTO Shutoff4
6340      GOTO 6160
6350      END IF
6351      GOTO 6170
6360     RETURN !COOLING RIG 4
6361   !****************************************
6370     Cyt44=TIMEDATE
6380     Ht44=(Cyt44-Hti44)/60
6390     PRINT TABXY(27,1);"HT T";DROUND(Ht44,3);"F/A";DROUND(F4,4)
6391     PRINT TABXY(27,8);"AIR FL";DROUND(Airflow,5)
6400     Nx=0
6510   IF Two>=1648 AND Two<=1654 THEN GOSUB End4
6511   IF Control4=2 THEN GOTO 450
6513   IF Ht44>10 OR Fupress>155 THEN GOTO Shutoff4
6520     IF Two>1620 AND Two<1650 THEN
6530     Outfuel4=Outfuel4+4
6540     GOTO 6160
6550     END IF
6551     IF Two>1653 THEN
6552     Outfuel4=Outfuel4-4
6553     GOTO 6160
6554     END IF
6560     GOTO 6150
6561 End3:!
6562       Control3=2
6563       GOSUB Clearscreen
6564       GOSUB Display1
6565       RETURN
6566 End4:!
6567       Control4=2
6568       GOSUB Clearscreen
6569       GOSUB Display2
6570       RETURN
6572    STOP
6573   !****************************************************
6574   !           SCREEN DISPLAY RIGS 3&4
6575   !^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^
6580 Display1: !
6590  GINIT
6600  GRAPHICS ON
6610  PRINT CHR$(12);
6620  VIEWPORT 0,60,10,70
6630  WINDOW 0,60,0,60
6640  AXES 15,15
6641  CSIZE 3.8,.5
6650  LORG 2
6660  U=860
6670  FOR Hzzz=15 TO 45 STEP 15
6680  MOVE 0,Hzzz
6690  U=U+20
6700  LABEL U
6710  NEXT Hzzz
6720  LORG 7
6730  FOR Hz2=15 TO 45 STEP 15
6740  MOVE Hz2+5,0
6750  LABEL Hz2
6760  NEXT Hz2
6770  RETURN
6780 Display2:!
6781  GINIT!CLEARS GRAPHICS
6790  GRAPHICS ON
6791  PRINT CHR$(12);!CLEARS ALPHA
6800  VIEWPORT 70,130,10,70
6810  WINDOW 0,60,0,60
6820  AXES 15,15
6821  CSIZE 3.8,.5
```

```
6830  LORG 2
6840  U=860
6850  FOR Inn=15 TO 45 STEP 15
6860  MOVE 0,Inn
6870  U=U+20
6880  LABEL U
6890  NEXT Inn
6900  LORG 7
6910  FOR Hz=15 TO 45 STEP 15
6920  MOVE Hz+5,0
6930  LABEL Hz
6940  NEXT Hz
6950  RETURN
6951  !*****************************************************
6952  !          RIG PARAMETER MEASUREMENTS AND CALCULATIONS
6953  !^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^
6955 Meas: !
6957        Sumfuel=0
6958        Sumairfl=0
6959        Sumto=0
6960        Sumrater=0
6961        Sumbpr=0
6962        Sumerrt=0
6963        Sumerrp=0
6964   IF Rignum=3 THEN Afl=33
6965   IF Rignum=4 THEN Afl=27
6966   IF Rignum=3 THEN Ful=23
6967   IF Rignum=4 THEN Ful=28
6968   IF Rignum=3 THEN Chatemp=20
6969   IF Rignum=4 THEN Chatemp=25
6970   IF Rignum=3 THEN Chapress=21
6971   IF Rignum=4 THEN Chapress=30
6972   IF Rignum=3 THEN Wai=Wai3
6973   IF Rignum=4 THEN Wai=Wai4
6974 FOR Gz=1 TO 4
6975       OUTPUT 709;"AI"&VAL$(Ful)
6976       ENTER 709;Fle
6977   IF Rignum=3 THEN Fuel=1.83348+(.37836*1000*Fle)
6978   IF Rignum=4 THEN Fuel=1.7715+(.28282*1000*Fle)
6979       Sumfuel=Sumfuel+Fuel
6980       OUTPUT 709;"AI"&VAL$(Afl)
6981       ENTER 709;Afle
6982       Zx1=Afle*1000
6984   IF Rignum=3 THEN Airfl=113.91+(38.075*Zx1)
6985   IF Rignum=4 THEN Airfl=107.04+(33.366*Zx1)
6986       Sumairfl=Sumairfl+Airfl
6987  NEXT Gz
6988         Airflow=Sumairfl/4
6989         Fuelflow=Sumfuel/4
6990         Ftoair=Fuelflow/Airflow
6991   !--------------------------------------
6992   IF Rignum=3 THEN F3=Ftoair
6993   IF Rignum=4 THEN F4=Ftoair
6994   !####################################
6996   IF Rignum=3 AND Control3=1 THEN GOTO 4860
6997   IF Rignum=4 AND Control4=1 THEN GOTO 6070
6998   !**************************************
7002 FOR Nzz=1 TO Wai
7003   OUTPUT 709;"AI"&VAL$(Chatemp)
7004   ENTER 709;Rzz
7005   IF Rignum=3 THEN Tconst=4400
7006   IF Rignum=4 THEN Tconst=3800
7008        Tot(Nzz)=(800+(Rzz*Tconst))*1.8+32
7009        Errrt(Nzz)=Tot(Nzz)-Spt
7010        Sumerrt=Sumerrt+Errrt(Nzz)
7011        Ti(Nzz)=TIMEDATE
```

```
7012   El(Nzz)=Ti(Nzz)-Ti(1)
7013       Sumto=Sumto+Tot(Nzz)
7014   OUTPUT 709;"AI"&VAL$(Chapress)
7015   ENTER 709;Zp
7016       Bprr(Nzz)=Zp*1000
7017       Sumbpr=Sumbpr+(Zp*1000)
7018       Sumerrp=Sumerrp+(Bprr(Nzz)-1.0)
7019   IF Nzz=1 THEN GOTO 7027
7020       Rater(Nzz)=(Tot(Nzz)-Tot(Nzz-1))/(Ti(Nzz)-Ti(Nzz-1))
7021       Intger=((Errrt(Nzz-1)+Errrt(Nzz))/2)*(Ti(Nzz)-Ti(Nzz-1))
7022    IF Rignum=3 AND N>=1 THEN GOTO 7027
7023    IF Rignum=4 AND L>=1 THEN GOTO 7027
7024   IF Rignum=3 THEN Sumint3=Sumint3+Intger
7025   IF Rignum=4 THEN Sumint4=Sumint4+Intger
7026       Sumrater=Sumrater+Rater(Nzz)
7027  NEXT Nzz
7028    IF Rignum=3 THEN Samp3=Samp3+(El(Wai)/60)
7029    IF Rignum=4 THEN Samp4=Samp4+(El(Wai)/60)
7030           Tempt=Sumto/Wai
7031            Rate=Sumrater/Wai
7032            Errt=Sumerrt/Wai
7033            Bp2=Sumbpr/Wai
7034            Errp=Sumerrp/Wai
7035  !++++++++++++++++++++++++++++++++++++++++
7036    IF Rignum=3 AND Tempt>=1651 AND Tempt<=1653 THEN Outf3=Outfuel3
7037    IF Rignum=4 AND Tempt>=1651 AND Tempt<=1653 THEN Outf4=Outfuel4
7038 !-----------------------------------------
7039   IF Mmm=0 THEN RETURN
7040!-----------------------------------------------------
7050 !         SHUTOFF RIG IF EXECUTION TIME ERROR DETECTED
7060 !^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^
7091 Error:!
7092       OUTPUT 709;"AO3,1,10"!FUEL OFF RIG3
7093       OUTPUT 709;"AO4,1,10"!FUEL OFF RIG4
7094       OUTPUT 709;"DC2,6"!PWR. OFF RIG3
7095       OUTPUT 709;"DC2,7"!PWR. OFF RIG4
7096       CLEAR 709!CLEARS 7 BUS
7097   PRINT "EXEC. TIME ERROR"
7098   DISP "Error No.=";ERRN
7099       PRINTER IS 701
7100       PRINT "EXEC. TIME ERROR";"ERROR NO.=";ERRN
7101       PRINTER IS 1
7103   GOTO 7123
7104   PRINTER IS 1
7105   PRINT TABXY(6,9);"TIMEOUT ERROR--IS PRINTER ON?"
7106       PRINTER IS 701
7107       PRINT "TIMEOUT ERROR ON BUS"
7108       PRINTER IS 1
7110   CLEAR 701
7111   CLEAR 709
7112   OUTPUT 709;"AO3,1,10"
7113   OUTPUT 709;"AO4,1,10"
7114   OUTPUT 709;"DC2,6"
7115   OUTPUT 709;"DC2,7"
7116   GOTO 7123
7117 !**************************************************
7118 !             STARTUP DETECTION FOR CELL AIR
7119 !^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^
7121 Abort:!
7122       PRINT "AIR OFF IN CELL --RIGS 3&4"
7123  STOP
7124  !*************************************************
7125  !            POWER FAIL ACTION
7126  !^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^
7128 Pfail: !
7129       OUTPUT 1;1,3
```

```
7130        OUTPUT 709;"AO3,1,10"
7131        OUTPUT 709;"AO4,1,10"
7132        OUTPUT 709;"DC2,6"
7133        OUTPUT 709;"DC2,7"
7134        CLEAR 709
7135        OUTPUT 1;"AC POWER FAILED"
7136        WAIT 5
7137            PRINTER IS 701
7138            PRINT "AC POWER FAILED"
7139            PRINTER IS 1
7140         CONTROL 5;1
7141   STOP
7142   !************************************************
7143   !          CHECK FUEL AND AIR TRANSDUCERS
7144   !^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^
7146 Check: !
7147   INPUT "RIG NO.=",Rignum
7148   IF Rignum=4 THEN F=28 !RIG 4 FUEL
7149   IF Rignum=3 THEN F=23 !RIG 3 FUEL
7150   IF Rignum=3 THEN A=33 !AIR RIG 3
7151   IF Rignum=4 THEN A=27 !AIR RIG 4
7152   Sumfu=0
7153   Sumai=0
7154   FOR Z=1 TO 10
7155   OUTPUT 709;"AI"&VAL$(F)
7159   ENTER 709;Fu
7169   Sumfu=Sumfu+(Fu*1000)
7179   OUTPUT 709;"AI"&VAL$(A)
7189   ENTER 709;Ai
7199   Sumai=Sumai+(Ai*1000)
7209   NEXT Z
7219   Fuel=Sumfu/10
7220   Airf=Sumai/10
7221   IF Rignum=3 THEN Fuels=1.83348+(.37836*Fuel)
7222   IF Rignum=4 THEN Fuels=1.7715+(.28282*Fuel)
7223   IF Rignum=3 THEN Airfs=113.91+(38.075*Airf)
7224   IF Rignum=4 THEN Airfs=107.04+(33.366*Airf)
7229   INPUT "FUEL ROT.(DECIMAL NO.)=",Frot
7230    Gph=-.573827+.672138*Frot-.124521*Frot^2+1.92399E-2*Frot^3
7231    Gph1=Gph-1.48557E-3*Frot^4+4.34668E-5*Frot^5
7233   Fpph=Gph1*6.78 !lbs/hr  FUEL
7234   INPUT "AIR ROT.(INTEGER NO.)=",Arot
7235   IF Arot=0 AND Rignum=4 THEN GOTO 7234
7236   IF Rignum=4 THEN Apph=((Arot/100)*5.3*60) !lbs/hr FISCHER FLOW METER
7237   IF Rignum=3 THEN Apph=31.494394+2.73432459364*Arot !lbs/hr LITE BROOKS FLO
AT
7238   PRINTER IS 701
7239   PRINT TABXY(6,2),"RIG NO.=",Rignum
7249   PRINT "SENSOR FUEL FL.",DROUND(Fuels,5),"SENSOR AIR FL.",DROUND(Airfs,6)
7251   PRINT "ROT. FUEL FL.",DROUND(Fpph,5),"ROT. AIR FL.",DROUND(Apph,6)
7252   PRINT "ROT F/A",DROUND(Fpph/Apph,5),"SEN F/A",DROUND(Fuels/Airfs,5)
7254   PRINTER IS 1
7255   RETURN
8020   END
```

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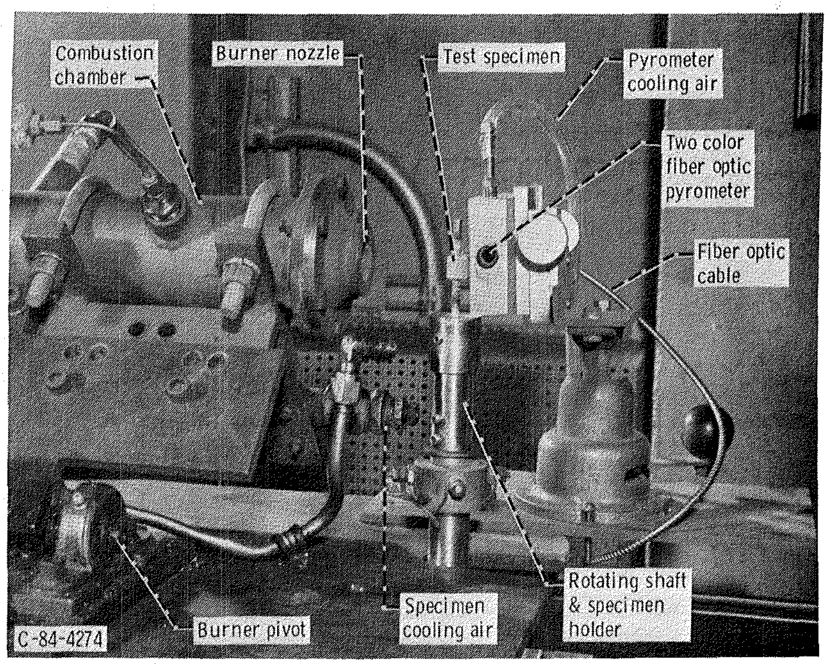
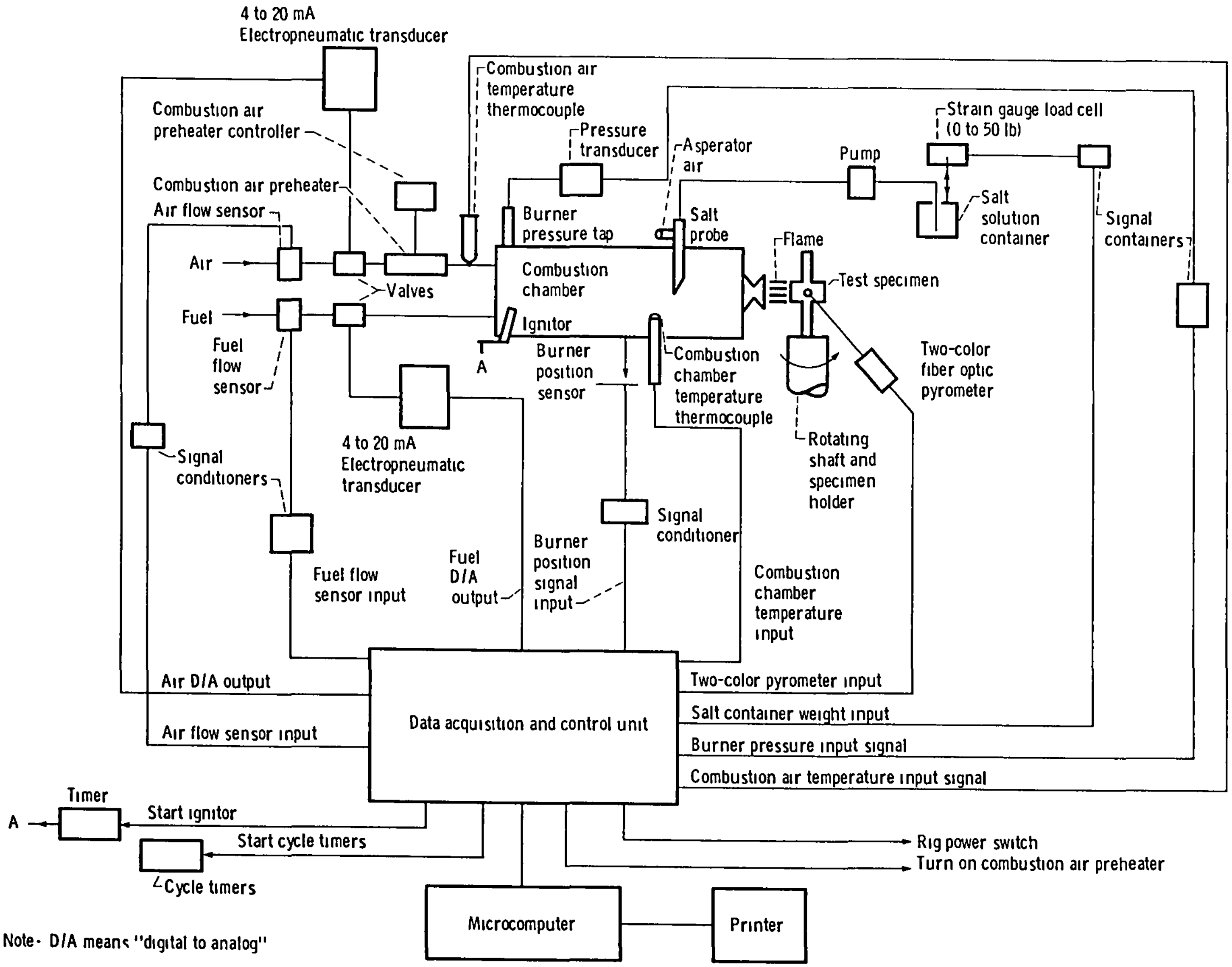
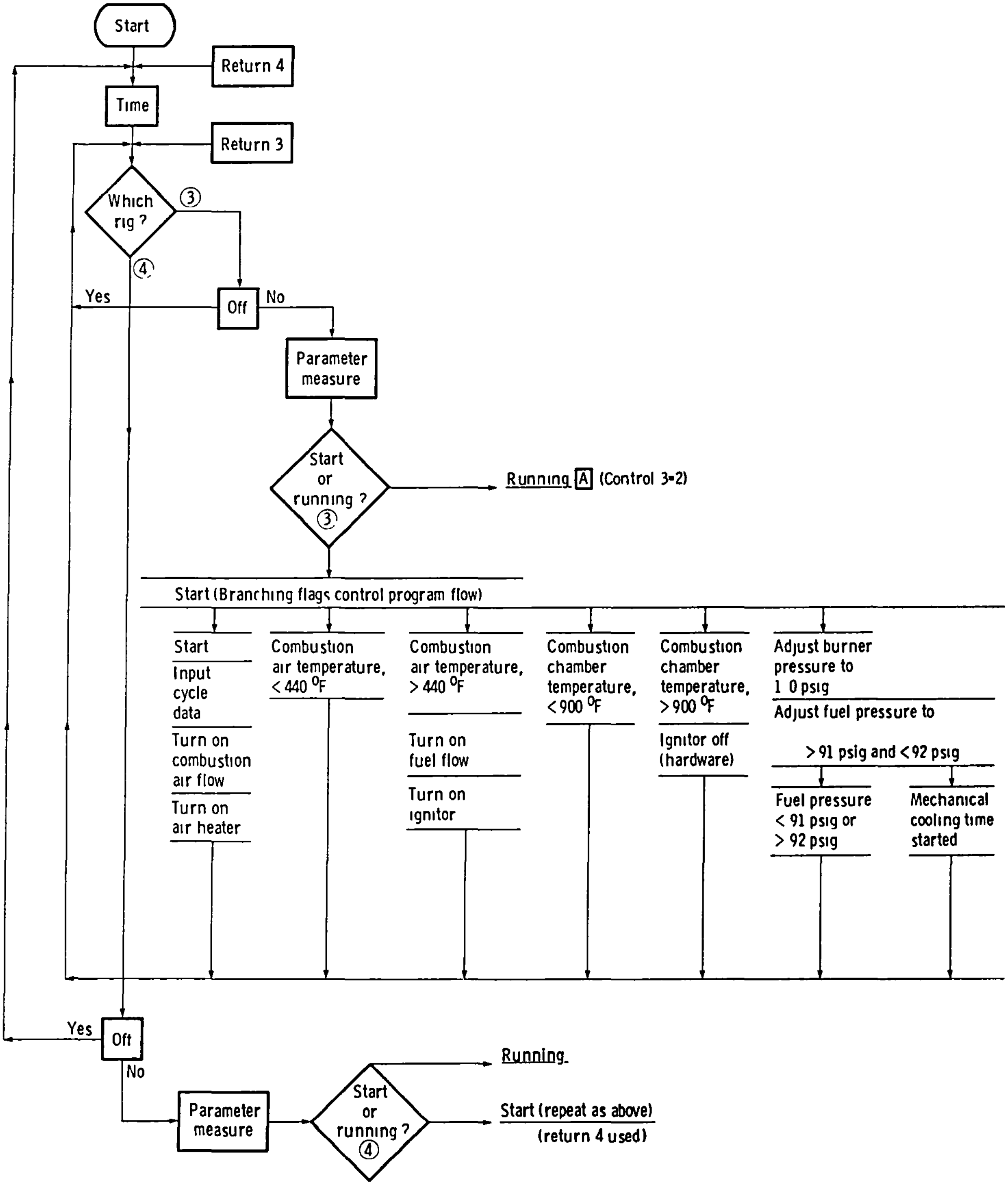


Figure 1. - Burner rig and specimen (heating position).



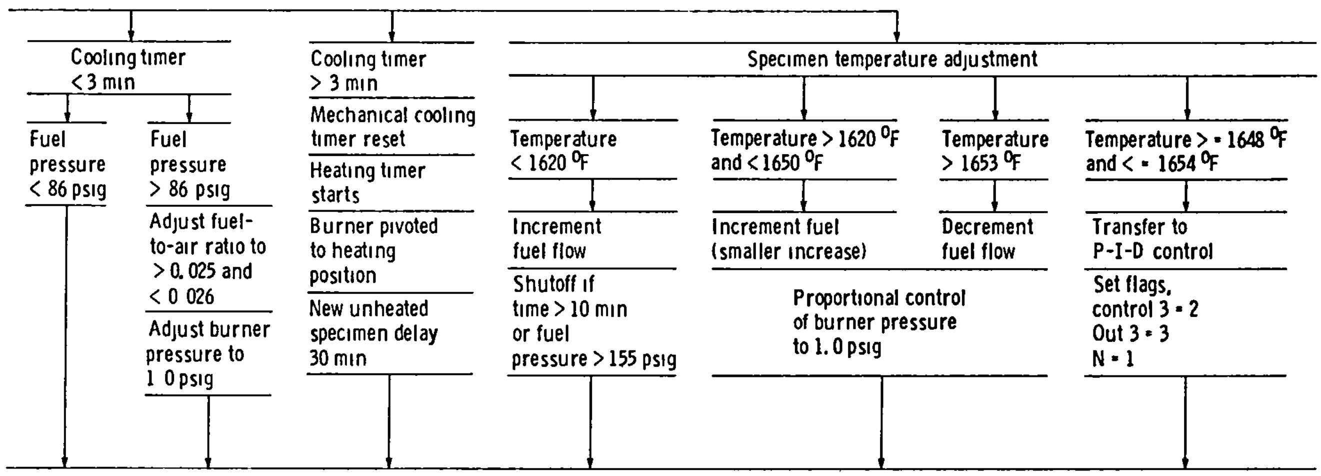
Note· D/A means "digital to analog"

Figure 2 - Schematic diagram of the burner rig control system hardware. (All thermocouples are room temperature compensated via software.)

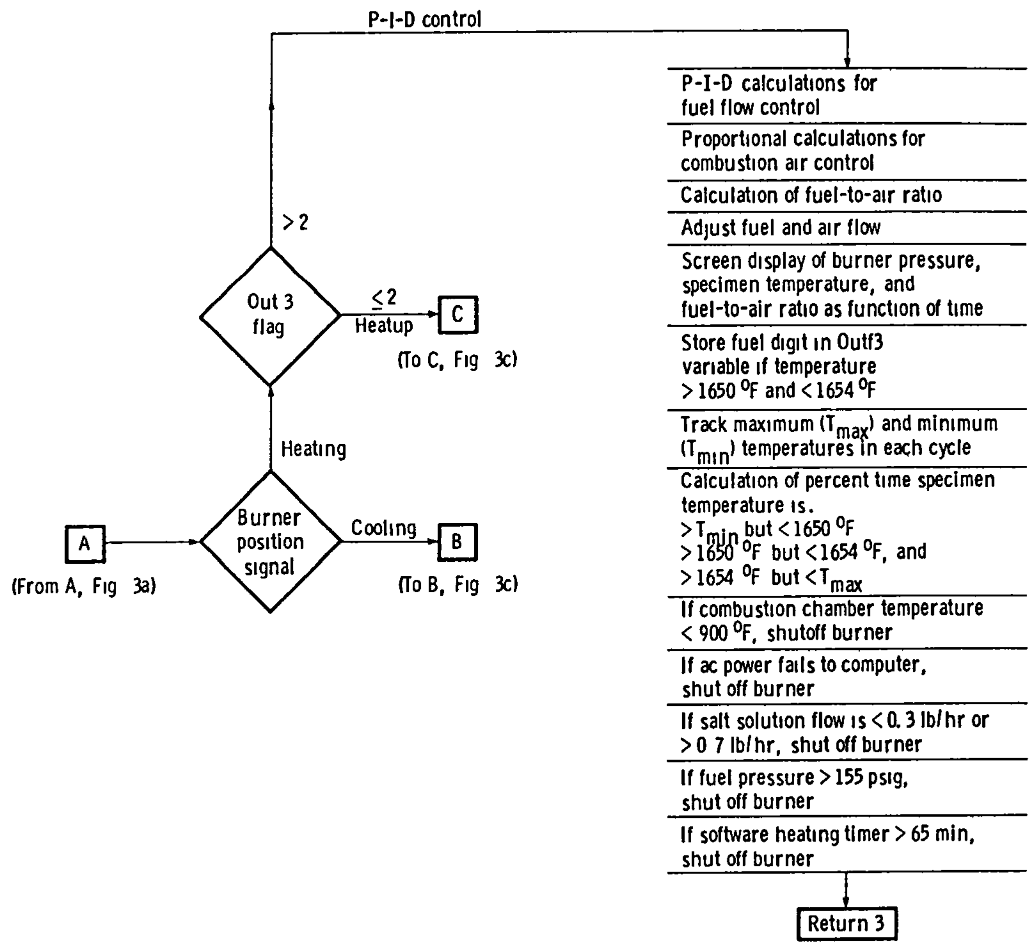


(a) First cycle startup loop.

Figure 3 - Schematic of software logic steps for digital-hybrid control system.

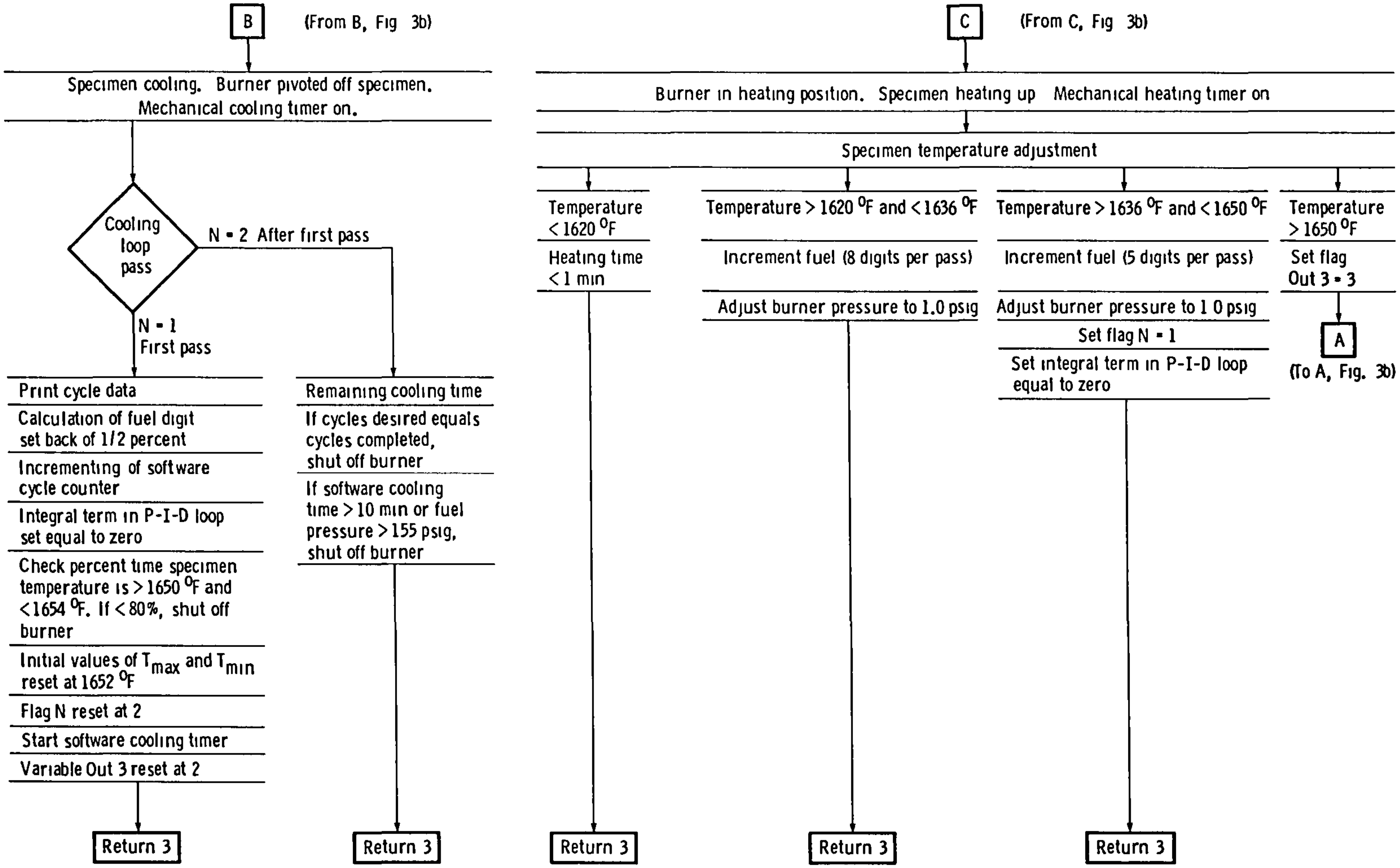


(a) Concluded



(b) P-I-D and proportional control loop for Rig 3

Figure 3 - Continued



(c) Cooling and heatup control for Rig 3.

Figure 3 - Concluded

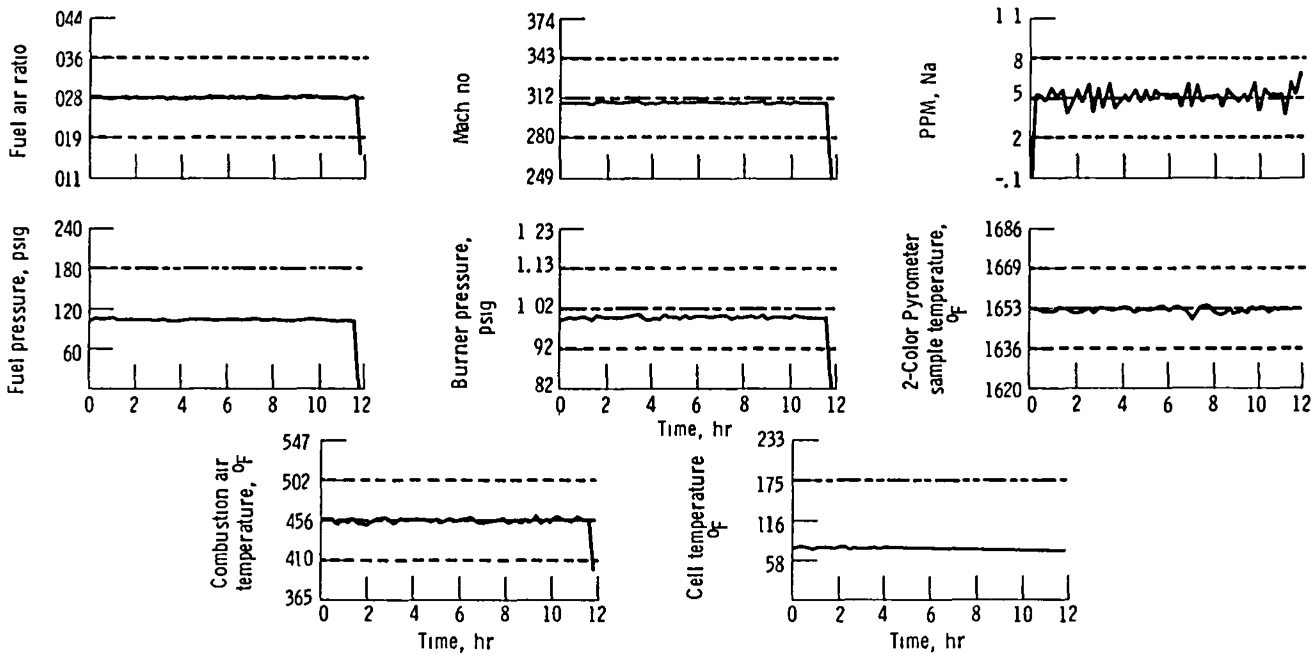
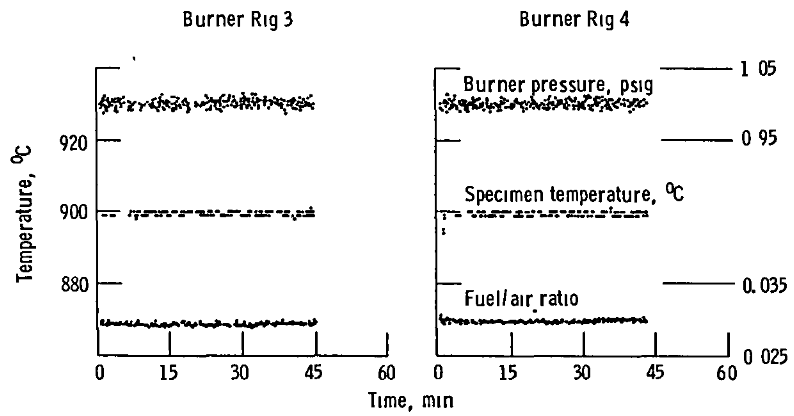


Figure 4 - Burner rig parameters using digital control (Measurement frequency was 15 min.)



(a) Screen display

Alloy identification	Burner rig. no	Current cycle no	Total no of cycles	T_{max} during cycle	Percent time temperature is >1654 °F but <T_{max}	Percent time temperature is >1650 °F but <1654 °F	Percent time temperature is >T_{min} but <1650 °F	T_{min} during cycle	Fuel/air ratio	Burner pressure, psig	Fuel nozzle pressure, psig
G28-1	3	5	5	1654	0 5	98 6	0 9	1649	0293	0.993	105
G27-1	4	5	37	1655	6	99 2	2	1650	0300	995	104
G28-1	3	6	6	1654	6	98 9	4	1650	0288	997	101
G27-1	4	6	38	1654	2	99 7	2	1649	0302	1 013	102

(b) Cycle data (set point = 1652 °F (900 °C))

Figure 5 - Screen display and cycle data printout.

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15 Supplementary Notes

16 Abstract

Hardware and software were developed to implement the hybrid digital control of two Jet A-1 fueled Mach 0.3 burners from startup to completion of a preset number of hot corrosion flame durability cycle tests of materials at 1652 °F. This was accomplished by use of a basic language programmable microcomputer and data aquisition and control unit connected together by the IEEE-488 Bus. The absolute specimen temperature was controlled to ±3 °F by use of digital adjustment of the fuel flow using a P-I-D (Proportional-Integral-Derivative) control algorithm. The specimen temperature was within ±2 °F of the set point more than 90 percent of the time. Pressure control was achieved by digital adjustment of the combustion air flow using a proportional control algorithm. The burner pressure was controlled at 1.0±0.02 psig. Logic schemes were incorporated into the system to protect the test specimen from abnormal test conditions in the event of a hardware or software malfunction.

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