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EXPERIMENTAL SCALING OF MODIFIED FUEL BREAKUP

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AUGUST 1977

INTERIM REPORT

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16. Abstract

A small-scale test configuration was developed for modified fuel breakup and ignition testing. The configuration consisted of a 1/4-inch fuel delivery tube within a 1-inch air atomization pipe followed by a deceleration cone. Photographic evaluation required design of a unique fuel spray photographic chamber which has the capability of photomicrographic, schlieren, and stroboscopic photographic techniques. The chamber employs positive pressurization with diluent air to prevent spray recirculation and fuel deposition on optical components. The spark photographs proved that the breakup phenonomen can be scaled down without obliteration of the dominant rheological effects. Motion pictures of ignition show the same flammability behavior shown in larger scale tests. It is concluded that the concentric tube atomization technique provides a practical method for comparative evaluation of modified fuels on a small scale.

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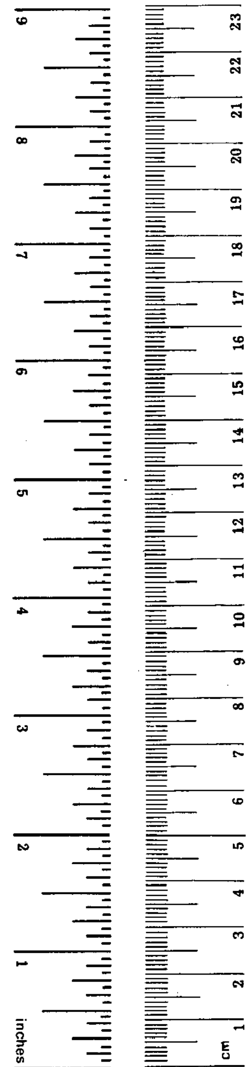
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

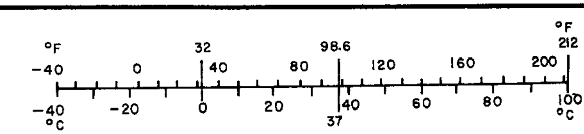
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



PREFACE

Messrs. William Neese, Irwin Block, and Louis Brown assisted in the instrumentation. Mr. Joseph Cox and Mr. Francis Valleley applied the photographic techniques.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

INTRODUCTION

PURPOSE.

The purpose of this program is the development of a small-scale test apparatus for comparison of the flammability of modified fuel sprays. Demonstrating the feasibility of scaling down the fuel breakup process is a prerequisite to designing a small-scale test. This interim report describes the design of a unique photographic chamber for the feasibility demonstration, presents a small-scale atomization technique, and presents photographic evidence for the validity of the technique.

BACKGROUND.

Extensive full-scale and large-scale tests have been conducted on flammability of sprays of antimisting fuel (references 1, 2, and 3). These large-scale tests are heavy consumers of manpower, equipment, and time. Generally, large-scale tests are limited in their control of test conditions where factors such as wind and ambient temperature have an adverse effect on repeatability. In addition, large amounts of fuel sample are required, while the availability of these prototype fuels is limited. Small-scale tests offer significant advantages, provided that sprays retain the characteristics found in larger scale tests.

The majority of relevant laboratory-scale tests have been directed at studies of fine sprays of Newtonian fuels (references 4, 5, and 6). The methods of spray generation (condensation, ultrasonic atomization, and pressure atomization) are not designed to produce the coarse, nonspherical particles that are characteristic of antimisting fuel breakup in an airstream (reference 3). In addition, the scale of laboratory experiments is generally too small to accommodate the particle sizes produced by antimisting fuels.

EXPERIMENTAL OBJECTIVE.

The experimental objective was to develop a facility that would require minimum fuel sample size and manpower expended, while providing fuel sprays similar to those observed in larger scale tests. In addition, the requirements included capability of spark photography, remote operation, and controlled air and fuel flow rates. The experimental facility also needed the flexibility to handle varying spray sources, as there was initial uncertainty as to the number of trial configurations needed before simulation was achieved.

DISCUSSION

DESIGN.

Figure 1 shows an overall photograph of the fuel spray photographic chamber. Figure 2 shows a top view sketch of the chamber interior. The chamber is an 8-foot by 8-foot metal chamber with a 5-foot frontal depth increasing to 6 1/2 feet at the rear. A fuel-air mixture is fed to the chamber through a 1-inch inner diameter pipe. Dilution air is provided by twin ducts fed parallel to the fuel pipe. The fuel and air then pass into an exhaust duct within the chamber. Provisions for photography include 90° double bends in the ductwork, covers for the observation windows, black painted interior, and caulked seams throughout.

The role of the diluent air is two-fold. By passing diluent over the photographic components, deposition of liquid fuel drops is minimized. Also, since the blower is located upstream of the chamber, there is a slight overpressure in the test area during operation. As a result, the diluent air entrains the fuel spray into the exhaust duct. This prevents troublesome buildup of fuel drops in recirculation eddies caused by jet shear. Upstream blower location also prevents ignition of fuel by the blower as would be possible if the blower were positioned in the exhaust duct.

Figure 3 shows the front of the chamber. The blower is a 950 cubic feet per minute axivane fan (Joy Manufacturing model AVR 90-70D926). Also visible is the 12-inch circumferential bleed-off slide, immediately behind the blower. Included in figure 3 are the control solenoids for the oxygen-acetylene ignition torch, the fuel control solenoid valves, the atomization air pipe, and the tie-in for the carbon dioxide (CO_2) extinguishing system. Figure 4 shows the air supply system for the atomization pipe. Air from a facility storage tank passes through a gate valve and then through a Flodyne valve (model 15D153) prior to passage through a 1-inch flexible hose to the air atomization pipe. A gate valve at the start of the atomization air pipe allows for presetting the airflow rate. The atomization pipe is 57 inches long to ensure fully turbulent flow at its exit.

The spray system and igniter are shown in figure 5. The fuel enters the atomization pipe through a 1/4-inch tube and enters the air parallel to the flow and in the same direction. The fuel-air mixture is decelerated in a cone of 13-inches length and 4-inches diameter at the exit. Oxygen and acetylene are supplied through 1/8-inch stainless steel tubing and injected side by side to produce a steady ignition source downstream of the deceleration cone. The oxygen and acetylene are remotely ignited by electrodes attached to a single spark transformer (Jefferson Electric model 638-521-116). In the foreground of figure 5 is the optical bench used for mounting the photographic equipment. Also visible is one of the stroboscopic lights used in photographic determination of droplet trajectory and velocity. The oxygen-acetylene torch serves as an ignition source in ignitability tests of the modified fuels, and it has the ability to serve as a flameholder for measurement of flame speeds.

Chamber safety features include remote operating capability, a 36-by-10-inch blowout panel in the roof, and a redundant CO_2 extinguishing system. After the fuel and air are turned OFF, residual fuel may continue occasionally to burn in the exhaust duct. A short burst of CO_2 from a 50-pound bottle in the control room will usually extinguish this duct fire. An additional 50-pound CO_2 bottle is tied to the chamber roof. In the event of fire in the lower chamber areas, the roof system can quickly flood the whole chamber.

CONTROLS.

Figures 6 and 7 show views of the control apparatus. Tests are monitored by means of a video camera located in the spray chamber. Fuel flow is controlled by pressurization of the fuel cylinder. The tank in figure 7 acts as a pressurized reservoir. Capability for temperature measurement of diluent air, fuel, and atomization air is provided by a strip chart recorder attached to thermocouples. Separate ON/OFF switches control atomizer pipe air, oxygen and acetylene, ignition spark, diluent air blower, and liquid fuel flow. The manometer in figure 6 is connected to a pitot tube in the atomizer air pipe. This provides a convenient means of establishing a nominal airflow rate and of duplication of airflow from test to test.

Actual calibration of air velocities in the photographic section is done by hot-wire anemometry. A schematic of the flow field 3 1/2-inches downstream of the torch tip is presented in figure 8. The nominal air atomization pipe velocity was 200 miles per hour (mi/h). Due to the offset of the cone from the chamber centerline, there is some distortion of the flow field. This flow field was mapped with zero fuel flow.

PHOTOGRAPHS.

Figures 9, 10, 11, and 12 show photographs of fuel patterns from Jet A, FM-9 (Imperial Chemical Industries), FM-4 (Imperial Chemical Industries), and AM-1 (Conoco), respectively. The photographs were all taken 11 inches downstream of the deceleration cone edge. The additives were mixed with the neat fuel to form the following weight percentages in Jet A: 0.4 percent FM-4, and 0.2 percent AM-1. The FM-9 arrived from the Royal Aircraft Establishment as 0.3 weight percent in Avtur. The nominal atomization pipe air velocity was 200 mi/h in the top photographs and 285 mi/h in the lower photographs. The fuel delivery rates were approximately 12 cubic centimenters per second (cm^3/s) in these tests. What is most apparent is the decreased particle size with increased atomization air velocity. Similarity of these photographs to those in reference 3 indicates that the same mechanism controls the fuel breakup in this test as in the larger scale tests previously conducted. It should be apparent that the fuel is accelerated as it leaves the fuel tube and is decelerated by the air as it passes through the cone.

Figure 13 shows a sketch of the test section along with a photograph of the oxygen-acetylene ignition torch. Figure 14 shows photographs of ignition attempts in the sprays of Jet A, FM-9, FM-4, and AM-1. Again, the ignitability and flame propagation are qualitatively similar to the observations in reference 3. The Jet A burns intensely throughout the spray cone. The AM-1 shows a burning tail. This demonstrates the ease of ignitability of the AM-1 strands. However, the ease of flame spreading normal to the burning tail is not clearly defined at this time. Both FM-4 and FM-9 showed poor ignitability in these tests. The FM-9 droplets are similar to the XD8132.01 (Dow Chemical) droplets discussed in reference 3. There are also rheological similarities in the behavior of the XD8132.01 and the FM-9.

Preliminary attempts to measure the flame speeds were made. The greatest difficulty involves Jet A spray fires where back scattering and reflections of radiation into the unburnt spray obliterate the flame front. A schlieren system can be employed to provide clearer flame front definition in the future.

CONCLUSIONS

Comparison of the photographs from the fuel spray photographic chamber with earlier data from the 5-foot airflow facility leads to two conclusions:

1. The breakup phenomenon can be scaled down without obliteration of the dominating rheological effects.

2. This atomization technique provides a basis for the development of a go/no go bench scale test for modified fuel flammability.

REFERENCES

1. Ahlers, R. H., Full-Scale Aircraft Crash Tests of Modified Jet Fuel, Report FAA-RD-77-13, Federal Aviation Administration, 1977.

2. Salmon, R. F., Zinn, S. V., Russell, R. A., and Eklund, T. I., Wing Spillage Tests of Antimisting Fuels, National Aviation Facilities Experimental Center, Data Report 128, May 1977.

3. Zinn, S. V., Eklund, T. I., and Neese, W. E., Photographic Investigation of Modified Fuel Breakup and Ignition, Report FAA-RD-76-109, Federal Aviation Administration, 1976.

4. Burgoyne, J. H. and Cohen, L., The Effect of Drop Size on Flame Propagation in Liquid Aerosols, Proc. Roy. Soc. A225, 375 (1954).

5. Wood, B. J., Rosser, W. A., and Wise, H., The Ignition and Combustion of Drops in Sprays of No. 2 Heating Oil, Conference Paper CP63-7, Presented at 1963 API Research Conference on Distillate Fuel Combustion.

6. Polymeropoulos, C. E. and Das, S., The Effect of Droplet Size on the Burning Velocity of Kerosene - Air Sprays, Combustion and Flame 25, 247 (1975).

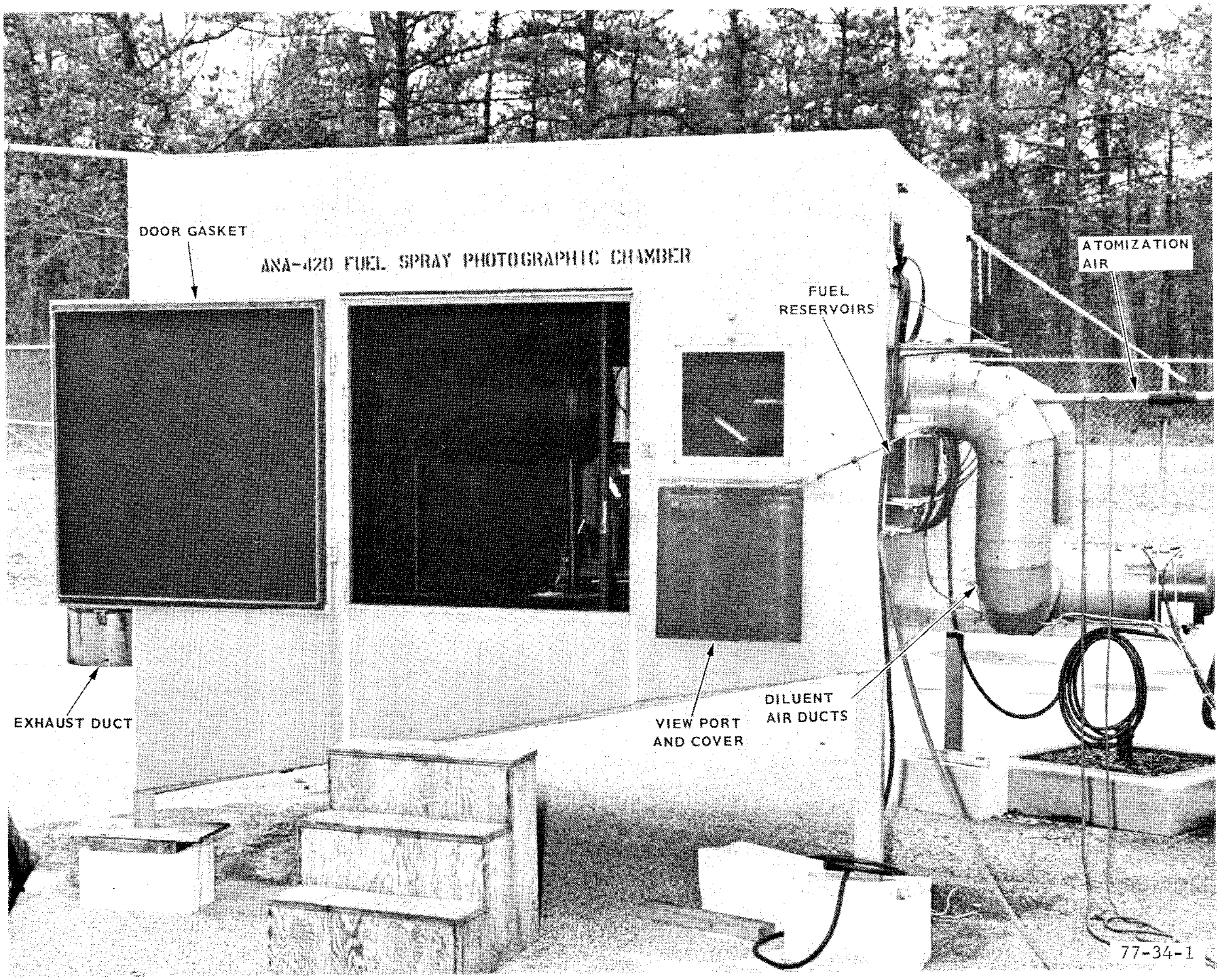


FIGURE 1. FUEL SPRAY PHOTOGRAPHIC CHAMBER

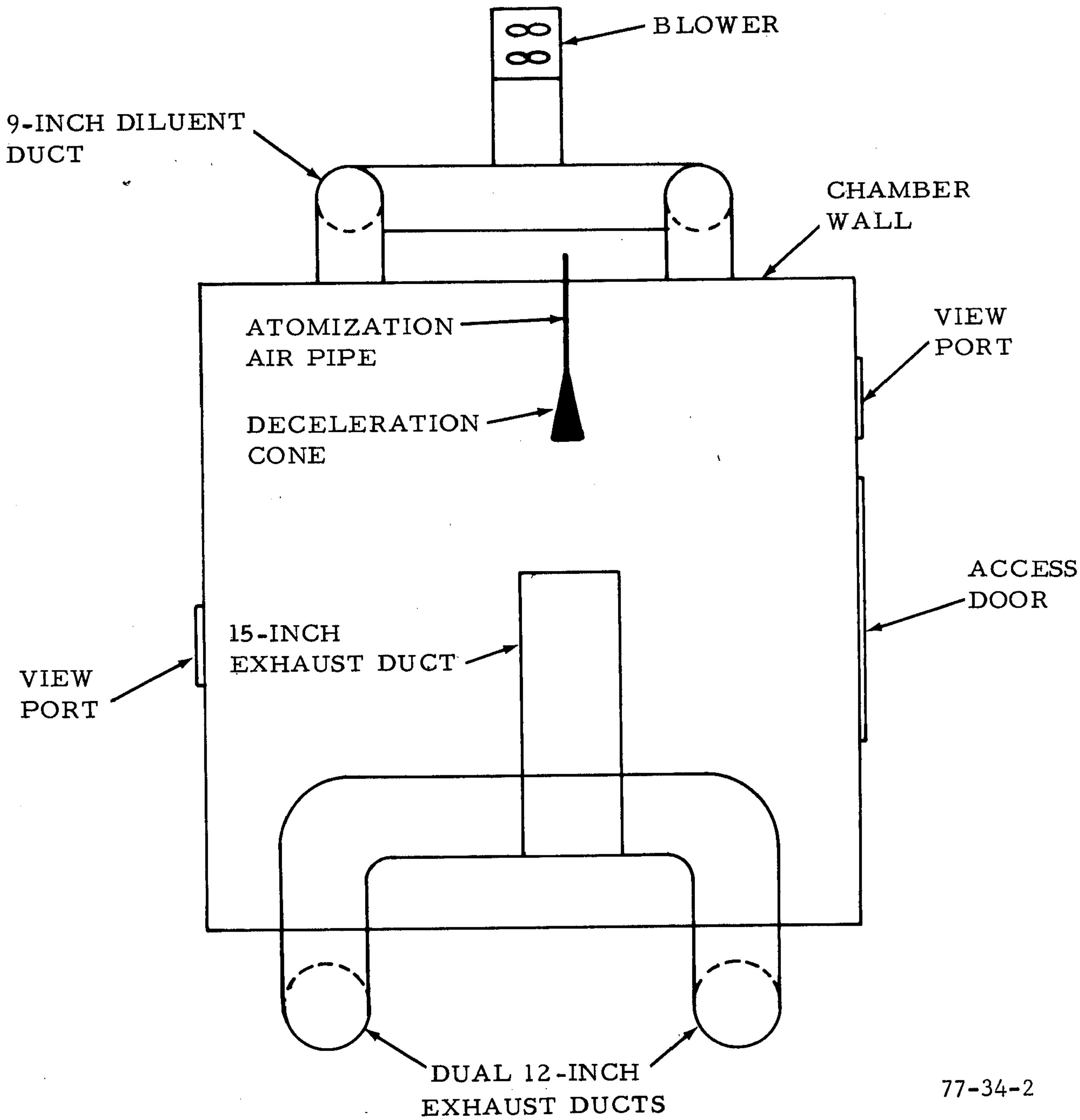


FIGURE 2. CHAMBER SCHEMATIC

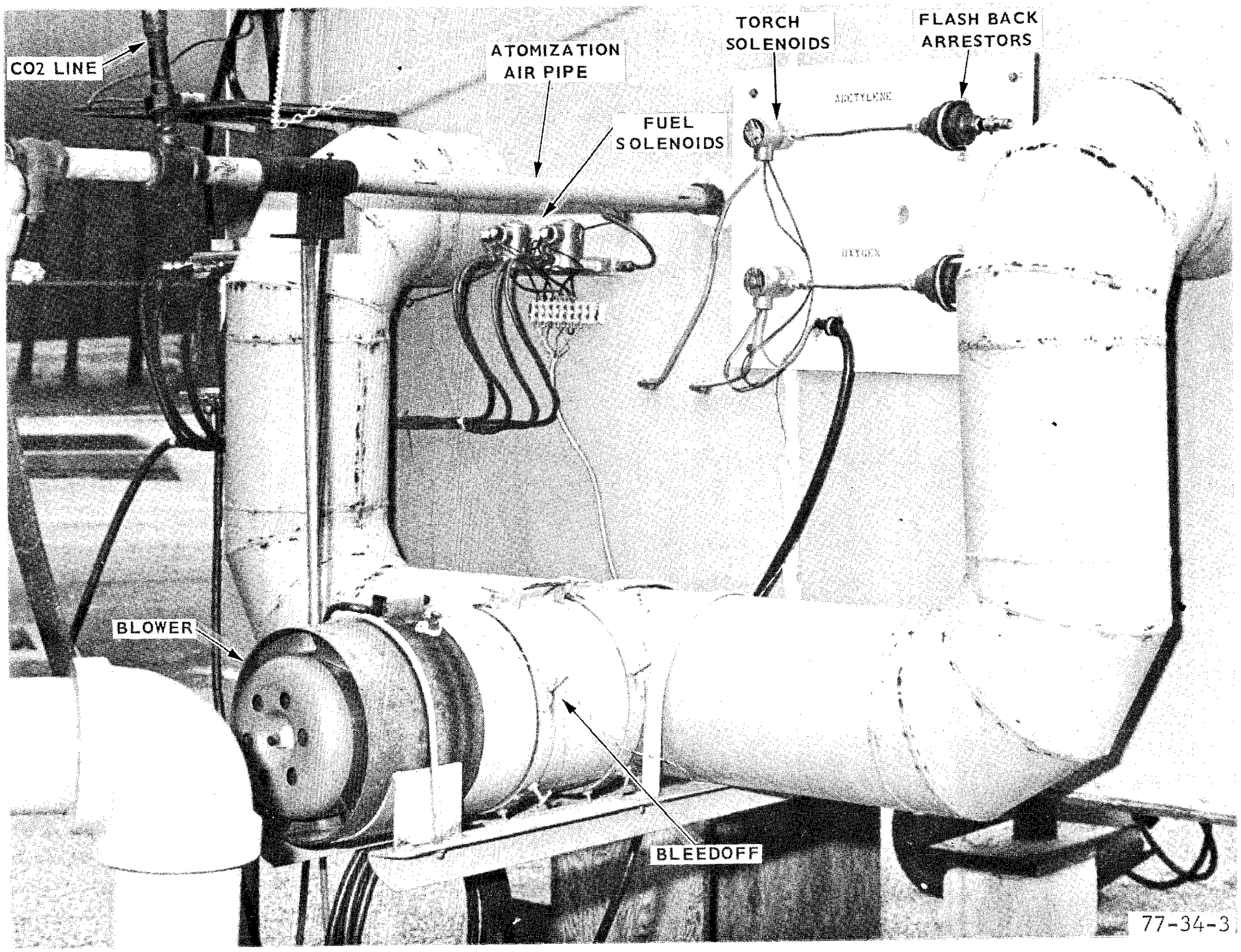


FIGURE 3. CHAMBER FRONTAL VIEW

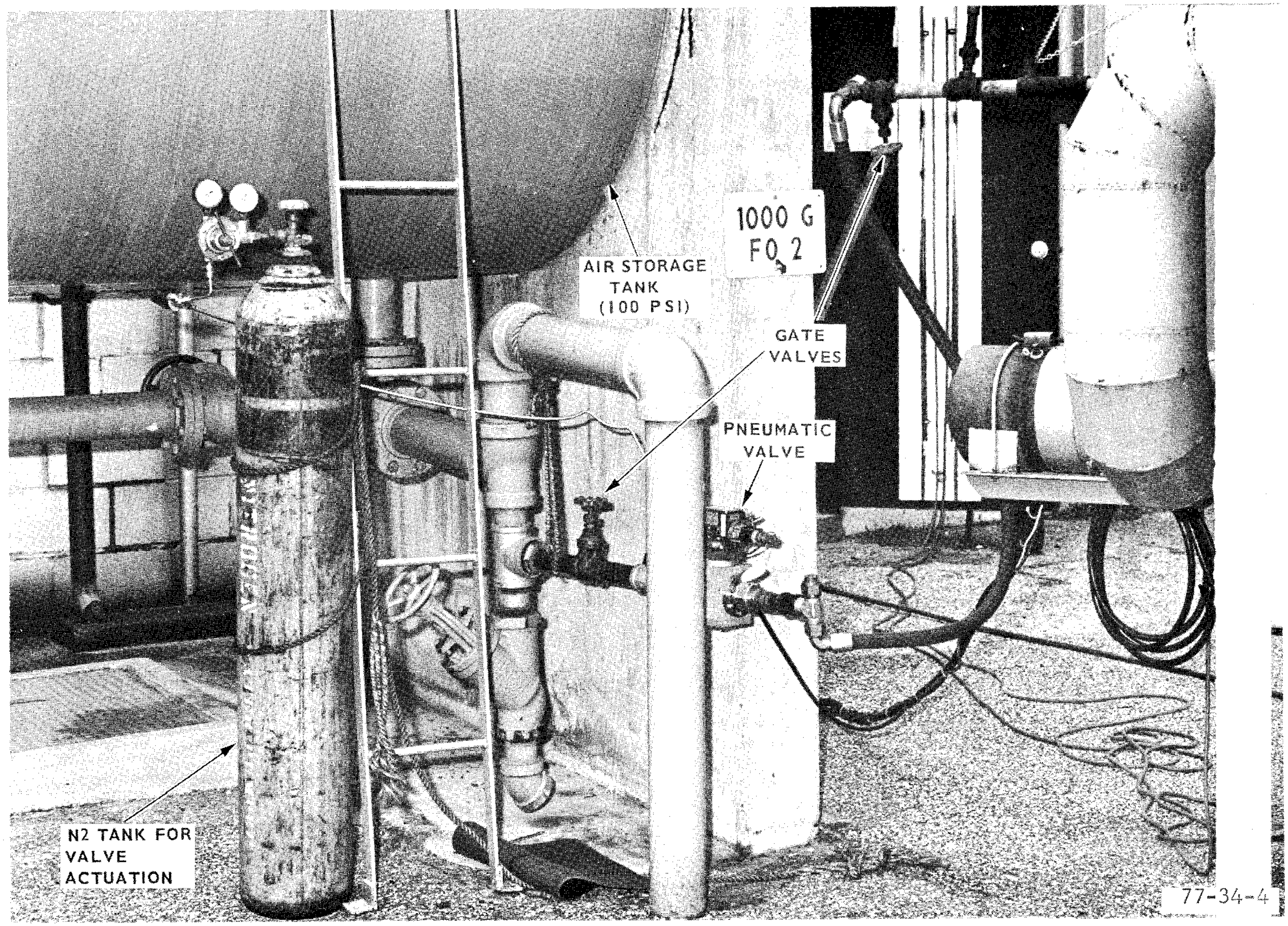


FIGURE 4. ATOMIZATION AIR SUPPLY

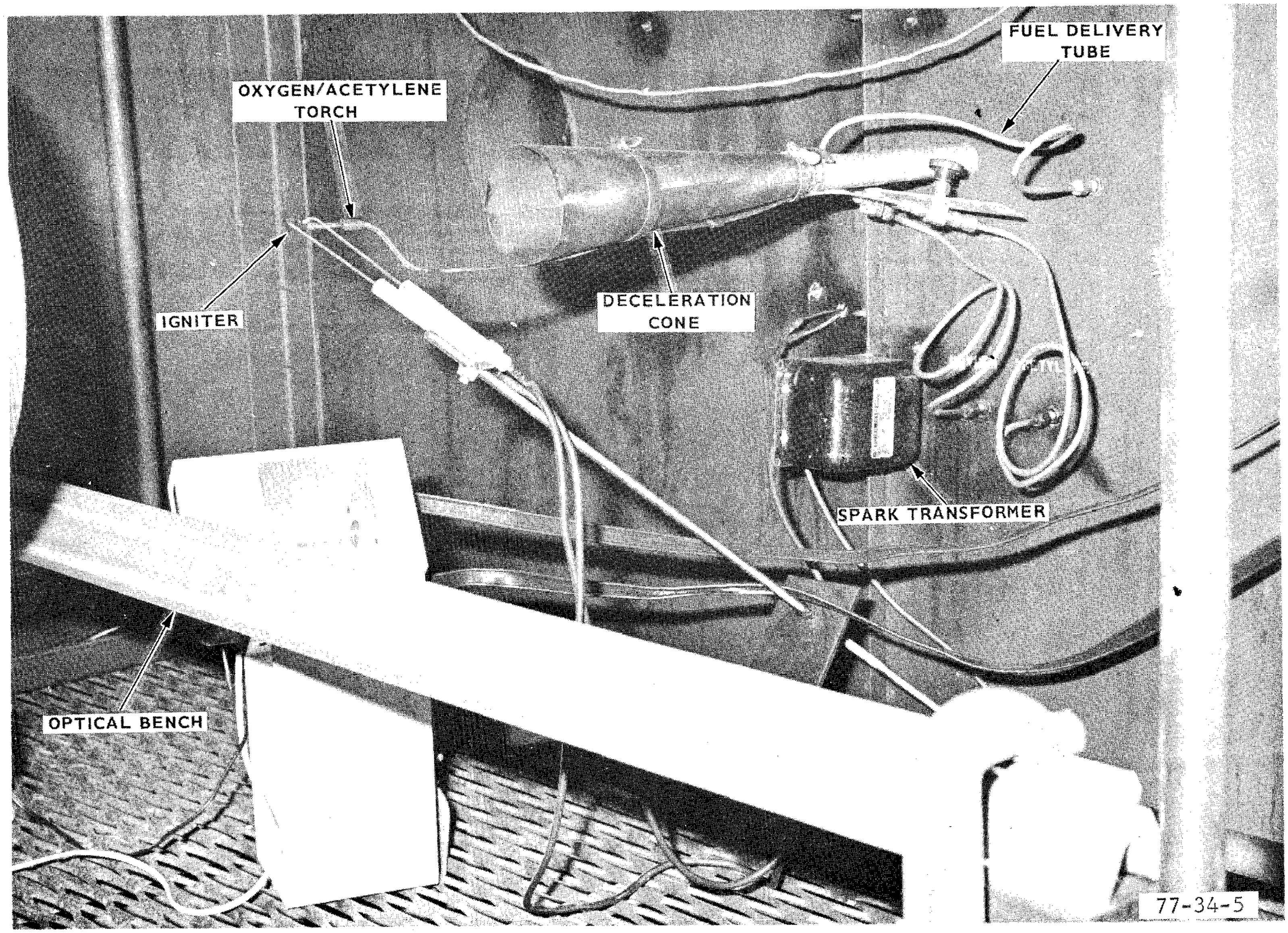


FIGURE 5. CHAMBER TEST SECTION

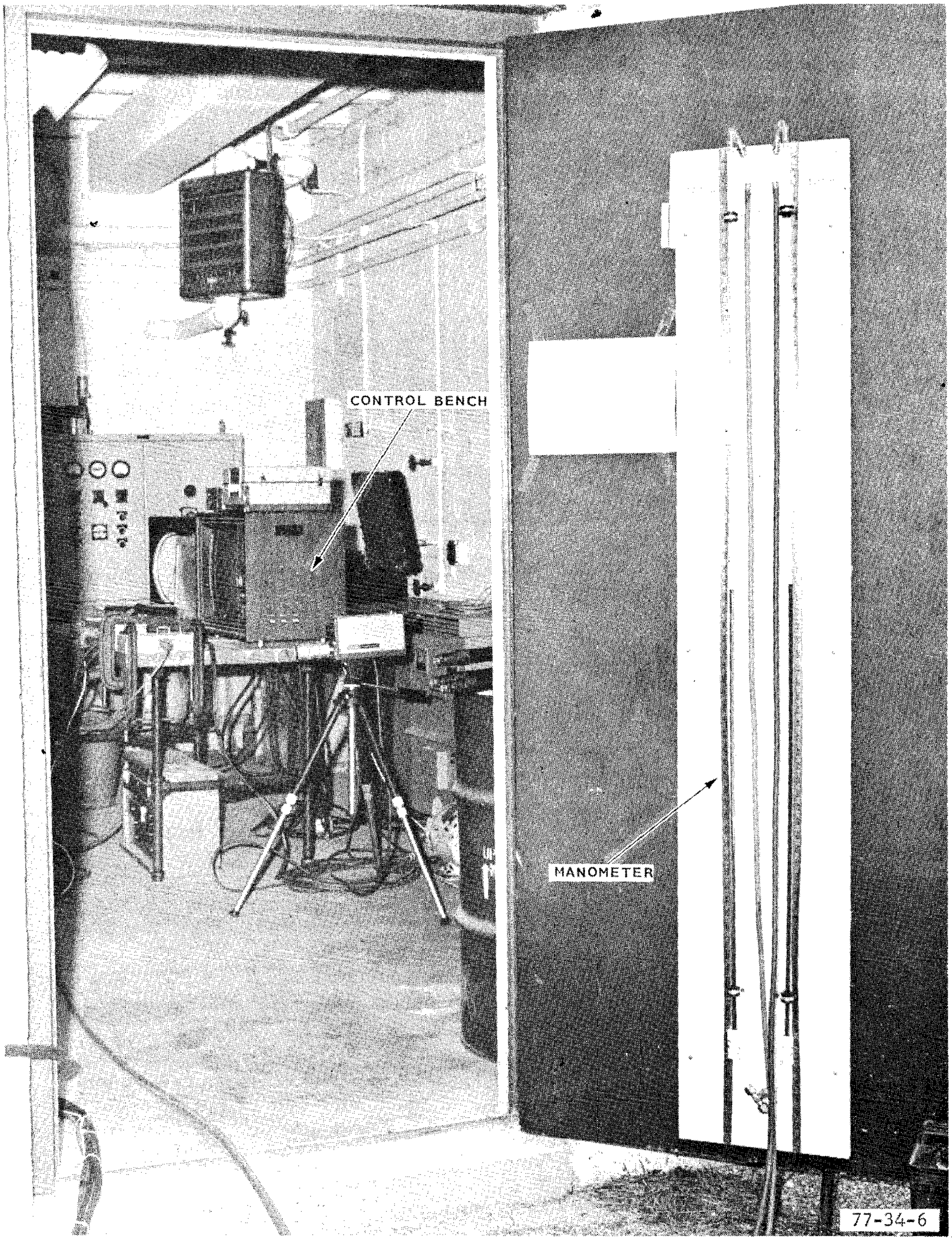


FIGURE 6. MANOMETER AND CONTROL ROOM

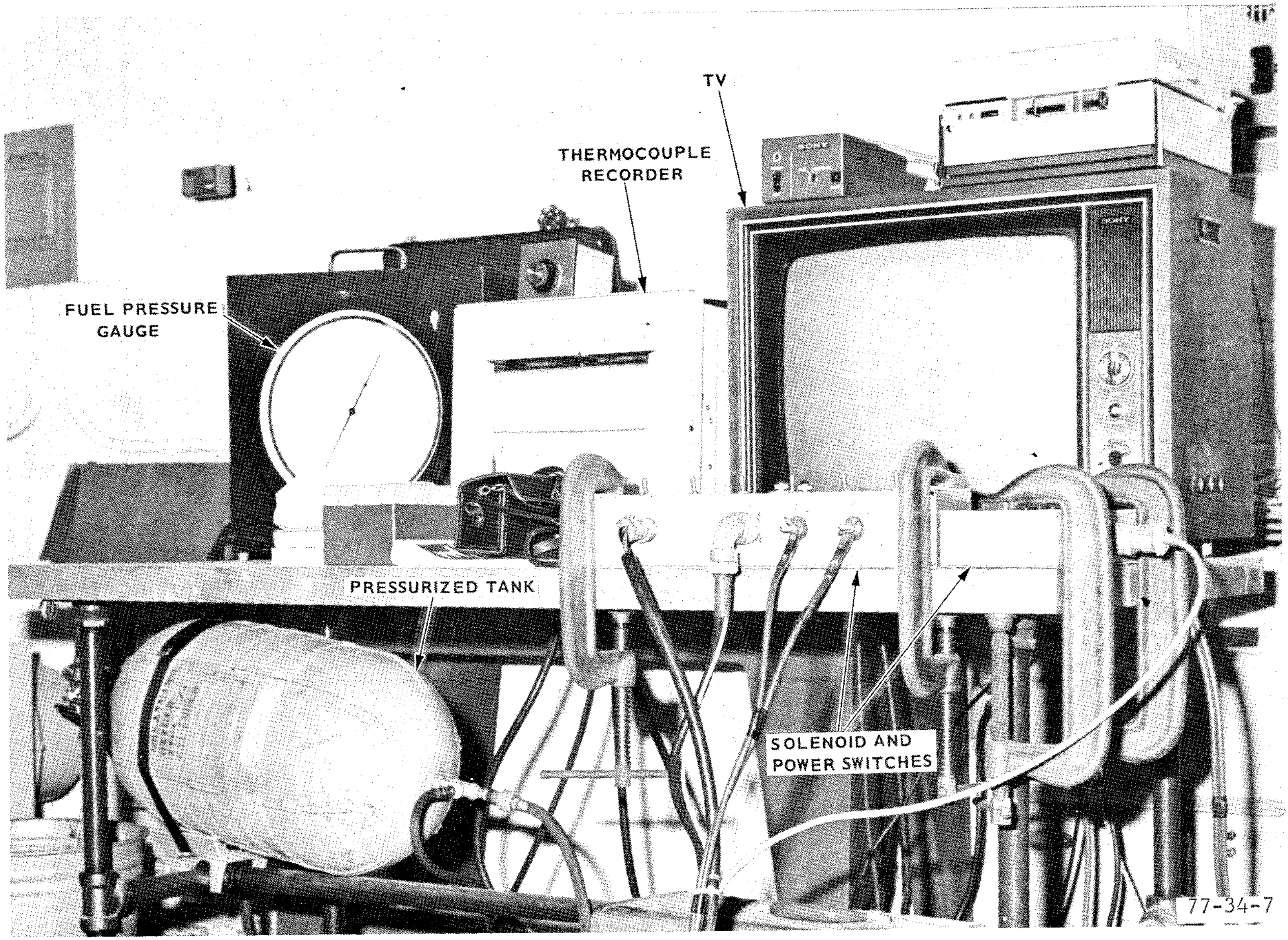


FIGURE 7. CONTROL TABLE

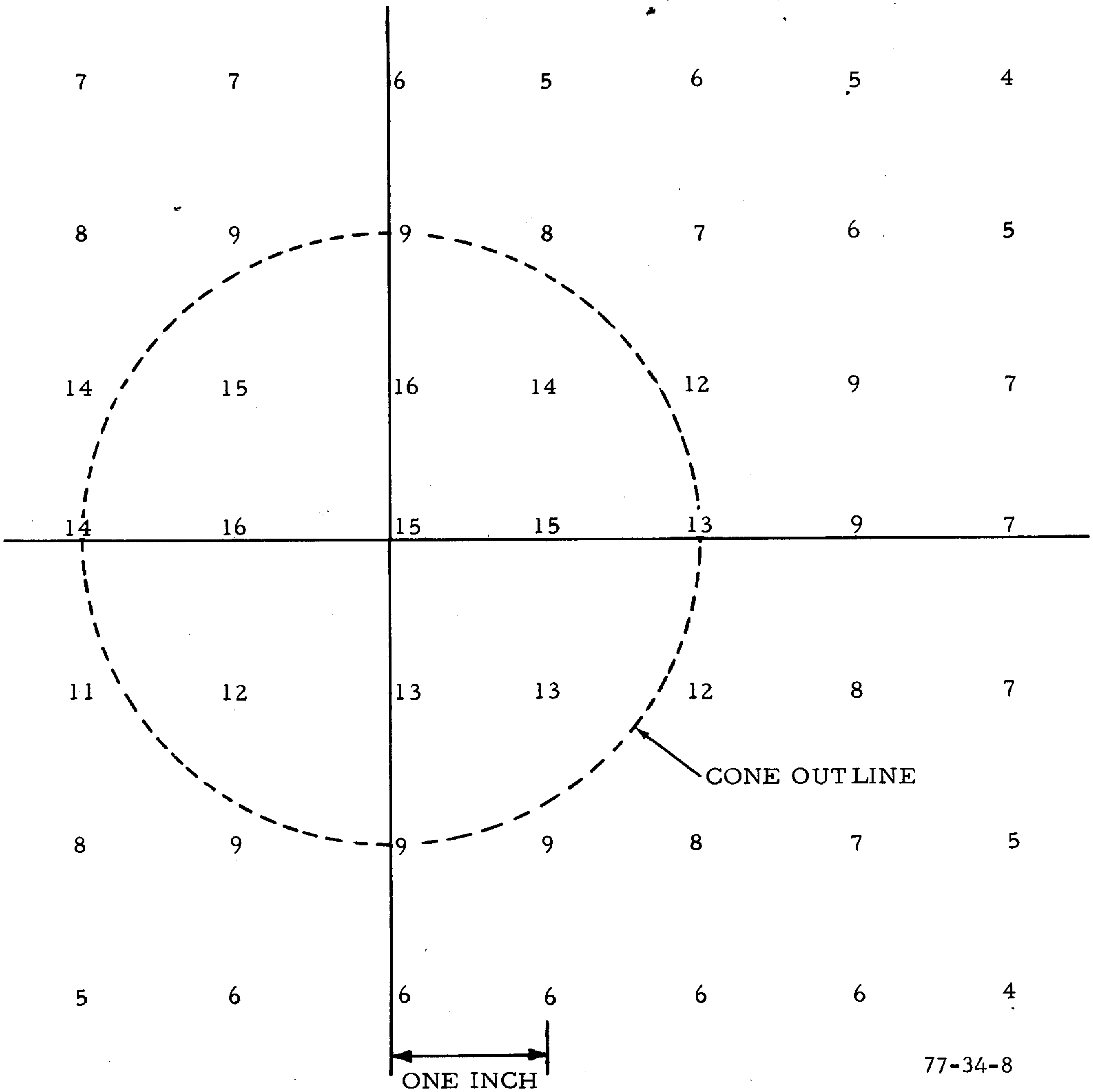
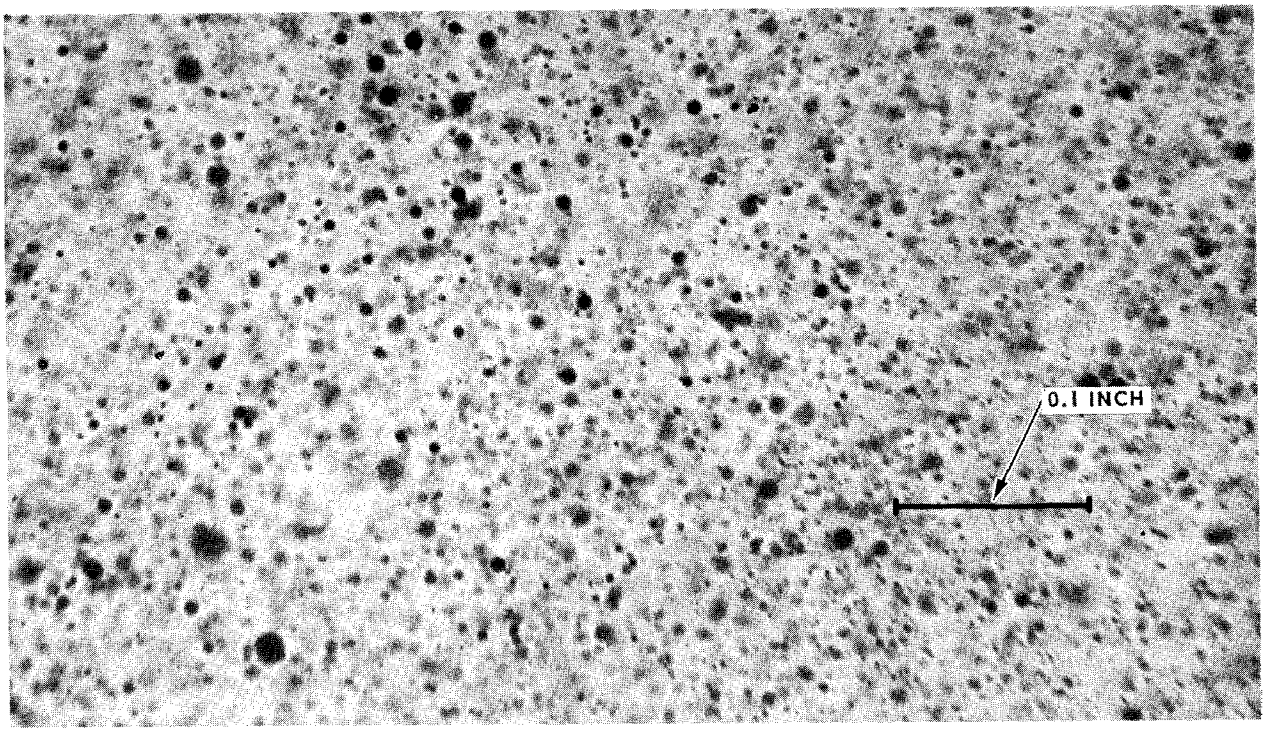
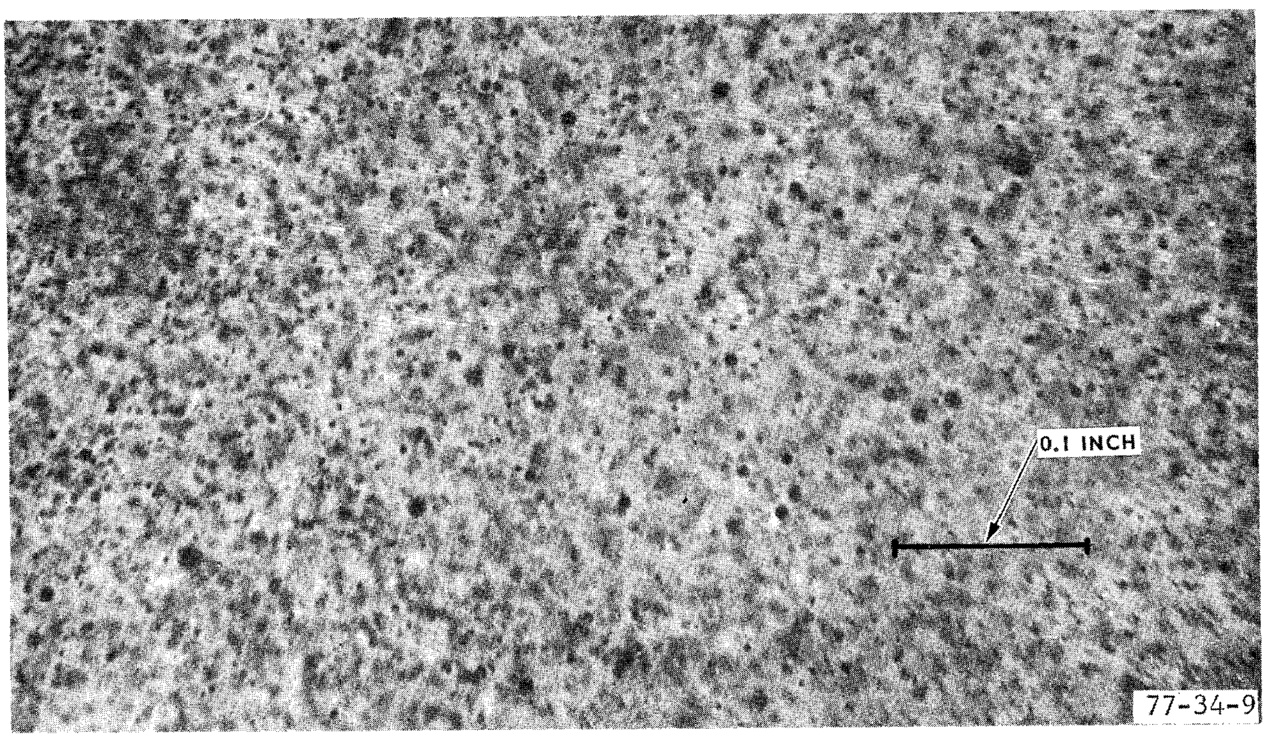


FIGURE 8. FLOW FIELD DOWNSTREAM OF IGNITER
(Plotted Digits in mi/h)

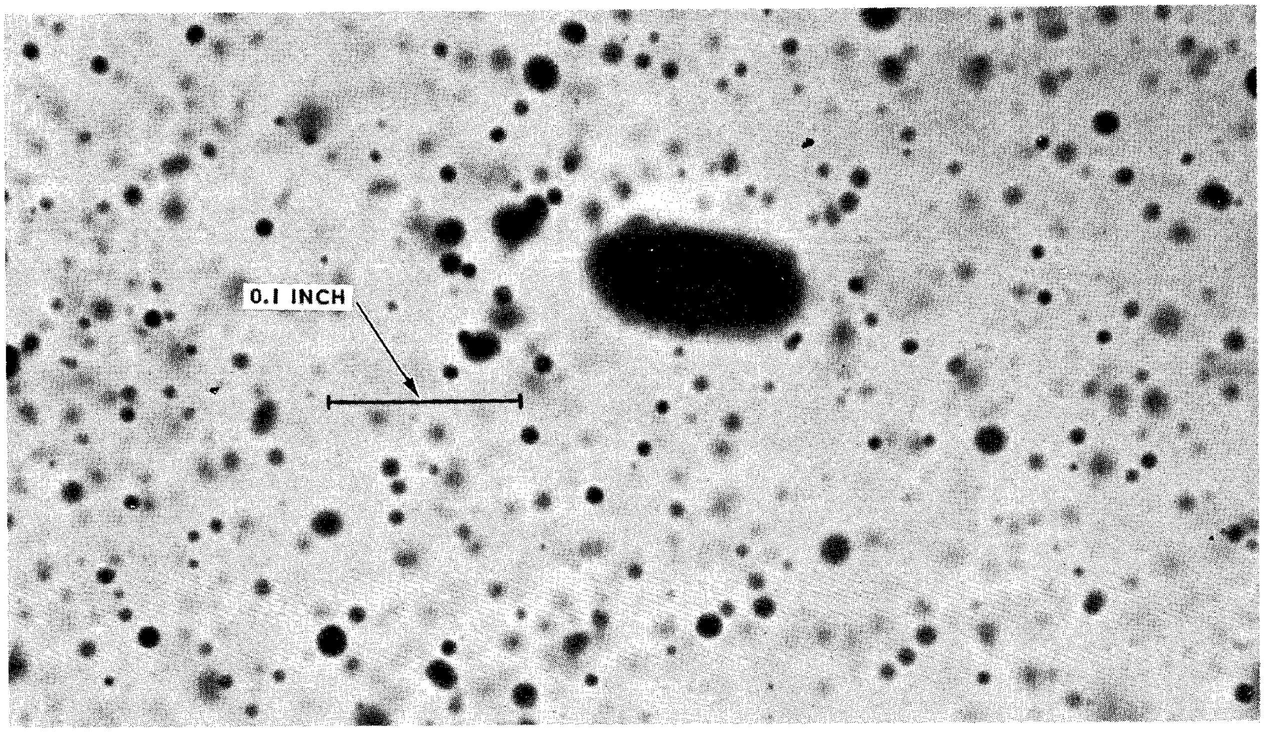


a. 200 mph

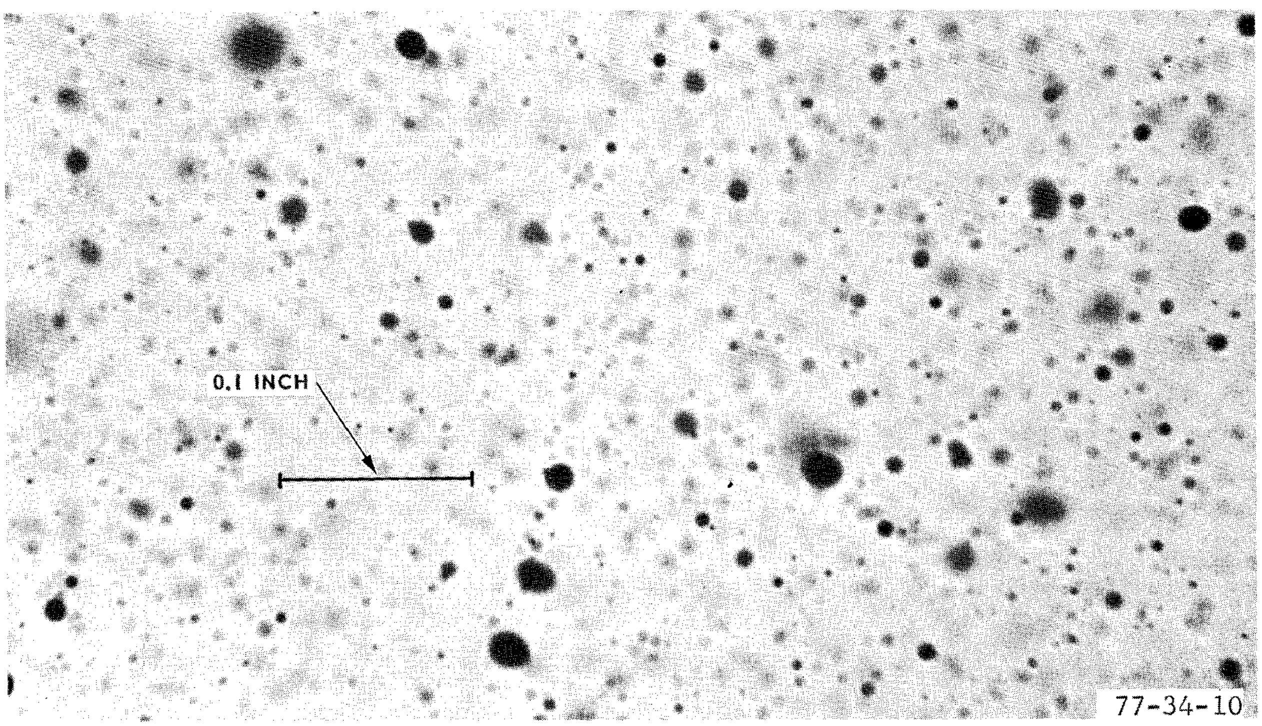


b. 285 mph

FIGURE 9. NEAT JET A SPRAYS

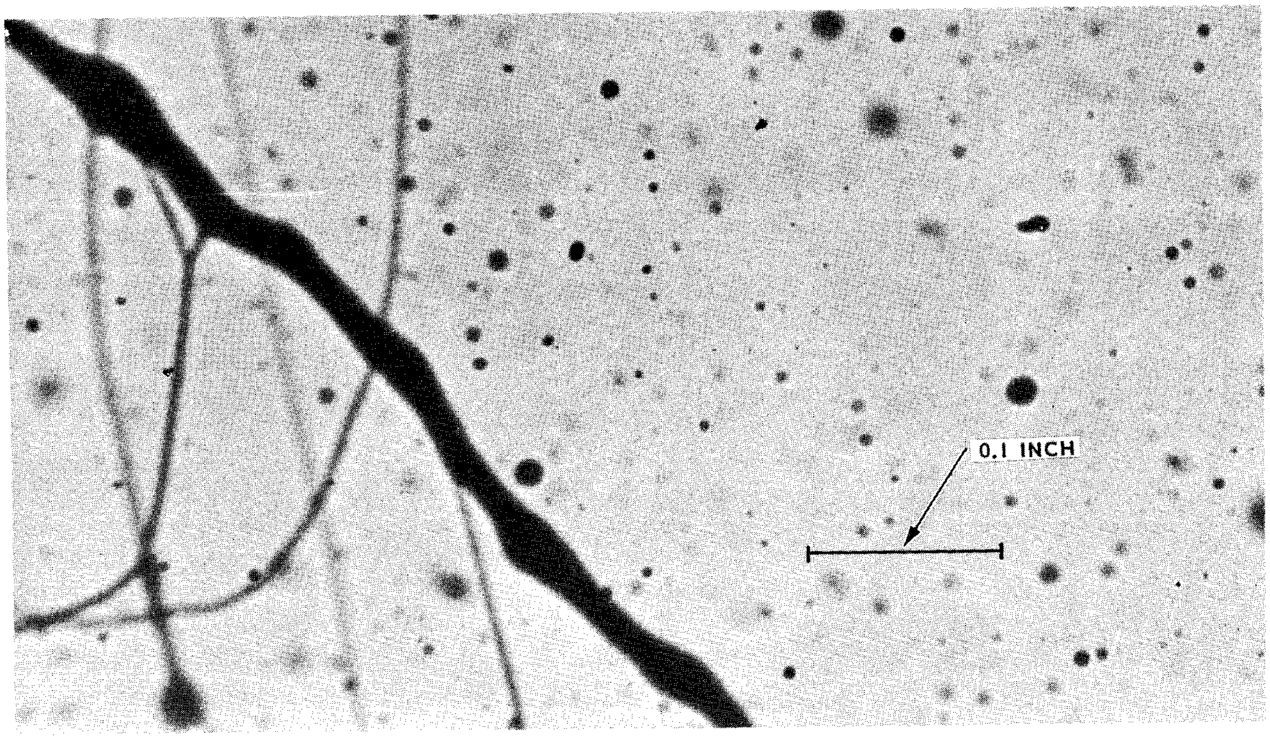


a. 200 mph

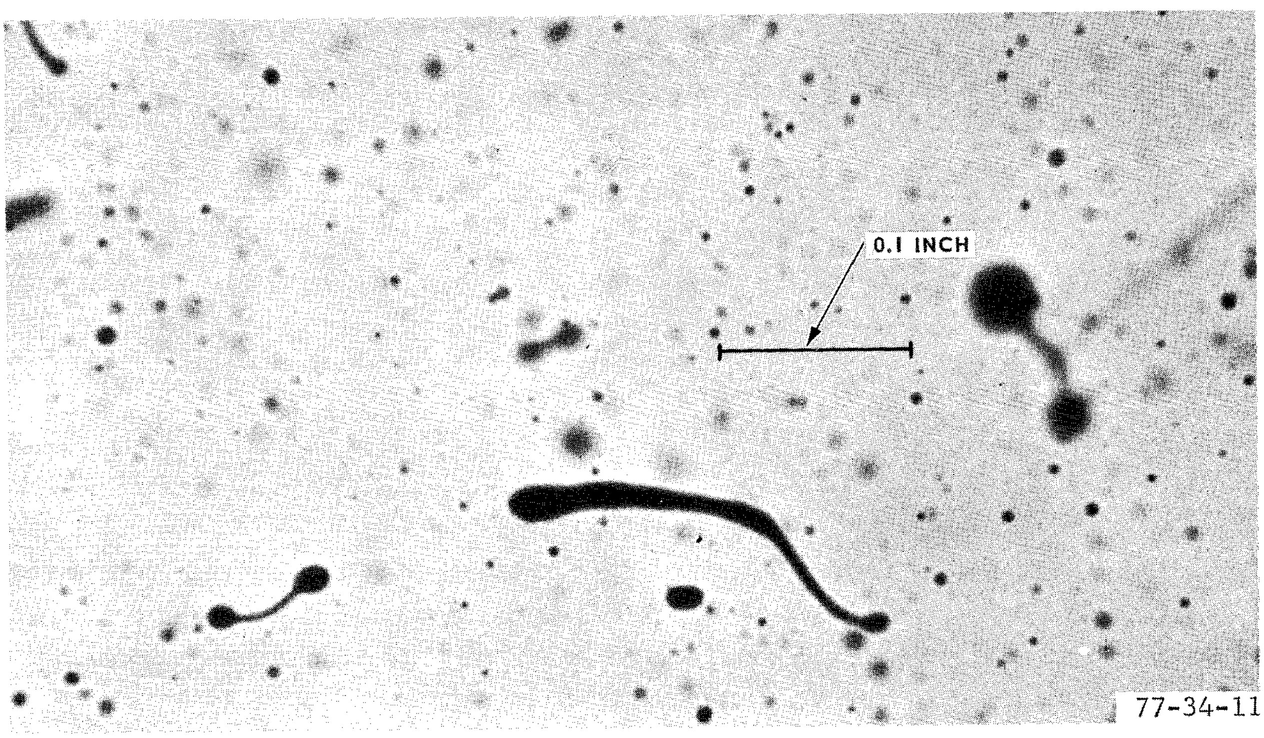


b. 285 mph

FIGURE 10. FM-9 SPRAYS

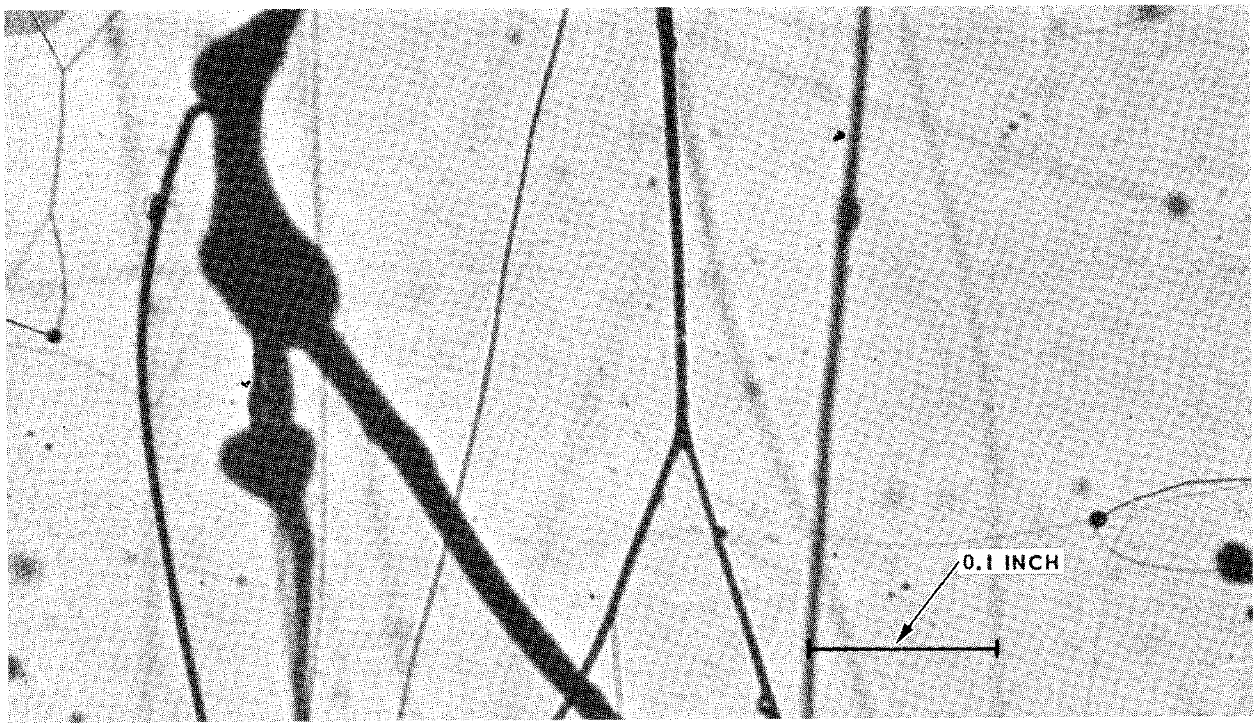


a. 200 mph

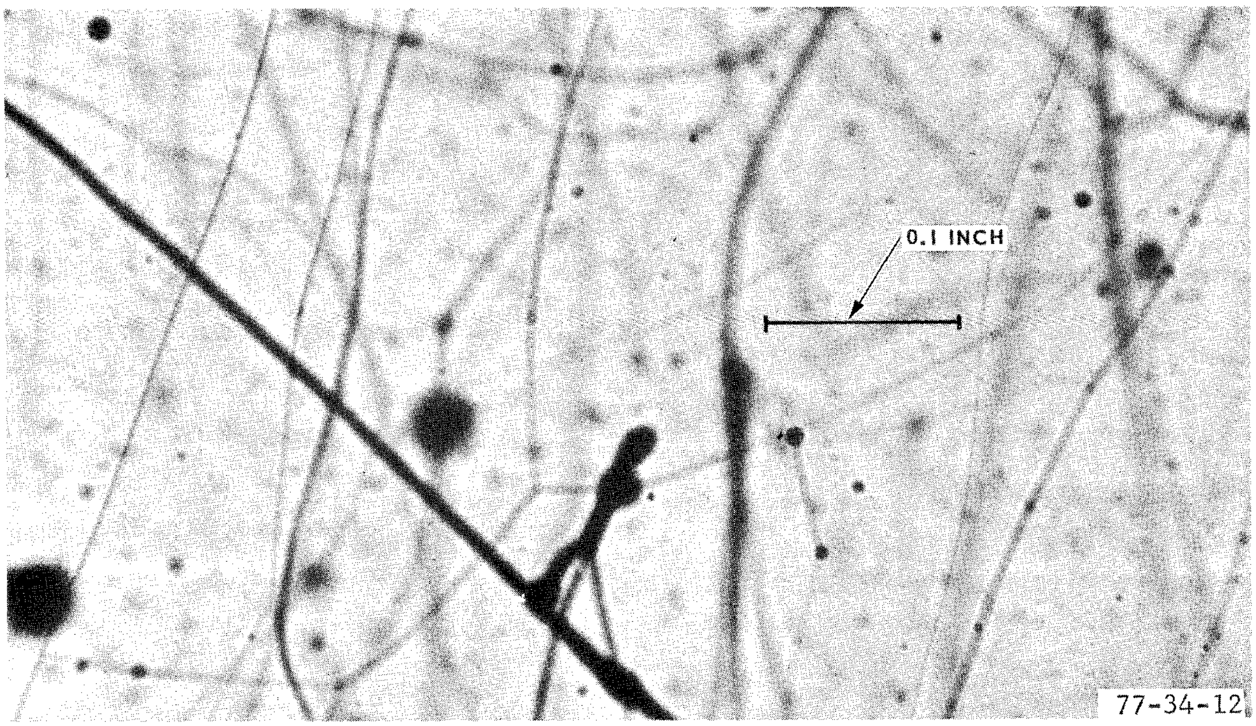


b. 285 mph

FIGURE 11. FM-4 SPRAYS

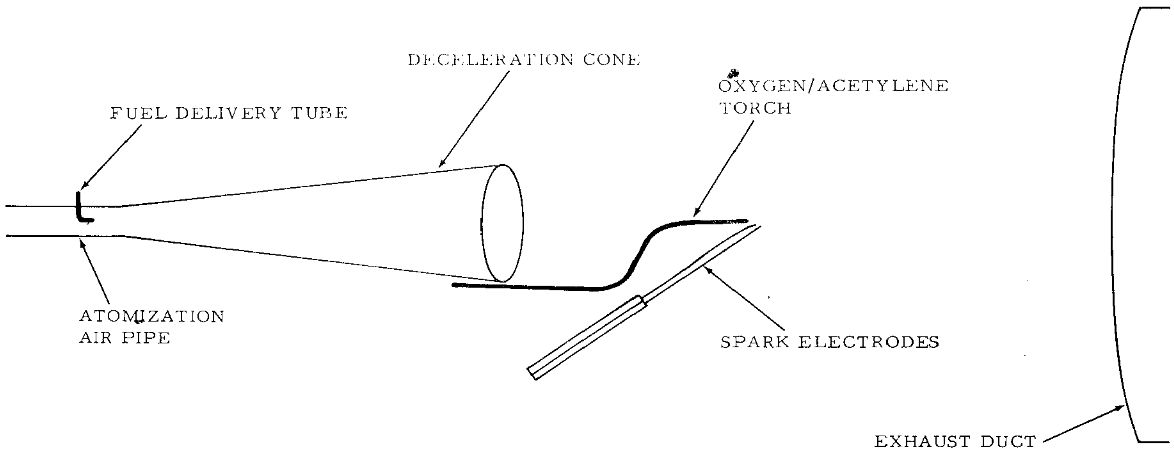


a. 200 mph



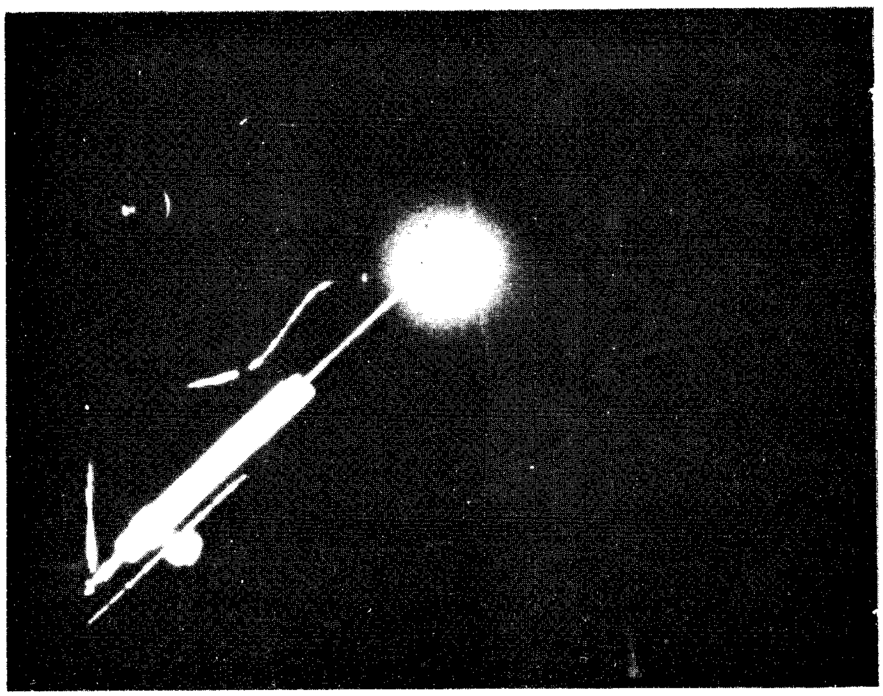
b. 285 mph

FIGURE 12. AM-1 SPRAYS



A. TEST SECTION SCHEMATIC

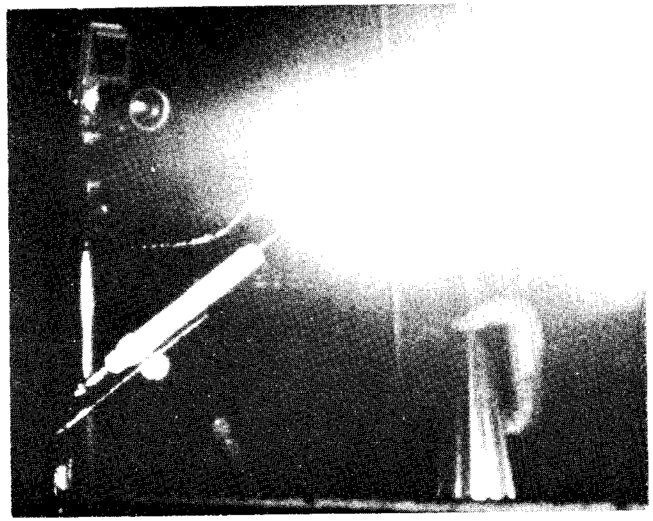
77-34-13a



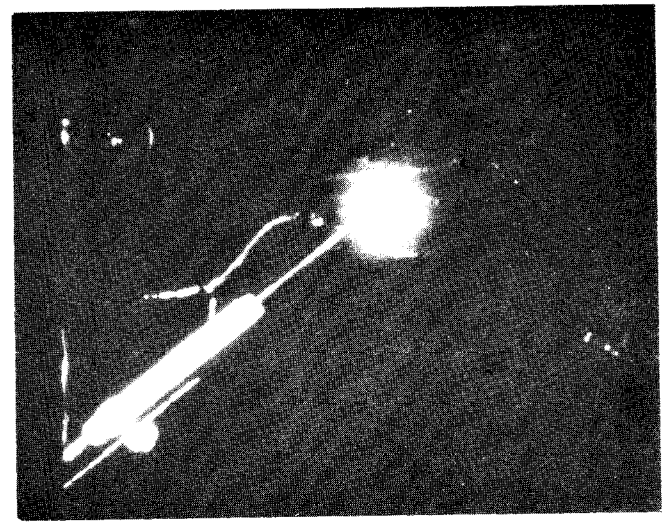
B. IGNITED TORCH

77-34-13b

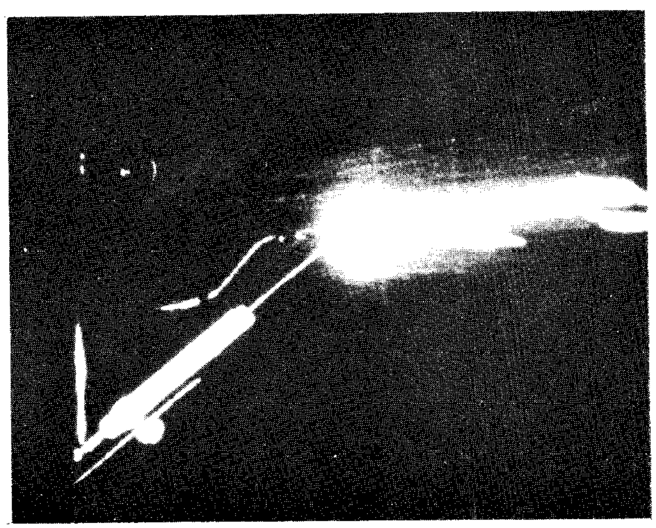
FIGURE 13. TORCH PHOTOGRAPH AND TEST SECTION SCHEMATIC



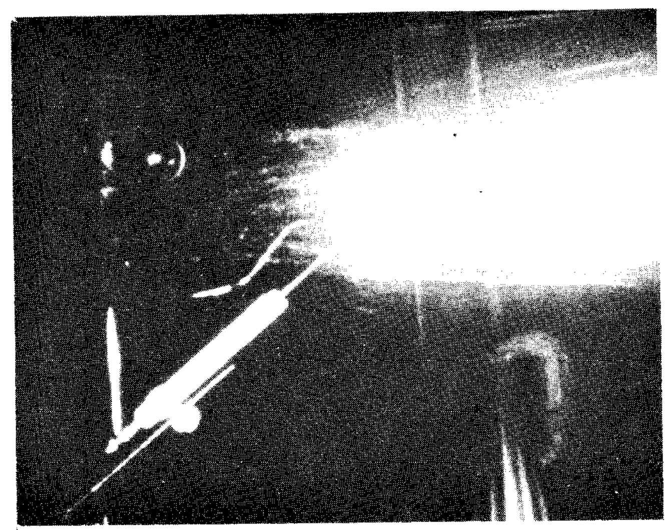
a. JET A SPRAY



b. FM-9 SPRAY



c. FM-4 SPRAY



d. AM-1 SPRAY

FIGURE 14. BURNING FUEL SPRAYS