AN EXPERIMENTAL INVESTIGATION OF FUEL REGRESSION RATE CONTROL IN SOLID FUEL RAMJETS (U) NAVAL POSTGRADUATE SCHOOL MONTEREY CA B N KO DEC 84
THESIS

AN EXPERIMENTAL INVESTIGATION
OF FUEL REGRESSION RATE CONTROL
IN SOLID FUEL RAMJETS

by

Ko, Bog Nam

December 1984

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regression rate, indicating that variable inlet swirl may be a viable technique for providing in-flight fuel flow rate modulation in the solid fuel ramjet.
An Experimental Investigation of Fuel Regression Rate Control in Solid Fuel Ramjets

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ABSTRACT

An experimental investigation was conducted to examine fuel regression rate control methods other than variable bypass air flow rates in the solid fuel ramjet. Air and oxygen injection at various axial locations within the fuel grain were examined as well as air, oxygen and ethylene injection through the step face. One inlet swirl design was also tested. Secondary gas injection was found to be inadequate for regression rate control. A small amount of inlet swirl resulted in a significant increase in fuel regression rate, indicating that variable inlet swirl may be a viable technique for providing in-flight fuel flow rate modulation in the solid fuel ramjet.
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I. INTRODUCTION

Ramjets operate with much higher specific impulse than rockets since ramjets use inlet air as a source of oxygen. Self-sufficient rockets, on the other hand, must carry their own oxidizer and bear the consequent penalty. Accordingly, although rockets must be chosen for propulsion outside of the atmosphere, and solid propellant rockets are unchallenged for short-range tactical applications, ramjets can generally outperform rockets in the medium and long range tactical environments.

Because the ramjet depends only on its forward motion at supersonic speeds to effectively compress intake air, the engine, in principle, can employ very few, if any, moving parts. It is therefore capable of simplicity, lightness of construction, and high flight speed not possible in other air-breathing engines. These features, plus the high thermal efficiency it can achieve, make the ramjet a particularly attractive choice for propelling vehicles at supersonic speeds.

One of the significant difference between rockets and ramjets is thrust at zero speed. Rockets can deliver thrust at any speed, whereas a ramjet requires an auxiliary boost system to accelerate it to its supersonic operating regime so that its forward motion can compress the inlet air. To operate at practical efficiency a ramjet must be moving at about a Mach number of 1.5 or greater so that the margin of thrust over drag will be satisfactory.

The solid fuel ramjet (SFRJ) employs solid fuel for the combustor walls. Its distinguishing feature is the absence of fuel tankage, fuel delivery, and fuel control systems. The solid fuel ramjet offers this simplicity while providing excellent density impulse and combustion efficiency.
Figure 1.1 Schematic of the SFRJ.
flow was passed through a central swirl element which extended 0.5 inches into the combustor. The swirl was induced by machining six flutes with a twist of one turn in five inches. The latter resulted in an inlet swirl angle of approximately 5 degrees to the motor centerline.

During the normal ignition sequence, the air flow rate was set at the desired value before the ignition switch was activated. When the ignition circuit was activated, ethylene gas was introduced upstream of the fuel grain along with primary air flow. This mixture was ignited with an oxygen-ethylene torch which issued from the face of the step inlet. Normally, two to three seconds of ignition time was required for PMM combustion to sustain.

The step insert section was provisioned for variations in inlet diameters to make the sudden expansion. The fuel grain itself, when mounted in the motor, became the mid-body of the ramjet. The fuel grain (and injection ring, if used) mounted between the head-end assembly and the aft mixing chamber. The aft-mixing chamber had a length-to-diameter ratio of 2.9. The entire motor was held together by four threaded rods and nuts. The ramjet motor was then mounted on the thrust stand.

B. AIR SUPPLY SYSTEM

A schematic of the ramjet air supply system is shown in figure 3.2. From the air tanks, the air flows through a pressure regulator, a sonic choke, a vitiated air heater and finally to the head-end assembly. The air flow can be either vented into the atmosphere or vented through the ramjet motor by the control of two pneumatically operated valves. Two flexible air flow lines were used to connect the main air line to the air heater. The latter was mounted on the thrust stand.
III. DESCRIPTION OF APPARATUS

A. RAMJET MOTOR

The ramjet motor assembly used in this experiments was that used previously at NPS [Ref. 1, 2].

Figure 3.1 shows a schematic drawing of the ramjet, illustrating the main sections. These are, the head-end assembly, step insert section, fuel grain, aft mixing chamber and exhaust nozzle. For the tests with secondary injection, the injection ring was used.

The head-end assembly contains a central opening for the introduction of the primary air-flow, and ports for introduction of the ignition fuel and the igniter torch.

The fuel wall injection is shown in Figure 2.1, Figure 2.2 and Figure 2.3. Injection velocity varied between approximately 30 and 200 ft/sec as the injection mass flow rate was increased from 1% to 5% of the inlet air flow. A nominal one dimensional flow port velocity was approximately 300 ft/sec.

For the face injection tests, air, oxygen or gaseous fuel was introduced using a differently designed step insert(Figure 2.4 and Figure 2.5). The injection was provided through eight equally spaced, 0.047 diameter holes. For an injection gas mass flow rate equal to 1% of the inlet air flow rate, the injection velocity was approximately 65 ft/sec.

To provide a swirl at the air inlet, a specially designed insert was used(Figure 2.6). This device was a tube-in-hole type injector. Approximately 43% of the air flow passed through the outer annulus to maintain the recirculation region/flame holder. The other 57% of the air
where $P_e =$ exit pressure of the nozzle

$P_o =$ ambient pressure. Then for a choked converging nozzle, this equation can be simplified to

$$C_{F \text{ exp}} = \sqrt{\left(\frac{2}{Y+1}\right)\left(\frac{2}{Y+1}\right)^{\frac{Y+1}{Y-1}} + \left(\frac{2}{Y+1}\right)^{\frac{Y}{Y-1}} + \frac{P_o}{P_e}}$$  \hspace{1cm} (2.13)

where $R$ and $Y$ are determined using PEPCODE

Then efficiency based on thrust is calculated from

$$\eta_{TF} = \frac{C_{\text{ exp}}}{C_{\text{ th}}} \frac{C_{\text{ exp}}^2 - C_a^2}{C_{\text{ th}}^2 - C_a^2}$$  \hspace{1cm} (2.14)

where $C_{\text{ exp}} = \frac{F_{\text{ ge}}}{(\dot{M}_C C_{\text{ F exp}})}$

$C_a = \frac{F}{(\dot{M}_p i C_F)}$ (determined before ignition)

$\bar{F} =$ average thrust from analog record

$\dot{M}_p i =$ pre-ignition flow rate
\[ D_{\text{th}} = \sqrt{\frac{C_{\text{air}}^* \cdot \dot{m}_{\text{air}}}{P_{\text{ca}} \cdot \frac{\pi}{4} \cdot g_e}} \]  

(2.8)

Then temperature-rise combustion efficiency based on nozzle stagnation pressure can be calculated using \( c^* \)

\[ \eta_{T_1} = \frac{C_{\text{exp}}^* - C_{\text{a}}^*}{C_{\text{th}}^* - C_{\text{a}}^*} \]  

(2.9)

where \( C_{\text{a}}^* \) = characteristic exhaust velocity for air flow before ignition

\( C_{\text{exp}}^* \) = experimental characteristic exhaust velocity based on \( P_c \), the average combustion pressure

\( C_{\text{th}}^* \) is obtained from equation (2.7) using \( \gamma \), \( R \) and \( T_t \) from PEPCODE with inputs of \( P_c \), \( T_a \), \( \dot{m}_{\text{air}} \), \( \dot{m}_f \), \( \dot{m}_{\text{H}_2} \) and \( \dot{m}_{\text{C}_2\text{H}_4} \). The latter two flow rates are used in the vitiated air heater.

The thrust equation is

\[ F = \dot{m}_t \cdot U_e + (P_e - P_0) \cdot A_e \]  

(2.10)

where \( \dot{m}_t = \dot{m}_{\text{air}} + \dot{m}_f + \dot{m}_x + \dot{m}_{\text{H}_2} + \dot{m}_{\text{C}_2\text{H}_4} \)

A thrust coefficient, \( C_F \), can be defined such that

\[ F = C_F \cdot P_t \cdot A_{th} \]  

(2.11)

\[ C_{\text{F exp}} = \sqrt{\left( \frac{2 \cdot \frac{\gamma^2}{\gamma - 1}}{\gamma + 1} \right) \left( \frac{2}{\gamma + 1} \right) \left( \frac{Y+1}{Y-1} \right) \left( 1 - \left( \frac{P_e}{P_c} \right)^{\frac{Y-1}{Y}} \right) + \left( \frac{P_e - P_0}{P_c} \right) \cdot \frac{A_e}{A_{th}}} \]  

(2.12)
based on thrust. The one dimensional continuity equation (\( \dot{m} = \oint A V \)) can be expressed in terms of the chamber stagnation properties for a choked converging nozzle.

\[
\dot{m}_t = \frac{P_t A_{th}}{R T_t} \sqrt{g_c \gamma \left( \frac{2}{\gamma+1} \right)^{\frac{\gamma+1}{\gamma-1}}} \tag{2.5}
\]

where \( \dot{m}_t \) = total flow rate
\( P_t = P_c \), chamber pressure (for low Mach number)
\( A_{th} \) = effective nozzle throat area
\( R \) = gas constant

The characteristic exhaust velocity, \( c^* \) is defined as

\[
c^* = \frac{P_c A_{th} g_c}{\dot{m}_t} = \frac{F g_c}{C_F \dot{m}_t} \tag{2.6}
\]

where \( C_F \) = thrust coefficient

For a sonically choked exhaust nozzle,

\[
c^* = \sqrt{\frac{g_c}{\dot{m}_t} \left( \frac{\gamma+1}{\gamma-1} \right)^{\frac{\gamma+1}{\gamma-1}}} \frac{R T_t}{\dot{m}_t} \tag{2.7}
\]

Using pre-test air flow through the motor, equations (2.6) and (2.7) can be used to determine the effective exhaust nozzle throat diameter (\( D_{th} \)).
\[
\frac{Df}{D_i} = \sqrt{\frac{4 \Delta W}{\pi \rho L}} + \frac{D_i^2}{D_L}
\]  
(2.2)

where \( \Delta W \) = weight change
\( L \) = length of the fuel grain
\( \rho \) = density of the fuel grain
\( D_L \) = average initial port diameter of the

PMM grain

The average fuel regression rate was then computed using

\[
\bar{r}_{avg} = \frac{D_f - D_i}{2 \cdot t_b}
\]  
(2.3)

The mixture ratio, chamber pressure and motor air inlet temperature were used as input into the Naval Weapons Center (NWC) China Lake, Ca., Propellant Evaluation Program (PEPCODE) computer program to obtain the theoretical adiabatic combustion temperature and the combustion gas properties (\( \gamma \) and \( R \)). This temperature was used to calculate temperature rise combustion efficiencies based on thrust and based on nozzle stagnation pressure, where

\[
\eta_{T} = \frac{T_{exp} - T_a}{T_{th} - T_a}
\]  
(2.4)

and  
\( T_{exp} \) = combustor stagnation temperature  
\( T_{th} \) = theoretical combustor temperature  
\( T_a \) = inlet air temperature

Experimental values of combustor stagnation temperatures were calculated in two ways, one based on pressure and one
Figure 2.6 Swirl Element Inlet Injector.

Temperatures were only recorded digitally. Average values of the thrust and chamber pressure were determined using a compensating polar planimeter on the analog record.

The mass flow rate of air was obtained by using sonically choked nozzles. Average fuel mass flow rate was calculated by using the weight loss during the burn time

\[ \dot{M}_f = \frac{\Delta W}{t_b} \]  \hspace{1cm} (2.1)

where \( \Delta W \) = weight change during the run

\( t_b \) = burn time

The average internal diameter of the fuel grain was measured prior to the run. The final average diameter was determined based on weight loss and fuel length by using
Figure 2.5 Drawing of Step Insert for Gaseous Injection.
Figure 2.3 Injection Ring for Side Wall Injection.

Figure 2.4 Step Insert For Gaseous Face Injection.
conditions found to significantly affect chamber pressure (or thrust) were further evaluated using full-length burn times of approximately 30 seconds (in order to accurately determine regression rate and combustion efficiency).

B. DATA COLLECTION METHOD

The data collected during the regression rate control tests consisted of air flow rates, oxygen, air or fuel flow rates for the injection, motor head-end and chamber pressures, weight changes of the fuel grain, pre-ignition air flow time, ignition time, burning time, purge time, thrust and ignition gas flow rate. All pressures and the thrust were recorded both digitally and analog.

Figure 2.1 Fuel Configurations for Side Wall Injection.
II. METHOD OF INVESTIGATION

A. TEST CONDITIONS AND METHODS

The experimental investigation was begun by selecting several configurations for regression rate control through the utilization of secondary injection. It was decided to examine secondary injection at three locations through the fuel grain wall: in the recirculation zone (flame holder area), just downstream of flow reattachment and further downstream within the region of the developing boundary layer (in which is located a turbulent diffusion flame). In addition, gaseous injection on the inlet step face and inlet air swirl were examined.

Polymethylmethacrylate (PMM) was used as the fuel and had a nominal length of 12 inches and an internal diameter of 1.5 inches. A sudden expansion inlet was used which provided an inlet step height of 0.49 inches.

Flow reattachment normally occurs between 7 and 8 step heights (i.e., 3.5 - 4 inches). Thus the three injection location chosen were 2, 5, and 8 inches from the head end (See Figure 2.1).

The injection ring was designed to provide radial injection through eight equally spaced, 0.0625 inches diameter holes (See Figure 2.2 and Figure 2.3).

Gaseous injection was also used through the inlet step face as shown in Figure 2.4 and Figure 2.5.

Swirl was provided to the inlet air flow through the use of a swirl element inlet injector (Figure 2.6).

Initial screening tests of short duration were made in which no injection or swirl was used, followed by tests with various amounts of gaseous injection or swirl. Those
oscillations. Therefore, other fuel regression rate control techniques should be pursued.

One possible alternative technique is the use of variable swirl at the air inlet. Increased swirl may increase the regression rate. This technique would require a vane control device. Another possibility is the use of secondary injection of air, oxygen or gaseous fuel into one or more locations within the combustor. This may lead to both increased fuel regression rate and combustion efficiency. If oxygen were used it would require an auxiliary supply system. Therefore, it would be a practical possibility (to maintain simplicity) for a one-time augmentation in thrust (at take-over from booster, at terminal maneuver, etc).

In this investigation tests were conducted to examine the effects of secondary gaseous injection and inlet air swirl on regression rate and combustion efficiency.

A new ramjet thrust stand was installed in the combustion laboratory and required calibration and certification. A second part of this investigation was to conduct tests using high temperature inlet air and then to ensure that combustion efficiencies based on thrust and based on measured chamber pressure were in agreement.
Fig 1.1 shows a schematic of a SFRJ combustor. One inherent problem with the SFRJ is the dependence of fuel regression on the air mass flux through the fuel grain. The fuel regression rate generally behaves according to

\[ \dot{r} = k \left( \frac{M_{\text{air}}}{A_p} \right)^x f(T_{\text{air}}, P) \]  

(1.1)

where \( \dot{r} \) = fuel regression rate
\( M_{\text{air}} \) = air flow rate
\( A_p \) = port area
\( f(T_{\text{air}}, P) \) = a weaker function of inlet air temperature and pressure
\( x \) is between .3 and .6

If the air flow rate increases or decreases, then the fuel flow rate varies in the correct direction, but not enough to maintain design fuel-air ratio. This can significantly affect propulsive thrust.

The range of application and the performance of the SFRJ could be significantly improved if fuel regression rate could be controlled in some manner. Perhaps the most obvious method for fuel regression rate control is to use variable bypass air flow.

Bypass designs are often desired in order to increase fuel loading, and can also improve combustion efficiency. A valve in the bypass line could be used to vary the bypass ratio, thus producing changes in the fuel flow rate according to equation 1.1. (since only the fuel port air mass flux affects the regression rate). However, combustion efficiency may vary significantly with the amount of bypass air and a control valve must be used in the inlet air ducting. In addition, flow coupling may lead to undesired
Figure 3.2 Schematic of Air Supply System.
C. AIR HEATER

To simulate actual flight condition, air should be heated to the appropriate stagnation temperature. In this investigation ethylene gas used in the air heater. The oxygen in the air which is consumed during the heating must be replaced before injection into the ramjet combustor. Figure 3.2 shows a schematic diagram of the air heater. The air heater and the ramjet motor assembly were mounted together on the thrust stand.

D. DATA ACQUISITION AND CONTROL SYSTEM

The primary instrumentation used in this investigation consisted of various individual pressure transducers and thermocouples and a strain gage load cell for the thrust measurement. All transducer outputs were recorded both with a Honeywell 1508 Visicorder and HP-9836S computer using a HP-3054A AUTOMATIC DATA ACQUISITION/CONTROL SYSTEM. A timing reference signal was provided to the analog record by feeding a 10 Hz signal from a laboratory signal generator to the timing channel of the Visicorder. During the test, the HP-9836S computer system was used to record the temperatures, and thrust, and calculate the flow rates of the ignition gas, purge gas, air heater ethylene and oxygen, air and secondary injection gas. It was necessary to record the PMM fuel grain weight and inner diameter before and after each run. The fuel grain weight was measured using a balance. All thermocouples used were chromel vs alumel (type K) with electronic ice points.

The computer was used to both control the test sequence and to provide data acquisition during the experiment. Figure 3.3 is a block diagram of the computer program. (See Appendix A. for a complete listing). Data acquisition for all fourteen channels were recorded every 0.5 seconds.
Variable definitions and nomenclature

Transducer calibrations
- main air sonic choke pressure
- chamber pressure
- motor head pressure
- air heater fuel sonic choke pressure
- oxygen make-up sonic choke pressure
- ignition fuel sonic choke pressure
- purge gas sonic choke pressure
- thrust transducer

Pre-run input
- test number, date
- fuel I.D
- fuel dimensions and weight
- air heater fuel type
- motor throat diameter
- ignition delay time
- ignition time
- burning time
- purge time
- sonic choke diameters, discharge coefficients
- gas constants and desired flow rates

Flow rates set-up
- main air
- heater fuel
- make-up oxygen
- ignition fuel
- purge gas

Test and data collection
- pressures and temperature in voltages

Data extraction
- pressures, temperatures and flow rates

Print results

Figure 3.3 Block Diagram of the Computer Data Acquisition/Control Program.
IV. EXPERIMENTAL PROCEDURES AND TEST CONDITIONS

A. TRANSDUCER CALIBRATION

A dead-weight tester was used for the calibration of all pressure transducers. Initially all transducers were checked for linearity and the Visicorder (analog) display positions were labeled. For the computer data acquisition, voltages corresponding to atmospheric pressure and the maximum pressure were measured. From these readings a calibration constant (K) was determined for each transducer.

\[
K = \frac{V_{p_{\text{max}}} - V_{p_0}}{P_{\text{max}}} \quad (4.1)
\]

where

- \( V_{p_{\text{max}}} \) = voltage reading at the applied maximum pressure
- \( V_{p_0} \) = voltage reading at atmospheric pressure
- \( P_{\text{max}} \) = maximum applied pressure

The thrust transducer was calibrated in-place by applying known weights to the transducer through a pulley system attached to the thrust stand.

B. FLOW RATES SET-UP

By use of the computer, the gas flow rates could be set up before the hot firing. These were determined from short duration flows using the equation
\[ M = \frac{C_d \cdot k_m \cdot P_t \cdot \frac{\pi}{4} \cdot D_{choke}^2}{\sqrt{T_t}} \]  

(4.2)

where \( k_m = \) constant \( (a \ function \ of \ R \ and \ \gamma) \)

\( C_d = \) discharge coefficient

\( P_t = \) total pressure of the gas flow

\( D_{choke} = \) sonic choke diameter

\( T_t = \) total temperature of the gas flow

C. TEST SEQUENCE

1. Thrust Stand Calibration

   The thrust stand was calibrated to determine the difference between the measured thrust and the actual or theoretical thrust. The measured thrust can be in error primarily due to the variation in flex-line stiffness with changing pressure levels. The process was begun by dead-weight calibration of the load cell. Cold air was then flowed through the motor with a choked exhaust nozzle. Measured thrust was recorded and compared to the theoretical thrust. The latter was calculated using Equations (2.11) and (2.13). This was repeated for increasing air flow rates and for three different exhaust nozzle throat diameter. An additional test was made using hot air \( (1200^\circ R) \) and a 12 inches long HTPB fuel grain. This test was conducted in order to compare the temperature rise combustion efficiency determined by using chamber pressure and by using thrust.

2. Fuel-wall Injection Tests

   For the fuel-wall injection tests, three injection location were used as discussed above. Each test lasted for approximately six seconds, three seconds without injection
and three seconds with injection. Air injection mass flows of 2, 5 and 7 percent of the main air flow rate were used. For oxygen injection, 1.5, 2 and 5 percent were used. Those conditions which resulted in the greatest increases in chamber pressure/thrust were repeated with full duration (30 sec) tests.

3. **Face Injection Tests**

   In these experiments a twelve inches long cylindrically perforated PMM fuel grain was used. Air injection flow rates of 2, 5 and 7 percent of the main air flow rate were examined. For oxygen injection, 1.5, 2 and 5 percent were used. Ethylene was also used with 0.5, 1.25 and 2.5 percent. Testing methods were identical to those discussed above for fuel-wall injection.

4. **Inlet Air Swirl Tests**

   Several inlets were initially tried which induced swirl to the entire inlet air flow. Swirling the entire flow apparently destroys the flameholding recirculation zone, and resulted in no ignition. The tube-in-hole injector discussed above was then tested using a twelve inch PMM fuel grain.
V. RESULTS AND DISCUSSION

Summaries of the experimental results obtained during the initial screening tests are presented in Table 1 and Table 2 for fuel-wall and inlet step-face injection respectively. Results from the subsequent full duration tests are presented in Table 3.

A. FUEL WALL INJECTION

In data presented in Table 1 shows that air injected through the fuel grain surface was generally detrimental to combustion. Air injection rates up to approximately 7% of the inlet air flow rate had little if any effects on combustion pressure when introduced downstream of flow reattachment. Small amounts of air injected into the recirculation zone appeared to provide small improvements. The injected air was quite cold (approximately 500°R) and therefore could have had a quenching effect on the boundary layer combustion. Use of "in-flight" high air should be examined in the future.

Unheated oxygen injection resulted in significant increases in combustion pressure, especially when introduced into the recirculation zone in small amounts. Based on these screening test results two additional tests were conducted with test times of approximately 30 seconds. These tests were made to examine the effects of 1% oxygen injection into the recirculation region.

In these tests, a total grain length of fourteen inches was used; two inches of PMM, then the injection ring and then twelve inches of PMM. One test (Table 3, no. 30) was made without injection and one with (Table 3, no. 29).
Oxygen injection resulted in approximately a 5% increase in fuel regression rate (when adjusted for the different air flowrate) but a decrease of 21% in combustion efficiency. The recirculation zone is generally fuel rich. Thus, oxygen injection should increase the "flame-holder" temperature. This was evident during the test from increased flame luminosity.

It is not clear at this point why the combustion efficiency decreased or, for that matter, why the presence of the ring alone increased combustion efficiency. The oxygen injection velocity was approximately 30 ft/sec which is less than 30% of typical recirculation zone, near-wall velocities. However, the injected oxygen may have penetrated the shear layer.

Further testing would be beneficial, especially using HTPB, but at this point it does not appear that fuel wall injection of small amounts of air or oxygen is a viable method for providing fuel mass flowrate control since combustion efficiency was decreased significantly and the increase in regression rate was small.

B. INLET STEP FACE INJECTION

The data from the screening tests with step-face injection are presented in Table 2. Unheated air had no significant effect on combustion pressure. Oxygen injection resulted in increased flame luminosity in the recirculation zone but apparently did not significantly affect downstream combustion (even though the overall equivalence ratio was approximately 0.7). Injection of ethylene resulted in significant increases in combustion pressure.

A full duration test (Table 3, no. 28) was conducted using 1% of ethylene with an injection velocity of approximately 65 ft/sec. Comparison of the results with
those for no injection (Table 3, no. 27) showed that only a small increase occurred in fuel regression rate.

Some of the ethylene apparently escaped the recirculation region and burned downstream in the central air or in the aft mixing region, resulting in little effect on regression rate.

C. INLET AIR SWIRL

Only one test was conducted using inlet air swirl (Table 3, no. 31). Approximately 43% of the air was injected axially to maintain the recirculation zone flame holding ability. This could be reduced to perhaps only 10 - 20%, resulting in more air with swirl. The amount of swirl was also intentionally kept small (5 degrees from the axial direction) to determine if regression rate was sensitive to the swirl.

The small amount of swirl increased the fuel regression rate by 15%. This resulted in an increase in equivalence ratio ratio from 0.69 to 0.79. Some non-uniformity in regression rate was also evident.

These initial results indicate that fuel regression rate is quite sensitive to inlet air swirl. Further testing is necessary using varying amounts of swirl, but the technique appears viable for in-flight fuel mass flow modulation.

D. THRUST STAND CALIBRATION

The results from the cold-flow tests for comparison of measured and calculated thrust are in Figure 5.1. Excellent agreement was attained. A least-square fit of the data resulted in the following equation for relating measured thrust to the "actual" thrust

\[ F_a = 1.0149 \times F_m + 0.4 \]  

(5.1)
where \( F_a \) = actual thrust, based on \( P_c \) and throat diameter

\[ F_m = \text{measured thrust} \]

A test was then conducted (Table 3, no. 32) in which HTPB fuel was used with an inlet air temperature of approximately 1200 R. This test was made in order to compare the combustion efficiencies based on chamber pressure and based on thrust. The two efficiencies were within 5%, with the value based on \( P_c \) being greater. This difference is not large when it is realized that small errors in determining \( F \) and \( P_c \) from the analog traces are squared when calculating \( C \) for the efficiency based on thrust determination.
<table>
<thead>
<tr>
<th>test number</th>
<th>Mair (Lbm/sec)</th>
<th>Minj (Lbm/sec)</th>
<th>Minj/Mair</th>
<th>( \Delta P_c/P_c )</th>
<th>Injected gas</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 inches and 4 inches configuration</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
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<td>Min/Mair (lbm/sec)</td>
<td>M_air/Min (lbm/sec)</td>
<td>Pc/Pc%</td>
<td>Injected gas</td>
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<td>Condition</td>
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<td>1% C$_2$H$_4$ face injection</td>
<td>1% O$_2$ recirculation zone</td>
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<td>0.737</td>
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<td>0.203</td>
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<td>504</td>
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<td>MF (Lbm/sec)</td>
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<td>0.0063</td>
<td>0.00634</td>
<td>0.0058</td>
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</table>
6550 ENTER 722;'phf
6560 OUTPUT 709;'AC10`
6570 OUTPUT 722;'T3`
6580 ENTER 722;'vhf
6590 CLEAR 799
6600 OUTPUT 709;'DC10.0`
6610 PRINT "MANUALLY TURN OFF AIR 'HEATER GAS' SWITCH"
6620 BEEP
6630 DISP "HIT CONTINUE TO PROCEED"
6640 PAUSE
6650 OUTPUT 709;'DC10.0`
6660 Phf=(Vphf-(4phf#)Kphf#Pbar
6670 Volts=Uthf
6680 GOSub Tcalc
6690 Thf=Thf*2/(Thf*2)
6700 Mhf=Khf*Cthf#Phf#*.78'54*(Dthfchoke^2)/(ThfA.5)
6710 PRINT USING fhf=*hf;'/hf
6720 PRINT USING '4A.DDDDDD%''hf='-,hf
6730 PRINT USING '1 A.DDDDDDhf
6740 Ratio=Mhf/Mhf
d
6750 PRINT USING '18A,D.DDDD,2X,4A,DDD.DD,1A";"Mhf/ Mhf DESIRED=";Ratio,"Thf="
6760 P=Phf-Pbar
6770 PRINT USING '5A,D.DDDD,4A,3X,4A,DDD.DD,1A,A,4A,DDD.DD,1A";"Phf= ";P;
6780 IF Xsz*Ysz* THEN GOTO Phfset
6801 Phfnew=(Phf#Mhf#Phf#Pbar
6810 PRINT USING '13A,D DDD DD,4A";"RESET Phf TO";Phfnew;"Psig"
6820 DISP "HIT CONTINUE AFTER RESET OF Phf"
6830 PAUSE
6840 GOTO Phfset
6850 Phfnew:
6860 DISP "HIT CONTINUE TO PROCEED TO NEXT FLOW RATE SET UP"
6870 PAUSE
6880 Phfset:
6890 PRINT USING "Y"
6900 INPUT "DO YOU WANT TO PRESET THE HEATER OXYGEN FLOW RATE?(Y/N)";Xsz
6910 IF Xsz=N THEN GOTO Phfset:
6920 PRINT "THE DESIRED VALUE OF Pho USING THE HAND LOADER/ PRESURE GAUGE"
6930 PRINT "MANUALLY TURN ON AIR 'HEATER GAS' SWITCH"
6940 PRINT "HIT CONTINUE TO PROCEED"
6950 PAUSE
6960 Phfset:
6970 PRINT "MANUALLY TURN OFF AIR 'HEATER GAS' SWITCH"
6980 PRINT "HIT CONTINUE TO PROCEED"
7000 BEEP
7010 OUTPUT 709;'AC11`
7020 OUTPUT 722;'T3`
7030 ENTER 722;'tho
7040 OUTPUT 709;'AC11`
7050 OUTPUT 722;'T3`
7060 ENTER 722;'tho
7070 CLEAR 799
7080 OUTPUT 709;'DC10.0`
7090 PRINT "MANUALLY TURN OFF AIR 'HEATER GAS' SWITCH"
7100 BEEP
7110 PRINT "HIT CONTINUE TO PROCEED"
7120 PAUSE
7130 OUTPUT 709;'DC10.0`
7140 Phs=(Vphs-(4phs#)Kphs#Pbar
7150 Volts=Utho
7160 GOSub Tcalc
7170 Tho=Tho#Phs#Phs#785#(Dthochoke^2)/(Tho*.5)
7180 PRINT USING fhf=*fhf;'/fhf
7190 PRINT USING '5A,D.DDDD,4A,3X,4A,DDD.DD,1A,A,4A,DDD.DD,1A";"Phs= ";Phs
7200 PAUSE
7210 OUTPUT 709;'AC10`
7220 OUTPUT 709;'AC11`
7230 ENTER 722;'tho
5900  IF Xs='Y' THEN GOTO Dtheffcalc
5910  Pa=new=(Pa1*Maird1*Mmir)-Pbar
5920  PRINT "RESET Pa TO: Pa1=P"$"'Psiq""
5930  DISP 'HIT CONTINUE AFTER RESET CF Pa
5940  PAUSE
5950  GOTO Paset
5960  Dtheffcalc:
5970  Cstar=(Cc*RairT1*((aM~aar+1)/2)((Gaaar+l)(aMalr-I))/GaaIr)A.5
5980  Cfair=7396+.5293-(14./Pc)
5990  Dtheff=((Cstar*Mair)/(.7854*Pc*Gc))A.5
6000  PRINT 'Cstar=air(BASED ON Ti)=';Cstar,'(ft/sec)'
6010  PRINT "Cfair='"Cfair
6020  PRINT 'Dtheff=';Dtheff,'(in)"
6030  PRINT 'Pco='Pc','Psia'
6040  PRINT 'Ti='T'
6050  F=(Vf-Uf0)*f
6060  Fair=Cfair*Pc*.7854*(Dtheff*2)
6070  PRINT 'Fair(BASED ON Pc)=';Fair,'(Lbf)'
6080  PRINT 'Fair(MEASURED)=';F,'(Lbf)'
6090  IF K=0 THEN GOTO 6170
6100  INPUT "DO YOU WANT PRINTOUT OF POST RUN DATA?(Y/N)',Yy$
6110  IF Yy$='N' THEN GOTO Finish
6120  Headincprint:
6130  PRINT USING 6/**** POST RUN DATA COLD AIR, CHOKED *****/
6140  PRINT USING 12A2X,8A"i'TEST DATE IS',Date1
6150  PRINT 'Cstarair(BASED ON Ti)=';Cstar,'(ft/sec)'
6160  PRINT 'Cfair=';Cfair
6170  Dtheff=%Deff,(ln)”
6180  PRINT 'Pco='Pc','Psia'
6190  PRINT 'Ti='T'
6200  PRINT 'Fair(BASED ON Pc)=';Fair,'(Lbf)'
6210  PRINT 'Fair(measured)=';F,'(Lbf)'
6220  IF K=0 THEN GOTO 6170
6230  INPUT "DO YOU WANT PRINTOUT OF PRE-RUN DATA?(Y/N)',Xx$
6240  IF Xx$='Y' THEN GOTO Preprint
6250  GOTO Skipprint
6260  Preprint:
6270  IF Ko=1 THEN GOTO 6240
6280  INPUT "YOU WANT TO PRESET THE HEATER FUEL FLOW RATE! (Y/N)',Z2$
6290  IF Z2$='N' THEN GOTO Phfskip
6300  PRINT "SET IHE DESIRED VALUE OF Ph USING THE HAND LOADER/PRESSURE GAGE"
6310  PRINT "HIT CONTINUE WHEN READY"
6320  PAUSE
6330  Phfset:
6340  PRINT "**PRE-RUN DATA, USING COLD AIR ONLY AND CHOKED**"
6350  PRINT "**FLOW RATE**"
6360  PRINT "**TEST DATE IS*,Date1"
6370  PRINT "Cstarair(BASED ON Ti)=';Cstar,'(ft/sec)'
6380  PRINT 'Cfair=';Cfair
6390  PRINT 'Dtheff=';Dtheff,'(in)"
6400  PRINT 'Pco='Pc','Psia'
6410  PRINT 'Ti='T'
6420  PRINT 'Fair(BASED ON Pc)=';Fair,'(Lbf)'
6430  PRINT 'Fair(measured)=';F,'(Lbf)'
6440  PRINT 'M1=;MStair,'(ft/sec)'
6450  PRINT 'Pco='Pc','Psia'
6460  PRINT 'Ti='T'
6470  PRINT 'Fair(BASED ON Pc)=';Fair,'(Lbf)'
6480  PRINT 'Fair(MEASURED)=';F,'(Lbf)'
6490  IF K=0 THEN GOTO Finish
6500  Skipprint:
6510  DISP 'HIT CONTINUE TO PROCEED TO NEXT FLOW RATE SET UP'
6520  PAUSE
6530  Phfskip:
6540  PRINT "**PRE-RUN DATA**"
5250 IF Zz$='Y' THEN GOTO Nochange
5270 PRINT "INPUT VARIABLE NAME: CORRECTED VALUE"
5280 PRINT "A STRING VARIABLE MUST BE ENCLOSED IN QUOTATION MARKS"
5290 DISP "HIT EXECUTE AND THEN CONTINUE AFTER CORRECTION"
5300 PAUSE
5310 GOTO Change1
5330 Changevariable:
5340 *****************************************************************************
5350 ; B. FLOW RATE SET-UPS
5360 *****************************************************************************
5370 PRINT USING "B"
5380 INPUT "DO YOU WANT TO PRESET THE AIR FLOW RATE?(Y/N)";Zz$
5390 IF Zz$="Y" THEN GOTO Psh$p
5395 PRINT "SET THE DESIRED VALUE OF Pa(psu) USING THE HAND LOADER /PRESSURE GAGE"
5400 INPUT "A STRING VARIABLE MUST BE ENCLOSED IN QUOTATION MARKS"
5410 PRINT USING "3/
5420 PRINT USING "31"
5430 PRINT "THE HAND LOADER SHOULD BE 20 PSIG MORE THAN DESIRED PRESSURE"
5440 Paset:
5450 PRINT USING "31"
5460 PRINT "MANUALLY INITIATE AIR FLOW BY TURNING 'MAIN AIR' TO 'ON' AND PUSH 'PRI' ON CONTROL PANEL"
5470 DISP "HIT CONTINUE WHEN READY"
5480 PAUSE
5490 WAIT 3
5500 OUTPUT 709;'AC2''
5510 OUTPUT 729;'T3''
5520 OUTPUT 709;'AC9''
5530 OUTPUT 729;'T3''
5540 OUTPUT 709;'AC5''
5550 OUTPUT 729;'T3''
5560 OUTPUT 709;'AC8''
5570 OUTPUT 732;'T3''
5580 OUTPUT 709;'AC3''
5590 OUTPUT 729;'T3''
5600 OUTPUT 709;'DC10,1'' ! DIGITALLY CLOSE CIRCUIT 1
5610 OUTPUT 709;'DO10,1'' ! DIGITALLY OPEN CIRCUIT 1
5620 BEEP
5630 OUTPUT 709;'AC3''
5640 OUTPUT 709;'AC9''
5650 OUTPUT 709;'AC5''
5660 OUTPUT 709;'DC10,1''
5670 OUTPUT 709;'DO10,1''
5680 PRINT "TURN OFF 'MAIN AIR'"
5690 OUTPUT 709;'AC8''
5700 OUTPUT 709;'AC5''
5710 OUTPUT 709;'AC2''
5720 OUTPUT 729;'T3''
5730 OUTPUT 709;'AC9''
5740 OUTPUT 729;'T3''
5750 OUTPUT 709;'DC10,1''
5760 OUTPUT 709;'DO10,1''
5770 COSUB Tcalc ! CONVERSION FROM VOLTAGE TO TEMPERATURE
5780 T4=T1
5790 V4=V1
5800 Tcalc:
5810 Ti=T1
5820 Mair=Mair*Cdair*Pa*,7854*(Dairchoke"2)/(Ta*,5)
5830 PRINT USING "A" & Mair & "(psia)"
5840 PRINT USING "A",Mair!
5850 PRINT USING "A",Mair!
5860 PRINT USING "A",Mair!
5870 PRINT USING "A",Mair!
5880 IF X1=E THEN GOTO Determine: ! DETERMINE PRE-RUN OR POST-RUN
5890 INPUT "IS AIR FLOW RATE ACCURATE ENOUGH? (Y/N)";X$
4650 INPUT "THE AIR CHOKE DISCHARGE COEFFICIENT", Cdair
4660 INPUT "THE AIR HEATER FUEL CHOKE DISCHARGE COEFFICIENT", Cdf
4670 INPUT "THE AIR HEATER OXYGEN CHOKE DISCHARGE COEFFICIENT", Cdho
4680 INPUT "THE IGNITION GAS CHOKE DISCHARGE COEFFICIENT", Cdif
4690 INPUT "THE PURGE GAS CHOKE DISCHARGE COEFFICIENT", Cdp
4700 INPUT "THE AIR HEATER FUEL FLOW RATE CONSTANT", Kmhf, Kmf
4710 INPUT "THE IGNITION GAS FLOW RATE CONSTANT", Kmif, Kmf
4720 INPUT "THE PURGE GAS FLOW RATE CONSTANT", Kmp, Kmp
4730 INPUT "GAMMA FOR HEATER FUEL, Gammahf" Gammahf
4740 INPUT "GAMMA FOR IGNITION FUEL, Gammaf", Gammaf
4750 INPUT "GAMMA FOR PURGE GAS, Gamma", Gamma
4760 INPUT "GAMMA FOR OXYGEN", Gammap, Gammap

4770 "PRINT USING "14A, DDDD.DDDD,5X,14A, DDDD, DDDD,5X,14A, DDDD, DDDD"; Tref="; Tref
4780 "PRINT USING "14A, DDDD.DDDD,5X,14A, DDDD, DDDD,5X,14A, DDDD, DDDD"; Tbar="; Tbar
4790 "PRINT USING "14A, DDDD.DDDD,5X,14A, DDDD, DDDD,5X,14A, DDDD, DDDD"; Stn="; Stn
4800 "PRINT USING "14A, DDDD.DDDD,5X,14A, DDDD, DDDD,5X,14A, DDDD, DDDD"; Testn="; Testn
4810 "PRINT USING "14A, DDDD.DDDD,5X,14A, DDDD, DDDD,5X,14A, DDDD, DDDD"; Thhf="; Thhf
4820 "PRINT USING "14A, DDDD.DDDD,5X,14A, DDDD, DDDD,5X,14A, DDDD, DDDD"; Tmhf="; Tmhf
4830 "PRINT USING "14A, DDDD.DDDD,5X,14A, DDDD, DDDD,5X,14A, DDDD, DDDD"; Thmf="; Thmf
4840 "PRINT USING "14A, DDDD.DDDD,5X,14A, DDDD, DDDD,5X,14A, DDDD, DDDD"; Tmhf="; Tmhf
4850 "PRINT USING "14A, DDDD.DDDD,5X,14A, DDDD, DDDD,5X,14A, DDDD, DDDD"; Thmf="; Thmf

4900 "PRINT USING "14A, DDDD.DDDD,5X,14A, DDDD, DDDD,5X,14A, DDDD, DDDD"; Gammahf= Gammahf
4910 "PRINT USING "14A, DDDD.DDDD,5X,14A, DDDD, DDDD,5X,14A, DDDD, DDDD"; Gammaf= Gammaf
4920 "PRINT USING "14A, DDDD.DDDD,5X,14A, DDDD, DDDD,5X,14A, DDDD, DDDD"; Gammap= Gammap
4930 "PRINT USING "14A, DDDD.DDDD,5X,14A, DDDD, DDDD,5X,14A, DDDD, DDDD"; Kmhf= Kmhf
4940 "PRINT USING "14A, DDDD.DDDD,5X,14A, DDDD, DDDD,5X,14A, DDDD, DDDD"; Kmhf= Kmhf
4950 "PRINT USING "14A, DDDD.DDDD,5X,14A, DDDD, DDDD,5X,14A, DDDD, DDDD"; Kmhf= Kmhf

5000 "PRINT USING "14A, DDDD.DDDD,5X,14A, DDDD, DDDD,5X,14A, DDDD, DDDD"; Kmhf= Kmhf
5010 "PRINT USING "14A, DDDD.DDDD,5X,14A, DDDD, DDDD,5X,14A, DDDD, DDDD"; Kmhf= Kmhf
5020 "PRINT USING "14A, DDDD.DDDD,5X,14A, DDDD, DDDD,5X,14A, DDDD, DDDD"; Kmhf= Kmhf

5030 "PRINT USING "14A, DDDD.DDDD,5X,14A, DDDD, DDDD,5X,14A, DDDD, DDDD"; Kmhf= Kmhf
5040 "PRINT USING "14A, DDDD.DDDD,5X,14A, DDDD, DDDD,5X,14A, DDDD, DDDD"; Kmhf= Kmhf

5100 "PRINT USING "14A, DDDD.DDDD,5X,14A, DDDD, DDDD,5X,14A, DDDD, DDDD"; Kmhf= Kmhf
5110 "PRINT USING "14A, DDDD.DDDD,5X,14A, DDDD, DDDD,5X,14A, DDDD, DDDD"; Kmhf= Kmhf
5120 "PRINT USING "14A, DDDD.DDDD,5X,14A, DDDD, DDDD,5X,14A, DDDD, DDDD"; Kmhf= Kmhf
5130 "PRINT USING "14A, DDDD.DDDD,5X,14A, DDDD, DDDD,5X,14A, DDDD, DDDD"; Kmhf= Kmhf

5200 "PRINT USING "14A, DDDD.DDDD,5X,14A, DDDD, DDDD,5X,14A, DDDD, DDDD"; Kmhf= Kmhf
5210 "PRINT USING "14A, DDDD.DDDD,5X,14A, DDDD, DDDD,5X,14A, DDDD, DDDD"; Kmhf= Kmhf
5220 "PRINT USING "14A, DDDD.DDDD,5X,14A, DDDD, DDDD,5X,14A, DDDD, DDDD"; Kmhf= Kmhf
5230 "PRINT USING "14A, DDDD.DDDD,5X,14A, DDDD, DDDD,5X,14A, DDDD, DDDD"; Kmhf= Kmhf

5300 "PRINT USING "14A, DDDD.DDDD,5X,14A, DDDD, DDDD,5X,14A, DDDD, DDDD"; Kmhf= Kmhf
5310 "PRINT USING "14A, DDDD.DDDD,5X,14A, DDDD, DDDD,5X,14A, DDDD, DDDD"; Kmhf= Kmhf
5320 "PRINT USING "14A, DDDD.DDDD,5X,14A, DDDD, DDDD,5X,14A, DDDD, DDDD"; Kmhf= Kmhf
5330 "PRINT USING "14A, DDDD.DDDD,5X,14A, DDDD, DDDD,5X,14A, DDDD, DDDD"; Kmhf= Kmhf

5400 "PRINT USING "14A, DDDD.DDDD,5X,14A, DDDD, DDDD,5X,14A, DDDD, DDDD"; Kmhf= Kmhf
5410 "PRINT USING "14A, DDDD.DDDD,5X,14A, DDDD, DDDD,5X,14A, DDDD, DDDD"; Kmhf= Kmhf
5420 "PRINT USING "14A, DDDD.DDDD,5X,14A, DDDD, DDDD,5X,14A, DDDD, DDDD"; Kmhf= Kmhf
5430 "PRINT USING "14A, DDDD.DDDD,5X,14A, DDDD, DDDD,5X,14A, DDDD, DDDD"; Kmhf= Kmhf

5500 "PRINT USING "14A, DDDD.DDDD,5X,14A, DDDD, DDDD,5X,14A, DDDD, DDDD"; Kmhf= Kmhf
5510 "PRINT USING "14A, DDDD.DDDD,5X,14A, DDDD, DDDD,5X,14A, DDDD, DDDD"; Kmhf= Kmhf
5520 "PRINT USING "14A, DDDD.DDDD,5X,14A, DDDD, DDDD,5X,14A, DDDD, DDDD"; Kmhf= Kmhf

5600 "PRINT USING "14A, DDDD.DDDD,5X,14A, DDDD, DDDD,5X,14A, DDDD, DDDD"; Kmhf= Kmhf
4000  \( K_{dp}=P_{max}/(Vp_{max}-Vdp) \)
4100  PRINT "Kdp=";Kdp
4110  IF FF=0. THEN GOTO Focal
4120  PRINT "CALIBRATION OF F, THE THRUST STAND LOAD CELL";
4130  -----------------------------------------------------------------------------------
4140  **************************************************************************************
4150  **************************************************************************
4160  4010  PRINT "Xpp=';Rpp
4170  4020  PEEP
4180  4010  INPUT 'READING OK? (Y/N)',77$
4190  4010  IF Zz$='N' THEN GOTO Ppmaxcal
4200  4010  IF Ff=0. THEN GOTO Endcal
4210  4010  IF Zz$='N' THEN GOTO Fmaxcal
4220  4010  PRINT "**ZERO CALIBRATION OF F, THE THRUST STAND LOAD CELL**
4230  4010  FOcal:
4240  4010  IF Zz$='N' THEN GOTO Fmaxcal
4250  4010  PRINT "**APPLY MAXIMUM WEIGHT TO THE TRAY**
4260  4010  INPUT 'ENTER THE MAXIMUM WEIGHT IN LBS',Fmax
4270  4010  DISP 'HIT CONTINUE WHEN READY'
4280  4010  REMOTE 709
4290  4010  OUTPUT 729;'ACS'
4300  4010  OUTPUT 722;'T3'
4310  4010  ENTER 722;Vmax
4320  4010  PRINT "Vmax=';Vmax
4330  4010  Kf=Vmax/(Vmax-Vdp)
4340  4010  PRINT 'Kf=';Kf
4350  4010  BEEP
4360  4010  INPUT 'READING OK? (Y/N)',Zz$
4370  4010  IF Zz$='N' THEN GOTO Fmaxcal
4380  4010  PRINT 'THIS ENDS THE CALIBRATIONS'
4390  4010  Focal:
4400  4010  PRINT 'THIS ENDS THE PRE-RUN INPUTS, FLOW RATE SET-UP
4410  4010  Endcal:
4420  4010  PRE-RUN INPUTS
4430  4010  INPUTvariables:
4440  4010  INPUT "DO YOU WANT TO INPUT NEW VARIABLES (Y/N)?",Y$
4450  4010  IF Y$='N' THEN GOTO Nochange
4460  4010  PRINT 'INPUT THE FOLLOWING TEST VARIABLES'
4470  4010  PRINT 'STRING VARIABLES MUST BE ENCLOSED IN QUOTATION MARKS'
4480  4010  INPUT 'THE TEST IDENTIFICATION NUMBER A STRING VARIABLE',Tests$
4490  4010  INPUT 'TODAY'S DATE AS MO.DAY.YEAR A STRING VARIABLE ',Date$
4500  4010  INPUT 'THE BAROMETRIC PRESSURE',Pbar
4510  4010  INPUT 'THE FUEL IDENTIFICATION,A STRING VARIABLE ',Fuelid$
4520  4010  INPUT 'THE INITIAL FUEL GRAIN LENGTH (IN)',Lp
4530  4010  INPUT 'THE AIR INLET DIAMETER (IN)',Di
4540  4010  INPUT 'THE DESIRED AIR INLET TEMPERATURE (K)',Tid
4550  4010  INPUT 'THE DESIRED IGNITION DELAY TIME (SEC)',Tma
4560  4010  INPUT 'THE DESIRED IGNITION TIME (SEC)',Tma
4570  4010  INPUT 'THE DESIRED BURN TIME (SEC)',Tma
4580  4010  INPUT 'THE DESIRED PURGE TIME (SEC)',Tma
4590  4010  PRINT 'THE DESIRED PURGE TIME (SEC)',Tma
4600  4010  IF Y$='N' THEN GOTO Nochange
4610  4010  INPUT 'DO YOU WANT TO INPUT NEW VARIABLES (Y/N)?',Y$
4620  4010  IF Y$='N' THEN GOTO Nochange
4630  4010  PRINT 'INPUT THE FOLLOWING TEST VARIABLES'
4640  4010  PRINT 'STRING VARIABLES MUST BE ENCLOSED IN QUOTATION MARKS'
4650  4010  PRINT 'THE INITIAL FUEL GRAIN DIAMETER (IN)',Dp
4660  4010  PRINT 'THE INITIAL FUEL GRAIN LENGTH (IN)',Lp
3320 ENTR 722:Vpomax
3330 PRINT "Vphomax=",Vphomax,"Phomax=",Phomax
3340 ko=Phomax/(Vphoma-Vpho)
3350 PRINT "ko=",ko
3360 BEEP
3370 INPUT "READING OK? (Y/N)",Zz$
3380 IF Zz$="N" THEN GOTO Phomaxcal
3390 PHOMAXCAL:
3400 ********************************************
3410 PRINT "***CALIBRATION OF Phomax, THE SFRI IGNITION FUEL PRESSURE TRANSDUCER***"
3420 ********************************************
3430 PHOMAXCAL:
3440 PRINT "**CALIBRATION OF Pif, THE SFRI IGNITION FUEL PRESSURE TRANSDUCER**"
3450 PRINT "**ZERO CALIBRATION**"
3460 PRINT "INSURE THAT NO PRESSURE IS APPLIED TO THE TRANSDUCER"
3470 DISP "HIT CONTINUE WHEN READY"
3480 PAUSE
3490 REMOTE 709
3500 OUTPUT 709;"AC6"
3510 INPUT 722:*T3*
3520 ENTER 722;Vpif
3530 PRINT "Vpif=",Vpif
3540 INPUT "READING OK? (Y/N)",Zz$
3550 IF Zz$="N" THEN GOTO Pifcal:
3560 PIFCAL:
3570 PRINT "**CALIBRATION***"
3580 PRINT "APPLY THE MAXIMUM PRESSURE USING DEAD-WEIGHT TESTER"
3590 INPUT "ENTER THE MAXIMUM PRESSURE IN psig",Pifmax
3600 DISP "HIT CONTINUE WHEN READY"
3610 PAUSE
3620 REMOTE 709
3630 OUTPUT 709;"AC6"
3640 OUTPUT 722;*T3*
3650 ENTER 722;Vpifmax
3660 PRINT "Vpifmax=",Vpifmax,"Pifmax=",Pifmax
3670 Kpif=Pifmax/(Vpifmax-Vpif)
3680 PRINT "Kpif=",Kpif
3690 BEEP
3700 INPUT "READING OK? (Y/N)",Zz$
3710 IF Zz$="N" THEN GOTO Pifmaxcal
3720 PIFMAXCAL:
3730 ********************************************
3740 PRINT "***CALIBRATION OF Pp, THE SFRI PURGE GAS PRESSURE TRANSDUCER***"
3750 ********************************************
3760 PPICAL:
3770 PRINT "**ZERO CALIBRATION***"
3780 PRINT "INSURE THAT NO PRESSURE IS APPLIED TO THE TRANSDUCER"
3790 DISP "HIT CONTINUE WHEN READY"
3800 PAUSE
3810 REMOTE 709
3820 OUTPUT 709;"AC7"
3830 OUTPUT 722;*T3*
3840 ENTER 722;Vpp
3850 PRINT "Vpp=",Vpp
3860 INPUT "READING OK? (Y/N)",Zz$
3870 IF Zz$="N" THEN GOTO Ppocal
3880 PPOCAL:
3890 PRINT "**CALIBRATION***"
3900 PRINT "APPLY THE MAXIMUM PRESSURE USING DEAD-WEIGHT TESTER"
3910 INPUT "ENTER THE MAXIMUM PRESSURE IN psig",Ppmax
3920 DISP "HIT CONTINUE WHEN READY"
3930 PAUSE
3940 REMOTE 709
3950 OUTPUT 709;"AC7"
3960 OUTPUT 722;*T3*
3970 ENTER 722;Vppmax
3980 PRINT "Vppmax=",Vppmax,"Ppmax=",Ppmax
3990 PPOCAL:
2640 WAIT 2
2650 OUTPUT 722;'T3'
2660 ENTER 722;Vphmax
2670 PRINT "Vphmax=';Vphmax,";Phmax=';Phmax
2680 Kph=Phmax/(Vphmax-Vph0)
2690 PRINT 'Kph=';Kph
2700 BEEP
2710 INPUT "READING OK? (Y/N)' ,Zz$
2720 IF Zz='N' THEN GOTO Phmaxcal
2730 Phmaxcal:
2740 *********************************************
2750 PRINT "CALIBRATION OF Pn, THE AIR HEATER FUEL PRESSURE TRANSDUCER"*
2760 *********************************************
2770 Phmaxcal:
2780 PRINT "ZERO CALIBRATION***"
2790 PRINT "INSURE THAT NO PRESSURE IS APPLIED TO THE TRANSDUCER"*
2800 DISP "HIT CONTINUE WHEN READY"*
2810 PAUSE
2820 REMOTE 709
2830 OUTPUT 709;'AC3'
2840 OUTPUT 722;'T3'
2850 ENTER 722;Vphfo
2860 PRINT "Vphfo=';Vphfo,";Phfo
2870 INPUT "READING OK? (Y/N)' ,Zz$
2880 IF Zz='N' THEN GOTO Phfoocal
2890 Phfoocal:
2900 PRINT USING '9"
2910 PRINT "CALIBRATION***"
2920 PRINT "APPLY THE MAXIMUM PRESSURE USING DEAD-WEIGHT TESTER"*
2930 INPUT "ENTER THE MAXIMUM PRESSURE IN psig",Phmax
2940 DISP "HIT CONTINUE WHEN READY"*
2950 PAUSE
2960 REMOTE 709
2970 OUTPUT 709;'AC4'
2980 OUTPUT 722;'T3'
2990 ENTER 722;Vphoo
3000 PRINT "Vph=';Vphoo,";Phoo
3010 INPUT "READING OK? (Y/N)' ,Zz$
3020 IF Zz='N' THEN GOTO Phoocal
3030 Phoocal:
3040 *********************************************
3050 PRINT "CALIBRATION OF Pho, THE AIR HEATER OXYGEN PRESSURE TRANSDUCER"*
3060 *********************************************
3070 Phoocal:
3080 PRINT "ZERO CALIBRATION***"
3090 PRINT "INSURE THAT NO PRESSURE IS APPLIED TO THE TRANSDUCER"*
3100 DISP "HIT CONTINUE WHEN READY"*
3110 PAUSE
3120 REMOTE 709
3130 OUTPUT 709;'AC4'
3140 OUTPUT 722;'T3'
3150 ENTER 722;Vph0
3160 PRINT "Vph0=';Vph0,";Ph0
3170 INPUT "READING OK? (Y/N)' ,Zz$
3180 IF Zz='N' THEN GOTO Ph0ocal
3190 Ph0ocal:
3200 *********************************************
3210 PRINT "CALIBRATION***"
3220 PRINT "APPLY THE MAXIMUM PRESSURE USING DEAD-WEIGHT TESTER"*
3230 INPUT "ENTER THE MAXIMUM PRESSURE IN psig",Phmax
3240 DISP "HIT CONTINUE WHEN READY"*
3250 PAUSE
3260 REMOTE 709
3270 OUTPUT 709;'AC4'
3280 OUTPUT 722;'T3'
3290 }
1.960
1960 KNZ(P) = (Vpaxmax - VpaO)
1970 PRINT "Kpa = ipa"
1980 1990 BEEP
2000 INPUT "READIG OK? (Y/N)", Zz$
2010 IF Zz$ = 'N' THEN GOTO Pmaxacal
2020 Pmaxacal:
2030 PRINT **CALIPRATION OF PC, THE SFRI MOTOR CHAMBER PRESSURE TRANSDUCER**
2040 2050
2065 Pcal:
2070 PRINT *ZERO PRESSURE***
2080 PRINT 'INSURE THAT NO PRESSURE IS APPLIED TO THE TRANSDUCER'
2090 DISPE 'HIT CONTINUE WHEN READY'
2100 PAUSE
2110 REMOTE 709
2120 OUTPUT 709;'A1'
2130 WAIT 2
2140 OUTPUT 722;'T3'
2150 ENTER 722;VpcO
2160 PRINT 'VpcO=';VpcO
2170 FEP
2180 INPUT 'READING OK? (Y/N)', Zz$
2190 IF Zz$ = 'N' THEN GOTO Pmaxacal
2200 Pmaxacal:
2210 PRINT USING "@**CALIBRATION***'
2220 PRINT 'APPLY THE MAXIMUM PRESSURE USING DEAD-WEIGHT TESTER'
2230 INPUT 'ENTER THE MAXIMUM PRESSURE IN psig', Pmax
2240 DISP 'HIT CONTINUE WHEN READY'
2250 PAUSE
2260 REMOTE 709
2270 OUTPUT 709;'A1'
2280 WAIT 2
2290 OUTPUT 722;'T3'
2300 ENTER 722;Vpcmax
2310 PRINT 'Vpcmax=';Vpcmax
2320 KPC = Pmaxc(Vmax - PpcO)
2330 PRINT "Kpc = Kpc"
2340 BEEP
2350 INPUT 'READING OK? (Y/N)', Zz$
2360 IF Z$ = 'N' THEN GOTO Pcal:
2370 Pcal:
2380 PRINT **CALIBRATION OF Ph, THE SFRI MOTOR HEAD-END PRESSURE TRANSDUCER**
2390 PhOcal:
2400 PRINT **ZERO PRESSURE***
2410 PRINT 'INSURE THAT NO PRESSURE IS APPLIED TO THE TRANSDUCER'
2420 DISPE 'HIT CONTINUE WHEN READY'
2430 PAUSE
2440 REMOTE 709
2450 OUTPUT 709;'A1'
2460 WAIT 2
2470 OUTPUT 722;'T3'
2480 ENTER 722;VphO
2490 PRINT 'VphO=';VphO
2500 FEP
2510 INPUT 'READING OK? (Y/N)', Zz$
2520 IF Zz$ = 'N' THEN GOTO PhOcal
2530 PhOcal:
2540 PRINT USING @**CALIBRATION***
2550 PRINT 'APPLY THE MAXIMUM PRESSURE USING DEAD-WEIGHT TESTER'
2560 INPUT 'ENTER THE MAXIMUM PRESSURE IN psig', PhMax
2570 DISP 'HIT CONTINUE WHEN READY'
2580 PAUSE
2590 REMOTE 709
2600 OUTPUT 709;'A1'
2610 WAIT 2
2620 OUTPUT 722;'T3'
2630 ENTER 722;Vphmax
2640 PRINT 'Vphmax=';Vphmax
2750 KPC = PhMax/(Pmax - PhO)
I: RETURN
1430 PRINT "TEMPERATURE SET AT 1460 R"
1440 PRINT "E=",1
1450 PRINT Flurf
1460 PRINT "BEER: C04, 1"
1470 PRINT "WAT: 1"
1480 PRINT "RUN: 1"
1520 PRINT "Temps: 1"
1530 "******************************************************************************
1540 "14 TEMP CALIBERATIONS"
1550 "******************************************************************************
1560 "THE TESTING SITE "AND "LOAD CELL FOR thrust WHICH
1570 "MUST BE CALIBRATED. TRANSDUCER LINEARITY MUST BE VERIFIED BEFORE THIS
1580 "CALIBRATION PROCEDURE IS EMPLOYED. THE ORDER OF CALIBRATION IS AS
1590 "COLLINES: P,, P,, P,, P,, P,, P,, P,, P,, P,
1600 "THE FOLLOWING TWO LINES SET UP .722 AND .709 FOR DATA ACQUISITION"
1610 CLEAR 709 ! CLEAR 3497A DATA ACQUISITION/CONTROL UNIT
1620 CLEAR 722 ! CLEAR 3456A DIGITAL VOLTMETER
1630 REMOTE 709 ! MAKE 3497A UNIT TO REMOTE HOME
1640 OUTPUT 722: "L1K31STNXIIOST414X1" ! 10 READING PER TRIGGER AND STORE
1650 Pascal: 1
1660 "******************************************************************************
1670 "PRINT ** CALIBRATION OF P,, THE AIR SONIC CHOKING PRESSURE TRANSDUCER"
1680 "******************************************************************************
1690 Pascal: 1
1700 PRINT "**** ZERO PRESSURE ****"
1710 PRINT "INSURE THAT NO PRESSURE IS APPLIED TO THE TRANSDUCER"
1720 DISP "HIT CONTINUE WHEN READY TO TAKE ZERO READING"
1730 PAUSE
1740 REMOTE 709
1750 OUTPUT 709: "AC2" ! ACQUIRE CHANNEL 2
1760 "IT 2
1770 OUTPUT 722: "T3" ! INITIATE SINGLE TRIGGER
1780 ENTER 722; vR8 ! READ VOLTAGE
1790 PRINT "vB0=",vB0
1800 BEEP
1810 INPUT "READING OK? (Y/N)", Z2
1820 IF Z2=:"N" THEN GOTO Pascal
1830 Pascal: 1
1840 PRINT USING "R" ! CLEAR SCREEN
1850 PRINT "**** CALIBRATION N****
1860 PRINT "APPLY MAXIMUM PRESSURE USING THE DEAD-WEIGHT TESTER"
1870 INPUT "SWEEP THE MAXIMUM PRESSURE IN P,,", Panax
1880 DISP "HIT CONTINUE WHEN READY"
1890 PAUSE
1900 REMOTE 709
1910 OUTPUT 709: "AC2"
1920 "IT 2
1930 OUTPUT 722: "T3"
1940 ENTER 722; vB0
1950 PRINT "vB0=",vB0,"Pana= ", Panax
Tma
Tmb
Tmi
Tmo
Ti
Wti

TIME BETWEEN SFRI AIR FLOW AND IGNITION, sec
BURN TIME AFTER Tma, sec
IGNITION DURATION AFTER Tma, sec
DUR. AFTER Tmb, sec
TEMPERATURE, PURGE GAS SONIC CHOKE, R
INITIAL FUEL GRAIN WEIGHT, Lbm

HEEP 1000.1
PRINT USING "*8"
PRINT USING "$/

THE RECORDED VARIABLES (VOLTAGES) AND LOCATIONS ARE:
(Note: the maximum allowable voltage into the system is 1.2 Volts)

VARIABLE 3497 DACU SCANNER NUMBER 0

---

P3
Pc
Ph
Phf
Pho
Pif
PP
Pf
Ta
Tf
Thf
Tho
Tii

---

1000
1001
1020
1030
1040
1050
1070
1080
1090
1100
1110
1120
1130
1150
1180
1190
1200
1210
1220
1250
1260
1270
1300
1310
1320
1330
1340

ALL FLOW RATES ARE CALCULATED USING THE ONE-DIMENSIONAL, ISENTROPIC
FLOW EQUATIONS WITH FIXED PROPERTIES. SMALL SONIC NOZZLES HAVE
MEASURED DISCHARGE COEFFICIENTS. THE AIR FLOW NOZZLE USES AN ASSUMED
DISCHARGE COEFFICIENT (Cd) OF 0.97.

Km IS THE GAS-DEPENDENT SONIC CHOKE FLOW RATE CONSTANT

Km = 50R((Gamma+Gc/R)*(2/(Gamma+1))*((Gamma+1)/(Gamma-1)))

APPROPRIATE CONSTANTS ARE:

GAS MOLECULAR WT,
1150
1170
1180
1200
1210
1230
1250
1260
1270
1300
1310
GAMMA

AIR 29.0
O2 32.0
CH4 16.03
C2H4 28.03
ARGON 39.9

---

ALL THERMOCOUPLES USED ARE CHROMEL vs ALUMEL (TYPE K) WITH
ELECTRONIC ICE POINTS. TEMPERATURE READINGS (VOLTAGES) ARE
CONVERTED TO DEGREES RANKINE (R) PER "INDUSTRIAL INSTRUMENTATION" BY
D. P. ECKMAN (PAGE 359). THIS CALCULATION IS PERFORMED IN SURROUTINE
Tcalc. TEN VOLTAGE INTERVALS ARE USED BETWEEN 460 AND 1460 R.

Cc = 32.174
1290
Ke = 8
1320
GOT0 Transcal

IF Volts>.00153 THEN T=((Volts+.00058)/.0000220)+468
IF Volts>.00382 THEN T=((Volts-.00153)/.0000220)+468
1340

GOT0 Transcal

44
APPENDIX A
COMPUTER PROGRAM FOR EXPERIMENT CONTROL AND DATA REDUCTION

10 !SFRJTEST
20 !SOLID FUEL RAMJET DATA ACQUISITION AND DATA REDUCTION PROGRAM,
30 THIS PROGRAM IS DIVIDED INTO FIVE PARTS:
40 (1) VARIABLE DEFINITIONS AND NOMENCLATURE
50 (2) TRANSDUCER CALIBRATIONS
60 (3) PRE-RUN INPUTS, FLOW SET-UPS
70 (4) THE TEST SEQUENCE AND DATA COLLECTION
80 (5) POST-RUN OPERATIONS

(1) VARIABLE DEFINITIONS AND NOMENCLATURE

120 SYMBOL DEFINITION

A ANALOG CHANNEL NUMBER

Cair DISCHARGE COEFFICIENT, HEATER FUEL SONIC CHOKE

Chf DISCHARGE COEFFICIENT, OXYGEN MAKE-UP SONIC CHOKE

Cho DISCHARGE COEFFICIENT, IGNITION FUEL SONIC CHOKE

Cdif DISCHARGE COEFFICIENT, PURGE GAS SONIC CHOKE

Cdo DISCHARGE COEFFICIENT, PURGE GAS SONIC CHOKE

Cf THRUST COEFFICIENT

Cstarth THEORETICAL CL, FT/SEC

Cstarair C* FOR AIR FLOW BASED ON Dtheff

DaieS Test Date lo-Day-Yr

Dhfchoke AIR HEATER FUEL SONIC CHOKE DIAMETER

Dhochoke OXYGEN MAKE-UP SONIC CHOKE DIAMETER

Di MOTOR INLET DIAMETER, IN.

Difchoke IGNITION FUEL SONIC CHOKE DIAMETER

Do MOTOR FUEL PORT DIAMETER, IN.

Dth EFFECTIVE THROAT DIAMETER, IN.

Dtheff EFFECTIVE THROAT DIAMETER, IN.

FuelidS FUEL IDENTIFICATION

Cc GRAVITATIONAL CONSTANT (32,174)

Heaterfuel$ FUEL IDENTIFICATION

Ignitionfuel$ IGNITION FUEL I.D

Kair AIR SONIC CHOKE FLOW RATE CONSTANT

Khf HEATER FUEL SONIC CHOKE FLOW RATE CONSTANT

Kho OXYGEN MAKE-UP SONIC CHOKE FLOW RATE CONSTANT

Kmf IGNITION FUEL SONIC CHOKE FLOW RATE CONSTANT

Kmo PURGE GAS SONIC CHOKE FLOW RATE CONSTANT

Ls FUEL GRAIN LENGTH, IN.

Maie AIR FLOW RATE, LBM/SEC

Mhf HEATER FUEL FLOW RATE, LBM/SEC

Mhd DESIRED HEATER FUEL FLOW RATE, LBM/SEC

Mo OXYGEN MAKE-UP FLOW RATE, LBM/SEC

Mho DESIRED HEATER OXYGEN FLOW RATE, LBM/SEC

Mif IGNITION FUEL FLOW RATE, LBM/SEC

Mifd DESIRED IGNITION FUEL FLOW RATE, LBM/SEC

Mo PURGE GAS FLOW RATE, LBM/SEC

Mgd DESIRED PURGE GAS FLOW RATE, LBM/SEC

Pa PRESSURE, AIR SONIC CHOKE, PSIA

Ph PRESSURE, CHAMBER, PSIA

Phf PRESSURE, HEATER FUEL SONIC CHOKE, PSIA

Pho PRESSURE, HEATER OXYGEN SONIC CHOKE, PSIA

Psg PRESSURE, IGNITION FUEL SONIC CHOKE, PSIA

Ppg PRESSURE, PURGE GAS SONIC CHOKE, PSIA

Porpress PURGE GAS I.D

P h TEMPERATURE, AIR SONIC CHOKE, R

Th TEST TEMPERATURE, HEATER FUEL SONIC CHOKE, R

Tho TEMPERATURE, OXYGEN MAKE-UP SONIC CHOKE, R

Ti TEMPERATURE, MOTOR AIR INLET, R

Tid TEMPERATURE, DESIRED MOTOR AIR INLET, R

Tif TEMPERATURE, IGNITION FUEL SONIC CHOKE, R
VI. CONCLUSIONS AND RECOMMENDATIONS

Additional tests using fuel-wall and step face injection of oxygen, gaseous fuel and/or heated air should be conducted to verify the initial results found in this investigation. However, the initial data from this investigation indicates that gaseous injection is not a viable technique for fuel regression rate control.

Fuel regression rate was found to be quite sensitive to small amounts of inlet air swirl without large changes in combustion efficiency. Additional testing is recommended.
Figure 5.1  Thrust Calibration Curve, Measured vs Actual.
<table>
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<th>Test number</th>
<th>27</th>
<th>28</th>
<th>29</th>
<th>30</th>
<th>31</th>
<th>32</th>
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<td>$\phi$ (psia)</td>
<td>0.69</td>
<td>0.70</td>
<td>0.82</td>
<td>0.81</td>
<td>0.79</td>
<td>1.374</td>
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<tr>
<td>Pc (psia)</td>
<td>55.4</td>
<td>59.1</td>
<td>57.7</td>
<td>55.9</td>
<td>55.8</td>
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<td>PEP/CO results</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>Tth (K)</td>
<td>3398</td>
<td>3917</td>
<td>3737</td>
<td>3724</td>
<td>3662</td>
<td>4283</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>1.265</td>
<td>1.254</td>
<td>1.256</td>
<td>1.256</td>
<td>1.258</td>
<td>1.257</td>
</tr>
<tr>
<td>R (ft Lbf/Lbm*R)</td>
<td>56.18</td>
<td>55.93</td>
<td>54.93</td>
<td>53.27</td>
<td>55.68</td>
<td>56.82</td>
</tr>
<tr>
<td>Efficiency (based on Pc, analog)</td>
<td>83.4</td>
<td>81.5*</td>
<td>78.9</td>
<td>100</td>
<td>85.5</td>
<td>(82.7)**</td>
</tr>
</tbody>
</table>

* based on Pc, digital
** based on Ft, analog
PRINT USING "11A,DD.DDDD";"Mairinject=";Mho
PRINT USING "18Afl0.DDDDD";"Mho DESIRED=";Mmod
THF=";THF;"Mho/";Mho;"Mho DESIRED=";Rat
PRINT USING "5A,DDDDD,IX,4A,DDDD.DD,1A";"Mho=Mho/";Mho;"Mho DESIRED=";Rat
PRINT USING "18Afl0.DDDDD";"Mho DESIRED=";INnod
Rati=THF/MHod
PRINT USING "33A,DDDD.DDDD,IX,4ADDIDDD,IA";"Nho/Mho DESIRED=.Rji
PTHOF=THOF-Pbar
PRINT USING "14A,DDDD.DD,IX,4A";"RESET Ph. TO ";Phonpw;"Psiq"
Pho=(Pht#4lhod/MQho)-Fbar
PRINT USING "12ADDD,IX,4A,5X,4A,DDDD.1X,2A";"Pho=";Pg;"Psiq"
IF Xx$="Y" THEN GOTO Phofin
Phofin:
Phonew=(Pht#4lhod/MQho)-Fbar
PRINT USING "12ADDD,IX,4A,5X,4A,DDDD.1X,2A";"Pho=";Pg;"Psiq"
PAUSE
GOTO Phoset
Phoset:
DISP 'HIT CONTINUE TO PROCEED TO NEXT FLOW RATE SET UP'
PAUSE
Phoset:
PRINT USING "@@4"
INPUT "DO YOU WANT TO PRESET THE PURGE FLOW RATE? (Y/N)" , Z$ 

IF Z$ = "Y" THEN GOTO Ppskip 

PRINT "SET THE DESIRED VALUE OF P0 USING THE HANDLOADER/PRESSURE GAGE" 

PRINT "HIT CONTINUE WHEN READY" 

PAUSE 

Ppskip: 

CLEAR 709 

OUTPUT 709 ; "DC10.1" 

WAIT 2 

OUTPUT 709 ; "AE7" 

ENTER 722 ; T3 

OUTPUT 709 ; "4C13" 

ENTER 722 ; T3" 

ENTER 722 ; Vtp 

OUTPUT 709 ; "3D10.1" 

Pps= (Vpp-Vpp0)*Kpp+Pbar 

Volts= Vtp 

CGSIB Tcalc 

T=1 

Mo=Mo*Kop*Pg, 7854*(Dpchax=2.0/(Tps*.5) 

PRINT USING "E" 

PRINT USING "3A, DDDD, DDDD, DDDD, DDDD, DDDD, DDDD, DDDD, 1A" ; "Mo = Mo" 

PRINT USING "13A, DDDD, DDDD, DDDD, DDDD, DDDD, DDDD, DDDD, 1A" ; "Mo" 

R= Mo/Mpd 

PRINT USING "16A, DDDD, DDDD, DDDD, DDDD, DDDD, DDDD, DDDD, DDDD, 1A" ; "Mo/Mp DESIRED = " ; R, "Tp = " Tp 

PRINT USING "13ADDD, DDDD, DDDD, DDDD, DDDD, DDDD, DDDD, DDDD, 1A" ; "Pp = " Pp ; "Psia" 

INPUT "IS THE PURGE GAS FLOW RATE ACCURATE ENOUGH? (Y/N)" , Xx$ 

IF Xx$ = "Y" THEN GOTO Ppskip 

PRINT "THIS COMPLETES PRE-RUN SETUP" 

PRINT "THE FOLLOWING PROGRAMS THE 3456A DVM" 

INPUT "ENTER Tma, Tm1, Tmb, Tmp SEPARATED BY COMMA, THEN HIT CONTINUE" , Tma, Tm1, Tmb, Tmp 

Tsh= Tma+Tm1+Tmb+ Tmp 

ONE MORE SECOND FOR TAIL PART READING 

Tsh+ Tmp 

I=14+Tm1 

I5= I+Tm1 

T6 = T5+ Tmp 

OPTION BASE 1 

DIM In(500, 14) 

I CONTROL FLAGS
VOLTS
0.8
PRINT USING "G"
DISP "TO INITIATE RUN, PUSH 'PRI-AIR SWITCH'"

Monvtor: WAIT UNTIL INITIATE
OUTPUT 709;'AC14'
OJTPUT 722;'T3'
Enter 722;14
IF V14)=.5 THEN GOTO Startrun IF INITIATE RUN, IT WILL GIVE

Monvtor

Startrun: TO-TIMEDATE
ON CYCLE .5 GOSUB Data
ON DELAY Ishut GOTO Shutdown
Timewait: WAIT 0.5 SECOND
A=3+1
GOTO Timewait

Data: READ ALL DATA EVERY 0.5 SECONDS
OUTPUT 709;'AC140AL13'
FOR I=1 TO 14
OUTPUT 722;'T3'
Enter 722 USING "G,K";In(J,1)
OUTPUT 709;'A5'
NEXT I
I=J+1
Ti:TIMEDATE
IF A1=1 THEN GOTO Tmabypass
Ti=TAFDATE
IF DROUND(Ti-T0,3))=Tha THEN
OUTPUT 709;'DO0,2'
OUTPUT 709;'DO10,3 '
A2=1
END IF
Tmabypass:
Ti:TIMEDATE
IF A2=1 THEN GOTO T4bypass
Ti=TAFDATE
IF DROUND(Ti-T0,3))=T4 THEN
OUTPUT 709;'DO10,2'
OUTPUT 709;'DO10,3 '
A3=1
END IF
T4bypass:
Ti:TIMEDATE
IF A3=1 THEN GOTO T5bypass
Ti=TAFDATE
IF DROUND(Ti-T0,3))=T5 THEN
OUTPUT 709;'DO10,1'
OUTPUT 709;'DO10,0 '
A4=1
END IF
T5bypass:
Ti:TIMEDATE
IF A4=1 THEN GOTO T6bypass
Ti=TAFDATE
IF DROUND(Ti-T0,3))=T6 THEN
OUTPUT 709;'DO15,1'
OUTPUT 709;'DO10,0 '
A5=1
END IF
T6bypass:
OUTPUT 709;'DO15,0 '
A6=1
END IF
RETURN

GOTO 9080 !* THIS NUMBER WILL BE CHANGED WHEN RENUMBER.

RETURN
OFF CYCLE
Imax=J-1
PRINT USING "G"
PRINT "TEST COMPLETE, TURN OFF 'MAIN-AIR', AND TURN OFF 'HEATER CASES'"
BEEP
I

END IF
9720 IF I=6 AND FF=1 THEN
9730 VF=ln(J,1)
9740 F=(VF-VF+1)*WF
9750 END IF
9760 IF I=6 AND FF=0 THEN
9770 F=8
9780 END IF
9790 IF I=7 THEN
9800 Vpf=ln(J,1)
9810 Pif=(Vpf-Unif)*Kpi
9820 IF Pif=(Ph+20) THEN
9830 Pif=0.
9840 END IF
9850 END IF
9860 IF I=8 THEN
9870 Vpp=ln(J,1)
9880 Pp=(Vpp-Unpp)*Kpp
9890 IF Pp=(Ph+20) THEN
9900 Pp=0.
9910 END IF
9920 IF I=9 THEN
9930 Volts=ln(J,1)
9940 GOSUB Tcalc
9950 Ti=T
9960 END IF
9970 IF I=10 THEN
9980 Volts=ln(J,1)
9990 GOSUB Tcalc
10000 Ta=T
10010 END IF
10020 IF I=11 AND Ht=1, THEN
10030 Volts=ln(J,1)
10040 GOSUB Tcalc
10050 Th=T
10060 END IF
10070 IF I=11 AND Ht=2, THEN
10080 Volts=ln(J,1)
10090 GOSUB Tcalc
10100 Th=T
10110 END IF
10120 IF I=12 AND Ht=1, THEN
10130 Volts=ln(J,1)
10140 GOSUB Tcalc
10150 Th=T
10160 END IF
10170 IF I=12 AND Ht=2, THEN
10180 Volts=ln(J,1)
10190 GOSUB Tcalc
10200 Th=T
10210 END IF
10220 NEXT J
10230 NEXT I
10240 T=1/2
10250 Mair=Kmin*Cmin*Pa/.7854*(Dainchke*2)/(Ta.5)
10260 Mhf=Kmin*Cmin*Ph*Pa/.7854*(Dchke*2)/(Th.5)
10270 Mhf=Kmin*Cmin*Ph/7854*(Dainchke*2)/(Th.5)
10280 Mhf=Kmin*Cmin*Ph/7854*(Dchke*2)/(Th.5)
10290 Mhf=Kmin*Cmin*Ph/7854*(Dchke*2)/(Th.5)
10300 PRINT USING "*2X.DD.DD,3X.DD.DD,4(3X.D.DDDD),5(3X.D.DDDD.DD)";T,Mair,Mhf,Mf,Fo,
10310 INPUT "DO YOU WANT TO MAKE POST-RUN AIR CALCULATION? (Y/N)";Y
10320 IF Y='Y' THEN K=1
10330 IF Y='N' THEN GOTO Finish
10340 GOTO Poset 1 TO CALCULATE THE EFFECTIVE THROAT DIAMETER
10380 Finish: !
10390 PRINT "DATA OUTPUT IS COMPLETE"
10400 DISP "SECURE TEST CELL !!!"
10410 LOCAL 799
10420 END ! RETURN LOCAL MODE
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