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REPORT NO. RK-TR-72-19

**EXPERIMENTAL INVESTIGATION
OF RAMBURNER PERFORMANCE:
PART I, LIQUID PROPELLANT RUNS**

by

R. A. Meese and J. G. Skifstad

July 1972

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U.S. ARMY MISSILE COMMAND

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**EXPERIMENTAL INVESTIGATION
OF RAMBURNER PERFORMANCE:
PART I, LIQUID PROPELLANT RUNS**

by

R. A. Meese* and J. G. Skifstad

*Jet Propulsion Center
School of Mechanical Engineering
Purdue University
Lafayette, Indiana

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Propulsion Directorate
Directorate for Research, Development, Engineering
and Missile Systems Laboratory
U.S. Army Missile Command
Redstone Arsenal, Alabama 35809

ABSTRACT

This report describes the results of a series of connected-pipe runs with an air-augmented rocket system burning liquid rocket propellants. The liquid propellant runs served to evaluate the behavior of the facility and instrumentation with regard to accuracy and to provide performance data for combustion where the chemical rate processes were relatively fast compared with those of metal combustion. The ramburner was designed to provide axisymmetric, coaxial mixing of the primary and secondary streams in a constant area duct. No mixing aids were employed.

Nitrogen tetroxide and Aerozine-50 served as the rocket propellants. The secondary air was preheated by combustion to a nominal temperature of 1100°R to simulate flight stagnation conditions. Runs were made with nominal pressures in the ramburner of 90 and 175 psia. The air/propellant ratio was varied from 5 to 13 (approximately 250 to 600 percent theoretical air). Two oxidizer-to-fuel ratios were employed for the primary rocket: 0.8 (fuel rich) and 2.0 (stoichiometric).

Combustion efficiencies between 75 and 90 percent were observed for the complete system, decreasing with increasing air/propellant ratio. Estimated uncertainties in the efficiency values were ± 3 percent. Ramburner efficiencies tended to be 10 to 15 percent lower and were subject to uncertainties in the neighborhood of ± 6 percent. A slight decrease in efficiency with decreasing pressure was also observed.

FOREWORD

The authors wish to extend their thanks to the personnel of the Jet Propulsion Center whose advice was freely drawn upon during the investigation. The guidance of C. M. Ehresman in the methods of operation of much of the test equipment and the aid and assistance of the test mechanics, Mr. Gordon Hurst and Mr. Bill Timmons, is gratefully acknowledged.

The research program was sponsored by the U.S. Army Missile Command, Redstone Arsenal, Alabama. The support of Dr. Richard Rhoades, the project monitor at the U.S. Army Missile Command, has been appreciated.

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NOTATIONS

A	Area
A/P	Ratio of air flow rate to primary rocket propellant flow rate
C_d	Discharge coefficient
C_p	Specific heat at constant pressure, Btu/lb _m °R
F	Thrust, lb _f
g_c	Gravitational constant
H	Enthalpy, Kcal/gmole or Btu/lb _m
I_n	Normalized light intensity
k	Calibration constant
L/D	Length-to-diameter ratio
M	Molecular weight
$\dot{m}$	Mass flow rate, lb _m /sec
n	Number of moles
O/F	Ratio of primary rocket oxidizer to fuel flow rates
P, p	Pressure, psi
$\bar{P}$	Average pressure, psi
Q	Heat transfer rate per unit length, Btu/ft
$\dot{Q}$	Heat transfer rate, Btu/sec
R	Universal gas constant = 1545 ft lb _f /lb _m °R
r	Radius of the ramburner, in.; burning rate, in /sec
s	Specific gravity
T, t	Temperature, °R
V	Velocity, ft/sec
v	Voltage
vi	

$\dot{w}$	Flow rate, lb/sec
x	Voltage per 250 cycles/sec produced by a flowmeter
y	Run duration, sec

Subscripts

a	Air
ah	Air heater
ao	Air orifice
c	Rocket chamber
cs	Complete system
d	Duct (ramburner)
e	Experimental
f	Fuel, final condition
hf	Heater fuel
i	Initial condition, specie index
ideal	Ideal
inj	Injection
in	Entering condition
iw	Inside wall
j	Propellant substance index
o	Reference state
oa	Overall (complete system)
out	Exiting condition
ow	Outside wall
ox	Oxidizer
p	Propellant

pr	Primary rocket
r	Release
sa	Air stagnation state
sec	Secondary combustor (ramburner)
sj	Exhaust jet stagnation condition
1	Inside surface
2	Outside surface

Greek Symbols

ρ	Density
η	Combustion efficiency
γ	Ratio of specific heats

Section I. INTRODUCTION

This report describes the results of a series of connected-pipe runs with a ramburner simulating conditions encountered in air-augmented rocket systems. The research was part of Phase I of a four-phase program of research on air-augmented rockets sponsored by the U.S. Army Missile Command (MICOM) under Contract No. DAAH01-69-C-1109.* Investigations with both liquid and solid propellants were included in the research program. In the series of runs reported herein, liquid propellants were employed in the primary rocket: nitrogen tetroxide and Aerozine-50. The objectives of the liquid propellant run series were (1) to evaluate the experimental facility, including measurement accuracies and the determination of sources of error, and (2) to obtain secondary mixing and combustion data under conditions most likely to be controlled by mixing rates and not by chemical kinetic rates. The data serve to provide a basis for comparison with analytical studies in progress as part of the research program. Results of experiments using solid propellants are to be reported in Part II [1] of this report.

The configuration of an air-augmented rocket is illustrated in Figure 1. Air from the atmosphere is inducted and mixed with the exhaust gases of a primary rocket motor in the secondary mixing and combustion duct (ramburner). The exhaust products of the primary rocket motor are generally chosen to be fuel-rich, and the combustible material is mixed and burned with the air in the ramburner. Liquid propellants may be employed in the primary rocket motor, but principal interest is in the use of solid propellants. The fuel-rich exhaust products of suitable solid propellants frequently contain appreciable amounts of combustible material in condensed phases. Because of the relatively low rate of combustion of the condensed matter with the attendant difficulty in achieving high combustor performance, the interest throughout this investigation has been in mixing and combustion phenomena in the ramburner.

The facility employed for this test series was described in MICOM Report No. RK-TR-68-8 [2]. Figure 2 illustrates schematically the configuration of the facility. The principal elements of the experimental system were an air heater, a rocket motor, and a secondary mixing and combustion duct. Air passing through the air heater was heated to simulate representative flight conditions by combustion with RP-1. The rocket chamber was mounted outside the ducting for the hot air flow, as shown in Figure 2, with an exhaust pipe (blast tube) configuration

*The research program was initiated under Contract No. DA-01-021-AMC-15096(Z) and continued under Contracts DAAH01-67-C-C01678 and DAAH01-68-C-1917. Refer to Reference [2] for a description of the other aspects of the program.

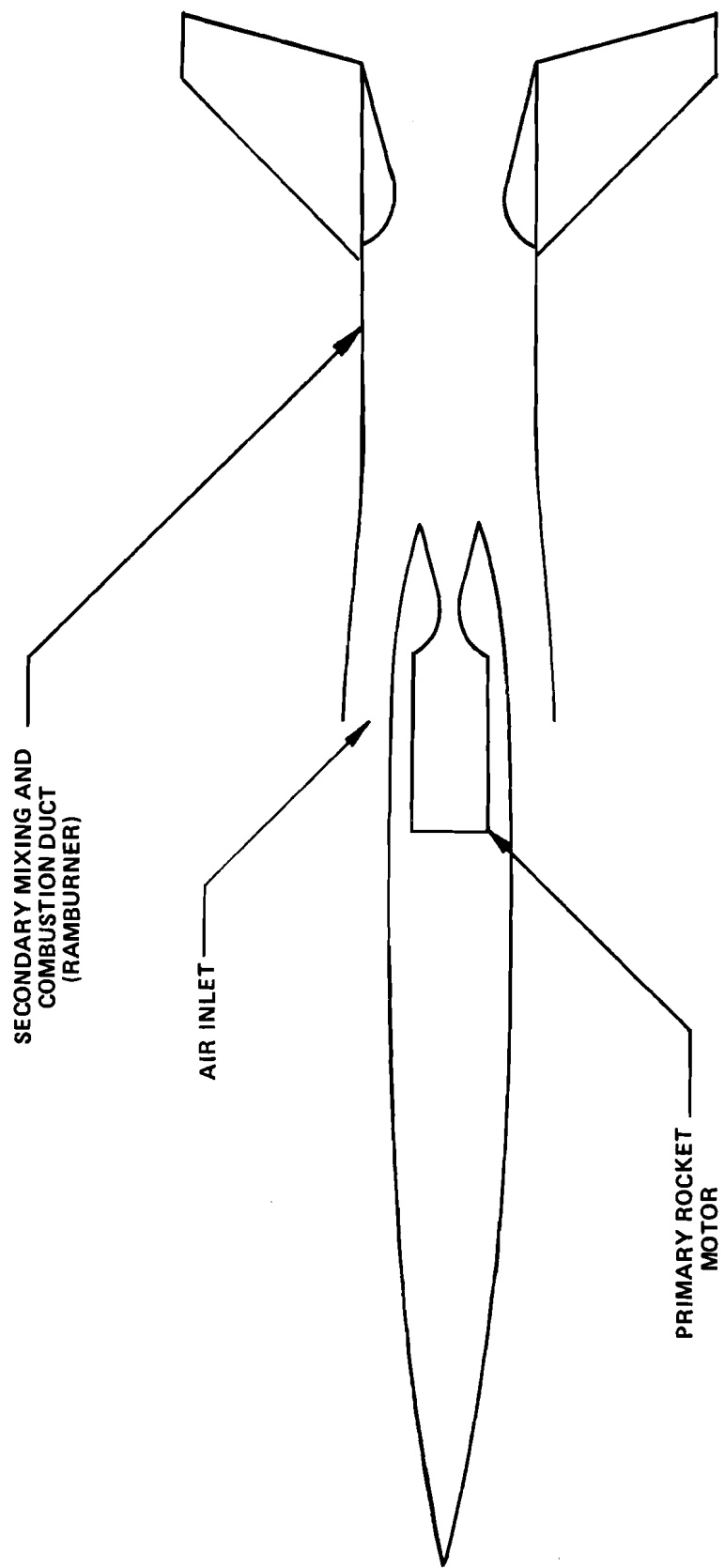


Figure 1. Configuration of an Air-Augmented Rocket

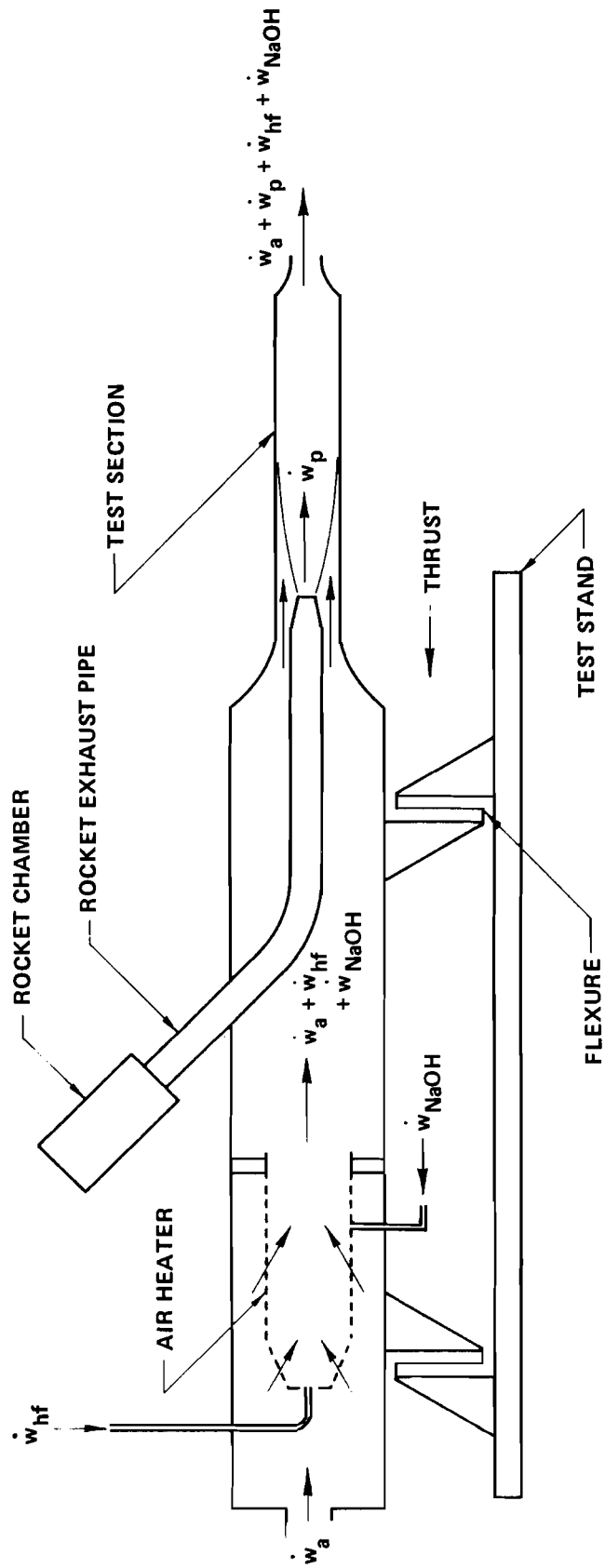


Figure 2. Layout of the Experimental Apparatus

to avoid the necessity for cooling the solid propellant primary rocket motors. Combustion products from the primary rocket motor and the heated air flowed coaxially into the secondary duct (ramburner) where mixing of the two streams and combustion of the excess fuel in the rocket exhaust products occurred. Constant area ducts were employed for the ramburner section. No mixing aids were employed. The bipropellant rocket, the air heater, and the ramburner were all mounted on a thrust stand. All input lines to the thrust stand were flexible and were mounted to avoid forces in the thrust direction. Subsystems not shown in Figure 2 included the bipropellant system to supply the propellant flows to the primary rocket, the laboratory blowdown air supply system, and the air heater fuel supply system. A methane-oxygen torch was employed to ignite the fuel in the air heater.

For the series of runs reported herein, two flight conditions were simulated: Mach 2.4 at an altitude of 1000 feet and Mach 3 at 40,000 feet. A diffuser total pressure recovery factor of 0.75 percent was assumed. The stagnation conditions at the respective flight conditions are 1108°R and 155 psia and 1100°R and 75 psia. In the experimental run series, measurements of the stagnation air temperature during the rocket firing fell between 996° and 1223°R and the measured stagnation pressures ranged from 82 to 104 psia and from 155 to 182 psia. The Mach number of the air entering the ramburner was in the low subsonic range, between 0.09 and 0.25. The air-propellant (A/P) ratio was varied from 5 to 13. The chamber pressure of the primary rocket ranged from 270 to 322 psia. The primary rocket was operated with two oxidizer-to-fuel (O/F) ratios, nominally 0.8 and 2.0. Stoichiometric O/F ratio for the rocket was 2.0. Approximate residence times of the gases in the ramburner were estimated to be between 3 and 8 milliseconds.

Measurements taken during each run included the air stagnation temperature and pressure, the air flow rate, the heater fuel and rocket propellant flow rates, the gross thrust, and the chamber pressure of the primary rocket. In the ramburner section, the wall static pressure was measured at five points along the length of the ramburner. In addition, the emitted radiation intensity in the visible range was detected at five locations along the ramburner. A traversing pressure probe was employed in an attempt to measure the stagnation pressure profile in the exhaust jet 1/16 to 1/8 inch downstream from the exit plane of the ramburner nozzle. The runs also served to evaluate the operation of a sampling probe system situated in the exhaust jet.

The normal run procedure, following calibration of all instrumentation, was initiated by setting the tank pressures for the rocket fuel, oxidizer, and coolant, and setting the heater fuel to give the desired flow rates. The air flow was established and combustion was initiated in the air heater. When the air heater was operating at the desired conditions, all data recorders were started. As soon as all data recorders were determined to be operating satisfactorily, the primary rocket was fired for a period of 3.5 seconds. Data recording was terminated approximately 3 seconds after the shutdown of the primary rocket.

Most of the data were recorded on digital tape through an analog-to-digital converter and sampling system; the tape was then processed and employed as input to a data reduction computer program. The data reduction program performed all necessary calibration transformations, sorting, and averaging the data as specified. Flow rates and other parameters for the system were computed. Routines were included in the program to perform thermochemistry computations to compare the measured data with theoretical values for the determination of combustion efficiencies.

Section II. EXPERIMENTAL FACILITY

A rather complete description of the facility employed for the experiments may be found in Reference [2]. The principal features, including minor modifications, are summarized in this section

A schematic diagram illustrating the different flow systems of the experimental apparatus is shown in Figure 3. The basic flow systems comprised the following:

- a) A blow-down air system for supplying the secondary air to the experimental apparatus
- b) A fuel system for the air heater
- c) A liquid bipropellant system
- d) A sodium hydroxide seeding system
- e) A water coolant system for supplying coolant to the liquid rocket combustion chamber.

Figure 3 shows the air storage tanks and the regulation and metering system for supplying air to the experimental apparatus. High-pressure air from the tanks first passed through a pressure regulator, then through an orifice-type flow meter, and finally to the air heater on the test stand. The connection to the air heater was made through four, flexible, 1-inch hoses mounted normal to the thrust axis.

The air heater, mounted on the thrust stand, consisted of a gas turbine burner can housed in a 9-inch duct. Fuel for the air heater, RP-1, was supplied by a pressure-fed system. The combustion process in the air heater consumed 9 to 14 percent of the available oxygen in the air stream. Oxygen depleted by combustion in the heater was not replenished. This was not judged to be of primary importance in that the mixture ratio in the secondary combustor provided several hundred percent theoretical air. All theoretical comparisons accounted for the actual chemistry in any event. The principal attribute of the vitiated air stream of importance in the secondary combustion process would probably be the water and CO_2 produced in the air heater, rather than the depleted oxygen content.

Ignition of the fuel in the air heater was achieved by means of a methane-oxygen torch which operated continuously during a run. The gas feed system for the igniter torch is also shown in Figure 3.

The liquid bipropellant system supplied propellants under pressure to the bipropellant valve on the test stand. The propellants were pressurized with nitrogen from the pressurization system of the laboratory.

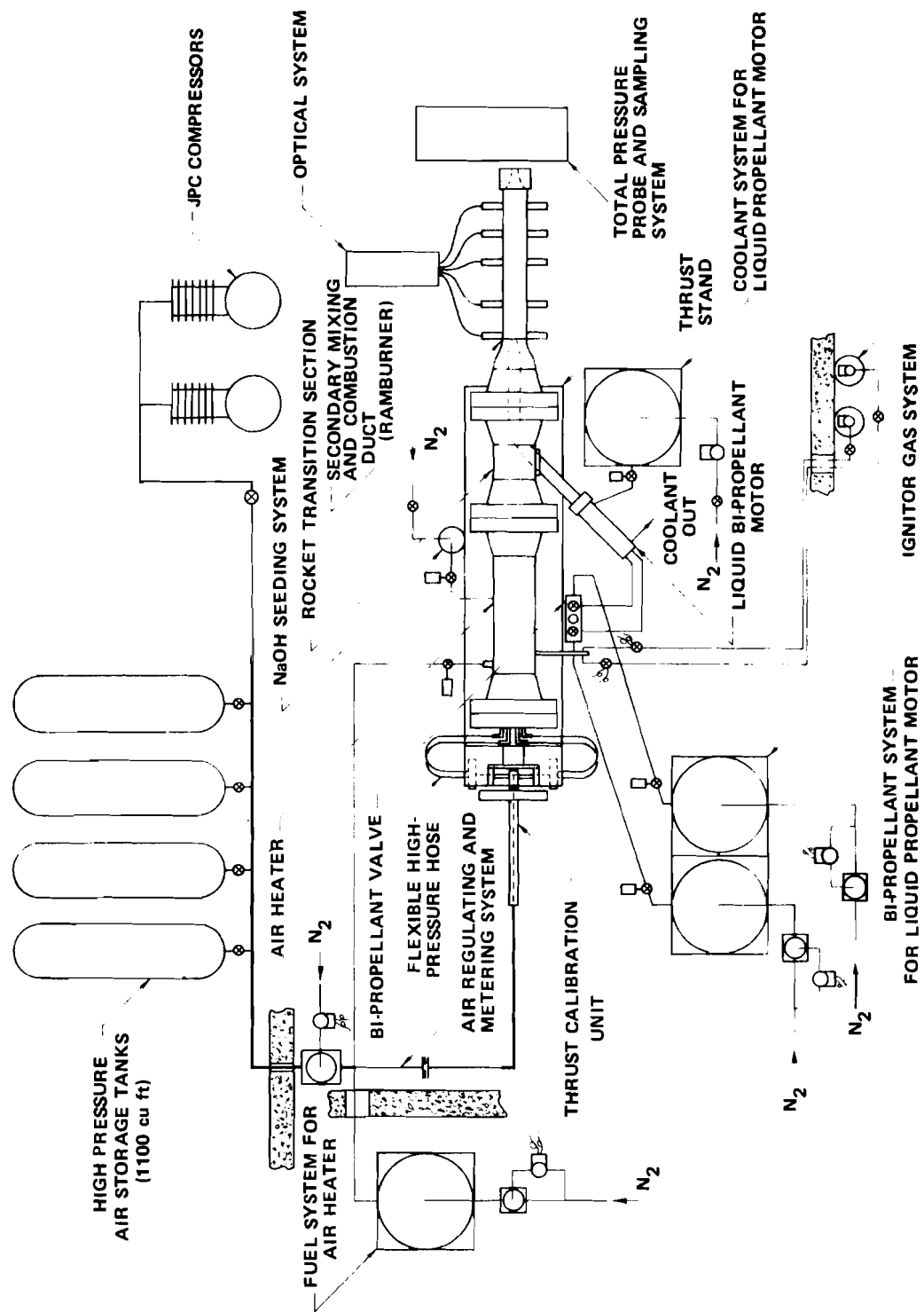


Figure 3. Schematic Diagram of the Flow Systems

The air heater, rocket section, test section, and much of the plumbing and instrumentation were mounted on the thrust stand, the details of which may be found in Reference [2].

Two modifications were made on the basic system described in Reference [2]. The first modification consisted of changing the air orifice instrumentation to extend the measurement capability to a higher range, allowing the air flow rate to be increased from the original maximum of 15 lb_m/sec to a new maximum of 25 lb_m/sec. The second modification was the installation of a backpressure plate downstream from the heater section. This was found to be necessary to maintain stable combustion in the air heater at the higher air flow rates.

1. Test Section

Figure 4 illustrates the design of the test sections employed in this series of runs. Three different test sections of this design were employed. They provided a constant area flow passage for the ram-burner mixing and combustion processes. The ducts were uncooled for the run periods of interest in the investigation. Table I presents a list of the dimensions of the three test sections. All of the ducts had a nominal length/diameter ratio of 10. The only exception to the design illustrated in Figure 4 was for the largest duct. That deviation involved the addition of a 10-inch extension to the entrance end of the test section. To compensate for the increased duct length, the rocket exhaust pipe was also lengthened 10 inches resulting in essentially no change in the configuration of the ramburner. The extension of this duct was made to accommodate hardware designed for use in other experiments. For ducts A and B, the distance from the beginning of the constant area section to the exit plane of the primary nozzle was approximately 1.5 inches.

Table I. Test Section Dimensions

Duct	Inside Diameter (in.)	Effective Length* (in.)	Wall Thickness (in.)	Duct Material (Type)**
A	3.78	38.3	0.375	347
B	4.79	47.0	0.375	347
C	6.50	65.0	0.500	321

*Length from primary nozzle exit plane to entrance of the ramburner nozzle.

**Stainless steel type.

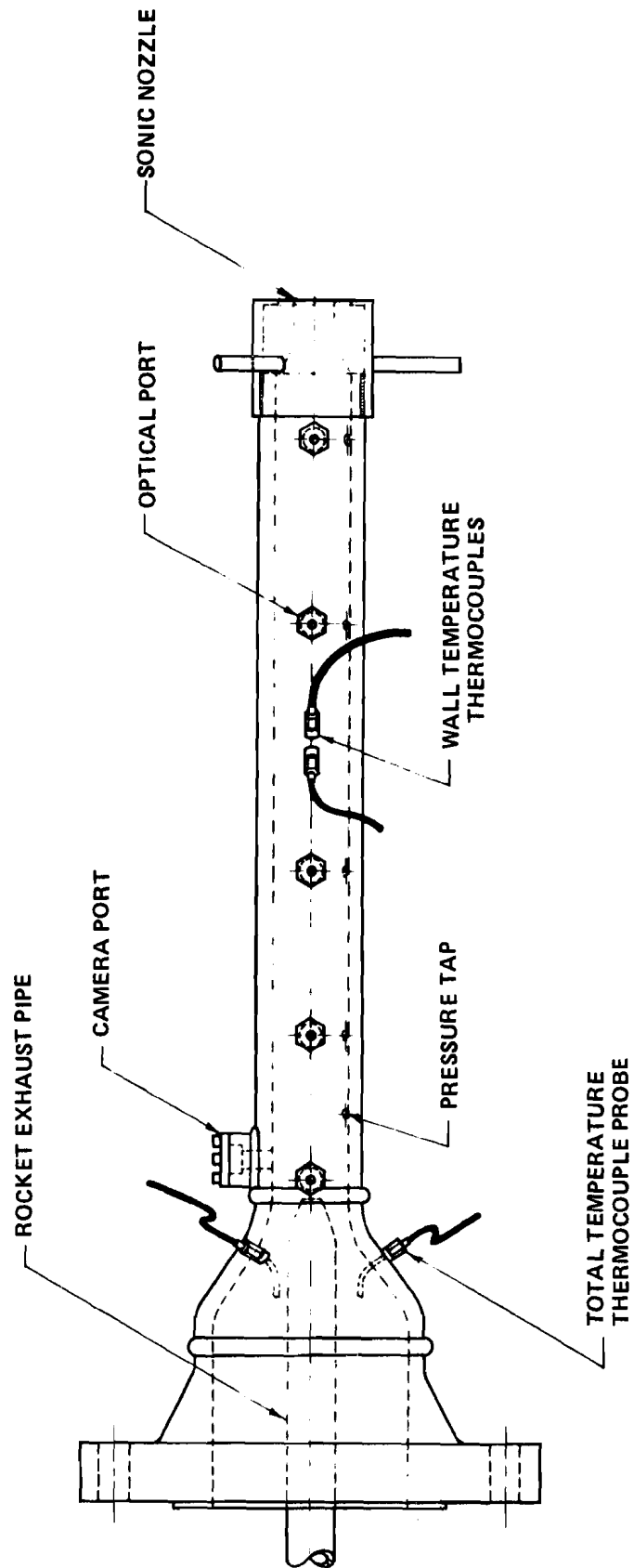


Figure 4. The Test Section

Wall static pressure taps were situated at the locations $x/D = 1, 2, 4, 7$, and 9 ; x is the distance measured downstream from the exit plane of the rocket nozzle, and D is the diameter of the ramburner duct. The optical ports were situated at the locations $x/D = 0, 2, 4, 7$, and 9 . A complete description of the optical ports and the system used in making radiation measurements may be found in Reference [2]. The ramburner wall temperatures were measured at the location $x/D = 5$.

Design computations for the ducts were made by means of an equilibrium thermochemistry program assembled for general usage in the research program [3]. This program was also used to obtain the throat dimensions for the rocket and ramburner nozzles. The ramburner nozzles were long-radius, sonic nozzles designed in accordance with the recommendations of Reference [4]. All of the nozzles were fabricated with carbon inserts held in place by a threaded retaining collar, facilitating replacement of the inserts.

2. Bipropellant Rocket

The primary rocket employed during this series of runs was a bipropellant rocket using liquid propellants; the oxidizer was nitrogen tetroxide and the fuel was Aerozine-50. Figure 5 illustrates the rocket chamber, the blast tube, and the nozzle. A modified Lark motor was employed for the rocket chamber using water as a coolant. The normal operating chamber pressure of the primary rocket was 300 psig. The blast tube, fabricated of type 347 stainless steel, was operated uncooled. The overall length of the blast tube was 35-1/8 inches; it had an inside diameter of 1.5 inches and a wall thickness of 0.438 inch. The radius of curvature of the bend in the blast tube was 12 inches. The resulting L^* for the primary rocket was 100 to 120 inches depending upon the nozzle throat diameter. Nozzles for the primary rocket were sonic nozzles fabricated with carbon inserts in a stainless steel retaining sleeve. The sonic nozzle provided an approximate pressure match with the air stream entering the ramburner when the air stagnation pressure was 175 psia. For the runs at a lower air stagnation pressure, the air static pressure did not match the pressure of the exhaust from the primary rocket. The sonic rocket exhaust stream was underexpanded.

3. Instrumentation and Procedures

a. Instrumentation

Table II lists the measurements recorded during each of the experimental runs. The type of transducer utilized and the recording device employed are listed in Tables III and IV for each measurement, along with the channel designation.

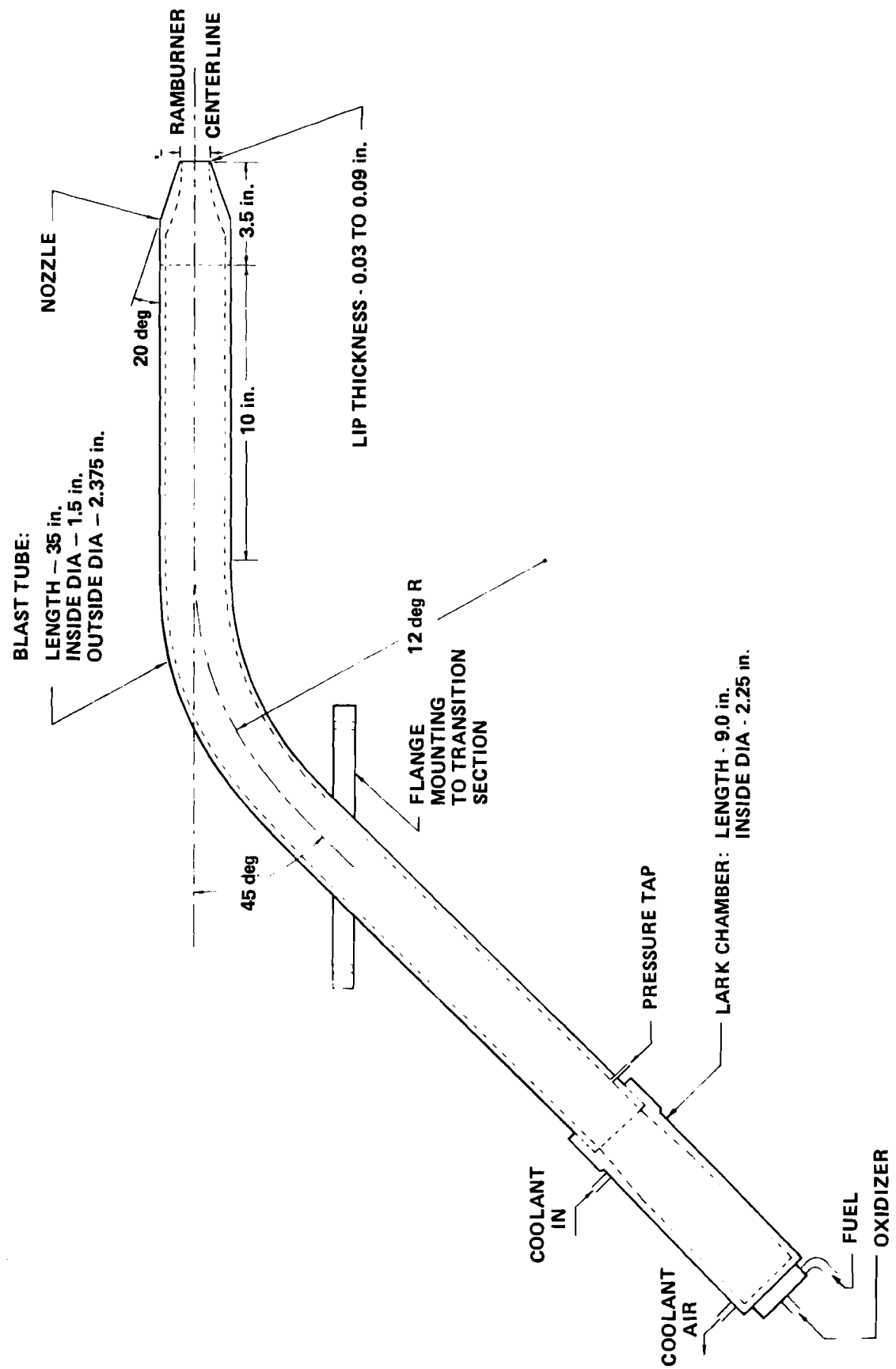


Figure 5. Bipropellant Rocket and Blast Tube Arrangement

Table II. Measurements Made During a Run

P_{ox}	Rocket oxidizer tank pressure
P_f	Rocket fuel tank pressure
$\dot{w}_{ox}$	Rocket oxidizer flow rate
$\dot{w}_f$	Rocket fuel flow rate
P_c	Rocket chamber pressure
P_{hf}	Heater fuel tank pressure
$\dot{w}_{hf}$	Heater fuel flow rate
P_{ao}	Pressure upstream of the air orifice
ΔP_{ao}	Pressure change across the air orifice
T_{ao}	Air temperature downstream of the air orifice
P_{sa}	Stagnation pressure in the rocket transition section
P_{inj}	Air stream static pressure at $x/D = 1$
ΔP_1	Pressure change in the ramburner from $x/D = 1$ to 2
ΔP_2	Pressure change in the ramburner from $x/D = 2$ to 4
ΔP_3	Pressure change in the ramburner from $x/D = 4$ to 7
ΔP_4	Pressure change in the ramburner from $x/D = 7$ to 9
T_{sa}	Stagnation temperature in the rocket transition section
$T_{11, 2, 3}$	Air stagnation temperature at the ramburner entrance
T_{ow}	Ramburner outside wall temperature at $x/D = 5$
T_{iw}	Ramburner inside wall temperature at $x/D = 5$
P_{sj}	Exhaust jet stagnation pressure at the nozzle exit plane
F	Gross thrust
I_{1-5}	Emitted radiation intensity at optical ports 1 through 5

Table III. Recording Devices Employed for the Various Measurements

Channel	Measurement	Visicorder	Strip Chart	Magnetic Tape
1	ΔP_{ao}	×	×	×
2	ΔP_4	×		×
3	P_{inj}	×		×
4	P_{hf}		×	×
5	P_c	×		×
6	P_{sa}	×	×	×
7	P_{ao}	×	×	×
8	ΔP_1	×		×
9	ΔP_2	×		×
10	ΔP_3	×		×
11	P_f		×	×
12	P_{ox}		×	×
13	F	✓		✓
14	T_{I1}			✓
15	T_{I2}			×
16	T_{I3}			×
17	$\dot{w}_f$		×	✓
18	$\dot{w}_{ox}$		×	✓
19	$\dot{w}_{hf}$	✓		✓
20	P_{sj}			✓
	T_{iw}		×	
	T_{ow}		×	
	T_{ao}		×	
	I_{1-5} (stepped)	×		

Table IV. Transducers Employed for the Measurements

Channel	Measurement	Transducer	Model	Serial	Operating Range
1	ΔP_{ao}	Statham	PM280TC	5116	0 to +10 psid
2	ΔP_4	Statham	PM280TC	5113	0 to ± 100 psid
3	P_{inj}	Taber	217	671043	0 to 200 psig
4	P_{hf}	Taber	206	662582	0 to 1000 psig
5	P_c	Taber	206	662585	0 to 1000 psig
6	P_{sa}	Taber	206	662660	0 to 1000 psig
7	P_{ao}	Taber	206	662583	0 to 1000 psig
8	ΔP_1	Statham	PM280TC	5112	0 to ± 10 psid
9	ΔP_2	Statham	PM280TC	5115	0 to ± 10 psid
10	ΔP_3	Statham	PM280TC	5114	0 to ± 10 psid
11	P_f	Taber	206	662581	0 to 1000 psig
12	P_{ox}	Taber	206	662584	0 to 1000 psig
13a	F	BLH	C3-P1	50686	0 to 1000 lb _f
13b	F	BLH	C3-P1	42860	0 to 2000 lb _f
14	T_{I1}	Fabricated	CA		-300 to 1800°F
15	T_{I2}	Fabricated	CA		-300 to 1800°F
16	T_{I3}	Fabricated	CA		-300 to 1800°F
17	w_f	Potter	1/2-3/90	PURD-1/2-3	0.5 to 9 gpm
18	w_{ox}	Potter	1/2-3/90	PURD-1/2-2	0.5 to 9 gpm
19	w_{hf}	Brooks	FLF-8-	6711-82129	0.06 to 0.5 gpm
20	P_{sj}	Taber	206	67143	0 to 300 psig

(1) Bipropellant Rocket System. Measurements associated with the bipropellant rocket system were the oxidizer and fuel tank pressures, the oxidizer and fuel flow rates, and the rocket chamber pressure. The rocket chamber pressure was not measured directly in the chamber but rather 3 inches downstream from the chamber in the rocket blast tube. This was required because a pressure tap could not readily be placed through the water coolant jacket of the chamber or through the injector. The chamber pressure measurement was corrected for the reduction in diameter between the chamber and the exhaust pipe and the resulting increase in flow velocity at the point of measurement, the correction being on the order of 2 percent.

(2) Air Flow and Heater System. The air flow rate was measured by means of an air orifice. A Daniel Simplex Orifice Plate Holder using flange taps with appropriate orifice plates of concentric design was employed. The orifice meter installation was designed as prescribed in Chapter 4 of the ASME Power Test Codes [4]. The pressure upstream of the air orifice, the pressure drop across the orifice, and the upstream air temperature were measured. The pressure drops for all of the run conditions were within the recommended limits for acceptable accuracy for the given beta ratio (ratio of the orifice diameter to the pipe diameter) of the orifice. The air temperature was measured with a chromel-alumel thermocouple in the early runs but this was later changed to iron-constantan to make the chromel-alumel data channel available for other purposes. The pertinent design factors and the dimensions of the orifice plates employed are listed in Section II.3.b(4).

Fuel (RP-1) was supplied to the air heater by means of a pressure fed system, the flow rate of which was measured by means of a turbine flow meter. During several of the runs, it was found that the sudden pressure rise in the air heater due to ignition in the ramburner caused oscillation in the heater fuel flow which in turn gave rise to a questionable measurement of the fuel flow rate. For subsequent runs, an orifice was placed in the fuel line and the fuel tank pressure was increased to provide the appropriate flow rate. This eliminated the oscillations.

(3) Rocket Transition Section. The rocket transition section contained instrumentation necessary to monitor the air temperature and to measure the air pressure during a run. The air temperature was sensed by means of a deep well chromel-alumel thermocouple and was displayed on a strip chart as a means of observing the air temperature before ignition of the primary rocket. A static pressure tap was installed in the transition section. This pressure measurement and the calculated air velocity in the section (on the order of 100 fps) were employed to obtain the stagnation pressure of the heated air entering the ramburner.

(4) Test Section. Instrumentation was provided in the test section to measure the static pressure of the air at the duct inlet, the static pressure distribution along the length of the duct, the stagnation temperature of the air entering the ramburner, and the inside and outside wall temperatures at the mid-point of the test section (ramburner).

The inlet air stagnation temperature was measured by means of three chromel-alumel temperature probes of the Pratt and Whitney type. The temperature probes were located at the position $x/D = -1.5$ (upstream from the exit plane of the primary nozzle) for ducts A and B and at the position $x/D = -2.2$ for duct C. The temperature probes were positioned approximately 2 inches from the duct wall. The temperature recovery factor was simply assumed to have a value of one; the estimated actual value was extremely close to unity for the operating conditions. The three recorded temperatures were averaged to provide a measure of the bulk stagnation temperature of the air entering the ramburner.

The inside and outside wall temperatures of the ramburner duct were measured by means of chromel-alumel thermocouples. The outside wall thermocouple was staked on the outside wall while the inside wall thermocouple was placed in a well drilled in the wall from the outside. The bottom of the well was 0.03 inch from the inside surface of the ramburner.

The differential pressure measurements, employed to obtain the distribution of static pressure along the ramburner duct, presented special problems because the magnitude of the static pressure change between any two adjacent taps appeared to be of the same order of magnitude as the random fluctuations in the ramburner. The connecting lines from the taps to the transducers were damped to enable the recording of a mean signal. The earlier runs were made with the lines damped with a fibrous material. Maximum acceptable damping was obtained when sufficient material was used to cause a delay of 0.2 to 0.3 second in reaching a steady state value. Between runs, however, the damping material was found to absorb moisture and swell so that the response time became too long, necessitating the replacement of the damping material before each run. To avoid this problem, the fibrous material was replaced with a length of stainless steel hypodermic tubing which was silver soldered into the center of the line. The length of the hypodermic tubing was adjusted until the line had a response time of approximately 0.2 second. This damping method tended to allow the passage of higher frequency oscillations, but did not change with time.

For this series of runs, the differential pressure transducers employed to measure the pressure distribution were mounted on the thrust stand with the transducer diaphragms lying perpendicular to the thrust direction. Upon completion of the run series, it was revealed that one of the transducers was sensitive to vibration when mounted in this position. Data obtained from that transducer were suspect. To determine the

magnitude of the error, the transducers were remounted so that the transducer diaphragms were parallel to the thrust direction. Two additional runs were then made. Those runs indicated that the data obtained from the sensitive transducer during the previous runs were inaccurate. This inaccuracy was shown by the fact that only in the cases rerun did the computed final static pressure approximately match the final static pressure obtained from the given measurements. In all of the original runs, the measured final static pressure was higher than that calculated thus indicating that the transducer sensitive to the vibration failed to measure the pressure drop in the first section of the ramburner. The cases rerun indicated that the pressure drop measured by the vibration sensitive transducer should have been lower by 1 to 4 psi, the magnitude of the correction being dependent upon the inlet stagnation pressure.

Five pairs of diametrically opposed optical ports were positioned along the duct to enable observation of the radiation due to either emission from or transmission through the gases in the ramburner. A system for introducing small amounts of sodium hydroxide into the air stream in the air heater section was provided. It was felt that an indication of the progress of the combustion in the ramburner could then be obtained by observing the variation along the duct of the sodium line radiation intensity.

The design of the optical port is described in detail in Reference [2]. Quartz windows were employed in the design. The ports were purged with nitrogen to keep the windows free of contaminants. Calibrations before and after runs with the air heater and the liquid bipropellant rocket showed no measurable contamination of the windows.

For the emission observations, optical fiber bundles were fitted to the ports on one side of the test section. They conducted the visible radiation to an optical switching device which transmitted the radiation to a photomultiplier (PM) tube. Between the output of the optical switch and the PM tube, the radiation passed through a neutral density filter with 10 percent transmittance in the visible spectrum. The voltage output of the PM tube was then recorded, indicating a measure of the relative light intensity at the window.

(5) Thrust Stand. The air heater, bipropellant rocket, transition section, and the test section were mounted on the thrust stand. A strain gauge load cell was employed to measure the gross thrust of the complete system. Felt padding was applied to the rear flexures of the stand to damp the thrust oscillations which were found to occur during a run.

(6) Additional Measurements. An additional measurement recorded during these runs was the stagnation pressure profile of the ramburner exhaust jet. The measurement was taken 1/16 inch downstream from the sonic nozzle of the ramburner by means of a traversing probe. It was found, however, that the rise time of the probe was too long for the allowed traverse time and thus the data obtained from this system were inaccurate. A modification was made to the probe to correct this situation for subsequent runs. This modification consisted of drilling out the pressure tap in the probe from 0.0625 to 0.0935 inch thus lowering the rise time of the probe from approximately 0.1 second to approximately 0.03 second as compared to the traverse time of the probe of approximately 1.5 seconds. Reference [2] contains a complete description of the original probe system.

b. Calibration Procedures and Estimated Accuracy

One of the objectives of this series of runs was to obtain data of known reliability, notably efficiencies of the several systems. The physical measurements were intended to be accurate to within a proximately ± 1 percent of full scale. While the goal of approximately ± 1 percent accuracy may not be the best obtainable accuracy, it is representative of the accuracy usually obtainable in cases where exceptionally elaborate calibration methods are not available. In an attempt to achieve the desired accuracy, much time was spent in calibrating the instrumentation and in determining possible sources of error in each measurement. As a general policy, all the instruments, except as noted below, were calibrated immediately prior to each run and each instrument was checked for drift immediately after the run. Normally no instrumentation drift was detectable after the run.

A typical link between a strain gauge transducer and the digital recorder is shown in Figure 6. The electrical leads from the transducer were connected to the test cell junction box. Power was supplied to the transducer by a range and balance unit appropriately connected to the transducer via the cell junction box connection. The output signal of the transducer was connected through the cell junction box to a patch board in the control room. The signal was patched through a amplifier, the output of which passed to the digital recorder. The signal conditioning chain from the transducer to the recorder was calibrated by applying a known reference signal from a Power Design Model 2005 precision power supply to the transducer connection and comparing it with the signal recorded on the digital recorder. The known input signal was varied from 0 to 50 millivolts, the highest voltage being above the maximum output signal for any of the transducers.

The previous description of the signal conditioning chain also holds for the thermocouple channels except that the range and balance unit would be replaced by a temperature reference junction. For the flowmeter channels, the signal from the transducer was fed directly to a

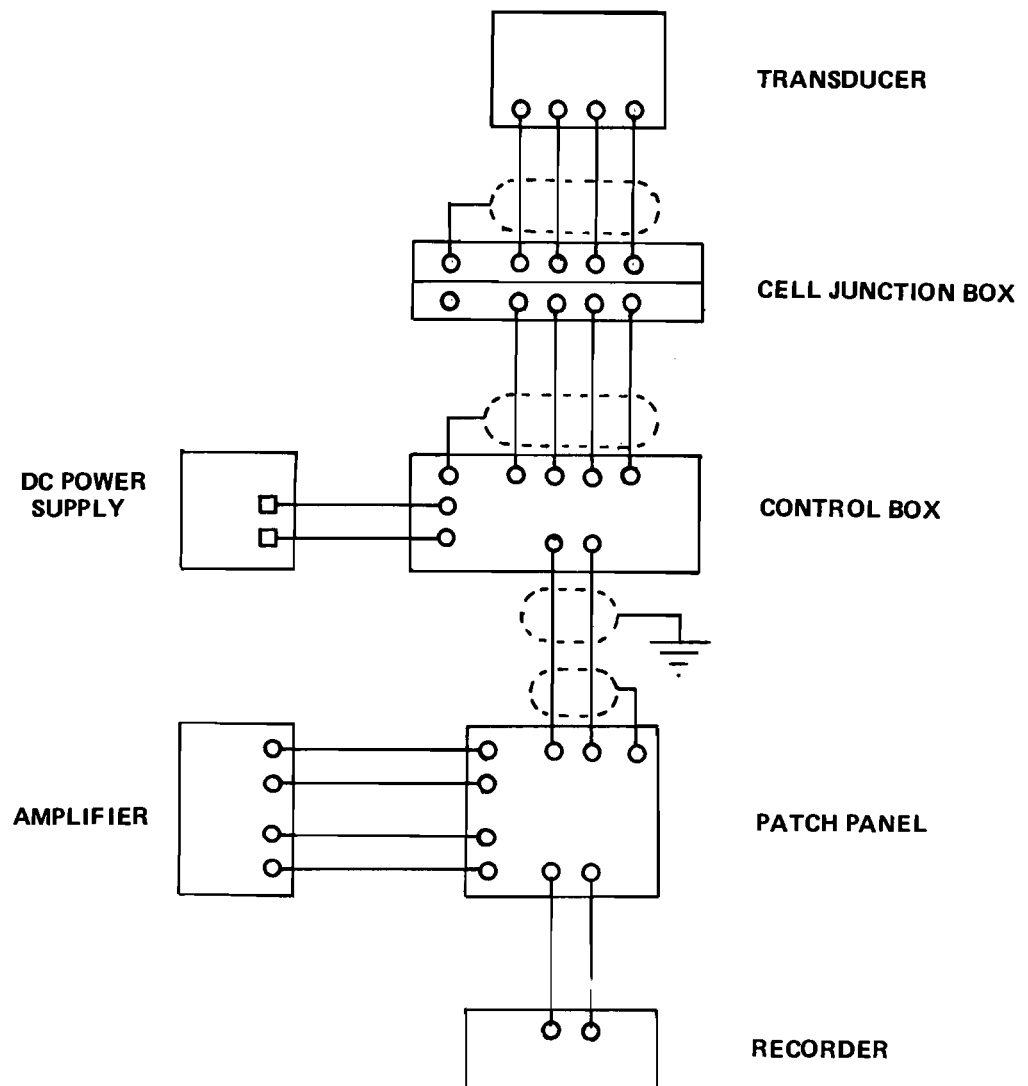


Figure 6. A Typical Signal Conditioning Chain

frequency-to-voltage converter unit. This output voltage signal was then patched into the digital recorder. The thermocouple signal conditioning chain was calibrated by applying a known millivolt signal to the thermocouple input leads and following the same procedure as previously discussed. The flowmeter chain was calibrated by applying a signal of known frequency from a Hewlett-Packard Model 200AB signal generator to the transducer connection leads and comparing the voltage output recorder on the digital tape with the design voltage output of the signal converter unit for the given input frequency.

The following paragraphs contain a complete description of the procedures for calibrating each particular measurement device along with an estimate of the accuracy expected from each measurement

(1) Pressure Measurements. Calibration of the gauge pressure transducers was accomplished by means of an Ashcroft Type 1305 dead-weight tester. Before the calibrations were performed, the signal conditioning and recording equipment was turned on and allowed to warm up for at least 1 hour. After the system had warmed up, the transducer signal was displayed on the digital display unit of the analog-to-digital converter unit (four digits plus sign). The fourth digit on the display indicated thousandths of volts. Normal amplifier gain used with these transducers was 100. The analog-to-digital converter unit doubled the signal so that a 1-millivolt signal would normally be displayed as 0.200 volt. The maximum transducer output was 30 millivolts, corresponding to a maximum signal to the digital tape of 6 volts. That was below the maximum allowable signal to the digital tape of 10 volts.

To begin the calibration of a transducer, with no load on the transducer, the balance unit was adjusted until a zero signal was obtained from the transducer as read on the digital display. The maximum load was then placed on the transducer by means of the dead-weight tester. In all cases where the dead-weight tester was used, the weights on the tester were pumped up to a point midway between the lower and upper stops and then the weights were spun in order to avoid static friction in the tester unit. When the signal from the transducer was steady at the maximum load condition, the range unit was adjusted so that the maximum signal was between 4 and 6 volts. The load was removed from the transducer and the zero was again checked. This was repeated as necessary until the transducer range and balance were properly adjusted.

The calibration range of each transducer was selected to be from 0 psig to a value 50 to 100 percent above the expected operating pressure on the transducer. The dead-weight tester was then employed to apply pressure at four to six equal increments over the calibration range with the voltage output manually recorded from the digital display unit. These calibration values were subsequently punched on cards for use with the data reduction computer program.

The repeatability, i.e. hysteresis, of the gauge pressure transducers was assumed to be that published by the manufacturer, ± 0.25 percent. The manufacturer's statement of the static accuracy of the dead-weight tester was assumed to be correct; the figure was ± 0.1 percent. The maximum measured error in the signal conditioning chain for strain gauge transducer channels was ± 0.4 percent. All pressure taps were designed in accordance with the recommended procedures given in Reference [4]; no source of inaccuracy associated with the actual taps were presumed.

The uncertainty in the gauge pressure measurements was computed from the methods outlined in Reference [6], assuming all instrumentation had zero bias and that the transducer hysteresis reported by each manufacturer was based on 30 or more calibration points. Under these assumptions, the measurement uncertainty associated with a level of confidence of 95 percent may be computed from

$$U_{95} = \pm 2s = \pm 2 \sqrt{s_i^2} \quad (\text{II-1})$$

where s is the precision index of the system and s_i is the precision index* of each component contributing to the measurement error. From Equation (II-1), the computed uncertainty at a 95-percent confidence level was computed to be ± 1.0 percent of the full scale reading. This measurement uncertainty for the gauge pressure transducers, along with the measurement uncertainties computed for the other instruments are given in Table V. Full scale values for each transducer are listed in Table IV.

The differential pressure transducer employed with the air flow orifice meter was calibrated in the same manner as the gauge pressure transducers. In this case, however, both sides of the transducer (pressure rise and pressure drop) were calibrated with respect to atmospheric pressure, a positive voltage being associated with a pressure drop and a negative voltage being associated with a pressure rise. The manufacturer's statement of transducer repeatability was ± 1.0 percent so that, using the cited accuracy for the dead-weight tester and the signal conditioning chain, the computed uncertainty for this transducer was ± 2.2 percent.

*The precision index, s_i , is defined as the statistical standard deviation of each component based on the number of calibration points minus one.

Table V. Estimated Measurement Uncertainties

A. <u>System Errors</u>		
1. Signal conditioning equipment for strain gauge transducers		= ± 0.40 percent
2. Signal conditioning equipment for flowmeters		= ± 0.15 percent
3. Signal conditioning equipment for thermocouples		= ± 0.80 percent
4. Dead-weight tester		= ± 0.10 percent
5. Heise Gauge (estimated)		= ± 0.10 percent
6. Load cell weights		= ± 0.50 percent
B. <u>Transducer Errors</u>		
1. Gauge pressure transducers		= ± 0.25 percent
2. Differential pressure transducer on the ramburner		= ± 0.40 psid
3. Differential pressure transducer for the air orifice		= ± 1.0 percent
4. Load cell		= ± 0.1 percent
5. Flowmeters		= ± 0.50 percent
6. Ramburner thermocouples		= ± 0.75 percent
7. Air orifice thermocouple		= ± 0.90 percent
C. <u>Expected Accuracy of Instrumentation (at the 95 percent confidence level)</u>		
1. Gauge pressure transducers		= ± 1.0 percent
2. Differential pressure transducers on the ramburner		= ± 0.5 psid
3. Differential pressure transducers for the air orifice		= ± 2.2 percent
4. Load cell		= ± 1.3 percent
5. Flowmeters		= ± 1.0 percent
6. Pratt and Whitney type thermocouples		= ± 2.2 percent
7. Air orifice thermocouple		= ± 2.4 percent
8. Ramburner wall thermocouples		= ± 2.2 percent

The range and balance settings for the differential pressure transducers associated with the test section were adjusted in the same manner as previously described. However, in this case, a Heise Gauge was used in calibrating the transducers instead of the dead-weight tester. This was necessary because of the small range (± 10 psid) over which each transducer was calibrated. The transducers were calibrated such that a negative voltage output was associated with a pressure drop and a positive voltage output associated with a pressure rise. The estimated accuracy of the Heise Gauge was ± 0.1 percent. During this series of runs, the transducers employed were operated over only approximately 10 percent of their maximum rated range. Therefore, instead of using the transducer hysteresis stated by the manufacturer for the complete range of the transducer, the actual hysteresis for the range used was measured. The maximum resulting precision index for the transducers was ± 1.7 percent of full scale. Because only 8 calibration points were used to measure the hysteresis, the coefficient in Equation 11-1 becomes 2.306 rather than 2.0 as shown in Reference [6]. Therefore, the maximum measurement uncertainty for the ram burner differential pressure transducers was computed to be ± 4.0 percent of full scale or ± 0.40 psid. As was discussed previously, the connecting lines to these transducers were damped during a run. Runs 22 through 31 were performed using the fibrous material damping. With this method, the magnitude of the pressure oscillations recorded were as much as ± 3 psid about the indicated mean pressure difference when the mean value was determined over a time interval of 0.1 second. The ± 3 psid oscillations were recorded on two runs only (22 and 30). The other runs between 22 and 31 exhibited oscillations on the order of ± 1 psid around the mean value. Runs 41 through 44 were made with the hypodermic tubing as the damping device. For this damping method, the oscillations recorded were a maximum of ± 0.7 psid around the mean value. Changing the time period over which the mean value was determined from 0.1 to 0.05 second resulted in a maximum change in the average value of ± 0.4 psid; the variation appeared to be random with the particular set of points averaged. With these factors recognized, it was felt that the mean differential pressure measurements could be taken to be accurate to within ± 0.5 psid.

(2) Thrust Measurement. A strain gauge type load cell was employed to measure the gross thrust of the system. The signal conditioning chain was similar to that for the gauge pressure transducers, differing only in that the electrical leads from the load cell were not connected through the cell junction box, but rather ran continuously to the control room patch panel. The load cell was positioned such that with no flow through the system, a preload of approximately 75 pounds was applied to the load cell. This was done to assure firm contact between the thrust stand and the load cell. The load cell range and balance unit was then adjusted so that a zero reading was obtained from the cell under this preload condition.

The thrust transducer was calibrated by applying known weights to a 10 to 1 advantage lever which, in turn, forced the thrust stand against the load cell. The lever application device is described in Reference [2]. The load cell was calibrated approximately every 200 pounds up to its maximum load. It was found that the load cell was linear throughout the calibration range. On two runs (30 and 31) it was found that the measured thrust exceeded the calibration range by 12 and 25 percent, respectively. To ensure that a linear extrapolation of the calibration data would provide the proper thrust value, the load cell was recalibrated to 150 percent of its normal calibration range. It was found that the load cell did maintain its linearity at this maximum overload condition.

It was found that when the primary rocket ignited, the sudden increase in thrust, in effect, pulsed the thrust stand and caused it to ring; that is, the thrust measurement tended to oscillate about a mean value. These oscillations were cyclic, at approximately 12 Hz, with rather weak damping. Due to the short run duration of the primary rocket, the oscillations were not completely damped before the run ended. Felt padding was applied to the rear flexures of the stand in an effort to further damp the oscillations. This succeeded in decreasing the amplitude of the oscillations but did not terminate the oscillations altogether in the run period. Care was taken to account for the oscillations in the thrust readings in the data reduction procedure.

The manufacturer's statement of the repeatability of the load cell was ± 0.1 percent. The accuracy of the load cell signal conditioning chain was again ± 0.4 percent. The estimated accuracy of the calibration weights and the lever applicator was ± 0.5 percent. Thus from Equation (II-1) the computed measurement uncertainty of the thrust reading was ± 1.3 percent of full scale. No significant loss of accuracy could be attributed to the ringing of the thrust stand when proper mean values were determined.

(3) Liquid Flow Rates. The liquid flow rates were measured by means of turbine flowmeters. The flowmeters were calibrated by the manufacturer by flowing water through the flowmeter at 24 different rates over the range of the flowmeter and counting the total number of cycles the turbine made in passing a known amount of water. The average number of cycles required to pass 1 gallon of water was then computed; the factor was termed the flowmeter K-factor. This factor was accurate to within ± 0.5 percent over the full range of the flowmeter.

Following the same calibrations procedure as the manufacturer, the flowmeters were recalibrated before installation. It was found that the manufacturer's K-factor was more accurate than that determined at this laboratory and thus the manufacturer's K-factor was used for all flowmeters. The specific gravity of the various fluids was measured by means of a hydrometer. The flow rate through the turbine flowmeter was then calculated from Equation (A-1) of Appendix A.

The accuracy of the K-factor for the turbine flowmeter was ± 0.5 percent over the range tested. The measured accuracy of the signal conditioning chain for the flowmeters was ± 0.15 percent. Therefore, the computed measurement uncertainty of the turbine flowmeters could be estimated at ± 1.0 percent.

(4) Air Flow Rate. The air orifice meter probe was not calibrated. Rather, the computation of the air flow rate was made in accord with the relation given in Reference [4] and repeated in Appendix A, Equation (A-2). The straight entrance pipe to the air orifice was bored to an inside diameter of 1.939 inches for a distance of 30 pipe diameters. The downstream pipe section was held at the same diameter for a distance of 18 pipe diameters. A complete description of the air orifice installation may be found in Reference [2]. An orifice plate diameter of 1.360 inches was employed throughout the series of runs reported herein.

As described in Reference [7], the accuracy of the air orifice meter was expected to be within ± 2 percent exclusive of uncertainties in the transducer measurements.

(5) Temperature Measurements. The three Pratt and Whitney type probes used to measure the stagnation temperature of the air entering the ram burner were made from Aeropack stainless steel sheathed chromel-alumel wire manufactured by Aero Research Instrument Company, Inc. The stated tolerance for the thermocouple wire was $\pm 4^\circ\text{F}$ up to 530°F and $\pm 3/4$ percent above 530°F . The stated tolerances were assumed to be correct and no calibration of the thermocouples was performed. No corrections for heat conduction along the leads or for differences between the junction temperature and the gas temperature was considered. These thermocouples were used with a reference junction at 32°F . The temperatures associated with the thermocouple measurements were evaluated from the standard thermocouple tables given in Reference [8]. The measured accuracy of the thermocouple signal conditioning chain was ± 0.8 percent. The computed measurement uncertainty under the conditions previously stated was ± 2.1 percent of the measured value.

The thermocouple employed to measure the temperature of the air at the air orifice meter was a simple, exposed junction thermocouple made from iron-constantan thermocouple wire. This thermocouple was used with a 150°F reference junction. The temperature associated with the thermocouple measurement was evaluated from the thermocouple tables given in Reference [9]. The tolerance of the thermocouple wire was ± 0.9 percent at the conditions used, thus the measurement uncertainty was ± 2.4 percent of the measured value.

The thermocouples for measurement of the ramburner wall temperatures were simple, exposed junction thermocouples made from chromel-alumel thermocouple wire having a tolerance of ± 0.75 percent. It was assumed that the temperature of the junction was the temperature of the wall. These thermocouples were used with the reference junction at 32°F and the temperatures were evaluated using the tables given in Reference [8]. The information from these thermocouples were recorded on strip charts only. The accuracy of the strip charts was ± 0.25 percent. The computed measurement uncertainty of these temperature measurements was ± 2.2 percent of the measured value.

(6) Optical Measurements. A complete description of the optical measurement system may be found in Reference [2]. For each run, the recorded intensity values were corrected in accord with calibration data and were normalized with respect to the highest value occurring at the five ports. No attempt was made to relate the relative radiation intensities between runs, nor to obtain further information from the data.

To prepare the optical system for a run, a current of 30 amperes was applied to an uncalibrated tungsten strip lamp for a period of not less than 30 minutes. The power supply to the PM tube was set at 750 volts. A 1-percent and a 10-percent neutral density filter were placed in front of the PM tube. Then one optical fiber bundle was exposed to the lamp and the gain of the PM tube amplifier was adjusted to give an output of 1 volt. The output of the optical system was recorded on a visicorder. One by one, the other optical fiber bundles were exposed to the lamp and the output from each was recorded. Because the transmissivity of the fiber bundles varied between bundles, the recorded calibration outputs were used to adjust the run measurements for the variance in transmissivity between the optical fiber bundles. A similar technique was employed to measure the relative transmissivity of the quartz windows. In this case, a single fiber bundle was exposed to this the lamp and the output of the PM tube was recorded. One by one, each quartz window was placed between the end of the fiber bundle and the PM tube and the output of the PM tube was again recorded. The ratio of the PM tube output with the window in place to the PM tube output without the window in place was taken as the transmissivity of the window. The sensitivity of the optical system was such that no differences between the transmissivities of the quartz windows could be detected. For the runs reported, the 1-percent neutral density filter was removed, leaving only the 10-percent neutral density filter in place.

(7) Summary. Table V lists the expected accuracy of each measurement under the previously described assumptions. Care was taken to insure proper installation and use of the various measurement and recording devices. It is felt that the stated accuracies are reasonable and within the measurement uncertainties that might be expected from such a facility not equipped with exceptional calibration

devices required to obtain a high degree of precision in the various measurements. Note that it was not possible to reach the desired goal of ± 1 -percent accuracy in all cases. This was due in part to the doubling factor incurred in the analog-to-digital converter unit which doubled the error of the signal conditioning chain and could not be avoided. Given these measurement uncertainties, Section V presents a discussion of the expected accuracy to which the combustion efficiency of the various systems could be computed.

c. Run Procedure

The procedure for making a run was as follows. All instruments were turned on and allowed to warm up for a minimum of 1 hour before calibrating the various transducers. All of the instruments and transducers were then calibrated according to the procedures outlined previously and the ambient temperature and pressure were recorded. As actual firing of the bipropellant rocket was controlled by an automatic sequencer unit, an automatic sequence was executed and any timing adjustments to set the firing durations of the primary rocket were made before loading the propellant tanks.

With the propellant tanks still empty, the tanks were pressurized with nitrogen and the tanks and propellant lines were checked for leaks. The propellant tanks were then loaded. Each tank had an 18-gallon capacity; however, no more than approximately 6 gallons were loaded in each tank so that a large enough volume remained in the tank to ensure that a large pressure excursion would not be experienced when the bipropellant valve was opened. A small pressure was then applied to each tank and the propellant lines were filled up to the bipropellant valve. Next, the methane and oxygen pressures for the air heater ignitor were set, the pressure in the rocket coolant tank was set, the hydraulic pressure in the exhaust jet probe drive unit was set, and the nitrogen flow to the optical ports was initiated.

All recording devices were then rechecked for proper operation and all transducers were checked for drift. When all systems were judged to be operating satisfactorily, the bipropellant tanks and the air heater fuel tank were pressurized. The air flow was then initiated, the heater ignitor was turned on, and the heater fuel flow was initiated. After ignition of the air heater, the air flow rate was increased to the desired value and the pressure in the heater fuel tank was adjusted so that the heater produced the desired air temperature. The output of the thermocouple located in the transition section was displayed on a strip chart to facilitate this operation.

After ensuring the proper operation of the air heater, all recording devices were initiated from a single switch. After a quick check of the recording devices to ascertain their proper operation, the automatic

sequence unit was triggered. That unit, in turn, controlled the firing of the primary rocket, caused the exhaust probe to traverse the jet, and caused the propellant lines to be purged after the shutdown of the primary rocket. Approximately 3 to 5 seconds after shutdown of the primary rocket, the recording devices were stopped, the heater fuel valve closed, and the heater ignitor turned off. The air flow was maintained for approximately 1 additional minute to cool down the system.

After all propellant tanks were vented and the air flow stopped, the instrumentation was checked for any drift of the zero points. The system was then visually checked for any visible signs of system malfunctions and the optical port windows were recalibrated as was done before the run as a check for contamination which may have occurred during the run. No detectable contamination was ever found on the windows following a run. All data obtained from the run were then collected from various recorders and prepared for data reduction as described in Section III.

Section III. DATA REDUCTION

The data for each run were either in binary form on magnetic tape or were recorded directly on strip chart recorders. Table III presented a listing of the principal measurements showing the recording devices employed for each and Table IV listed the pertinent information for each transducer. In Addition to the measurements listed in Table III, calibration data, barometric pressure, and ambient temperature were recorded for each run. Those data, together with certain thermochemical property information and coded instructions, were processed to yield the run performance results by means of a computer program developed for that purpose. The data recorded on magnetic tape were employed in the data reduction procedure in preference to those recorded on strip charts because of the difficulty in reading the strip chart data compared with the higher accuracy available with the analog-to-digital sampling system.

1. Run Data and Auxiliary Data

Transducer signals to be recorded on the magnetic tape were sampled sequentially at a rate of 4000 samples per second by means of a multiplexer unit. Thus, each of the 20 data channels was sampled at a rate of 200 per second. The sampled signals were processed by an analog-to-digital converter where the signal amplitudes were doubled and coded in the form of four digit numbers plus the decimal point and sign. The resulting signals were then recorded in binary form on the magnetic tape in a block length of 262 binary words.

Several temperature measurements and the PM output for the optical measurements were recorded only on chart-type instruments, as indicated in Table III. Points on those records at the times during the run selected for data reduction were read and punched on cards for use with the data reduction program. The time base could be determined with sufficient accuracy for this purpose from the known instrument speeds. All instruments were started simultaneously by means of a single switch.

Calibration data for each transducer were punched on cards. Normally six points spanning the anticipated range for the measurement were provided. Measurements of the nozzle throat diameters before and after each run were also provided in punched card form.

The thermochemical data provided included designation of the chemical species to be considered for each aspect of the thermochemical computations together with the relevant thermodynamic property data for those species.

The coded instructions prepared for each run included the designation of the points during the run period to be analyzed, the number of points to be averaged for the analysis, and a number of instructions regarding program options. A complete description of the input card deck for the program may be found in Appendix C together with related user information.

2. Data Reduction Procedure

A flow diagram for the data reduction program is presented in Figure 7. The ordering of the steps in the data reduction process is essentially sequential, as indicated in Figure 7. Thermochemistry routines for use in various parts of the procedure were incorporated in the program. The principal aspects of the data reduction procedure related to the interpretation of the measurements are described as follows. Appendix A contains a detailed description of the relations employed for the computations performed by the program. A complete listing of the program, including notes on the subroutines is compiled in Appendix B. The program was coded in Fortran IV and was arranged to be run on a CDC 6500 computer with the MACE system using the FUN compiler.

Two points during each run period were selected for data reduction purposes. Referring to Figure 8, a trace of the primary rocket chamber pressure signal, those points were labeled DATAB and DATAD. DATAB corresponded normally to a time approximately 1/2 second before ignition of the primary rocket. DATAD corresponded to a point during the rocket firing normally chosen to be late in the steady state portion of the chamber pressure trace.

As a preliminary step in the data reduction procedure, it was necessary to unpack the binary tape data with an IBM 7094 computer, converting the data to BCD form, to make it compatible with standard input format for the CDC 6500. A program for that purpose also sorted the data into files for each data channel. Data on the original binary tape prior to TIMEO (Figure 8), approximately 2 seconds before the rocket firing, and after TIMEF, approximately 2 seconds following termination of the rocket firing, were discarded. The BCD tape consisting of a series of files of data arranged sequentially with time in each file, served as the input data for the computations by the CDC 6500. The data in that form were also copied on a master tape for retention.

The first step in the data reduction procedure was to average the signal voltages about the points selected for analysis. Provisions were included in the program to average up to 10 adjacent points on both sides of the selected point, at the discretion of the user. The averaging involved fitting a straight line through the data by a least squares method. The results reported herein were averaged using 7-9 points

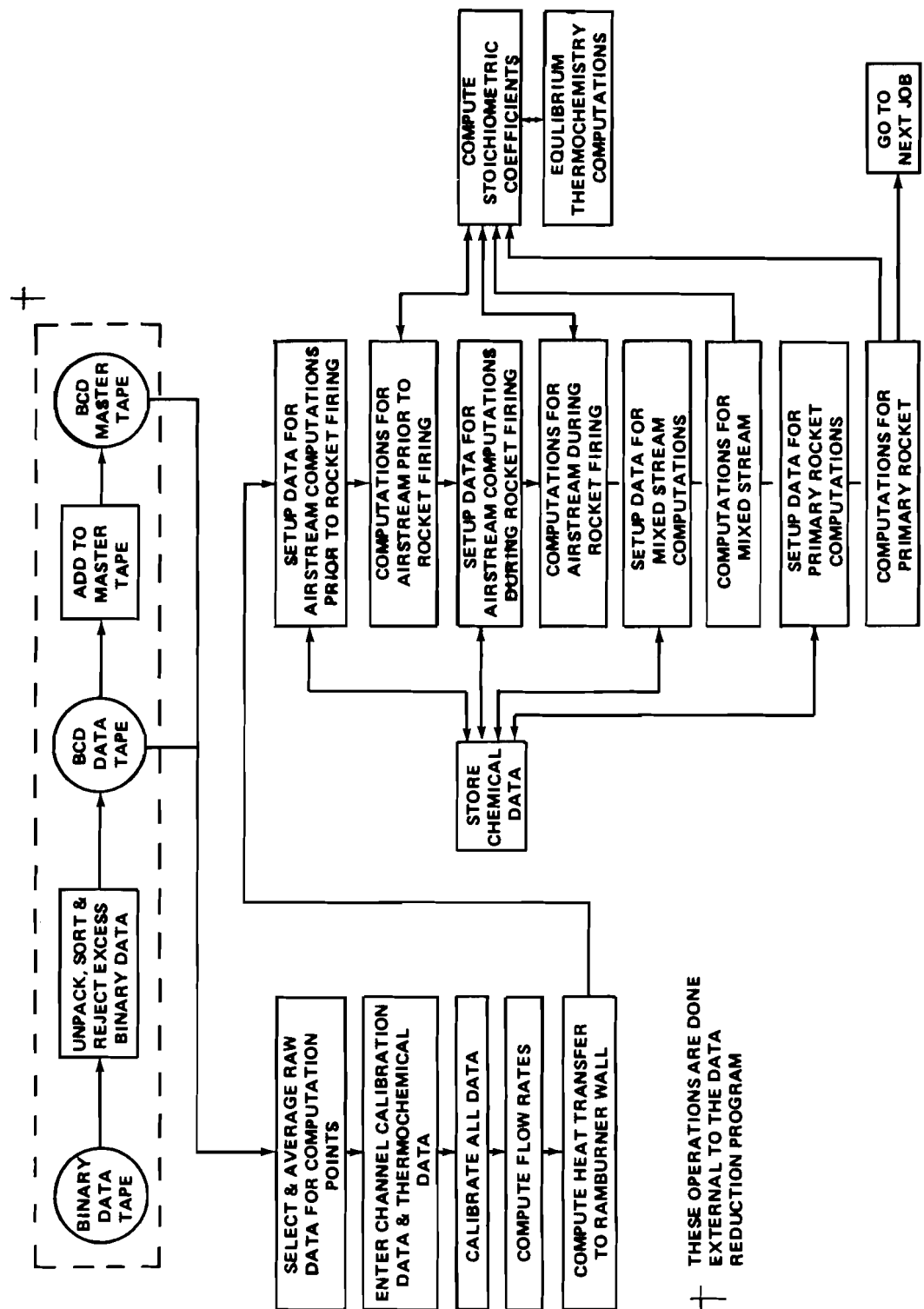


Figure 7. Flow Diagram of the Data Reduction Program

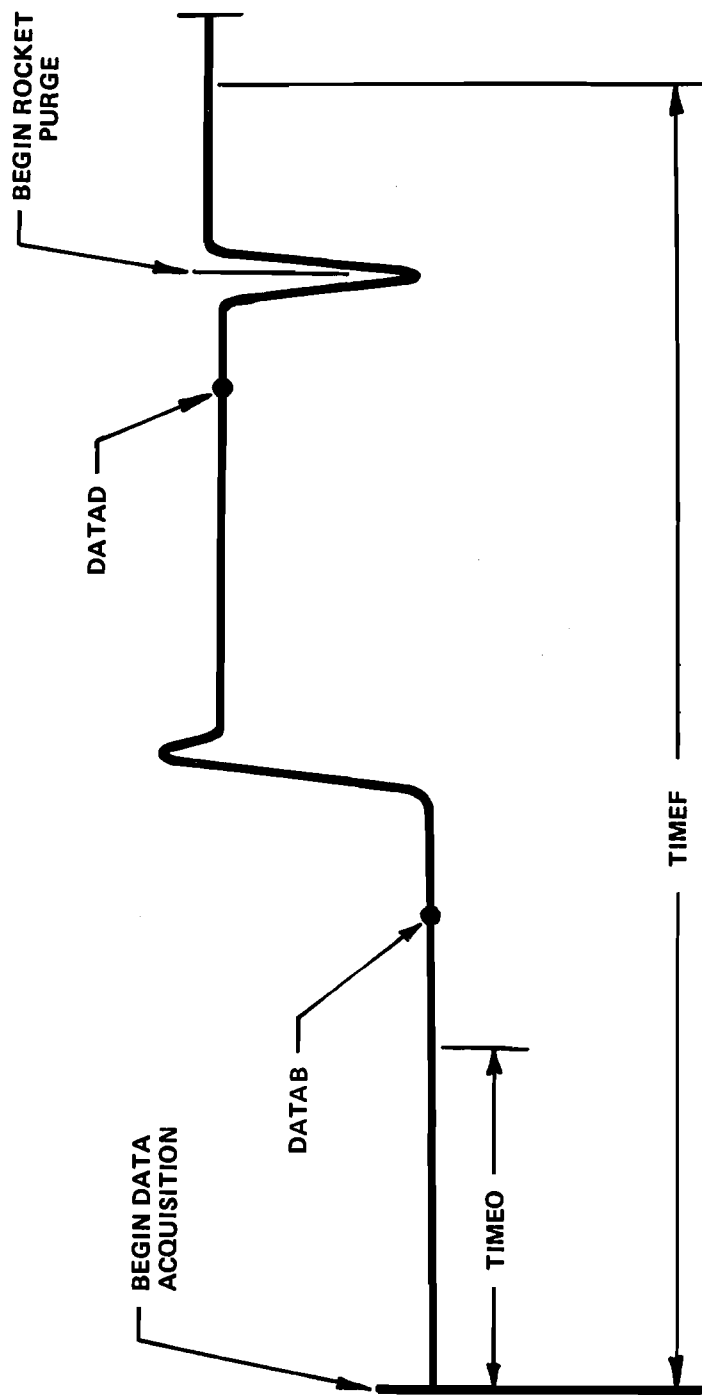


Figure 8. Data Reduction Points with Reference to a Typical Primary Rocket Chamber Pressure Measurement

corresponding to ± 70 -90 milliseconds, on each side of the point selected during the run.

The measured value on each channel obtained from the tape at the two points of analysis together with the measured data provided on punched cards were converted to physical values employing the calibration data. Each measured signal was compared with the tabular calibration data for the measurement under consideration. When the table scan yielded points on either side of the measured value, an interpolation function (a parabola) was generated and used to determine the appropriate physical value. Most of the measurements were handled in this manner. The calibration data for the thermocouples consisted of a tabular listing of standard reference tables [8, 9] stored in the program. An exception was the turbine flowmeter data for which the calibration was presumed to be linear as recommended by the manufacturer. The calibration routine included provisions for signals outside the range of the calibration data. A message indicating that circumstance would be printed in the output and an extrapolated value obtained by means of a parabola fitted to the closest three calibration points would be generated. The only instances where extrapolation was necessary in the run data reported herein were for Runs 30 and 31 where the thrust exceeded the calibration range. For those cases, the calibration curves were straight lines and recalibration, well above the measured values, showed linear calibration curves, as mentioned in Section II.

Following the calibration transformation, several preliminary computations were made by the program. From the measured physical variables (pressure, temperature, etc.) the air flow rate, absolute pressures and temperatures, average air temperature at the inlet of the ramburner, stagnation pressure of the air in the transition section, flow rates of the fuel and oxidizer for the ignitor, and the flow rate of the seeding NaOH solution were computed. In addition, several computations employing tank pressures and approximate calibrations for the line pressure drops were made to determine the liquid flow rates, as auxiliary checks on the values measured with transducers. Computations employing the inner and outer wall temperatures were also made to estimate the rate of heat transfer to the ramburner duct. Routines for the computation of the propellant flow rate for the solid propellant primary rocket were included at this point. They were simply bypassed, of course, for the liquid propellant firings. The details of the computations may be found in Appendix A.

Interpretation of the measured data in terms of the combustion performance and the evaluation of the consistency of the different measurements were handled as follows. Thermochemistry computations were performed to construct tables of solutions covering a narrow range of conditions for a given run, centered about the measured parameters. A matrix of 25 stagnation (chamber) solutions at 5 assigned values of stagnation pressure and 5 assigned value of stagnation temperature were obtained and stored. Five stagnation solutions corresponding to assigned

values for stagnation pressure and stagnation enthalpy were also computed and stored. The latter served as reference (ideal) values. For each stagnation solution, four equilibrium expansion solutions were normally computed, corresponding to choking conditions and three assigned expansion pressures, covering conditions in the ramburner duct. All computations assumed equilibrium thermochemistry and that the proportions of the chemical substances entering the system were those corresponding to the relative measured flow rates for the run. The gas dynamic relations employed were for one-dimensional flow. Three separate sets of tables were prepared for each run to analyze; the heated air flow immediately prior to the rocket firing, the complete system during the rocket firing, and the rocket alone. The performance of the air heater during the rocket firing was computed directly from the measured air stagnation temperature and pressure. The product species considered for the liquid propellant runs reported herein were N_2 , O_2 , H_2O , CO_2 , NO , OH , CO , H_2 , and H .

The thermochemical solutions computed and stored in the program for each run were employed as follows.

a. Heated Air Flow Prior to the Rocket Firing

For these conditions, only the air flow, air heater fuel flow, ignitor propellant flows, and the NaOH solution flow (if applicable) were present. The program initially determined the points in the matrix of stagnation solutions (pressure versus temperature) for which the theoretical mass velocity for choked flow* was equal to the measured value and fitted a quadratic polynomial curve to those points by means of a least squares method. The same was done for the thrust per unit area for choked flow, including the pressure term at the exit plane of the sonic nozzle. Three independent measures of the stagnation state could thus be obtained:

- 1) Direct measurement of the stagnation pressure
- 2) Measurement of the stagnation pressure and the measured mass velocity for choked flow
- 3) Measurement of the thrust and the mass velocity choked flow.

For each independent set of measurements, computations were included to determine what values of the other measurements should have occurred if the two independent measurements were correct. Comparisons between the different solutions could provide a measure of the consistency of the

*For all calculations, the nozzle discharge coefficients were simply assumed to have a value of 1.0. The actual discharge coefficients, from Figure 10 of Reference [3] were approximately 0.98 - 0.99.

measurements immediately prior to the rocket firing. For comparison purposes, the solution obtained employing the measured stagnation pressure and the ideal stagnation enthalpy (depending on the relative proportions of chemical substances entering the system) were taken as the ideal reference solution. Combustion efficiencies were evaluated for the air heater system employing the reference solution and treating the combustion inefficiency as a simple heat loss. No distinction was made between actual heat losses and incomplete combustion in the analysis of the data. A brief discussion of the definition of combustion efficiency is included at the end of this section and in Appendix A.

b. Heated Air Flow During the Rocket Firing

For the flow entering the ramburner during the rocket firing, the measurements of the stagnation pressure and temperature were the principal sources defining the stagnation state. A check was also provided by employing the measured mass velocity of the air at the ramburner inlet and the measured static pressure at that location. Thermochemistry computations for the measured stagnation pressure and temperature were made to determine the mass velocity as a function of pressure in the range corresponding to the ramburner inlet conditions. Given the measured mass velocity, the theoretical inlet static pressure could be compared with the measured value.

c. Complete System During the Rocket Firing

In a manner similar to that discussed for the airstream prior to the rocket firing, two measures of the stagnation state of the combustion products in the ramburner could be obtained:

- 1) Measurement of the thrust per unit area and the mass velocity for choked flow
- 2) Measurement of the static pressure in the ramburner just upstream from the exhaust nozzle and the mass velocity for choked flow.

An additional estimate of the stagnation state could be obtained by equating the stream thrust entering the ramburner with that at the downstream end, neglecting wall friction, given the measured mass velocity in the duct and a measure of the efficiency of the rocket combustion process alone. A separate computation accounting for an estimated rate of heat loss based on the measured wall temperatures was also made.

d. Rocket

The only measure of the stagnation state of the rocket combustion products obtained during a run was that computed from the measured stagnation pressure, together with the flow rates of the propellants (yielding the mass velocity for choked flow). Calibration runs with the secondary duct removed and with no air flow were also made, providing a thrust measurement as well as the chamber pressure, to evaluate performance by an independent means for representative run conditions.

e. Combustion Efficiency

The reference value chosen for comparison with the actual combustion performance was the ideal, adiabatic rise in sensible enthalpy of the matter of the combustion process. The ideal sensible enthalpy rise corresponds to the heat which would be released if the reactants were to react at constant pressure, reaching the equilibrium state in an adiabatic system, and if the products were to be cooled at constant pressure and at frozen composition to the initial temperature of the reactants. That is, the initial and final chemical enthalpies are expressed as

$$\begin{aligned}
 H_{\text{reactants}} &= \sum_j \text{propellants} n_j H_{j,T_{\text{reactants}}} = \sum_j n_j H_{f,j,T_o} \\
 &\quad + \sum_j n_j \left(H_{j,T_{\text{reactants}}} - H_{j,T_o} \right) \\
 H_{\text{products}} &= \sum_i \text{species} n_i H_{i,T_{\text{prod.}}} = \sum_i n_i H_{f,i,T_o} \\
 &\quad + \sum_i n_i \left(H_{i,T_{\text{prod.}}} - H_{i,T_o} \right)
 \end{aligned}$$

where the n_i are the equilibrium mole fractions for the species at the temperature of the products $T_{\text{prod.}}$, and T_o is the reference temperature for the thermodynamic data.

The ideal heat release would be given by

$$\Delta H_{R_{ideal}} = \sum_j n_j H_{f_{j_{T_o}}} + \sum_j n_j \left(H_{j_{T_{reactants}}} - H_{j_{T_o}} \right) - \sum_i n_i H_{f_{i_{T_o}}} - \sum_i n_i \left(i_{T_{prod.}} - H_{i_{T_o}} \right) . \quad 1$$

If it is presumed here that all of the reactants enter at the same temperature and if that temperature happens to be T_o , then

$$\Delta H_{R_{ideal}} = \sum_j n_j H_{f_{j_{T_o}}} - \sum_i n_i H_{f_{i_{T_o}}} .$$

The combustion efficiency is defined as

$$\eta_c = \Delta H_R / \Delta H_{R_{ideal}}$$

where ΔH_R is the observed rise in sensible stagnation enthalpy determined from the experimental measurements. Given the evaluation of the experimental stagnation state as discussed previously, the observed sensible enthalpy rise ΔH_R may be evaluated by the thermochemistry routines for use in computing the combustion efficiency. For all the runs presented, $\Delta H_{R_{ideal}}$ was calculated using the measured air orifice temperature for the air and 298°K for the liquid propellants. The reference temperature, T_o , for the air stream calculations and the complete system calculations was chosen to be the measured air temperature at the air orifice. For the primary rocket calculations, T_o was chosen to be 298°K. The selection of 298°K as the temperature of the liquid propellants was made because the propellant temperatures were not measured, but they were kept in an inclosed area in which the temperature was approximately 298°K.

As with most definitions of combustion efficiency, the one previously described has shortcomings. The most obvious is that the efficiency is based on equilibrium thermochemistry which immediately contradicts the principal physical cause of combustion inefficiency.

That is, the combustion inefficiency is treated as a simple heat loss from the system. If the combustion efficiency is relatively high, that should not be a serious objection because the composition of the combustion gases will be nearly that given in the equilibrium computations. For the liquid bipropellant runs, the combustion efficiency could be expected to be reasonably high.

An alternative means for performing the computations, based substantially on the same experimental data, would be to single out one or two prime causes for the combustion inefficiency. For example, one might isolate the incomplete combustion of elemental boron (or one of its suboxides) as the prime cause. Then the computations could be made on the basis that different fractions of the one or two species remain chemically inert in the combustion process, yielding lower sensible enthalphy rises with the equilibrium values. Assuming the choice of frozen combustibles to be accurate, the energy balance based on the resulting composition of the combustion gases would be more accurate. The obvious drawback is in the not-so-obvious choice of combustible species to isolate as the prime factors retarding the approach to equilibrium. While this approach better represents the actual physics of the system, it requires specie information not normally available or easy to obtain.

As with other experimental programs, this program does not lead to direct evaluation of the ramburner performance, but rather obtains the performance of the ramburner from the performance of the system in its entirety and the performance of the components (rocket, air heater). The accuracy with which the performance of the ramburner may be obtained in this manner is compromised slightly as a consequence. Further discussion of this point is included in Section IV and the method of computing the ramburner efficiency is presented in Appendix A.

f. Program Output

The output of the data reduction program contained a list of the nominal run conditions, the makeup of each instrumentation channel, the calibration list for each channel, and a list of the propellants used together with data for the atomic and molecular species considered in the thermochemistry computations. At both the DATAB and DATAD points, the physical value occurring on each channel was presented along with the mean variation for each recorded variable. The air flow rate, flow rates of methane and oxygen, flow check results, and mean temperature of the air entering the ramburner were also presented. Next, the performance computations for the air heater at the DATAB point were presented. Following this, the performance calculations for the air heater, the complete system, and the primary rocket were presented. For each performance calculation, the results of the thermochemical calculations for each point in the respective solution matrices were presented along with each solution matrix. A further discussion of these matrices may be found in Appendix A.

Section IV. RESULTS FOR THE LIQUID PROPELLANT RUNS

This section contains the data obtained from the liquid propellant runs and the results of performance computations made for each run. A summary of the runs performed is presented in Table VI. Note that runs were made with the primary rocket operating both fuel rich ($O/F = 0.8$) and at nearly stoichiometric conditions ($O/F = 2.0$). The runs of primary interest were those with the primary motor operated under fuel rich conditions with secondary combustion in the ramburner. The runs with the stoichiometric primary rocket were to provide additional data for comparison with theoretical analyses and also to provide data for the optical measurements. Runs in the series which are not listed in Table VI were made to test hardware and instrumentation aspects of the facility for which complete sets of run data were not required.

1. Experimental Data

Tables VII through XX present the physical values obtained from the data for each run at the DATAB and DATAD points. Note again, that for each run, the value of each measurement is an average over a time interval of approximately 0.1 second. The temperature of the air at the orifice meter was always the same at the DATAB and DATAD points so that only one temperature is reported. The nozzle diameters reported are the diameters of the throats of the primary and secondary nozzles before and after the run. Table I contains the dimensions of the ramburner ducts. Measurements left blank were either not recorded or the particular instrumentation failed during the run. Values of ΔP_1 were estimated from the best available data as discussed previously and below.

It should be noted that for Runs No. 22, 26, and 28, a sizeable oscillation in the fuel flow rate to the air heater was experienced upon the initiation of secondary combustion in the ramburner. As mentioned in Section II, that peculiarity was attributable to the original fuel injector design. Modifications made in the fuel system eliminated the phenomena in subsequent runs.

Runs No. 31 through 44 were made with a backpressure plate installed downstream from the combustor in the transition section. Previous runs were made with no backpressure plate present. The backpressure plate was required to maintain stable combustion conditions in the air heater for the higher flow rates and lower pressures of the later runs.

During the last four runs (41 through 44) only one thermocouple was available to record the air stagnation temperature. This was due to

Table VI. Run Schedule

Run No.	O/F	P _c (psia)	Primary Nozzle Throat Diameter (in.)	A/P	P _{sa} (psia)	T _{inj} (°R)	Ramburner Nozzle Throat Diameter (in.)	Duct Diameter (in.)	Inlet Air Velocity (ft/sec)
18	0.71	319.0	0.819	--	--	--	--	--	--
19	1.85	322.0	0.866	--	--	--	--	--	--
22	0.84	322.0	0.817	5.22	175.0	1215.0	2.341	3.78	200.0
23	0.97	315.0	0.817	6.02	93.0	1223.0	3.238	3.78	425.0
26	2.36	299.0	0.868	4.92	165.0	1041.0	2.106	3.78	190.0
27	2.06	290.0	0.928	5.32	103.0	1161.0	2.857	3.78	370.0
28	2.20	309.0	0.847	8.12	156.0	1003.0	2.475	4.79	170.0
29	2.16	293.0	0.894	7.97	89.0	1040.0	3.418	4.79	330.0
30	0.79	319.0	0.817	9.04	182.0	1025.0	2.729	4.79	170.0
31	0.76	319.0	0.818	10.37	104.0	996.0	3.816	4.79	340.0
41	0.78	310.0	0.822	12.97	83.0	1074.0	4.601	6.50	305.0
42	0.78	318.0	0.822	12.96	166.0	1065.0	3.291	6.50	150.0
43	2.18	291.0	0.868	13.05	83.0	1048.0	4.250	6.50	310.0
44	2.02	274.0	0.932	12.05	166.0	1052.0	3.078	6.50	150.0

Table VII. Run 18 Data

Duct:						
Primary nozzle diameter:		0.819 in. before run 0.820 in. after run				
Secondary nozzle diameter:		-- in. before run -- in. after run				
Air temperature at the orifice meter		-- °R				
Ambient conditions:		533.0°R, 14.60 psia				
Duration of rocket firing:		3.22 sec				
Time from rocket ignition to DATAD:		2.72 sec				
Time prior to rocket igniton for DATAB:		-- sec				
<u>Run Data</u>						
Measured	DATAB	DATAD	Computed	Measured	DATAB	DATAD
P _{ox} (psig)	--	342.9		ΔP ₃ (psid)	--	--
P _f (psig)	--	512.0		ΔP ₄ (psid)	--	--
P _c (psia)	--	319.4		T _{I1} (°R)	--	--
P _{hf} (psig)	--	--		T _{I2} (°R)	--	--
P _{ao} (psia)	--	--		T _{I3} (°R)	--	--
ΔP _{ao} (psid)	--	--		F (lb)	--	198.0
P _{sa} (psia)	--	--		$\dot{w}_{ox}$ (lb/sec)	--	0.655
P _{inj} (psia)	--	--		$\dot{w}_f$ (lb/sec)	--	0.468
ΔP ₁ (psid)	--	--		$\dot{w}_{hf}$ (lb/sec)	--	--
ΔP ₂ (psid)	--	--	$\dot{w}_{O_2}$ (lb/sec)		--	--
			$\dot{w}_{CH_4}$ (lb/sec)		--	--
			$\dot{w}_{NaOH}$ (lb/sec)		--	--
			$\dot{w}_{air}$ (lb/sec)		--	--
Ramburner Wall Temperatures						
Time (sec)*	T _{IW} (°R)	T _{OW} (°R)	Remarks			
--	--	--	Fired rocket motor only with the ram-burner duct removed.			

*Timed from start of data acquisition.

Table VIII. Run 19 Data

Duct:						
Primary nozzle diameter:		0.866 in. before run 0.883 in. after run				
Secondary nozzle diameter:		-- in. before run -- in. after run				
Air temperature at the orifice meter:		-- °R				
Ambient conditions:		533.0°R, 14.60 psia				
Duration of rocket firing:		3.28 sec				
Time from rocket ignition to DATAD:		2.78 sec				
Time prior to rocket ignition for for DATAB		-- sec				
Run Data						
Measured	DATAB	DATAD	Computed	Measured	DATAB	DATAD
P _{ox} (psig)	--	402.9		ΔP ₃ (psid)	--	--
P _f (psig)	--	377.3		ΔP ₄ (psid)	--	--
P _c (psia)	--	321.7		T _{I1} (°R)	--	--
P _{hf} (psig)	--	--		T _{I2} (°R)	--	--
P _{ao} (psia)	--	--		T _{I3} (°R)	--	--
ΔP _{ao} (psid)	--	--		F (lb)	--	218.1
P _{sa} (psia)	--	--		$\dot{w}_{ox}$ (lb/sec)	--	0.723
P _{inj} (psia)	--	--		$\dot{w}_f$ (lb/sec)	--	0.394
ΔP ₁ (psid)	--	--		$\dot{w}_{hf}$ (lb/sec)	--	--
ΔP ₂ (psid)	--	--	$\dot{w}_{O_2}$ (lb/sec)		--	--
			$\dot{w}_{CH_4}$ (lb/sec)		--	--
			$\dot{w}_{NaOH}$ (lb/sec)		--	--
			$\dot{w}_{air}$ (lb/sec)		--	--
Ramburner Wall Temperatures						
Time (sec)*	T _{IW} (°R)	T _{OW} (°R)	Remarks			
--	--	--	Fired rocket motor only with the ram-burner duct removed.			

*Timed from start of data acquisition.

Table IX. Run 22 Data

Duct:	A					
Primary nozzle diameter:	0.817 in. before run 0.817 in. after run					
Secondary nozzle diameter:	2.341 in. before run 2.341 in. after run					
Air temperature at the orifice meter:	476.0°R					
Ambient conditions:	520.0°R, 14.53 psia					
Duration of rocket firing:	3.17 sec					
Time from rocket ignition to DATAD:	2.67 sec					
Time prior to rocket ignition for DATAB:	0.5 sec					
Run Data						
Measured	DATAB	DATAD	Computed	Measured	DATAB	DATAD
P _{ox} (psig)	349.1	343.5		ΔP ₃ (psid)	-0.26	0.65
P _f (psig)	470.1	454.8		ΔP ₄ (psid)	0.70	0.91
P _c (psia)	101.1	321.6		T _{I1} (°R)	1184.0	1214.0
P _{hf} (psig)	372.0	373.4		T _{I2} (°R)	1197.0	1216.0
P _{ao} (psia)	234.4	240.3		T _{I3} (°R)	--	--
ΔP _{ao} (psid)	95.6	56.7		F (lb)	490.0	904.1
P _{sa} (psia)	102.1	175.0		(lb/sec)		
P _{inj} (psia)	100.5	174.9		w _{ox}	0.000	0.480
ΔP ₁ (psid)	0.25	-5.50		w _f	0.000	0.571
ΔP ₂ (psid)	-0.09	0.48		w _{hf}	0.068	0.046
			w _{O2} (lb/sec)		0.007	0.007
			w _{CH4} (lb/sec)		0.005	0.005
			w _{NaOH} (lb/sec)		0.000	0.000
			w _{air} (lb/sec)		6.57	5.49
Ramburner Wall Temperatures						
Time (sec)*	T _{IW} (°R)	T _{OW} (°R)	Remarks			
4.68	763.0	749.0	No backpressure plate. Air heater fuel flow rate showed sharp oscillation upon pressure rise due to secondary combustion. T _{I3} amplifier unstable.			
5.26	785.0	750.0				
5.91	819.0	752.0				
6.56	868.0	757.0				
7.20	919.0	781.0				
7.85	961.0	817.0				

*Timed from start of data acquisition.

Table X. Run 23 Data

Duct:	A					
Primary nozzle diameter:	0.817 in. before run 0.817 in. after run					
Secondary nozzle diameter:	3.238 in. before run 3.238 in. after run					
Air temperature at the orifice meter:	475.0°R					
Ambient conditions:	520.0°R, 14.53 psia					
Duration of rocket firing:	3.29 sec					
Time from rocket ignition to DATAD	2.79 sec					
Time prior to rocket ignition for DATAB:	0.5 sec					
Run Data						
Measured	DATAB	DATAD	Computed	Measured	DATAB	DATAD
P _{ox} (psig)	345.5	339.6		ΔP ₃ (psid)	-0.63	-2.88
P _f (psig)	431.6	317.6		ΔP ₄ (psid)	0.34	0.12
P _c (psia)	47.1	315.4		T _{I1} (°R)	1210.0	1225.0
P _{hf} (psig)	365.3	366.0		T _{I2} (°R)	1202.0	1221.0
P _{ao} (psia)	216.1	216.2		T _{I3} (°R)	--	--
ΔP _{ao} (psid)	94.9	88.7		F (lb)	410.2	868.9
P _{sa} (psia)	51.5	92.5		(lb/sec)		
P _{inj} (psia)	45.4	89.9		$\dot{w}_{ox}$	0.000	0.498
ΔP ₁ (psid)	0.27	-2.50		$\dot{w}_f$	0.000	0.511
ΔP ₂ (psid)	-0.58	-2.43		$\dot{w}_{hf}$	0.072	0.068
				$\dot{w}_{O_2}$ (lb/sec)	0.007	0.007
				$\dot{w}_{CH_4}$ (lb/sec)	0.005	0.005
				$\dot{w}_{NaOH}$ (lb/sec)	0.000	0.000
				$\dot{w}_{air}$ (lb/sec)	6.21	6.08
Ramburner Wall Temperatures						
Time (sec)*	T _{IW} (°R)	T _{OW} (°R)	Remarks			
5.04	766.0	758.0	No backpressure plate. T _{I3} amplifier out.			
5.70	783.0	760.0				
6.36	810.0	766.0				
7.02	840.0	776.0				
7.68	884.0	796.0				
8.33	931.0	832.0				

*Timed from start of data acquisition.

Table XI. Run 26 Data

Duct:	A					
Primary nozzle diameter:	0.868 in. before run 0.868 in. after run					
Secondary nozzle diameter:	2.106 in. before run 2.106 in. after run					
Air temperature at the orifice meter:	473.0°R					
Ambient conditions:	5.20°R, 14.53 psia					
Duration of rocket firing:	3.81 sec					
Time from rocket ignition to DATAD:	3.31 sec					
Time prior to rocket ignition to DATAB:	0.5 sec					
<u>Run Data</u>						
Measured	DATAB	DATAD	Computed	Measured	DATAB	DATAD
P _{ox} (psig)	395.9	383.4		ΔP ₃ (psid)	0.03	0.76
P _f (psig)	336.7	327.7		ΔP ₄ (psid)	0.61	0.93
P _c (psia)	113.8	299.2		T _{I1} (°R)	1100.0	1132.0
P _{hf} (psig)	342.7	343.5		T _{I2} (°R)	1112.0	1148.0
P _{ao} (psia)	224.7	230.6		T _{I3} (°R)	1084.0	1115.0
ΔP _{ao} (psid)	86.7	56.2		F (lb)	453.9	699.9
P _{sa} (psia)	112.1	165.4		(lb/sec)		
P _{inj} (psia)	113.8	167.3		$\dot{w}_{ox}$	0.000	0.764
ΔP ₁ (psid)	0.18	-5.50		$\dot{w}_f$	0.000	0.324
ΔP ₂ (psid)	0.06	2.93		$\dot{w}_{hf}$	0.059	0.027
				$\dot{w}_{O_2}$ (lb/sec)	0.007	0.007
				$\dot{w}_{CH_4}$ (lb/sec)	0.005	0.005
			$\dot{w}_{NaOH}$ (lb/sec)	0.000	0.000	
			$\dot{w}_{air}$ (lb/sec)	6.20	5.35	
Ramburner Wall Temperatures						
Time (sec)*	T _{IW} (°R)	T _{OW} (°R)	Remarks			
9.16	784.0	786.0	No backpressure plate. Air heater fuel flow rate showed sharp oscillation upon pressure rise due to secondary combustion.			
9.92	791.0	787.0				
10.68	805.0	792.0				
11.44	819.0	799.0				
12.21	841.0	815.0				
12.97	864.0	832.0				

*Timed from start of data acquisition.

Table XII. Run 27 Data

Duct:	A					
Primary nozzle diameter:	0.928 in. before run 0.965 in. after run					
Secondary nozzle diameter:	2.857 in. before run 2.857 in. after run					
Air temperature at the orifice meter:	473.0°R					
Ambient conditions:	520.0°R, 14.53 psia					
Duration of rocket firing:	3.87 sec					
Time from rocket ignition to DATAD:	3.37 sec					
Time prior to rocket ignition for DATAB:	0.5 sec					
Run Data						
Measured	DATAB	DATAD	Computed	Measured	DATAB	DATAD
P _{ox} (psig)	393.8	381.0		ΔP ₃ (psid)	-0.36	1.41
P _f (psig)	348.4	340.0		ΔP ₄ (psid)	0.60	0.88
P _c (psia)	62.4	290.2		T _{I1} (°R)	1159.0	1165.0
P _{hf} (psig)	351.5	351.4		T _{I2} (°R)	1148.0	1157.0
P _{ao} (psia)	223.9	220.8		T _{I3} (°R)	1118.0	1124.0
ΔP _{ao} (psid)	97.1	89.2		F (lb)	451.5	812.5
P _{sa} (psia)	65.4	102.6		(lb/sec)		
P _{inj} (psia)	61.6	101.3		ḡ _{ox}	0.000	0.783
ΔP ₁ (psid)	0.40	-2.50		ḡ _f	0.000	0.380
ΔP ₂ (psid)	-0.22	0.94		ḡ _{hf}	0.069	0.066
			ḡ _{O2} (lb/sec)		0.007	0.007
			ḡ _{CH4} (lb/sec)		0.005	0.005
			ḡ _{NaOH} (lb/sec)		0.000	0.000
			ḡ _{air} (lb/sec)		6.42	6.19
Ramburner Wall Temperatures						
Time (sec)*	T _{IW} (°R)	T _{OW} (°R)	Remarks			
3.39	741.0	716.0	No backpressure plate. T _{I3} appears to be reading low.			
4.13	749.0	726.0				
4.88	752.0	740.0				
5.62	766.0	760.0				
6.36	780.0	783.0				
7.21	805.0	808.0				

*Timed from start of data acquisition.

Table XIII. Run 28 Data

Duct:	B					
Primary nozzle diameter:	0.847 in. before run 0.847 in. after run					
Secondary nozzle diameter:	2.475 in. before run 2.475 in. after run					
Air temperature at the orifice meter:	482.0°R					
Ambient conditions:	520.0°R, 14.53 psia					
Duration of rocket firing:	3.77 sec					
Time from rocket ignition to DATAD:	3.27 sec					
Time prior to rocket ignition for DATAB:	0.5 sec					
<u>Run Data</u>						
Measured	DATAB	DATAD	Computed	Measured	DATAB	DATAD
P _{ox} (psig)	387.7	377.4		ΔP ₃ (psid)	0.12	1.16
P _f (psig)	347.2	340.7		ΔP ₄ (psid)	1.08	2.25
P _c (psia)	108.5	309.3		T _{I1} (°R)	1013.0	1001.0
P _{hf} (psig)	394.8	395.1		T _{I2} (°R)	1007.0	1004.0
P _{ao} (psia)	305.1	307.8		T _{I3} (°R)	982.0	977.0
ΔP _{ao} (psid)	130.3	117.1		F (lb)	578.8	894.2
P _{sa} (psia)	107.2	155.8		(lb/sec)		
P _{inj} (psia)	107.3	157.5		$\dot{w}_{ox}$	0.000	0.710
ΔP ₁ (psid)	0.06	-5.50		$\dot{w}_f$	0.000	0.323
ΔP ₂ (psid)	0.19	1.62		$\dot{w}_{hf}$	0.067	0.052
				$\dot{w}_{O_2}$ (lb/sec)	0.007	0.007
				$\dot{w}_{CH_4}$ (lb/sec)	0.005	0.005
				$\dot{w}_{NaOH}$ (lb/sec)	0.000	0.000
			$\dot{w}_{air}$ (lb/sec)	8.64	8.39	
Ramburner Wall Temperatures						
Time (sec)*	T _{IW} (°R)	T _{OW} (°R)	Remarks			
4.20	706.0	677.0	No backpressure plate. Air heater fuel flow rate showed some oscillation upon pressure rise due to secondary combustion. T _{I3} appears to be reading low.			
4.95	714.0	682.0				
5.71	725.0	688.0				
6.46	738.0	696.0				
7.21	751.0	703.0				
7.97	765.0	715.0				

*Timed from start of data acquisition.

Table XIV. Run 29 Data

Duct:	B					
Primary nozzle diameter:	0.894 in. before run 0.962 in. after run					
Secondary nozzle diameter:	3.418 in. before run 3.418 in. after run					
Air temperature at the orifice meter:	481.0°R					
Ambient conditions:	520.0°R, 14.53 psia					
Duation of rocket firing:	3.81 sec					
Time from rocket ignition to DATAD:	3.31 sec					
Time prior to rocket ignition for DATAB:	0.5 sec					
<u>Run Data</u>						
Measured	DATAB	DATAD	Computed	Measured	DATAB	DATAD
P _{ox} (psig)	389.7	378.4		ΔP ₃ (psid)	-0.25	0.53
P _f (psig)	343.7	336.4		ΔP ₄ (psid)	1.31	1.01
P _c (psia)	59.4	293.1		T _{I1} (°R)	1012.0	1049.0
P _{hf} (psig)	496.2	499.7		T _{I2} (°R)	1003.0	1032.0
P _{ao} (psia)	314.7	315.1		T _{I3} (°R)	977.0	1003.0
ΔP _{ao} (psid)	136.6	136.7		F (lb)	556.4	941.1
P _{sa} (psia)	59.0	89.2		(lb/sec)		
P _{inj} (psia)	56.6	88.7		w _{ox}	0.000	0.770
ΔP ₁ (psid)	0.02	-2.50		w _f	0.000	0.357
ΔP ₂ (psid)	0.19	0.83		w _{hf}	0.081	0.081
				w _{O2} (lb/sec)	0.007	0.007
				w _{CH4} (lb/sec)	0.005	0.005
				w _{NaOH} (lb/sec)	0.000	0.000
			w _{air} (lb/sec)	8.97	8.98	
Ramburner Wall Temperatures						
Time (sec)*	T _{IW} (°R)	T _{OW} (°R)	Remarks			
4.16	799.0	765.0	No backpressure plate. T _{I3} appears to be reading low.			
4.92	806.0	759.0				
5.68	817.0	778.0				
6.45	830.0	787.0				
7.21	841.0	800.0				
7.97	850.0	812.0				

*Timed from start of data acquisition.

Table XV. Run 30 Data

Duct:	B					
Primary nozzle diameter:	0.817 in. before run 0.817 in. after run					
Secondary nozzle diameter:	2.729 in. before run 2.729 in. after run					
Air temperature at the orifice meter:	487.0°R					
Ambient conditions:	520.0°R, 14.53 psia					
Duration of rocket firing:	3.74 sec					
Time from rocket ignition to DATAD:	3.24 sec					
Time prior to rocket ignition for DATAB:	0.5 sec					
Run Data						
Measured	DATAB	DATAD	Computed	Measured	DATAB	DATAD
P _{ox} (psig)	342.3	335.6		ΔP ₃ (psid)	-0.16	0.37
P _f (psig)	485.0	467.1		ΔP ₄ (psid)	1.09	0.64
P _c (psia)	105.3	319.0		T _{I1} (°R)	1039.0	1023.0
P _{hf} (psig)	532.2	533.6		T _{I2} (°R)	1028.0	1026.0
P _{ao} (psia)	352.7	354.9		T _{I3} (°R)	1001.0	998.0
ΔP _{ao} (psid)	153.5	134.9		F (lb)	686.3	1206.0
P _{sa} (psia)	104.9	182.0		(lb/sec)		
P _{inj} (psia)	103.9	182.6		ṡ _{ox}	0.000	0.463
ΔP ₁ (psid)	0.07	-5.50		ṡ _f	0.000	0.596
ΔP ₂ (psid)	0.14	-0.29		ṡ _{hf}	0.082	0.075
				ṡ _{O2} (lb/sec)	0.007	0.007
				ṡ _{CH4} (lb/sec)	0.005	0.005
				ṡ _{NaOH} (lb/sec)	0.000	0.000
				ṡ _{air} (lb/sec)	9.99	9.62
Ramburner Wall Temperatures						
Time (sec)*	T _{IW} (°R)	T _{OW} (°R)	Remarks			
4.69	783.0	747.0	No backpressure plate. T _{I3} appears to be reading low.			
5.44	796.0	748.0				
6.18	815.0	758.0				
6.93	837.0	774.0				
7.68	855.0	786.0				
8.43	871.0	803.0				

*Timed from start of data acquisition.

Table XVI. Run 31 Data

Duct:	B					
Primary nozzle diameter:	0.818 in. before run 0.821 in. after run					
Secondary nozzle diameter:	3.816 in. before run 3.816 in. after run					
Air temperature at the orifice meter:	489.0°R					
Ambient conditions:	520.0°R, 14.53 psia					
Duration of rocket firing:	3.86 sec					
Time from rocket ignition to DATAD:	3.36 sec					
Time prior to rocket ignition for DATAB:	0.5 sec					
Run Data						
Measured	DATAB	DATAD	Computed	Measured	DATAB	DATAD
P _{ox} (psig)	339.8	334.3		ΔP ₃ (psid)	-0.38	-2.25
P _f (psig)	489.1	471.2		ΔP ₄ (psid)	0.31	0.11
P _c (psia)	54.7	318.9		T _{I1} (°R)	915.0	1002.0
P _{hf} (psig)	723.5	725.4		T _{I2} (°R)	907.0	990.0
P _{ao} (psia)	391.5	391.5		T _{I3} (°R)	885.0	962.0
ΔP _{ao} (psid)	171.4	171.2		F (lb)	636.2	1344.0
P _{sa} (psia)	55.4	104.2		(lb/sec)		
P _{inj} (psia)	51.1	101.4		w _{ox}	0.000	0.463
ΔP ₁ (psid)	0.02	-2.50		w _f	0.000	0.606
ΔP ₂ (psid)	0.05	-2.58		w _{hf}	0.098	0.100
				w _{O2} (lb/sec)	0.007	0.007
				w _{CH4} (lb/sec)	0.005	0.005
				w _{NaOH} (lb/sec)	0.000	0.000
				w _{air} (lb/sec)	11.10	11.10
Ramburner Wall Temperatures						
Time (sec)*	T _{IW} (°R)	T _{OW} (°R)	Remarks			
5.39	746.0	720.0	No backpressure plate. T _{I3} appears to be reading low.			
6.15	756.0	721.0				
6.91	774.0	723.0				
7.67	790.0	731.0				
8.44	805.0	738.0				
9.20	817.0	756.0				

*Timed from start of data acquisition.

Table XVII. Run 41 Data

Duct:	C					
Primary nozzle diameter:	0.822 in. before run 0.822 in. after run					
Secondary nozzle diameter:	4.601 in. before run 4.601 in. after run					
Air temperature at the orifice meter:	490.0°R					
Ambient conditions:	544.0°R, 14.46 psia					
Duration of rocket firing:	2.74 sec					
Time from rocket ignition to DATAD:	2.14 sec					
Time prior to rocket ignition for DATAB:	0.5 sec					
Run Data						
Measured	DATAB	DATAD	Computed	Measured	DATAB	DATAD
P _{ox} (psig)	338.1	333.0		ΔP ₃ (psid)	-0.02	-0.21
P _f (psig)	474.6	459.3		ΔP ₄ (psid)	0.69	0.96
P _c (psia)	53.1	309.7		T _{I1} (°R)	1072.0	1074.0
P _{hf} (psig)	641.7	640.6		T _{I2} (°R)	--	--
P _{ao} (psia)	494.8	494.7		T _{I3} (°R)	--	--
ΔP _{ao} (psid)	212.3	212.7		F (lb)	900.2	1541.0
P _{sa} (psia)	52.8	83.1		(lb/sec)		
P _{inj} (psia)	51.8	82.6		$\dot{w}_{ox}$	0.000	0.468
ΔP ₁ (psid)	0.34	-2.50		$\dot{w}_f$	0.000	0.603
ΔP ₂ (psid)	0.23	-0.41		$\dot{w}_{hf}$	0.167	0.207
				$\dot{w}_{O_2}$ (lb/sec)	0.007	0.007
				$\dot{w}_{CH_4}$ (lb/sec)	0.005	0.005
				$\dot{w}_{NaOH}$ (lb/sec)	0.203	0.200
				$\dot{w}_{air}$ (lb/sec)	13.91	13.92
Ramburner Wall Temperatures						
Time (sec)*	T _{IW} (°R)	T _{OW} (°R)	Remarks			
3.88	683.0	670.0	Backpressure plate installed T _{I2} and T _{I3} amplifiers out NaOH solution seeding.			
4.43	685.0	672.0				
4.97	692.0	676.0				
5.52	697.0	681.0				
6.07	707.0	685.0				
6.62	714.0	694.0				

*Timed from start of data acquisition.

Table XVIII. Run 42 Data

Duct:	C					
Primary nozzle diameter:	0.822 in. before run 0.822 in. after run					
Secondary nozzle diameter:	3.291 in. before run 3.291 in. after run					
Air temperature at the orifice meter:	497.0°R					
Ambient conditions:	544.0°R, 14.46 psia					
Duration of rocket firing:	3.06 sec					
Time from rocket ignition to DATAD:	2.36 sec					
Time prior to rocket ignition for DATAB:	0.5 sec					
Run Data						
Measured	DATAB	DATAD	Computed	Measured	DATAB	DATAD
P _{ox} (psig)	344.9	333.8		ΔP ₃ (psid)	0.08	-0.14
P _f (psig)	479.4	468.1		ΔP ₄ (psid)	0.94	0.79
P _c (psia)	103.1	318.1		T _{I1} (°R)	1049.0	1065.0
P _{hf} (psig)	627.4	630.7		T _{I2} (°R)	--	--
P _{ao} (psia)	503.5	500.5		T _{I3} (°R)	--	--
ΔP _{ao} (psid)	215.4	212.4		F (lb)	1024.0	1666.0
P _{sa} (psia)	107.7	166.5		(lb/sec)		
P _{inj} (psia)	107.9	167.0		$\dot{w}_{ox}$	0.000	0.473
ΔP ₁ (psid)	0.04	-5.50		$\dot{w}_f$	0.000	0.603
ΔP ₂ (psid)	0.09	0.10		$\dot{w}_{hf}$	0.255	0.207
			$\dot{w}_{O_2}$ (lb/sec)		0.007	0.007
			$\dot{w}_{CH_4}$ (lb/sec)		0.005	0.005
			$\dot{w}_{NaOH}$ (lb/sec)		0.200	0.184
			$\dot{w}_{air}$ (lb/sec)		14.07	13.95
Ramburner Wall Temperatures						
Time (sec)*	T _{IW} (°R)	T _{OW} (°R)	Remarks			
2.99	695.0	651.0	Backpressure plate installed. T _{I2} and T _{I3} amplifiers out. NaOH solution seeding.			
3.60	663.0	654.0				
4.21	669.0	656.0				
4.82	676.0	659.0				
5.44	684.0	663.0				
6.05	692.0	668.0				

*Timed from start of data acquisition.

Table XIX. Run 43 Data

Duct:	C					
Primary nozzle diameter:	0.868 in. before run 0.932 in. after run					
Secondary nozzle diameter:	4.250 in. before run 4.250 in. after run					
Air temperature at the orifice meter:	495.0°R					
Ambient Conditions:	544.0°R, 14.46 psia					
Duration of rocket firing:	3.03 sec					
Time from rocket ignition to DATAD:	2.53 sec					
Time prior to rocket ignition for DATAB:	0.5 sec					
Run Data						
Measured	DATAB	DATAD	Computed	Measured	DATAB	DATAD
P _{ox} (psig)	391.7	379.1		ΔP ₃ (psid)	-0.02	0.31
P _f (psig)	338.5	331.7		ΔP ₄ (psid)	0.73	0.75
P _c (psia)	63.8	290.9		T _{I1} (°R)	1049.0	1048.0
P _{hf} (psig)	637.8	638.3		T _{I2} (°R)	--	--
P _{ao} (psia)	510.3	510.7		T _{I3} (°R)	--	--
ΔP _{ao} (psid)	218.7	219.0		F (lb)	957.2	1344.0
P _{sa} (psia)	63.4	82.5		(lb/sec)		
P _{inj} (psia)	62.7	82.7		$\dot{w}_{ox}$	0.000	0.752
ΔP ₁ (psid)	0.34	-2.50		$\dot{w}_f$	0.000	0.345
ΔP ₂ (psid)	0.14	0.52		$\dot{w}_{hf}$	0.239	0.228
				$\dot{w}_{O_2}$ (lb/sec)	0.007	0.007
				$\dot{w}_{CH_4}$ (lb/sec)	0.005	0.005
				$\dot{w}_{NaOH}$ (lb/sec)	0.199	0.200
				$\dot{w}_{air}$ (lb/sec)	14.30	14.31
Ramburner Wall Temperatures						
Time (sec)*	T _{IW} (°R)	T _{OW} (°R)	Remarks			
2.78	607.0	600.0	Backpressure plate installed. T _{I2} and T _{I3} amplifier out. NaOH solution seeding.			
3.39	613.0	609.0				
4.01	617.0	612.0				
4.62	621.0	614.0				
5.24	628.0	617.0				
5.85	633.0	623.0				

*Timed from start of data acquisition.

Table XX. Run 44 Data

Duct:	C					
Primary nozzle diameter:	0.932 in. before run 0.996 in. after run					
Secondary nozzle diameter:	3.078 in. before run 3.078 in. after run					
Air temperature at the orifice meter:	492.0°R					
Ambient conditions:	544.0°R, 14.46 psia					
Duration of rocket firing:	3.00 sec					
Time from rocket ignition to DATAD:	2.50 sec					
Time prior to rocket ignition for DATAB:	0.5 sec					
Run Data						
Measured	DATAB	DATAD	Computed	Measured	DATAB	DATAD
P _{ox} (psig)	383.8	371.1		ΔP ₃ (psid)	-0.09	0.10
P _f (psig)	336.4	328.4		ΔP ₄ (psid)	0.84	0.63
P _c (psia)	124.4	274.1		T _{I1} (°R)	1055.0	1052.0
P _{hf} (psig)	643.0	643.9		T _{I2} (°R)	--	--
P _{ao} (psia)	503.0	504.4		T _{I3} (°R)	--	--
ΔP _{ao} (psid)	216.0	213.4		F (lb)	1047.0	1053.0
P _{sa} (psia)	123.9	166.3		(lb/sec)		
P _{inj} (psia)	124.4	167.0		ṡ _{ox}	0.000	0.783
ΔP ₁ (psid)	0.07	-5.50		ṡ _f	0.000	0.388
ΔP ₂ (psid)	0.10	0.48		ṡ _{hf}	0.214	0.180
				ṡ _{O2} (lb/sec)	0.007	0.007
				ṡ _{CH4} (lb/sec)	0.005	0.005
				ṡ _{NaOH} (lb/sec)	0.194	0.184
			ṡ _{air} (lb/sec)	14.15	14.12	
Ramburner Wall Temperatures						
Time (sec)*	T _{IW} (°R)	T _{OW} (°R)	Remarks			
2.72	674.0	672.0	Backpressure plate installed. T _{I2} and T _{I3} amplifiers out. NaOH solution seeding.			
3.32	679.0	675.0				
3.92	683.0	679.0				
4.52	690.0	681.0				
5.12	698.0	686.0				
5.73	707.0	691.0				

*Timed from start of data acquisition.

the simultaneous failure of two signal amplifiers which could not be replaced during the available run period. NaOH seeding solution was employed during Runs No. 41 through 44, but not in the other runs in the series. Measurements of the stagnation pressure profile in the jet are not reported. These measurements were determined to be in error because of the poor time response of the original probe design, as discussed in Section II.

Figures 9, 10, and 11 show typical time variations of thrust, static pressure at the ramburner nozzle inlet, and rocket chamber pressure, respectively. The relative magnitude and period of the thrust oscillations discussed previously are shown to scale in Figure 9. The rocket chamber pressure did not fall to its prefire value after the firing because of the immediate purge of the rocket propellant lines and chamber following the run.

Figures 12 and 13 show the results of the static pressure measurements along the duct for the stoichiometric cases. The reference pressure, P_{inlet} , was computed from the measured stagnation properties of the airflow and the geometry of the system, assuming one-dimensional flow up to the exit plane of the rocket exhaust nozzle. Figures 14 and 15 show the comparable static pressure distributions along the ramburner for the fuel rich rocket runs. To obtain these pressure plots, it was considered best to calculate the static pressure at the downstream end of the ramburner from the thrust and flow rate data and to plot the measured pressure changes along the duct upstream from this point. This was because the first differential pressure measurement at the entrance to the ramburner was affected by thrust stand oscillations and the measured values were not considered as reliable.

The pressure plotted at $L/D = 1$ is the measured static pressure, P_{inj} . In all of the runs, this P_{inj} was higher than P_{inlet} . In fact, it could be argued that P_{inj} could not be distinguished from the stagnation pressure of the airflow within the experimental uncertainty in the measurements. If the experimental measurement of P_{inj} was biased for some reason, it could also be argued that the apparent pressure rise from $L/D = 0$ to $L/D = 1$ may not exist for some of the runs, but not for all of them, subject to the measurement errors. The former argument seems more plausible. A small pressure rise would be anticipated because of the distortion of the streamlines caused by the ejector action of the jet, possibly resulting in a region of recirculation as shown in Figure 16 and discussed in Reference [10].

The pressure variation for the stoichiometric rocket (Figures 12 and 13) showed the anticipated increase along the duct due to ejector action; the magnitude of the rise decreased with increasing A/P ratio, except for Run 43. The runs with combustion in the ramburner exhibited decreasing or nearly uniform pressure variation as a result of the

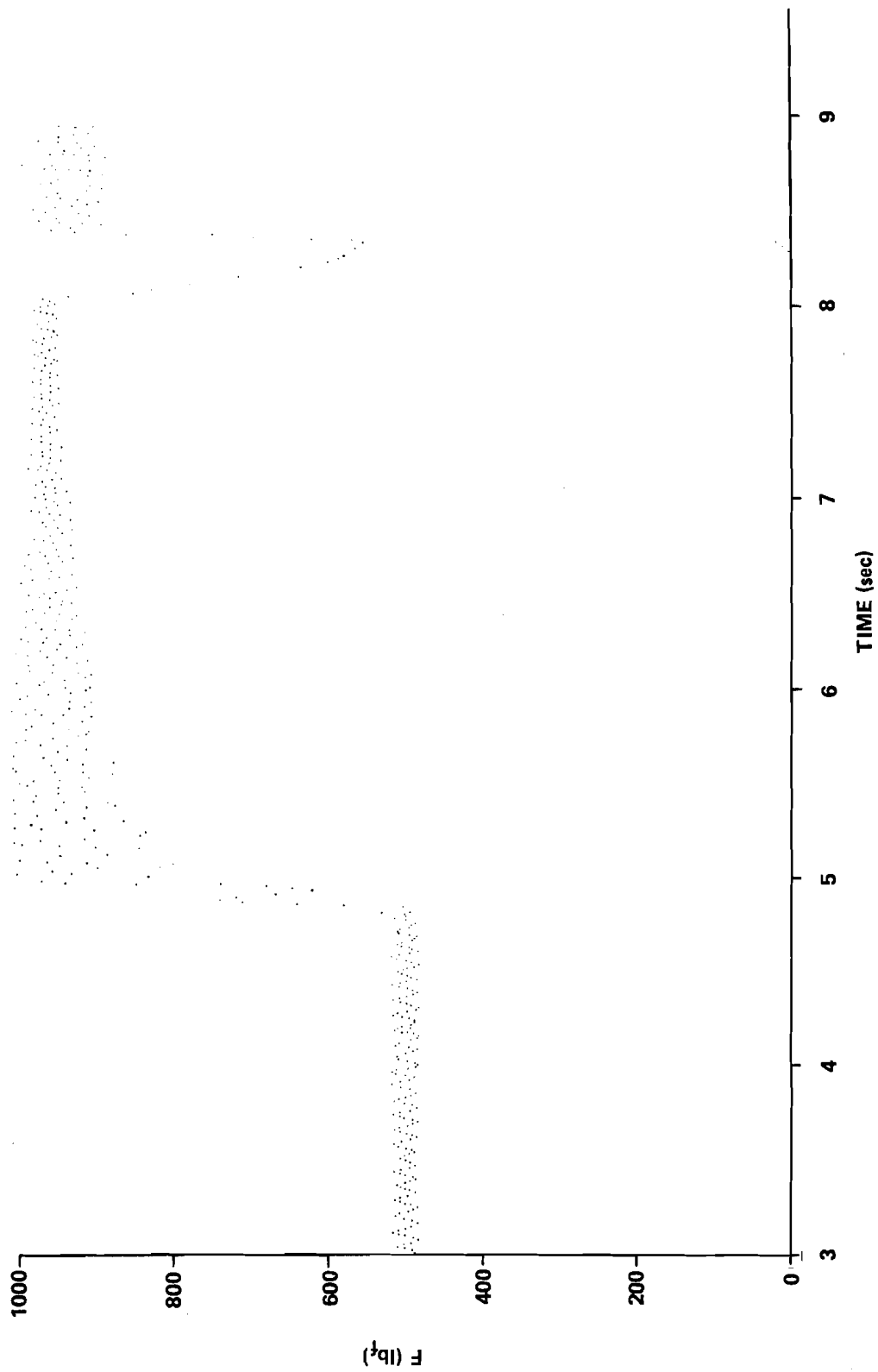


Figure 9. A Typical Thrust Measurement

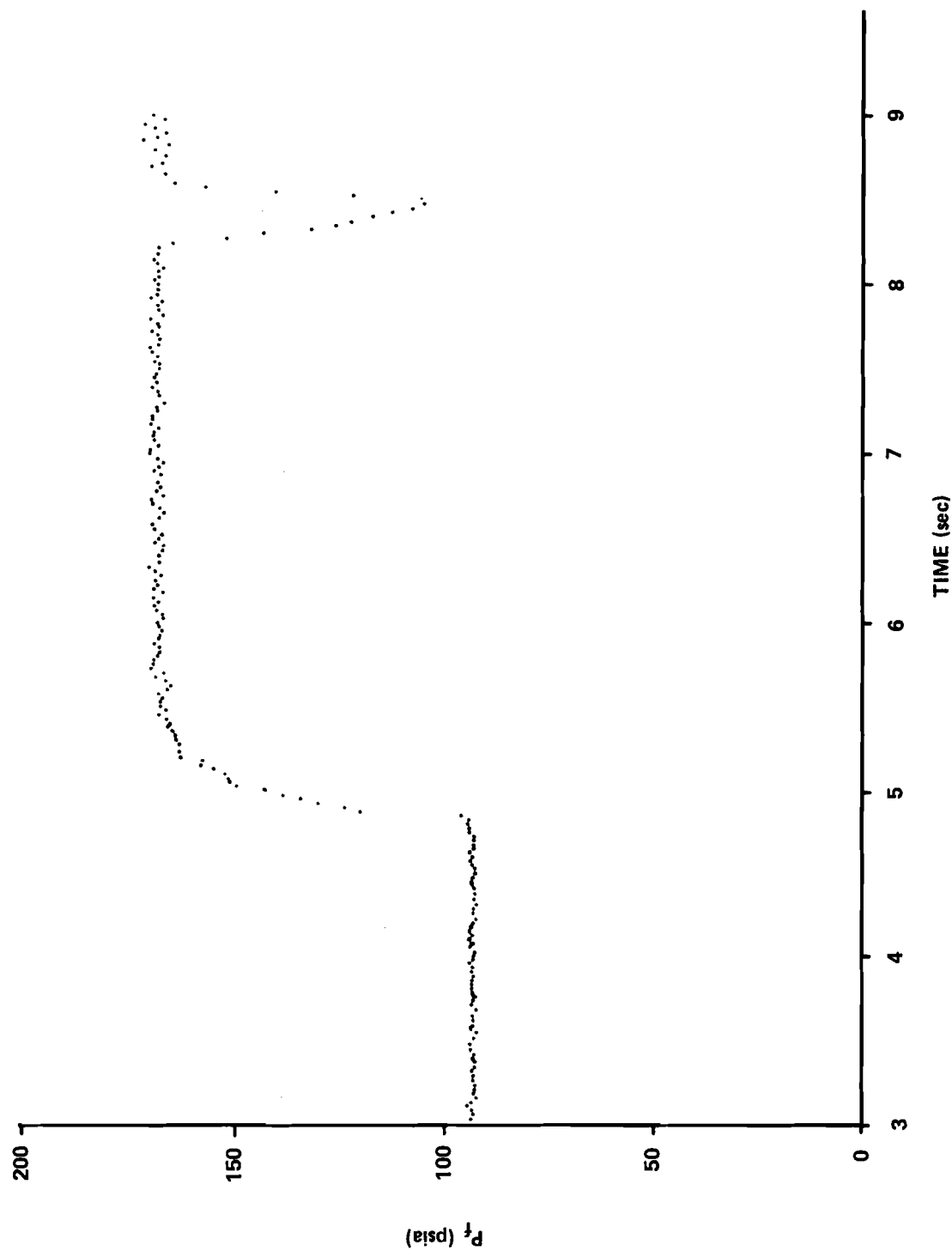


Figure 10. A Typical Ramburner Final Static Pressure Measurement

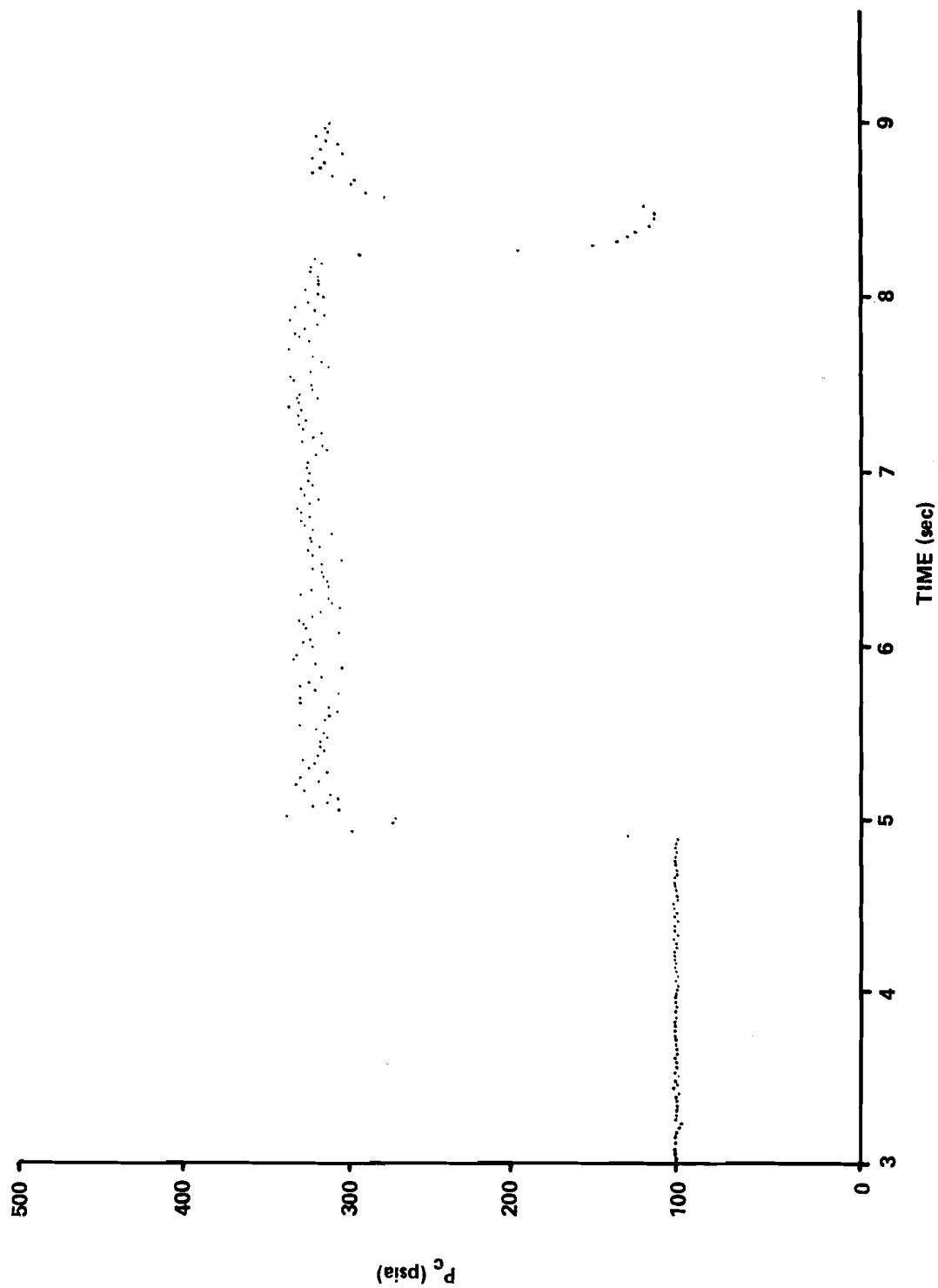


Figure 11. A Typical Primary Rocket Chamber Pressure Measurement

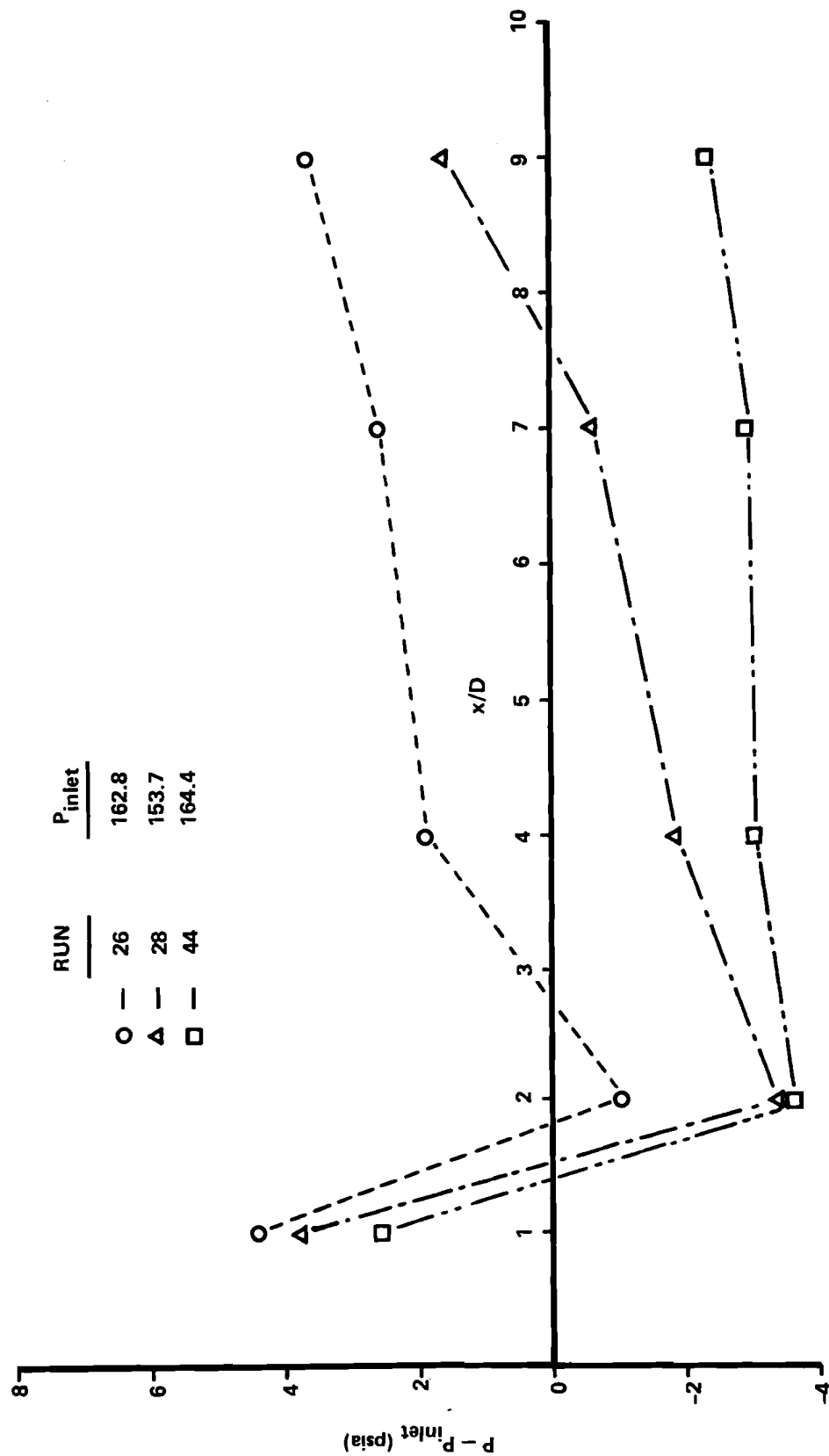


Figure 12. Measured Distribution of Static Pressure Along the Ramburner: Stoichiometric Rocket, Higher Ramburner Pressure

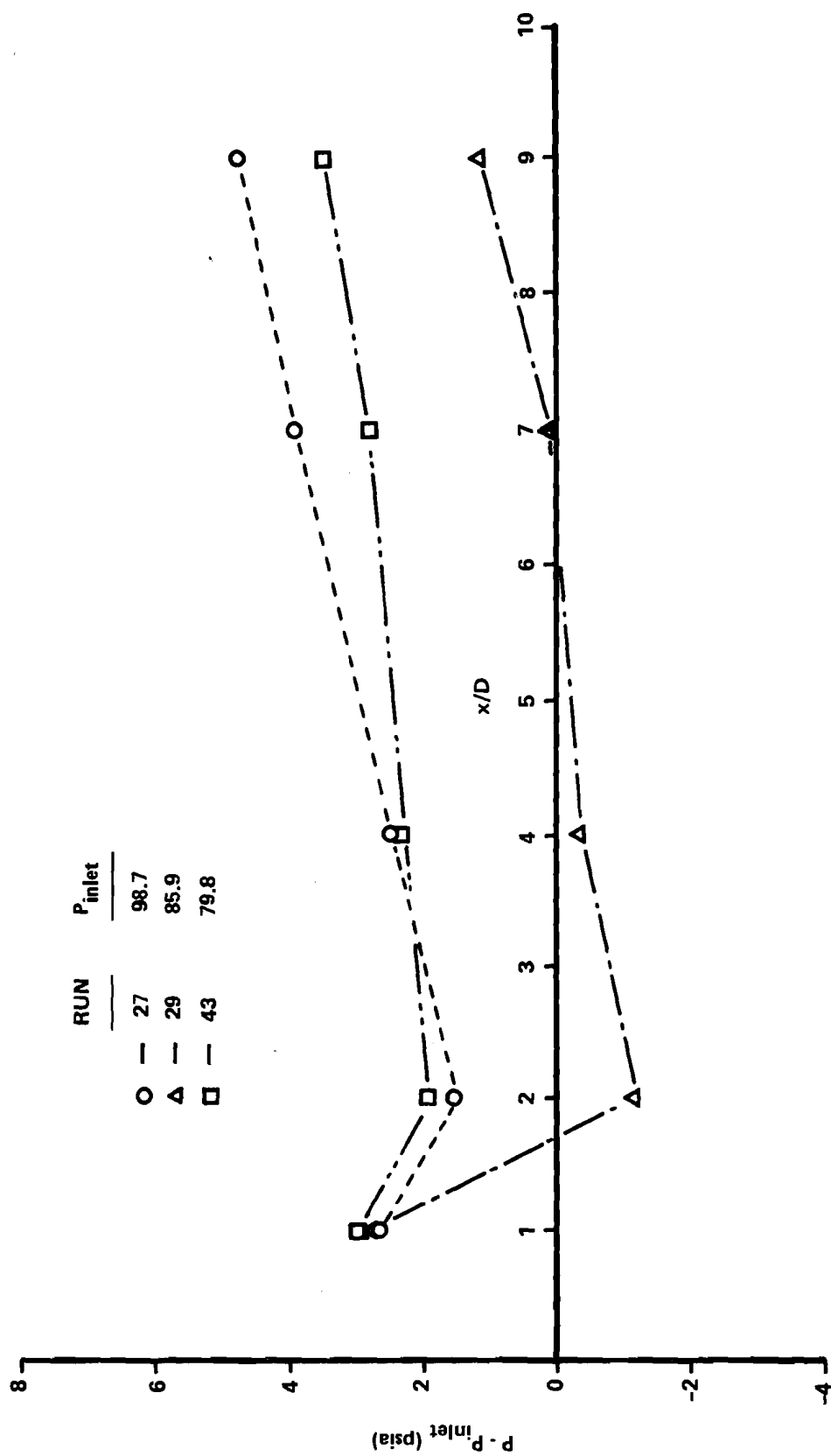


Figure 13. Measured Distribution of Static Pressure Along the Ramburner:
Stoichiometric Rocket, Lower Ramburner Pressure

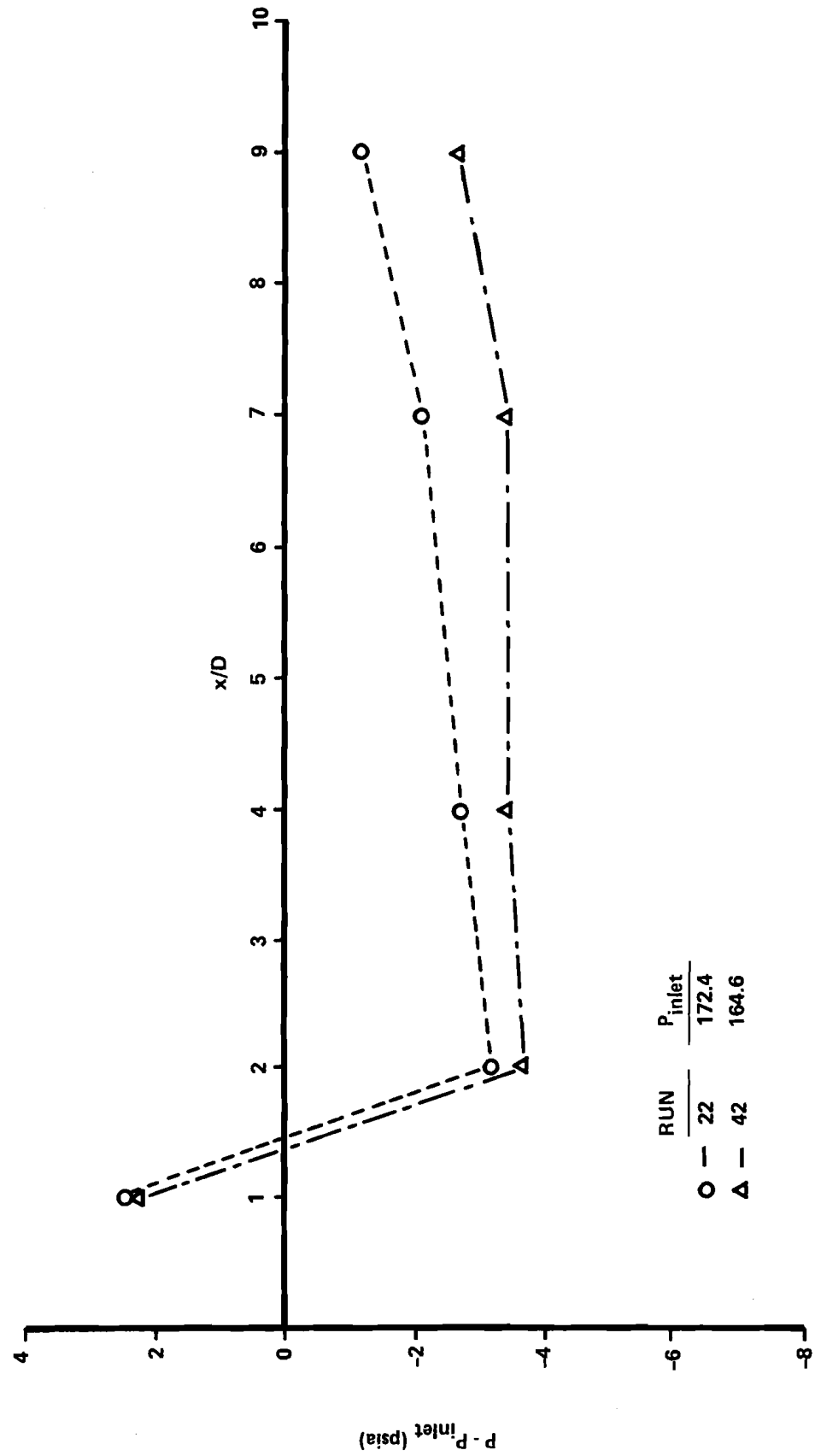


Figure 14. Measured Distribution of Static Pressure Along the Ramburner:
Fuel Rich Rocket, Higher Ramburner Pressure

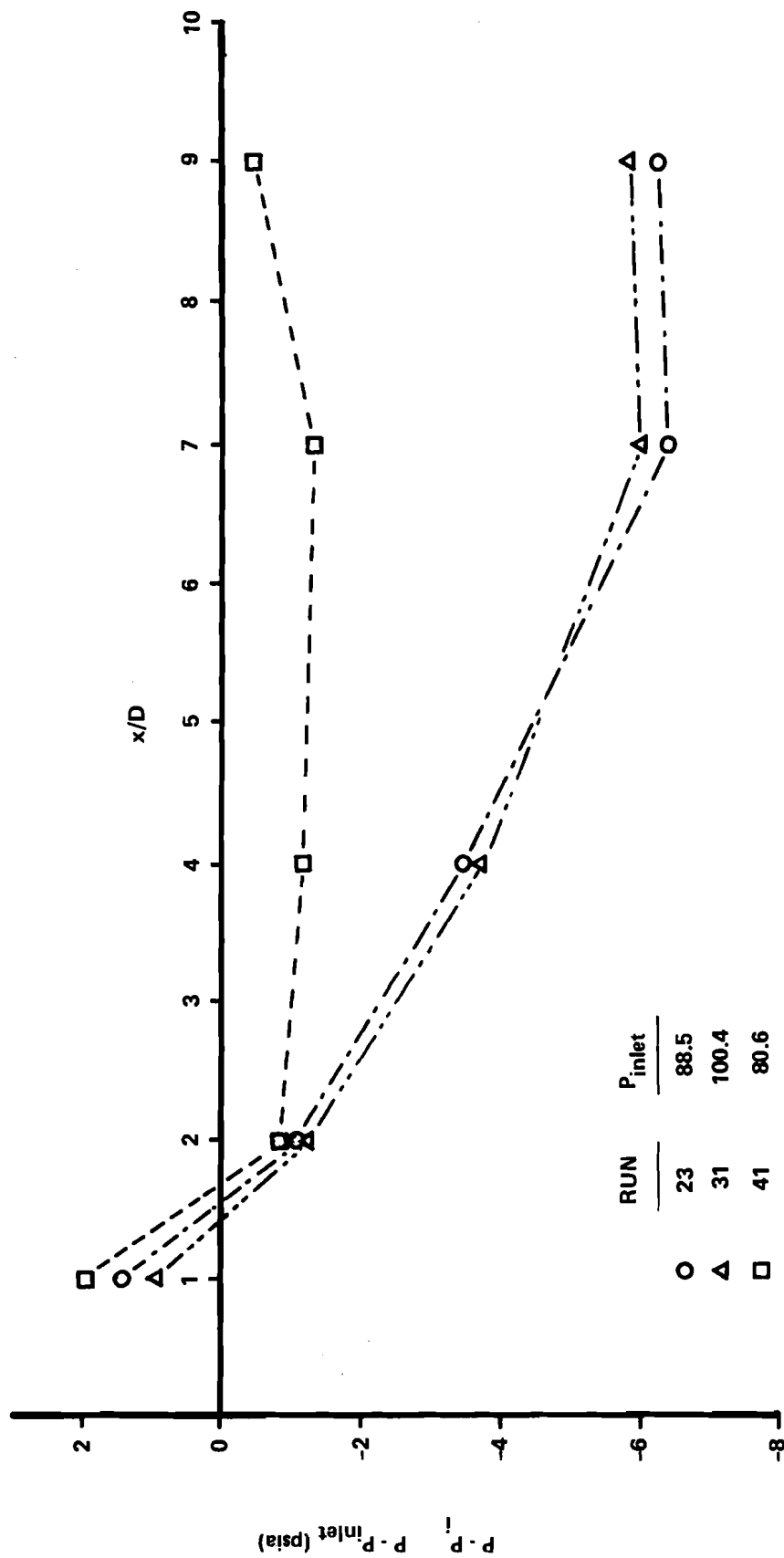


Figure 15. Measured Distribution of Static Pressure Along the Ramburner:
Fuel Rich Rocket, Lower Ramburner Pressure

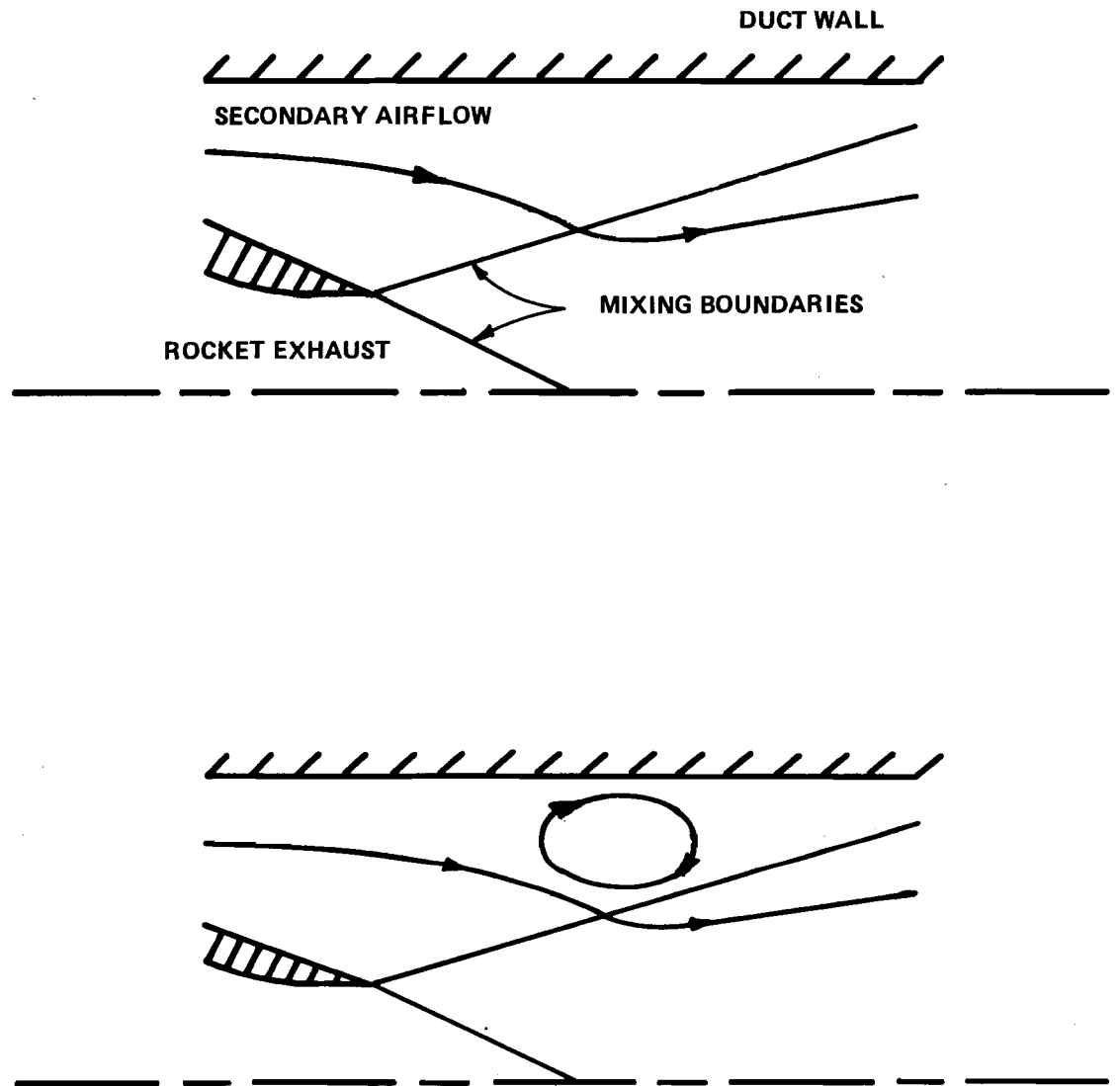


Figure 16. Possible Streamline Patterns Near the Ramburner Inlet

competition between the ejector action and combustion process. The largest overall static pressure change along the duct amounted to approximately 6 percent of the static pressure level. All of the runs exhibited relatively strong axial pressure variations near the entrance of the ramburner. Because of the difficulty experienced in these measurements, there is no clear way to evaluate the uncertainty level, but the relative value shown in Figures 12 through 15 should probably be accurate to within a factor of 2.

The optical measurements in this series of runs involved deviations from the planned program because of oversights in setting up the apparatus. In particular, the sodium D-line filter was not employed to limit the spectral range of the detected radiation. Except for two runs, the NaOH seeding solution also was not provided to seed the airstream. The utility of the data may not be seriously impaired, however, because (1) the data were originally intended to serve as qualitative indicators of the progress of the combustion process, and (2) measurements obtained in the initial stages of the investigation showed little difference in the gross behavior of the normalized distribution whether or not the D-line filter was employed and whether or not the airflow was seeded. The level of emitted radiation differed substantially. Only the relative variation of the detected light intensity was of interest in the investigation.

The optical system employed was arranged so that the sensitivity of the system was nominally the same for all ports. Small differences due to variations in the transmission through the optical elements were accounted for through individual calibrations.

The runs with the stoichiometric mixture ratio in the rocket exhibited an optical signal at the first optical port, $L/D = 0$, and generally no detectable signal at ports farther downstream. This simply indicated radiation from the relatively hot rocket exhaust plume which decayed strongly as the rocket exhaust products mixed with the cooler air.

The optical data for the runs with the fuel-rich rocket exhibited stronger emission, growing to a peak at distances from 13 to 20 inches downstream of the rocket exhaust nozzle ($x/d_{pr} = 15$ to 25, based on the exit diameter of the rocket nozzle, d_{pr}). The data are shown in Figure 17. The nearly common location of the peak suggests that the mixing and combustion processes behave more like those in a free jet than a confined configuration. Because strong pressure variations did not exist, the influence of the duct would not be expected to be of dominant significance in the initial regions of the jet. The decay of the radiation following the peak may be due to mixing of the combustion products with the cooler air by flattening the temperature profile. The intensity of the emitted radiation should be a strong function of the temperature

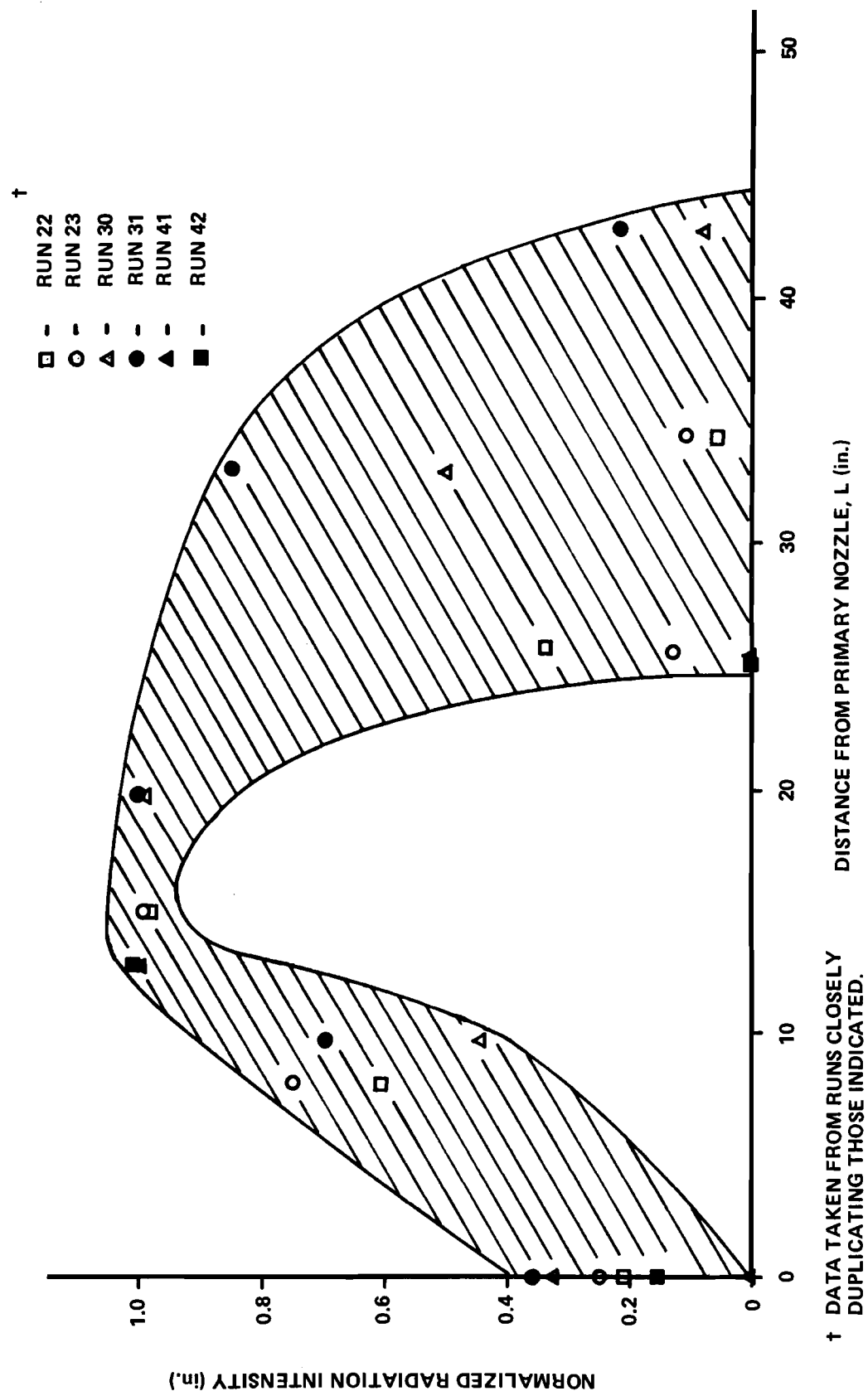


Figure 17. Optical Measurements Obtained from the Ramburner

($> T^4$) for the range of temperatures involved. Computations made with axisymmetric mixing and combustion theories, assuming trace quantities of sodium, for example, should probably show a similar axial distribution of the intensity of emission. As this is quite sensitive to the local properties in the flow, agreement with the theory would be useful evidence as to its merit. The utility of measurements of this type for other purposes is discussed further in Section V.

2. Analysis of the Experimental Data

a. Air Heater Data and Analysis of Measurement Uncertainties

The data obtained for the air heater prior to the rocket firing served primarily as a useful check on the measurement systems. Four independent means of determining the stagnation pressure of the heated air were available from the measured data and the known geometry of the system:

- 1) The measured value of the stagnation pressure
- 2) A value computed from the measured thrust and flow rate
- 3) A value computed from the measured stagnation temperature and flow rate
- 4) A value computed from the measured flow rate and static pressure at the first pressure tap in the ramburner.

The last three values make use of the assumption that the gas dynamic relations for one-dimensional flow apply and that the system is adiabatic.

Given those four values for the stagnation pressure, it is possible to estimate the underlying uncertainties in the measurements subject to certain assumptions:

- 1) The measurements were subject to random, unbiased error
- 2) The equations relating the measurements to the pressure were precisely applicable
- 3) The relative magnitudes of the uncertainties in the different measurements corresponded to the values listed in Table V.

There was no apparent reason to assume that the measurement errors were biased because no consistent pattern was present. An exception to that,

however, was the measurement of the stagnation temperature. That reading appeared to be consistently on the low side, as the analysis indicated. As there was no a priori reason to reject the temperature measurement, it was included in the analysis, but was subject to qualification in the outcome of the analysis. There was no reason to expect the one-dimensional gas dynamic relations to be significantly in error for the flow conditions involved. Nonetheless, deviations from one-dimensional flow could be one factor involved in the outcome of the analysis. The last assumption involves some level of uncertainty in that deviations from the values given in Table V would be attributed here to changes in all of the measurement inaccuracies, even though only one or two of the measurements might have deviated. There was no reason to suspect the latter, however, except, as the analysis indicated, in the case of the measured temperature.

The analysis involved statistical methods described in References [11, 12]. Appendix D presents the relations employed. Given a set of 4 values for the stagnation pressure as determined above for each run, together with relations between the measured quantities and the stagnation pressure, and the relative magnitudes of the errors involved in the measurements, a "most probable" value for the stagnation pressure could be obtained. A weighted mean of the four values was employed. Weighting factors, related to the relative uncertainties in the measurements were determined in the analysis. From the "most probable" value of the stagnation pressure, "most probable" values for the other measurements could be found by interpolation among the results obtained in the data reduction process.

In addition to the "most probable" value for the stagnation pressure, the expected uncertainty in the value could be obtained at the 95 percent confidence level in terms of the uncertainty in one of the measurements (e.g., the measured pressure). This underlying value of uncertainty was chosen to be such that the experimental data for all of the runs yielded stagnation pressures which fell within the 95 percent uncertainty band.* The corresponding uncertainty levels for the measured quantities determined in this fashion are presented in Table XXI.

By comparison with Table V, the values in Table XXI are approximately 0.5 percent higher, suggesting that the original estimates were somewhat low. Errors in the temperature measurement were biased toward the low side, presumably because of deposits formed on the bead. The

*The results based on the measured stagnation temperature were excluded from this evaluation. The measured temperature was found to lie consistently below the "most probable" values. A biased error of that type could have been attributable to carbon deposits observed to form on the bead of the thermocouple.

value for the uncertainty in that measurement listed in Table XXI simply denotes the biased excursion rather than a random error, and cannot be compared with the corresponding value in Table V. Reasons for the generally higher levels of uncertainty in the experimental results could be attributable to flow nonuniformity or simply to the fact that the run measurements were not strictly static as assumed in the original error analysis. The differences were not large enough to seek further reasons for the discrepancy. Rather, the values listed in Table XXI should be taken as those effective in the outcome of the results.

The stagnation properties, thrust, flow rate, and corresponding combustion efficiency for each of the runs are listed in Table XXII. The values in the table represent the "most probable" values determined from the set of redundant measurements as previously described. For comparison purposes, the same parameters are shown in Table XXIII based on selected combinations of the measured variables, regarding the pair of variables in parentheses as precise.

The efficiency of the air heater was generally not high because, in all cases, the gas turbine burner can was operated at flow rates in excess of its design value. It can be seen that the efficiency of the heater dropped off sharply for Runs 31 through 44 involving the highest flow rates. It was just prior to these runs that a backpressure plate was installed downstream of the air heater, as required to maintain stable combustion. A later investigation indicated that the particularly low efficiency for those runs was caused by not allowing a sufficient heat up time for the hardware before conducting a run. The backpressure plate acted as a heat sink resulting in the low indicated performance. Given ample heat-up time, the indicated efficiency of the air heater was found to increase by approximately 10 to 15 percent.

Although the efficiency of the combustion process in the air heater was generally low, the effective chemical combustion efficiency (excluding heat losses included in the values tabulated in Table XXII) was high enough (75 to 90 percent) so that the ignition and combustion processes in the ramburner would not be seriously effected. As far as the overall energy release in the system was concerned, the energy release in the ramburner was generally large enough so that combustion of unburned material from the air heater would not be influential in the ramburner performance evaluation.

Efficiency values and the stagnation properties of the air from the air heater during the rocket firing are listed in Table XXIV. As discussed earlier, the efficiency of three of the runs could not be reliably evaluated due to oscillations in the fuel flow which caused the measurement of the heater fuel flow rate to be in error. In general, the indicated heater efficiencies were comparable with those computed before the rocket firing for the majority of the runs. Because more redundant measurements related to the air flow prior to the rocket firing were

Table XXI. Measurement Uncertainties Compatible with the Experimental Results

Measurement	Uncertainty at 95% Confidence Level (%)
P_{sa}	± 1.5
F	± 1.5
T_{inj}	± 4.2
P_{inj}	± 1.5
$\dot{w}$	± 2.7

Table XXII. Most Probable Experimental Values for the Air Heater Before the Rocket Firing, Based on all of the Experimental Measurements

Run	P_{sa} (psia)	T_{inj} (°R)	F (lb/ft)	$\dot{w}$ (lb/sec)	Efficiency
22	103.0	1218.0	495.0	6.7	0.89
23	52.0	1258.0	417.0	6.3	0.85
30	105.0	1038.0	695.0	10.1	0.84
31	56.0	904.0	643.0	11.2	0.58
41	54.0	1090.0	898.0	14.3	0.72
42	108.0	1077.0	1040.0	14.5	0.48
26	114.0	1107.0	450.0	6.3	0.82
27	66.0	1155.0	444.0	6.5	0.79
28	108.0	987.0	588.0	8.7	0.80
29	60.0	1016.0	560.0	9.1	0.74
43	65.0	1065.0	955.0	14.8	0.48
44	124.0	1105.0	1061.0	14.6	0.58

Table XXIII. Stagnation States of the Combustion Products of the Air Heater Before the Rocket Firing Based on Selected Combustions of Redundant Measurements

Run	(F, $\dot{w}$)				(P _{sa} , T _{inj})				(P _{sa} , $\dot{w}$)				(T _{inj} , $\dot{w}$)			
	P _{sa} (psia)	T _{inj} (°R)	F (lb _f)	$\dot{w}$ (lb _m /sec)	P _{sa} (psia)	T _{inj} (°R)	F (lb _f)	$\dot{w}$ (lb _m /sec)	P _{sa} (psia)	T _{inj} (°R)	F (lb _f)	$\dot{w}$ (lb _m /sec)	P _{sa} (psia)	T _{inj} (°R)	F (lb _f)	$\dot{w}$ (lb _m /sec)
22	101.6	1196.0	490.0	6.65	102.1	1191.0	492.8	6.70	102.1	1207.0	492.8	6.65	101.3	1191.0	491.1	6.65
23	50.9	1228.0	410.2	6.30	51.5	1206.0	416.8	6.43	51.5	1254.0	416.5	6.30	50.5	1206.0	406.0	6.35
30	104.2	1016.0	686.3	10.09	104.9	1033.0	691.5	10.07	104.9	1029.0	691.5	10.09	105.1	1033.0	693.0	10.09
31	55.4	893.0	636.2	11.21	55.4	911.0	636.3	11.09	55.4	893.0	636.5	11.21	56.0	911.0	640.9	11.21
41	54.3	1094.0	900.2	14.30	52.8	1072.0	869.6	14.06	52.8	1037.0	870.0	14.30	53.7	1072.0	888.1	14.30
42	106.8	1070.0	1024.0	14.54	107.7	1050.0	1035.0	14.81	107.7	1089.0	1035.0	14.54	105.7	1050.0	1010.6	14.54
26	114.6	1122.0	453.9	6.27	112.1	1106.0	442.9	6.19	112.1	1075.0	433.1	6.27	113.5	1106.0	449.1	6.27
27	67.2	1214.0	451.5	6.50	65.4	1154.0	437.1	6.50	65.4	1151.0	437.1	6.50	65.4	1154.0	437.1	6.50
28	106.6	963.0	578.9	8.72	107.2	1010.0	582.7	8.56	107.2	974.0	582.9	8.72	109.2	1010.0	596.2	8.72
29	59.4	1006.0	556.4	9.06	59.0	1008.0	551.9	9.00	59.0	993.0	552.0	9.06	59.4	1008.0	556.4	9.06
43	64.8	1068.0	957.2	14.75	63.4	1049.0	932.3	14.56	63.4	1024.0	932.5	14.75	64.2	1049.0	946.6	14.75
44	122.8	1080.0	1047.0	14.56	123.9	1055.0	1057.0	14.87	123.9	1098.0	1057.0	14.57	121.3	1055.0	1045.6	14.57

Table XXIV. The Efficiency of the Air Heater During the Rocket Firing Based on the Measured Stagnation Pressure and Temperature

Run	P _{sa} (psia)	T _{inj} (°R)	$\dot{w}_{air}$ (lb _m /sec)	Combustion Efficiency
22	175.0	1215.0	5.49	*
23	92.0	1223.0	6.08	0.84
30	182.0	1023.0	9.62	0.86
31	104.0	996.0	11.10	0.71
41	83.0	1074.0	13.92	0.56
42	166.0	1065.0	13.95	0.54
26	166.0	1141.0	5.35	*
27	103.0	1161.0	6.19	0.80
28	156.0	1003.0	8.39	*
29	89.0	1040.0	8.98	0.78
43	83.0	1048.0	14.31	0.49
44	166.0	1052.0	14.12	0.52

*Large oscillations in heater fuel flow rate encountered, efficiencies could not be accurately evaluated.

available, those values are probably more reliable indicators of the performance of the air heater. Nonetheless, changes in the flow rates did occur upon firing of the primary rocket and small changes in the performance of the air heater could thus be expected.

Employing the measurement uncertainties obtained from the statistical analysis and using the efficiency sensitivities presented in Appendix A, the accuracy of the efficiencies presented in Table XXIV was ± 5 percent at the 95 percent confidence level. Accounting for the observed bias in the temperature measurement in the data prior to the rocket firing, the values in Table XXIV should probably be increased by approximately 2 percent and the temperature increased by 30°R .

b. Rocket Performance

The stagnation properties, combustion efficiency, and conventional C^* efficiency of the primary rocket are listed in Table XXV. As may be seen in the table, the performance of the rocket varied only slightly in the series of runs for each O/F ratio. The value for Run 18 appeared slightly below those for the other fuel rich runs, but the O/F ratio for that run was significantly lower as well. The values for the last two runs, 43 and 44, were approximately 10 percent lower in efficiency compared with other runs at the same nominal O/F ratio. Those two low values were attributed to the occurrence of a small crack in the coolant jacket which was observed upon completion of the runs.

c. Performance of the Complete System and the Ramburner

The stagnation properties, the total flow rate, and the sonic thrust for the complete system are presented in Table XXVI. Those results are based on the thrust and flow rate as principal observations in determining the stagnation state. The thrust value listed for Run 30 was obtained in a rerun under identical operating conditions because the thrust value obtained in the original run appeared to be anomalously low*.

Results for the conditions where the O/F of the rocket was nearly stoichiometric reflect primarily the efficiency of the air heater since combustion in the ramburner would be minimal. The combustion efficiency of the complete system was nearly uniform for all conditions at about 80 percent. Except for Runs No. 43 and 44, that was also the level of combustion efficiency for the air heater. Presumably some combustion of the residual combustible matter from the air heater did occur in the ramburner to raise the overall efficiency in Runs No. 43 and 44.

* Substantially outside the uncertainty band found in all of the other measurements.

Table XXV. Combustion Efficiency of the Primary Rocket

Run	O/F	P _c (psia)	T _c (°R)	Combustion Efficiency	C* Efficiency
18	0.67	319.0	3142.0	0.85	0.92
19	1.85	322.0	5512.0	0.89	0.96
22	0.84	322.0	3811.0	0.91	0.96
23	0.97	315.0	4159.0	0.91	0.96
30	0.79	319.0	3566.0	0.90	0.95
31	0.76	319.0	3519.0	0.90	0.95
41	0.78	310.0	3397.0	0.86*	0.92
42	0.78	318.0	3551.0	0.89*	0.95
26	2.36	299.0	5404.0	0.90	0.99
27	2.06	290.0	5552.0	0.93	0.99
28	2.20	309.0	5622.0	0.94	0.99
29	2.16	293.0	5347.0	0.88	0.99
43	2.18	291.0	5089.0	0.81*	0.98
44	2.02	274.0	5130.0	0.83*	0.98

*Small crack in the rocket coolant jacket was found upon completion of the runs.

Table XXVI. Combustion Efficiency of the Complete System

Run	A/P	O/F	P _{sa} (psia)	T _{inj} (°R)	V _{air} (ft/sec)	V _{pr} (ft/sec)	P _{stag} (psia)	T _{stag} (°R)	Combustion Efficiency
22	5.22	0.84	175.0	1215.0	200.0	3542.0	180.0	3435.0	0.90
23	6.92	0.97	93.0	1223.0	425.0	3594.0	96.0	3068.0	0.85
30	9.04	0.79	182.0	1023.0	170.0	3468.0	185.0	2560.0	0.88
31	10.37	0.76	104.0	996.0	340.0	3462.0	105.0	2496.0	0.86
41	12.97	0.78	83.0	1074.0	305.0	3392.0	85.0	2257.0	0.76
42	12.96	0.78	166.0	1065.0	150.0	3460.0	168.0	2272.0	0.77
26	4.92	2.36	165.0	1141.0	190.0	3457.0	172.0	2225.0	0.81
27	5.32	2.06	103.0	1161.0	370.0	3589.0	113.0	2451.0	0.80
28	8.12	2.20	156.0	1003.0	170.0	3584.0	159.0	1743.0	0.85
29	7.97	2.16	89.0	1040.0	330.0	3471.0	93.0	1866.0	0.79
43	13.05	2.18	83.0	1048.0	310.0	3338.0	87.0	1662.0	0.73
44	12.05	2.02	166.0	1052.0	150.0	3406.0	167.0	1716.0	0.80

*Velocity at the primary nozzle exit plane.

**At the entrance to the secondary (ramburner) nozzle.

The combustion efficiency for the complete system as a function of the A/P ratio is shown in Figure 18 for the runs with a fuel rich mixture in the primary rocket. The values in Figure 18 are shown with uncertainty limits obtained from the values in Table XXI for the measurements together with an analysis of the sensitivity of the uncertainty in the efficiency to measurement uncertainties (Appendix A). The efficiency falls roughly from 0.90 to 0.75 as the A/P ratio increases from 5 to 13. The A/P value for overall stoichiometry was approximately 2.45, so the overall equivalence ratios were well on the lean side in the run series. A slight decrease in efficiency level may be noted at the lower pressure level.

It was possible to check the performance values shown in Table XXVI by an independent means. Measurements of the static pressure at the entrance of the ramburner together with the measurements of the pressure distribution along the duct could be employed to obtain the static pressure near the entrance of the ramburner nozzle. This, together with the flow rate could be employed, as discussed in Section III, to obtain the stagnation state of the ramburner exhaust products. Those measurements were found to be somewhat less accurate, in general, as discussed in Section III. In particular, one of the transducers for measuring a differential pressure was found to be quite sensitive to vibrations in its original mounting. Reruns with a more stable configuration enabled a comparison with the original results. Corrections so determined were applied to the data from the first Δp transducer. The combustion efficiency based on the corrected data was found to agree with the values shown in Figure 18 within ± 2 percent, in general, deviating by at most ± 3 percent for Run 27. All of the results fell within the uncertainty bands taken from the air heater data, as they should if the uncertainty bands are reliable.

Figure 19 shows the combustion efficiency of the ramburner alone, as determined from the component efficiencies and the efficiency of the complete system, in accord with Equation (A-19). The uncertainty bands are also indicated in the plot. The trends are similar to those shown for the complete system, Figure 18, in that the efficiency decreases with increasing A/P ratio and decreases slightly with decreasing pressure. The efficiency level for the ramburner is somewhat lower than for the complete system, and the uncertainty limits are necessarily wider (by a factor of 2).

In all cases, the efficiency was calculated making no distinction between combustion inefficiency and heat loss. Rough calculations were made to determine the heat loss from the ramburner by utilizing the measured inside and outside wall temperatures at the midpoint of the ramburner. Table XXVII presents the results of the heat loss calculations as the amount the computed efficiency was reduced due to heat transfer for the runs with a fuel rich primary rocket. These calculations indicated that heat losses were encountered which caused the computed

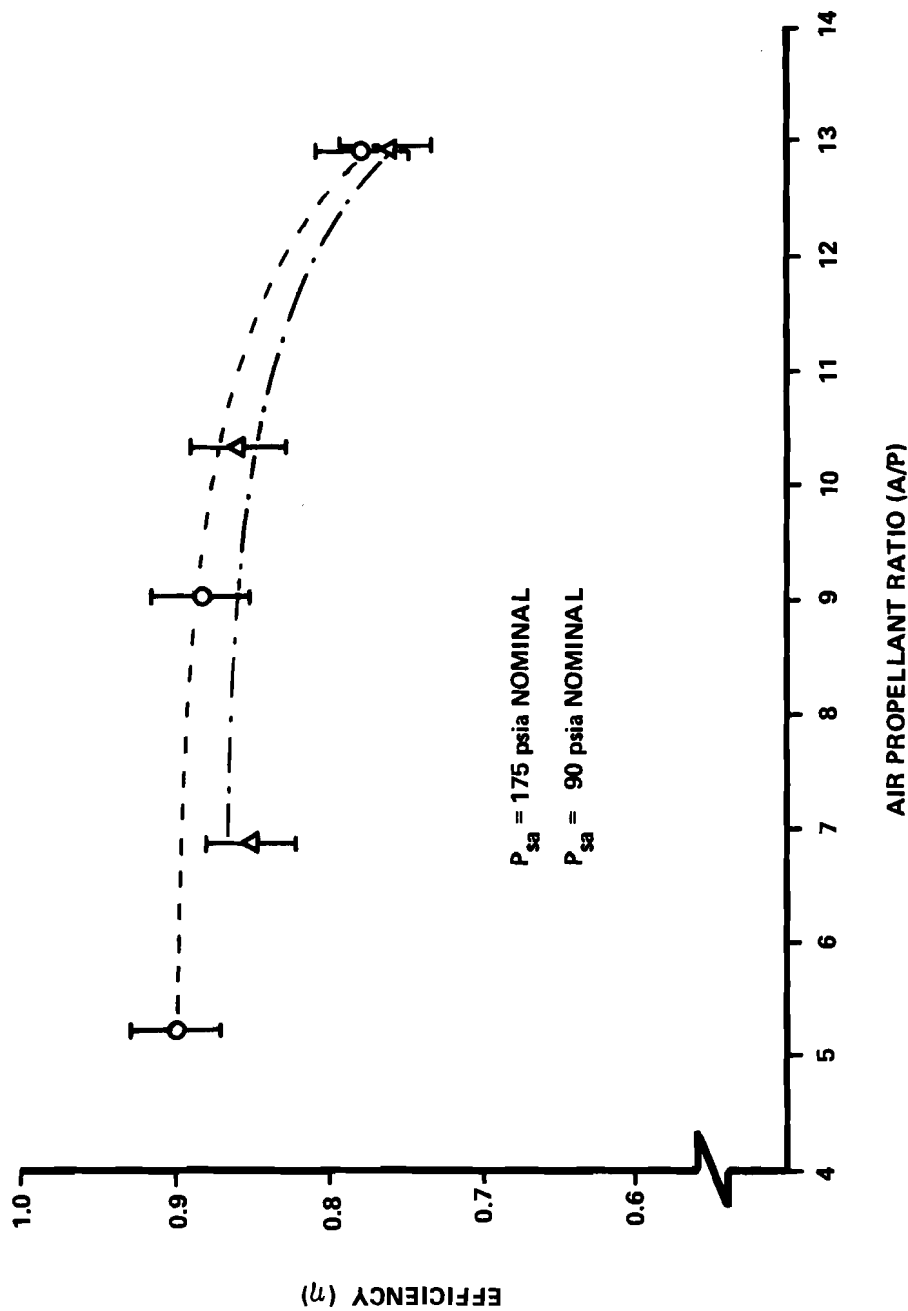


Figure 18. Combustion Efficiency for the Complete System Operating with the Fuel-Rich Primary Rocket

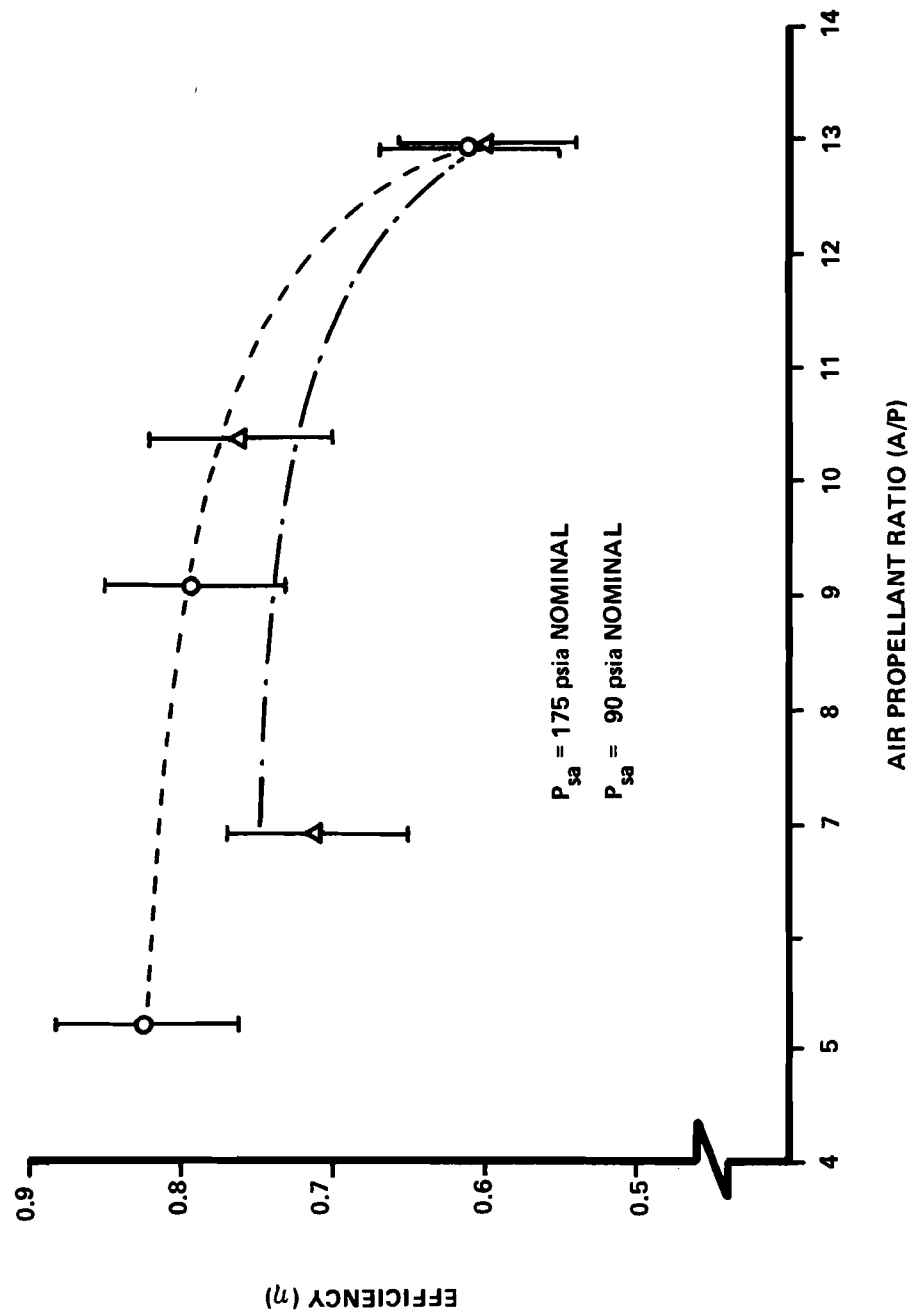


Figure 19. Combustion Efficiency of the Ramburner

combustion efficiency to be reduced by 0.01 to 0.02. It should be noted that this was only a rough estimate of the heat loss and was in all likelihood too high since the wall temperature measurements were made at a point along the ramburner where the heat release could be expected to be near its maximum rate.

Table XXVII. Computed Energy Loss from the Ramburner
Due to Heat Transfer

Run	Efficiency Loss Due to Heat Transfer*
22	0.02
23	0.02
30	0.02
31	0.02
41	0.01
42	0.01

*Indicates that the true adiabatic combustion efficiency would be that given in Figures 18 and 19 increased by this amount.

Section V. DISCUSSION

As was stated earlier in this report, the purposes of this series of runs were to examine the experimental facility and the accuracy of the instrumentation, and to obtain data from a system for which the chemical rates were likely to be faster than the mixing rates. Several modifications of the facility were suggested by the results of the run series. The most important modifications indicated were the need to reduce the response time of the stagnation pressure probe and the need to remount the differential pressure transducers located along the ramburner.

The analysis of the measurement errors (Table V), the level of uncertainty in the measurements consistent with the experimental results for the air heater (Table XXI), and the resulting uncertainty levels of the combustion efficiency for the complete system (± 3 percent) and for the ramburner (± 6 percent), based on the analysis in Appendix D, show that results of high precision may not be expected in the system. Measurements of higher precision than those made, requiring exceptional control and calibration precautions, would be necessary, for example, to obtain combustion efficiency values at 1 or 2 percent uncertainty levels. However, data of that precision would require theories capable of interpreting the results to the higher precision. Turbulent mixing and combustion theories are available to refine the interpretation considered in this report (as that at this laboratory). However, the level of precision involved would hardly be expected to fall within the 1 or 2 percent range (although possibly quite close in terms of integrated parameters).

Probably the most significant aspect of the relatively high level of uncertainty found for the liquid propellant runs is that the level of uncertainty of comparable results for solid propellant runs can be expected to be even higher. That is simply because the parameters such as the flow rate will be known with less precision.

The results obtained in the liquid propellant run series may be employed to compare with theoretical predictions from analytical models accounting for the two-dimensional character of the flow. The chemical rates should be relatively fast compared with the rate of mixing, so that a mixing theory with equilibrium thermochemistry should represent the data as well as could be expected. Given the experimental conditions at the entrance of the ramburner, comparisons against the static pressure distribution, the sonic mass velocity and the thrust of the system may be made. Identification of the level of loss due to nonuniformity of the flow may also be obtained. Computations of the relative intensity distribution of radiation from trace quantities of sodium may be compared with those measured.

Appendix A. DESCRIPTION OF THE METHODS FOR DATA REDUCTION

This appendix contains the equations and information regarding the relations employed in the data reduction procedure. Certain other aspects of the data handling have also been included for the benefit of potential program users. The program, as well as the experimental apparatus, have been employed for other research activities at this laboratory.

1. Times Employed in the Program

Figure A-1 serves to illustrate the relations among the times employed by the program. The lower curve in Figure A-1 is a typical trace of the rocket chamber pressure. The left end of the trace represents the beginning of data acquisition when the complete instrumentation system is activated. Recall that the air heater was operated for some time prior to that point and was operating under steady conditions when the instrumentation system was activated.

The times TIME0 and TIMEF denote the times measured from the beginning of data acquisition between which data are retained for record purposes. Normally TIME0 was chosen to be approximately 1 second prior to the rocket ignition and TIMEF was 1 second following the rocket purge (shutdown). Data outside those limits were discarded. TIME2 was typically about 1 second. The DATAB point was normally taken at approximately 0.5 second prior to ignition so that SECB and TDATB were both about 0.5 second. TDATD was the time measured from the point where data were retained to the data reduction point DATAD. A typical value was 4 seconds. That point was chosen approximately 0.5 second prior to rocket shutdown, so that SECD was about 0.5. The other times indicated in Figure A-1 are computed and employed in various ways by the program.

The upper curve in Figure A-1 shows a typical trace of the position of the stagnation pressure probe as it traversed the jet. The points (a) and (b) denote the beginning and the end of the probe traverse, respectively. The associated times on the diagram are self-explanatory.

2. Data Averaging Procedure

The program was designed to first sort the data into files by channel. Given the time at which the data were to be evaluated (e.g., TDATD), the program would skip through the file to the point corresponding to that time minus $NSD / (2 \times \text{sampling rate per channel})$ where NSD is the number of points to be employed in the averaging as designated by the user. For all of the data reported herein, NSD was chosen to

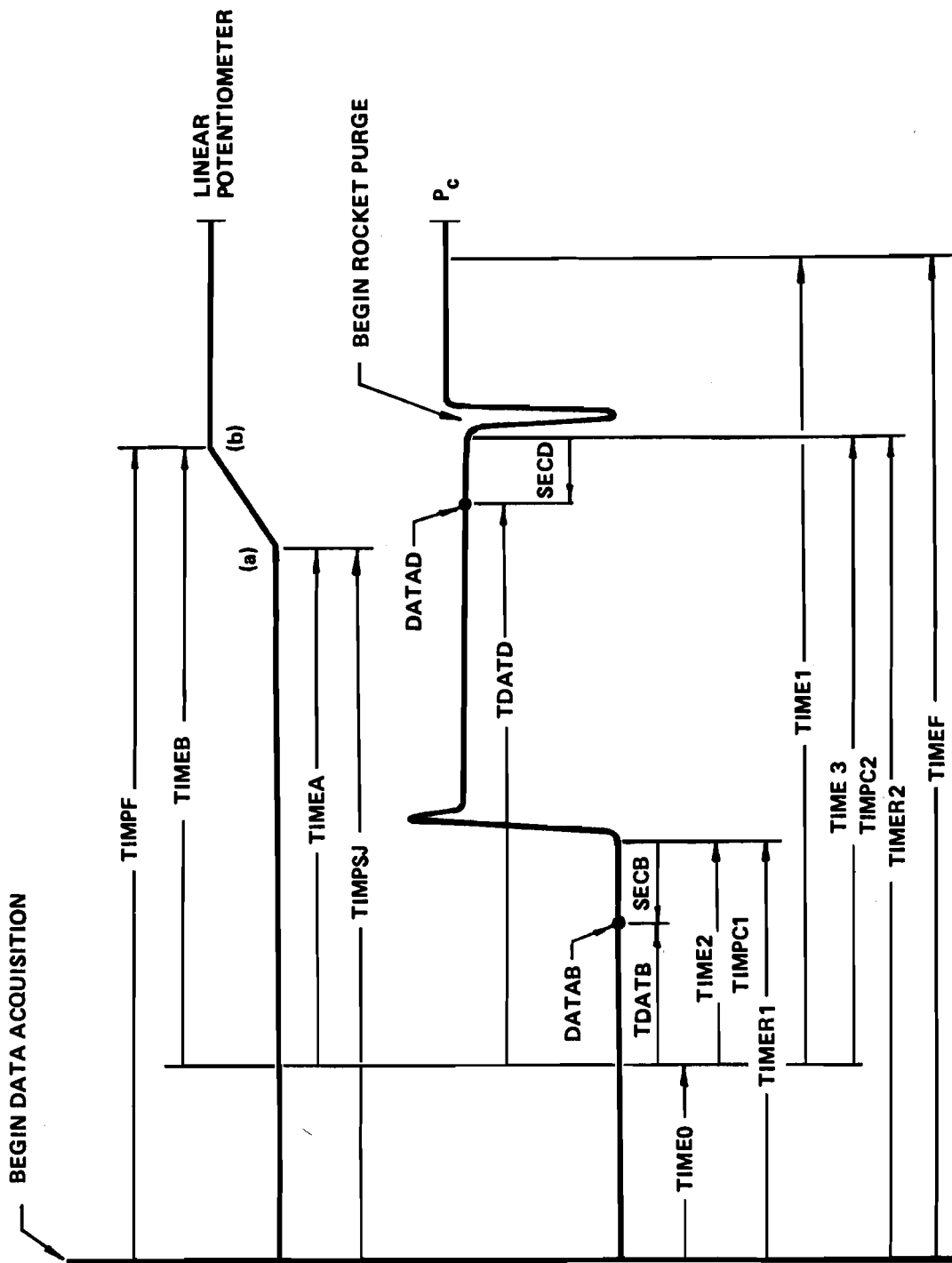


Figure A-1. Times Pertinent to Data Reduction

correspond exactly to one cycle of oscillation of the thrust measurement. The sampling rate per channel was 200 per second. The raw data corresponding to the NSD points for each channel were written in the program output for review by the user. The program was arranged to determine the best least-squares straight line through the NSD points and the value at the time in question was determined from that straight line. The program also indicated in the output the standard deviation as a measure of the fluctuation in the data.

3. Flow Rates

Flow rates of the liquid rocket propellants were measured by means of turbine-type flow meters. The meter operated in such a manner that the flow rate was directly proportional to the frequency of the output signal and to the density of the liquid. Calibration constants relating the output frequency to the flow rate of water were supplied by the manufacturer. Calibration at this laboratory indicated that the constants were accurate. If x denotes the recorded signal strength for a standard reference signal of 250 hertz, then the flow rate could be computed from the relation

$$\dot{w} = 2086.29 \frac{vs}{kx} \text{ (lb/sec)} \quad (\text{A-1})$$

where

v = the output signal, volts

s = the specific gravity of the liquid

k = the calibration constant (hertz per gallon of H_2O)

x = the output voltage for a 250 hertz reference signal, volts.

Specific gravity values for the propellants were measured by means of a hydrometer.

The flow rate of air was computed from the relation

$$\dot{w} = 359 c F d_a^2 Y \sqrt{h_w / v_l} \text{ lb/sec} \quad (\text{A-2})$$

where

c = discharge coefficient

F = velocity approach factor

d = diameter of the orifice, inches

F_a = thermal expansion factor for the orifice plate

Y = expansion factor, accounting for multidirectional expansion

h_w = differential pressure head, inches of water at 68°F

v_1 = the specific volume, ft³/lb.

This is in accord with Equation (7-4) of Reference [4] and recommended procedures for determining the various factors involved were utilized. The values necessary for all parameters were taken from Reference [4].

In addition to the air, fuel, and propellant flow rates, account was taken of the methane and oxygen flow rates supplied to the ignitor torch in the air heater. Those flow rates were determined by means of sonic ports in the flow lines. Discharge coefficients determined for turbulent flow with water were measured. Assuming the discharge coefficients to be independent of Reynolds number and making use of gas dynamic relations for one-dimensional flow, one obtains

$$\dot{w} = C_d \sqrt{\frac{g_c \gamma M}{\bar{R}} \frac{2}{\gamma + 1} \frac{\gamma + 1}{\gamma - 1} \frac{PA}{\sqrt{T}} \left(\frac{1b}{sec} \right)} \quad (A-3)$$

where

C_d = the discharge coefficient

γ = the ratio of specific heats for the gas C_p/C_v

M = the molecular weight of the gas

$\bar{R}$ = the universal gas constant, 1545.4 ft-lb_f/lb_m-mole °R

g_c = gravitational constant, 32.174 ft/sec²

P = the pressure of the gas in the line upstream from the sonic port, psia

T = the temperature of the gas on the line upstream from the sonic port, °R

A = the flow area of the sonic port, in.²

Data employed in the computations were as follows. For methane, $M = 16.04$, $\gamma = 1.30$, $A = 6.16 \times 10^{-4} \text{ in.}^2$, and C_d was measured to be 0.72. For oxygen, $M = 32$, $\gamma = 1.40$, $A = 6.16 \times 10^{-4} \text{ in.}^2$, and C_d was measured to be 0.70.

Since the data reduction program is also to be used in cases employing solid propellant primary rockets, calculations were included to compute the instantaneous propellant flow rate from a cored, cylindrical solid propellant grain. It was assumed that the ends of the grain were unrestricted. Initially, in this calculation procedure, the primary rocket chamber pressures at 50 points in time during the run were computed by averaging 10 adjacent data points about each time value using the same averaging procedure as previously described. Knowing the chamber pressure at each point, the burning rate, r , may be calculated from

$$r = c p_c^n \quad (\text{A-4})$$

where the coefficient c and the exponent n are known for the given propellant. With the initial grain geometry and the burning rate at each point in time, the propellant surface area could be computed as a function of time and the flow rate of propellant at each point in time could be calculated.

Once the flow rate of propellant was known as a function of time, the total mass expelled could be calculated by integrating the instantaneous flow rates over the total run time. This computed total mass was then compared to the measured total mass expelled which was determined from measurements of the weight of the original propellant on the residue following a firing. The instantaneous rate of mass flow was adjusted so that the computed total mass expelled equalled the experimental mass value. Finally, once the DATAD point in time was selected, a linear interpolation was made between the two adjacent points to the DATAB point to obtain the instantaneous flow rate of solid propellant at the DATAD reduction point. No account was taken of the adjustment necessary to account for the increased chamber volume because the relative increase in volume over the period of time in which the flow rate was calculated was small (on the order of a few tenths of a percent).

4. Stagnation State of the Secondary Air, the Rocket Chamber Pressure Correction, and Changes in Geometry During a Run

The stagnation temperature of the air entering the test section was determined by means of three thermocouple probes of the Pratt and Whitney design. The program computed a simple mean of the

three temperatures for use in subsequent computations. No recovery factor correction or heat loss corrections were applied.

A measurement of the static pressure in the transition section served as one means for determining the stagnation pressure of the air entering the test section. The static pressure, stagnation temperature, flow rate, and flow area were known from the available measurements. A value for the Mach number could be found from the relation

$$M = \frac{\dot{w}}{AP} \sqrt{\frac{RT}{\gamma g_c}} \quad (A-5)$$

where it was assumed that, because the Mach number present was so low, the static temperature was equal to the measured stagnation temperature. Given the Mach number, the ratio of the stagnation pressure to the static pressure could be determined from

$$\frac{P_o}{P} = \left(1 + \frac{\gamma-1}{2} M^2 \right)^{\frac{\gamma}{\gamma-1}} \quad (A-6)$$

This procedure was followed in the computations although the difference between the stagnation and static pressures in the transition section was generally small (on the order of 0.5 to 1.0 percent).

In preliminary calculations, it was assumed that the erosion of the primary and secondary nozzles began immediately upon ignition of the primary rocket and proceeded linearly throughout the run. This resulted in the calculation of primary rocket efficiencies slightly lower than expected. After studying the output of the optical system from several of the runs, it was noticed that an increase in the average light intensity from the ramburner occurred in each run approximately 2 seconds after ignition. This phenomenon could be associated with the beginning of the erosion of the primary rocket; the increase in light intensity was attributed to hot, radiating carbon particles from the nozzle erosion. It was assumed in all reported computations that erosion of the primary nozzle began 2 seconds after ignition and then proceeded linearly until the end of the run. Because no similar case could be made for the erosion of the secondary nozzle, it was assumed that the erosion of the secondary nozzle began immediately upon ignition of the primary rocket.

5. Estimate of the Rate of Heat Loss to the Wall of the Ramburner

It was desired to have at least some estimate of the rate of heat loss from the gas to the wall of the ramburner. As noted in Section III the evaluation of the combustion performance will not necessarily distinguish between incomplete combustion and simple heat losses. An

estimate of the rate of heat loss would at least provide some indication as to the extent of that influence on the results of the study.

Only two thermocouple channels were available for this purpose in the laboratory system. They were employed to measure the inner and outer wall temperatures of the ram burner duct at its midpoint ($x/D = 5$) for each run. The wall thicknesses, length dimensions, and positions of the inner thermocouples are as follows:

<u>Duct</u>	<u>OD (in.)</u>	<u>Wall (in.)</u>	<u>Distance of Thermocouple from Inner Wall (in.)</u>
A	3.78	0.375	0.03
B	4.79	0.375	0.03
C	6.50	0.500	0.03

The outer thermocouple was simply staked to the outer wall surface. Both thermocouples were chromel-alumel.

The two temperature measurements were employed as follows to obtain an estimate of the rate of heat transfer to the duct. The following was assumed for this purpose:

a) Losses of heat to the atmosphere due to free convection at the outer surface could be neglected during the run period of several seconds, i.e., the outer wall of the duct was adiabatic.

b) The duct temperature was uniform in the axial direction and varied linearly with radius. The former was certainly not true, but the measurement was taken at the midpoint of the duct which would be at least indicative of some suitable mean temperature. The actual radial distribution would have been approximately logarithmic but for the relatively thin wall, and in the character of the entire approximation, a linear profile could be accepted.

Subject to those rather rough approximations then, the heat absorbed by the duct during the run period, per unit length of duct may be expressed as

$$\begin{aligned}
\dot{Q} &= \int_{r_1}^{r_2} \rho_s C_{p_s} (T_f - T_i) 2\pi r dr \\
&= 2\pi p_s C_{p_s} \left[\frac{(T_f - T_i)}{6} 1 \left(r_2^2 + r_1 r_2 - 2r_1^2 \right) \right. \\
&\quad \left. + \frac{(T_f - T_i)}{6} 2 \left(2r_2^2 - r_1 r_2 - r_1^2 \right) \right] \text{ Btu/ft} \quad (A-7)
\end{aligned}$$

where

T = temperature, °R

ρ_s = the density of stainless steel, lb_m/ft³

C_{p_s} = the specific heat of stainless steel, Btu/lb_m °R

f,1 = denote final and initial conditions, respectively

1,2 = denote inner and outer wall positions, respectively.

The rate of heat loss to the duct wall, then, would be

$$\dot{Q} = \frac{QL}{\tau} \text{ Btu/sec} \quad (A-8)$$

where

L = the length of the duct, ft

τ = the run duration, sec.

This may finally be related to the specific enthalpy change of the combustion gases in the ramburner.

$$\dot{w} (H_2 - H_1) = \dot{Q} \quad (A-9)$$

where the subscripts 1 and 2 denote upstream and downstream stations in the ramburner and H denotes the specific stagnation enthalpy of the combustion gases (including heats of formation, not sensible values).

6. Combustion Efficiency

The combustion efficiency employed herein was defined as the ratio of the rise in sensible stagnation enthalpy to the ideal rise in sensible stagnation enthalpy. The ideal sensible enthalpy rise is the heat which would be released if the reactants were to react at constant pressure, reaching the equilibrium state in an adiabatic pressure and at frozen composition to the temperature of the reactants. If the initial and final total chemical enthalpies are expressed as

$$H_{in} = \sum_{j \text{ propellants}} n_j H_{jT_{in}} = \sum_j n_j H_{fjT_o} + \sum_j n_j \left(H_{jT_{in}} - H_{jT_o} \right) \quad (A-10)$$

$$H_{out} = \sum_{i \text{ species}} n_i H_{iT_{out}} = \sum_i n_i H_{fiT_{out}} + \sum_i n_i \left(H_{iT_{out}} - H_{iT_o} \right) \quad (A-11)$$

then the ideal heat release would be

$$\begin{aligned} \Delta H_{R_{ideal}} &= \sum_j n_j H_{fjT_o} + \sum_j n_j \left(H_{jT_{in}} - H_{jT_o} \right) \\ &\quad - \sum_i n_i H_{fiT_o} + \sum_i n_i \left(H_{iT_{in}} - H_{iT_o} \right) \end{aligned} \quad (A-12)$$

where T_{out} is the ideal adiabatic flame temperature and T_o is a reference temperature. If $T_{in} = T_o$, then

$$\Delta H_{R_{ideal}} = \sum_j n_j H_{fjT_o} - \sum_i n_i H_{fiT_o} \quad (A-13)$$

Now, given some measure of the actual sensible enthalpy rise occurring in the system, the combustion efficiency, η , was defined as

$$\eta = \frac{\Delta H_R}{\Delta H_{R_{ideal}}} \quad (A-14)$$

Note that while the ideal heat release was defined for a constant pressure process, it is not especially sensitive to small variations in pressure. Since the change in pressure in the system is relatively small in comparison to the total pressure, the small change in the ideal heat release accompanying the small pressure change was neglected in the computations. The combustion efficiency was calculated for the air heater, primary rocket, and the complete system, in this manner.

The combustion efficiency of the ramburner section alone may be defined as

$$\eta_{sec} = \frac{\Delta H_{R_{cs}} - \Delta H_{R_e}}{\Delta H_{R_{ideal_{cs}}} - \Delta H_{R_e}} \quad (A-15)$$

where $\Delta H_{R_{cs}}$ is the actual rise in sensible enthalpy for the complete system, $\Delta H_{R_{ideal_{cs}}}$ is the ideal rise in sensible enthalpy for the complete system, and ΔH_{R_e} is the actual sensible enthalpy rise of the substances entering the ramburner. Letting the subscript "sec" denote the ramburner, "ah" denote the air heater, "pr" denote the primary rocket, and "cs" denote the complete system, then

$$\dot{w}_{sec} = \dot{w}_{ah} + \dot{w}_{pr} \quad (A-16)$$

and

$$\dot{w}_{sec} \Delta H_{R_e} = \dot{w}_{sh} \eta_{ah} \Delta H_{R_{ideal_{ah}}} + \dot{w}_{pr} \eta_{pr} \Delta H_{R_{ideal_{pr}}} \quad (A-17)$$

and

$$\dot{w}_{sec} \Delta H_{R_{cs}} + \dot{w}_{sec} \eta_{cs} \Delta H_{R_{ideal_{cs}}} \quad (A-18)$$

then combining these equations yields

$$\eta_{sec} = \frac{\eta_{cs} \Delta H_{R_{ideal_{cs}}} - \beta}{\Delta H_{R_{ideal_{cs}}} - \beta} \quad (A-19)$$

where

$$\beta = \frac{\dot{w}_{ah} \eta_{ah} \Delta H_{R_{ideal_{ah}}} + \dot{w}_{pr} \eta_{pr} \Delta H_{R_{ideal_{pr}}}}{\dot{w}_{sec}} .$$

Since all the terms on the right hand side of Equations (A-16) through (A-19) were either measured or calculated by the program, this expression could then be used to determine the combustion efficiency of the ramburner section along.

The thermochemistry routines as described in Reference [3] compute the chamber, throat, and expansion conditions of the air stream, the primary rocket, and the complete system as noted in Section III. The specific quantities listed by the program for each condition are the pressure, temperature, enthalpy, sensible enthalpy, density, molecular weight, entropy, and velocity. To compute the combustion efficiency of a particular system, it was necessary to determine the stagnation temperature of the flowing medium at the system exit. To enable the evaluation of the stagnation temperature from the experimental data, several different methods were employed. A description of the methods employed for the complete system will be given. The calculations for the air stream and the primary rocket follow similar techniques.

Initially, using the measured propellant flow rates and assuming that the air was at the temperature measured at the air orifice and that all other propellants were at 298°K upon entering the system, the program computed the stagnation enthalpy entering the system. Five stagnation pressures were chosen by the program in a narrow range about the measured stagnation pressure of the air entering the ramburner. For each of those values, together with the inlet stagnation enthalpy, the program computed the ideal stagnation state variables and the associated sonic conditions. Those solutions were stored for reference purposes in the program. In addition, the stream conditions were computed at three expansion* static pressures designated PE(1), PE(2), and PE(3) for each

*Reversible adiabatic expansion from the stagnation state.

assignment chamber stagnation pressure. The three expansion pressures normally selected by the program were, respectively, 0.95, 1.0, and 1.05 times the static pressure measured at the entrance to the secondary nozzle. If the highest computed expansion pressure chosen in this manner happened to be higher than the stagnation pressure, the expansion pressures were lowered by the program such that the highest expansion was slightly below the stagnation pressure.

Next, the actual sensible stagnation enthalpy at the system exit was determined for various combinations of the various (redundant) measured parameters. Initially, a matrix of 25 stagnation solutions at five assigned stagnation temperatures were obtained. These are the solutions lying in the "stagnation state" plane denoted in Figure A-2. The assigned pressures and temperatures were selected as the five equally spaced points between specified limits, PSJMIN, PSJMAX and TSJMIN, TSJMAX, respectively. If these limits were not specified by the program user, the program selected the limits as 0.9 and 1.1 times the ideal stagnation temperature and 0.9 and 1.1 times the measured stagnation pressure. Then, as was done for the ideal cases, the throat solution and three expansion solutions were done for each chamber stagnation solution as shown pictorially in Figure A-2.

Given the array of thermochemical solutions, the next step was to determine the stagnation states corresponding to the various combinations of the experimental measurements. To accomplish that, three additional matrices were computed. The first matrix was the value of the function, g , corresponding to the various combinations of the experimental measurements. To accomplish that, three additional matrices were computed. The first matrix was the value of the function, g , corresponding to each of the 25 calculated throat solutions:

$$g = (\rho^* V^*)_{\text{calculated}} - \left(\frac{\dot{W}}{A^*} \right)_{\text{measured}} \quad (\text{A-20})$$

where "*" indicates conditions at the throat of the secondary nozzle. An example of this matrix is shown in Figure A-3(a). Note that if the matrix was such that the experimental values fell within it, a region occurred where the function was positive and a second region occurred where the function was negative. The program computed the coordinates of points lying on the line of zeros in this matrix. A quadratic equation was then fitted by least squares to those points. This quadratic equation represented the locus of all points in the plane of chamber conditions satisfying the measured sonic mass velocity.

The next matrix computed was termed the "stream thrust matrix." The function represented by this matrix is

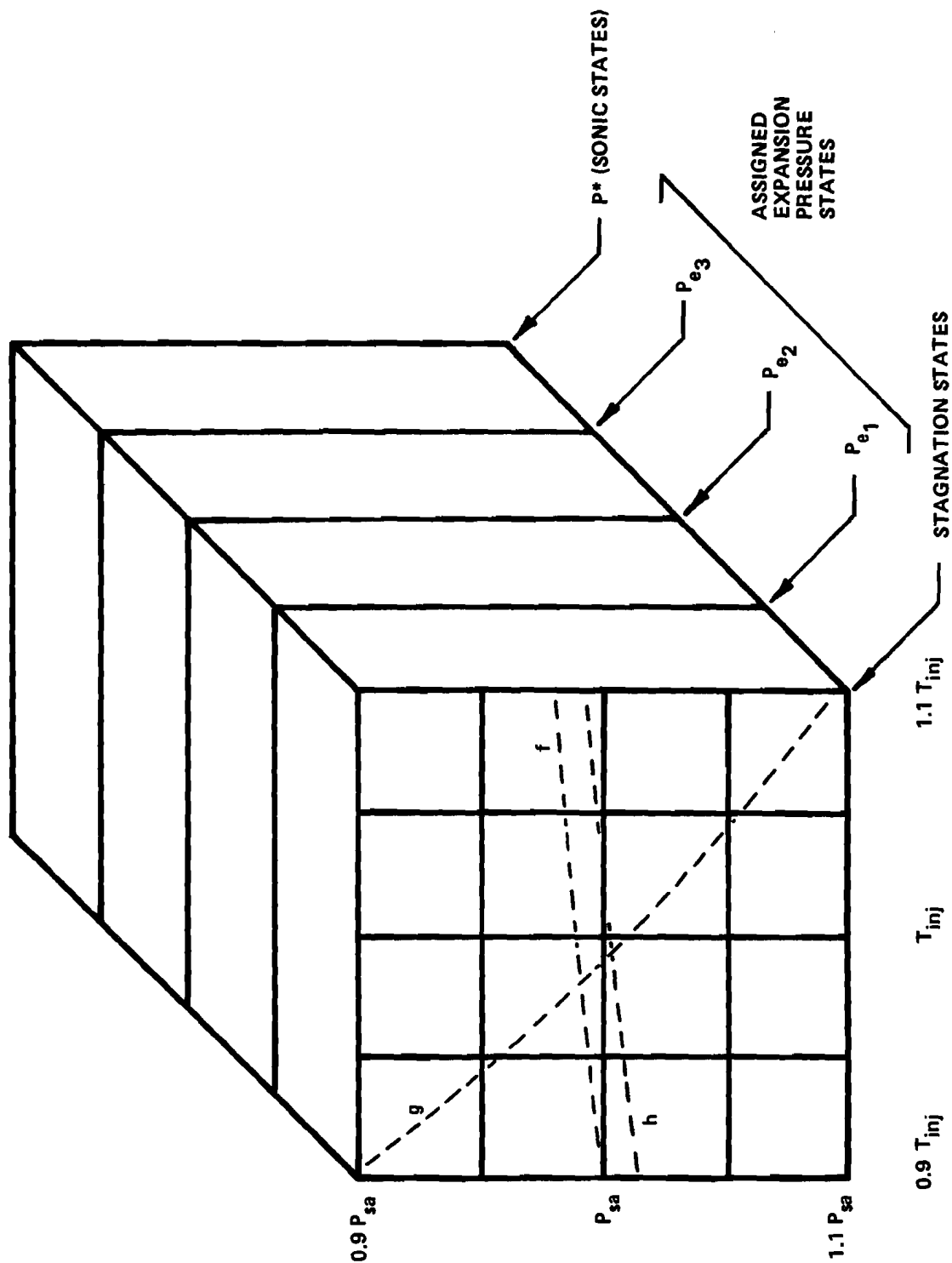


Figure A-2. System State Matrices

(a) MASS VELOCITY MATRIX

	1	2	3	4	5
1	-7.75290E+00	-1.09332E+01	-1.38747E+01	-1.66059E+01	-1.90549E+01
2	-1.31149E+00	-4.66842E+00	-7.77339E+00	-1.06564E+01	-1.32414E+01
3	5.12992E+00	1.59630E+00	-1.67209E+00	-4.70678E+00	-7.42789E+00
4	1.15713E+01	7.86103E+00	4.42922E+00	1.24279E+00	-1.61438E+00
5	1.80127E+01	1.41258E+01	1.05305E+01	7.19236E+00	4.19914E+00

(b) STREAM THRUST MATRIX

	1	2	3	4	5
1	-1.26474E+03	-1.26742E+03	-1.27013E+03	-1.27284E+03	-1.27097E+03
2	-7.82447E+02	-7.85283E+02	-7.88140E+02	-7.91006E+02	-7.89030E+02
3	-3.00159E+02	-3.03143E+02	-3.06151E+02	-3.09167E+02	-3.07088E+02
4	1.82130E+02	1.78996E+02	1.75839E+02	1.72671E+02	1.74855E+02
5	6.64419E+02	6.61136E+02	6.57828E+02	6.54509E+02	6.56797E+02

(c) MASS VELOCITY RATIO MATRIX

	1	2	3	4	5
1	-10.88109E-01	-10.88901E-01	-10.89742E-01	-10.90592E-01	-10.91564E-01
2	-91.95976E-02	-92.02941E-02	-92.10355E-02	-92.17895E-02	-92.26472E-02
3	-64.23492E-02	-64.27244E-02	-64.31242E-02	-64.35321E-02	-64.39954E-02
4	-29.43262E-05	23.99515E-05	94.27669E-05	15.32996E-04	21.98522E-04
5	18.35686E-02	18.42857E-02	18.51308E-02	18.59058E-02	18.67816E-02

Figure A-3. Computation Matrices

$$f = \left[\frac{\rho^* V^{*2}}{g_c} - (P^* - P_{atm}) A^* \right] - \left[\frac{F}{A^*} \right]_{\text{measured}} \quad . \quad (A-21)$$

An example of this matrix is shown in Figure A-3(b). Again, if the limits of the matrix were such as to contain the experimental results, a positive and negative region occurred and a null curve could be determined. A quadratic equation was determined by least squares for this line representing the locus of all points in the plane of chamber conditions which satisfied the measured sonic stream thrust.

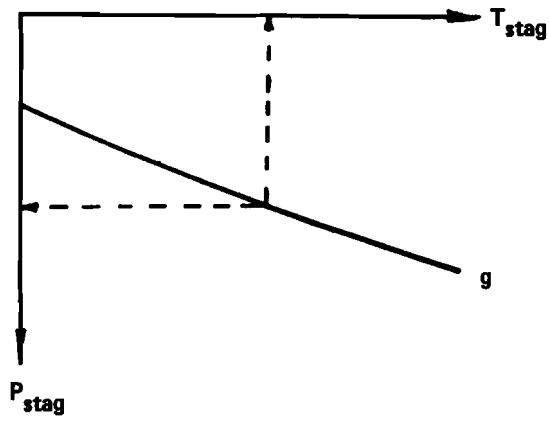
The third matrix computed was termed the "mass velocity ratio matrix," an example of which is shown in Figure A-3(c). The function represented by this matrix is

$$h = \frac{\rho_d V_d}{\rho^* V^*} - \frac{A^*}{A_d} \quad (A-22)$$

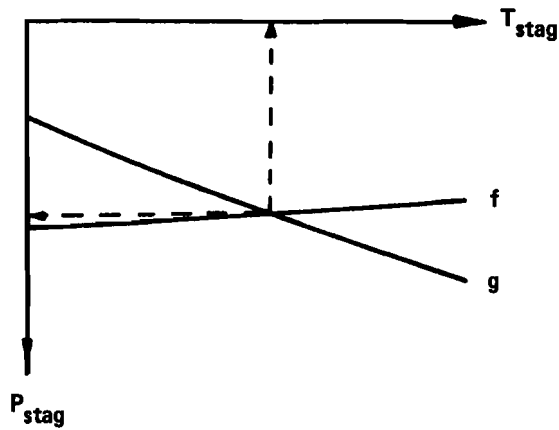
where the subscript d denotes conditions at the end of the ramburner section but upstream from the nozzle. Since the term $\rho_d V_d / \rho^* V^*$ corresponded to expansion from the stagnation state to the measured static pressure, the line of zeros in this matrix represented the locus of all points in the plane of chamber conditions satisfying the measured static pressure at the secondary nozzle entrance.

Several means were then available to determine the actual stagnation temperature occurring in the system. Three methods were employed in the data reduction program to determine the stagnation temperature. These methods are illustrated in Figures A-4(a)-(c). Figure A-4(a) illustrates how the actual stagnation state was obtained from the measured thrust and flow rate. Figure A-4(b) shows how the stagnation temperature was obtained from the measured thrust and flow rate. Figure A-4(c) shows how the stagnation temperature was obtained for the measured parameters of final static pressure and flow rate. By these means, the stagnation temperatures corresponding to the measured values were obtained. The corresponding values for the sensible enthalpy rises were then obtained by interpolation among the matrix of 25 assigned pressure and temperature solutions. Several independent measures of the combustion efficiency could then be calculated from Equation (A-19).

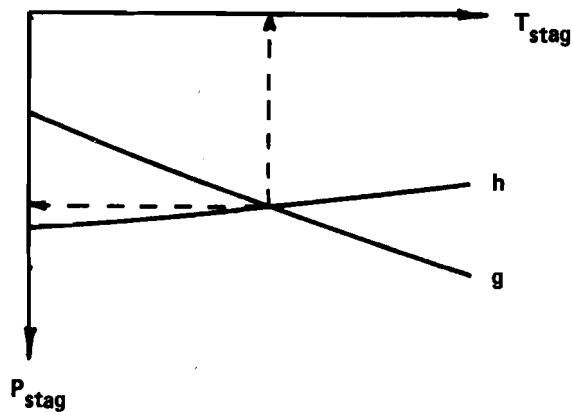
Note that if all the measurements obtained during a run were accurate, all three solutions for the actual stagnation temperature would result in the same stagnation temperature and, subsequently, the same combustion efficiency. Thus, one may evaluate the consistency of the measurements in this manner. If two pairs of measurements result in approximately the same combustion efficiency which is substantially different, this



a. DETERMINATION OF THE STAGNATION STATE
GIVEN EXPERIMENTAL VALUES FOR P_{sa} AND w



b. DETERMINATION OF THE STAGNATION STATE
GIVEN EXPERIMENTAL VALUES FOR F AND w .



c. DETERMINATION OF THE STAGNATION STATE
GIVEN EXPERIMENTAL VALUES FOR P_f AND w .

Figure A-4. Illustration of the Solution Methods

indicates that one of the measurements in this pair is possibly in error. A more complete means for testing the consistency was described in Section IV.

Finally, for each set of chamber conditions determined, the associated expansion conditions were obtained by interpolation between the planes of solution obtained at the PE(1), PE(2), and PE(3) expansion pressures which were illustrated in Figure A-2. The expansion states solved were for the flow rate, sonic thrust, stagnation enthalpy, stagnation temperature, stagnation pressure, static pressure, static temperature, velocity, mass velocity, and molecular weight. The results were printed in the program output.

From the results of the computations based on the various independent sets of measurements, it was determined to what extent the computed combustion efficiency would vary with changes in different measured quantities. The sensitivity of the overall combustion efficiency and the ram-burner efficiency for each run is shown in Table A-I. This study revealed that a 1-percent variation in the thrust or pressure measurement would result in a 2-percent change in the overall combustion efficiency and a 4-percent change in the computed ramburner efficiency.

Table A-I. Sensitivity of the Combustion Efficiency to Variations in Several Measured Quantities (Percent Efficiency per Percent Change)

Run	Sensitivity of η_{oa}			Sensitivity of η_{sec}	
	$\frac{d\eta_{oa}}{dF}$ (%F)	$\frac{d\eta_{oa}}{dP_{sa}}$ (%P _{sa})	$\frac{d\eta_{oa}}{dP_f}$ (%P _f)	$\frac{d\eta_{oa}}{d\dot{w}_{air}}$ (% $\dot{w}_{air}$)	$\frac{d\eta_{sec}}{dx^*}$
22	2.19	2.18	2.10	-1.22	4.04
23	1.98	2.08	2.33		4.69
30	2.05	2.10	1.91		4.24
31	2.11	2.26	2.65		4.17
41	1.85	2.02	2.07		3.60
42	2.10	2.19	1.89		4.14
26	2.19	2.14	2.51		
27	2.03	1.86	2.70		
28	2.04	2.07	2.09		
29	1.90	1.95	2.05		
43	1.67	1.69	2.36		
44	1.99	2.06	1.65		

*x = percent change in thrust or pressure measurement

Appendix B. THE COMPUTER PROGRAM FOR DATA REDUCTION

The computer program employed for reduction of the data was coded in Fortran IV for use on a CDC 6500 computer. It was organized into a main program and several SUBROUTINES and FUNCTION SUBROUTINES. In addition, the program was broken up into four primary overlays; one of the four primary overlays had three secondary overlays. All transfer of stored variables was accomplished by the utilization of COMMON storage. Such organization allowed the program to be run with a minimal amount of storage capacity.

An illustration of structure of the computer program is shown in Figure B-1. Beside each overlay is its name as used by the program. The overlay leg denoted by (DIX4,1,0) primarily consists of the equilibrium thermochemistry program described in Reference [3], and was employed to perform all thermochemical calculations required during the data reduction process. Each of the routines appearing in the program is briefly described in the following.

1. (DIX0,0,0)

a. MAIN Program

The MAIN program served as a traffic control program. It directed the program to proceed in the proper routines in accord with the JOBTYP code read in.

b. Subroutine CROUT

CROUT was a linear equation solving routine which made use of a modification of the Gauss reduction technique. A description of the method may be found in Reference [13].

c. Subroutine STOICH

The subroutine STOICH computed the stoichiometric coefficients for the set of independent reactions taking place among the products of combustion. A complete description of this routine may be found in Reference [3].

2. (DIX1,1,0)

a. Subroutine AVDATA

The subroutine AVDATA read the digital data tape, sorted, and averaged the data for use in later computations. The value of each

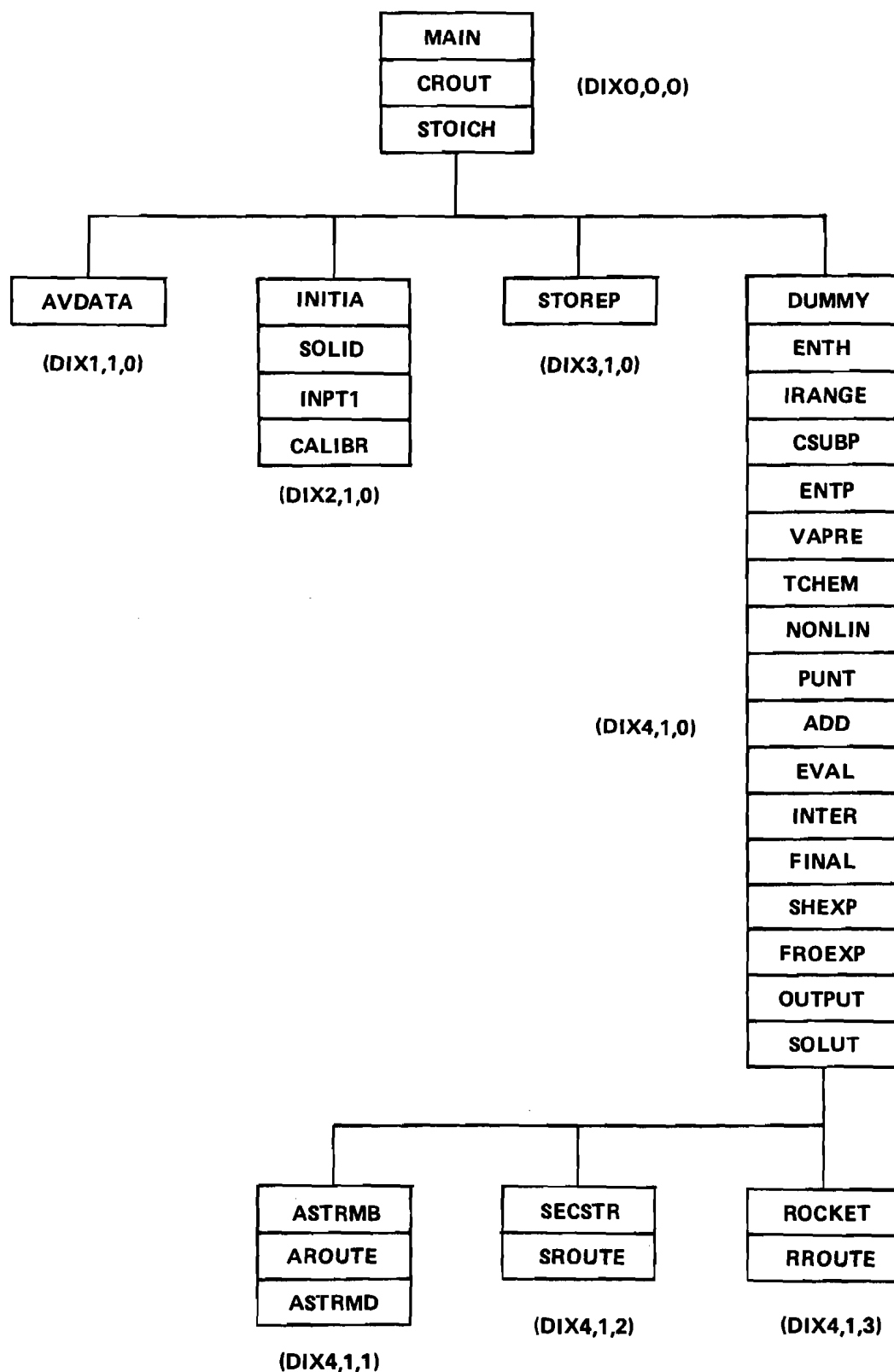


Figure B-1. Structure of the Data Reduction Computer Program

measured parameter at the desired point in time was determined from a least squares straight line through the NSB or NSD sequential values on that channel surrounding the desired point in time. The mean variation of the sequential values from the straight line was also calculated.

3. (DIX2,1,0)

a. Subroutine INITIA

The subroutine INITIA computed the flow rates of all the substances entering the system. In addition, INITIA computed the heat loss from the ramburner and computed the stagnation pressure and temperature of the air entering the ramburner.

b. Subroutine SOLID

The subroutine SOLID computed the instantaneous flow rate from a solid propellant motor having an unrestricted end and internal burning cylindrical grain.

c. Subroutine INPT1

The subroutine INPT1 read in the majority of the card input required by the program and stored the data in the proper arrays for use by other routines.

d. Subroutine CALIBR

The subroutine CALIBR transform the signal data from the digital tape to physical quantities employing the calibration data. The explanation of how the calibration transformations were performed was discussed in Section III-1.

4. (DIX3,1,0)

a. Subroutine STOREP

The subroutine STOREP selected the propellants, atoms, and chemical species to be used for each calculation and stored the required information in the appropriate arrays as required for the thermochemical calculations.

5. (DIX4,1,0)

All subroutines in the primary overlay except the ones which follow are explained in Reference [3] and will not be repeated here.

a. Subroutine VAPRE

The function subroutine VAPRE contained the integrated form of the Clapeyron equation. It was used to calculate the saturated vapor pressure of a condensed specie at any desired temperature.

b. Subroutine SOLUT

The subroutine SOLUT computed the mass velocity, stream thrust, and mass velocity ratio matrices as required by the calling routines. In addition, it computed the null curve of each matrix. Finally, after the chamber conditions were determined, the subroutine was recalled to compute the expansion conditions (pressure, temperature, etc.) of the flowing stream under consideration.

6. (DIX4,1,1)

a. Subroutine ASTRMB

The subroutine ASTRMB controlled the computations made to determine the performance of the air heater prior to ignition of the primary rocket. The number of moles of each propellant entering the air heater were calculated along with the ideal stagnation enthalpy. ASTRMB then called the thermochemistry routines to compute a matrix of assigned pressure and enthalpy solutions and a matrix of assigned pressure and temperature solutions. The matrices were then used by the subroutine AROUTE to compute the air heater performance.

b. Subroutine AROUTE

The subroutine AROUTE is the routine which prepared the necessary indices and variables required by the subroutine SOLUT to calculate the condition of the air stream leaving the air heater. For the air heater before the firing of the primary rocket, solutions were attempted for each of the following pairs of measurements: $(F, \dot{w})$, (P_{sa}, T_{inj}) , and $(P_{sa}, \dot{w})$. For each solution obtained, the subroutine computed the combustion efficiency of the air heater. For the air heater during the firing of the primary rocket, only the solution corresponding to the measured pair (P_{sa}, T_{inj}) was computed.

c. Subroutine ASTRMD

The subroutine ASTRMD performed the same functions as did ASTRMB except that ASTRMD was used to compute the performance at the air heater during the firing of the primary rocket motor.

7. (DIX4,1,2)

a. Subroutine SECSTR

The subroutine SECSTR performed functions similar to those performed by ASTRMB except SECSTR considered the complete system including the air heater, primary rocket, and ramburner, and set up the matrices required to compute the performance of the complete system.

b. Subroutine SROUTE

The subroutine SROUTE was similar to AROUTE differing only in that it computed the combustion efficiencies of the complete system.

8. (DIX4,1,3)

a. Subroutine ROCKET

The subroutine ROCKET performed the same functions for the primary rocket as ASTRMB did for the air heater.

b. Subroutine RROUTE

The subroutine RROUTE performed the same function for the primary rocket as the subroutine AROUTE did for the air heater before the primary rocket firing.

This appendix contains a complete listing of the data reduction program. The control cards used with the program are not shown as they vary from facility to facility. On the CDC 6500 at Purdue University, a field length of 50400₈ was required to load and field length of 63000₈ was required to execute. The program was run under the MACE system using the FUN compiler. The central processor time required for a complete data reduction of a liquid propellant run averaged approximately 5 minutes.


```

OVERLAY(DIX2,1,0)
PROGRAM LINK 20
CALL INITIA
RETURN
END
SUBROUTINE INITIA
INTEGER RANGE
REAL MOLEWT,NU,MU
COMMON/RLK/AA(30,R),AFACA(120),AFACR(120),ALPHA,ATOM(10,30),
1ATWT(10),RRRR(30,R),RFTA(10),CCCC(30,R),CHAMM,CHAMS,ERROR,
2FORMA(120),FORMWT,GA(120),G0,HCHAMA(120),H0(30,R),HTOT,TD(30),
3IREAC,ISCOND(10),ISOL,ISW,JOB(10),KON(30),MMMA,MMMA,MOLEWT(30),
4MU(30),NATOMS,NOVAP(30),NPRE5,NREAC,NSPEC,NU(30,30),PA(120),
5PE(120),PMOLE(10),PNAME(10,2),PO,POUT,PRES,RANGE,SDENS(30),
6ASHSJ(10),SNAMF(2,30),SO(30,R),TEMP,TINIT(K),TMELT(30),TVAP(30),
7VA(120),VAPRES(30),X(30)
COMMON/RLK/RFORMR(30),GR(30),NOSPF,VR(30),XMOLES(20)
COMMON/RLK/AA(30,R),A2,AAAAX(30,R),ADUCT,ADUCT1,AFP,AMASS1,AMASS2,
1AMP(20),AP,ATOMX(10,30),ATP,ATS,ATWTX(10),R0,R1,R2,RRRRX(30,R),
2PRRC,PRNE,RVOLT,C0,C1,C2,CCCCX(30,R),CDATE1,CDATE2,
3CDATE3,CHAOH,COMPAS(10),D0A,DATA(20,20),DATAB(20),NDAT(20),
4DATE1,DATE2,DATE3,DDUCT,DEPA,DEPB,DOMP,OTPA,DTPB,DTSA,DTSP,
5EASTRM,FALR,FLORAT(55),FUEL1,FUEL2,FUEL3,FUELH1,FUELH2,FUELH3,
6HITF,H0X(30,R),HPPROP(10),HPPROPX(10),HSENSE,HFNSE,HSNAOH,IASAVE,
7ICAL,ICHAMB(20),ICHAN,ICDEF(20),ICDEF1(2,10),ICDEF2(2,10),
8ICDEF3(2,10),IDPA,IDP1,IDP2,IDP3,IDP4,IOX(30),IF,IFATAL,ITPF,IPAO,
9IPAC,IPF,IP1,IPS,IPSA,IPSAVF,IPSJ,IROUTE,IS,ISCOND(30)
COMMON/RLK/ISOLTD,ISOLUT,IST,ISTORF,ISU,ISV,ISX,ISY,ISZ,ISSAVE,
1ITABLE,ITANK(20),ITSI(1),IWF,IWHF,IWOX,JOBTYP,JS,KCAL,KCHAN,KDAT,
2KONX(30),KPROP,M,M0,M1,M2,MOLWTX(30),N,N0,NATOM1,NATOM2,NCAL,
3NCALCK,NDAT(20),NPLIF,NOVAPX(30),NP1,NP2,NPROP,NPTS,NSP,
4NSD,NSPEC,NSPEC2,NSPTS,NT,NTST,NW,NUMBER,NWCK(20),OF(15,10),
5OFX,OX1,OX2,OX3,PRAR,PCMAX,PCMIN,PEDES,PF(6),PHF,PNAMEX(10,2),
6POX,PRC,PROPAT(10,10),PRPATX(10,10),PSA,PSAWAX,PSAMIN,PSJMAX,
7PSJMIN,RAD1,RAD2,RAD3,RAT10,PHOP,RUNDIR,SDENX(30),SFCR,
8SECD,SNAMFX(2,30),SOX(30,R),TAMP,TAO,TCMAX,TCHIN,TIMBRN(55),TIME0,
9TIME1,TIME2,TIMEF,TIMEP1,TIMEP2,TIMEP3,TIMEP4,TIMEP5,TIMEP6,
COMMON/RLK/TMELTX(30),TRANSO(21,10),TSA,TSAMAX,TSAMIN,TSIRAV,
1TSDAV,TSIDAT(20),TSJMAX,TSJMIN,TVAPX(30),UN1,UN2,UN3,UN4,UN5,
2UNITS(20),UNITSP,UNITST,VARB(20),VARO(20),VAPDAT(20,20),WA,WAR,
3WAP(20),WFFDCK,WHF,WHFCK,WFFDCK,WNAOHR,WNAOHD,WXCK,WX,
4XX(5),XXX,XXX0,Y0,YY(5),YYY,Z0,ZMW(10),WAD
COMMON/RLK/AM(5,5),D1,D2,GVD(6),PSJ,TSJ,YFACT
COMMON/RLK/GW0R,W020,WNR,WND,ODATAD
COMMON/RLK/TW1(10),TW10(10),TIME(10)
COMMON/RLK/ICHAN,ITEST,LOROP,LIOUID
COMMON/RLK/PPPSAV,ATMSAV,SPCSAV
DIMENSION ASIG(55),RFTA0(15),CALR(20,20),CALRCK(20,20),CALT(20,20)
1,CALTK(20,20),FCDEF(15,15),RE(15),
2TCAL(610),
37X(20,20),XZX(20)
DIMENSION Q(20),QMASS(20),NTW(20),NTWO(20),XOTIM(20)
DIMENSION DPCH(20),WDOTNA(20),WDOT(20)
DIMENSION RTIME(20),THOLD(20),THOLD(20)
CALL INPT1
28 IF(ICAL,EQ,0) GO TO 13
READ(5,103) ICAL,NCAL
DO 10 I=1,NCAL
READ(5,103) ICHAN,NDAT(ICHAN)
READ(5,101) CDATF1,CDATF2,CDATF3
READ(5,101) (TRANSO(21,K),K=1,4)
READ(5,101) UNITST,UNITSP
NN = NDAT(ICHAN)
READ(5,105) (CALT(ICHAN,J), CALR(ICHAN,J), J=1,NN)
READ(5,105) RVOLT
IF(ICAL,EQ,0) GO TO 10
Z1 = I
Z1 = Z1/2,
IX = Z1
IX = 2*IX
IF(IX,NE,1) WRITE(6,134)
WRITE(6,135) ICHAN,CDATF1,CDATF2,CDATF3,(TRANSO(21,K),K=1,4)
WRITE(6,136) UNITST,UNITSP
WRITE(6,137) (CALT(ICHAN,J),CALR(ICHAN,J),J=1,NN)
WRITE(6,138) RVOLT
10 CONTINUE
DO 16 I = 1,NCALCK
READ(5,103) ICHAN,NWCK(ICHAN)
NN = NWCK(ICHAN)
READ(5,10A) (CALTK(ICHAN,J),CALRCK(ICHAN,J),J=1,NN)
IF(ICAL,EQ,0) GO TO 16
Z1 = I
Z1 = Z1/2,
IX = Z1
IX = 2*IX
IF(IX,NE,1) WRITE(6,134)
WRITE(6,12A) ICHAN
WRITE(6,12A) (CALTK(ICHAN,J),CALRCK(ICHAN,J),J=1,NN)
16 CONTINUE
READ(5,110) NT,(ICHAN,AMP(ICHAN),I=1,NT)
IF(ICAL,EQ,0) GO TO 14
WRITE(6,14A) (AMP(I),I=1,20)
GO TO 14
13 READ(5,101) CDATF1,CDATF2,CDATF3
WRITE(6,142) CDATF1,CDATF2,CDATF3
14 IF(ITABLE,EQ,0) GO TO 17
ITABLE = 0
II = 1
DO 4 I = 1,61
READ(5,107) TCAL(II),TCAL(II+1),TCAL(II+2),TCAL(II+3),TCAL(II+4),
1TCAL(II+5),TCAL(II+6),TCAL(II+7),TCAL(II+8),TCAL(II+9)
4 II = II+10
READ(5,109) (FCDEF(I,J),I=1,15),J=1,15)
READ(5,102) (RE(J),J=1,15)
READ(5,102) (REAR(J),J=1,15)
READ(5,101) UN1,UN2,UN3,UN4,UN5
17 IF(JOBTYP,NE,10) GO TO 530
READ(5,102) (DATAB(I),I=1,20)
READ(5,102) (DATAB(I),I=1,20)
READ(5,102) ((DATA(I,J),J=1,NPTS),I=1,20)
DO 531 I = 1,20
VARB(I) = 1,
531 VARO(I) = 1,
530 IPSAVE = NPROP
IASAVE = NATOMS
ISSAVE = NSPEC
DO 500 J = 1,NPROP
PNAMEX(J,1) = PNAME(J,1)
PNAMEX(J,2) = PNAME(J,2)
HPPROPX(J) = HPPROP(J)
DO 500 I = 1,NATOMS
500 PRPATX(J,I) = PRPAT(J,I)
DO 501 I = 1,NATOMS
501 ATWTX(I) = ATWT(I)

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C
C CALIBRATION TRANSFORM*****
C
C
701 CALL CALIBR(CALR,CALT,TCAL)
RTIME(1) = 0.0
ANPTS = NPTS
DELTA T = (TIMEP2-TIMEP1)/ANPTS
NPTS = NPTS+1
DO 910 JJ=2,NPTS
RTIME(JJ)=RTIME(JJ-1)+DELTA T
910 CONTINUE
WRITE(6,9101)
PUNCH 9101
DO 9102 JJ=1,NPTS
WRITE(6,9103) RTIME(JJ)
9102 PUNCH 9119, RTIME(JJ)
L=IPC
WRITE(6,9104)
PUNCH 9104
DO 9105 I=1,NPTS
WRITE(6,9103) DATA(L,I)
9105 PUNCH 9119, DATA(L,I)
L=IF
WRITE(6,9106)
PUNCH 9106
DO 9107 I=1,NPTS
WRITE(6,9103) DATA(L,I)
9107 PUNCH 9119, DATA(L,I)
L=IDP1
WRITE(6,9108)
PUNCH 9108
DO 9109 I=1,NPTS
WRITE(6,9103) DATA(L,I)
9109 PUNCH 9119, DATA(L,I)
L=IDP2
WRITE(6,9110)
PUNCH 9110
DO 9111 I=1,NPTS
WRITE(6,9103) DATA(L,I)
9111 PUNCH 9119, DATA(L,I)
L=IDP3
WRITE(6,9112)
PUNCH 9112
DO 9113 I=1,NPTS
WRITE(6,9103) DATA(L,I)
9113 PUNCH 9119, DATA(L,I)
L=IDP4
WRITE(6,9114)
PUNCH 9114
DO 9115 I=1,NPTS
WRITE(6,9103) DATA(L,I)
9115 PUNCH 9119, DATA(L,I)
IF(IPSJ,EQ,0) GO TO 9116
L=IPJS
WRITE(6,9117)
PUNCH 9117
DO 9118 I=1,NPTS
WRITE(6,9103) DATA(L,I)
9118 PUNCH 9119, DATA(L,I)
9116 CONTINUE
C
C COMPUTATIONS*****
C
C *****FLOW CHECKS AND NAOH FLOW RATE
C
532 IF(JOBTYP,EQ,3) GO TO 302
ISW = -1
II = IWHF
III = ITANK(IWHF)
IIII = ICHAMR(IWHF)
DELP = DATAB(III) + PRAR - DATAB(IIII)
NN = NWCK(II)
DO 91 I = 1,NN
SIG = CALRCK(II,I)
IF(DELP,LT,SIG) GO TO 94
91 CONTINUE
96 CC = ((CALTK(II,I) - CALTK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
1-((CALTK(II,I-1)-CALTK(II,I-1))/(CALRCK(II,I-1) - CALRCK(II,I-1))
2-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
3-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
4-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
5-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
6-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
7-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
8-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
9-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
10-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
11-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
12-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
13-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
14-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
15-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
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21-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
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119-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
120-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
121-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
122-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
123-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
124-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
125-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
126-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
127-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
128-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
129-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
130-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
131-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
132-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
133-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
134-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
135-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
136-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
137-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
138-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
139-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
140-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
141-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
142-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
143-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
144-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
145-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
146-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
147-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
148-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
149-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
150-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
151-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
152-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
153-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
154-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
155-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
156-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
157-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
158-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
159-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
160-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
161-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
162-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
163-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
164-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
165-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
166-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
167-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
168-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
169-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
170-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
171-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
172-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
173-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
174-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
175-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
176-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
177-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
178-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
179-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
180-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
181-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
182-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
183-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
184-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
185-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
186-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
187-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
188-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
189-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
190-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
191-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
192-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
193-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
194-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
195-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
196-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
197-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
198-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
199-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
200-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
201-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
202-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
203-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
204-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
205-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
206-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
207-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
208-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
209-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
210-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
211-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
212-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
213-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
214-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
215-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
216-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
217-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
218-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
219-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
220-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
221-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
222-((CALRCK(II,I) - CALRCK(II,I-1))/(CALRCK(II,I) - CALRCK(II,I-1))
223-((CAL
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K = J-1
DWDOT = (WDOTNA(L)-WDOTNA(K))*((XDPCHB-DPCH(K))/(DPCH(L)-DPCH(K)))
WNAOHB=WDOTNA(K) + DWDOT
DO 3304 J=1,NPCH
IF(XDPCHD,LE,DPCH(J)) GO TO 3305
3304 CONTINUE
3305 L=J
K=J-1
DWDOT=(WDOTNA(L)-WDOTNA(K))*((XDPCHD-DPCH(K))/(DPCH(L)-DPCH(K)))
WNAOHD=WDOTNA(K) + DWDOT
GO TO 330
301 WNAOHB = 0.0
WNAOHD = 0.0
***** IGNITOR FLOW RATES
300 READ(5,102) A2,PLINOX,TLINOX,PLINM,TLINM,GAMMAO,GAMMAM
READ (5,102) XMWO,XMWM,CD0,CDM
GO = (GAMMAO-1.)/GAMMAO
GM = (GAMMAM-1.)/GAMMAM
TRATM = 1. + ((GAMMAM-1.)/2.)
TRATM = 1./TRATM
XGM = 1./GM
PRATM = (TRATM)**XGM
TRATO = 1. + ((GAMMAO-1.)/2.)
TRATO = 1./TRATO
XGO = 1./GO
PRATO = (TRATO)**XGO
PR = (DATAB(IPSA) - PDB)/PLINOX
IF(PR,GT,PRATO) GO TO 201
P02P = PRATO*PLINOX
GO TO 202
201 P02B=DATAB(IPSA)
202 T02P=TLINOX*(P02B/PLINOX)**GO
PR = (DATAB(IPSA) - PDB)/PLINM
IF(PR,GT,PRATO) GO TO 203
P02D = PRATO*PLINM
GO TO 204
203 P02D=DATAB(IPSA)
204 T02D=TLINM*(P02D/PLINM)**GO
PR = (DATAB(IPSA) - PDB)/PLINM
IF(PR,GT,PRATM) GO TO 205
PMB = PRATM*PLINM
GO TO 206
205 PMB=DATAB(IPSA)
206 TMB=TLINM*(PMB/PLINM)**GM
PR = (DATAB(IPSA) - PDB)/PLINM
IF(PR,GT,PRATM) GO TO 207
PMD = PRATM*PLINM
GO TO 208
207 PMD=DATAB(IPSA)
208 TMD=TLINM*(PMD/PLINM)**GM
C02=12.*SQRT(GAMMAO*32.17*1545.*(TLINOX/XMWO))
CM = 12.*SQRT(GAMMAM*32.17*1545.*(TLINOX/XMWM))
RHOOXB = (XMWO/12.)*P02B/(1545.*T02B)
RHOOXD = (XMWO/12.)*P02D/(1545.*T02D)
RHOMB = (XMWM/12.)*PMB/(1545.*TMB)
RHOMD = (XMWM/12.)*PMD/(1545.*TMD)
W02B = RHOOXB*A2*CO2
W02D = RHOOXD*A2*CO2
WMB = RHOMB*A2*CM
WMD = RHOMD*A2*CM
WMO = RHOMD*A2*CM
W02B = CD0*W02B
W02D = CD0*W02D
WMB = CDM*WMB
WMD = CDM*WMD
*****AVERAGE TEMPERATURES
IF(JOBTYP,EQ,10) GO TO 310
IF(JOBTYP,NE,1) GO TO 303
310 TSIBAV = 0.
TSIDAV = 0.
X1 = NTS1
DO 150 J = 1,NPTS
TSIDAT(J) = 0.
DO 151 I = 1,NTS1
I1 = ITS1(I)
TSIBAV = TSIBAV + DATAB(I1)/X1
TSIDAV = TSIDAV + DATAB(I1)/X1
DO 151 J = 1,NPTS
151 TSIDAT(J) = TSIDAT(J) + DATAB(I1)/J/X1
*****AIR FLOW RATES
303 IF(JOBTYP,NE,3) GO TO 311
WAD=1.0
W02D=0.0
WMD=0.0
GO TO 304
311 SIG = WA
READ(5,102) SF
ISIG = -1
163 REYNO = 48.*SIG/(3.141596*118.E-7*1.939)
IF(REYNO - 1.E06) 160,161,161
161 JJ = 1
ISW = 1
GO TO 165
160 DO 162 I = 1,15
RFDIF = REYNO - RE(I)
IF(RFDIF,LE,0.)GO TO 164
162 CONTINUE
164 JJ = I
ISW = -1
165 X1 = DAO/DOMP
DO 166 I = 1,15
RFDIF = X1-BETA0(I)
IF(BETDIF,LE,0.)GO TO 168
166 CONTINUE
168 KK = I
IF(ISW) 170,171,171
170 FC1 = FCOEF(KK-1,JJ-1) + (REYNO-RE(JJ-1))*(FCOEF(KK-1,JJ) -
1 FCOEF(KK-1,JJ-1))/(RE(JJ) - RE(JJ-1))
FC2 = FCOEF(KK,JJ-1) + (REYNO - RE(JJ-1))*(FCOEF(KK,JJ) -
1 FCOEF(KK,JJ-1))/(RE(JJ) - RE(JJ-1))
FC = FC1 + (DAO/DOMP -BETA0(KK-1))*(FC2 - FC1)/(BETA0(KK)- BETA0
1 KK-1))
GO TO 175
171 FC = FCOEF(KK-1,15) + ((DAO/DOMP) -BETA0(KK-1))*(FCOEF(KK,15)
1 - FCOEF(KK-1,15))/(BETA0(KK)-BETA0(KK-1))
175 IF(ISIG) 176,177,178
176 DPAO = DATAB(IPAO)/0.03606

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GAMMA = DATAB(IPAO)*144./(53.342*TAO)
GAMMA=GAMMA*SF
YFACT=1.0-(0.41+0.35*(X1**4.))*((DATAB(IPAO)/DATAB(IPAO))/1.4)
WAB = 359.*FC*DAO**2*YFACT*SQRT(DPAO*GAMMA)/3600000.
RATIO = (WAB - SIG)/SIG
IF(ABS(RATIO),LT,0.2) GO TO 177
SIG = WAB
GO TO 163
177 DPAO = DATAB(IPAO)/0.03606
GAMMA = DATAB(IPAO)*144./(53.342*TAO)
GAMMA=GAMMA*SF
YFACT=1.0-(0.41+0.35*(X1**4.))*((DATAB(IPAO)/DATAB(IPAO))/1.4)
WAD = 359.*FC*DAO**2*YFACT*SQRT(DPAO*GAMMA)/3600000.
RATIO = (WAD-SIG)/SIG
IF(ABS(RATIO),LT,0.2) GO TO 178
SIG = WAD
ISIG = 0
GO TO 163
178 ISIG = 1
DO 180 I = 1,NPTS
DPAO = DATA(IPAO,I)/0.03606
GAMMA = DATA(IPAO,I)*144./(53.342*TAO)
GAMMA=GAMMA*SF
YFACT=1.0-(0.41+0.35*(X1**4.))*((DATA(IPAO,I)/DATA(IPAO,I))/1.4)
180 WAP(I) = 359.*FC*DAO**2*YFACT*SQRT(DPAO*GAMMA)/3600000.
CORRECT PSA MEASUREMENTS FOR AIR VELOCITY
AREA=3.14189*(0.064**2)/4.
SVELB=SQRT(1.4*32.17*53.342*TSIBAV)
SVELD=SQRT(1.4*32.17*53.342*TSIDAV)
RHOB=DATAB(IPSA)*144./(53.342*TSIBAV)
RHOD=DATAB(IPSA)*144./(53.342*TSIDAV)
VELB=WAB*144./(RHOB*AREA)
VELD=WAD*144./(RHOD*AREA)
XMACHB=VELB/SVELB
XMACHD=VELD/SVELD
DATAB(IPSA)=DATAB(IPSA)*((1.+0.2*XMACHB**2.))**3.5
DATAB(IPSA)=DATAB(IPSA)*((1.+0.2*XMACHD**2.))**3.5
IF(JOBTYP,EQ,2) GO TO 411
*****STAGNATION PRESSURE IN JET -- COMPUTATIONS IN AVDAT
*****HEAT ABSORBED BY THE SECONDARY DUCT
READ(5,102) RHODUT,CPDUCT,R1,R0
NNTW = NTW-1
DO 81 J=1,NNTW
DTW(J) = TW(J+1)-TW(J)
DTWO(J) = TWO(J+1)-TWO(J)
Q(J) = (3.1416*P0)*RHODUT*CPDUCT*(DTW(J)*(R0**2-R1**2)+
1 DTWO(J)*(R1**2-R0**2-R1**2))/(2.*10.*R1/12.)
QTIME = TIME(J+1) - TIME(J)
QDOT = Q(J)/QTIME
OMASS(J) = QDOT
XQTIM(J) = (TIME(J)+TIME(J+1))/2.
81 CONTINUE
DATTIM = TIMER2-SECO
DO 84 J=1,NNTW
THOLD(J) = XQTIM(J)
OHOLD(J) = OMASS(J)
84 CONTINUE
DO 85 J = 1,NNTW
L = J+1
OMASS(L) = OHOLD(J)
XQTIM(L) = THOLD(J)
85 CONTINUE
OMASS(1) = 0.0
XQTIM(1) = TIMER1
K = NNTW + 2
OMASS(K) = OMASS(NNTW + 1)
XQTIM(K) = TIMER2
DO 82 J=1,K
IF(DATTIM,LE,XQTIM(J)) GO TO 83
82 CONTINUE
L = J
QO = (OMASS(L)-OMASS(K))*((DATTIM-XQTIM(K))/(XQTIM(L)-XQTIM(K)))
QQTAD = OMASS(K) + QO
*****SOLID PROPELLANT FLOW RATE COMPUTATION
304 IF(1SOLID,EQ,0) GO TO 411
XXCHAN = CHAN
CALL SOLID(XXCHAN,CALT,CALR,ASIG)
411 WRITE(6,134)
DIGIT=0.0
TINIT(1)=298.0
DO 3 L=2,6
DIGIT=1000.0 + DIGIT
3 TINIT(L) = DIGIT
MMA = 0
MMB = 0
DO 9 I = 1,8
9 JOB(I) = 0
DO 6 J = 1,30
1SCOND(J) = 1
6 VAPRES(J) = 0.
ISW = 0
ERROR = .0001
IREAC = 0
1STORE = 1
NPROP = NP1
NATOWS = NATOW1
NSPEC = NSPEC1
RETURN
C
C
C
170 FORMATS *****
101 FORMAT(12A6)
102 FORMAT(7E10,3)
103 FORMAT(20I1)
105 FORMAT(6E12,5)
107 FORMAT(10F5,0)
108 FORMAT(2E10,3)
109 FORMAT(15F9,0)
110 FORMAT(12/(13,E10,3))
128 FORMAT(1H0////1H ,40X,37HSPECIAL CALIBRATION DATA FOR CHANNEL ,
113/1H0,47X,6HCALTCK,14X,6HCALRCK //1
129 FORMAT(1H ,45X,1PE10,3,10X,1PE10,3)
134 FORMAT(1H1)
135 FORMAT(1H , 52X, 16HCALIBRATION DATA/ 1H , 52X, 16H*****

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18/ 1H0, 40X, 40H***** / 1H0, 41X,
27HCHANNEL, 1X, 12, 10X, 36/ 1H, 40X, 40H*****
3***** / 1H0, 47X, 2A6, 1X, 10HTRANSUDCER/ 1H0, 39X, 13HAMPLIFIER
4 NO, 1X, A6, 6X, 13H GAGE UNIT NO., 1X, A6, 1H, 40X, 40H*****
5*****
176 FORMAT(1H0, 42X, 6HTEST (, A6, 1H), 10X, 9HREADING (, A6, 1H)/ 1H +
142X, 13H***** / 10X, 16H***** //)
137 FORMAT(1H, 43X, E12, 5, 10X, E12, 5)
138 FORMAT(1H0, 42X, 16HBRIDGE VOLTAGE = , 1X, E12, 5, 1X, 5HVOLTS/ 1H0
1, 40X, 40H***** //)
142 FORMAT(1H1, 25X, 71H CALIBRATION DATA NOT REQUESTED FOR THIS JOB - US
1E DATA FOR PREVIOUS JOB/ 1H, 40X, 40H LISTING OF CALIBRATION DATA WAS
20 GIVEN ON , 3A6 //)
148 FORMAT(1H1, 79X, 43H AMPLIFICATION VALUES (IN ORDER OF CHANNELS) //
1(1H, 55X, F10, 3))
1022 FORMAT(2F10, 3)
0101 FORMAT(1H, 9HTIME AXIS)
0103 FORMAT(2X, F10, 3)
0104 FORMAT(1H, 16HCHAMBER PRESSURE)
0106 FORMAT(1H, 6HTHRUST)
0108 FORMAT(1H, 4HDELTA P1)
0110 FORMAT(1H, 4HDELTA P2)
0112 FORMAT(1H, 4HDELTA P3)
0114 FORMAT(1H, 4HDELTA P4)
0117 FORMAT(1H, 23HJET STAGNATION PRESSURE)
0119 FORMAT(1F10, 3)
END

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SUBROUTINE SOLID(CXCHAN, CALT, CALR, ASIG)
  INTEGER RANGE
  REAL VOLEWT, NU, MU
  COMMON/BLK A/AAA(30, 8), AFACA(120), AFACB(120), ALPHA, ATOM(10, 30),
  1ATWT(10), BBBB(30, 8), BETA(10), CCCC(30, 8), CHAMH, CHAMS, ERROR,
  2FORMA(120), FORMAT, GA(120), GO, HCHAMA(120), HO(30, 8), HTOT, ID(30),
  3IREAC, ISCOND(30), ISOL, ISW, JOB(10), KON(30), MMA, MMB, MOLEWT(30),
  4MU(30), NATOMS, NOVAP(30), NPRES, NREAC, NSPEC, NU(30, 30), PA(120),
  5PEI(120), PMOLEI(10), PRAME(10, 2), PO, POUT, PRES, RANGE, SDENS(30),
  6SHFJ(30), SNAME(2, 30), SO(30, 8), TEMP, TINIT(6), TMELT(30), TVAPI(30),
  7VA(120), VAPRES(30), X(30)
  COMMON/BLK B/FORMB(30), GB(30), NOSPE, VS(30), XMOLES(120)
  COMMON/BLK C/AO, A1, A2, AAAA(30, 8), ADUCT, ADUCT1, AEP, AMASS1, AMASS2,
  1AMP(20), AP, ATOMX(10, 30), ATP, ATS, ATWTX(10), BO, B1, B2, BBBX(30, 8),
  2BRNC, BRNE, BVOLT, CO, C, C2, CCCC(30, 8), CDAT1, CDAT2,
  3CDAT3, CNAOH, COMPOS(10), DAO, DATA(20, 20), DATAS(20), DATAD(20),
  4DATF1, DATE2, DATE3, DOUCT, DEPA, DEPB, DOMP, DTPA, DTPB, DTS, DTS6,
  5FATRM, FCALR, FLORAT(55), FUEL1, FUEL2, FUEL3, FUELH1, FUELH2, FUELH3,
  6HITES, HOX(30, 8), HPROP(10), HPROP1(10), HSENSF, HSENSP, HSNADOH, IASAVE,
  7ICAL, ICHAMS(120), ICHAN, ICODE(20), ICODEA(2, 10), ICODEP(2, 10),
  8ICODES(12, 10), IDPA, IDP1, IDP2, IDP3, IDP4, IDX(30), IF, IFATAL, IIPF, IPAQ,
  9IPC, IPE, IPI, IPS, IPSA, IPSAVE, IPSJ, IROUTE, IS, ISCOND(30),
  10COMMON/BLK D/ISOL, ISOLUT, IST, ISTORE, JSU, JSV, ISX, ISY, ISZ, ISSAVE,
  11TABLE, ITANK(20), ITS(3), IWF, IWHF, IWOX, JOBTYP, JS, KCAL, KCHAN, KDAT,
  12KONX(30), KPROP, KMO, MO, M1, M2, MOLWTX(30), N, NO, NATOM1, NATOM2, NCAL,
  13NCALCK, NDAT(20), NFILES, NOVAPX(30), NP1, NP2, NPROP, NPTS, NSB,
  14NSD, NSPEC1, NSPEC2, NSPTS, NT, NTS, NTW, NUMBER, NWCK(20), OF(15, 10),
  15OFX, OX1, OX2, OX3, PBAR, PCMAX, PCMIN, PEDES, PF(6), PHF, PNAMEX(10, 2),
  16POX, PRC, PRODAT(10, 10), PRATX(10, 10), PS4, PSAMAX, PSAMIN, PSUMAX,
  17PSUMIN, RAD1, RAD2, RAD3, RATIO, RHOP, ROUNDR, SDENSX(30), SECB,
  18SECD, SNAMEX(12, 30), SOX(30, 8), TAMB, TAO, TCMAX, TCMIN, TIMBRN(55), TIMEO,
  19TIMEI, TIMEP, TIMEF, TIMER1, TIMER2, TNP(1), TNP2,
  20COMMON/BLK E/TMELTX(30), TRANS(2, 10), TSA, TSAMAX, TSAMIN, TS, TPAV,
  21TSDAV, TSDAT(20), TSJMAX, TSJMIN, TVAPX(30), UN1, UN2, UN3, UN4, UNS,
  22UNITS(120), UNITS, UNITST, VARB(20), VARD(20), VARDAT(20, 20), WA, WAB,
  23WAP(20), W, WFDCK, WFF, WFFCK, WFFDCK, WNAOH, WNAOH, WOXCK, WP, XO,
  24XX(15), XXX, XXXQ, YO, YY(5), YYY, ZO, ZMWT(10), ZAG
  25COMMON/BLK F/AM(15, 5), D1, D2, GVD(6), PSJ, TSJ, YFACT
  26COMMON/BLK G/ W02B, W02D, W0B, W0D, QDADAT
  27COMMON/BLK H/TW(10), TWG(10), TIME(10)
  28DIMENSION ASIG(55), BETA(15), CALR(20, 20), CALRCK(20, 20), CALT(20, 20),
  29CALTCK(20, 20), FCOEF(15, 15), RE(15),
  30TCAL(610), ZX(20, 20), ZXZ(20), ZO(20)
  NF = 0
  B14 IF(NF, EO, NFILES) GO TO B12
  B11 READ(9, 68) (ZQ(I), I=1, 20)
  IF(EO, 9) B13, 5
  5 IF(ZQ(5), EO, 0, 0) AND,
  1 ZQ(6), EO, 0, 0) AND,
  1 ZQ(12), EO, 0, 0) AND,
  2 ZQ(13), EO, 0, 0) GO TO 6
  GO TO B11
  6 NF=NF+1
  GO TO B14
  B17 RETURN
  B12 NCHAN = CXCHAN
  CHAN = CXCHAN
  TIMP(1) = TIMER1 - TIMEO
  NN = TIMP(1)/4000./CHAN) - 5.
  JJ = 0
  DO 423 I=1, NN
  423 READ(9, 68) (ZQ(I), I=1, 20)
  DELTAT = (TIMER2 - TIMER1)/50.
  K=1
  NLNL=0
  ZAP=0.0

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451 DO 424 I=1, 10
424 READ(9, 68) (ZX(I), I=1, NCHAN)
  J = IPC
  JJ = JJ + 1
  DO 427 I=1, 10
  427 XZX(I) = ZX(I, J)
  DENOMJ = 825.
  SUMXX = 0.0
  TXXJ = 0.0
  DO 422 J=1, 10
  SUBJ = J
  XXJ = SUBJ * XZX(J)
  422 TXXJ = TXXJ + XXJ
  DO 442 J=1, 10
  442 SUMXX = SUMXX + XZX(J)
  COEFA = (10. * TXXJ - 55. * SUMXX) / DENOMJ
  COEFB = (385. * SUMXX - 55. * TXXJ) / DENOMJ
  SURJ = 5.
  ASIG(K) = COEFA * SURJ + COEFB
  J = IPC
  NN DAT = NN DAT
  ISIG = 99
  DO 435 J=1, NN DAT
  DIF = ASIG(K) - CALT(I, J)
  IF (DIF, LE, 0.0) GO TO 436
  IF (J, EO, NN DAT) GO TO 438
  435 CONTINUE
  438 WRITE (6, 139) I, 1, ISIG, JJ
  JCAL = NN DAT - 1
  GO TO 441
  436 JCAL = J
  IF (JCAL - 1) 439, 439, 440
  439 WRITE (6, 140) I, 1, ISIG, JJ
  JCAL = 2
  GO TO 441
  440 IF (JCAL, EO, NN DAT) JCAL = NN DAT - 1
  441 CC = ((CALT(I, JCAL) - CALT(I, JCAL - 1)) / (CALT(I, JCAL) - CALR(I, JCAL - 1))
  1 - (CALT(I, JCAL + 1) - CALT(I, JCAL)) / (CALT(I, JCAL + 1) - CALR(I, JCAL -
  2))) / ((CALT(I, JCAL) - CALR(I, JCAL + 1))
  3 - (CALT(I, JCAL) - CALT(I, JCAL - 1)) / (CALT(I, JCAL) - CALR(I, JCAL - 1
  4))) - (CALT(I, JCAL) + CALR(I, JCAL - 1)) * CC
  AA = CALT(I, JCAL) - BB * CALR(I, JCAL) - CC * CALR(I, JCAL) * **2
  ASIG(K) = AA + BB * ASIG(K) + CC * ASIG(K) * **2 + PBAR
  BRATE = BRNC * (ASIG(K) * **BRNE)
  TIMBRN(K) = ZAP * DELTAT
  RAD1 = RAD1 + BRATE * DELTAT
  RAD2 = RAD2 + BRATE * DELTAT
  HITE = HITE + 2. * BRATE * DELTAT
  IF (RAD3 - RAD1) 426, 426, 425
  425 SSS = SORT (HITE * **2 + (RAD1 - RAD2) * **2)
  ABURN = 3.1416 * ((RAD1 + RAD2) * SSS + 2. * RAD3 * **2 - RAD1 * **2 - RAD2 * **2)
  ZAP = ZAP + 1.
  FLORAT(K) = RHOP * ABURN * BRATE
  IF (ZAP, GF, 51.0) GO TO 452
  K = K + 1
  NND = (4000. / CHAN) * DELTAT - 10.
  DO 443 I=1, NND
  443 READ(9, 68) (ZQ(I), I=1, 20)
  GO TO 451
  426 IF (RAD3 - RAD2) 429, 429, 430
  430 RAD1 = RAD3
  IF (NLNL) 444, 444, 425
  444 WRITE (6, 431) TIMBRN(K)
  NLNL = 1
  GO TO 425
  429 WRITE (6, 432) TIMBRN(K)
  452 REWIND 9
  JK = K
  LL = K - 1
  503 TOTFLO = 0.0
  DO 437 MM=1, LL
  ABAB = (DELTAT/2.) * (FLORAT(MM) + FLORAT(MM + 1))
  437 TOTFLO = TOTFLO + ABAB
  OFLMA5 = AMASS1 - AMASS2
  RATIO = DELMAS / TOTFLO
  WRITE (6, 445) RATIO
  IF (RATIO, LE, 1.0) AND (RATIO, GE, 0.99) GO TO 500
  IF (RATIO, GE, 1.1) GO TO 501
  RED = ((1 - RATIO) / 50.) + 1.
  DO 504 IJ=1, K
  504 FLORAT(IJ) = FLORAT(IJ) / RED
  GO TO 503
  501 RED = ((RATIO - 1.) / 50.) + 1.
  DO 509 IJ=1, K
  509 FLOPAT(IJ) = RED * FLORAT(IJ)
  GO TO 503
  509 WRITE (6, 446)
  WRITE (6, 450) (FLOPAT(L), TIMBRN(L), L=1, K)
  T = (TIMER2 - TIMER1) - SECD
  WRITE (6, 8307) T, JK
  8307 FORMAT(1H, 20X, 2HT = , 2X, F10, 5, 5X, 3HJK = , 2X, 13)
  DO 818 IJ=1, JK
  IF (TIMBRN(IJ), LE, T) GO TO 818
  GO TO 819
  818 CONTINUE
  819 WP = FLORAT(IJ)
  WRITE (6, 8306) WP
  8306 FORMAT(1H, 20X, 3HWP = , 2X, F10, 5, 2X, 6HLB/SEC)
  RETURN
  C
  C 1/0 FORMATS *****
  C
  68 FORMAT(20F6, 3)
  139 FORMAT(1H1, 21H*****WARNING MESSAGE****/ 1H0, 19HREADING ON CHANNEL ,
  1 12, 25HEXCEEDS CALIBRATION RANGE/ 1H0, 10HCODES I = , 12, 4X,
  2 29HANO JJ = , 12/ 1H0, 17HISIG = -1 - DATAB/ 1H, 8X, 9HO - DATAD/ 1H
  3 3X, 13H1 - DATA(I, J)/ 1H0, 39HJJ DENOTES JTH RUN POINT IN DATA
  4 MATRIX)
  140 FORMAT(1H1, 21H*****WARNING MESSAGE****/ 1H0, 19HREADING ON CHANNEL ,
  1 12, 23HBELOW CALIBRATION RANGE/ 1H0, 10HCODES I = , 12, 4X,
  2 29HANO JJ = , 12/ 1H0, 17HISIG = -1 - DATAB/ 1H, 8X, 9HO - DATAD/ 1H
  3 3X, 13H1 - DATA(I, J)/ 1H0, 39HJJ DENOTES JTH RUN POINT IN DATA
  4 MATRIX)
  450 FORMAT(1H0, 45X, F7, 2, 12X, F7, 2)
  431 FORMAT(1H1, 37HINSIDE BURNING SURFACE REACHED CASING, 2X, F10, 2, 1X, 18
  1HSEC AFTER IGNITION//)
  432 FORMAT(1H1, 21HPROPELLANT BURNED OUT, 1X, F10, 2, 1X, 18HSEC AFTER IGNIT
  1ION//)
  445 FORMAT(1H0, 45HTHE RATIO OF EXP. TO CALC. TOTAL MASS FLOW IS, F10, 2/
  1/ )
  446 FORMAT(1H0, 45X, 9HFLOW RATE, 10X, 12HBURNING TIME, / 1H, 45X, 10HLB PER
  1 SEC, 13X, 3HSEC/ 1H, 44X, 12H***** , 8X, 12H***** //)
  END

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3***** / 1H0.42X.19HBAROMETRIC PRESSURE.4X. F7.3
4.1X.4HPSIA/ 1H.42X.19H AMBIENT TEMPERATURE. 6X. F5.0.1X.1HR/
5 1H0.40X.40H*****
132 FORMAT ( 1H0.49X.22H DESIRED RUN CONDITIONS/1H.49X.22H*****
[***** / 1H0.32X.7HWA = .1PE10.3.1X.6HLB/SEC.10X.
25HNP = .1PE10.3.1X.6HLB/SEC/1H.32X.6HWP = .1X.1PE10.3.1X.6HLB/
35EC.9X.6HOF = .1PE10.3/ 1H.32X.6HPSA = .1X.1PE10.3.1X.4HPSIA/
4.1X.6HDPX = .1PE10.3.1X.4HPSIG/ 1H.32X.6HTSA = .1X.1PE10.3.
5 1X.1HR.14X.6HMF = .1PE10.3.1X.4HPSIG/ 1H.32X.6HPSA = .1
61X.1PE10.3.1X.4HPSIG.11X.6HPRC = .1PE10.3.1X.4HPSIG/1H0.55X.
7 5HAP = .1X.1PE10.3/ 1H.46X.14H RUN DURATION = .1X.1PE10.3.
81X.3HSEC/ 1H0.40X.40H*****
133 FORMAT(1H0.54X.11HNOZZLE DATA/ 1H.54X.11H***** / 1H0.48X.
1 23H PRIMARY THROAT DIAMETER/ 1H.47X.13H BEFORE RUN = . F6.3.1X.
2 6HINCHES/ 1H.47X.13H AFTER RUN = . F6.3.1X.6HINCHES/ 1H0.
348X.21H PRIMARY EXIT DIAMETER/1H.47X.13H BEFORE RUN = . F6.3.
41X.6HINCHES/ 1H.47X.13H AFTER RUN = . F6.3.1X.6HINCHES/ 1H0.
547X.25H SECONDARY THROAT DIAMETER/1H.47X.13H BEFORE RUN = .
6 F6.3.1X.6HINCHES/1H.47X.13H AFTER RUN = . F6.3.1X.6HINCHES/
71H0.34X.23H SECONDARY DUCT DIAMETER.15X.2H = .F7.3/
81H0.40X.40H*****
134 FORMAT(1H1.52X.15H TRANSDUCER DATA/ 1H.52X.15H*****
1 1H0.16X.7H CHANNEL.5X.11H MEASUREMENT. 6X.10H TRANSDUCER.9X.5H MODEL.
210X.6H SERIAL.7X.13H MAXIMUM RANGE/ 1H.16X.7H*****.5X.11H*****
3*****.6X.10H*****.9X.5H*****.10X.6H*****.7X.13H*****
4//1H.16X.6.8X.46.6X.2A6.5X.2A6.5X.2A6.4X.2A6)
143 FORMAT(1H0.50X.19H COMPOSITION BY MASS/1H.50X.19H*****
1H0.46X.10H PROPELLANT.10X.8H FRACT10N/1H.50X.13.12X.F10.5)
144 FORMAT(1H0.45X.30H SPECIE DATA ENTERED IN PROGRAM/1H.45X.30H*****
[***** / 1H0.33X.6H NUMBER.12X.4H NAME.4X.14H ATOM(1.
2K).1 = .1013)
145 FORMAT(1H.34X.13.10X.2A6.15X.10F3.0)
146 FORMAT(1H0.30X.26H SPECIE CODES FOR STREAM 1/2013)
147 FORMAT(1H0.40X.40H***** / 1H0.
137X.45H TANK AND CHAMBER PRESSURE CHANNEL ASSIGNMENTS/1H0.30X.
212H FLOW CHANNEL.10X.12H TANK CHANNEL.10X.15H CHAMBER CHANNEL//)
148 FORMAT(1H0.30X.26H SPECIE CODES FOR STREAM 2/2013)
150 FORMAT(1H0.45X.30H ATOMIC ELEMENTS IN THE PROGRAM/1H.45X.30H*****
[***** / 1H0.47X.6H NUMBER.12X.4H NAME//)
151 FORMAT(1H.49X.13.9X.2A6)
152 FORMAT(1H0.45X.24H ATOM CODES FOR STREAM 1/1013)
153 FORMAT(1H0.45X.24H ATOM CODES FOR STREAM 2/1013)
154 FORMAT(1H0.43X.34H PROPELLANT DATA ENTERED IN PROGRAM/1H.43X.34H**
[***** / 1H0.35X.6H NUMBER.13X.4H NAME.15X.
221H ENTHALPY(KCAL/G MOLE) //)
155 FORMAT(1H.37X.13.10X.2A6.10X.F10.3)
156 FORMAT(1H0.40X.30H PROPELLANT CODES FOR STREAM 1/1013)
157 FORMAT(1H0.40X.30H PROPELLANT CODES FOR STREAM 2/1013)
420 FORMAT (4F10.3)
421 FORMAT (4F10.2,F10.3)
500 FORMAT(1H0.51X.14H JOBTYP CODE = .13)
5001 FORMAT(8F10.4)
5002 FORMAT(2A6)
5003 FORMAT(2F10.3,12F5.2)
5005 FORMAT(16F5.2)
5006 FORMAT(3F10.3,11)
5007 FORMAT(6E13.6)
5008 FORMAT(1H0.43X.34H MAKEUP OF INSTRUMENTATION CHANNELS/1H.43X.34H**
[***** / 1H0)
5009 FORMAT(26X.4HECC0.5X.7HBECKMAN.5X.4HGAGE.5X.6HPOTTER.5X.12HTHERMOC
10UPLE.5X.5HSTRIP.5X.10HV15ICORDER/1H.27X.4HCHAN.7X.3HAMP.7X.4HUNI

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2T.6X.4HCHAN.10X.3HAMP.10X.5HCHART.8X.4HCHAN/1H.27X.4H****.5X.7H**
3*****.5X.4H****.5X.6H****.5X.12H****.5X.5H****.5X.10H**
4***** / 1H0)
5010 FORMAT(29X.12.9X.12.8X.12.8X.12.10X.12.14X.12.10X.12)
5011 FORMAT(712)
END

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SUBROUTINE CALIBR(CALR,CALT,TCAL)
COMMON/BLK/AAAA(30,8),AFAC(120),AFAC3(120),ALPHA,ATOM(10,30),
1ATWT(10),EBUB(30,8),BETA(10),CCCC(30,8),CHAMH,CHAMS,ERROR,
2FORMA(120),FORMWT,GA(120),GO,HCHAMA(120),HO(30,8),HTOT,1D(30),
3IREAC,15COND(30),ISOL,1SW,JOB(10),KON(30),MMA,MMMB,MOLEWT(30),
4MU(30),NATOMS,NOVAP(30),NPHES,NREAC,NSPEC,NUI(30,30),PA(120),
5PE(120),PMOLE(10),PNAME(10,2),PO,POUT,PRES,RANGE,SDENS(30),
6SHS(30),SNAME(2,30),SO(30,8),TEMP,TINIT(6),TMELT(30),TVAP(30),
7VA(120),VAPRES(30),X(30)
COMMON/BLK/FORMB(30),GR(30),NOSPE,V(30),XMOLES(20)
COMMON/BLK/AA(8),AA2,AAAX(30,8),ADUCT,ADUCT1,ADP,AMASS1,AMASS2,
1AMP(20),AP,ATOMX(10,30),ATP,ATS,ATWTX(10),B0,B1,B2,BBBX(30,8),
2BRNC,BRNE,BVOLT,C0,C1,C2,CCCC(30,8),CDATE1,CDATE2,
3CATE3,CN0H,COMPOS(10),DAQ,DATA(20,20),DATAB(20),DATAD(20),
4DATE1,DATE2,DATE3,DDUCT,DEPA,DEPB,DOMP,DTPA,DTPB,DTSA,DTSB,
5FASTRM,FCALR,FLORAT(55),FUEL1,FUEL2,FUEL3,FUELH1,FUELH2,FUELH3,
6HITE,HOX(30,8),HPROP(10),HPROPX(10),HSENSF,HSENSP,HSNAOH,IASAVE,
7ICAL,ICHAMP(20),ICHAN,ICODE(20),ICODEA(2,10),ICODER(2,10),
8ICODES(2,10),IDPA,1DP1,1DP2,1DP3,1DP4,1DX1301,1F,1FATAL,11PF,1PAQ,
9IHC,1IP,1PI,1PS,1PSA,1PSAVE,1PSJ,1ROUTE,1S,1SCNDX(30)
COMMON/BLK/DISOLID,ISOLUT,1ST,1STORE,1SU,1SV,1SX,1SY,1SZ,1SSAVE,
11TABLE,1TANK(20),1TS1(3),1WF,1WFF,1WOX,1JOBTYP,JS,KCAL,KCHAN,KOAT,
2KONX(30),KPROP,M,MO,M1,M2,MOLEWTX(30),N,N0,NATOM1,NATOM2,NCAL,
3NCALCK,NNDAT(20),NPF,LES,NOVAPX(30),NP1,NP2,NPROP,NPTS,NSB,
4NSO,NSPEC1,NSPEC2,NSPTS,NT,NTS,NTW,NUMBER,NWCK(20),OF(15,10),
5OFX,OX1,OX2,OX3,PBAR,PCMAX,PCMIN,PEDES,PF(6),PHF,PNAMEX(10,2),
6PROX,PRC,PROPAT(10,10),PPRATX(10,10),PSA,PSAMAX,PSAMIN,PSJMAX,
7PSJMIN,RAD1,RAD2,RAD3,RAT10, RHOP,RUNDUR,SDENSX(30),SECB,
8SECD,SNAMEX(2,30),SOX(30,8),TAMB,TAQ,TCMAX,TCMIN,TIMBRN(55),TMEQ,
9TIME1,TIME2,TIMEF,TIMEF2,TIMEF3,TIMEF4,TIMEF5,TIMEF6,TIMEF7,
COMMON/BLKE/TMELTX(30),TRANS(21,10),TSA,TSAMAX,TSAMIN,TSIBAV,
1TSIDAV,TSIGAT(20),TSJMAX,TSJMIN,TVAPX(30),UN1,UN2,UN3,UN4,UN5,
2UN1,UN2,UN3,UN4,UN5,UN6,UN7,UN8,UN9,UN10,UN11,UN12,UN13,UN14,UN15,
3WAP(20),WF,WFDCK,WFF,WFFBCK,WFFDCK,WNAOH,WNAOHD,WOXCK,WP,X0,
4XX(5),XXX,XXX0,Y0,YY(5),YYY,ZZ,2MW(10),WAD
COMMON/BLKF/AM(5,5),D1,D2,GV(6),PSJ,TSJ,YFACT
DIMENSION CALR(20,20),CALT(20,20),TCAL(610)
ICL = ICAL
ISWOUT = 1
540 DO 30 J=1,20
IF(ICODE(1).NE.3) GO TO 541
DATAB(1) = 0.0
DATAD(1) = 0.0
DO 542 JJ=1,NPTS
542 DATA(1,JJ) = 0.0
GO TO 30
541 IF(ICODE(11-2) 31,31,32
C
C
C
*****PRESSURES*****
31 UNITS(1) = UN1
IF(ICODE(11).EQ.0) GO TO 130
50 ISIG = -1
SIG = DATAB(1)
NNDAT = NNDAT(1)
DO 35 J=1,NNDAT
OIF = SIG - CALR(1,J)
IF(DIF.LE.0.) GO TO 36
IF(J.EQ.NNDAT) GO TO 38
CONTINUE
38 WRITE(6,139) 1,ISIG,JJ
C
C
C
JCAL = NNDAT-1
GO TO 41
36 JCAL = J
IF(JCAL-1) 39,39,40
39 WRITE(6,140) 1,ISIG,JJ
JCAL = 2
GO TO 41
40 IF(JCAL.EQ.NNDAT) JCAL = NNDAT-1
41 CC = ((CALT(1,JCAL)-CALT(1,JCAL-1))/(CALR(1,JCAL)-CALR(1,JCAL-1))
1-(CALT(1,JCAL+1)-CALT(1,JCAL))/(CALR(1,JCAL+1)-CALR(1,JCAL-
21))/(CALR(1,JCAL)-CALR(1,JCAL+1))
BB = (CALT(1,JCAL)-CALT(1,JCAL-1))/(CALR(1,JCAL)-CALR(1,JCAL-1)
) - (CALR(1,JCAL)+CALR(1,JCAL-1))*CC
AA = CALT(1,JCAL)-BB+CALR(1,JCAL)-CC+CALR(1,JCAL)**2
IF(ICAL.EQ.0) GO TO 80
ISWOUT = -ISWOUT
IF(15WOUT.GE.0.) WRITE(6,150)
DX = (CALR(1,NNDAT) - CALR(1,1))/10.
X1 = CALR(1,1)
WRITE(6,151) 1
DO 81 K = 1,11
X2 = AA + BB*X1 + CC*X1*X1
WRITE(6,152) X2,X1
81 X1 = X1 + DX
ICAL = 0
80 SIG = AA + BB*SIG + CC*SIG**2
IF(15IG.EQ.44.45)
DATAB(1) = SIG
ISIG = 0
SIG = DATAD(1)
GO TO 50
44 DATAD(1) = SIG
ISIG = 1
SIG = DATA(1,1)
JJ = 1
GO TO 50
45 DATA(1,JJ) = SIG
IF(JJ.EQ.NPTS) GO TO 312
JJ = JJ+1
SIG = DATA(1,JJ)
GO TO 50
C
C
C
*****THRUST*****
32 IF(ICODE(11-4) 34,33,53
34 NNDAT = NNDAT(1)
UNITS(1)=UN3
SCALE = FCALR/CALR(1,NNDAT)
DO 51 K = 1,NNDAT
51 CALR(1,K) = CALR(1,K)*SCALE
GO TO 59
C
C
C
*****FLOW RATES*****
33 IEV = -1
UNITS(1)=UN4
FACTOR = 62.46*250.*CALT(1,1)/(CALR(1,1)*CALT(1,2)*7.481)
DATAB(1) = FACTOR*DATAB(1)
DATAD(1) = FACTOR*DATAB(1)
DO 27 J=1,NPTS
27 DATA(1,JJ) = FACTOR*DATA(1,JJ)

```

```

GO TO 30
*****TEMPERATURES*****
63 SIG = DATA(1)
UNITS(1)=UNZ
ISW = 1
67 IF(SIG) 61,62,62
IT = 2
77 = IT
XDIF = Z-ZZ
IT = 61-IT
SIG = TCAL(IT) - (TCAL(1) - TCAL(IT-1))*XUIF
GO TO 64
62 Z = SIG*.24/AMP(1)
IT = 2
77 = IT
XDIF = Z-ZZ
IT = IT + 61
SIG = TCAL(IT) - (TCAL(IT) - TCAL(IT+1))*XDIF
64 IF(SIG) 65,66,67
65 DATA(1) = SIG + 459.67
ISW = 0
SIG = DATA(1)
GO TO 63
66 DATA(1) = SIG + 459.67
ISW = 1
JJ = 1
SIG = DATA(1,1)
GO TO 63
67 DATA(1,JJ) = SIG + 459.67
IF(JJ.EQ.NPTS) GO TO 30
JJ = JJ+1
SIG = DATA(1,JJ)
GO TO 63
130 DATA(1) = 0.
DATA(1) = 0.
DO 131 J = 1,NPTS
131 DATA(1,J) = 0.
112 TCAL = 1CL
30 CONTINUE

ABSOLUTE PRESSURES *****
DO 69 I = 1,20
IF(1CODE(1).NE.2) GO TO 60
UNITS(1)=UNZ
DATA(1) = DATA(1) + PBAR
DATA(1) = DATA(1) + PBAR
DO 69 J = 1,NPTS
59 DATA(1,J) = DATA(1,J) + PBAR
60 CONTINUE
IF(1SOLID.NE.0) GO TO 68
DATA(1PC) = DATA(1PC)/0.9788
68 RETURN
139 FORMAT(1H , 21H***WARNING MESSAGE**/ 1H0,19HREADING ON CHANNEL ,
1 12, 25HEXCEEDS CALIBRATION RANGE/ 1H0,10HCODES 1 = , 12, 4X,
20HANO JJ = ,12/ 1H0, 17H(SIG = -1 - DATA/ 1H ,8X,9H0 - DATA/1H
3 , 8X, 13H) - DATA(1,J)/ 1H0, 39HJJ DENOTES JTH RUN POINT IN DATA
4 MATRIX)
140 FORMAT(1H , 21H***WARNING MESSAGE**/ 1H0,19HREADING ON CHANNEL ,
1 12, 23HNO CALIBRATION RANGE/ 1H0,10HCODES 1 = , 12, 4X,
20HANO JJ = ,12/ 1H0, 17H(SIG = -1 - DATA/ 1H ,8X,9H0 - DATA/1H
3 , 8X, 13H) - DATA(1,J)/ 1H0, 39HJJ DENOTES JTH RUN POINT IN DATA
4 MATRIX)
150 FORMAT(1H)
151 FORMAT(1H0//////1H ,38X,43HPOINTS ON THE CALIBRATION CURVE FOR CHAN
1NEL ,13/1H0,44X,10HTEST VALUE,14X,7HREADING//)
152 FORMAT(1H ,43X, E12,5,10X, E12,5)
END

OVERLAY(DIX3,1,0)
PROGRAM LINK 30
CALL STOREP
RETURN
FNC
SUBROUTINE STOREP
INTEGER RANGE
REAL MOLFWT,NU,MU
COMMON/BLKA/AAAA(30,8),AFACA(120),AFACB(120),ALPHA,ATOM(10,30),
1ATWT(10),BBBB(30,8),BETA(10),CCCC(30,8),CHAMH,CHAMS,ERROR,
2FORMA(120),FORMWT,GA(120),GO,HCHAMA(120),HO(30,8),HTOT,IO(30),
3IREAC,15COND(30),15OL,15W,JOB(10),KON(30),MMA,MMMB,MOLEWT(30),
4MU(30),NATOMS,NOVAR(30),NPRES,NREAC,NSPEC,NU(30,30),PA(120),
5PE(120),PMOLE(10,2),PNAME(10,2),PO,POUT,PRES,RANGE,SDENS(30),
6SHS(30),SNAME(2,30),SO(30,8),TEMP,TJNT(6),TMELT(30),TVAP(30),
7VA(120),VAPRES(30),X(30)

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COMMON/BLKX/FORMB(30),GB(30),NOSPE,VB(30),XMOLES(20)
COMMON/BLKC/AG,A1,A2,AAAAA(30,8),ADUCT,ADUCT1,AEP,AMASS1,AMASS2,
1AMP(20),AP,ATOMX(10,30),ATP,ATS,ATWTX(10),B0,B1,B2,BBBB(30,8),
2BRN,BRNE,BVOL,CO,CI,C2,CCCC(30,8),CDATE1,CDATE2,
3CDATE3,CNAOH,COMP05(10),DAO,DATA(20,20),DATAB(20),DATAD(20),
4DATE1,DATE2,DATE3,DDUCT,DEPA,DEPB,DOMP,OTPA,OTPB,OTSA,OTSB,
5FASTRM,FCALR,FLORAT(55),FUEL1,FUEL2,FUEL3,FUELH1,FUELH2,FUELH3,
6H1TE,HOX(30,8),HPROP(10),HPROPX(10),HSENSP,HSENSP,H5NAOH,IASAVE,
7ICAL,ICHAMB(20),ICHAN,ICODE(20),ICODEA(2,10),ICODEP(2,10),
8ICODES(2,10),IDPA,IDP1,IDP2,IDP3,IDPA,IDX(30),IF,IFATAL,IIPF,IPAO,
9IPC,IPF,IPI,IPI,IPS,IPSA,IPSAVE,IPSJ,ITROUTE,IS,ISCNDX(30)
COMMON/BLKD/ISOLID,ISOLUT,IST,ISTORE,ISU,ISV,ISX,ISY,ISZ,ISSAVE,
1ITABLE,ITANK(20),ITS(3),IWF,IWHF,IWOX,JOBTYP,JS,KCAL,KCHAN,KDAT,
2KONX(30),KPROP,M,M0,M1,M2,MOLWTX(30),N,N0,NATOM1,NATOM2,NCAL,
3NCALCK,NDAT(20),NFILES,NOVAPX(30),NP1,NP2,NPROP,NPTS,NSB,
4NSD,NSPEC,NSPEC2,NSPTS,NT,NTS1,NTW,NUMBER,NWCK(20),OF(15,10),
5OFX,OX1,OX2,OX3,IPSA,IPCMAX,PCMIN,PEDES,PF(6),PHF,PNAMEX(10,2),
6POX,PRC,PRPDAT(10,10),PRPATX(10,10),PSA,PSAMAX,PSAMIN,PS,MAX,
7PSMIN,RAD1,RAD2,RAD3,RATIO, RHOP,RUNDR,SDENSX(30),SECB,
8SECCO,SNAMEX(2,30),SOX(30,8),TAMB,TAO,TCMAX,TCMIN,TIMBRN(55),TIMED,
9TIME1,TIME2,TIMELT,IMER1,IMER2,TIMPC1,TIMPC2
COMMON/BLKE/TMELTX(30),TRANSD(21,10),TSA,TSAMAX,TSAMIN,TS,BAV,
1TS,DAV,TSIDAT(20),TSJMAX,TSJMIN,TVPARX(30),UNI,UN2,UN3,UNA,UNE,
2UN,ITS(20),UNITSR,UNITS,VARB(20),VARD(20),VARDAT(20,20),WA,WAB,
3WAP(20),WDF,WFDCK,WHF,WHFCK,WHFDCK,WNAOH,WNAOHD,WOXCK,WP,XO,
4XX(5),XXX,XXXO,YO,YY(5),YYY,ZO,ZMWT(10),WAD
COMMON/BLKF/AM(5,5),D1,D2,GVD(6),PSJ,TSJ,YFACT
COMMON/BLKM/BLKX,INTROU,THOLD,MIXR,NOSCIL,LSR,SHOLD,NSPCT,KLPM
IF(ISTORE,NE,1) GO TO 700
NPROP=PPRPAV
NATOMS=ATMSAV
NSPEC=SPCSAV
700 DO B I = 1,30
8 X(I) = I,
DO 520 J = 1,NPROP
IF(ISTORE = 1) 701,702,702
702 NN = ICODEP(ISTORE,J)
GO TO 703
701 NN = J
703 PHAME(J,1) = PHAMEX(NN,1)
PHAME(J,2) = PHAMEX(NN,2)
HPRDP(J) = HPRDP(NN)
DO 520 I = 1,NATOMS
IF(ISTORE = 1) 705,706,706
706 NNN = ICODEA(ISTORE,I)
GO TO 520
705 NNN = I
520 PRPDAT(J,I) = PRPATX(NN,NNN)
DO 421 I = 1,NATOMS
IF(ISTORE = 1) 708,709,709
709 NNN = ICODEA(ISTORE,I)
GO TO 521
708 NNN = I
521 ATWT(I) = ATWTX(NN)
KLM = 0
K = 0
NOSPE = NSPEC
DO 522 J = 1,NSPEC
KLM = KLM + 1
K = K + 1
IF(ISTORE = 1) 710,711,711
711 NN = ICODES(ISTORE,KLM)
IF(ISTORE,EO,1) GO TO 712
GO TO 712
710 NN = KLM
712 SNAME(1,K) = SNAMEX(1,NN)
SNAME(2,K) = SNAMEX(2,NN)
DO 523 I = 1,NATOMS
IF(ISTORE = 1) 713,714,714
714 NNN = ICODEA(ISTORE,I)
GO TO 523
713 NNN = I
523 ATOM(I,K) = ATOMX(NN,NN)
MOLWT(K) = MOLWTX(NN)
TMELT(K) = TMELTX(NN)
TVAP(K) = TVAPX(NN)
NOVAP(K) = K
ID(K) = IDX(NN)
IF(ID(K),NE,1) SDENS(K) = SDENSX(NN)
DO 524 I = 1,8
HD(K,I) = HOX(NN,I)
SOX(K,I) = SOX(NN,I)
AAAA(K,I) = AAAAX(NN,I)
BBBB(K,I) = BBBBX(NN,I)
714 CCCC(K,I) = CCCCX(NN,I)
IF(ID(K),EQ,1) GO TO 525
K1 = K + 1
K2 = K + 2
IF(ID(K),EQ,3) GO TO 526
KON(K) = 1
KON(K1) = 2
KON(K2) = 3
GO TO 427
526 ISCOND(K1) = 0
527 NOVAP(K1) = K
NOVAP(K2) = K
MOLWT(K1) = MOLWTX(NN)
MOLWT(K2) = MOLWTX(NN)
SNAME(1,K1) = SNAMEX(1,NN)
SNAME(2,K1) = SNAMEX(2,NN)
SNAME(1,K2) = SNAMEX(1,NN)
SNAME(2,K2) = SNAMEX(2,NN)
DO 528 I = 1,NATOMS
IF(ISTORE = 1) 715,716,716
716 NNN = ICODEA(ISTORE,I)
GO TO 717
715 NNN = I
717 ATOM(1,K1) = ATOMX(NN,NN)
528 ATOM(1,K2) = ATOMX(NN,NN)
K = K2
GO TO 522
525 KON(K) = 1
522 CONTINUE
NSPEC = K
I1 = NOSPE + 1
I2 = M1 + 1
RETURN
END

```



```

FUNCTION ENTP(J,T,PPRES)
INTEGER RANGE
REAL MOLEWT,NU,MU
COMMON/RLKA/AAAA(30,8),AFACA(120),AFACB(120),ALPHA,ATOM(10,30),
1ATWT(10),BBBB(30,8),BETA(10),CCCC(30,8),CHAMH,CHAMS,ERROR,
2FORMA(120),FORMWT,GA(120),GO,HCHAMA(120),HO(30,8),HTOT,ID(30),
3IREAC,ISCOND(30),ISOL,ISW,JOB(10),KON(30),MMA,MMMB,MOLEWT(30),
4MU(30),NATOMS,NOVAP(30),NPRES,NREAC,NSPEC,NU(30,30),PA(120),
5PE(120),PMOLE(10),PNAME(10,2),PO,POUT,PRES,RANGE,SDENS(30),
6SHSJ(30),SNAME(2,30),SO(30,8),TEMP,TINIT(6),TMELT(30),TVAP(30),
7VA(120),VAPRES(30),X(30)
COMMON/BLKS/FORMB(30),GB(30),NOSPE,VB(30),XMOLES(20)
IF (KON(J),EQ,1) GO TO 1
IF (KON(J),EQ,2) GO TO 2
IF (KON(J),EQ,3) GO TO 3
IF (KON(J),EQ,4) GO TO 2
IF (KON(J),EQ,5) GO TO 3
1 I=RANGE
INDEX=J
TO=TINIT(I)
GO TO 20
2 I=7
INDEX=NOVAP(J)
TO=TMELT(INDEX)
GO TO 20
3 I=R
INDEX=NOVAP(J)
TO =298.0
20 S11=50(INDEX,1)+AAAA(INDEX,1)*ALOG(T/TO)+BBBB(INDEX,1)*
1IT-TO) - 0.5*CCCC(INDEX,1)*((1.0/T**2)-(1.0/TO**2))
IF (DPPRES,EQ,1.0) GO TO 10
S22=1.98725*ALOG(PPRES)
GO TO 21
10 ENTP=S11
RETURN
21 ENTP=S11 - S22
RETURN
END

```

```

FUNCTION VAPRE(J)
COMMON/RLKA/AAAA(30,8),AFACA(120),AFACB(120),ALPHA,ATOM(10,30),
1ATWT(10),BBBB(30,8),BETA(10),CCCC(30,8),CHAMH,CHAMS,ERROR,
2FORMA(120),FORMWT,GA(120),GO,HCHAMA(120),HO(30,8),HTOT,ID(30),
3IREAC,ISCOND(30),ISOL,ISW,JOB(10),KON(30),MMA,MMMB,MOLEWT(30),
4MU(30),NATOMS,NOVAP(30),NPRES,NREAC,NSPEC,NU(30,30),PA(120),
5PE(120),PMOLE(10),PNAME(10,2),PO,POUT,PRES,RANGE,SDENS(30),
6SHSJ(30),SNAME(2,30),SO(30,8),TEMP,TINIT(6),TMELT(30),TVAP(30),
7VA(120),VAPRES(30),X(30)
ZZ=0.0
ZZZ=0.0
ZZZZ=0.0
R=1.986
IR1=IRANGE(TVAP(J))
IR2=IRANGE(TEMP)
JK=IR2-IR1
IF (JK,GT,20) 30
20 KLLL=1
LLLL=1
I=IR1
T1=TEMP
GO TO 100
30 IF (JK,GT,1) GO TO 110
KLLL=1
LLLL=0
I=IR1
K=IR2
GO TO 100
110 I=IR1
K=IR2
KLLL=0
LLLL=0
LL=IR1+1
NN=IR2-1
GO TO 100
10 IF (JK,LT,-1) GO TO 120
KLLL=1
LLLL=1
I=IR1
K=IR2
GO TO 100
120 I=IR1
K=IR2
LLLL=-1
KLLL=-1
LL=IR2+1
NN=IR1-1
100 AL=AAAA(J,7)
BL=BBBB(J,7)
CL=CCCC(J,7)
TM=TMELT(J)
HL=HO(J,7)
Z=AL*ALOG(TEMP/TVAP(J))-AL*TM*((1./TEMP)-(1./TVAP(J)))-(BL/2)*((1./
1MP-TVAP(J))-BL*((1./TM**2)/2.)*((1./TEMP)-(1./TVAP(J)))-(CL/2.)*((1./
2TEMP**2)-(1./TVAP(J)**2)))+(CL/TM)*((1./TEMP)-(1./TVAP(J)))+HL*((1./
3TEMP)-(1./TVAP(J)))
A1=AAAA(J,1)
B1=BBBB(J,1)
C1=CCCC(J,1)
IF (LLLL) 75,80,90

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```

75 T1=TINIT(I)
T1=TINIT(I)
GO TO 95
80 T1=TINIT(I+1)
90 T1=TINIT(I)
95 HL=HO(J,1)
ZZ=A1*ALOG(T1/TVAP(J))+A1*T1*((1./T1)-(1./TVAP(J)))+(B1/2.)*((T1-
1VAP(J))+B1*((1./T1**2)/2.)*((1./T1)-(1./TVAP(J)))+(C1/2.)*((1./T1**2
2)-(1./TVAP(J)**2))-(C1/T1)*((1./T1)-(1./TVAP(J)))-H1*((1./T1)-(1./
3TVAP(J)))
IF (LLLL) 70,70,60
70 AK=AAAA(J,K)
BK=BBBB(J,K)
CK=CCCC(J,K)
IF (LLLL) 85,86,86
85 TK=TINIT(K)
TK=TINIT(K+1)
GO TO 87
86 TK=TINIT(K)
TK=TK
87 HK=HO(J,K)
ZZZ=AK*ALOG(TEMP/TK)+AK*TK*((1./TEMP)-(1./TK))+(BK/2.)*((TEMP-TK)+
1RK*((1./TK**2)/2.)*((1./TEMP)-(1./TK)))+(CK/2.)*((1./TEMP**2)-(1./TK*
2**2))-(CK/TK)*((1./TEMP)-(1./TK))-HK*((1./TEMP)-(1./TK))
60 IF (KLLL) 45,45,50
45 DO 40 MM=LL,NN
ALL=AAAA(J,MM)
BL=BBBB(J,MM)
CL=CCCC(J,MM)
TLL=TINIT(MM)
TLL=TINIT(MM)
HLL=HO(J,LL)
TN=TINIT(MM+1)
ZZZZ=ALL*ALOG(TN/TLL)+ALL*TLL*((1./TN)-(1./TLL))+(BL/2.)*((TN-TL
1L)+BL*((1./TN**2)/2.)*((1./TN)-(1./TLL)))+(CL/2.)*((1./TN**2)-(1./
2TLL**2))-(CL/TLL)*((1./TN)-(1./TLL))-HLL*((1./TN)-(1./TLL))
ZZZZ=ZZZZ+ZZZZ
40 CONTINUE
IF (KLLL,EQ,-1) ZZZZ=-1.0*ZZZZ
90 VAPRE=EXP((ZZ+ZZZ+ZZZZ)/Z)/R
RETURN
END

```

```

SUBROUTINE TCHEM
INTEGER RANGE,SPECIE
REAL MOLEWT,NU,MU
COMMON/RLKA/AAAA(30,8),AFACA(120),AFACB(120),ALPHA,ATOM(10,30),
1ATWT(10),BBBB(30,8),BETA(10),CCCC(30,8),CHAMH,CHAMS,ERROR,
2FORMA(120),FORMWT,GA(120),GO,HCHAMA(120),HO(30,8),HTOT,ID(30),
3IREAC,ISCOND(30),ISOL,ISW,JOB(10),KON(30),MMA,MMMB,MOLEWT(30),
4MU(30),NATOMS,NOVAP(30),NPRES,NREAC,NSPEC,NU(30,30),PA(120),
5PE(120),PMOLE(10),PNAME(10,2),PO,POUT,PRES,RANGE,SDENS(30),
6SHSJ(30),SNAME(2,30),SO(30,8),TEMP,TINIT(6),TMELT(30),TVAP(30),
7VA(120),VAPRES(30),X(30)
COMMON/BLKA/FORMB(30),GB(30),NOSPE,VB(30),XMOLES(20)
COMMON/AA1/ISORT(60),SPECIE(30),NNSPEC,ISL,NOSOLN,XMIN
COMMON/BLK1/CHAN,ITEST,LDROP,LIOUID
COMMON/BLKN/MIX,INTROU,THOLD,MIXR,NOSCIL,LSR,SHOLD,NSPCT,KLPM,HOLD
ID
XMIN=1.E-10
NOSOLN=0
LSR=0
NOSCIL=0
5 LDROP=0
KSK=0
NSTORF=0
LIOUID=0
ITEST=0
INTROU=0
JJJ=0
LLLL=0
MMA,NATOMS,NREAC
IF (NNSPEC,EQ,M) GO TO 20
LIOUID=1
IRAC=IREAC
ISL=ISOL
10 ISOL=1
IREAC=0
KKK=0
20 CONTINUE
IF (ISOL,EQ,1) LL=1+M
IF (ISOL,EQ,2) LL=2+M
IF (ISOL,EQ,3) LL=2+M
IF (ISOL,EQ,4) LL=2+M
IF (ISOL,EQ,5) LL=3+M
IF (ISOL,EQ,6) LL=3+M
40 CALL NONLIN (LL)
IF (LIOUID,EQ,0.AND,ITEST,EQ,1) NOSOLN=1
IF (NOSOLN,EQ,1) RETURN
IF (LIOUID,EQ,0) RETURN
C
CHECK TO SEE IF A PHASE HAS CONDENSED THAT SHOULD NOT HAVE.
C IF SO, IT WILL HAVE A NEGATIVE NORMALIZED MOLE FRACTION.
C
50 M=0
DO 70 J=1,NSPEC
IF (SPECIE(J),NE,0) GO TO 70
IF (ISCOND(J),EQ,1) GO TO 60
IF (KON(J),EQ,1) GO TO 70
M=M+1
IF (X(M),GE,0.0) GO TO 70
INPX=NOVAP(J)
ISCOND(J)=1
ISCOND(INDEX)=1

```

```

WRITE (6,190) (SNAME(I,INDEX),I=1,2)
KKK=INDEX
ITEST=0
ASPE=NNSPEC
X(M)=PRES/ASPE
WRITE (6,220) TEMP,ISOL
IF (LLL.EQ.INDEX) INTROU=INTROU+1
LLL=INDEX
IF (INTROU.GE.3) GO TO 150
GO TO 40
C
C
60 IF (KON(J).NE.1) GO TO 70
M=M+1
70 CONTINUE
IF (IREAC.NE.0) GO TO 10
C
C CHECK FOR CONDENSED PHASES. IF A SPECIE SHOULD BE CONDENSED
C ITS VAPOR PRESSURE WILL BE LESS THAN THE NORMALIZED MOLE FRACTION
C CALCULATED.
C
M=0
DO 90 J=1,NSPEC
IF (SPECIE(J).NE.0) GO TO 90
IF (ISCOND(J).EQ.1) GO TO 80
IF (KON(J).EQ.1) GO TO 90
M=M+1
GO TO 90
C
80 IF (KON(J).NE.1) GO TO 90
M=M+1
IF (ID(J).NE.2) GO TO 90
IF (KKK.GE.J) GO TO 90
KKK=0
JJ=J+1
IF (TVAP(J).EQ.0.0) JJ=J+2
IF (TEMP.LT.TMELT(J)) JJ=J+2
IF (VAPRES(JJ).GT.X(M)) GO TO 90
X(M)=X(M)-VAPRES(JJ)
ISCOND(JJ)=0
ISCOND(J)=0
ITEST=0
INDEX=NOVAP(J)
WRITE (6,180) J,(SNAME(I,INDEX),I=1,2),JJ
WRITE (6,220) TEMP,ISOL
IF (JJ.EQ.0) INTROU=INTROU+1
TSTORE=TEMP
JJ=JJ
GO TO 40
C
90 CONTINUE
IF (KKK.EQ.0) GO TO 100
KKK=0
GO TO 50
C
100 CONTINUE
C
C CHECK TO SEE IF A SPECIE HAS SOLIDIFIED THAT SHOULD NOT HAVE.
C IF SO THE CALCULATED STATIC TEMPERATURE WILL EXCEED ITS MELTING
C TEMPERATURE.
C
DO 120 J=1,NSPEC
IF (SPECIE(J).NE.0) GO TO 120
IF (KON(J).EQ.1) GO TO 120
IF (ISCOND(J).EQ.1) GO TO 120
K=NOVAP(J)
IF (KON(J).EQ.3) GO TO 110
IF (KON(J).EQ.5) GO TO 110
IF (TEMP.GE.TMELT(K)) GO TO 120
IF (TVAP(K).EQ.0.0) GO TO 120
ISCOND(J)=1
JJ=J+1
IF (K.EQ.KSK) NOSCIL=NOSCIL+1
KSK=K
ISCOND(JJ)=0
ITEST=0
WRITE (6,200) (SNAME(I,K),I=1,2)
IF (NOSCIL.LT.3) GO TO 40
WRITE (6,300) (SNAME(I,K),I=1,2)
IF (ISOL.EQ.4) LSR=1
IF (ISOL.EQ.3) LSR=2
ISOL=1
TEMP=TMELT(K)+0.001
300 M1=NATOMS+NREAC+1
M2=M1+1
X(M2)=TEMP
SHOLD=CHAMS
HHOLD=CHAMH
GO TO 5
C
110 IF (TEMP.LT.TMELT(K)) GO TO 120
IF (TVAP(K).EQ.0.0) GO TO 120
JJ=J+1
ISCOND(JJ)=0
ISCOND(J)=1
ITEST=0
WRITE (6,210) (SNAME(I,K),I=1,2)
GO TO 40
C
120 CONTINUE
IF (ISOL.EQ.ISL) GO TO 130
ISOL=ISL
IREAC=0
GO TO 30
C
130 CONTINUE
IF (ITEST.EQ.0) GO TO 140
GO TO 30
C
140 INTROU=0
RETURN
150 CONTINUE
IF (ISL.EQ.5) GO TO 160
IF (ISL.EQ.4) WRITE (6,240) (SNAME(I,INDEX),I=1,2)
ISOL=1
GO TO 5
C
160 WRITE (6,230) (SNAME(I,INDEX),I=1,2)
M=NATOMS+NREAC
M2=M+2
X(M2)=(TEMP+TSTORE)/2.
TEMP=X(M2)
ISOL=1
NSTORE=NSTORE+1
IF (NSTORE.LT.2) GO TO 170
NO=NOLN+1
WRITE (6,250)
RETURN
170 INTROU=0
GO TO 5
C
C
180 FORMAT (///,5X,11HSPECIE NO. ,12,2H,(,2A6,2H),,26HHAS BEEN CONDENS
190 ED TO NO. ,12,/)
200 FORMAT (///,5X,2A6,23HSHOULD NOT BE CONDENSED,/)
210 FORMAT (///,5X,2A6,28HCHANGED FROM LIQUID TO SOLID,/)
220 FORMAT (2X,14HTEMPERATURE = ,F8,1,2X,7HISOL = ,12)
230 FORMAT (///,15X,2A6,89HHAS BEEN CONDENSED AND VAPORIZED 3 CONSEC
240 UATIVE TIMES INDICATING A TEMPERATURE OSCILLATION,/,10X,96HTO ABOVE
250 2 AND BELOW ITS VAPORIZATION TEMPERATURE. USE THE AVERAGE TEMPERATU
260 3RE FOR THE NEXT GUESS,/)
270 FORMAT (///,15X,2A6,89HHAS BEEN CONDENSED AND VAPORIZED 3 CONSEC
280 UATIVE TIMES INDICATING A TEMPERATURE OSCILLATION,/,10X,122HTO ABOVE
290 2E AND BELOW ITS VAPORIZATION TEMPERATURE. FOR THIS EXPANSION THEN,
300 3 AN ASSIGNED TEMPERATURE SOLUTION FOR THE CURRENT,/,10X,29HTEMPER
310 4ATURE WILL BE GENERATED)
320 FORMAT (///,10X,30HSOLUTION TERMINATED IN TCHAM, //)
330 FORMAT(20X,46HSOLUTION LIES IN LIQUID-SOLID TWO PHASE REGION//20X,
340 14HPUT ,2A6,67HINTO SOLID PHASE AND DO ASSIGNED TEMP. SOLUTION AT T
350 2EMP=TMELT-.001K//20X,39HERROR FOR THIS ASSUMPTION PRINTED BELOW//)
END
SUBROUTINE NOMLIN (N)
INTEGER RANGE,SPECIE
REAL MOLEWT,NU,MU
COMMON/BLKA/AAAA(30,8),AFACA(120),AFACB(120),ALPHA,ATOM(10,30),
1ATWT(10),BBBB(30,8),BETA(10),CCCC(30,8),CHAMH,CHAMS,ERROR,
2FORMA(120),FORMWT,GA(120),GO,HCHAMA(120),HO(30,8),HTOT,FO(30),
3IREAC,ISCOND(30),ISOL,ISW,JOE(10),KON(30),MMMA,MMMB,MOLEWT(30),
4MU(30),NATOMS,NOVAP(30),NPRES,NREAC,NSPEC,NU(30,30),PA(120),
5PRE(120),PMOLE(10),PNAME(10,2),PO,POUT,PRES,RANGE,SDENS(30),
6SHSJ(30),SNAME(2,30),SO(30,8),TEMP,TINIT(6),TMELT(30),TVAP(30),
7VA(120),VAPRES(30),X(30)
COMMON/BLKB/FORMB(30),GB(30),NOSPE,VB(30),XMOLES(20)
COMMON/AA1/ISORT(60),SPECIE(30),NNSPEC,ISL,NOSOLN,XMIN
COMMON/BLK1/CHAN,ITEST,LOROP,LIQUID
COMMON/BLKJ/DELT(30),A(30,31),F(30,30)
COMMON/BLKK/INDEX(30)
COMMON/BLKN/MIX,INTROU,THOLD,MIXR,NOSCIL
DIMENSION REST(30), CYCLE(30,5), G(30), REX(30), S(30)
C
C SET MAXIMUM NUMBER OF ITERATIONS.
C
ICC=30
IF (NOSCIL.GE.2) ICC=40
IF (INTROU.GE.1) ICC=40
C
IF (ITEST.EQ.0) GO TO 10
L=1
CALL PUNT (L,BEST,ICC,ICB,N,ITRPT,REX,S)
IF (NOSOLN.EQ.1) RETURN
10 EPS=ERROR
REPS=.01*EPS
DO 20 I=1,30
G(I)=0.0
DO 20 J=1,30
F(I,J)=0.0
20 SSAEX=1.E6
SSAET=0.0
IC=0
ISC=1
K=0
C
C LIMIT THE NORMALIZED MOLE FRACTION TO XMIN UNLESS THE SPECIES
C IS IN THE GAS PHASE AND HAS A POSSIBLE LIQUID PHASE. IN THIS CASE
C THE SPECIE IS LIMITED TO ONE HALF ITS VAPOR PRESSURE.
C
M=0
DO 80 J=1,NSPEC
IF (SPECIE(J).NE.0) GO TO 80
IF (ISCOND(J).EQ.1) GO TO 50
IF (KON(J).EQ.1) GO TO 80
GO TO 60
C
50 IF (KON(J).NE.1) GO TO 80
M=M+1
IF (X(M).LE.0.0) GO TO 80
IF (X(M).GT.XMIN) GO TO 80
IF (KON(J).EQ.1,AND,MOLEWT(J+1).EQ,MOLEWT(J)) GO TO 70
X(M)=XMIN
GO TO 80
C
70 JJ=J+1

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      IF (VAPRES(JJ+1),LT,VAPRES(JJ)) JJ=J+2
      IF (TVAP(J),EQ,0.0) JJ=J+2
      XXMIN=5*VAPRES(JJ)
      IF (X(M),LT,XXMIN) X(M)=XXMIN
80  CONTINUE
C
90  CALL EVAL (G)
      IF (TEST,EQ,10) RETURN
      DO 100 I=1,N
100  G(I)=G(I)
C
C  G(I) IS THE RESIDUALS VECTOR COMPUTED IN SUBROUTINE EVAL
C
      DO 110 I=1,N
110  S(I)=G(I)
      OM=1.0
      NN=N+1
      DO 120 I=1,N
      DO 120 J=1,N
120  A(I,J)=F(I,J)
      DO 130 I=1,N
130  A(I,NN)=G(I)
      L=1
      CALL CROUT (A,N,L,NN,DETERM,INDEX)
      DO 140 IJK=1,N
140  DELT(IJK)=A(IJK,1)
      IF (ABS(DETERM)-1.E-20) 150,150,210
150  K=K+1
      GO TO (160,170,180), K
160  X(ISC)=1.*X(ISC)
      GO TO 40
C
170  X(ISC)=.9*X(ISC)/1.1
      GO TO 40
C
180  X(ISC)=1.1*X(ISC)
      ISC=ISC+1
      IF (ISC=N) 190,190,200
190  K=0
      GO TO 150
C
200  L=1
      IST=N
      CALL PUNT (L,BEST,IC,ICC,ICB,N,ITRPT,REX,S)
      ISC=1
      K=0
      IF (IST,NE,N) GO TO 90
      IF (LIQUID,EQ,0) ITEST=1
      RETURN
C
C  ZILCH
C
210  DO 220 I=1,N
220  REX(I)=ABS(DELT(I)/X(I))
      SSAET=0.0
      DO 230 I=1,N
230  SSAET=SSAET+S(I)**2
C
240  DO 250 I=1,N
250  BEST(I)=X(I)
      SSAEX=SSAET
      ICB=IC+1
260  DO 270 I=1,N
      IF (REX(I)-REPS) 270,270,290
270  CONTINUE
      DO 280 I=1,N
      IF (ABS(S(I))-EPS) 280,280,290
280  CONTINUE
      GO TO 450
C
290  IC=IC+1
      IF (ISW,LT,1) GO TO 300
      CALL INTER (N,IC,REX,S,DELT)
300  IF (IC-ICC) 310,310,480
310  M=0
      K=0
      DO 350 J=1,NSPEC
      IF (SPECIE(J),NE,0) GO TO 350
      IF (ISCOND(J),EQ,1) GO TO 320
      IF (KON(J),EQ,1) GO TO 350
      M=M+1
      IF (KON(J),GE,4) GO TO 330
      GO TO 340
C
320  IF (KON(J),NE,1) GO TO 350
      M=M+1
330  IF ((X(M)+DELT(M)),LE,0.0) DELT(M)=-0.99999*X(M)
340  IF (ABS(DELT(M)),GT,(PRES/10.0)) DELT(M)=0.1*PRES*DELT(M)/ABS(D
      ELT(M))
      X(M)=X(M)+DELT(M)
      IF (X(M),GT,0.0) GO TO 350
      IF (ISOL,EQ,1) GO TO 350
      IF (ISOL,EQ,4) GO TO 350
      IF (IREAC,NE,0) GO TO 350
      IREAC=1
      K=1
350  CONTINUE
      M1=M+1
      IF ((X(M1)+DELT(M1)),LE,0.0) DELT(M1)=-0.5*X(M1)
      X(M1)=X(M1)+DELT(M1)
      IF (ISOL,LE,2) GO TO 360
      M2=M+2
      IF (ABS(DELT(M2)),GT,(X(M2)/10.0)) DELT(M2)=0.1*X(M2)*DELT(M2)/ABS
      (DELT(M2))
      IF (X(M2)+DELT(M2),GT,6000.) DELT(M2)=-.5*DELT(M2)
      IF (X(M2)+DELT(M2),LT,298.) DELT(M2)=(298.-TEMP)/2.
      IF (NOSCIL,GE,2) DELT(M2)=DELT(M2)*0.1
      IF (INTROU,GE,1) DELT(M2)=DELT(M2)*0.1
      X(M2)=X(M2)+DELT(M2)
      TEMP=X(M2)
360  CONTINUE
      IF (ISOL,LT,5) GO TO 370
      M3=M+3
      IF (ABS(DELT(M3)),GT,(X(M3)/10.0)) DELT(M3)=0.1*X(M3)*DELT(M3)/ABS
      (DELT(M3))
      X(M3)=X(M3)+DELT(M3)
      PRES=X(M3)
370  CONTINUE
      IF (K,EQ,1) RETURN
      JC=MOD((IC-1),5)+1
      DO 380 I=1,N

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380  CYCLE(I,JC)=X(I)
      IF (IC-5) 390,400,400
390  K=IC
      GO TO 410
C
400  K=5
410  DO 420 J=1,K
      IF (J-JC) 420,440,420
420  DO 430 I=1,N
      IF (CYCLE(I,JC)-CYCLE(I,J)) 440,430,440
430  CONTINUE
      ITRPT=IC-MOD((5+JC-J),5)
      L=3
      IST=N
      CALL PUNT (L,BEST,IC,ICC,ICB,N,ITRPT,REX,S)
      ISC=1
      K=0
      IF (IST,NE,N) GO TO 90
      IF (LIQUID,EQ,0) ITEST=1
      RETURN
440  CONTINUE
C
C  AFTER 10 ITERATIONS SUBROUTINE STOICH IS CALLED TO REPICK THE
C  INDEPENDENT SPECIES SO THAT ONLY DOMINATE SPECIES ARE INCLUDED
C
      IF (IC,EQ,10) CALL STOICH
      GO TO 30
C
450  SSREX=0.0
      DO 460 I=1,N
460  SSREX=SSREX+REX(I)**2
      IF (ISW,LT,1) GO TO 470
      CALL FINAL (N,SSREX,SSAEX)
470  CONTINUE
      RETURN
480  L=2
      IST=N
      CALL PUNT (L,BEST,IC,ICC,ICB,N,ITRPT,REX,S)
      ISC=1
      K=0
      IF (IST,NE,N) GO TO 90
      IF (LIQUID,EQ,0) ITEST=1
      RETURN
      END
      SUBROUTINE PUNT (IGOTO,BEST,IC,ICC,ICB,N,ITRPT,REX,S)
      INTEGER RANGE,SPECIE
      REAL MOLEWT,NU,MU
      COMMON/BLKA/AAAA(30,8),AFACA(120),AFACB(120),ALPHA,ATOM(10,30),
      1ATWT(10),BBBB(30,8),BETA(10),CCCC(30,8),CHAMH,CHAMS,ERROR,
      2FORMAI(120),FORMWT,GA(120),GO,HCHAMAI(120),HO(30,8),HTOT,ID(30),
      3IREAC,ISCOND(30),ISOL,ISW,JOB(10),KON(30),MMA,MMA,MOLEWT(30),
      4MU(30),NATOMS,NOVAP(30),NPRES,NREAC,NSPEC,NU(30,30),PA(120),
      5SPE(120),PMOLE(10),PNAME(10,2),PO,POUT,PRES,RANGE,SDENS(30),
      6SHSJ(30),SNAME(2,30),SO(30,8),TEMP,TINIT(6),TMELT(30),TVAP(30),
      7VA(120),VAPRES(30),X(30)
      COMMON/BLKB/FORMBI(30),GB(30),NOSPE,VB(30),XMOLES(120)
      COMMON/AL1/ISORT(60),SPECIE(30),NNSPEC,ISL,NOSOLN,XMIN
      COMMON/BLK1/CHAN,ITEST,LDRDP,LIQUID
      COMMON/BLKN/MIX,INTROU,THOLD,MIXR,NOSCIL,LSR,SHOLD,NSPCT,KLPM
      DIMENSION BEST(30), REX(30), S(30)
      GO TO (10,40,60,70), IGOTO
10  ICT=IC+1
      WRITE (6,320) ICT
      WRITE (6,350) (X(I),I=1,N)
      IF (IC,EQ,0) GO TO 30
      IF (IREAC,EQ,0,AND,ISL,EQ,ISOL) GO TO 30
      DO 20 I=1,N
20  X(I)=BEST(I)
      GO TO 70
C
30  ITEST=1
      RETURN
40  IF (ISW,LT,1) GO TO 50
      WRITE (6,330) ICC,ICB
      WRITE (6,350) (BEST(I),I=1,N)
50  IF (LIQUID,EQ,0) GO TO 70
      IF (IREAC,EQ,0,AND,ISL,EQ,ISOL) ITEST=1
      RETURN
60  WRITE (6,340) ITRPT,IC
      WRITE (6,350) (BEST(I),I=1,N)
C
C  DROP SPECIE IF ITS NORMALIZED MOLE FRACTION IS LESS THAN XMIN.
C  SPECIES WITH NO VAPOR PHASE ARE TESTED FIRST.
C
70  CONTINUE
      K=0
      MA=0
80  DO 170 J=1,NSPEC
      IF (SPECIE(J),NE,0) GO TO 170
      IF (ISCOND(J),EQ,1) GO TO 170
      IF (KON(J),EQ,1) GO TO 170
      GO TO 100
C
90  IF (KON(J),NE,1) GO TO 170
      M=M+1
100  IF (X(M),LT,0.0,OR,X(M),GT,XMIN) GO TO 170
      IF (KON(J),LT,4,AND,K4,EQ,0) GO TO 170
      INDEX=NOVAP(J)
      L=NNSPEC+1
      LL=L+NATOMS-1
      DO 110 JJ=L,LL
      IF (INDEX,EQ,ISORT(JJ)) GO TO 170
110  CONTINUE
      ITEST=0
      SPECIE(J)=2

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      NNSPEC=NNSPEC-1
      WRITE (6,370) (SNAME(I,INDEX),I=1,2)
      MM=NATOMS+NREAC-1
      IF (MM.LT.NATOMS) GO TO 270
      IF (ID(J),EQ.1) GO TO 150
      IF (MOLEWT(J-2),NE.MOLEWT(J)) GO TO 120
      SPECIE(J-2)=2
      NNSPEC=NNSPEC-1
      IF (MOLEWT(J-1),NE.MOLEWT(J)) GO TO 130
      SPECIE(J-1)=2
      NNSPEC=NNSPEC-1
      IF (MOLEWT(J+1),NE.MOLEWT(J)) GO TO 140
      SPECIE(J+1)=2
      NNSPEC=NNSPEC-1
      IF (MOLEWT(J+2),NE.MOLEWT(J)) GO TO 150
      SPECIE(J+2)=2
      NNSPEC=NNSPEC-1
      CONTINUE
      LL=N-1
      DO 160 L=M,LL
        X(L)=X(L+1)
        M=M-1
      GO TO 180
C
170 CONTINUE
      K4=K4+1
      IF (K4.EQ.1) GO TO 80
      GO TO 200
C
180 CALL STOICH
      IC=0
      N=N-1
      IF (LIQUID.EQ.0) RETURN
      ISOL=1
      N=NATOMS+NREAC+1
      NN=N+1
      X(NN)=TEMP
      IF (ISW.LT.1) GO TO 190
      WRITE (6,360)
      WRITE (6,350) (X(I),I=1,NN)
190 CONTINUE
      RETURN
200 IC=0
      IF (LIQUID.EQ.0) GO TO 210
      IF (ITEST.EQ.0) RETURN
C
C DROP DEPENDENT SPECIES WHICH CANNOT SATISFY THE ERROR BOUND AFTER
C ALL OTHER METHODS FAIL.
C
210 REPS=.01*ERROR
      ITES=0
220 HIGH=TEMP
      M=0
      MM=0
      DO 250 J=1,NNSPEC
        IF (SPECIE(J),NE.0) GO TO 250
        IF (ISCOND(J),EQ.1) GO TO 230
        IF (KON(J),EQ.1) GO TO 250
        GO TO 240
C
230 IF (KON(J),NE.1) GO TO 250
C
240 M=M+1
      IF (REX(M),LE.REPS) GO TO 250
      IF (X(M),GT.HIGH) GO TO 250
      HIGH=X(M)
      MM=M
      INDEX=NOVAP(J)
250 CONTINUE
      IF (MM.NE.0) GO TO 260
      WRITE (6,400)
      NOSOLN=1
      RETURN
260 IF (M.GT.NATOMS) GO TO 280
      WRITE (6,390) (SNAME(I,INDEX),I=1,2)
270 NOSOLN=1
      WRITE (6,380)
      WRITE (6,400)
      RETURN
280 CONTINUE
      L=NNSPEC+1
      LL=NATOMS-1
      DO 290 JJ=L,LL
        IF (INDEX.EQ.ISORT(JJ)) GO TO 310
290 CONTINUE
      K4=1
      X(MM)=XMIN
      LDROP=LOROP+1
      WRITE (6,390) (SNAME(I,INDEX),I=1,2)
      KHM=NOSPE-NATOMS
      IF (LDROP.LT.KHM) GO TO 300
      NOSOLN=1
      WRITE (6,410)
      WRITE (6,400)
      RETURN
300 CONTINUE
      GO TO 70
C
310 REX(MM)=0.0
      GO TO 220
C
C
320 FORMAT (1H 31H SYSTEM IS IN A SINGULAR REGION/1H 35H SINGULARITY 0
      OCCURRED ON ITERATION 14/1H 27H THE SINGULAR POINT FOLLOWS)
330 FORMAT (////15X,28HNUMBER OF ITERATIONS EXCEEDS,13,12H, ITERATION
      1,13,48H) IS THE BEST ESTIMATE SO FAR AND IS GIVEN BELOW,/)
340 FORMAT (13H, ITERATIONS 13,4H AND 13,46H ARE IDENTICAL INDICATING
      1A CYCLIC CONDITION,43H THE BEST RESULTS SO FAR ARE GIVEN BELOW,
      2)
350 FORMAT (E20,8)
360 FORMAT (//10X,24HINITIAL SOLUTION VECTOR,/)
370 FORMAT (//10X,2A6,18H IS BEING DROPPED,/)
380 FORMAT (//34X,52HMAXIMUM ALLOWABLE NUMBER OF SPECIES ALREADY DROP-
      PED,//40X,40HNUMBER OF SPECIES LEFT * NUMBER OF ATOMS,/)
390 FORMAT (//10X,2A6,41H CANNOT SATISFY THE RELATIVE ERROR BOUND,/)
400 FORMAT (//10X,39HSOLUTION TERMINATED IN SUBROUTINE PUNT,/)
410 FORMAT (//10X,71HMAXIMUM OF NOSPE-NATOMS SPECIES DROPPED FOR NOT
      MEETING ERROR CRITERIA,/)
      END

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SUBROUTINE ADD
  INTEGER RANGE,SPECIE
  REAL MOLEWT,NU,MU
  COMMON/BLKA/AAAA(30,8),AFACA(120),AFACB(120),ALPHA,ATOM(10,30),
  1ATWT(10),BBBB(30,8),BETA(10),CCCC(30,8),CHAMH,CHAMS,ERROR,
  2FORMA(120),FORMWT,GA(120),GO,HCHAMA(120),HO(30,8),HTOT,10(30),
  3IREAC,ISCOND(30),ISOL,ISW,JOE(10),KON(30),MMA,MMMB,MOLEWT(30),
  4MU(30),NATOMS,NOVAP(30),NPRES,NREAC,NSPEC,NU(30,30),PA(120),
  5SPE(120),PMOLE(10),PNAME(10,2),PO,POUT,PRES,RANGE,SDENS(30),
  6SHA(30),SNAME(2,30),SO(30,8),TEMP,TINIT(6),TMELT(30),TVAP(30),
  7VA(120),VAPRES(30),X(30)
  COMMON/BLKB/FORMB(30),GB(30),NOSPE,VB(30),XMOLES(20)
  COMMON/AA/ISORT(60),SPECIE(30),NNSPEC,ISL,NOSOLN,XMIN
C
C THIS SUBROUTINE WILL RETURN SPECIES DROPPED DURING A SOLUTION
C ATTEMPT.
C
      LL=NATOMS+NREAC+3
      IFLAG=0
      DO 10 J=1,NNSPEC
        IF (SPECIE(J),NE.2) GO TO 10
        IFLAG=1
10 CONTINUE
      IF (IFLAG.EQ.0) RETURN
      INSERT=0
      M=0
      DO 60 J=1,NNSPEC
        IF (SPECIE(J),NE.2) GO TO 20
        SPECIE(J)=0
        NNSPEC=NNSPEC+1
        INSERT=1
20 IF (SPECIE(J),NE.0) GO TO 60
        IF (ISCOND(J),EQ.1) GO TO 30
        IF (KON(J),EQ.1) GO TO 60
        GO TO 40
C
30 IF (KON(J),NE.1) GO TO 60
40 M=M+1
      IF (INSERT.NE.1) GO TO 60
      INSERT=LL+1
      DO 50 I=M,LL
        X(INSERT)=X(INSERT-1)
        INSERT=INSERT-1
50 CONTINUE
      LL=LL+1
      ASPE=NSPEC
      X(M)=PRES/ASPE
      INDEX=NOVAP(J)
      WRITE (6,70) (SNAME(I,INDEX),I=1,2)
60 INSERT=0
      CALL STOICH
      RETURN
C
70 FORMAT (//10X,2A6,16H HAS BEEN ADDED,/)
      END

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SUBROUTINE EVAL (G)
  INTEGER RANGE,SPECIE
  REAL MOLEWT,NU,MU
  COMMON/BLKA/AAAA(30,8),AFACA(120),AFACB(120),ALPHA,ATOM(10,30),
  1ATWT(10),BBBB(30,8),BETA(10),CCCC(30,8),CHAMH,CHAMS,ERROR,
  2FORMA(120),FORMWT,GA(120),GO,HCHAMA(120),HO(30,8),HTOT,10(30),
  3IREAC,ISCOND(30),ISOL,ISW,JOE(10),KON(30),MMA,MMMB,MOLEWT(30),
  4MU(30),NATOMS,NOVAP(30),NPRES,NREAC,NSPEC,NU(30,30),PA(120),
  5SPE(120),PMOLE(10),PNAME(10,2),PO,POUT,PRES,RANGE,SDENS(30),
  6SHA(30),SNAME(2,30),SO(30,8),TEMP,TINIT(6),TMELT(30),TVAP(30),
  7VA(120),VAPRES(30),X(30)
  COMMON/BLKB/FORMB(30),GB(30),NOSPE,VB(30),XMOLES(20)
  COMMON/AA/ISORT(60),SPECIE(30),NNSPEC,ISL,NOSOLN,XMIN
  COMMON/BLKJ/EQUIL(30),A(30,31),F(30,30)
  COMMON/BLKI/CHAN,ITEST,LDROP,LIQUID
  COMMON/BLKN/MIX,INTROU,THOLD,MIXR,NOSCIL,LSR,SHOLD,NSPCT,KLPM
  DIMENSION G(30)
  RANGE=IRANGE(TEMP)
C
C CHEMICAL POTENTIAL
C
      DO 10 J=1,NNSPEC
        IF (SPECIE(J),NE.0) GO TO 10
        MU(J)=ENTH(J,TEMP)-TEMP*ENTP(J,TEMP,1.0)
10 CONTINUE
      DO 50 K=1,NREAC
        M=0
        SUM=0.0
        DO 40 J=1,NNSPEC
          IF (SPECIE(J),NE.0) GO TO 40
          IF (ISCOND(J),EQ.1) GO TO 20
          IF (KON(J),EQ.1) GO TO 40
          PROD=MU(K,J)*MU(J)
          GO TO 30
C
20 IF (KON(J),NE.1) GO TO 40
30 PROD=MU(K,J)*MU(J)
          SUM=SUM+PROD
          M=M+1
40 CONTINUE
50 EQUIL(K)=SUM/(1.98725*TEMP)
      M1=M+1
C
C CALCULATE VAPOR PRESSURES
C
      M=0
      DO 60 J=1,NNSPEC
        IF (SPECIE(J),NE.0) GO TO 60
        IF (KON(J),EQ.1) GO TO 55
        IF (KON(J),EQ.4) M=M+1
        IF (KON(J),GE.4) GO TO 60
        INDEX=NOVAP(J)
        IF (KON(J),EQ.3) GO TO 52
        VAPRES(J)=VAPRE(INDEX)
        IF (VAPRES(J),LE.PRES) GO TO 60
        IF (ISCOND(INDEX),EQ.1) GO TO 60
        X(M)=1
        ITES=10
        RETURN
52 CONTINUE
      PRELN=(MU(J)-MU(INDEX))/1.98725*TEMP

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      VAPRES(J)=EXP(PRELN)
      GO TO 60
55  M=M+1
60  CONTINUE
65  IF (ISW+LT,2) GO TO 70
      WRITE (6,330) ISOL
      WRITE (6,340) TEMP
      WRITE (6,360) (MU(J),J=1,NSPEC)
      WRITE (6,350)
      WRITE (6,360) (VAPRES(J),J=1,NSPEC)
70  NSP1=NATOMS+NREAC+1
      K=0
C
C  ATOM BALANCE EQUATIONS
C
      DO 100 I=1,NATOMS
        K=K+1
        M=0
        SUM=0.0
        DO 90 J=1,NSPEC
          IF (SPECIE(J).NE.0) GO TO 90
          IF (ISCOND(J).EQ.1) GO TO 80
          IF (KON(J).EQ.1) GO TO 90
          M=M+1
          PROD=ATOM(I,J)*X(M)
          F(K,M)=ATOM(I,J)/X(NSP1)
          SUM=SUM+PROD+ATOM(I,J)*VAPRES(J)
          GO TO 90
60  IF (KON(J).NE.1) GO TO 90
          M=M+1
          PROD=ATOM(I,J)*X(M)
          F(K,M)=ATOM(I,J)/X(NSP1)
          SUM=SUM+PROD
90  CONTINUE
      G(J)=RETA(I)-SUM/X(NSP1)
100  F(K,NSP1)=SUM/(X(NSP1)**2)
      F(NSP1,NSP1)=0.0
C
C  EQUILIBRIUM CORRECTION EQUATIONS
C
      NNN=NREAC
      K=NATOMS
      DO 130 I=1,NNN
        K=K+1
        SUM=0.0
        M=0
C
C  REACTION EQUATION
C
        DO 120 J=1,NSPEC
          IF (SPECIF(J).NE.0) GO TO 120
          IF (ISCOND(J).EQ.1) GO TO 110
          IF (KON(J).EQ.1) GO TO 120
          M=M+1
          F(K,M)=0.0
          GO TO 120
110  IF (KON(J).NE.1) GO TO 120
          M=M+1
          IF (X(M).GT.0.0) GO TO 115
120  CONTINUE
      G(K)=EQUIL(I)+SUM
130  F(K,NSP1)=0.0
C
C  PARTIAL PRESSURE EQUATION
C
      SUM=0.0
      M=0
      DO 150 J=1,NSPEC
        IF (SPECIE(J).NE.0) GO TO 150
        IF (ISCOND(J).EQ.1) GO TO 140
        IF (KON(J).EQ.1) GO TO 150
        M=M+1
        F(NSP1,M)=0.0
        SUM=SUM+VAPRES(J)
        IF (KON(J).NE.1) GO TO 150
        M=M+1
        SUM=SUM+X(M)
        F(NSP1,M)=1.0
150  CONTINUE
C
C  PRESSURE BALANCE EQUATION
C
      G(NSP1)=SUM-PRES
C
      NSP2=NSP1+1
C
      NSP2=NSP1+1
      NSP3=NSP1+2
      IF (ISOL.EQ.1) GO TO 320
      IF (ISOL.EQ.2) GO TO 320
C
C  CORRECTION EQUATIONS FOR ADIABATIC COMBUSTION
C
      DO 160 K=1,NATOMS
        F(K,NSP2)=0.0
        K=NATOMS
        DO 190 I=1,NREAC
          K=K+1
          SUM=0.0
          M=0
          DO 180 J=1,NSPEC
            IF (SPECIE(J).NE.0) GO TO 180
            IF (ISCOND(J).EQ.1) GO TO 170
            IF (KON(J).EQ.1) GO TO 180
            SUM=SUM+NU(I,J)*ENTH(J,TEMP)
            IF (KON(J).NE.1) GO TO 180
            SUM=SUM+NU(I,J)*ENTH(J,TEMP)
170  CONTINUE
          F(K,NSP2)=SUM/(1.98725*(TEMP**2))
          F(NSP1,NSP2)=0.0
          IF (ISOL.EQ.6) GO TO 200
          IF (ISOL.EQ.3) GO TO 240
200  SUM1=0.0

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      SUM2=0.0
      M=0
220  J=1,NSPEC
      IF (SPECIE(J).NE.0) GO TO 220
      IF (ISCOND(J).EQ.1) GO TO 210
      IF (KON(J).EQ.1) GO TO 220
      M=M+1
      F(NSP2,M)=ENTH(J,TEMP)/X(NSP1)
      SUM1=SUM1+X(M)*ENTH(J,TEMP)
      SUM2=SUM2+X(M)*CSUBP(J,TEMP)
      IF (KON(J).GE.4) GO TO 220
      INDEX=NOVAP(J)
      SUM1=SUM1+VAPRES(J)*ENTH(INDEX,TEMP)
      SUM2=SUM2+VAPRES(J)*CSUBP(INDEX,TEMP)
210  IF (KON(J).NE.1) GO TO 220
      M=M+1
      F(NSP2,M)=ENTH(J,TEMP)/X(NSP1)
      SUM1=SUM1+X(M)*ENTH(J,TEMP)
      SUM2=SUM2+X(M)*CSUBP(J,TEMP)
220  CONTINUE
      F(NSP2,NSP1)=SUM1/(X(NSP1)**2)
      F(NSP2,NSP2)=SUM2/X(NSP1)
      DO 230 I=1,NSP2
        F(NSP2,I)=F(NSP2,I)/CHAMH
C
C  ENTHALPY BALANCE EQUATION
C
      G(NSP2)=SUM1/(X(NSP1)*CHAMH)-1.0
C
      IF (ISOL.EQ.6) GO TO 250
      IF (ISOL.EQ.4) GO TO 280
240  SUM1=0.0
      SUM2=0.0
      K=NSP2
      IF (ISOL.EQ.6) K=K+1
      M=0
      DO 270 J=1,NSPEC
        IF (SPECIE(J).NE.0) GO TO 270
        IF (ISCOND(J).EQ.1) GO TO 260
        IF (KON(J).EQ.1) GO TO 270
        M=M+1
        F(K,M)=ENTP(J,TEMP,1.0)/X(NSP1)
        SUM1=SUM1+X(M)*ENTP(J,TEMP,1.0)
        SUM2=SUM2+X(M)*CSUBP(J,TEMP)
        IF (KON(J).GE.4) GO TO 270
        INDEX=NOVAP(J)
        PP=VAPRES(J)
        SUM1=SUM1+PP*ENTP(INDEX,TEMP,PP)
        SUM2=SUM2+PP*CSUBP(INDEX,TEMP)
260  IF (KON(J).NE.1) GO TO 270
        M=M+1
        PP=X(M)
        SUM1=SUM1+PP*ENTP(J,TEMP,PP)
        SUM2=SUM2+PP*CSUBP(J,TEMP)
        F(K,M)=ENTP(J,TEMP,PP)-1.98725/X(NSP1)
270  CONTINUE
      F(K,NSP1)=SUM1/(X(NSP1)**2)
      F(K,NSP2)=SUM2/(X(NSP1)*TEMP)
C
C  ENTROPY BALANCE EQUATION
C
      G(K)=SUM1/X(NSP1)-CHAM5
C
      F(NSP1,NSP1)=1.0
      IF (ISOL.EQ.5) GO TO 320
280  IF (ISOL.EQ.5) GO TO 320
C
C  CONSTANT AREA MIXING
C
      IF (ISOL.LT.5) GO TO 320
      F(NSP1,NSP3)=1.0
      SUM=0.0
      SUM1=0.0
      SUM2=0.0
      M=0
      DO 300 J=1,NSPEC
        IF (SPECIE(J).NE.0) GO TO 300
        IF (ISCOND(J).EQ.1) GO TO 290
        IF (KON(J).EQ.1) GO TO 300
        M=M+1
        F(NSP2,M)=0.0
        F(NSP3,M)=ENTH(J,TEMP)/X(M)*FORMWT
        SUM=SUM+X(M)*CSUBP(J,TEMP)
        SUM1=SUM1+X(M)*ENTH(J,TEMP)
        IF (KON(J).GE.4) GO TO 300
        INDEX=NOVAP(J)
        SUM=SUM+VAPRES(J)*CSUBP(INDEX,TEMP)
        SUM1=SUM1+VAPRES(J)*ENTH(INDEX,TEMP)
        SUM2=SUM2+ENTH(INDEX,TEMP)-ENTH(J,TEMP)*VAPR
        F(S(J)
290  IF (KON(J).NE.1) GO TO 300
        M=M+1
        F(NSP2,M)=0.0
        F(NSP3,M)=ENTH(J,TEMP)/X(M)*FORMWT
        SUM=SUM+X(M)*CSUBP(J,TEMP)
        SUM1=SUM1+X(M)*ENTH(J,TEMP)
300  CONTINUE
      F(NSP2,NSP1)=-GO*TEMP/(X(M1)**2)*FORMWT*0.76067)
      F(NSP2,NSP2)=GO/(X(M1)*FORMWT+0.76067)
      F(NSP2,NSP3)=68135.2/GO
      SV=0.191804*(GO*TEMP/(X(M1)*FORMWT)**2)/10000.0
      F(NSP3,NSP1)=-SUM1/(X(M1)**2)*FORMWT)-2.0*SV/X(M1)
      F(NSP3,NSP2)=SUM/(X(M1)*FORMWT)+2.0*SV/TEMP+SUM2/(X(M1)*FORMWT*1.9
      18725*(TEMP**2))
      F(NSP3,NSP3)=0.0
      G(NSP2)=(68135.2*PRES/GO+GO*TEMP/(0.76067*X(M1)*FORMWT))/PO-1.0
      G(NSP3)=(SUM1/(X(M1)*FORMWT)+SV)/HTOT-1.0
      DO 310 I=1,NSP3
        F(NSP3,I)=F(NSP3,I)/HTOT
310  F(NSP2,I)=F(NSP2,I)/PO
320  CONTINUE
      RETURN
C
C
330  FORMAT (50X,6HISOL=,I3)
340  FORMAT (//,40X,3AHCHEMICAL POTENTIALS FOR TEMPERATURE =,E16.6)
350  FORMAT (//,40X,15HVAPOR PRESSURES)
360  FORMAT (6(2X,E16.6))
      END

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SUBROUTINE INTER (N,IC,REX,S,DELTA)
COMMON/BLKA/AAAA(30,8),AFACA(120),AFACB(120),ALPHA,ATOM(10,30),
1ATWT(10),BBBB(30,8),BETA(10),CCCC(30,8),CHAMH,CHAMS,ERROR,
2FORMA(120),FORMWT,GA(120),GO,HCHAMA(120),HO(30,8),HTOT,1D(30),
3IREAC,ISCOND(30),ISOL,ISW,JOB(10),KON(30),MMA,MMB,MOLEWT(30),
4MU(30),NATOMS,NOVAP(30),NPRES,NREAC,NSPEC,NU(30,30),PA(120),
5PE(120),PMOLE(10),PNAME(10,2),PO,POUT,PRES,RANGE,SDENS(30),
6SHSJ(30),SNAME(2,30),SO(30,8),TEMP,TINIT(6),TMELT(30),TVAP(30),
7VA(120),VAPRES(30),X(30)
COMMON/BLKB/FORMB(30),GB(30),NOSPE,VB(30),XMOLES(20)
DIMENSION DELT(30),REX(30),S(30)
WRITE (6,10) IC
WRITE (6,20)
WRITE (6,30) (X(I),REX(I),DELT(I),S(I),I=1,N)
RETURN
C
C
10 FORMAT (1H020H ITERATION COUNT IS I3)
20 FORMAT (1H 5X,78H ESTIMATED ROOT          RELATIVE ERROR    CORRECTIO
IN VECTOR    RESIDUALS VECTOR)
30 FORMAT (1H 4E20,8)
END

SUBROUTINE FINAL (N,SSREX,SSAEX)
COMMON/BLKA/AAAA(30,8),AFACA(120),AFACB(120),ALPHA,ATOM(10,30),
1ATWT(10),BBBB(30,8),BETA(10),CCCC(30,8),CHAMH,CHAMS,ERROR,
2FORMA(120),FORMWT,GA(120),GO,HCHAMA(120),HO(30,8),HTOT,1D(30),
3IREAC,ISCOND(30),ISOL,ISW,JOB(10),KON(30),MMA,MMB,MOLEWT(30),
4MU(30),NATOMS,NOVAP(30),NPRES,NREAC,NSPEC,NU(30,30),PA(120),
5PE(120),PMOLE(10),PNAME(10,2),PO,POUT,PRES,RANGE,SDENS(30),
6SHSJ(30),SNAME(2,30),SO(30,8),TEMP,TINIT(6),TMELT(30),TVAP(30),
7VA(120),VAPRES(30),X(30)
COMMON/BLKB/FORMB(30),GB(30),NOSPE,VB(30),XMOLES(20)
WRITE (6,10)
WRITE (6,20) (X(I),I=1,N)
WRITE (6,30) SSREX
WRITE (6,40) SSAEX
RETURN
C
C
10 FORMAT (1H020X,12H FINAL ROOT )
20 FORMAT (1H 20X,E20,8)
30 FORMAT (1H 10X,38H SUM OF SQUARES OF RELATIVE ERRORS IS E20,9)
40 FORMAT (1H 10X,32H SUM OF SQUARES OF RESIDUALS IS E20,9)
END

SUBROUTINE SHEXP
INTEGER RANGE
REAL MOLEWT,NU,MU
COMMON/BLKA/AAAA(30,8),AFACA(120),AFACB(120),ALPHA,ATOM(10,30),
1ATWT(10),BBBB(30,8),BETA(10),CCCC(30,8),CHAMH,CHAMS,ERROR,
2FORMA(120),FORMWT,GA(120),GO,HCHAMA(120),HO(30,8),HTOT,1D(30),
3IREAC,ISCOND(30),ISOL,ISW,JOB(10),KON(30),MMA,MMB,MOLEWT(30),
4MU(30),NATOMS,NOVAP(30),NPRES,NREAC,NSPEC,NU(30,30),PA(120),
5PE(120),PMOLE(10),PNAME(10,2),PO,POUT,PRES,RANGE,SDENS(30),
6SHSJ(30),SNAME(2,30),SO(30,8),TEMP,TINIT(6),TMELT(30),TVAP(30),
7VA(120),VAPRES(30),X(30)
COMMON/BLKB/FORMB(30),GB(30),NOSPE,VB(30),XMOLES(20)
COMMON/AA1/ISORT(60),SPECIE(30),NNSPEC,ISL,NOSOLN,XMIN
COMMON/BLKN/MIX,INTROU,THOLD
PSAVE=PRES
IF (JOB(2),EQ.2) GO TO 30
C
C
C THROAT SOLUTION
C
M1=NATOMS+NREAC+1
M2=M1+1
X(M2)=TEMP
ISOL=0
T=TEMP
P=PRES
CALL FROEXP
ISOL=4
CALL TCHM
IF (NOSOLN,EQ.1) MMA=MMB+NPRE+1
IF (NOSOLN,EQ.1) RETURN
X1=ABS((P-PRES)/PRES)
X2=ABS((T-TEMP)/TEMP)
IF ((X1+X2),GT.ERROR) GO TO 10
CALL OUTPUT
PSAVE=PRES
IF (NPRES,EQ.0) RETURN
IF (JOB(2),NE.3) GO TO 30
1=JOB(3)
JOB(3)=2
CALL FROEXP
JOB(3)=1
20 CONTINUE
30 CONTINUE
IF (JOB(2),EQ.3) RETURN
DO 60 I=1,NPRES
PRES=PE(I)
M1=NATOMS+NREAC+1
DO 40 J=1,M1
X(I)*X(J)*PRES/PSAVE
ISOL=4
TEMP=0.99*THOLD
M2=M1+1
X(M2)=TEMP
CALL TCHM
IF (NOSOLN,EQ.0) GO TO 50
XIKI=(NPRES-I+1)*1
MMA=MMB+KIKI
WRITE (6,110)
NOSOLN=0
GO TO 60
50 CONTINUE
PSAVE=PRES
CALL OUTPUT
NOSOLN=0
WRITE (6,100)
IF (NOSOLN,EQ.1) WRITE (6,100)
NOSOLN=0
CONTINUE
PSAVE=PRES
CALL OUTPUT
IF (NOSOLN,EQ.1) WRITE (6,100)
NOSOLN=0
CONTINUE
RETURN
C
C
100 FORMAT (///,10X,37HNEGATIVE SQUARE OF VELOCITY COMPUTED.,//)
110 FORMAT (///,10X,18HSOLUTION DIVERGED.,//)
END

SUBROUTINE FROEXP
INTEGER RANGE,SPECIE
REAL MOLEWT,NU,MU
COMMON/BLKA/AAAA(30,8),AFACA(120),AFACB(120),ALPHA,ATOM(10,30),
1ATWT(10),BBBB(30,8),BETA(10),CCCC(30,8),CHAMH,CHAMS,ERROR,
2FORMA(120),FORMWT,GA(120),GO,HCHAMA(120),HO(30,8),HTOT,1D(30),
3IREAC,ISCOND(30),ISOL,ISW,JOB(10),KON(30),MMA,MMB,MOLEWT(30),
4MU(30),NATOMS,NOVAP(30),NPRES,NREAC,NSPEC,NU(30,30),PA(120),
5PE(120),PMOLE(10),PNAME(10,2),PO,POUT,PRES,RANGE,SDENS(30),
6SHSJ(30),SNAME(2,30),SO(30,8),TEMP,TINIT(6),TMELT(30),TVAP(30),
7VA(120),VAPRES(30),X(30)
COMMON/BLKB/FORMB(30),GB(30),NOSPE,VB(30),XMOLES(20)
COMMON/AA1/ISORT(60),SPECIE(30),NNSPEC,ISL,NOSOLN,XMIN
SW=0.0
SUMSC=0.0
SUMHC=0.0
M=0
DO 20 J=1,NSPEC
IF (SPECIE(J),NE.0) GO TO 20
IF (ISCOND(J),EQ.1) GO TO 10
IF (KON(J),EQ.1) GO TO 20
M=M+1
PP=VAPRES(J)
I=NOVAP(J)
SUMSC=SUMSC+X(M)*ENTP(J,TEMP,1.0)+PP*ENTP(I,TEMP,1.0)
SW=SW+X(M)*MOLEWT(I)
SUMHC=SUMHC+X(M)*ENTH(J,TEMP)+PP*ENTH(I,TEMP)
GO TO 20
C
C
10 IF (KON(J),NE.1) GO TO 20
M=M+1
SUMSC=SUMSC+X(M)*ENTP(J,TEMP,1.0)
SUMHC=SUMHC+X(M)*ENTH(J,TEMP)
20 CONTINUE
M1=M+1
IF (ISOL,EQ.1) CHAMH=SUMHC/X(M1)
R=1.98725
T=TEMP
IT=0
SUMS=0.0
SUMC=0.0
SUMP=0.0
SUMH=0.0
IT=IT+1
IF (IT,LE.50) GO TO 50
WRITE (6,340)
RETURN
50 CONTINUE
M=0
RANGE=IRANGE(T)
DO 70 J=1,NSPEC
IF (SPECIE(J),NE.0) GO TO 70
IF (ISCOND(J),EQ.1) GO TO 60
IF (KON(J),EQ.1) GO TO 70
M=M+1
I=NOVAP(J)
PP=VAPRES(J)
SUMS=SUMS+X(M)*ENTP(J,T,1.0)+PP*ENTP(I,T,1.0)
SUMC=SUMC+X(M)*CSUBP(J,T)+PP*CSUBP(I,T)
SUMH=SUMH+X(M)*ENTH(J,T)+PP*ENTH(I,T)
K=KON(J)+5
IF (KON(J),GE.4) K=K-2
SUMP=SUMP+X(M)*(BBBB(J,K)-2.0*CCCC(J,K)/(T*T*T))
SUMP=SUMP+PP*(BBBB(I,K)-2.0*CCCC(I,K)/(T*T*T))
IF (KON(J),NE.1) GO TO 70
M=M+1
SUMS=SUMS+X(M)*ENTP(J,T,1.0)
SUMC=SUMC+X(M)*CSUBP(J,T)
SUMH=SUMH+X(M)*ENTH(J,T)
SUMP=SUMP+X(M)*(BBBB(J,K)-2.0*CCCC(J,K)/(T*T*T))
70 CONTINUE
DELH=2.0*(X(M1)*CHAMH-SUMH)
PD=SUMC*(T+R*PRES-DELH)+R*PRES*DELH
DFOOT=SUMP*(T+R*PRES-DELH)+SUMC*(2.0*SUMC-R*PRES)
DELT=-PD/DFOOT
T=T+0.98*DELT
IF (ABS(DELT/T),GT.ERROR) GO TO 40
SUM=(SUMS-SUMSC)/(R*PRES)
PRES=EXP(SUM)
TEMP=T
RETURN
340 FORMAT (///,10X,42HITERATIONS EXCEED 50. SOLUTION TERMINATED.,//)
END

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SUBROUTINE OUTPUT
  INTFGR RANGE,SPECIE
  REAL MOLEWT,NU,MU
  COMMON/BLKA/AAAA(30,8),AFACA(120),AFACB(120),ALPHA,ATOM(10,30),
  1ATWT(10),BBBB(30,8),BETA(10),CCCC(30,8),CHAMH,CHAMS,ERROR,
  2FORMA(120),FORMWT,GA(120),GO,HCHAMA(120),HO(30,8),HTOT,ID(30),
  3IREAC,ISCOND(30),ISOL,ISW,JOB(10),KON(30),MMA,MMMB,MOLEWT(30),
  4MU(30),NATOMS,NOVAP(30),NPRES,NREAC,NSPEC,NU(30,30),PA(120),
  5PE(120),PMOLE(10),PNAME(10,2),PO,POUT,PRES,RANGE,SDENS(30),
  6SHSJ(30),SNAME(2,30),SO(30,8),TEMP,TINIT(6),TMELT(30),TVAP(30),
  7VA(120),VAPRES(30),X(30)
  COMMON/BLKB/FORMB(30),GB(30),NOSPE,VB(30),XMOLES(20)
  COMMON/AA1/ISORT(60),SPECIE(30),NNSPEC,ISL,NOSOLN,XMIN
  COMMON/BLKN/IX,INTROU,THOLD,MIXR,NOSCIL,LSR,SHOLD,NSPCT,KLPM,HMOL
  10
  COMMON/BLKD/ISOLID,ISOLUT,IST,ISTORE,ISU,ISV,ISX,ISY,ISZ,ISSAVE,
  11TABLE,ITANK(20),ITS(3),IWF,IWHF,IWOX,JOBTYP,JS,KCAL,KCHAN,KDAT,
  2KONX(30),KPROP,M,M0,M1,M2,MOLWTX(30),N,NO,NATOM1,NATOM2,NCAL,
  3NCALCK,NDAT(20),NFILES,NOVAPX(30),NP1,NP2,NPROP,NPTS,NSB,
  4NSD,NSPEC1,NSPEC2,NSPTS,NT,NTS1,NTW,NUMBER,NWCK(20),OF(15,10),
  5OFX,OX1,OX2,OX3,PBAR,PCMAX,PCMIN,PEDES,PF(6),PHF,PNAMEX(10,2),
  6POX,PRC,PROPAT(10,10),PRPATX(10,10),PSA,PSAMAX,PSAMIN,PSUMAX,
  7PSJMIN,RAD1,RAD2,RAD3,RATIO,PHOP,RUNDUR,SDENSX(30),SECB,
  8SECD,SNAMEX(2,30),SOX(30,8),TAMB,TAO,TCMAX,TCMIN,TIMGRN(55),TIME0,
  9TIME1,TIME2,TIMEF,TIMER1,TIMER2,TIMPC1,TIMPC2
  XTAO=TAO/1.8
  IF(LSR.EQ.1) ISOL=4
  IF(LSR.EQ.2) ISOL=3
  IF(ISOL.EQ.1) MMMB = MMMB + 1
  IF(ISOL.EQ.3) MMMB = MMMB + 1
  SUM1=0.0
  SUM2=0.0
  SUM3=0.0
  SUM4 = 0.
  SUM5 = 0.
  SUMD=0.0
  RANGE=IRANGE(TEMP)
  M=0
  DO 5 J=1,NSPEC
  IF(SPECIE(J).NE.0) GO TO 5
  IF(ISCOND(J).EQ.1) GO TO 10
  IF(KON(J).EQ.1) GO TO 5
  M=M+1
  ZX = ENTH(J,TEMP)
  INDEX=NOVAP(J)
  SUM1 = SUM1 + ZX*X(M)
  SUM2=SUM2+ENTP(J,TEMP,1.0)*X(M)
  SUM3=SUM3+X(M)
  IF(ISTORE.NE.2) GO TO 700
  IF(KON(J).EQ.1) ZX=HO(INDEX,1)
  IF(KON(J).EQ.2.OR.KON(J).EQ.4) ZX=ENTH(J,TEMP)
  IF(KON(J).EQ.3.OR.KON(J).EQ.5) ZX=HO(INDEX,8)
  GO TO 701
700 IF(KON(J).EQ.1) ZX=ENTH(INDEX,XTAO)
  IF(KON(J).EQ.2.OR.KON(J).EQ.4) ZX=ENTH(J,XTAO)
  IF(KON(J).EQ.3.OR.KON(J).EQ.5) ZX=ENTH(INDEX,XTAO)
701 SUM4=SUM4+(ZX-ZX)*X(M)
  IF(KON(J).GE.4) GO TO 5
  PP=VAPRES(J)
  SUMD=SUMD+MOLEWT(INDEX)*X(M)/SDENS(INDEX)
  ZX = ENTH(INDEX,TEMP)

  SUM1 = SUM1 + ZX*PP
  SUM2=SUM2+ENTP(INDEX,TEMP,PP)*PP
  SUM3=SUM3+PP
  IF(ISTORE.NE.2) GO TO 702
  SUM4=SUM4+(ZX-HO(INDEX,1))*PP
  GO TO 10
702 SUM4=SUM4+(ZX-ENTH(INDEX,XTAO))*PP
  10 IF(KON(J).NE.1) GO TO 5
  M=M+1
  ZX = ENTH(J,TEMP)
  SUM1 = SUM1 + ZX*PP
  SUM2=SUM2+ENTP(J,TEMP,PP)*PP
  SUM3=SUM3+PP
  IF(ISTORE.NE.2) GO TO 703
  SUM4=SUM4+(ZX-HO(J,1))*PP
  GO TO 704
703 SUM4=SUM4+(ZX-ENTH(J,XTAO))*PP
704 CONTINUE
  SUM5 = SUM5+MOLEWT(J)*PP
  5 CONTINUE
  IF(LSR.EQ.0) GO TO 60
  WRITE(6,270)
  M1=M+1
  SDIF=SHOLD-(SUM2/X(M1))
  IF(LSR.EQ.1) WRITE(6,250) SDIF
  HDIF=SUM1/X(M1)
  IF(HHOLD.NE.0) HDIF=(HHOLD-HDIF)/HHOLD
  IF(LSR.EQ.2) WRITE(6,260) HDIF
60 M1=M+1
  CHAMS=SUM2/X(M1)
  HPG=SUM1/X(M1)*FORMWT*1000.0
  IF(ISOL.EQ.4) GO TO 50
  GB(MMB) = HPG*1000.
  SHSJ(MMB) = SUM4/(X(M1)*FORMWT)
  CHAMH = HPG*FORMWT*1000.
  VB(MMB) = TEMP
50 SPG=SUM2/X(M1)*FORMWT
  TOHMOL=SUM3
  DEN5=X(M1)*FORMWT/(1.3145*TEMP+SUMD)
  PS1A=PRES*14.696
  IF(ISOL.NE.4) RETURN
  HEXP=SUM1/X(M1)
  SUM=(CHAMH-HEXP)/FORMWT
  IF(SUM.GE.0.0) GO TO 45
  SUM=-1.0*SUM
  VEL=-300.216*SQRT(SUM)
  GO TO 46
45 VEL=300.216*SQRT(SUM)
46 VELMAS=DEN5*VEL
20 MMA=MMMA+1
  FORMA(MMMA) = SUM5/PRES
  AFACA(MMMA)=X(M1)
  GA(MMMA)=VELMAS
  VAIMMMA=VEL
  HCHAMA(MMMA)=CHAMH*FORMWT
  PA(MMMA)=PRES
  AFACB(MMMA) = TEMP
615 CONTINUE
250 FORMAT(//,10X,59HDIFFERENCE BETWEEN ASSIGNED ENTROPY AND COMPUTED
  *ENTROPY IS,E16.6,13H CAL/MOLE-K,/)

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260 FORMAT(//,10X,58H(ASSIGNED ENTHALPY-COMPUTED ENTHALPY)/ASSIGNED EN
  *THALPY IS,E16.6,/)
270 FORMAT(//,35X,39H*****ASSIGNED TEMPERATURE SOLUTION*****
  RETURN
  END

SUBROUTINE SOLUT
  INTEGER RANGE
  REAL MOLEWT,NU,MU
  COMMON/BLKA/AAAA(30,8),AFACA(120),AFACB(120),ALPHA,ATOM(10,30),
  1ATWT(10),BBBB(30,8),BETA(10),CCCC(30,8),CHAMH,CHAMS,ERROR,
  2FORMA(120),FORMWT,GA(120),GO,HCHAMA(120),HO(30,8),HTOT,ID(30),
  3IREAC,ISCOND(30),ISOL,ISW,JOB(10),KON(30),MMA,MMMB,MOLEWT(30),
  4MU(30),NATOMS,NOVAP(30),NPRES,NREAC,NSPEC,NU(30,30),PA(120),
  5PE(120),PMOLE(10),PNAME(10,2),PO,POUT,PRES,RANGE,SDENS(30),
  6SHSJ(30),SNAME(2,30),SO(30,8),TEMP,TINIT(6),TMELT(30),TVAP(30),
  7VA(120),VAPRES(30),X(30)
  COMMON/BLKB/FORMB(30),GB(30),NOSPE,VB(30),XMOLES(20)
  COMMON/BLKC/AA1,A2,AAAX(30,8),ADUCT,ADUCT1,AEPA,AMASS1,AMASS2,
  1AMP(20),AP,ATOMX(10,30),ATP,ATS,ATWTX(10),B0,B1,B2,BBBB(30,8),
  2BRNC,BRNE,BVOLT,C0,C1,C2,CCCC(30,8),CDATE1,CDATE2,
  3CDATE3,CNADH,COMPOS(10),DAO,DATA(20,20),DATAB(20),DATAO(20),
  4DATE1,DATE2,DATE3,DDUCT,DEPA,DEPB,DOMP,OTPA,OTPB,OTSA,OTSB,
  5FASTRM,FCALR,FLORAT(55),FUEL1,FUEL2,FUEL3,FUELH1,FUELH2,FUELH3,
  6HITE,HOX(30,8),HPROP(10),HPROPX(10),HSENF,HSENSP,HSNAOH,IASAVE,
  7ICAL,ICHAMB(20),ICHAN,ICODE(20),ICODEA(2,10),ICODEP(2,10),
  8ICODES(2,10),IDPA,IDP1,IDP2,IDP3,IDPA,IDX(30),IF,IFATAL,IPF,JPAD,
  9IPC,IPF,IP1,IPS,IPSA,IPSAVE,IPSJ,IROUTE,IS,ISCNXX(30)
  COMMON/BLKD/ISOLID,ISOLUT,IST,ISTORE,ISU,ISV,ISX,ISY,ISZ,ISSAVE,
  11TABLE,ITANK(20),ITS(3),IWF,IWHF,IWOX,JOBTYP,JS,KCAL,KCHAN,KDAT,
  2KONX(30),KPROP,M,M0,M1,M2,MOLWTX(30),N,NO,NATOM1,NATOM2,NCAL,
  3NCALCK,NDAT(20),NFILES,NOVAPX(30),NP1,NP2,NPROP,NPTS,NSB,
  4NSD,NSPEC1,NSPEC2,NSPTS,NT,NTS1,NTW,NUMBER,NWCK(20),OF(15,10),
  5OFX,OX1,OX2,OX3,PBAR,PCMAX,PCMIN,PEDES,PF(6),PHF,PNAMEX(10,2),
  6POX,PRC,PROPAT(10,10),PRPATX(10,10),PSA,PSAMAX,PSAMIN,PSUMAX,
  7PSJMIN,RAD1,RAD2,RAD3,RATIO,PHOP,RUNDUR,SDENSX(30),SECB,
  8SECD,SNAMEX(2,30),SOX(30,8),TAMB,TAO,TCMAX,TCMIN,TIMGRN(55),TIME0,
  9TIME1,TIME2,TIMEF,TIMER1,TIMER2,TIMPC1,TIMPC2
  COMMON/BLKE/BLKE/TMELT(30),TRANSO(2,10),TSA,TSAMAX,TSAMIN,TSIBAV,
  1TSIDAV,TSIDAT(20),TSJMAX,TSJMIN,TVAPX(30),UN1,UN2,UN3,UN4,UN5,
  2UNITS(20),UNITSR,UNITST,VARB(20),VARO(20),VAROAT(20,20),WA,WAB,
  3WAP(20),WF,WFDCK,WHF,WHFBC,WHFDOCK,WNAOH,WNAOH,WOXK,WP,X0,
  4XX(5),XXX,XXX0,Y0,YY(5),YYY,Z0,ZMW(10),ZAD
  COMMON/BLKF/AM(5,5),D1,D2,GVD(6),PSJ,TSJ,YFACT
  DIMENSION ZX(20),ZY(20)
  PO = 1.
  IST = 0
  IFATAL = 0
  GO TO (720,779,773,774,745,775,500,746),ISOLUT
720 DO 780 I = 1,5
  DO 780 J = 1,5
  M = M+N
780 AM(I,J) = GA(M)-Y0
  WRITE(6,660) (I,(AM(I,J),J=1,5),I=1,5)
779 NN = 0
  DO 781 I = 1,5
  JSN = AM(I,1)/ABS(AM(I,1))
  DO 781 J = 2,5
  JS = AM(I,J)/ABS(AM(I,J))
  IF(JS.EQ.JSN) GO TO 781
  NN = NN+1
  ZX(NN) = J-1
  ZX(NN) = ZX(NN) + AM(I,J-1)/(AM(I,J-1)-AM(I,J))
  ZY(NN) = I
  JSN = JS
781 CONTINUE
  DO 782 J = 1,5

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JSGN = AM(1,J)/ABS(AM(1,J))
DO 782 I = 2,5
JS = AM(1,J)/ABS(AM(1,J))
IF(JS.EQ.JSGN) GO TO 782
NN = NN+1
ZK(NN) = J
ZY(NN) = 1-1
ZY(NN) = ZY(NN) + AM(1-1,J)/(AM(1-1,J)-AM(1,J))
JSGN = JS
782 CONTINUE
WRITE(6,662) (ZX(I),ZY(I),I=1,NN)
IF(NN-3) 932,773,773
932 IST = 1
WRITE(6,667)
IF(PO.EQ.1) GO TO 810
RETURN
500 M = 25
DO 820 I = 1,5
M = M+1
ZY(I) = GA(M) - Y0
820 ZX(I) = 1
773 S0 = NN
S1 = 0.
S2 = 0.
S3 = 0.
S4 = 0.
S5 = 0.
S6 = 0.
S7 = 0.
DO 783 I = 1,NN
S1 = S1 + ZX(I)
S2 = S2 + ZX(I)**2
S3 = S3 + ZX(I)**3
S4 = S4 + ZX(I)**4
S5 = S5 + ZY(I)
S6 = S6 + ZY(I)*ZY(I)
783 S7 = S7 + ZY(I)**2*ZY(I)
D = (S0*S5+S2*S1+S2*S3-S2**3-S0*S3**2-S1**2*S4
A0 = (S5*S2*S4+S1*S3*S5+S2*S3*S6-S2**2*S7-S3**2*S5-S4*S1*S6)/D
A1 = (S0*S6*S4+S2*S3*S5+S2*S1*S7-S2**2*S6-S7*S3*S0-S4*S5*S1)/D
A2 = (S0*S2*S7+S1*S6*S2+S5*S3*S1-S2**2*S5-S3*S6*S0-S7*S1**2)/D
810 IF(15X.GT.2) RETURN
WRITE(6,664)
Z1 = 0.5
DO 663 I=1,9
Z1 = Z1+0.5
Z2 = A0+A1*Z1+A2*Z1**2
663 WRITE(6,665) Z1,Z2
GO TO (775,784),15X
775 B0 = A0
B1 = A1
B2 = A2
PO = 2.
15X = 2
M = M0
DO 785 I = 1,5
DO 785 J = 1,5
SN = 1.
IF(VA(M).LT.0.) SN = -1.
785 AM(1,J) = SN*GA(M)+VA(M)/32.174 + (PA(M)*14.696-PBAR)*144. - X0

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WRITE(6,661) (I,(AM(1,J),J=1,5),I=1,5)
GO TO 779
784 CP = A2 - B2
C1 = A1 - B1
CO = A0 - B0
15U = 1
YYY = 0.
774 D = C1*C1 - 4.*C2*C0
IF(D) 742,743,743
742 CONTINUE
IFATAL = 1
XXX0 = 5.
WRITE(6,668)
RETURN
743 D = SQRT(D)
S1 = (-C1+D)/(2.*C2)
S2 = (-C1-D)/(2.*C2)
IF(S1-1.) 786,787,787
786 IF(S2-1.) 742,789,789
787 IF(S2-1.) 790,791,791
789 XXX = S2
GO TO 794
790 XXX = S1
GO TO 794
791 D = S1-S2
IF(D) 792,793,793
792 XXX = S1
IF(XXX.GT.XXX0) GO TO 793
GO TO 794
793 XXX = S2
794 IF(YYY.EQ.0.) YYY = A0 + A1*XXX + A2*XXX**2
15 = YYY
JS = XXX
IF(XXX-XXX0) 796,796,742
796 XXX0 = 7.
IF(YYY-5.) 798,798,742
798 IF(15Y.GT.2) RETURN
GO TO (744,746),15Y
744 M0 = 0
N = 1
N0 = 5
746 D1 = JS
D1 = XXX-D1
TSJ = XX(JS) + D1*(XX(JS+1) - XX(JS))
D2 = 15
D2 = YYY - D2
PSJ = YY(15) + D2*(YY(15+1) - YY(15))
PSJ = PSJ*14.696
745 N1 = (15-1)*N0 + JS*N + M0
N2 = N1+N
N3 = N1+N0
N4 = N2+N0
772 HSJ = (HCHAMA(N1) + D1*(HCHAMA(N2) - HCHAMA(N1)))*(1.-D2) + D2*
(HCHAMA(N3)+D1*(HCHAMA(N4) - HCHAMA(N3)))
GJ = (GA(N1)+D1*(GA(N2)-GA(N1)))*(1.-D2)+D2*(GA(N3)+D1*(GA(N4)-GA
(N3)))
VJ = (VA(N1)+D1*(VA(N2)-VA(N1)))*(1.-D2) + D2*(VA(N3)+D1*(VA(N4)-
VA(N3)))
PJ = (PA(N1)+D1*(PA(N2)-PA(N1)))*(1.-D2)+D2*(PA(N3)+D1*(PA(N4)-
PA(N3)))
PJ = PJ*14.696

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TJ = (AFACB(N1)+D1*(AFACB(N2)-AFACB(N1)))*(1.-D2) + D2*(AFACB(N3)
+D1*(AFACB(N4)-AFACB(N3)))
AMJ = (FORMA(N1) + D1*(FORMA(N2)-FORMA(N1)))*(1.-D2) + D2*(FORMA(N
13) +D1*(FORMA(N4)-FORMA(N3)))
W = GJ*ATS
FB = W*VJ/32.174 + (PJ-PBAR)*ATS*144.
TSX = TSJ*9./5.
TJ = TJ*1.8
WRITE(6,560) W,FB,HSJ,TSX,PSJ,PJ,TJ,VJ,GJ,AMJ
RETURN
560 FORMAT(1H0,34X,33RESULTS OF CALCULATIONS*****/1H0,34X,
19HFLOW RATE*21X,2H= + F10,4,7H LB/SEC/1H ,34X,12HSDNIC THRUST*18X,
22H= +
3F10,1,4H LBF/1H ,34X,19HSTAGNATION ENTHALPY*11X,2H= + F10,3,
47H CAL/GM/ 1H ,34X,22HSTAGNATION TEMPERATURE*8X,2H= + F10,1,2H R/
51H ,34X,19HSTAGNATION PRESSURE*11X,2H= + F10,2,5H PSIA/1H ,34X,15H
65TATIC PRESSURE*15X,2H= + F10,2,5H PSIA/1H ,34X,18HSTATIC TEMPERAT
7URE*12X,2H= + F10,1,2H R/1H ,34X,8HVELOCITY*22X,
82H= + F10,1,7H FT/SEC/1H ,34X,13HMASS VELOCITY*17X,2H= + F10,1,
911H LB/FT2 SEC /1H ,34X,16HMOLECULAR WEIGHT*14X,2H= + F10,3,3
660 FORMAT(1H1,50X,20HMASS VELOCITY MATRIX/1H0,31X,1H1,14X,1H2,14X,1H3
1,14X,1H4,14X,1H5//1H ,19X,13, 5E15,5)
661 FORMAT(1H1///1H ,50X,20HSTREAM THRUST MATRIX/1H0,31X,1H1,14X,1H2,1
14X,1H3,14X,1H4,14X,1H5//1H ,19X,13, 5E15,5)
662 FORMAT(1H0,41X,38HPDINTS USED TO GENERATE SOLUTION CURVE/1H0,
152X,1H1,14X,1H2//1H ,43X, 2E15,5)
664 FORMAT(1H0,48X,24HPDINTS ON SOLUTION CURVE/1H0,52X,1H1,14X,1H2//)
665 FORMAT(1H ,43X, 2E15,5)
667 FORMAT(1H0,25X,69HNUMBER OF SOLUTION POINTS INSUFFICIENT. PROGRAM
1PROCEEDS TO NEXT CASE /1H1)
668 FORMAT(1H0,33X,53HNO ACCEPTABLE SOLUTION. PROGRAM PROCEEDS TO NEXT
1CASE /1H1)
END

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OVERLAY(D1X4,1,1)
PROGRAM LINK 41
CALL ASTRMB
RETURN
FND
SUBROUTINE ASTRMB
INTEGER RANGE
REAL MOLTNUM,MU
COMMON/BLKA/AAAA(30,8),AFACA(120),AFACB(120),ALPHA,ATOM(10,30),
1ATWT(10),BBBB(30,8),BETA(10),CCCC(30,8),CHAMH,CHAMS,ERROR,
2FORMA(120),FORMWT,GA(120),GO,HCHAMA(120),HO(30,8),HTOT,1D(30),
3IREAC,ISCOND(30),ISOL,15W,JDB(10),KOM(30),MMA,MMMB,MOLEWT(30),
4MU(30),NATOMS,NOVAP(30),NPRES,NREAC,NSPEC,NUI(30,30),PA(120),
5SPE(120),PMOLE(10),PNAME(10,2),PO,POUT,PRES,RANGE,SDENS(30),
6SHSJ(30),SNAME(2,30),SO(30,8),TEMP,TINIT(6),TMELT(30),TVAP(30),
7VA(120),VAPRES(30),X(30)
COMMON/BLKB/FORMB(30),GB(30),NOSPE,VB(30),XMOLES(20)
COMMON/BLKC/AD,A1,A2,AAAA(30,8),ADUCT,ADUCT1,AEPA,AMASS1,AMASS2,
1AMP(20),AP,ATOMX(10,30),ATPAT,ATWTX(10),BO,B1,B2,BBBX(30,8),
2BRNC,BRNE,BVOLT,CO,C1,C2,CCCC(30,8),CDATE1,CDATE2,
3CDATE3,CNAOH,COMPOS(10),DAO,DATA(20,20),DATAB(20),DATAD(20),
4DATE1,DATE2,DATE3,DDUCT,DEPA,DEPB,DOMP,DTPA,DTPB,DTSA,DTSB,
5FASTRM,FCALR,FLORAT(35),FUEL1,FUEL2,FUEL3,FUELH1,FUELH2,FUELH3,
6HITE,HOX(30,8),HPROP(10),HPROPX(10),HSENSF,HSENSP,H5NAOH,IASAVE,
7ICAL,ICHAMB(20),ICHAN,ICODE(20),ICODEA(2,10),ICODEP(2,10),
8ICODES(2,10),IDPA,IDP1,IDP2,IDP3,IDP4,IDX(30),IF,IFATAL,IFPF,IPAO,
9IPCP,IPF,IP1,IP2,IPSA,IPSAVE,IPSA,IPROUTE,IS,ISCOND(30)
COMMON/BLKD/SOLID,ISOLUT,IST,ISTORE,ISU,ISV,ISX,ISY,ISZ,ISSAVE,
1ITABLE,ITANK(20),ITS(3),1WF,1WHF,1WOK,JDBTYP,JS,KCAL,KCHAN,KDAT,
2KONX(30),KPROP,M,M0,M1,M2,MOLWTX(30),N,N0,NATOM1,NATOM2,NCAL,
3NCALCK,NODAT(20),NFILES,NOVAPX(30),NP1,NP2,NPROP,NPTS,NSB,
4NSD,NSPEC1,NSPEC2,NSPTS,NT,NTS1,NTW,NUMBER,NWCK(20),OF(15,10),
5OFX,OX1,OX2,OX3,PBAR,PCMAX,PCMIN,PEDES,PF(6),PHF,PNAMEX(10,2),
6POX,PRC,PROPAT(10,10),PRPATX(10,10),PSA,PSAMAX,PSAMIN,PSJMAX,
7PSJMIN,RAD1,RAD2,RAD3,RAT10, RHOP,RUNDR,SDENSX(30),SECB,
8SECD,SNAMEX(2,30),SOX(30,8),TAMB,AD,TCMAX,TCMIN,TIMBRN(55),TIME0,
9TIME1,TIME2,TIMEF,TIME01,TIME02,TIME03,TIME04,TIME05,TIME06,
COMMON/BLKE/TMELTX(30),TRANSD(21,10),TSA,TSAMAX,TSAMIN,TSIBAV,
1TSDAV,TSIDAT(20),TSJMAX,TSJMIN,TVAPX(30),UNI,UN2,UN3,UN4,UN5,
2UNITS(20),UNITSR,UNITST,VARB(20),VARD(20),VARDAT(20,20),WA,WAB,
3WAP(20),WF,WFDCK,WHF,WHFCK,WFDCK,WNAOH,WNAOH,WOXCK,WP,X0,
4XX(5),XXX,XXX0,YO,YY(5),YYY,Z0,ZMWT(10),WAD
COMMON/BLKF/AM(5,5),D1,D2,GVD(6),PSJ,TSJ,YFACT
COMMON/BLKG/W02B,W020,WMB,WMD,ODATAD
COMMON/BLKH/TW(10),TW01(10),TIME(10)
COMMON/BLKN/MIX
MIX=0
731 DO 740 J = 1,NPROP
SUM = 0.
DO 741 I = 1,NATOMS
741 SUM = SUM + PROPAT(J,I)*ATWT(I)
740 ZMWT(J) = SUM
XMOLES(1) = 1.
XMOLES(2) = 21./79.
XMOLES(2) = 21./79. + W02B*(ZMWT(1)+XMOLES(2)*ZMWT(2))/(ZMWT(2)*WA
1B)
XMOLES(3) = DATAB1*WFF*(ZMWT(1)+XMOLES(2)+ZMWT(2))/(ZMWT(3)*WAB)
XMOLES(4) = WNAOH*(ZMWT(1)+XMOLES(2)+ZMWT(2))/(ZMWT(4)*WAB*(1.+CNA
1OH))
XMOLES(5) = XMOLES(4)*CNAOH*(ZMWT(4)+ZMWT(5))
XMOLES(6) = WMB*(ZMWT(1)+XMOLES(2)+ZMWT(2))/(ZMWT(6)*WAB)

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DO 756 I=1,6
756 PMOLE(I) = XMOLES(I)
DO 750 I = 1,NATOMS
SUM = 0.
DO 751 J = 1,NPROP
SUM = SUM + XMOLES(J) * PROPAT(J,1)
751 SUM = SUM + XMOLES(J) * PROPAT(J,1)
750 BETA(1) = SUM
SUM = 0.
DO 752 I = 1,NATOMS
752 SUM = SUM + ATWT(I) * BETA(1)
FORMWT = SUM
SUM = 0.
DO 753 J = 1,NPROP
753 SUM = SUM + XMOLES(J) * HPROP(J)
CHAMHX4 SUM*1000.
IF (PSAMIN) 20,20,21
20 YY(1) = DATAB(IPSA)/14.696
YY(5) = 1.1*YY(1)
YY(1) = 0.9*YY(1)
GO TO 22
21 YY(1) = PSAMIN/14.696
YY(5) = PSAMAX/14.696
22 IF (TSAMIN) 23,23,24
23 XX(5) = TSIBAV*1.1
XX(1) = TSIBAV*0.9
GO TO 24
24 XX(1) = TSAMIN
XX(5) = TSAMAX
25 DX = (XX(5)-XX(1))/4.
DY = (YY(5) - YY(1))/4.
DO 26 I = 2,5
XI = I-1
XX(I) = XX(1) + XI*DX
26 YY(I) = YY(1) + XI*DY
DO 400 I = 1,5
750 XX(I) = XX(I)*5./9.
PRES = YY(I)
ASPE = NOSPE
DO 754 J = 1,NDSPE
754 X(J) = PRES/ASPE
NPRES = 0
X(M1) = YY(1)
X(M2) = XX(1)
DO 760 I = 1,5
DO 760 J = 1,5
PRES = YY(I)
TEMP = XX(J)
ISOL = 1
ISW=0
CALL TCHEM
CALL OUTPUT
ISW=0
PRES = YY(I)
JOB(2)=3
760 CALL SHEXP
CHAMH = CHAMHX
JOB(1) = 1
DO 770 I = 1,5
PRES = YY(I)
ISOL = 3

ISW=0
CALL TCHEM
CALL OUTPUT
ISW=0
PRES = YY(1)
JOB(2)=3
770 CALL SHEXP
XO = DATAB(IF)
YO = DATAB(IWHF) + WAB + WNAOHB + WMB + W02B
ATS = 3.141596*DTSSB**2/(4.*144.)
YO = YO/ATS
XO = XO/ATS
XXO = 5.
MO = 0
ISZ = 1
ISY = 3
ISX = 1
ISU = 1
IST = 0
WRITE(6,153) NSB,SECB,(TRANSO(1,1),TRANSO(1,2),DATAB(1),UNITS(1),
IVAR(1,1),1,20)
WRITE(6,154) WHFBC
WRITE(6,155) TSIBAV
WRITE(6,156) WAB
WRITE(6,157) WNAOHB
WRITE(6,158) W02B,WMB
IROUTE = 1
CALL AROUTE
CALL ASTRMD
IROUTE = 2
CALL AROUTE
RETURN
153 FORMAT(1H1,46X,33H RUN DATA - PRIOR TO ROCKET FIRING/1H,46X,33H***
1*****/1H0,17X,26H MEASUREMENTS AVERAGED OV
2ER,13,1X,16H SAMPLES OF DATA,,F6.3,1X,33H SECOND PRIOR TO THE ROCKET
3 FIRING//1H0,26X,7H CHANNEL,7X,11H MEASUREMENT,13X,5H VALUE,13X,
419H FRACTIONAL VARIANCE //1H,27X,A6,10X,A6,10X,F10,3,1X,A6,10X,
5F7.4))
154 FORMAT(1H0,40X,40H*****/1H0,
129X,61H FUEL FLOW RATE (CHECK) COMPUTED FROM FUEL TANK PRESSURE, PH
2F,1H,28X,64H AIR STAGNATION PRESSURE, PSA, AND LINE/INJECTOR CALI
3BRATION DATA //1H0,45X,12HWHF(CHECK) = ,F10,3,1X,6HLB/SEC/1H0,
440X,40H*****
155 FORMAT(1H0,26X,67H AVERAGE STAGNATION TEMPERATURE OF THE AIR ENTERI
NG THE TEST SECTION/1H0,51X,5HTSI = ,F10,1,2H R/1H0,40X,
240H*****
156 FORMAT(1H0,53X,13H AIR FLOW RATE/1H0,49X,4HWA = ,F10,4,1X,6HLB/SEC/
1H0,40X,40H*****
157 FORMAT(1H0,47X,26H FLOW RATE OF NAOH SOLUTION/1H0,48X,7H WNAOH = ,
F10,4,1X,6HLB/SEC/1H0,40X,40H*****
2****
158 FORMAT(1H0,42X,37H IGNITOR OXYGEN AND METHANE FLOW RATES/1H0,36X,6H
1WO2 = ,F8,5,1X,6HLB/SEC,6X,5HWM = ,F8,5,1X,6HLB/SEC/1H0,40X,40H***
2*****
END

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SUBROUTINE AROUTE
INTEGER RANGE
REAL MOLEWT,NU,MU
COMMON/BLKA/AAAA(30,8),AFACA(120),AFACB(120),ALPHA,ATOM(10,30),
1ATWT(10),BBBB(30,8),BETA(10),CCCC(30,8),CHAMH,CHAMS,ERROR,
2FORMA(120),FORMWT,GA(120),GO,HCHAMA(120),HO(30,8),HTOT,10(30),
3IREAC,15COND(30,1),ISOL,15W,JOB(10),KON(30),MMA,MMMB,MOLEWT(30),
4MU(30),NATOMS,NOVAP(30),NPRES,NREAC,NSPEC,NU(30,30),PA(120),
5PE(120),PMOLE(10),PNAME(10,2),PO,POUT,PRES,RANGE,SDENS(30),
6SHSJ(30),SNAME(2,30),SO(30,8),TEMP,TINIT(6),TMELT(30),TVAP(30),
7VA(120),VPRES(30),X(30)
COMMON/BLKB/FORMB(30),GB(30),NOSPE,VB(30),XMOLES(20)
COMMON/BLKC/AO,A1,A2,AAAAX(30,8),ADUCT,ADUCT1,AEP,AMASS1,AMASS2,
1AMP(20),AP,ATOMX(10,30),ATP,ATS,ATWTX(10),B0,B1,B2,BBBX(30,8),
2BRNC,BRNE,BVOLT,CO,C1,C2,CCCCX(30,8),CDATE1,CDATE2,
3CDATE3,CNAOH,COMPOS(10),DOAO,DATA(20,20),DATAB(20),DATAD(20),
4DATE1,DATE2,DATE3,DOUCT,DEPA,DEPB,DOMP,DTPA,DTPB,DTSA,DTSB,
5FASTRM,FCLR,FLOPAT(55),FUEL1,FUEL2,FUEL3,FUELH1,FUELH2,FUELH3,
6HITE,HGX(30,8),HPROP(10),HPROPX(10),HSENSF,HSENSP,HNAOH,IASAVE,
7ICAL,1CHAMB(20),1CHAN,1CODE(20),1CODEA(2,10),1CODEP(2,10),
8ICODES(2,10),IDPA,1DP1,1DP2,1DP3,1DP4,1DX(30),1F,1FATAL,11PF,1PA0,
91PC,1PF,1PI,1PS,1PSA,1PSAVE,1PSJ,1ROUTE,1S,1SCNDX(30)
COMMON/BLKD/ISOL,10,ISOLUT,1ST,1STORE,1SU,1SV,1SX,1SY,1SZ,1SSAVE,
11TABLE,1TANK(20),1TS1(3),1WF,1WHF,1WOX,1JOSTYP,JS,KCAL,KCHAN,KDAT,
2KONX(30),KPROP,M,MO,M1,M2,MQLWTX(30),N,N0,NATOM1,NATOM2,NCAL,
3NCALCK,NDAT(20),NFILES,NOVAPX(30),NP1,NP2,NPROP,NPTS,NSB,
4NSD,NSPEC1,NSPEC2,NSPTS,NT,NTS1,NTW,NUMBER,NWCK(20),OF(15,10),
5OFX,OX1,OX2,OX3,PBAR,PCMAX,PCMIN,PEDES,PF(6),PHF,PNAMEX(10,2),
6POX,PRC,PROPAT(10,10),PRPATX(10,10),PSA,PSAMAX,PSAMIN,PSJMAX,
7PSJMIN,RAD1,RAD2,RAD3,RAT10, RHOP,RNDUR,SDENSX(30),SECB,
8SECD,SNAMEX(2,30),SDX(30,8),TAMB,TAO,TCMAX,TCMIN,TIMBRN(55),TIME0,
9TIME1,TIME2,TIMEF,TIMER1,TIMER2,TIMPC,TIMPC2
COMMON/BLKE/TMELTX(30),TRANSO(21,10),TSA,TSAMAX,TSAMIN,TSIBAV,
1TSDAV,TSIDAT(20),TSJMAX,TSJMIN,TVAPX(30),UN1,UN2,UN3,UN4,UN5,
2UNITS(20),UNITSR,UNITST,VARB(20),VARD(20),VARDAT(20,20),WA,WAB,
3WAP(20),WF,WDFCK,WHF,WHFBC,WHFDC,WNAOHB,WNAOHD,WDXCK,WP,XO,
4XX(5),XXO,XXO,XO,YY(5),YYW,ZO,ZMWT(10),ZWA
COMMON/BLKF/AM(5,5),D1,D2,GVD(6),PSJ,TSJ,YFACT
COMMON/BLKG/W02B,W02D,WMB,WMD,ODATAD
COMMON/BLKH/TW(10),TW0(10),TIME(10)
DIMENSION ZX(20),ZY(20)
KSW = 0
IOUT = 1
GO TO (10,735),1ROUTE
C
C
C *****ASSIGNED F.W COMPUTATIONS
10 WRITE(6,600)
WRITE(6,601) (GB(1),SHSJ(1),VB(1),HCHAMA(1),AFACB(1),PA(1),FORMA(
1),GA(1),VA(1),1,1,30)
MO = 0
NO = 5
N = 1
M = 0
ISOLUT = 1
CALL SOLUT
IF(1ST.EQ.0) GO TO 771
KSW = 0
GO TO 800
771 WRITE(6,158)
IOUT = -IOUT

Z1 = XO*ATS
Z2 = YO*ATS
WRITE(6,159) Z2,Z1
IF(1FATAL.EQ.1) GO TO 800
ISOLUT = 1
CALL SOLUT
HR = SHSJ(15+25) + D2*(SHSJ(15+26)-SHSJ(15+25))
N1 = (15-1)*5 + JS
N2 = N1+1
N3 = N1+5
N4 = N2+5
HRP = (SHSJ(N1)+D1*(SHSJ(N2)-SHSJ(N1)))*(1.-D2) + D2*(SHSJ(N3)
+D1*(SHSJ(N4)-SHSJ(N3)))
ETAC = HRP/HR
WRITE(6,561) HRP,HR,ETAC
C
C
C *****ASSIGNED P.T COMPUTATIONS
800 IF(1FATAL.FO.1) WRITE(6,568)
NO 801 I = 1,5
D2 = DATAB(IPSA)/14.696 - YY(1)
IF(D2) 802,801,801
801 CONTINUE
802 IS = I-1
DO 803 J = 1,5
D1 = TSIBAV*5./9. - XX(J)
IF(D1) 804,803,803
803 CONTINUE
804 JS = J-1
PSJ = DATAB(IPSA)
TSJ = TSIBAV*5./9.
D1 = 1+D1/1X(J+1)-XX(JS)
D2 = 1+D2/1Y(15+1)-YY(15)
ISZ = 2
IF(IOUT.GE.0) WRITE(6,568)
IOUT = -IOUT
WRITE(6,562)
ISOLUT = 5
CALL SOLUT
HR = SHSJ(15+25) + D2*(SHSJ(15+26)-SHSJ(15+25))
N1 = (15-1)*5 + JS
N2 = N1+1
N3 = N1+5
N4 = N2+5
HRP = (SHSJ(N1)+D1*(SHSJ(N2)-SHSJ(N1)))*(1.-D2) + D2*(SHSJ(N3)
+D1*(SHSJ(N4)-SHSJ(N3)))
ETAC = HRP/HR
WRITE(6,561) HRP,HR,ETAC
C
C
C *****ASSIGNED P.W COMPUTATIONS
IF(KSW.EQ.1) RETURN
PSJ = DATAB(IPSA)
PASSGN = PSJ/14.696
ISY = 2
ISZ = 3
768 DO 816 I = 1,5
D = PASSGN - YY(I)
IF(D) 817,816,816
816 CONTINUE
817 IS = I-1

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D2 = (PASSGN - YY(5))/((YY(5+1) - YY(5)))
VYV = 15
YYY = YYY+D2
C2 = 92
C1 = 81
C0 = 80 - YYY
IF (IOUT.GE.0) WRITE(6,56B)
IOUT = -IOUT
WRITE(6,56A)
ISOLUT = 4
CALL SOLUT
IF (IFATAL.FO.1) GO TO 765
HR = SHSJ(15+25) + D2*(SHSJ(15+26)-SHSJ(15+25))
N1 = (15-1)*5 + J5
N2 = N1+1
N3 = N1+5
N4 = N2+5
HRP = (SHSJ(N1)+D1*(SHSJ(N2)-SHSJ(N1)))*(1-D2) + D2*(SHSJ(N3)
+D1*(SHSJ(N4)-SHSJ(N3)))
ETAC = HRP/HR
WRITE(6,561) HRP,HR,ETAC
*****ASSIGNED H-W COMPUTATIONS
765 NN = 5
ISX = 3
ISOLUT = 7
CALL SOLUT
767 C0 = A0
C1 = A1
C2 = A2
J5Y = 3
YYY = 1
IF (IOUT.GE.0) WRITE(6,56B)
IOUT = -IOUT
WRITE(6,565)
ISOLUT = 4
CALL SOLUT
IF (IFATAL.FO.1) RETURN
766 IY = XXX
DY = IY
DY = XXX - DY
M = 25+IY
PSJ = YY(IY) + DY*(YY(IY+1)-YY(IY))
PSJ = PSJ+14.696
TSJ = VR(M) + DY*(VR(M+1)-VR(M))
HSJ = HCHAMA(M)+DY*(HCHAMA(M+1)-HCHAMA(M))
GJ = GA(M) + DY*(GA(M+1)-GA(M))
VJ = VA(M) + DY*(VA(M+1)-VA(M))
PJ = PA(M) + DY*(PA(M+1)-PA(M))
PJ = PJ+14.696
TJ = AFACB(M) + DY*(AFACB(M+1) - AFACB(M))
AMJ = FORMA(M) + DY*(FORMA(M+1) - FORMA(M))
W = GJ*ATS
FB = W*VJ/32.174 + (PJ-PBAR)*ATS*144.
TSX = TSJ*9./5.
TJ = TJ*1.8
WRITE(6,560) W,FB,HSJ,TSX,PSJ,PJ,TJ,VJ,GJ,AMJ
RETURN
C
C AIR STREAM COMPUTATIONS DURING THE ROCKET FIRING*****

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C
735 WRITE(6,602)
WRITE(6,603) (GB(I),SHSJ(I),VB(I),HCHAMA(I),AFACB(I),PA(I),FORMA(I)
1)GA(I),VA(I),I=1,21)
WRITE(6,603) (HCHAMA(I),AFACB(I),PA(I),FORMA(I),GA(I),VA(I),I=3,4)
ISOLUT = 4
CALL SOLUT
IF (IFATAL.EQ.1) RETURN
350 XXX = XXX-1.
PINJ = PE(1) + XXX*(PE(3)-PE(1))/2.
GINJ = Y0
Z1 = VA(1)
Z2 = -3.0*VA(1) + 4.*VA(2) - VA(3)
Z3 = 2.*VA(1) - 4.*VA(2) + 2.*VA(3)
XXX = XXX/2.
VINJ = Z1 + Z2*XXX + Z3*XXX*2
FASTRM = PINJ*14.696*144. + GINJ*VINJ/32.174
IF (IPI.FO.0) GO TO 351
PJ = DATAD(IPI)
GO TO 352
351 PJ = DATAD(IPI)-DATAD(IOP1)-DATAD(IOP2)-DATAD(IOP3)-DATAD(IOP4)
352 HCHAM = GB(2)
HSJ = HCHAM
HR = SHSJ(2)
HRP = SHSJ(1)
ETAC = HRP/HR
TJ = VB(2)*1.8
W = DATAD(IWHF) + WNAOH + WAD + WMD + W02D
PINJ = PINJ+14.696
WRITE(6,566) DATAD(PSA),TSJ,DAV,TJ,W,HCHAM,HR
WRITE(6,567) HSJ,HRP,PINJ,PJ,VINJ,GINJ,FASTRM,ETAC
RETURN
158 FORMAT(1H,29X,60HRESULTS OF THERMOCHEMICAL COMPUTATIONS BASED ON
1THE MEASURED/1H,26X,69HVALUES FOR THRUST, TOTAL FLOW RATE, AND CHI
2THE MEASURED MAKEUP OF THE STREAM /1H,26X,69H*****
3*****
4*****
5*****
159 FORMAT(1H,34X,18HMEASURED FLOW RATE,12X,2H= ,F10.4,7H LB/SEC/
11H ,34X,15HMEASURED THRUST,15X,2H= ,F10.1,4H LBF)
560 FORMAT(1H,34X,33HRESULTS OF CALCULATIONS*****/1H,34X,
19HFLOW RATE,21X,2H= ,F10.4,7H LB/SEC/1H ,34X,12HSONIC THRUST,18X,
22H= ,
3F10.1,4H LBF/1H ,34X,19HSTAGNATION ENTHALPY,11X,2H= ,F10.3,
47H CAL/GM /1H ,34X,22HSTAGNATION TEMPERATURE,8X,2H= ,F10.1,2H R/
51H ,34X,19HSTAGNATION PRESSURE,11X,2H= ,F10.2,5H PSIA/1H ,34X,15H
6STATIC PRESSURE,15X,2H= ,F10.2,5H PSIA/1H ,34X,18HSTATIC TEMPERAT
7URE,12X,2H= ,F10.1,2H R/1H ,34X,8HVELOCITY,22X,
82H= ,F10.1,7H FT/SEC/1H ,34X,13HMASS VELOCITY,17X,2H= ,F10.1,
911H LB/FT2 SEC /1H ,34X,16HMOLECULAR WEIGHT,14X,2H= ,F10.3/1H1)
561 FORMAT(1H,34X,35HSENSIBLE STAGNATION ENTHALPIES*****, 6HCAL/GM/
11H,39X,12HMIXED STREAM,
2 ,13X,2H= ,F10.4/1H ,39X,25HTHEORETICAL MIXED STREAM,2H= ,F10
34,1H,34X,21HCOMBUSTION EFFICIENCY,9X,2H= ,F10.5 //1)
562 FORMAT(1H,35X,51HCOMPUTATIONS AT ASSIGNED STAGNATION TEMPERATURE
1AND/1H ,38X,45HPRESSURE CORRESPONDING TO THE MEASURED VALUES ///)
563 FORMAT(1H,34X,32HSENSIBLE STAGNATION ENTHALPY = ,F10.3, 7H CAL/G
1M/1H,34X,21HCOMBUSTION EFFICIENCY,9X,2H= ,F10.5)
564 FORMAT(1H,36X,48HCOMPUTATIONS AT ASSIGNED STAGNATION PRESSURE AND
1/1H ,37X,46HFLOW RATE CORRESPONDING TO THE MEASURED VALUES ///)
565 FORMAT(1H,34X,72HCOMPUTATIONS AT ASSIGNED STAGNATION ENTHALPY AND
1FLOW RATE CORRESPONDING/1H ,32X,55HTO THE MEASURED VALUES OF FLOW
2 RATE AND CHEMICAL MAKEUP ///)

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566 FORMAT(1H,36X,48HAIIR STREAM COMPUTATIONS DURING THE ROCKET FIRING
1/1H ,36X,48H*****//1H,
230X,60HVALUES BASED ON MEASURED STAGNATION PRESSURE AND TEMPERATUR
3E/1H,30X,19HSTAGNATION PRESSURE,21X,3H= ,F10.3,5H PSIA/1H ,30X,
422HSTAGNATION TEMPERATURE,18X,3H= ,F10.1,2H R/1H ,30X,34HTHEORET
5ICAL STAGNATION TEMPERATURE,6X,3H= ,F10.1,2H R/1H ,30X,20HFLOW RA
6TE (MEASURED),20X,
7 3H= ,F10.4,7H LB/SEC/1H ,30X,31HTHEORETICAL STAGNATION ENT
8HALPY,9X,3H= ,F10.3, 7H CAL/GM/1H ,30X,43HTHEORETICAL SENSIBLE S
9TAGNATION ENTHALPY = ,F10.3, 7H CAL/GM )
567 FORMAT(1H ,30X,19HSTAGNATION ENTHALPY,21X,3H= ,F10.3, 7H CAL/GM/
11H ,30X,28HSENSIBLE STAGNATION ENTHALPY,12X,3H= ,F10.3, 7H CAL/G
2M/1H ,30X,36HSTATIC PRESSURE AT DUCT INLET (CALC),4X,3H= ,F10.3,
35H PSIA/1H ,30X,36HSTATIC PRESSURE AT DUCT INLET (MEAS),4X,3H= ,
4F10.3,5H PSIA/
5 1H ,30X,22HVELOCITY AT DUCT INLET,18X,3H= ,F10.1,7H FT/SEC/
61H ,30X,27HMASS VELOCITY AT DUCT INLET,13X,3H= ,F10.1,
711H LB/FT2 SEC /
81H ,30X,27HSTREAM THRUST AT DUCT INLET,13X,3H= ,F10.1,8H LBF/FT2
9/1H,30X,21HCOMBUSTION EFFICIENCY,19X,3H= ,F10.5)
568 FORMAT(1H1)
600 FORMAT(1H,9X,101HINTERMEDIATE RESULTS FROM THE THERMOCHEMISTRY CO
1MPUTATIONS FOR THE AIRSTREAM BEFORE THE ROCKET FIRING/1H ,40X,40H*
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DO 191 I = 1,NATOMS
  SUM = 0.
DO 192 J = 1,NPROP
192 SUM = SUM + XMOLES(J)*PROPAT(J,I)
191 BETA(1) = SUM
  SUM = 0.
DO 193 I = 1,NATOMS
193 SUM = SUM + ATWT(I)*BETA(1)
  FORMWT = SUM
  SUM = 0.
DO 194 J = 1,NPROP
194 SUM = SUM + XMOLES(J)*HPROP(J)
  CHAMHX = SUM*1000.
  PRES = DATAD(1PSA)/14.696
  TEMP = TS(NAV*5./9.
  NPRES = 3
  IF (IP1) 188,188,189
188 IF (IPF.NE.0) GO TO 200
  PE(2) = 0.95*DATAD(1PSA)
  GO TO 187
200 PE(2) = (DATAD(1PF) - DATAD(1DP1) - DATAD(1DP2) - DATAD(1DP3) -
  1 DATAD(1DP4))/14.696
  GO TO 187
189 PE(2) = DATAD(1PI)/14.696
187 PE(1) = Z1*PE(2)
  PE(3) = Z2*PE(2)
  IF (PE(3).LE.PRES) GO TO 1
  PE(2) = PRES/1.051
  Z1 = 0.95
  Z2 = 1.05
  GO TO 187
  X(MP) = TEMP
  THOLD = TEMP
  ISOL = 1
  IAW = 0
  CALL TCHFM
  CALL OUTPUT
  IAW = 0
  PRES = DATAD(1PSA)/14.696
  JOR(2) = 2
  CALL SHEXP
  CHAMHX = CHAMHX
  X(MP) = TEMP
  PRES = DATAD(1PSA)/14.696
  NPRES = 0
  ISOL = 3
  IAW = 0
  CALL TCHFM
  CALL OUTPUT
  Y0 = (WAD+DATAD(1WHF)+WNAOHD+WMD+W02D)/ADUCT1
  Z1 = GA(1)-Y0
  Z2 = GA(2)-Y0
  Z3 = GA(3)-Y0
  C0 = 3*Z1-3*Z2+Z3
  C1 = -2.5*Z1+4*Z2-1.5*Z3
  C2 = 0.5*Z1-2.2*Z0.5*Z3
  XXX0 = 3.
  YYY = 1.
  ISY = 1.
  ISY = 6
  II = IP1

OVPLAY(DIX*1.2)
PROGRAM LINK 42
CALL SECSTR
RETURN
FND
SUBROUTINE SECSTR
  INTFGR RANGE
  REAL MOLEWT,NU,MU
  COMMON/BLKA/AAA(30,8),AFACA(120),AFACB(120),ALPHA,ATOM(10,30),
  1ATWT(10),BBBB(30,8),BETA(10),CCCC(30,8),CHAMH,CHAMS,ERROR,
  2FORMA(120),FORMWT,GA(120),GO,HCHAMA(120),HO(30,8),HTOT,10(30),
  3IREAC,ISCOND(30),ISOL,ISWJOB(10),KON(30),MMA,MHB,MOLEWT(30),
  4MU(30),NATOMS,NOVAP(30),NPRES,NREAC,NSPEC,NU(30,30),PAI(120),
  5PE(120),PMOLE(10),PNAME(10,2),PO,POUT,PRES,RANGE,SDENS(30),
  6SHSJ(30),SNAME(2,30),SO(30,8),TEMP,TINIT(6),TMELT(30),TVAP(30),
  7VA(120),VAPRES(30),X(30)
  COMMON/BLKB/FORMB(30),GB(30),NOSPE,VB(30),XMOLES(20)
  COMMON/BLKC/A0,A1,A2,AAAAX(30,8),ADUCT,ADUCT1,AEP,AMASS1,AMASS2,
  1AMP(20),AP,ATOMX(10,30),ATP,ATS,ATWTX(10),B0,B1,B2,BBBX(30,8),
  2BRNC,BRNE,BVOLT,CO,C1,C2,CCCCX(30,8),COATE1,COATE2,
  3CATE3,CHADH,COMPDS(10),DAD,DAT(120,20),DATA8(120),DATAD(120),
  4DATE1,DATE2,DATE3,DUCT,DEPA,DEPB,DIMP,DIPA,DTPB,DTSA,DTSS,
  5F4STRM,F4CALP,FLORAT(95),FUEL1,FUEL2,FUEL3,FUELH2,FUELH3,
  6HITE,HOX(30,8),HPROP(10),HPROPX(10),HSENF,HSENSP,HNAOH,IASAVE,
  7ICAL,ICHAMB(20),ICHAN,ICODE(20),ICODEA(2,10),ICODEP(2,10),
  8ICODES(2,10),IDPA,1DP1,1DP2,1DP3,1DPA,1DX(30),IF,IFATAL,1PF,1PA0,
  9IPC,1PF,1PI,1PS,1PSA,1PSAVE,1PSJ,1ROUTE,1S,1SCNDX(30)
  COMMON/BLKD/ISOLID,1SOLUT,1ST,1STORE,1SU,1SV,1SX,1SY,1SZ,1SSAVE,
  11TABLE,1TANK(20),1TS1(3),1WF,1WHF,1WOX,JOBTYP,JS,KCAL,KCHAN,KDAT,
  2KONX(30),KPROP,M,M0,M1,M2,MOLWTX(30),N,N0,NATOM1,NATOM2,NCAL,
  3NCALCK,NDAT(20),NFILES,NOVAPX(30),NP1,NP2,NPROP,NPTS,NSB,
  4NSD,NSPEC1,NSPEC2,NSPTS,NT,NTS1,NTW,NUMBER,NWCK(20),OF(15,10),
  5OFX,OX1,OX2,OX3,PBAR,PCMAX,PCMIN,PEDES,PF(6),PHF,PNAMEX(10,2),
  6POX,PRC,PROPAT(10,10),PRPATX(10,10),PSA,PSAMIN,PSJMAX,
  7PSJMIN,RAD1,RAD2,RAD3,RATIO, RHOP,RUNDUR,SDENSX(30),SECB,
  8SECD,SNAMEX(2,30),SOX(30,8),TAMB,TAO,TCMAX,TCHIN,TIMBRN(55),TIME0,
  9TIME1,TIME2,TIMEF,TIMER1,TIMER2,TIMPC1,TIMPC2
  COMMON/BLKF/TMELTX(30),TRANSD(21,10),TSA,TSAMAX,TSAMIN,TSJAV,
  1TSIDAV,TSIDAT(20),TSJMAX,TSJMIN,TVAPX(30),UNI1,UN2,UN3,UNA,UNS,
  2UNITS(20),UNITSR,UN1TST,VARB(20),VARD(20),VARDAT(20,20),WA,WAB,
  3WAP(20),WF,WFDCK,WHF,WHFCK,WHFCK,WNAOHD,WNAOHD,WOXCK,WP,XO,
  4XX(5),XXX,XXX0,Y0,YY(5),YYY,Z0,ZMWT(10),WAD
  COMMON/BLKG/AM(5,5),D1,D2,GVD(6),PSJ,TSJ,YFACT
  COMMON/BLKH/W02B,W02D,WMB,WMD,ODATAD
  COMMON/BLKN/MIX,INTROU,THOLD,MIXR
  MIX = 0
  MIXR = 0
  IF (ISOLID.EQ.1) MIX = 1
  IXX = 0
730 DO 240 J = 1,NPROP
  SUM = 0.
  DO 241 I = 1,NATOMS
  241 SUM = SUM + PROPAT(J,I)*ATWT(I)
  240 ZMWT(J) = SUM
  IF (ISOLID) 242,242,243
  242 XMOLES(7) = DATAD(1WOX)*ZMWT(1)*103./179.*WAD*ZMWT(7)
  XMOLES(8) = DATAD(1WF)*ZMWT(1)*103./179.*WAD*ZMWT(8)
  GO TO 245
  243 XMOLES(7) = WF*COMPDS(1)*ZMWT(1)*103./179.*WAD*ZMWT(7)
  DO 244 I = 2,NP2
  244 XMOLES(1+6) = WF*COMPDS(1)*ZMWT(1)*103./179.*WAD*ZMWT(1+6)

245 DO 246 I = 1,NPROP
246 PMOLE(I) = XMOLES(I)
DO 247 I = 1,NATOMS
  SUM = 0.
DO 248 J = 1,NPROP
248 SUM = SUM + XMOLES(J)*PROPAT(J,I)
247 BETA(1) = SUM
  SUM = 0.
DO 249 I = 1,NATOMS
249 SUM = SUM + ATWT(I)*BETA(1)
  FORMWT = SUM
  SUM = 0.
DO 250 J = 1,NPROP
250 SUM = SUM + XMOLES(J)*HPROP(J)
  CHAMHX = SUM*1000.
  IF (PSJMIN) 251,251,252
251 YY(1) = DATAD(1PSA)/14.696
  YY(5) = 1.1*YY(1)
  YY(1) = 0.9*YY(1)
  GO TO 253
252 YY(1) = PSJMIN/14.696
  YY(5) = PSJMAX/14.696
253 DY = (YY(5)-YY(1))/4.
  DO 254 I = 2,4
254 YY(I) = YY(I-1)+DY
  PRES = YY(1)
  ASPE = NOSPE
  DO 255 J = 1,NOSPE
255 X(J) = 1.0
  NPRES = 3
  IF (IXX.EQ.1) GO TO 258
  IF (IPF.NE.0) GO TO 257
  IF (IP1.NE.0) GO TO 256
  PE(2) = DATAD(1PSA)/14.696
  GO TO 258
256 PE(2) = (DATAD(1PI)+DATAD(1OP)+DATAD(1DP2)+DATAD(1DP3)+DATAD(1DP4)
  1)/14.696
  GO TO 258
257 PE(2) = DATAD(1PF)/14.696
258 PE(1) = .95*PE(2)
  PE(3) = 1.05*PE(2)
  PXP = PE(2)
300 CHAMH = CHAMHX
  M1 = NOSPE + 1
  M2 = M1+1
  X(M1) = 1.0
  X(M2) = 2500.
  TEMD = X(M2)
  THOLD = X(M2)
  IF (MIX.EQ.1) MIX = 2
DO 259 I = 1,5
  PRES = YY(1)
  IXP = 0
  IF (PE(3).LE.PRES) GO TO 305
  PE(3) = PRES - (PE(3)-PRES)
  IXP = 1
  IF (PXP.LE.PRES) GO TO 305
  PE(2) = PRES - (PXP-PRES)
  IXP = 2
  IF (PE(1).LE.PRES) GO TO 305
  PE(1) = PRES - (PE(1)-PRES)

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      IXP = 3
305 ISOL = 3
      ISW=0
      CALL TCHEN
      CALL OUTPUT
      ISW=0
      PRES = YY(1)
      JOB(2) = 1
      CALL SNEXP
      PE(1) = 0.95*PXP
      PE(2) = PXP
      PE(3) = 1.05*PXP
      IF(IXP.EQ.0) GO TO 259
      IL = 0
      DO 301 K = 1, IXP
      IK = 3-IL
      IIL = MMMA - IL
      GA(IIL) = -GA(IIL)
      VA(IIL) = -VA(IIL)
      PA(IIL) = PE(IK)
301 IL = IL+1
259 CONTINUE
      IF(MIX.EQ.2) MIX=1
      IF(TSJM IN) 260, 260, 261
260 XX(1) = VB(3)
      XX(5) = 1.1*XX(1)
      XX(1) = 0.9*XX(1)
      GO TO 262
261 XX(1) = TSJM IN*5./9.
      XX(5) = TSJM IN*5./9.
262 DX = (XX(5) - XX(1))/4.
      DO 263 I = 2, 4
      XX(I) = XX(I-1) + DX
      DO 264 I = 1, 5
      IXP = 0
      M1=NATOMS+NREAC+1
      M2=M1+1
      PRES = YY(1)
      TEMP = XX(IJ)
      X(M1)=YY(1)
      X(M2)=TEMP
      THOLD=TEMP
      IF(PE(3).LE.PRES) GO TO 306
      PE(3) = PRES - (PE(3)-PRES)
      IXP = 1
      IF(PXP.LE.PRES) GO TO 306
      PE(2) = PRES - (PXP-PRES)
      IXP = 2
      IF(PE(1).LE.PRES) GO TO 306
      PE(1) = PRES - (PE(1) - PRES)
      IXP = 3
306 ISOL = 1
      ISW=0
      CALL TCHEN
      CALL OUTPUT
      PRES = YY(1)
      ISW=0
      JOB(2) = 1
      CALL SNEXP
      PE(1) = 0.95*PXP

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      PE(2) = PXP
      PE(3) = 1.05*PXP
      IF(IXP.EQ.0) GO TO 264
      IL = 0
      DO 302 K = 1, IXP
      IK = 3-IL
      IIL = MMMA - IL
      GA(IIL) = -GA(IIL)
      VA(IIL) = -VA(IIL)
      PA(IIL) = PE(IK)
302 IL = IL+1
264 CONTINUE
      CALL SROUT
      RETURN
      END

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SUBROUTINE SROUT
INTEGER RANGE
REAL MOLEWT, NU, MU
COMMON/BLKA/AAAA(30,8), AFACA(120), AFACB(120), ALPHA, ATOM(10,30),
1ATWT(10), BBBB(30,8), BETA(10), CCCC(30,8), CHAMH, CHAMS, ERROR,
2FORMA(120), FORMWT, GA(120), GO, HCHAMA(120), HO(30,8), HTOT, ID(30),
3IREAC, ISCOND(30), ISOL, ISW, JOB(10), KON(30), MMMA, MMBB, MOLEWT(30),
4MU(30), NATOMS, NOVAP(30), NPRES, NREAC, NSPEC, NU(30,30), PA(120),
5PRE(120), PMOLE(10), PNAME(10,2), PO, POUT, PRES, RANGE, SDENS(30),
6SHSJ(30), SNAME(2,30), SO(30,8), TEMP, TINIT(6), TMELT(30), TVAP(30),
7VA(120), VAPRES(30), X(30)
COMMON/BLKB/FORMB(30), GB(30), NOSPE, VB(30), XMOLES(20)
COMMON/BLKC/A0, A1, A2, AAAAX(30,8), ADUCT, ADUCT1, AEP, AMASS1, AMASS2,
1AMP(20), AP, ATOMX(10,30), ATP, ATS, ATWTX(10), B0, B1, B2, BBBBX(30,8),
2BRNC, BRNE, BVOLT, CO, C1, C2, CCCCX(30,8), CDATE1, CDATE2,
3CDATE3, CNAOH, COMPS(10), DA0, DATA(20,20), DATAB(20), DATAD(20),
4DATE1, DATE2, DATE3, DDUCT, DEPA, DEPB, DOMP, DTPA, DTPB, OTSA, OTSB,
5FASTRM, FCALR, FLORAT(55), FUEL1, FUEL2, FUEL3, FUELH1, FUELH2, FUELH3,
6HITE, HOX(30,8), HPROP(10), HPRORX(10), HSENSF, HSENSP, HSNAOH, IASAVE,
7ICAC, ICHAMB(20), ICHAN, ICODE(20), ICODER(12,10), ICODEP(2,10),
8ICODES(2,10), IDPA, IDP1, IDP2, IDP3, IDPA, IDX(30), IF, IFATAL, IIPF, IPAO,
9IPC, IPI, IPI, IPS, IPSA, IPSAVE, IPSJ, IROUTE, IS, ISCNX(30)
COMMON/BLKD/ISOLID, ISOLUT, IST, ISTORE, ISU, ISV, ISX, ISY, ISZ, ISSAVE,
1ITABLE, ITANK(20), ITS(13), IWF, IWHF, IWOX, JOBTYP, JS, KCAL, KCHAN, KDAT,
2KONX(30), KPROP, M, MO, M1, M2, MOLWTX(30), N, NO, NATOM1, NATOM2, NCAL,
3NCALCK, NDAT(20), NFILES, NOVAPX(30), NP1, NP2, NPROP, NPTS, NSB,
4NSD, NSPEC1, NSPEC2, NSPTS, NTS, NTS1, NTW, NUMBER, NWCK(20), OF(15,10),
5OFX, OX1, OX2, OX3, PBAR, PCMAX, PCMIN, PEDES, PF(6), PHF, PNAMEX(10,2),
6POL, PRC, PROPAT(10,10), PRDATX(10,10), PSA, PSAMAX, PSAMIN, PSJMAX,
7PSJMIN, RAD1, RAD2, RAD3, RAT10, RHOP, RUNDOR, SDENSX(30), SECB,
8SECD, SNAMEX(2,30), SDX(30,8), TAMB, TAD, TCMAX, TCMIN, TIMBRN(55), TIME0,
9TIME1, TIME2, TIMEF, TIMER1, TIMER2, TIMPC1, TIMPC2
COMMON/BLKE/TMELTX(30), TRANSD(2,10), TSA, TSAMAX, TSAMIN, TSBAV,
1TSIDAV, TSIDAT(20), TSJMAX, TSJMIN, TVAPX(30), UN1, UN2, UN3, UN4, UN5,
2UNITS(20), UNITSR, UNITST, VARB(20), VARO(20), VADAT(20,20), WA, WAB,
3WAP(20), W, WFDCK, WFF, WFFBCK, WFFDCK, WNAOH, WNAOH, WOXCK, WP, XO,
4XX(5), XXX, XX0, Y0, YY(5), YYY, Z0, ZMWT(10), WAD
COMMON/BLKF/AM(5,5), D1, D2, GVD(6), PSJ, TSJ, YFACT,
COMMON/BLKG/ W02B, W02D, WMB, WMD, QDATAD
COMMON/BLKH/TW(10), TW0(10), TIME(10)
DIMENSION HH(3), FF(3), GG(3), GO(6)
WRITE(6,600)
600 FORMAT(1H,10X,99HINTERMEDIATE RESULTS FROM THE THERMOCHEMISTRY CO
1MPUTATIONS FOR THE MIXED FLOW IN THE SECONDARY DUCT/ 1H,40X,
240H*****
3UTATIONS,41X,22HEXPANSION COMPUTATIONS/ 1H0,2X,8HENTHALPY,4X,8HSEN
4SIBLE,2X,11HTEMPERATURE,13X,7HCHAMBER,3X,11HTEMPERATURE,3X,8HPRESS
5URE,3X,9HMOLECULAR,6X,6HMASS,6X,8HVELOCITY/ 1H,14X,8HENTHALPY,
626X,6HENTHALPY,28X,6HWEIGHT,6X,8HVELOCITY//
7WRITE(6,601) (GB(I),VA(I),I=1,30)
11:GA(I),VA(I),I=1,30)
601 FORMAT(1H,3E12,5,10X,6E12,5)
602 FORMAT(1H,46X,6E12,5)
KSW = 0
IOUT = 1
C
C *****COMPUTATIONS FOR ASSIGNED F.W *****
C
XO = DATAD(1F)
IF(ISOLID) 266,266,267
266 Y0 = WAD + DATAD(IWHF)+DATAD(IWF) + DATAD(IWOX) + WMD + W02D
GO TO 268
267 Y0 = WAD + DATAD(IWHF) + WP + WMD + W02D
268 Y0 = Y0/ATS
X0 = XO/ATS
DO 60 I=1,6
60 GVD(I) = 0.
M = 17
MO = 17
N = 4
ISX = 1
ISY = 3
NO = 20
YYY = 0.
ISZ = 4
ISOLUT = 1
CALL SOLUT
IF(IST.EQ.0) GO TO 20
WRITE(6,567)
KSW = PO
GO TO 330
20 IF(IFATAL.EQ.1) GO TO 51
WRITE(6,565)
IOUT = -IOUT
ISOLUT = 8
CALL SOLUT
HR = SHSJ(15) + D2*(SHSJ(15+1)-SHSJ(15))
N1 = 5 + (IS-1)*5 + JS
N2 = N1+1
N3 = N1+5
N4 = N2+5
HRP = (SHSJ(N1)+D1*(SHSJ(N2)-SHSJ(N1)))*(1.-D2) + D2*(SHSJ(N3)
1+D1*(SHSJ(N4)-SHSJ(N3)))
ETAC = HRP/HR
WRITE(6,561) HRP,HR,ETAC
WTOTAL = WAD + DATAD(IWHPD) + WP + WMD + W02D
QDATAD = QDATAD/WTOTAL
DELTAH = QDATAD * 0.555919
HRMO = HR-DELTAH
GEFF1 = HRP/HR
EFFM = HRP/(HR-DELTAH)
265 IIPF = 1
ISU = 1
ISV = 1
GO TO 736
51 WRITE(6,567)
C
C *****ASSIGNED P.W COMPUTATIONS*****
C
330 WRITE(6,577)
WRITE(6,578)
WRITE(6,562) HR,HRMO,HRP,GEFF1,EFFM
IF(KSW.NE.1) GO TO 50
IF(IOUT.GE.0) WRITE(6,581)
WRITE(6,566)
GO TO 278
50 IPS = IPSJ
IF(IPSJ.EQ.0) IPS=IPSA
PASSGN = DATAD(IPS)/14.696
ISY = 2

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      ISZ = 5
      N = 4
      NO = 20
      MO = 17
768 DO 816 I = 1,5
      D = PASSGN - YY(1)
      IF (D) 817,816,816
816 CONTINUE
817 IS = 1-1
      D2 = (PASSGN - YY(IS))/(YY(IS+1) - YY(IS))
      VVV = 15
      VVV = VVV+D2
      VVV0 = VVV
      C2 = B2
      C1 = B1
      CO = B0 - VVV
      IF (IOUT.GE.0) WRITE(6,581)
      WRITE(6,564)
      IOUT = -IOUT
      ISOLUT = 4
      CALL SOLUT
      IF (IFATAL.EQ.1) GO TO 52
      HR = SHSJ(IS) + D2*(SHSJ(IS+1)-SHSJ(IS))
      N1 = 5 + (IS-1)*5 + JS
      N2 = N1+1
      N3 = N1+5
      N4 = N2+5
      HRP = (SHSJ(N1)+D1*(SHSJ(N2)-SHSJ(N1)))*(1.-D2) + D2*(SHSJ(N3)
      +D1*(SHSJ(N4)-SHSJ(N3)))
      ETAC = HRP/HR
      WRITE(6,561) HRP,HR,ETAC
279 ISV = 2
      IIPF = 2
      ISU = 2
      GO TO 736
52 WRITE(6,566)
C
278 CONTINUE
331 N = 4
      M = 19
      DO 284 I = 1,5
      DO 284 J = 1,5
      M = MAX
      IF (G(M-2).NE.0.) GO TO 284
      WRITE(6,661)
661 FORMAT(10X,43HMASS VELOCITY RATIO MATRIX CANNOT BE FORMED/10X,47HD
      UE TO ZERO ELEMENTS IN THE MASS VELOCITY MATRIX/X/)
      RETURN
284 AMI(I,J) = G(M)/G(M-2)-20
      WRITE(6,660) (1,1AM(I,J),J=1,5),I=1,5)
660 FORMAT(1H,147X,26HMASS VELOCITY RATIO MATRIX/1H,31X,1H,14X,1H,2
      114X,1H,3,14X,1H,4,14X,1H,5//((1H,19X,13,1P5E15,5))
      IOUT = -1
      E0 = B0
      E1 = B1
      E2 = B2
      B0 = A0
      B1 = A1
      B2 = A2
      ISX = 4
      ISOLUT = 2
      CALL SOLUT
332 CONTINUE
C
*****ASSIGNED P.F.W COMPUTATIONS*****
C
333 IF (KSW.NE.1) GO TO 58
      IF (IOUT.GE.0) WRITE(6,581)
      WRITE(6,575)
      RETURN
58 CO = A0-E0
      C1 = A1-E1
      C2 = A2-E2
      ISV = 2
      ISZ = 9
      MO = 17
      NO = 20
      N = 4
      VVV = 0.
      IF (IOUT.GE.0) WRITE(6,581)
      WRITE(6,576)
      ISOLUT = 4
      CALL SOLUT
      IF (IFATAL.EQ.1) GO TO 59
      HR = SHSJ(IS) + D2*(SHSJ(IS+1)-SHSJ(IS))
      N1 = 5 + (IS-1)*5 + JS
      N2 = N1+1
      N3 = N1+5
      N4 = N2+5
      HRP = (SHSJ(N1)+D1*(SHSJ(N2)-SHSJ(N1)))*(1.-D2) + D2*(SHSJ(N3)
      +D1*(SHSJ(N4)-SHSJ(N3)))
      ETAC = HRP/HR
      WRITE(6,561) HRP,HR,ETAC
283 IIPF = 6
      ISU = 6
      ISV = 6
      XXX = 2.
      GO TO 737
49 WRITE(6,575)
300 RETURN
C
*****MASS VELOCITY AND MOMENTUM STORAGE ROUTINE*****
C
736 N1 = (IS-1)*NO + JS*N + MO
      N2 = N1+N
      N3 = N1+NO
      N4 = N2+NO
      GJ = (G(N1)+D1*(G(N2)-G(N1)))*(1.-D2)+D2*(G(N3)+D1*(G(N4)-G(
      IN3)))
      DO 738 I = 1,3
      N1 = N1+1
      N2 = N2+1
      N3 = N3+1
      N4 = N4+1
738 FF(I) = (G(N1)+D1*(G(N2)-G(N1)))*(1.-D2) + D2*(G(N3)+D1*(G(
      IN4)-G(N3)))/GJ - 20
      CO = 3.*FF(1)-3.*FF(2)+FF(3)
      C1 = -2.5*FF(1)+4.*FF(2)-1.5*FF(3)
      C2 = (FF(3)+FF(1)-2.*FF(2))/2.
      ISY = 4
      XXX0 = 3.
      VVV = 1.

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      ISOLUT = 4
      CALL SOLUT
      IF (IFATAL.EQ.0) GO TO 737
      WRITE(6,603)
      GO TO (330,278,331,332,333,300),ISU
737 XXX = XXX-1.
      PF(IIPF) = PF(1)+XXX*(PF(3)-PF(1))/2.
      N1 = N1-1
      N2 = N2-1
      N3 = N3-1
      N4 = N4-1
      DO 739 I = 1,3
      N1 = N1+1
      N2 = N2+1
      N3 = N3+1
      N4 = N4+1
      HH(I) = (AFACB(N1)+D1*(AFACB(N2)-AFACB(N1)))*(1.-D2) + D2*(AFACB(N
      13) + D1*(AFACB(N4)-AFACB(N3)))
      FF(I) = (G(N1)+D1*(G(N2)-G(N1)))*(1.-D2) + D2*(G(N3)+D1*(G(
      IN4)-G(N3)))
      GG(I) = (VA(N1)+D1*(VA(N2)-VA(N1)))*(1.-D2)+D2*(VA(N3)+D1*(VA(
      IN4)-VA(N3)))
739 GG(I) = GG(I)*FF(I)/32.174 + PF(IIPF)*14.696*144.
      GO(IIPF) = FF(1) + (-1.5*FF(1) + 2.*FF(2)-0.5*FF(3))*XXX + (0.5*
      IFF(1) - FF(2) + 0.5*FF(3))*XXX**2
      GVD(IIPF) = GG(1)+(-1.5*GG(1)+2.*GG(2)-0.5*GG(3))*XXX + (0.5*
      1GG(1)-GG(2)+0.5*GG(3))*XXX**2
      PFOUT = PF(IIPF)*14.696
      TF = HH(1) + XXX*(HH(3) - HH(1))/2.
      IF = 1.8*TF
      WRITE(6,580) PFOUT,TF,GO(IIPF),GVD(IIPF)
      GO TO(330,278,331,332,333,300),ISV
561 FORMAT(1H,34X,35HSENSIBLE STAGNATION ENTHALPIES*****, 6HCAL/GM/
      11H,39X,12H MIXED STREAM,
      2 13X,2H = ,F10,4/1H,139X,25H THEORETICAL MIXED STREAM ,2H = ,F10
      3,4/1H,14X,21H COMBUSTION EFFICIENCY,9X,2H = ,F10,5 )
564 FORMAT(1H,136X,48H COMPUTATIONS AT ASSIGNED STAGNATION PRESSURE AND
      1/1H,137X,46H FLOW RATE CORRESPONDING TO THE MEASURED VALUES////)
565 FORMAT(1H,130X,59H RESULTS OF THERMOCHEMICAL COMPUTATIONS FOR THE M
      IXXED STREAM/1H,135X,49H BASED ON MEASURED VALUES FOR THRUST AND FLO
      2W RATE/1H,140X,40H*****
566 FORMAT(1H,38X,43H NO SOLUTION AVAILABLE FOR ASSIGNED P.W CASE////)
567 FORMAT(1H,38X,43H NO SOLUTION AVAILABLE FOR ASSIGNED P.W CASE////)
575 FORMAT(1H,38X,44H NO SOLUTION AVAILABLE FOR ASSIGNED F.W CASE////)
576 FORMAT(1H,28X,64H COMPUTATIONS AT ASSIGNED FLOW RATE, NOZZLE INLET
      1 STATIC PRESSURE/1H,142X,38H CORRESPONDING TO THE MEASURED VALUES/
577 FORMAT(1H,1H,1H,40X,40H*****
      135X,47H CALCULATION OF THE COMBUSTION EFFICIENCY IN THE/1H,142X,33
      2H SECONDARY DUCT WITH HEAT TRANSFER/1H,40X,40H*****
      3*****/1H,1H,35X,53H HEAT LOSS TO THE DUCT CALCULATED F
      4ROM MEASURED INSIDE/1H,135X,48H AND OUTSIDE DUCT WALL TEMPERATURES
      5AT TIME DATAD/1H,135X,49H ASSUMING THE INSIDE AND OUTSIDE WALL TEMP
      6ERATURES/1H,135X,50H FOR THE ENTIRE LENGTH OF THE DUCT ARE CONSTANT
      7 AND/1H,135X,45H EQUAL TO THE MEASURED VALUES WHICH WERE TAKEN/1H,
      835X,46H AT STATION L/D = 5. ALSO A LINEAR VARIATION OF/1H,135X,40H T
      9EMPERATURE THROUGH THE WALL IS ASSUMED./)
578 FORMAT(1H,1H,40X,40H*****
      144H THEORETICAL MIXED STREAM STAGNATION ENTHALPY IS/1H,135X,50H THE
      2N REDUCED BY THE CALCULATED HEAT LOSS TO OBTAIN/1H,135X,46H THE ASS
      3UMED ACTUAL IDEAL MIXED STREAM SENSIBLE/1H,135X,19H STAGNATION ENTH
      4ALPY/1H,40X,40H*****

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OVERLAY(01X4,1,3)
PROGRAM LINK 43
CALL ROCKET
RETURN
END
SUBROUTINE ROCKET
INTEGER RANGE
REAL MOLEWT,NU,MU
COMMON/BLK1/AA(30,8),AFACA(120),AFACB(120),ALPHA,ATOM(10,30),
1ATWT(10),BBBB(30,8),BETA(10),CCCC(30,8),CHAMH,CHAMS,ERROR,
2FORMA(120),FORMWT,GA(120),GO,HCHAMA(120),HO(30,8),HTOT,ID(30),
3IREAC,ISCOND(30),ISOL,ISW,JOB(10),KON(30),MMA,MMB,MOLEWT(30),
4MU(30),NATOMS,NOVAP(30),NPRES,NREAC,NSPEC,NU(30,30),PA(120),
5PE(120),PMOLE(10),PNAME(10,2),PO,POUT,PRES,RANGE,SDENS(30),
6SHSJ(30),SNAME(2,30),SO(30,8),TEMP,TINIT(6),TMELT(30),TVAP(30),
7VA(120),VPRES(30),X(30)
COMMON/BLK2/FORMB(30),GB(30),NOSPE,VB(30),XMOLES(20)
COMMON/BLK3/AD(1),A2,AAAAX(30,8),ADUCT,ADUCT1,AEP,AMASS1,AMASS2,
1AMP(20),AP,ATOMX(10,30),ATP,ATS,ATWTX(10),B0,B1,B2,BBBX(30,8),
2BRNC,BRNE,BVOLT,C0,C1,C2,CCCC(30,8),CDATE1,CDATE2,
3CDATES,CNADH,COMPOS(10),DAO,DATA(20,20),DATAR(20),DATAD(20),
4DATE1,DATE2,DATE3,DOUCT,DEPA,DEPB,DOMP,OTPA,OTPB,OTSA,OTSB,
5FASTRM,FCALR,FLORAT(55),FUEL1,FUEL2,FUEL3,FUELH1,FUELH2,FUELH3,
6HITE,HOX(30,8),HPROP(10),HPROPX(10),HSENF,HSENSP,HSNAOH,IASAVE,
7ICAL,ICHAMB(20),ICHAN,ICODE(20),ICODEA(2,10),ICODEP(2,10),
8ICODES(2,10),IDPA,IDP1,IDP2,IDP3,IDP4,IDX(30),IF,IFATAL,IPF,IPAO,
9IPC,IPF,IP1,IP5,IPSA,IPSAVE,IPSJ,IROUTE,IS,ISCOND(30)
COMMON/BLK4/ISOLID,ISOLUT,IST,ISTORE,ISU,ISV,ISX,ISY,ISZ,ISSAVE,
1ITABLE,ITANK(20),ITS(3),IWF,IWHF,IWOX,JOBTYP,JS,KCAL,KCHAN,KDAT,
2KONX(30),KPROP,M,M0,M1,M2,MOLWTX(30),N,N0,NATOM1,NATOM2,NCAL,
3NCALCK,NDAT(20),NFILES,NOVAPX(30),NP1,NP2,NPROP,NPTS,NSB,
4NSD,NSPEC1,NSPEC2,NSPTS,NT,NTS1,NTW,NUMBER,NWCK(20),OF(15,10),
5OFX,OX1,OX2,OX3,PBAR,PCMAX,PCMIN,PEDES,PF(6),PHF,PNAMEX(10,2),
6POX,PRC,PROPAT(10,10),PRPATX(10,10),PSA,PSAMAX,PSAMIN,PSJMAX,
7PSJMIN,RAD1,RAD2,RAD3,RAT10,RHOP,RUNDUR,SDENSX(30),SECB,
8SECD,SNAMEX(2,30),SOX(30,8),TAMB,TAD,TCMAX,TCMIN,TIMBRN(55),TIME0,
9TIME1,TIME2,TIMEF,TIMER1,TIME2,TIMEP1,TIMEP2
COMMON/BLK5/TMELTX(30),TRANSO(2,10),TSA,TSAMAX,TSAMIN,TSIBAV,
1TSDAV,TSIDAT(20),TSJMAX,TSJMIN,TVAPX(30),UN1,UN2,UN3,UN4,UN5,
2UNITS(20),UNITSR,UNITST,VARB(20),VARD(20),VARDAT(20,20),WA,WAB,
3WAP(20),WF,WFOCK,WHF,WHFCK,WHFDOCK,WNAOH,WNAOHD,WOCK,WP,X0,
4XX(5),XXX,XXX0,Y0,YY(5),YYY,Z0,ZMWT(10),WAD
COMMON/BLK6/AM(5,5),D1,D2,GVD(6),PSJ,TSJ,YFACT
COMMON/BLK7/MIX,INTROU,THOLD,MIXR
MIX=0
IF(ISOLID.EQ.1) MIX=1
IF(MIX.EQ.1) MIXR=1
IXX=0
300 ZMWT1=ZMWT(1)
IF(JOBTYP.EQ.3) ZMWT1=28.016
DTPD=OTPB+(TIME3-TIME2-SECO-2.0)/(TIME3-TIME2)*(IDETA-DETB)
ATP=3.141596*OTPD**2/(4.*144.)
ZO=ATP/AEP
732 MMA=0
MMB=0
DO 220 J=1,NPROP
SUM=0.
DO 221 I=1,NATOMS
221 SUM=SUM+PROPAT(J,I)*ATWT(I)
220 ZMWT(J)=SUM
IF(ISOLID) 222,222,223
222 XMOLES(1)=DATAD(IWOX)*ZMWT1/103./(79.*WAD*ZMWT1)
XMOLES(2)=DATAD(IWF)*ZMWT1/103./(79.*WAD*ZMWT1)
GO TO 225
223 XMOLES(1)=WP*COMPOS(1)*ZMWT1/103./(79.*WAD*ZMWT1)
DO 224 I=2,NP2
224 XMOLES(I)=WP*COMPOS(I)*ZMWT1/103./(79.*WAD*ZMWT1)
225 DO 226 I=1,NPROP
226 PMOLE(I)=XMOLES(I)
DO 227 I=1,NATOMS
SUM=0.
DO 228 J=1,NPROP
228 SUM=SUM+XMOLES(J)*PROPAT(J,I)
227 BETA(I)=SUM
SUM=0.
DO 229 I=1,NATOMS
229 SUM=SUM+ATWT(I)*BETA(I)
FORMWT=SUM
SUM=0.
DO 230 J=1,NPROP
230 SUM=SUM+XMOLES(J)*HPROP(J)
CHAMH=SUM*1000.
IF(PCMIN) 231,231,232
231 YY(1)=DATAD(IPC)/14.696
YY(5)=1./YY(1)
YY(1)=0.9*YY(1)
GO TO 233
232 YY(1)=PCMIN/14.696
YY(5)=PCMAX/14.696
233 DY=(YY(5)-YY(1))/4.
DO 234 I=2,4
234 YY(I)=YY(I-1)+DY
PRES=YY(1)
ASPE=NOSPE
DO 235 U=1,NOSPE
235 X(I)=1.0
NPRES=3
IF(IXX.EQ.1) GO TO 501
PE(2)=PEDES/14.696
-501 PE(1)=0.8*PE(2)
PE(3)=1.2*PE(2)
IF(PE(3).LE.YY(1)) GO TO 500
Z1=(PEDES-DATAD(IPC))/14.696*2.
YY(1)=Z1
PE(2)=Z1/1.1
IXX=1
GO TO 233
500 M1=NOSPE+1
M2=M1+1
X(M1)=1.0
X(M2)=2500.
IF(ISOLID.EQ.1) X(M2)=1500.
TEMP=X(M2)
IF(MIX.EQ.1) MIX=2
IF(MIX.EQ.1) CHAMH=CHAMH*2
DO 236 I=1,5
236 PRES=YY(I)
END
CALL TCHEM
CALL OUTPUT
THOLD=TEMP

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15W=0
PRES=YY(1)
JOB(2)=1
239 CALL SHEXP
IF(TCMIN) 213,213,214
213 XX(1)=VR(1)
XX(5)=1./XX(1)
XX(1)=0.9*XX(1)
GO TO 215
214 XX(1)=TCMIN*5./9.
XX(5)=TCMAX*5./9.
215 DX=(XX(5)-XX(1))/4.
DO 216 I=2,4
216 XX(I)=XX(I-1)+DX
IF(MIX.EQ.2) MIX=1
DO 217 I=1,5
DO 217 J=1,5
M1=NATOMS+NREAC+1
M2=M1+1
PRES=YY(1)
TEMP=XX(J)
X(M2)=TEMP
X(M1)=YY(I)
THOLD=TEMP
ISOL=1
15W=0
CALL TCHEM
CALL OUTPUT
15W=0
PRES=YY(1)
JOB(2)=1
217 CALL SHEXP
CALL ROUTE
RETURN
END
SUBROUTINE ROUTE
INTEGER RANGE
REAL MOLEWT,NU,MU
COMMON/BLK1/AA(30,8),AFACA(120),AFACB(120),ALPHA,ATOM(10,30),
1ATWT(10),BBBB(30,8),BETA(10),CCCC(30,8),CHAMH,CHAMS,ERROR,
2FORMA(120),FORMWT,GA(120),GO,HCHAMA(120),HO(30,8),HTOT,ID(30),
3IREAC,ISCOND(30),ISOL,ISW,JOB(10),KON(30),MMA,MMB,MOLEWT(30),
4MU(30),NATOMS,NOVAP(30),NPRES,NREAC,NSPEC,NU(30,30),PA(120),
5PE(120),PMOLE(10),PNAME(10,2),PO,POUT,PRES,RANGE,SDENS(30),
6SHSJ(30),SNAME(2,30),SO(30,8),TEMP,TINIT(6),TMELT(30),TVAP(30),
7VA(120),VPRES(30),X(30)
COMMON/BLK2/FORMB(30),GB(30),NOSPE,VB(30),XMOLES(20)
COMMON/BLK3/AD(1),A2,AAAAX(30,8),ADUCT,ADUCT1,AEP,AMASS1,AMASS2,
1AMP(20),AP,ATOMX(10,30),ATP,ATS,ATWTX(10),B0,B1,B2,BBBX(30,8),
2BRNC,BRNE,BVOLT,C0,C1,C2,CCCC(30,8),CDATE1,CDATE2,
3CDATES,CNADH,COMPOS(10),DAO,DATA(20,20),DATAR(20),DATAD(20),
4DATE1,DATE2,DATE3,DOUCT,DEPA,DEPB,DOMP,OTPA,OTPB,OTSA,OTSB,
5FASTRM,FCALR,FLORAT(55),FUEL1,FUEL2,FUEL3,FUELH1,FUELH2,FUELH3,
6HITE,HOX(30,8),HPROP(10),HPROPX(10),HSENF,HSENSP,HSNAOH,IASAVE,
7ICAL,ICHAMB(20),ICHAN,ICODE(20),ICODEA(2,10),ICODEP(2,10),
8ICODES(2,10),IDPA,IDP1,IDP2,IDP3,IDP4,IDX(30),IF,IFATAL,IPF,IPAO,
9IPC,IPF,IP1,IP5,IPSA,IPSAVE,IPSJ,IROUTE,IS,ISCOND(30)
COMMON/BLK4/ISOLID,ISOLUT,IST,ISTORE,ISU,ISV,ISX,ISY,ISZ,ISSAVE,
1ITABLE,ITANK(20),ITS(3),IWF,IWHF,IWOX,JOBTYP,JS,KCAL,KCHAN,KDAT,
2KONX(30),KPROP,M,M0,M1,M2,MOLWTX(30),N,N0,NATOM1,NATOM2,NCAL,
3NCALCK,NDAT(20),NFILES,NOVAPX(30),NP1,NP2,NPROP,NPTS,NSB,
4NSD,NSPEC1,NSPEC2,NSPTS,NT,NTS1,NTW,NUMBER,NWCK(20),OF(15,10),
5OFX,OX1,OX2,OX3,PBAR,PCMAX,PCMIN,PEDES,PF(6),PHF,PNAMEX(10,2),
6POX,PRC,PROPAT(10,10),PRPATX(10,10),PSA,PSAMAX,PSAMIN,PSJMAX,
7PSJMIN,RAD1,RAD2,RAD3,RAT10,RHOP,RUNDUR,SDENSX(30),SECB,
8SECD,SNAMEX(2,30),SOX(30,8),TAMB,TAD,TCMAX,TCMIN,TIMBRN(55),TIME0,
9TIME1,TIME2,TIMEF,TIMER1,TIME2,TIMEP1,TIMEP2
COMMON/BLK5/TMELTX(30),TRANSO(2,10),TSA,TSAMAX,TSAMIN,TSIBAV,
1TSDAV,TSIDAT(20),TSJMAX,TSJMIN,TVAPX(30),UN1,UN2,UN3,UN4,UN5,
2UNITS(20),UNITSR,UNITST,VARB(20),VARD(20),VARDAT(20,20),WA,WAB,
3WAP(20),WF,WFOCK,WHF,WHFCK,WHFDOCK,WNAOH,WNAOHD,WOCK,WP,X0,
4XX(5),XXX,XXX0,Y0,YY(5),YYY,Z0,ZMWT(10),WAD
COMMON/BLK6/AM(5,5),D1,D2,GVD(6),PSJ,TSJ,YFACT
COMMON/BLK7/MIX,INTROU,THOLD,MIXR
DIMENSION BM(5,5)
ATS=ATP
1OUT=1
15W=0
WRITE(6,603)
603 FORMAT(1H,19X,BIINTERMEDIATE RESULTS FROM THE THERMOCHEMISTRY CO
1NPUTATIONS FOR THE PRIMARY ROCKET / 1H,40X,
240H*****
3UTATIONS,41X,22HEXPANSION COMPUTATIONS/ 1H,7X,20HCHAMBER COMP
4UTATIONS,41X,22HEXPANSION COMPUTATIONS/ 1H,7X,20HCHAMBER COMP
5UTATIONS,41X,22HEXPANSION COMPUTATIONS/ 1H,7X,20HCHAMBER COMP
6UTATIONS,41X,22HEXPANSION COMPUTATIONS/ 1H,7X,20HCHAMBER COMP
7UTATIONS,41X,22HEXPANSION COMPUTATIONS/ 1H,7X,20HCHAMBER COMP
8UTATIONS,41X,22HEXPANSION COMPUTATIONS/ 1H,7X,20HCHAMBER COMP
9UTATIONS,41X,22HEXPANSION COMPUTATIONS/ 1H,7X,20HCHAMBER COMP
10UTATIONS,41X,22HEXPANSION COMPUTATIONS/ 1H,7X,20HCHAMBER COMP
11UTATIONS,41X,22HEXPANSION COMPUTATIONS/ 1H,7X,20HCHAMBER COMP
12UTATIONS,41X,22HEXPANSION COMPUTATIONS/ 1H,7X,20HCHAMBER COMP
13UTATIONS,41X,22HEXPANSION COMPUTATIONS/ 1H,7X,20HCHAMBER COMP
14UTATIONS,41X,22HEXPANSION COMPUTATIONS/ 1H,7X,20HCHAMBER COMP
15UTATIONS,41X,22HEXPANSION COMPUTATIONS/ 1H,7X,20HCHAMBER COMP
16UTATIONS,41X,22HEXPANSION COMPUTATIONS/ 1H,7X,20HCHAMBER COMP
17UTATIONS,41X,22HEXPANSION COMPUTATIONS/ 1H,7X,20HCHAMBER COMP
18UTATIONS,41X,22HEXPANSION COMPUTATIONS/ 1H,7X,20HCHAMBER COMP
19UTATIONS,41X,22HEXPANSION COMPUTATIONS/ 1H,7X,20HCHAMBER COMP
20UTATIONS,41X,22HEXPANSION COMPUTATIONS/ 1H,7X,20HCHAMBER COMP
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270 Y0 = DATAD(1W0X)+DATAD(1WF)
GO TO 272
271 Y0 = W0
272 Y0 = Y0/ATP
M = 17
M0 = 17
N0 = 20
N = 4
IST = 4
ISX = 5
ISOLUT = 1
CALL SOLUT
IF(IST.EQ.0) GO TO 273
WRITE(6,700)
IOUT = -IOUT
KSW = 1
GO TO 276
273 ISY = 2
ISJ = 10
ISZ = 10
PASSGN = DATAD(1PC)/14.696
WRITE(6,701)
IOUT = -IOUT
304 DO 274 I = 1,5
D = PASSGN - YY(I)
IF(D) 275,274,274
274 CONTINUE
275 IS = I-1
D2 = (PASSGN-YY(IS))/(YY(1S+1)-YY(1S))
YYY = 1S
YYY = YYY + D2
C2 = A2
C1 = A1
C0 = A0 - YYY
ISOLUT = 4
CALL SOLUT
IF(1SX.EQ.6) GO TO 308
IF(1FATAL.NE.0) GO TO 30
HR = SHSJ(1S) + D2*(SHSJ(1S+1)-SHSJ(1S))
N1 = 5 + (1S-1)*5 + JS
N2 = N1+1
N3 = N1+5
N4 = N2+5
HRP = (SHSJ(N1)+D1*(SHSJ(N2)-SHSJ(N1)))*(1.-D2) + D2*(SHSJ(N3)
+D1*(SHSJ(N4)-SHSJ(N3)))
ETAC = HRP/HR
WRITE(6,561) HRP,HR,ETAC
GO TO 276
50 WRITE(6,702)
IOUT = 1
C
C *****ASSIGNED PC,FSTRM AND W,FSTRM COMPUTATIONS*****
C
276 IF(JOBTYP.F0.3) RETURN
M=18
I = 1
J = 1
277 W = M+4
IF(Z0.NE.1.)GO TO 55
XXX = 1.+(PA(M-1)-PA(M))*Z0/(PA(M+2)-PA(M))
GO TO 305

55 GST = GA(M-1)
Z1 = GA(M)/GST-Z0
Z2 = GA(M+1)/GST - Z0
Z3 = GA(M+2)/GST - Z0
C0 = 3.*Z1-3.*Z2+Z3
C1 = -2.5*Z1+4.*Z2-1.5*Z3
C2 = 0.5*Z1-Z2+0.5*Z3
XXX0 = 3.
YYY = 1.
ISY = 5
ISJ = 11
ISOLUT = 4
CALL SOLUT
IF(1FATAL.EQ.0) GO TO 305
WRITE(6,702)
RETURN
305 BM(1,J) = (XXX-1.)/2.
PPA = PA(M) + BM(1,J)*(PA(M+2)-PA(M))
GGA = GA(M) + BM(1,J)*(GA(M+2)-GA(M))
VVA = VA(M) + BM(1,J)*(VA(M+2)-VA(M))
BM(1,J) = PPA*14.696*144. + GGA*VVA/32.174
J = J+1
IF(J.LE.5) GO TO 277
I = I+1
J = 1
IF(I.LE.5) GO TO 277
FSTRMO = 0.
K = 1
307 IF(GVD(K).NE.0.)GO TO 51
WRITE(6,703) K
K = K+1
IF(K-A) 307,307,301
51 FSTRM = GVD(K)-FSTRM*ADUCT1/ADUCT
DO 303 I = 1,5
DO 303 J = 1,5
303 AM(1,J) = BM(1,J)*AEP/ADUCT - FSTRM
WRITE(6,600) (I,AM(1,J),J=1,5,I=1,5)
IST = 5
ISX = 6
B0 = A0
B1 = A1
B2 = A2
ISOLUT = 2
CALL SOLUT
IF(IST.EQ.0) GO TO 309
WRITE(6,703) K
GO TO 301
309 PASSGN = DATAD(1PC)/14.696
ISJ = 12
ISY = 2
XXX0 = 5.
IF(IOUT.GE.0) WRITE(6,750)
WRITE(6,704) K
IOUT = -IOUT
GO TO 304
308 IF(1FATAL.NE.0) GO TO 52
HR = SHSJ(1S) + D2*(SHSJ(1S+1)-SHSJ(1S))
N1 = 5 + (1S-1)*5 + JS
N2 = N1+1
N3 = N1+5
N4 = N2+5
HRP = (SHSJ(N1)+D1*(SHSJ(N2)-SHSJ(N1)))*(1.-D2) + D2*(SHSJ(N3)
+D1*(SHSJ(N4)-SHSJ(N3)))
ETAC = HRP/HR
WRITE(6,561) HRP,HR,ETAC
FSTRMO = FSTRM
301 K = K+1
IF(K.LE.6) GO TO 307
RETURN
561 FORMAT(1H0,34X,35HSENSIBLE STAGNATION ENTHALPIES****,6HCAL/GM/
11H0,39X,17H MIXED STREAM,
213X,2H = ,F10.4/1H ,39X,25HTHEORETICAL MIXED STREAM ,2H = ,F10.4/
3 1H0,34X,21H COMBUSTION EFFICIENCY,9X,2H = ,F10.5/****)
600 FORMAT(1H1,47X,26H MASS VELOCITY RATIO MATRIX/1H0,31X,1H1,14X,1H2,1
14X,1H3,14X,1H4,14X,1H5//1H ,19X,13,1PSE15.5)
700 FORMAT(1H1,31X,50HNO SOLUTION AVAILABLE FOR PC,W CASE FOR THE PRIM
IARY ROCKET ///)
701 FORMAT(1H1,30X,61HRESULTS OF THERMOCHEMICAL COMPUTATIONS FOR THE P
RIMARY ROCKET/1H ,30X,63HBASED ON MEASURED VALUES FOR THE FLOW RAT
2E AND CHAMBER PRESSURE /1H ,40X,40H*****
3***** ///)
702 FORMAT(1H1,29X,62HAT LEAST ONE SOLUTION IS NOT AVAILABLE IN THE EX
PANSION MATRIX / 1H ,29X,62HPROGRAM DOES NOT PROCEED WITH PC,FSTRM
2 OR W,FSTRM COMPUTATIONS ///)
703 FORMAT(1H0,21X,77HNO SOLUTION AVAILABLE FOR FSTRM COMPUTATION US
ING MIXED STREAM DATA FOR CASE , 13//)
704 FORMAT(1H0,30X,60HCOMPUTATIONS FOR ASSIGNED CHAMBER PRESSURE AND S
TREAM THRUST / 1H ,40X,34H CORRESPONDING TO MIXED STREAM CASE,13//)
705 FORMAT(1H0,33X,53HCOMPUTATIONS FOR ASSIGNED FLOW RATE AND STREAM T
HRUST / 1H ,40X,34H CORRESPONDING TO MIXED STREAM CASE,13//)
706 FORMAT(1H0,34X,52HNO SOLUTION AVAILABLE FOR ASSIGNED PC,FSTRM FOR
1CASE , 13//)
707 FORMAT(1H0,34X,51HNO SOLUTION AVAILABLE FOR ASSIGNED W,FSTRM FOR C
1ASE ,13//)
750 FORMAT(1H1)
END

```

1

The sequence of data cards required for the complete reduction of a ramburner run using liquid propellants is presented in this appendix.* Note that if JOBTYP $\neq$ 10 the program assumed the data were to be read from a BCD tape containing the values of the signal voltages from each measurement device during a run arranged in the form of 20 files.** In general, the tape being read contained the results of several runs, each run being separated from the previous ones by a single record containing all 1000's. One record consisted of NCHAN numbers, each number corresponding to the voltage reading on each channel at that point in time and written on the digital tape in the format F6.3. The last run on the tape was followed by one record of all 1000's and another record of all 9000's. The program was written assuming NCHAN = 20 and that the channels were recorded at the rate of 4000/sec.

If any one of the 20 channels was not used, the program automatically set the values associated with that channel to zero. The initial data point before the run (DATAB point) and the plotted data points were assumed to be sufficiently separated in time so that the point sets averaged for each data point did not overlap. Similarly, in computing the flow rate of the solid propellant, it was assumed that the propellant burn time was sufficiently long so that 50 point sets consisting of 10 points each could be obtained with no overlap between the point sets.

The first series of cards in the data pack contained the information of the run to be reduced, the number of points' to be averaged for each data reduction point, and the times concerning that run.

READ (5, 103) NFILES, ITABLE

103 FORMAT (10I3)

where

NFILES = The number of runs on the master tape to be skipped, i.e., the (NFILES + 1) run is to be reduced.

*The program is coded in the FORTRAN IV language.

****Refer to Section III for a discussion of the preparation of the BCD tape from the original binary tape.**

ITABLE = 1 if the thermocouple table, the FCOEF(J), RE(J), and BETA0(J) tables for the air orifice, and the calibration units are to be entered.
= 0, if tables previously entered are to be used.

READ (5, 103) NSB, NSD, NPTS, NSPTS

103 FORMAT (10I3)

where

NSB = The number of data points to be averaged for computations before the primary rocket firing, ≤ 20 .
NSD = The number of data points to be averaged for computations during the primary rocket firing, ≤ 20 .
NPTS = The number of plot points desired during the rocket firing, ≤ 20 .
NSPTS = The number of points to be averaged for computations at each plot point.

READ (5, 102) SECB, SECD, TIME0, TIMEF, TIMER1, TIMER2

102 FORMAT (7E10.3)

where

SECB = The number of seconds before ignition of the primary rocket at which the air heater computations are to be performed.
SECD = The number of seconds before shutdown of the primary rocket at which the complete system computations are to be performed.
TIME0 = The time in seconds after the beginning of data acquisition before which the data were discarded.
TIMEF = The time in seconds after the beginning of data acquisition after which the data were discarded.
TIMER1 = The time in seconds after the beginning of data acquisition at which the primary rocket chamber pressure begins to rise (ignition).
TIMER2 = The time in seconds after the beginning of data acquisition at which the primary rocket chamber pressure begins to fall (shutdown).

READ (5, 102) CHAN

102 FORMAT (7E10.3)

where

CHAN = The number of channels recorded on digital tape, = 20.

If more than one run was to be reduced in succession and each run happened to have the same instrument calibrations, it was not necessary to reenter the propellant data, the specie data, or the pressure and temperature limits for the solution matrices. The specifications as to whether or not reenter these cards was given in the following read statement.

READ (5, 103) JOBTYP, KCHAN, KCAL, KPROP, KDAT

103 FORMAT (10I3)

where

JOBTYP	=	1, complete run reduction 2, air heater reduction only 3, primary rocket reduction only 10, complete run reduction, all data to be entered from cards
KCHAN	=	0, previous channel information used 1, channel information to be entered
KCAL	=	0, calibration data already stored in the memory are to be employed 1, new calibration data are to be entered
KPROP	=	0, propellant data already stored in the memory are to be employed 1, new propellant data are to be entered
KDAT	=	0, pressure and temperature limits already stored in the memory are to be employed 1, new pressure and temperature limits are to be entered

READ (5, 103) IPSJ

103 FORMAT (10I3)

where

IP SJ = The number of the channel on which the stagnation pressure profile of the jet was recorded, = 0 if the stagnation pressure profile was not recorded

if IP SJ $\neq$ 0, the following read statement was encountered.

READ (5, 2101) TIMPSJ, TIMPF

2101 FORMAT (2E10.3)

where

TIMPSJ = The number of seconds after the beginning of data acquisition at which the stagnation pressure probe began to enter the exhaust jet.

TIMPF = The number of seconds after the beginning of data acquisition at which the stagnation pressure probe exited from the exhaust jet

The next series of read statements provided general information about the run.

READ (5, 100) NUMBER, DATE1, DATE2, DATE3

100 FORMAT (12, 3A6)

where

NUMBER = The run number

DATE1,
DATE2,
DATE3 = Storage for alphanumeric specification of the date of the run

READ (5, 102) PBAR, TAMB

102 FORMAT (7E10.3)

where

PBAR = Ambient pressure, psia

TAMB = Ambient temperature, °R

READ (5, 101) FUEL1, FUEL2, FUEL3, OX1, OX2, OX3, FUELH1, FUELH2, FUELH3

101 FORMAT (10A6)

where

FUEL1,
FUEL2,
FUEL3 = Storage for alphanumeric specifications of the name of the
 rocket fuel

OX1,
OX2,
OX3 = Storage for alphanumeric specifications of the name of
 the rocket oxidizer

FUELH1,
FUELH2,
FUELH3 = Storage for alphanumeric specification of the name of the
 air heater fuel

READ (5, 102) WA, WHF, PSA, TSA, PHF, WP, OFX, POX, PX, PRC, AP, RUNDUR

102 FORMAT (7E10.3)

where

WA = Nominal air flow rate, lbm/sec

WHF = Desired air heater fuel flow rate, lbm/sec

PSA = Nominal air stagnation pressure, psia

TSA = Nominal air stagnation temperature, °R

PHF = Nominal air heater fuel tank pressure, psia

WP = Nominal total flow rate of rocket propellants, lbm/sec

OFX = Nominal rocket oxidizer/fuel ratio

POX = Nominal rocket oxidizer tank pressure, psia

PX = Nominal rocket fuel tank pressure, psia

PRC = Nominal rocket chamber pressure, psia

AP = Nominal air flow rate/rocket propellant flow rate ratio

RUNDUR = Nominal run duration of the primary rocket, seconds

The next card read contained the dimensions of the ramburner and of the primary and secondary nozzles. Note that the ramburner was taken to be of constant area.

```
READ (5, 102) DDUCT, DTPB, DTPA, DEPB, DEPA, DTSB, DTSA
```

```
102 FORMAT (7E10.3)
```

where

DDUCT	=	Ramburner inside diameter, inches
DTPB	=	Throat diameter of the primary nozzle before the rocket firing, inches
DTPA	=	Throat diameter of the primary nozzle after the rocket firing, inches
DEPB	=	Exit diameter of the primary nozzle before the rocket firing, inches
DEPD	=	Exit diameter of the primary nozzle after the rocket firing, inches
DTSB	=	Throat diameter of the ramburner nozzle before the run, inches
DTSA	=	Throat diameter of the ramburner nozzle after the run, inches

Before each run, the calibration of the load cell was spot checked by applying the maximum calibration weight to the load cell. The voltage output of the cell at this point was entered in the program as the variable FCALR. The program then formed the ratio of this spot check reading to the corresponding value in the load cell calibration pack and scaled the load cell calibration according to this ratio. For the runs reported herein this ratio was always one.

```
READ (5, 102) FCALR, TAO, DAO, DOMP
```

```
102 FORMAT (7E10.3)
```

where

FCALR	=	Output of the load cell in volts corresponding to the maximum calibration load
TAO	=	The air temperature at the air orifice, °R

DAO = The diameter of the air orifice, inches

DOMP = The diameter of the air line containing the air orifice, inches

To obtain an estimate of the heat loss from the ramburner during a run, the inside and outside wall temperatures of the ramburner at a point midway along the duct were taken at several points in time during a run. The recorded wall temperatures at several points during the run were entered through the next two read statements.

READ (5, 103) NTW

103 FORMAT (20I3)

where

NTW = The number of pairs of inside and outside wall temperatures recorded

READ (5, 104) (TIME(J), TWI(J), TWO(J), J=1, NTW)

104 FORMAT (3E10.3)

TIME(J) = The time in seconds after the beginning of data acquisition at which the temperature was recorded

TWI(J) = The inside wall temperature, °R

TWO(J) = The outside wall temperature, °R

Provisions for the seeding of the air stream with a sodium hydroxide solution were included; the concentration of the solution was specified on the next card.

READ (5, 102) CNAOH

102 FORMAT (7E10.3)

where

CNAOH = The concentration of sodium hydroxide in the seeding solution, lbm of NaOH/lbm H₂O. If no seeking was used, = 0.0

If KDAT was equal to 1, the following three cards were read.

READ (5, 102) PSAMIN, PSAMAX, TSAMIN, TSAMAX

102 FORMAT (7E10.3)

where

- PSAMIN = The lowest value expected for the air stagnation pressure, psia. If equal 0.0, the program selects 0.9 times the measured air stagnation pressure.
- PSAMAX = The highest value expected for the air stagnation pressure, psia. If equal 0.0, the program selects 1.1 times the measured air stagnation pressure.
- TSAMIN = The lowest value expected for the air stagnation temperature, °R. If equal 0.0, the program selects 0.9 times the measured air stagnation temperature.
- TSAMAX = The highest value expected for the air stagnation temperature, °R. If equal 0.0, the program selects 1.1 times the measured air stagnation temperature.

READ (5, 102) PSJMIN, PSJMAX, TSJMIN, TSJMAX

102 FORMAT (7E10.3)

where

- PSJMIN = The lowest value expected for the ramburner stagnation pressure, psia. If equal 0.0, the program selects 0.9 times the calculated value.
- PSJMAX = The highest value expected for the ramburner stagnation pressure, psia. If equal 0.0, the program selects 1.1 times the calculated value.
- TSJMIN = The lowest value expected for the ramburner stagnation temperature, °R. If equal 0.0, the program selects 0.9 times the calculated value.
- TSJMAX = The highest value expected for the ramburner stagnation temperature, °R. If equal 0.0, the program selects 1.1 times the calculated value.

READ (5, 102) PCMIN, PCMAX, TCMIN, TCMAX, PEDES

102 FORMAT (7E10.3)

where

PCMIN = The lowest value expected for the primary rocket chamber pressure, psia. If equal 0.0, the program selects 0.9 times the measured pressure.

PCMAX = The highest value expected for the primary rocket chamber pressure, psia. If equal 0.0, the program selects 1.1 times the measured pressure.

TCMIN = The lowest value expected for the rocket chamber temperature, °R. If equal 0.0, the program selects 0.9 times the calculated temperature.

TCMAX = The highest value expected for the rocket chamber temperature, °R. If equal 0.0, the program selects 1.1 times the calculated temperature, °R. If equal 0.0, the program selects 1.1 times the calculated temperature.

PEDES = The nominal operating pressure for the ramburner, psia.

If KCHAN equaled 1, the following six read statements were encountered. These cards provided the program with information as to the channel assignments and the makeup of the instrumentation channels.

READ (5, 106) (ICODE(J), J=1, 20)

106 FORMAT (22I1)

where

ICODE(J) = 0, if channel J was not used
= 1, if channel J is pressure in psig or psid
= 2, if channel J is pressure in psia
= 3, if channel J is thrust
= 4, if channel J is a flow rate
= 5, if channel J is a temperature

READ (5, 103) IDPA, IDP4, IPI, IPC, IPSA, IPAO, IDP1, IDP2, IDP3, IF, NTSI, (ITSI(J), J=1, NTSI), IWF, IWOX, IWHF, IPSJ, IPF

103 FORMAT (20I3)

where

NCALCK = The number of flowmeter channels for which pressure drop
 versus flow rate data are to be entered as a check against
 the flowmeter reading

DO 15 I=1, NCALCK

READ (5, 103) ICHAN, ITANK(ICHAN), ICHAMB(ICHAN)

103 FORMAT (20I3)

 .
 .
15 .

where

ICHAN = The channel number of the flowmeter to be checked

ITANK(ICHAN) = The tank pressure channel corresponding to ICHAN

ICHAMB(ICHAN) = The chamber pressure channel corresponding to ICHAN
 i.e., the propellant flowing through the ICHAN flow-
 meter left the tank containing the pressure
 ITANK(ICHAN) and entered the chamber containing the
 pressure ICHAMB(ICHAN).

If KPROP equaled 1, the following seven read statements were encountered.
They provided the program with information on the propellants, atoms,
and molecular species used in the combustion solutions.

READ (5, 103) NPROP, NATOMS, NSPEC

103 FORMAT (20I3)

where

NPROP = The total number of propellants used, ≤ 10 .

NATOMS = The total number of types of atoms used, ≤ 10 .

NSPEC = The total number of species used, ≤ 30 .

Note: If all the species to be considered occurred only in the gas
phase, the maximum value for NSPEC was 30. However, for each condensible
specie considered this number must be reduced by 2.

READ (5, 103) NP1, (ICODEP(1,J),J=1,NP1)

103 FORMAT (20I3)

where

NP1 = The number of propellants used in the air stream, = 6

ICODEP(1,J) = K, indicating the Kth propellant in the propellant list
 is to be used

It was assumed that the air stream was made up of six propellants and that the propellants were those given below and that they occurred in the order stated: (1) nitrogen, N₂, (2) oxygen, O₂, (3) the heater fuel, (4) water, H₂O, (5) sodium hydroxide, NaOH, (6) methane, CH₄. The nitrogen and oxygen formed the air, the water and sodium hydroxide came from the seeding solution, and the methane came from the ignitor torch. The ignitor torch remained on throughout the run. If the seeding was not used, the enthalpy of the water and sodium hydroxide was set equal to zero in the propellant list.

READ (5, 103) NP2, (ICODEP(2,J), J = 1, NP2)

103 FORMAT (20I3)

where

NP2 = The number of propellants to be used in the primary
 rocket, = 2 for a liquid propellant rocket

ICODEP(2,J) = K, indicating the Kth propellant in the propellant list
 was present

READ (5, 103) NATOM1, (ICODEA(1,J), J=1, NATOM1)

103 FORMAT (20I3)

where

NATOM1 = The number of atom types occurring in the air stream

ICODEA(1,J) = K, indicating the Kth atom in the atom list was present

READ (5, 103) NATOM2, (ICODEA(2,J), J=1, NATOM2)

103 FORMAT (20I3)

where

NATOM2 = The number of atom types occurring in the primary rocket
ICODEA(2,J) = K, indicating the Kth atom in the atom list was present
READ (5, 103) NSPEC1, (ICODES(1,J),J=1, NSPEC1)
103 FORMAT (20I3)

where

NSPEC1 = The number of species to be considered in the air stream
 calculations
102 FORMAT (7E10.3)

where

COMPOS(J) = The mass fraction of the Jth propellant in the solid grain

It was assumed that the grain had a cylindrical shape with a tapered core. Figure C-1 shows the grain shape assumed.

READ (5, 420) RAD1, RAD2, RAD3, HITE
420 FORMAT (4F10.3)

where

RAD1 = The largest inside radius of the grain, inches
RAD2 = The smallest inside radius of the grain, inches
RAD3 = The outside radius of the grain, inches
HITE = The length of the grain, inches

The program computed the burn rate, r (in./sec), from the equation
 $r = cp^n$, where p is the chamber pressure (psia).

READ (5, 420) BRNC, BRNE
420 FORMAT (4F10.3)

where

BRNC = The burn rate constant (c)
BRNE = The burn rate exponent (n)

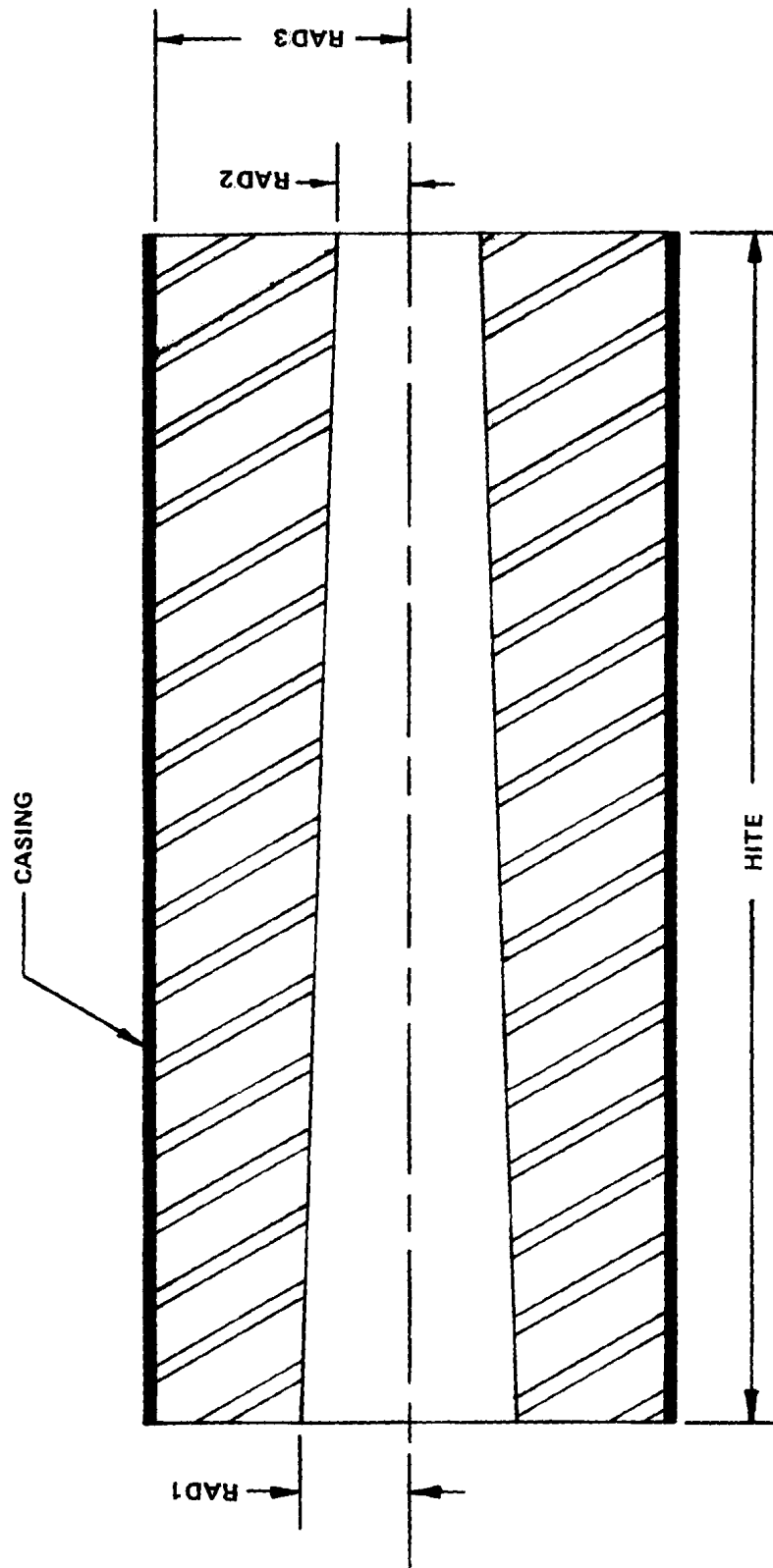


Figure C-1. Assumed Shape for a Solid Propellant Grain

400 CONTINUE

The next cards read were the calibration packs for each digital tape channel, except the thermocouple channels. If KCAL equalled 1, the calibration packs were read, if KCAL equalled 0, the program used the calibrations entered during the previous data reduction run. There must be a minimum of 3 calibration points for each channel. A typical calibration pack is shown in Table C-I (a).

103 FORMAT (20I3)

where

ICAL = 0, if the calibrations are not to be printed

= 1, if the calibrations are to be printed

NCAL = The number of calibration packs to be read in (=20 minus the number of thermocouple channels)

DO 10, I = 1, NCAL

READ (5, 103) ICHAN, NDAT(ICHAN)

103 FORMAT (20I3)

where

ICHAN = The channel number

NDAT(ICHAN) = The number of calibration points to be read in, ≤ 3
NDAT(ICHAN) ≤ 20

READ (5, 101) CDATE1, CDATE2, CDATE3

101 FORMAT (12A6)

where

CDATE1,

CDATE2,

CDATE3 = Storage for the alphanumeric specification of the date on which the calibration was performed

Table C-I. Typical Calibration Data Input Packs

(a) For a Pressure or Thrust Measurement									
1	5	October 28, 1969		1					
		STATHAM		1					
		PSID	VOLTS						
		0.000E 00	0.000E 00	1.000E 02	1.012E 00	2.000E 02	1.993E 00		
		3.000E 02	2.994E 00	4.000E 02	4.000E 00				
		5.028E 00							
(b) For a Flowmeter									
19	2	October 28, 1969							
		POTTER							
		CPS	VOLTS	3					
		0.807E 00	3216.32E 00	-2.0000E 00					
		- blank card -							

READ (5, 101) (TRANSD(21,k), K = 1, 4)

101 FORMAT (12A6)

where

(TRANSD(21, K), K = 1,2) = Storage for the alphanumeric specification of the transducer type

(TRANSD(21,K), K = 3) = Storage for the alphanumeric specification of the amplifier number

(TRANSD(21,K), K = 4) = Storage for the alphanumeric specification of the control unit number

READ (5, 101) UNITST, UNITSR

101 FORMAT (12A6)

where

UNITST = Storage for the alphanumeric specification of the units of the physical variable, i.e., psia, etc.

UNITSR = Storage for the alphanumeric specification of the units of the recorded variables, i.e., volts

The next card(s) contained the actual calibration points. Note that $NN = NDAT(ICHAN)$

READ (5, 105) (CALT(ICHAN,J), CALR(ICHAN,J), J = 1,NN)

105 FORMAT (6E12.5)

where

CALT(ICHAN,J) = The value of the physical variable, i.e., lb_f

CALR(ICHAN,J) = The value of the recorded quantity, i.e., volts

READ (5, 105) BVOLT

105 FORMAT (6E12.5)

where

BVOLT = The bridge voltage applied to the transducer

.

.

10 CONTINUE

For the flowmeter channels, NDAT(ICHAN) = 3, CALT(ICHAN,1) = the specific gravity of the fluid, CALR(ICHAN,1) = the number of volts per 250 cycles/second, and CALT(ICHAN,2) = the number of cycles per gallon of water passing through the flowmeter. The BVOLT card was left blank. A typical flowmeter calibration pack is shown in Table C-I(b).

As a check on possible flowmeter error, a set of calibration points of pressure drop versus flow rate could also be entered for each flowmeter channel.

DO 16 I = 1, NCALCK

READ (5, 103) ICHAN, NWCK(ICHAN)

103 FORMAT (20I3)

where

ICHAN = The flowmeter channel number

NWCK(ICHAN) = The number of calibration points to be read

Note: NN = NWCK(ICHAN)

READ (5, 108)(CALTK(ICHAN,J), CALRK(ICHAN)J,J = 1,NN)

108 FORMAT (2E10.3)

where

CALTK(ICHAN,J) = The flow rate in lbm/sec

CALTR(ICHAN,J) = The pressure drop in psid

The voltages recorded from the thermocouples were calibrated by using the thermocouple table included in the input data. The following card contained the amplification factor which was applied to each thermocouple signal.

```
READ (5, 110) NT, (ICHAN, AMP(ICHAN), I = 1, NT)
```

```
110 FORMAT (I2, I3, E10.3)
```

where

NT = The number of thermocouple channels used

ICHAN = The thermocouple channel number

AMP(ICHAN) = The amplification factor used

The thermocouple table was then read if ITABLE = 1. The thermocouples used in the series of runs were chromel-alumel thermocouples. The required table was obtained from Reference [8] and is repeated in Table C-II. It consisted of 61 cards, each card containing 10 temperatures, each temperature corresponding to a reading of 0.1 millivolt higher than the previous temperature. The range of the table is from -460° to 2499°F.

```
DO 4I = 1, 61
```

```
READ (5, 107) TCAL(II), TCAL(II+1),  
TCAL(II+2), TCAL(II+3), TCAL(II+4),  
TCAL(II+5), TCAL(II+6), TCAL(II+7),  
TCAL(II+8), TCAL(II+9)
```

```
107 FORMAT (10F5.0)
```

where

TCAL() = Temperature in °F

```
4 II = II+10
```

By means of the following three read statements, the F-factor table for the air orifice (if ITABLE = 1) was entered. This table may be found as Table 4 of Reference [4]. The table was entered through the first read statement, the table abscissa was entered by means of the second read statement, and the table ordinate was entered through the third read statement. Note that the order of the ordinate was reversed from the original table in Reference [4]. The table used in the series of runs reported herein along with the abscissa and ordinate values are given in Table C-III.

Table C-II. Chromel-Alumel Thermocouple Table as Used by the Data Reduction Program

-460	-460	-460	-460	-310	-299	-289	-280	-270	-262
-253	-245	-240	-237	-220	-222	-215	-200	-193	-187
-180	-174	-167	-161	-155	-149	-143	-137	-131	-125
-119	-114	-108	-103	-97	-92	-86	-81	-76	-70
-65	-60	-55	-50	-45	-40	-35	-30	-25	-20
-15	-11	-6	-1	4	9	14	18	23	27
32	37	41	46	50	55	59	64	68	73
77	82	86	90	95	99	104	108	113	117
121	126	130	134	139	143	147	152	156	160
165	169	173	178	182	186	191	195	199	203
208	212	216	221	225	230	234	238	243	247
251	256	260	265	269	273	278	282	287	291
296	300	305	309	314	318	323	327	332	336
241	345	350	355	359	364	368	372	377	381
386	390	395	400	404	408	413	417	422	426
431	435	440	444	449	453	457	462	466	471
475	480	484	488	493	497	501	506	510	515
519	524	528	532	536	541	545	550	554	558
563	567	572	576	580	585	589	593	598	602
606	610	615	619	624	628	632	636	641	645
649	653	658	662	667	671	675	680	684	688
692	697	701	705	709	714	718	722	727	731
735	739	743	748	752	756	761	765	769	773
778	782	786	790	795	799	803	807	812	816
820	824	829	833	837	842	846	850	854	858
862	867	871	875	880	884	888	892	896	901
905	909	913	917	922	926	930	934	939	943
947	951	955	960	964	968	972	977	981	985
989	993	998	1002	1006	1010	1014	1019	1023	1027
1031	1036	1040	1044	1048	1052	1057	1061	1065	1069
1074	1078	1082	1086	1090	1094	1099	1103	1107	1112
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2452	2457	2462	2467	2473	2478	2483	2489	2494	2499

If JOBTYP = 10, the following three read statements were encountered which provided the values of the measured quantities.

```
READ (5, 102) (DATAB(I), I = 1,20)
```

```
102 FORMAT (7E10.3)
```

where

DATAB(I) = The value of the Ith measured quantity at the data reduction point prior to the primary rocket firing, where I equal the corresponding digital tape channel (volts)

```
READ (5, 102) (DATAD(I), I = 1, 20)
```

```
102 FORMAT (7E10.3)
```

where

DATAD(I) = The value of the Ith measured quantity at the data reduction point during the primary rocket firing (volts)

```
READ (5, 102) ((DATA(I,J), J = 1, NPTS), I = 1, 20)
```

```
102 FORMAT (7E10.3)
```

where

DATA (I,J) = The value of the Ith measured quantity at the jth plot point

The next set of cards provided information necessary to calculate the flow rates of the sodium hydroxide seeding solution and the methane and oxygen for the air heater ignitor.

```
READ (5, 102) PDB, PDD, PNATNK
```

```
102 FORMAT (7E10.3)
```

where

PDB = The pressure drop across the air heater back pressure place before the firing of the primary rocket, psi

PDD = The pressure drop across the air heater back pressure plate during the firing of the primary rocket, psi

PNATNK = The pressure in the seeding solution tank, psig, = 0 if no seeding was used

If CNAOH did not equal 0, the following cards were read. These cards were a calibration table of the pressure difference between the seeding solution tank and the air heater chamber versus the flow rate of the seeding solution.

READ (5, 102) NPCH

103 FORMAT (20I3)

where

NPCH = The number of calibration points to be read

READ (5, 1022) (DPCH(J), WDOTNA(J), J = 1, NPCH

1022 FORMAT (2E10.3)

where

DPCH(J) = Pressure difference, psid

WDOTNA(J) = Flow rate of seeding solution, lbm/sec

The ignitor gases each passed through a critical flow orifice, both orifices being of the same diameter.

READ (5, 102) A2, PLINOX, TLINOX, PLINM, TLINM, GAMMAO, GAMMAM

102 FORMAT (7E10.3)

where

A2 = The area of the orifice, square inches

PLINOX = The oxygen pressure upstream of the orifice, psia

TLINOX = The temperature of the oxygen upstream of the orifice, °F

PLINM = The methane pressure upstream of the orifice, psia

TLINM = The temperature of the methane upstream of the orifice

GAMMAO = The ratio of specific heats for oxygen

GAMMAN = The ratio of specific heats for methane

READ (5, 102) XMWO, XMWM, CDO, CDM

102 FORMAT (7E10.3)

where

XMWO = The molecular weight of oxygen

XMWM = The molecular weight of methane

CDO = The discharge coefficient of the oxygen orifice

CDM = The discharge coefficient of the methane coefficient

The next card contained the supercompressibility factor for the air at the air orifice for the conditions under which it was operated. This may be obtained from Figure 45 of Reference [4]. If JOBTYP equalled 3, this card was not included in the data pack.

READ (5, 102) SF

102 FORMAT (7E10.3)

where

SF = The supercompressibility factor

To obtain the estimate of the heat loss from the ramburner during a run, the following information was entered. If JOBTYP equalled 3 this card was not included in the data pack.

READ (5, 102) RHODUT, CPDUCT, RI, RO

102 FORMAT (7E10.3)

where

RHODUT = The density of the ramburner material, lbm/in.^3

CPDUCT = The specific heat at constant pressure of the ramburner material

RI = The inside radius of the ramburner, inches

RO = The outside radius of the ramburner, inches

The last card in the data pack contained the maximum allowable error for the thermochemistry calculations. The use of this value is explained in Reference [3].

```
READ (5, 102) ERROR
```

```
102 FORMAT (7E10.3)
```

where

ERROR = The maximum allowable error for the thermochemical calculations (usually = 0.01)

Appendix D. METHODS FOR THE ANALYSIS OF MEASUREMENT UNCERTAINTIES

This appendix presents the equations employed in the statistical analysis of the measurement uncertainties as discussed in Section IV. It was assumed that the flow was one dimensional and consisted entirely of air for the purpose of obtaining the partial derivatives employed in the statistical analysis. The flow computations employed equilibrium thermochemistry which accounted for the actual composition of the mixture.

The statistical analysis was based on four separate determinations of the stagnation pressure in the rocket transition section: (1) the measured pressure, along with the pressure calculated from measurements of (2) the stagnation temperature and flow rate, (3) the thrust and flow rate, and (4) the static pressure at the ramburner inlet and the flow rate.

For case (1), it was assumed that

$$\sigma_{P_{sa}} = \epsilon \quad (D-1)$$

where $\sigma_{P_{sa}}$ = standard deviation, ϵ = standard deviation of the measured P_{sa1} .

For case (2), the stagnation pressure was calculated from

$$P_{sa2} = \frac{\dot{w} \sqrt{T_{inj}}}{A^* K} \quad (D-2)$$

where

$$K = \sqrt{\frac{\gamma}{R}} \left(\frac{2}{\gamma + 1} \right)^{\frac{\gamma + 1}{\gamma - 1}} \quad (D-3)$$

Then, as shown in Reference [12],

$$\sigma_{P_{sa2}} = \sqrt{\left(\frac{\partial P_{sa}}{\partial \dot{w}} \right)^2 \sigma_{\dot{w}}^2 + \left(\frac{\partial P_{sa}}{\partial T_{inj}} \right)^2 \sigma_{T_{inj}}^2} \quad (D-4)$$

where it was assumed that $\sigma_{\dot{w}}$ and $\sigma_{T_{inj}}$ were equal to ϵ times the ratio of the expected uncertainty in the respective measurement to the expected uncertainty of the stagnation pressure measurement as given in Table V.

For case (3), the stagnation pressure was computed by the data reduction program by the methods discussed in Section III. The partial derivatives of the stagnation pressure with respect to thrust and flow rate were derived from the following equation which was obtained by combining the thrust equation with Equation (D-2) and the isentropic relation between static and stagnation temperature.

$$P_{sa_3} = \frac{\left(\frac{F^*}{A^*}\right) - P_{exit} + P_{atm}}{\frac{k}{g} \sqrt{\frac{g\gamma R}{1 + \frac{\gamma - 1}{2}}}} \quad (D-5)$$

The standard deviation for the stagnation pressure was then computed from

$$\sigma_{P_{sa_3}} = \sqrt{\left(\frac{\partial P_{sa}}{\partial F}\right)^2 \sigma_F^2 + \left(\frac{\partial P_{sa}}{\partial \dot{w}}\right)^2 \sigma_{\dot{w}}^2} \quad (D-6)$$

where σ_F and $\sigma_{\dot{w}}$ were obtained by the same method as stated above for $\sigma_{T_{inj}}$.

In case (4), to relate the stagnation pressure in the transition section to the ramburner static pressure and flow rate, it was assumed that the flow was isentropic up to the exit plane of the primary nozzle, defined as station 1, and then the momentum equation was applied between station 1 and the static pressure tap, station 2. This resulted in the following set of equations

$$P_{sa_4} = X = \frac{P_2}{\frac{M_2 \left(1 + \frac{\gamma - 1}{2} M_1^2\right)^{(\gamma + 1)/(2(\gamma - 1))}}{M_1 \left(1 + \frac{\gamma - 1}{2} M_2^2\right)^{(3\gamma + 1)/(2(\gamma - 1))}}} \quad (D-7)$$

$$P_{sa_4} = Y = \frac{\dot{w} \left(1 + \frac{\gamma - 1}{2} M_1^2\right)^{(\gamma + 1)/(2(\gamma - 1))}}{A_1 M_1 \sqrt{\frac{g\gamma}{R T_{inj}}}} \quad (D-8)$$

and

$$c = d \quad (D-9)$$

where

$$c = \frac{A_1}{A M_1 \sqrt{\frac{g\gamma}{R T_{inj}}}} \left[\frac{1}{\left(1 + \frac{\gamma - 1}{2} M_1^2\right)^{1/2}} - \frac{M_2}{M_1} \frac{\left(1 + \frac{\gamma - 1}{2} M_1^2\right)^{(\gamma + 1)/(\gamma - 1)}}{\left(1 + \frac{\gamma - 1}{2} M_2^2\right)^{(2\gamma + 1)/(2(\gamma + 1))}} \right]$$

$$d = \frac{\sqrt{g\gamma R T_{inj}}}{g_c} \left[\frac{M_2}{\left(1 + \frac{\gamma - 1}{2} M_2^2\right)^{1/2}} - \frac{M_1}{\left(1 + \frac{\gamma - 1}{2} M_1^2\right)^{1/2}} \right]$$

M is the Mach number determined at each station from the measured quantities at each station and T_{inj} is the average stagnation temperature.

While the Mach numbers computed at each station were not exact, they would not be much in error and small changes in the Mach number do not significantly change the results. These equations were then solved for P_{sa_4} .

It was then possible to obtain the required partial derivatives of the stagnation pressure with respect to static pressure and flow rate by applying the chain rule for partial differential equations to equations (D-7), (D-8) and (D-9). This resulted in the following expressions for the partial differentials.

$$\left(\frac{\partial P_{sa_4}}{\partial p_2} \right)_{\dot{w}} = \left(\frac{\partial X}{\partial p_2} \right)_{M_1, M_2} + \left[\left(\frac{\partial X}{\partial M_1} \right)_{p_2, M_2} + \left(\frac{\partial X}{\partial M_2} \right)_{p_2, M_1} \left(\frac{dM_2}{dM_1} \right) \right] \left(\frac{\partial M_1}{\partial p_2} \right)_{\dot{w}} \quad (D-10)$$

$$\left(\frac{\partial P_{sa_4}}{\partial \dot{w}} \right)_{p_2} = \left[\left(\frac{\partial X}{\partial M_1} \right)_{p_2, M_2} + \left(\frac{\partial X}{\partial M_2} \right)_{p_2, M_1} \left(\frac{dM_2}{dM_1} \right) \right] \left(\frac{M_1}{\partial \dot{w}} \right)_{p_2} \quad (D-11)$$

where

$$\left(\frac{\partial M_1}{\partial p_2} \right)_{\dot{w}} = \frac{\left(\frac{\partial X}{\partial p_2} \right)_{M_1, M_2}}{\left[\left(\frac{\partial X}{\partial M_1} \right)_{p_2, M_2} + \left(\frac{\partial X}{\partial M_2} \right)_{p_2, M_1} \left(\frac{dM_2}{dM_1} \right) - \left(\frac{\partial Y}{\partial M_1} \right)_{\dot{w}} \right]}$$

$$\left(\frac{\partial M_1}{\partial \dot{w}} \right)_{p_2} = \frac{\frac{\partial Y}{\partial \dot{w}} M_1}{\left[\left(\frac{\partial X}{\partial M_1} \right)_{p_2, M_2} + \left(\frac{\partial X}{\partial M_2} \right)_{p_2, M_1} \left(\frac{dM_2}{dM_1} \right) - \left(\frac{\partial Y}{\partial M_1} \right)_{\dot{w}} \right]}$$

where (dM_1/dM_2) was evaluated from Equation (D-9). In this manner, the necessary partial differentials were evaluated and the standard deviation of the stagnation pressure based on the static pressure at the ramburner inlet and the flow rate was evaluated from

$$\sigma_{P_{sa_4}} = \sqrt{\left(\frac{\partial P_{sa}}{\partial p_2} \right)^2 \sigma_{p_2}^2 + \left(\frac{\partial P_{sa}}{\partial \dot{w}} \right)^2 \sigma_{\dot{w}}^2} \quad (D-12)$$

where $p_2 = p_{inj}$.

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The "most probable" stagnation pressure was then computed as the weighted mean of the four stagnation pressures obtained as above. The weighting factors were obtained from

$$W_i = \frac{1}{\sigma_{P_{sa_i}}^2} \quad (D-13)$$

as given in Reference [12], and the most probable stagnation pressure was computed from

$$\bar{P}_{sa} = \frac{\sum_i W_i P_{sa_i}}{\sum_i W_i} \quad (D-14)$$

and the standard deviation of $\bar{P}_{sa}$ was obtained from

$$\frac{1}{\sigma_{\bar{P}_{sa}}^2} = \sum_i \frac{1}{\sigma_{P_{sa_i}}^2} \quad (D-15)$$

as shown in Reference [12]. At the 95 percent confidence level as shown in Reference [11], the four stagnation pressures should fall within a band of $\pm 2.13 \sigma_{\bar{P}_{sa}}$. Since ϵ was carried through these calculations,

a value for ϵ was determined which made each of the four stagnation pressures fall within the 95 percent confidence band around $\bar{P}_{sa}$.

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d.

10. DISTRIBUTION STATEMENT

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11. SUPPLEMENTARY NOTES

None

12. SPONSORING MILITARY ACTIVITY

Propulsion Directorate
Directorate for Research, Development,
Engineering and Missile Systems Laboratory
U.S. Army Missile Command
Redstone Arsenal, Alabama 35809

13. ABSTRACT

This report describes the results of a series of connected-pipe runs with an air-augmented rocket system burning liquid rocket propellants. The liquid propellant runs served to evaluate the behavior of the facility and instrumentation with regard to accuracy and to provide performance data for combustion where the chemical rate processes were relatively fast compared with those of metal combustion. The ram-burner was designed to provide axisymmetric, coaxial mixing of the primary and secondary streams in a constant area duct. No mixing aids were employed.

Nitrogen tetroxide and Aerozine-50 served as the rocket propellants. The secondary air was preheated by combustion to a nominal temperature of 1100°R to simulate flight stagnation conditions. Runs were made with nominal pressures in the ramburner of 90 and 175 psia. The air/propellant ratio was varied from 5 to 13 (approximately 250 to 600 percent theoretical air). Two oxidizer-to-fuel ratios were employed for the primary rocket: 0.8 (fuel rich) and 2.0 (stoichiometric).

Combustion efficiencies between 75 and 90 percent were observed for the complete system, decreasing with increasing air/propellant ratio. Estimated uncertainties in the efficiency values were ± 3 percent. Ramburner efficiencies tended to be 10 to 15 percent lower and were subject to uncertainties in the neighborhood of ± 6 percent. A slight decrease in efficiency with decreasing pressure was also observed.

14.	KEY WORDS	LINK A		LINK B		LINK C	
		ROLE	WT	ROLE	WT	ROLE	W
	Air-augmented rockets Connected pipe tests Secondary combustion Combustion efficiency						