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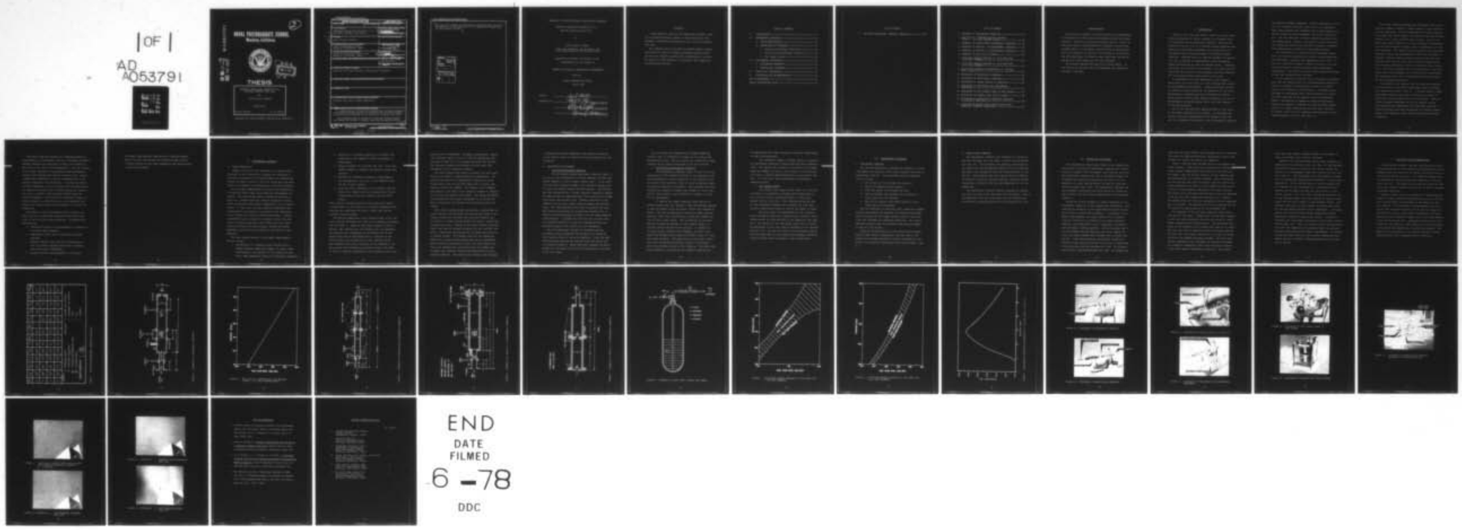

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Monterey, California

THESIS

COMBUSTOR DESIGN AND OPERATION FOR A
SUB-SCALE TURBOJET TEST CELL

by

Jerry Russell Charest

March 1978

Thesis Advisor: D. W. Netzer

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The combustor can be utilized to perform further studies concerning the effects of engine operating characteristics

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Combustor Design and Operation for a

Sub-Scale Turbojet Test Cell

by

Jerry Russell Charest

Lieutenant Commander, United States Navy
B.S., University of West Florida, 1973

Submitted in partial fulfillment of the

requirements for the degree of

MASTER OF SCIENCE IN AERONAUTICAL ENGINEERING

from the

NAVAL POSTGRADUATE SCHOOL

March 1978

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ABSTRACT

A high pressure, water-cooled ramjet-type combustor capable of producing various amounts of particulates has been designed, constructed and operated in the sub-scale turbojet test cell.

The combustor can be utilized to perform further studies concerning the effects of engine operating characteristics and test cell design on particulate concentrations, and also the effects of fuel additives on the amount and composition of particulates emitted.

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ACKNOWLEDGMENT

The author is indebted to several people in the Department of Aeronautics for their advice and support during this investigation: foremost to Associate Professor David W. Netzer for his thesis advice (superb guidance), optimistic attitude and friendly manner; to Don Harvey, whose meticulous machine-shop work could always be relied upon; and finally to an outstanding aero-technician, Pat Hickey, whose individual instruction and generous ideas always got the task completed.

My sincerest appreciation goes to my loving family: my wife Eileen and son Tom, whose encouragement and understanding made it possible.

I. INTRODUCTION

Turbojet test cells are usually located at airport maintenance facilities for static testing of jet engines prior to installation in an operational aircraft. The major objective of the test cell is to achieve optimum operating conditions so that engine performance can be monitored in an environment which closely simulates the installed engine operation. Although there are numerous designs, the typical test cell is usually an independently housed rectangular shaped building with an inlet and exhaust stack. A particular design is a function of the engines to be tested and the objectives of the tests to be performed, with some flexibility for possible future modifications to the cell.

A consideration of major importance in the design or modification of a test cell is to meet existing laws concerning environmental disturbances. Chemical pollution control is currently a major problem in the operation of test cells. Environmental standards have been established for disturbances such as noise, smoke, gaseous pollutants, etc. by the Environmental Protection Agency (EPA), and local Regional Air Quality Districts.

One of the more difficult design problems in test cells is the proper treatment of the exhaust. As mentioned previously, an acute consideration in the design of the test cell is to preserve the quality of the environment by meeting the imposed stringent standards. Various techniques for control of pollutants have been used in test cell operations. They include exhaust gas scrubbing such as water droplet adhesion, mechanical grid entrapment, electronic ionization, etc., and fuel additives to remove chemical pollutants from the exhaust gases. Methods to decrease the noise from test cell operations have been in the area of acoustic treatment with combinations of baffles and absorbing materials.

The installation of various pollution abatement equipment can cause new constraints on exhaust stack temperature, flow uniformity, pressure, and augmentation ratio [Ref. 1]. Test cell operations require a uniform flow with a low turbulence intensity to obtain accurate engine performance measurements. The effects from the various abatement methods on test cell operation must be known.

In the operation of the test cell, secondary air entrainment into the exhaust gases of a non-afterburning engine reduces the pollutant concentrations but has only a minor effect on the change in total emittants. Secondary and/or tertiary air entrainment and/or water quenching can affect the total emittants in the exhaust from an afterburning engine. Optimization of augmentor design and quenching methods with regard to chemical and noise pollution minimization as a design criterion has not been fully explored. At present, there is not a suitable technology base for the optimum design of the test cell [Ref. 1].

The current abatement methods and techniques used in test cells are complex, leading to great expense in their construction and operation. With the large mass flow rates necessary for current and future engines, the effects from these various methods on test cell operation must be known. Costs to do these full-scale studies such as fuel, equipment, maintenance, and qualified personnel becomes a major consideration of test cell operation. The combined costs associated with full-scale abatement studies and optimization of test cell operation to simulate installed engine operation indicates the need for a sub-scale test facility which can be used to perform design and operating optimization studies to minimize emitted pollution. With minor drawbacks due to scaling effects, sub-scale studies have the advantages of low construction, maintenance and operating costs, ease of instrumentation and data acquisition, and minimum personnel.

A one-eighth scale turbojet test cell has been designed and constructed at the Naval Postgraduate School's Aeronautics Laboratories [Refs. 2 and 3]. A variable bypass, sudden dump ramjet combustor was used to simulate the exhaust of mixed-flow turbofan engines as well as turbojets. This provided an adequate simulation of the jet exhaust (nozzle total pressure and temperature) for operations from idle through military power with afterburner for initial investigations into augmentor design effects and analytical model validation.

The ramjet combustor operated at a maximum pressure of approximately 2.5 atmospheres (typical of tailpipe pressures), whereas combustor can pressures in today's gas turbine engines are on the order of 8-20 atmospheres. The low pressure of the ramjet combustor (no appreciable smoke production), compared with turbofan and turbojet combustor cans, creates a significant difference in species concentrations in the exhaust, especially for particulates. To study the effects of engine operation, test cell design, and fuel additives on the quantity and composition of emitted pollutants requires the use of a combustor that operates between eight and twenty atmospheres. Construction of a subscale turbojet or turbofan engine is prohibitive from a cost standpoint and defeats the original goals for the program of low cost and flexibility.

The purpose of this investigation was to design, construct and test a ramjet-type combustor which would allow study of test cell particulate emissions. Characteristics required were:

a. Combustor pressures of nine atmospheres or greater to facilitate smoke formation.

b. Long duration test time to facilitate pollution sampling.

c. Variable fuel/air ratio and fuel distribution in order to provide variable particulate concentrations and exhaust temperatures.

d. Accurate control and measurement of flow rates.

The ramjet dump-combustor employed was a multiple-chamber device in which the pressure was reduced through a series of sonic nozzles and the total temperature was reduced using a water-cooled jacket.

II. EXPERIMENTAL APPARATUS

A. DESIGN METHODOLOGY

Design, construction and operation of a combustor with pressures of nine atmospheres or greater was desirable to provide an inexpensive and versatile means for studying the effects of engine operation, test cell design and fuel additives on the quantity and composition of emitted pollutants.

An air supply (approximately 150 psia) was available at the facility from a large volume positive displacement compressor. The decision was made to design and construct a dump (i.e., sudden expansion) combustor apparatus in which smoke concentration and exhaust temperature could be readily varied. In this unit, the high combustor temperature and pressure had to be reduced to low pressure and temperature at the exhaust exit without turbine work removal. Another consideration was to design the combustor without the presence of strong shocks which could affect both the concentration and size of the particulates, thereby preventing meaningful results from the studies of the effects of fuel additives.

The basic design features of the ramjet dump-combustor were as follows:

1. Introduction of a primary air/fuel mixture into a sudden expansion combustion chamber (to obtain flame stabilization), and ignition of this mixture to provide a high temperature source for additional combustion.

2. Injection of a variable quantity of secondary fuel downstream in the chamber to vary the quantity of particulates.

3. Supply secondary air flow near the exit of the combustion chamber to regulate the desired exhaust temperature.

4. Decrease the combustion pressure to approximately two atmospheres at the exit of the combustor with the use of sonic nozzles.

5. Lower the total temperature at the exhaust exit and protect the chamber walls by incorporating a water-cooled jacket around the combustor and the first nozzle.

These features included provisions for varying the amounts of particulates in the exhaust at a suitable temperature and pressure with sufficient run time to obtain data for the pollution control studies.

The desired temperature of the combined flows of the combustor exhaust and bypass air flow in the tailpipe was between 800° and 1000° R. Combustor flow rates between 0.5 and 1.5 lbm/sec. were required for the existing test cell apparatus. The required total temperature at the exhaust of the combustor could then be determined and is a function of the fuel/air ratio and the heat loss to the combustor walls. Heat transfer rates across the walls of the chambers to the water jacket were estimated using several water flow rates so that the required temperature at the entrance to the first nozzle could be determined. Assuming stoichiometric combustion (air/fuel ratio of 14.5 to 1 with an approximate temperature of 4200° R) of the primary air/total fuel mixture, the necessary primary and secondary air flow rates were determined for the combustion chamber.

The sonic nozzles were sized to decrease the total pressure at the exhaust to approximately two atmospheres. Two nozzles were used in the experimental combustor to avoid strong shocks (and the resulting rapid rise in static temperature) within the chamber. The lengths of the chambers were chosen so the ratio of the length of chamber to diameter of the nozzle was greater than eight. This design consideration allowed for the viscous dissipation of the nozzle exhaust velocity and the decrease in the pressure within the chamber.

With initial design dimensions derived, a preliminary uncooled combustor was designed, constructed and tested to determine primary and secondary fuel manifold locations and the ability to create varying amounts of smoke by controlling secondary fuel flow. Because of the short duration operating times (less than 30 seconds) necessary for the uncooled combustor, temperature and pressure at the nozzle exit were not of primary concern. This design used only the combustion chamber and a single nozzle exhausting into the atmosphere. After obtaining satisfactory results, the water-cooled combustor was designed and constructed using the primary and secondary fuel manifold locations determined from the preliminary combustor. The water-cooled combustor was designed to provide the desired temperature and pressure conditions at the exhaust nozzle to simulate full-scale engine test cell operation.

B. DESCRIPTION OF APPARATUS

1. Uncooled Preliminary Combustor

The preliminary sudden dump ramjet combustor (Figs. 1, 10, and 13) was constructed in several component sections and welded together to form a single integral unit. An air inlet tube with fuel injected through a fuel manifold ring was used to obtain the desired primary fuel/air mixture. This mixture was then introduced into a sudden expansion combustion chamber and ignited with an oxygen-ethylene torch located in the flame stabilizing recirculation zone. Further downstream in the combustor section were located three secondary fuel manifold rings. The three manifolds were used to determine the optimum location and spacing for introducing secondary fuel to obtain the desired quantity of smoke (only two rings operated simultaneously). Secondary air flow was then injected into the combustion mixture to lower the temperature before exhausting through a sonic nozzle into the atmosphere.

Fuel flow resistance through the manifolds was precalibrated using a simulated fuel manifold with identical fuel injection holes to the actual manifold. Fuel flow rate versus manifold pressure was obtained from this device and is plotted in Figure 2. These data were necessary for determination of the proper size of cavitating venturi to be used in the fuel lines.

Air flow rates were measured with standard ASME-type orifices [Ref. 4] installed in flanges of the primary and secondary air lines. The flow rates were controlled by hand-operated valves located downstream of the flow orifices.

2. Water-Cooled Experimental Combustor

The experimental combustor (Figs. 3-5 and 11-13) was constructed in five separate sections so the apparatus could be disassembled for visual inspection of the interior walls and nozzles after operation (also to allow replacement and/or re-design of nozzles if necessary). The individual sections included the combustion chamber with primary air inlet tube and two sonic nozzles, each followed by a chamber to allow for jet dissipation.

To achieve the longer operating times required to perform studies with the combustor, water-cooling was employed to keep the chamber walls and nozzle within safe temperature limits. This was accomplished by placing a larger diameter stainless steel tube concentrically around each chamber section to form a water jacket. The circulation of the water flow was directed by placing 1/4 inch copper tubing in a "spiral" pattern between the two casings. In addition to the water jacket cooling of the chambers, the first sonic nozzle was designed with a water circulation cavity for cooling during operation. Two-tube entry and exit water connections were utilized with external tubing to interconnect water flow between sections of the combustor. The water flow rate available at the facility was capable of meeting the pre-determined flow needs through the combustor (approximately eight gallons/minute).

The combustion chamber, although similar in design to the preliminary combustor, incorporated some minor modifications. The ignitor was relocated to the face of the sudden expansion chamber (an area of low velocity in the recirculation zone) to achieve improved ignition of the fuel/air mixture. "O" ring seals were used between the individual chambers/nozzles.

3. Fuel Supply System

The portable fuel supply system (Figs. 6, 14 and 15) consisted of two regulated, nitrogen pressurized tanks of JP-4 jet fuel, with an associated panel to control and measure the fuel flow rate. This two-tank system was used so that independent primary and secondary fuel flow rates could be selected and varied to control the amount of smoke.

From each tank, the pressurized fuel was filtered, passed through an electrical solenoid valve, through a cavitating venturi and then directed to the respective fuel manifold. The function of the cavitating venturi was to permit the adjustment of fuel flow rate by variation of the upstream pressure only. The fuel flow rates versus upstream pressure were pre-calibrated for the primary and secondary cavitating venturis and are shown in Figures 7 and 8 respectively.

III. EXPERIMENTAL PROCEDURES

A. PRELIMINARY COMBUSTOR

The uncooled preliminary combustor was adapted to a modified engine test stand in a full-scale turbojet test cell for operational check-out. The procedures used for operation were as follows:

1. Set primary air flow through the combustor.
2. Ignite the oxygen-ethylene ignitor.
3. Start and adjust the secondary air flow.
4. Open the primary and secondary fuel solenoids to inject fuel into the combustor.
5. Turn off the ignitor once engine ignition occurs (flame was self-sustaining).

With the combustor in operation, data (combustion chamber pressure and primary and secondary air pressure and differential pressures at the flange orifice plates in each flow line) were recorded on a Honeywell Visicorder. The venturi upstream pressures were also recorded from pressure gauges on the fuel tank system.

Using the recorded data, air flow rates could be determined by ASME orifice calculations, and fuel flow to the primary and secondary manifolds could be determined by reference to the specific cavitating venturi plots (Figs. 7 and 8).

B. WATER-COOLED COMBUSTOR

The experimental combustor was installed in conjunction with the sub-scale test cell [Refs. 2 and 3] for operational use (Fig. 16). The procedures for operation were basically the same as for the preliminary combustor with the exception that water flow through the unit was initiated prior to combustion. Data obtained were also similar with the addition of combustor intake and exhaust pressures, combustor exhaust temperature, and water flow rate and temperature at the discharge port.

The experimental combustor exhaust replaced the primary air flow line used in the sub-scale test cell [Refs. 2 and 3]. Instrumentation and data acquisition for the combustor was provided by the existing system for the sub-scale test cell.

IV. RESULTS AND DISCUSSION

The high-pressure ramjet-type combustor was designed and constructed to provide an experimental apparatus for future pollution studies in the one-eighth scale turbojet test cell. The preliminary combustor was used to determine primary and secondary fuel manifold locations and the ability of the apparatus to create varying amounts of smoke by using different secondary fuel flows. The experimental combustor was then designed, constructed and tested using the optimum design features from the results obtained from the preliminary combustor.

During the initial attempts to obtain combustion in the preliminary combustor, a minor problem was encountered. This involved the operation of the oxygen-ethylene ignitor torch, which would not ignite when energized. A relocation of the ignitor approximately two inches forward of its original location (closer to the entrance of the sudden expansion chamber), and modification to the operational procedures were necessary to obtain ignition. Initial procedure was to set both primary and secondary air flow rates, ignite the torch, and inject primary and secondary fuel to obtain combustion. Using this procedure, unsuccessful attempts at combustion were caused by failure of the torch to ignite due to back pressure from the secondary air flow. To alleviate this problem a modified procedure was used: set primary air flow rate and inject primary and secondary fuel for combustion. Utilizing this modified procedure, satisfactory results were obtained for further testing of the combustor.

Table I shows the data obtained from the preliminary combustor testing. These tests were conducted for considerably hotter exhaust temperatures than desired for the test cell. Run number 1 was the initial check-out of the combustor and was approximately of 5 seconds duration. After determining the fuel and air flow rates and ratios from this initial run, minor adjustments were made to obtain higher air-fuel ratios (closer to stoichiometric combustion) for further testing. The initial fuel flow rates used had been based on an expected total air flow rate (primary and secondary) of 1 lb_m/sec. The maximum total air flow rate obtainable from the compressor was 0.61 lb_m/sec. The reduced air flow rate required the use of a smaller cavitating venturi for the secondary fuel.

The remainder of the runs were completed using various fuel and air flow rates. Primary fuel flow was kept constant on all runs, while secondary fuel flow was varied to obtain higher concentrations of particulates. The operational run times of the combustor were increased with each run to determine the time limit of operation without structural failure. The final run (30 seconds) resulted in a hot spot in the aft section of the chamber requiring shutdown. For these high exhaust temperature runs, secondary air actually increased the combustion temperature rather than diluting as desired in the lower exhaust temperature conditions. The results from these runs showed a marked increase in the amount of smoke as secondary fuel flow was increased.

Operation of the experimental water-cooled combustor exhausting into the sub-scale test cell (Fig. 16) had similarly satisfactory results, as shown by the varying exhaust gas opacity in the photographs taken while varying the fuel flow rate (Figs. 17). The photographs were taken against a bright blue sky background, making opacity difficult to record photographically. In the initial check-out tests performed with the combustor in this investigation, no difficulties were observed for the water cooling, air flow control, or fuel control systems. With the initial cavitating venturies, use of only minimum primary fuel flow resulted in exhaust temperatures from the first chamber of approximately 1800°R. This condition resulted in a small amount of exhaust smoke (Fig. 17b) and the maximum desired exhaust temperature. Increasing primary fuel flow increased exhaust temperature without appreciable increase in exhaust gas opacity. Increase in secondary fuel flow greatly increased the particulate concentration (Fig. 17d). Thus, the two-fuel system was demonstrated to have the capability for producing widely varying particulate concentrations and exhaust temperatures. To produce the desired smoke levels at lower exhaust temperatures will require the use of smaller cavitating venturies in the fuel control system.

V. CONCLUSIONS AND RECOMMENDATIONS

A water-cooled combustor has been constructed and tested. It was demonstrated to have operational characteristics which adequately met the objectives for future pollution studies in a sub-scale turbojet test cell. The combustor exhausts into the existing low pressure/afterburner apparatus of the sub-scale test cell. The previous fuel injection system was left in the new combustor exhaust line and can be used to simulate afterburner operation.

Further studies can now be performed for determining the effects of engine operating characteristics and test cell design on particulate concentrations at the engine and test cell exhausts. For this study, transmissometers and 3-frequency light absorption methods will be used to measure the variations in opacity, particulate concentration, and mean particulate size between the engine nozzle and stack exhausts in the sub-scale test cell. Additional studies will be concerned with the effects of fuel additives (such as ferrocene) on the amount and composition of particulates emitted. The analysis of particulates in this latter study will utilize sampling probes and a scanning electron microscope.

RUN	P_{pf}	$\dot{M}_{pf}$	P_{sf}	$\dot{M}_{sf}$	P_p	ΔP_p	P_s	ΔP_s	P_c	$\dot{M}_{pa}$	$\dot{M}_{sa}$	$(\frac{A}{F})_p$	$(\frac{A}{F})_{p\&s}$
1	550*	.017	665+	.044	150	4.5	135	4	-	.148	.319	8.7	7.7
2	315*	.013	315#	.023	155	6.5	137	7	130	.182	.423	14.0	16.8
3	315*	.013	415#	.026	155	5	137	5.5	130	.160	.376	12.3	13.7
4	315*	.013	515#	.029	152	6.5	135	4.2	130	.180	.327	13.9	12.1

LEGEND:

P - Pressure (psia)

$\dot{M}$ - Flow Rate (lbs_m/sec)

ΔP - Pressure Differential (psi)

$(\frac{A}{F})$ - Air/Fuel Ratio

<u>Venturi Diameters</u>:
* - .016"
# - .021"
+ - .0225"

Subscripts:
p - primary air orifice
s - secondary air orifice
f - fuel
a - air
c - chamber

TABLE I. DATA FROM PRELIMINARY COMBUSTOR OPERATION

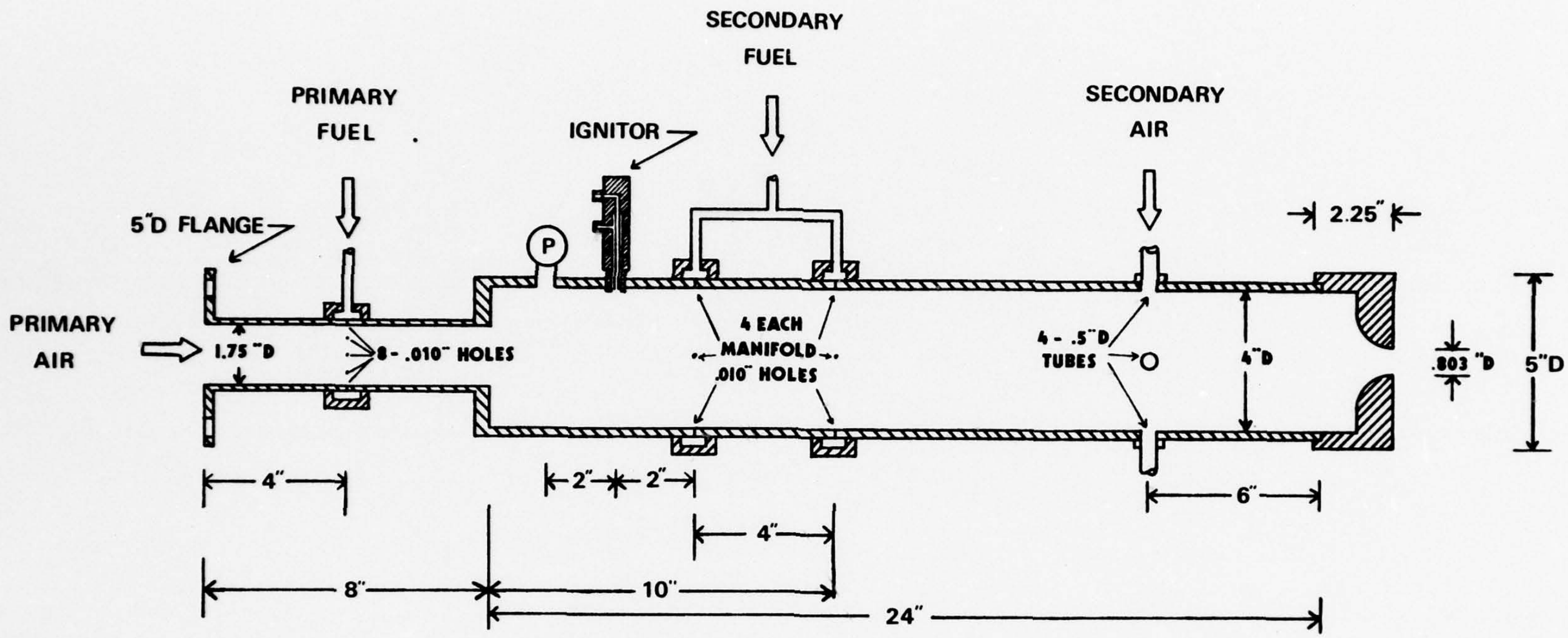

FIGURE 1. SCHEMATIC OF PRELIMINARY COMBUSTOR

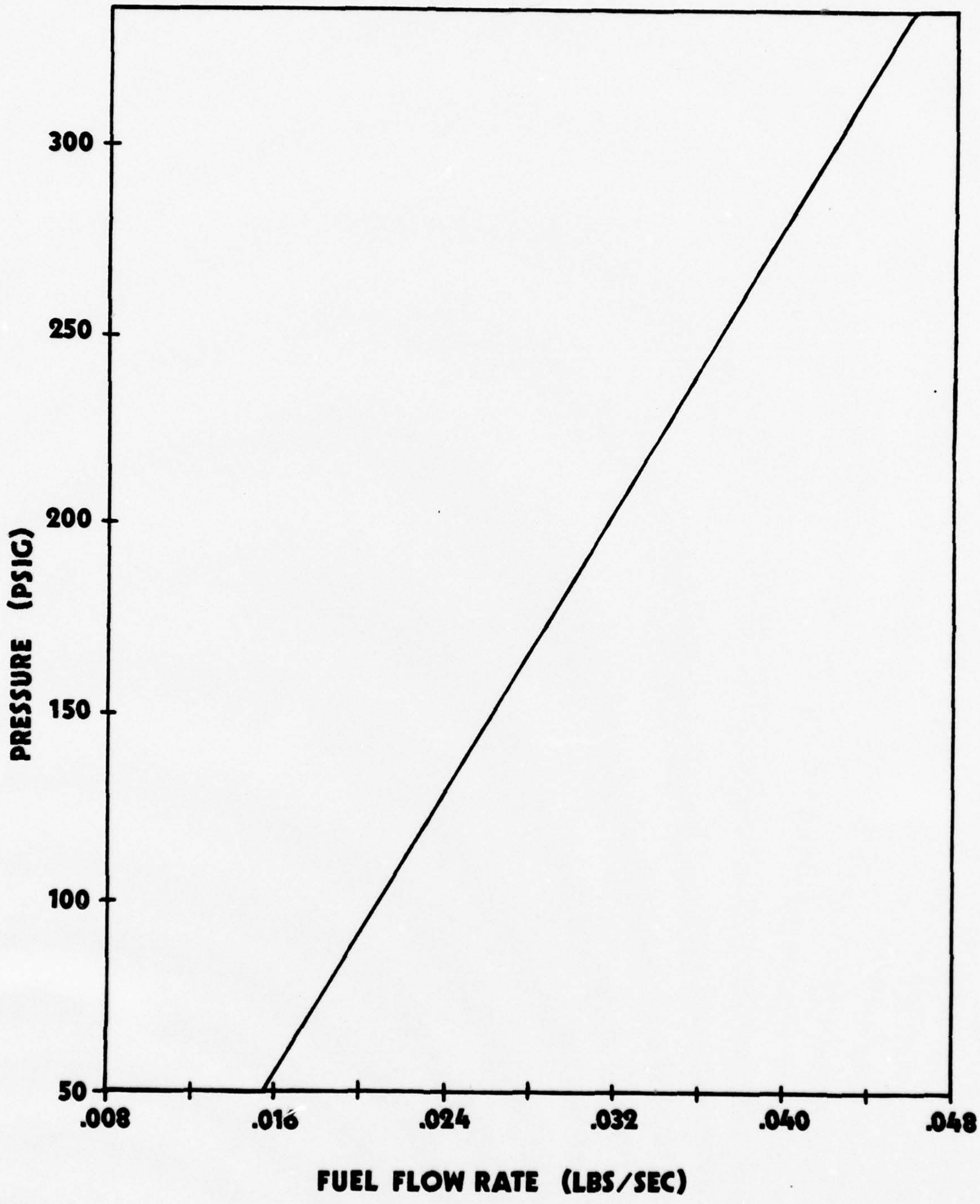

FIGURE 2. FUEL FLOW VS. PRESSURE FOR FUEL MANIFOLD
(EIGHT - .010 INCH DIAMETER HOLES)

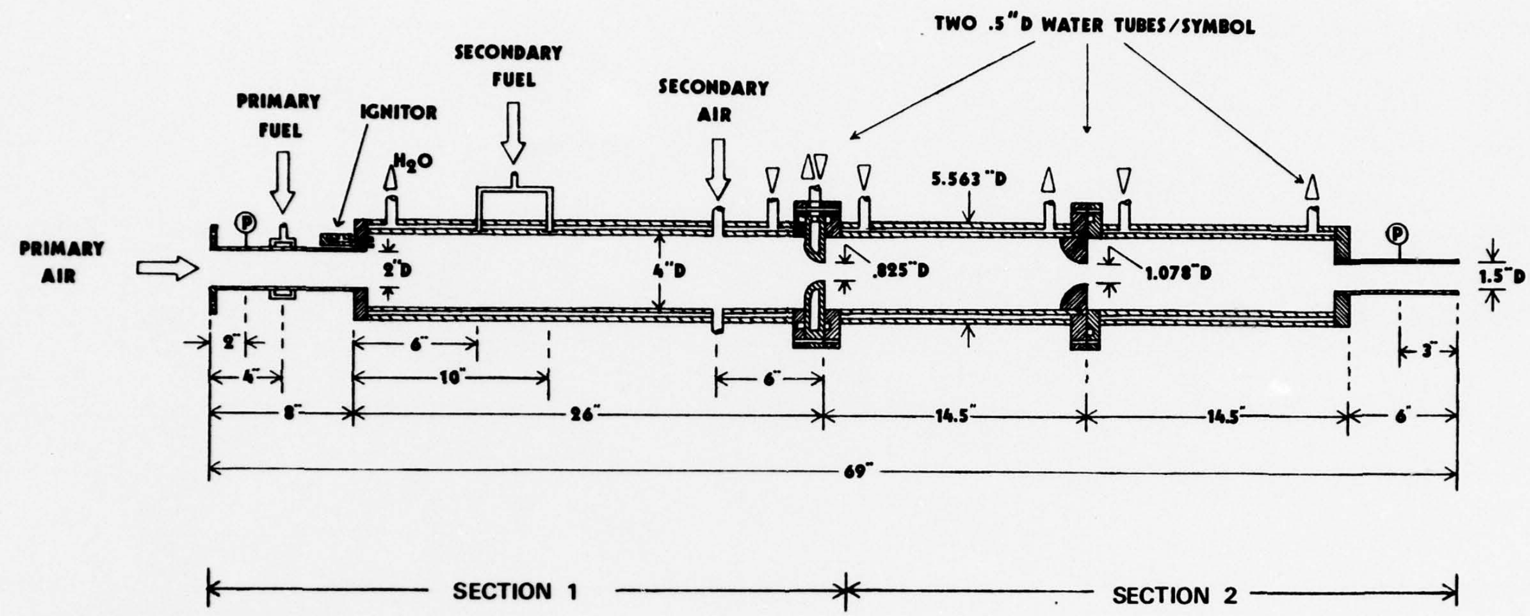

FIGURE 3. SCHEMATIC OF WATER-COOLED EXPERIMENTAL COMBUSTOR

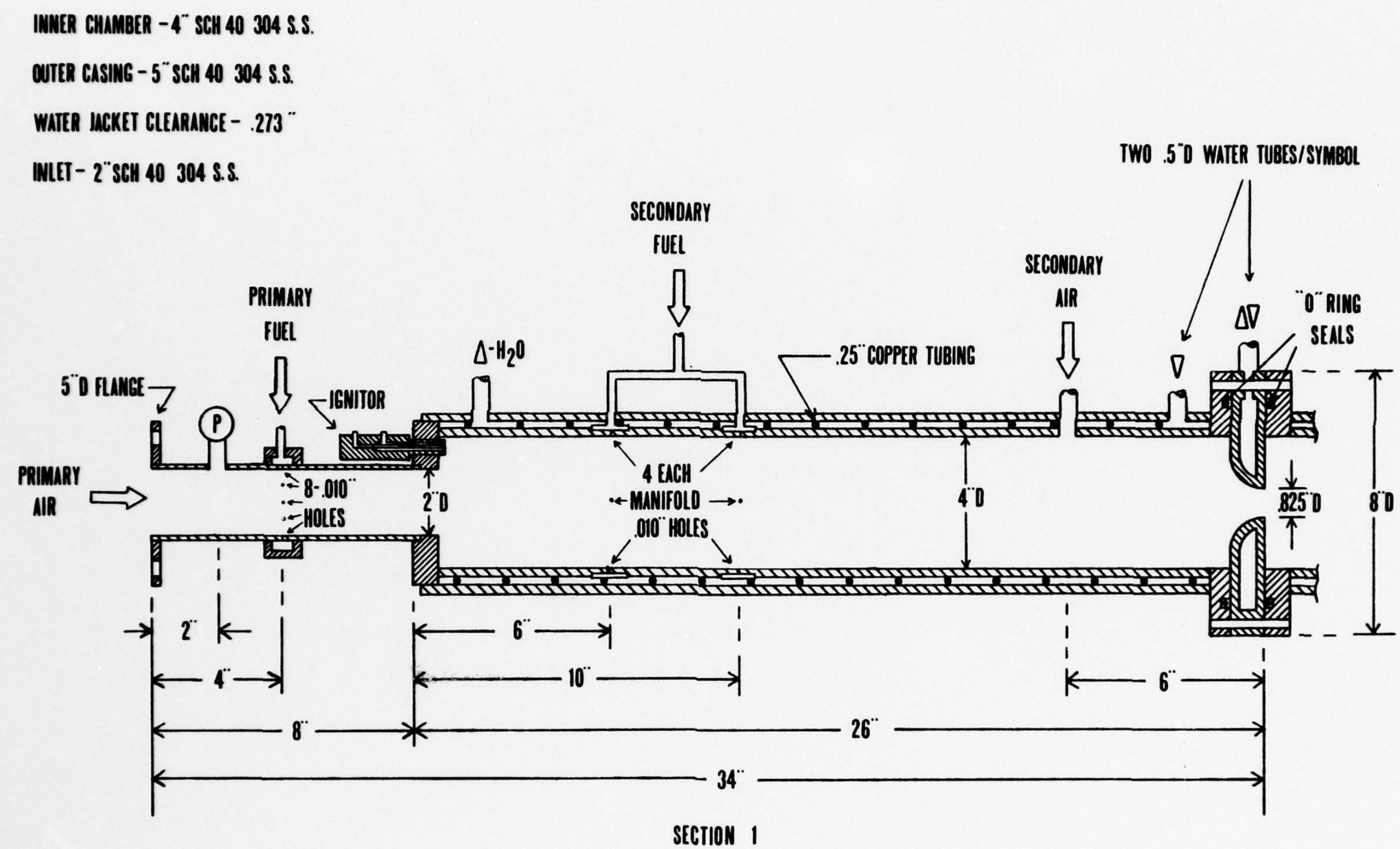

FIGURE 4. SCHEMATIC OF SECTION 1 OF EXPERIMENTAL COMBUSTOR

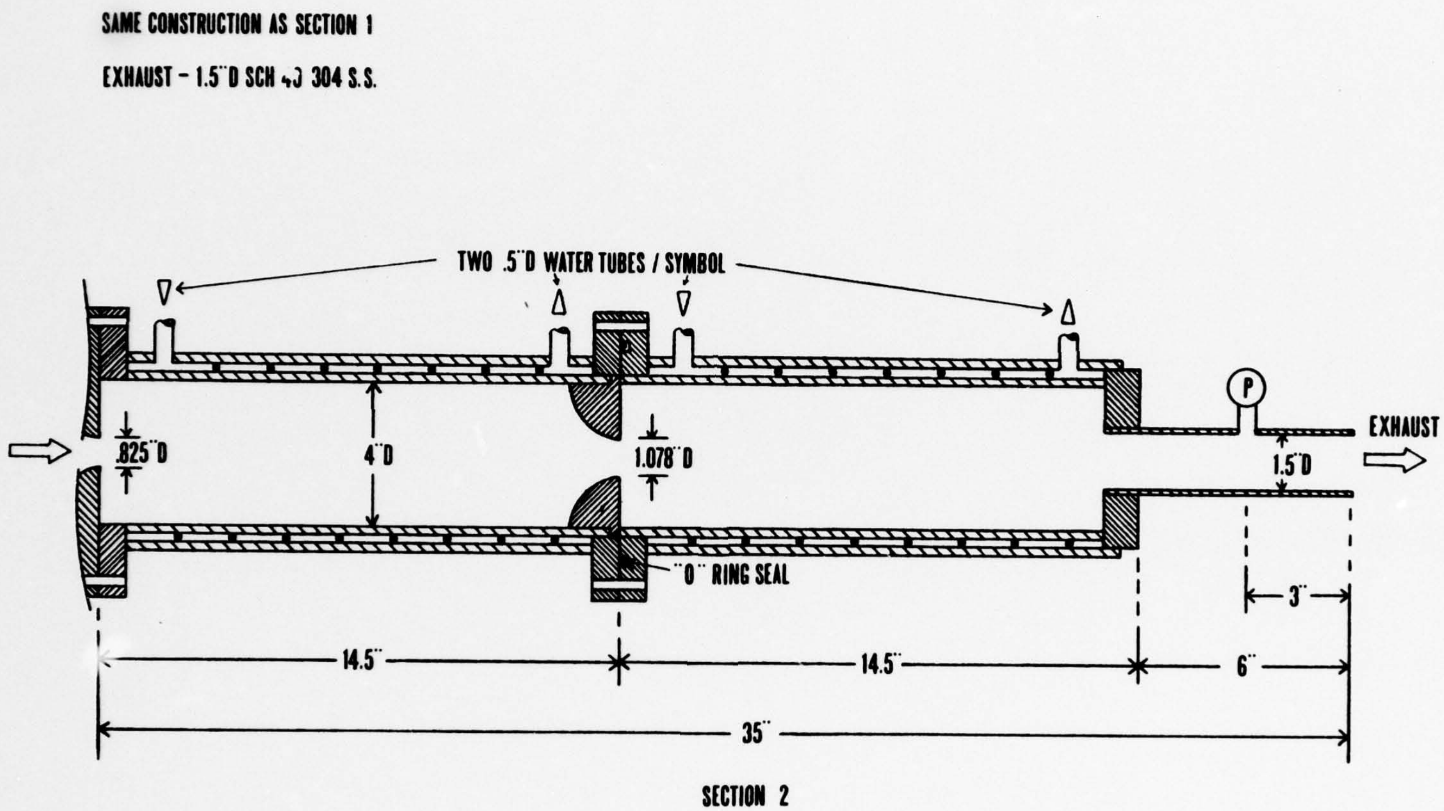

FIGURE 5. SCHEMATIC OF SECTION 2 OF EXPERIMENTAL COMBUSTOR

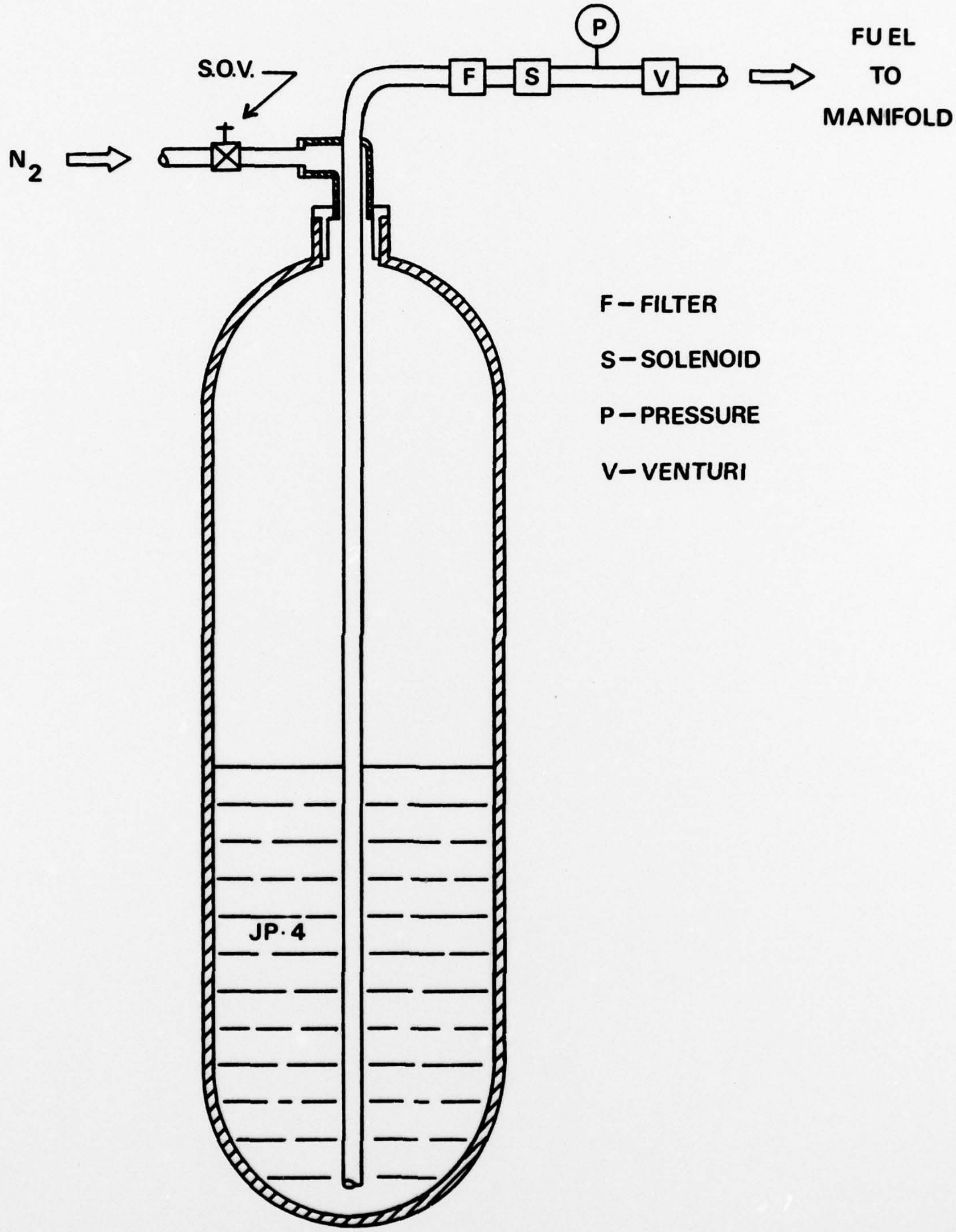

FIGURE 6. SCHEMATIC OF FUEL SUPPLY SYSTEM (TWO TANKS)

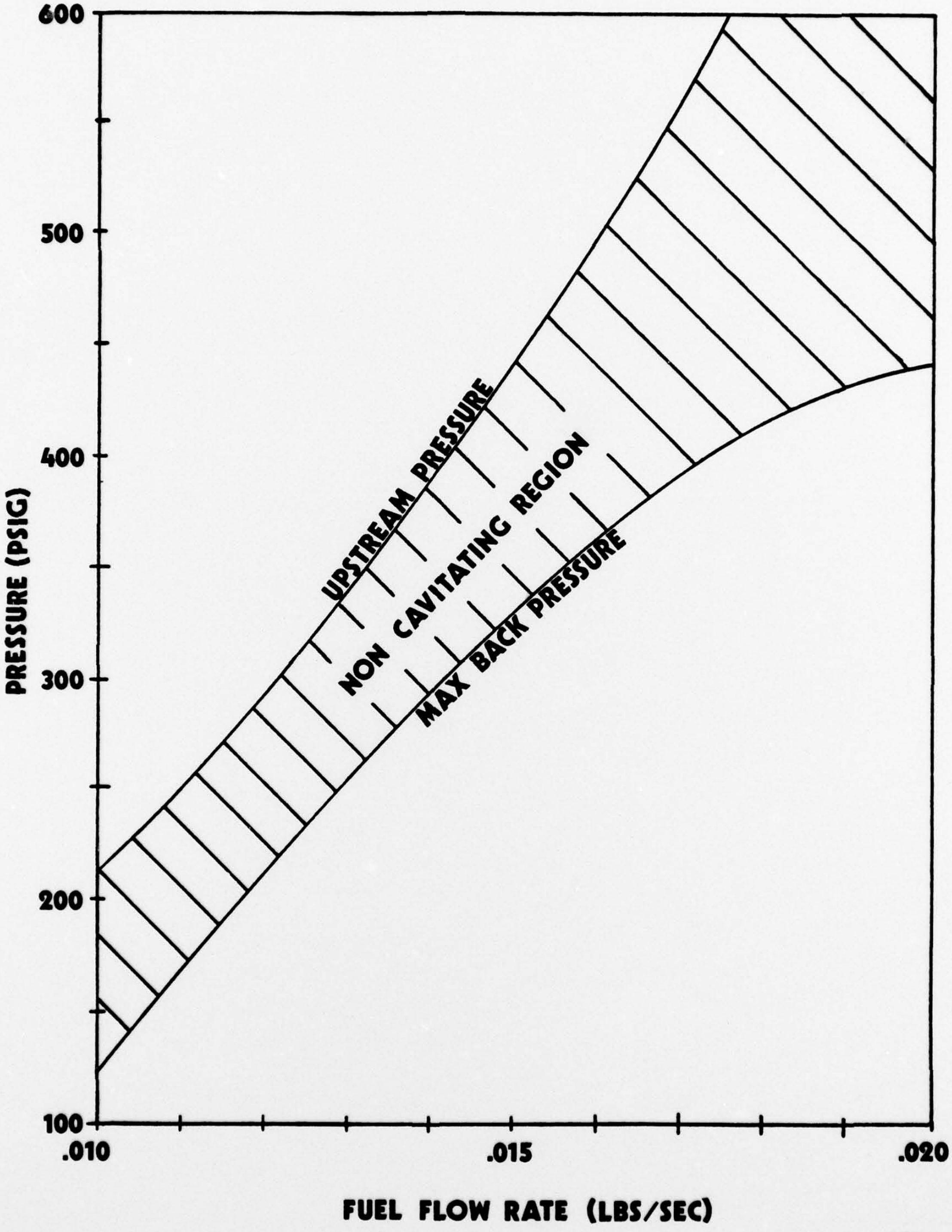

FIGURE 7. CAVITATING VENTURI PRESSURE VS. FLOW RATE PLOT (.016 INCH DIAMETER)

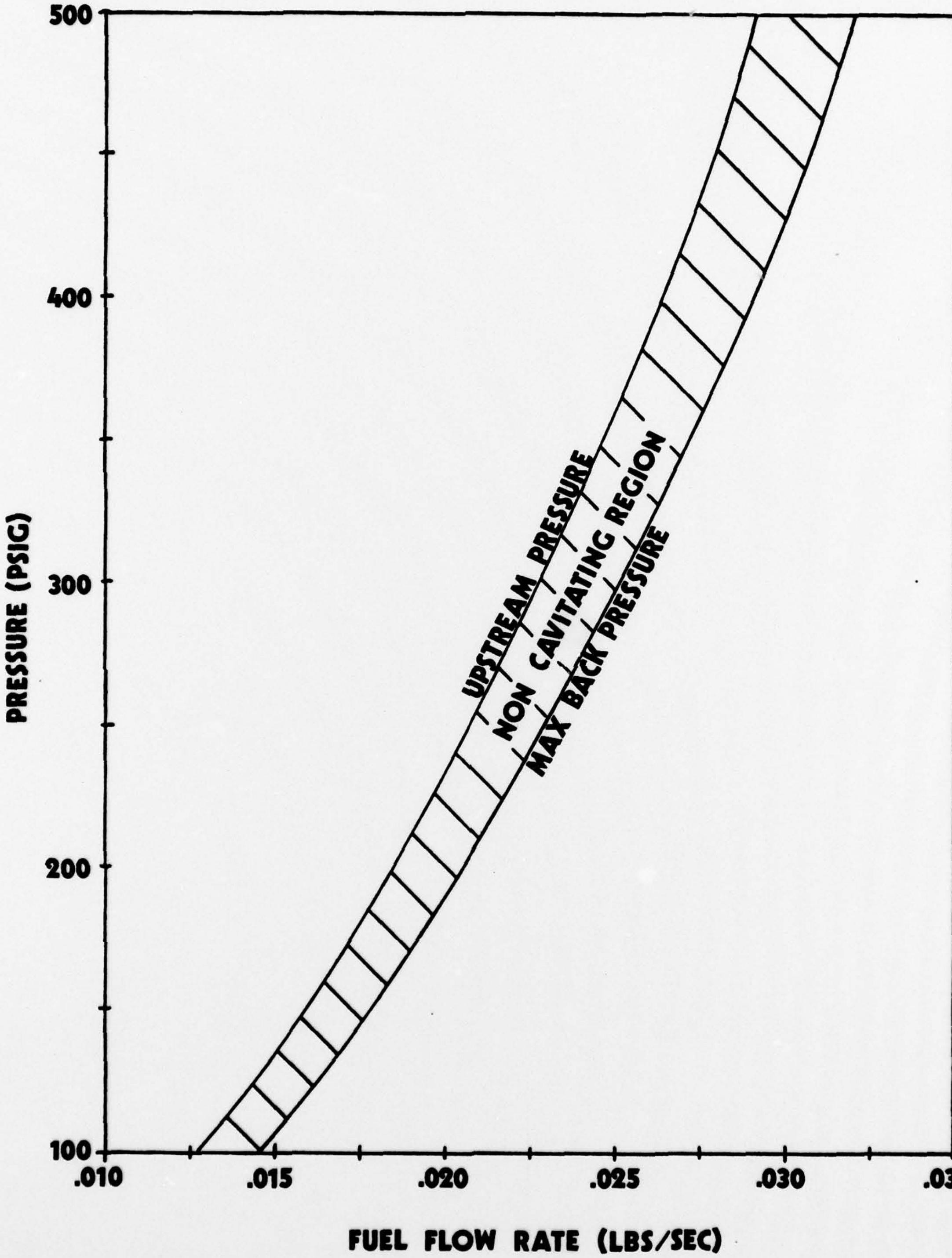

FIGURE 8. CAVITATING VENTURI PRESSURE VS. FLOW RATE PLOT (.021 INCH DIAMETER)

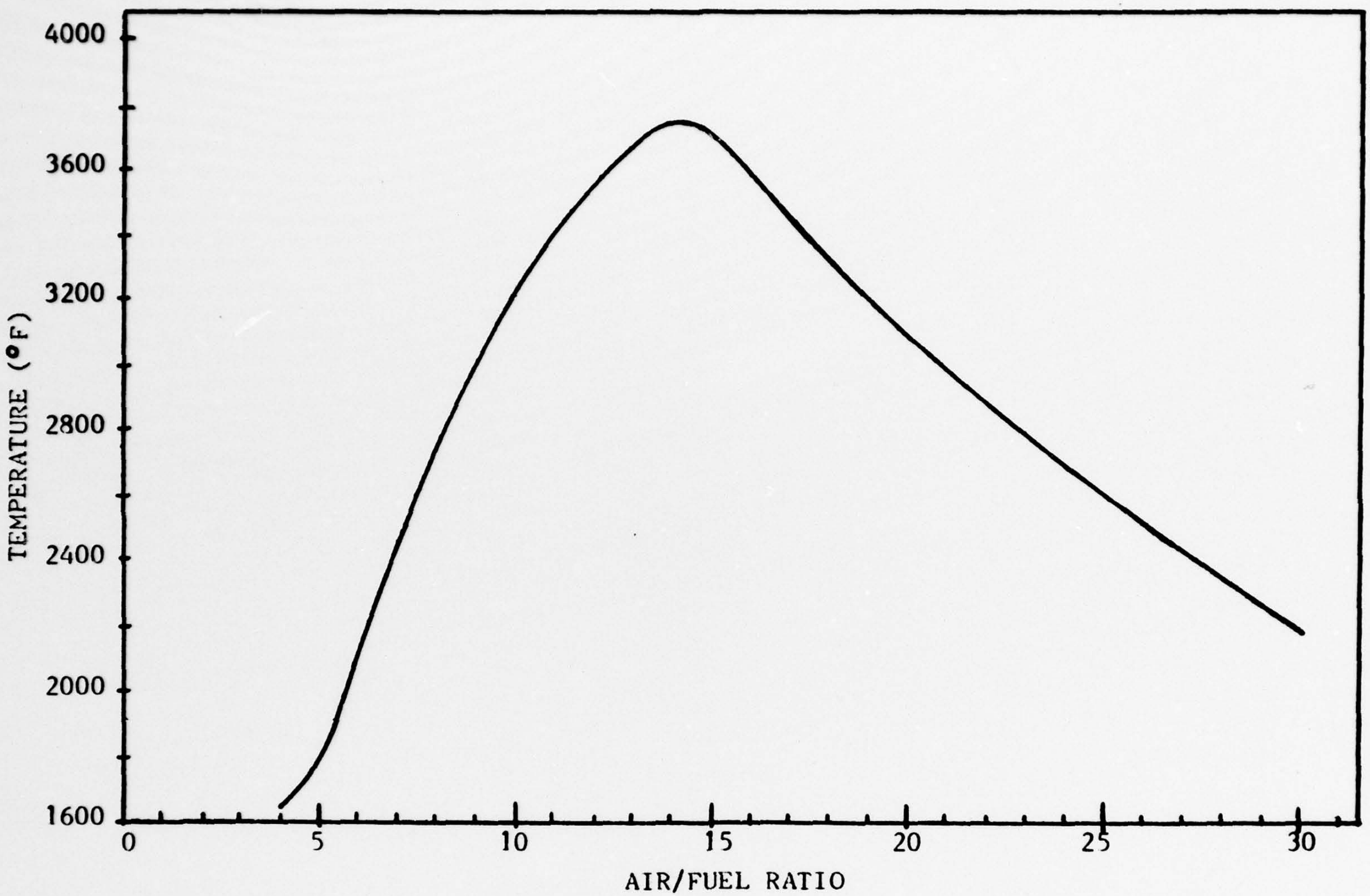

FIGURE 9. EQUILIBRIUM COMBUSTION TEMPERATURE VS. AIR-FUEL RATIO (AIR/JP-4)

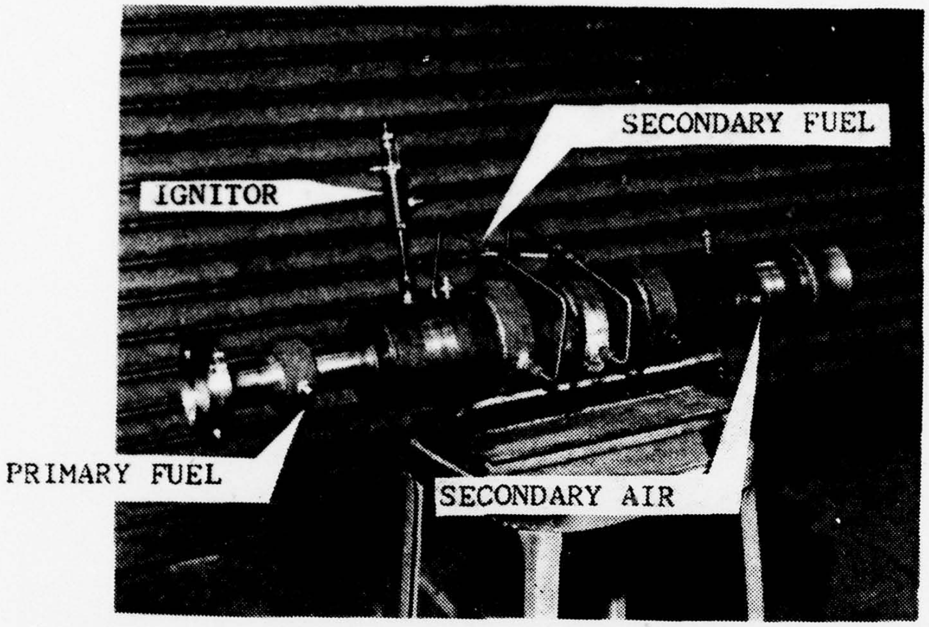

FIGURE 10. PHOTOGRAPH OF PRELIMINARY COMBUSTOR

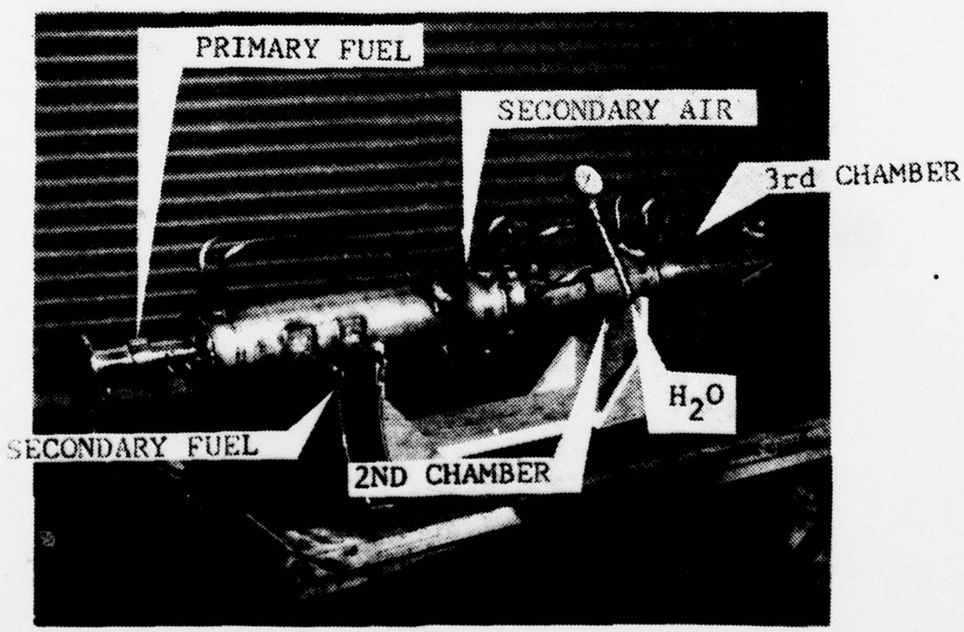

FIGURE 11. PHOTOGRAPH OF WATER-COOLED COMBUSTOR

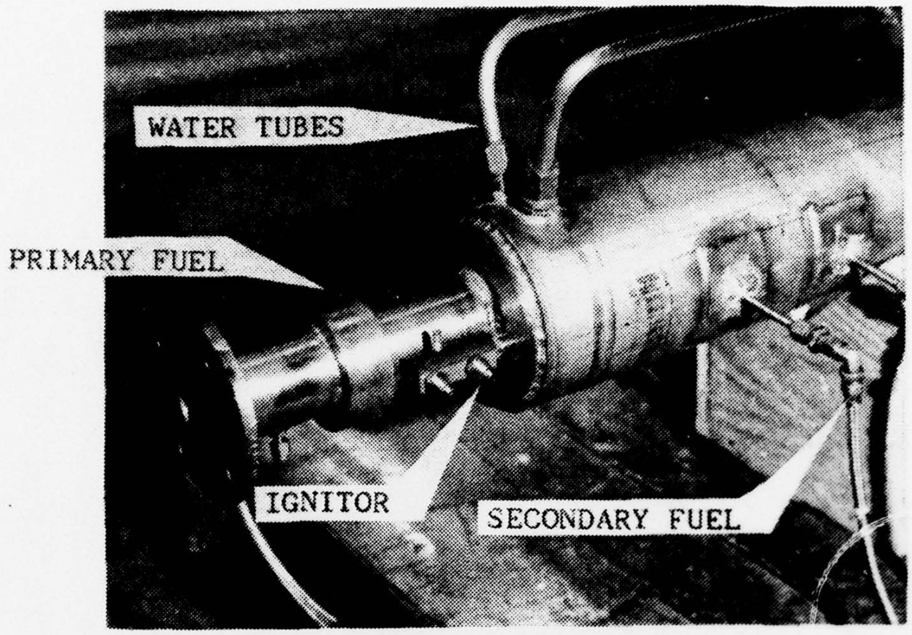

FIGURE 12. PHOTOGRAPH OF INTAKE SECTION OF COMBUSTOR

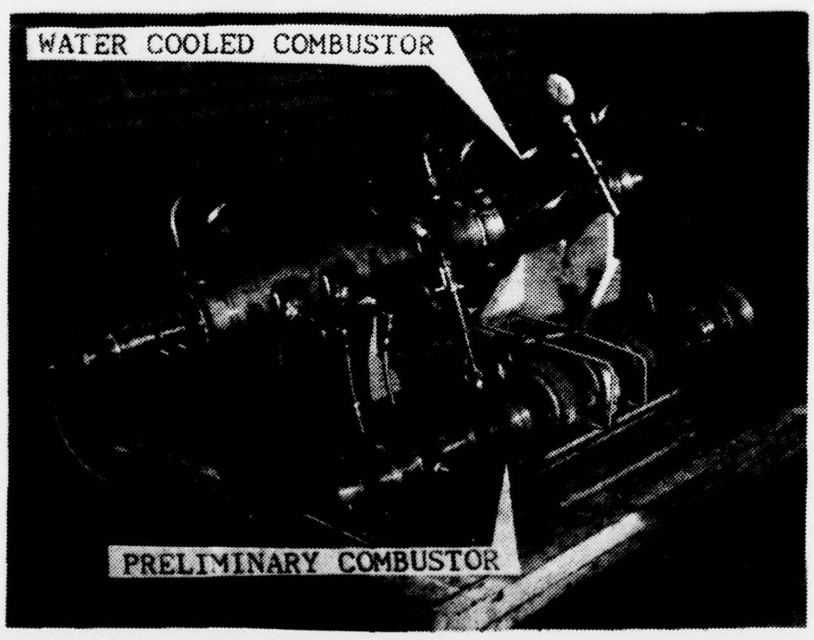

FIGURE 13. PHOTOGRAPH OF PRELIMINARY AND EXPERIMENTAL COMBUSTORS

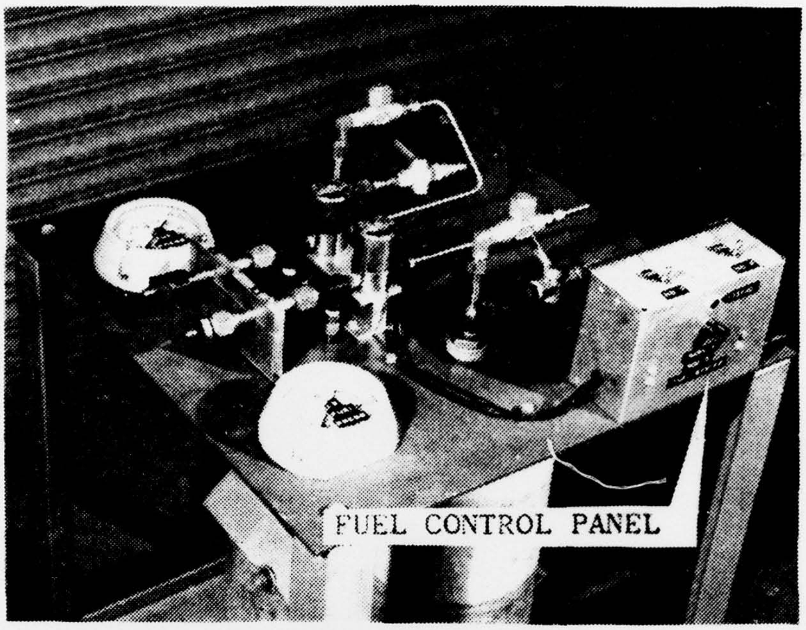

FIGURE 14. PHOTOGRAPH OF FUEL CONTROL PANEL OF FUEL SYSTEM

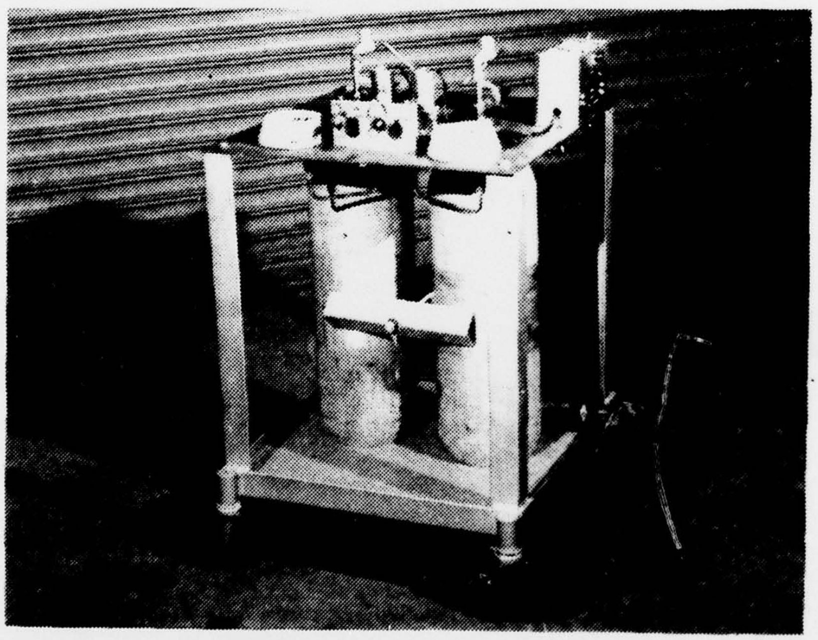

FIGURE 15. PHOTOGRAPH OF PORTABLE FUEL SUPPLY SYSTEM

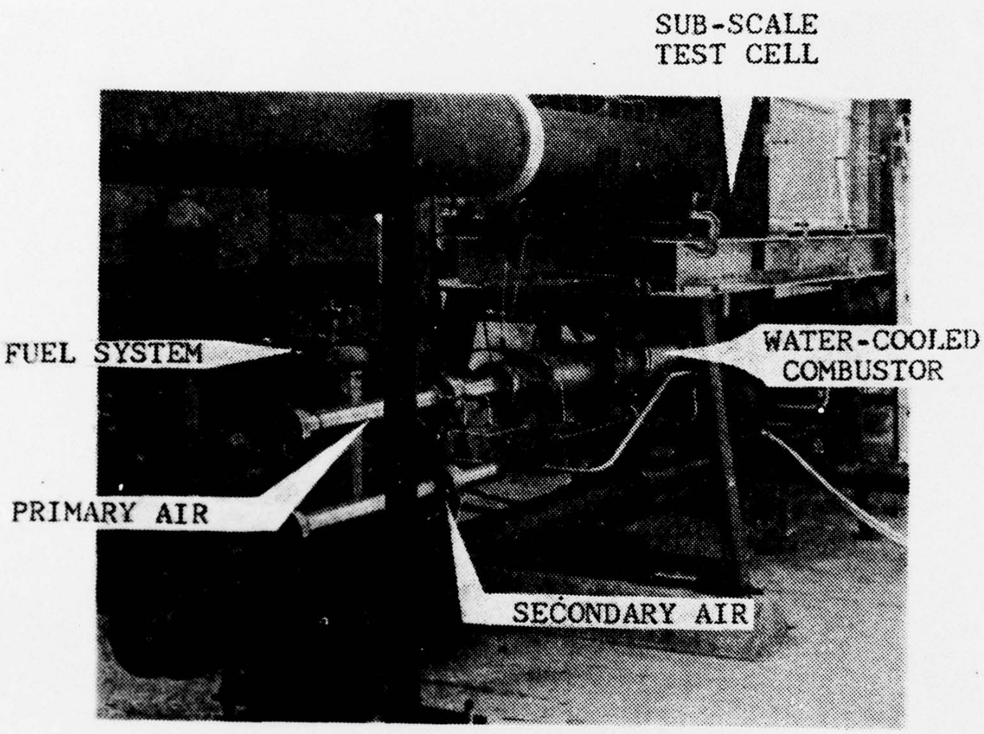

FIGURE 16. PHOTOGRAPH OF WATER-COOLED COMBUSTOR INSTALLED IN SUB-SCALE TEST CELL

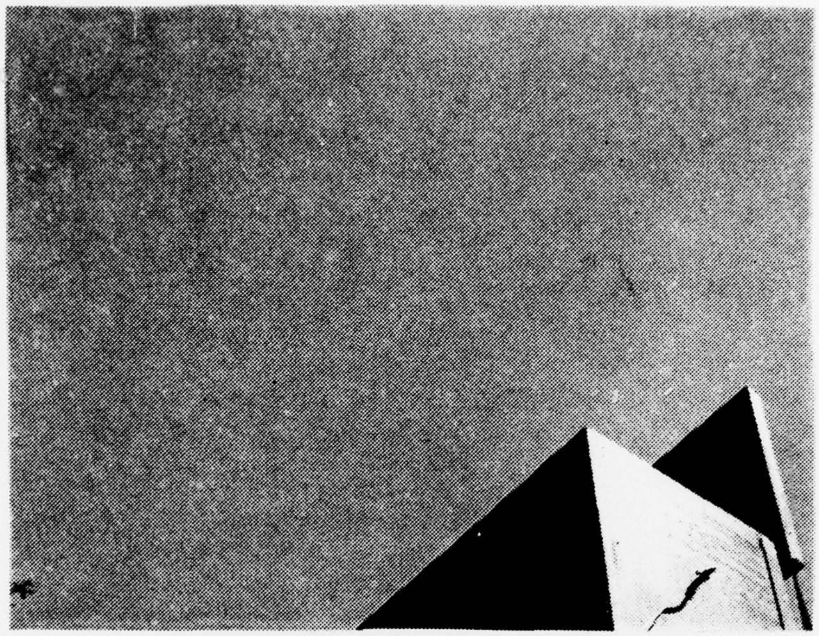

FIGURE 17. VARIATION OF EXHAUST STACK SMOKE OPACITY WITH COMBUSTOR OPERATING CONDITIONS
a. NO BURNING

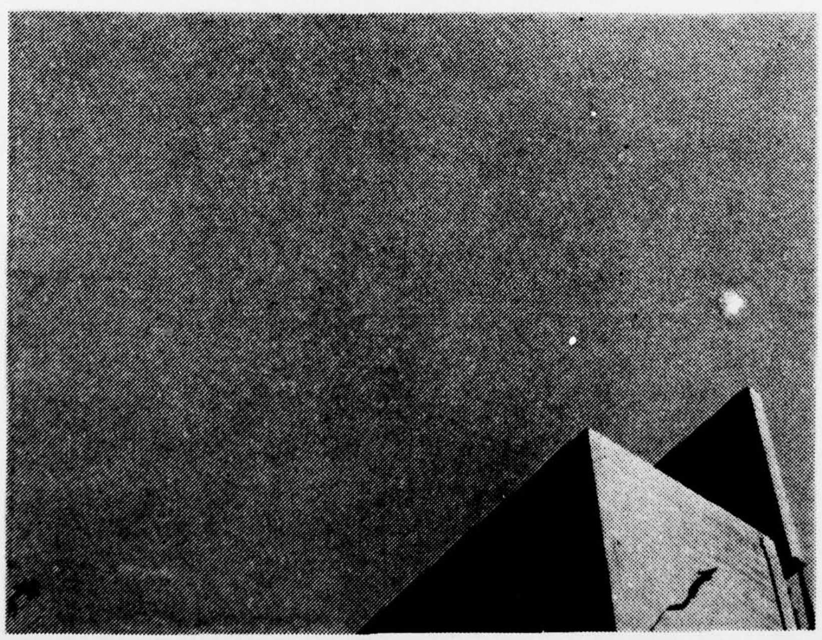

FIGURE 17.(CONTINUED) b. LOW PRIMARY/NO SECONDARY FUEL FLOW

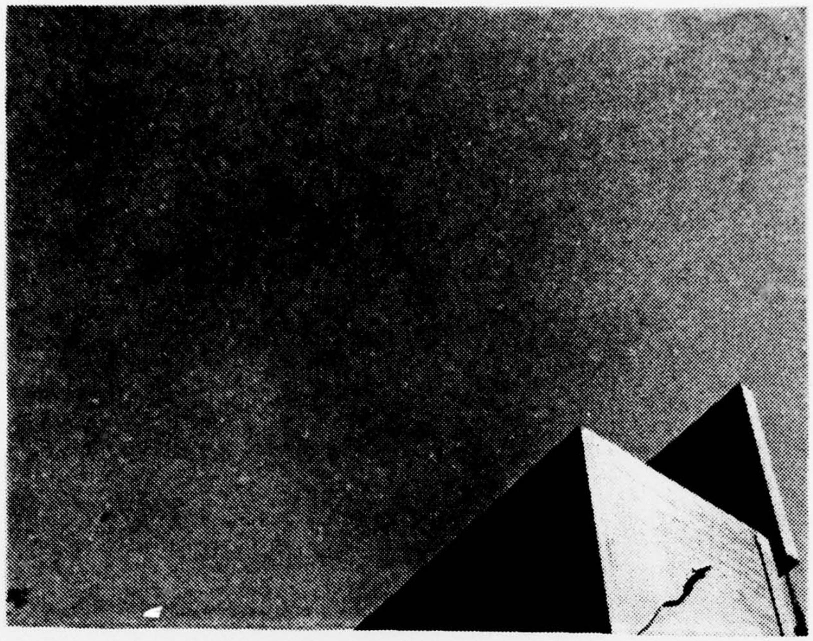

FIGURE 17. (CONTINUED) c. MODERATE PRIMARY/SECONDARY FUEL FLOW

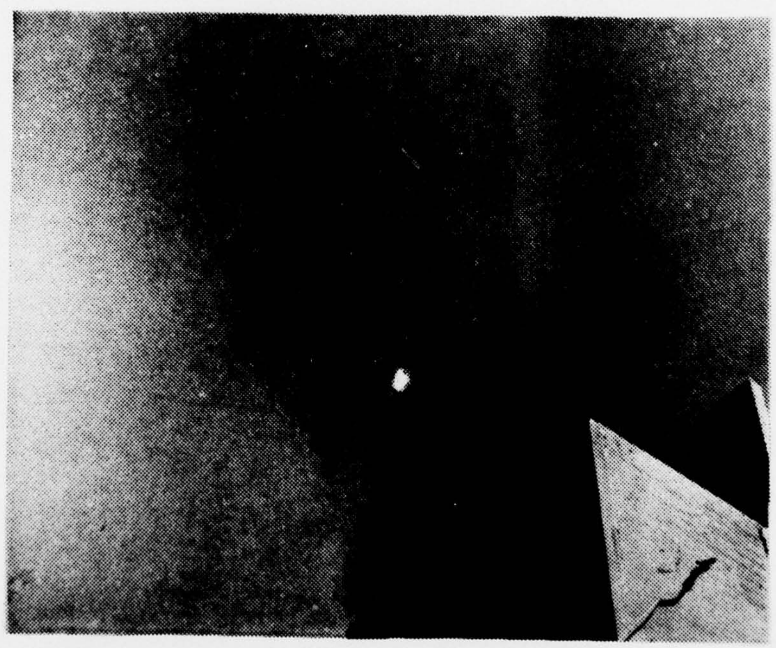

FIGURE 17. (CONTINUED) d. HIGH PRIMARY/SECONDARY FUEL FLOW

LIST OF REFERENCES

1. Advisory Group for Aerospace Research and Development, Report 125, "Pollution Control of Airport Engine Test Facilities," by D. L. Bailey, P. W. Tower, and A. E. Fuhs, April 1973.

2. Hewlett, Holden W., Design, Construction and Testing of a Sub-Scale Turbojet Test Cell, Masters Thesis, Naval Postgraduate School, Monterey, California, March 1977.

3. H. W. Hewlett, P. J. Hickey, D. W. Netzer, A Sub-Scale Turbojet Test Cell for Design Evaluations and Analytical Model Validation, Naval Postgraduate School Report No. NPS-67Nt77091, Monterey, California, September 1977.

4. The American Society of Mechanical Engineers (ASME) PTC 19.5.4, "Flow Measurement, Instruments and Apparatus," United Engineering Center, 345 East 47th Street, New York, N.Y. 10017, 1959.

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