AEROTHERM
FINAL REPORT NO. 69-51

A STUDY OF THE BOUNDARY FLOW IN A ROCKET COMBUSTION CHAMBER

PART IV

DEVELOPMENT OF EXPERIMENTAL HARDWARE AND TECHNIQUE

by

Ronald D. Grose

AEROTHERM CORPORATION

ADVANCES IN AEROTHERMOCHEMISTRY

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Ronald D. Grose

Prepared for

Jet Propulsion Laboratory
Pasadena, California

Contract No. NAS7-463

JPL Technical Monitor - D. L. Bond

FOREWORD

This report is one of a four part final report which describes the research conducted with a liquid rocket motor utilizing hydrogen and nitrogen tetroxide propellants with which heat transfer and chemical composition data were obtained. The development of the experimental hardware is the subject matter of this particular document. The subject matter of each in the series are:

Part I - Summary
Part II - Data Analysis, Correlation and Theoretical Predictions
Part III - Data Report
Part IV - Development of Experimental Hardware and Technique

This effort was conducted for the Jet Propulsion Laboratories of the National Aeronautics and Space Administration under Contract No. NAS7-463. Mr. Donald L. Bond and William H. Tyler were the technical monitors.

The work reported here is based largely on a compilation of the progress reports issued during the course of the program. It represents the culmination of contributions of many individuals both in and outside Aerotherm Corporation. Particular credit is due to West Coast Technical Company's Dwight Fisher for cooperation and help in solving the vexing sample analysis problem, to United Technology Center's Leo Linn and his technical staff headed by Bill Cooper for the successful conduct of the test program, and to the technical monitors for their guidance and understanding during these difficult portions of the contract. To these and to all the others who contributed ideas, suggestions, and devoted labor which in the end lead to successful resolution of the projects goals, the author expresses his sincere gratitude.

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LIST OF SYMBOLS

A	area
CO_2	carbon dioxide
C_H	heat transfer coefficient
d	diameter
F	species mass spectrometer response factor
h (H in figures)	enthalpy
H_2	hydrogen
He	helium
L	length
$\dot{m}$	flow rate
$\mathcal{M}$	molecular weight
N	boundary layer velocity profile exponent $\frac{u}{u_e} = (y/\delta)^{1/N}$, nitrogen atom
N_2	nitrogen
O_2	oxygen
O/F	mixture ratio
P	pressure
$\dot{q}$	wall heat rate
R	radius, oscillograph reading
$\bar{R}$	gas constant
R_i	inner radius of rocket motor wall
R_o	outer radius of rocket motor wall
$Re_{\theta,t}$	transition Reynolds number based on momentum thickness
T	temperature
u	velocity
u_τ	velocity

LIST OF SYMBOLS (continued)

$\dot{V}$	volumetric flow rate
x	axial position, partial pressure
x,y,z	coordinates
α	viscous resistance coefficient
α_{ij}	number of atoms i in molecule j
β	inertial resistance coefficient
Γ	energy thickness
δ	boundary layer height
$\delta*$	displacement thickness
Δ_p	pressure differential
μ	viscosity
ν	kinematic viscosity
ρ	density
ρ_s	density at standard temperature (70°F) and pressure (1 atm)
τ	time, shear
ϕ	injector position
χ	mole fraction

SUBSCRIPTS

c	combustion chamber
e	edge
f	fuel
g	sampling gas
H	helium, hydrogen
i,j	indexes
m	mean (sampling gas)
N	nitrogen

LIST OF SYMBOLS (concluded)

o	oxidizer
p	porous plug
s	sublayer (boundary flow laminar sublayer)
t	test
w	wall

SECTION 1

INTRODUCTION

The study of boundary flow composition in a rocket motor combustion chamber appears to be a subject not too extensively investigated although exhaust stream sampling is performed on a relatively routine basis. A major problem is the severe environment in which the system for obtaining the boundary flow gas samples must operate. Because there existed a lack of suitable equipment with which the problem could be investigated, the Jet Propulsion Laboratory undertook the development of such equipment with the view of generating valuable data for injector designers confronted with providing high performance injectors for both albative and nonablative rocket motor chambers.

Aerotherm's role in this research program has been to 1) develop the manufactured hardware into a working research tool, 2) acquire and reduce the data produced by developed apparatus, and 3) analyze and correlate the data to injector design parameters. This part of the final report (Part IV) is concerned principally with the first of these activities. Besides the development of the actual research hardware this report describes analysis used in supporting the hardware development, the development of certain data reduction computer codes, and the development of technique for the chemical analysis of the gas samples taken with the equipment.

This research activity began at Aerotherm in July of 1966. It was scheduled to be completed in a 12-month period. The program was significantly delayed however first by production delays of certain of the valve and injector components, then by problems at the rocket site both with regard to the thrust stand instrumentation and the apparatus itself. The most significant delay was the result of the determination of the chemistry of the collected sample--a problem which was totally unexpected. With these delays the development effort spanned a period 2 years in duration and the prime testing (the second activity) was not initiated until late in 1968.

SECTION 2

RESEARCH EQUIPMENT DEVELOPMENT

The Jet Propulsion Laboratory as part of its Advanced Liquid Propulsion Studies (ALPS) program undertook rocket motor boundary flow research to provide data and increased understanding of combustion chamber processes so that injector design techniques, for example, could be improved.

In the mid 1960's a sampling scheme was conceived which employed a unique-zero-leakage, minimal-dead-volume valve which had been developed for propellant flow control on the Mariner Program. Using this valve as a basis for the research equipment concept, the Jet Propulsion Laboratory proceeded to have constructed a copper heat sink combustion chamber and suitable injector, the latter embodying certain design features established in the ALPS program which provide exceptionally good stability, repeatability and ruggedness--all highly useful features for a research program. The combustion chamber was machined to house six of the zero leakage valves at approximately equal axial increments between the injector and combustion chamber throat at the same azimuth. A separate housing attached to the chamber contained gas actuation mechanisms for these valves. Provision was also made in the combustion chamber for six heat flux gages located directly opposite from the sampling ports. These heat flux gages and all requisite valve parts were designed and manufactured when Aerotherm was introduced into the program. This section of Volume 3--the development of the research equipment hardware--is concerned with providing a record of the effort expended by the Aerotherm Corporation in the development of the apparatus past the initial hardware construction phase to the point of making it a useful research tool. The principle objective of the development activity was to produce a research apparatus that would operate in a known, repeatable fashion such that the acquisition of meaningful data would be assured. The description of the accomplishment of this objective has been divided into subsections which correspond to the principal hardware development phases. Subsection 2.1 describes the development of the sampling system, including the zero leakage JPL valve, its problems, and the system which eventually replaced it; subsection 2.2 describes the development of the heat flux gages which replaced the original gages damaged during installation and which embodied certain improvements thereto; subsection 2.3 describes the development activities which were incidental to the aforementioned objective but were nonetheless important to successfully achieving it, and subsection 2.4 describes the final developments leading to the actual use of the apparatus and the preliminary firings which were obtained therefrom.

The heat sink combustion chamber was machined from a solid piece of high purity copper to give a chamber diameter of two inches, a constant area length of 5 inches and a wall thickness of 1-1/2 inches. The injector can be clamped to this chamber in such a fashion that it can be rotated between firings to any desired position. A 1/2 scale drawing of the chamber is presented in Figure 1. Detail A of this figure shows the essentials of the hard seat valve concept less the actuator details. The relative locations of these sampling valves and heat flux gages are shown in the cutaway views. Because an adaptor flange is required between the injector face and block mounting flange the actual distance from the injector face to the center of the first sampling station is slightly in excess of one inch.

The injector, shown in side view in Figure 2, features long tube orifices arranged to form 10 doublet pairs such that a relatively uniform cross-sectional mass flux distribution in the chamber is produced. The jet emanating from these long tubes has a fully developed turbulent velocity profile combined with a large pressure drop which tends to make the jet insensitive to upstream disturbances thereby yielding an injector with repeatable characteristics. Moreover this injector has been found to yield high C* efficiencies both in work reported here and in previous testing at JPL.(1,2)*

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*Number in parentheses refer to reference at end of text

2.1 SAMPLING SYSTEM

The development of the sampling system initially posed the greatest uncertainty in achieving the objective of acquiring meaningful data with reliable and repeatable equipment. Although it was found possible to achieve sampling with the zero leakage-minimal volume-hard-seat valve, significant disadvantages,as far as the requirements of this program were concerned, prompted the development of an alternate sampling system. It is concluded that a modified form of the JPL hard-seat-valve would be appropriate for those situations where the soft seat material currently available would be damaged or destroyed by chemical activity with the sample gases.

This subsection describes the effort expended in making the JPL valve successfully operate in a rocket motor environment and also describes the evolution of the sampling of flow rate control method from the use of a porous sintered element to a more conventional drilled orifice. Supporting experimental and theoretical detailed studies are presented as they applied to the development of the sampling system.

2.1.1 Hard Seat Prototype Valve Development

The development of the sapphire-ball-hard-seat-valve proceeded in two stages. The first stage was the operation of a full scale prototype valve in a system simulating the environment in which the valve was to be operated. The second developmental stage involved resolving the problems associated with the successful operation of six of these modified hard-seat-valves in the chamber. This second stage is discussed in Section 2.1.3.

One of the stated objectives of the program is to provide a sampling apparatus which operates in a known, repeatable fashion and in such a way that the acquisition of meaningful data is assured. To effect this objective, tests of the sampling valve components, backup valves, and the overall rocket motor-sampling system were conducted. These tests were made to ensure proper mechanical operation and survivability of the sampling system.

A flow testing circuit was constructed at the Aerotherm Laboratory with which the prototype hard-seat-valve and other sampling system components could be tested using various commercially available gases. A flowmeter, thermocouple and pressure gage instrumentation made possible an accurate determination of flow rate. Figure 3 presents a schematic of the flow circuit.

Several salient features of the flow circuit should be noted. The design philosophy was to have one leak tight circuit which could be used for testing several different components. Thus, the components tested in this circuit included the copper-block-JPL-valve assembly with stainless-steel-block-actuator assembly, sintered-plug flow controllers, back-up valves, and other circuit components. The supply gases for the circuit were either helium (for leak testing components) or a mixture of helium and nitrogen (for flow characteristic determination). A 50/50 mixture (by mole fraction) of the gases was chosen to simulate the density of the combustion products at the combustion chamber wall temperature.

The resistance-heated coil of tubing shown in Figure 3 was used to raise the test gas temperature to at least 300°F. By heating the test gas in this manner (and simultaneously heating the valve body) those valves with soft seat material (such as the sampling cylinder shutoff valve) were evaluated for contamination and durability characteristics.

The downstream side of the components could be: a) connected to a sampling bottle for contamination evaluation, b) connected to a check valve for vacuum testing, c) unconnected for leak testing.

A two piece test block was constructed in which the JPL sampling control valve (Figure 4) was inserted. This test block modeled the copper rocket motor combustion chamber and the stainless steel upper valve housing. When connected to the flow circuit, the test block enabled testing of the JPL valve under hot conditions for both mechanical integrity and leakage characteristics.

In the JPL valve design, shown in Figure 4-a, the gas flow is controlled by a precision sapphire sphere (ball) which contacts a spherical stainless steel seat. Such a design has the potential for controlling the high temperature gases to be taken from the rocket motor boundary flow. The Jet Propulsion Laboratory has had much experience with valves of this type and has found them capable of exhibiting zero leakage characteristics under less severe operating conditions than those anticipated in this program. In the particular design under evaluation, the ball is held to the seat by a small return spring and is disengaged from the seat by a gas actuated piston-pintal arrangement. The design is noteworthy, especially in comparison to standard gas valves, in the extensive use of O-rings. O-rings are found in the piston assembly, around the seat assembly, and between valve housing components. Operational difficulties were encountered which have been traced to these O-rings and also to the proper seating of the ball in its seat. These difficulties will be briefly discussed in the following paragraphs.

The evaluation of the JPL valve was first limited to cold flow testing. In the attempt to demonstrate the operation of the valve for these less stringent conditions, several problem areas were uncovered. These problems fell into two categories: 1) O-ring distortion and 2) contamination.

Initial tests with the valve were encouraging. The most significant problem appeared to be a tendency for the actuating piston to hang-up (probably O-ring seizure). The seizure problem was largely eliminated when the piston return-spring force was increased (by stretching the spring) and when the piston-shaft O-ring was lubricated. However, the leakage characteristics of the valve became increasingly degraded as testing progressed and completely satisfactory performance of the valve was not achieved even for the cold flow condition.

Significant leakage between housing components was observed and this was traced to a lack of sufficient O-ring groove depth in the copper test block. The internal O-rings were also found to be highly susceptible to damage during assembly. Leakage past the seat was the most difficult problem. Various causes were uncovered but the principle one, was contamination. Contamination arose from adjacent parts rather than from improper assembly procedures. It was found necessary to ultrasonically clean all adjacent parts, especially those upstream of the seat. A predominant source of contamination was found to be the cage for the sapphire ball. Microscopic examination of the ball showed the existance of both an oily substance and minute metal particles on the ball surface. Both contaminants were traced to the cage. It was also discovered that the metal particles even produced mircoscopic chipping of the sapphire surface when trapped between the ball and the seat.

Another source of performance degradation was also traced to the sapphire ball cage. The clearance between the cage walls and the sapphire ball which it encloses is only several thousandths. When this clearance was increased to prevent cocking the ball away from the seat then the tangs forming the cage were weakened to the point where it was difficult to assemble the valve without bending the cage tangs which then also prevented the ball from seating properly.

Following the cold flow testing the prototype valve was reassembled using ultra clean procedures and tested under conditions more representative of the chamber environment. The valve body was heated to at least 300°F and the inlet side of the valve was pressurized to about 150 psia. The gases were also heated by a resistance heater although the temperatures produced by the heater were far below what were to be experienced in an actual firing. Table 1-a presents a summary of the range of conditions which were produced for the prototype testing. Gas pressures and temperatures and valve body temperatures were recorded and the downstream side of the valve was either evacuated or opened to atmosphere in these tests.

Some of the test results obtained during the development testing are presented in Table 1-b. In these tests, pressures and temperatures were measured over a period of time and after the valve had been cycled many times.

The tests were repeated several times after the valve had been disassembled and reassembled to preclude the possibility of having obtained excellent results from a fortuitous and unique assembly.

The data presented are results from time - leakage tests in which the pressure rise in a small volume downstream of the valve is measured over a period of time. Prior to these tests, the valve assemblies had successfully passed bubble and "snoop" tests.

The leakage rates demonstrated by the prototype valve in this pressure rise data were low enough to guarantee successful performance during a firing. In the firing sequence the valve needs to be in a good shutoff condition for only several seconds before the sample is taken and further, the pressure in the sample bottle after a firing is about three atmospheres. Under such conditions the leakage gases would be a trivial fraction of the mass of gas collected during the sampling process.

One of the potential problem areas confronting the sampling scheme was the possibility of contaminating the boundary flow sample gases in the process of collecting the sample. This contamination can be of various forms. Two potential sources of contamination were (1) the actuating gas for the valve (the actuating gas could contaminate the sample by leaking past the piston "O" ring seal) (2) leaks to the ambient.

Chemical reactions between the sampling gas and component parts can also change the sample composition but this could not be investigated because of the limited temperature range of the sample gas heater.

In the contamination test a gas mixture of known composition was heated and supplied to the upstream port of the valve at high pressure. The downstream side was connected to a small sample bottle and evacuated. The valve body itself was heated to simulate the actual conditions to be encountered in the rocket firings. The valve was actuated several times during which the valve was open for about one second per cycle. The sample bottle was removed from the system and analyzed by gas chromatography for molecular composition. The results, presented in Table 2 show only a small level of contamination was detected.

The prototype valve was subjected to a severe heating test to ascertain the susceptibility of certain valve components to thermal shock, distortion from impulse heating, and mechanical failure. In this test an acetelyne torch was directed at the upstream port. The downstream port was connected to an evacuated bottle. When the valve was actuated, the acetelyne torch flame was drawn into the interior of the valve. This internal heating was maintained for about one second.

The valve was then placed in the flow circuit for evaluation. Although actuation was found to be normal, a good shutoff condition could not be achieved. Upon disassembly it was found that the ball return spring had collapsed and partially fused together. The ball and the stainless steel seat appeared to be in good mechanical condition so that, on the basis of this test, thermal shock can be largely ruled out as a problem area.

These results reinforced the conclusion drawn from the results of the earlier tests--that is, it appeared unlikely that the JPL valve would withstand the rigors of rocket-firing-sampling for several tests in a row and would require tear-down and build-up operations frequently, perhaps at the end of every test.

Several vulnerabilities of this valve design concept were noted during this development period. As borne out by the difficulties outlined above, the sapphire ball and stainless steel seat are extremely susceptible to minute foreign object adhesion which prevents the ball from attaining the extremely small seat tolerances necessary for leak-free operation. In some cases foreign particles can even cause surface damage to the sapphire ball. During operation with the rocket motor the valves would probably have to be disassembled for cleaning after each test firing because the scale formed on the combustion chamber walls during the firing and sampling sequence will probably flake off and enter the valve. Not only is the sapphire ball damaged by foreign objects, but the impact forces on the ball from both the seat and the pintal (which pushes the ball off the seat) cause surface marring. This surface marring prevents the ball from seating properly when it is reassembled since the position of the ball relative to the seat cannot be reproduced and the ball must be replaced. Similar comments apply to the seat itself since the surface finish of the seat can be damaged when the ball seats upon a foreign object. If the valve seats are frequently damaged in this fashion, then valve seats would have to be replaced because the seats can only be lapped a few times before the land becomes excessively wide.

Certain experimental and theoretical studies were conducted in parallel with, and in support of, these experimental studies on the hard seat valve. The combined results of these efforts led to a modified hard seat valve design. The performance of the valve was found to be effected by the flow rate of gases through the valve. In the next section these experiments and analysis will be described.

2.1.2 Sampling Flow Rate Control and System Analysis

Considerable attention was given to the problem of properly controlling the rate at which the sample gases were to be drawn from the boundary flow in the rocket motor. Factors considered included boundary flow disturbance, sampling time duration and sample receiver size. Attention was also given to the method of flow control and the durability of the controller to the severe environment which could be found near the vicinity of the chamber wall. Originally flow control was to be accomplished by a sintered porous element. Following an evaluation of the above factors this method of flow control was discarded in favor of a drilled-orifice. Subsequently certain modifications to the hard seat valve design were also made. These facets to the sampling system design are described in the following paragraphs.

2.1.2.1 Sintered Element Flow Characteristics

Several grades of sintered elements were ordered from Pacific Sintered Metals and copper holders for these elements were constructed. The initial tests of the sintered elements were with elements tested by JPL previously and used only N_2 as a test gas as per JPL test conditions.

The sintered elements were tested over a range of pressures expected to encompass those pressures to which the elements would have been exposed in the motor. Five grades of sintered elements were tested and are identified by their commercial grade number. The element configuration tested corresponded to that for the original element location as shown in Figure 4-a.

The data obtained in these nitrogen tests is presented in Table 3. Comparison of this data with vendor data is shown in Figure 5 where good agreement can be noted. The volumetric flow rate, $\dot{V}$, in Figure 5, is that obtained for standard conditions, i.e.;

$$\dot{V} = \dot{m}_t/\rho_s \tag{2-1}$$

This data provides the means for selecting the proper grade of sintered material for controlling the rate of flow into the sampling bottle. For a 100 cc size sample bottle, and a one second sample duration time, the volume flow rate of nitrogen equivalent to the actual gases is about 20 (in^3/sec.), and for a 150 psi pressure drop a grade of sintered materials of 100 appears to be appropriate. For the 300 cc size bottle, grade 40 would be appropriate. This sizing procedure must be approximate since the flow can vary 20% from element to element of the same grade and moreover the pressure drop characteristics of the sampling circuit and the mean gas temperature in the element can not be established with certainty.

The equivalent nitrogen flow rate was obtained in the following manner. From Reference 3 the Reynolds equation for flow in porous media is given as:

$$\frac{\Delta p}{L} = \alpha\mu u + \beta\rho u^2 \tag{2-2}$$

using the first term of this expression (the viscous influence term) a proportionality expression can be readily derived which relates flow rate and viscosity for two different gases flowing through the same media:

$$\frac{\dot{m}_g}{\dot{m}_N} = \frac{\nu_N}{\nu_g} \tag{2-3}$$

The preceding flow rate is obtained for the calculated gas flow rate, $\dot{m}_g$, needed to fill the 100 cc bottle in one second and the appropriate thermodynamic data.

The gases in the bottle were assumed to have a molecular weight of 20 and to be at a temperature of 300°F and a pressure of 50 psia.

The viscosity data for nitrogen, ν_N, was obtained from Reference 4 and that for the gas from the Aerotherm Chemical Equilibrium program for the mean chamber composition (O/F = 1.2) at a presumed mean temperature of 800°R and pressure of 150 psia ($\nu_g = 3.7\text{x}10^{-4}$ ft²/sec).

A precise analysis of the physical situation is difficult as the following considerations show. Initially the sampling flow is at the wall temperature since the sample is drawn from the gas next to the wall. Since this occurs about one second after the firing commences, the gas at that time is already hotter than 760°R. As the sampling progresses the wall and plug front face temperatures continue to rise and further the sample gas is drawn from a volume of gas whose bulk mean temperature is higher than that of the wall. Superimposed on these variations in temperature are local variations of molecular weight and other properties due to local concentration variation.

It was desirable to demonstrate that sampling rates of this magnitude did not disturb the flow field to the extent that the gases collected would not be representative of the undisturbed flow near the wall. Aerotherm had originally suggested that a suction ratio, $\rho_p u_p/\rho_e u_e$, of 0.001 was an appropriate value for the sampling rate to assure low disturbance of the gas composition next to the wall. With this suction value and the specified propellant flow rate ($w_T \simeq 0.4$ lb/s), the fill time was found to be much greater than the run time suggested by JPL (six seconds). This can be shown as follows. The mass velocity through the porous element is found to be (using the foregoing suction ratio)

$$\rho_p u_p \simeq 1.3\text{x}10^{-4} \ (\text{lb/s-in}^2)$$

The volumetric flow rate can be obtained by dividing $\rho_p u_p$ by the density of the gas (conditions as above) and multiplying by the cross-sectional area of the sintered element. Thus:

$$\dot{V} = \rho_p u_p \, A_p/\rho_g$$

$$\dot{V} \cong 1 \times 10^{-2} \ (\text{in}^3/\text{s.}) \qquad 2\text{-}4$$

Comparing this volume flow rate with that calculated previously it can be seen that the time required to fill one cylinder is approximately 2000 seconds, which is several orders of magnitude greater than the run time. This unacceptable result led to further detailed study.

It can be shown (see Appendix A) that the mass flux in the laminar sublayer taken in through the porous plug is given approximately by the following expression:

$$\rho_s u_s \simeq 60\mu/d_p \qquad 2\text{-}5$$

Using the previous gas viscosity value and $d_p = 0.158$ inches

$$\rho_s u_s \simeq 1\text{x}10^{-3} \ (\text{lb/s-in}^2)$$

Thus, comparing this rate with the rate determined previously, by removing the entire laminar sublayer (a slight disturbance to the flow field) the sampling times will still be much greater than the firing time.

The conclusion made from these preliminary results was that filling the sample cylinders in several seconds with the initial sample design (sintered plug) would disturb the flow field somewhat since a suction ratio of about 0.1 would be required. For such a suction rate the sample will be taken from regions well into the turbulent boundary layer. There are significant changes in composition and gas conditions in the laminar sublayer. Thus withdrawing gases from a region larger than this sublayer means that the gas composition obtained is not truly representative of the wall condition (because of unequal diffusion effects) even though there is only a moderate disturbance to the boundary layer flow field. The estimate of this effect was deemed to be outside the scope of the effort at this stage in the program.

Since the greatest temperature drop between the boundary layer edge (presumably at flame temperature) and the wall occurs in the laminar sublayer, it follows that the gases entering the sampling system will have a high mean temperature. Accordingly a more detailed aerothermodynamic treatment of the entrance condition and the porous plug response was performed. This detailed treatment is described in the next subsection.

2.1.2.2 Sintered Element Thermal Analysis

The Aerotherm Real Gas Boundary Layer program (Reference 4) was used to calculate heat transfer coefficient and boundary layer thermal property data for the theoretical mean-gas-composition to be found in the rocket motor. The gas composition data was generated by the Aerotherm Chemical Equilibrium program.* Figure 6 presents the composition data as a function of the oxidizer to fuel ratio. The design point mixture ratio is 1.22, as shown on the figure, and it is for this composition that the boundary layer program was run.

Figure 7 presents the most pertinent results from the boundary layer calculations. The boundary layer was presumed to start at the injector face and to be laminar initially. Transition to a turbulent boundary layer occurred somewhat less than halfway down the chamber where the calculated momentum thickness Reynolds number equaled 300. It is seen in Figure 7 that the boundary layer is quite thin. As a consequence even very small flow rates remove the laminar sublayer across which the greatest temperature rise in the boundary layer is found. It was found that approximate calculations(using the flow rate required to fill a 300 cc sample bottle) showed about one third of the displacement thickness was removed. This means that such sampling rates disturb the boundary layer somewhat (and hence the flow field adjacent to the port as well). It was felt, however, that the effect of such disturbances on the local O/F ratio would not be large. Since the use of the smaller sampling bottles reduce the possibility of obtaining erroneous data in the majority of the tests, 75 cc sample flasks were used.

Comparison of the heat transfer predicted by this program with that measured experimentally at JPL, using the same motor configuration and propellant, is favorable as shown in Figure 8. The predicted values are somewhat higher than the experimental data taken from Reference 1. When the difference in wall temperature between the predicted and experimental cases is considered the discrepancy is about

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*A more extensive description of these programs and their use in these types of problems is presented in Part II.

30%. More recent data, Reference 5, shows the same discrepancy is found in the high heat transfer region near the throat. More detailed predictions are presented in Part II.

The sintered element was analyzed theoretically using the Aerotherm Axisymmetric Transient Conduction computer program, Reference 6, in conjunction with the results obtained with the aforementioned boundary layer program. In performing this analysis it was assumed that the sintered plug was in thermal equilibrium with the gas entering the plug. The validity of this assumption is generally accepted because of the high surface area to volume ratio which is characteristic of sintered materials.

In the computer solution an approximate value of contact resistance of 3.0 (ft^2-sec. °R/Btu) was chosen for the interface between the sintered element and its holder and between the holder and the motor wall. The sampling gas was assumed to be in thermal equilibrium with the front face of the sintered element and solid copper properties were used for the sintered element. Even with such optimistic assumptions, the sintered element was found to have temperatures in excess of the melting temperature of copper in less than one-half second after initiation of sampling (initiation of firing was assumed to have occurred three-quarters of a second earlier). Figure 9 shows the predicted temperature distribution in both the element and its holder.

A solid copper plug with a small hole through the center was an obvious alternative to the sintered element since some means of support for the ball return spring (see Figure 4) had to be provided. Accordingly, this design was analyzed next. The thermal entry length theory of Reference 7 was applied to obtain the flow of thermal energy from the gas to the walls forming the plug passage. The predicted response of the solid drilled plug showed that this design approach would survive the hot environment but other practical problems were encountered. For one, the ball check return spring becomes extremely hot (near the melting point) and means other than the spring held ball for containing the collected sample obviously had to be provided.

The foregoing considerations led to the conclusion that the sintered element could not be used in the original location as shown in Figure 4-a. The findings suggested that it was unlikely that the plug could be designed such that the sampling gases were cooled in passing through the plug to the point that the spring did not lose its temper without the plug itself failing. However, by reducing the flow rate requirements through the use of smaller sampling bottles the likelihood of the ball-return spring melting would be reduced. Aerotherm therefore recommended that the drilled-solid-plug design (in conjunction with smaller sampling bottles) be used. The gas analysis subcontractor indicated that a 75 cc sampling bottle size would be adequate for determination of the sample chemistry and as noted previously, this size was used for the test program.

The design modifications are shown in Figure 4-b (which can be compared to the original design in Figure 4-a). In this design, the plug was brazed into the motor wall to ensure high thermal energy transfer between the plug and the motor wall. Note that by brazing the plug in place one of the "O" ring seals was no longer needed. The other seal, located nearby, was relocated in a cooler region to prevent vulcanization of the "O" ring material. The high wall temperatures predicted for the motor wall in the vicinity of the plug made the survival of such soft materials at that point unlikely. Figure 10 shows the predicted wall temperature distribution at the end of six seconds of firing. For the sampling station farthest downstream (near the throat) temperatures of about 1200°R are predicted near the sampling port. The recommended upper limit for such materials is about 200 degrees less than this.

The sintered element was moved to a point downstream of the JPL control valve where it both controlled the flow and ensured that the sampling gas emerge from the valve at a temperature no higher than the environmental temperature of the motor (300°F). It was believed that such a design would allow the use of a remotely actuated positive shut-off valve with a teflon insert. Because of the environment to which the ball return spring is exposed, it was felt that its performance was marginal to the extent that the use of such a positive shut-off valve was advisable.

The sintered elements were eventually replaced by drilled orifices when bits of metallic contamination in the teflon pintal tip in the Whitey positive shutoff valve were detected and this contamination was traced to the sintered element. These orifices were constructed of copper slugs approximately 3/16" OD and 3/4" long in the center of which a hole 0.0125 inches in diameter was drilled. These slugs were crimped into 1/4" holder tubes that formed part of the sampling system tubing connecting the sample cylinders to the motor block.

2.1.3 Development of the Final Hard Seat Valve System

Following successful completion of the prototype testing and development in which successful operation of the valve was demonstrated, the modified sampling system design as shown in Figure 4-b was constructed. The following subsection describes first the assembly of the modified system--in particular the hard seat valves in the rocket motor--and then the operational experience gained in the use of these valves in the developmental rocket firings. The description of the firings themselves is deferred tp Section 2.4.

The JPL sampling valve components were thoroughly inspected and ultrasonically cleaned, and the six seats were hand lapped according to lapping instructions received from JPL to achieve perfect seating of the sapphire ball on the stainless steel seat. The assembly of the JPL sampling valves proceeded without significant difficulty although assembly was frequently vexing because of the relative inacessibility of sampling system parts located in the combustion chamber. This was particularly true for the number six port (near the nozzle throat).

The O-ring seals between the copper chamber block and the stainless steel valve body block could not be made to seal properly. To solve this problem the depth of the O-ring grooves were decreased by milling the copper motor block.

It was found that the valve-seat-ball cage piece for valve number six was brazed into the chamber at a skewed angle. This caused binding of the ball in the cage and successful operation could not be obtained. To solve this problem the cage tangs were milled off and a new "floating" cage was constructed. This prevented binding and seizing and yielded the most reliable valve of the six. Any future valve construction of this type should incorporate the floating cage concept. The chamber wall was also modified to accept an O-ring along the shank of the ball seat assembly for all six valves.

Six pneumatically actuated valves were connected in series with the JPL valve to give positive shutoff to the sample gases once they were collected in the sample bottles. For each sampling circuit there was a cylinder, cylinder-toggle-valve, positive shutoff valve, pressure transducer connection, and connecting tubing. The sampling cylinder pneumatic shutoff valves were actuated through a common manifold. A description of these pneumatic valves is given in the following subsection. The components and the instrumented chamber, and sampling cylinders were assembled into the case and taken to United Technology Center for set-up on the rocket test stand. A preliminary firing was performed to "shake down" the equipment and the sampling valves were not actuated. In the first developmental firing the sampling valves were actuated in an operational shake-down of the sampling system, however, neither pre-firing pump-down nor case heating was performed. In subsequent firings, conditions representative of the main test sequence were reproduced as vacuum pump down and case heating were performed. The following paragraphs summarize the results of these experiments.

Following the second firing, attempts to obtain shutoff of the hard-seat sampling valves were not successful. Upon disassembly of the sampling valves a large amount of greenish blue powdery residue was found throughout the sampling system and small volcano shaped mounds around several of the sampling ports was observed. The substance was subsequently identified as copper nitrate ($Cu(OH)NO_3$(8)). The presence of this substance was hypothesized to be a result of a surge of N_2O_4 into the sampling system during the start up transient since the JPL valve check balls were held against their seats only by the ball return springs. It was felt that this problem would be eliminated by vacuum pump-down of the sampling system which would hold the ball tightly to the seat prior to firing and by a reduction in the amount of oxidizer lead-in prior to ignition.

This test demonstrated the susceptibility of the hard seat concept to contamination. As noted previously, any minute particles trapped between the stainless steel valve seat and the synthetic sapphire ball will prevent the ball and seat from mating to the tolerances necessary for good sealing. The results of this test showed that the formation of precipitates in the chamber contaminate the valves. The leakage caused by the contamination was so severe the proper valve seating was obtained only after the valves were disassembled, thoroughly cleaned, and the seats relapped.

In the third firing the sampling valves failed to operate (see Section 2.4.

Following the fourth firing the JPL valves again could not be made to seal although actuation could be accomplished. "Post mortum" examination showed high contamination of all valves in the seat region with a powderish blue and black residue which prevented the sapphire balls from seating properly.

In the fourth firing one of the JPL valves had been replaced by the alternate "purge" sampling system design. The purge system operated satisfactorily, and because of the continuing contamination problem with the hard-seat valves, it was decided to convert the apparatus to the purge system completely and firing number four was the last one in which the hard-seat JPL valves were used.

2.1.4 Purge Sampling System Development

After it became apparent that the hard-seat-sapphire ball valve design would cause undue operational expense and uncertainty because of contamination susceptibility, alternate sampling systems were studied. The alternative studies started gradually, beginning as a backup to the hard seat valve to provide redundant shutoff capability in case of failure of the sapphire ball return spring. The discovery of a valve suitable for this application led to a "purge" type sampling system design employing many of these valves. First a prototype system was constructed which replaced one of the hard seat valves and finally the entire sampling system was converted to the purge design as described in the following paragraphs.

2.1.4.1 Backup Valves

Backup valves were mentioned previously as components which were tested in the flow circuit. Because of the operational uncertainties in applying the sophisticated JPL controlled ball check valve to the rocket motor environment, several standard commercial valves were considered for backing up the JPL valve. The following remotely controlled sampling cylinder shutoff valves were evaluated:

1. Hoke-440 series, stainless steel-teflon plug
2. Whitey, stainless steel-teflon plug
3. Skinner-V56 series, stainless steel-teflon plug.

The Hoke valve (HV), which is of the bellows type, is guaranteed to be leak tested to 0.005 MCFH (cubic feet of helium leaked per hour at a helium density produced by one micron of pressure at standard temperature). Such a leakage rate is several orders of magnitude lower than required by this program and this valve was chosen as the standard for valve comparison. The HV is capable of being provided with an air actuator for remote control. Unfortunately, the envelope of the HV air-actuator-valve unit is large in comparison to the space available within the rocket motor case. The Whitey valve (WV) was smaller but had unknown leakage characteristics. The same was true of the Skinner 3-way valve (SV).

As previously indicated, these valves were considered for various alternate sampling systems. Figure 11-a - 11-d show views of these systems. At first the intent of all of these alternate systems was to remove from the JPL valve design the operational requirement of sealing leak-tight for the 1/2 hour or so after a test run when the cylinder is full and the chamber is at atmospheric pressure. The system shown on the right in Figure 11-a was the one used in the previously described developmental firings with the JPL valve.

The three valves were leak tested under static conditions more severe than would be encountered in actual use on the rocket motor. The two soft seat valves showed a significant leakage rate under these conditions. The pressure upstream of the valve was maintained at about the combustion chamber pressure of 150 psi and the downstream side was evacuated to about 0.35 mm of Hg. The results of the test are shown in Table 4.

In the course of determination of the optimum sampling system it was necessary to have a consistent means for evaluating the leakage characteristics of various system components, since this leakage has a direct bearing on the test data accuracy. It was initially believed that the determination of the gas composition in the sample bottles could be performed at an accuracy level of about 2 percent (i.e., the mole fraction determination would have about a 1 percent spread for each specie). It can be shown that the leakage rate of the entire system cannot exceed 100 MCFH (micron-cubic feet per hour) when the sample bottles are in the system (i.e., not shut off from the system by the bottle valve) for 30 minutes if such accuracies are to be achieved.

It is seen that the valves tested easily met this requirement. However, the cylinder shutoff valve must be leak-tight for at least a 24 hour period in which case it is seen that only the needle valve could be used with certainty. However, since it is known that needle valves are subject to galling damage, the sample cylinders were equipped with toggle valves with teflon plug inserts which could be readily closed after a firing.

2.1.4.2 Purge System

The purge system concept for sampling the boundary flow was introduced to overcome certain of the deficiencies inherent in the original sampling concept. One of the design features of the original concept is the small volume between the chamber wall opening and the sample-gas-flow-control-valve seat. Ideally this volume should be vanishingly small to avoid collecting nonrepresentative species prior to the sampling event. Because of the proximity of the valve seat to the chamber wall, the use of high temperature and, hence, nonsoft material was mandatory.

Another way of avoiding collecting nonrepresentative gases is to continuously purge the sampling system with an inert gas up to the instant of sampling. This approach has been used successfully at Aerotherm in connection with arc plasma stream sampling. After the hard seat valves continued to demonstrate contamination susceptibility, a pilot purge system was designed, constructed, and successfully tested. A complete purge sampling system was then designed, constructed and successfully operated.

The purge-sampling system is simple in concept. It consists of several remotely actuated valves connected to a manifold which in turn terminates at the chamber wall orifice. One valve connects to an inert gas supply, the other to the sampling flask. Prior to sampling, the sampling system is purged with the inert gas by opening the purge valve. The purge pressure is regulated so that the purge gas flow rate is very low such that the boundary layer flow is not significantly disturbed.

A prototype purge sampling system was created by removing the internal parts of the number four (4) JPL sampling valve and putting the helium purge control valve in parallel with the sample shutoff valve. Both valves were pneumatically controlled and capable of operating while at elevated temperatures. A two stage purge supply control was employed using standard solenoid valves. It was deemed desirable to employ a high pressure, high flow rate initially to prevent a surge of nonrepresentative gases into the sampling system during the ignition transient. (A low flow purge might not have sufficient time to effectively scavenge the nonrepresentative gas species before the sampling event. Such a phenomenon has been encountered in the arc plasma sampling work.)

Following the successful operation of the prototype purge sampling system, the same concept was duplicated for the other sampling locations. The original valve actuator housing block which mounts to the copper chamber was replaced with a similar stainless steel block which was appropriately drilled to serve as a compact manifold to which the pneumatic valves were attached.

A schematic of the purge system is shown in Figure 12. There are 3 fluid circuits and two electrical control circuits to the system. One of the fluid circuits is for the sampling gas itself which goes between the chamber wall orifice and the collecting bottle. The other two fluid circuits are for helium. One helium circuit for the purge gas and the other helium circuit to actuate the pneumatic valves - valve (a) to control the sampling gas flow and valve (b) to control the purge flow into the sampling circuit. The two helium circuits are, in turn, controlled by solenoid valves which themselves are controlled by the automatic sequencer in the firing control center.

It is to be expected that a simple concept such as the purge system should perform without difficulty and this indeed was the case. An initial problem with pneumatic valve hang-up was experienced because of thermal stress induced binding. This was remedied by the simple expedient of tube bending and by adjusting the housing for the valve actuating diaphrams.

The purge sampling system was designed to provide flexibility in the sampling operation. It is possible to sample each port individually or in any combination, through the use of hand actuated control valves on the sampling and bleed pneumatic actuation circuits shown schematically in Figure 13.

The motor chamber was drilled at five other circumferential and longitudinal positions. Sampling circuits were not constructed for these alternate positions pending the outcome of tests investigating the effect of upstream sampling.

2.1.5 SUMMARY AND CONCLUSIONS

From the operational experience gained with the JPL valve concept under rocket firing conditions, comments on the behavorial characteristics of the valve under such conditions can be made.

The principal judgments that can be rendered on the JPL hard-seat-sapphire-ball valve concept can be summarized as follows: The JPL valve concept can be made to operate in the environment of a rocket combustion chamber but its sensitivity to solid particles in the gaseous environment makes it unsatisfactory for repetitive sampling at short intervals for some propellant combinations.

This comment is supported both by development testing work done with the valve and with the hot firing experience reported above. There are several important conclusions which can be drawn from this. In a sampling system where the environment is so severe that valves which use soft materials are impractical, the disadvantages of contamination susceptibility becomes less important and the sapphire-stainless steel combination may well be the only practical solution. For such a situation the present design should be modified in the following ways:

1. The valve should be designed for rapid assembly and disassembly.
2. The seat should be well exposed to permit rapid lapping and easy visual inspection.
3. The sapphire ball should have positive opening and closing action. (This could possibly be done by fusing the sapphire ball onto the actuating pintal.)
4. The actuating piston and all O-rings should be well removed from severe environment.
5. The seat and ball should be protected as much as possible from contamination.

2.2 HEAT FLUX GAGE DEVELOPMENT

The heat flux gages originally procurred by the Jet Propulsion Laboratory for installation in the motor were damaged beyond repair in the process of installation in the chamber because of the high temperature braze required by the particular design concept employed.

Aerotherm Corporation contracted to make the replacement gages employing a proprietary manufacturing process.* Manufacturing difficulties required by the application constraints resulted in abandonment of this process and the final heat flux gages were made by a conventional furnace brazed technique. In the following paragraphs the development of these replacement heat flux gages are described.

A portion of a gage drawing, presented in Figure 14, shows some of the construction details. Each unit is designed to be replaceable in event of failure as each gage is bolted to the back wall of the chamber and sealing takes place at this cool (relatively) back wall surface.

The basic calorimeter was made from a round copper slug 1/4" in diameter. An insulating air gap .005 inches across was machined into the slug so that the heat flux through the gage would be one-dimensional and the temperature data thereby ammenable to a one-dimensional analysis. A 0.020 inch hole was drilled into this slug to accept the chromel-alumel inconel sheathed thermocouple wire. The juncture of the thermocouple (the bead) was positioned such that after final machining (after installation) of the face, the bead was located .01 inches from the surface.

Aerotherm originally intended to manufacture the heat flux gages by a relatively new electroforming technique. Many gages of this type were made by Aerotherm without the failure rate experienced with the gages made for this project. Three sets of gages were produced which failed either in the final manufacturing process or during calibration testing.

One of the failed gages was sectioned and microscopically examined. This examination disclosed that poor bonding existed between

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*This work was not initiated until the developmental firings were completed so that heat flux data was not obtained until the prime testing phase (see Part III).

the copper body of the gage and the electroformed tip and more importantly between the sheathed wires of the thermocouple and the electroformed copper. The bond between the thermocouple wires and the copper apparently failed as it is weakened under stress induced either by the final machining or brazing operations.

Rather than continue to build strengthened gages of this type and risk building gages having improper response because of poor junctions and discontinuities with the electroformed material, it was decided to sacrifice precision of junction location possible with the electroformed technique in favor of the more positive brazed construction which had been used successfully in the past in rocket motor installations. Accordingly, several prototype brazed gages were successfully built and tested. However, difficulties with the revised manufacturing process were encountered both with regard to the brazing process and with the leadout junction potting compound. However, with perseverence, six gages were produced which survived the calibration testing.*

The set of six gages were calibrated against a slug calorimeter using a hydrogen-oxygen torch heat source. These calibration tests were principally intended to show functionality and demonstrate duplicity of response, gage to gage. They were not intended to provide absolute calibration since neither the boundary conditions nor the driving potential which exist in the motor can be readily duplicated. The gages were then installed in the rocket motor and final machining of the interior surface was accomplished such that the gage surface was continuous with the rocket chamber surface. This was accomplished by casting an impression of the motor combustion chamber and using this impression as a machining template.

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*Two of these failed after installation in the rocket motor--See Part III.

2.3 MISCELLANEOUS DEVELOPMENTS

2.3.1 Assembly of Injector-Instrumented Chamber-Case

Several basic modifications to the equipment were found necessary in order to properly assemble the unit. It was found that the chamber diameter was undersized so that the injector face would not properly mate with the chamber. The case was found to be oversize for the chamber and an adapter ring had to be manufactured to fit between the nozzle and the case. Several other minor case modifications were also found to be necessary to provide instrumentation access and mounting of the position indicating dial.

2.3.2 Thrust Stand Assembly

No outstanding problems were encountered during the installation of the instrumented chamber assembly at the United Technology rocket stand in Sunnyvale, California. The case was bolted to the thrust stand cradle thereby permitting thrust determination. Transducers for monitoring sampling cylinder pressure were installed and a thermocouple was installed downstream of the number six pneumatic shutoff valve for determination of sampling gas temperature at that point. Figures 15 and 16 present two views of the assembled apparatus on the thrust stand.

2.3.3 Instrumentation

Several modifications were made to the temperature instrumentation. It was discovered that an erroneously high temperature signal was being generated by the thermocouple attached to the stainless steel valve body due to a combination of high thermal resistance of the stainless steel, external heating of the thermocouple, and contact resistance between the thermocouple and the valve body.

The situation was rectified by relocating the thermocouple to the bottom portion of the copper chamber which was drilled to receive the thermocouple bead.

A sensor was also placed on the number one pneumatic sample valve body to ensure that valve temperature limits were not exceeded. Another thermocouple was located in the hot gas supply line to monitor the temperature of the incoming gas.

A pressure tap was placed in the spacer shroud downstream of the nozzle exit to measure the static pressure in this region.

2.3.4 Test Stand Improvements

Several modifications were also made to the test stand at the United Technology Center to increase the accuracy with which certain motor performance data were determined. In addition to the increased amount of equipment and instrumentation, refinements in propellant feed control and instrumentation were also carried out by UTC personnel. This refinement involved replacement of regulating valves with valves having smaller capacity and hence better control for the small flow rates required by this program. Pressure gages were also relocated and recalibrated to afford the console operator improved and more direct control over tank pressurization. The flow turbine meters were checked and one was replaced with a newly calibrated unit. The flow meter instrumentation was modified to permit direct readout of the a-c signal. (Previously, a rectified signal was transmitted to the recording oscillograph.)

2.3.5 Motor Heater

Difficulty was experienced in the first series of preliminary tests in obtaining the desired motor-sampling system temperature. To avoid problems with water condensation during sampling, the system is designed to be heated to 300°F which exceeds the saturation temperature of water at the pressures in the sample flasks. Originally the sampling system motor was to be heated by hot gas circulated throughout an enclosing sheet metal case. The use of the pneumatic valves which have soft material in the actuating diaphram and seats (which have an upper service temperature of about 350°F) severely limited the temperatures to which the gas could be heated.

Subsequently, the experimental apparatus was provided with an electrical heating system to assist the hot gas supply in obtaining the desired temperature. A set of resistance heaters was strapped to the motor and provided with a thermal heat path to the chamber by the use of thermal putty.

2.4 PRELIMINARY ROCKET MOTOR FIRINGS

All tests of the research apparatus in which the rocket motor was operated were conducted under subcontract at the Sunnyvale test site of the United Technology Corporation. This facility is of the pressurized tank propellant delivery type with all operations controlled by an automatic sequencer capable of being programmed in a flexible and convenient fashion. There were a total of sixteen firings conducted in the development period of the program. The first was utilized for a shake-down of the test facility and to uncover any operational difficulties with the motor itself. The next eight firings were used in both development of the sampling system and to acquire preliminary sample data. The remaining seven firings were used by the testing subcontractor to tune the pressurization/flow control system so that a more accurate and repeatable mixture ratio could be obtained. The following is a chronological description of the developmental firings.

The initial testing of the research apparatus (which utilized the hard seat valves) was very successful in terms of mechanical operation. The firings went smoothly as no hard start or combustion chamber instabilities were detected.

2.4.1 Sequence of Events With Sampling

The sequence of events used in the first three sampling runs is shown in Table 5. The detailed items for firing the motor are not presented since these are standard operating procedures.

The test was begun by heating the motor block and sampling system to 300°F and then pumping down the unit to near vacuum to remove all foreign gases and condensed liquids. A standard roughing pump was used for the latter operation. Following the set up of the propellant feed system the motor firing was initiated (time 0). At 1 (one) second following firing initiation, the ballistic analyzer (digital integrator) for P_c and thrust was gated on and at 3 seconds it was gated off. The sampling valves were activated open at 1.5 seconds and activated closed at 2.5 seconds. The JPL and pneumatic valves were activated simultaneously. The firing was terminated at 4 seconds.

The more complicated procedure followed for the firings using the purge sampling system is presented in Appendix B.* The procedure, which is largely self explanatory, is divided into three phases: 1) pre-firing, 2) firing and 3) post-firing, each of which prescribes the special functions which need to be performed in addition to the details normally associated with firing a liquid rocket motor.

2.4.2 Firing Two

It was the principal objective of this test to demonstrate the successful operation of the sampling system under the severe conditions imposed by the rocket motor. Neither vacuum pump-down of the sampling system nor heating of the unit was attempted as this would have increased the severity of conditions--which was deemed unwise for the first attempt. The sampling bottles were filled with gaseous N_2 at atmospheric pressure.

Successful demonstration of valve mechanical operation in the rocket motor environment was achieved in this test. Gas samples were collected in all six bottles.

The firing again was smooth, although proper motor mixture was not achieved. Subatmospheric pressure at the nozzle exit was again determined precluding an instrumentation fault. It was decided that the spacer shroud, aft of the nozzle had a sufficient length to diameter ratio to cause ejector pump-down phenomena and the shroud was ventilated to remedy the situation.

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*This procedure was used for all firings of the prime testing portion of the contract.

2.4.3 Firing Three

Following the first two relatively successful firings in which the principal objectives were attained, on the third firing it was decided to attempt sampling under conditions as severe as would be encountered in the prime test program. The accomplishment of this objective was thwarted by an unexplained failure of the sampling valves to actuate. Only one gas sample was obtained and that one because the number four valve failed to fully close after the pump down sequence.

The firing itself went well but again subsequent data analysis indicated that the desired motor conditions were not obtained.

Two of the most likely causes for the sampling valves to not actuate appeared to be: 1) actuating piston seizure, and 2) loss of actuating signal. Post firing analysis of the valves indicated no mechanical failures in the valves and successful operation was obtained in a heated oven. Post firing check of the electronic equipment such as the automatic sequencer and solenoid valves indicated that no circuit discontinuities existed. Other less likely possible causes were examined such as lack of sufficient actuation pressure but none proved to be at fault.

The fact that the sampling valves were successfully actuated a short time before the firing during the vacuum pump-down and the fact that this actuation was accomplished while the system was hot, tends to indicate that a temporary loss of actuation signal did occur.

The vacuum pump down procedure and the reduction in oxidizer lead-in time apparently eliminated the massive contamination observed after the second firing. Only trace amounts of the greenish-blue deposits were found and instead the commonly observed black precipitate, copper oxide, was observed.

2.4.4 Firing Four

The principal goals of this test were: 1) obtain samples under conditions representative of those for the prime test program, and 2) demonstrate the purge system of sampling. Both of these goals were successfully realized.

In the previous test (Firing 3) the JPL sampling valves failed to actuate. In this test all systems performed their mechanical function and samples were obtained from all six sampling ports. In this test certain precautions were taken to attempt to eliminate the CO_2 contamination detected in previous tests (see Section 3.0). Sampling cylinders were helium leak-checked and thoroughly rinsed and oven baked.

Several deficiencies were noted during the conduct of the test. First, the temperature sensor on the valve body indicated a surprisingly rapid tempeature rise. Faulty sensor mounting was suspected and subsequently confirmed as noted previously. Mixture ratio problems continue to plague the operation of the test. Post test data reduction indicated CO_2 contamination problems persisted.

2.4.5 Firing Five

Following the successful operation of the prototype purge sampling system, a conversion of the equipment was made to permit this method of sampling at all port locations. This firing had as its principal goal, the checkout of the purge system under normal operating conditions. Test stand improvements were made in addition. These consisted of propellant pressurization instrumentation and valve changes, the relocation of the body temperature indicating thermocouple to the bottom of the motor, and the addition of a liquid nitrogen cold trap on the motor pump down circuit to prevent backflowing of pump oil into the chamber.

The firing proceeded normally and successful operation of the sampling system was accomplished. However, several new difficulties were encountered, the most serious of which was the loss of helium pressurization due to excessive consumption of helium during the pre-fire purge operation. It was fortuitous that valve actuation was obtained since post firing examination disclosed that insufficient actuation pressure existed in the helium supply bottle. Because of the lack of sufficient helium pressure some doubt must be cast on the validity of the data since proper purge operation seems doubtful.

An additional problem was that the body temperature could not be brought to the desired temperature even when the case was wrapped with insulation.

2.4.6 Firing Six

This firing and the three subsequent firings were originally intended to display the repeatability of the sampling system and to gain confidence with the technique. This goal was defeated by the continuing mixture ratio problem and more importantly by the gas analysis problem described in the following section.

Prior to firing six, the equipment had been modified with the installation of electrical strip heaters. The excessive helium utilization was eliminated by modifying the duty cycle and restricting the flow for all but the impulse period. All "O-rings" in the entire apparatus (including the 18 pneumatic valves) were replaced with ethylene propylene in an effort to combat the CO_2 problem. The entire system (sampling purge and motor) was passivated with a nitric acid solution and helium leak-checked. Instrumentation was modified to:
1) permit display of flow turbine a-c signal instead of the amplified d-c signal used previously; 2) record additional temperatures.

This firing was successful in all aspects except for the mixture ratio problem which for this particular test was 10 percent from the desired value. This problem seemed to be a consequence of equipment tolerances, and/or operator interaction. Plans were made to combat this problem by conducting tests without sampling and to make additional system changes.

2.4.7 Firing Seven

Firing seven caused the most concern in the test series in that the automatic sequencer failed after having opened the sampling control valves. The firing proceeded for about 10 seconds before it was realized that something was wrong and the manual shutdown control could be actuated. Samples were obtained but some doubt as to their validity must be cast since some portions of the sample were collected with an unchoked sampling flow control orifice (that is, sample flask pressure approached chamber pressure).

It was discovered that the power supply to the sequencer was malfunctioning. It is possible, but not clearly so, that such malfunction occurred during firing three, in which test, valve opening did not occur.

No structural damage to the motor could be ascertained and measurements of the throat were within drawing tolerances. It would seem from this that the current firing time of 4 seconds is quite conservative.

2.4.8 Firings Eight and Nine

In the last two developmental firings all systems worked satisfactorily save for the control on mixture ratio which produced an O/F about 5 percent low.

2.4.9 Mixture Ratio Check-out Firings

The problem of obtaining the desired motor propellant mixture ratio plagued the experimental program from its initiation. To rectify this situation a series of additional firings of the motor were conducted by the subcontractor once the propellant system modifications mentioned previously were completed. These firings were performed without heating the unit, or collecting samples.

These tests successfully demonstrated that repeatable operating conditions can be realized. Desired mixture ratio values were obtained as well as a range of preselected mixture ratio values. The tolerances were within one percent as shown in Table 6.

SECTION 3

SAMPLE CHEMICAL ANALYSIS

In this section the techniques devised for the chemical analysis of the samples collected from the experimental apparatus are described. Initially it had been naively presumed that the chemical determination would be routinely simple since only common gases were expected. The most difficult specie was thought to be water but it had also been expected that this compound could be redundantly determined either theoretically or thermodynamically by the mixture pressure-temperature characteristics at the saturation point. Preliminary results quickly dashed this optimism and the sample chemical analysis unexpectedly became the dominant problem area of the project. To summarize--the evidence of this problem area was: first, data repeatability for the same sample could not be obtained; second, the data departed significantly from theory; third, substantial amounts of ammonia (an unexpected specie) were found which due to solubility in water precluded the use of techniques initially presumed to be applicable.

The unfolding of this problem area, the solution to it and detailed discussion of the techniques used are described in the following paragraphs. This activity progressed in parallel with the development of sampling system--rocket apparatus during the firings at UTC.

As the solution to the problem progressed more and more rocket sample data became available. The following discussion is not necessarily in chronological order as most of the various attempts to solve the problem proceeded concurrently.

Two methods are currently favored in the industry for determining gas composition. These two are mass spectroscopy (MS) and gas chromatography (GS). The two methods apply entirely different principles to detect and quatify the gas specie present in the sample being analyzed. In the mass spectrograph the specie molecules are ionized and accelerated in a magnetic field, and separation is based on charge to mass ratios of these ionized molecules. In the gas chromatograph the separation is affected by preferential adsorption and liquid film partitioning of the species by a variety of media. Various detectors are used for identifying and quantifying the separated species but that most commonly used is the thermal conductivity detector.

Each method has its advantages and disadvantages. The MS is the most direct and least expensive method and was favored initially for these reasons and initial sample analysis was conducted on mass spectrometer equipment. As the following paragraphs make clear, the results from these initial samples showed the mass spectrometer to have some significant shortcomings.

3.1 INITIAL MASS SPECTROGRAPHIC DATA COMPARISON

Table 7 presents a summary of the data from the gas analysis performed on bottle number 6 from firing -2, (run-1) and bottle number 4 from firing -3 (run-2). The data was obtained from two different mass spectrometers--each a different type and at a different location. The two sets of data appear to be not only dissimilar but to be completely uncorrelated. However, in the first run (firing -2, run-1) a general pattern is discernable in both analysis--high N_2, some hydrogen, and traces of other gases. In the second run some of the discrepancy is apparently due to a difference in experimental technique. For this test the gas samples were collected in small stainless steel tubes instead of the 300 cc bottles used in the first run. This change in size was made to determine proper sampling cylinder size. The entire contents of the small tube were introduced into the MS at low pressure in the SRI test so that any liquid water was vaporized. This could possibly explain why a much greater percentage of H_2O appears in column 3 of the table.

There also appears to be some correlation with time. In the run 1, test (a) was conducted before (b) whereas for run 2, test (b) was conducted before (a). If one conjectures that a microscopic leak existed in this bottle, then, because of preferential leakage of the hydrogen, the disparity in ratios of hydrogen to nitrogen, for example, would be explained. To insure that such leaks did not occur again, all sample bottles, with valves attached, were helium leak-checked.

It has been pointed out in previous sections that the appearance of CO_2 gas species in the sample was not an expected result. The quantities of CO_2 that were detected are relatively small--on the order of a percent or less. Nonetheless its presence in the analysis caused increased lack of confidence in the results.

It was imperative that these difficulties be resolved and a choice of gas analysis method be made before the prime testing was initiated so that valid O/F data could be generated in the program. The resolution was attempted by:

1. Reviewing the experimental technique used by the mass spectroscopist.
2. Conducting comparative tests with mass spectrometers and duplicate tests with gas chromatographic equipment.
3. Conducting an intensive research and contracting testing organizations and research groups, etc.
4. Obtaining laboratory standard gas mixtures for reference.
5. Conducting experiments designed to uncover the source, if any, of the CO_2 contamination.

3.2 OUTSIDE RESEARCH

Considerable effort was made in the search for qualified laboratories to perform analysis employing techniques suitable for the problem at hand. Firms were also sought for supplying precision gas mixtures having about the same composition as that obtained on an average from our tests which gas mixture could be used for a calibration standard.

Most firms and research centers declined to attempt the analysis, or to supply such a gas standard. One firm claimed it could be done with a combination of gas chromatography, titration, and thermal-diffusion separation. The cost was prohibitive and the firm had never done this type of test before. Several research organizations such as SRI suggested a form of wet chemistry approach which was, admittedly, limited in accuracy by the small sample size involved. Such a technique was attempted by the JPL Laboratory and a discussion of this experiment follows.

Several gas chromatography and mass spectroscopy equipment manufacturers were contacted also without success. Knowledgeable individuals at the Universities of Stanford, Santa Clara and California at Berkely were contacted and although interesting discussions ensued, nothing of tangible value to the problem at hand was forthcoming.

3.3 TEST RESULTS FROM WET CHEMISTRY

Chemical analyses or tests were performed by JPL personnel on two of the sample flasks obtained during the preliminary firings. In this analysis a technique was employed which combined both the mass spectrometer and wet chemistry. In this subsection a description of these tests, the test results, and a comparison of the results with other data will be presented.

One possible way of avoiding the apparent problem of determining the amount of water in the sample with a mass spectrometer is to separate the water from the sample and then determine the water concentration through gravimetric techniques. This is basically the procedure followed at the Jet Propulsion Laboratory in the analysis of the flask (7-1) which had previously been analyzed repeatedly on another mass spectrometer. The gases from the flask, which was heated to put all compounds present (NH_3, H_2O in particular) in a vapor phase, were passed through a liquid nitrogen trap in which the ammonia and water were captured. The gases passing through the trap were then analyzed on the mass spectrometer and the composition determined. Next the trap was heated to the vaporization temperature of ammonia and the evolved gases (largely NH_3) were next analyzed on the mass spectrometer following a determination of their volume. Finally, the residue was weighed and titrated to determine the mass of water and ammonia. The original volume of sample (at a given pressure and temperature) was also determined. These data allow a determination of the original sample using standard chemistry relations including the thermodynamic properties of aqueous ammonia solutions. The data reduction was performed by Aerotherm and the procedure followed to reduce the data is presented in Appendix C.

A summary of the resultant JPL data in terms of relative concentration of the various species is shown in the leftmost column of Table 8. Table 8 compares this JPL data with the concentration data from the same flask as obtained from a mass spectrometer (of different manufacture than the JPL unit) where no separation of the water and ammonia was attempted. While there was no water and ammonia separation in these latter tests, the flask was heated to vaporize the condensibles. The second and third columns from the left in Table 8 give this unseparated data. Run "b" is a repeat of "a" performed at a later period of time. Ideally these three leftmost columns should agree precisely.

There is considerable variation between the "a" and "b" runs in themselves--the principle variation is found in the nitrogen and ammonia values. No explanation for this variation is obvious at this time except for "inlet phenomena" which could, presumably, be a non-repeatable event. The "a" and "b" data bear little resemblance to the JPL data. The fact that all the noble gases are greatly reduced suggests a leak may possibly have existed in the flask valve. However, this does not explain the difference in the water-to-ammonia ratio between the two. The leakage possibility is also somewhat discounted by the results from the cold tests (column "c"), and the JPL non-condensible analysis, the rightmost column. Presumably these two columns should also agree since column "c" data was obtained from flask 7-1 at, or near, liquid nitrogen temperature.* An examination of the nitrogen mole fraction data from these two runs tends to indicate that little or no nitrogen had escaped.

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*The WCT non-condensible data does not agree with the JPL non-condensible data possibly because of the particular cooling technique used at WCT (there exists some question as to how cold the valve end of the flask was at the time of sampling in the WCT test). This is evidenced by the appearance of H_2O in the WCT results which should not occur, of course, had 1) the sample been properly cooled, or possibly, 2) had all the residual water in the M.S. inlet system been removed.

3.4 GAS CHROMATOGRAPHY ANALYSIS

In the search for qualified laboratories contact was made with the Dye-Oxygen Co., a supplier of precision gas mixtures, which, by reason of extensive experience with gas mixtures such as those in this study, seemed qualified both to attempt analysis of the rocket motor samples and to supply the desired laboratory sample standard. This laboratory was supplied with two of the sample flasks from the preliminary rocket firings. The intent was to obtain agreement between the Dye-Oxygen laboratory technique, which employs a research grade gas chromatograph with proprietary columns, and the Jet Propulsion Laboratory mass spectrometric-wet chemistry analysis technique--reported previously.

This effort was frustrated by the inability to resolve a significant and ill-defined peak with large tail-off found during the eluding process. This peak was initially identified by Dye-Oxygen personnel as NO_2 based upon the point in time in which it eluded from the gas chromatograph column(9). Such a finding was in complete contradiction to all previous mass spectrometric analyses in which only trace quantities of NO_2 were detected and even these were suspected to be a consequence of the curve fitting procedures employed. It was also contrary to the observation that when the sample flasks are exhausted into the glass inlet system of the mass spectrometer a brownish colored gas (characteristic of NO_2) is not observed. To further study this curious development, the substance producing the mysterious peak was trapped and analyzed further. The compound was subsequently identified as being principally nitric acid, HNO_3, which exhibits the same elution times as NO_2. This was confirmed by injecting dilute nitric acid solutions into the gas chromatograph.

The determination of nitric acid came as much of a surprise as NO_2 since there has been no indication of nitric acid in the mass spectrometer results that had been obtained even though the possibility had been considered. Reaction of a trapped portion of the peak with sodium bicarbonate produced only a trace amount of carbon dioxide proving that only a small portion of the peak was due to nitric acid. Infrared spectroscopic analysis of the peak compound by Dye-Oxygen personnel was largely inconclusive because the water molecules present made interpretation difficult. An educated guess by the laboratory personnel(9) based on the evidence at hand, is that the peak was caused by a mixture of gases, predominantly hydrazine, with trace amounts of H_2O, NO_2, and nitric acid, HNO_3. If it is presumed that the peak is largely hydrazine, then the approximate analysis of bottle 8-4, shown in Table 9, is obtained.

Such a large percentage (50%) of hydrazine is unexpected. Although no reason can be found at this time that makes such a composition impossible, it is highly unlikely. If unreacted hydrazine is streaming down the rocket motor chamber walls and if the walls are cooler than supposed, then it can be argued that the hydrazine does not decompose and large proportions of hydrazine could possible be drawn off in the sampling process.

This analysis does have a favorable characteristic. The hydrogen-to-nitrogen atomic ratio is reasonable; that is, the ratio of the summation of hydrogen atoms to summation of nitrogen atoms in the various species is less than the two-to-one ratio found for fuel alone ($\Sigma H/\Sigma N < 2$). Presumably, with some oxidizer reactions taking place as evidenced by the appearance of nitric oxides, there should be less than twice as much hydrogen as nitrogen unless some quite unusual diffusion or recirculation-condensation phenomenon is occurring. Table 10 gives a sampling of the ratios that are obtained from the preliminary analyses. In this table the first column gives the source of the composition data (from three of the five organizations that have attempted this analysis). The second column gives the sample number --a two-digit number, the first of which specifies the run, the second the position in the motor starting from the injector end. The third column gives the ratio of hydrogen-to-nitrogen atomic summations and the fourth, that for oxygen and nitrogen. The last column is the sum of the preceding two columns entries which theoretically should be equal to 2.0. The degree to which this entry departs from 2.0 can possibly be interpreted as a measure of the inaccuracy of the analysis. The reason for this is based on a simple balance with the presumption of equal diffusion of all species everywhere in the combustion chamber and during sampling. Thus we have that the number of nitrogen atoms, N, can be thought as being the sum of two groups--those associated with the fuel N(H) and those with the oxidizer N(O).

Thus we may write:

$$N = N(H) + N(O) \qquad 3\text{-}1$$

For either N(H) or N(O) there is twice as much fuel and oxidizer, respectively, such that N(H) and N(O) can be replaced by:

$$N = \frac{H}{2} + \frac{O}{2} \qquad 3\text{-}2$$

where H and O are the summation of fuel and oxidizer atoms, respectively. Dividing by N and showing the summation explicitly results in:

$$\frac{\Sigma H}{\Sigma N} + \frac{\Sigma O}{\Sigma N} = 2 \qquad 3\text{-}3$$

It is apparent that although the hydrogen-to-nitrogen ratio for the gas chromatography analysis appears to be reasonable (row number one of Table 2), there remains some question about the analysis since the 'SUM' entry does not equal 2. Admittedly there exists the possibility that the assumptions necessary to deduce this factor of two is not justified--on the other hand, the WCT mass spectrometric analysis of bottle 7-1 (row number 3) is substantially in better agreement with the hypothesis. The JPL mass spectrometric-wet chemistry analysis is obviously in complete disagreement with the hypothesis and the foregoing data. The remaining two entries were chosen to show that the variance in the results from the bulk of the analyses on the mass spectrometer is such that both extremes (2<SUM<2) are supported. Two conclusions were drawn from the foregoing observations. These are:

(1) Some physical process occurs in the analysis process which produces erroneous results. Here the analysis process is meant to include the technique whereby samples are brought into the equipment.

(2) The physical process involves the hydrazine-ammonia decomposition phenomenon, complicated by the presence of water and the oxides of nitrogen.

The data of Table 10 suggest (but it cannot yet be concluded) that the supposition is not quite right which postulates that the ill-defined peak in the GLC analysis is mostly hydrazine. If, for instance, it is assumed that the peak is due to a mixture of half water, half hydrazine, then the summation of the ratios does equal 2. Of course, this presumes the instrument's sensitivity remains unchanged for this mixture compared to pure hydrazine.

Because of these difficulties and uncertainties the comparison of results from the same bottle between D/O and JPL was not completed as intended especially since, as is apparent in Table 10, there appeared to be little hope that agreement could be obtained.

3.5 COMPARISON OF MASS SPECTROMETER DATA

While these comparative and exploratory chemical analyses were being conducted, the bulk of the data continued to be analyzed at West Coast Technical using the mass spectrometer alone and performing the analysis as carefully as possible using conventional procedures for introduction of the samples into the MS. This work continued because in the opinion of the Aerotherm staff the MS offered the best hope of problem resolution because of the inherent simplicity of both the technique and physics involved. The results presented in Section 5 include this data. Furthermore the results from this laboratory's MS seemed more credible than the data obtained elsewhere. [In the following paragraphs a detailed examination of this data (the majority of which is taken from Section 5) will be presented.] The results of this study led to a modification of the sample preparation procedure (described in the next subsection) which led (apparently) to a successful resolution of the problem.

All the samples taken from the preliminary firings were for one position of the injector relative to the chamber. Except for variations in mixture ratio from run to run the same composition should be found in the same bottle position run to run and moreover a reasonable trend should be apparent bottle to bottle for a given run.

A comparison by run for a given sampling station (bottle number) is presented in Tables 11-a through 11-f. Much of the contents of Table 11-a for station 1 have already been discussed. The additional data shows the large variation in composition noted previously. This randomness is generally found for all the stations although there seems to be some improvement in consistency towards the latter runs and for stations nearer the throat. In fact there is good repeatability between runs 7 and 8 for the last (6) station in Table 11-f.

Several qualitative trends were noted in the mass spectrometer data. First the data appeared to be "better" when the ammonia concentration was lower and this situation tended to occur for stations nearer the throat. Second--it was noted that the data appeared to be "better" when there was agreement between the sum of the specie partial pressures and the measured inlet pressure on the mass spectrometer. These two factors contributed to the evidence suggesting that an inlet phenomenon was involved in causing the difficulty. Accordingly, considerable effort was expended to improve the method by which samples were introduced to the spectrometer. The next subsection discusses these activities.

3.6 STANDARD SAMPLE PREPARATION DESIGN CONCEPTS

A principle limiting factor in the acquisition of meaningful gas analysis data seemed to be the manner in which the sample was brought into the mass spectrometer used for determining gas composition. Water and ammonia are particularly difficult substances to analyze in this regard because of their polar properties which cause them to easily adsorb. These and other problem areas which were considered in the preparation of gas samples will be discussed in the following paragraphs.

Originally it was thought that the samples obtained in the rocket firings could be analyzed directly from the flasks into which the samples were collected during the firing. Since the samples were at relatively high pressure, samples were taken into the analyzing equipment by slightly "cracking" the valve on the flask. In effect, the sample gases were throttled in the valve to the desired pressure which in the case of mass spectroscopy, was typically 30mm of mercury pressure--a near vacuum. Typically, the inlet system on the mass spectrometers have been at room temperature at this low pressure. These two conditions lead to the possible--although as yet unsubstantiated--existence of the following problems.

1. Mass fractionation of the heavy molecules in the throttling process
2. Adsorption of water and ammonia on the cool inlet system.

An article was obtained which contains confirmation of these adhesion problems with mass spectroscopy.(10) The article also confirms opinions expressed in other quarters concerning the "memory" phenomenon wherein (it can be conjectured) the background correction to the peak data does not properly measure the true number of residual molecules adhering to the inlet system which are susceptible to "liberation" by an incoming sample. Thus, for example, nitric acid may be trapped in the inlet system and not detected while certain other molecules are simultaneously overdetected. For such polar compounds a mass spectrometer with a conventional inlet system can require literally hours of "pre-conditioning" with representative mixtures before good quantitative data can be obtained. It was obvious that to get away from the first of these problem areas a nonflowing sampling system would be desirable and for such a system, isothermal conditions are desirable to prevent thermal diffusion from causing concentration gradients. The second problem area could possibly be reduced by operating the inlet system at high temperature and at the samllest possible volume. Various experts in the field of gas analysis also pointed out the desirability of analyzing the entire sample i.e., introducing the entire sample into the analysis equipment.

A number of techniques were considered for introducing and preparing samples which could overcome these difficulties. There is little point in dwelling on systems which, although considered at some length, were discarded in favor of an obviously superior technique so that the former will be mentioned only in passing. The methods considered but discarded include:

1. Direct Sampling Analysis - where either a gas chromatograph or a mass spectrometer is connected directly to the rocket motor
2. Heated Sample-Injection - which is basically an elaborate form of hypodermic syringe and which could be used with or without the septum method of injection commonly used on gas chromatography analysis (with this method a known volume of gas at a known temperature can be directly injected into the analyzing equipment.)

These techniques were discarded in favor of a more simple technique. This method has been labeled the Micro-tube sampling system. The principle involved is that a sample is introduced into a metal tube having a very small bore under controlled conditions and the sample is then sealed off by crimping the tube. The tube is reopened at the analyzing equipment and the entire contents of the tube is taken into the equipment. The tubes are nickel alloy with a 3 mil wall thickness and an outside diameter of 0.064 inches.

Experiments were conducted on sealing such tubes once they are filled with the sample gases. These experiments were performed on the above tube size as well as on 0.125 inch O.D. tubing with a 0.02 inch wall. It was possible to obtain helium leak-tight seals (by crimping) using moderate pressures and with a commerically available crimping tool. The leak rates obtained were as low as 10^{-8} atm-cc/sec.

Two techniques for opening the sealed tubes were investigated. These two techniques were 1) opening the tube by slicing one end open or completely off, and 2) opening one of the sealed ends by crushing the seal perpendicular to the crimp line. This has been found to open the seal provided no strong mechanical welding had taken place. A prototype guillotine assembly demonstrated that successful tube opening could be accomplished but some sealing of the cut-off end during the guillotining process was noticed.

On the basis of these results the de-crimping method for opening the tubes was selected and a device employing this principle was constructed.

Figures 17 and 18 shows the completed de-crimper assembly. Constructed entirely of stainless steel and glass (save for the operating handle), the unit features all welded construction. The microtube containing the sample to be analyzed on the left of Figure 18 is inserted in the tube (the end pointing away from the unit is inserted first) and the fittings tightened to effect a vacuum-tight seal. On the right is the thermal expansion bellows and glass connecting tubing which attaches to the leak chamber on the mass spectrometer. A plunger within the housing, connected to an actuating knob by a leak-tight bellows, first contacts the crimp, normal to the crimp line, and then opens the crimp as the motion continues. The de-crimper assembly was mounted inside of a temperature controlled box so that it could be be heated to the same temperature as the mass spectrometer (about 200°C).

The principal problem associated with the microtube approach was to assure that the tubes are filled with a representative sample from the supply whether the supply be a gas bottle of known composition (a sample standard) or a flask from the rocket motor containing unknown gases. Several problem areas which required attention were 1) mass fractionation of the lighter species during the filling procedure, 2) thermal diffusion caused composition gradients, 3) adsorption of polar molecules on the walls of the filling system. The last two of these problem areas was adequately eliminated by filling the microtube in an isothermal environment at elevated temperature. The first problem area was thwarted by avoiding a flowing system as much as possible. This was accomplished by allowing the microtubes to come into equilibrium with the sample source. This also means, of course, that the pressure in the tubes is equal to that of the source. In the case of direct injection into a mass spectrometer it was initially thought that such a pressure level would, in general, be too high. To reduce the pressure in the microtubes to the desired level, a system of ballast flasks was constructed into which the microtubes could be exhausted and with which the microtubes could be brought into equilibrium at the reduced pressure.

The microtube filling apparatus is shown in Figure 19. The essential features of this apparatus are a sample source, microtube, ballast flask array with connecting manifolds, and shutoff valves, pressure gage, vacuum pump lead and connecting tubing. The whole assembly is contained in an oven capable of heating the apparatus to 300°F. Samples are drawn into the apparatus from the rocket motor sample flasks in the foreground of the picture (the horizontal bottle lying on the shelf). The microtube is located directly above this bottle and microtube samples are obtained from this length of tubing. In the background are the ballast flasks with which the pressure in the microtube can be reduced below that existing in the sample flask. The desired pressure in the microtube is about 1/2 atmosphere. The tubing and valve at the left (leading out of the cabinet) go to the sample standard cylinder. The valve and tubing on the right (leading out of the cabinet) go to a vacuum pump with which the entire system is evacuated before processing begins.

Because of difficulties in obtaining Helium leak-tight fittings with stainless steel, almost all fittings on the apparatus were welded with the exception of sample flask and microtube attachment points. Certain sections of the apparatus were constructed of 1/8" tubing and fittings (near the pressure gage and microtube attachment) to keep the charging volume as low as possible. It was thought that leak-tight fitting joints could be obtained but because of the close coupling involved, final Helium weep leaks had to be silver-soldered shut.

The filling procedure was as follows:

1. Heat apparatus to 150°C.
2. Open all ballast flask valves
3. Pump apparatus to vacuum and close vacuum and ballast flask valves
4. Open sample flask valve and equilibrate with microtube
5. Close sample valve and open desired ballast flask valves and again equilibrate
6. Crimp microtubes and remove

Figures 20 and 21 show two views of a typical microtube. One is a view of a crimped tube as it appears following the crimping operation in the oven-preparation apparatus and the other, the opened crimped seal created by the de-crimper.

Three exploratory sampling tests were conducted with the microtubes. Two of these tests were conducted to demonstrate that the microtubes provided a means whereby a molecule such as NH_3 could be reduced to N_2 and H_2. These tests were only partially successful. The remaining test was performed to demonstrate that a microtube sample at or near atmospheric pressure could be analyzed directly in the mass spectrometer. This was a highly desirable feature since considerable difficulty was experienced with contamination of the samples due to leaks through the manifold valves in the ballasting system. This test was quite successful.

Table 12 presents the results from these tests. Samples 1 and 2 show significant contamination since they were taken from a cylinder of pure ammonia. The presence of water indicates a simple air leak did not exist and the most probable source of this contamination is the spectrometer itself. These two samples were at low pressure and the results indicate that the relatively few molecules of sample present cleaned the machine and the true sample was lost in the resultant "noise." It is significant to note the tenfold decrease in ammonia between samples 1 and 2. These two samples were taken simultaneously and sample 2 was subsequently heated above 1000°F. It is interesting to note and also unexplicable that there was no concurrent increase in hydrogen with the ammonia decrease as would be expected. A minor increase in nitrogen is observed, however.

Sample 3 was obtained from sample flask 7-2 at a pressure of about 18 psia (at 300°F). There are two reasons for high pressure microtube samples to be superior to the low pressure samples. The risk of contaminating the sample in the valving and dumping operation is eliminated and, secondly, the amount of sample is greatly increased so that the signal-to-noise ratio in the spectrometer is improved. This should eliminate the type of erroneous spectrometer response believed to have occurred in samples one and two.

The comparison between 3 and 7-2 was encouraging. For most of the specie the agreement is good--hydrogen, ammonia and helium in particular. In the case of water and nitrogen, the agreement is not so good, but, interestingly enough, the values of sample 3 are more reasonable than those from 7-2. They produce a hydrogen-to-nitrogen ratio less than 2.0 as it is expected to be. The microtube technique seemed to offer a means for delivering samples to mass spectrometer in a more positive, precise fashion than was the case with the large sample flask where it was difficult to maintain the cylinder at the desired environmental conditions. Therefore the microtube technique was used on the prime testing portion of the program in the expectation that it would effect an increase in the quality of the data.

3.7 CO_2 ANALYSIS

Several tests were conducted to attempt a verification of the CO_2 concentration and also to attempt to pinpoint the source of the CO_2 contamination which was detected in the preliminary tests.

3.7.1 CO_2 Verification Tests

Two CO_2 verification tests were attempted. One was conducted by a Varian-Aerograph representative on several of their gas chromatographs without producing definitive results. The other was conducted by Liquid Carbonic on a cold sample. The results of the latter test confirmed the presence of CO_2. The same sample was then sent to WCT. The results are shown in Table 13.

A sample of the N_2 pressurization gas used at UTC for propellant pressurization was sent to Liquid Carbonic for analysis and this analysis showed that CO_2 was not present even in trace amounts.

3.7.2 Fuel Tests

A sample of the fuel used at UTC for this program was sent to Lockheed Research Laboratories in Palo Alto for analysis. The sample was neutralized with a 50% normal solution of sulfuric acid in a nitrogen atmosphere. The gases evolved from this boiling procedure were dryed and passed through an ascarate tube for CO_2 removal. The results of this analysis showed that the fuel contains only about 0.1% dissolved CO_2.

3.7.3 "O"-Ring Tests

Because all system components, which could possibly contribute to the CO_2 contamination were examined and eliminated save for the

O-rings--it was decided to conduct qualitative tests on the O-ring material alone. Flasks containing water and oxidizer mixtures (to form nitric acid) were made up, into which a piece of O-ring material (Viton-A) was placed. Flasks were sent to Liquid Carbonic and to WCT. The results obtained are shown in Table 14.

It was subsequently learned that Viton is not a recommended material for use in systems exposed to nitric acid. An alternative material, ethylene propylene was substituted for the Viton-A and the test repeated at WCT. The results are shown in Table 15.

As a result of the favorable reduction in CO_2 noted in Table 15 the Viton-A O-rings in the apparatus were replaced with ethylene propylene O-rings.

SECTION 4

RESULTS FROM DEVELOPMENTAL TESTS OF THE MOTOR-SAMPLING SYSTEM

The data obtained from the developmental firings has been reduced through the use of an Aerotherm developed computer code (described in Section 5.

The computer reduced data from the developmental firings is presented in Appendix F. There are four pages of data per firing. The first page of the four presents the local O/F determined from the gas analysis and reduced engine and system data. The second page presents the mole fractions of gas species present in each sampling bottle. The next page presents the oscillograph data from which the performance parameters on the first page were obtained and also the principal data reduction constants and coefficients which may change from test to test. The fourth page is reserved for comments about the firing and data reduction.

4.1 FIRING DATA REDUCTION

The run-0 data set presents the data obtained from the checkout firing. The comment page and bottle data page normally part of the program output have not been included.

The first page presents the engine performance parameters and system data. Since no samples were taken there is no boundary flow O/F data. The motor O/F is seen to be 1.1598 instead of the desired 1.2. The chamber pressure is low by about 10% when compared to the results obtained from firings of similar injectors at the NASA-Edwards facility. A comparison of the data from the first three firings with the NASA-Edwards data is presented in Table 16.

The run-1 data set presents the data from the second firing. Because of the conditions under which the test was conducted and because of the presence of a large amount of contamination it was elected to only analyze the gas in the number six cylinder. The purpose of conducting the gas analysis was principally to establish both the analysis procedure and the accuracy level of mass spectroscopy for the gas compositions to be encountered in the program. It must be noted that the bottle oscillograph data on page 1-3 and the bottle pressure data on page 1-1 are correct for bottle six only. The fact that the pressure data from the other bottles were ignored was a data reduction oversight.

The O/F in the boundary flow calculated by the program although of reasonable magnitude, cannot be considered an accurate measure of the boundary flow composition because of the residual N_2 in the bottles prior to sampling and the possible initial N_2O_4 surge mentioned previously. Because the data was obtained cold (i.e., room temperature) only some of the water present in the boundary flow was obtained. The gas analysis was also performed cold so that any water condensed in the bottle was not detected. Thus the .22% mole fraction of H_2O reported is probably the vapor pressure over a liquid phase although a subsequent analysis detected no water vapor at all.

The gas analysis of the bottle by the mass spectrometer showed the existance of 8 molecular species: H_2, H_2O, O_2, N_2, NO, NH_3, A, CO_2. The first five were expected based on preliminary chemical solutions using the Aerotherm Chemical Equilibrium Computer program. The presence of Argon is due to leakage past the actuating pistons on the JPL valves since Argon was used for the actuating gas.

In the third firing, run number 2, the O/F in bottle four was calculated to be 1.0875 as shown on page 2-1. This value is based on a cold analysis of the bottle and the formulation based on redundancy between H, O, and N mass balances which circumvents the necessity for measuring H_2O concentration. The gas sample data, page 2-2 again shows the presence of CO_2.

4.2 ENGINE PERFORMANCE

Two of the most conspicuous features of the engine data presented in Appendix F are (1) the departure of the O/F ratio from the desired value of 1.2, and (2) the reduced performance which is reflected in low values for specific impulse, I_s, and characteristic velocity, C^*. Here attention is focused on the mixture ratio difficulty. When the injector pressure drop characteristics are plotted as in Figure 22, then it is readily discerned that a pressurization difficulty is involved except in the case of run number 5 where the data completely departs from the established injector characteristic. The other data falls in line with the injector data taken at the Edwards JPL installation. In the number 5 run either a calibration was in error or the injector became temporarily sedimented during the firing (as indicated by some drop in both chamber pressure and flow rate).

The pressure tap in the downstream shroud indicate, for all practical purposes, ambient pressure; from which it can be inferred that the ventilating holes placed in the shroud spacer are adequately preventing asperation of the shroud. It was initially feared that the ejector action of the exhaust jet would asperate the shroud downstream of the motor nozzle exit and thereby reduce the measured thrust performance of the motor. Therefore ventilating holes were drilled into the shroud to prevent such asperation.

4.3 SAMPLE CHEMISTRY RESULTS

The sample chemistry data presented in the data reports in the appendix is again largely self evident. The O/F ratios are seen to be consistently fuel rich for the particular injector position ($\theta = 0°$). Figure 23 presents a plot of the O/F data. Other than the fact there is this overall fuel rich characteristic, the data exhibits considerable scatter. The exception to this appears to be for the axial position nearest the throat where some repeatability is found especially between the last two runs where nearly identical results were obtained.

When the chemistry analysis is examined (second page of each data summary report) a significant trend is found. For stations near the injector end, the concentrations of ammonia are much higher than for those near the nozzle end. Also for these ammonia rich samples, the ratio of hydrogen atoms to nitrogen atoms is greater than the maximum one would expect from the fuel alone--i.e., a ratio greater than 2:1. This also coincides with a significant variance in the consistancy of the mass spectrometer pressure measurements. It is found that when the ammonia concentrations are high, that the partial pressure summation of all species departs from the measured sample pressure by up to 30%. This evidence suggests that there is a better than average possibility that analysis difficulties are being encountered in the mass spectrometer. This is substantiated to some extent by the fact that no inter-laboratory agreement has been obtained with two different mass spectrometers.

Note also in these data reports that the pressure of the number 5 bottle is much higher than the others. This is apparently a consequence of progressive failure of the sampling circuit. In most cases the higher sampling flow rate did not seem to produce a significantly different sample which is encouraging since it is highly desired to have the situation where the boundary layer chemistry determination is not dependent upon the sampling rate.

SECTION 5

DATA REDUCTION COMPUTER CODE

Preliminary results from this program were discussed in Section 4. The program (or code) was written in Fortran IV for use on the Aerotherm in-house 1130. In the following paragraphs, the principal features of the code will be outlined. A listing of the code is presented in Appendix E.

5.1 GAS ANALYSIS DATA REDUCTION

The local O/F ratio in the boundary flow gas is determined from the gas analysis results of each of the sampling cylinders. The gas analysis (either mass spectroscopy or gas chromatography (see Section 2.5) yields the gas composition in the bottles in terms of mole percent of each molecular species. From this data the code determines the O/F ratio in one of two ways.

One way is to ratio the atoms of oxygen to the atoms of hydrogen. Mathematically this may be expressed:

$$\frac{O}{F} = \frac{\mathcal{M}_o}{\mathcal{M}_f} \frac{\sum_{j=1}^{N} \alpha_o \chi_j}{\sum_{j=1}^{N} \alpha_H \chi_j} \qquad \text{5-1}$$

where χ_j is the mole fraction of the j^{th} molecule of the N molecular species present. α_{ij} is the number of atoms of the i^{th} type (oxidizer (O) or fuel (H)) present in the j^{th} molecule. The molecular weight ratio $\mathcal{M}_o/\mathcal{M}_f$ is taken as that of the oxidizer N_2O_4 and fuel H_2H_4 in order to keep the O/F in the propellant mass ratio frame of reference.

Because the amount of nitrogen in the chemical system is also known, two more redundent ratios can be used to obtain O/F. Thus the elemental O to N ratios and H/N ratios can also be used to determine local O/F. The data must be self consistent to the extent that the O/F determined by three ratios must agree.

This redundancy makes it possible to obtain the local O/F without the knowledge of the amount of condensed water in the bottles (if the dissolution of ammonia in the water is ignored). The equations for this waterless determination can be cast in two forms depending upon which is the most convenient with regard to the amount of fuel or oxidizer present.

$$O/F = \frac{\eta_o(2R_1 + 2R_2 - 1)}{\eta_f(4R_1 - 2R_2 + 1)} \; ; \qquad 5\text{-}2$$

or

$$O/F = \frac{\eta_o(2R_3 - R_4 + 2)}{\eta_f(4R_3 + R_4 - 2)} \qquad 5\text{-}3$$

where

$$R_i = \sum_{j=1}^{N} (\alpha_a \chi_j) \Bigg/ \sum_{j=1}^{N} (\alpha_b \chi_j) \qquad 5\text{-}4$$

and where

$i=1 \rightarrow a=N \quad b=f$
$i=2 \rightarrow a=O \quad b=f$
$i=3 \rightarrow a=n \quad b=o$
$i=4 \rightarrow a=f \quad b=o$

The derivation of these equations are presented in Appendix D.

5.2 ROCKET ENGINE PERFORMANCE DATA REDUCTION

The performance of the rocket motor is described by commonly accepted parameters--such as specific impulse and chamber characteristic velocity, C^*. The data is reduced from the oscillograph tracings using the appropriate conversion factors and calibration coefficients.

The program averages the calibration step data (which is taken in the linear regime of transducer operation) e.g.:

$$C = \frac{1}{N} \sum_{i=1}^{N} \left(R_i - B\right) / S_i \qquad 5\text{-}6$$

where

C = calibration constant
R = reading
B = base reading
S = signal
N = number of calibration steps

As can be noted the format of the printed results from the data reduction have also been modified beginning with run 5. The oscillograph channel reading and the associated channel calibration have been presented together in a more readable format.

5.3 MASS SPECTROMETER DATA REDUCTION

A significant modification to the manner in which the gas analysis data are obtained was affected during the course of the program. Initially, the mole fraction data was obtained from the laboratory performing the analysis and this in turn was used to determine the oxidizer to fuel ratio in the boundary flow. The current technique is to take the mass spectroscopy data directly (oscillograph traces) and obtain from them the mole fraction data from which point the data analysis proceeds as before. There existed two motivations for performing this effort--one, the solution technique performed by the computer is more powerful and more accurate than the hand computations performed by the analysis laboratory and second, the computer determinations provided a more rapid data reduction and thereby makes possible the testing and data reduction of several firings per day on a steady production basis. The modification was made possible by the utilization of existing Aerotherm computer codes for the matrix inversion process associated with the least square fitting of data such as obtained from the mass spectrograph. In the following paragraphs a brief outline of the technique will be given.

5.3.1 Mass Spectrographic Data

The data from the mass spectrograph used in this effort consists of an oscillograph trace on which there are four channels recorded each of which correspond to four different amplification levels of the detected signal. An example is presented in Figure 24. The x-coordinate of the trace relates to magnetic field strength or ultimately mass number of the molecules in the sample being analyzed. The trace, then, shows a series of rather discrete peaks as the different molecules are charged and then attracted to the detector.

In the charging process, where the gas sample molecules are bombarded with an electron beam, the molecules are generally disintegrated so that each gas specie, such as NH_3 for instance, generates peaks of varying magnitude over a range of mass numbers. This display is known as a cracking pattern. Each gas molecular specie, such as NH_3, has a characteristic cracking pattern which has been found to be largely independent of the equipment manufacturer. Because of the quantum nature of molecular structure, the cracking patterns superimpose (i.e., certain peaks represent contributions from more than one specie). The quantitative determination of each specie involves the solution of simultaneous linear equations which solution is described in Section 5.3.3.

5.3.2 Calibration

Besides the determination of cracking data which consists of ratios of peak heights for the various mass numbers for each gas specie, the relative effects of the different species must be ascertained by calibration. For the work reported here all species were independently calibrated relative to Argon. This calibration is principally machine configuration dependent and does not vary with time and machine adjustment. Such a calibration procedure presumes that interactions between species does not significantly affect cracking patterns nor the relationship to the calibration standard (in this case Argon).

5.3.3 Determination of Gas Species Mole Fraction

The determination of gas species mole fraction as indicated previously is essentially performed by the solution of a set of linear algebraic equations. If a particular gas specie is present in amount x_i and if the species at a particular peak has the calibration C_{ij} where j is the j^{th} peak for the i^{th} species and where the calibration constant is the product of the cracking pattern ratio and the argon calibration:

$$C_{ij} = F_{ij} A_i \qquad 5\text{-}7$$

then for a given peak having a peak height, R_j;

$$R_j = \sum_{j=1}^{N} x_i C_{ij} \qquad 5\text{-}8$$

which produces a system of M equations, j = 1,M, for the M peaks on a given trace. In general, since experimental data is involved, the set is nondeterministic and moreover it is generally redundant in that there are usually more peaks than unknown species.

In general such problems are best solved by the least squares technique wherein the square of the largest residue from the set of equations is driven to the smallest possible value. Aerotherm has developed computer routines for performing this operation using a rapid matrix inversion technique. This routine is highly generalized and was easily adapted to this particular problem.

The x_i in equation 5-8 that are determined by the least square program, are physically partial pressure of the species in microns due to the way the calibration is performed. The mole fraction of each species is thus obtained from the relation

$$\chi_i = \frac{x_i}{\sum_{i=1}^{N} x_i} \qquad 5\text{-}9$$

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TABLE 1

JPL VALVE TESTS

a. Nominal Values

Test Description	Valve Housing Temperature	Valve Part Conditions			
		Upstream		Downstream	
		Pressure (psia)	Temperature (°F)	Pressure	Temperature (°F)
Cold	70°F	100.	70.	14.7 psia	70.
Cold-Vacuum	70°F	14.7-100.	70.	40.μ	70.
Hot	300°F	100.	170.-345.	14.7 psia	140.-320.

Activation Pressure All Runs ≈ 150 psia

Note: Upstream port is on the chamber side - downstream port is on the sampling cylinder side

b. Typical Test Results

Test Description	Operating Cycles	Leakage Measurement	
		Time Interval (min)	Pressure Change
1. Cold	25	60	17 psi**
2. Cold-Vacuum	25	60	35 mm Hg*
3. Hot	31	210	3.15 psi**

*Measured at upstream port

**Measured at downstream port

TABLE 2
VALVE SAMPLE CONTAMINATION CHARACTERISTIC

(a) Test Conditions

	Composition	Temperature	Pressure
Test Gas	N_2/H_2 - 50/50	300 F	100 psia
Actuating Gas	CO_2	70 F	100 psia
Valve Body	---	300 F	---

(b) Test Results

Gas	Percent Contamination (Mole Fraction)
O_2	0.37%
CO_2	0.0055%

TABLE 3

SINTERED ELEMENT FLOW HANDLING

Gas - N_2 Temperature - 70°F Back Pressure - 1 atm.

Grade	ΔP (psi)	Flow Rate ($\dot{m}_t \times 10^4$ lb/sec)
F-100	75.	3.50
	100.	4.62
	150.	7.22
F-60	75.	5.59
	100.	7.23
	150.	11.02
F-40	75.	9.28
	100.	11.88
F-30	75.	15.26
	90.	17.56

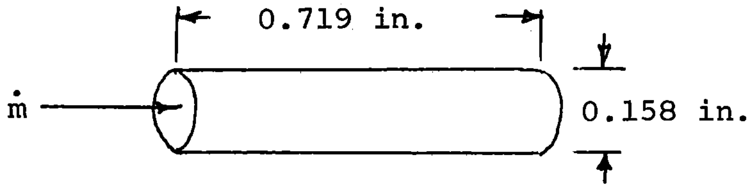


TABLE 4

BACK-UP VALVE LEAKAGE CHARACTERISTICS

Gas 50/50 He-N_2 Driving pressure - 150 psi (gage)

Valve body temperature = 350°F
Elapsed time = 30 minutes
Volume = 1.27 in^3

Valve	Back Pressure (mm Hg)		Leakage Rating (MCFH)
	Initial	Final	
Hoke needle all stainless	0.27	0.60	0.03 0.005*
Hoke bellows soft seat	0.30	2.25	1.95
Whitney soft seat	0.35	2.70	2.35

---

*Manufacturer quoted rating @ one atm. driving pressure

TABLE 5

FIRING SEQUENCE

Event	Critical Time (sec)
Heat up apparatus and pump down sampling system (firing # 3 only)	
Pressurize Tanks	
Arm instrumentation	
Initiate firing	0
Gate ballistic analyzer	1.0
Open sampling valves and pneumatic redundant valve (firing 2 and 3 only)	1.5
Close sampling valve and pneumatic redundant valve	2.5
Gate balistic analyzer	3.0
Terminate firing	4.0

TABLE 6

MIXTURE RATIO TESTS

Firing	Desired O/F	Measured O/F	Percent Error
10	1.25	1.24	-0.8
11	1.20	1.21	+0.8
12	1.20	1.20	0
13	1.20	1.21	+0.8
14	1.25	1.24	-0.8
15	1.15	1.15	0
16	1.20	1.20	0

TABLE 7

GAS ANALYSIS RESULTS
(Percent Mole Fraction)

	Firing 2 - Run # 1 Bottle 6		Firing 3 - Run # 2 Bottle 4	
	a	b	a	b
H_2	13.65	2.87	1.9	16.5
NH_3	.14	--	1.4	7.39
H_2O	.22	--	72.8	1.32
N_2	84.83	96.5	17.4	73.85
NO	.08	.05	.9	.2
O_2	.69	.06	4.0	.04
A_n	.16	.13	.2	.2
CO_2	.24	.37	1.4	.5

a. Stanford Research Institute - CEC mass spectrometer

b. West Coast Technical - Hitashi - P.E. mass spectrometer

TABLE 8

ANALYSIS OF BOTTLE 7-1

Gas	JPL	WCT			JPL*
		a	b	c	
H_2	4.1	18.26	20.46	37.39	40.9
H_2O	30.1	7.51	10.72	11.75	--
O_2	--	1.32	0.03	0.02	--
N_2	5.9	28.81	18.34	42.67	56.2
NH_3	57.9	42.7	46.38	0.18	--
N_2O	1.8	0.07	--	--	--
NO	t*	--	0.01	--	0.01
NO_2	--	--	--	--	--
CO	0.1	--	--	--	1.14
CO_2	t	0.56	0.80	0.06	0.02
A	t	0.06	0.01	0.01	0.02
He	0.1	0.70	3.25	7.92	1.32
CH_2	t	--	--	--	0.42

a. First test - data reduction by Aerotherm - hot

b. Second test - data reduction by WCT - hot

c. Third test - data reduction by WCT - cold (t << 70°F)

* t designates trace amounts

** non-condensible analysis

TABLE 9

APPROXIMATE ANALYSIS OF BOTTLE 8-4 GLC TECHNIQUE

(Presuming ill-defined peak to be N_2H_4)

H_2	2%
N_2	30%
NO	1%
NH_3	7%
H_2O	10%
N_2H_4	50%

TABLE 10

ATOMIC RATIO ANALYSIS OF SELECTED COMPOSITION DATA

Number	Laboratory	Sample	$\frac{\Sigma H}{\Sigma N}$	$\frac{\Sigma O}{\Sigma N}$	Sum
1	D/O - GLC	8-4	1.436	0.064	1.500
2	JPL - M.S.	7-1	3.31	0.437	3.747
3	WCT - M.S.	7-1(a)	1.78	0.11	1.89
4	WCT - M.S.	8-6	1.29	0.196	1.486
5	WCT - M.S.	8-2	2.72	0.108	2.83

TABLE 11

COMPARISON OF MASS SPECTROMETER ANALYSES

a) Bottle 1

Run No.	3	4	4	5	6	7	7	7	7	7
		COLD	HOT			← HOT →	JPL		← COLD →	JPL
H_2	15.3	25.5	38.5	15.4	12.9	18.3	4.1	20.5	37.4	41.9
H_2O	0.7	–	7.9	15.6	11.8	7.5	30.1	10.7	11.7	–
O_2	8.4	–	–	0.1	–	1.3	–	–	–	–
N_2	57.9	39.5	25.1	32.6	18.6	28.8	5.9	18.3	42.7	56.2
NH_3	11.9	33.3	26.7	31.0	54.0	42.7	57.9	46.4	0.2	–
N_2O	0.1	–	–	1.2	0.6	0.1	1.8	–	–	–

b) Bottle 2

Run No.	3	4	5	7	8
H_2	17.4	30.0	15.3	10.8	14.0
H_2O	0.5	3.5	21.3	17.1	6.2
O_2	–	–	–	–	0.6
N_2	31.5	24.8	33.0	15.2	20.1
NH_3	35.1	38.0	18.9	50.6	54.3
N_2O	–	–	1.6	–	0.1

Table 11 - Continued

c) Bottle 3

RUN NO.	3	4	5	6	7	8
H_2	16.2	25.8	20.9	16.1	19.6	14.2
H_2O	1.3	16.1	4.1	7.3	1.1	8.9
O_2	-	-	0.1	-	0.2	0.2
N_2	39.0	21.4	30.9	26.8	30.2	22.5
NH_3	29.5	34.4	39.8	45.1	45.1	50.5
N_2O	-	-	1.9	1.3	0.2	0.1

d) Bottle 4

RUN NO.	2	3	3	5	6	7	8
		COLD	HOT				
H_2	16.5	8.0	8.5	14.7	10.0	18.4	16.3
H_2O	1.3	14.9	-	11.1	31.0	9.0	8.1
O_2	-	-	-	-	-	1.1	0.2
N_2	73.9	18.5	18.4	27.8	18.9	37.4	31.7
NH_3	7.4	13.1	13.4	40.3	37.8	29.1	37.8
N_2O	-	-	-	2.3	-	0.1	0.1

Table 11 - Concluded

e) Bottle 5

Run No.	3	4	5	6	7	8
H_2	8.2	30.3	17.8	11.3	28.5	8.6
H_2O	21.3	7.4	7.3	20.4	7.6	45.6
O_2	.3	–	–	–	1.4	.4
N_2	40.7	31.3	23.7	23.7	44.7	15.3
NH_3	8.8	26.3	45.9	41.0	12.9	27.3
N_2O	2.3	–	.7	.3	–	–

f) Bottle 6

Run No.	1	3	4	5	6	7	8
H_2	13.7	17.5	20.2	13.6	14.7	18.2	18.8
H_2O	.2	.6	3.4	11.4	25.1	14.2	14.3
O_2	.7	–	–	–	–	.3	.4
N_2	84.8	62.7	64.3	19.9	31.0	38.5	36.4
NH_3	.1	.2	7.3	51.8	24.0	17.8	19.0
N_2O	–	5.7	–	1.0	1.3	1.3	1.3
NO	–	–	–	–	1.2	–	–
NO_2	–	–	–	–	2.0	1.0	1.1

TABLE 12

MASS SPECTROSCOPY RESULTS

Constituent	Sample 1	Sample 2 (Flamed)	Sample 3	7-2
Hydrogen	0.00	71.78	6.62	10.8
Helium	0.00	0.00	4.64	3.1
Ammonia	11.54	1.51	46.79	50.6
Water	6.01	6.92	8.44	17.1
Nitrogen	65.93	71.78	31.33	15.2
Nitric Oxide	0.00	0.01	0.19	----
Oxygen	14.19	16.69	0.04	----
Argon	0.80	1.24	0.17	----
Hydrocarbons as Butane	0.02	0.03	0.02	----
Carbon Dioxide	1.49	1.70	11.73	0.7
Nitrogen Dioxide	0.02	0.03	0.03	----
Hydrazine	---	----	----	2.5

TABLE 13

SAMPLE CO_2 TEST

	Liquid Carbonic	WCT
N_2	71.	24.74
O_2	3.	15.84
CO_2	2.	0.84

TABLE 14

VITON O-RING TEST DATA

	WCT	L.C.
He	73.4	--
H_2O	0.99	--
N_2	21.52	--
NO	0.12	--
O_2	2.73	--
A	0.27	--
CO_2	0.96	--

TABLE 15

O-RING MATERIAL TEST DATA

	Viton-A	E.P.
He	73.4	84.33
H_2O	00.99	--
N_2	21.52	14.01
NO	0.12	--
O_2	2.73	1.56
A	0.27	--
CO_2	0.96	0.10

TABLE 16

COMPARISON OF MOTOR PARAMETER VALUES

RUN	P_c	O/F	$\dot{W}_t$	$\dot{W}_o$	$\dot{W}_f$
Dy84*	154	1.22	.402	.221	.181
1	141.7	1.1598	.404	.217	.187
2	147.7	1.1745	.4121	.2226	.1895
3	142.7	1.1638	.4129	.2221	.1908

* run at NASA-Edwards (typical data)

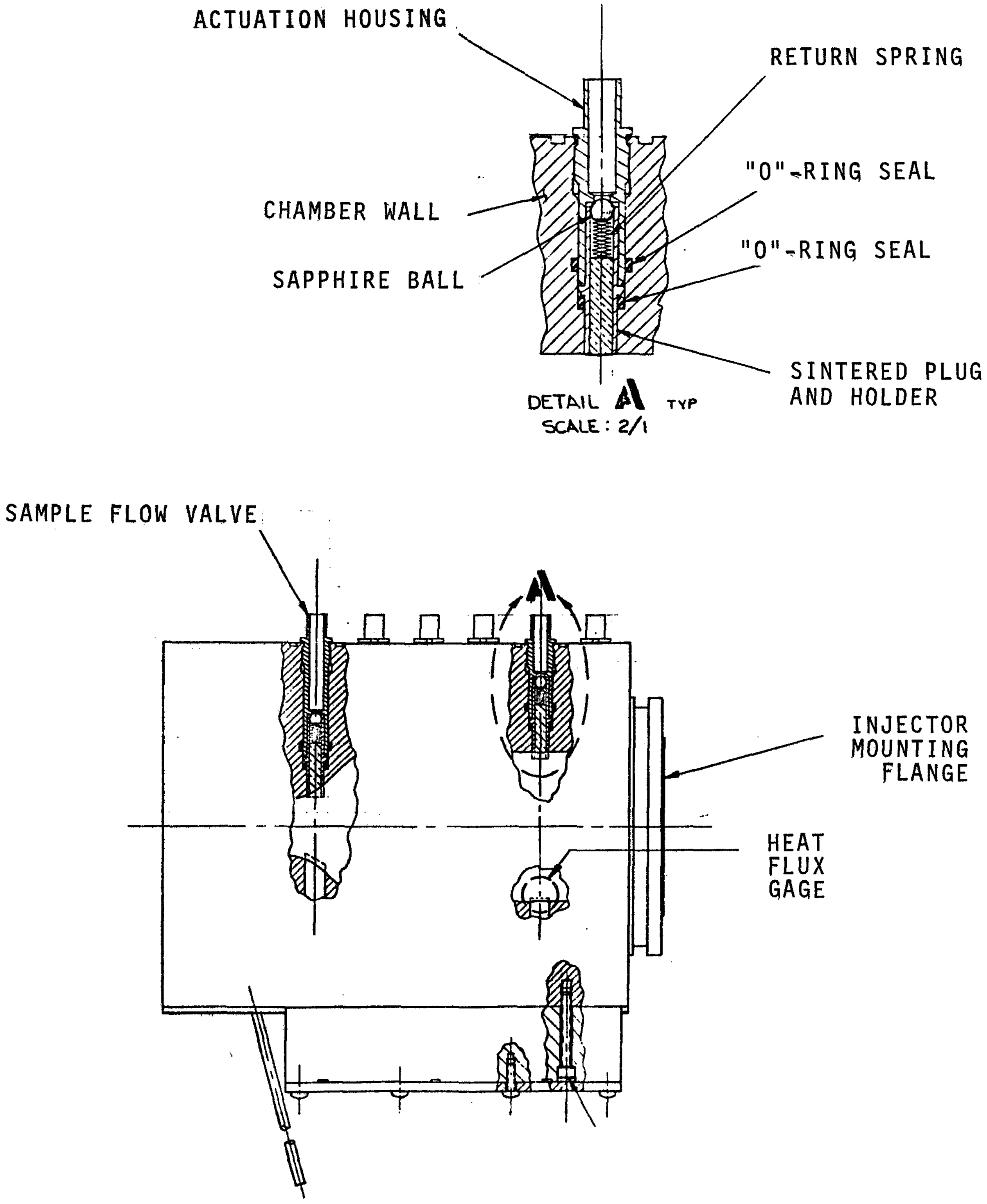


Figure 1. Combustion Chamber Showing Sampling Portion and the Heat Flux Gage Location

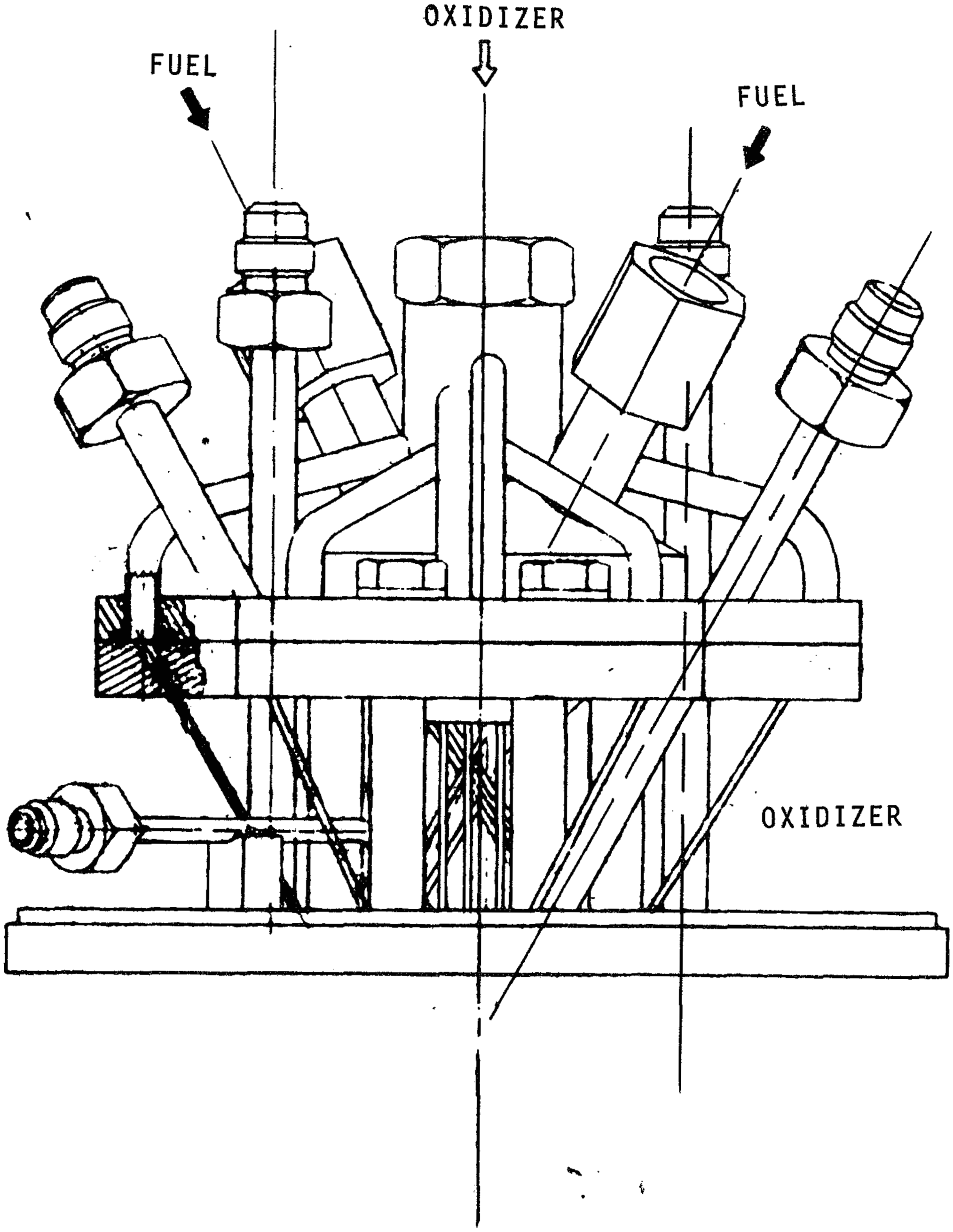


Figure 2. Injector Type Used in the Experimental Program

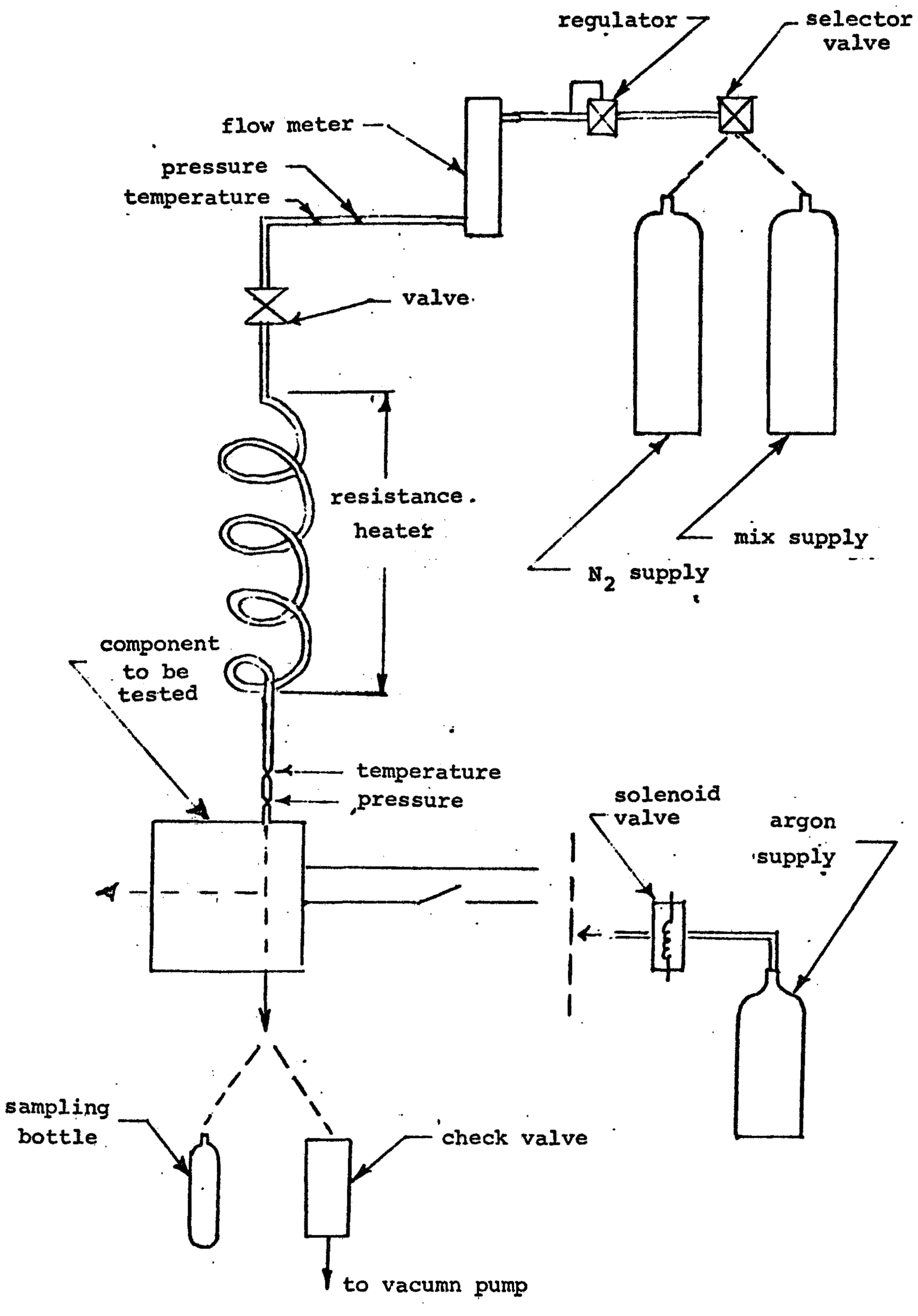


Figure 3. Sampling System Component Test Circuit

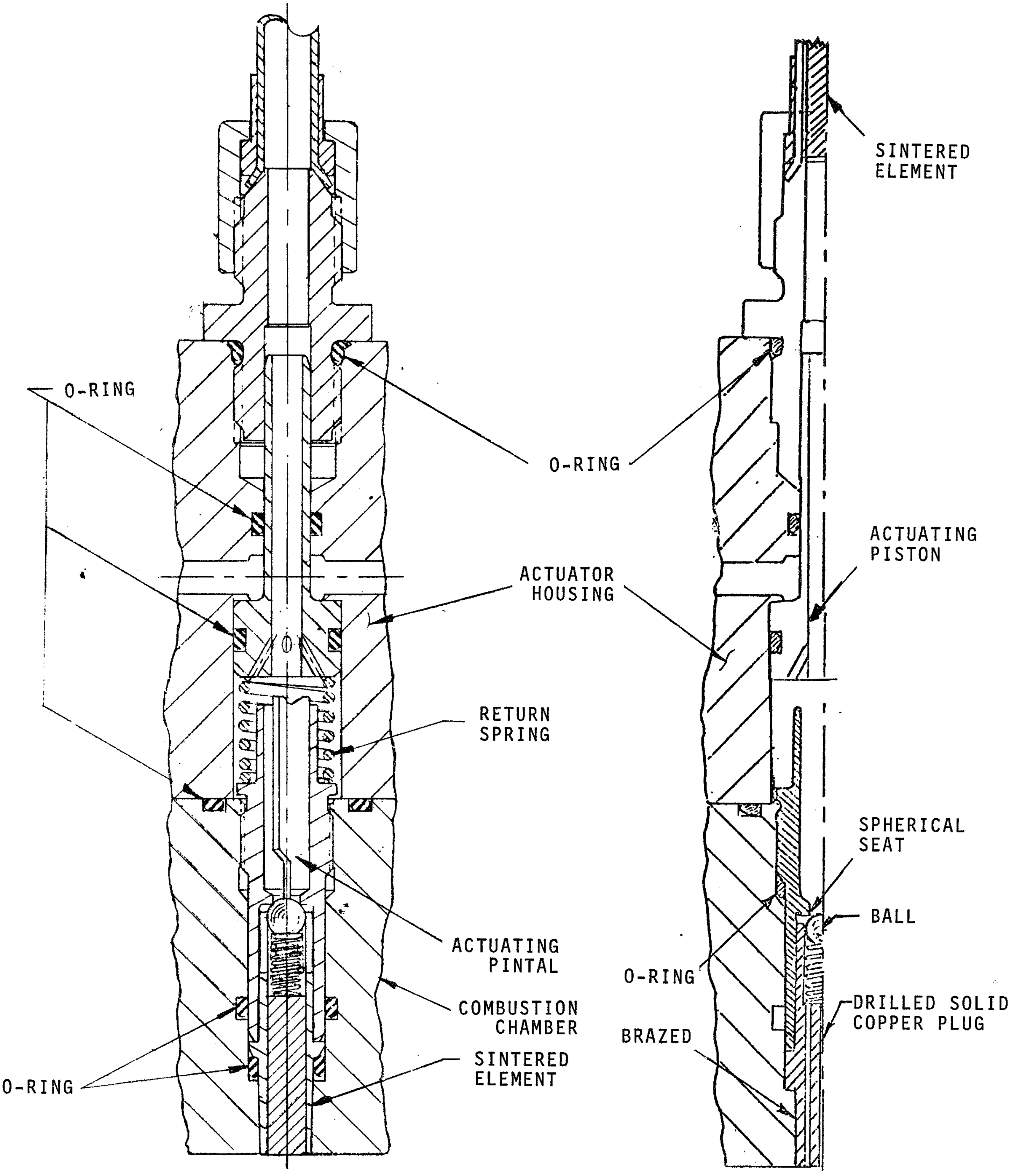


Figure 4-a
Original Design

Figure 4-b
Modified Design

Figure 4. Design Modification to the Sampling Valve

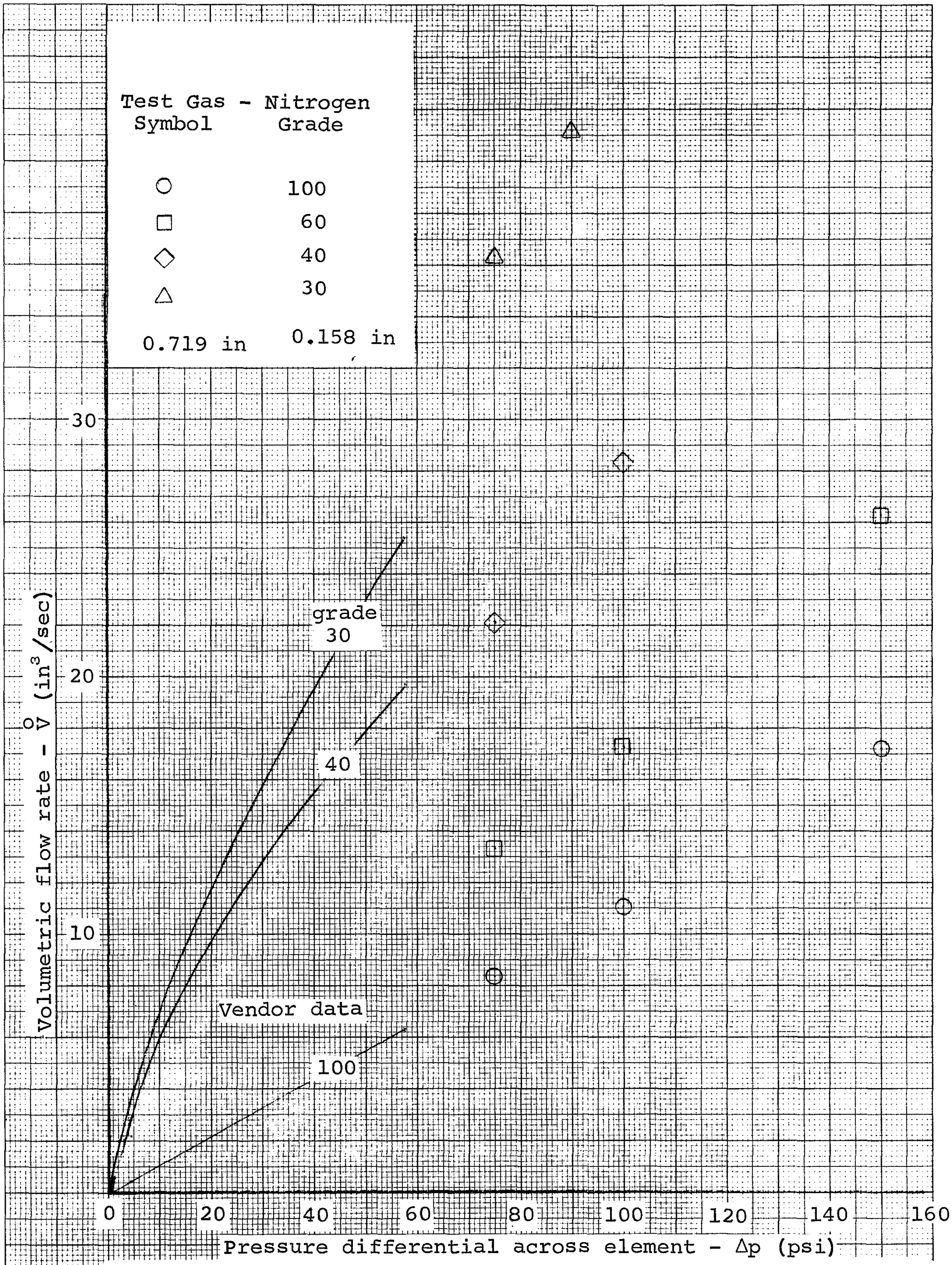


Figure 5. Flow Handling Characteristics of Sintered Element

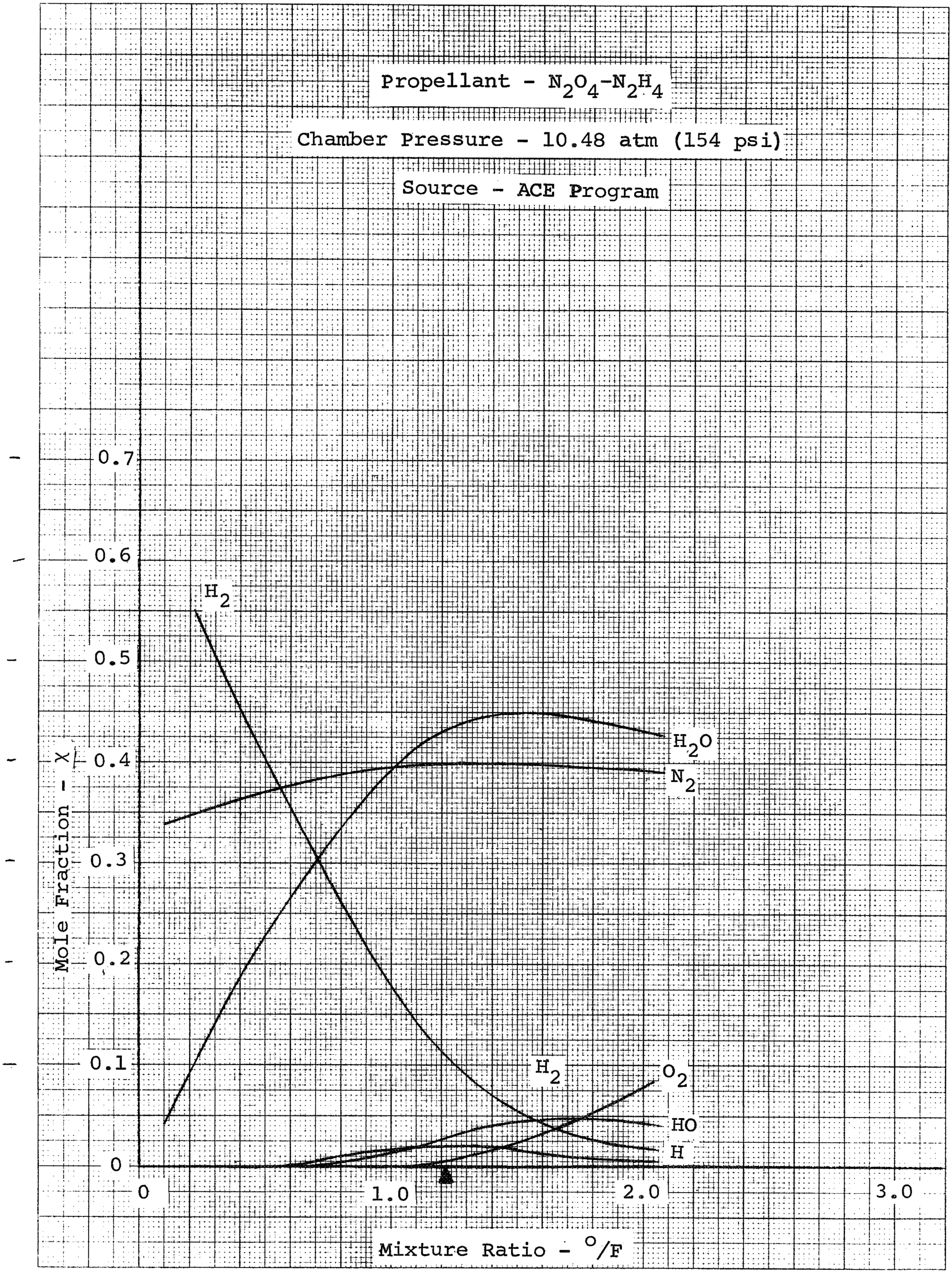
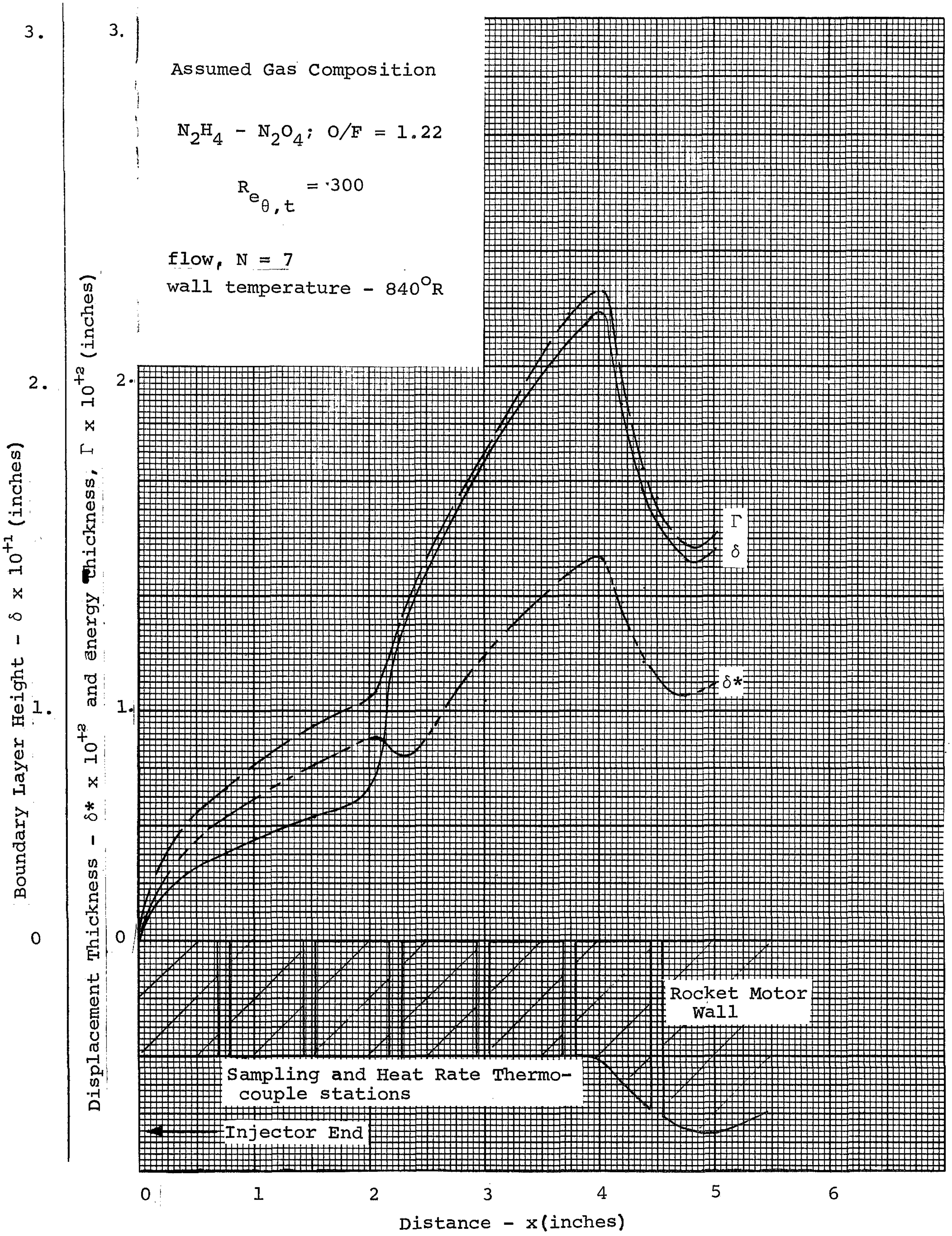


Figure 6. Theoretical Equilibrium Composition for Various O/F Ratios



*This prediction was completed before it was known that a spacer would be used between the rocket motor and injector

Figure 7. Predicted Rocket Motor Boundary Layer Properties

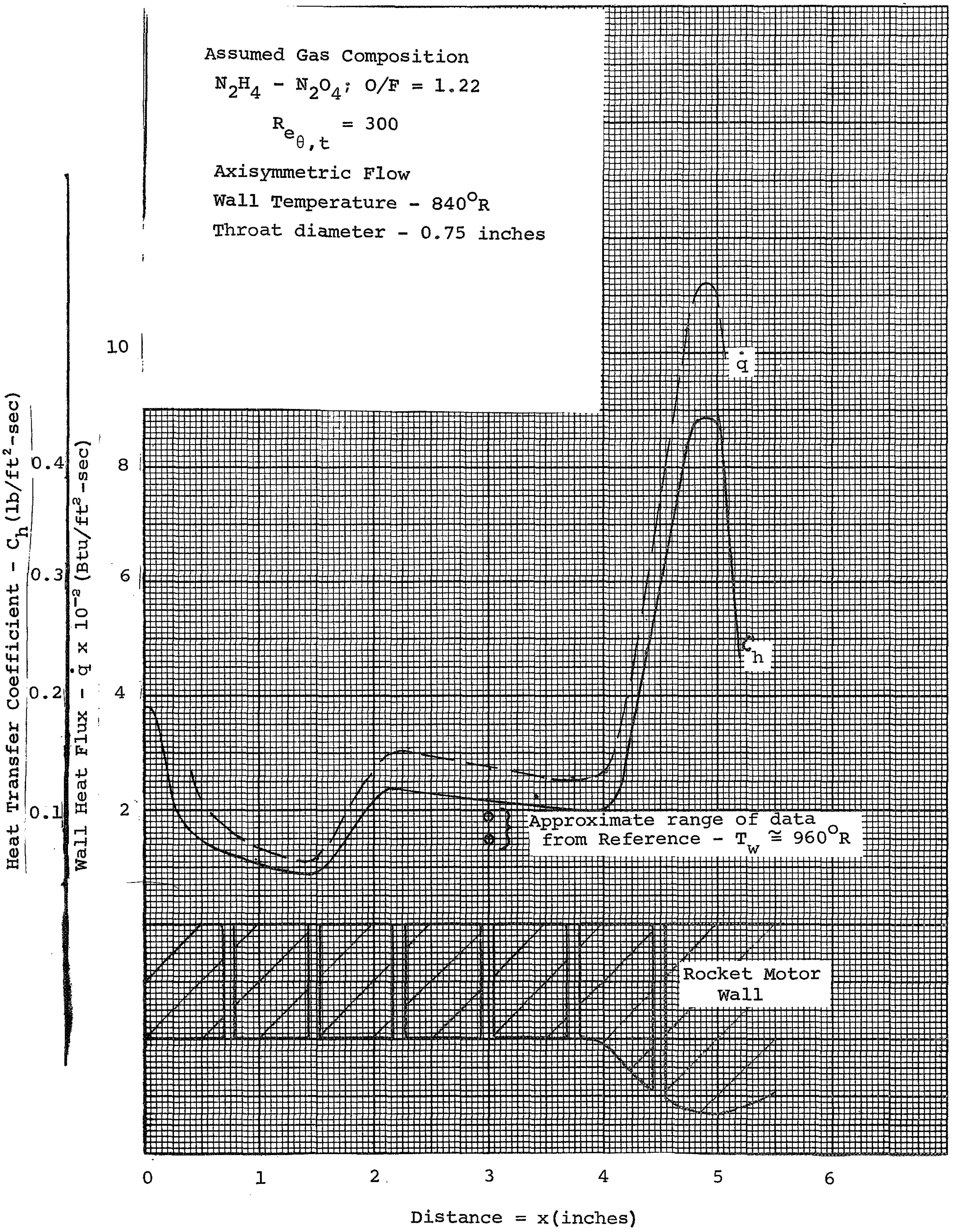
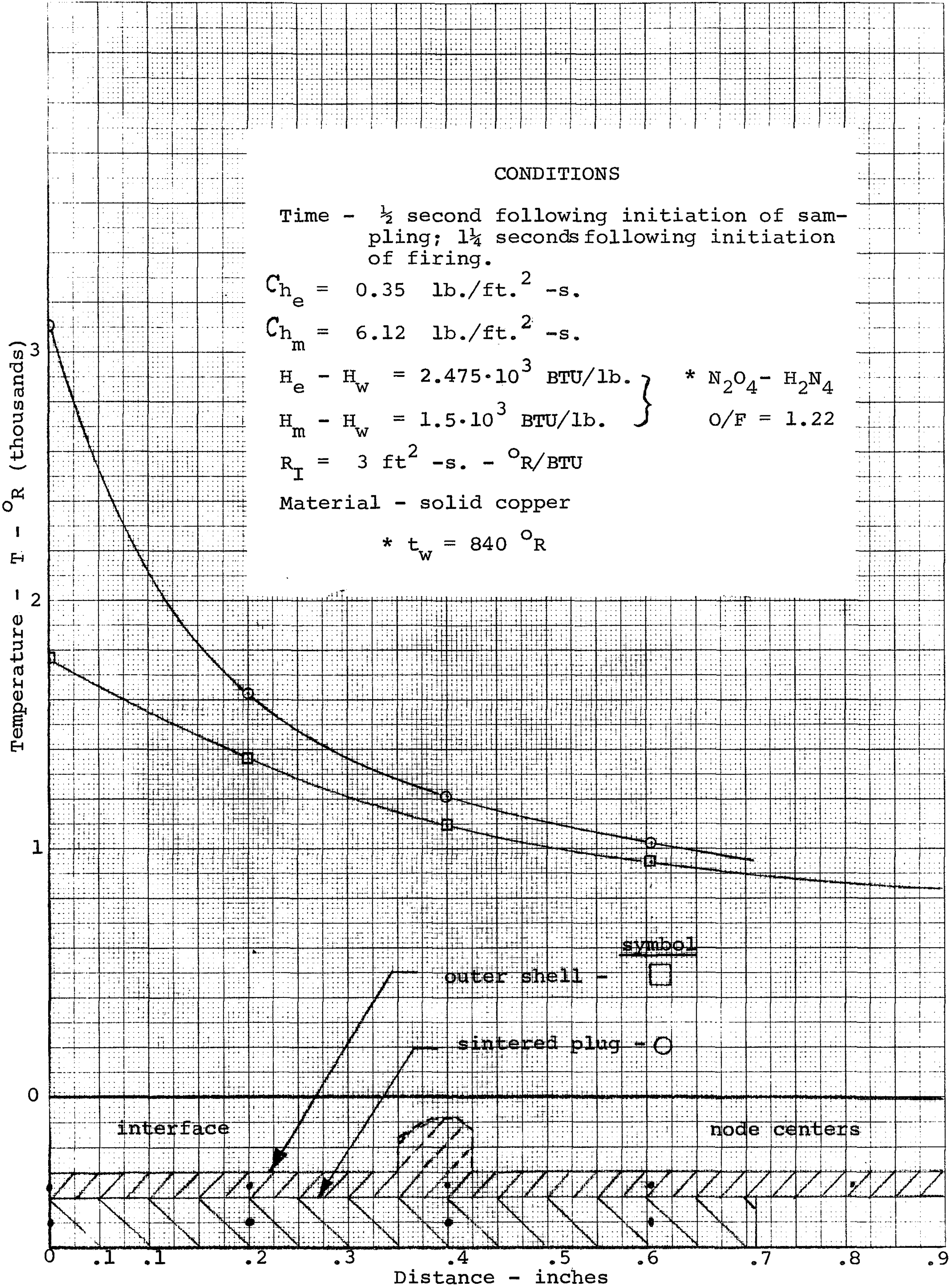


Figure 8. Predicted Wall Heat Transfer Coefficient and Heat Flux



CONDITIONS

Time - ½ second following initiation of sampling; 1¼ seconds following initiation of firing.

C_{h_e} = 0.35 lb./ft.^{2} -s.

C_{h_m} = 6.12 lb./ft.^{2} -s.

$H_e - H_w = 2.475 \cdot 10^3$ BTU/lb.

$H_m - H_w = 1.5 \cdot 10^3$ BTU/lb.

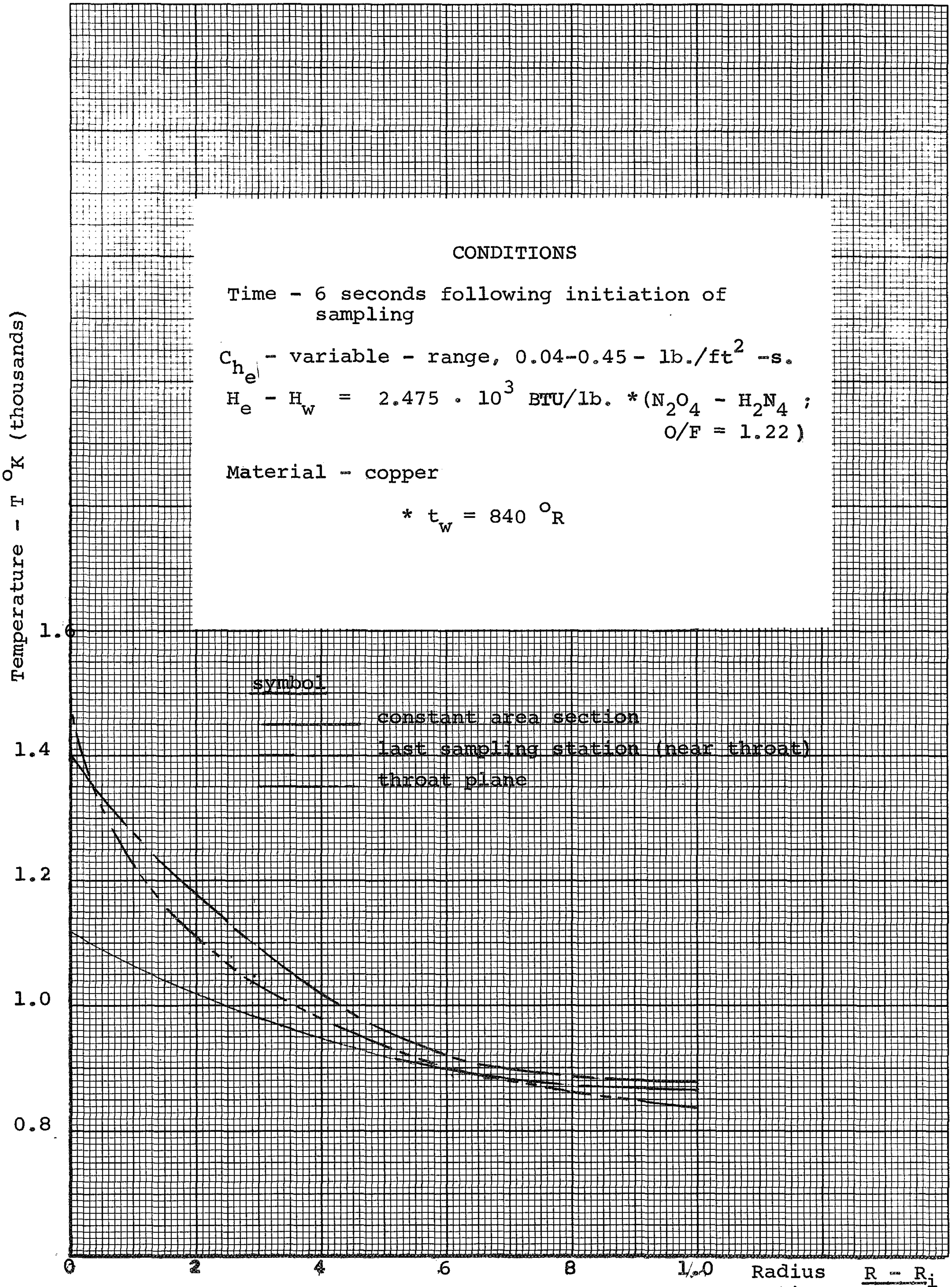
$\}$ * $N_2O_4 - H_2N_4$ O/F = 1.22

R_I = 3 ft^2 -s. - ^oR/BTU

Material - solid copper

* t_w = 840 ^oR

Figure 9. Temperature Distribution in the Sintered Element



CONDITIONS

Time - 6 seconds following initiation of sampling

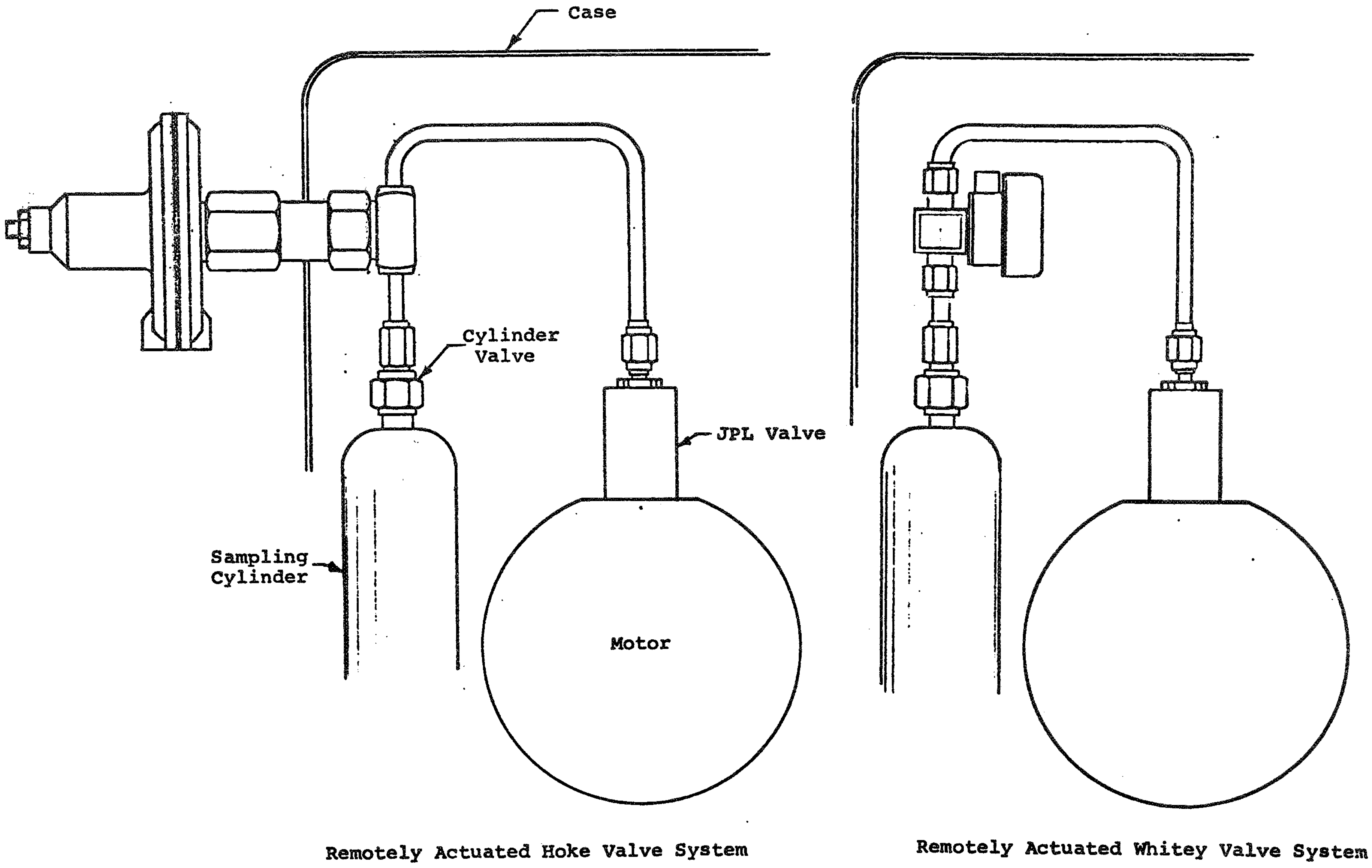
C_{h_e} - variable - range, 0.04-0.45 - lb./ft^2 -s.

$H_e - H_w = 2.475 \cdot 10^3$ BTU/lb. *(N_2O_4 - H_2N_4 ; O/F = 1.22)

Material - copper

* t_w = 840 °R

Figure 10. Temperature Distribution in Rocket Motor



Remotely Actuated Hoke Valve System

Remotely Actuated Whitey Valve System

Figure 11-a. Backup Valve Arrangements

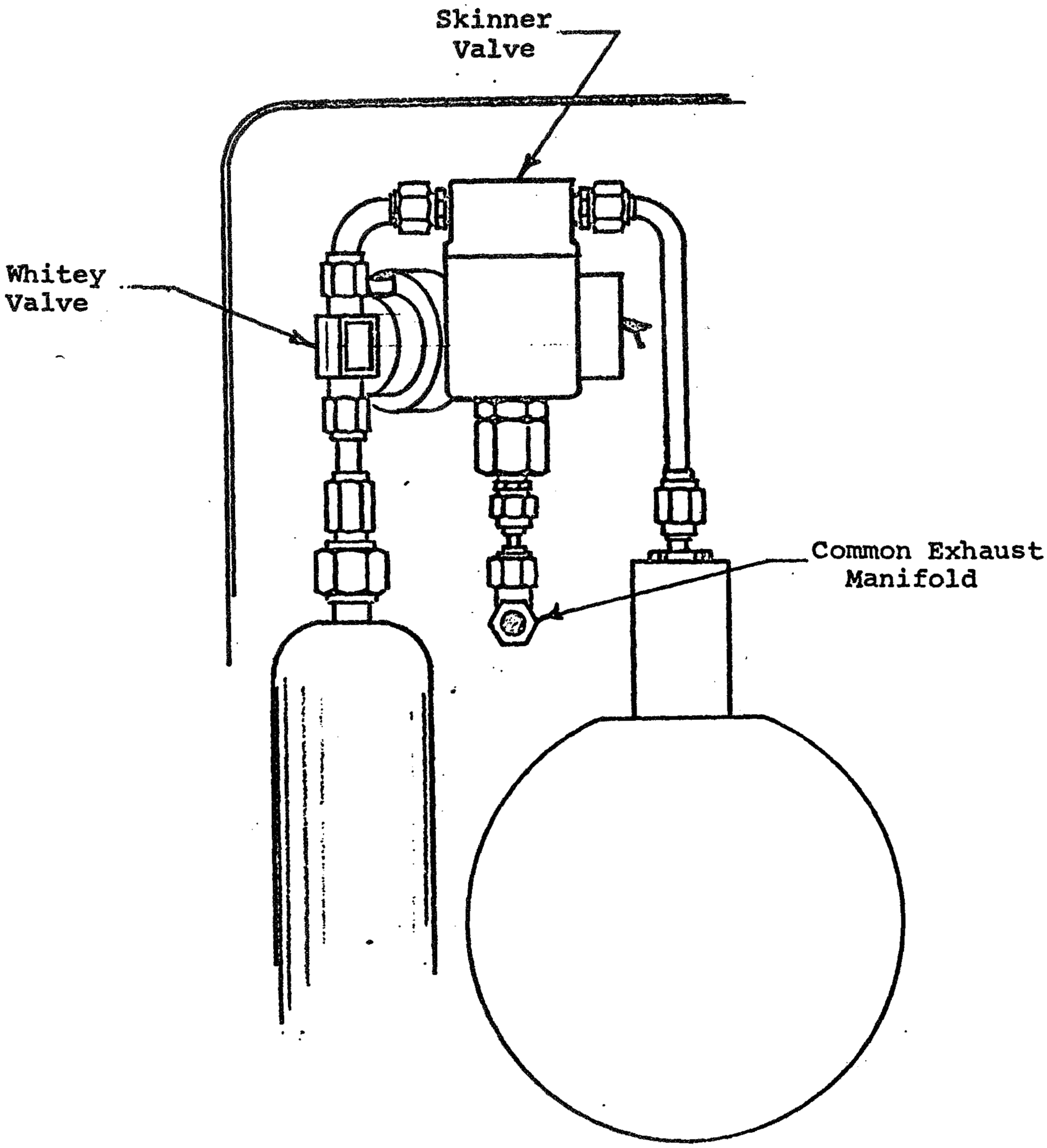


Figure 11-b. Combined Whitey Valve with Skinner 3-Way Solenoid Valve and Bleed Manifold

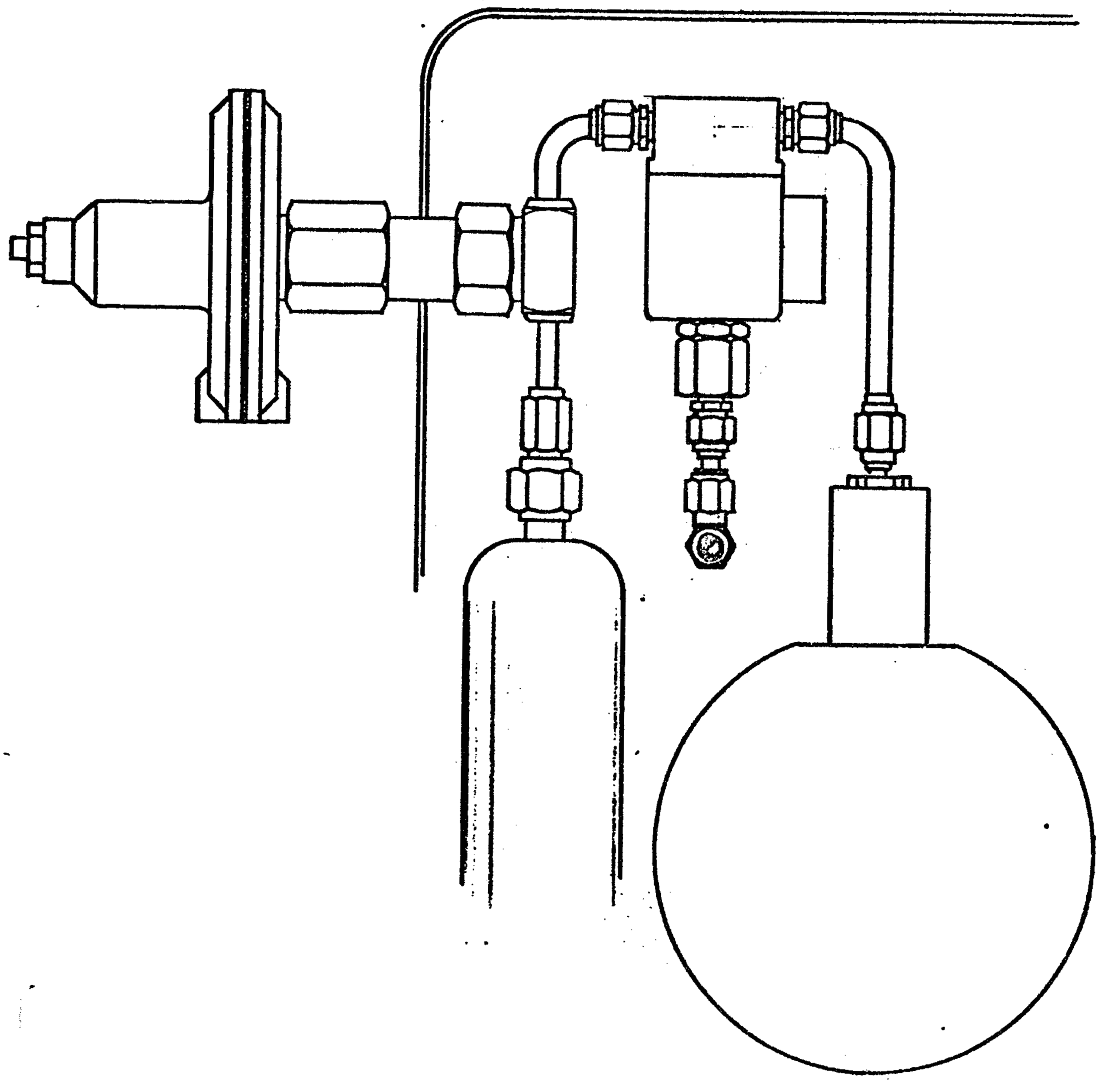


Figure 11-c. Combined Hoke and Skinner Valve Bleed System

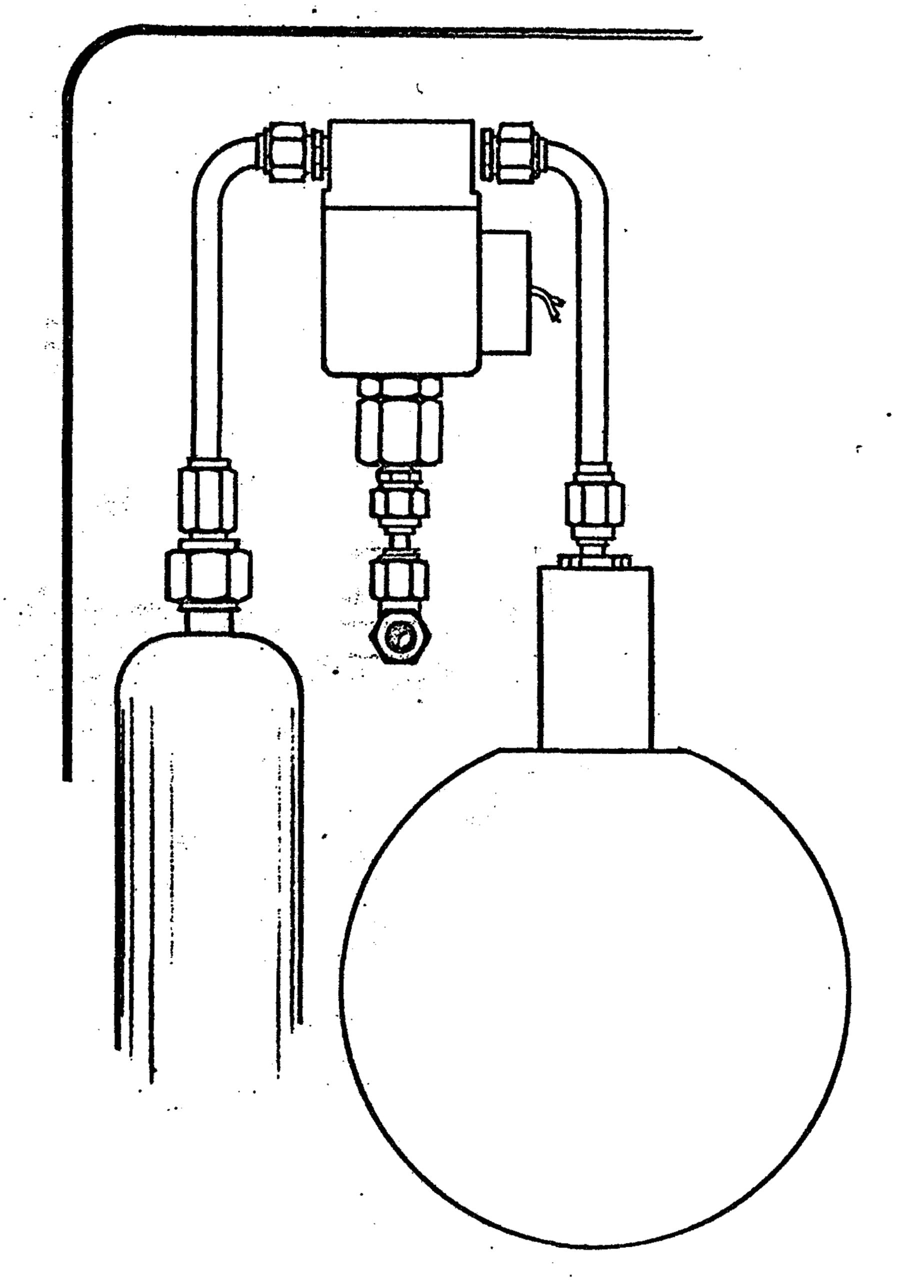


Figure 11-d. Skinner Valve Bleed System Alone

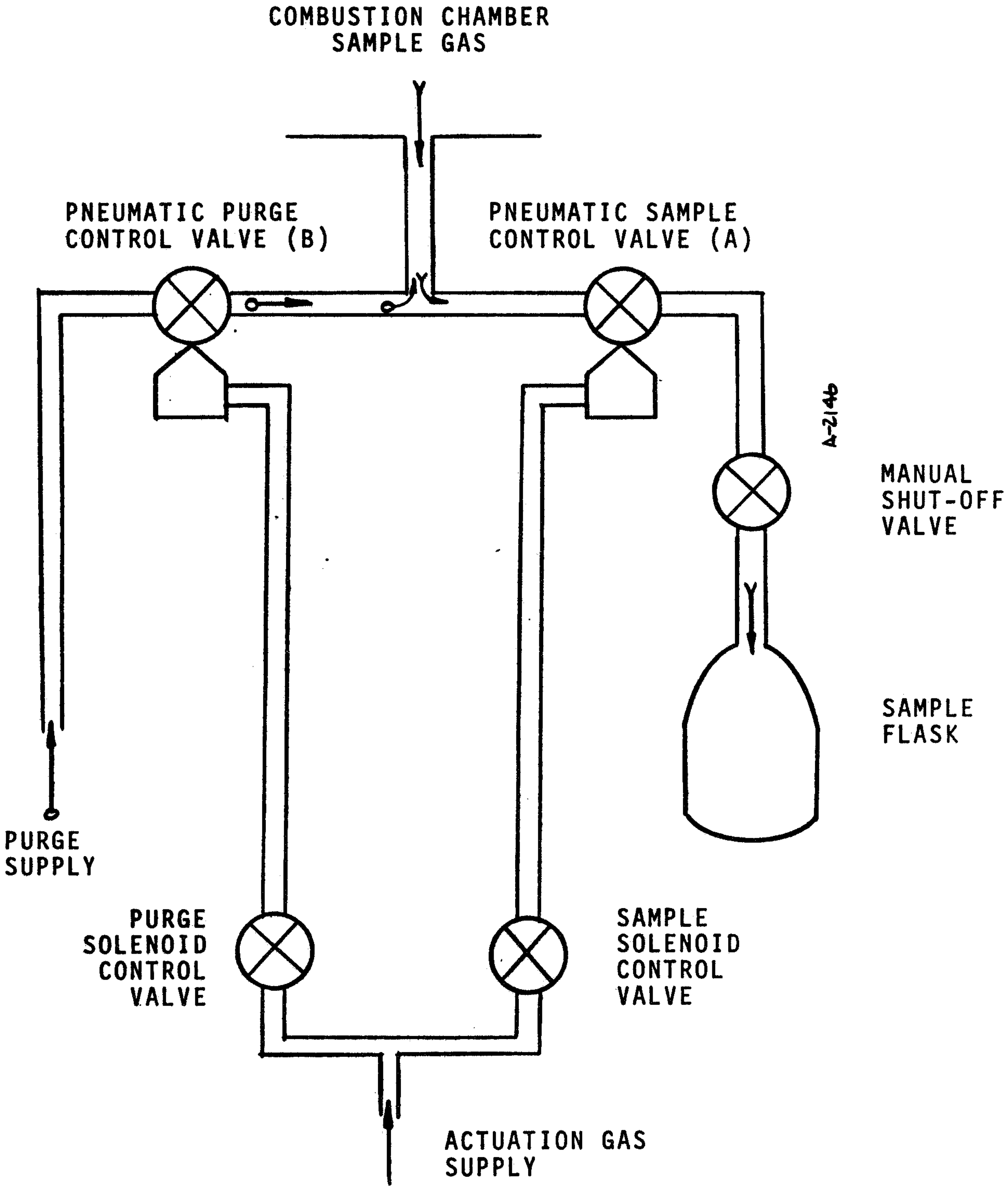


Figure 12. Purge System Schematic

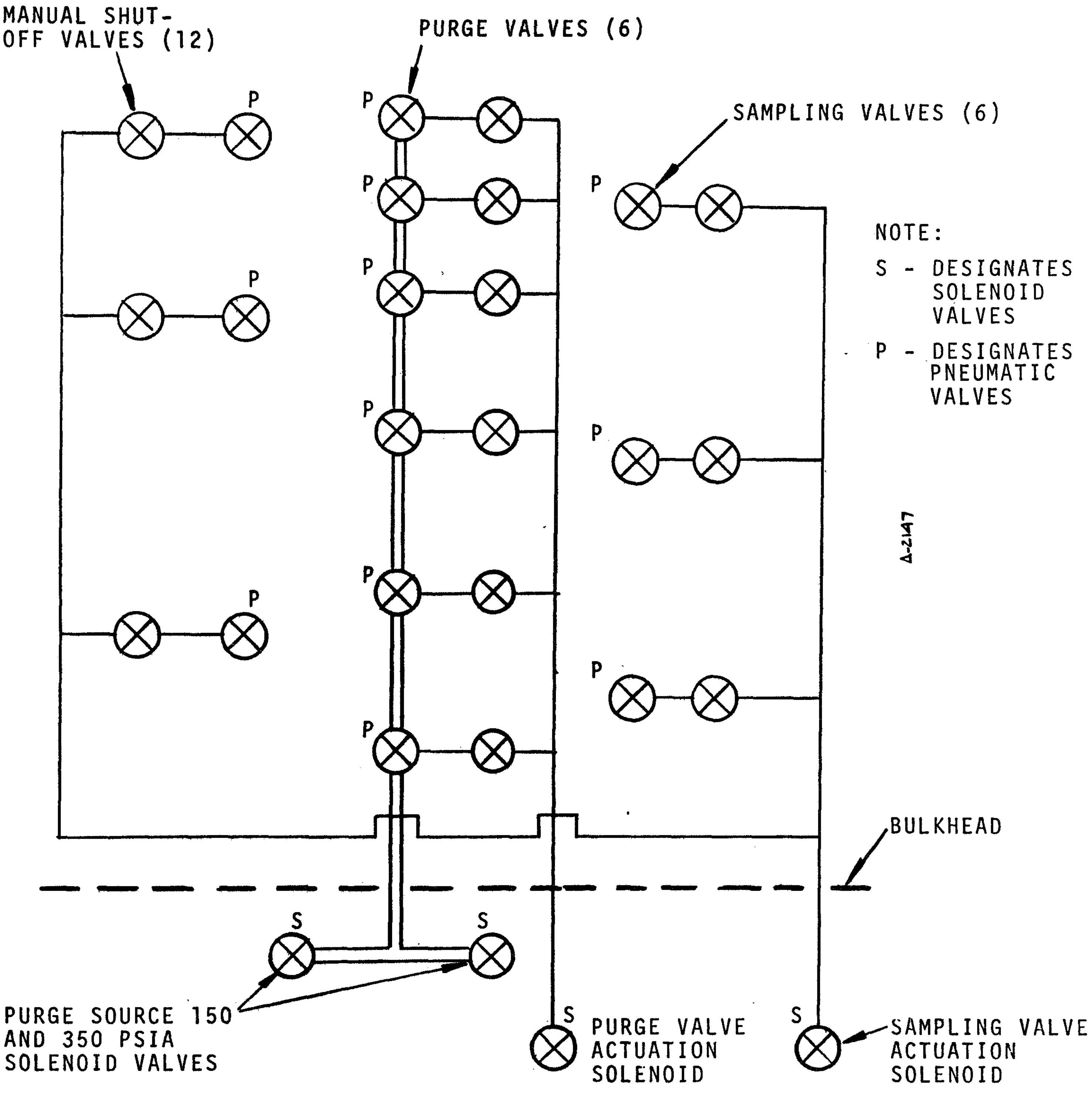


Figure 13. Pneumatic Circuit Schematic

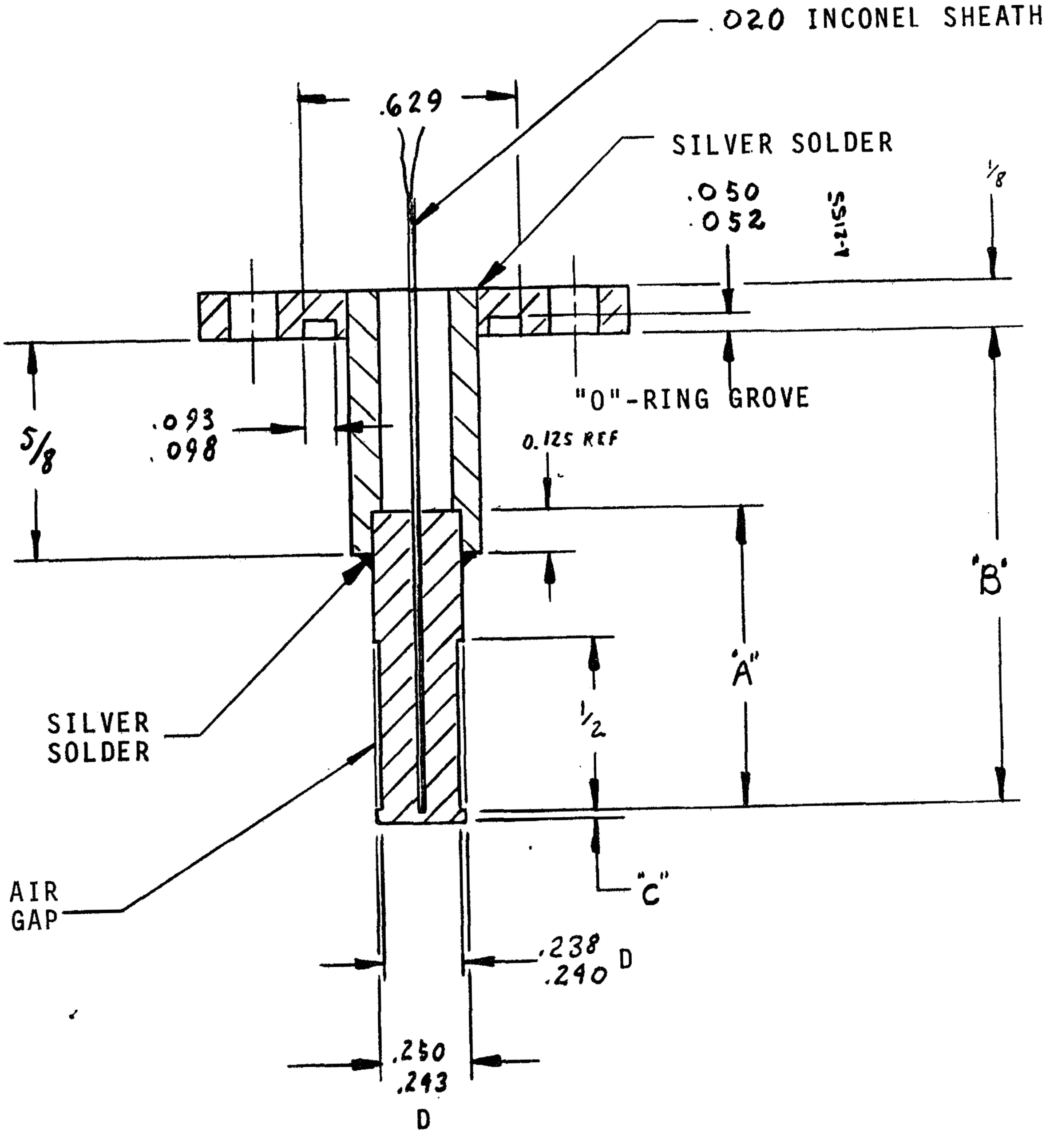


Figure 14. Heat Flux Gage Manufacturing Details

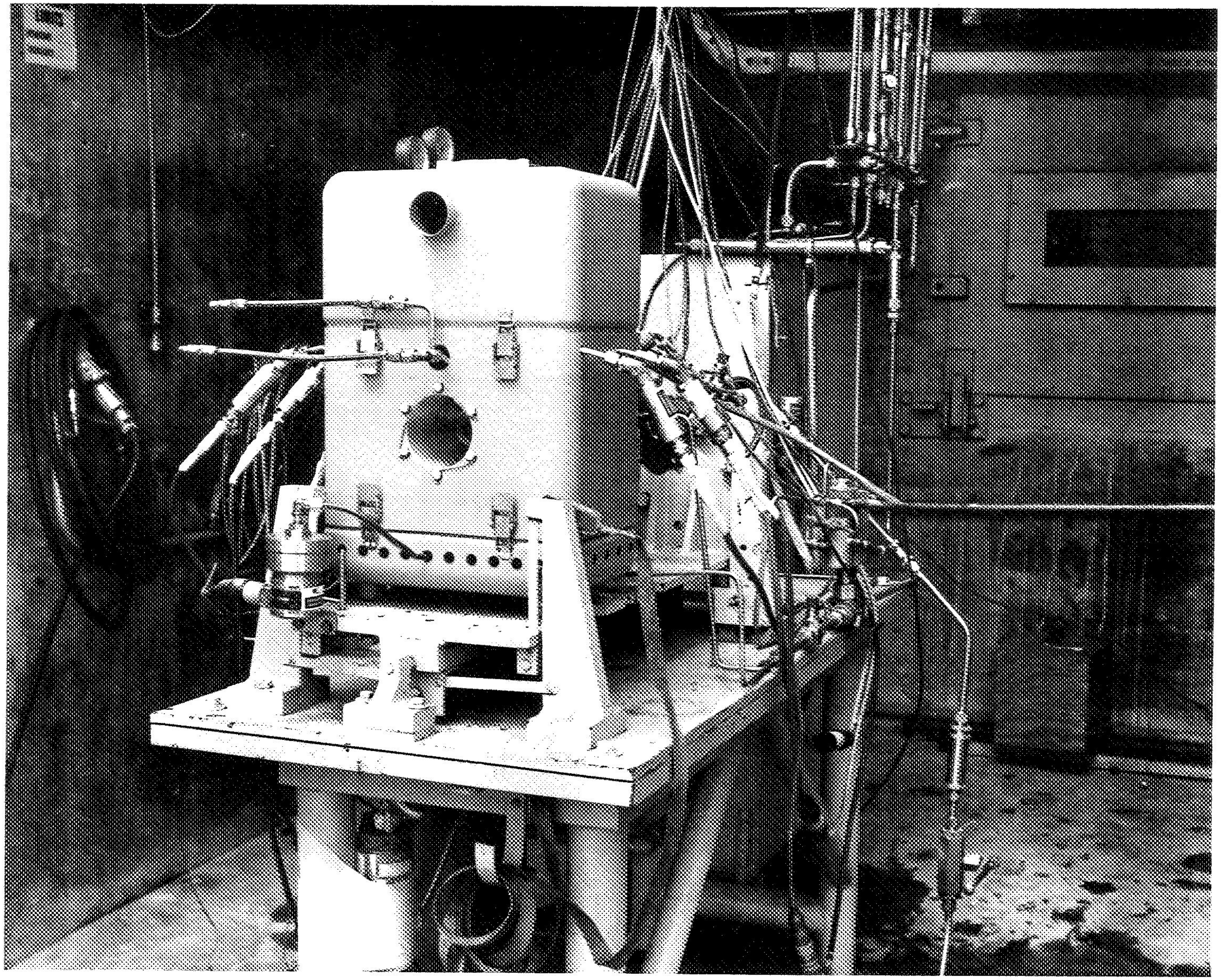


Figure 15. Instrumented Chamber Assembly on Thrust Stand

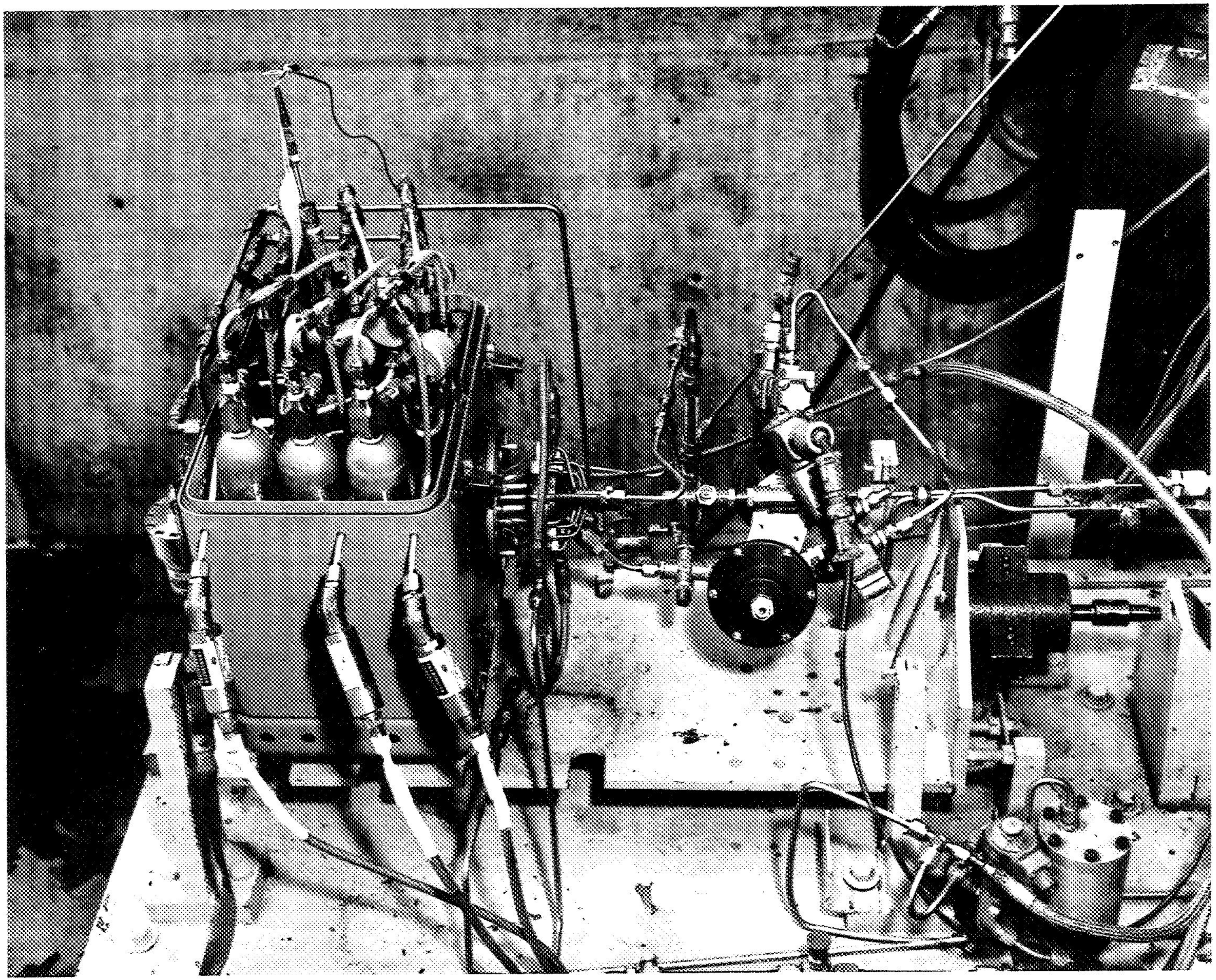


Figure 16. View of Sampling System and Propellant Feed System

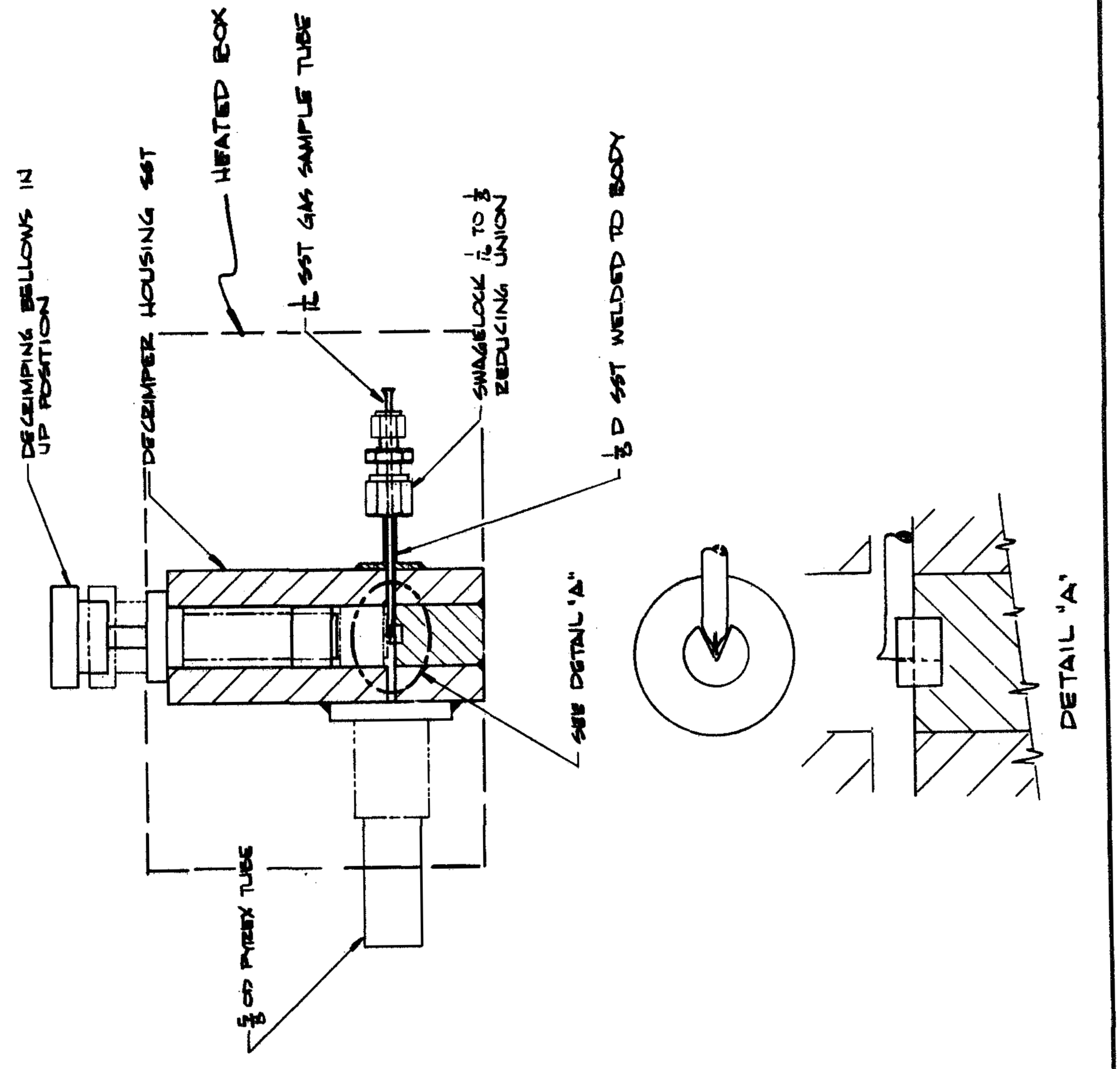


Figure 17. Microtube Opener

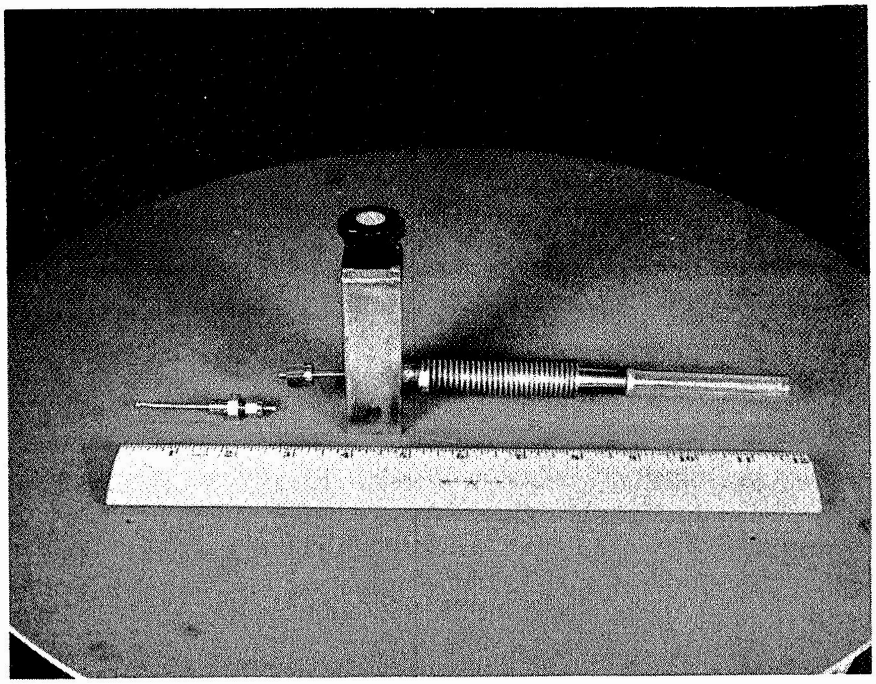


Figure 18. De-Crimper and Microtube Assembly

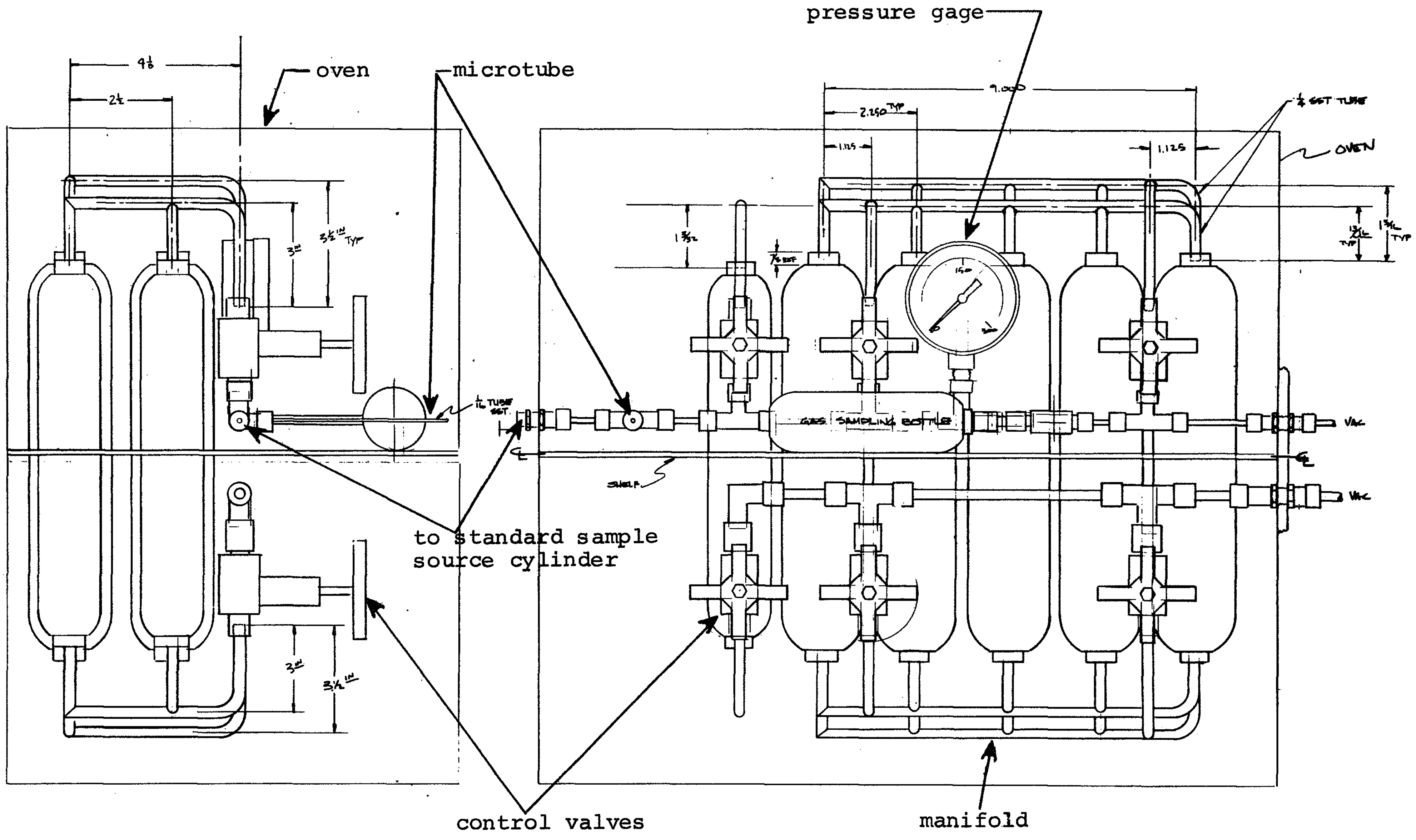


Figure 19. Microtube Filling Apparatus

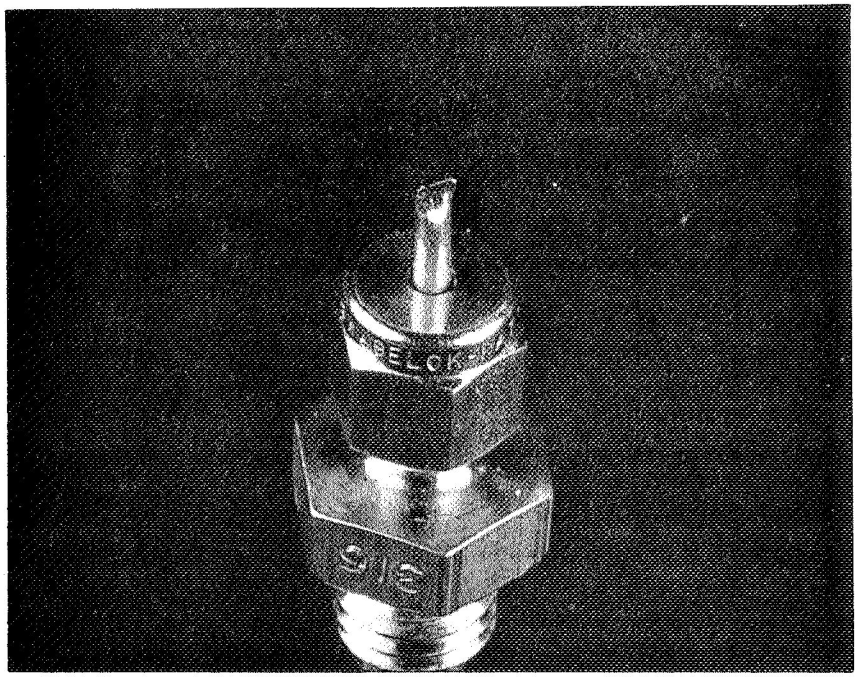


Figure 20. Microtube Showing Crimped Seal

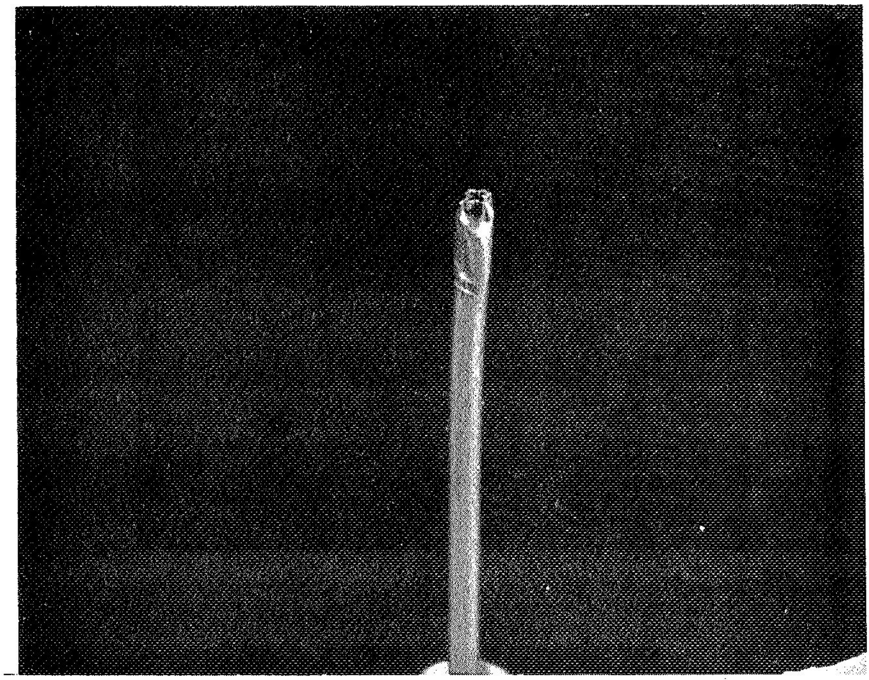


Figure 21. Microtube Showing Opened Seal

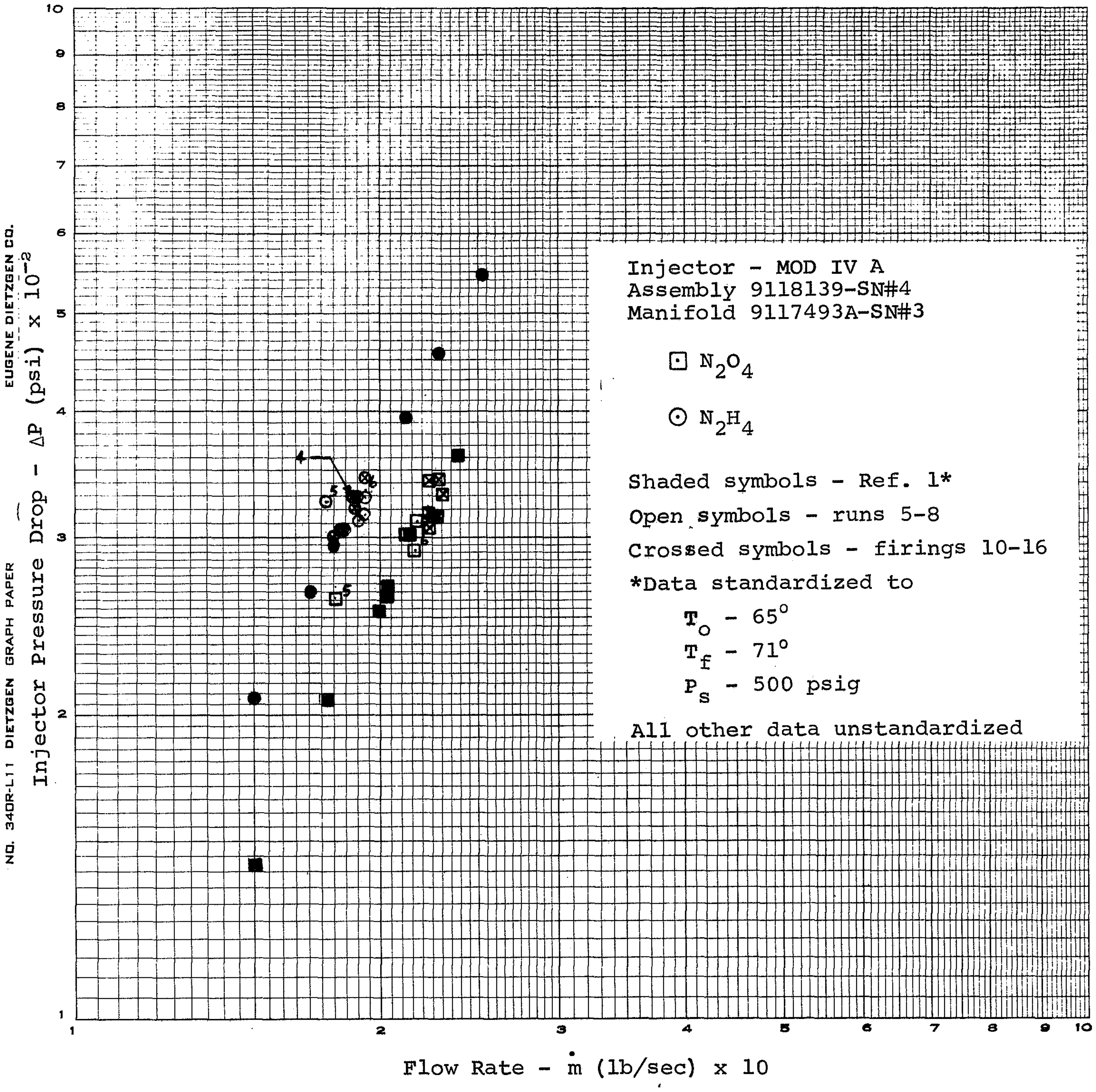


Figure 22. Measured Injector Flow Characteristic Comparison

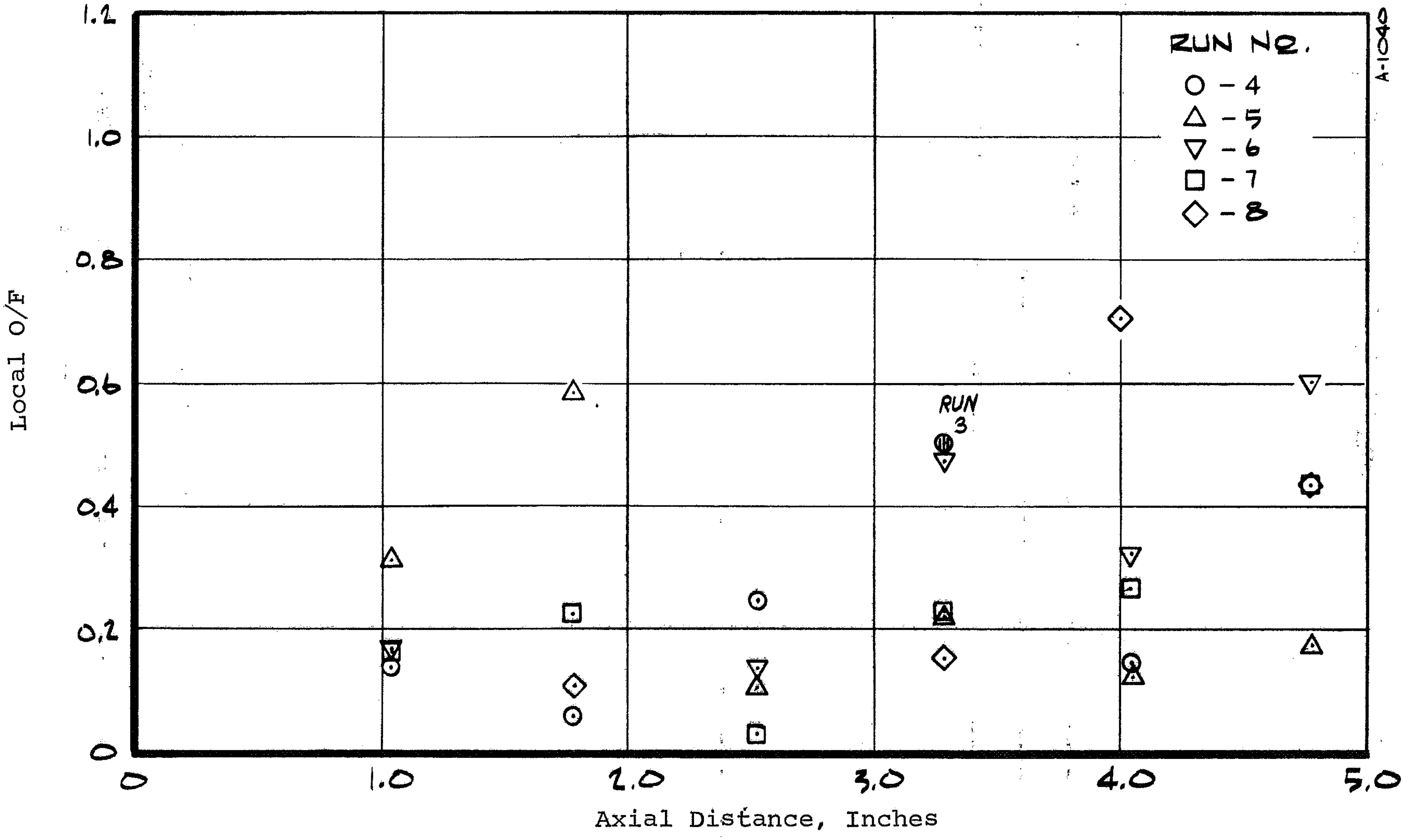


Figure 23. Local O/F Variation for Runs 3-8

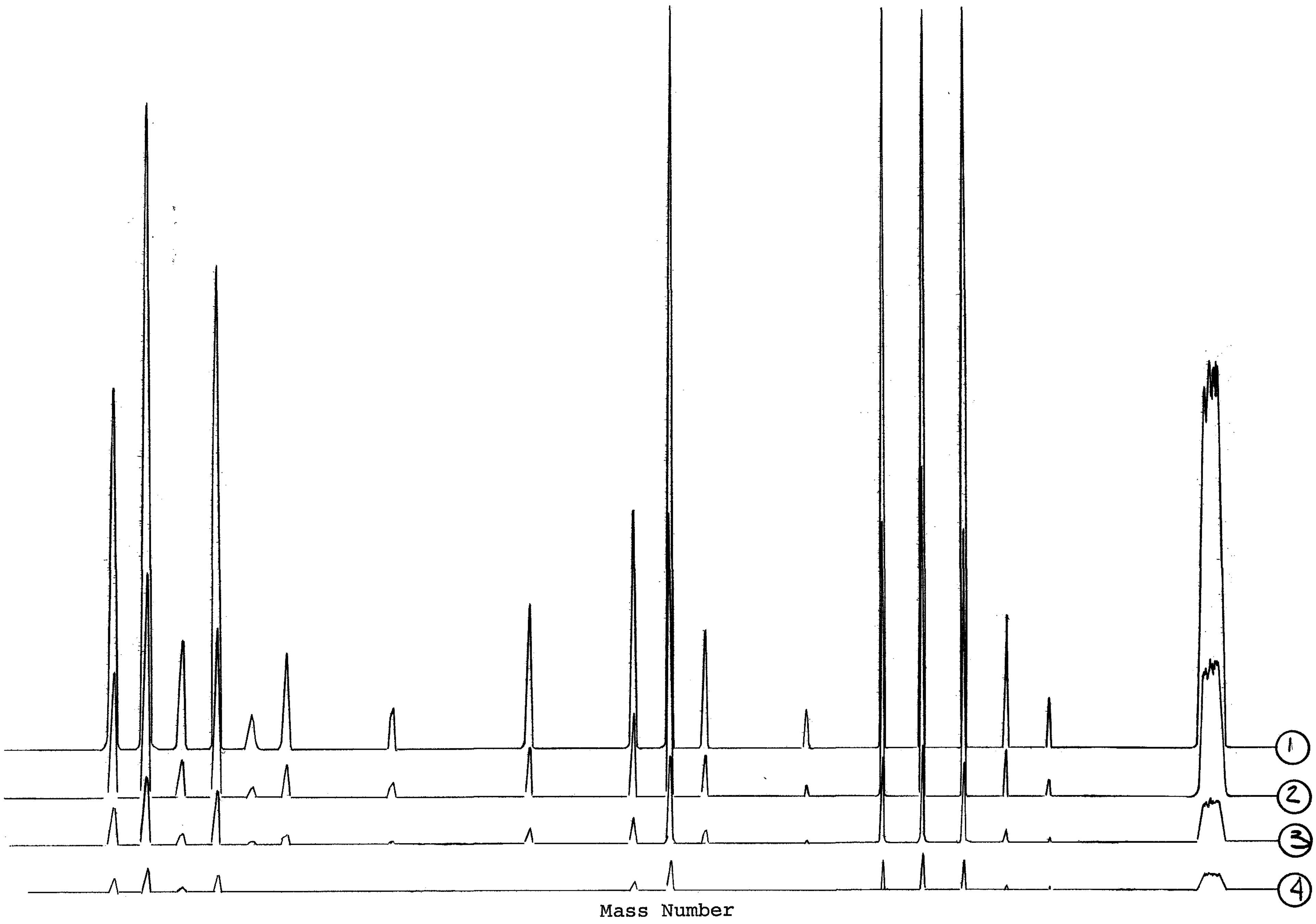


Figure 24. Typical Mass Spectrometer Trace

APPENDIX A

MASS VELOCITY IN THE LAMINAR SUBLAYER AND IN THE SINTERED ELEMENT

APPENDIX A

MASS VELOCITY IN THE LAMINAR SUBLAYER AND IN THE SINTERED ELEMENT

The starting point is taken to be the integral equation for the mass flow per unit width in the laminar sublayer for the axisymmetric or 2-dimensional case:

$$\frac{\dot{m}}{z} = \int_0^{y_e} \rho u \, dy$$

where y_e is defined to be the edge of the laminar sublayer. It is known from experimental results that the non-dimensional distance to the edge, y_e^+, is practically a constant

$$y_e^+ = y_e u_\tau / \nu \simeq 11$$

Further it is also found that the non-dimensional velocity goes like y^+, i.e.:

$$u^+ = u/u_\tau \simeq y^+$$

Using these results, transforming to the non-dimensional variables, and presuming constant density (open to question for the rocket motor situation) it follows that:

$$\frac{\dot{m}}{z} = \rho \int_0^{y_e^+} \nu \frac{u}{u_\tau} \, d\left(\frac{y u_\tau}{\nu}\right) = \rho \nu \int_0^{y_e^+} u^+ dy^+$$

$$\frac{\dot{m}}{z} = \mu \int_0^{y_e^+} y^+ dy^+ = \mu (y_e^+)^2 / 2$$

from which it follows:

$$\dot{m} \simeq 60 \mu z$$

The mass velocity for the sintered element is obtained directly by specifying z to be like the element diameter:

$$\overline{\rho_s u_s} \simeq 60 \mu / d$$

APPENDIX B

FIRING PROCEDURE

APPENDIX B
FIRING PROCEDURE

The following sequence of operations and checks are to be performed for each firing.

PRE-FIRING SEQUENCE

Seq. No.	Operation
1	Rotate injection to proper position
2	Circuit and sequencer check
2.1	Verify 150 and 350 psia solenoid valve actuation
2.2	Connect 150 and 350 psia purge lines to case, verify 80-psi-purge-actuation-circuit solenoid valve actuation; connect line to case and with 150 psia purge on, verify flow in chamber
2.3	Verify 80 psi-sampling-valve-circuit solenoid valve actuation
2.4	Complete and check all connections necessary for the foregoing procedure
3	Open sampling cylinder toggle valves
4	Secure case - begin heating to 300°F
5	Install nozzle plug, begin vacuum pump down, open sampling valves
6	When chamber temperature $(T_b) = 300^{\circ}F$, close pneumatic sampling valve, bring chamber to atmospheric pressure, verify no rise in pressure in sampling cylinders
7	Pump chamber down (vacuum), release (2) nuts on pump down fixture, open helium purge valves with 150 psia supply circuit open; maintain 150 psia purge until firing sequence

FIRING SEQUENCE

Seq. No.	Operation	Time
1	Actuate 350 psia helium-purge-supply-circuit with 80 psi purge-valve-actuation-curcuit open	-10(1)
2	Begin firing sequence	0
3	Close 350 psi helium purge supply, open 150 psi Argon purge supply	0.5
4	Gate ballistic analyzer	1.
5	Close 80 psi helium purge actuation circuit	1.4
6	Open pneumatic sampling valves	1.5
7	Close pneumatic sampling valves	2.5
8	Open 80 psi helium purge actuation circuit	2.6
9	Gate ballistic analyzer	3
10(2)	Terminate firing	4

(1) Approximate time

(2) 150 psi helium purge still operating

POST-FIRING SEQUENCE

1	Close toggle valves, remove sampling cylinders
2	Install nozzle test plug fixture with fitting open
3	Open sampling valves, purge lines to cylinders by capping nozzle plug fixture(2)
4	Remove cylinder pressure transducers
5	Cycle 350 psi helium purge to purge all lines
6	Close helium purge, close sampling valve

(2) 150 psi helium purge still operating

POST-FIRING SEQUENCE (Concluded)

Seq. No.	Operation
7	Install (6) sampling cylinders with toggle valves closed
8	Open 350 psi helium purge, open sampling valve; verify no leakage at cylinder inlets
9	Close 350 psi helium purge, release pressure from chamber
10	Close sampling valves

APPENDIX C

DATA REDUCTION PROCEDURE FOR WET CHEMISTRY GAS ANALYSIS

APPENDIX C

DATA REDUCTION PROCEDURE FOR WET CHEMISTRY GAS ANALYSIS

1. Data

1. Initial conditions (pressure and temperature of the unsampled flask) and sample flask volume
2. Non-condensible analysis
    a. LN_2 temperature
    b. LNH_3 temperature
3. Condensate analysis

Parts 2b and 3, made possible a determination of the mass of HN_3 and H_2O contained in the sample. This plus the data of 1 and 2a is sufficient to determine the mass of all other species and hence their relative amounts.

2. Analysis

Were it not for the presence of ammonia and water vapor at the time (1) was obtained, the mass of the other species could be obtained from (1) and 2a directly. It is necessary to account for the presence of these vapors and this is complicated by the fact that some of the ammonia is in solution with the water. The philosophy for the data reduction is to subtract the moles of NH_3 in the vapor phase from the moles of gas determined by (1); where the ammonia vapor fraction is determined from data on the vapor pressure of ammonia-water solutions.

If we designate the molar volume of the various gas phase species as V_i then a molar balance can be written in which the sum of the vapor molar volumes for each species equals the measured molar volume of the sample, V.

$$\sum V_i = V \quad \text{(mols)} \tag{1}$$

When the sample pressure, P_s, was measured at temperature T_s corresponding to V, the water and the ammonia were condensed forming an aqueous ammonia solution.

If x is the mass concentration of the ammonia in the water then the molar volume of ammonia in the vapor phase is given by difference

$$V_A = (W_A - x\,\dot{W}_{wc})/\mathfrak{m}_A \tag{2}$$

where W_{wc} is the mass of water in the condensed phase. This must be equal to the measured mass of water less the water in vapor phase or

$$W_{wc} = W - \frac{P_w}{P_s}\,V\mathfrak{m}_w \tag{3}$$

where the partial pressure of water vapor, P_w, is a function of X; and finally

$$V_w = \frac{W_w - W_{wc}}{\mathfrak{m}_w} \tag{4}$$

Now when V was determined the bottle was actually devoid of sample so that V must be corrected for the volume of the condensed phase in the bottle at the time P_s was determined. The volume of gas v_g in cc can then be found from the measured volume, v_m, by

$$v_g = v_m - \frac{W_{wc}}{\rho_w} - \frac{xW_{wc}}{\rho_A} \quad \text{(cc)} \tag{5}$$

where ρ is the density of the condensed phase in grams/cc. Then

$$V = \left(\frac{V_m}{V_g}\right)\left(\frac{P_s}{P^o}\right)\left(\frac{T^o}{T_s}\right) \quad \text{(moles)} \tag{6}$$

where P^o and T^o are the pressure and temperature for standard conditions and V_m the molar volume for standard conditions-22.4 liters. The molar concentration X depends upon the mole fractions of the noncondensed species present since the absorption of ammonia in water depends upon the partial pressures of the vapor (ammonia and water) above the liquid phase.

Two of the gas phase components N_2 and N_2O were partially removed in the liquid nitrogen trap and their STP molar volumes can be determined from

$$V_i = X_i V_t \tag{7}$$

where V_t is the molar volume of the trapped gas pumped off at $-30^0C < T < 40^0C$ and X_i the mole fraction of the trapped gas determined by the M.S. If the nontrapped gases are designated by subscript "j", the unknown molar volume of those gases by V_j, and the M.S. mole fraction data by X_j, then equation (1) may be written

$$V_j \sum_j X_j + V_t \sum_i X_i + V_A(x) + V_w(x) = V(x) \tag{8}$$

containing the explicit unknown V_j and x implicitly in V(via equations 2 and 5) The required defining relationship needed for a solution is the ammonia vapor pressure characteristic for the aqueous ammonia solution in which the vapor pressure for a solution of concentration x must equal

$$P_a(x) = \frac{V_A(x)}{V(x)} P_s \tag{9}$$

Having found V_j from (8) the mole fraction of all species (considering everything to be gaseous) is found from:

$$X_i = \frac{V_i}{V_t}$$

when V_t is the total of all specie molar volumes:

$$V_t = V + \left(\frac{1}{\eta_w} + \frac{x}{\eta_A} \right) \underline{W_{wc}}$$

APPENDIX D

FORMULATION OF OXIDIZER TO FUEL RATIO EQUATIONS

APPENDIX D

FORMULATION OF OXIDIZER TO FUEL RATIO EQUATIONS

1. EQUATION FOR O/F WITHOUT WATER

Two relations relating oxidizer and fuel atoms can be written based on the fact that a proportionality exists between the number of fuel molecules and hyrdogen atoms and oxidizer molecules and oxygen atoms. These two equations yield a solution in terms of the knowns N_2 and H_2 and O_2 which eliminates the unknown H_2O.

From the fact that N_2 is in both the oxidizer and fuel in the same atomic arrangement, then the O/F ratio is related to a nitrogen/ oxygen ratio. If we denote x as the fraction of hydrogen or oxygen mole fractions bound as water, then:

$$\frac{N_m}{O_m + O_x} = \left[\frac{N}{O}\right] = \frac{N_2(\text{fuel}) + N_2(\text{ox.})}{2\,O_2(\text{ox.})} = \frac{F^* + O^*}{2\,O^*} = \frac{1}{2}\left(\left[\frac{F}{O}\right]^+ + 1\right) \qquad (1)$$

and similarly for hydrogen:

$$\frac{H_m + 2O_x}{O_m + O_x} = \left[\frac{H}{O}\right] = \left[\frac{F}{O}\right]^+ \qquad (2)$$

where the $2O_x$ term represents the hydrogen contained in the water. Putting these equations in terms of percent O_m yields

$$\frac{N_m}{O_m(1+X)} = \frac{1}{2}\left(\left[\frac{F}{O}\right]^+ + 1\right) \qquad (3)$$

$$\frac{H_m}{O_m(1+X)} + \frac{2X}{1+X} = \left[\frac{F}{O}\right]^+ \qquad (4)$$

Solving (4) for x and substituting into (3) yields an expression for F/O in terms of N, H, and O mole fractions (viz:)

$$x = \frac{\left[\frac{F}{O}\right]^{+} - \left(\frac{H}{O}\right)_m}{2 - \left[\frac{F}{O}\right]^{+}} \tag{5}$$

$$\left[\frac{F}{O}\right]^{+} = \frac{2}{(1+x)}\left(\frac{N}{O}\right)_m - 1 \tag{6}$$

$$\left[\frac{F}{O}\right]^{+} = \frac{2}{\left(\frac{\left[\frac{F}{O}\right]^{+} - \left(\frac{H}{O}\right)_m}{2 - \left[\frac{F}{O}\right]^{+}} + 1\right)}\left(\frac{N}{O}\right)_m - 1$$

which after several lines of algebra yields:

$$\left[\frac{F}{O}\right]^{+} = \frac{4\left(\frac{N}{O}\right)_m + \left(\frac{H}{O}\right)_m - 2}{2 - \left(\frac{H}{O}\right)_m + 2\left(\frac{N}{O}\right)_m} \tag{7}$$

Since

$$\frac{o}{f} = \frac{\mathcal{M}_o}{\mathcal{M}_f}\left[\frac{O}{F}\right]^{+} \tag{8}$$

$$\therefore \quad \frac{o}{f} = \frac{\mathcal{M}_o}{\mathcal{M}_f}\left\{\frac{2\left(\frac{N_2}{O_2}\right)^{*} - \left(\frac{H_2}{O_2}\right)^{*} + 2}{4\left(\frac{N_2}{O_2}\right)^{*} + \left(\frac{H_2}{O_2}\right)^{*} - 2}\right\} \tag{9}$$

Equation (9) can be normalized with respect to H_2 such that:

$$\frac{o}{f} = \frac{\mathcal{M}_o}{\mathcal{M}_f}\left\{\frac{2\left(\frac{N_2}{H_2}\right)^{*} - 1 + 2\left(\frac{O_2}{H_2}\right)^{*}}{4\left(\frac{N_2}{H_2}\right)^{*} + 1 - 2\left(\frac{O_2}{H_2}\right)^{*}}\right\} \tag{10}$$

APPENDIX E

```
// JOB

LOG DRIVE   CART SPEC   CART AVAIL  PHY DRIVE
  0000        0007        0007        0000

// DUP

*DELETE                 PROD
D 26 NAME NOT FOUND IN LET/FLET


// FOR
*IOCS(CARD,1132 PRINTER,DISK,PLOTTER)
*ONE WORD INTEGERS
*LIST ALL
C      7009 DATA REDUCTION PROGRAM
C
      DIMENSION J(10),LB(10),LID(21)
         COMMON KB,KD,IMA,ICO,MAS,ITER,J,LB,MAS2
      DEFINE FILE 1(100,100,U,KB)
      DEFINE FILE 2(100,100,U,KD )
      DEFINE FILE 3(100,100,U,IMA)
      DEFINE FILE 4(100,100,U,ICO)
      DEFINE FILE 5(200,100,U,MAS)
      DEFINE FILE 6(100,100,U,MAS2)
  101 FORMAT(20I1)
  102 FORMAT(I5)
  201 FORMAT(5X20I1)
    1 ICT=0
      JMS=0
      MAS=1
      READ(2,101)J,LB
      WRITE(3,201) J,LB
      JCT=1
      IF(J(5)) 9,10,9
    9 READ (2,102) JICO
      JCT=2
      GO TO 11
   10 IF(J(6)-1) 13,13,112
  112 IF(J(6)-4) 12,13,13
   13 NTB=1
      IF(J(4)-1) 4,5,55
   55 IF(J(4)-4) 5,54,5
   54 JMS=1
      J(4)=3
    4 NTB=NTB+1
      CALL MASS(ICONT,NTB,KD,NRUN)
      ITER=0
      JM2=1
    6 CALL FILQ3(JSW,LID,NBOT)
      IF(JSW) 2,2,3
    2 CALL FINEQ(N)
      IF(ITER) 6,3,6
    3 CALL FILQ4(JSW,LID,NTB,NBOT,JICO,JICP,JICB)
      IF(JM2-3) 8,8,7
    8 CALL MASS2(ICT,JM2,JICB,JICP,NRUN)
      IF(ICT) 1,7,6
    7 IF(ICONT) 5,4,5
    5 CALL COMP(JICO,JMS)
```

```
   12 CALL HEAT
      IF(J(6)-1) 15,15,14
   15 CALL PO
   11 CALL COMM (JICO,JCT,JMS)
   14 PAUSE
      GO TO 1
      END
VARIABLE ALLOCATIONS
     KB(IC)=7FFF          KD(IC)=7FFE          IMA(IC)=7FFD          ICO(IC)=7FFC
      J(IC)=7FF9-7FF0     LB(IC)=7FEF-7FE6   MAS2(IC)=7FE5          LID(I )=003E-
   JCT(I )=0041        JICO(I )=0042          NTB(I )=0043       ICONT(I )=0044
   JSW(I )=0047        NBOT(I )=0048            N(I )=0049        JICP(I )=004A

STATEMENT ALLOCATIONS
 101   =0054  102   =0057  201   =0059  1     =0076  9     =009F  10    =00AA  112
 4     =00DA  6     =00FE  2     =00F7  3     =00FF  8     =010D  7     =011A  5
 14    =0133

FEATURES SUPPORTED
 ONE WORD INTEGERS
 IOCS

CALLED SUBPROGRAMS
 MASS     FILQ3    FINEO    FILQ4    MASS2    COMP     HEAT     PO       COMM     FLD
 SWRT     SCOMP    SFIO     SIOAI    SIOI     PAUSE    SDFIO

INTEGER CONSTANTS
     0=004E       1=004F       2=0050       3=0051       4=0052       0=0053

CORE REQUIREMENTS FOR
 COMMON      28  VARIABLES      78  PROGRAM     234

 END OF COMPILATION

// DUP

*STORE        WS  UA  PROD
CART ID 0007   DB ADDR  3953   DB CNT   0012
```

```
      SUBROUTINE FINEQ(N)
      DIMENSION IZ(7),CL(20),X(20),AL(20,20),M(20),AUC(20)
      DIMENSION ICON(21),NS(21),IPNT(21),NPERM(21)
      COMMON KB,KD,IMA,ICO,MAS,ITER
      IPM=0
      NPERM(1)=0
      LSI=0
      NS(1)=0
      IZ(1)=ITER
      IR=4
      ICO=1
      JCON=1
      LOOP=0
   34 READ(IR'ICO)(IZ(I),I=2,7),AUC,CL,X,AL
      N=IZ(2)
       GO TO (31,32),JCON
   31  DO 61 L=1,N
   61 IPNT(L)=0
      GO TO 331
   32 DO 41 L=1,I2
      I=ICON(L)
   41 AL(I,I)=10.E20
  331 DET=0.
      IR=0
      PRD=1.
      ALT=1.
      DO 15  J=1,N
      ALTA=-ALT
      BIG=0.
      DO 8  I=1,N
      IRHO=1
      IF(IR)21,5,3
    6 IRHO=IRHO+1
    3 IF(I-M(IRHO))4,8,4
    4 IF(IR-IRHO)21,5,6
    5 ALTA=-ALTA
      V= ABS(AL(I,J))
      IF(V-BIG)8,8,7
    7 BIG=V
      ALT=ALTA
      M(IR+1)=I
    8 CONTINUE
      IF(BIG)21,21,9
    9 I=M(IR+1)
      PRD=PRD*AL(I,J)
      CL(I)=CL(I)/AL(I,J)
      IF(J-N)10,16,21
   10 L=J+1
      DO 11  K=L,N
   11 AL(I,K)=AL(I,K)/AL(I,J)
      IR=IR+1
      DO 14  IU=1,N
      DO 12  IRHO=1,IR
      IF(IU-M(IRHO))12,14,12
   12 CONTINUE
      DO 13  K=L,N
   13 AL(IU,K)=AL(IU,K)-AL(IU,J)*AL(I,K)
      CL(IU)=CL(IU)-AL(IU,J)*CL(I)
  14  CONTINUE
   15 CONTINUE
      GO TO 21
   16 DET=ALT*PRD
      I=M(N)
```

```
     X(N)=CL(I)
  17 IF(J-1)20,21,18
  18 L=J
     J=J-1
     I=M(J)
     X(J)=CL(I)
     DO 19  K=L,N
  19 X(J)=X(J)-AL(I,K)*X(K)
     GO TO 17
  20 DET=0.
  21 IR=4
     SNEG=0.
     DO 36 I=1,N
     IF(X(I)&.00001) 33,36,36
  33 IF(SNEG&X(I)) 46,36,36
  46 SNEG=X(I)
     ISNEG=I
  36 CONTINUE
       IF(SNEG)47,35,47
  47 I=ISNEG
     IPNT(I)=IPNT(I)&1
     IF(IPNT(I)-2) 94,52,94
  52 IPM=IPM&1
     NPERM(IPM)=I
  94 DO 44 L=1,LSI
     IF(NS(L   )-I) 44,45,44
  45 I2=0
     DO 56 L2=L,LSI
     I3=NS(L2)
     IF(X(I3)&.00001) 48,56,56
  48 IPNT(I3)=IPNT(I3)&1
     IF(IPNT(I3)-2) 89,50,89
  50 IPM=IPM&1
     NPERM(IPM)=I3
  89 I2=I2&1
     ICON(I2)=NS(L2)
  56 CONTINUE
     GO TO  49
  44 CONTINUE
     DO 301 L=1,21
     IPNT(L)=0
 301 NPERM(L)=0
     IPM=0
     LSI=LSI&1
     NS(LSI)=I
     I2=1
     ICON(I2 )=I
  49 LOOP=LOOP&1
      DO 73 L=1,I2
     DO 71 L2=1,IPM
     IF(ICON(L)-NPERM(L2)) 71,72,71
  71 CONTINUE
     GO TO 73
  72 NPERM(L2)=-NPERM(L2)
  73 CONTINUE
     DO 74 L2=1,IPM
     IF(NPERM(L2))76,74,75
  75 I2=I2&1
     ICON(I2)=NPERM(L2)
     GO TO 74
```

```
   76 NPERM(L2)=-NPERM(L2)
   74 CONTINUE
      JCON=2
      ICO=1
      IR=4
      CALL DATSW(1,ISWI)
       GO TO (91,92),ISWI
   91 WRITE(3,201 )(ICON(L),L=1,I2)
  201 FORMAT(/10I8)
      CALL DATSW(2,ISWI)
      GO TO(35,92),ISWI
   92 IF(LOOP-20) 34,35,35
   35 ICO=1
      WRITE(IR'ICO)(IZ(I),I=2,7),AUC,CL,X,AL
      RETURN
      END
// DUP
*STORE      WS  UA  FINEQ
```

```
PAGE    1

// JOB

LOG DRIVE    CART SPEC    CART AVAIL   PHY DRIVE
  0000          0006         0006         0000

// DUP

*DELETE                 FUNXS
CART ID 0006    DB ADDR   3DC1    DB CNT    0007

// FOR
*ONE WORD INTEGERS
*LIST ALL
      SUBROUTINE FUNXS(C,F,X,Y,N,NDP,NC)
      DIMENSION F(1)
      DIMENSION J(10),LB(10)
      COMMON KB,KD,IMA,ICO,MAS,ITER,J,LB,MAS2
  101 FORMAT( 8F10.4)
    1 I=6
      READ(I'MAS2)(F(I),I=1,NC)
    3 C=Y
      RETURN
      END
VARIABLE ALLOCATIONS
    KB(IC)=7FFF           KD(IC)=7FFE         IMA(IC)=7FFD            ICO(IC)=7FFC
     J(IC)=7FF9-7FF0     LB(IC)=7FEF-7FE6   MAS2(IC)=7FE5              I(I  )=0000

UNREFERENCED STATEMENTS
 1       3

STATEMENT ALLOCATIONS
 101   =0004   1     =0015   3     =002F

FEATURES SUPPORTED
 ONE WORD INTEGERS

CALLED SUBPROGRAMS
 FLD       FSTO     SUBSC    SUBIN    SDRED    SDFX

INTEGER CONSTANTS
     6=0002        1=0003

CORE REQUIREMENTS FOR FUNXS
 COMMON      28  VARIABLES       2  PROGRAM      52

 END OF COMPILATION

// DUP

*STORE       WS   UA   FUNXS
CART ID 0006    DB ADDR   47EA    DB CNT    0005
```

6

```
PAGE    1

// JOB

LOG DRIVE   CART SPEC   CART AVAIL  PHY DRIVE
  0000        0006        0006        0000

// DUP

*DELETE                 COMM
CART ID 0006   DB ADDR  46F3   DB CNT   0026

// FOR
*ONE WORD INTEGERS
*LIST ALL
      SUBROUTINE COMM(JSW,JCT,JMS)
      DIMENSION          PREAD(50),WF(50)
      DIMENSION  I3(6),X(13),I5(3),ICOMM(40) ,J(10),I4(6) ,VID(21),LID(2
     11)
      COMMON KB,KD,IMA,ICO,MAS,ITER,J,LB,MAS2
  101 FORMAT(40A2)
  201 FORMAT(     64X11HPAGE 4 OF 4//21X35HCOMMENTS ON DATA AND DATA REDU
     1CTION//29X11HRUN NUMBER-I3,
     2      ///77(1H-)////)     .
  202 FORMAT(/1X39A2)
  203 FORMAT(//10X37HO/F ANALYZED BY ELEMENTAL COMPOSITION)
  204 FORMAT(//10X37HO/F ANALYZED BY WATERLESS FORMULATION)
  205 FORMAT(//10X23HH2O DETERMINED FROM O/F)
  206 FORMAT(1H1)
  207 FORMAT(I3,1XI1,1XI2,1XI1,5(1XI2,1XE10.4)/ 5(1XI2,1XE10.4))
  208 FORMAT (I3,2XI2,2XI3,4X,4(I3,E13.6)/ 5(I3,E13.6))
      ICONT=0
      IS=4
      ICO=JSW
        GO TO (9,2),JCT
    9 KA=1
      KB=1
      READ(KA'KB) I3,X
      READ(KA'KB)I4,X,(X(I),I=1,11),I5
      WRITE(3,201) I3(1)
      IF(J(1))4,5,4
    5 WRITE(3,203)
      GO TO 3
    4 WRITE(3,204)
      IF(J(3))3,8,3
    8 WRITE(3,205)
    3 READ(2,101) ICOMM
      IF(ICOMM(1)-16448) 1,2,1
    1 WRITE(3,202)(ICOMM(I),I=2,40)
      GO TO 3
    2      IF(J(4)-1) 42,99,499
  499 IF(JMS) 42,99,42
   42 JJ=0
   17 JJ=JJ+1
       READ(IS'ICO)LCI,IBOT,K2,(LID(L),VID(L),L=1,K2)
      IF(JJ-LCI   ) 33,31,33
   31 ICONT=1
      IF(LCI-6) 33,20,33
   20 ICONT=2
   33 WRITE(2,207)I3(1) ,IBOT,K2,ICONT ,(LID(L),VID(L),L=1,K2)
      IF(JJ-LCI) 17,18,18
```

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PAGE    2

   18    MAS=1
      I=5
      DO 99 L=1,LCI
      READ(I'MAS) NC,NDP,NBOT
      READ(I'MAS) (LID(IS),IS=1,NC)
      DO 98 IP=1,NDP
      READ(I'MAS) FNP,PREAD(IP),WF(IP)
   98 LID(IP)=FNP
      WRITE(2,208) I3(1),NBOT,NDP,(LID(IP),PREAD(IP),IP=1,NDP)
   99 CONTINUE
      WRITE(3,206)
      RETURN
      END
VARIABLE ALLOCATIONS
    KB(IC)=7FFF          KD(IC)=7FFE          IMA(IC)=7FFD          ICO(IC)=7FFC
     J(IC)=7FF9-7FF0     LB(IC)=7FEF         MAS2(IC)=7FEE       PREAD(R )=0062-0000
   VID(R )=010A-00E2   FNP(R )=010C           I3(I )=0113-010E    I5(I )=0116-0114 I
   LID(I )=0159-0145 ICONT(I )=015A           IS(I )=015B          KA(I )=015C
   LCI(I )=015F        IBOT(I )=0160          K2(I )=0161           L(I )=0162
  NBOT(I )=0165          IP(I )=0166

STATEMENT ALLOCATIONS
 101   =0174  201   =0177  202   =01AB  203   =01B0  204   =01C8  205   =01E0  206   =01F
 5     =0272  4     =0278  8     =0282  3     =0286  1     =0294  2     =02AD  499   =02B
 20    =02F8  33    =02FC  18    =032A  98    =0367  99    =03A0

FEATURES SUPPORTED
 ONE WORD INTEGERS

CALLED SUBPROGRAMS
 FLD     IFIX    SRED    SWRT    SCOMP   SIOAI   SIOFX   SIOIX   SIOI    SUBSC   S
 SDIX    SDF     SDI

INTEGER CONSTANTS
     0=016A      4=016B      1=016C      11=016D      3=016E      2=016F   16448=017

CORE REQUIREMENTS FOR COMM
 COMMON      18  VARIABLES     362  PROGRAM      582

 END OF COMPILATION

// DUP

*STORE        WS  UA  COMM
CART ID 0006   DB ADDR  47CB   DB CNT   0026
```

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PAGE    1

// JOB

LOG DRIVE   CART SPEC   CART AVAIL  PHY DRIVE
  0000        0008        0008        0000

// FOR
*ONE WORD INTEGERS
*IOCS(CARD,1132 PRINTER)
*LIST ALL
      DIMENSION P(46),NP(30),RES(30)
      DIMENSION X(11),C(11),R(11),PC(11),S(11),SP(6)
      DATA S/'H2  ','H2O ','O2  ','N2  ','NH3 ','NO  ','NO2 ','N2H4',
     1   'A   ','HE  ','CO2 '/
      KIN=2
      KOUT=3
      C(2)=1.696
      C(3)=.8976
      C(4)=.999
      C(5)=.505
      C(6)=.9298
      C(7)=.195
      C(8)=.524
      C(11)=1.033
   67 READ(KIN,7) C(9),C(10),C(1)
    7 FORMAT(3F10.3)
      WRITE(3,53)
   53 FORMAT(1H1)
      INDEX=1
   70 DO 75 I=1,46
   75 P(I)=0.
      DO 80 I=1,30
   80 RES(I)=0.
      READ(KIN,1) IRUN,IBOT,NUM,(NP(I),RES(I),I=1,NUM)
    1 FORMAT(I3,2X,I2,3X,I2,4X,4(1X,I2,E13.6)/5(1X,I2,E13.6))
      IF (IRUN)  67,200,12
   12 DO 15 I=1,NUM
      J=NP(I)
      IF (J*(47-J)) 15,15,13
   13 P(J)=RES(I)
   15 CONTINUE
      X(11)=P(44)
      P(28)=P(28)-X(11)*.1017
      P(46)=P(46)-.0041*X(11)
      IF (P(46)) 16,16,17
   16 P(46)=0.
   17 X(7)=P(46)/.37
      P(30)=P(30)-X(7)
      X(9)=P(40)
      X(8)=P(31)/.473
      P(17)=P(17)-.261*X(8)
      P(28)=P(28)-.214*X(8)
      P(30)=P(30)-.313*X(8)
      P(32)=P(32)-X(8)
      IF (P(32)) 18,18,19
   18 P(32)=0.
   19 X(3)=P(32)
      X(2)=P(18)
      P(17)=P(17)-.2291*X(2)
      IF (P(17)) 211,211,212
```

```
PAGE    2

  211 P(17)=0.
  212 X(5)=P(17)
      IF (P(30)) 20,20,21
   20 P(30)=0.
   21 X(6)=P(30)
      IF (P(28)) 22,22,23
   22 P(28)=0.
   23 X(4)=P(28)
      X(10)=P(4)
      X(1)=P(2)
      SUM=0.
      DO 30 I=1,11
   30 SUM=SUM+X(I)/C(I)
      DO 40 I=1,11
      R(I)=X(I)/C(I)
   40 PC(I)=R(I)/SUM*100.0
      WRITE(KOUT,2)    IRUN,IBOT
    2 FORMAT(1H0,17X,4HRUN ,I3,5X,6HFLASK ,I2/1H ,9X,7HSPECIES,14X,
     1    8HPEL PRES,9X,7HPERCENT)
      SUM=0.
      DO 60 I=1,6
   60 SUM=SUM+PC(I)
      DO 65 I=1,6
   65 SP(I)=PC(I)/SUM*100.
      DO 90 I=1,6
   90 WRITE (KOUT,3) S(I),X(I),R(I),PC(I),SP(I)
      DO 95 I=7,11
   95 WRITE (KOUT,3) S(I),X(I),R(I),PC(I)
    3 FORMAT(1H ,A4,2X,F10.3,6X,3(6X,F10.3))
      SUM=0.
      DO 52 I=1,5
   52 SUM=SUM+PC(I)
      DO 54 I=1,5
   54 PC(I)=PC(I)/SUM
      SUM=2.*PC(1)+3.*PC(2)+2.*PC(3)+2.*PC(4)+4.*PC(5)
      HY=(2.*PC(1)+2.*PC(2)+3.*PC(5))/SUM
      OX=(PC(2)+2.*PC(3))/SUM
      EN=(2.*PC(4)+PC(5))/SUM
      WRITE(3,55) HY,OX,EN
   55 FORMAT(1H0,6X,1HH,F9.5,12X,1HO,F9.5,6X,1HN,F9.5//)
      INDEX=INDEX+1
      IF (INDEX-4) 70,85,85
   85 INDEX=1
      WRITE(3,53)
      GO TO 70
  200 STOP
      END
VARIABLE ALLOCATIONS
     P(R )=005A-0000   RES(R )=0096-005C      X(R )=00AC-0098      C(R )=00C2-00.
     S(R )=0104-00F0    SP(R )=0110-0106   SUM(R )=0112             HY(R )=0114
    NP(I )=013F-0122   KIN(I )=0140        KOUT(I )=0141         INDEX(I )=0142
  IBOT(I )=0145        NUM(I )=0146           J(I )=0147

STATEMENT ALLOCATIONS
 7     =0188  53    =018B  1     =018E  2     =01A0  3     =01C3  55    =01CE  67
 12    =029A  13    =02B0  15    =02C0  16    =02F0  17    =02F6  18    =0355  19
 21    =0399  22    =03A8  23    =03AE  30    =03CE  40    =03F3  60    =0416  65
 54    =04A2  85    =0536  200   =0540
```

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PAGE   3

FEATURES SUPPORTED
 ONE WORD INTEGERS
 IOCS

CALLED SUBPROGRAMS
 FADDX   FSUBX   FMPY    FMPYX   FDIV    FDIVX   FLD     FLDX    FSTO    FSTOX
 SCOMP   SFIO    SIOFX   SIOIX   SIOF    SIOI    SUBSC   STOP

REAL CONSTANTS
  .169600E 01=0152     .897600E 00=0154     .999000E 00=0156     .505000E 00=0158
  .524000E 00=015E     .103300E 01=0160     .000000E 00=0162     .101700E 00=0164
  .473000E 00=016A     .261000E 00=016C     .214000E 00=016E     .313000E 00=0170
  .200000E 01=0176     .300000E 01=0178     .400000E 01=017A

INTEGER CONSTANTS
     2=017C       3=017D       1=017E       46=017F       30=0180       47=0181       11=
     4=0186       0=0187

CORE REQUIREMENTS FOR
 COMMON       0  VARIABLES     238  PROGRAM    1098

 END OF COMPILATION

// XEQ
```

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PAGE   1

// JOB

LOG DRIVE   CART SPEC   CART AVAIL  PHY DRIVE
  0000        0008         0008        0000

// DUP

*DELETE                 ECHF
CART ID 0008   DB ADDR  311B   DB CNT   0099

// FOR
*ONE WORD INTEGERS
*IOCS(CARD,1132 PRINTER,PLOTTER)
*LIST ALL
      DIMENSION S(8),X(65),Y(65),ICLBL(6),Z(65),T(65),XQ(65),XT(65),
     1YLBL1(10),YLBL2(10),XLBL(10),HEAD(10),SUB(20),XFLUX(6),
     2CALS(8),CALR(8),XEAD(65),TEMW(65),XREAD(65),IXBLK(20),IYBLK(20),
     3IHBLK(20),ISUBL(40),XTRA(10)
      DATA IXBLK/20*'    '/,IYBLK/20*'    '/,IHBLK/20*'    '/,ISUBL/40*'    '/
      DATA YLBL2/      '    ','TEMP','ERAT','URE ','RISE',' DEG','.F. '
     1,'    ','    '/
      DATA YLBL1/'    ','    ','    ','HEAT',' FLU','X BT','U/FT',
     1'2-SE','C.  ','    '/
      DATA XLBL/'    ','    ','    ','    ','TIME','-SEC','ONDS','    ',
     1'    ','    '/
      DATA HEAD/'    ','    ','MOTO','R HE','AT F','LUX ','CALC','ULAT',
     1'ION ','    '/
      DATA COND2,RHO2,CP2,RHO1,CP1,D/ .06     ,  559.0  ,  0.0915  ,0.,0
     1.,0./
      DATA ICLBL/6*'    '/
  100 FORMAT(20A4)
  300 FORMAT(4X, 2F6.2,2E9.4,I2)
  500 FORMAT(//10X4HTIMES5X7HREADING4X10MILLIVOLTS3X,8HTEMP. F., 6X,
     19HHEAT FLUX)
  600 FORMAT(8X,F6.3,6X,F6.3,6X,F6.2,6X,F8.2,4X,F10.2)
  700 FORMAT(I5,3F10.4,2I5)
  800 FORMAT(I5,3F10.4,I5,F10.4)
  701 FORMAT(I3,14XI1,2XF5.2,5XI2,4(F5.2,F5.0) )
  702 FORMAT(2I5,6(1XI1,F9.2 ))
  703 FORMAT(///20X25HHEAT FLUX FOR STATION NO.I2,1H=F8.2,12HBTU/FT2-SEC
     1.   )
  706 FORMAT(//16X5HAXIAL8X13HSAMPLING TIME8X9HM.V. BASE8X9HTIME STEP
     1/15X7HSTATION10X7HSECONDS29X7HSECONDS/ 18XI1, 9XF10.2,13XF6.2,10X
     2    F6.3,20XI2)
  707 FORMAT(/30X11HCALIBRATION//5X3HRUN1X7HSTATION1X4HZERO2X9HNUMBER OF
     1     14X15HREADING/SIGNAL /15X7HREADING3X5HSTEPS/)
  708 FORMAT( 5XI2,4XI1,  F10.4,4XI1,4X4(F6.2,2XF4.1))
  900 FORMAT(1H116X20A4)
 1100 FORMAT(/10X     20A4)
      DO 43 L=1,6
   43 XFLUX(L)=0.
   56 WRITE(3,900) (HEAD(I),I=1,10)
      READ(2,100) (SUB(I),I=1,20)
      WRITE(3,1100) (SUB(I),I=1,20)
      READ(2,700)NSTA,TIME,BASE,DT ,IPLOT,IB
C     IB IS THE NUMBER OF POINTS READ ON THE FIRST PART OF THE CURVE
      WRITE(3,706)NSTA,TIME,BASE,DT    ,IPLOT
      IPLOT=IPLOT+1
      DT=DT+.00001
```

```
  1 IC1=1
    IC2=4
    I=1
    JC1=1
    WRITE(3,707)
 87 READ(2,701)NRUN,NSTA,ZRO,NSTP,(CALR(L),CALS(L),L=IC1,IC2)
    WRITE(3,708)NRUN,NSTA,ZRO,NSTP,(CALR(L),CALS(L),L=IC1,IC2)
    IF(NSTP-4) 85,85,86
 86 IF(IC1-1)89,89,85
 89 IC1=5
    IC2=8
    GO TO 87
 85 CAL=0.
    DO 88 L=1,NSTP
 88 CAL=CAL+(CALS(L)-BASE)/(CALR(L)-ZRO)
    FNS=NSTP
    CAL =CAL/FNS
 84 READ(2,300)       ZERO,XREAD(I),TIM1,TIM2,     NCONT
    XEAD(I)=(XREAD( I)-ZRO)*CAL+BASE
    CALL TCRAL(XEAD(I),TEMP)
    TEMP=TEMP-460.
    T(I)=TEMP
    TEMW(I)=TEMP
    I=I+1
    IF(NCONT) 82,84,82
 82 N=I-1
    WRITE(3,500)
    FXT=T(1)
    DO 50 I=1,N
 50 T(I)=T(I)-FXT
    DIT=0.
    CON1=0.
    CON2=0.
    Z(1)=0.
    JOKE=0
    K1=2
    K2=IB
    KN=IB
    J1=2
    J2=IB
 11 DO 5 I=1,8
  5 S(I)=0.
    DO 10 I=K1,K2
    Y(I) = (I-1)*DT-DIT
    X(I) = SQRT(Y(I))
    S(1) = S(1) + Y(I)
    S(2) = S(2) + X(I)*Y(I)
    S(3) = S(3) + Y(I)*Y(I)
    S(4) = S(4) + X(I)**5
    S(5) = S(5) + Y(I)**3
    S(6) = S(6) + (T(I)-CON1)*X(I)
    S(7) = S(7) + (T(I)-CON1)*Y(I)
 10 S(8) = S(8) + (T(I)-CON1)*Y(I)*X(I)
    DO 15 I=1,8
 15 S(I) = S(I)/FLOAT(KN)
    A1 = S(2)*S(2)-S(1)*S(3)
    A2 = S(2)*S(3)-S(1)*S(4)
    B1 = S(3)*S(3)-S(2)*S(4)
    B2 = S(3)*S(4)-S(2)*S(5)
```

```
      C1 = S(2)*S(6)-S(1)*S(7)
      D1 = S(3)*S(7)-S(2)*S(8)
      D = A1*B2-A2*B1
      B = (C1*B2-D1*A2)/D
      C = -(C1*B1-D1*A1)/D
      A = (S(6)-B*S(2)-C*S(3))/S(1)
      DO 35 I=J1,J2
   35 Z(I)=X(I)*(A+B*X(I)+C*Y(I)) + CON2
      IF (JOKE) 37,36,37
   36 K1=IB
      K2=N
      KN=N-IB+1
      J1=IB+1
      J2=N
      DIT=(IB-1)*DT
      CON1 = T(IB)
      CON2 = Z(IB)
      JOKE=1
      GO TO 11
   37 XQ(1)=0.
      C1=.5*SQRT(3.1416*COND2*RHO2*CP2/DT)
      C2=RHO1*CP1*D/(2.0*DT)
      XT(1)=0.0
      K=N-1
      DO 30 I=2,K
      Q=0.0
      A=I
      KX=I-1
      DO 20 J=1,KX
      B=J
      XX=(Z(I)*SQRT(B-.5)-(Z(J+1)+Z(J))/2.0*SQRT(A-1.0))/(A-B-.5)**1.5
   20 Q=Q+XX
      XQ(I)=C1/SQRT(A-1.0)*(Z(I)+Q/3.1416)+C2*(Z(I+1)-Z(I-1))
      XT(I)=XT(I-1)+DT
      IF(XT(I)-TIME) 40,41,41
   41 GO TO (42,40),JC1
   42 JC1=2
      ISAV=I
      XFLUX(NSTA)=XQ(I-1)+(XQ(I)-XQ(I-1))/DT*(TIME-XT(I-1))
   40 WRITE(3,600) XT(I), XREAD(I),XEAD(I),TEMW(I),      XQ(I)
   30 CONTINUE
      IF(IPLOT-1) 2,998,2
  998 XTMIN=XT(1)
      XTMAX=XT(1)
      XRMIN=XREAD(1)
      XRMAX=XREAD(1)
      TMIN=T(1)
      TMAX=T(1)
      ZMIN=Z(1)
      ZMAX=Z(1)
      DO 101 I=2,K
      XTMIN=AMIN1(XTMIN,XT(I))
      XTMAX=AMAX1(XTMAX,XT(I))
      XRMIN=AMIN1(XRMIN,XREAD(I))
      XRMAX=AMAX1(XRMAX,XREAD(I))
      TMIN=AMIN1(TMIN,T(I))
      TMAX=AMAX1(TMAX,T(I))
      ZMIN=AMIN1(ZMIN,Z(I))
  101 ZMAX=AMAX1(ZMAX,Z(I))
```

```
       CALL GRID(0.,6.,XTMIN,XTMAX,XRMIN,XRMAX,IHBLK,ISUBL,IXBLK,
      1IYBLK,XTRA)
       CALL LINE(XT,XREAD,K,6,ICLBL,XTRA)
       CALL FINSH(XTRA)
       TMIN=AMIN1(TMIN,ZMIN)
       TMAX=AMAX1(TMAX,ZMAX)
       CALL GRID(0.,6.,XTMIN,XTMAX,TMIN,TMAX,IHBLK,ISUBL,IXBLK,IYBLK,
      1XTRA)
       CALL LINE(XT,T,K,6,ICLBL,XTRA)
       CALL LINE(XT,Z,K,-6,ICLBL,XTRA)
       CALL FINSH(XTRA)
     2 WRITE(3,703)                      NSTA,XFLUX(NSTA)
       CALL DATSW (15,IDIOT)
       IF (IDIOT-1) 822,56,822
   822 READ(2,100) DUM
       IPLOT=3
       WRITE(2,100) (SUB(I),I=1,20)
       WRITE(2,800) NSTA,TIME,BASE,DT,IPLOT,EXT
       M=N-1
       DO 825 I=1,M
   825 WRITE(2,826) NRUN,NSTA,Z(I)
   826 FORMAT(I3,I2,7X,F15.6)
       ID=1
       WRITE(2,827) NRUN,NSTA,Z(N),ID
   827 FORMAT(I3,I2,7X,F15.6,16X,I1)
       GO TO 56
       END
VARIABLE ALLOCATIONS
     S(R )=000F-0000      X(R )=0090-0010      Y(R )=0112-0092      Z(R )=0194-0114
    XT(R )=031A-029A YLBN1(R )=032F-031C YLBL2(R )=0342-0330  XLBL(R )=0356-0344
 XFLUX(R )=039F-0394   CALS(R )=03AF-03A0   CALR(R )=03BF-03B0  XEAD(R )=0440-03C0
  XTRA(R )=0558-0546   TIME(R )=055A        BASE(R )=055C         DT(R )=055E
   ENS(R )=0564        ZERO(R )=0566        TIM1(R )=0568       TIM2(R )=056A
   DIT(R )=0570        CON1(R )=0572        CON2(R )=0574         A1(R )=0576
    B2(R )=057C          C1(R )=057E          D1(R )=0580          D(R )=0582
     A(R )=0588       COND2(R )=058A        RHO2(R )=058C        CP2(R )=058E
   CP1(R )=0594           Q(R )=0596          XX(R )=0598      XTMIN(R )=059A
 XRMAX(R )=05A0        TMIN(R )=05A2        TMAX(R )=05A4       ZMIN(R )=05A6
 ICLBL(I )=05BB-05B6 IXBLK(I )=05CF-05BC IYBLK(I )=05E3-05D0 IHBLK(I )=05F7-05E4
     I(I )=0621        NSTA(I )=0622       IPLOT(I )=0623         IB(I )=0624
   JC1(I )=0627        NRUN(I )=0628        NSTP(I )=0629      NCONT(I )=062A
    K1(I )=062D          K2(I )=062E          KN(I )=062F         J1(I )=0630
    KX(I )=0633           J(I )=0634        ISAV(I )=0635      IDIOT(I )=0636

UNREFFERENCED STATEMENTS
 702      1

INVALID STATEMENTS
 C 27 ERROR AT STATEMENT NUMBER 500

OUTPUT HAS BEEN SUPPRESSGD

 END OF COMPILATION

// DUP
M 13  DUP SUPPRESSED
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```
      SUBROUTINE FILQ4(JSW,LID ,NTB,NBOT,JICO,JICP ,JICB)
C     GENERAL LEAST SQUARE CURVE FIT PROGRAM  (FISLQ)    / RMK      PART
      DIMENSION ALPH(20),JCT(20),S(20),T(20),U(20),V(20),C(20),A(20,20),
     *AC(20),X(20),Y(20),FXY(20),F(20,20),W(20),H(20),AUC(20)
      DIMENSION K(10),LB(10),LID(20)
      COMMON KB,KD,IMA,ICO,MAS,ITER,K,LB
      EQUIVALENCE(X(1),AC(1))
    2 FORMAT(1XE11.7,2F12.7)
    6 FORMAT(1H /25H CURVE FIT CONSTANTS  ---/10X26HF(X,Y) = SUM( AI*FI(
     1X,Y) )/(2XA1,I1,2H =  E14.7,8XA1,I1,2H =  E14.7,8XA1,I1,2H =  E14.
     27))
    7 FORMAT(2XA1,I2,1H= E14.7,8XA1,I2,1H=  E14.7,8XA1,I2,1H=  E14.7)
    8 FORMAT(1H /25H IMPOSED CONSTRAINTS  --- /10X34HG(S,T,U,V) = SUM( A
     1I*GI(S,T,U,V) ) /12H I    OUTPUT6X9(3H-  )5HINPUT9(3H  -)/27H D  G
     2(S,T,U,V)   G(S,T,U,V)7X1HS12X1HT11X1HU12X1HV)
    9 FORMAT(I2,6(1XE12.5))
   10 FORMAT(1H /46H CURVE FIT COMPARISON AND SUPPLEMENTARY OUTPUT  /
     17X1HX12X1HY9X6HWEIGHT5X23HINPUT - F(X,Y) - OUTPUT5XA1,6H1(X,Y))
   11 FORMAT(30XA1,I1,5H(X,Y)6XA1,I1,5H(X,Y)6XA1,I1,5H(X,Y)A1,I1,5H(X,Y)
     1)
   12 FORMAT(6(1XE12.5))
   13 FORMAT(27XE12.5,1XE12.5,1XE12.5,1XE12.5)
   17 FORMAT(1H /23H NO CONSTRAINTS IMPOSED )
   18 FORMAT (17H END OF CURVE FIT)
      ICO=1
      MA=4
      READ(MA'ICO)N,NDP,NC,NDPS,NCT,NADP,AUC,C,ALPH,A,JCT,S,T,U,V,W,X,Y,
     *FXY,F,I,NCP,NCPC,J,NAUXF,NLF,NHI,IDK,NL,IMA
      MA=3
      IALT=16577
      IHLT=16584
      IF(JSW)509,51,51
  509 READ(MA'IDK)A,C
      IDK=IMA
   51 NCS=NC
      IDK=1
      IF(NTB-2) 301,301,303
  303 ICO=JICP
      GO TO 302
  301 JICO=ICO
  302 J=4
      JICB=ICO
      WRITE(J'ICO)NTB,NBOT,NC,(LID(I),ALPH(I),I=1,NC)
      JICP=ICO
      IF(NC-9)502,502,511
  511 NCS=9
  502 WRITE(3,6)(IALT,I,ALPH(I),I=1,NCS)
      IF(NC-9)504,504,503
  503 WRITE(3,7)(IALT,I,ALPH(I),I=10,NC)
  504 IF(NCT)54,54,52
   52 NCP=NCPC-NCT
      WRITE(3,8)
      DO 531  I=1,NCT
      GXY=0.
      NCP=NCP+1
      DO 53  J=1,NC
   53 GXY=GXY+A(NCP,J)*ALPH(J)
  531 WRITE(3,9)JCT(I),GXY,C(NCP),S(I),T(I),U(I),V(I)
      GO TO 541
   54 WRITE(3,17)
```

```
 541 NSUM=NDP+NADP
     IF(NSUM)21,21,551
 551 IF(NAUXF)552,552,553
 552 WRITE(3,10)
     GO TO 55
 553 DO 554  I=1,NAUXF
 554 H(I)=0.
     WRITE(3,10)IHLT
     IF(NAUXF-1)55,55,555
 555 WRITE(3,11)(IHLT,I,I=2,NAUXF)
  55 N=0
     IMA=IDK
     NHI=NDP
     NLF=NDP
     IF(NDP)72,72,556
 556 IF(NDP-NL)60,60,56
  56 NHI=NL
     GO TO 59
  57 IF(NLF-NL)58,58,59
  58 NHI=NLF
  59 READ(MA'IMA)(FXY(I),(F(J,I),J=1,NC),X(I),Y(I),W(I),I=1,NHI)
     IDK=IMA
  60 DO 70  I=1,NHI
     N=N+1
     GXY=0.
     IF(NLF)62,62,61
  61 XI=X(I)
     YI=Y(I)
     WI=W(I)
     FY=FXY(I)
     GO TO 63
  62 READ( 2,2)XI,YI
     CALL FUNXS(FY,F(1,I),XI,YI)
  63 DO 64  J=1,NC
  64 GXY=GXY+F(J,I)*ALPH(J)
     IF(NAUXF)69,69,65
  65 CALL AUXF(XI,YI,FY,GXY,H,ALPH,N)
     WRITE(3,12)XI,YI,WI,FY,GXY,H(1)
     IF(NAUXF-1)70,70,68
  68 WRITE(3,13)(H(J),J=2,NAUXF)
     GO TO 70
  69 WRITE(3,12)XI,YI,WI,FY,GXY
  70 CONTINUE
     NLF=NLF-NHI
     IF(NLF)21,71,57
  71 IF(NADP)21,21,72
  72 NHI=NADP
     WRITE(3,18)
     WI=0.
     GO TO 60
  21 MA=4
     ICO=1
     WRITE(MA'ICO)N,NDP,NC,NDPS,NCT,NADP,AUC,C,ALPH,A,JCT,S,T,U,V,W,X,Y
    1,FXY,F,I,NCP,NCPC,J,NAUXF,NLF,NHI,IDK,NL,IMA
     WRITE(3,19)
  19 FORMAT(/5X  24HEND OF CURVE FIT ROUTINE)
     RETURN
     END
// DUP
*STORE      WS  UA  FILQ4
```

```
      SUBROUTINE FILO3(JSW,LID,NBOT)
C     GENERAL LEAST SQUARE CURVE FIT PROGRAM  (FISLQ)     / RMK   PART 1
      DIMENSION ALPH(20),JCT(20),S(20),T(20),U(20),V(20),C(20),A(20,20),
     *AC(20),X(20),Y(20),FXY(20),F(20,20),W(20),        AUC(20)
      DIMENSION JJ(10),LB(10),LID(20)
      COMMON KB,KD,IMA,ICO,MAS,ITER,JJ,LB
    1 FORMAT(9I5)
    2 FORMAT(1XF11.7,2E12.7)
    3 FORMAT(19A4,A3)
    4 FORMAT(1X19A4,A3)
    5 FORMAT(1H19X59HGENERALIZED LEAST SQUARE CURVE FIT PROGRAM  - -  AE
     1ROTHERM   /1H )
   14 FORMAT (30H UNACCEPTABLE INPUT BECAUSE OFI2/10X64H1  NO.OF CONSTAN
     1TS EXCEEDS NO.OF DATA PTS.PLUS NO.OF CONSTRAINTS/10X52H2  NO.OF CO
     2NSTANTS PLUS NO.OF CONSTRAINTS EXCEEDS 20/10X44H3  NO.OF CONSTRAIN
     3TS EXCEEDS NO.OF CONSTANTS/10X60H4  NO.OF CONSTANTS EXCEEDS 20   (
     4FULLY CONSTRAINED SOLUTION))
   15 FORMAT(6E12.7)
   16 FORMAT(I1,F11.7,3E12.7)
      IF(ITER) 52,54,52
   52 MA=4
      ICO=1
      READ(MA'ICO)N,NDP,NC,NDPS,NCT,NADP,AUC,C,ALPH,A,JCT,S,T,U,V,W,X,Y,
     *FXY,F,I,NCP,NCPC,J,NAUXF,NLF,NHI,IDK,NL,IMA
   54 MA=3
      NL=20
      NL=10
      IDF=1
      L=1
      IDK=1
      IF(ITER)161,21,27
  161 ITER=-ITER
      GO TO 27
   21 IF(JJ(9))56,55,56
   55 IF=5
      READ(IF'MAS) NC,NDP,NBOT
      NCT=0
      NADP=0
      NALM=0
      NAUXF=0
      JSW=0
      ITER=0
      NAUC=0
      READ(IF'MAS)(LID(I),I=1,NC)
      GO TO 67
   56 READ( 2,1)NC,NDP,NCT,NADP,NALM,NAUXF,JSW,ITER,NAUC
   67 IF(NAUC)212,212,213
  213 READ( 2,15)(AUC(I),I=1,NAUC)
  212 ITER=-ITER
      NDPS=NDP
      WRITE(3,5)
  211 IF(JSW)22,23,22
   22 READ( 2,15)(ALPH(I),I=1,NC)
   23 IF(NALM)26,26,24
   24 DO 25  I=1,NALM
      READ( 2,3)(S(J),J=1,20)
   25 WRITE(3,4)(S(J),J=1,20)
   26 IF(JSW)30,27,30
   27 IF(NDP+NCT-NC)28,31,29
   28 WRITE(3,14)L
      CALL EXIT
   29 L=3
```

```
      IF(NCT-NC)40,30,28
   30 NADP=NADP+NDP
      NDP=0
   31 NCP=NDP
      NCPC=NC
      L=4
      IF(NC-20)311,311,28
  311 IF(NCT)35,35,33
   32 NCP=NC+1
      DO 321  I=NCP,NCPC
      DO 321  J=NCP,NCPC
  321 A(I,J)=0.
      NCP=NC
   33 IF(ITER)335,335,336
  335 READ( 2,16)(JCT(I),S(I),T(I),U(I),V(I),I=1,NCT)
  336 N=0
      DO 34  I=1,NCT
      NCP=NCP+1
      C(NCP)=0.
      DO 331  J=1,NC
  331 AC(J)=0.
      IF(JCT(I))332,332,333
  332 CALL FUNXS(C(NCP),AC,S(I),T(I),N,NDP,NC)
      GO TO 334
  333 CALL TRINT(JCT(I),C(NCP),AC,S(I),T(I),U(I),V(I))
  334 DO 34  J=1,NC
   34 A(NCP,J)=AC(J)
   35 IF(JSW)36,36,51
   36 JSW=-1
      IF(NCPC-NC)37,37,43
   37 IF(NDP)501,501,38
   38 IF(ITER)381,381,382
  381 IF(JJ(9)) 59,60,59
   60 DO 61 I=1,NDP
   61 READ(IF'MAS) X(I),Y(I),W(I)
       GO TO 382
   59 READ( 2,2)(X(I),Y(I),W(I),I=1,NDP)
  382 DO 39  I=1,NDP
      CALL FUNXS(C(I),F(1,I),X(I),Y(I),N,NDP,NC)
      FXY(I)=C(I)
      DO 39  J=1,NC
   39 A(I,J)=F(J,I)
      GO TO 502
   40 NCPC=NC+NCT
      L=2
      IF(NCPC-20)41,41,28
   41 IF(NCT)43,43,32
   43 DO 44  I=1,NC
      C(I)=0.
      DO 44  J=1,I
   44 A(I,J)=0.
      NLF=NDP
      NHI=NL
      N=0
  441 IF(NLF-NL)45,46,46
   45 NHI=NLF
   46 IF(ITER)465,465,463
  463 IF(NDP-NL)466,466,464
  464 IMA=IDF
      READ(MA'IMA)(FXY(I),(F(J,I),J=1,NC),X(I),Y(I),W(I),I=1,NHI)
       IDF=IMA
```

```
      GO TO 466
  455  IF(JJ(9)) 471,470,471
  470 DO 472 I=1,NHI
  472 READ(IF'MAS) X(I), Y(I),W(I)
       GO TO 466
  471 READ( 2,2)(X(I),Y(I),W(I),I=1,NHI)
  466 DO 47  K=1,NHI
      N=N+1
      IF(W(K))461,461,462
  461 W(K)=1.0
  462 CALL FUNXS(FXY(K),F(1,K),X(K),Y(K),N,NDP,NC)
      DO 47  I=1,NC
      FIK=F(I,K)*W(K)
      C(I)=C(I)+FXY(K)*FIK
      DO 47  J=1,I
   47 A(I,J)=A(I,J)+FIK*F(J,K)
      IF(NDP-NL)49,49,48
   48 IMA=IDK
      WRITE(MA'IMA)(FXY(I),(F(J,I),J=1,NC),X(I),Y(I),W(I),I=1,NHI)
      IDK=IMA
      NLF=NDP-N
      IF(NLF)49,49,441
   49 DO 50  J=1,NC
      JP=J+1
      DO 50  I=JP,NCPC
   50 A(J,I)=A(I,J)
  501 IF(JSW)502,51,502
  502 IDA=IDK
      WRITE(MA'IDA)A,C
      IDA=IMA
   51 N=NCPC
      MA=4
      ICO=1
      WRITE(MA'ICO)N,NDP,NC,NDPS,NCT,NADP,AUC,C,ALPH,A,JCT,S,T,U,V,W,X,Y
     1,FXY,F,I,NCP,NCPC,J,NAUXF,NLF,NHI,IDK,NL,IMA
      RETURN
      END
// DUP
*STORE      WS  UA  FILQ3
```

```
      SUBROUTINE MASS(ICONT,NTB,KZ,NRUN)
      DIMENSION NPEAK(3),IGALV(  3),IGAIN(  3),READ(3),BACK(50),
     1 NP(50),NUMP(3),SENS(3),F(20,50),GAL(4),GAIN(4),ID(21),IE(21),LID(
     221),PREAD(50),IDATE(3),NBP(30),NBB(30),KSPE(21),WF(50)
      DIMENSION J(10),LB(10)
      COMMON KB,KD,IMA,ICO,MAS,ITER,J,LB,MAS2
      DATA ID          /-10794,-14123,-14122,-14094,-10510,-10794,-10766,
     1  -14123,-14123,-14123,-10688,-14122,-14272,-14094,-10944, -10766,
     2-10808,-15402,-16064,-10766,-14139/
      DATA IE         /-3520,-10510,-3520,16448,16448,16448,-10688,-10509,
     1     16448,-10688,16448,16448,16448,-10688,16448,16448,-3264,-3520,
     216448,-14092,16448/
      DATA GAL             /1.,2.868,9.414,27.59/
      DATA GAIN             /1.,10.,100.,1000./
  101 FORMAT(I3,I2,I3,2X3(I4,2I2,F7.2,5X),2X2I2,I1,I3)
  102 FORMAT(2A2,3X,I1,2X3(I4,2I2,F8.3,4X),2X,2I2,I1,I3)
  103 FORMAT(I3,I2,I3,2X3(I4,2I2,E7.2,5X),2X2I2,I1,I3)
  201 FORMAT(/20X3(I10,5X),3I5//(10X  I10,5X2I10,E10.3)   )
  202 FORMAT(/10X2A2,2X4I5//2X3(I4,2I5,2XF10.4,2X) //)
  203 FORMAT(11H  ERROR 203 2A2)
  204 FORMAT(26H  NO SPECIES DATA FOR PEAK  I5,  14HPEAK DISCARDED)
  205 FORMAT(///10XI5,5XI5,2E12.4//)
  206 FORMAT(I5,5XI5,5X,2A2,5XE12.4)
  210 FORMAT(10X34HNO GALV OR GAIN DATA  FOR RUN      I5,6HBOTTLE I5)
  211 FORMAT(10X21HNO GALVO OR GAIN FOR   2A2)
  212 FORMAT(//10X17HNO PEAK DATA FOR  2A2,1X15HSPECIE AT PEAK I5//10X16
     1HSPECIE DISCARDED//)
  213 FORMAT(//10X17HNO PEAK DATA FOR  2A2,1X15HSPECIE AT PEAK I5//10X20
     1HSPECIE NOT DISCARDED//)
  214 FORMAT(//10X40HDEFLECTION LESS THAN BACKGROUND FOR PEAK  I10,3(3X,
     1F12.3))
  215 FORMAT(30X6HSPECIE//    10(2X2A2))
      KD=1
      ICONT=0
      ICON=0
      ISW=1
       JC=1
       DO 6 L=1,20
      KSPF(L)=0
       DO 6 L2=1,50
      BACK(L2)=0.
    6 F(L,L2)=0.
      IB=1
      IP=1
   20 IF(NTB-2) 84,85,84
   85 READ(2,101)NRUN,NBOT,ITYPE,(NPEAK(I),IGALV(  I),IGAIN(   I),READ(I
     1),I=1,3),IDATE,ICARD
      I=2
      WRITE(I'KD)NRUN,NBOT,ITYPE,(NPFAK(I),IGALV(I),IGAIN(I),READ(I),I=1
     Z,3),IDATE,ICARD
      GO TO 86
   84 GO TO(87,85),ISW
   87 I=2
       READ(I'KD)NRUN,NBOT,ITYPE,(NPFAK(I),IGALV(I),IGAIN(I),READ(I),I=1
     Z,3),IDATE,ICARD
      GO TO 89
   86 IF(LB(7)) 886,89,886
  886 WRITE(3,201)NRUN,NBOT,ITYPE,IDATE,(NPEAK(I),IGALV(  I),IGAIN(  I),
     1READ(I),I=1,3)
   89 DO 1L=1,3
      IF(NPFAK(L)) 18,1 ,18
```

21

```
  18 IF(IGALV(    L)) 11,12,11
  12 WRITE(3,210) NRUN,NBOT
     A=0.
     B=0.
     GO TO 15
  11 L2=IGALV(L)
     A=GAL(L2)
     IF(IGAIN(    L)) 17,12,17
  17 I=IGAIN(    L)
     B     =GAIN(I)
  15 IF(ITYPE) 91,90,91
  91 BACK(IB)=A/B*100. *READ(L)
     NBP(IB)=NPEAK(L)
     IB=IB&1
     GO TO 1
  90 DO 93 L2=1,NBPF
     IF(NBP(L2)-NPEAK(L) ) 93,94,93
  93 CONTINUE
       NBPF=NBPF&1
     L2=NBPF
     BACK(NBPF)=0.
     NBP(NBPF)=NPEAK(L)
  94 PREAD(IP)=A/B*READ(L)*100.-BACK(L2)
     NP(IP)=NPEAK(L)
      IF(PREAD(IP))321,322,322
 321 PREAD(IP)=0.
     WRITE(3,214) NPEAK(L),READ(L),BACK(L2),PREAD(IP)
 322 IP=IP&1
   1 CONTINUE
  92 IF(ICARD) 19,20,19
  19 GO TO (38,39),ISW
  38 NBPF=IB-1
      ISW=2
      GO TO 20
  39 NDP=IP-1
     IF(ICARD-1) 95,96,95
  95 ICONT=1
  96 IS=0
     KB=1
  28 JC=1
     IF(ICON) 30,37,30
  37 IF(NTB-2)  98,98,97
  98 READ(2,102)IA,IB,IREL,(NUMP(I),IGALV(I),IGAIN(I),SENS(I),I=1,3),ID
    1ATE,ICON
     I=1
     WRITE(I'KB)IA,IB,IREL,(NUMP(I),IGALV(I),IGAIN(I),SENS(I),I=1,3),ID
    1ATE,ICON
     GO TO 309
  97 I=1
      READ(I'KB)IA,IB,IREL,(NUMP(I),IGALV(I),IGAIN(I),SENS(I),I=1,3),ID
    1ATE,ICON
     GO TO 399
 309 IF(IREL) 3309,399,3309
3309 IF(LB(7)) 3308,399,3308
3308 WRITE(3,202)IA,IB,IREL,IDATE,(NUMP(I),IGALV(I),IGAIN(I),SENS(I),I
    1=1,3)
 399 GO TO (49,48,45),JC
  49 IGAL=IGALV(1)
     IGAI=IGAIN(1)
     IF(IGAL   ) 51,52,51
  52 IF(IREL) 53,21,53
```

```
 53 WRITE(3,211) IA,IB
    A=1
    B=1
    GO TO  22
 51 A    =GAL(IGAL)
    IF(IGAI) 54,55,54
 55 IF(IREL) 53,21,53
 54 B    =GAIN(IGAI)
 56 IF(IREL-2)21,22,22
 22 PRIM=SENS(1)*A    /B    *100.
 21 I=1
 29 DO 23 L=1,NDP
     IF(NUMP(I)-NP(L )) 23,424,23
424 IF(PREAD(L)) 24,23,24
 23 CONTINUE
 48 JC=2
337 IF(ICON-2) 28,37,28
 24 CONTINUE
324 IS=IS&1
 34 DO 3L=1,21
    IF(IA-16448) 36,35,36
 36 IF(IA-ID(L))3,32,3
 32 IF(IB-IE(L))3,33,3
  3 CONTINUE
 35 WRITE(3,203)IA,IB
    GO TO 48
 33 LID(IS)=L
    L=1
    AS=1.
 45 IF(NUMP(L))44,28,44
 44 IPP=NUMP(L)
    DO   9 L2=1,NDP
    IF(IPP-NP(L2)) 9,72,9
 72 IP=L2
    GO TO  73
  9 CONTINUE
    IF(SENS(L)-.01) 348,348,27
 27 L2=LID(IS)
    WRITE(3,212) ID(L2),IE(L2),NUMP(L)
366 IS=IS-1
    GO TO 48
348 L2=LID(IS)
      WRITE(3,213) ID(L2),IE(L2),NUMP(L)
    KSPE(IS)=1
    GO TO 46
 73 IF(IREL-1) 41,42,43
 43 F(IP,IS)=PRIM
    GO TO 46
 42 F(IP,IS)=SENS(L)*AS*A    /B    *100.
    GO TO 46
 41 F(IP,IS)=SENS(L)*PRIM*AS
 46 L=L&1
    IF(L-3) 26,26,338
338 JC=3
    L=1
    GO TO 337
 26 AS=SENS(1)
    GO TO 45
 30 NC=IS
    NCC=0
```

```
      DO 4 L=1,NDP
  378 DO 5 L2=1,NC
      IF(NP(L)) 347,78,347
  347  IF(F(L,L2)) 4 ,5,4
    5 CONTINUE
      WRITE(3,204) NP(L)
      NCC=NCC&1
      LLL=NDP-NCC
      LL=L
      DO 77 L2=LL,LLL
      PREAD(L2)=PREAD(L2&1)
      DO 377 L3=1,NC
  377  F(L2,L3)=F(L2&1,L3)
   77 NP(L2)=NP(L2&1)
      NP(LLL&1)=0
      GO TO 378
    4 CONTINUF
   78 NDP=NDP-NCC
      IF(ICONT-1)  999,998,999
  998 NTB=NTB-1
  999 DO 385 L=1,NDP
  385 WF(L)=1.0
  383 READ(2,103) IB,IP     ,ITYPE,(NPEAK(I),IGALV(I),IGAIN(I),
     1READ(I),I=1,3),NUMP ,ICARD
      IF(LP(7)) 3001,3002,3001
 3001 WRITF(3,201)  IB,IP     ,ITYPE,NUMP ,(NPEAK(I),IGALV(I),IGAIN(I),
     1READ(I),I=1,3)
 3002 DO 381 I=1,3
      DO 381 IP=1,NDP
      IF (NP(IP)-NPFAK(I)) 381,382,381
  382 WF(IP)=RFAD(I)
  381 CONTINUE
      IF(ICARD) 384,383,384
  384 CONTINUE
      IF(LP(8)) 301,333,301
  301 DO 7 IP=1,NDP
      WRITE(3,205) IP,NP(IP),PREAD(IP),WF(IP)
      DO 7 IS=1,NC
      I=LID(IS)
      IF(F(IP,IS)) 499,7,499
  499 WRITE(3,206) IS,I,ID(I),IE(I),F(IP,IS)
    7 CONTINUE
  333 DO 334 IS=1,NC
      I=LID(IS)
      NBB(IS)=ID(I)
  334 NBP(IS)=IE(I)
      WRITE(3,215)(NBB(IS),NBP(IS),IS=1,NC)
  303 I=5
      MASAV=MAS
      WRITE(I'MAS) NC,NDP,NBOT
      WRITE(I'MAS) (LID(IS),           IS=1,NC)
       DO 8 IP=1,NDP
      FNP=NP(IP)
      WRITE(I'MAS) FNP,PREAD(IP),WF(IP)
    8 CONTINUE
      I=6
      MAS2=1
       DO 10 IP=1,NDP
      WRITF(I'MAS2)(F(IP,IS),IS=1,NC)
   10 CONTINUE
      MAS2=1
      MAS=MASAV
```

```
      RETURN
      END
// DUP
*STORE      WS  UA  MASS
```

```
      SUBROUTINE COMP (JSW,JMS)
      DIMENSION I1(9),I2(3),J(10),V(5),VID(21),NFO(21),IA(5),IB(5),
     1ID(21),IF(21),LID(21),I5(3),OF(6) ,WAT(6),WATE(6), VONR(6)
      DIMENSION I3(6),I4(6),PB(6),LB(10),P(8),T(5),CALR(8),CALS(8),
     1IF(17)
      DIMENSION IX(59 ),XX(45)
      COMMON KP,KD,IMA,ICO,MAS,ITER,J,LB
      EQUIVALENCE (IX(1),I1(1)),(IX(10),I2(1)),
     1            (IX(13),IA(1)),(IX(18),IB(1)),
     2                           (IX(23),LID(1)),(IX(44),I5(1)),
     3            (IX( 47),I3(1)),(IX( 53),I4(1))
      EQUIVALENCE (XX(1),V(1)),(XX(6),VID(1)),(XX(25),OF(1)),
     1             (XX(31),WAT(1)),(XX(37),PB(1))
      DATA AT,G,WD /.4445,32.174,62.4/
      DATA ID          /-10794,-14123,-14122,-14094,-10510,-10794,-10766,
     1  -14123,-14123,-14123,-10688,-14122,-14272,-14094,-10944, -10766,
     2-10808,-15402,-16064,-10766,-14139/
      DATA IF        /-3520,-10510,-3520,16448,16448,16448,-10688,-10509,
     1     16448,-10688,16448,16448,16448,-10688,16448,16448,-3264,-3520,
     216448,-14092,16448/
      DATA NFO/102,112,012,020,002,101,201,113,110,111,001,011,010,021,1
     1100,200,130,0,0,240,0/
      DATA IF /-6458,-14784,-10301,-10282,-10298,-10267,-10266,-10283,-1
     10270,-10269,-6442,-7230,-7198,-7210,-7226,-7183,-6426/
  102 FORMAT(I3,2I1,I4,2I2,I1,I2,I1,1X,A2,4(2A2,1X,E10.5))
  103 FORMAT(I3,2I1,5(2A2,1X,E10.5))
  104 FORMAT(I3,I4,2I2,I1, I3,     3F10.4)
  107 FORMAT(I3,1XI1,1XI2,1XI1,5(1XI2,1XE10.4)/ 5(1XI2,1XE10.4))
  117 FORMAT(I3,12X,A2,3X,2F5.2,I2,F5.2,F5.0,F5.2,F5.0,F5.2,F5.0,
     1F5.2,F5.0,6X,I1)
  203 FORMAT(//7(2XF10.4))
  204 FORMAT(1XI5  /2X7(E14.5,2X))
  205 FORMAT(3I10,3X2A2,3X2A2,I10,2E15.5)
  206 FORMAT(4I10,3E15.5)
  207 FORMAT(3X3I5/1X5(2A2,1XF15.5,2X))
  208 FORMAT(                      //10X,    3(3XF10.4))
  209 FORMAT(1H1,64X,11HPAGE 3 OF 4/35X,11HRUN NUMBER I2//
     132X,17HOSCILLOGRAPH DATA//10X,8HQUANTITY,4X,7HREADING4X,3HCAL
     2     7X8HQUANTITY5X7HREADING5X3HCAL/24X6H(IN.)*
     329X5H(IN.)//37X5HMOTOR/)
  210 FORMAT(/28X23HBALLISTIC ANALYZER DATA//12X2HPB4XF10.2,6H(PSIA)21X,
     12HFB,4X,F10.2,5H(LB.))
  212 FORMAT(12X,A2,4XF10.2,2X,F7.2,9X,A2,4X,F10.2,2X,F7.2/)
  213 FORMAT (/32X,15HBOTTLE PRESSURE/)
  214 FORMAT(//30X2HOF/6(5XE12.4)//30X3HOFR//6(5XE12.4)////30X3HWAT/6(5X
     1F12.4)//30X5HERROR/6(5XF12.4))
  215 FORMAT(//28X,18HMISCELLANEOUS DATA//12X,3HPAM,3X,F10.3,6H(PSIA),
     112X,2HIS,4X,F10.2,5H(SEC)//12X,2HOD,4X,F10.3,9H(LB/CUFT), 9X,3HCSI
     2, 3X,F10.2,8H(FT/SEC)//12X,2HFD,4X,F10.3,9H(LB/CUFT),9X,2HAT,4X,
     3F10.2,6H(SQIN)//30X,19H* CPS FOR WF AND WO/1H1)
  216 FORMAT(12X1HPI1,4XF10.2,2XF7.2,9X1HPI1,4XF10.2,2XF7.2/)
  217 FORMAT(10XI3,2XA2,2(3XF7.2),I5,4(3XF5.2,3XF5.0)//10X,
     14(3XF5.2,3XF5.0)2XI1)
C
C     CONSTANTS
C
      DO 1000 I=1,59
 1000 IX(I)=0
      DO 1001 I=1,42
 1001 XX(I)=0.0
      ICO=JSW
```

```
      UF=231./(144.*12)
      I=0
      JA=1
      KA=1
      KB=1
      KC=2
      LC=1
      TM=0.
      C=92.016/32.048
      LB1=LB(1) &1
      IF(J(2)) 66,67,66
   66 LCI=J(2)
      GO TO 68
   67 LCI=6
   68 READ(2,104)           I3    ,PAM,PBA,FB
      WRITE(3,208)           PAM,PBA,FB
      PBA=PBA&PAM
      WM=0
      K=0
      JW=1
      WRITE(3,209) I3(1)
  443 K=K&1
      IC1=1
      IC2=4
      DO 51 I=5,8
      CALR(I)=0.
   51 CALS(I)=0.
   60 READ(2,117) I3(1),NAME,ZRO,READ,NS,(CALR(I),CALS(I),I=IC1,IC2),IWC
      IF(NS-4) 361,361,360
  360 IF(IC1-1) 3361,3361,361
 3361 IC1=5
      IC2=8
      GO TO 60
  361 WRITE(KA'KB)I3(1),NAME,ZRO,READ,NS,(CALR(I),CALS(I),I=1,8),IWC
      IF(I3(1)) 333,334,333
  333 IF(NS) 331,332,331
  332 CAL=CALR(1)
      GO TO 334
  331 CAL=0
      DO 30 L=1,NS
   30 CAL=CAL&CALS(L)/(CALR(L)-ZRO)
      FNS=NS
      CAL=CAL/FNS
      READ=READ-ZRO
  334 GO TO (81,82,83,83,83,83,83,83,83,83,84,85,85,85,85,85,86,87,87,87
     1,87,87), K
   81 FFM=READ/CAL
      GO TO 40
   82 FM=READ*CAL
      GO TO 40
   83 I=K-2
      P(I)=READ*CAL&PAM
      GO TO 40
   84 FOM=READ/CAL
      GO TO 40
   85 I=K-11
      TM=READ*CAL
      IF(IWC) 445,994,445
  445 KKK=K&1
      WM=TM*WD/60.*UF
```

```
      GO TO 442
   96 WRITE(3,213)
   97 I=K-16
      PB(I)=READ*CAL&PAM
      GO TO 344
  994 IF(TM-1.)  999,999,998
  999 T(I)=(TM&5.175)/.0345
      GO TO 995
  998 IF(TM-8.5) 997,997,996
  997 T(I)=(TM&6.15)/.0395
      GO TO 995
  996 T(I)=(TM&7.1)/.042
  995 TM=T(I)
      GO TO ( 40, 40,993,992, 40, 40),I
  993 OD=95.75-.082*TM
      FOM=FOM*OD/62.43
      GO TO 40
  992 FD=-.0304*TM&65.05
      FFM=FFM*FD/62.43
   40 GO TO (441,448), JW
  448 KKK=K
  442 KK=K-1
      WRITE(3,212) IF(KK),SREAD,SCAL,IF(KKK),READ,CAL,STM
      JW=1
      GO TO 443
  441 JW=2
      SREAD=READ
      SCAL=CAL
      STM=TM
      GO TO 443
  344 GO TO (441,345), JW
  345 II=I-1
      WRITE(3,216) II,SREAD,SCAL,I,READ,CAL
      JW=1
      IF(K-22) 443,341,341
  341 WRITE(3,210) PBA,FB
      KD=1
      WT=FOM&FFM
      OFX=FOM/FFM
      CSI=(-933.33*OFX&1953.33)*OFX&4809.
      SI=(-30.*OFX&63.)*OFX&196.6
      WRITE(3,215) PAM,SI,OD,CSI,FD,AT
      KB=1
      DO 50 L=1,22
      READ(KA'KB) I3(1),NAME,ZRO,READ,NS,(CALR(I),CALS(I),I=1,8),IC1
      IF( LB(6)) 556,50,556
  556 WRITE(3,217)I3(1),NAME,ZRO,READ,NS,(CALR(I),CALS(I),I=1,8),IC1
   50 CONTINUE
      SI1=FB/WT
      SI2=FM/WT
      CSTR=G*P(1)*AT/WT
      CSR=CSTR/CSI
      SR1=SI1/SI
      SR2=SI2/SI
      P(6)=P(6)/P(1)
      CF=FM/(P(1)*AT)
      P(7)=P(7)/PAM
      WRITE(KC'KD)I3,I1,I5,PBA,FFM,FOM,WM,FM,WT,SI1,SI2,CSTR,CSR,SR1,
     1SR2,OFX,CF,FB,PB,P,T
      J4=J(4)&1
   31 GOTO(25,6,71,96,61),J4
   71 DO 72 L=1,6
```

```
      OF(L)=0.
      WAT(L)=0.
   72 WATF(L)=0.
      GO TO 61
    6 READ(2,103)I2,IA(1),IB(1),V(1),IA(2),IB(2),V(2),IA(3),IB(3),V(3),I
     1A(4),IB(4),V(4),IA(5),IB(5),V(5)
      KX=KP
      WRITE(KA'KB)I2,IA(1),IB(1),V(1),IA(2),IB(2),V(2),IA(3),IB(3),V(3),
     1IA(4),IB(4),V(4),IA(5),IB(5),V(5)
      LL=5
      DO 2 L=1,LL
      DO 3 LA=1,21
      IF(IA(L)-16448) 26,25,26
   26 IF(IA(L)-ID(LA)) 3,32,3
   32 IF(IB(L)-IE(LA)) 3,33,3
   33 K2=I&L
      IF(K2-21) 27,27,25
   27 LID(K2 )=LA
      VID(K2 )=V(L)
      GO TO 2
    3 CONTINUE
      GO TO( 2,52),LB1
   52 WRITE(3,205)L,LA,K2,IA(L),IB(L),ID(LA),IE(LA),LID(K2),VID(K2),V(L)
    2 CONTINUE
      I=I&LL
      IF(K2-I1(8))6,25,25
   96 READ(2,107) IRUN,IC,K2,ICONT,(LID(L),VID(L),L=1,K2)
      ICONT=ICONT&1
       GO TO (95,95,93),ICONT
   94 J4=1
      LC=1
      GO TO 95
   93 IF(JMS) 94,893,94
  893 J4=5
      GO TO 95
   25  GO TO (29,28,61,29),J4
   29 KM=4
      READ(KM'ICO)LCX,IC,K2,(LID(L),VID(L),L=1,K2)
      IF(JMS) 95,541,95
  541 LCI=LCX
   95 CALL PP(K2,VID)
   28 OSUM=0.
      FSUM=0.
      SUMN=0.
      WRITE(KC'KD) LCI,IC,K2,(LID(L),VID(L),L=1,K2)
      WAT(IC)=0.
      DO 4L=1,K2
      IL=LID(L)
      IF(LID(L)-14) 18,19,18
   19 WAT(IC)=VID(L)*100.
   18 KL=NFO(IL)
      IFN=KL/100
      FN=IFN
      IFM=(KL-IFN*100)/10
      FM=IFM
       OM=KL-IFN*100.-IFM*10
      J1=J(1)&1
      GO TO (35,53),LB1
   53 WRITE(3,206)L,IL,NFO(IL),KL,FN,OM,FM
   35 OSUM=OSUM&OM*VID(L)
      FSUM=FSUM&FM*VID(L)
```

```
      SUMN=SUMN&FN*VID(L)
      LB2=LB(2)&1
      GO TO (4,55), LB2
   55 WRITE(3,204)L,OSUM,OM,VID(L  ),FSUM,FM  ,SUMN,FN
    4 CONTINUE
      OF(IC)=C*OSUM/FSUM
      IF(OSUM-.001) 43,43,41
   43 IF(FSUM-0.) 41,41,44
   44 RAN=SUMN/FSUM
      RAO=OSUM/FSUM
      PB(IC)=C/(4.*RAN-2*RAO&1.)*(2.*RAN&2.*RAO-1.)
      GOTO 42
   41 RAN=SUMN/OSUM
      RAO=FSUM/OSUM
      PB(IC)=C/(4.*RAN&RAO-2.)*(2.*RAN-RAO&2.)
   42 WATE   (IC)  =(C*OSUM-PB(IC)*FSUM)/(2.*PB(IC)-C  )   *100.
      VONR(IC)=1./RAN
      WRITE(3,203)OF(IC)  ,C,OSUM,FSUM
      GO TO  (34,54,34),J1
   54 OF(IC)=PB(IC)
   34 I=0
      LC=LC&1
      IF(LC-LCI)31,31,61
   61 WRITE(KC'KD  ) OF,WAT  ,WATE,VONR
      WRITE(3,214) OF,PB,   WAT        ,WATE
      RETURN
      END
// DUP
*STORE        WS   UA   COMP
```

```
      SUBROUTINE PO
      DIMENSION I5(3),                LID(21),VID(21) ,IDN(21),LB(10)
      DIMENSION X(6),I1( 9),VC(6,21),I3(6),PB(6),FOF(6),       J(10)
      DIMENSION NAME(21,2) ,ID(21),IE(21),P(8),T(5),XFLUX(6) ,WATE(6),
     1VONR(6),HNR(6)
      COMMON KB,KD,IMA,ICO,MAS,ITER,J,LB
      DATA X /1.028,1.778,2.528,3.278,4.028,4.778/
      DATA ID         /-10794,-14123,-14122,-14094,-10510,-10794,-10766,
     1  -14123,-14123,-14123,-10688,-14122,-14272,-14094,-10944, -10766,
     2-10808,-15402,-16064,-10766,-14139/
      DATA IE         /-3520,-10510,-3520,16448,16448,16448,-10688,-10509,
     1     16448,-10688,16448,16448,16448,-10688,16448,16448,-3264,-3520,
     216448,-14092,16448/
      DATA IDN /16,7,5,2,11,14,15,8,9,6,10,3,1,4,12,13,17,20,19,18,21/
114   FORMAT(/2X3H114 2I10,4E14.4   )
115   FORMAT(/2X3H1152I10, 3I10)
220   FORMAT(1H1,64X11HPAGE 1 OF 4//21X,41HROCKET MOTOR BOUNDARY FLOW DA
     1TA REDUCTION// ,10X,23HJPL CONTRACT - NAS7-463,19X,22HAEROTHERM PR
     2OJECT 7009// ,10X,13HRUN NUMBER - I3,26X,20HINJECTOR POSITION - ,
     3I3,//10X16HFIRING NUMBER - ,I4,22X,17HDATE OF FIRING - ,I2,1H/,I2,
     42H/6I1//)
221   FORMAT(                                                77H----------
     1------------------------------------------------------------------
     2-///30X,22HDATA REDUCTION RESULTS// 10X,19HAXIAL STATION (IN.),4X2
     31HO/F IN BOUNDARY LAYER6X9HHEAT FLUX/59X11HBTU/FT2-SEC /(1H015XF6.
     44,16XF8.4,15XF8.1))
222   FORMAT(1H0/27X29HENGINE PERFORMANCE PARAMETERS//10X6HO/F   F6.4,
     110X6HCSTAR F6.0,1X6H(FT/S)3X6HCSR   F6.4,//10X6HISR   F6.4,10X7HPN
     2PC   ,F6.4,9X,6HCF    F6.4//10X6HIS    F6.2,1X5H(SEC)4X6HF    F6.
     32,1X4H(LB)5X6HPC    F6.2,1X6H(PSIA)//10X6HISB   F6.2,1X5H(SEC)4X,6
     4HFB    F6.2,1X4H(LB)5X6HPCB   F6.2,1X6H(PSIA)//10X6HWO    F6.4,1X,
     56H(LB/S)3X7HWF     F6.4,1X6H(LB/S)2X6HWW    F6.4,1X6H(LB/S)/ )
226   FORMAT(10X,6HPSP   F6.4//)
223   FORMAT(1H0 33X,11HSYSTEM DATA//15X,15HPRESSURE (PSIA)19X,19HTEMPER
     1ATURE (DEG.F),//10X4HPF   F8.2,4X,4HPFT F8.2,10X,4HTB   F6.2,4X,4HTO
     2  ,F6.2//10X4HPO   F8.2,4X,4HPOT F8.2,10X,4HTS   F6.2,4X,4HTF   F6.2,
     3//10X,4HPW  F8.2,26X,4HTV1 F6.2//)
224   FORMAT(1H1,64X,11HPAGE 2 OF 4//15X15HGAS COMPOSITION,10X,10HRUN NU
     1MBER I3    ,//)
225   FORMAT(14X,63H****************************************************
     1***********      //5X, 8HPRESSURE1X6(4XF6.2)/6X6H(PSIA))
229   FORMAT(  5X,2A2,5X,1H*,6(4XF6.3)/14X,1H*)
230   FORMAT(1H1)
231   FORMAT(14X
     1       63H********************************************************
     2*******/14X1H*/14X,1H*,24X,13HMOLE FRACTION/14X,1H*/14X,1H* )
232   FORMAT(14X,1H*,24X,13HBOTTLE NUMBER/14X,1H*/5X,8HGAS      2H *6X
     11H1, 9X,1H2, 9X,1H3, 9X,1H4, 9X,1H5, 9X,1H6/14X1H*/14X1H*)
233   FORMAT(/5X3HH/N6X6(4XF6.2)//5X3HO/N6X6(4XF6.2)//5X3HH2O6X6(4XF6.2
     1))
      COF=92.016/32.048
      DO 4 L=1,6
      FOF(L)=0.0
      DO 4 L2=1,21
    4 VC(L,L2)=0.0
      KA=1
      KB=1
      KC=2
      KD=1
      READ(KC'KD) I3,I1,I5,PBA,FFM,FOM,WM,FM,WT,SI1,SI2,CSTR,CSR,SR1,
     1SR2,OFX,CF,FB,PB,P,T
```

```
      IF(J(4)-2) 18,17,18
   18 DO 1 L=1,6
      READ(KC'KD)LCI,IC,K2,(LID(L2),VID(L2),L2=1,K2)
      DO 2 L2=1,K2
      I=LID(L2)
      II=IDN(I)
      NAME(II,1)=ID(I)
      NAME(II,2)=IF(I)
    2 VC(IC,II)=VID(L2)*100.
      IF(L-LCI) 1,3,3
    1 CONTINUE
    3 L2=L
   17 IF(LP(1)) 14,13,14
   14 WRITE(3,114) KC,KD,R(1),P(6),FFM,FOM
      WRITE(3,115)KC,KD,LCI,IC,K2
   13 IF(J(1))16,11,16
   16 IF(J(3)) 11,10,11
   10 READ(KC'KD) FOF,(VC(L2,4),L2=1,6) ,WATE,VONR
      GO TO 12
   11 READ(KC'KD) FOF,(VID(L2),L2=1,6) ,WATE   ,VONR
   12 DO 306 L=1,6
  306 HNR(L)=VONR(L)/FOF(L) *COF
      READ(KC'KD) XFLUX
      WRITE(3,220)I3(1),I3(6),I3(2),I3(3),I3(4),I3(5)
      WRITE(3,221)        (X(L),FOF(L),XFLUX(L),L=1,6)
      WRITE(3,222) OFX,CSTR,CSR,SR2,P(6),CF,SI2,FM,P(1),SI1,FB,PBA,FOM,
     1FFM,WM
      WRITE(3,226) P(7)
      WRITE(3,223) P(3),P(8),T(1),T(3),P(2),P(4),T(2),T(4),P(5),T(5)
      IF(J(10)) 39,40,39
   40 JREP=2
      GO TO 38
   39 JREP=1
   38 IF(J(4)-2) 19,24,19
   19 WRITE(3,224) I3(1)
      WRITE(3,231)
      WRITE(3,232)
      DO 23 L=1,21
      DO 20 L2=1,6
      IF(VC(L2,L)) 22,20,22
   20 CONTINUE
      GO TO 23
   22 WRITE(3,229) NAME(L,1),NAME (L,2),(VC(L2,L),L2=1,6)
   23 CONTINUE
      WRITE(3,225) PB
      WRITE(3,233) HNR,VONR,WATE
       GO TO (888,24 ),JREP
  888 JREP=JREP&1
      DO 895 L=1,6
      SUM=0.
      VC(L, 4)=VC(L, 4)&WATE(L)
      DO 896 LL=1,21
  896 SUM=SUM&VC(L,LL)
      DO 895 LL=1,21
  895 VC(L,LL)=VC(L,LL)/SUM  *100.
      GO TO 19
   24 WRITE(3,230)
      RETURN
      END
// DUP
*STORE      WS  UA  PO
```

```
       SUBROUTINE HEAT
      DIMENSION T( 40),XQ( 40),XT( 40),YLBL1(10),YLBL2(10),XLBL(10),HEAD
     1(10),SUB(20),XFLUX(6),RAZZ(4),CALS(8),CALR(8),XEAD(40),NSP(6)
     2,JJ(10),TEMW(40) ,XREAD(40) ,XBLK(10),YBLK(10),HBLK(10),SUBL(20)
      COMMON KB,KD,IMA,ICO,MAS,ITER,JJ,LB,MAS2
      DATA XBLK/'    ','    ','    ','    ','    ','    ','    ','    ',
     1'    ','    '/
      DATA YBLK/'    ','    ','    ','    ','    ','    ','    ','    ',
     1'    ','    '/
      DATA HBLK/'    ','    ','    ','    ','    ','    ','    ','    ',
     1'    ','    '/
      DATA SUBL/'    ','    ','    ','    ','    ','    ','    ','    ',
     1'    ','    ','    ','    ','    ','    ','    ','    ','    ','    ',
     2'    ','    ','    '/
      DATA YLBL2/       '    ','TEMP','ERAT','URE ','    ',' DEG','.F. '
     1,'    ','    '/
      DATA YLBL1/'    ','    ','    ','HEAT',' FLU','X BT','U/FT',
     1'2-SE','C.  ','    '/
      DATA XLBL/'    ','    ','    ','    ','TIME','-SEC','ONDS','    ',
     1'    ','    '/
      DATA HEAD/'    ','    ','MOTO','R HE','AT F','LUX ','CALC','ULAT',
     1'ION ','    '/
      DATA COND2,RHO2,CP2,RHO1,CP1,D/ .06      ,  559.0  ,  0.0915  ,0.,0
     1.,0./
  100 FORMAT(20A4)
  300 FORMAT(4A1,2F6.2,2E9.4,I2)
  500 FORMAT(//10X4HTIME5X7HREADING4X10HMILLIVOLTS6X5HTEMP.5X10HTEMP. RI
     1SE   4X9HHEAT FLUX                    )
  600 FORMAT( 8XF6.3,6XF6.3,6XF6.2,6XF8.2,5XF8.2,4XF10.2)
  700 FORMAT(I5,3F10.4,I5,F10.4)
  701 FORMAT(I3,14XI1,2XF5.2,5XI2,4(F5.2,F5.0) )
  702 FORMAT(2I5,6(1XI1,F9.2 ))
  703 FORMAT(///20X25HHEAT FLUX FOR STATION NO.I2,1H=F8.2,12HBTU/FT2-SEC
     1.    )
  706 FORMAT(//16X5HAXIAL8X13HSAMPLING TIME8X9HM.V. BASE8X9HTIME STEP
     1/15X7HSTATION10X7HSECONDS29X7HSECONDS/ 18XI1, 9XF10.2,13XF6.2,10X
     2    F6.3,20XI2)
  707 FORMAT(/30X11HCALIBRATION//5X3HRUN1X7HSTATION1X4HZERO2X9HNUMBER OF
     1      14X15HREADING/SIGNAL /15X7HREADING3X5HSTEPS/)
  708 FORMAT( 5XI2,4XI1,  F10.4,4XI1,4X4(F6.2,2XF4.1))
  709 FORMAT (12X,F15.6,16X,I1)
  900 FORMAT(1H116X20A4)
 1100 FORMAT(/10X     20A4)
      KC=2
      DO 43 L=1,6
   43 XFLUX(L)=0.
      J6=JJ(6)&1
      GO TO (56,55,56,55,46),J6
   55 READ(2,702) NRUN,NPS,(NSP(L),CALS(L),L=1,NPS)
      WRITE(3,702) NRUN,NPS,(NSP(L),CALS(L),L=1,NPS)
      DO 57 L=1,NPS
      IF(NSP(L)) 61,57,61
   61 I=NSP(L)
      XFLUX(I)=CALS(L)
   57 CONTINUE
   56 WRITE(3,900) (HEAD(I),I=1,10)
      READ(2,100) (SUB(I),I=1,20)
      JC1=1
      WRITE(3,1100) (SUB(I),I=1,20)
      READ(2,700)NSTA,TIME,BASE,DT ,IPLOT,FXT
```

```
    WRITE(3,706)NSTA,TIME,BASE,DT       ,IPLOT
    IPLOT=IPLOT&1
    GO TO (35,35,35,36),IPLOT
 36 I=1
 37 READ(2,709) T(I),NCONT
    TEMW(I)=T(I)&FXT -460.
    IF(NCONT) 38,39,38
 39 I=I&1
     GO TO 37
 38 N=I
    GO TO 53
 35 DT=DT&.00001
    IF(NSTA) 1,46,1
  1 IC1=1
    IC2=4
    I=1
    WRITE(3,707)
 87 READ(2,701)NRUN,NSTA,ZRO,NSTP,(CALR(L),CALS(L),L=IC1,IC2)
    WRITE(3,708)NRUN,NSTA,ZRO,NSTP,(CALR(L),CALS(L),L=IC1,IC2)
    IF(NSTP-4) 85,85,86
 86 IF(IC1-1)89,89,85
 89 IC1=5
    IC2=8
    GO TO 87
 85 CAL=0.
    DO 88 L=1,NSTP
 88 CAL=CAL&(CALS(L)-BASE)/(CALR(L)-ZRO)
    FNS=NSTP
    CAL =CAL/FNS
 84 READ(2,300) RAZZ,ZERO,XREAD(I),TIM1,TIM2,     NCONT
    XEAD(I)=(XREAD( I)-ZRO)*CAL&BASE
    CALL TCRAL(XEAD(I),TEMP)
    T(I)=TEMP
    TEMW(I)=TEMP
    I=I&1
    IF(NCONT) 82,84,82
 82 N=I-1
    WRITE(3,500)
    FXT=T(1)
    DO 50 I=1,N
 50 T(I)=T(I)-FXT
 53 XQ(1)=0.
    C1=.5*SQRT(3.1416*COND2*RHO2*CP2/DT)
    C2=RHO1*CP1*D/(2.0*DT)
    XT(1)=0.0
    K=N-1
    DO 30 I=2,K
    Q=0.0
    A=I
    KX=I-1
    DO 20 J=1,KX
    B=J
    XX=(T(I)*SQRT(B-.5)-(T(J&1)&T(J))/2.0*SQRT(A-1.0))/(A-B-.5)**1.5
 20 Q=Q&XX
    XQ(I)=C1/SQRT(A-1.0)*(T(I)&Q/3.1416)&C2*(T(I&1)-T(I-1))
    XT(I)=XT(I-1)&DT
    IF(XT(I)-TIME) 40,41,41
 41 GO TO (42,40),JC1
 42 JC1=2
    ISAV=I
    XFLUX(NSTA)=XQ(I-1)&(XQ(I)-XQ(I-1))/DT*(TIME-XT(I-1))
```

```
 40 WRITE(3,600) XT(I), XREAD(I),XEAD(I),TEMW(I),T(I),XQ(I)
 30 CONTINUE
    GO TO (3,2,4,3),IPLOT
  4 CALL  GRAPH(XT,XREAD,XBLK,YBLK,9.,6.,HBLK,SUBL,K,6)
    CALL  GRAPH(XT,XQ    ,XBLK,YBLK,9.,6.,HBLK,SUBL,K,6)
    GO TO 2
  3 CALL GRAPH(XT,XQ,XLBL,YLBL1,9.,6.,HEAD,SUB,K,6)
    CALL GRAPH(XT,TEMW,XLBL,YLBL2,9.,6.,HEAD,SUB,K,6)
  2 WRITE(3,703)                    NSTA,XFLUX(NSTA)
    IF(NCONT-2) 56,46,56
 46 WRITE(KC'KD)XFLUX
    RETURN
    END
// DUP
*STORE      WS  UA  HEAT
```

Atom Gram

```
      DIMENSION X(5),T1(3),T2(3),T3(3),W(3),RES(20),IS(20),NUM(5),T(5)
      DATA T1/'  1H','YDRO','GEN '/
      DATA T2/'  7N','ITRO','GEN '/
      DATA T3/'  8O','XYGE','N   '/
      DATA W/1.0080,14.0067,16.0000/
      DATA NUM/4,5,16,17,14/
      DATA T/'H2  ','O2  ','N2  ','NH3 ','H2O '/
      DEFINE FILE 1(200,8,U,KD)
      KA=1
      KD=1
      WRITE(3,1)
    1 FORMAT(1H1)
  100 SUM=0.
      DO 10 I=1,5
   10 X(I)=0.
      READ(2,2) IRUN,IBOT,N,(IS(I),RES(I),I=1,N)
    2 FORMAT(I3,I2,I3,2X,5(I3,1X,E10.4)/5(I3,1X,E10.4))
      IF (IRUN-999) 12,70,70
   12 DO 30 I=1,5
      DO 20 J=1,N
      IF (IS(J)-NUM(I)) 20,15,20
   15 X(I)=RES(J)
      GO TO 30
   20 CONTINUE
   30 CONTINUE
      DO 40 I=1,5
   40 SUM=SUM&X(I)
      DO 50 I=1,5
   50 X(I)=X(I)/SUM
      SUM=2.*X(1)&2.*X(2)&2.*X(3)&4.*X(4)&3.*X(5)
      H=(2.*X(1)&3.*X(4)&2.*X(5))/SUM
      XN=(2.*X(3)&X(4))/SUM
      O=(2.*X(2)&X(5))/SUM
      WRITE(3,3) IRUN,IBOT,(T(I),X(I),I=1,5),H,XN,O
    3 FORMAT(1H ,3HRUN,2X,I2,5X,6HBOTTLE,2X,I2/1H ,5(A4,2X,F8.5,5X)/1H ,
     18HHYDROGEN,2X,F8.6/1H ,8HNITROGEN,2X,F8.6/1H ,6HOXYGEN,4X,F8.6/)
      WRITE(KA'KD) H,XN,O,IRUN,IBOT
      GO TO 100
   70 H=10.
      XN=0.
      O=0.
      IRUN=0
      IBOT=0
      WRITE(KA'KD) H,XN,O,IRUN,IBOT
      READ(2,4) IDUM
    4 FORMAT(I2)
      KA=1
      KD=1
   80 READ(KA'KD) H,XN,O,IRUN,IBOT
      IF (H-2.) 90,200,200
   90 WRITE(2,5) T1,W(1),H,IRUN,IBOT
      WRITE(2,5) T2,W(2),XN,IRUN,IBOT
      WRITE(2,5) T3,W(3),O,IRUN,IBOT
    5 FORMAT(3A4,6X,F7.4,F7.5,28X,4HRUN ,I2,8H BOTTLE ,I1)
      GO TO 80
  200 STOP
      END
```

```
      SUBROUTINE TCRAL(XALUE,TEMP)
C     SUBROUTINE FOR THERMOCOUPLE OF CROMEL-ALUMEL
      VALUE =XALUE
      IF(VALUE-10.57)1,2,3
    1 TEMP=492.&43.3*VALUE
      GO TO 10
    2 TEMP=960.
      GO TO 10
    3 IF(VALUE-22.26)4,5,6
    4 VALUE=VALUE-10.57
      TEMP=960.&42.9*VALUE
      GO TO 10
    5 TEMP=1460.
      GO TO 10
    6 IF(VALUE-33.93)7,8,9
    7 VALUE=VALUE-22.26
      TEMP=1460.&42.8*VALUE
      GO TO 10
    8 TEMP=1960.
      GO TO 10
    9 IF(VALUE-44.91)11,12,13
   11 VALUE=VALUE-33.93
      TEMP=1960.&45.2*VALUE
      GO TO 10
   12 TEMP=2460.
      GO TO 10
   13 VALUE=VALUE-44.91
      TEMP=2460.&49.0*VALUE
   10 RETURN
      END
// DUP
*STORE       WS  UA  TCRAL
```

```
      SUBROUTINE MASS2(ICT,JM2,JICB,JICP,NRUN)
       DIMENSION J(10),LB(10),LID(21),PREAD(21)
      COMMON KB,KD,IMA,ICO,MAS,ITER,J,LB,MAS2
  101 FORMAT(I3,I2,F10.2)
  201 FORMAT(//10X6HSPECIE I5,12H ELIMINATED  )
  202 FORMAT(/10X2I10,2(5XF12.4))
  204 FORMAT(/10X5I10//4(I10,F15.4))
      IS=4
      READ(IS'JICB) NTB,NBOT,NC,(LID(I),PREAD(I),I=1,NC)
      PNH3=0.
      NCP=1
      NCC=0
      DO 1 L=1,NC
    6 IF(LID(L))1,1,4
    4 IF(PREAD(L)-.0001) 2,2,1
    2 NCC=NCC&1
      LP=L&NCC -1
      WRITE(3,201) LP
      LL=NC-NCC
      DO 5 L2 =L,LL
      LID(L2)=LID(L2&1)
    5 PREAD(L2)=PREAD(L2&1)
      LID(LL&1)=-1
      GO TO 6
    1 CONTINUE
      NC=NC-NCC
      LNH2=NC&1
      PREAD(LNH2)=0.
      SUM=0.
      DO 7 L=1,NC
    7 SUM=SUM&PREAD(L)
      READ(2,101) N,NB,PRES
      WRITE(3,202 ) N,NB,PRES,SUM
      WRITE(3,204)IS,JICB, NTB,NBOT,NC,(LID(I),PREAD(I),I=1,NC)
      WRITE(IS'JICB) NTB,NBOT,NC,(LID(I),PREAD(I),I=1,NC)
      JICP=ICO
      ICT=0
   12 RETURN
      END
// DUP
*STORE       WS   UA   MASS2
```

APPENDIX F

DATA TABULATION, RUNS 0-8

DATA PRINT-OUT NOMENCLATURE

A. Gas Analysis - Engine Performance (page one)

CF - C_f - thrust coefficient
CSR - C*ratio - (c^*/c^* ideal)
CSTAR - C^*
F - Thrust
IS1 - I_{s_1} - specific impulse (oscillograph)
IS2 - I_{s_2} - specific impulse (ballistic analyzer)
ISR - I_{s_r} - specific impulse ratio $(I_{s_1}/I_{s_{ideal}})$
O/F - oxidizer - fuel ratio
P1-P6 - P_1-P_6 - gas sample bottle pressure after sampling
PC - P_c - chamber pressure (oscillograph)
PF - P_f - fuel pressure at injector
PFT - $P_{f,t}$ - fuel tank pressure
PO - P_o - oxidizer pressure at injector
POT - $P_{o,t}$ - oxidizer tank pressure
PCBA - P_c - chamber pressure (ballistic analyzer)
PNPC - P_n/P_c - motor pressure ratio
PW - P_w - water pressure at injector
TB - T_b - motor temperature during sampling
WF - $\dot{W}_f$ - fuel flow rate
WO - $\dot{W}_o$ - oxidizer flow rate
WW - $\dot{W}_o$ - water flow rate

B. Gas Analysis - (Page 2)

H	H	atomic hydrogen
H2	H_2	hydrogen
HO	HO	hydrogen peroxide
H2O	H_2O	water
HO2	HO_2	
HNO	HNO	
HNO2	HNO_2	nitrous acid
HNO3	HNO_3	nitric acid
HN	HN	
O	O	atomic oxygen
O	O_2	oxygen
N	N	atomic nitrogen
N2	N_2	nitrogen
NO	NO	nitrogen dioxide
N2O	N_2O	nitrogen monoxide
NO2	NO_2	nitrogen tetroxide
NH3	NH_3	ammonia
A	A	argon
CO2	CO_2	carbon dioxide

C. Oscillograph Readings (Page 3)

AT - A_t - throat area
CF - C_f - flow rate calibration
CFA - $C_{f,a}$ - thrust calibration
CPB - $C_{p,b}$ - bottle pressure calibration
CPC - $C_{p,c}$ - Chamber pressure calibration
CPE - $C_{p,e}$ - motor exit pressure calibration
CPI - $C_{p,i}$ - injector pressures calibration
CPV - $C_{p,v}$ - tank pressure calibration
CSI - $C^*_{s(ideal)}$ ideal C*
CTB - $C_{t,b,}$ - motor temperature calibration
F - F - force (thrust) (ballistic analyzer)
FD - ρ_f - fuel density
FFM - $\dot{W}_f$ - fuel flow rate
FOM - $\dot{W}_o$ - oxidizer flow rate
FM - F - force
IS - $I_{s(ideal)}$ Ideal specific impulse
OD - ρ_o - oxidizer density
PAM - P_a - ambient pressure
PBI-PB6-P_{bi}-P_{b6}- bottle pressures
PC - P_c - chamber pressure (ballistic analyzer)
PCM - P_c - chamber pressure
PFM - P_f - fuel pressure at injector
PFT - $P_{f,t}$ - fuel pressure at tank
PEM - P_e - motor exit pressure
POM - P_o - oxidizer pressure at injector
POT - $P_{o,t}$ - oxidizer pressure at tank
PNM - P_n - nozzle exit pressure
PWI - P_w - cooling water pressure
TBM - T_b - motor temperature
WM - $\dot{W}_w$ - cooling water flow rate

```
                                                         PAGE 1 OF 2

                 ROCKET MOTOR BOUNDARY FLOW DATA REDUCTION

     JPL CONTRACT - NAS7-463                    AEROTHERM PROJECT 7009

     RUN NUMBER -   0                         DATE OF FIRING -  9/ 7/67

     FIRING NUMBER -    1            DATE OF DATA REDUCTION - 11/ 2/67

                      INJECTOR POSITION -   0 DEGREES

-----------------------------------------------------------------------------


                          GAS ANALYSIS RESULTS

     AXIAL STATION (IN.)                   O/F IN BOUNDARY LAYER

          1.0280                                 0.0000

          1.7780                                 0.0000

          2.5280                                 0.0000

          3.2780                                 0.0000

          4.0280                                 0.0000

          4.7780                                 0.0000


                       ENGINE PERFORMANCE PARAMETERS

     O/F   1.1598          CSTAR  4962.         CSR    0.86

     ISR   0.8660          PNPC   0.0860        CF     1.1034

     IS1   173.35          IS2    170.18        PC     141.70(PSIA)

     WO    0.217  (LB/S)   WF     0.187  (LB/S) F       69.50(LB)

     PCBA  138.20(PSIA)    WW     0.0000(LB/S)
                             SYSTEM DATA

     FINAL BOTTLE PRESSURE (PSIA)              FLUID PRESSURES (PSIA)

     P1-14.70          P4-14.70          PF-   462.20       PFT-   969.69

     P2-14.70          P5-14.70          PO-   439.70       POT-   954.69

     P3-14.70          P6-14.70          PW-    95.69

                         TB-  464.00(DEG R)
```

```
                                OSCILLOGRAPH DATA

                                 RUN NUMBER  1
                 ENGINE                                    BOTTLE

        QUANTITY  READING (INCHES)               QUANTITY  READING (INCHES)

        PCM      1.2700                            PB1       0.0000

        PNM      ******                            PB2       0.0000

        PFM      3.5800                            PB3       0.0000

        POM      3.4000                            PB4       0.0000

        PFT      3.8200                            PB5       0.0000

        POT      3.7600                            PB6       0.0000

        FFM      4.0600

        FOM      3.2900

        PWI      0.8100

        WM       0.0000                            PEM       0.0000

        FM       1.3900                            TBM       0.0200


                              BALLISTIC ANALYZER DATA

            PC  123.50 (PSI)                         F   70.73 (LB)
                                   OTHER DATA

        CALIBRATION CONSTANTS                        MISCELLANEOUS


     CFA  50.(LB/IN)   CPN   5.(PSI/IN)  PAM  14.700(PSI)     IS   200.00(S)

     CPC 100.(PSI/IN)  CTB 200.(F/IN)    AT  0.44450(SQIN)    OD    89.84(*)

     CPI 125.(PSI/IN)  CPE   0.(F/IN)    CSI   5808.          FD    62.77(*)

     CPV 250.(PSI/IN)  CF  0.33(G/IN)          *-(LB/CUFT)

     CPB  0.00(PSI/IN)
```

```
                                                              PAGE 1 OF 4
                ROCKET MOTOR BOUNDARY FLOW DATA REDUCTION
       JPL CONTRACT - NAS7-463                    AEROTHERM PROJECT 7009
       RUN NUMBER -   1                        DATE OF FIRING -  8/12/67
       FIRING NUMBER -    2            DATE OF DATA REDUCTION - 11/ 2/67
                   INJECTOR POSITION -   0 DEGREES
------------------------------------------------------------------------

                        GAS ANALYSIS RESULTS
       AXIAL STATION (IN.)                  O/F IN BOUNDARY LAYER
            1.0280                                 0.0000
            1.7780                                 0.0000
            2.5280                                 0.0000
            3.2780                                 0.0000
            4.0280                                 0.0000
            4.7780                                 1.2839

                     ENGINE PERFORMANCE PARAMETERS
       O/F   1.1745        CSTAR  5124.          CSR    0.8823
       ISR   0.8765        PNPC   0.0866         CF     1.1042
       IS1   175.31        IS2    175.89         PC     147.70(PSIA)
       WO    0.2226(LB/S)  WF     0.1895(LB/S)   F       72.50(LB)
       PCBA  146.26(PSIA)  WW     0.0000(LB/S)
                            SYSTEM DATA
       FINAL BOTTLE PRESSURE (PSIA)              FLUID PRESSURES (PSIA)
       P1-14.70         P4-14.70            PF-   498.45       PFT- 1054.70
       P2-14.70         P5-14.70            PO-   459.70       POT-  997.20
       P3-14.70         P6-19.64            PW-   152.70
                        TB-  362.00(DEG R)
```

```
          GAS SAMPLE DATA   RUN NUMBER   1

          SAMPLES ANALYZED AT  SR      8/12/67

                  PER CENT MOLE FRACTION

    *************************************************************
    *
    *                        BOTTLE NUMBER
    *
GAS *       1          2          3          4          5          6
    *
    *

H          0.000      0.000      0.000      0.000      0.000      0.000

H2         0.000      0.000      0.000      0.000      0.000     13.649

HO         0.000      0.000      0.000      0.000      0.000      0.000

H20        0.000      0.000      0.000      0.000      0.000      0.220

HO2        0.000      0.000      0.000      0.000      0.000      0.000

HNO        0.000      0.000      0.000      0.000      0.000      0.000

HNO2       0.000      0.000      0.000      0.000      0.000      0.000

HNO3       0.000      0.000      0.000      0.000      0.000      0.000

HN         0.000      0.000      0.000      0.000      0.000      0.000

O          0.000      0.000      0.000      0.000      0.000      0.000

O2         0.000      0.000      0.000      0.000      0.000      0.690

N          0.000      0.000      0.000      0.000      0.000      0.000

N2         0.000      0.000      0.000      0.000      0.000     84.830

NO         0.000      0.000      0.000      0.000      0.000      0.079

N20        0.000      0.000      0.000      0.000      0.000      0.000

NO2        0.000      0.000      0.000      0.000      0.000      0.000

NH3        0.000      0.000      0.000      0.000      0.000      0.140

A          0.000      0.000      0.000      0.000      0.000      0.159

CO2        0.000      0.000      0.000      0.000      0.000      0.239
```

```
                         OSCILLOGRAPH DATA

                          RUN NUMBER  1
           ENGINE                                  BOTTLE

   QUANTITY  READING (INCHES)           QUANTITY  READING (INCHES)

   PCM       1.3300                       PB1       0.0000

   PNM       ******                       PB2       0.0000

   PFM       3.8700                       PB3       0.0000

   POM       3.5600                       PB4       0.0000

   PFT       4.1600                       PB5       0.0000

   POT       3.9300                       PB6       0.1400

   FFM       4.0700

   FOM       3.3400

   PWI       1.3800

   WM        0.0000                       PEM       0.0000

   FM        1.4500                       TBM       ******


                       BALLISTIC ANALYZER DATA

      PC  131.56 (PSI)                       F   72.26 (LB)

                             OTHER DATA

   CALIBRATION CONSTANTS                        MISCELLANEOUS


CFA  50.(LB/IN)    CPN   5.(PSI/IN)  PAM  14.700(PSI)     IS   200.00(S)

CPC 100.(PSI/IN)   CTB 200.(F/IN)    AT  0.44450(SQIN)    OD     89.84(*)

CPI 125.(PSI/IN)   CPE   0.(F/IN)    CSI   5808.          FD     62.77(*)

CPV 250.(PSI/IN)   CF  0.33(G/IN)          *-(LB/CUFT)

CPB 35.32(PSI/IN)
```

COMMENTS ON DATA AND DATA REDUCTION

RUN NUMBER- 1 DATE OF DATA REDUCTION-11/ 2/67

O/F ANALYZED BY WATERLESS FORMULATION

H2O DETERMINED FROM O/F

THIS IS AN SRI ANALYSIS

OXIDIZER AND FUEL DENSITIES WERE DETERMINED USING 75 DEG F

FIRST ATTEMPT - CSI 5808.0, SI 200.0

```
              ROCKET MOTOR BOUNDARY FLOW DATA REDUCTION

     JPL CONTRACT - NAS7-463                        AEROTHERM PROJECT 7009

     RUN NUMBER -    2                           DATE OF FIRING -  9/20/67

     FIRING NUMBER -     3               DATE OF DATA REDUCTION - 11/ 2/67

                        INJECTOR POSITION -   0 DEGREES

----------------------------------------------------------------------------


                             GAS ANALYSIS RESULTS

     AXIAL STATION (IN.)                    O/F IN BOUNDARY LAYER

           1.0280                                  0.0000

           1.7780                                  0.0000

           2.5280                                  0.0000

           3.2780                                  1.0875

           4.0280                                  0.0000

           4.7780                                  0.0000

                         ENGINE PERFORMANCE PARAMETERS

     O/F    1.1523          CSTAR  4985.             CSR    0.8583

     ISR    0.8919          PNPC   0.0865            CF     1.1508

     IS1    178.39          IS2    178.31            PC     142.70(PSIA)

     WO     0.2191(LB/S)    WF     0.1901(LB/S)      F       73.00(LB)

     PCBA   140.93(PSIA)    [illegible]     0.2127(LB/S)
                                 SYSTEM DATA

     FINAL BOTTLE PRESSURE (PSIA)                FLUID PRESSURES (PSIA)

     P1-14.70          P4-*****              PF-   478.44       PFT- 1027.19

     P2-14.70          P5-14.70              PO-   538.44       POT-  977.20

     P3-14.70          P6-14.70              PW-   147.70

                             TB-  684.00(DEG R)
```

```
          GAS SAMPLE DATA   RUN NUMBER   2

          SAMPLES ANALYZED AT  WT      9/28/67

                    PER CENT MOLE FRACTION

    ***************************************************************
    *
    *                         BOTTLE NUMBER
    *
GAS *       1         2         3         4         5         6
    *
    *

H         0.000     0.000     0.000     0.000     0.000     0.000

H2        0.000     0.000     0.000    16.500     0.000     0.000

HO        0.000     0.000     0.000     0.000     0.000     0.000

H2O       0.000     0.000     0.000     1.32      0.000     0.000

HO2       0.000     0.000     0.000     0.000     0.000     0.000

HNO       0.000     0.000     0.000     0.000     0.000     0.000

HNO2      0.000     0.000     0.000     0.000     0.000     0.000

HNO3      0.000     0.000     0.000     0.000     0.000     0.000

HN        0.000     0.000     0.000     0.000     0.000     0.000

O         0.000     0.000     0.000     0.000     0.000     0.000

O2        0.000     0.000     0.000     0.039     0.000     0.000

N         0.000     0.000     0.000     0.000     0.000     0.000

N2        0.000     0.000     0.000    73.850     0.000     0.000

NO        0.000     0.000     0.000     0.199     0.000     0.000

N2O       0.000     0.000     0.000     0.000     0.000     0.000

NO2       0.000     0.000     0.000     0.000     0.000     0.000

NH3       0.000     0.000     0.000     7.390     0.000     0.000

A         0.000     0.000     0.000     0.199     0.000     0.000

CO2       0.000     0.000     0.000     0.500     0.000     0.000
```

```
                          OSCILLOGRAPH DATA

                           RUN NUMBER  2
          ENGINE                                   OTTLE

   QUANTITY  READING (INCHES)             QUANTITY  READING (INCHES)

   PCM       1.2800                         PB1     0.0000

   PNM       ******                         PB2     0.0000

   PFM       3.7100                         PB3     0.0000

   POM       4.1900                         PB4     2.8200

   PFT       4.0500                         PB5     0.0000

   POT       3.8500                         PB6     0.0000

   FFM       2.7200

   FOM       2.1900

   PWI       1.3300

   WM        3.0600                         PEM     0.0000

   FM        1.4600                         TBM     1.1200


                       BALLISTIC ANALYZER DATA

        PC  126.23 (PSI)                    F   73.03 (LB)

                            OTHER DATA

   CALIBRATION CONSTANTS                       MISCELLANEOUS


CFA  50.(LB/IN)    CPN   5.(PSI/IN)  PAM  14.700(PSI)     IS   200.00(S)

CPC 100.(PSI/IN)   CTB 200.(F/IN)    AT  0.44450(SQIN)    OD    89.84(*)

CPI 125.(PSI/IN)   CPE   0.(F/IN)    CSI   5808.          FD    62.77(*)

CPV 250.(PSI/IN)   CF  0.50(G/IN)          *-(LB/CUFT)

CPB 35.18(PSI/IN)
```

```
                    COMMENTS ON DATA AND DATA REDUCTION

      RUN NUMBER-  2                      DATE OF DATA REDUCTION-11/ 2/67

-----------------------------------------------------------------------------



      O/F ANALYZED BY WATERLESS FORMULATION

      H2O DETERMINED FROM O/F


  THIS IS A WCT ANALYSIS


  OXIDIZER AND FUEL DENSITIES DETERMINED USING 75 DEG F


  FIRST ATTEMPT - CSI 5808.0, SI 200.0
```

```
                                                              PAGE 1 OF 4

                  ROCKET MOTOR BOUNDARY FLOW DATA REDUCTION

        JPL CONTRACT - NAS7-463                      AEROTHERM PROJECT 7009

        RUN NUMBER -    3                         DATE OF FIRING - 10/ 3/67

        FIRING NUMBER -    4               DATE OF DATA REDUCTION - 10/24/67

                     INJECTOR POSITION -   0 DEGREES

-----------------------------------------------------------------------------

                           GAS ANALYSIS RESULTS

        AXIAL STATION (IN.)                    O/F IN BOUNDARY LAYER

             1.0280                                  0.0000

             1.7780                                  0.0000

             2.5280                                  0.0000

             3.2780                                  0.5036

             4.0280                                  0.0000

             4.7780                                  0.0000

                        ENGINE PERFORMANCE PARAMETERS

        O/F    1.3503          CSTAR  4823.         CSR    0.8305

        ISR    0.8626          PNPC   0.1263        CF     1.1675

        IS1    172.53          IS2    175.04        PC     139.70(PSIA)

        WO     0.2379(LB/S)    WF     0.1762(LB/S)  F       72.50(LB)

        PCBA   139.17(PSIA)    WW     0.2585(LB/S)
                              SYSTEM DATA

        FINAL BOTTLE PRESSURE (PSIA)              FLUID PRESSURES (PSIA)

        P1-14.70         P4-28.08          PF-   435.95        PFT-   887.19

        P2-65.99         P5-88.66          PO-   459.70        POT- 1034.70

        P3-33.28         P6-50.38          PW-   202.70

                         TB-   758.00(DEG R)
```

```
                 GAS SAMPLE DATA   RUN NUMBER   3

                 SAMPLES ANALYZED AT  WT     10/12/67

                           PER CENT MOLE FRACTION

          ***************************************************************
          *
          *                          BOTTLE NUMBER
          *
  GAS     *       1          2          3          4          5          6
          *
          *

  H           0.000      0.000      0.000      0.000      0.000      0.000

  H2          0.000      0.000      0.000      8.049      0.000      0.000

  HO          0.000      0.000      0.000      0.000      0.000      0.000

  H2O         0.000      0.000      0.000     14.916      0.000      0.000

  HO2         0.000      0.000      0.000      0.000      0.000      0.000

  HNO         0.000      0.000      0.000      0.000      0.000      0.000

  HNO2        0.000      0.000      0.000      0.000      0.000      0.000

  HNO3        0.000      0.000      0.000      0.000      0.000      0.000

  HN          0.000      0.000      0.000      0.000      0.000      0.000

  O           0.000      0.000      0.000      0.000      0.000      0.000

  O2          0.000      0.000      0.000      0.000      0.000      0.000

  N           0.000      0.000      0.000      0.000      0.000      0.000

  N2          0.000      0.000      0.000     18.480      0.000      0.000

  NO          0.000      0.000      0.000      0.039      0.000      0.000

  N2O         0.000      0.000      0.000      0.000      0.000      0.000

  NO2         0.000      0.000      0.000      0.000      0.000      0.000

  NH3         0.000      0.000      0.000     13.110      0.000      0.000

  A           0.000      0.000      0.000     52.599      0.000      0.000

  CO2         0.000      0.000      0.000      0.340      0.000      0.000
```

```
                                                                      PAGE 3 OF 4

                                     OSCILLOGRAPH DATA

                                      RUN NUMBER  3
                      ENGINE                                   BOTTLE

          QUANTITY  READING (INCHES)              QUANTITY  READING (INCHES)

          PCM        1.2500                         PB1      0.0000

          PNM       -0.5900                         PB2      1.3800

          PFM        3.3700                         PB3      0.5000

          POM        3.5600                         PB4      0.3600

          PFT        3.4900                         PB5      1.9900

          POT        4.0800                         PB6      0.9600

          FFM        2.5200

          FOM        2.3800

          PWI        1.8800

          WM         3.7200                         PEM      0.0000

          FM         1.4500                         TBM      1.4900


                                 BALLISTIC ANALYZER DATA

               PC  124.47 (PSI)                          F   71.46 (LB)

                                       OTHER DATA

          CALIBRATION CONSTANTS                           MISCELLANEOUS

       CFA  50.(LB/IN)     CPN   5.(PSI/IN)  PAM  14.700(PSI)      IS   200.00(S)

       CPC 100.(PSI/IN)    CTB 200.(F/IN)    AT  0.44450(SQIN)     OD     89.75(*)

       CPI 125.(PSI/IN)    CPE   0.(F/IN)    CSI   5808.           FD     62.77(*)

       CPV 250.(PSI/IN)    CF  0.50(G/IN)          *-(LB/CUFT)

       CPB 37.17(PSI/IN)
```

COMMENTS ON DATA AND DATA REDUCTION

RUN NUMBER- 3 DATE OF DATA REDUCTION-10/24/67

O/F ANALYZED BY ELEMENTAL COMPOSITION

COMMENTS ON FIRING-

PURGE VALVE USED ON NUMBER FOUR CYLINDER, JPL VALVE USED (OTHER 5. NUMBER 6 VALVE LEAKED. NUMBER 1 CYLINDER PRESSURE TRACE LOST. EXIT PLANE PRESSURE TRANSDUCER NOT INSTALLED . APPROXIMATE IDEAL SPECIFIC IMPULSE USED.

COLD MASS SPECTOGRAPHIC ANALYSIS OF BOTTLE NUMBER 4 ONLY

H2O MOLE FRACTION DATA FROM BACK CALCULATION USING WATERLESS FORMULATION

```
                                                          PAGE 1 OF 4

            ROCKET MOTOR BOUNDARY FLOW DATA REDUCTION

   JPL CONTRACT - NAS7-463                    AEROTHERM PROJECT 7009

   RUN NUMBER -    4                      DATE OF FIRING - 11/ 7/67

   FIRING NUMBER -    5            DATE OF DATA REDUCTION - 12/15/67

                   INJECTOR POSITION -   0 DEGREES
-----------------------------------------------------------------------

                       GAS ANALYSIS RESULTS

   AXIAL STATION (IN.)                    O/F IN BOUNDARY LAYER

        1.0280                                 0.1360

        1.7780                                 0.0582

        2.5280                                 0.2499

        3.2780                                 0.0000

        4.0280                                 0.1459

        4.7780                                 0.1611

                    ENGINE PERFORMANCE PARAMETERS

   O/F    1.2389          CSTAR   5007.           CSR     0.8622

   ISR    0.9103          PNPC   0.0850           CF      1.2002

   IS1    182.07          IS2    186.82           PC      138.69(PSIA)

   WO     0.2191(LB/S)    WF     0.1769(LB/S)     F        74.00(LB)

   PCBA   139.52(PSIA)    WT     0.2377(LB/S)
                          SYSTEM DATA

   FINAL POTILE PRESSURE (PSIA)             FLUID PRESSURES (PSIA)

   P1-31.56         P4-14.70              PF-  439.70         PFT-  909.70

   P2- 7.41         P5-23.13              PO-  434.70         POT-  974.69

   P3-22.36         P6- 3.20              PW-  185.69

                      TB-  636.00(DEG R)
```

```
              GAS SAMPLE,DATA    RUN NUMBER    4

              SAMPLES ANALYZED AT  WT      12/12/67

                        PER CENT MOLE FRACTION

     ******************************************************************************
     *
     *                           BOTTLE NUMBER
     *
GAS  *       1          2          3          4          5          6
     *
     *

H          0.000      0.000      0.000      0.000      0.000      0.000

H2        38.519     30.049     25.809      0.000     30.299     20.240

HO         0.000      0.000      0.000      0.000      0.000      0.000

H2O        7.039      3.460     16.099      0.000      7.419      3.430

HO2        0.000      0.000      0.000      0.000      0.000      0.100

HNO        0.000      0.000      0.000      0.000      0.000      0.000

HNO2       0.000      0.000      0.000      0.000      0.000      0.000

HNO3       0.000      0.000      0.000      0.000      0.000      0.000

HN         0.000      0.000      0.000      0.000      0.000      0.000

O          0.000      0.000      0.000      0.000      0.000      0.000

O2         0.079      0.039      0.000      0.000      0.009      0.000

N          0.000      0.000      0.000      0.000      0.000      0.000

N2        25.05      24.820     21.380      0.000     31.289     64.259

NO         0.090      0.129      0.170      0.000      0.399      0.459

N2O        0.000      0.000      0.000      0.000      0.000      0.000

NO2        0.000      0.000      0.000      0.000      0.000      0.000

NH3       26.659     37.959     34.370      0.000     26.250      7.319

A          1.190      2.750      1.299      0.000      2.300      3.559

CO2        0.449      0.770      0.859      0.000      2.019      0.720
```

```
                           OSCILLOGRAPH DATA

                            RUN NUMBER  4
            ENGINE                                      BOTTLE

    QUANTITY  READING (INCHES)             QUANTITY  READING (INCHES)

    PCM       1.2400                        PB1       0.4400

    PNM       ******                        PB2       ******

    PFM       3.4000                        PB3       0.2000

    POM       3.3600                        PB4       0.0000

    PFT       3.5800                        PB5       0.2200

    POT       3.8400                        PB6       ******

    FFM       2.5300

    FOM       2.1900

    PWI       1.7100

    [illegible]  3.4200                     PEM       0.0000

    FM        1.4800                        TBM       0.8800


                         BALLISTIC ANALYZER DATA

         PC   124.83 (PSI)                         F    72.12 (LB)

                               OTHER DATA

    CALIBRATION CONSTANTS                          MISCELLANEOUS

 CFA   50.(LB/IN)    CPN    5.(PSI/IN)  PAM  14.700(PSI)      IS    200.00(S)

 CPC 100.(PSI/IN)    CTB 200.(F/IN)     AT  0.44450(SQIN)     CD     89.84(*)

 CPI 125.(PSI/IN)    CPE    0.(F/IN)    CSI   5808.           FD     62.77(*)

 CPV 250.(PSI/IN)    CF   0.50(G/IN)          *-(LB/CUFT)

 CP5 38.33(PSI/IN)
```

COMMENTS ON DATA AND DATA REDUCTION

RUN NUMBER- 4 DATE OF DATA REDUCTION-12/15/67

O/F ANALYZED BY ELEMENTAL COMPOSITION

THIS IS UTC RUN NO LIB-5

HOT DATA CYLINDERS 1-3 AND 5 THRU 6

ELEMENTAL COMPOSITION

```
                                                                    PAGE 1 OF 4

                    ROCKET MOTOR BOUNDARY FLOW DATA REDUCTION

          JPL CONTRACT - NAS7-463                        AEROTHERM PROJECT 7009

          RUN NUMBER -     5                             INJECTOR POSITION -    0

          FIRING NUMBER -     6                          DATE OF FIRING - 12/29/67

----------------------------------------------------------------------------------

                              GAS ANALYSIS RESULTS

          AXIAL STATION (IN.)                        O/F IN BOUNDARY LAYER

                1.0280                                     0.3262

                1.7780                                     0.5868

                2.5280                                     0.1060

                3.2780                                     0.2219

                4.0280                                     0.1223

                4.7780                                     0.1736

                           ENGINE PERFORMANCE PARAMETERS

          O/F    1.0266            CSTAR  5315. (FT/S)    CSR    0.9112

          ISR    0.8149            PNPC   0.0819          CF     1.1892

          IS     196.46 (SEC)      F      70.54 (LB)      PC     133.45 (PSIA)

          ISB    187.00 (SEC)      FB     67.15 (LB)      PCB    134.40 (PSIA)

          WO     0.1819 (LB/S)     WF     0.1771 (LB/S)   WW     0.2312 (LB/S)

          PSR    1.0278

                                  SYSTEM DATA

              PRESSURE (PSIA)                       TEMPERATURE (DEG.R)

          PF     445.94     PFT    896.07         TB   740.60      TO   534.00

          PO     394.08     POT   1022.26         TS   854.50      TF   510.50

          PW     163.12                           TV1    0.00
```

```
          GAS COMPOSITION          RUN NUMBER  5

          ******************************************************************
          *
          *                      MOLE FRACTION
          *
          *

          *                      BOTTLE NUMBER
          *
GAS       *      1         2         3         4         5         6
          *
          *         *
H2        *    15.381    15.287    20.948    14.738    17.818    13.598
          *
H2O       *    15.616    21.284     4.109    11.062     7.317    11.409
          *
O2        *     0.052     0.000     0.102     0.000     0.000     0.000
          *
N2        *    32.621    33.002    30.876    27.835    23.713    19.871
          *
NO        *     0.000     0.664     0.000     0.000     0.000     0.000
          *
N2O       *     1.156     1.568     1.943     2.280     0.689     1.006
          *
NO2       *     0.369     1.506     0.000     0.000     0.000     0.000
          *
NH3       *    30.955    18.881    39.766    40.335    45.857    51.764
          *
N2H4      *     0.039     0.000     0.002     0.000     0.000     0.000
          *
A         *     0.004     0.006     0.009     0.001     0.000     0.003
          *
CO2       *     1.156     0.000     0.636     0.943     0.222     0.358
          *
HE        *     2.645     7.798     1.605     2.802     4.380     1.986
          *
          ******************************************************************
PRESSURE

 (PSIA)        21.83     20.26     29.01     13.39    103.85      9.78
```

```
                                                     PAGE 3 OF 4
                           RUN NUMBER  5

                          OSCILLOGRAPH DATA

QUANTITY     READING    CAL       QUANTITY      READING     CAL
              (IN.)*                             (IN.)

                              MOTOR

   WF         72.60    58.00        F              1.27    55.11           0.000            0.000
   PC          2.15    55.23        PO             3.03   125.20           0.000            0.000
   PF          3.45   124.99        PV             4.03   250.01           0.000            0.000
   PW          1.47   100.28        PN            -0.73     5.08           0.000            0.000
   PS          0.07     5.11        PT             3.49   252.54           0.000            0.000
   WO        127.20   140.00        TB             1.21     4.02           0.000            4.908
   TS          2.29     4.13        TO            -0.64     4.13           9.478           -2.645
   TF         -0.78     4.34        WW             3.20     0.51          -3.434            1.663

                          BOTTLE PRESSURE

   P1          0.19    35.67        P2             0.17    30.90
   P3          0.44    31.81        P4            -0.03    43.50
   P5          1.86    47.67        P6            -0.12    40.98

                      BALLISTIC ANALYZER DATA

   PB        134.40(PSIA)                    FB           67.15(LB.)

                      MISCELLANEOUS DATA

   PAM       14.700(PSIA)           IS        229.48(SEC)
   OD        89.860(LB/CUFT)        CSI      5833.00(FT/SEC)
   FD        63.530(LB/CUFT)        AT          0.44(SQIN)

                        * CPS FOR WF AND WO
```

COMMENTS ON DATA AND DATA REDUCTION

RUN NUMBER- 5 DATE OF DATA REDUCTION- 0/ 0/60

O/F ANALYZED BY ELEMENTAL COMPOSITION

```
                                                          PAGE 1 OF 4

                 ROCKET MOTOR BOUNDARY FLOW DATA REDUCTION

         JPL CONTRACT - NAS7-463                AEROTHERM PROJECT 7009

         RUN NUMBER -    6                      INJECTOR POSITION -   0

         FIRING NUMBER -    7                   DATE OF FIRING - 12/29/67

-------------------------------------------------------------------------------


                          GAS ANALYSIS RESULTS

         AXIAL STATION (IN.)                O/F IN BOUNDARY LAYER

             1.0280                             0.1687

             1.7780                             0.0000

             2.5280                             0.1357

             3.2780                             0.4722

             4.0280                             0.3210

             4.7780                             0.5993

                      ENGINE PERFORMANCE PARAMETERS

         O/F     1.1172         CSTAR  4910. (FT/S)   CSR    0.8425

         ISR     0.0000         PNPC   0.0812         CF     1.1189

         IS      170.77 (SEC)   F      70.16 (LB)     PC     141.07 (PSIA)

         ISB       0.00 (SEC)   FB      0.00 (LB)     PCB     14.70 (PSIA)

         WO      0.2168 (LB/S)  WF     0.1940 (LB/S)  WW     0.0000 (LB/S)

         PSR     1.0000


                              SYSTEM DATA

             PRESSURE (PSIA)                   TEMPERATURE (DEG.R)

         PF      469.13    PFT    980.59       TB   748.30     TO   522.50

         PO      432.90    POT    979.30       TS   925.68     TF   516.87

         PW      158.08                        TV1  809.70
```

```
          GAS COMPOSITION          RUN NUMBER   6

          ******************************************************************
          *
          *                        MOLE FRACTION
          *
          *
          *                        BOTTLE NUMBER
          *
GAS       *     1          2          3          4          5          6
          *
          *               *
H2        *   12.894     0.000     16.104     10.038     11.301     14.662
          *
H2O       *   11.757     0.000      7.348     30.948     20.417     25.075
          *
N2        *   18.563     0.000     26.788     18.942     23.700     30.989
          *
NO        *    0.000     0.000      0.000      0.000      0.000      1.189
          *
N2O       *    0.659     0.000      1.271      0.000      0.283      1.328
          *
NO2       *    0.000     0.000      0.000      0.596      0.077      2.015
          *
NH3       *   54.008     0.000     45.129     37.820     41.028     24.008
          *
A         *    0.005     0.000      0.037      0.000      0.000      0.000
          *
CO2       *    0.553     0.000      0.794      1.413      0.954      0.000
          *
HE        *    1.558     0.000      2.526      0.240      2.235      0.731
          *
          ******************************************************************

PRESSURE
 (PSIA)        14.70    120.10     123.74     134.19     169.32     121.08
```

```
                                                    PAGE 3 OF 4
                         RUN NUMBER  6

                       OSCILLOGRAPH DATA

   QUANTITY      READING    CAL       QUANTITY       READING      CAL
                  (IN.)*                              (IN.)

                             MOTOR

      WF          70.00    50.90        F              1.41     49.40                 0.000              0.000

      PC           2.51    50.34        PO             3.38    123.36                 0.000              0.000

      PF           3.67   123.82        PV             3.90    247.33                 0.000              0.000

      PW           1.45    98.88        PN            -0.62      5.13                 0.000              0.000

      PS           4.54     0.00        PT             3.66    263.90                 0.000              0.000

      WO         150.00   140.00        TB             1.26      4.13                 0.000              5.207

      TS           2.91     4.27        TO            -0.73      4.12                12.448             -3.050

      TF          -0.75     4.28        T1             1.71      4.47                -3.213              7.655

                       BOTTLE PRESSURE

      P1           0.00     0.00        P2             3.40     30.90

      P3           3.10    35.17        P4             2.83     42.07

      P5           3.29    46.85        P6             2.61     40.76

                    BALLISTIC ANALYZER DATA

      PB         14.70(PSIA)                  FB            0.00(LB.)

                    MISCELLANEOUS DATA

      PAM        14.700(PSIA)           IS         228.98(SEC)

      OD         90.820(LB/CUFT)        CSI       5828.00(FT/SEC)

      FD         63.330(LB/CUFT)        AT             0.44(SQIN)

                      * CPS FOR WF AND WO
```

COMMENTS ON DATA AND DATA REDUCTION

RUN NUMBER- 6 DATE OF DATA REDUCTION- 0/ 0/60

O/F ANALYZED BY ELEMENTAL COMPOSITION

FIRING RAN OVERTIME. SAMPLING VALVES
OPEN FOR ABOUT 10 SECONDS.

BOTTLE 2 LOST. OVERPRESSURED MASS SPECTROMETER

```
              ROCKET MOTOR BOUNDARY FLOW DATA REDUCTION

JPL CONTRACT - NAS7-463                     AEROTHERM PROJECT 7009

RUN NUMBER -    7                           INJECTOR POSITION -    0

FIRING NUMBER -    8                        DATE OF FIRING - 12/29/67

------------------------------------------------------------------------------


                    GAS ANALYSIS RESULTS

AXIAL STATION (IN.)                     O/F IN BOUNDARY LAYER

     1.0280                                  0.1633

     1.7780                                  0.2252

     2.5280                                  0.0281

     3.2780                                  0.2279

     4.0280                                  0.2679

     4.7780                                  0.4367

               ENGINE PERFORMANCE PARAMETERS

O/F    1.1086          CSTAR  4922. (FT/S)   CSR    0.8446

ISR    0.7730          PNPC   0.0815         CF     1.1497

IS     175.91 (SEC)    F      71.74 (LB)     PC     140.37 (PSIA)

ISB    177.01 (SEC)    FB     72.19 (LB)     PCB    145.69 (PSIA)

WO     0.2144 (LB/S)   WF     0.1934 (LB/S)  WW     0.0000 (LB/S)

PSR    0.9965


                        SYSTEM DATA

    PRESSURE (PSIA)                        TEMPERATURE (DEG.R)

PF     457.43    PFT    954.86            TB   772.70     TO   535.30

PO     443.80    POT    976.60            TS   903.30     TF   523.50

PW      14.70                             TV1  772.75
```

```
          GAS COMPOSITION            RUN NUMBER  7

          *****************************************************************
          *
          *                       MOLE FRACTION
          *
          *
          *
          *                       BOTTLE NUMBER
          *
 GAS      *      1          2          3          4          5          6
          *
          *              *
 H2       *    18.262     10.769     19.642     18.425     28.518     18.172
          *
 H2O      *     7.508     17.070      1.090      9.003      7.617     14.218
          *
 O2       *     1.319      0.000      0.239      1.115      1.391      0.267
          *
 N2       *    28.814     15.233     30.228     37.366     44.704     38.475
          *
 N2O      *     0.074      0.000      0.160      0.060      0.000      1.316
          *
 NO2      *     0.000      0.000      0.000      0.000      0.000      0.968
          *
 NH3      *    42.697     50.602     45.092     29.142     12.938     17.808
          *
 N2H4     *     0.000      2.514      0.000      0.000      0.095      0.042
          *
 A        *     0.059      0.006      0.010      0.050      0.066      0.010
          *
 CO2      *     0.559      0.743      0.984      0.518      0.369      0.020
          *
 HF       *     0.705      3.058      2.550      4.318      4.296      8.698
          *
          *****************************************************************

 PRESSURE

  (PSIA)        39.19      27.68      38.26      27.32     100.91      18.36
```

```
                                                             PAGE 3 OF 4
                           RUN NUMBER  7

                              OSCILLOGRAPH DATA

 QUANTITY      READING     CAL        QUANTITY       READING      CAL
                (IN.)*                                 (IN.)

                                  MOTOR

     WF         70.00    50.90          F             1.45     49.47              0.000               0.000

     PC          2.51    50.06          PO            3.42    125.10              0.000               0.000

     PF          3.57   123.66          PV            3.91    245.38              0.000               0.000

     PW          0.00    98.39          PN           -0.62      5.24              0.000               0.000

     PS         -0.01     5.08          PT            3.75    250.71              0.000               0.000

     WO        150.00   140.00          TB            1.49      4.13              0.000               6.157

     TS          2.69     4.27          TO           -0.63      4.12             11.507              -2.[illegible]

     TF         -0.69     4.28          T1            1.38      4.47             -2.999               6.178

                              BOTTLE PRESSURE

     P1          0.69    35.50          P2            0.42     30.90

     P3          0.67    35.17          P4            0.29     42.07

     P5          1.83    46.85          P6            0.08     40.76

                          BALLISTIC ANALYZER DATA

     PB       145.69(PSIA)                        FB           72.19(LB.)

                          MISCELLANEOUS DATA

     PAM      14.700(PSIA)              IS         228.98(SEC)

     OD       89.820(LB/CUFT)           CSI       5828.00(FT/SEC)

     FD       63.120(LB/CUFT)           AT           0.44(SQIN)

                          * CPS FOR WF AND WO
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COMMENTS ON DATA AND DATA REDUCTION

RUN NUMBER- 7 DATE OF DATA REDUCTION- 0/ 0/60

O/F ANALYZED BY ELEMENTAL COMPOSITION

SIGNAL ON WATER PRESSURE LOST

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                                                                  PAGE 1 OF 4

                   ROCKET MOTOR BOUNDARY FLOW DATA REDUCTION

         JPL CONTRACT - NAS7-463                   AEROTHERM PROJECT 7009

         RUN NUMBER -    8                         INJECTOR POSITION -   0

         FIRING NUMBER -    9                      DATE OF FIRING - 12/29/67

--------------------------------------------------------------------------------------

                            GAS ANALYSIS RESULTS

         AXIAL STATION (IN.)                    O/F IN BOUNDARY LAYER

              1.0280                                  3.0113

              1.7780                                  0.1084

              2.5280                                  0.1371

              3.2780                                  0.1525

              4.0280                                  0.7019

              4.7780                                  0.4366

                         ENGINE PERFORMANCE PARAMETERS

         O/F    1.1425          CSTAR  4900. (FT/S)    CSR    0.8416

         ISR    0.7732          PNPC   0.0814          CF     1.1538

         IS     175.73 (SEC)    F      71.74 (LB)      PC     139.87 (PSIA)

         ISB    176.74 (SEC)    FB     72.15 (LB)      PCB    154.82 (PSIA)

         WO     0.2176 (LB/S)   WF     0.1905 (LB/S)   WW     0.0000 (LB/S)

         PSR    0.9930

                                 SYSTEM DATA

             PRESSURE (PSIA)                      TEMPERATURE (DEG.R)

         PF     452.48    PFT    934.81          TB   751.30     TO   536.70

         PO     450.06    POT    981.51          TS   964.10     TF   523.30

         PV     169.18                           TV1  850.30
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         GAS COMPOSITION            RUN NUMBER  8

         ********************************************************************
         *
         *                            MOLE FRACTION
         *
         *

         *                            BOTTLE NUMBER
         *
GAS      *        1           2           3           4           5           6
         *
         *             *
H2       *      0.057      14.045      14.240      16.299       8.574      18.819
         *
H2O      *      0.203       6.249       8.882       8.045      45.597      14.320
         *
O2       *      0.845       0.650       0.223       0.193       0.446       0.412
         *
N2       *      3.455      20.069      22.479      31.726      15.293      36.430
         *
N2O      *      0.000       0.134       0.115       0.087       0.000       1.335
         *
NO2      *      0.000       0.000       0.000       0.000       0.000       1.152
         *
NH3      *      0.428      54.303      50.502      37.245      27.254      19.006
         *
N2H4     *      0.000       0.000       0.000       0.000       0.012       0.058
         *
A        *      0.026       0.029       0.007       0.002       0.002       0.014
         *
CO2      *      0.000       0.186       1.260       1.431       1.042       0.000
         *
HE       *     94.982       4.330       2.287       4.967       1.775       8.448
         *
         ********************************************************************

PRESSURE

 (PSIA)          31.38       28.91       37.91       26.48      164.64       19.56
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                                                            PAGE 3 OF 4
                              RUN NUMBER   8

                           OSCILLOGRAPH DATA

  QUANTITY        READING    CAL        QUANTITY        READING     CAL
                   (IN.)*                                 (IN.)

                                 MOTOR

     WF             68.96     50.90       F               1.45     49.47                 0.000                 0.000

     PC              2.50     50.06       PO              3.48    125.10                 0.000                 0.000

     PF              3.53    123.66       PV              3.94    245.38                 0.000                 0.000

     PW              1.56     98.39       PN             -0.62      5.24                 0.000                 0.000

     PS             -0.02      5.08       PT              3.67    250.71                 0.000                 0.000

     WO            152.50    140.00       TB              1.28      4.13                 0.000                 [illegible]

     TS              3.28      4.27       TO             -0.62      4.12                14.074                 [illegible]

     TF             -0.69      4.28       T1              2.08      4.47                -2.956                 9.312

                            BOTTLE PRESSURE

     P1              0.46     35.50       P2              0.46     30.90

     P3              0.65     35.17       P4              0.27     42.07

     P5              3.20     46.85       P6              0.11     40.54

                        BALLISTIC ANALYZER DATA

     PB            154.82(PSIA)                   FB             72.15(LB.)

                        MISCELLANEOUS DATA

     PAM           14.700(PSIA)           IS              228.57(SEC)

     OD            89.700(LB/CUFT)        CSI            5822.00(FT/SEC)

     FD            63.120(LB/CUFT)        AT                0.44(SQIN)

                          * CPS FOR WF AND WO
```

COMMENTS ON DATA AND DATA REDUCTION

RUN NUMBER- 8 DATE OF DATA REDUCTION- 0/ 0/60

O/F ANALYZED BY ELEMENTAL COMPOSITION

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

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