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AFAPL AIRCRAFT FIRE TEST PROGRAM WITH FAA 1967-1970

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DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
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Atlantic City, New Jersey 08405

JUNE 1971

FINAL REPORT

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Prepared for

AIR FORCE AERO PROPULSION LABORATORY
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13. ABSTRACT A number of aircraft propulsion and fuel system fire protection test programs were conducted. NARMCO prototype "Fibercell" Overheat Detector, the Panametrics Inc. Prototype Hazardous Vapor Detector and a McGraw-Edison Co. Ultra-Violet Fire Detection System underwent limited evaluation in a Jet powerplant fire test environment. The Walter Kidde and Company, Inc. pyrotechnic generated gas discharge fire extinguishing agent container, and the E. W. Bliss Co. high-expansion foam/bromotrifluoromethane extinguishing agent combination fire extinguishing system were evaluated in a simulated aircraft powerplant nacelle. Fire resistance tests in a standard 2000°F flame-test environment were conducted on specific stainless-steel tubing as well as various size stainless-steel tubing assemblies with several combinations of stainless steel and aluminum connectors (nuts, sleeves, and unions). Some tubing was tested while either fluid or air under pressure was trapped (no pressure relief provided) in the tubing. The tubing assemblies with connectors were tested while fluid either was flowing through or was static in the tube assembly system. Pressure relief for the static fluid conditon was provided. Evaluation of a Fenwal Explosion Suppression System for an aircraft fuel tank was conducted. Testing envolved the measurement of relative concentration of an extinguising agent discharged by the system into the fuel tank cavity to determine agent distribution in the cavity. Specialized gas analyser equipment was used to measure the relative concentration of the agent. An investigation of the vulnerability of

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Gunfire Tests						
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13. Abstract (continued)

JP-4 and JP-8 fuel, contained in a fuel tank, to ignition by incendiary gunfire was made. Dynamic incendiary gunfire tests were conducted utilizing either JP-4 or JP-8 fuel and varying the following parameters; (1) standoff distance between the fuel cavity and test article skin, (2) airflow over the test article surface, and (3) ventilation rate in standoff space. A few tests were conducted with JP-4 and JP-8 fuels utilizing porous polyurethane foam in either the fuel cavity portion of the tank or the standoff space portion.

AFAPL-TR-70-93

AFAPL AIRCRAFT FIRE TEST PROGRAM WITH FAA 1967 - 1970

D. E. SOMMERS
J. H. O'NEILL

FOREWORD

This report was prepared by the National Aviation Facilities Experimental Center of the Federal Aviation Administration, under USAF Contract No. F33615-67-M-5000. The contract was initiated under Project 3048, Task 304807, "Aerospace Vehicle Hazard Protection". The program was administered under the direction of the Air Force Aero Propulsion Laboratory, with R. G. Clodfelter (AFAPL/SFH) as program manager.

This report is a summary of work completed on this contract during the period 3 April 1967 to 30 September 1970.

Mr. John Schaffer was the Administrator of the Federal Aviation Administration, Mr. Jack Webb, Director of the Center, and Messrs. Daniel E. Sommers, Program Manager, John O'Neill, Julius J. Gassmann, Eugene P. Klueg, James E. Demaree, and Eldon B. Nicholas participated in this effort at FAA's National Aviation Facilities Experimental Center, Atlantic City, New Jersey.

This technical report has been reviewed and is approved.

Benito P. Botteri, Chief
Fire Protection Branch
Fuels and Lubrication Division

ABSTRACT

A number of aircraft propulsion and fuel system fire protection test programs were conducted.

The NARMCO prototype "Fibercell" Overheat Detector, the Panametrics Inc. Prototype Hazardous Vapor Detector and a McGraw-Edison Co. Ultra-Violet Fire Detection System underwent limited evaluation in a Jet powerplant fire test environment.

The Walter Kidde and Company, Inc. pyrotechnic generated gas discharge fire extinguishing agent container, and the E. W. Bliss Co. high-expansion foam/bromotriflouromethane extinguishing agent combination fire extinguishing system were evaluated in a simulated aircraft powerplant nacelle.

Fire-resistance tests in a standard 2000°F flame-test environment were conducted on specific stainless-steel tubing as well as various size stainless-steel tubing assemblies with several combinations of stainless steel and aluminum connectors (nuts, sleeves, and unions). Some tubing was tested while either fluid or air under pressure was trapped (no pressure relief provided) in the tubing. The tubing assemblies with connectors were tested while fluid either was flowing through or was static in the tube assembly system. Pressure relief for the static fluid conditon was provided.

Evaluation of a Fenwal Explosion Suppression System for an aircraft fuel tank was conducted. Testing involved the measurement of relative concentration of an extinguishing agent discharged by the system into the fuel tank cavity to determine agent distribution in the cavity. Specialized gas analyser equipment was used to measure the relative concentration of the agent.

An investigation of the vulnerability of JP-4 and JP-8 fuel, contained in a fuel tank, to ignition by incendiary gunfire was made. Dynamic incendiary gunfire tests were conducted utilizing either JP-4 or JP-8 fuel and varying the following parameters; (1) standoff distance between the fuel cavity and test article skin, (2) airflow over the test article surface, and (3) ventilation rate in standoff space. A few tests were conducted with JP-4 and JP-8 fuels utilizing porous polyurethane foam in either the fuel cavity portion of the tank or the standoff space portion.

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SECTION I

INTRODUCTION

The Federal Aviation Administration's (FAA) National Aviation Facilities Experimental Center (NAFEC) provided engineering and technical assistance and facilities to conduct various investigations involving fire safety in aircraft propulsion and fuel systems for the Air Force Aero Propulsion Laboratory, Wright-Patterson Air Force Base, during the past 3 1/2 years. This work included:

1. Limited exploratory tests of a prototype overheat detection system, a prototype fire detection system and a prototype hazardous vapor detection system for aircraft power plant fire safety application;

2. Tests of (1) a fire extinguishing agent container which utilized gas pressure generated by a pyrotechnic to effect agent discharge, and (2) a high expansion foam fire extinguishing system for aircraft power plant application;

3. Fire resistance tests of stainless steel tubing as well as various combinations of stainless steel and aluminum connectors connecting sections of the stainless steel tubing;

4. Evaluation tests of an explosion suppression system for a fuel tank in regards to the distribution and concentration of the suppressing agent within the tank; and

5. Incendiary gunfire tests of fuel tanks using two fuels (JP-4 and JP-8) and simulating flight airflows over the tank surface.

Each of the foregoing areas of testing is discussed under separate sections in this report. The test work which was conducted entirely by NAFEC personnel is discussed in detail. The test work, in which NAFEC provided facilities and limited technical assistance only to another Air Force (AF) contractor, is discussed only to the limit of the NAFEC input and reference is made to the other AF contractors' completed report on the work where applicable.

SECTION II

DETECTION

1. OVERHEAT, FIRE, AND HAZARDOUS VAPOR DETECTION SYSTEMS

1.1 General

Exploratory tests were conducted on a prototype NARMCO "fibercell" overheat detector, a prototype Panametrics hazardous vapor detector and a prototype Edison Ultra-Violet (UV) fire detection system in an aircraft turbo-jet power plant environment. The testing of the overheat detector and the hazardous vapor detector was directed by NARMCO and Panametrics, Inc., engineering personnel. NAFEC was limited to providing and operating the test facility and assisting in the installation of the detection systems and the test instrumention. The testing of the UV fire detection system was conducted by NAFEC.

1.2 Test Facility

The detection systems were installed and tested in the compressor and accessory compartment (Zone II) of the C-140 Jet Star engine and nacelle installation. The C-140 power plant, including the No. 2 nacelle, pylon and JT-12 engine, has been installed and operated in an open circuit induction type wind tunnel facility. Figure 1 shows the power plant installation in the test section of the wind tunnel. The wind tunnel provided aerodynamic conditions within the nacelle similar to those which exist in flight at approximately Mach 0.5 and 5000-foot altitude.

Cooling airflow entered the compressor and accessory compartment of C-140 nacelle through four small blast tubes (7/16-inch diameter) and amounted to an approximate total of 0.2 pound per second. Air exits for this compartment consisted of two 2-by-7-inch rectangular openings located in the top aft area of the compartment between Stations Nos. 107 and 114 at the 11 and 1 o'clock positions.

Test fires within the nacelle resulted from releasing JP-4 fuel as a spray and igniting the spray with a spark ignitor. Fuel leaks of 0.1, 0.25, and 0.3 gallon-per-minute were simulated during these fire, overheat, and hazardous vapor detector tests. The start and duration of the test fires were determined from a thermocouple output signal recorded on an oscillograph.

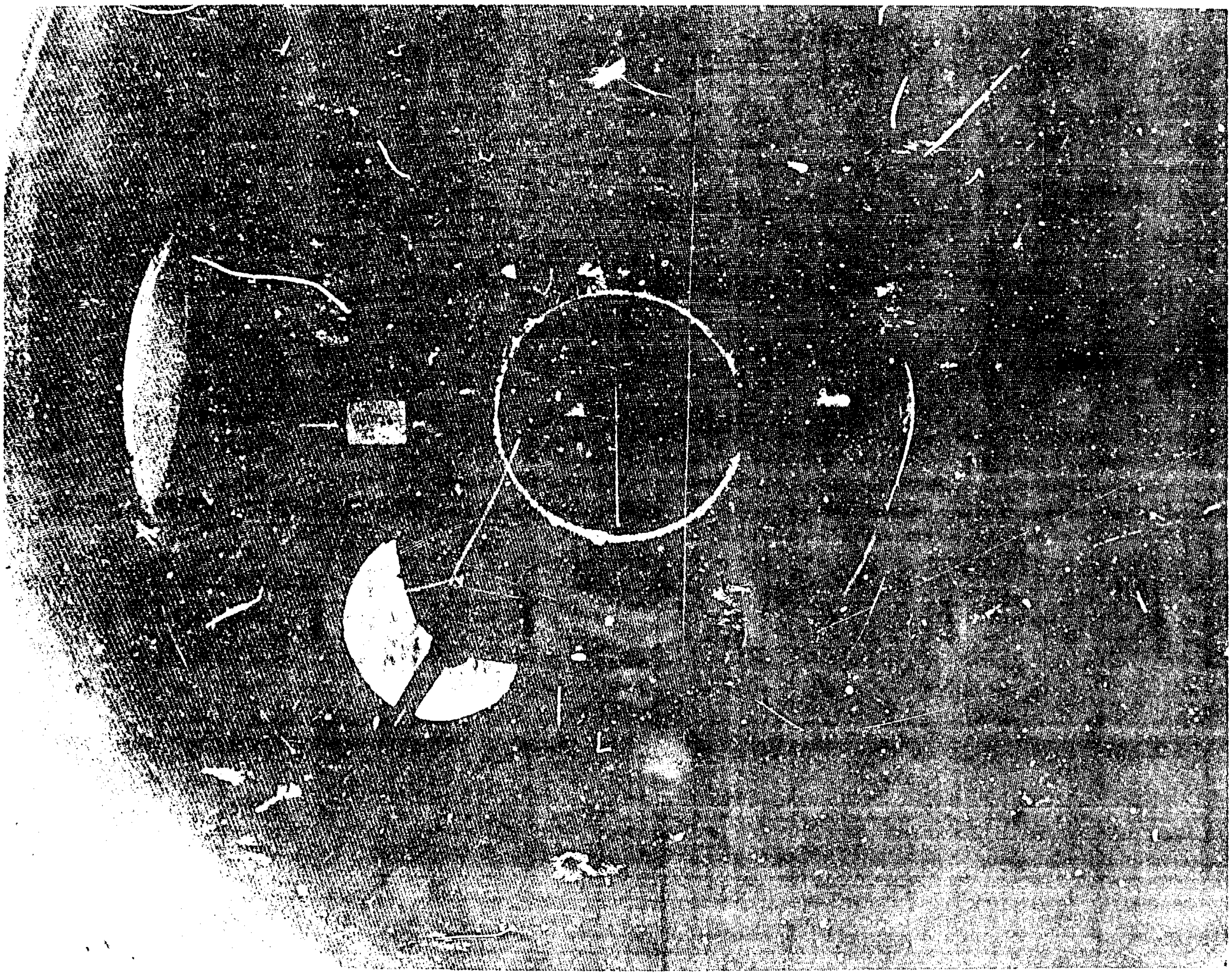


FIGURE 1 - C-140 POWERPLANT INSTALLATION IN WIND TUNNEL TEST SECTION

1.3 Test Procedure

The test procedure generally consisted of establishing a stabilized test section air velocity and engine power (95 percent rated rotor speed) conditions, followed by releasing and igniting the test fire fuel. In the case of the hazardous vapor detection test, the fuel was released but not ignited.

1.4 Fibercell Overheat Detector Tests

The fibercell overheat detector is a power-generating ceramic cell in fiber form. It has a metallic core covered with a vitreous sheath, then a coat of a second metal. The metals are the cathode and anode couple, and the vitreous substance is the electrolyte. This electrolyte electrochemical cell depends on its temperature for electrical power output. The electrolyte's resistance is logarithmic in relation to temperature and cell power increases with an increase in temperature of the electrolyte.

Two prototype NARMCO fibercell overheat detector units were installed in Zone II of the C-140 nacelle for exploratory tests under simulated flight conditions. One unit was installed on the Zone II main access door at approximately 5:30 o'clock and between nacelle Stations 91 and 103, and the other was installed between nacelle Stations 103 and 115 on the louvered air-exit panel located at the top aft portion of Zone II. A 0.3 gpm JP-4 fuel-to-fire spray nozzle was located at the 4:30 o'clock position, nacelle Station 76 (Location 5) and was directed aft. Figures 2 and 3 show the location of the detector units and fuel-to-fire nozzles in the C-140 power plant installation. Figure 4 shows the fibercell detector at the 5:30 o'clock position.

Tests of the fibercell units included obtaining output signal information over a range of engine power setting in combination with facility mach number as well as under conditions of a nacelle compartment fire. The output of the fibercell unit was monitored with a microammeter and recorded by the NARMCO engineer.

A complete report of this work is contained in Technical Report AFAPL-TR-68-44 of May 1968, entitled "Fibercell Overheat Hazard Detection System."

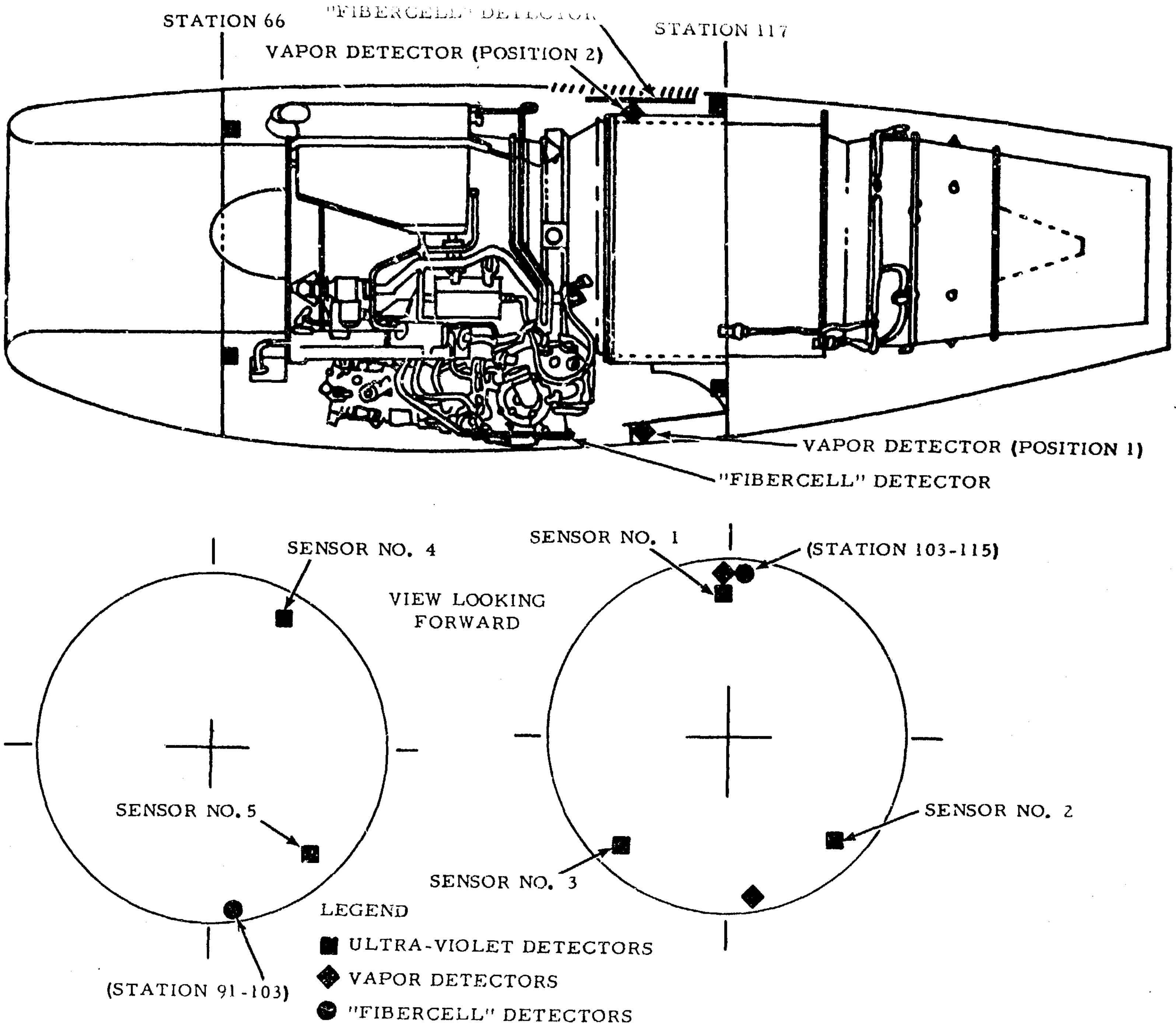
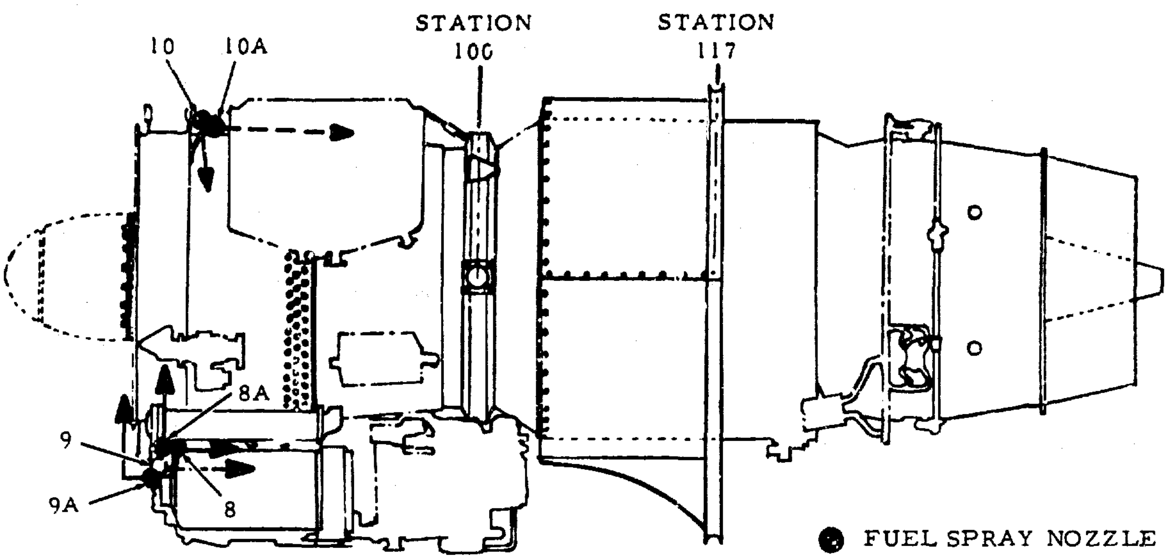
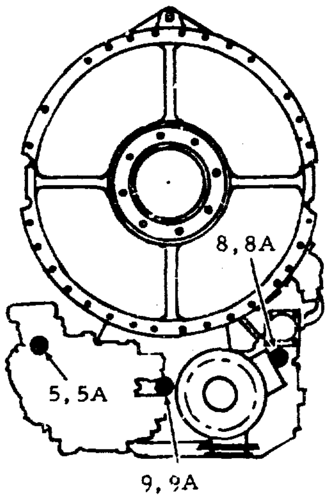


FIGURE 2 - LOCATION OF ULTRA-VIOLET, FIBERCELL AND VAPOR DETECTIONS IN C-140 POWERPLANT



FUEL NOZZLE LOCATIONS (ZONE II)



5- NACELLE STATION 76, 4:30 O'CLOCK, DIRECTED TO SPRAY FUEL AFT.

5A- SAME AS 5 EXCEPT FUEL SPRAY WAS DIRECTED TOWARD ENGINE CENTERLINE.

6- NACELLE STATION 104.5, 4:30 O'CLOCK, DIRECTED TO SPRAY FUEL FORWARD AND UP 10°.

6A- SAME AS 6 EXCEPT FUEL WAS SPRAYED TOWARD ENGINE CENTERLINE.

8A- NACELLE STATION 78, 7:30 O'CLOCK, DIRECTED TO SPRAY FUEL TOWARD ENGINE CENTERLINE.

9- NACELLE STATION 77, 6:00 O'CLOCK, DIRECTED TO SPRAY FUEL AFT.

9A- NACELLE STATION 75, 6:00 O'CLOCK, DIRECTED TO SPRAY FUEL TOWARD ENGINE CENTERLINE.

10- NACELLE STATION 79, 12:00 O'CLOCK, DIRECTED TO SPRAY FUEL DOWN AND SLIGHTLY AFT ONTO ENGINE CASE.

10A- SAME AS 10, EXCEPT DIRECTED TO SPRAY FUEL AFT AND 10° DOWN.

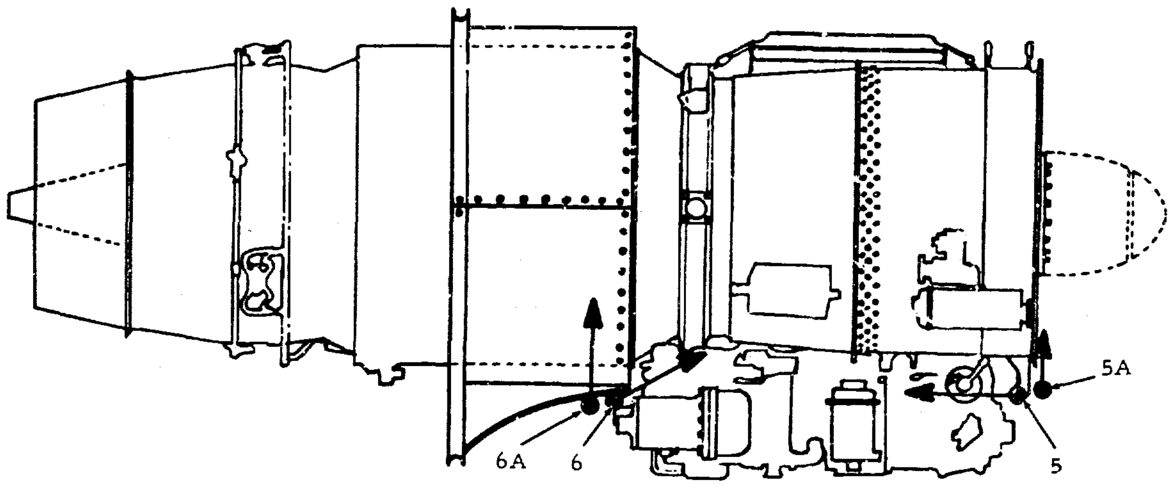


FIGURE 3 - LOCATION OF FUEL TO FIRE LOCATIONS FOR DETECTOR TESTS

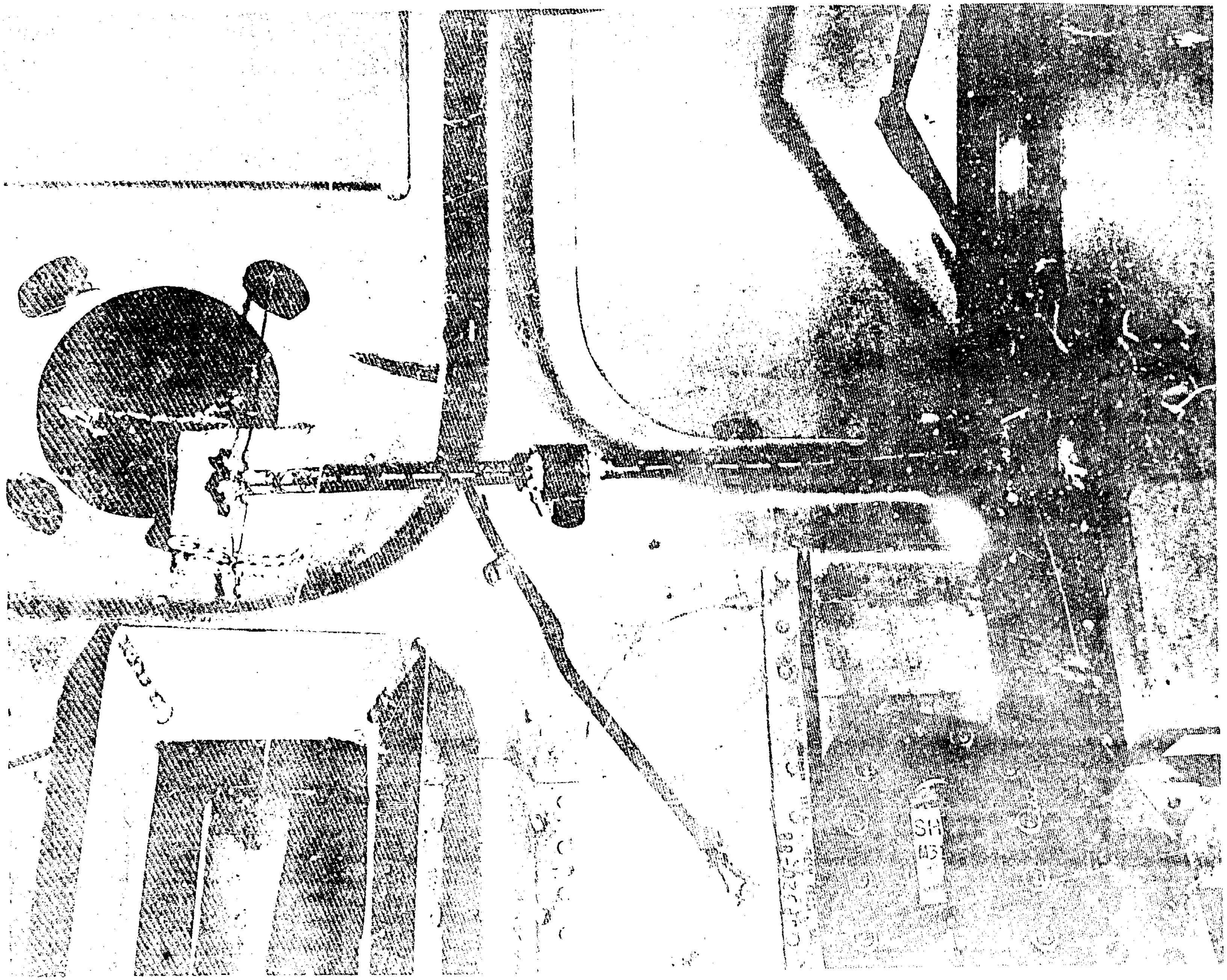


FIGURE 4 - FIBERCELL OVERHEAT DETECTOR AT THE 5:30 O'CLOCK POSITION

1.5 Hazardous Vapor Detector Tests

The Panametrics Hazardous Vapor Detector uses the principle of catalytic oxidation to detect jet fuel vapors. In the jet fuel detector the fuel vapor is oxidized by ambient air. The oxidation reaction occurs at the surface of a thin layer of "platinum black" catalyst, which is coated over a thermistor embedded in a heated metal block. The reaction is exothermic and heat is released to the catalyst, resulting in a slight increase in its temperature which is sensed by the thermistor. A change in thermistor temperature results in a change in its electrical resistance. The change in resistance is sensed by a sensitive Wheatstone bridge circuit.

A hydrocarbon fuel vapor detector unit was installed at two locations in the C-140 engine/nacelle for limited tests under simulated flight conditions. The unit was placed initially at nacelle Station 111, 5:30 o'clock, in the aft portion of Zone II. The second location for the unit was approximately 12 o'clock near the cooling air exit louvers in the aft portion of Zone II. Both locations are shown in Figure 2. The fuel spray nozzle used to simulate a fuel leak was located at nacelle Station 77, 6 o'clock position (Location 9), as shown in Figure 3. The Panametrics engineering personnel monitored all tests and recorded the following parameters during each test; tunnel Mach number, engine power setting, temperature in the area of the detector unit, Zone II static pressure, fuel leak rate, time fuel leak was initiated, time vapor was detected, and JP-4 vapor detector meter reading.

Results of these tests were provided in Technical Report AFAPL-TR-67-123 Supplement I of June 1968, entitled "Development of A Hazardous Vapor Detection System for Advanced Aircraft."

1.6 Ultra-Violet Flame Detector Tests

The ultra-violet flame detection system was developed by McGraw-Edison Company, Thomas A. Edison Industries, under an Air Force Contract No. AF 33 (615)-3531. This development is discussed in Technical Report AFAPL-TR-69-107 of February 1970, entitled "An Ultra-Violet Sensing Flame Detector For Use On High Performance Military Aircraft." The system consisted of three detectors with test lamps connected to a junction connector by metal-clad cables. The junction connector was connected to a control by a single metal-clad cable. Test circuits, a fire warning circuit, and power inputs were connected to the control. Two detector system installations were selected. The detectors were initially located at the rear of the compartment (nacelle Station 117) viewing forward between the engine and the nacelle from positions at 12, 4:30, and 7:30 o'clock (Figure 2). Figure 5 shows the UV sensor installation on the firewall at 7:30 o'clock. The junction connector was mounted to the airframe portion of the nacelle as shown in Figure 6. The control was mounted outside the test section at the top of the tunnel. The metal-clad cables were safety wired to the engine and nacelle to facilitate installation. Two of the detectors were relocated on the forward bulkhead of the compressor and accessory compartment (nacelle Station 66) for the last two fire test runs. These detectors were positioned at 1 and 4:30 o'clock on the forward bulkhead so that they were viewing aft between the engine and the nacelle (Figure 2). The third leg or junction connector was disconnected and remained uncovered for these test runs.

The objectives of this evaluation were to determine the following items under actual powerplant fire conditions;

a. The system sensitivity, coverage, and optical limitations.

b. Minimum number of sensors required and the optimum locations of the sensors.

c. The amount of overlapping coverage provided by a three-sensor system.

d. Sensitivity of sensors to the reflective radiation produced in a nacelle during a fire.

e. The effect of engine oil covering the sensors on the system's performance.

The ultra-violet flame detector system produced false alarms during the initial checkout of the system. The operating voltage range of the control is 108 to 118 volts, 400 Hz. When a 400-Hz-motor-generator power supply output voltage was set between 105 and 110 volts the control would

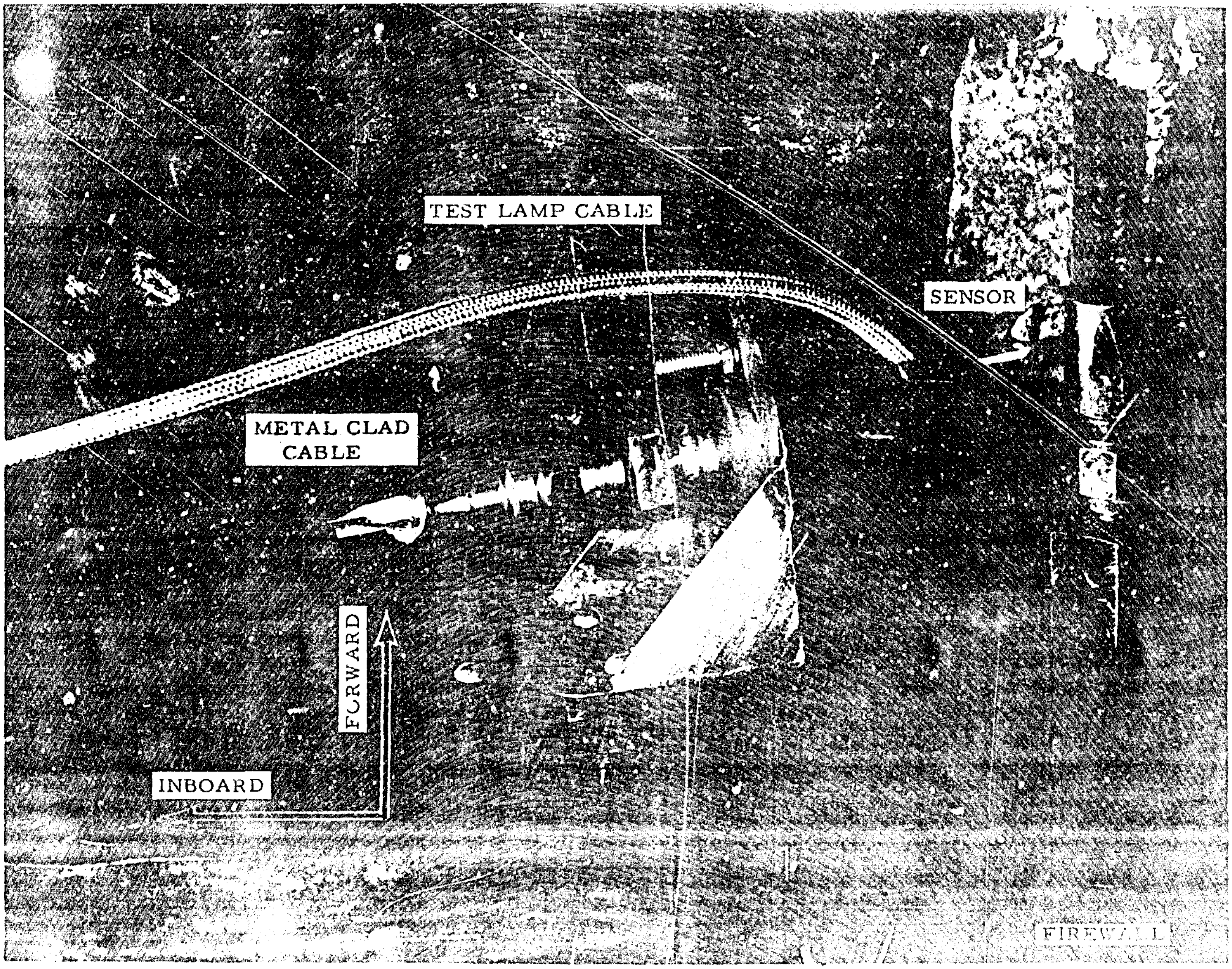


FIGURE 5 - UV SENSOR NO. 3 INSTALLATION

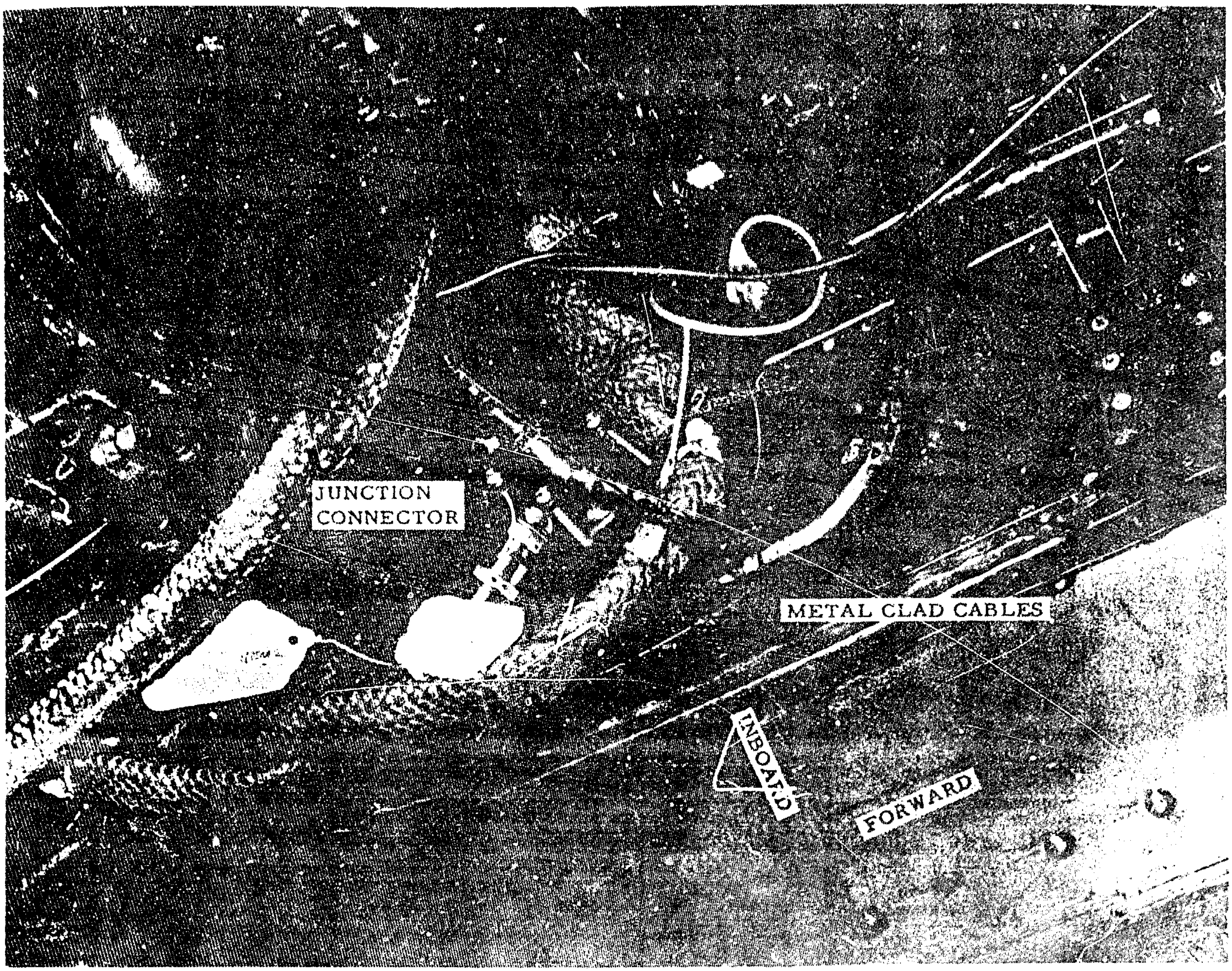


FIGURE 6 - UV JUNCTION CONNECTOR INSTALLATION

actuate the alarm circuit whenever a slight fluctuation of the voltage occurred. The alarm light would remain on until the power to the control was switched off. At voltages between 110 and 120 volts, the control produced an alarm signal when the power was switched on and the alarm signal continued until the power was switched off. It was also found that in the lower voltage range the alarm signal would not clear after releasing the test lamp switch or exposing a sensor to a test fire.

An oscilloscope study of the 400-Hz power supply showed that a high frequency transient voltage was being carried on the 400-Hz signal when the voltage regulator was in use. The transient voltages were identified as having between 78 and 85 volts peak-to-peak and a frequency estimated to be greater than 10,000 Hz. The transient voltages were eliminated by manually controlling the voltage with the regulator out of the circuit. The ultra-violet flame detection system no longer false alarmed and properly cleared when functionally checked using the manually controlled 400-Hz power. The original control was replaced with a second control and operated on the regulated 400-Hz power with the transient voltage. It was found that the second control malfunctioned in essentially the same manner as the original control. All remaining tests were conducted with the original control and with the 400-Hz voltage manually controlled.

Fourteen fire test runs were conducted with the detector system installed in the C-140 engine and nacelle installation. The test conditions and results are summarized in Table I. The fuel release locations are shown in Figure 3.

The metal-clad cable to detector no. 2 at the 4:30 o'clock position developed a 500-ohm short between the central conductor and the case following the first fire test run. When the short occurred, the system failed to produce a fire warning when each of the three test switches were closed and when small test fires were located in view of each detector. During the first test run the system was exposed to approximately 5 minutes of engine-facility operating time and had alarmed during an 11-second fire. The system cleared as the fire was extinguished with carbon dioxide.

On several occasions during the test period the system produced an intermittent false alarm signal. The signal was found to be a function of the tunnel power setting and not of

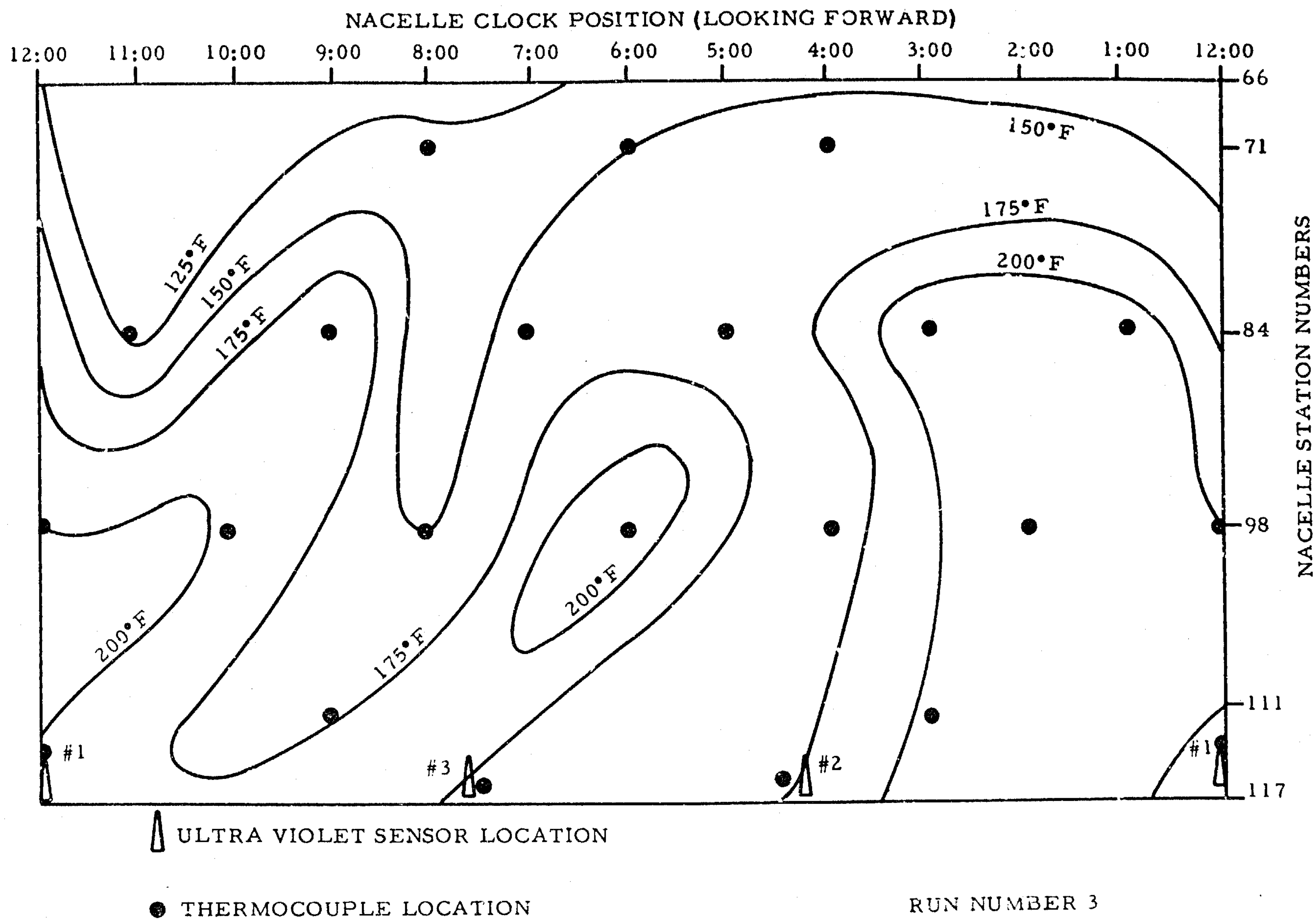
TABLE I.--SUMMARY OF UV DETECTOR TEST RESULTS

Run No.	Date	Fuel Release Location	Fuel Release Rate (gal/min)	UV Sensors Operative	Fire Duration (sec)	Detection Time (sec)	Remarks
1	6-30	5A	0.10	1, 2 & 3	11	0.68	Cable to UV Sensor No. 2 shorted after run.
2	7-2	5A	0.10	3	18.2	No Detection	
3	7-2	5A	0.10	1 & 3	11.3	No Detection	
4	7-2	8A	0.10	1 & 3	9.6	4.65	
5	7-2	8A	0.10	1	10.6	No Detection	
6	7-2	10	0.10	1 & 3	15.0	No Detection	Access door burned open.
7	7-2	10A	0.10	1 & 3	5.6	4.02	
8	7-7	10A	0.10	3	10	No Detection	
9	7-7	10A	0.10	1 & 3	10.5	No Detection	UV sensors painted with engine oil.
10	7-7	10A	0.10	1 & 3	11	No Detection	UV sensors painted with engine oil.
11	7-7	5A	0.10	1 & 3	12.3	No Detection	Cowl door sprayed with aluminum paint.
12	7-7	8A	0.25	1	11.0	No Detection	
13	7-25	6A	0.10	4 & 5	5.3	0.10	
14	7-25	6A	0.10	4	8.9	No Detection	

signals were not being produced by the detectors, the metal-clad cable from the junction to the control was disconnected at the control, eliminating the detectors from the circuit. The tunnel was then operated at the power setting which had produced the previous intermittent false alarm signals and a fire-warning signal was again obtained.

The typical ambient temperatures in the compressor and accessory compartment prior to releasing the fuel are shown in Figure 7 for the flight conditions simulated during the fire tests. An estimate of the isothermal pattern throughout the compartment as determined from the thermocouple readings is also shown in this figure. The temperature rises and changes in the isothermal pattern in the compressor and accessory compartment as a result of fire for three tests are shown in Figures 8, 9, and 10. These temperatures represent the difference between the stabilized temperatures during a fire (5 seconds after ignition) and the normal ambient temperatures. Also the isothermal pattern was indicative of the flame path within the nacelle compartment.

Test results indicate that only one detector provided an alarm to fires at fuel release Locations 5A, 8A, and 10A. The fire at Location 5A (Run No. 1) was detected by Sensor No. 2 located at 4:30 o'clock on the firewall. This fire was not detected when Sensor No. 2 was disconnected (Run Nos. 2, 3, and 11). The fire at Location 8A was detected by Sensor No. 3 located on the firwall at the 7:30 o'clock position (Run No. 4). When Sensor No. 3 was disconnected, Sensor No. 1 at the 12 o'clock position did not detect fires at Location 8A (Run Nos. 5 and 12). The isothermal patterns of Run Nos. 5 and 12, (Figures 8 and 9) indicated that Sensor No. 2, had it been operative, would not have detected the fire at Location 8A. The fire at location 10A was detected by Sensor No. 1 (Run No. 7). In Run No. 8, Sensor No. 3 did not detect the fire initiated at Location 10A. Again, the isothermal pattern of the fire at Location 10A (Figure 10) indicated that Sensor No. 2 would not have detected this fire had it been operating. A single fire at Location 10 (Run No. 6) was not detected by Sensors Nos. 1 and 3. This was a smaller fire than the Location 10A fire and was concentrated more in the top forward area of the compartment. The fire at Location 10 was not repeated since it had damaging effects on



RUN NUMBER 3

FIGURE 7 - STABILIZED AMBIENT TEMPERATURE IN COMPRESSOR COMPARTMENT

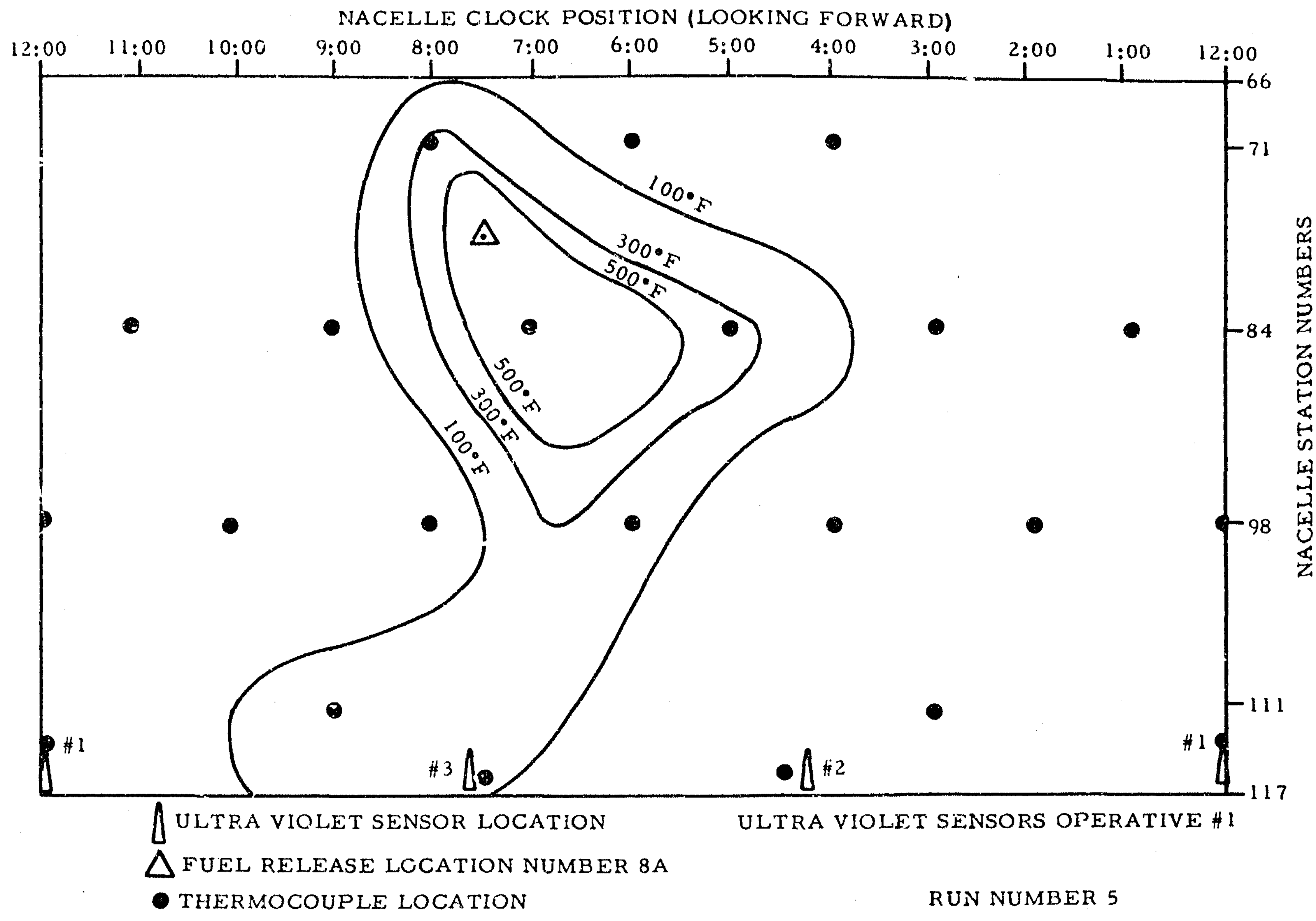


FIGURE 8 - STABILIZED AIR TEMPERATURE RISE IN COMPRESSOR COMPARTMENT

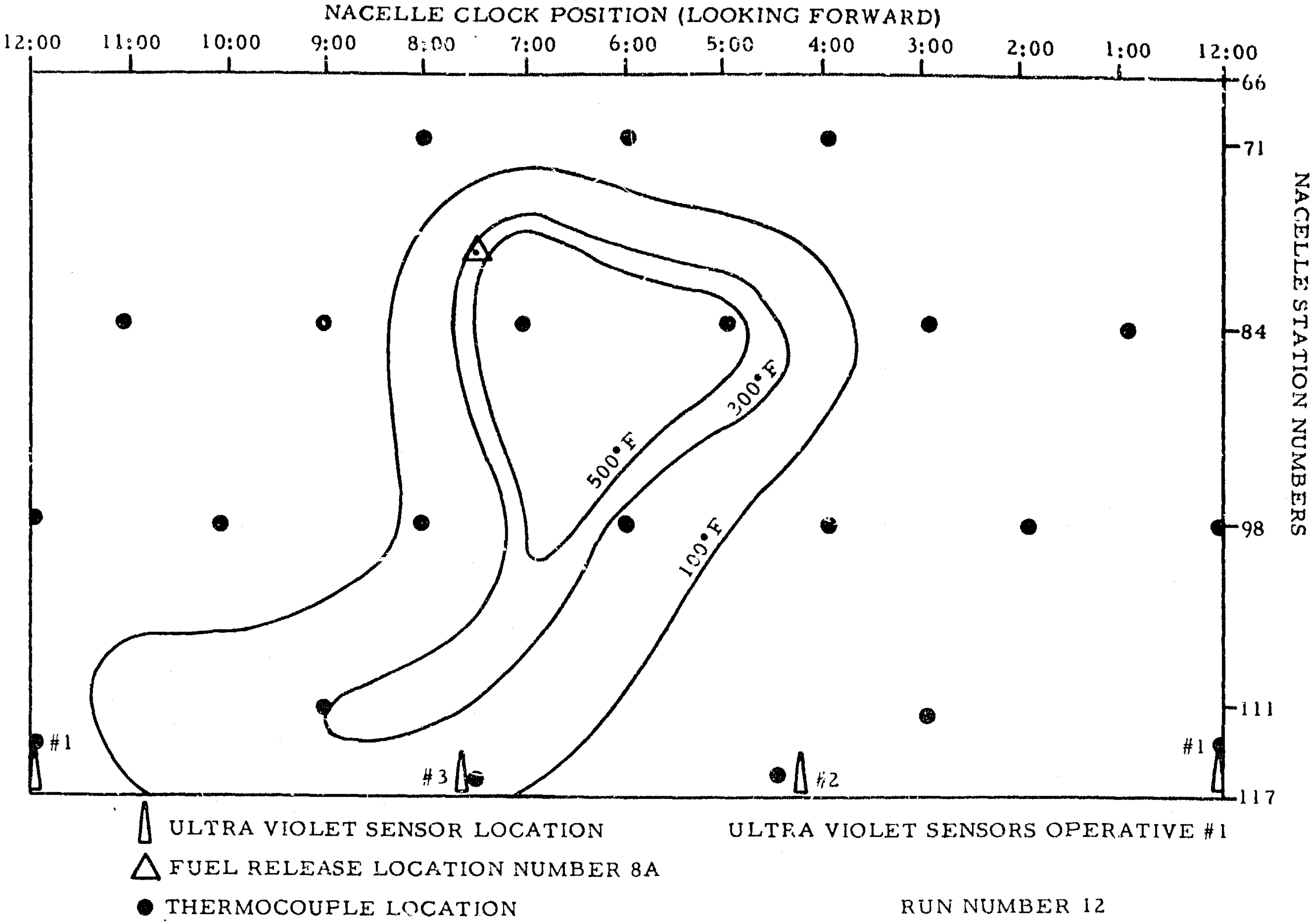
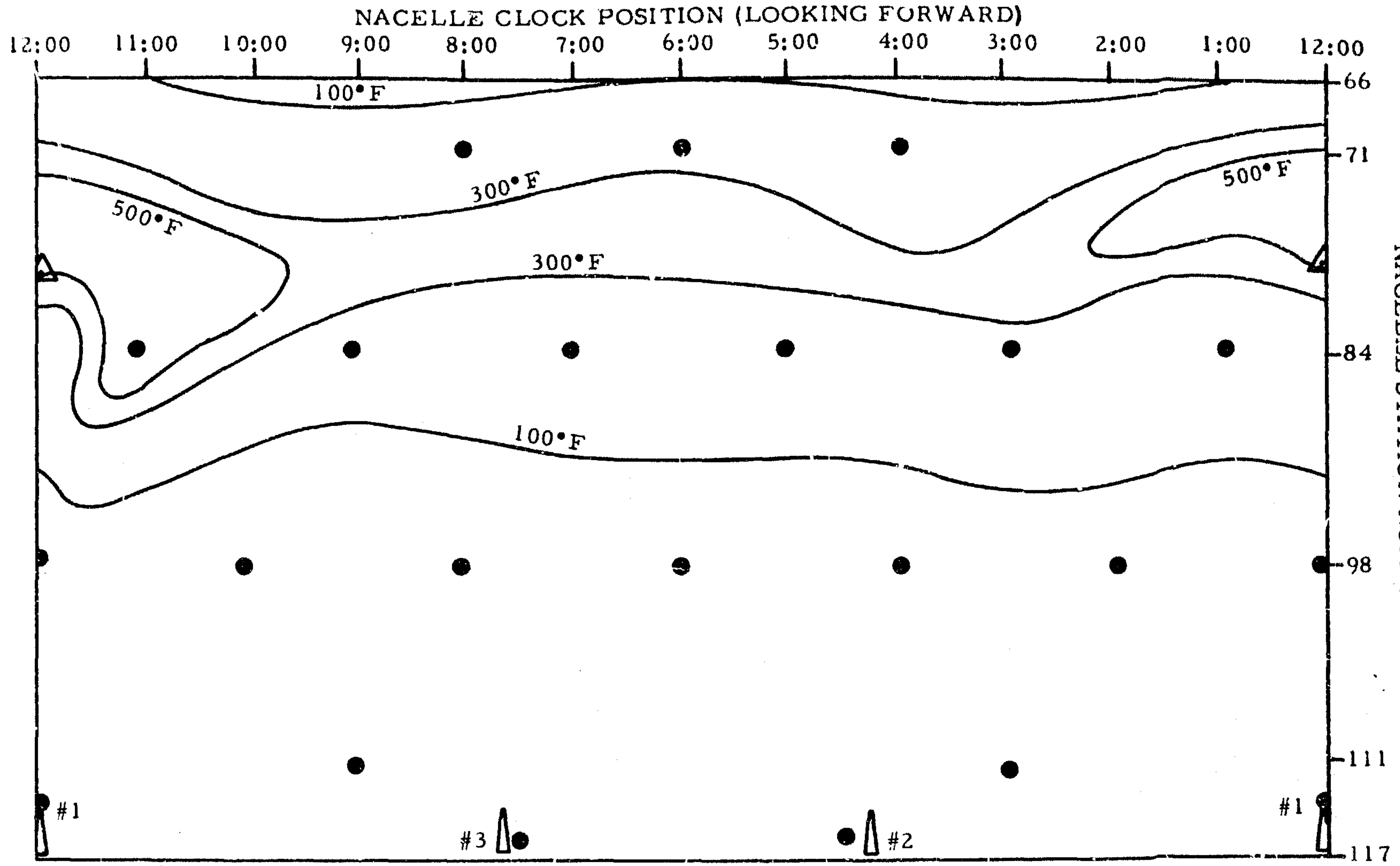


FIGURE 9 - STABILIZED AIR TEMPERATURE RISE IN COMPRESSOR COMPARTMENT



ULTRA VIOLET SENSOR LOCATION

ULTRA VIOLET SENSORS OPERATIVE #1 & 3

FUEL RELEASE LOCATION NUMBER 10A

THERMOCOUPLE LOCATION

RUN NUMBER 8

FIGURE 10 - STABILIZED AIR TEMPERATURE RISE IN COMPRESSOR COMPARTMENT

a nacelle access panel near the point of fuel release. During Run No. 6, fire exited the nacelle at the aft edge of the access panel which was partially opened when the aluminum receptacles for camlock type fasteners holding the panel were damaged by the fire.

Run No. 7, in which the fire was detected by Sensor No. 1 in 4 seconds, was repeated twice with the sensors painted with Mil-L-7808D lubricating oil taken from the JT-12 engine. During these tests (Run Nos. 9 and 10) 11-second fires were not detected by the oil-covered sensors.

The fires at Location 5A were repeated with the bottom cowl door between 4 and 7:30 o'clock positions painted with aluminum paint. The test engine was covered with carbon and oil residue as a result of being exposed to many fires in a previous powerplant fire protection investigation. The aluminum paint improved the reflective characteristics of the door. The intent of the test was to determine if sufficient ultra-violet radiation from a fire originating at a 4:30 o'clock position could be reflected by the door to alarm the sensor located at 7:30 o'clock on the firewall. The results of Run No. 11 indicated that there was not sufficient radiation reflection to cause the system to alarm during the 12-second fire.

Test Run Nos. 4 and 5 were repeated to determine whether increasing the fuel to fire released at 7:30 o'clock (Location 8A) from 0.10 to 0.25 gallon-per-minute would increase the size of the fire to enable Sensor No. 1 above the engine to detect the fire. An 11-second test fire (Run No. 12) at the higher fuel flow was not detected by Sensor No. 1. A comparison of the compartmental temperature rise (Figures 8 and 9) as a result of the fires at the two flow rates indicated that increasing the fuel flow did not substantially affect the size of the fire. This was considered to be due to the limited airflow into the nacelle.

The fire at Location 6A was detected by Sensor No. 5 at 4:30 o'clock on the forward bulkhead (Run No 13). In Run No. 14, Sensor No. 4 at the 1 o'clock position on the forward bulkhead did not detect the fire at this location.

The system did not malfunction as a result of one leg of the junction connector being open during these fire tests. To determine the effect of foreign matter on the system, residue was removed from the case of the JT-12 engine and liberally brushed into the junction connector open leg. The system produced fire warning signals and did not false alarm when functionally checked and when small test fires were located in view of each detector.

Test results with the ultra-violet flame detection system installed in a C-140 aircraft engine and nacelle installation indicated the following:

a. A minimum of three sensors was necessary for prompt detection and full coverage of the compressor and accessory section of the nacelle.

b. The system alarm cleared immediately after the fire was extinguished.

c. The detector required a direct line of sight with the fire and did not alarm to reflective radiation produced by a fire in the nacelle.

d. A film of engine oil on the sensors substanially reduced the sensitivity of the system to fire.

e. Malfunctions of the system experienced during the tests indicated a need for more development and experimentation to assure a high degree of reliablility. Following further development and modification to the system, the test program should be repeated.

SECTION III

FIRE EXTINGUISHMENT

1. AIRCRAFT POWERPLANT FIRE EXTINGUISHING SYSTEMS

1.1 General

Evaluation tests on a Walter Kidde pyrotechnic generated gas discharge fire extinguishing agent container and exploratory tests with an E. W. Bliss Company high expansion foam extinguishing system were conducted. The testing of these extinguishing systems was directed by Walter Kidde and E. W. Bliss Company engineering personnel. NAFEC provided the facility and the technical assistance in preparing the test environment and operating the test facility during the test runs.

1.2 Test Facility

A simulated aircraft powerplant nacelle in the Equipment Safety Test Laboratory was utilized for extinguishing system tests. This nacelle was 50 inches in diameter and 8 feet long. A simulated engine inside the nacelle was 36 inches in diameter and 8 feet long. Five 1-inch angle ribs were used inside the nacelle to provide the desired degree of roughness. Airflow was created by drawing air through this nacelle with a 100-horsepower electric-driven fan. The airflow was regulated to provide 3 pounds per second by enclosing the forward end with a 1/4-inch-thick acrylic plastic sheet in which 89 1-1/8-inch-diameter holes were cut. The plastic sheet was located in a bellmouth entrance ahead of the simulated nacelle. The test facility sufficed in providing conditions of fire which required 2 pounds of bromotrifluoromethane (CB_rF_3) agent to effect extinguishment. Later in the test series there was a need to increase the severity of the fire so that approximately 5 pounds of extinguishing agent were required. This required a test facility modification which amounted to rearranging the electrically-driven fan to force the air through the simulated nacelle. This test facility is shown as Figure 11.

The fuel-to-fire nozzle was located on the port horizontal center line and 35 inches aft of the forward edge of the nacelle. This nozzle directed a 2.2 gallon-per-minute stream of JP-4 fuel downward at a 45° angle.

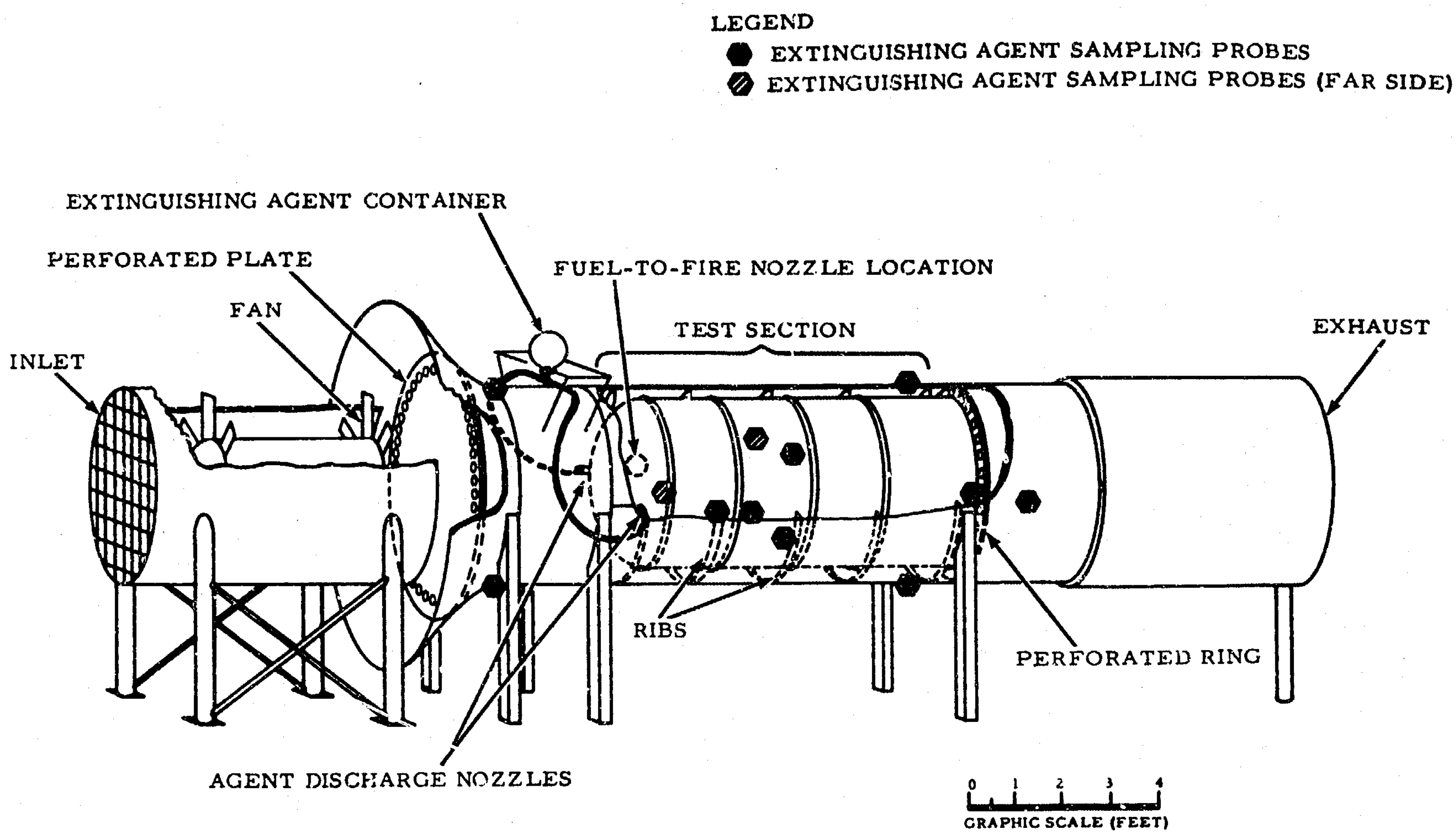


FIGURE 11 - SIMULATED ENGINE FACILITY

1.3 Tests on the Pyrotechnic-Pressurized Extinguishing Agent Container

The distribution system through which agent was discharged consisted of an AN "T" fitting at the agent container bonnet and two 1/2-inch copper lines each 7 feet long which terminated as open-end tubing nozzles. The nozzles were located on each side and 6 inches aft of the forward edge of the nacelle. One nozzle was directed up and the other down to provide maximum distribution of extinguishing agent around the inside periphery of the nacelle. Also, the agent was discharged at right angle to the airflow in the nacelle. A third branch of the agent distribution system which acted as a proportioner was a 19/64-inch hole drilled in the "T" at right angles to the three normal openings. Through this hole agent was discharged external of the nacelle. Later in the test program, this third branch of the agent distribution system was eliminated. This particular system was used with both the small experimental pyrotechnic-generated gas discharge extinguisher and a conventional high-rate-discharge (HRD) system which was used as a basis for evaluating the former. Later in the program when the larger capacity pyrotechnic container and conventional container were used, the agent distribution system was changed to incorporate a 3/4-inch-diameter tubing system. The conventional system's nitrogen pressurized container was changed from a 65-cubic-inch spherical container to a 224-cubic-inch spherical container.

The general test procedure included; (1) preheating the simulated nacelle wall in the vicinity of the fire by short duration fires above 300°F, (2) then starting and sustaining the test fire for 20 seconds at which time the extinguishing agent was discharged, and (3) shutting off the fuel-to-fire after results of discharging the extinguishing agent were observed.

For the small capacity extinguishing agent container tests, the fire intensity was regulated so that 1 1/2 pounds of $CBrF_3$ discharged from the conventional nitrogen pressurized container was just on the borderline of effective extinguishment. Generally, 1 3/4 pounds extinguished the test fire and 1 1/4 pounds did not.

There were 114 fire extinguishing tests conducted using the small capacity conventional extinguishing agent container. The agent container was maintained at room temperature (approximately 70°F). Eighty-five fire extinguishing tests were conducted using the small experimental pyrotechnic gas-generated extinguishing agent container. These tests included operation of the pyrotechnic extinguisher under container environmental temperatures of -65°, 250°, 400°, and 500°F. Results of this work were provided in Technical Report AFAPL-TR-68-47 of May 1968, entitled "Investigation of Pyrotechnic Generated Gas Discharge Fire Extinguishing System."

Fire extinguishing tests were conducted using the larger prototype pyrotechnic discharge extinguisher container. These tests consisted of operation of the pyrotechnic extinguisher under container environmental temperatures of ambient (approximately 70°F), -65° and 500°F. The 3/4-inch-diameter distribution system was used for these tests and identical fire conditions in the simulated nacelle test facility were maintained for each test. Comparison tests were conducted with the conventional nitrogen pressurized container utilizing the same extinguishing agent distribution system and identical fire conditions.

Additional tests were conducted to determine the suitability of utilizing the FAA Extinguishing Agent Concentration Recorder Equipment as a means of evaluating a pyrotechnic discharge extinguisher system. The equipment consisted of a recording oscillograph, a vacuum pump, a control unit, three gas analyzer units, and 12 agent sampling probes. FAA's Technical Development Report No. 403, entitled "Aircraft Installation and Operation of an Extinguishing Agent Concentration Recorder," dated September 1959, provided a description and basic installation and operation procedures for the equipment. The 12 gas sampling probe locations in the simulated nacelle test facility are shown in Figure 11. For the pyrotechnic discharge system tests, suitable filters were placed in the sampling lines to filter possible residue from the pyrotechnic discharge. Two extinguishing agents, Halon 2402 ($CBrF_2$-$CBrF_2$) and Halon 1301 ($CBrF_3$) were used during these tests. The filters and sampling tubes were heated for those runs in which Halon 2402 was discharged since this agent is in a liquid state, while Halon 1301 is in a gaseous state under ambient conditions. A total of six tests was conducted. Three tests were conducted with extinguishing agent Halon 1301 discharged from the standard container to reassure repeatability. One test was conducted with Halon 1301 discharged from the pyrotechnic container to determine if a significant deviation of readings would result from the different method of discharge. Two tests were conducted with extinguishing agent Halon 2402 discharged from the pyrotechnic to determine if suitable and significant gas sampling measurements were possible using the gas analyzer method of obtaining agent concentration. A review of the preliminary data indicated that the gas analyzer as used in these tests provided equally good results in taking measurements for each of the three extinguishing arrangements used in this series of tests.

The results of these tests as well as the evaluation tests on the large prototype pyrotechnic discharge extinguisher were reported in detail by the Walter Kidde and Company in AFAPL-TR-69-65, "Development of Full Scale Pyrotechnic Generated Gas Discharge Fire Extinguishing System," dated April 1969.

1.4 High Expansion Foam Fire Extinguishing System Tests

Limited exploratory tests were conducted with a high expansion foam fire extinguishing system, manufactured by the E. W. Bliss Company, in the simulated aircraft powerplant nacelle facility to determine the feasibility of utilizing such a system for aircraft powerplant fire protection application. The principal parts of the system consisted of ducting from a foam generator to the nacelle, the foam generator, and a supply of foam producing solution. The generator consisted of a water reaction motor, an axial fan on a common hollow shaft, a screen, and a protective housing. The fan was driven by the discharge of foam solution under pressure through a series of reaction nozzles. When the solution passed through the motor, it was discharged onto the screen. The high expansion foam was produced when air passed through the holes in the screen while it was wet with the solution. The foam concentrate was a synthetic material which was protein reinforced. A method of adding $CBrF_3$ extinguishing agent to the air which passes through the screen was adapted to the system for some tests. The system could produce foam from the solution in an expansion ratio range of 300-700 to 1 (1 cubic foot of foam solution would produce 300-700 cubic feet of foam).

To adapt the foam generator to the simulated nacelle, a 23-square-inch hole was cut in the top forward portion of the nacelle, and a 90° duct extending from this hole was welded to the nacelle. The foam generator was attached to this duct. This arrangement is shown in Figure 12.

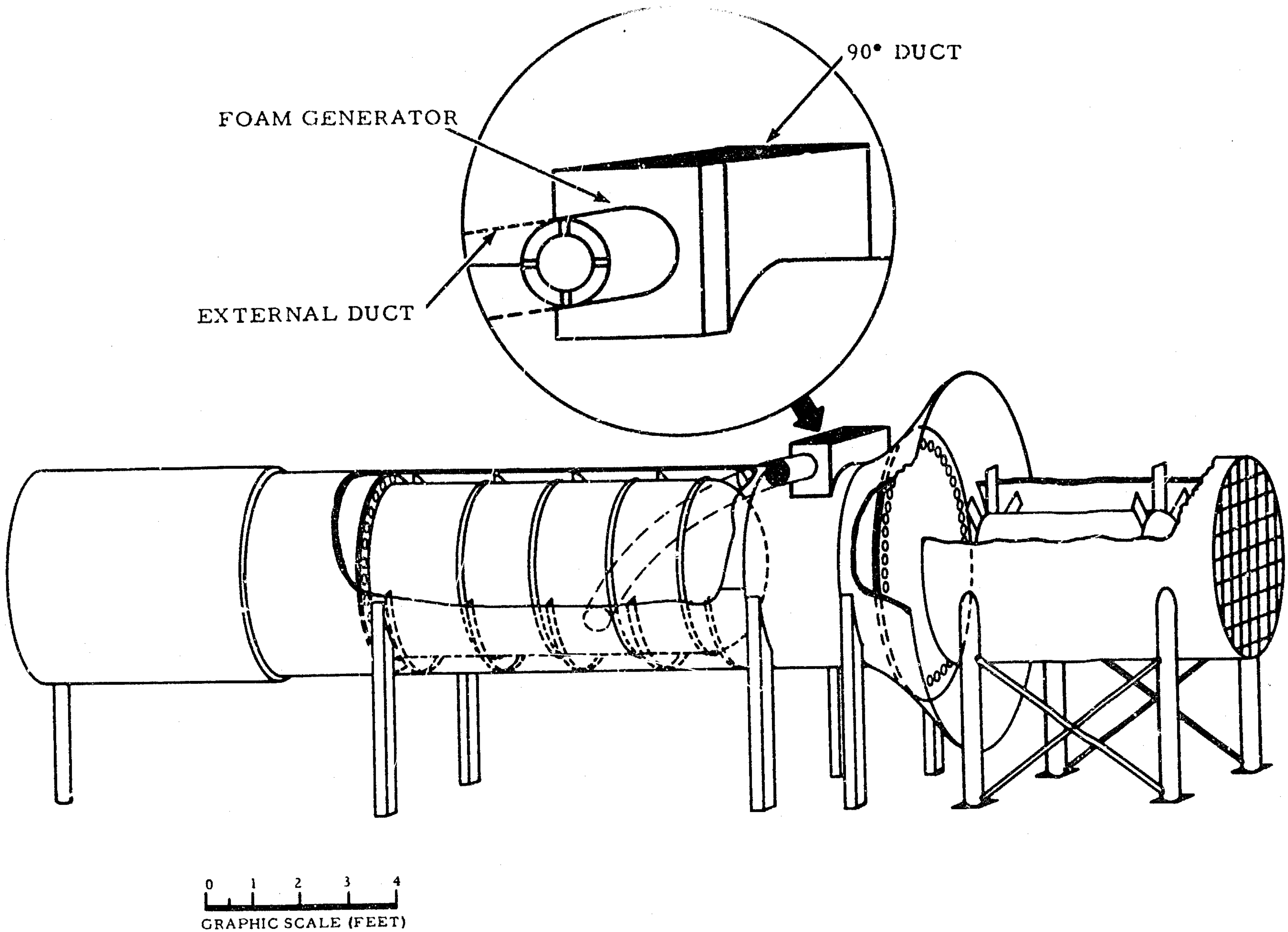


FIGURE 12 - HIGH-EXPANSION FOAM INSTALLATION

The test conditions were those used for the standard fire which were determined for this test bed in the previous extinguishing system program. Conditions included: (1) Airflow rate through the test bed of 3 pounds per second, (2) fuel to fire flow rate of 2.3 gallons of JP-4 per minute, (3) preheating the test-bed wall in the vicinity of the test fire to 300°F by the test fire and (4) fire duration was 20 seconds prior to discharging extinguishant. These conditions required 2 pounds of $CBrF_3$ pressurized with nitrogen to 600 psi at 70°F and discharged through the 1/2-inch-diameter tube distribution system to provide consistant extinguishment.

A total of 11 tests was conducted in which the foam generator was used. Nine of these tests were fire tests in which the high expansion foam combined with $CBrF_3$ was used as the fire suppressant. In none of these tests did the foam/ $CBrF_3$ combination completely extinguish the fire. However, there were indications that this could be effective if a more efficient distribution method were employed. The foam retention, even after the fire, seemed very good for this particular application.

SECTION IV

FIRE RESISTANCE

1. FIRE RESISTANCE TESTS OF TUBING AND TUBING ASSEMBLIES

1.1 General

Fire resistance tests were conducted on stainless steel tubing as well as various sizes of stainless steel tubing in combination with various connectors including both stainless steel and aluminum nuts, sleeves and unions.

1.2 Test Facilities

The fire test burner used for these tests was a 2-gallon-per-hour kerosene burner. The burner provided a 2000°F flame environment for standard fire resistance tests of flammable fluid lines which are used in designated fire zone compartments of aircraft powerplant installations. A description of the burner and its use is contained in the Federal Aviation Administration's Power Plant Engineering Report No. 3.

1.3 Standard Burner Tests on Stainless Steel Tubing

Fire resistance tests were conducted on three stainless steel tubing specimens which were under either static hydraulic or static air pressure during the test. Figure 13 shows the general test setup.

The first test specimen was a 38-inch length of 1/4-inch O.D.X.020-inch wall stainless steel tubing obtained from a DC-7 aircraft hydraulic system. A 5000-psig pressure gage was placed in the line. The line was filled with Mil Spec 5606 hydraulic fluid and was closed at both ends with high pressure stainless steel valves. The hydraulic fluid was initially pressurized to 60 psi. A 12-inch section of the tubing was then exposed to the 2000°F flame of the kerosene burner. Pressure in the tubing reached 5000 psig in 22 seconds and failure occurred in 23 seconds. The approximate pressure in the tube at the time of failure was 5500 psig. The tubing completely separated at the point of failure (Figure 14). An explosive sound similar to that of firing a 22-caliber rifle was heard at the time of failure. The fluid released at failure did not ignite.

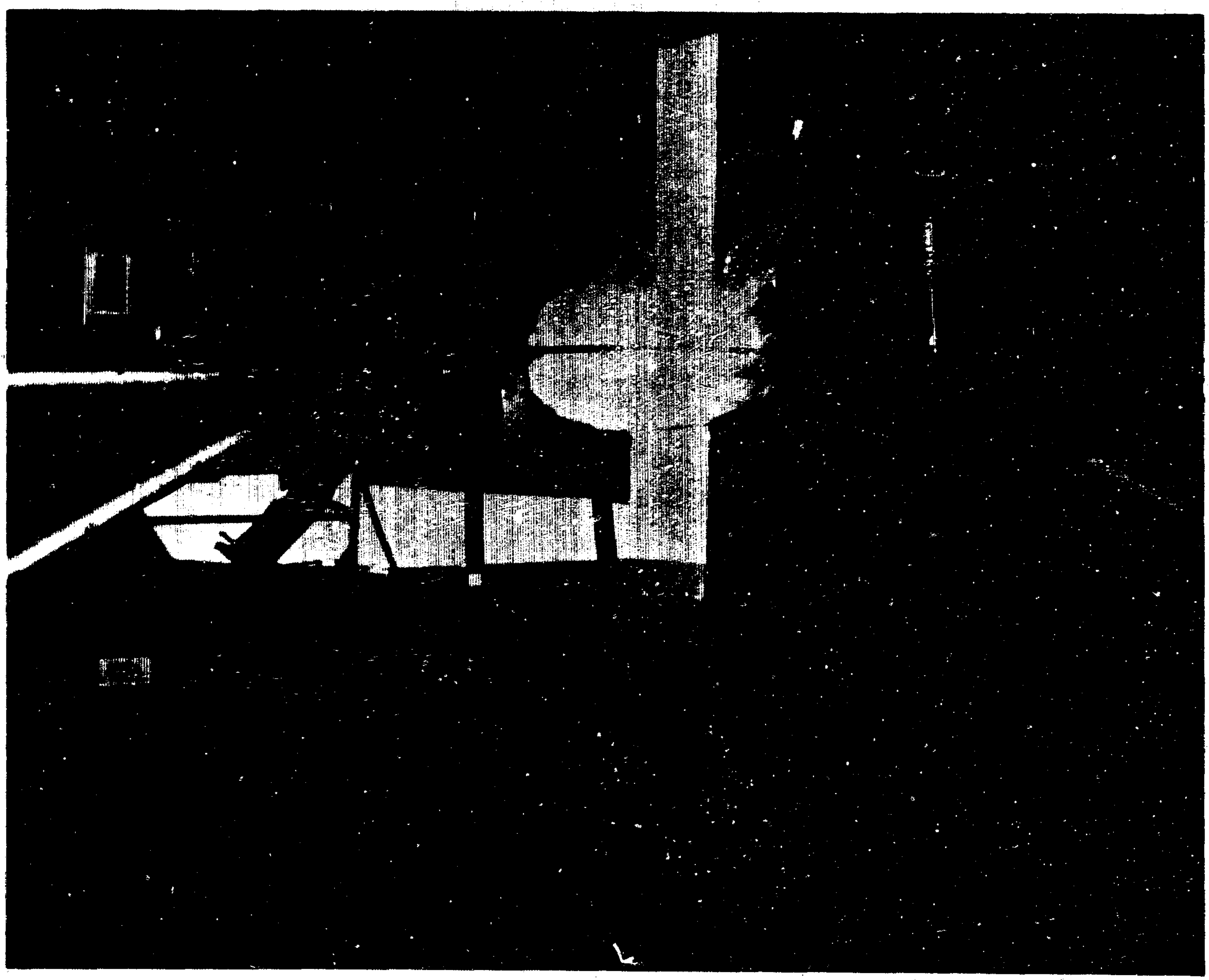


FIGURE 13 - TUBING FIRE-RESISTANCE TEST SETUP

The second test specimen was a 26-inch length of new 1/4-inch O.D.X.028-inch wall, Mil-T-6845B, wall tube T304 seamless, HT#60964, one-eighth hard stainless steel tubing. A 5000-psig pressure gage placed in the line, and the line was closed off at both ends with high pressure stainless steel valves. The line was pressurized to 1800 psig with air. A 12-inch section of the line was exposed to the 2000°F flame of the kerosene burner. Pressure in the tube reached 2100 psig after 10 seconds, 2300 psig after 30 seconds, and 2400 psig after 5 minutes exposure to the flame. Failure occurred after 5 minutes and 44 seconds and the pressure at the time of failure was 2400 psig. An explosive sound louder than that in the previous test was heard. The tubing did not completely separate at failure (See Figure 14).

The third test specimen was a 26-inch length of the same tubing as the second test specimen. The test conditions and test procedure were identical to those used to test the second specimen except that the tubing was pressurized with air to an initial pressure of 3000 psig. Pressure in the tubing reached 3500 psig after 10 seconds and 3600 psig after 45 seconds exposure to the 2000°F flame. Failure occurred after 53 seconds and the pressure at the time of failure was 3600 psig. An explosive sound equal in intensity to that resulting from the failure in the previous test was heard. The tubing did not completely separate at failure (See Figure 14).

Figure 14 shows the failures to tubing specimens which were subjected to the standard burner during these tests.

1.4 Standard Burner Tests of Tubing Assemblies

Fire resistance tests were conducted on various tubing assemblies. The assemblies consisted of stainless steel tubing with aluminum and stainless steel nuts, sleeves and unions, and were tested in various combinations as shown in Figure 15. The tubing assemblies were subjected to the 2000°F flame of the 2-gallon-per-minute kersone burner under conditions in which oil was flowing through the tubing and also in which the oil flow was stopped, except that oil pressure buildup in the tubing was relieved through a valve (V_1 in Figure 16) and a relief valve in the pump. A schematic and photograph of the test setup are shown in Figures 16 and 17. The flow rate of the oil circulated

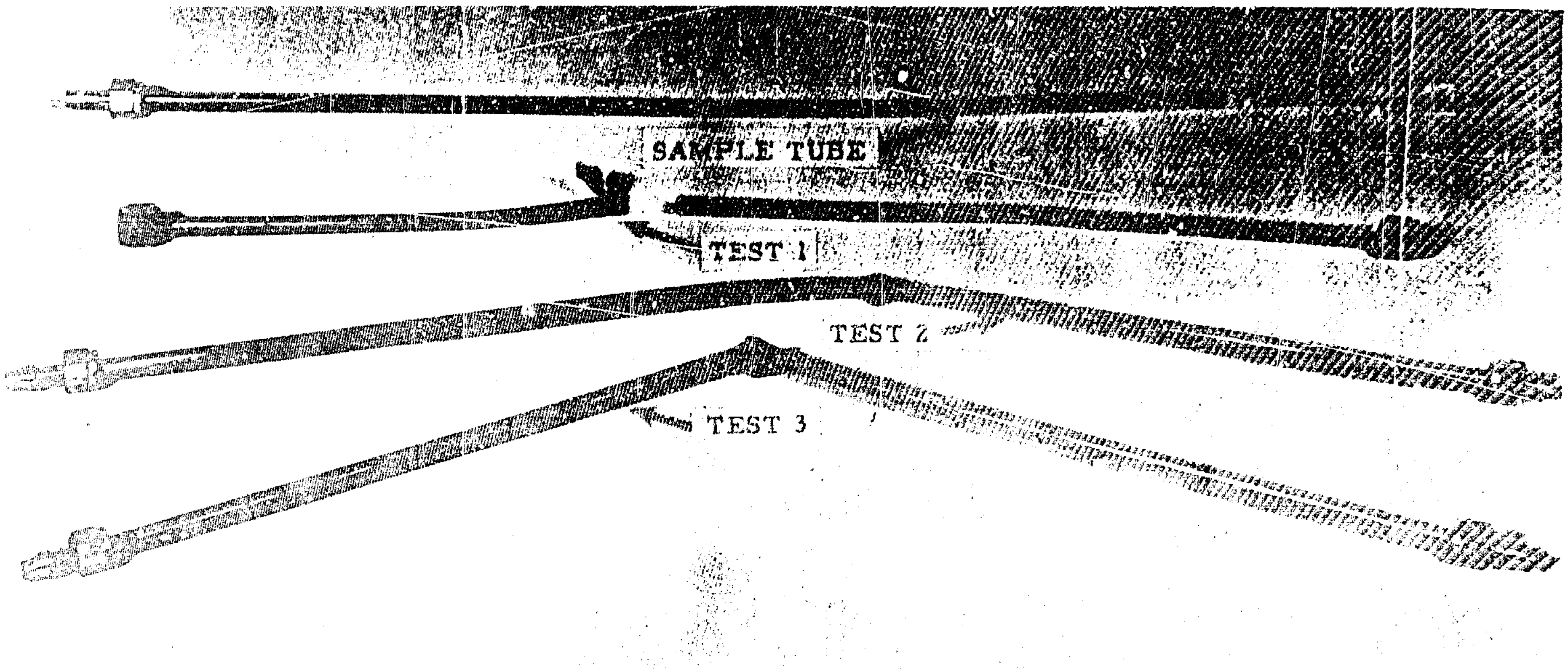
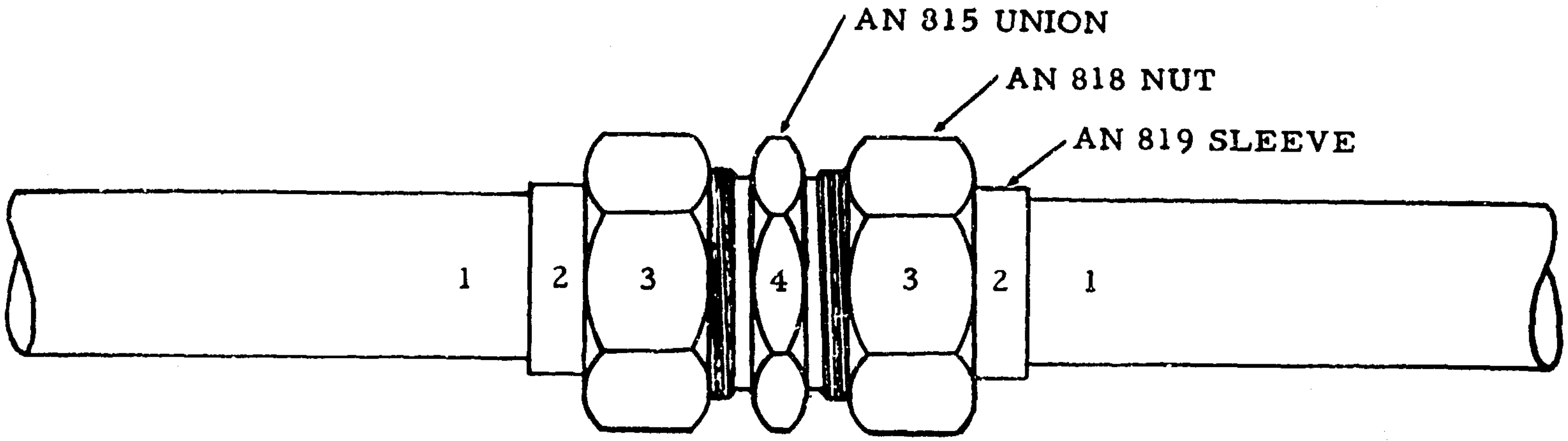


FIGURE 14 - DAMAGE TO STAINLESS STEEL-TUBING SPECIMENS



ASSEMBLY	TUBE (1)	SLEEVE (2)	NUT (3)	UNION (4)
1	C	C	C	C
2	C	D	C	C
3	C	C	D	C
4	C	C	C	D
5	C	D	C	D
6	C	C	D	D

"D" ALUMINUM
"C" CORROSION RESISTANT STEEL

FIGURE 15 - TUBING ASSEMBLY COMBINATIONS

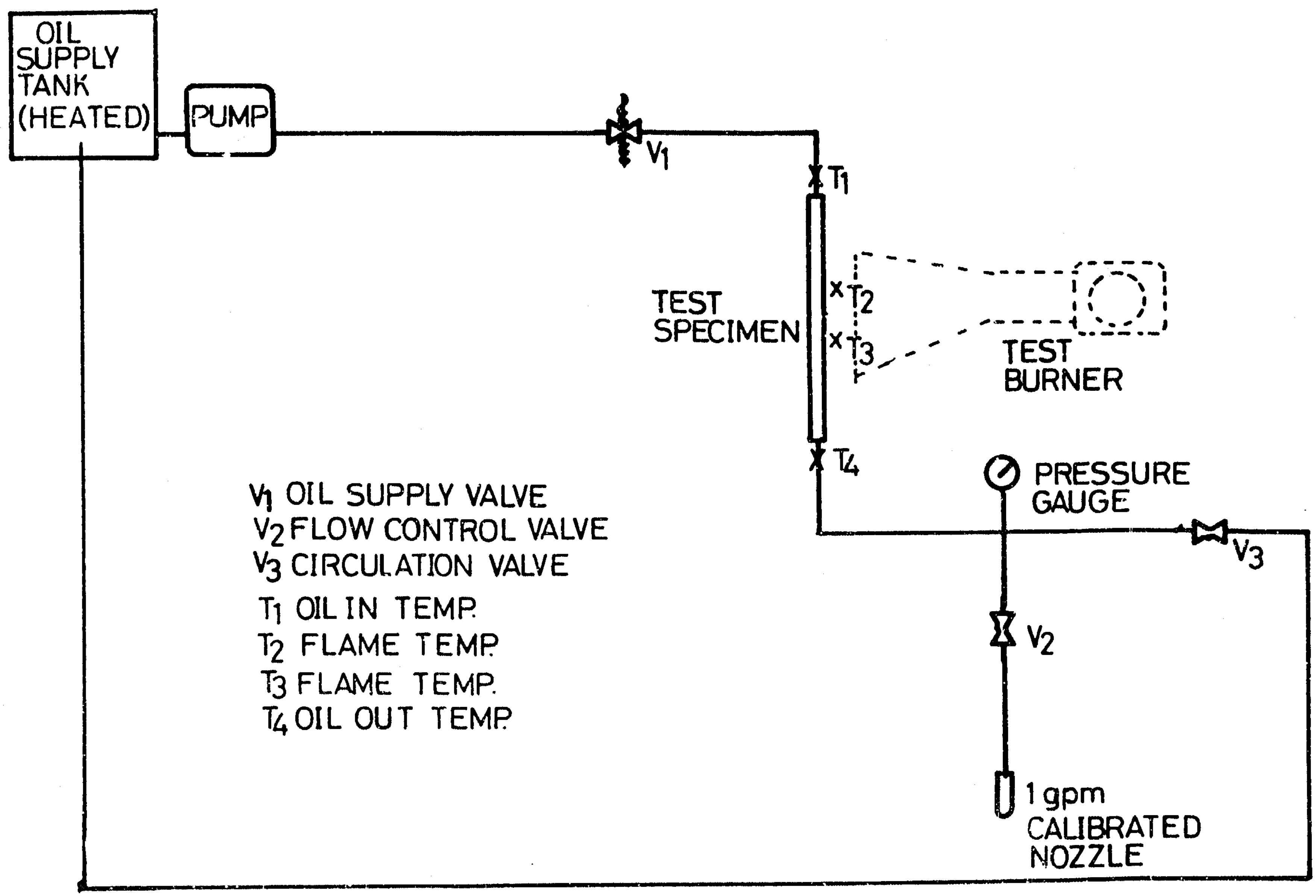


FIGURE 16 - TUBING ASSEMBLY SETUP

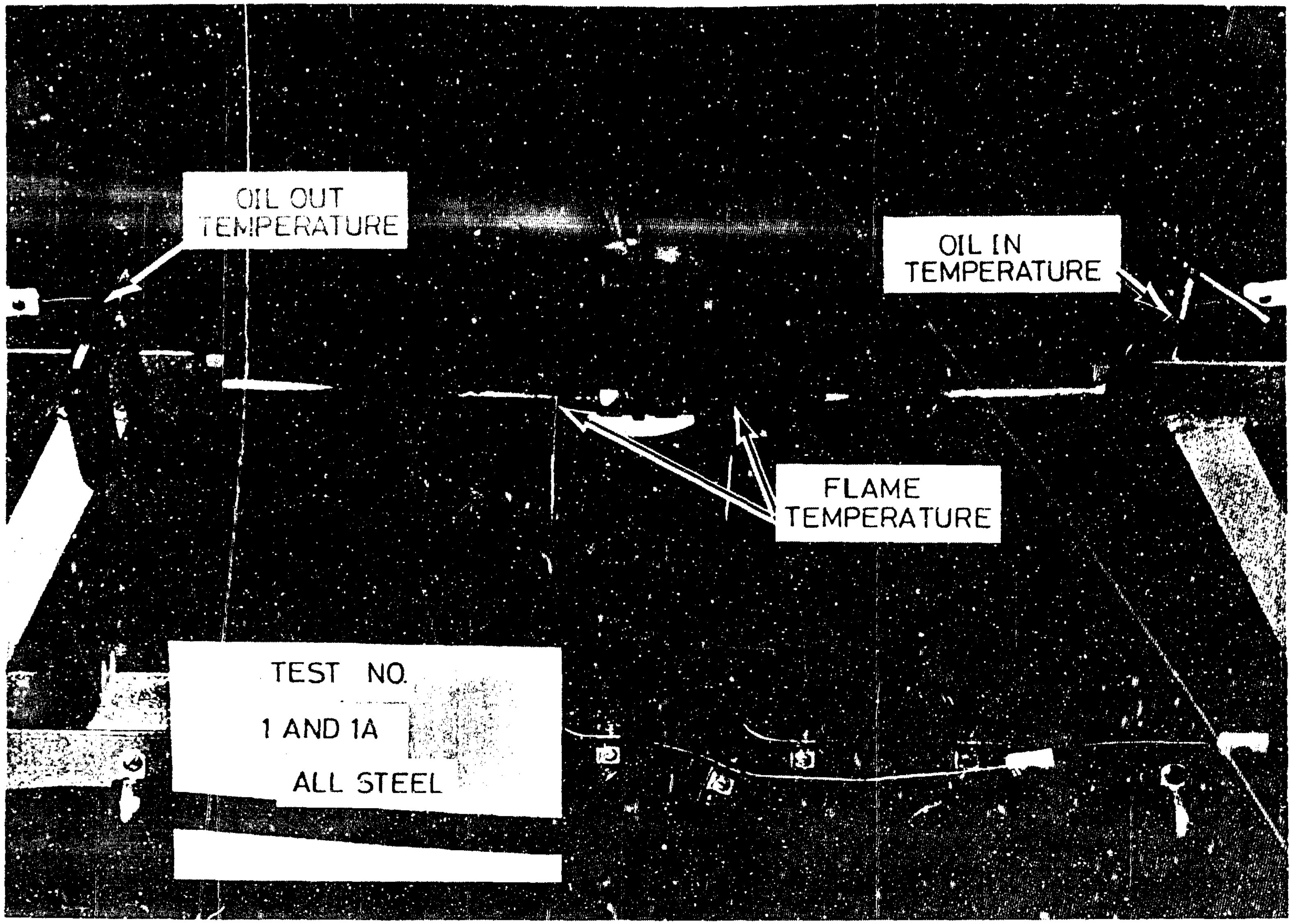


FIGURE 17 - TUBING ASSEMBLY FIRE-RESISTANCE TEST INSTALLATION

through the tubing assemblies was 2 gallons per minute and the temperature of the oil was maintained at 200°F (measured at T_1 and T_4, shown in Figure 16) for those tests in which the circulation of oil was required. The inlet and outlet oil temperatures were measured with immersed thermocouples and recorded simultaneously on a recording potentiometer. Temperature of the flame was measured with two thermocouples located on either side of the coupling assembly as shown in Figure 17. The burner nozzle was positioned approximately 4 inches from the front surface of the test assembly. A natural draft through the fire test tunnel in which tests were conducted provided an airflow across the test assembly, in direction of flame movement of approximately 400 to 600 feet per minute as measured by a hot-wire anemometer during a typical test. There was no attempt to control the airflow over the test article and occasionally a momentary back draft would cause a low average flame temperature. This is noted in Table II. The nuts on the test assemblies were torqued according to size to the following values; size 6 (3/8-inch O.D.)- 300-inch pounds, size 12 (3/4-inch O.D.)- 960-inch pounds, and size 20 (1 1/4-inch O.D.)- 1560-inch pounds.

The general procedure for each test was to install the tubing assembly on a fixture and properly position the fixture in front of the kerosene burner. Circulation of the heated oil was started through the tubing assembly and a return system to the heated oil tank at full flow, approximately 2 gallons per minute. The tubing assembly was pressure checked to assure that there were no leaks. Just prior to conducting a fire test under flow conditions, the return system valve (V_3) was closed and the flow was routed through a valve (V_2) and a 1-gallon-per-minute calibrated nozzle into a barrel. Then the tubing assembly was subjected to the 2000°F $\pm$ 100°F flame for 5 minutes, while the heated oil was flowing, or until a leak in the system was observed. The no-flow test was conducted by closing the downstream valve to the calibration nozzle (V_2), the valve to the return system (V_3), and the solinoid oil supply valve (V_1) shown in Figure 16. The pressure in this closed system generated from the heat of the burner flame was relieved through the solenoid oil supply valve (V_1). The internal pressure during flow conditions was 28 psig and during no-flow conditions was 40 psig. When the flame was removed from the tubing assembly and there was no apparant failure, the assembly was pressure checked at 40 psig. After the assembly

TABLE II.--TEST CONDITIONS AND RESULTS OF FIRE-RESISTANCE TESTS ON TUBING ASSEMBLIES

Test No.	Tube Type	Wall Thickness	Oil Temp In (°F)	Oil Temp Out (°F)	Avg. Flame Temp (°F)	Failure Time (sec)	Remarks
1-6	304	A	200	228	1940	--	No leak during test
1a-6(1)	304	A	725	160	1935	300	Prior to no-flow test nuts were not retorqued.
2-6	304	A	200	205	1925	--	No leaks
2a-6	304	A	385	155	1915	65	--
3-6	304	A	190	220	1920	--	"B" nuts loose after test
3a-6	304	A	170	170	1845	40	--
4-6	304	A	205	215	1920	--	No leaks
4a-6	304	A	480	200	1840	80	Crack in union
5-6	304	A	200	220	1940	--	No leaks, "B" nuts loose
5a-6	304	A	205	205	1880	40	"B" nuts very loose
6-6	304	A	190	208	1975	300	Leak during pressure check
6a-6	304	A	--	--	--	--	No test run
1-12	304	B	208	208	1960	300	Leak during pressure check
1a-12	304	B	630	300	1985	300	Leak during pressure check
2-12	304	B	200	230	1990	300	Leak during pressure check
2a-12	304	B	200	195	1970	175	--
3-12	304	B	190	215	1890	72	"B" nuts loose
3a-12	304	B	--	--	--	--	No test
4-12	304	B	200	215	1995	--	No leaks
4a-12	304	B	665	200	1930	165	Cracked union
5-12	304	B	185	220	1880	--	No leaks
5a-12	304	B	775	150	1925	295	--
6-12	304	B	185	228	1930	210	--
6a-12	304	B	--	--	--	--	No test

TABLE II.--TEST CONDITIONS AND RESULTS OF FIRE-RESISTANCE TESTS ON TUBING ASSEMBLIES (Continued)

Test No.	Tube Type	Wall Thickness	Oil Temp In (°F)	Oil Temp Out (°F)	Avg. Flame Temp (°F)	Failure Time (sec)	Remarks
1-20	304	C	190	210	1940	80	--
1a-20	304	C	--	--	--	--	No test
2-20	304	C	188	210	1910	123	--
2a-20	304	C	--	--	--	--	No test
3-20	304	C	165	205	1825	65	--
3a-20	304	C	--	--	--	--	No test
4-20	304	D	205	240	1990	--	No leaks
4a-20	304	D	655	200	2010	300	Leak developed during pressure check.
5-20	304	D	200	220	2020	300	Leak developed during post test pressure check.
5a-20	304	D	740	200	2015	300	Leak developed during post test pressure check.
6-20	304	D	220	225	2020	--	No leak
6a-20	304	D	800	265	2080	230	"B" nut cracked
2-20 (Repeat)	304	C	190	210	1825	140	--
3-20 (Repeat)	304	C	192	208	1845	110	Flare was polished prior to test
1-20 (Flareless)	304	C	180	200	1760	80	(2)

TABLE II.--TEST CONDITIONS AND RESULTS OF FIRE-RESISTANCE TESTS ON TUBING ASSEMBLIES (Continued)

Test No.	Tube Type	Wall Thickness	Oil Temp In (°F)	Oil Temp Out (°F)	Avg. Flame Temp (°F)	Failure Time (sec)	Remarks
1-20 (Full Flow)	304	C	200	235	2020	100	Oil flow increased to 1.9 gpm.
1-20 (Polished Flare)	304	C	195	210	1910	55	Flare was hand polished smooth.

NOTES:

A - Welded, .049-inch wall thickness
B - Welded, .065-inch wall thickness
C - Welded, 16-gauge wall thickness
D - Cold drawn, seamless, .049-inch wall thickness

(1) Test with the letter (a) denotes a no oil flow condition.

(2) Flareless assembly: "B" nut MS 21921-20, Union MS 21902-20, Sleeve MS 21922-20.

cooled, it was pressure checked again. After each test the tubing assembly was taken apart and thoroughly inspected, then reassembled, retorqued, and pressure-checked prior to the next test. Only failed parts of an assembly were replaced for subsequent tests.

The test condition and results are presented in Table II. Under the column designated "Test No.," the first number denotes the assembly configuration as indicated in Figure 15; the second number denotes the size tubing and fittings used; and the lower case "a" denotes a no-flow test condition. There were two deviations from the list of assembly configurations (Figure 15). These were: (1) a 1-20 assembly was tested with flareless fittings MS21921, MS21902, and MS21922; and (2) one 1-20 assembly was tested with an increase in oil flow to 1.9 gallons per minute. These deviations are noted in Table II. The values given in Table II for oil-in and oil-out temperatures were the maximum values reached during the fire test. During the no-flow condition tests, the oil-in temperature started to increase approximately 30 seconds after application of the flame. Internal pressure was 40 psig at this time and stabilized because of the pressure relief valve in the system. Also, during the no-flow condition tests, if there was no assembly failure, the oil temperature increased to a maximum level, stabilized and then decreased. At the point of temperature decrease, it was assumed that the oil level in the tubing assembly was below the immersed thermocouple. "Failure time" as expressed in Table II, Column 7, denoted time that a leak condition developed in a tubing assembly while it was undergoing fire tests. The following is a synopsis of test results:

Test No. 1 - 6: There was no evidence of leak during the 5-minute fire test. The "B" nuts were not retorqued prior to the no-flow test.

Test No. 1a - 6: There was no leak during this 5-minute fire test under no-flow conditions. The tubing became red hot during the test. After the flame was removed, oil was circulated through the assembly. During this operation the assembly leaked and a fire started. When the assembly cooled a pressure check was made. There was no evidence of a leak during this operation.

Test No. 2 - 6: There was no leak during the 5-minute fire test. After the fire test a pressure check was made and there was no evidence of leakage.

Test No. 2a - 6: The assembly "B" nuts were retorqued to 300-inch-pounds prior to this no-flow test. A leak developed 1 minute and 5 seconds after the flame was applied to the assembly and the test was stopped at 2 minutes and 7 seconds.

Test No. 3 - 6: There was no leak during the 5-minute fire test. The "B" nuts were loosened slightly during the fire test; however, there was no evidence of a leak during the pressure check.

Test No. 3a - 6: The "B" nuts were retorqued prior to the no-flow test. A leak developed after 40 seconds exposure to the flame. The test was stopped at 1 minute.

Test No. 4 - 6: Assembly was subjected to a 5-minute fire test and no leak developed during the test. The pressure check revealed no leak. The "B" nuts were loose when the assembly cooled to room temperature.

Test No. 4a - 6: The "B" nuts were retorqued. A leak developed after 1 minute and 20 seconds exposure time to the flame. The test was stopped at 1 minute and 22 seconds. A crack in the union in the wrenching area was the cause of excessive leaking.

Test No. 5 - 6: No leaks developed during the 5-minute exposure time to the flame. No leak developed during the post-test pressure check. After the assembly cooled the "B" nuts were very loose.

Test No. 5a - 6: The "B" nuts were retorqued. A leak developed after 40 seconds exposure time to flame. The test was stopped after 45 seconds. The "B" nuts were only finger tight after the assembly cooled.

Test No. 6 - 6: This assembly was subjected to a 5-minute fire test and did not develop any leaks. Pressure check following the fire test revealed a leak.

Test No. 6a - 6: No test.

Test No. 1 - 12: This assembly was subjected to a 5-minute fire test and no leak was observed. During a post-test pressure check a leak developed.

Test No. 1a - 12: The "B" nuts were retorqued. No leak developed during the 1-minute fire test. At the conclusion of the 5-minute test, the area of the assembly exposed to the flame was observed to be red hot. The oil flow was resumed and a large leak developed.

Test No. 2- 12: The assembly was subjected to a 5-minute fire test and no leak developed. After the assembly cooled the "B" nuts were loose; but no leak developed during a pressure check.

Test No. 2a - 12: The "B" nuts were retorqued. After 2 minutes and 55 seconds exposure to the flame, the assembly developed a leak. The test was stopped after 3 minutes and 5 seconds exposure time..

Test No. 3 - 12: After 1 minute and 12 seconds exposure time to the flame, a leak developed and the test was stopped at 2 minutes. The "B" nuts were loose after assembly cooled.

Test No. 4 - 12: No leak developed during the 5-minute fire test. A pressure check after the test indicated no leak.

Test 4a - 12: The "B" nuts were retorqued. Inadvertently the test was conducted with flow during the first minute and 40 seconds. The oil flow was discontinued and the no-flow test was started. A leak developed at 2 minutes and 45 seconds. The test was stopped at 2 minutes and 50 seconds. A post-test examination revealed that the union was cracked and the "B" nuts were finger tight.

Test No. 5 - 12: No leak was observed during the 5-minute fire test.

Test No. 5a - 12: Prior to this test the "B" nuts were retorqued to 950 inch pounds. Torque on the nuts prior to tightening was approximately 300-inch pounds. Pressure in the tube reached 40 psig and stabilized. A leak was observed after 4 minutes and 55 seconds. The test was stopped at 5 minutes. Fire from resulting leak lasted 2 minutes.

Test No. 6 - 12: A leak was observed after 3 minutes and 30 seconds exposure time to flame. The test was discontinued at 4 minutes and 30 seconds.

Test No. 1-20: The test article was assembled and the "B" nuts were torqued to 1560-inch pounds. A leak developed 1 minute and 20 seconds exposure time to flame. The test was terminated at 2 minutes and 20 seconds. When the unit was disassembled a torque of 960-inch pounds and 1500-inch pounds was required to loosen the "B" nuts. The leak developed at the junction where the 960-inch pounds of force were needed to loosen the "B" nut. The welded seam portion of the tubing was the suspected area of failure.

Test No. 2 - 20: No lubricant was used during assembly. A leak developed after 2 minutes and 3 seconds of testing. The test was stopped at 2 minutes and 30 seconds. The torques required to loosen the "B" nuts were greater than 300-inch pounds for one "B" nut and between 300- and 600-inch pounds for the other. No apparent failure of any component of the assembly was noticed. Only the welded seam in the tubing was suspected to be the leakage area.

Test No. 2 - 20 (Repeat): The test article was the same as used in Test No. 2 - 20 above. During the assembly, the union threads and sleeve shoulders were lubricated with dry graphite. The "B" nuts were torqued to 1560-inch pounds then loosened and retorqued. At 2 minute and 20 seconds a leak developed, and the test was terminated at 2 minutes and 40 seconds. During disassembly 960-inch pounds of torque were required to loosen the "B" nuts. There was no evidence of failure of any component in the assembly.

Test No. 3 - 20: The "B" nuts were loosened, then retorqued to 1560-inch pounds. Prior to assembly the union threads and sleeve shoulders were lubricated with graphite. At 1 minute and 5 seconds a leak developed. The test was terminated at 1 minute and 30 seconds. The torques required to loosen the "B" nuts were 960-inch pounds and 1020-inch pounds respectively. The only evidence of leaking was around the seam.

Test No. 3 - 20 (Repeat): This was the same test article as used in Test No. 3 - 20. Prior to this test the flare was polished smooth to remove the roughness of the welded seam. A dry lubricant was used during assembly. The "B" nuts were torqued to the specified value. A leak developed at 1 minute and 50 seconds, and the test was stopped at 2 minutes and 45 seconds.

Test No. 4 - 20: Tubing used in this test was cold drawn, seamless with a .049-inch wall thickness. The test article was assembled and subjected to a 5-minute fire test. No leak developed and the post-test pressure check revealed no leakage.

Test No. 4a - 20: The same article as used in Test No. 4 - 20 was utilized for this test. No leak developed during the 5-minute fire test. However, during the post-test pressure check a leak developed. The "B" nuts were only finger tight when checked after the test.

Test No. 5 - 20: The tubing used for this assembly was cold drawn, seamless with a .049-inch wall thickness. The test article was assembled and the "B" nuts were torqued to 1550-inch pounds. There was no evidence of leak during or after the fire test. After the assembly cooled, a leak developed and examination of the assembly revealed that both "B" nuts were extremely loose.

Test No. 5a - 20: The same assembly as used in Test No. 5 - 20 was used for the no-flow test. The "B" nuts were retorqued to 1560-inch pounds. The assembly was subjected to a 5-minute fire test. No leak developed during the test, but a pressure check after the test revealed a leak. Both "B" nuts were only finger tight.

Test No. 6 - 20: Tubing used for this test was cold drawn, seamless with a .049-inch wall thickness. The test assembly was subjected to a 5-minute fire test and no leak occurred. No leakage occurred during the post-test pressure check.

Test No. 6a - 20: The same test assembly as used in Test No. 6 - 20 was used during this no-flow test. The "B" nuts were retorqued to 1560-inch pounds prior to test. Inadvertently the first 2 minutes of the test were conducted with flow, a no-flow condition was then established and the test was continued. At 5 minutes and 50 seconds, a large leak developed and the test was discontinued. One of the "B" nuts split across the hexagon face as well as around the rear portion of the nut, where sleeve shoulder and "B" nut mate.

As evidenced by the cracked aluminum components during Test Numbers 4a - 6, 4a - 12, and 6a - 20, the specified torque values for steel tube assemblies were excessive and contributed to the severity of the failure from exposure to fire when aluminum nuts and/or unions were used in the assemblies.

Based on the results of a limited laboratory investigation of the fire resistance of stainless-steel tubing systems with a low pressure relief and having a flared tube union consisting of either all steel or a combination of steel and aluminum components, it is concluded that:

a. Without fluid flowing through the system

(1) The assembly is highly susceptible to leakage when exposed to fire.

(1) The resistance to failure from exposure to fire decreases as the size of the tube assembly decreases.

b. With fluid flowing through the system, the smaller the size of the tube assembly, the greater the resistance to failure from exposure to fire.

c. The use of aluminum nuts on either a steel or aluminum union substantially decreases the fire resistance of tube assembly.

d. With fluid flowing through the system, both the use of aluminum unions as opposed to steel unions with either steel or combination of steel and aluminim nuts and sleeves substantially increases the fire resistance of the tube assembly.

e. Exposure of a tube assembly to fire greatly reduces the amount of torque required to loosen the "B" nut connections regardless of the combination of steel and aluminum components used.

SECTION V

EXPLOSION-SUPPRESSION AGENT DISTRIBUTION

1. FUEL TANK-EXPLOSION SUPPRESSION AGENT DISTRIBUTION TESTS

1.1 General

Evaluation of a Fenwal explosion-suppression system for an aircraft fuel tank was conducted at AFAPL, WPAFB. This work is discussed in Technical Report AFAPL-TR-69-16, dated May 1969 (Contract AF-33615-68-C-N07). FAA provided technical assistance and specialize gas analyzer equipment.

1.2 Test Facility

The test-bed was a 900-gallon aircraft fuel tank. Two explosion-suppression units, each having a capacity of 700 cubic centimeters of Halon 2402 ($CBrF_2$-$CBrF_2$) extinguishing agent, were mounted in each end of the tank. There was one explosion detector for each set of extinguishing agent containers. Six extinguishing agent sampling points were selected. Five of these sampling points covered the area above the normal liquid level, and one was placed approximately 1 inch above the bottom of the tank. Figure 18 is a schematic of the fuel tank showing the relative positions of the suppression system and gas sampling probes. Also shown are the positions A2, B2, and C? where evacuated spheres were placed to obtain samples of the agent/air mixture for mass spectrometric analysis.

1.3 Test Procedure

The test procedure consisted of simulating the explosion by activating two light bulbs within the tank which in turn activated the explosion detectors. This initated the discharge of the extinguishant into the tank cavity. During this operation continuous sampling by the gas analyser was being taken, and relative concentration of agent to 100 percent air was recorded.

1.4 Discussion and Results

Suppressor units two and three were discharged during the first test. Units three and four were discharged during the second test and all four units were discharged during

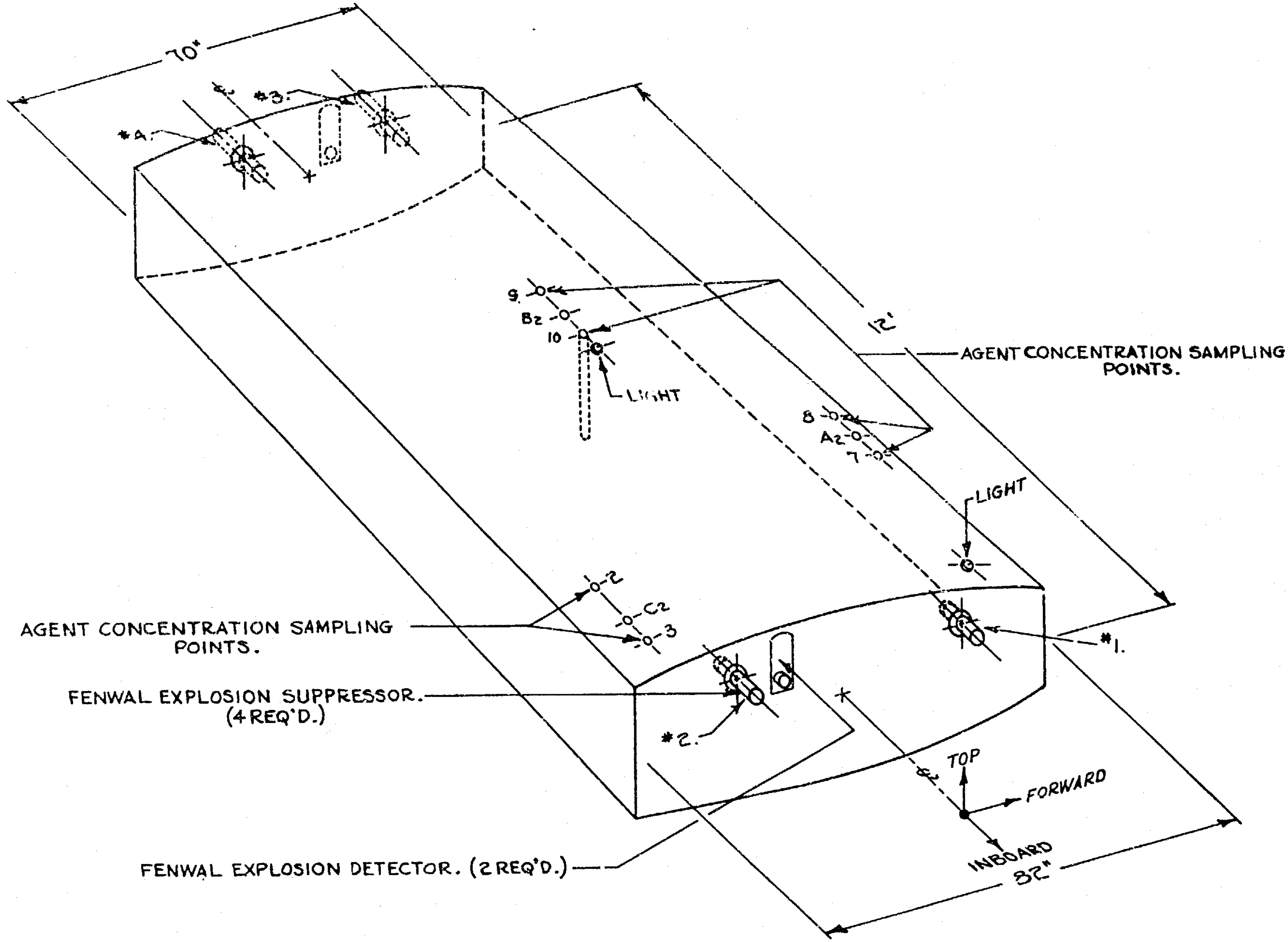


FIGURE 18 - GENERAL VIEW OF FUEL TANK SHOWING LOCATION OF SAMPLING POINTS AND EXPLOSION SUPPRESSION EQUIPMENT

the third test. Distribution of the agent in terms of relative concentration versus time at all sampling locations for the three tests is presented in Figures 19, 20, and 21. These data were sent to AFAPL for their interpretation and evaluation.

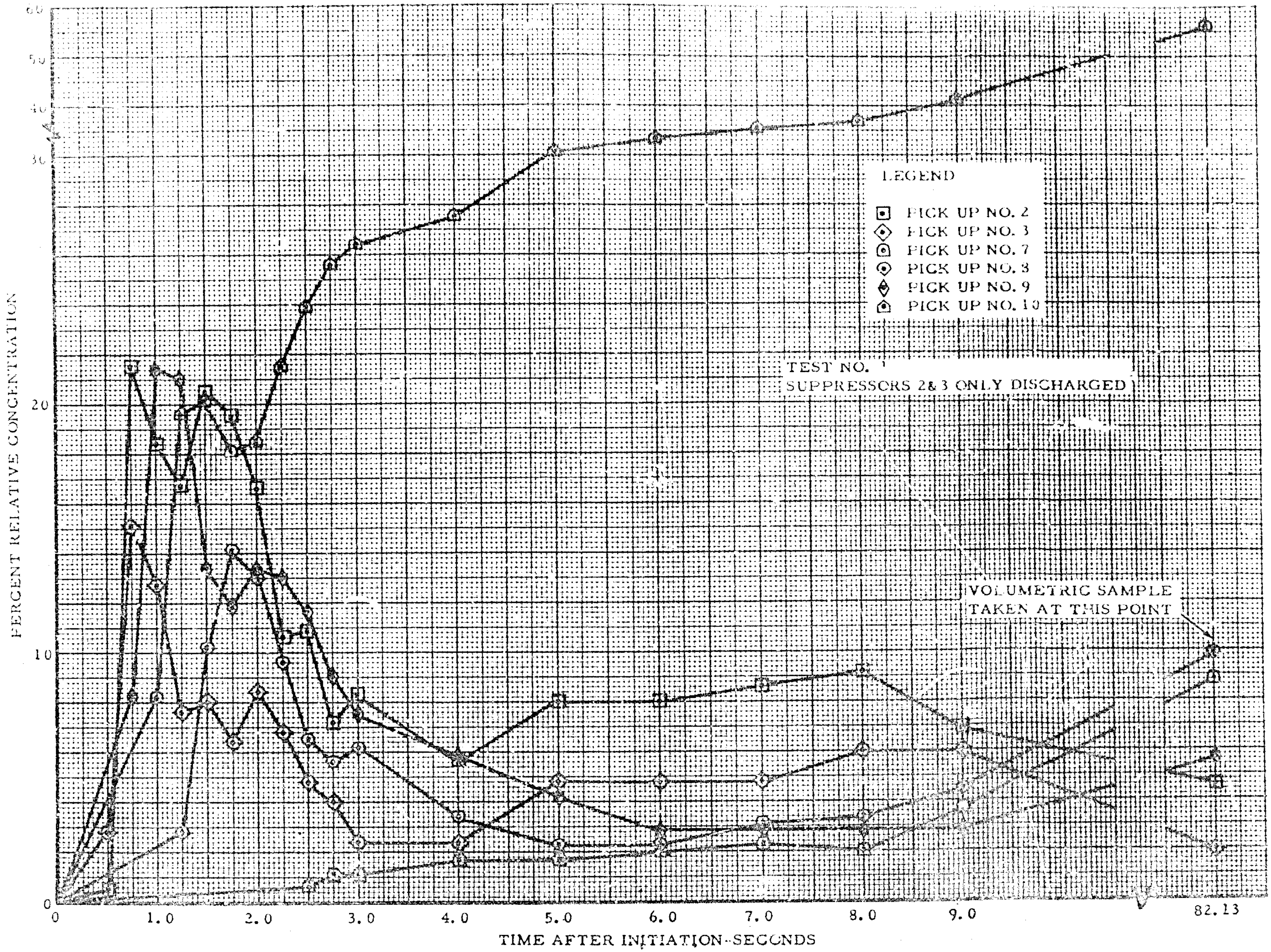


FIGURE 19 - FUEL TANK AGENT CONCENTRATION AND DISTRIBUTION FOR EXPLOSION SUPPRESSION SYSTEM DISCHARGE FOR TEST NO. 1

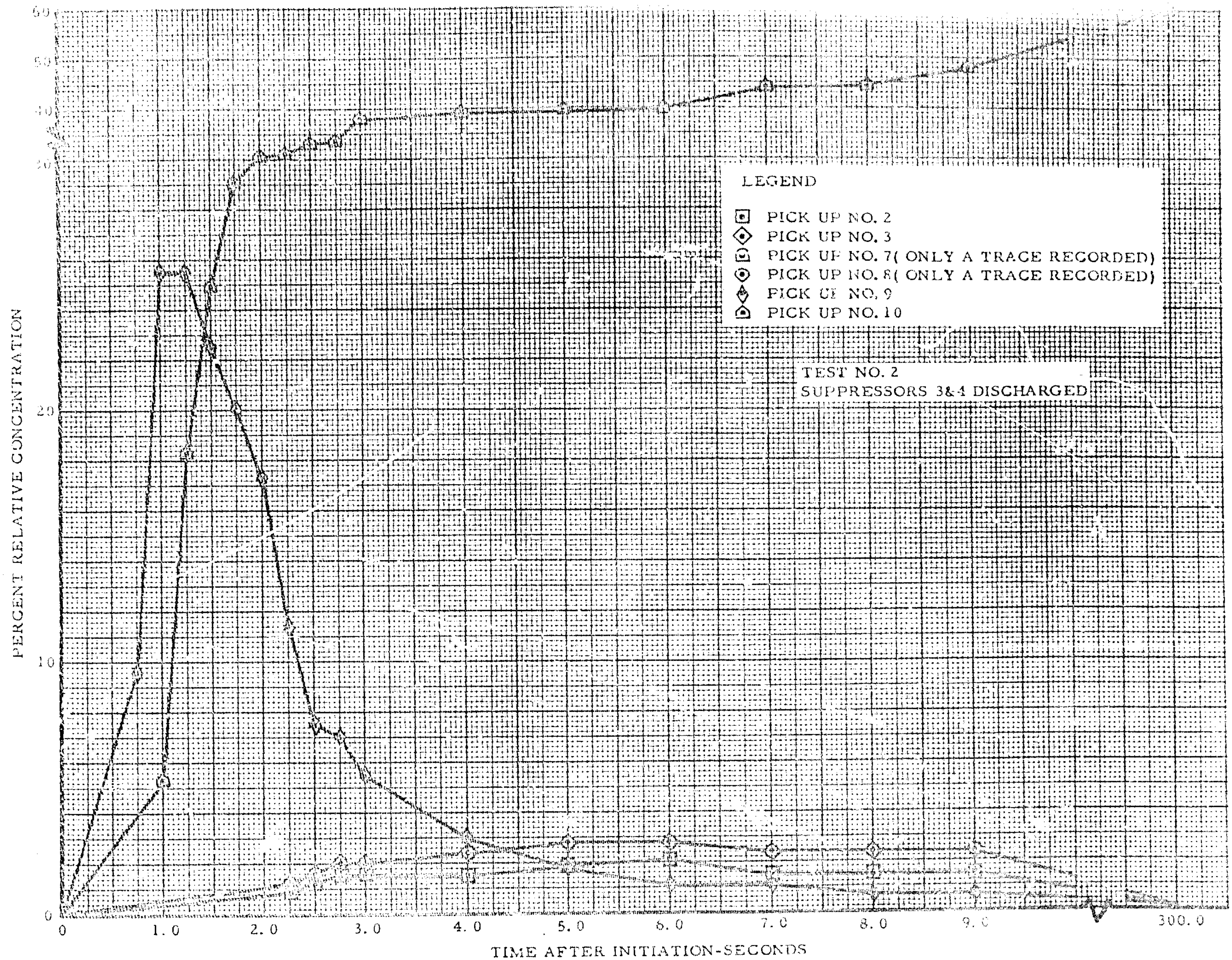


FIGURE 20 - FUEL TANK AGENT CONCENTRATION AND DISTRIBUTION FOR EXPLOSION SUPPRESSION SYSTEM DISCHARGE FOR TEST NO. 2

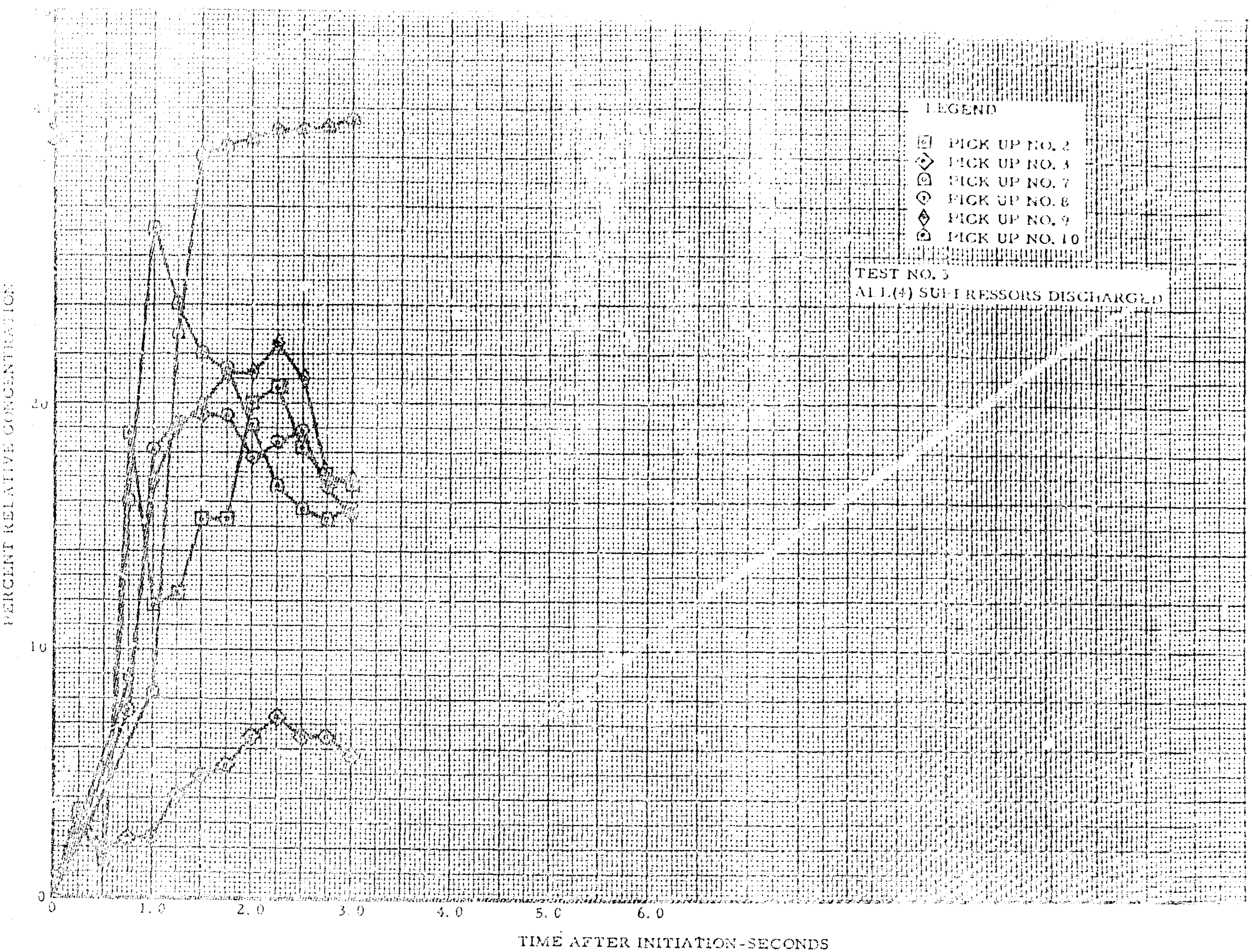


FIGURE 21 - FUEL TANK AGENT CONCENTRATION AND DISTRIBUTION FOR EXPLOSION SUPPRESSION SYSTEM DISCHARGE FOR TEST NO. 3

SECTION VI

DYNAMIC GUNFIRE TESTS

1. DYNAMIC GUNFIRE TESTS

1.1 General

The objective of the gunfire program conducted at FAA/NAFEC, Atlantic City, New Jersey, was to investigate the vulnerability of JP-4 and JP-8 fuels when subjected to penetration by a 50-caliber armor-piercing incendiary ordnance round and the generation of fire external to a fuel tank caused by the API projectile. For this evaluation, a series of liquid phase gunfire tests was conducted using mock fuselage fuel tanks under static and simulated flight conditions. The parameters for these tests were fuel type, standoff distance; i.e., the distance from a striker plate surface to the tank, ventilation rates in the standoff space, and external airflow. The remaining parameters were maintained at constant value. All tests were conducted using 50-caliber API ordnance rounds fired at 2400 ft/sec into the liquid area of the mock fuselage tank.

1.2 Test Facility

The test equipment developed for the gunfire program can be divided into two areas: (1) the air-supply system used to simulate the flight speed of the test fuel tank; and (2) the test fuel tank, instrumentation, heater tank, and the test weapon.

1.2.1 The Air-Supply System

In order to permit the tests to be observed and photographed under the best conditions, it was decided to design the air-supply system as a sort of open wind tunnel with the test article placed external to the tunnel and the air blowing around it so as to simulate flight conditions. To develop the required blast of air around the test article during any given test, the secondary fan air of a Pratt and Whitney YTF-33 engine was employed. Test stand ducts collected the fan air at the fan discharge. These ducts were modified so that the fan exhaust air was directed into two 20-inch diameter steel ducts as shown in figure 22.

FIGURE 22 - "Y" TRANSITION SECTION

The steel ducts joined together at a "y" transition section into a 30-inch diameter duct which carried the air approximately 100 feet from the test cell, where the engine was located, to the test pad. A 27-inch diameter nozzle was placed at the discharge end of the duct. This nozzle was sized to achieve maximum fan air velocity at maximum rated sea level static engine conditions, which incidentally was the design flow area of the fan air in a typical aircraft installation.

The velocity of the fan exhaust air was measured over the range of engine power settings and the relationship of the fan air velocity versus percent rpm, N_1, of the rotor was plotted. With corrections for other than standard day temperatures and pressures, a calibration curve was generated and was used to set the simulated flight velocity for the test tank during all tests. Figure 23 is the calibration curve which indicates the range of velocities which the system can provide. The lowest velocity occurred at engine idle where the fan discharge air had a velocity of 90 knots. The highest air velocity for continuous engine operation, with this configuration, was at 95 percent rpm of the N_1 rated rotor speed when the air velocity was 450 knots.

Due to the engine fan inefficiency and losses through the duct and nozzle, the static temperature of the moving air stream was increased. At the 90-knot discharge air speed, the average temperature rise in T static was 13°F. At the higher air velocity of 300 knots, this increase averaged 27°F. Figure 24 is a plot of the average temperature rise versus air velocity.

Figure 25 shows the overall test facility depicting the relative locations of the engine, ducts, test article, and the test weapon.

1.2.2 Test Article

The design of a test article which could reasonably simulate a fuselage fuel tank associated with aircraft and be readily repaired or replaced afforded some problems. The requirements to be met by the test article were; (1) a smooth aerodynamic shape, (2) a maximum fuel capacity of 120 gallons of fuel, (3) various standoff distances, i.e., the distance from the skin of the article to the fuel tank wall, (4) a capability of maintaining 5 psig in the fuel tank portion of the article, and (5) an overhead viewing port so that high speed filming of the interior of the standoff and tank spaces during the tests could be made.

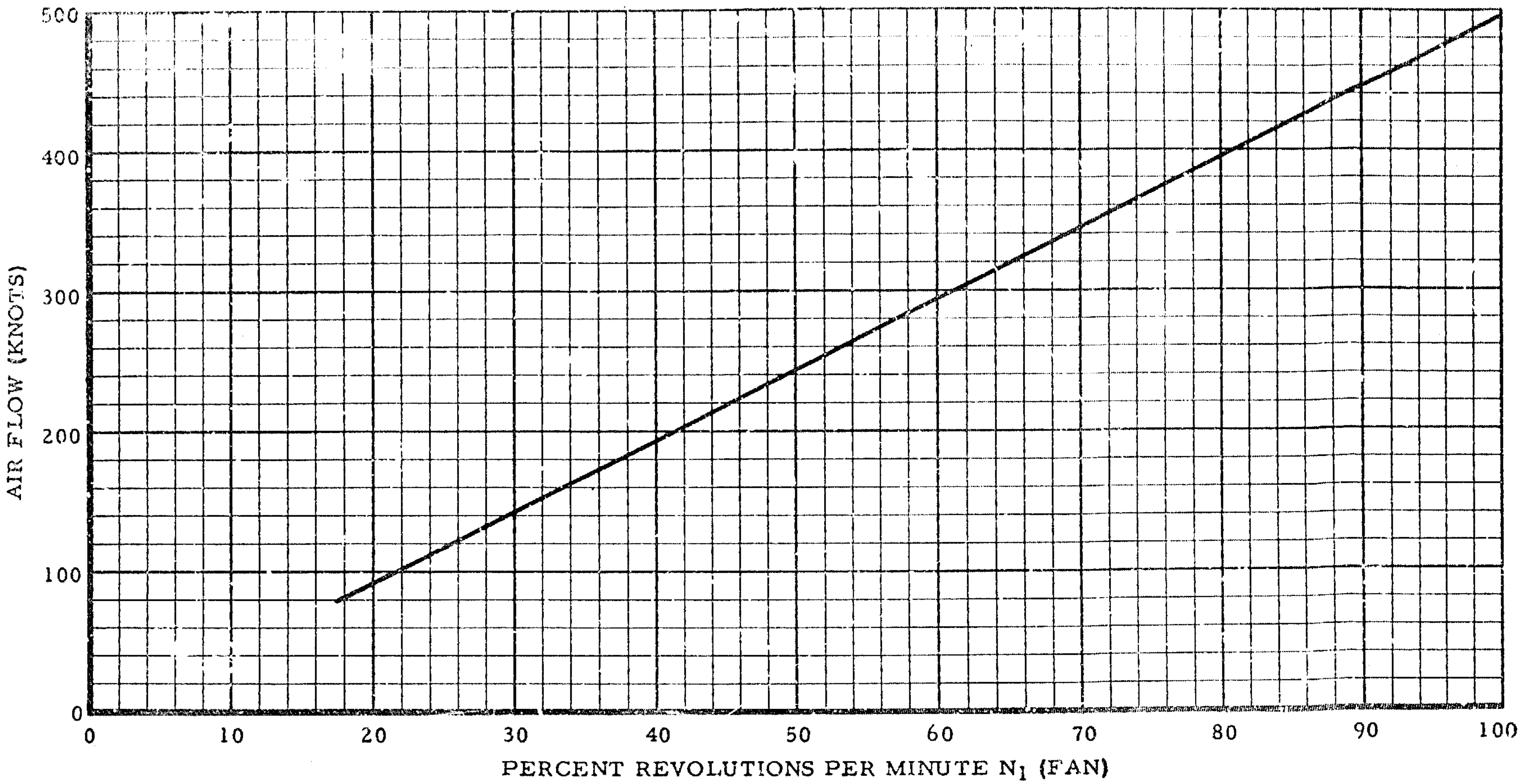


FIGURE 23 - CALIBRATION CURVE FOR GUNFIRE AIR SUPPLY SYSTEM

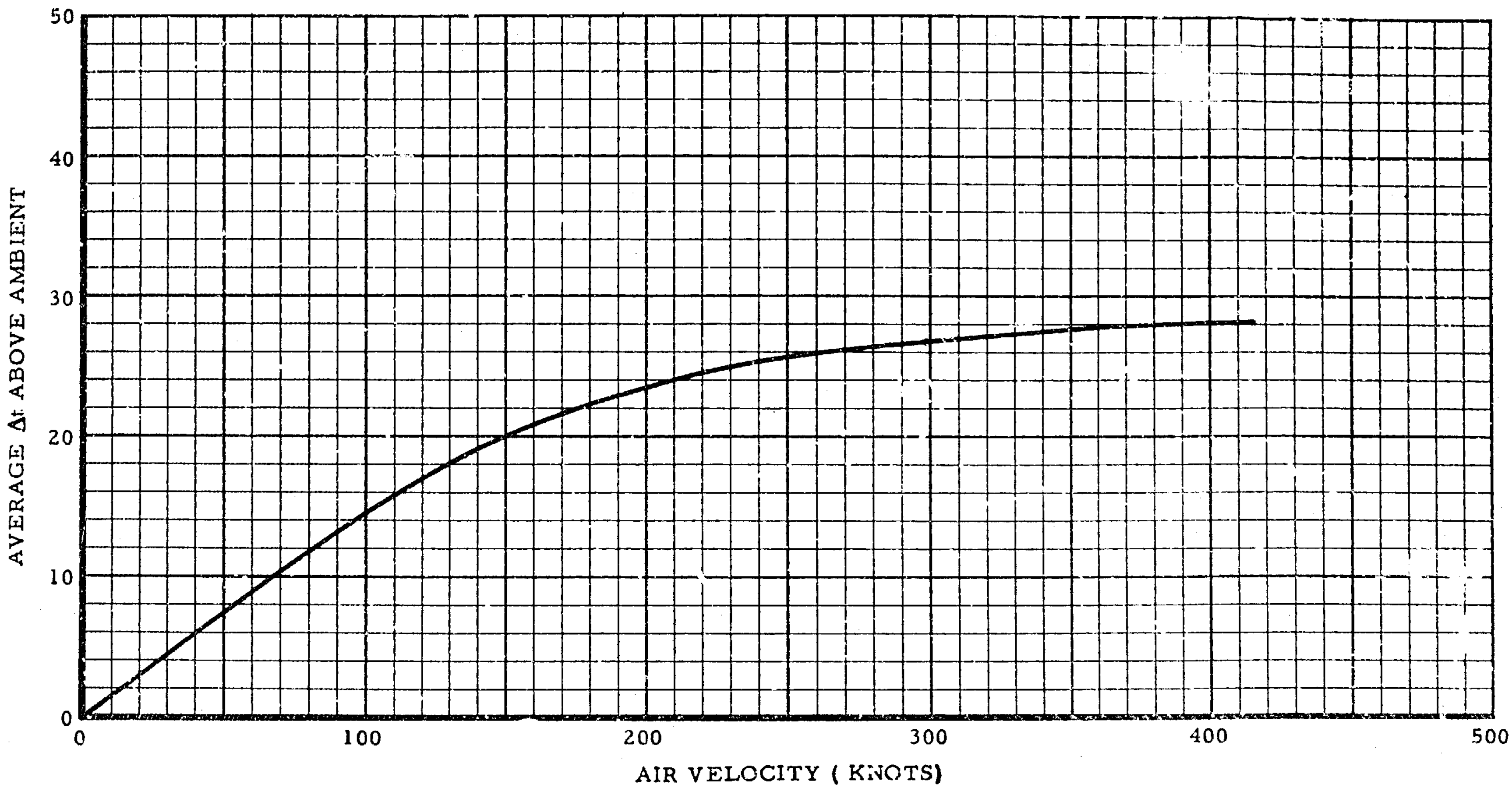


FIGURE 24 - TEMPERATURE RISE ABOVE AMBIENT AT DISCHARGE NOZZLE

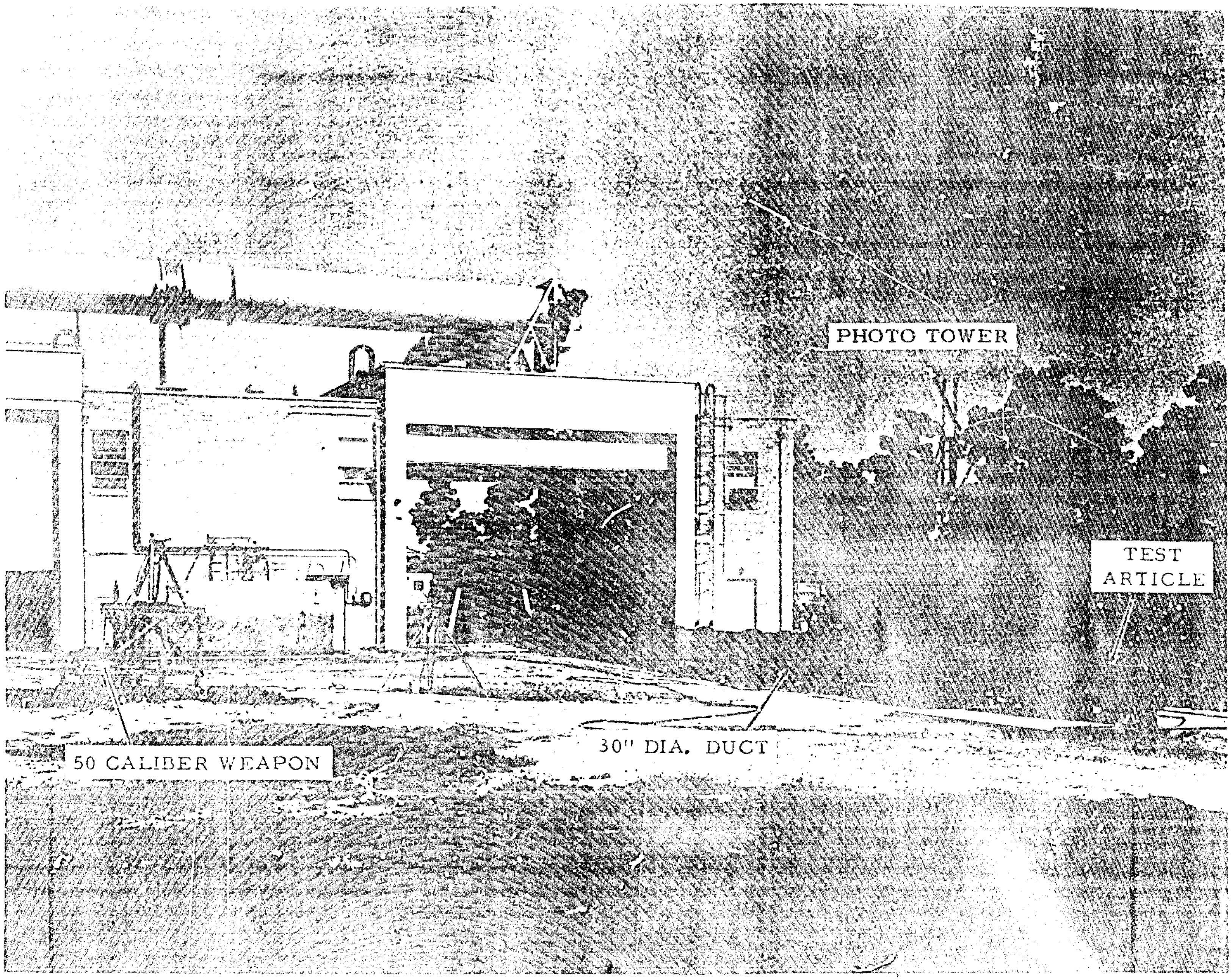


FIGURE 25 - OVERALL VIEW SHOWING ENGINE TEST WEAPON AND TEST ARTICLE

In order to fulfill the standoff distance requirements of 9 inches, 4 inches, and 1 inch, three separate test articles were constructed.

The test article design selected for the program had a rectangular box fuel section with a fairing section on each end as shown in Figure 26. The fairing sections, forward and aft, provided for an aerodynamic shape and housing for the instrumentation and internal fire extinguishing system.

The combined fuel and standoff volumes of the test article were 3' x 3' x 2' and constructed of 5/8-inch steel plate. A replaceable striker plate of 0.215 inch, 2024-T3 aluminum was flush mounted on the side of this section. A 1/4-inch steel plate with a special replaceable aluminum projectile entrance plate was utilized as the separator of the fuel and standoff spaces. Each of the dimensions, fuel and standoff, was fitted with a drain line to permit draining of fuel and water wash after each test.

To prevent the projectile from exiting the test article, an aluminum armor plate was mounted in the rear portion of the fuel tank section.

The overhead view port consisted of various thicknesses of plexiglas for ease of handling and minimizing damage due to fire. This view port permitted high speed photography to capture the action in the standoff and fuel areas and a closed circuit TV surveillance system permitted monitoring of the interior during the tests. This surveillance indicated to the test engineer whether activation of the extinguishing system was required to save the test article.

The forward fairing section of the article held the internal primary and secondary fire extinguishing systems. The extinguishing system used consisted of two pressurized containers of monobromotrifluoromethane ($CBrF_3$) extinguishing agent connected to the fuel and standoff areas of the article. Each system was independently activated by 28Vdc.

The structure of the aft section supplied the necessary protection from fire for the instrumentation located therein.

Upon completion of the initial phase of the program with the non-vented standoff spaces, two of the articles, the 9-inch and 4-inch standoff articles, were modified to

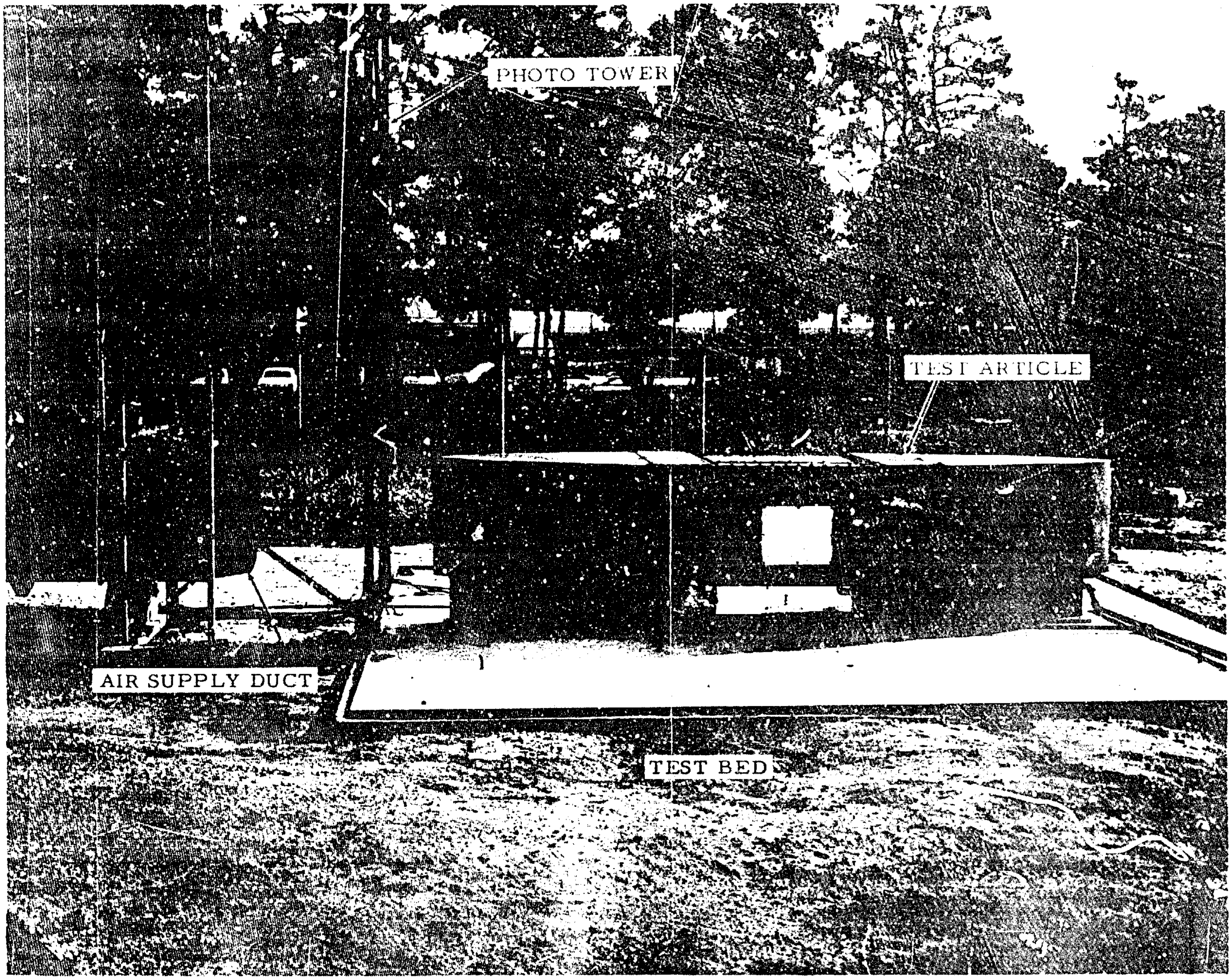


FIGURE 26 - TEST ARTICLE WITH FAIRING SECTIONS ON FORE AND AFT ENDS

permit venting of the standoff space. For venting, ram air from the air supply duct was directed into the standoff space by means of a 4-inch diameter duct and exhausted by a 4-inch diameter duct. Ventilation rates of 18 to 325 air changes per minute were obtained by varying the inlet nozzle diameter and the velocity of the ram air. The inlet nozzle diameters used were 3, 1 1/2, and 1 1/4 inches. Figure 27 shows the venting modifications made on the test articles.

1.2.3 Instrumentation

The test article instrumentation consisted of thermocouples for fuel, ullage, standoff space, and ambient air temperature measurements. Pressure transducers were used to measure the pressure in the standoff space and fuel tank ullage. Iron-constantan thermocouples were utilized for the fuel, ullage, and ambient air-temperature measurements. A chromel-alumel thermocouple was used in the standoff space. The thermocouple in the standoff space gave an indication of fire in this area and not the exact temperature rise due to the fire due to a lag in the response time (and the unpredictable location of the fire during a test).

The fuel tank ullage pressure was monitored with a 0 to 50 psig transducer, while the standoff space pressure was measured with a 0 to 100 psig transducer.

All measurements of temperature and pressure were recorded on an oscillograph.

Figure 28 indicates the location of the test article instrumentation. These locations were the same in all three test articles.

The projectile velocity was determined by recording the elapsed time between two light screens located 25 feet apart.

Photographic coverage of the tests consisted of two Hy-Cam cameras and a Lo-Cam camera. The Hy-Cam cameras, with film speeds of 7000 and 3500 frames per second, were positioned on top of a 30-foot tower to provide the overhead view of the action within the test article. The remaining camera, film speed of 500 frames per second, was placed to show a general coverage of the overall test article.

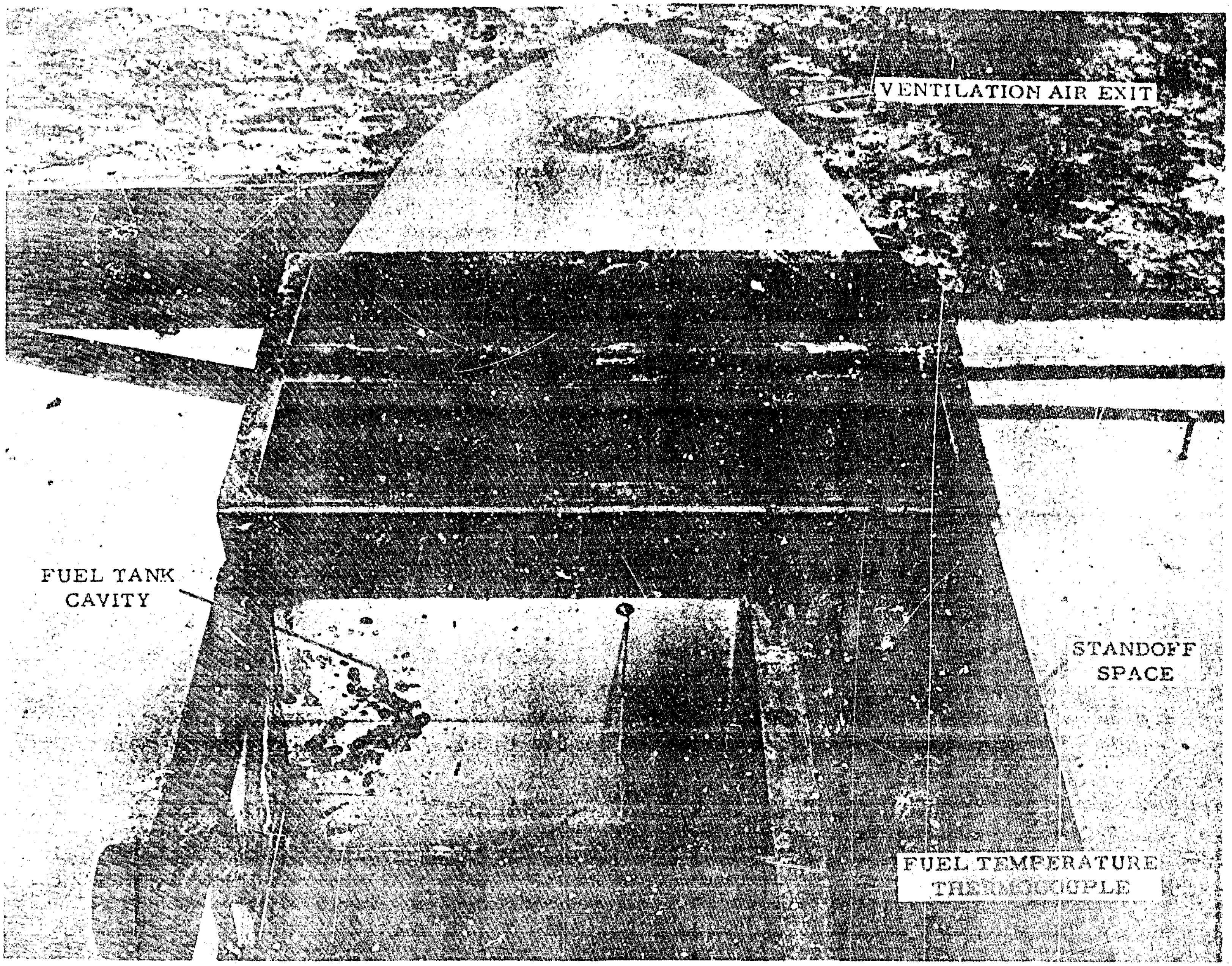


FIGURE 27 - TEST ARTICLE WITH VENTED STANDOFF AREA

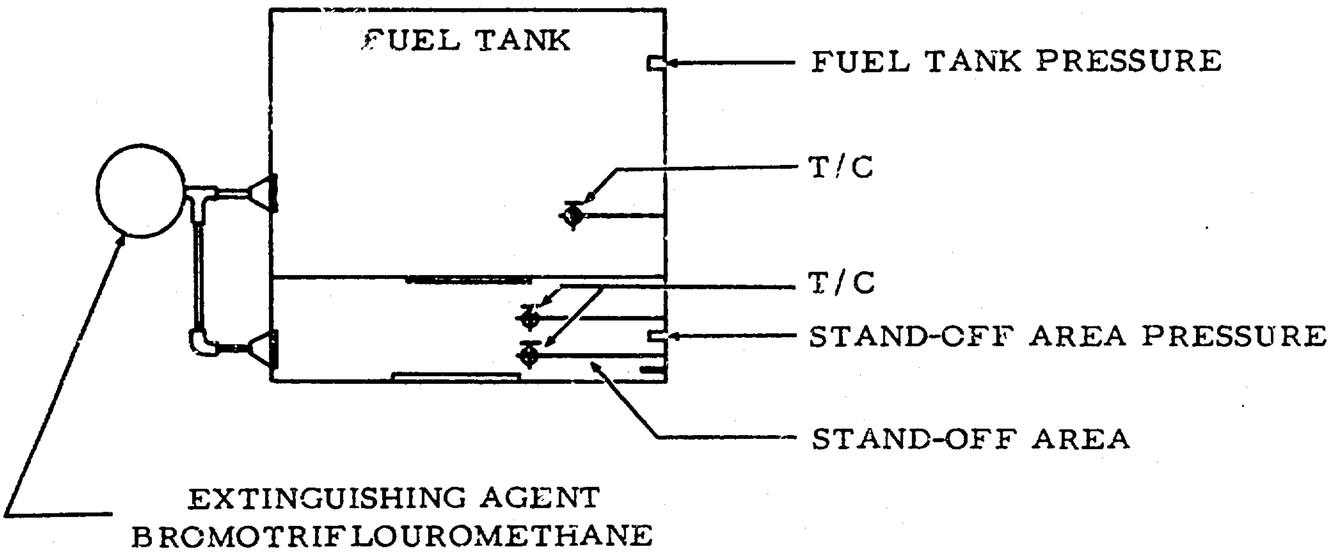


FIGURE 28 - INSTRUMENTATION IN TEST ARTICLE

1.2.4 Test Weapon

The test weapon used in all tests was a 0.50-caliber gun consisting of a 36-inch Mann barrel and receiver. The weapon was manually loaded and cocked. It was remotely fired by sending an electrical signal to a solenoid mounted on the weapon stand. The gun-mount containing the weapon was a standard Frankford Arsenal mount which was bolted to an I beam on a concrete pad. The test weapon and mount are shown in Figure 29.

1.2.5 Fuel Conditioning Equipment

Fuel for each test was temperature-conditioned with a system as shown in Figure 30. The fuel was heated to 90°F by four electrical immersion-type heating elements. A lid was placed over the heater tank to prevent the evaporation of the volatile ends of the fuel before the fuel was loaded into the test article.

1.2.6 Test Pad

The test pad, Figure 31, located at the discharge end of the air supply duct, was 15' x 15' x 2' and constructed of reinforced concrete. A 3-inch diameter drain, connected to a disposal tank, provided for easy removal of fuel spillage, tank drainage and test article wash-water.

1.3 Test Procedures

Since the objective was to determine the relative vulnerablility of JP-4 and JP-8 fuels, in spaces adjacent to an aircraft fuel tank, a series of incendiary functioning tests were conducted. These tests were for the purpose of determining which combination of function plate thickness and projectile velocity would provide the greatest incendiary action in the standoff spaces of 9 inches, 4 inches, and 1 inch, thereby making available the most severe ignition source. The projectile velocities tested were; the standard 50-caliber API ordnance round at 2900 feet per second, and off-loaded 50-caliber API rounds of 2400 feet per second and 1800 feet per second. Functioning plate thickness of 0.090 inches and 0.215 inches, 2024-T3 aluminum, were tested. From the analysis of high-speed data films and projectile hole damage to the aluminum plates, it was determined that the 2400 feet per second projectile

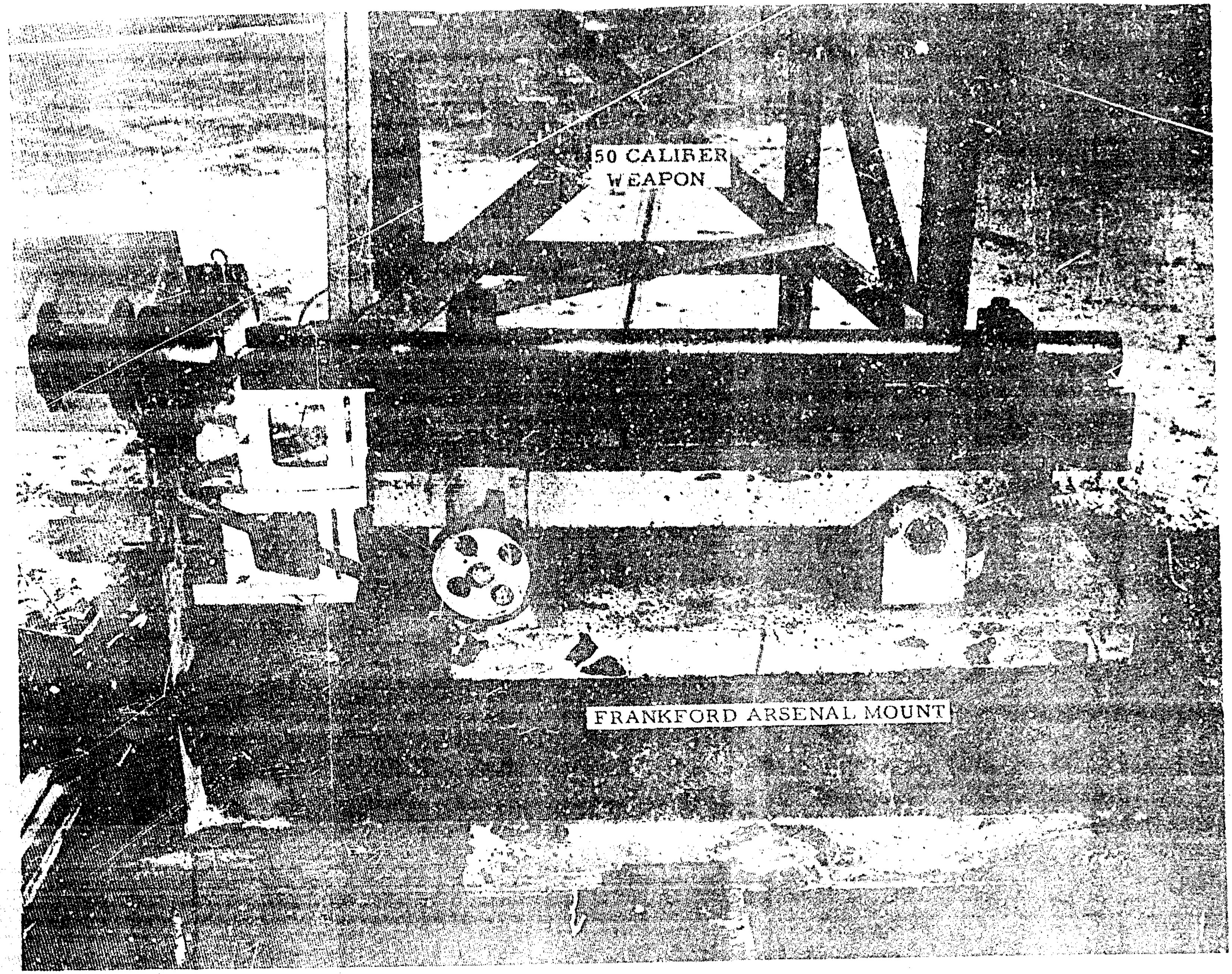


FIGURE 29 - TEST WEAPON USED TO FIRE .50 CAL API AT TEST ARTICLE

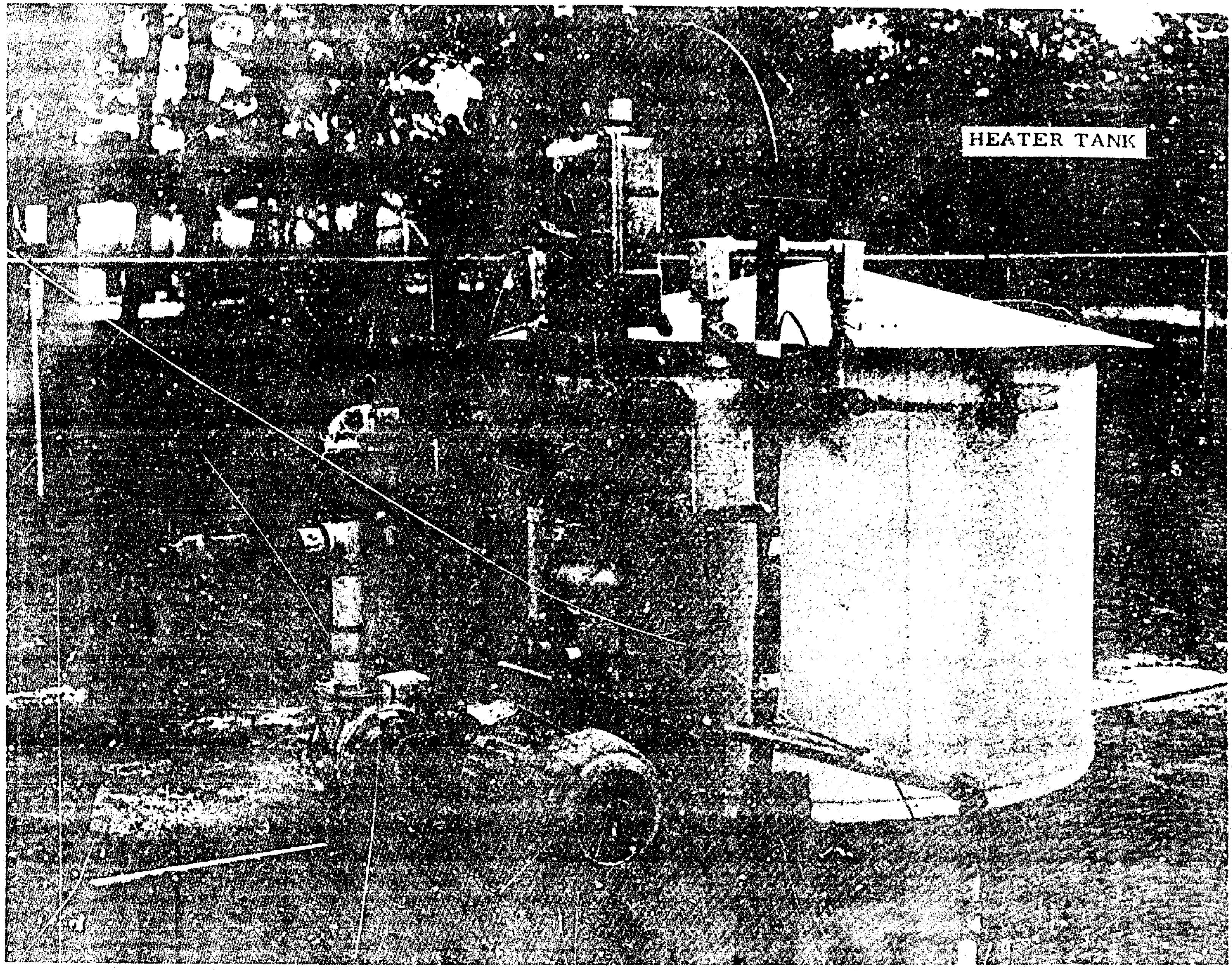


FIGURE 30 - FUEL CONDITIONING TANK

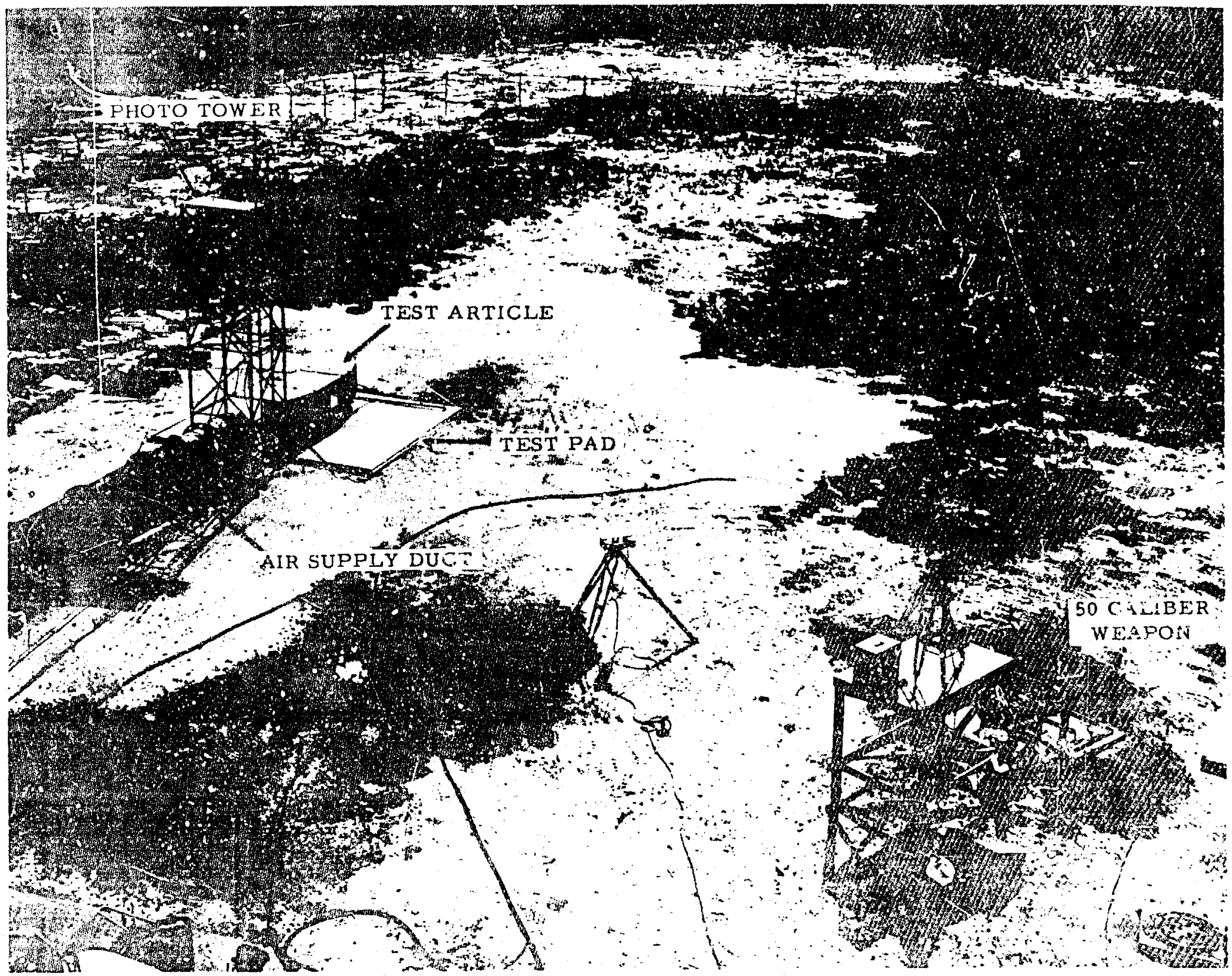


FIGURE 31 - OVERALL VIEW SHOWING THE TEST PAD

velocity in combination with the 0.215-inch function plate would provide the optimum in incendiary action for any given standoff space of 9 inches, 4 inches, or 1 inch.

Liquid phase tests were conducted with non-ventilated standoff spaces in the initial tests. Table III shows the parameters for these tests.

The second phase tests were conducted with various ventilation rates in the standoff area. The parameters for these tests were the same as those of the initial tests plus ventilation rates of 18 to 325 air changes per minute (ACPM) in the standoff area. Table IV indicates the various ventilation rates and simulated air velocities used for this phase of testing.

The test procedure followed for this program called for six tests to be conducted at each test condition. If similar results, such as standoff fire, fire external to the tank, and standoff space and tank pressure rise, were obtained during the first four tests, the remaining two tests of the series were cancelled.

For each test conducted, the fuel, JP-4 or JP-8, was temperature conditioned to 90° ± 5°F and then transferred into the tank. The test article was then sealed and pressurized at 5 psig. The YTF-33 engine was started and after achieving the percent N1 rotor speed for the desired air velocity over the article, a stabilization period was maintained. After stabilization, involving approximately 5 minutes of operation, a sequencer timer was started. This sequencer automatically controlled the powering of the three cameras, the oscillograph recorder, and the firing of the weapon.

TABLE III

TEST PARAMETERS FOR NON-VENTED STANDOFF ARTICLE GUNFIRE TESTS

Fuels	JP-4 or JP-8
Projectile Type	50-caliber API
Projectile Velocity	2400 fps
Impact Angle	30°
Tank Volume	60, 80, 100 gallons *
Fuel Temperature	90°F
Fuel Tank Pressure	5 psig
Fuel Height	18 inches
Impact Point	Mid-fuel
Ullage	25%
External Air Velocity	0, 90, 125 knots
Standoff Distance	1, 4, and 9 inches
Ventilation Rate	0 to 1 ACPM **

* Relates to the 1", 4", and 9" standoff distances.

** ACPM - air changes per minute in the standoff space - The 1 ACPM is an estimate of the air leakage through the striker plate seal.

TABLE IV

TEST VENTILATION RATES

Ventilation Rates for the 4" Standoff Test Article
18 ACPM at 90 knots external airflow
75 ACPM at 90 knots external airflow
58 ACPM at 300 knots external airflow
180 ACPM at 300 knots external airflow
Ventilation Rates for the 9" Standoff Test Article
23 ACPM at 90 knots external airflow
96 ACPM at 90 knots external airflow
101 ACPM at 300 knots external airflow
325 ACPM at 300 knots external airflow

1.4 Discussion and Results

The gunfire tests conducted at NAFEC, Atlantic City, N.J., were for the purpose of evaluating the vulnerability of JP-4 and JP-8 fuels when subjected to the penetration of 50-caliber armor piercing incendiary ordnance rounds. Information obtained during the course of these tests indicated that the pressure rise in the non-vented standoff space of the test article was significantly higher for JP-4 fuel than with JP-8 fuel. Under similar test conditions this difference averaged 7.0 psig. With similar test conditions and the standoff space vented, this pressure rise differential did not appear. The probable reason was the pressure release offered by the ventilation entrance and exit ports.

Analysis of the fire duration times from the data films indicated that the fire duration in the standoff space was considerably longer for tests with the JP-8 fuel than those with JP-4 fuel. Due to the lag in thermocouple reaction time, this fire duration for the tests with JP-8 fuel, permitted a higher temperature to be recorded on the oscillograph record.

In approximately 40 percent of the tests conducted with the 9-inch vented standoff test article, second pressure rises in the standoff space were noted. Since this condition was associated with only the 9-inch vented standoff article, the following explanation is suggested.

A "stagnant area," i.e., a flame holder, could have been present in the standoff space. After the initial fire was extinguished, either by ventilation air or by itself, a reignition occurred due to the ignition source available in the "stagnant area." This reignition source was not observed on the data film because after the initial fire had died out, the standoff space was clouded with smoke and the plexiglas observation window was sooted by the initial fire.

During the course of the gunfire program, several test article failures occurred. These failures included the blowing off of the striker plate, cracking of the welds within the tank, broken pressurization line, and failure of the standoff ventilation exhaust tube. The number of test article failures was much higher during the tests conducted with JP-4 fuel.

There were 13 test article failures with JP-4 in the fuel cavity and three with JP-8. In the case where the standoff space ventilation exit tube failed (four with JP-4 - one with JP-8), the fire in the standoff space propagated to the aft section of the article. With the JP-4 fuel, these fires were large and self-sustaining, but with JP-8 fuel they were not self-sustaining.

One important factor in the generation of fire external to the tank is the elapsed time between projectile penetration and initial external fuel spray. During analysis of the high-speed films of the test conducted during the program, it was noted that with the non-vented 9- and 4-inch standoff space test articles the time for the occurrence of initial external fuel spray averaged three times as long for the test with JP-8 fuel as with the JP-4 fuel. An explanation for this phenomenon could be that the longer burning characteristic, as observed on the test oscillograph records and during film analysis, of the JP-8 fuel caused the fuel to be consumed in the standoff fire rather than spurting out the projectile entrance hole.

During the majority of the tests conducted with other test article configurations, the elapsed time from projectile entrance to initial external fuel spray was similar for both JP-4 and JP-8 fuel.

The incendiary burn time in the standoff space was determined by analysis of the high speed data films and appeared to be unaffected by the type of fuel being tested or the standoff ventilation rate.

During the course of this program 198 tests were conducted. The results of these tests are presented with respect to the individual test article configuration used in a series of tests.

1.4.1 Nine-Inch Non-Vented Standoff Article

Thirty tests were conducted with the 9-inch non-vented standoff test article configuration. Eighteen tests were conducted with JP-4 fuel and 12 with JP-8 fuel. (The data collected from these tests are shown in Table V.)

TABLE V.--GUNFIRE TESTS WITH 9-INCH STANDOFF TEST ARTICLE

Test No.	Fuel Used	Fuel Temp. (°F)	Air Velocity (kts)	Standoff Fire Duration	Maximum Pressure In Tank (psig)	Time to Maximum Pressure In Tank	Maximum Pressure In Standoff (psig)	Time to Maximum Pressure In Standoff	Time Initial Fuel Spray	Incendiary Function Time	REMARKS
1	JP-4	90	Static	-	-	-	-	-	.018	.014	No oscillograph record, external fire.
2	JP-4	85	Static	.015	5.5	-	-	-	.053	.005	No pressure transducer in standoff, line broke on tank pressure.
3	JP-4	88	Static	-	6.5	0.007	22.0	.018	.017	.012	External fire.
4	JP-4	90	Static	.067	16.5	0.007	4.0	.101	-	.004	External fire.
5	JP-4	87	Static	.131	9.5	.025	26.3	.143	.216	.002	
6	JP-4	87	Static	.071	12.0	.015	24.5	.050	.192	.006	
7	JP-4	87	90	.022	12.0	.010	6.5	.026	.130	.006	
8	JP-4	91	90	.156	14.0	.046	18.0	.078	.966	.011	
9	JP-4	92	90	Indefinite	3.0	.050	11.0	.106	Indefinite	.021	Indefinite no 500 frame film. Airline connector broke.
10	JP-4	92	90	.059	16.7	.010	31.[illegible]	.055	.308	.023	
11	JP-4	90	90	.162	10.0	.037	29.0	.033	.570	.055	
12	JP-4	91	90	.086	14.0	.013	23.0	.015	.030	.014	Flash fire, started at .020 second.
13	JP-8	92	Static	.092+	9.0	.090	10.0	.096	1.142	.007	
14	JP-8	92	Static	.582+	5.5	.010	8.0	.040	1.620	.018	Pressure not hooked up.
15	JP-8	94	Static	.519	17.0	.015	12.0	.076	1.300	.035	
16	JP-8	95	Static	.534+	18.5	.010	10.5	.083	1.328	.058	
17	JP-8	95	Static	.405	17.5	.034	12.5	.135	1.212	.035	
18	JP-8	85	Static	-	12.0	.035	8.5	.023	0.160	.008	No fire in standoff space.
19	JP-4	84	125	.531	14.0	.028	11.5	.068	.860	.078	
20	JP-4	80	125	.199	10.0	.070	22.0	.040	.718	.054	

TABLE V.--GUNFIRE TESTS WITH 9-INCH STANDOFF TEST ARTICLE (Continued)

Test No.	Fuel Used	Fuel Temp. (°F)	Air Velocity (kts)	Standoff Fire Duration	Maximum Pressure In Tank (psig)	Time to Maximum Pressure In Tank	Maximum Pressure In Standoff (psig)	Time to Maximum Pressure In Standoff	Time Initial Fuel Spray	Incendiary Function Time	REMARKS
21	JP-4	86	125	.521	8.0	.050	11.0	.040	.202	.077	Pressure not hooked up.
22	JP-4	86	128	.135	15.0	.055	29.5	.033	.342	.054	
23	JP-4	80	125	.399	15.5	.035	11.5	.065	.778	.042	
24	JP-4	80	125	.059	10.0	.030	1.5	.014	.430	.082	
25	JP-8	86	90	.548	16.0	.016	8.5	.053	.100	.080	
26	JP-8	85	90	.492	14.0	.020	12.5	.065	.600	.057	
27	JP-8	85	90	.342	35.0	.040	9.0	.120	.372	.031	Fire flashed into tank.
28	JP-8	92	90	.335	9.0	.020	15.0	.080	.768	.032	
29	JP-8	92	90	.444	14.5	.010	14.0	.055	.820	.062	
30	JP-8	70	90	.494	14.0	.010	11.5	.095	.984	.030	

NOTE: 1. No external fires except where noted.

2. Fire in standoff area except Test No. 18 (noted).

3. Initial tank pressure 5 psig for all tests except Tests Nos. 14 and 21.

4. "+" indicates fire to end of film.

Analysis of the data films indicated that a fire occurred in the standoff space of the test article during all tests with JP-4 fuel and 11 of the 12 with JP-8 fuel. In one test, with JP-8 fuel, the fire in the standoff space propagated into the ullage area of the fuel tank. This fire lasted approximately 0.2 second and did not sustain itself. The probable reason for the occurrence of this ullage space fire was that standoff space fire duration was sufficiently long and permitted the tank fuel level to fall below the penetration hole allowing the flame to flash into the ullage area. A comparison of the standoff fire durations is shown in Figure 32. In all tests conducted, the fire duration in the standoff space was much greater with JP-8 than with JP-4 fuel.

The average maximum pressure rise in the standoff space was 17.8 psig for the test conducted with JP-4 fuel and 10.9 psig with JP-8 fuel.

Fire, external of the test article, was observed in four of the tests conducted with JP-4 fuel. Three of these fires occurred at zero airflow conditions and one at the 90-knot airflow over the test article. Since no external fire occurred at the 125-knot airflow condition, testing at increased air velocities over the test article was discontinued. Tests with JP-8 fuel had no external fires at either static or 90-knot airflows; therefore, it was decided not to increase the airflow over the test article for this fuel.

Analysis of the oscillograph traces for this series of tests indicated a distinct standoff space pressure characteristic for tests with external fire versus test with no external fire. When no external fire occurred, the pressure level in the standoff space built up rapidly when the incendiary round penetrated the striker plate but dissipated slowly (approximately .5 second). In tests where an external fire resulted, the pressure increase in the standoff space was again rapid but dissipated in approximately 0.03 second. The fuel tank pressure pattern was similar under both fire and no-fire conditions.

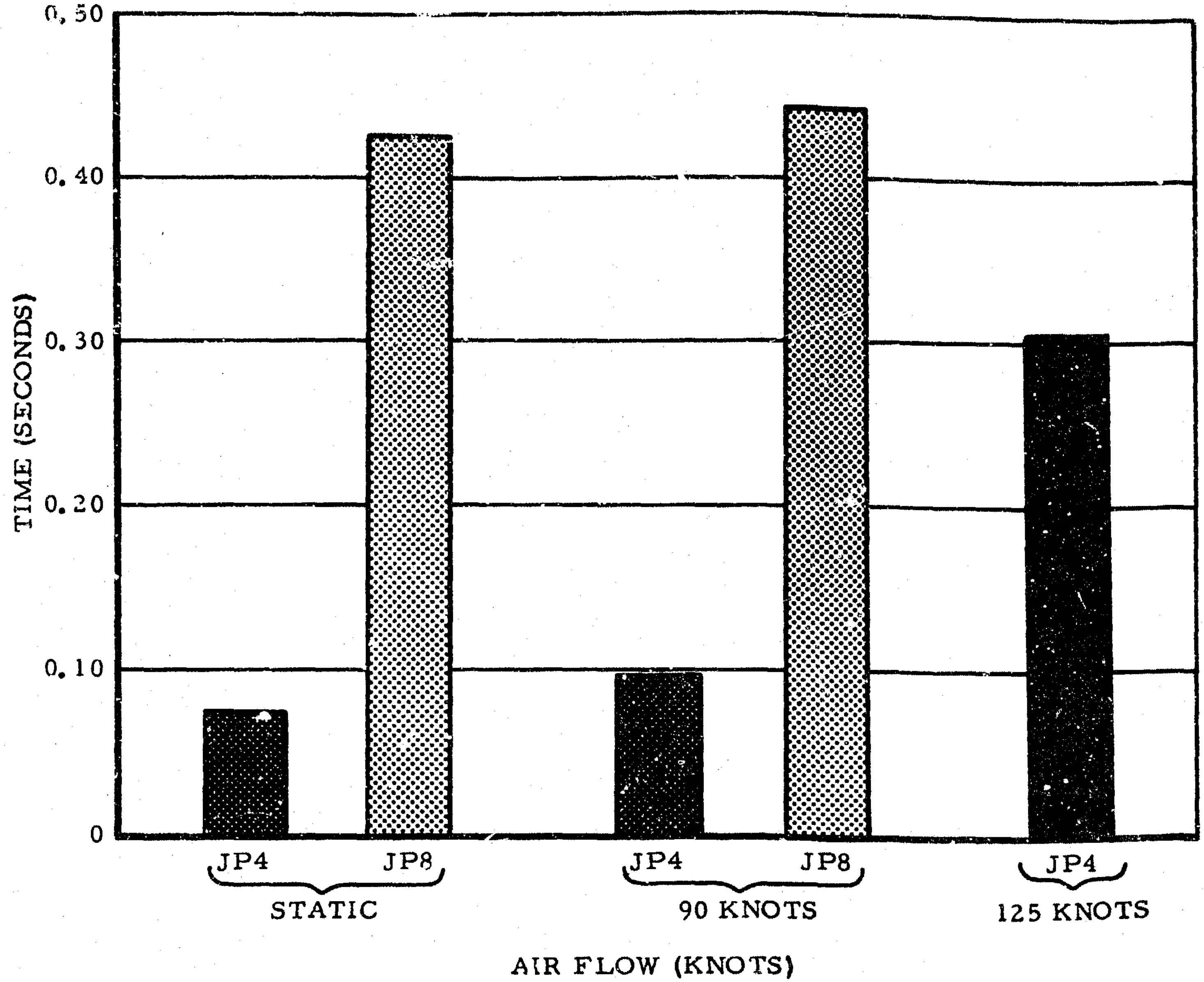


FIGURE 32 - COMPARISON OF 9" NON-VENTED STANDOFF FIRE DURATION JP-4 vs JP-8

A suggested explanation for this pressure phenomenon is as follows: In the no-fire situation, the standoff pressure rose and remained high while the tank pressure increased and decreased rapidly in an oscillatory manner. The high standoff pressure prevented fuel from spurting out of the tank during the time that the incendiary was still active. By the time the pressure in the standoff declined, thus permitting fuel to come through the penetration hole in the tank, the incendiary ignition source had been dissipated and the initial fire in the standoff space had gone out and no fire occurred. When a fire occurred, the standoff pressure increased and decreased rapidly and fuel rushed through the penetration hole and was ignited by the incendiary particles.

This theory (concerning the standoff pressure) was tested by using only half a striker plate; i.e., standoff volume was partly open to the atmosphere; this way, the standoff pressure could be quickly released and result in an external fire. Three such tests were conducted; two with JP-4 fuel and one with JP-8 fuel. In each case the pressure pattern was as predicted and a severe external fire resulted.

1.4.2 Four-Inch Non-Vented-Standoff Test Article

A total of 24 tests was conducted with the 4-inch non-vented standoff test article. Twelve tests were conducted with each fuel, JP-4 and JP-8, with air velocities ranging from 0 to 90 knots. Since no external fires resulted with either JP-4 or JP-8 fuels at the 0- and 90-knot airflow conditions, it was decided to discontinue testing at higher airflows over the test article.

The average maximum standoff space pressure rise was greater for JP-4 fuel, 22.7 psig, than with JP-8 fuel, 16.2 psig.

The fires occurring in the standoff space were of a longer duration with JP-8 than with JP-4 as indicated in Figure 33.

A tabulation of the results of these tests is shown in Table VI.

1.4.3 One-Inch Non-Vented-Standoff Test Article

The test work with the non-vented 1-inch standoff space test article included both static and 90-knot simulated airflow tests with either JP-4 or JP-8 fuel contained in the fuel cavity. Eighteen tests were conducted with this article. (Results of these tests are shown in Table VII.)

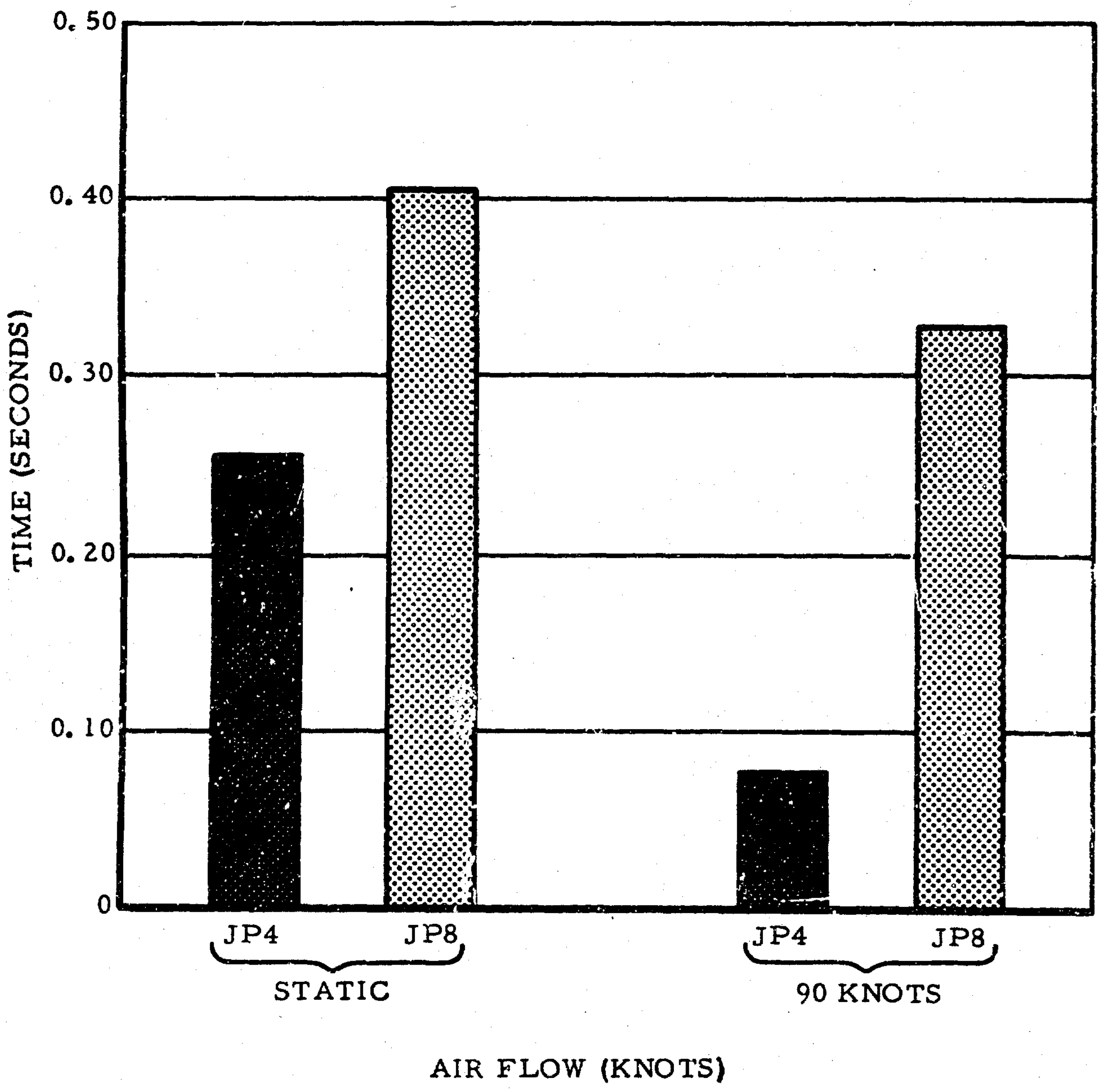


FIGURE 33 - COMPARISON OF 4" NON-VENTED STANDOFF FIRE DURATION JP-4 vs JP-8

TABLE VI.- CONFIRE TESTS WITH 4-INCH STANDOFF TEST ARTICLE

Test No.	Fuel Used	Fuel Temp. (°F)	Air Velocity (kts)	Standoff Fire Duration	Maximum Pressure In Tank (psig)	Time to Maximum Pressure In Tank	Maximum Pressure In Standoff (psig)	Time to Maximum Pressure In Standoff	Time Initial Fuel Spray	Incendiary Function Time	REMARKS
31	JP-4	95	Static	.010	8.0	.010	30.0	.020	.028	.019	Internal damage to test article.
32	JP-4	95	Static	.394	6.5	.015	31.0	.020	.298	.044	
33	JP-4	85	Static	.454+	5.5	.010	19.0	.040	.094	.024	
34	JP-4	85	Static	.193	7.5	.015	30.0	.030	.594	.035	
35	JP-4	95	Static	.392	8.5	.010	19.0	.025	.520	.032	
36	JP-4	85	Static	.068	4.0	.010	40.8	.037	.322	.037	
37	JP-4	90	90	.091	10.5	.010	28.5	.020	.144	.025	
38	JP-4	90	90	.016	5.5	[illegible]	5.5	.007	.430	.008	Damage to test article, weld cracked.
39	JP-4	90	90	.175	10.5	.010	20.5	.025	.606	.031	
40	JP-4	90	90	.078	8.5	.0075	30.5	.020	.314	.028	
41	JP-4	90	90	-	7.5	.010	9.0	.017	.132	.008	
42	JP-4	90	90	.032	11.5	.007	9.0	.013	.048	.039	
43	JP-8	90	Static	.441+	9.5	.013	18.0	.013	.074	.023	
44	JP-8	90	Static	.455	8.5	.011	18.0	.023	.876	.010	
45	JP-8	90	Static	.287	8.5	.010	9.3	.043	Immediately	.012	
46	JP-8	90	Static	.369	5.5	.020	9.0	.025	.860	.009	
47	JP-8	90	Static	.436	6.5	.010	13.7	.028	.974	.008	
48	JP-8	90	Static	.430	8.5	.010	12.0	.010	.740	.008	
49	JP-8	90	90	[illegible]	13.5	.008	[illegible]	.015	.964	.007	
50	JP-8	90	[illegible]	.367+	13.7	.008	22.0	.010	1.000	.008	

TABLE VI.--GUNFIRE TESTS WITH 4-INCH STANDOFF TEST ARTICLE (Continued)

Test No.	Fuel Used	Fuel Temp. (°F)	Air Velocity (kts)	Standoff Fire Duration	Maximum Pressure In Tank (psig)	Time to Maximum Pressure In Tank	Maximum Pressure In Standoff (psig)	Time to Maximum Pressure In Standoff	Time Initial Fuel Spray	Incendiary Function Time	REMARKS
51	JP-8	90	90	.324	11.0	.023	18.0	.044	.958	.009	
52	JP-8	90	90	.269	4.0	.015	19.0	.025	.962	.008	
53	JP-8	90	90	.343	12.5	.010	21.5	.015	.708	.008	
54	JP-8	90	90	.253	11.5	.014	22.5	.014	.478	.008	

NOTE:
1. No external fires, Tests Nos. 31 through 54.
2. Fire in standoff area in all tests except Test No. 41.
3. Initial tank pressure 5 psig except Test No. 38.

TABLE VII.--GUNFIRE TESTS WITH 1-INCH STANDOFF TEST ARTICLE

Test No.	Fuel Used	Fuel Temp. (°F)	Air Velocity (kts)	External Fire	External Fire Duration	Standoff Fire	Standoff Fire Duration	Maximum Pressure In Tank (psig)	Time to Maximum Pressure In Tank	Maximum Pressure In Standoff (psig)	Time to Maximum Pressure In Standoff	Time Initial Fuel Spray	Incendiary Function Time
55	JP-4	100	Static	Yes	Indefinite	Yes	Indefinite	14.0	.010	3.0	.005	Immediately	.032
56	JP-4	95	Static	No	No	Yes	Indefinite	-	-	-	-	.076	.076
57	JP-4	87	Static	Yes	Indefinite	Yes	Indefinite	11.5	.008	2.0	.073	Immediately	.036
58	JP-4	90	Static	Yes	Indefinite	Yes	Indefinite	8.5	.005	2.0	.068	Immediately	.040
59	JP-4	95	Static	Yes	Indefinite	Yes	Indefinite	13.5	.013	4.0	.027	Immediately	.034
60	JP-4	90	90	No	No	Flash	-	12.0	.040	4.0	.060	.020	.016
61	JP-4	90	90	Yes	.040	Flash	-	5.0	.008	4.0	.024	.058	.016
62	JP-4	95	90	No	No	-	-	8.0	.008	9.0	.024	-	-
63	JP-4	90	90	No	No	Flash	-	8.5	.010	5.0	.028	.060	.001
64	JP-8	95	Static	Yes	.954	Yes	Indefinite	11.0	.010	8.0	.088	.034	.016
65	JP-8	95	Static	No	No	Yes	Indefinite	11.0	.010	4.5	.029	.040	.016
66	JP-8	95	Static	Yes	.264	Yes	Indefinite	6.5	.010	18.5	.022	.036	.030
67	JP-8	90	Static	Yes	1.760	Yes	Indefinite	-	-	-	-	Immediately	.020
68	JP-8	90	Static	No	No	Flash	-	11.0	.009	3.5	.020	.064	.084
69	JP-8	90	90	No	No	Yes	.331+	9.5	.005	11.0	.035	.796	.003
70	JP-8	90	90	No	No	Yes	.291	8.5	.008	5.0	.022	.132	.001
71	JP-8	95	90	No	No	Yes	.344+	9.5	.010	6.0	.085	.252	.002
72	JP-8	95	90	No	No	Flash	-	8.5	.008	2.0	.165	.066	.002

NOTE: 1. Initial tank pressure 5 psig.
2. "+" indicates fire ran to end of film.
3. - indicates no oscillograph.
4. Tests Nos. 55, 56, 57, 58, 59, 64, 65, 66 and 67 were indefinite due to large external fire. No 500 film.

There were nine tests (five static, four 90 knots) conducted using JP-4 as candidate fuel. Of the five static, JP-4 tests, four resulted in extremely large external fires. In one test, at 90 knots, a small fire developed immediately after the penetration of the projectile (Figure 34) but was blown off the test article by the 90-knot airflow.

In the static, JP-8 liquid phase test, conducted during this sequence, there were no self-sustaining external fires. Three tests resulted in small fires on the test pad but in each case did not flash back to the JP-8 fuel which was spurting from the test article. No external fires resulted during any of the 90-knot airflow tests even though fire did exist in the standoff space.

Pressure rises in the fuel cavity were similar for both fuels but in the standoff space the rise was slightly higher for JP-8, 7.3 psig, than JP-4, 4.0 psig.

From observation of the static and 90 knot, JP-4-JP-8 liquid phase tests, it appeared that the difference in the results was directly related to the individual fuel characteristics. This was particularly evident in the static testing where the shots with JP-4 fuel resulted in extremely large fires while those with JP-8 fuel resulted in small fires on the test pad which were not self-sustaining.

1.4.4 Nine-Inch Vented Standoff Test Article

A total of 45 tests was conducted on the test article which had its 9-inch standoff space ventilated. External airflows over the test article during this series of tests were either 90 or 300 knots. Figures 35 and 36 show how the airflow entered and exited the standoff space. For each of the fuels (JP-4 and JP-8) used, tests were conducted with two airflows over the test article and four ventilation rates in the standoff space. At the 90-knot airflow over the test article, ventilation rates of 23 or 96 air changes per minute (acpm) were obtained by changing the size of the ram air inlet duct which was directed into the air stream. With the 300-knot airflow over the test article, ventilation rates of 101 or 325 acpm were obtained the same way.

The average maximum pressure rise in the standoff space, which was previously larger for JP-4, was essentially the same for both fuels. The pressure rise averaged 8.0 psig and the average time to the peak pressure was 0.024 seconds.

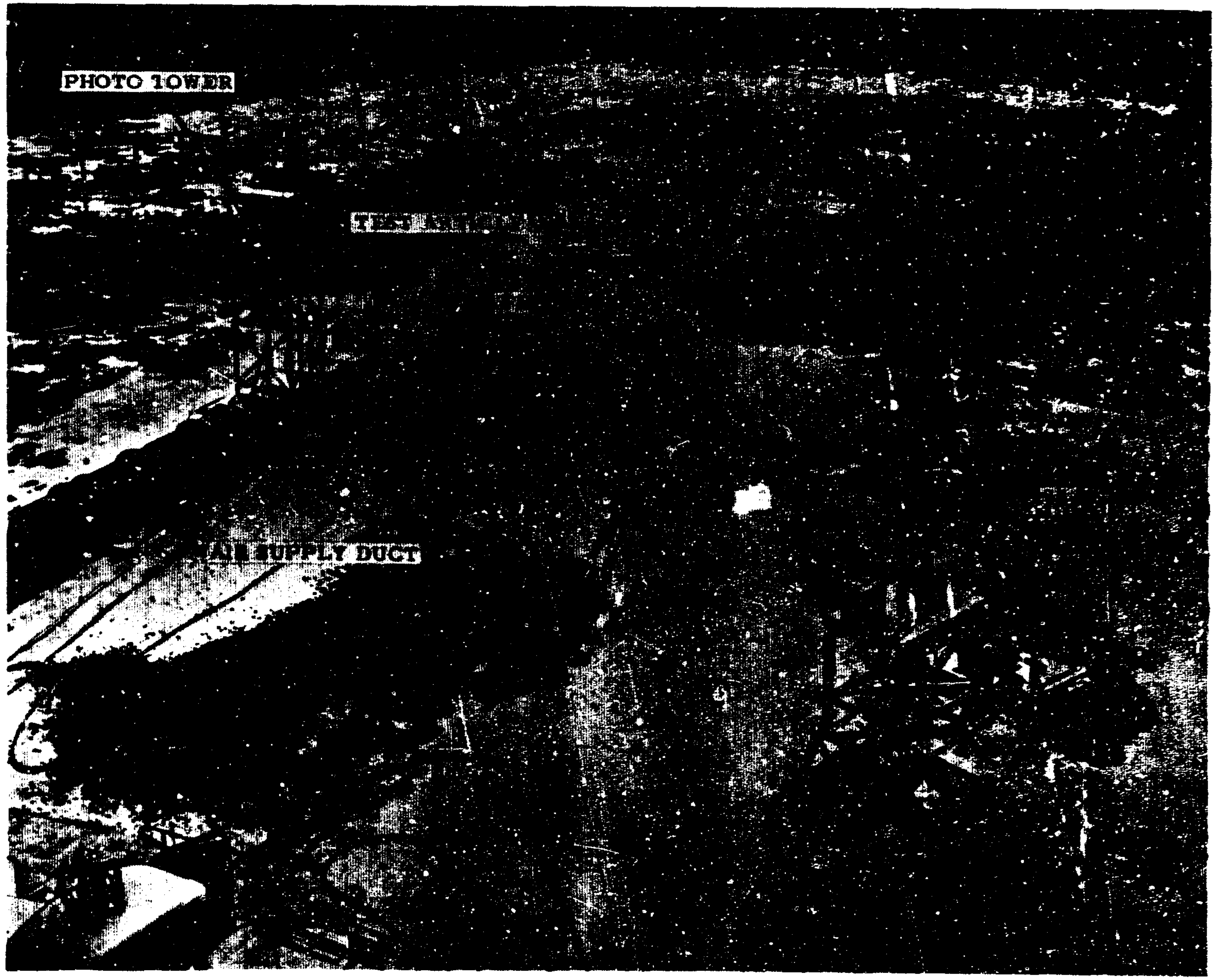


FIGURE 34 - FIRE BLOWN OFF TEST ARTICLE

FIGURE 35 - VENTILATION AIR ENTRANCE

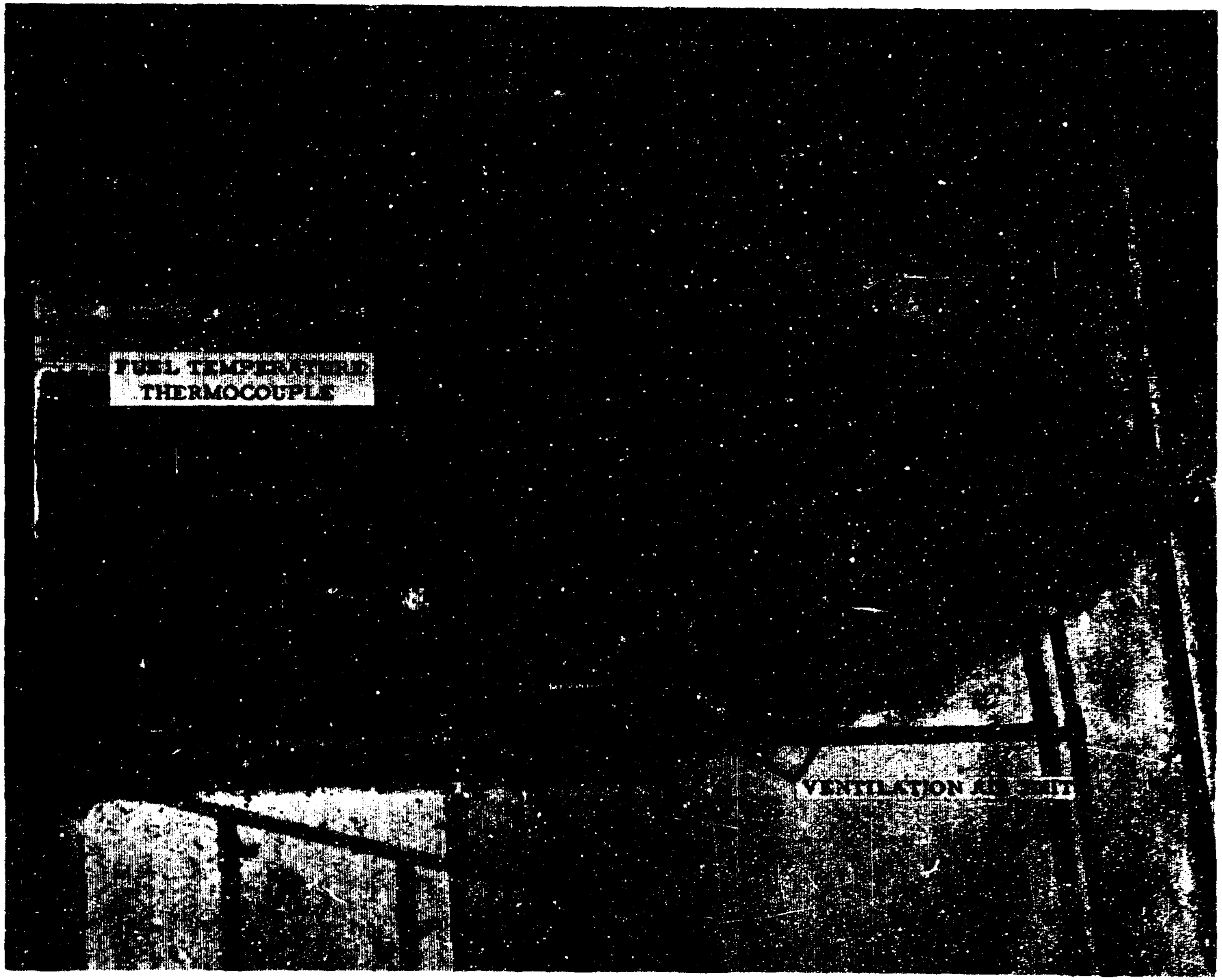


FIGURE 36 - VENTILATION AIR EXIT 9" STANDOFF T/A

During all tests, there was a fire in the standoff space directly after the incendiary projectile pierced the striker plate. This fire did not sustain itself. In 42 percent of the tests conducted with this test article and JP-8 fuel, a second pressure rise - smaller than the initial rise - was noted on the oscillograph record approximately 1.0 to 2.0 seconds after the initial ignition of the fuel. This second pressure rise possibly indicated a reignition of the fuel and explains the exceptionally long fire duration in the standoff space as depicted in Figure 37.

(Tabulated results of these tests are shown in Table VIII.)

1.4.5 Four-Inch Vented Standoff Test Article

Thirty-seven tests were conducted with the 4-inch ventilated standoff test article. The fuels utilized in these tests were JP-4 and JP-8. All of these tests were conducted with either of two simulated airflows (90 and 300 knots) over the test article and four ventilation rates in the standoff space for each of the fuels tested. At the 90-knot airflow over the test article, standoff space ventilation rates were 18 or 75 acpm and at the 300-knot airflow over the article, the ventilation rates were 58 or 180 acpm. These ventilation rates were achieved in the same manner as those with the 9-inch standoff article - by varing the size of a ram air inlet duct which was directed into the air stream.

(Results of these tests are presented in Table IX.)

In all tests, with both JP-4 and JP-8 fuels, a fire existed in the standoff space of the test article. The duration of this fire was much greater for JP-8 than JP-4 as shown in Figure 38.

During five tests, one with JP-8 fuel and four with JP-4 fuel, the ventilation exhaust tube was damaged thereby permitting fuel to spill into the aft section of the test article. The fire, which existed in the standoff space, propagated to the aft section of the test article. In the tests with JP-4 fuel, these fires were large and self-sustaining while the tests with the JP-8 fuel, fires were not self-sustaining.

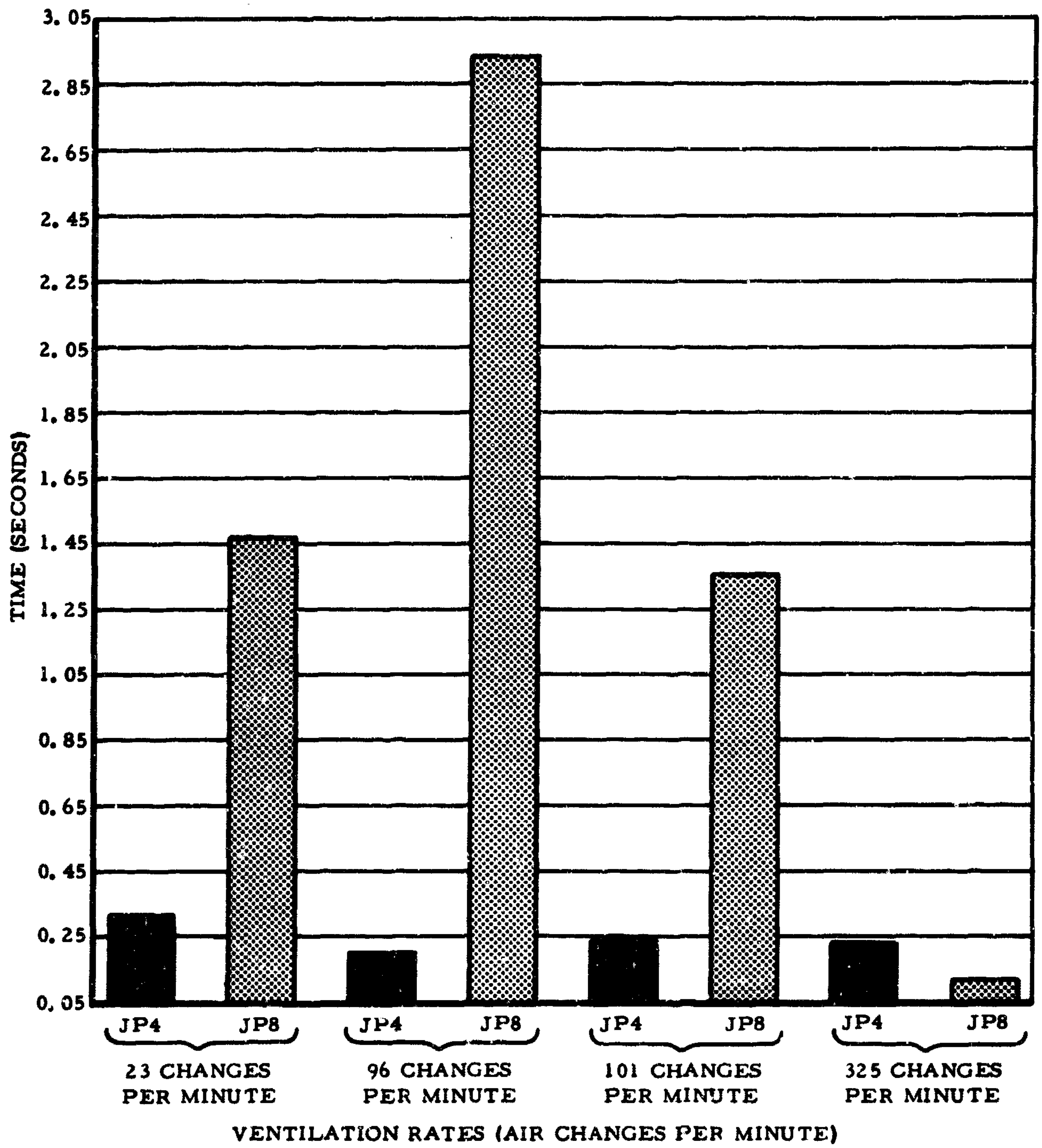


FIGURE 37 - 9" VENTED STANDOFF FIRE DURATION vs ACPM VENTILATION RATES

TABLE VIII.--GUNFIRE TESTS WITH 9-INCH VENTED TEST ARTICLE

Test No.	Fuel Used	Fuel Temp. (°F)	Air Velocity (kts)	Standoff Fire Duration	Maximum Pressure In Tank (psig)	Time to Maximum Pressure In Tank	Maximum Pressure In Standoff (psig)	Time to Maximum Pressure In Standoff	Time to External Fuel Spray	Incendiary Function Time	Air Changes Per Min Standoff	REMARKS
73	JP-4	98	90	.340	5.0	.140	2.0	.015	Indefinite	.010	23	Indefinite, no 500 frame film.
74	JP-4	90	90	.387	14.0	.020	4.0	.010	.040	.007	23	
75	JP-4	95	90	.342	14.0	.020	4.0	.005	.348	.006	23	
76	JP-4	95	90	.307	17.0	.040	4.0	.005	Indefinite	.007	23	Pressure line blown off. Indefinite, no 500 frame film.
77	JP-4	95	90	.238	18.5	.035	5.8	.050	Indefinite	.010	23	Indefinite, No 500 frame film.
78	JP-4	90	90	.342+	14.0	.045	6.2	.060	Indefinite	.010	23	Indefinite, No 500 frame film.
79	JP-4	90	90	.257	20.0	.045	5.4	.020	.268	.011	23	
80	JP-8	90	90	.181	25.3	.038	4.5	.020	Indefinite	.006	23	Indefinite, no 500 frame film.
81	JP-8	90	90	.277	11.4	.040	5.4	.030	.305	.028	23	
82	JP-8	90	90	.309	18.0	.018	5.7	.018	Indefinite	.011	23	Indefinite, no 500 frame film.
83	JP-8	90	90	.287	14.3	.026	5.2	.026	.327	.014	23	
84	JP-8	90	90	.269	18.0	.018	5.7	.018	Indefinite	.008	23	Indefinite, no 500 frame film.
85	JP-8	95	90	.253	20.3	.041	6.2	.015	Indefinite	.010	23	Indefinite, no 500 frame film.
86	JP-8	90	300	.410	17.0	.025	4.4	.015	.036	.011	101	
87	JP-8	90	300	.225	22.6	.018	6.0	.013	.172	.009	101	
88	JP-8	90	300	.254	16.0	.020	6.4	.020	.204	.010	101	
89	JP-8	90	300	.145	-	-	-	-	.174	.009	101	
90	JP-8	90	300	.229	21.0	.015	10.0	.025	.146	.024	101	
91	JP-8	90	300	.311	11.3	.025	10.8	.017	.026	.016	101	
92	JP-4	90	300	.275	13.4	.018	10.0	.008	.042	.009	101	
93	JP-4	90	300	.192	16.7	.010	7.8	.010	.156	.009	101	
94	JP-4	88	300	.142	17.4	.008	9.8	.013	.222	.008	101	
95	JP-4	90	300	.213	17.0	.010	6.5	.020	.208	.008	101	

TABLE VIII.--GUNFIRE TESTS WITH 9-INCH VENTED TEST ARTICLE (Continued)

Test No.	Fuel Used	Fuel Temp. (°F)	Air Velocity (kts)	Standoff Fire Duration	Maximum Pressure In Tank (psig)	Time to Maximum Pressure In Tank	Maximum Pressure In Standoff (psig)	Time to Maximum Pressure In Standoff	Time to External Fuel Spray	Incendiary Function Time	Air Changes Per Min Standoff	REMARKS
96	JP-4	90	300	.413+	20.5	.010	7.8	.025	.054	.006	101	
97	JP-4	90	300	.200	9.0	.015	10.2	.015	.044	.008	101	
98	JP-4	90	90	.267	13.2	.055	4.2	.015	.106	.008	96	
99	JP-4	90	90	.091	8.7	.040	6.1	.080	.322	.016	96	
100	JP-4	90	90	.214	15.5	.015	6.4	.060	.040	.025	96	
101	JP-4	90	90	.196	15.3	.020	7.2	.025	.110	.039	96	
102	JP-4	90	300	.268	8.2	.005	5.0	.040	.032	.025	325	
103	JP-4	90	300	.252	11.8	.035	5.6	.035	.184	.008	325	
104	JP-4	90	300	.234	15.7	.010	6.5	.035	.422	.019	325	
105	JP-4	90	300	.208	13.6	.020	6.2	.050	.064	.014	325	
106	JP-8	90	300	.042	-	-	-	-	.082	.037	325	
107	JP-8	90	300	.091	14.2	.050	15.9	.030	.078	.016	325	
108	JP-8	90	300	.048	19.5	.030	21.9	.045	.128	.043	325	
109	JP-8	90	300	.078	11.0	.060	18.6	.030	.122	.012	325	
110	JP-8	90	90	.371	11.5	.200	4.8	.010	.036	.007	96	
111	JP-8	90	90	Indefinite	18.7	.020	5.0	.010	.036	.007	96	
112	JP-8	90	90	2.604	11.5	.035	8.0	.030	.026	.006	96	
113	JP-4	90	90	.178	14.3	.060	5.6	.020	.036	.008	96	
114	JP-4	90	90	.269	13.7	.060	5.8	.025	.060	.025	96	
115	JP-4	90	90	.203	7.0	.100	4.4	.030	.118	.013	96	
116	JP-4	95	300	.086	20.0	.015	28.8	.025	.014	.016	325	
117	JP-4	90	300	.055	17.4	.060	26.8	.020	.010	.035	325	

NOTE:
1. No external fires.
2. Fire in standoff, all Tests Nos. 73-117.
3. "+" indicates fire to end of film.
4. Test No. 73 lost pressure in tank.
5. - indicates no record.
6. Initial tank pressure - 5 psig.

TABLE IX.--GUNFIRE TESTS WITH 4-INCH VENTED TEST ARTICLE

Test No.	Fuel Used	Fuel Temp. (°F)	Air Velocity (kts)	Standoff Fire Duration	Maximum Pressure In Tank (psig)	Time to Maximum Pressure In Tank	Maximum Pressure In Standoff (psig)	Time to Maximum Pressure In Standoff	Time External Fuel Spray	Incendiary Function Time	Air Changes Per Min Standoff	REMARKS
118	JP-4	90	90	.341	11.7	.010	4.5	.010	.058	.008	18	
119	JP-4	90	90	.221	9.8	.007	2.5	.086	.048	.015	18	
120	JP-4	95	90	.010	12.0	.020	2.4	.077	.068	.036	18	
121	JP-4	90	90	.133	13.4	.023	4.0	.086	.044	.006	18	
122	JP-4	87	90	.313+	11.5	.025	2.0	.080	.066	.013	18	
123	JP-4	90	90	Indefinite	12.5	.023	6.4	.098	.080	Indefinite	18	Indefinite due to light film.
124	JP-4	92	300	.327+	13.4	.021	4.0	.094	.038	.006	58	
125	JP-4	90	300	.295	11.8	.023	4.8	.085	.064	.008	58	
126	JP-4	87	300	.321	12.0	.024	3.2	.089	.026	.008	58	
127	JP-4	93	300	.381+	7.8	.023	5.4	.038	.026	.006	58	Airflow stopped prematurely.
128	JP-8	92	90	Indefinite	11.5	.023	3.2	.108	.026	Indefinite	18	Lost camera coverage.
129	JP-8	93	90	Indefinite	13.4	.250	5.3	.100	.158	.005	18	Indefinite due to light film.
130	JP-8	90	90	.260	-	-	-	-	.088	.007	18	Indefinite due to light film.
131	JP-8	90	90	.194	11.3	.025	7.0	.095	.006	.009	18	
132	JP-8	95	90	.279	12.7	.029	4.8	.100	.026	.006	18	
133	JP-8	90	90	.408	11.0	.029	4.2	.117	.038	.007	18	
134	JP-8	87	300	.277	12.0	.014	4.2	.065	.022	.003	58	
135	JP-8	93	300	.375+	12.3	.020	4.0	.076	Indefinite	.004	58	Indefinite due to leak in tank.
136	JP-8	95	300	Indefinite	11.7	.017	6.0	.085	.022	.003	58	Indefinite due to light film.
137	JP-8	90	300	.399+	11.3	.020	7.3	.067	Indefinite	.002	58	Indefinite due to leak in tank.
138	JP-8	90	90	.275	8.7	.023	2.5	.034	.200	.005	75	
139	JP-8	90	90	.411+	12.5	.024	3.5	.035	.050	.009	75	
140	JP-8	90	90	.415+	9.8	.020	7.4	.055	.256	.011	75	
141	JP-8	90	90	4.232+	12.5	.020	5.3	.073	.258	.018	75	
142	JP-8	90	300	.431+	11.5	.010	2.9	.057	.054	.009	180	

TABLE IX.--CONFINE TESTS WITH 4-INCH VENTED TEST ARTICLE (Continued)

Test No.	Fuel Used	Fuel Temp. (°F)	Air Velocity (kts)	Standoff Fire Duration	Maximum Pressure In Tank (psig)	Time to Maximum Pressure In Tank	Maximum Pressure In Standoff (psig)	Time to Maximum Pressure In Standoff	Time External Fuel Spray	Incendiary Function Time	Air Changes Per Min Standoff	REMARKS
143	JP-8	92	300	4.572+	11.7	.013	2.3	.100	.026	.018	180	
144	JP-8	95	300	1.474	11.5	.013	3.6	.135	.034	.016	180	
145	JP-8	90	300	3.844	10.5	.013	2.0	.110	.044	.016	180	
146	JP-4	95	300	.132	12.0	.010	4.7	.110	.026	.010	180	Damage to tank, weld cracked.
147	JP-4	90	300	.317+	8.5	.018	1.7	.120	.042	.011	180	
148	JP-4	90	300	.326+	10.0	.015	3.3	.060	.036	.010	180	
149	JP-4	90	300	.167	8.0	.020	5.5	.105	.012	.006	180	Damage to test article, cracked welds.
150	JP-4	90	90	Indefinite	11.5	.020	3.4	.063	.026	.012	75	Indefinite due to light film, vent tube blown off.
151	JP-4	90	90	.348	12.7	.010	2.3	.085	.082	.012	75	
152	JP-4	90	90	.233	10.3	.015	5.0	.092	.100	.009	75	
153	JP-4	90	90	.298	11.0	.013	4.5	.078	.184	.009	75	Exhaust tube blown off.
154	JP-4	90	90	Indefinite	12.0	.013	4.0	.038	.038	.009	75	Indefinite due to fight film. Damage to tank.

NOTE:
1. Test No. 154, fire started at rear of test article.
2. Initial tank pressure 5 psig all tests.
3. No external fires except Tests Nos. 127, 149, 154.
4. Fire in standoff space, all tests.
5. "+" indicates fire to end of film.
6. - indicates no record.

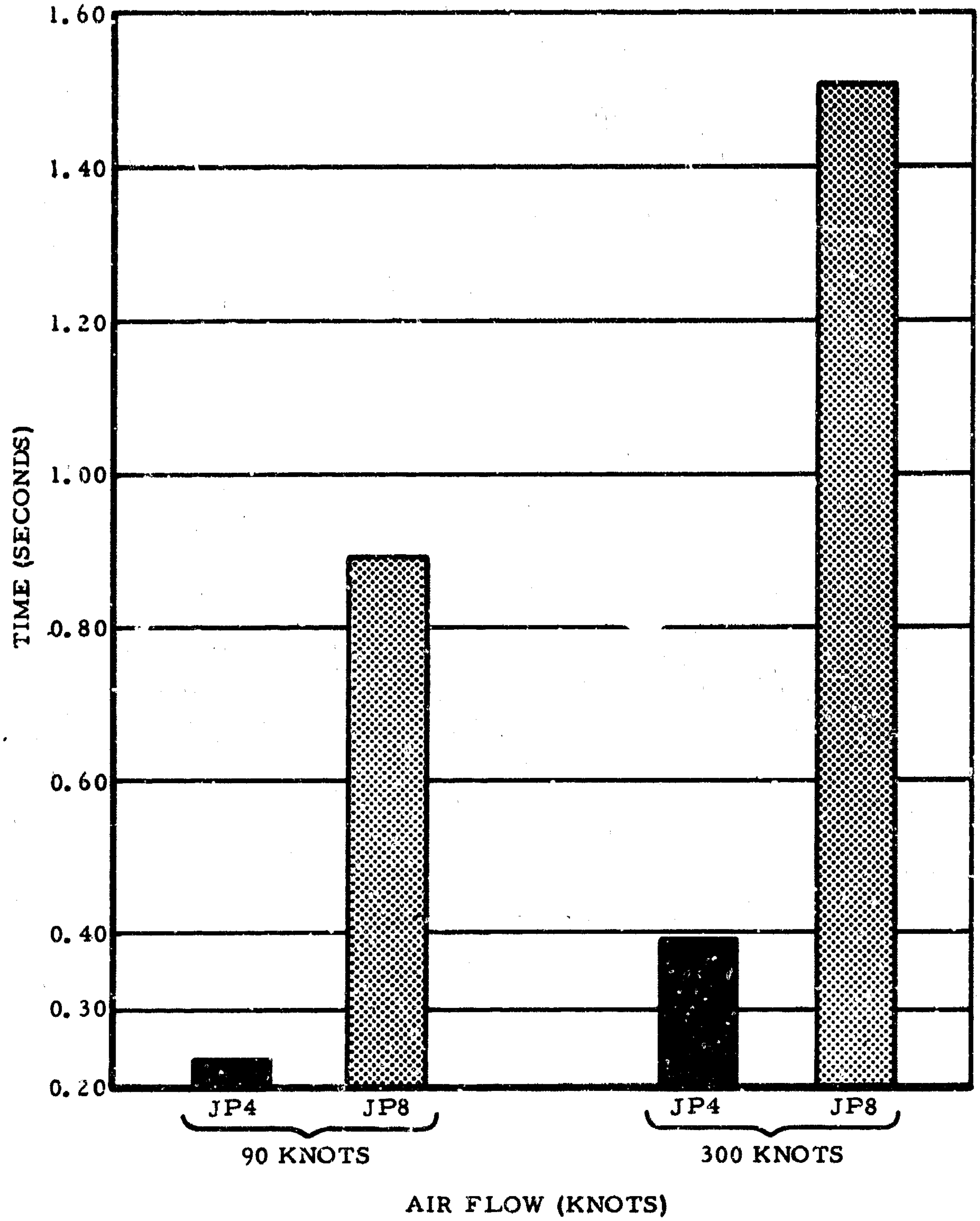


FIGURE 38 - FIRE DURATION JP-8 vs JP-4 4" VENTED TEST ARTICLE

During this series of tests, two fires, external of the test article, occurred. Both fires were with JP-4 fuel. The first fire occurred when the simulated airflow was prematurely stopped and the fire in the standoff space flashed out the ventilation entrance tube and ignited the fuel laying on the test pad. The other external fire resulted when the ventilation exhaust tube failed and standoff space fire propagated to the aft section of the test article and the fuel spillage on the test pad.

The pressure rises in the standoff space were similar for each fuel tested and averaged 4.2 psig. Fuel cavity pressure rises with both fuels, JP-4 and JP-8, averaged 11.0 psig.

It should be again noted that where fire occurred in the aft section of the test article due to the ventilation exhaust tube being damaged, the resultant fires with JP-4 fuel were large and self-sustaining while fires with JP-8 fuel were not self-sustaining.

1.4.6 Miscellaneous Tests

Additional tests were conducted utilizing the 9- and 4-inch ventilated standoff space test articles. The test conditions for these "shots" are presented in Table X. The fuel used in these tests was either JP-4 or JP-8 and the simulated airflow over the test article was maintained at 90 or 300 knots, depending on the test being conducted.

In the tests with the 9-inch standoff space test article, two standoff space ventilation rates, 23 and 97 acpm were employed. The results of these tests are shown in Table XI.

From visual observation, it was evident that a fire existed in the standoff space during each of the tests.

Analysis of the oscillograph records indicated that the average pressure rise in the standoff space for these tests was 6.4 psig for the tests with JP-4 and 8.2 psig for those with JP-8. The average tank pressure rise was 4.2 psig for JP-4 and 5.0 psig for JP-8. Although the absence of external fires during these tests and the similarity of test data indicated no distinct advantage of JP-8 over JP-4 fuel, it should be noted that in 41 percent of the tests conducted with JP-8 fuel a second pressure rise was indicated on the oscillograph record.

TABLE X.--MISCELLANEOUS TESTS-TEST CONDITIONS

Tank Configuration	Fuel Used	Fuel Temp. (°F)	Simulated Airflow (knots)	Ventilation Rate (changes/min)	Initial Tank Pressure (psig)	No. of Tests
9" Vented SO*	JP-4	75± 5	90	23	5.0	3
9" Vented SO	JP-4	75± 5	90	97	5.0	3
9" Vented SO	JP-8	75± 5	90	23	5.0	3
9" Vented SO	JP-8	75± 5	90	97	5.0	3
9" Vented SO	JP-4	90± 5	90	23	None	3
9" Vented SO	JP-4	90± 5	90	97	None	3
9" Vented SO	JP-8	90± 5	90	23	None	3
9" Vented SO	JP-8	90± 5	90	97	None	3
**4" Vented SO	JP-4	90± 5	90	18	5.0	3
**4" Vented SO	JP-8	90± 5	90	18	5.0	3
***4" Vented SO	JP-4	90± 5	90	18	None	3
***4" Vented SO	JP-8	90± 5	90	18	None	3
					Total Tests	36

*SO - Abbreviation for "Standoff Space."
**10-pore/inch polyurethane foam in the standoff space.
***2 inches fuel in tank plus 10-pore/inch polyurethane foam in tank.

TABLE XI.--GUNFIRE TESTS WITH 9-INCH VENTED TEST ARTICLE (MISCELLANEOUS TESTS)

Test No.	Fuel Used	Fuel Temp. (°F)	Initial Pressure	Air Velocity (kts)	Standoff Fire Duration	Maximum Pressure In Tank (psig)	Time to Maximum Pressure In Tank	Maximum Pressure In Standoff (psig)	Time to Pressure In Standoff	Time to External Fuel Spray	Incendiary Function Time	Air Changes Per Min Standoff	REMARKS
155	JP-4	75	2 psig	90	Indefinite	3.4	.010	7.5	.035	.566	.006	23	Indefinite, due to glare on Plexiglas.
156	JP-4	80	2 psig	90	Indefinite	3.0	.125	3.1	.040	.202	.007	23	Indefinite, due to glare on Plexiglas.
157	JP-4	80	5 psig	90	.201	6.1	.145	12.0	.060	.234	.011	23	
158	JP-4	75	5 psig	90	.312	10.5	.030	7.0	.030	Indefinite	.008	23	Indefinite, due to no 500 frame film.
159	JP-4	90	0 psig	90	.225	7.5	.049	6.5	.040	.294	.008	23	
160	JP-4	90	0 psig	90	.472+	2.5	.037	4.0	.097	.230	.011	23	
161	JP-4	90	0 psig	90	.450+	2.8	.095	6.0	.030	.342	.010	23	
162	JP-4	90	0 psig	90	.441+	2.5	.110	5.0	.030	.236	.009	23	
163	JP-8	75	5 psig	90	Indefinite	9.0	.040	2.5	.010	.456	.010	23	Indefinite, due to glare on Plexiglas.
164	JP-8	78	5 psig	90	.319	6.5	.085	8.0	.048	1.196	.007	23	Second pressure rise in standoff at 1.5 seconds 4.0 psig.
165	JP-8	75	5 psig	90	.436	8.0	.050	5.5	.040	.636	.006	23	Second pressure rise in standoff at 2.7 seconds 3.8 psig.
166	JP-8	90	0 psig	90	.457+	3.2	.080	5.6	.040	See Note	.010	23	
167	JP-8	90	0 psig	90	.438+	2.0	.100	11.5	.050	.604	.008	23	
168	JP-8	90	0 psig	90	0	2.5	.530	4.5	.040	See Note	.008	23	
169	JP-4	75	5 psig	90	.266+	4.1	.840	[illegible]	.045	.966	.012	101	
170	JP-4	75	5 psig	90	.289+	5.1	.950	5.6	.055	[illegible]	.311	101	Damage to tank.
171	JP-4	75	5 psig	90	.193+	4.9	.060	7.6	.041	.706	.012	101	
172	JP-4	90	0 psig	90	.530+	2.3	.125	6.0	.048	.654	.007	101	
173	JP-4	90	0 psig	90	.506	3.2	.155	7.0	.050	See Note	.006	101	
174	JP-4	90	0 psig	90	Indefinite	2.7	.185	6.5	.040	.450	.009	101	Indefinite, due to glare on Plexiglas.
175	JP-8	75	5 psig	90	.453+	11.0	.130	18.5	.042	1.160	.012	97	Second pressure rise in standoff at 1.4 seconds 2.7 psig.

TABLE XI.--GUNFIRE TESTS WITH 9-INCH VENTED TEST ARTICLE (MISCELLANEOUS TESTS) (Continued)

Test No.	Fuel Used	Fuel Temp. (°F)	Initial Pressure	Air Velocity (kts)	Standoff Fire Duration	Maximum Pressure In Tank (psig)	Time to Maximum Pressure In Tank	Maximum Pressure In Standoff (psig)	Time to Pressure In Standoff	Time to External Fuel Spray	Incendiary Function Time	Air Changes Per Min Standoff	REMARKS
176	JP-8	75	5 psig	90	.296	4.5	.122	12.6	.042	1.066	.007	97	Second pressure rise in standoff at 1.1 seconds 10.6 psig. Second pressure rise in tank at 1.10 seconds 4.7 psig.
177	JP-8	75	5 psig	90	Indefinite	6.0	.048	8.0	.045	.302	Indefinite	97	Second pressure rise in standoff at 1.22 seconds 10.6 psig. Second pressure rise in tank at 1.29 seconds 5.3 psig.
178	JP-8	87	0 psig	90	.343	1.8	.050	8.6	.040	See Note	.010	97	
179	JP-8	90	0 psig	90	.470+	2.4	.060	6.8	.040	3.020	.006	97	
180	JP-8	90	0 psig	90	.452+	1.7	.013	6.0	.050	1.032	.007	97	

NOTE:
1. Fire in standoff area all tests except Test No. 168. Tests Nos. 163 and 177 were indefinite.
2. No external fires, all tests.
3. "+" indicates fire to end of film.
4. Test No. 166 no fuel spray to end of film at 4.668 seconds.
5. Test No. 168 no fuel spray to end of film at 4.660 seconds.
6. Test No. 173 no fuel spray to end of film at 2.936 seconds.
7. Test No. 178 no fuel spray to end of film at 3.360 seconds.

A series of tests was conducted using the 4-inch ventilated standoff test article, 10-pore-per-inch polyurethane foam, and JP-4 and JP-8 fuels. For one set of tests in the series, the foam was placed in the standoff space of the test article (see Figure 39). In these tests the projectile was fired through the foam into the liquid fuel. Observations and analysis of the oscillograph records indicated that there was no reaction (fire) between the fuel (JP-4 or JP-8) and the incendiary projectile. The incendiary particles appeared to have been "wiped" from the projectile by the polyurethane foam.

The remaining tests of this series were conducted with polyurethane foam in the fuel tank portion of the test article (see Figure 40). For these the tank was filled to the 2-inch level with JP-4 or JP-8 fuel. The tank was then sealed and permitted to stand for approximately 30 minutes prior to the tests. The projectile was then fired through the standoff space and into the vapor portion of the fuel tank.

Analysis of the oscillograph records of these tests indicated the pressure rise in the tank to be negligible.

Visual observation of these tests showed that there was a fire in the standoff space during each of the tests and an increase of airflow in the standoff space caused an increase in the intensity of the fire. During all of the test conducted with JP-4, the fire propagated into the tank portion of the article and resulted in damage to the foam. Figures 41, 42, and 43 show the extent of the damage for a typical JP-4 test.

In the test conducted with JP-8, the fire in the standoff space did not propagate into the tank and little damage at the penetration hole resulted. Figure 44 shows the damage.

Tables XII and XIII present the results of the tests conducted using the polyurethane foam in either the standoff or tank space. Under these test conditions JP-8 appeared to be a safer candidate fuel than JP-4 because the JP-8 fuel fire in the standoff space did not propagate into the fuel tank portion of the test article.

A final series of tests was conducted with a simulated "skin type" test article. For these tests there was no standoff space; i.e., the projectile path was through the striker plate

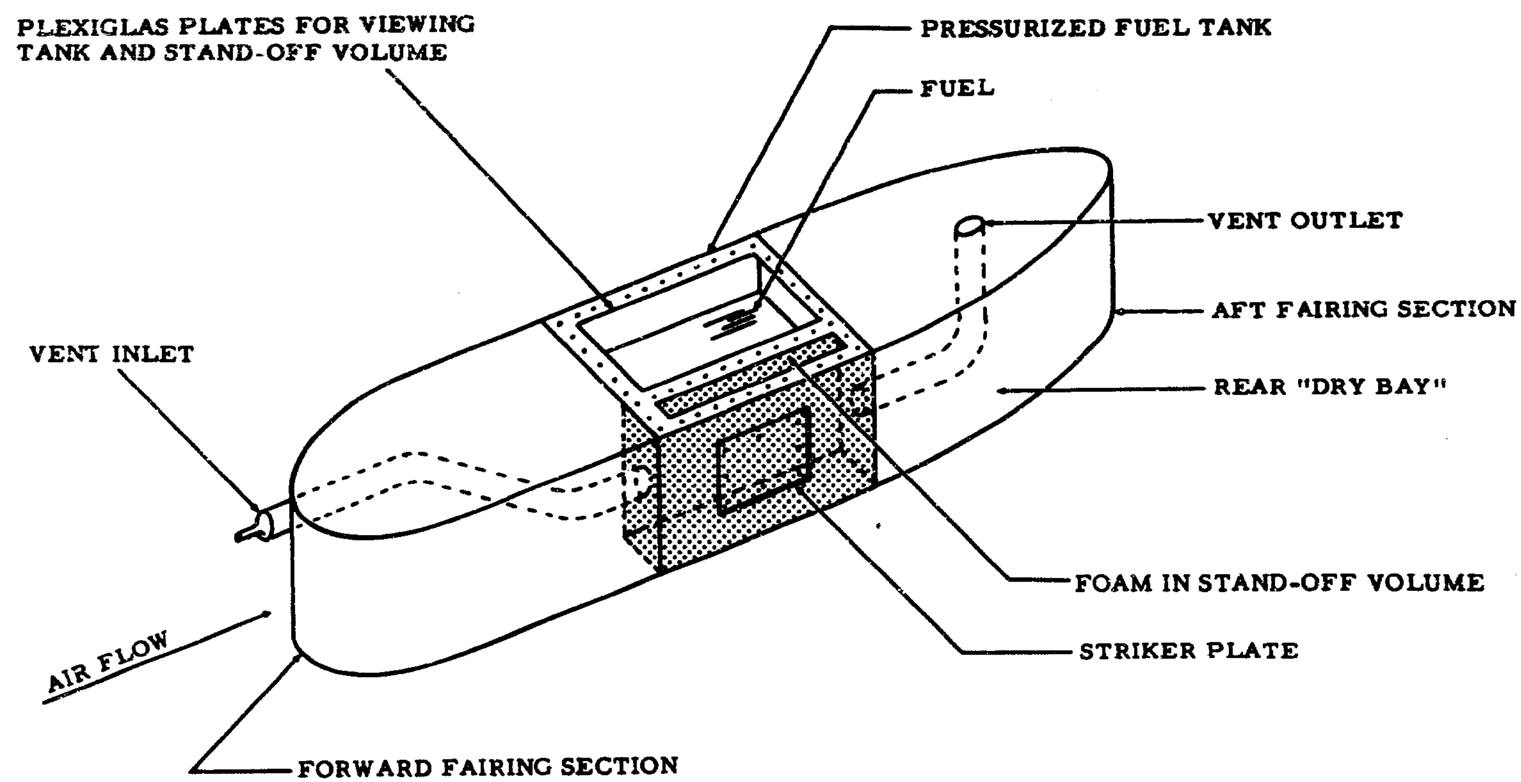


FIGURE 39 - GUNFIRE TEST ARTICLE WITH 10-PORE POLYURETHANE IN STANDOFF AREA

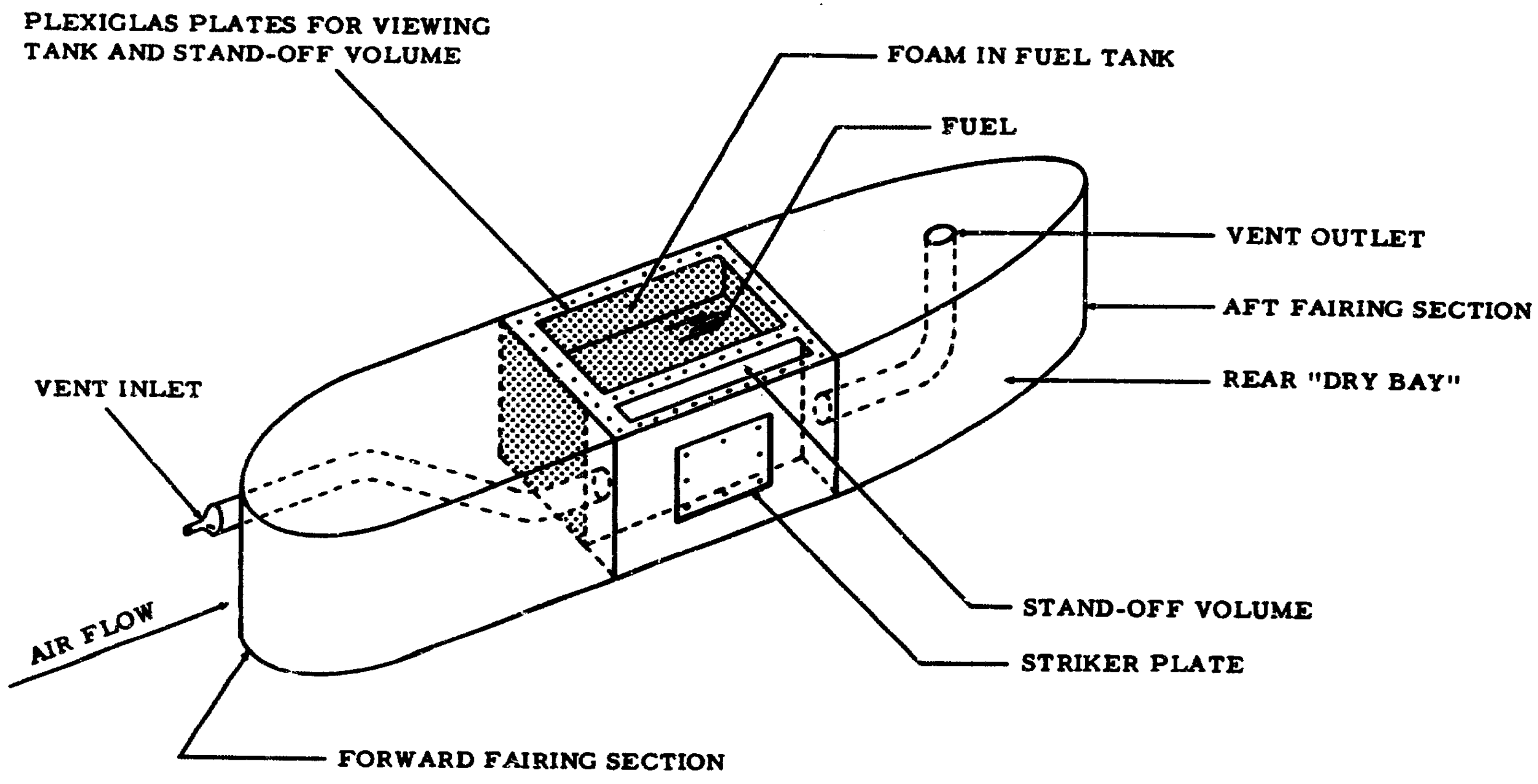


FIGURE 40 - GUNFIRE TEST ARTICLE WITH 10-PORE POLYURETHANE FOAM IN TANK AREA

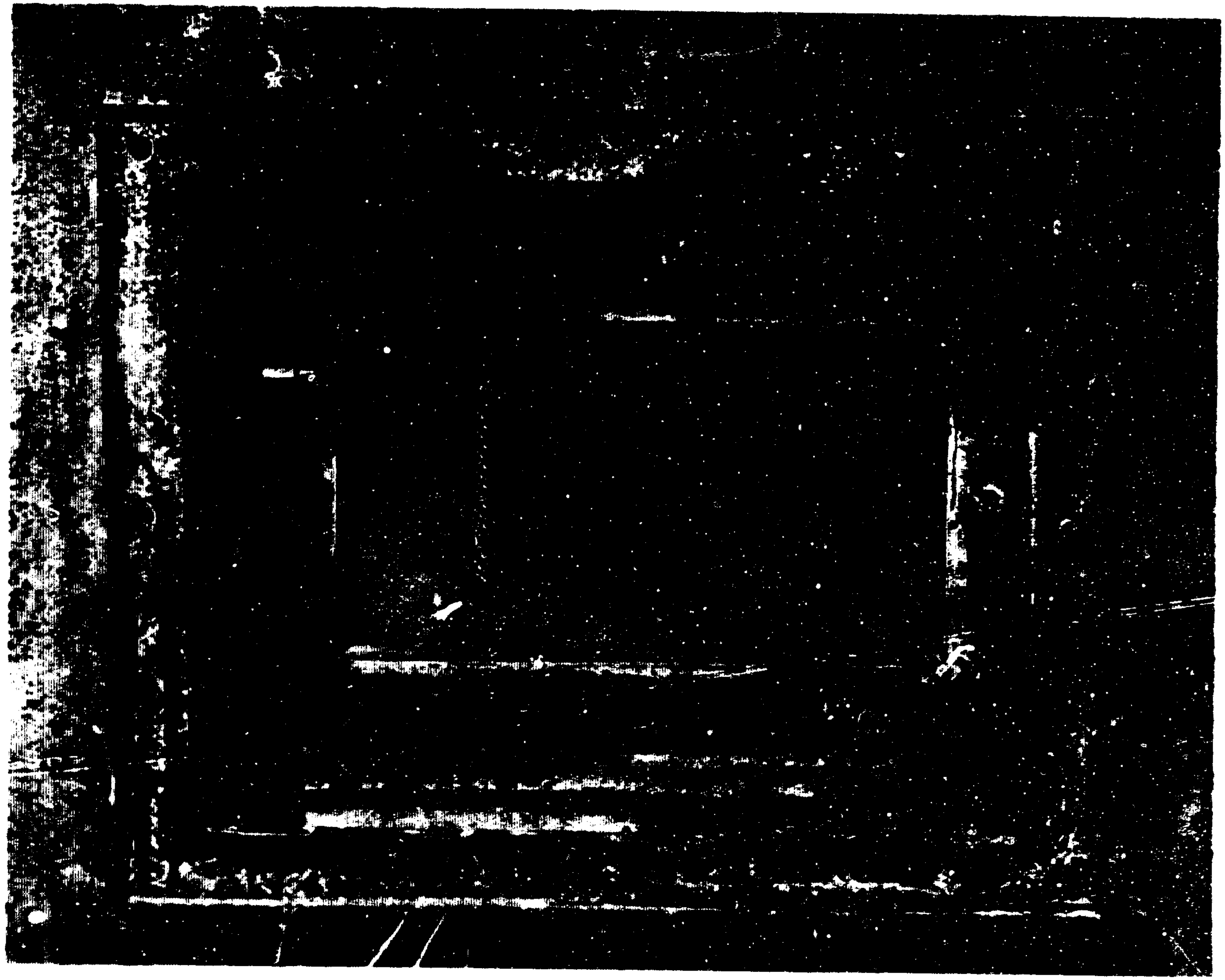


FIGURE 41 - DAMAGE TO POLYURETHANE FOAM IN TANK AREA
4" TEST ARTICLE AND JP-4

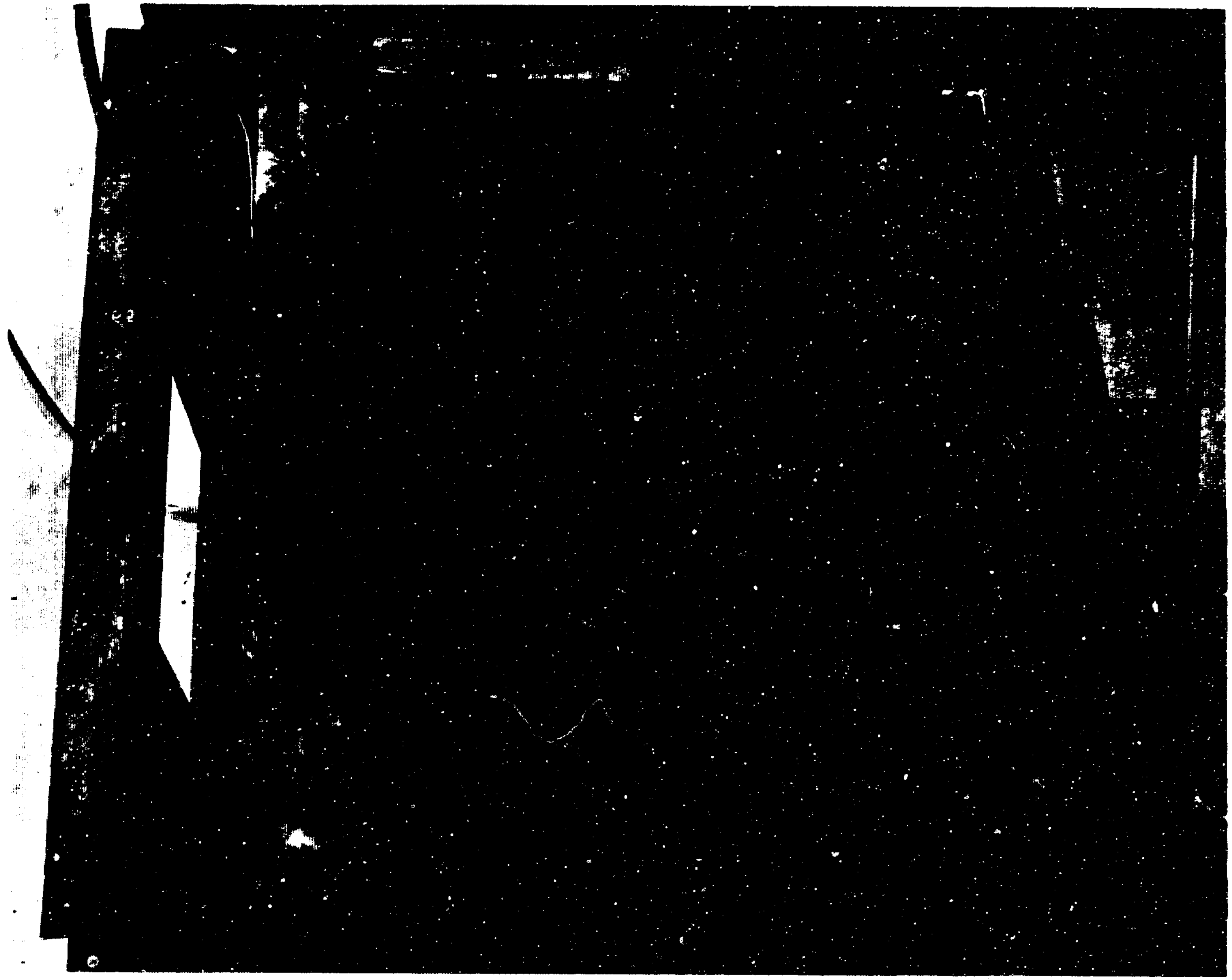


FIGURE 42 - DAMAGE TO POLYURETHANE FOAM IN TANK AREA
4" TEST ARTICLE AND JP-4

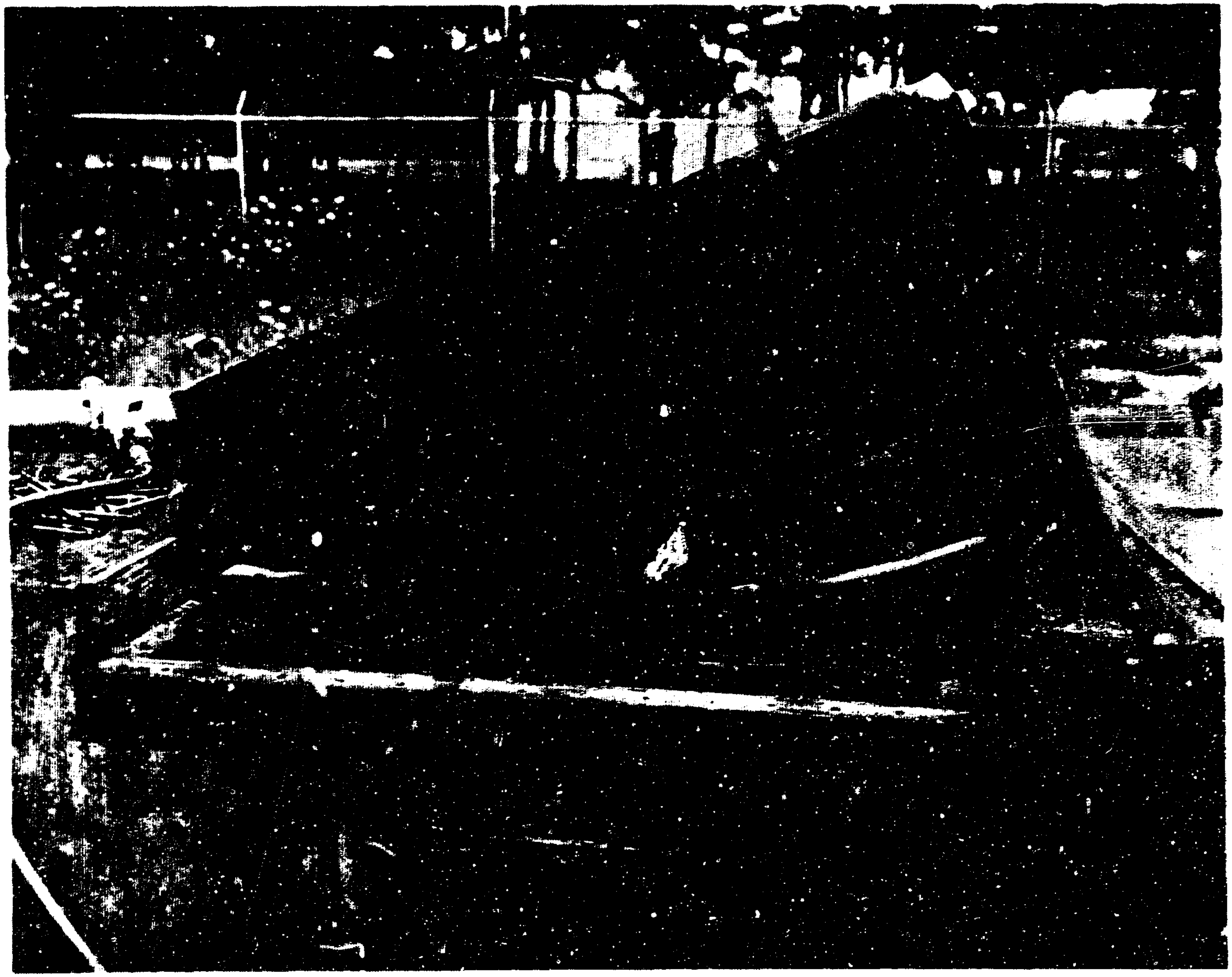


FIGURE 43 - FOAM SHOWING FIRE PROPAGATION LINES 4" STANDOFF
TEST ARTICLE AND JP-4

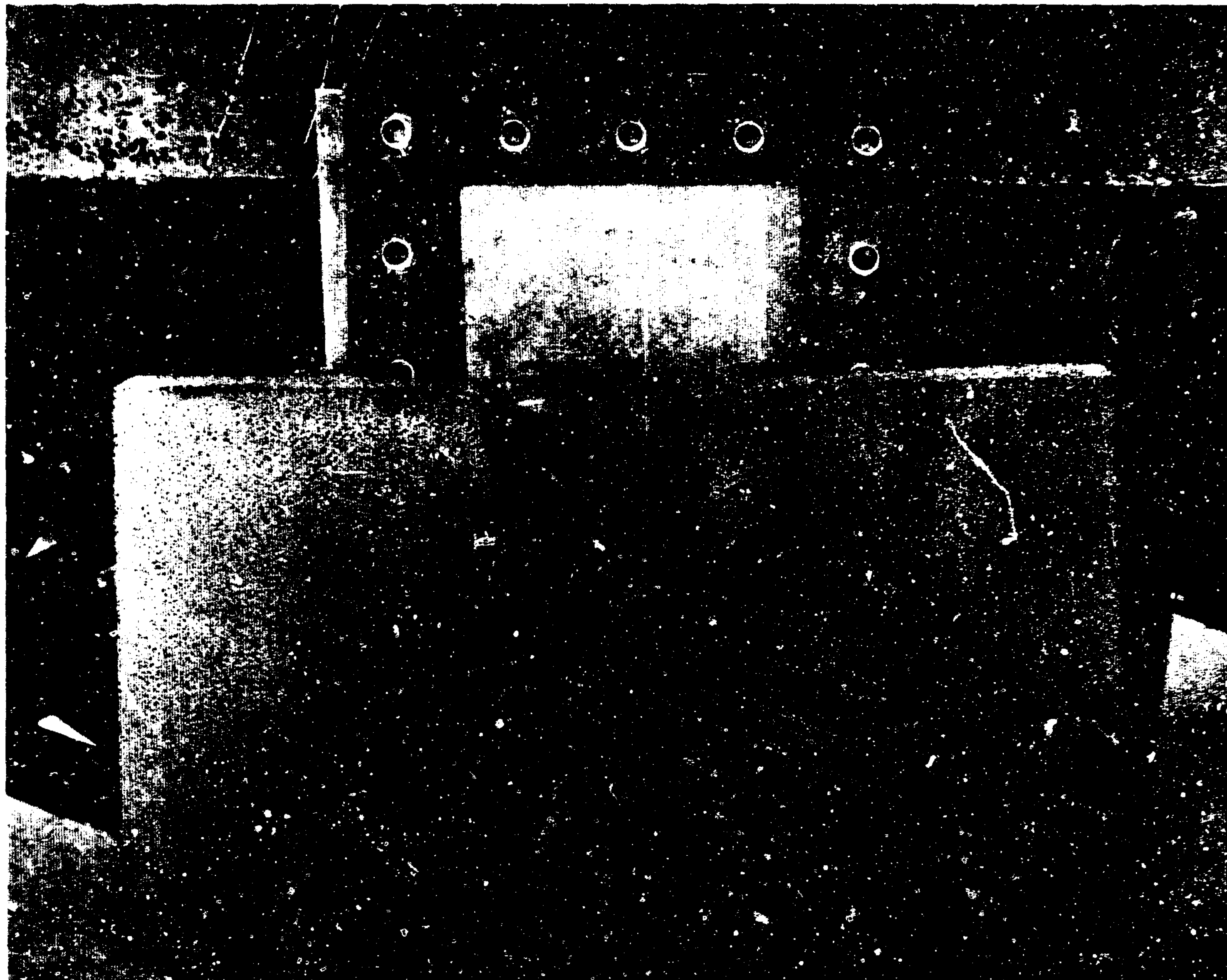


FIGURE 44 - DAMAGE TO FOAM IN 4" STANDOFF TEST ARTICLE AND JP-8

TABLE XII.--GUNFIRE TESTS 4-INCH VENTED STANDOFF WITH 10 PORE POLYURETHANE FOAM IN STANDOFF SPACE

Test No.	Fuel Used	Maximum Pressure In Tank (psig)	Time to Maximum Pressure In Tank	Maximum Pressure In Standoff (psig)	Time to Maximum Press In Standoff	Time to External Fuel Spray	Incendiary Function Time	Air Changes Per Min Standoff	REMARKS
181	JP-8	9.0	.025	.20	.035	Indefinite	See Note	18	Indefinite, due to no 500 frame film.
182	JP-8	10.5	.040	.20	.023	.080	See Note	18	
183	JP-8	7.5	.036	.60	.022	.146	See Note	18	
184	JP-4	10.5	.030	.60	.025	.302	See Note	18	
185	JP-4	4.9	.040	.60	.024	.146	See Note	18	
186	JP-4	7.5	.035	.10	.015	.068	See Note	18	

NOTE:
1. Initial tank pressure 5 psig.
2. Air velocity 90 knots all tests.
3. No external fires all tests.
4. Standoff fire indefinite due to foam in standoff.
5. Incendiary function time indefinite due to foam in standoff.
6. Fuel temperature 90°F, all Tests Nos. 181-186.

TABLE XIII.--VAPOR SHOTS 4-INCH VENTED STANDOFF 10 PORE POLYURETHANE FOAM IN TANK 2-INCH FUEL

Test No.	Fuel Used	Standoff Fire Duration	Maximum Pressure In Tank (psig)	Time Maximum Pressure In Tank	Maximum Pressure In Standoff (psig)	Time to Maximum Pressure In Standoff	Incendiary Function Time	Air Changes Per Min Standoff
187	JP-4	.050	2.0	.085	1.0	.030	.007	18
188	JP-4	.013	0.6	.075	.8	.030	.009	18
189	JP-4	.443+	2.5	.075	1.0	.030	.006	18
190	JP-8	.468+	3.5	.095	1.4	.030	.009	18
191	JP-8	.467+	2.0	.070	1.8	.030	.008	18
192	JP-8	.492+	1.4	.070	1.2	.030	.007	18

NOTE:
1. "+" indicates fire to end of film.
2. Initial tank pressure 0 psig.
3. Air velocity 90 knots.
4. No external fires.
5. Fire in standoff space all Tests Nos. 187-192.
6. Fuel temperature 90°F all Tests Nos. 187-192.
7. No external fuel spray.

and immediately into the fuel. The fuels used in these tests were JP-4 and JP-8, and the simulated airflow over the test article was 90 knots. (A tabulation of the test results is shown in Table XIV.)

Visual observation and analysis of the oscillograph records for these tests showed the fire reaction of the fuels, JP-4 or JP-8, to the penetration of an incendiary projectile under "skin type" conditions to be the same; i.e., no external fire.

In comparing the vulnerability of JP-4 and JP-8 fuels when subjected to incendiary penetration, it appeared that the JP-8 fuel was less hazardous than JP-4. The JP-8 fuel could be considered less hazardous than JP-4 from the standpoint of explosive damage, ignition difficulties, flame propagation and the non-self-sustaining fire characteristics seen during the program tests. The longer burning duration in the standoff space, noticed in all testing with JP-8 fuel, could present some problems.

Additional test work suggested from the results of the gunfire test program conducted are:

a. Projectile exit hole damage and possible exit side external fire.

b. Vertical test firing (liquid to vapor phase).

c. Liquid to vapor phase tests with fuselage style test article.

d. Additional tests with the 1-inch standoff space test article with the standoff space non-vented and vented.

e. Relationship of initial external fuel spray to the incendiary ignition source.

TABLE XIV.--LIQUID PHASE SHOT USING 4-INCH TEST ARTICLE WITH NO ENTRANCE PLATE

Test No.	Fuel Used	Maximum Pressure In Tank (psig)	Time to Maximum Pressure In Tank	REMARKS
193	JP-4	3.0	.039	Damage to Plexiglas.
194	JP-4	2.9	.035	
195	JP-4	3.0	.035	
196	JP-4	2.9	.040	
197	JP-8	2.9	.033	
198	JP-8	2.5	.040	

NOTE:
1. Fuel temperature 90°F all Tests Nos. 193-198.
2. All air velocity 90 knots, all Tests Nos. 193-198.
3. Initial tank pressure 5 psig Tests Nos. 193-198.
4. No standoff area tests.