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AEROSPACE VEHICLE HAZARD PROTECTION TEST PROGRAM: DETECTORS; MATERIALS; FUEL VULNERABILITY

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FINAL REPORT

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Prepared for

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FOREWORD

This report was prepared by the National Aviation Facilities Experimental Center, Federal Aviation Administration under USAF Contract No. F33615-71-M-5002. 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. E. Cretcher (AFAPL/SFH) as program manager.

This report is a summary of the work completed on this contract during the period 10 October 1970 to 30 September 1972.

Mr. John Schaffer was the Administrator of the Federal Aviation Administration and Mr. Cecil A. Commander was Director of the Center, Messrs. Daniel E. Sommers, Project Manager, John H. O'Neill, and Eldon B. Nicholas participated in this effort at the FAA's National Aviation Facilities Experimental Center, Atlantic City, New Jersey.

This technical report has been reviewed and is approved.

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ABSTRACT

Fire tests were conducted in a turbojet powerplant installation to determine the effectiveness of an Edison and a Honeywell Ultra-violet Fire Detection System. The four sensor units for each system were installed on the forward bulkhead of the engine nacelle's accessory and compressor compartment (Zone II) and provided surveillance aft to the firewall. Fires having fuel-flow rates of 0.04 and 0.13 gallons per minute were initiated about 12 inches forward of the firewall at several locations around the periphery of the engine.

Both systems provided adequate detection of the 0.13 gallon per minute fires, but generally there was limited detection of the small 0.04 gallon per minute fires, depending on the fire location. Both systems provided rapid response time to fires, within the range of 0.2 to 1.0 seconds after the fuel-to-fire was released. In this test installation the peripheral disposition of the sensor units on the forward bulkhead provided overlapping coverage by most units.

A study of flammability and smoke generation characteristics was performed on different types of litter pads and pillows. These items were subjected to the following tests; Horizontal Test Method No. 5906, Vertical Test Method No. 5903, Radiant Panel Test Method, ASTM E-162, and Smoke Measurement Test Method, ASTM STP No. 442.

Fire resistance tests in a standard 2,000°F flame-test environment were conducted on two flexible self-sealing low pressure Aeroquip hoses and an aluminized asbestos-faced flexible fiberglas cloth. One hose was coated with an AVCO Corp. intumescent paint identified as Flexible Flame Arrest; the other was uncoated. The hoses were tested while temperature-controlled oil was pumped through the hose.

An investigation of the vulnerability of JP-4 and JP-8 fuel, contained in a fuel tank, to ignition by incendiary gunfire was made. Tests were conducted utilizing a horizontal, liquid phase test article, either JP-4 or JP-8 fuel and varying the following parameters; (1) standoff distance between the fuel cavity and the test article skin, (2) volume of the standoff cavity, (3) ventilation rate in the standoff space, and (4) airflow over the test article surface. A series of tests was also conducted with an elevated fuel tank. This test configuration permitted fuel to vapor penetration by the incendiary projectile. These tests were conducted with either JP-4 or JP-8 fuel and simulated airflows of 0, 90, 150, and 390 knots over the test article.

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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 for the Air Force Aero Propulsion Laboratory, Wright-Patterson Air Force Base, starting 10 October 1970. The work reported on herein covered the completed task as of 30 September 1972.

This work included:

1. Exploratory tests of two ultraviolet flame detector systems for fire protection in aircraft powerplant installation.

2. A study of flammability and smoke generation characteristics of different types of litter pads and pillows.

3. Fire resistance tests of two flexible, self-sealing, low pressure Aeroquip hoses and an aluminized asbestos-faced flexible fiberglass cloth.

4. Incendiary gunfire tests of fuel tanks, horizontal and vertical, using two fuels (JP-4 and JP-8), and simulated airflows over the tank surface.

Each of the foregoing areas of testing is discussed under separate sections in this report.

An analysis of fire hazard potentials in engine compartment/nacelles of U.S. Army aircraft was initiated under this program, sponsored by the U.S. Army Ballistics Research Laboratory, Aberdeen Proving Ground, Md. The UH-1B aircraft was the subject of the initial study. This effort is being completed under a subsequent contract, D033615-73-M-2009 and is the subject of a separate Technical Report to be published in early 1974.

SECTION II

FIRE DETECTION

1. ULTRA-VIOLET FIRE DETECTION SYSTEMS

1.1 General

Fire detection tests were conducted on a prototype Edison Ultra-Violet (UV) fire detection system and a prototype Honeywell UV fire detection system in an aircraft turbojet powerplant environment. These tests were conducted to obtain operational experience with the sensors in an engine nacelle environment prior to flight testing these sensors. Of special interest was the UV sensors coverage capability and field of view. The Edison UV fire detector was developed for the USAF Aero Propulsion Laboratory by the Thomas A. Edison Instrument Division of the McGraw Edison Company under contract AF33(615)3531. The Honeywell UV sensors were developed in-house by the Aerospace Division of Honeywell Incorporated. They were provided to the Air Force for engine nacelle fire tests and flight tests. Both manufacturers' sensors were engineering prototypes. Tests of the Edison System were completed in October 1970. Tests of the Honeywell system were completed in January 1971.

1.2 Test Facility

The detection systems were installed and tested in the compressor and accessory compartment (Zone II) of the C-140 aircraft engine and nacelle installation. The C-140 powerplant, including the No. 2 nacelle, pylon and JT-12 engine, has been installed and operated in an open-circuit induction wind tunnel facility at NAFEC. The wind tunnel provided aero-dynamic conditions within the nacelle similar to those which exist in flight at approximately Mach 0.5 and 5,000-foot altitude.

Cooling airflow for the compressor and accessory compartment of the C-140 nacelle entered 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 in an access panel located in the top aft portion of the compartment. These openings were at 11 and 1 o'clock between Nacelle Stations 107 and 114.

Four individual Edison UV sensor units were installed on the forward bulkhead (Nacelle Station 66) of the C-140 compressor and accessory compartment. Figure 1 shows the position of each sensor unit. Location of the sensors was selected to provide optimum coverage of the compartment void space peripherally as well as to provide the optimum unobstructed view aft toward the firewall. UV sensor unit No. 1 was placed in the position indicated in Figure 1 because the engine oil tank on the forward part of the engine obstructed view aft from the forward bulkhead in the 10 to 12 o'clock sector of the compartment. Figure 2 is a photograph of the Edison sensors installed on the forward bulkhead of the Zone II compartment with the engine removed from the nacelle.

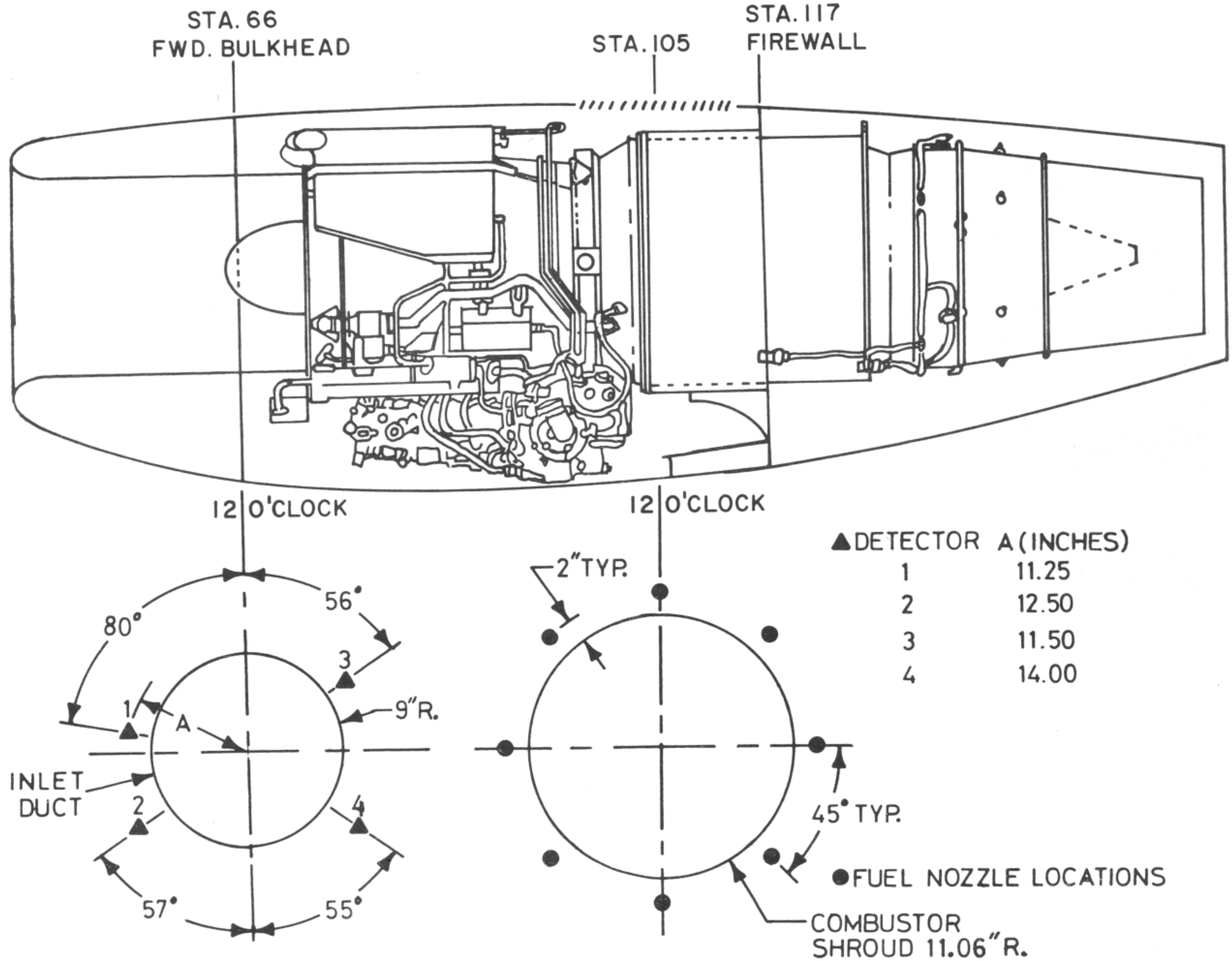


FIGURE 1. LOCATION OF UV SENSORS AND FUEL-TO-FIRE NOZZLES IN THE C-140 POWERPLANT INSTALLATION

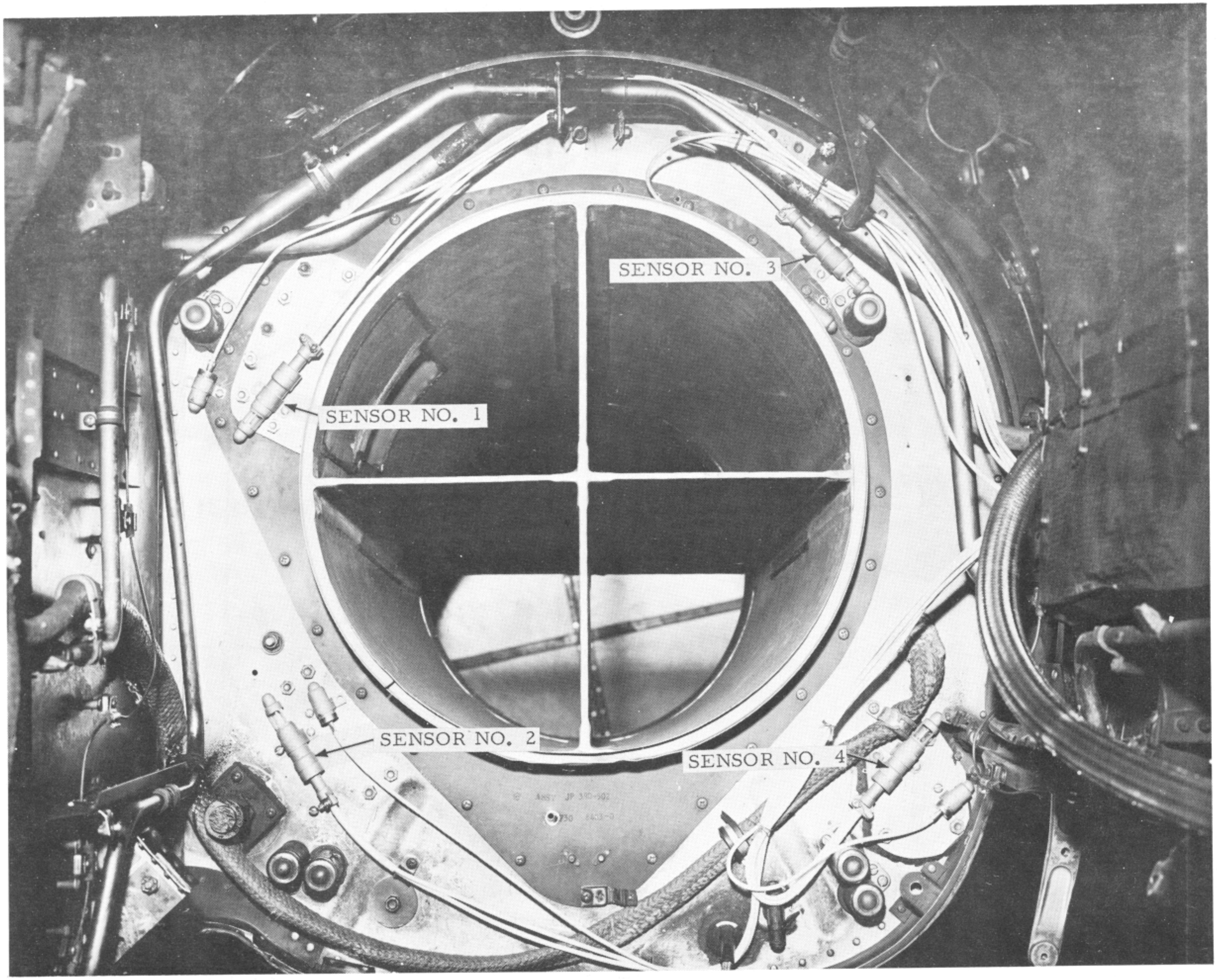


FIGURE 2.   EDISON UV SENSOR INSTALLATION ON FORWARD BULKHEAD OF NACELLE

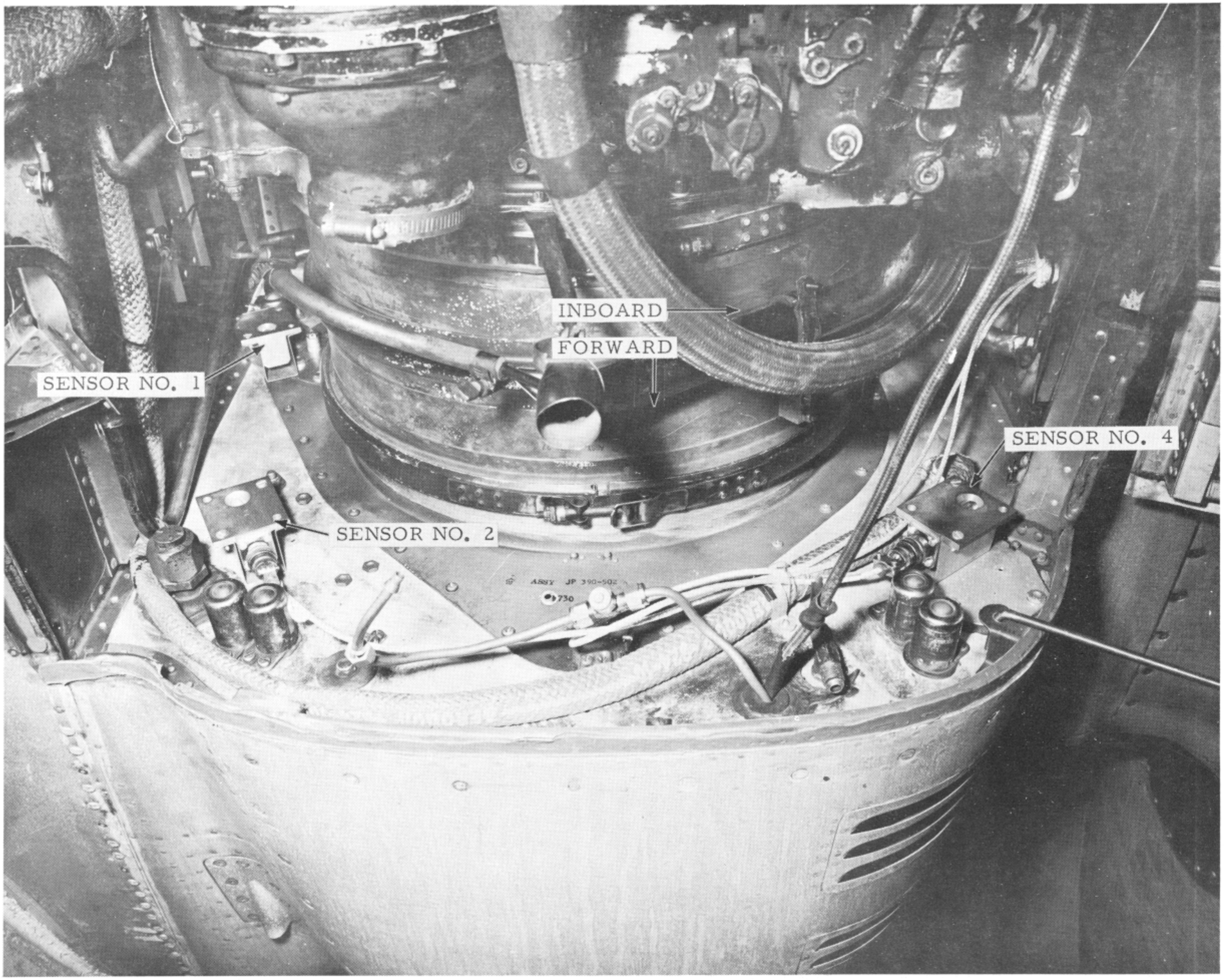


FIGURE 3. HONEYWELL UV SENSOR INSTALLATION ON FORWARD BULKHEAD OF NACELLE

For the Honeywell UV detection system tests, the four UV sensors were installed on the forward bulkhead of the nacelle's compressor and accessory compartment in the same positions as shown in Figure 1. Figure 3 is a photograph showing Honeywell sensor units Nos. 1, 2, and 4, installed on the forward bulkhead.

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 0.04, 0.13, and 0.2 gallons per minute were simulated. The 0.2 gallon per minute JP-4 fuel fire was eliminated later in the test program, because of the accumulative damage suffered by the nacelle from this particular fire. Figure 1 shows the general locations of the fuel-to-fire nozzles at the 12, 1:30, 3, 4:30, 6, 7:30, 9, and 10:30 o'clock positions at Nacelle Station 105 in Zone II. For the majority of the detector tests, the fuel nozzle was directed to spray fuel forward. Deviations from this included additional fires at the 6 o'clock Nacelle Station 105 position, and 10:30 Nacelle Station 102 position, in which the fuel spray was directed toward the engine centerline. Figure 4 is a photograph of the nacelle showing the fuel nozzle arrangement at the 6 o'clock Nacelle Station 105 position. For those tests conducted on the Honeywell system, a fuel manifold with permanent nozzle locations was constructed. At each clock position noted above, a tubing was fixed and extended from the firewall (Nacelle Station 117) and a manifold aft of the firewall directed fuel to all fixed tubing. Those fuel nozzle locations which were not used for a test, were capped off. Figure 5 is a photograph showing the fixed-nozzle arrangement at the 4:30, 6, and 7:30 o'clock positions, Nacelle Station 105.

The UV sensor was a photon detector, which was designed to respond to a specific UV radiation wavelength range. It had two specially prepared wires (cathode and anode) enclosed and sealed, along with a special gas in a high-temperature transparent bulb. An electrical potential was applied between the wires. UV light striking the cathode wire caused emission of photoelectrons. Photoelectrons in the electric field between the cathode and anode caused an avalanche which resulted in a gas discharge. This discharge was quenched by a drop in voltage in the sensor. The output (discharge pulses) for each UV sensor was obtained by two methods. One method utilized a digital-to-analogue converter and oscillograph to record pulse rate. The other method utilized an oscilloscope and a camera to photograph four traces (one connected to each sensor through a control box) on which the discharge pulses were generated.

The time at which ignition of released fuel occurred was obtained from a thermocouple placed in the path of the fuel spray. This indication was recorded on the oscillograph.

1.3 Test Procedure

The general test procedure consisted of establishing a stabilized test section average air velocity (0.5 Mach No.) and engine power condition (85 percent rated engine rotor speed) followed by initiating a sequencer which automatically turned on and off the recording oscillograph, the camera for the oscilloscope, the ignitor, and the fuel-to-fire. The sequence of events were as follows:

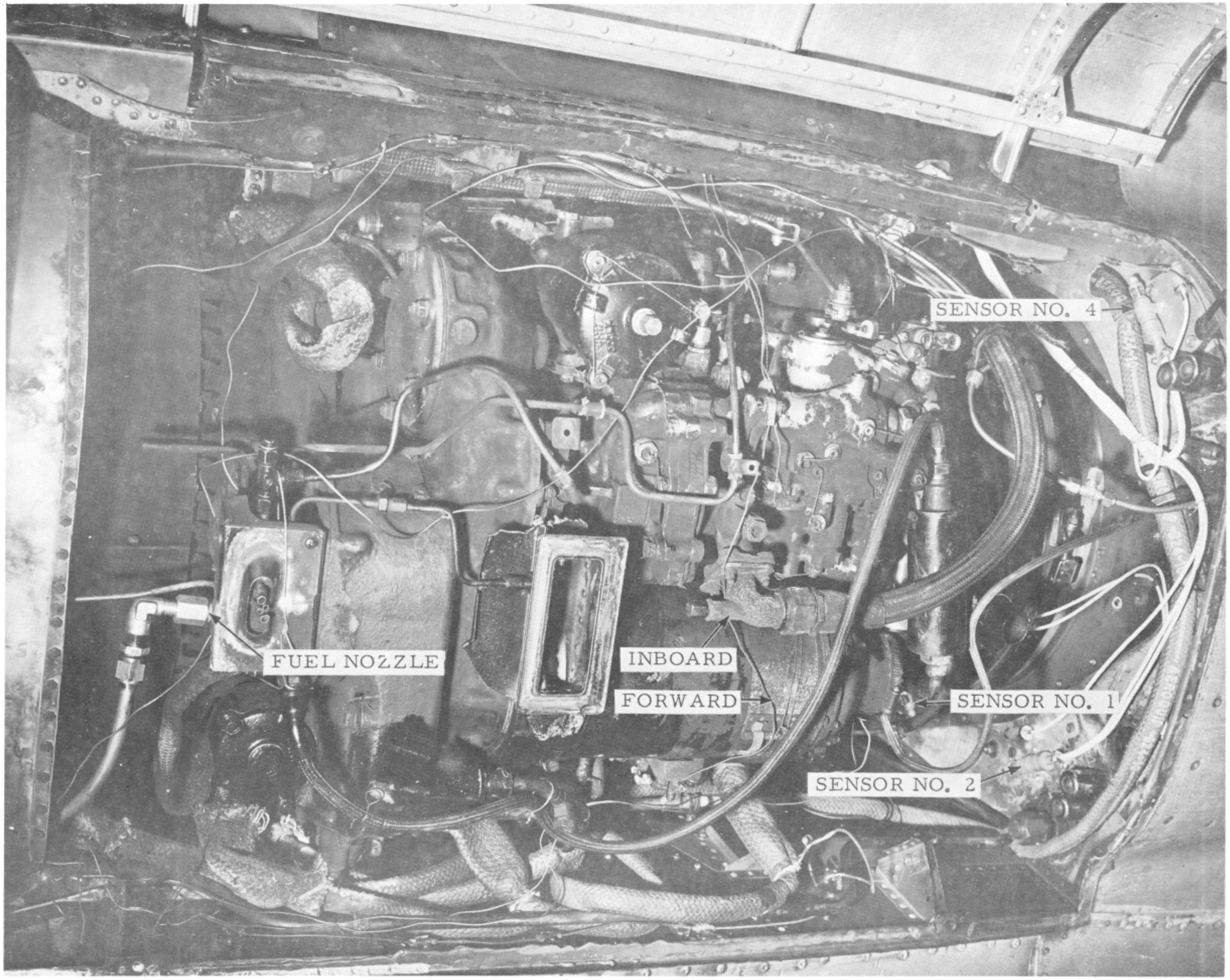


FIGURE 4. FUEL-TO-FIRE NOZZLE AT THE 6 O'CLOCK POSITION, NACELLE STATION 105

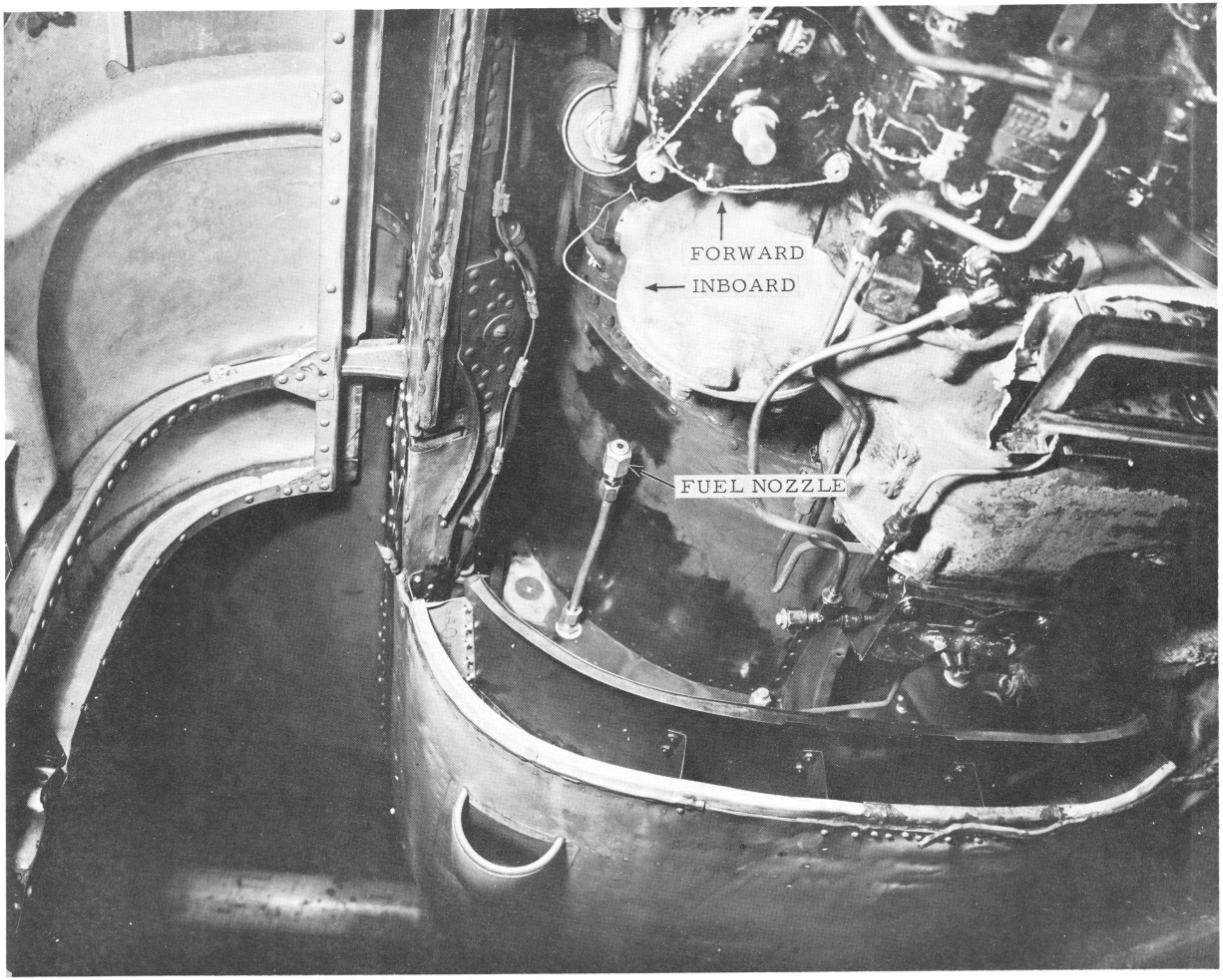


FIGURE 5. FUEL-TO-FIRE NOZZLE POSITIONS, NACELLE STATION 105.

Event	Time in Seconds
Recorder On	-6.3
Camera On	-1.35
Ignition On	-0.4
Fuel On	0
Ignition Off	+1.1
Fuel and Camera Off	+7.8
Recorder Off	+14.2

2. EDISON ULTRA-VIOLET FIRE DETECTION SYSTEM TESTS

Initial test runs indicated that the UV sensors were sensitive to the spark from the ignitor when it was energized to ignite the test-fire fuel. However, the pulse rate generated by this source was considered minimal. Also, it was found that when the test lamp for Sensor Unit No. 1 was initiated, both Sensor Units Nos. 1 and 2 were excited. The opposite occurred when the test lamp for Sensor Unit No. 2 was initiated. This occurred because of the necessity of locating these two sensors (1 and 2) fairly close to one another (Figures 1 and 2) since the oil tank on the engine interfered with Sensor Unit No. 1's view aft. The test lamp for either sensor was eliminated as a source of UV exciting the sensor which was further away. It was determined that the UV from the sensor being tested by the test lamp was reflected off the inside walls and structure of the nacelle and excited the other sensor.

The results of these tests are presented in Tables 1 and 2. These results indicated that Sensor Unit Nos. 1 and 2, located on the forward bulkhead (Nacelle Station 66) provided coverage of the 0.04 gallon per minute fires located around the periphery of the engine at Nacelle Station 105 from at least 7:30 through 10:30 o'clock. The limited size of the fire as well as the obstructions on the outboard side of the nacelle compartment contributed to the low to moderate response of Sensor Unit Nos. 1 and 2 to UV emitted by the test fires on the outboard side of the engine. Sensor Unit Nos. 3 and 4 provided coverage of the 0.04 gallon per minute fires located around the periphery of the engine at Nacelle Station 105 from at least 12:00 through 4:30 o'clock.

The small 0.04 gallon per minute fire located at Nacelle Station 105, 6 o'clock and directed forward was not detected. This fire location was well hidden from the sensor unit's view. It was directly behind the engine fuel drain tube area which fitted flush with an opening in the nacelle's main access door.

The 0.04 gallon per minute fire located at 6 o'clock, Nacelle Station 105 which was directed toward the engine case was detected by Sensor Unit No. 4. Apparently the fire was deflected enough towards the right side of the engine to be seen by this sensor unit.

The 0.04 gallon per minute fire which was intentionally hidden just aft of the engine oil tank at Nacelle Station 102, 10:30 o'clock and directed towards the diffuser case was detected by Sensor Unit No. 3. Again this fire was deflected off the case and towards the right side of the engine enough to be seen by this sensor.

When the fire size was increased by increasing the fuel-to-fire flow from 0.04 to 0.13 gallon per minute, there was a substantial increase in response (pulses/second) by the respective sensor units to the fires initiated at all locations around the periphery of the engine except at Station 105, 9 o'clock. Marginal detection of the fire at the 9 o'clock position was most likely due to two things: (1) obstruction of the view of the Sensor Unit Nos. 1 and 2 by asbestos covered electrical wiring and cable which were concentrated directly ahead of this fire location; and (2) deterioration of the

TABLE 1. SUMMARY OF EDISON UV DETECTION SYSTEM TEST RESULTS
(0.04 GPM JP-4 FUEL FIRES)

	OSCILLOGRAPH DETECTOR UNITS				OSCILLOSCOPE DETECTOR UNITS			
	1 Pulse/sec	2 Pulse/sec	3 Pulse/sec	4 Pulse/sec	1 Pulse/sec	2 Pulse/sec	3 Pulse/sec	4 Pulse/sec
Fire Location	Range	Range	Range	Range	Average**	Average**	Average**	Average**
Sta 105-12:00-D/F	0	0	0-163	0-53	0	0	31	0
Sta 105- 1:30-D/F	0	0	43-389	0	0	0	346	0
Sta 105- 3:00-D/F	0	0	25-386	01-100	0	0	371	24
Sta 105- 4:30-D/F	0	0	0-33	0-195	0	0	2	141
Sta 105- 6:00-D/F	X	X	X	X	0	0	0	0
Sta 105- 6:00-D/℄	0	0	0	03-92	0	0	0	22
Sta 105- 7:30-D/F	0-62	0-48	0	0	7	12	0	0
Sta 105- 9:00-D/F	0-108	0-160	0	0	56	99	0	0
Sta 105-10:30-D/F	03-77	0-40	0	0	26	8	0	0
Sta 102-10:30-D/C	0	0	37-169	0	0	0	77	0

D/F= Directed forward
D/℄= Directed at engine centerline
D/C= Directed at diffuser case

** This is average pulse rate over a 3-second period.
X Oscillograph record was not read.

TABLE 2. SUMMARY OF EDISON UV DETECTION SYSTEM TEST RESULTS (0.13 GPM JP-4 FUEL FIRES)

	OSCILLOGRAPH DETECTOR UNITS				OSCILLOSCOPE DETECTOR UNITS			
	1 Pulse/sec	2 Pulse/sec	3 Pulse/sec	4 Pulse/sec	1 Pulse/sec	2 Pulse/sec	3 Pulse/sec	4 Pulse/sec
Fire Location	Range	Range	Range	Range	Average**	Average**	Average**	Average**
Sta 105-12:00-D/F	0	0	53-257	0-59	0	0	204	0
Sta 105- 1:30-D/F	0	0	60-415	0	0	0	344	3
Sta 105- 3:00-D/F	0	0	301-500	11-113	0	0	728	60
Sta 105* 3:00-D/F	0	0	41-500	05-103	0	0	718	51
Sta 105- 4:30-D/F	0	0	0-58	158-372	0	0	14	237
Sta 105- 6:00-D/℄	0	0	0-85	89-219	0	0	25	158
Sta 105- 6:00-D/F	X	X	X	X	11	102	0	20
Sta 105- 7:30-D/F	0-158	0-168	0-52	0	103	116	7	0
Sta 105- 9:00-D/F	0-80	0-108	0	0	37	68	0	0
Sta 105-10:30-D/F	0-166	49-187	0	0	129	130	8	0
Sta 102-10:30-D/C	0	0	110-338	0	0	0	244	0

D/F= Directed forward
D/℄= Directed at engine centerline
D/C= Directed at diffuser case

* This run was made 5 minutes after previous run at 75% rated engine r/min(compressor bleed valves open).
** This is average pulse rate over 3-second period.
X Oscillograph record was not read.

tadpole tape seal at the firewall just aft of this fire location which allowed direct egress of the fire from Zone II to Zone I and limited the spread of fire upward and downward around the periphery of the engine ahead of the firewall.

This particular disposition of the sensor units peripherally on the forward bulkhead provided very good coverage of all fire locations in this nacelle with overlapping coverage between Sensor Unit Nos. 1 and 2, Sensor Unit Nos. 3 and 4, and Sensor Unit Nos. 2 and 4. Response time of the UV fire detector unit was rapid and indication of fire in these tests was generally within 0.2 to 1.0 seconds after the fuel-to-fire was turned on.

3. HONEYWELL ULTRA-VIOLET FIRE DETECTION SYSTEM TESTS

Prior to tests of the Honeywell System, fire damage to the nacelle from previous tests on the C-140 powerplant installation was repaired. This work included repair of the firewall tadpole compression seal where penetration and egress of fire from Zone II to Zone I was occurring. The repair work most likely changed the air flow pattern, thus, the fire path in Zone II of the nacelle differed from that which existed during previous UV detector tests. Therefore, any comparison of fire detection performance of the two different systems would be considered invalid.

The results of the Honeywell UV Detection System are presented in Table 3 and were prepared from oscilloscope data only. The first 3 seconds of film from the time of "fuel on" was read and an average pulse per second rate was obtained and presented in the table.

The initial tests were those in which the intention was to ignite and detect a small 0.04 gallon per minute JP-4 fuel fire at each of the eight clock positions as shown in Figure 1. Ignition of the 0.04 gallon per minute fuel spray was not attained at nozzle positions 10:30, 12, and 1:30 o'clock, Nacelle Station 105, even though numerous changes in locating the ignitor relative to the fuel spray and numerous attempts to ignite the spray were made. Ultra-violet emission from 0.04 gallon per minute fuel fires initiated at the 3, 4:30 and 9 o'clock locations, Nacelle Station 105, and directed forward was detected mainly by Sensor Unit Nos. 3, 4 and 1, respectively. The response to these fires was good. There was marginal detector response by UV Sensors 1 and 2 to the 0.04 gallon per minute fire initiated at the 7:30 o'clock, Nacelle Station 105 location. There was very poor detector response to the 0.04 gallon per minute fires initiated at the hidden fire location at 6 o'clock, Nacelle Station 105, when the fire was directed either forward or at the engine case. Also, there was poor detector response to the 0.04 gallon per minute fire which was hidden aft of the oil tank at the 10:30 o'clock, Nacelle Station 102, location and directed towards the diffuser gas.

Detection of UV from the 0.13 gallon per minute JP-4 fuel fire initiated at most of the locations around the periphery of the engine was good to excellent. There was marginal detector response to the hidden 0.13 gallon per minute fire which was directed at the diffuser case at the 10:30 o'clock, Nacelle Station 102 location.

Response of Sensor Unit No. 1 on the forward bulkhead to the 0.13 gallon per minute fires at the 6, and 7:30 locations, Nacelle Station 105 was greater than the response of Sensor Unit No. 2. Since Sensor Unit No. 2 was located (Figure 1) in a position where it should have sensed these fires with a greater response than Sensor Unit No. 1, it appeared that Unit No. 2 was not operating correctly. A check of all the sensor units by means of the test lamps appeared to confirm this, since the pulses per second generated by Sensor Unit No. 2 when exposed to the lamp were much lower than the other units. With test lamp operation, 300 pulses per second output was recorded for Sensor Unit No. 2 compared to 1,300, 2,000, and 3,200 pulses per second recorded for Sensor Units Nos. 4, 1, and 3, respectively.

TABLE 3. SUMMARY OF HONEYWELL UV DETECTION SYSTEM TEST RESULTS

Fire Location	0.04 GPM JP-4 FUEL FIRES – DETECTOR UNITS				0.13-GPM JP-4 FUEL FIRES – DETECTOR UNITS			
	1 Pulse/sec Average**	2 Pulse/sec Average**	3 Pulse/sec Average**	4 Pulse/sec Average**	1 Pulse/sec Average**	2 Pulse/sec Average**	3 Pulse/sec Average**	4 Pulse/sec Average**
Sta 105-12:00-D/F*		No Fire			--	--	420	--
Sta 105- 1:30-D/F*		No Fire			0	0	860	--
Sta 105- 3:00-D/F	0	0	927	--	0	0	299	13
Sta 105- 4:30-D/F	0	0	6	214	--	--	28	560
Sta 105- 6:00-D/F	0	0	0	5	91	32	0	34
Sta 105- 6:00-D/C	7	--	0	0	596	66	--	0
Sta 105- 7:30-D/F	57	34	0	0	667	101	--	0
Sta 105- 9:00-D/F	278	46	0	0	857	115	--	0
Sta 105-10:30-D/F*		No Fire			356	19	24	--
Sta 102-10:30-D/C	--	--	--	0	10	7	48	--

D/F= Directed forward
D/℄= Directed at engine centerline
D/C= Directed at diffuser case

* A fire could not be started at these locations when 0.04-gpm fuel-to-fire flow was used even though many attempts at ignition were made.
-- Only limited number of pulses (less than 12) were recorded for the 3-second period.
** This is average pulse rate over a 3-second period.

As expected, nearly all the sensor units increased in response level when the fuel-to-fire rate was increased from 0.04 to 0.13 gallons per minute, except for the fires initiated at the 3 o'clock location, Nacelle Station 105, where the opposite trend happened as shown in Table 3. This most likely was attributed to the necessity of changing the nozzle configuration to facilitate ignition of the 0.04 gallon per minute fuel spray. Although there was no change in fuel rate, there very well could have been a change in the direction in which the fire was deflected, allowing it to be more visible to Sensor Unit No. 3, which responded with the greatest number of pulses per second to both the 0.04 and 0.13 gallon per minute fires located at 3 o'clock location.

Response time of the Honeywell Detector Unit was rapid and indication of fire in these tests was generally within 0.2 to 1.0 seconds after fuel-to-fire was turned on. The specific location of the four Honeywell Sensor Units on the forward bulkhead of the C-140 nacelle provided very good coverage of fire locations in the compressor and accessory compartment (Zone II).

SECTION III

MATERIAL TESTS

1. FLAMMABILITY AND SMOKE GENERATION STUDIES OF LITTER MATERIAL

1.1 General

Flammability and smoke generation tests were conducted on two litter pads and three pillows used by the Air Force for evacuation of wounded personnel. Descriptions of these items are given in Table 4. These studies were requested by the Department of the Air Force, Headquarters Military Airlift Command, Scott Air Force Base, Illinois.

1.2 Test Procedure

Three different test methods were utilized for the flammability characteristics studies of the materials submitted.

1. Horizontal Rate of Burning, Test Method 5906 of Federal Specification CCC-T-191b.

2. Vertical Burn Test Method 5903 of Federal Specification CCC-T-191b.

3. Radiant Panel Flame-Spread Test Method, Federal Standard Number 00136b or the American Society for Testing and Materials (ASTM-E-162).

Federal Specification CCC-T-191b is available from the General Services Administration, Business Service Center, Region 3, Seventh and D Streets S.W., Washington, D. C. 20407.

The ASTM standards are available from the American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pennsylvania 19103.

A description of the terminology, test equipment, and an explanation of the methods used for determining the data and table headings contained in Tables 2, 3, and 4 are given in Federal Aviation Agency, Technical Report ADS-3, (AD600387), January 1964 and Federal Aviation Administration (FAA) Final Report Number NA-68-30, (AD673084), July 1968. Copies of these reports are available from the National Technical Information Service, Springfield, Virginia 22151.

Smoke generation studies were accomplished by using the test apparatus and procedures developed by the National Bureau of Standards and described in the Special Technical Publication, STP No. 422 published in 1967 by the American Society for Testing and Materials (ASTM).

A description of the terminology, equipment, and an explanation of the methods used for determining the data and table headings, contained in Table 5, are included in Federal Aviation Administration (FAA) Final Report Number NA-68-36 (AD675513). However, there is one column added to this table that is

TABLE 4. MATERIAL DESCRIPTION

Item No.	Air Force Part No.	Use	Composition
AF-1	No Part No. Given	Disposable Litter Pad	Plastic covering with fiberglass padding.
AF-2	6530-514-5837	Litter Mattress	Plastic covering with foam padding.
AF-3	7210-716-7000	Bed Pillow	Cotton ticking filled with feathers. Probably flame-retardant treated.
AF-4	7210-299-8520	Pneumatic Pillow	Rubberized cloth.
AF-5	Tomac Store-Ease	Disposable Pillow	

TABLE 5. HORIZONTAL TEST METHOD 5906

Item No.	Test No.	Ignition Time (min)	Flaming Time Measured From Start Wire (min)	Burn Length Measured from Start Wire (in)	Burn Rate Measured from Start Wire (in/min)	Remarks
AF-1	1	0.01	I (1)	0.0	0.0	Sooty acrid smoke. Results are the same for either cover, padding, or complete item.
	2	0.01	I	0.0	0.0 (2)	
	3	0.01	I	0.0	0.0	
	Avg.	0.01	I	0.0	0.0	
AF-2	1	0.01	0.62	7.5	12.1	Cover material only. Sooty acrid smoke.
	2	0.01	0.63	10.0	16.1	
	Avg.	0.01	0.63	8.7	14.1 (3)	
AF-2	1	0.02	7.89	10.0	1.3	Foam padding material only. Sooty acrid smoke.
	2	0.02	6.55	10.0	1.5	
	3	0.02	6.46	10.0	1.5	
	Avg.	0.02	6.97	10.0	1.4 (2)	
AF-2	1	0.01	I	0.0	0.0 (2)	Complete item.
AF-3	1	0.05	2.32	10.0	4.3	Cover material only. Very light smoke.
	2	0.04	1.88	10.0	5.3	
	3	0.04	1.85	10.0	5.4	
	Avg.	0.04	2.02	10.0	5.0 (3)	
AF-3	1	0.05	5.94	10.0	1.7 (2)	Complete item - material burned on bottom side only.
AF-4	1	0.04	2.46	10.0	4.1	One material only makes up complete item. Light gray smoke.
	2	0.05	2.39	10.0	4.2	
	3	0.05	2.50	10.0	4.0	
	Avg.	0.05	2.45	10.0	4.1 (3)	
AF-5	1	0.03	2.75	10.0	3.6	

Notes: (1) - Burned less than 1.5 inches (Zero burn rate).
(2) - Meets FAA standards (i.e., burn rate less than 4 inches per min).
(3) - Does not meet FAA standards.

not included in the report. The Smoke Obscuration Number (SON4) represents a weighted rate of smoke generation over a 4-minute interval of time, based on the simple addition of the specific optical density values at 1, 2, 3, and 4 minutes.

The horizontal and vertical test methods are specified in Federal Aviation Regulation, Part 25.853 for showing compliance with present federal standards of interior materials used in transport category aircraft. Under these regulations materials tested horizontally shall either be self-extinguishing or not have a burn rate exceeding 4 inches per minute. Materials tested vertically shall be self-extinguishing within 0.25 of a minute after removal of the burner, and the average burn length shall not exceed 8 inches.

The radiant panel flame-spread test method is not a requirement for testing aircraft interior materials. However, it does prove very useful for determining the flammability characteristics of materials when subjected to a more severe ignition source. This type of burning is believed to be more representative of conditions in a fully developed cabin fire.

The test method used for smoke measurements has been recommended to the Federal Aviation Administration, Flight Standards Service for establishing standards governing the smoke-emission characteristics of aircraft interior materials. An Advanced Notice for Proposed Rule Making (NPRM), Docket Number 9611, Compartment Interior Materials Smoke Emission, was issued by the Department of Transportation (DOT/FAA) on 30 July 1969. However, this notice did not set any limits for smoke or specify a test method which are to be issued in a forthcoming NPRM.

1.3 Summary of Test Results

1.3.1 Results from Table 5, horizontal test method, show that the disposable litter pad AF-1 not only when tested as a complete item but also the separate materials making up the pad have a zero-burn rate (i.e., did not reach the start wire for timing). The litter mattress (6540-514-5837) AF-2 also had a zero-burn rate when tested as a complete item. However, the average burn rate was 14.1 inches per minute for the plastic cover material and 1.4 inches per minute for the foam padding when each were tested separately.

The ticking or cover material for the feather bed pillow AF-3 had an average burn rate of 5 inches per minute, but when tested as a complete item the burn rate was only 1.7 inches per minute. The average burn rate for the pneumatic pillow AF-4 was 4.1 inches per minute. The burn rate for the Tomac Store-Ease Pillow (AF-5) averaged 3.6 inches per minute.

1.3.2 Results from Table 6, vertical test method, show that the disposable litter pad AF-1 had a burn length of 3.5 inches compared to 5.5 inches for the litter mattress AF-2. However, the burn length for the plastic cover material was 6.8 inches for AF-1 and only 4.8 inches for AF-2.

The feather bed pillow had a burn length of 7.2 inches and the Store-Ease pillow burn length was 3.5 inches. Not enough of material, AF-4, was provided for a test under this method.

TABLE 6. VERTICAL TEST METHOD 5903

Item No.	Test No.	Ignition Time (min)	Total Flaming Time (min)	Flame Out Time After Burner Removal (min)	Glow Time (min)	Burn Length (in)	Char Length (in)	Remarks
	1	0.01	0.17	0.00	0.00	6.5	5.0	Cover material only. Sooty
AF-1	2	0.01	0.16	0.00	0.00	7.5	6.0	acrid smoke. Material flame
	3	0.01	0.16	0.00	0.00	6.5	5.0	out before 0.20 burner
	Avg.	0.01	0.16	0.00	0.00	6.8	5.3	application completed.
AF-1	1	0.00	0.00	0.00	0.00	0.0	0.0	Fiberglas padding only.
	1	0.01	0.19	0.00	0.00	3.5	2.5	Complete item.
AF-1	2	0.01	0.23	0.04	0.00	3.5	2.0	Sooty acrid smoke.
	3	0.01	0.20	0.01	0.00	3.5	2.5	Cover material only burned.
	Avg.	0.01	0.21	0.02	0.00	3.5	2.3	
	1	0.02	0.27	0.09	0.00	4.8	0.8	Cover material only.
AF-2	2	0.02	0.29	0.11	0.00	4.8	0.4	
	Avg.	0.02	0.28	0.10	0.00	4.8	0.6	
AF-2	1	0.01	0.19	0.00	0.00	5.5	0.6	Complete item.
AF-3	1	0.02	0.55	0.37	5.40	7.2	2.4	Complete item.
AF-4	-	-	-	-	-	-	-	Not enough material for test.
AF-5	1	0.03	0.63	0.46	0.00	5.4	3.5	Complete item.

Note:

1. All items meet FAA standards (i.e., burn/char length 8 inches or less).

1.3.3 Radiant panel tests, Table 7, show that the litter mattress AF-2 had an average flame-spread index (I_s) more than three and one-half times larger than that of the disposable litter mattress AF-1. The pneumatic pillow AF-4, had a flame-spread index of more than two times that of the feather bed pillow. The flame-spread index of the Store-Ease pillow was Index No. 2.

Both the feather-bed pillow and the disposable pillow met the FAA flammability requirements for materials used in aircraft compartments. However, the feather-bed pillow (7210-716-7000) has the lower burn rate, is self-extinguishing and does not melt and continue to burn when exposed to the radiant panel tests. Even though the Store-Ease pillow flame-spread index is very much lower than that of the feather-bed pillow, this is without much practical significance. The Store-Ease pillow was not self-extinguishing. Rapid melting of this pillow was observed, and the melted material puddled on the floor and continued to flame for a period of time in excess of 1.5 minutes during the radiant panel tests.

For these tests, only the complete items were tested.

1.3.4 Smoke emission test results, given in Table 8, show that the maximum specific optical densities (D_s) were considerably less for the disposable litter pad AF-1 than for the litter mattress AF-2, when tested under either flaming or smoldering exposures.

The maximum specific optical density (D_m) and the time to reach D_m were about the same for the feather-bed pillow and the Tomac Store-Ease pillow for the smoke generation test under flaming conditions. These pillows had a lower maximum specific optical density than the pneumatic pillow AF-4.

A review of all the test results shows that: (1) The disposable litter pad AF-1 was the least flammable and produced the least amount of smoke of the two litter pads, (2) the feather-bed pillow AF-3 was less flammable and produced less smoke than the pneumatic pillow AF-4, and (3) the feather-bed pillow had a lower burn rate than the disposable pillow. The feather-bed pillow was self-extinguishing and did not melt and continue to burn when exposed to the radiant panel tests.

TABLE 7. RADIANT PANEL TEST METHOD ASTM E-162

Item No.	Test No.	Burn Length (in)	Heat Factor (deg.c)	Flame-Spread Factor F_s	Flame-Spread Factor I_s	Remarks
	1	15	15	75.7	150	Flashing.
AF-1	2	14	18	87.7	208	Heavy white acrid smoke.
	3	11	13	64.4	111	
	Avg.	13 (1)	15	75.9	156	
	1	15+	86	60.8	691	High flames.
AF-2	2	15+	72	54.5	518	Heavy gray acrid smoke.
	3	15+	73	52.7	508	
	Avg.	15+ (2)	77	56.0	572	
	1	5	42	4.3	24	Moderate gas flames. Moderate white smoke.
AF-3	2	12	45	20.9	124	Cover opened in Test No. 2 allowing
	Avg.	9 (1)	43	12.6	74	interior of pillow to burn.
	1	15+	73	17.8	172	High flames.
AF-4	2	15+	73	18.8	182	Light gray smoke.
	Avg.	15+ (2)	73	18.3	177	
AF-5	1	15+	1	15.6	2	

Notes: (1) - Test specimen did not burn completely in 15 minutes.
(2) - Test specimen burned completely in less than 15 minutes.

TABLE 8. SMOKE MEASUREMENTS - ASTM TEST METHOD STP NO. 422

Item No.	Test No.	Type of Exposure	Time to Reach $D_s = 16$ (min)	D_m Corrected	Time to D_m (min)	SON_4	Remarks
	1	Flaming	0.16	94.3	5.0	366	Flaming very rapid.
AF-1	2		0.15	96.9	4.5	370	Flames 6-8 inches high.
	3		0.15	94.3	5.0	355	Covering material only.
	Avg.		0.15	95.2	4.8	364	
	1	Smoldering	1.40	102.	15.0	115	Covering material only.
AF-1	2		0.67	107.	14.0	200	
	3		0.82	111.	12.5	190	
	Avg.		0.96	107.	13.8	168	
	1	Flaming	Never	0.5	9.0	2	Fiberglas padding only.
AF-1	2		Reached	1.2	7.0	3	
	3		$D_s = 16$	1.1	7.5	5	
	Avg.			0.9	7.8	3	
	1	Smoldering	Never	2.7	20.0	6	Fiberglas padding only
AF-1	2		Reached	2.1	13.0	7	
	3		$D_s = 16$	1.3	19.5	5	
	Avg.			2.0	17.5	6	
	1	Flaming	0.15	99.3	12.0	373	Complete item. Very rapid
AF-1	2		0.14	113.	7.5	409	flaming.
	3		0.13	89.7	11.0	369	Flames 8-10 inches high.
	Avg.		0.14	99.	10.2	384	
	1	Smoldering	0.43	137.	19.0	305	Complete item. Self ignition
AF-1	2		0.33	88.2	5.0	347	caused from radiant heat
	3		0.46	134.	18.0	291	exposure occurred during
	Avg.		0.40	120.	14.0	319	Test No. 2.

TABLE 8. SMOKE MEASUREMENTS - ASTM TEST METHOD STP NO. 422 (Continued)

Item No.	Test No.	Type of Exposure	Time to Reach $D_s = 16$ (min)	D_m Corrected	Time to D_m (min)	SON_4	Remarks
	1.	Flaming	0.11	112.	4.5	438	Cover material only.
AF-2	2		0.11	110.	4.0	429	Flames 6-8 inches high.
	3		0.12	122.	4.0	480	
	Avg.		0.11	115.	4.2	449	
	1		0.57	93.4	12.5	167	Cover material only.
AF-2	2	Smoldering	0.48	95.9	14.0	188	
	3		0.43	95.2	13.0	201	
	Avg.		0.50	94.8	13.2	185	
	1		0.21	469.	2.5	1777	Foam padding only.
AF-2	2	Flaming	0.25	463.	2.0	1741	Flames 6-8 inches high.
	3		0.21	350.	2.8	1533	
	Avg.		0.23	427.	2.4	1684	
	1		1.00	400.	15.0	386	Foam padding only.
AF-2	2	Smoldering	0.87	404.	13.0	442	Dense smoke.
	3		0.86	394.	13.5	420	
	Avg.		0.91	399.	13.8	416	
	1		0.19	804. +	4.5	2086	Complete item. Maximum
AF-2	2	Flaming	0.15	804. +	4.0	2445	specific density was above
	3		0.17	804. +	3.5	2570	the limits of measuring.
	Avg.		0.17	804. +	4.0	2367	
	1		0.72	773.	11.0	825	Complete item.
AF-2	2	Smoldering	0.57	804.	9.0	1235	Extremely dense smoke.
	3		0.53	804.	10.0	1205	
	Avg.		0.61	794.	10.0	1088	

TABLE 8. SMOKE MEASUREMENTS - ASTM TEST METHOD STP NO. 422 (Continued)

Item No.	Test No.	Type of Exposure	Time to Reach D_s = 16 (min)	D_m Corrected	Time to D_m (min)	SON_4	Remarks
	1	Flaming	Never	7.5	10.0	16	Cover material only. Flames
AF-3	2		Reached	8.1	10.0	15	4-6 inches high.
	3		D_s = 16	5.5	9.5	15	Very light smoke.
	Avg.			7.0	10.0	15	
	1	Smoldering	0.64	61.4	4.5	215	Cover material only.
AF-3	2		0.58	63.1	5.0	222	Light smoke.
	3		0.61	68.7	4.5	244	
	Avg.		0.61	64.4	4.7	227	
AF-3	1	Flaming	2.54	42.1	10.0	66	Complete item. Not enough material for more testing.
	1	Flaming	0.38	113.	3.5	453	Complete item.
AF-4	2		0.40	104.	3.0	411	Flames 8-10 inches high.
	3		0.28	106.	3.5	424	
	Avg.		0.35	108.	3.3	429	
	1	Smoldering	0.68	261.	4.0	748	Complete item.
AF-4	2		0.70	240.	4.5	712	
	3		0.72	233.	4.0	704	
	Avg.		0.70	245.	4.2	721	
AF-5	Avg.	Flaming	1.30	42.8	9.7	80	Complete item

2. FIRE TEST OF FLEXIBLE HOSES AND FIREWALL MATERIAL

2.1 General

Two flexible, self-sealing, low-pressure Aeroquip hoses (Part No. 305-16-100psi) and a 10 by 10 inch piece of an aluminized asbestos-faced flexible firewall backed with a silicone fiberglas cloth were tested as to their relative resistance to a 2,000°F flame produced by the FAA standard 2-gallon-per-hour burner.

2.2 Test Facility

The fire test burner used for these tests was a 2-gallon-per-hour kerosene burner. The burner provided a 2,000°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. A special fixture was constructed to hold the hose so that a 6-inch bend radius at the outlet end of the hose was achieved.

2.3 Fire Tests of Flexible Hoses

The general test set-up for the fire resistance test of the Aeroquip hoses is shown in Figure 6. For these tests, one hose was coated with an AVCO Corp. intumescent paint called "Flexible Flame Arrest" (Figure 7); the other was uncoated. The hoses were tested as close as possible to the SAE ARP (Aerospace Recommended Practice) 1055. The means to provide the vibration requirement and flow-pressure requirement as stated in the foregoing ARP was not available.

From a heated reservoir, hot oil was pumped through the hose and back to the reservoir. The temperature of the oil was thermostatically controlled at the reservoir. A thermocouple was placed at the inlet and outlet side of the hose undergoing tests. Downstream of the outlet side of the hose, a valve was placed to divert the oil through a nozzle calibrated for a known flow. The results of these tests are shown in Table 9.

Neither hose met the test criteria for fire resistance, i.e., 5-minute exposure to the 2,000°F flame of the standard burner, even though the actual test requirements were less stringent than those required by ARP 1055. However, the intumescent paint coating did provide an additional 2 minutes and 16 seconds protection for the original hose. Figure 8 shows the hose specimens which were subjected to the standard burner during these tests.

2.4 Fire Tests of Firewall Material

An aluminized asbestos-faced flexible firewall backed with a silicone fiberglas cloth was subjected to a 2000°F flame from the 2 gallon-per-hour kerosene standard burner. The firewall material weighed 0.4 pound per square foot and was 1/8 to 3/16 inches in thickness.

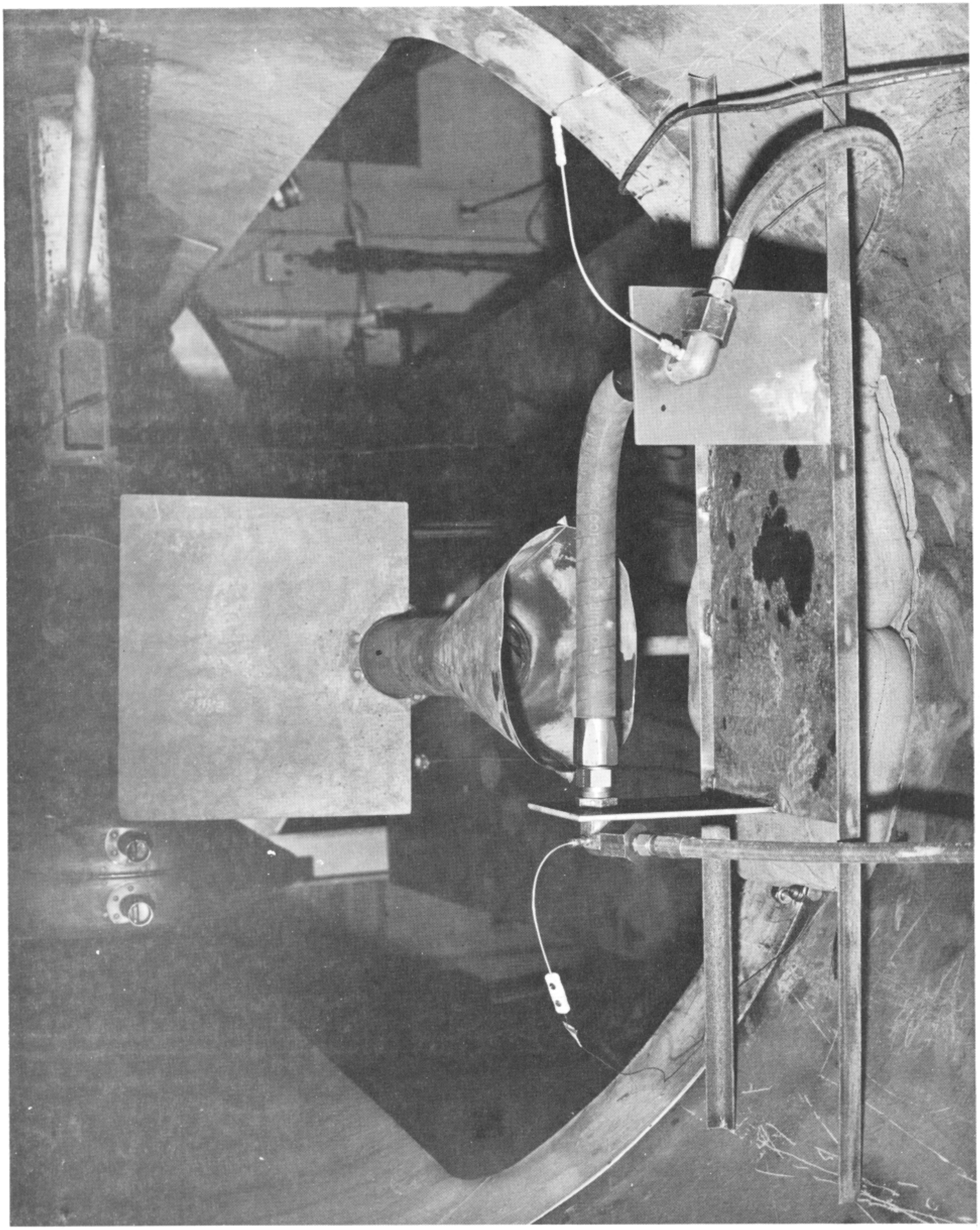


FIGURE 6. HOSE FIRE-RESISTANCE TEST SETUP

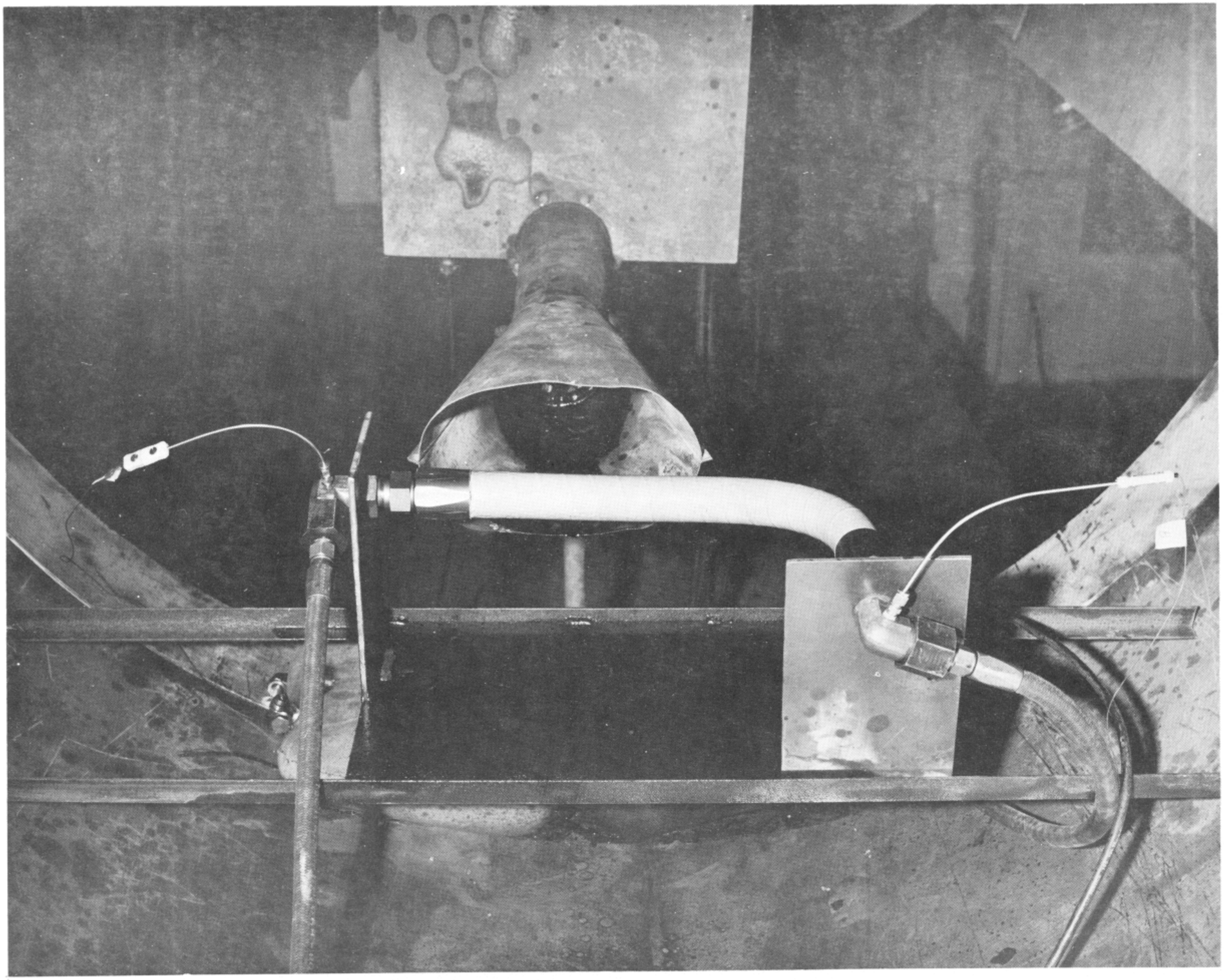


FIGURE 7. COATED HOSE FIRE RESISTANCE TEST SETUP

TABLE 9. FIRE TEST OF FLEXIBLE HOSES

Type Hose	Oil Temp.	Oil Pressure	Oil Flow	Time to Failure
Uncoated	150°F	27 psi	2 gpm	2 min 26 sec
*Coated	155°F	27 psi	2 gpm	4 min 42.5 sec

Note: * = Flexible flame arrest - intumescent paint.

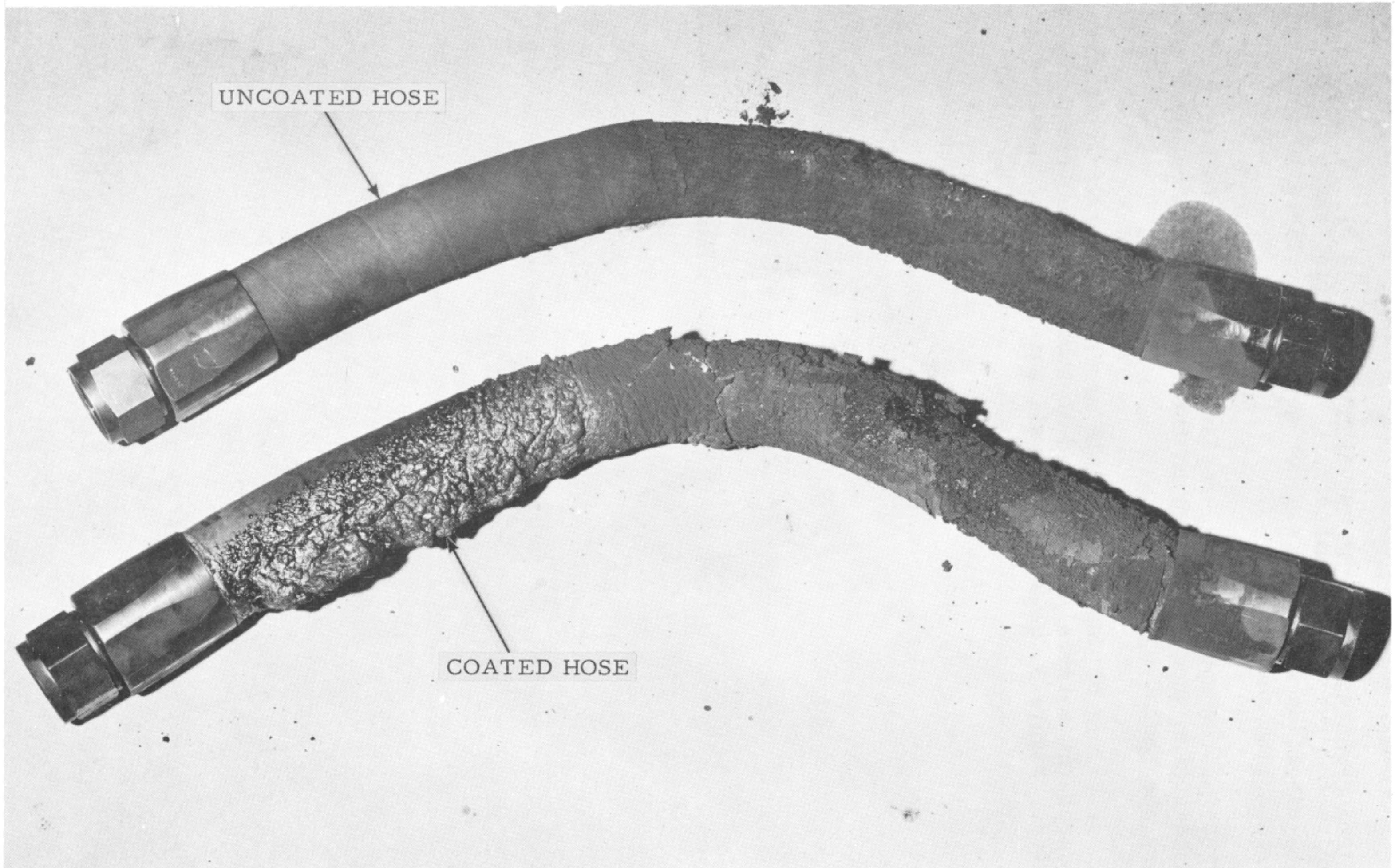


FIGURE 8. DAMAGE TO HOSE SPECIMENS

The flame temperature of the burner was measured at 2,050°F. The burner flame impinged on the face of the material. The material was not vibrated during the tests since vibration equipment was not available. Table 10 is a resume of what occurred during the tests.

In assessing the apparent fire-resistant/fireproof qualities of this material, consideration should be given to the fact that the material was not vibrated during the tests.

Normal procedure of testing flexible material for fire-resistant/proof qualities requires the material be vibrated at some specified frequency while undergoing tests. Figure 9 shows the firewall material after completion of test.

TABLE 10. RESUME OF FIREWALL MATERIAL TESTS

Exposure Time	Remarks
15 sec	Heavy grey smoke began emitting from back-side material.
30 sec	Backing material started to turn dark grey.
45 sec	A red glow appeared on the back side.
1 min 30 sec	Particles of asbestos started falling from the front side.
2 min	The metal frame which held the specimen started glowing red.
3 min 30 sec	Two or three small pinholes appeared in material, but there was no flame penetration observed.
5 min	Smoke from specimen had almost completely subsided.
11 min	More particles were observed falling from the front side.
15 min	Approximately 12 very small pinholes could be seen in the specimen, but no flame penetration was observed.
	When the burner was removed, 1- to 2-inch long tears in three areas were observed on the aluminized side of the test specimen.

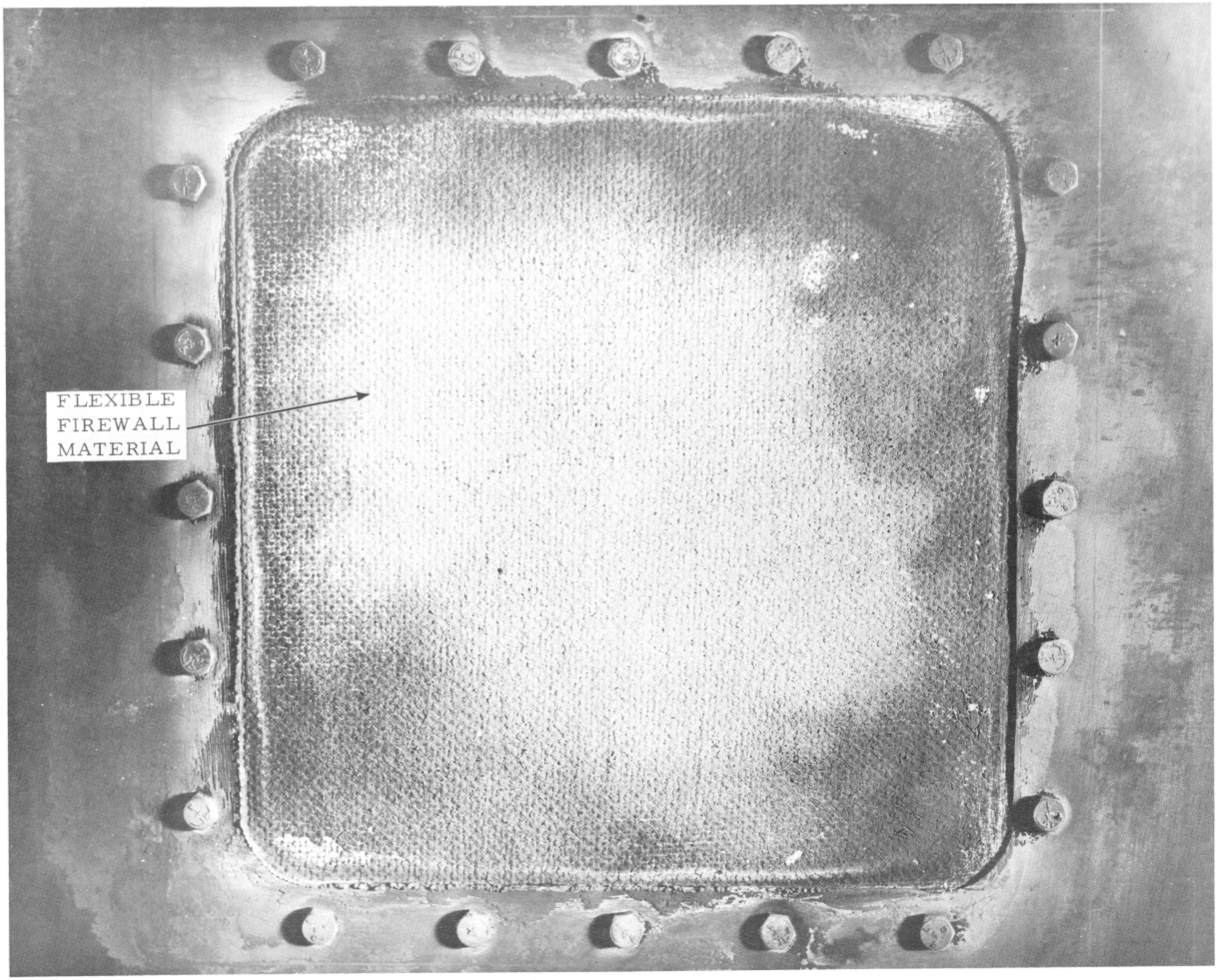


FIGURE 9. FIREWALL MATERIAL AFTER 2,000°F TESTS

SECTION IV

GUNFIRE TESTS

1. DYNAMIC GUNFIRE TESTS

1.1 General

The gunfire program conducted at FAA/NAFEC, Atlantic City, New Jersey, during this contract period was a continuing effort into the investigation of the vulnerability of JP-4 and JP-8 fuels to ignition when subjected to penetration by a 50-caliber armor-piercing incendiary ordnance round and the generation of fires both external to the fuel cell and in the dry bay areas adjacent to the fuel tanks.

In this evaluation, horizontal, liquid phase, and vertical, liquid-to-vapor, phase gunfire tests were conducted, using simulated fuselage and simulated wing-type fuel tanks. The variable parameters for the horizontal liquid phase tests were fuel type, dry bay (void space) volume, and dry bay ventilation rates.

The variable parameters for the vertical, liquid-to-vapor phase, tests were fuel type and air flow over the test article. The remaining parameters were maintained at a constant value.

All tests were conducted using a 50-caliber API ordnance round with a velocity of 2,400 ft/s.

1.2 Test Facility

The test facility utilized in the horizontal, liquid phase, gunfire test program consisted of an air supply system, to simulate the flight speed of the simulated fuselage fuel tank, a fuel tank, a fuel conditioning system, and a 0.50-caliber single-shot weapon. The air system can supply air at 90 knots, with the engine at idle, and increasing air flows of up to 450 knots with the engine at 95 percent r/min of the N1 rated rotor speed. Figure 10 is an overall view of the facility, showing the air supply system, the 0.50-caliber weapon and the horizontal test article. Figure 11 shows the fuel conditioning system. A complete description of this facility and its use is contained in the FAA/NAFEC Report No. FAA-NA-71-6 titled "AFAPL Aircraft Fire Test Program With the FAA, 1967-1970."

The vertical, liquid-to-vapor phase, gunfire test program required changes in the existing air supply system, relocating the 50-caliber weapon and designing a simulated wing-type fuel tank.

The air supply system had to be modified to permit the air to pass over the elevated test article. This was achieved by placing an "S" section and additional duct sections into the air system. Figure 12 shows these modifications. Due to these modifications, the air system was recalibrated.

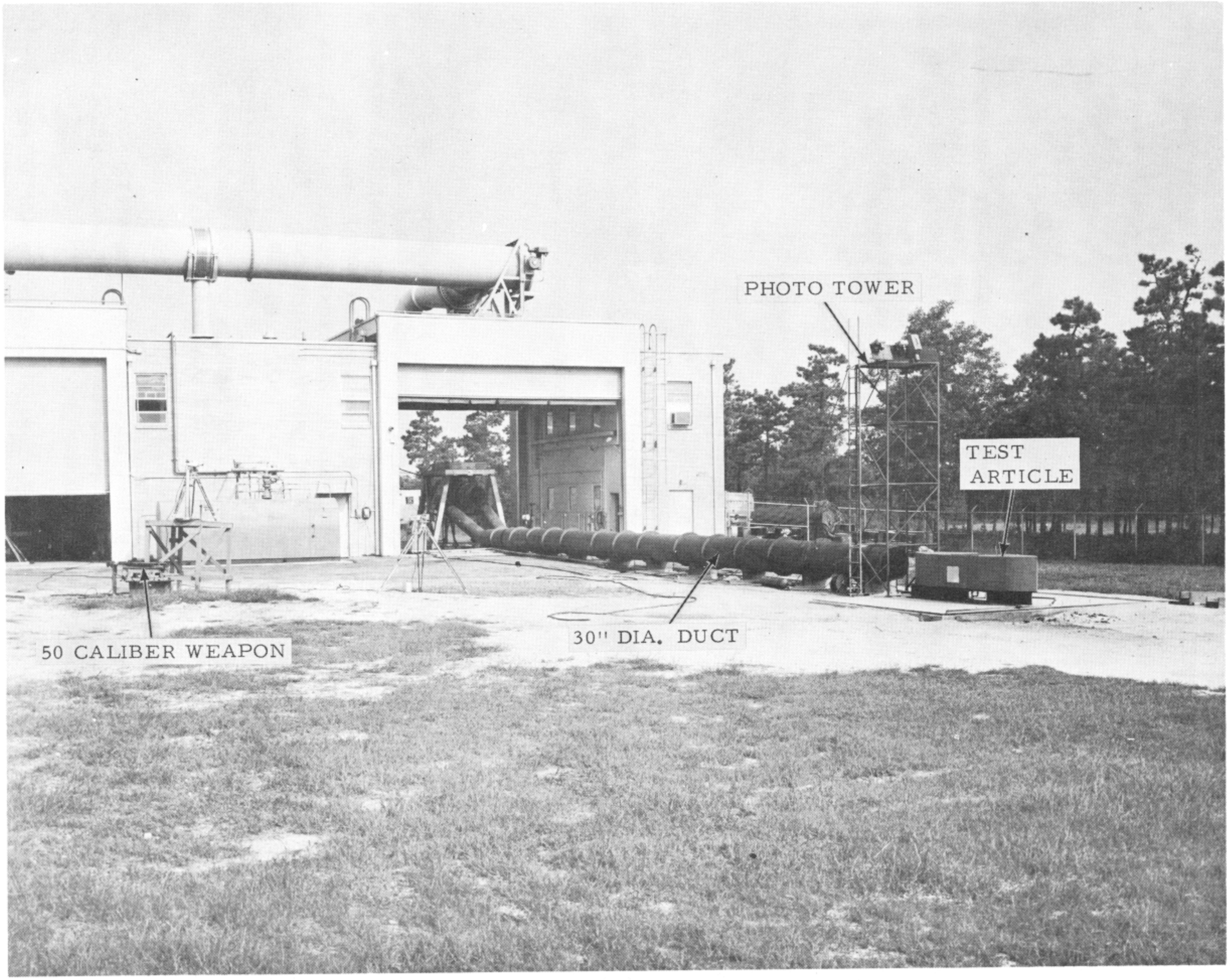


FIGURE 10. OVERALL VIEW SHOWING ENGINE TEST WEAPON AND TEST ARTICLE

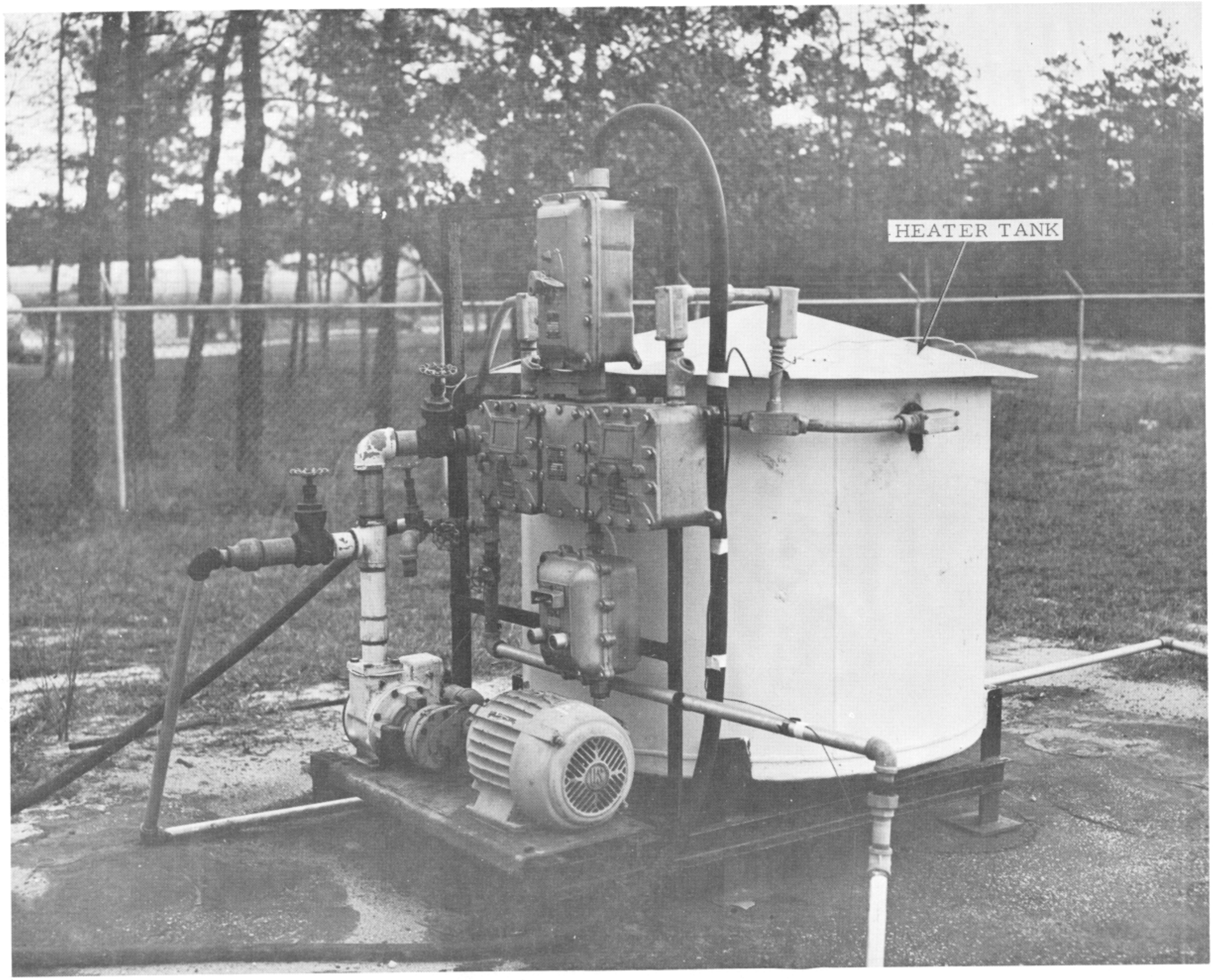


FIGURE 11. FUEL CONDITIONING SYSTEM

FIGURE 12. MODIFICATIONS TO AIR SUPPLY SYSTEM

The discharge air velocity was measured over a range of engine power settings. With corrections for other than standard day temperatures and pressures, a new calibration curve was generated. At 23 percent r/min of the N_1 rotor speed, a 90-knot air flow over the test article was achieved. The maximum air velocity, with this configuration, was 400 knots at 92 percent N_1. Figure 13 is the calibration curve which indicates the full range of velocities which the modified air supply system can provide. This curve was utilized in determining the simulated flight velocities for the vertical gunfire tests.

The weapon used in the vertical tests was a single-shot, 0.50 caliber, weapon 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 weapon mount was a standard Frankford Arsenal mount which was bolted to a steel frame and positioned in a pit at a 30 degree pitch-up angle. Figure 14 shows the location of the weapon.

The test article utilized in the vertical gunfire test program was a rectangular box fuel section with fairing sections on each end as shown in Figure 14. The fairing sections, leading and trailing, provided for an aerodynamic shape.

The fuel cell of the test article was 3 feet X 5 feet X 18 inches and constructed of 5/8-inch steel plate. A replaceable striker plate of 0.090-inch, 2024 - T3 aluminum was flush-mounted on the lower surface of the fuel cell and and additional plate of similar material was positioned on the upper surface to allow the projectile to exit the fuel cell.

An overhead viewport was located in the top of the test article so that high-speed filming of the interior of the fuel cell could be obtained during the test.

Instrumentation in the vertical test article consisted of thermocouples for the fuel, ullage, and ambient air temperatures. Pressure transducers were used to measure the pressure in the ullage space of the fuel cell. Figure 15 shows the location of the instrumentation in the test article.

All measurements of temperature and pressure were recorded by an oscillograph recorder.

Data films of each test were taken. The coverage consisted of three cameras, two at 3,500 frames per second (fps) and another at 64 fps for general coverage of the tests. One 3,500 fps camera was placed at the weapon angle to view the projectile entrance and action thereafter while the other 3,500 fps camera was positioned on top of a 30-foot tower to provide the overhead view of the action within the fuel cell.

1.3 Test Procedure

The test procedure employed in this program consisted of six tests to be conducted at each test condition. If similar results were obtained, such

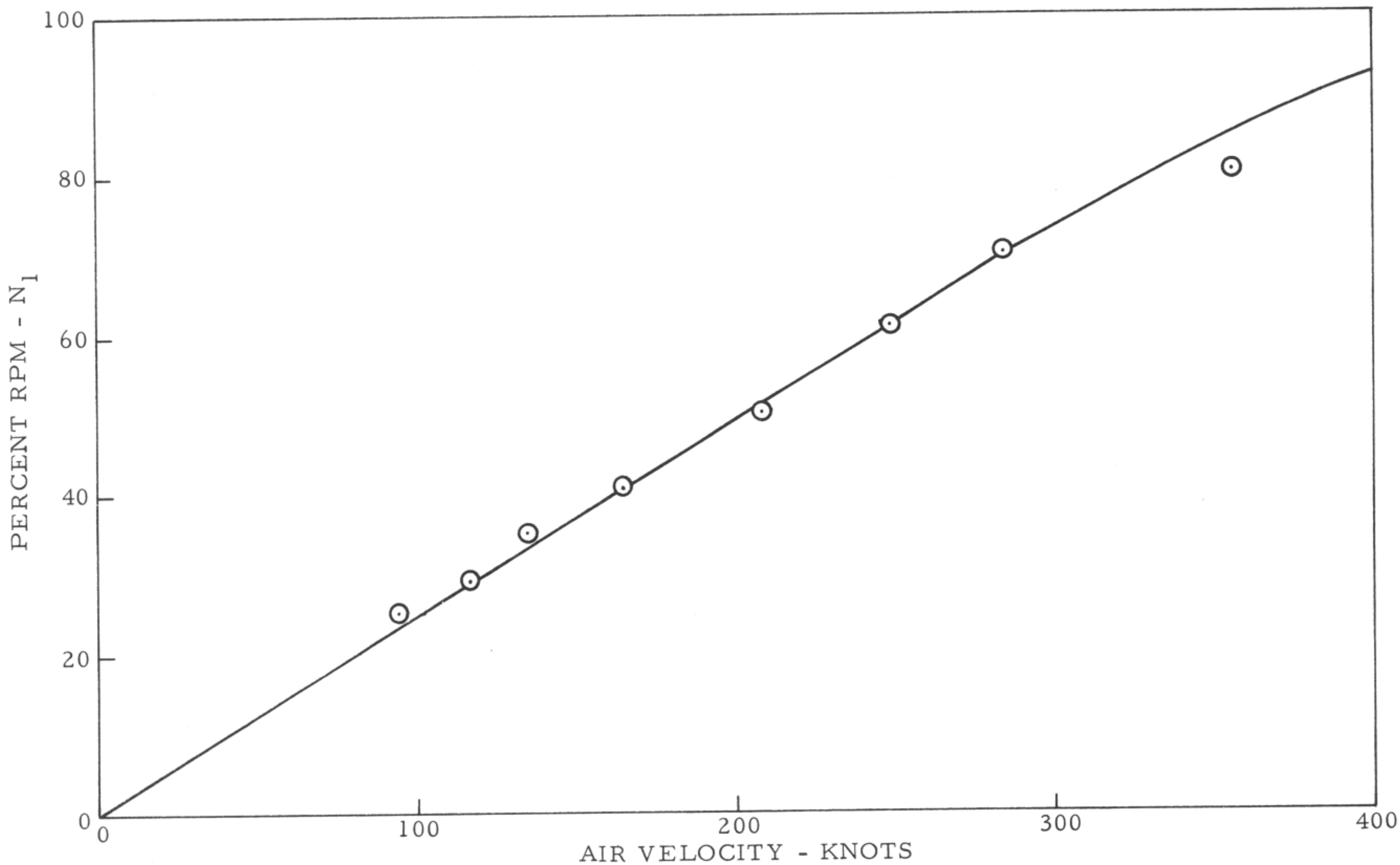


FIGURE 13. AIR SUPPLY SYSTEM CALIBRATION CURVE

FIGURE 14. VERTICAL GUNFIRE TEST ARTICLE AND WEAPON LOCATION

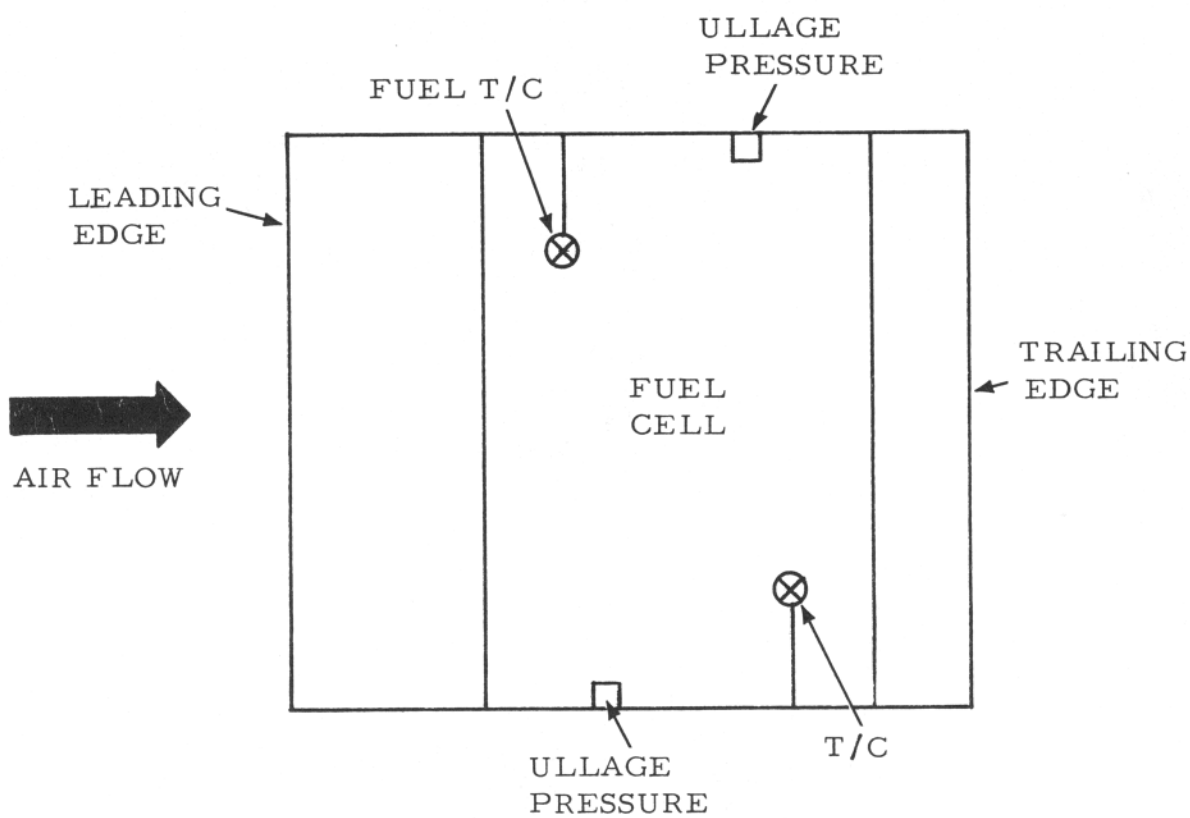


FIGURE 15. INSTRUMENTATION IN THE VERTICAL TEST ARTICLE

as fire external to the fuel cell, dry bay fire (horizontal tests), or pressure rise in the fuel cell, were obtained during the first four tests of a series, 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 fuel cell. The desired air velocity over the test article was then maintained for a stabilization period of approximately 5 minutes. After the stabilization period a sequence timer was started. This sequencer automatically controlled the powering of the cameras, the oscillograph recorder, and the firing of the weapon.

The test parameters for the horizontal, liquid phase, and gunfire tests are shown in Table 11, while a summary of the individual test conditions are given in Figure 16. The test parameters for the vertical, liquid to vapor phase, gunfire tests are given in Table 12.

1.4 Results and Conclusions

The gunfire test program conducted at NAFEC, Atlantic City, N. J., was a continuing effort in evaluating the vulnerability of JP-4 and JP-8 fuels when penetrated by a 50-caliber incendiary ordnance round. A series of 54 horizontal gunfire tests was conducted with various ventilation rates in the dry bay space adjacent to the fuel tank and various dry bay volumes as previously indicated in Figure 16. The data results of these tests are given in Table 13.

This data has been combined with data from previous horizontal gunfire tests conducted at NAFEC and a complete analysis of this combined data is presented in the Report, AFAPL-TR-72, "Vulnerability of Dry Bays Adjacent to Fuel Tanks Under Horizontal Gunfire."

The general conclusion (see Reference 2) developed thru the analysis of the combined horizontal gunfire test data was that JP-8 is less susceptible to fire and explosion induced by gunfire and structural damage should be less when compared to JP-4.

The vertical, liquid to vapor phase, gunfire tests portion of the program consisted of 54 tests utilizing the simulated wing type fuel cell. Thirty tests were conducted with JP-4 fuel and 24 with JP-8 fuel. The test results are given in Table 14.

Information obtained from the oscillograph records during the course of vertical test indicated the initial maximum overpressure in the ullage space of the fuel cell to be relatively small regardless of the fuel tested, i.e., in the order of 1.0 to 2.45 lb/in^2.

Figure 17 is a comparison of the maximum overpressure in the ullage space of the fuel cell versus time to maximum overpressure for the vertical test conducted with JP-4 and JP-8 fuels. The overlapping envelopes shown on this graph indicate no significant difference in ullage overpressure for either of the fuels tested.

TABLE 11. TEST PARAMETERS FOR HORIZONTAL, LIQUID PHASE, GUNFIRE TESTS

Fuels	JP-4 or JP-8
Projectile type and velocity	50 caliber API, 2400 fps
Projectile trajectory	horizontal w/impact angle of 30°
Tank volume	approximately 90 gallons
Fuel height	18 inches
Fuel temperature	90° ±5°F
Impact point	mid-fuel
Ullage	25 percent
External air velocity	90 knots
Stand-off distance (Strikerplate to Tank)	0, 27 inches

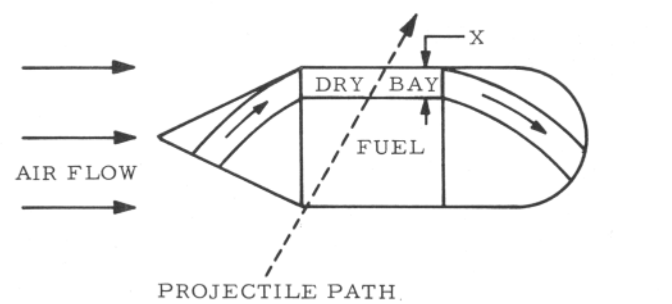
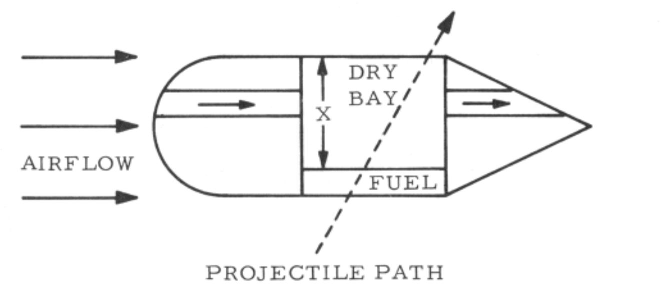
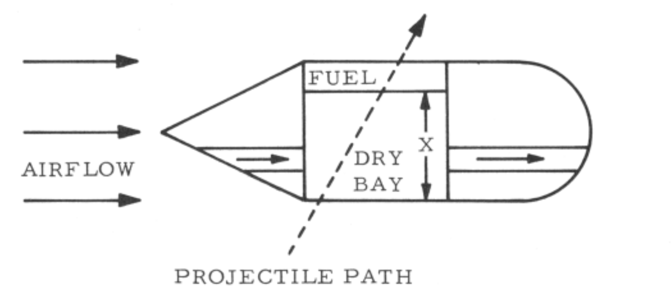
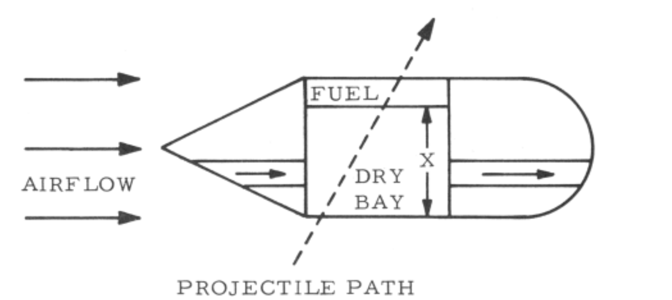
	TESTS 201 THRU 212 X = 9", VOL. 3.77 Ft^3 0 AND 23 DRY BAY ACPM EXTERNAL AIR FLOW 152 FPS FUEL TEMP. 90°F TANK PRESSURE 14.7 PSIA
	TESTS 213 THRU 230 X = 27", VOL. = 9.92 Ft^3 0, 7, AND 33 DRY BAY ACPM EXTERNAL AIR FLOW 152 FPS FUEL TEMPERATURE 90°F TANK PRESSURE 14.7 PSIA
	TESTS 231 THRU 242 X = 27", VOL. = 9.92 Ft^3 0 AND 7 DRY BAY ACPM EXTERNAL AIR FLOW 152 FPS FUEL TEMPERATURE 90°F TANK PRESSURE 14.7 PSIA
	TESTS 243 THRU 254 X = 27", VOL. = 19.9 Ft^3 (INCLUDES 10 Ft^3 HAT SECTION) 0 AND 4 DRY BAY ACPM EXTERNAL AIR FLOW 152 FPS FUEL TEMPERATURE 90°F TANK PRESSURE 14.7 PSIA

FIGURE 16. SUMMARY OF TEST CONDITIONS

TABLE 12. TEST PARAMETERS FOR VERTICAL, LIQUID-TO-VAPOR, GUNFIRE TESTS

Fuels	JP-4 or JP-8
Projectile type and velocity	50 caliber API, 2400 fps
Projectile path thru fuel	4 inches
Fuel height	approximately 2.5 inches
Fuel temperature	90° ±5°F
Ullage	85 percent
External air velocity	0, 90, 150, 390 knots

TABLE 13. HORIZONTAL GUNFIRE TEST RESULTS

Test No	Fuel Used	Fuel Temp °F	External Fire	Dry Bay Fire	Max Pressure in Tank	Time to Max Pr in Tank	Max Pressure Dry Bay	Time to Max Pr Dry Bay	Air cpm in Dry Bay
201	JP-4	90	No	No	2.7	.10	-	-	0
202	JP-4	90	No	No	2.9	.09	-	-	0
203	JP-4	90	Flash	No	2.3	.11	-	-	0
204	JP-8	90	Flash	No	2.6	.08	-	-	0
205	JP-8	90	No	No	2.6	.08	-	-	0
206	JP-8	90	No	No	2.7	.07	-	-	0
207	JP-8	90	No	No	3.5	.10	-	-	23
208	JP-8	90	No	No	2.3	.10	-	-	23
209	JP-8	90	No	No	2.25	.10	1	-	23
210	JP-4	90	Flash	No	1.3	.17	-	-	23
211	JP-4	90	No	No	2.5	.10	-	-	23
212	JP-4	90	No	No	1.2	.11	-	-	23
213	JP-4	90	No	No	6.6	.027	-	-	0
214	JP-4	90	No	No	6.4	.03	-	-	0
215	JP-4	90	No	No	8.0	.03	-	-	0
216	JP-8	90	Flash	No	9.0	.03	-	-	0
217	JP-8	87	Flash	No	6.8	.03	-	-	0
218	JP-8	90	No	Yes	6.2	.040	-	-	0
219	JP-8	85	No	No	6.6	.03	-	-	6-7
220	JP-8	75	Flash	Yes	14.4	.148	13.2	.074	6-7
221	JP-8	90	No	Yes	22.8	.095	23.2	.080	6-7
222	JP-4	90	No	Yes	6.6	.04	6.7	.086	6-7
223	JP-4	90	No.	No	7.6	.035	-	-	6-7
224	JP-4	90	No	No	8.6	.04	.4	-	6-7
225	JP-4	90	No	No	7.4	.035	-	-	33
226	JP-4	90	Flash	No	9.2	.035	.3	-	33
227	JP-4	87	No	No	7.8	.035	-	-	33
228	JP-8	88	No	No	8.8	.035	-	-	33
229	JP-8	92	No	No	10.8	.040	.4.	-	33
230	JP-8	90	No	Yes	7.6	.040	3.0	.316	33
231	JP-4	90	No	Yes	8.8	.04	32.8	.119	0
232	JP-4	88	No	Yes	10.6	.04	34.4	.216	0
233	JP-4	90	No	Yes	12.2	.03	34.0	.082	0
234	JP-4	90	No	Yes	9.0	.04	13.4	.078	6-7
235	JP-4	90	Yes	Yes	11.4	.04	9.9	.128	6-7
236	JP-4	90	Yes	No	No Record	No Record	No Record	-	6-7
237	JP-8	90	Yes	No	12.4	.04	0	-	0
238	JP-8	90	Yes	Yes	- 1.0	-.01	.7	.010	0
239	JP-8	90	No	Yes	13.0	.04	7.4	.134	0
240	JP-8	90	No	Yes	14.6	.04	1.1	.017	6-7
241	JP-8	88	Flash	Yes	10.0	.03	2.5	.057	6-7
242	JP-8	90	No	Yes	9.8	.04	1.6	.157	6-7
243	JP-4	90	No	Ind*	20.0	.16	25.4	.123	0
244	JP-4	90	Yes	Yes	40.8	.20	56.0	.171	0
245	JP-4	90	No	Ind*	4.0	.03	0	-	0
246	JP-4	90	Yes	Ind*	22.2	.16	27.5	.110	3.5-4
247	JP-8	90	No	Ind*	8.6	.14	15.8	.097	0
248	JP-8	90	No	Ind*	8.6	.17	8.7	.177	0
249	JP-8	90	No	Ind*	6.4	.04	7.3	.153	3.5-4
250	JP-8	90	No	Ind*	7.0	.045	.8	.013	3.5-4
251	JP-8	95	No	Ind*	9.4	.04	9.1	.176	3.5-4
252	JP-8	90	No	Ind*	8.2	.04	9.8	.258	0
253	JP-4	85	No	Ind*	22.4	.11	15.5	.086	3.5-4
254	JP-4	85	No	Ind*	31.2	.11	36.6	.080	3.5-4

NOTE: All tests at 90 knots airflow over the test article.

*Indeterminate

TABLE 14. VERTICAL GUNFIRE TEST RESULTS

Test No	Fuel Used	Fuel Temp (F°)	Air Vel Kts	Max Press In Tank	Time To Max Press In Tank	Exit Fire	Time Exit Fire Out	Time Exit Fire Start	Ext Fire At Striker	Time Ext Fire Out Striker Plate	Damage To Striker Plate	Remarks
301	JP-4	85	0	1.5	.006	No	-	-	No	-	C	
302	JP-4	89	0	3.8	.01	No	-	-	Yes	1.250	A	
303	JP-4	90	0	1.50	.005	No	-	-	Yes	1.234	A	Fire on ground till 7.54 + secs.
304	JP-4	90	0	1.7	.010	No	-	-	Flash	.192	C	
305	JP-4	90	0	2.4	.010	No	-	IMD	Flash	-	C	
306	JP-4	90	0	2.0	.005	No	-	-	Yes	1.110	A	Fire on ground till 7.82 + secs.
307	JP-4	90	0	1.75	.005	No	-	IMD	Flash	-	A	
308	JP-4	88	0	1.75	.007	Yes	.428	IMD	Yes	IND	A	Fire on pad ignited fuel @ 2.34 secs and striker area @ 3.31 secs
309	JP-4	90	0	2.4	.008	Yes	.562	IMD	Yes	IND	A	
310	JP-4	90	0	1.50	.007	No	-	IMD	Yes	4.36+	B	Second pressure rise - 1.75 psig @ .15 secs
311	JP-4	90	0	1.6	.009	Yes	1.612	IMD	Flash	-	A	
312	JP-4	92	0	1.10	.006	No	-	IMD	Yes	3.46+	C	3500 fps film indicates fire in tank
313	JP-4	95	90	1.65	.007	No	-	-	No	-	A	
314	JP-4	90	90	1.2	.006	No	-	IMD	Yes	.208	B	
315	JP-4	95	90	2.2	.009	No	-	IMD	Flash	-	C	
316	JP-4	85	90	1.60	.010	Yes	.818	IMD	Flash	-	B	Second pressure rise - 1.26 psig @ .94 secs
317	JP-4	90	90	4.2	.18	Yes	.658	-	Yes	6.286+	A	Second pressure rise - 5.10 @ .15 secs
318	JP-4	85	90	1.4	.009	No	-	IMD	Flash	-	C	
319	JP-4	90	150	1.8	.010	No	-	IMD	Flash	-	A	
320	JP-4	90	150	1.7	.010	No	-	-	No	-	C	Fuel very slow in exiting tank
321	JP-4	90	150	1.00	.010	No	-	-	No	-	A	
322	JP-4	90	150	2.2	.010	No	-	-	No	-	A	
323	JP-4	90	150	No Rec.	No Rec.	No	-	-	No	-	B	
324	JP-4	95	150	1.45	.04	No	-	-	No	-	C	
325	JP-4	90	390	2.1	.010	No	-	-	No	-	B	
326	JP-4	90	390	2.5	.015	Yes	.226	IMD	Flash	-	A	
327	JP-4	85	390	2.5	.010	No	-	-	No	-	B	
328	JP-4	95	390	2.8	.015	Yes	.274	IMD	Flash	-	A	
329	JP-4	95	390	1.7	.015	No	-	-	No*	-	A	
330	JP-4	90	390	1.3	.010	Yes	IND	IND	No	-	B	
331	JP-8	95	0	2.6	.15	IND	-	IMD	Yes	1.037	B	Additional pressure rises 3.2 psig @ .145 secs 2.8 psig @ .225 secs 1.35 psig @ .300 secs .65 psig @ .380 secs
332	JP-8	95	0	13.5	.25	Yes	IND	IMD	Yes	.815	B	Second pressure rise - 13.5 psig @ .35 secs
333	JP-8	95	0	21.6	.26	Yes	IND	IMD	Yes	1.481	A	Second pressure rise 21.25 psig @ .265 secs
334	JP-8	85	0	1.7	.008	No	-	-	Flash	-	C	
335	JP-8	90	0	16.0	.16	Yes	IND	IND	Yes	1.407	B	Second pressure rise - 16.4 psig @ .16 secs
336	JP-8	90	0	2.7	.19	Yes	IND	IND	Yes	1.03	B	Second pressure rise - 2.51 psig @ .19 secs
337	JP-8	90	90	4.1	.11	Yes	IND	IND	Yes	.740	B	Second pressure rise - 4.0 psig @ .25 secs
338	JP-8	90	90	1.2	.006	No	-	-	Flash	-	C	
339	JP-8	95	90	1.3	.010	No	-	-	Yes	.333	A	
340	JP-8	95	90	1.60	.008	No	-	-	Flash	-	B	
341	JP-8	90	90	1.8	.008	No	-	-	Yes	.259	A	
342	JP-8	87	90	1.50	.008	No	-	-	No	-	C	
343	JP-8	92	150	1.70	.007	No	-	-	Flash	-	B	
344	JP-8	90	150	1.7	.010	No	-	-	Flash	-	B	
345	JP-8	90	150	2.00	.010	No	-	-	Flash	-	B	
346	JP-8	92	150	1.45	.010	No	-	-	Flash	-	A	
347	JP-8	90	150	1.40	.008	No	-	-	Flash	-	B	
348	JP-8	90	150	2.00	.008	No	-	-	Flash	-	A	
349	JP-8	88	390	1.80	.006	No	-	-	Flash	-	A	
350	JP-8	90	390	1.65	.007	No	-	-	No	-	B	
351	JP-8	90	390	1.9	.008	No	-	-	No	-	A	
352	JP-8	90	390	2.5	.006	No	-	-	Flash	-	A	
353	JP-8	90	390	1.65	.008	No	-	-	No	-	A	
354	JP-8	90	390	2.5	.009	No	-	-	No	-	A	

*Indicates flash fire downstream of striker plate.
A - Severe
B - Average
C - Minor
IND - Indeterminate
IMD - Immediate
Projectile exits on all tests except 301 through 306
"+" - indicates to end of film

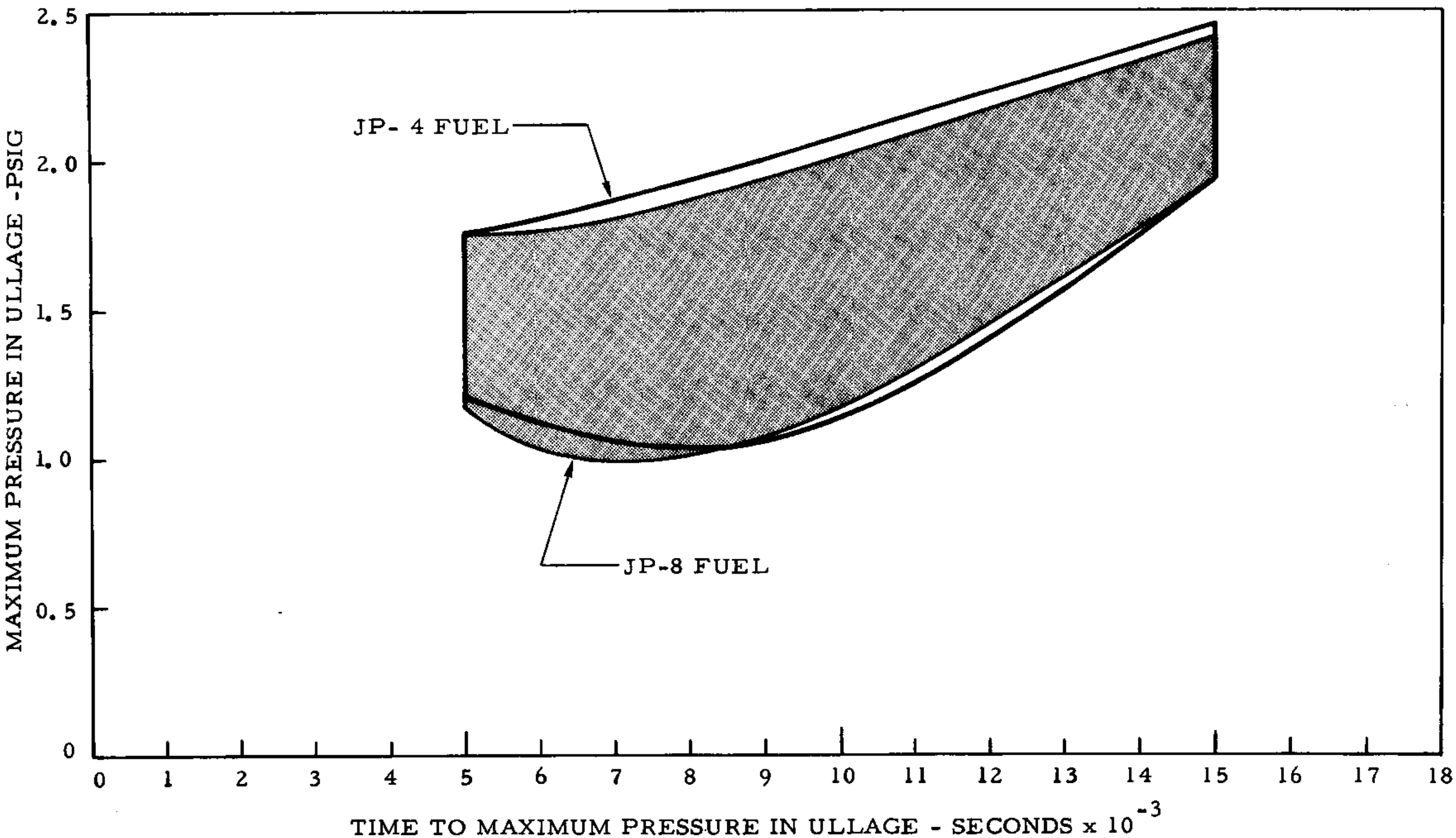


FIGURE 17. COMPARISON OF JP-4, JP-8 ULLAGE OVERPRESSURES

During the vertical gunfire tests, fire, external to the fuel cell, was noted in 30 percent of the tests conducted with each fuel as shown in Figure 18. These fires occurred at 0 and 90 knots simulated airflow over the test article. They were large self-sustaining fires. When the external fire erupted, the air velocity over the test article was increased to approximately 200 knots for 30 seconds so as to determine whether or not the fire could be blown off the test article. In most cases, (70 percent), the fire was blown downstream of the test article and extinguished.

In the tests conducted with higher airflows, 150 and 390 knots, over the simulated wing surfaces, external fires were either non-existant or of the flash fire variety.

Analysis of the external fire duration times from the high-speed data films indicated the duration of fire at the striker plate entrance to be considerably greater for JP-4 than JP-8. Figure 19 shows the average fire duration of JP-4 to be approximately three times longer than fires occurring with JP-8 fuel.

Although there was no clear difference indicated in the percentage of external fires obtained for each fuel tested, JP-4 and JP-8, the fact that there was a longer fire duration time at the striker plate entrance for JP-4 could be significant.

In the tests which resulted in large self-sustaining external fires, it was noted that damage to the entrance striker plate was more severe with JP-4 than JP-8 in the fuel cell. Typical striker plate damage, as shown in Figure 20, was categorized as: Type A, severe, Type B, average, and Type C, minor.

As noted in the test data, 67 percent of the self-sustaining, JP-4, external fires occurred with Type A damage to the striker plate while 38 percent of the tests with JP-8 fuel had similar type damage.

Within the limits of the vertical, liquid to vapor phase, gunfire tests conducted, it is concluded that:

1. There was no significant difference in ullage overpressure for either fuel tested.

2. The external fire duration at the entrance striker plate was considerably greater for JP-4 than JP-8.

3. The probability of sustained external fires is reduced as the airflow over the test article was increased.

4. The damage to the entrance striker plate is more severe during tests with JP-4 than with JP-8.

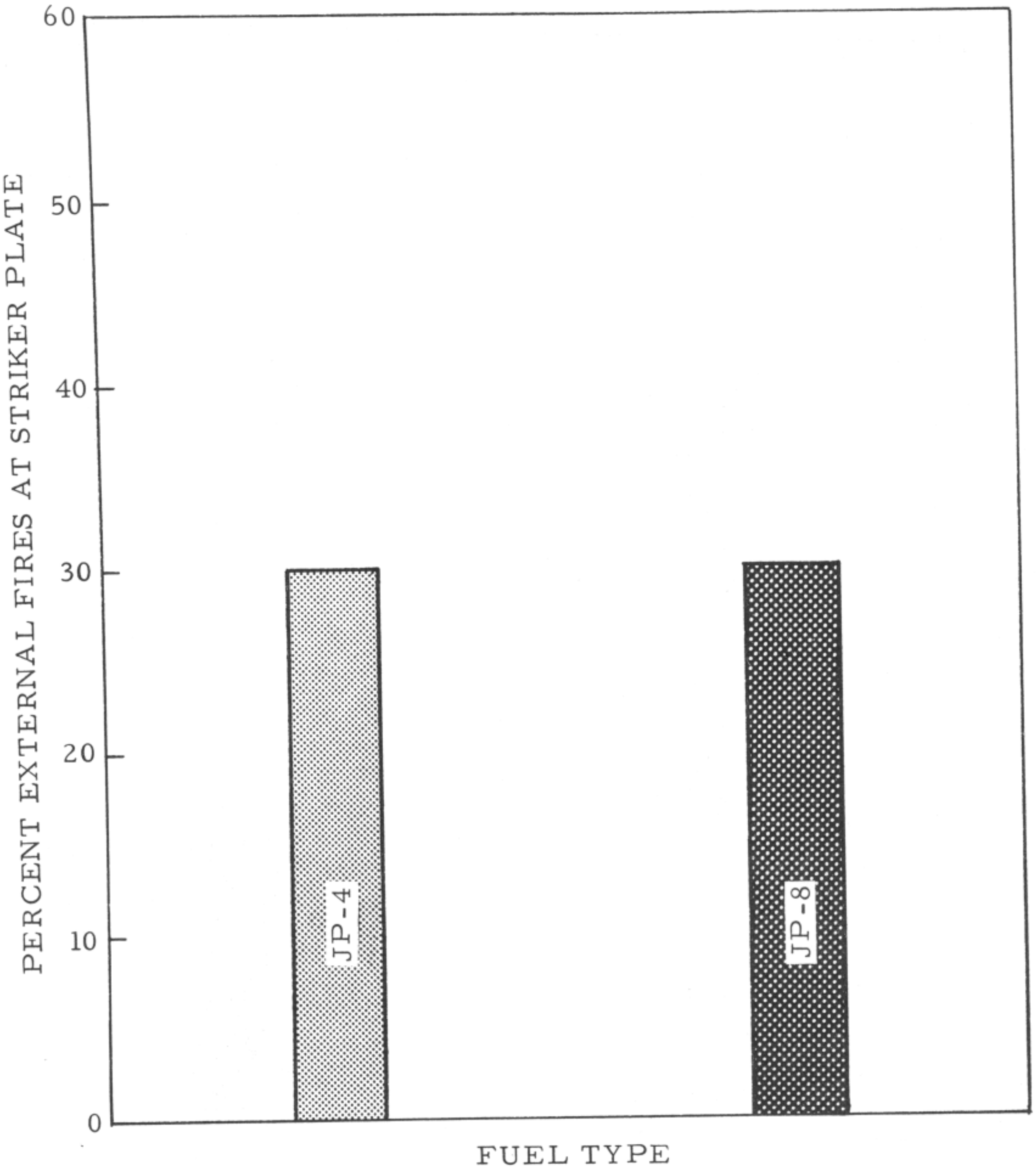


FIGURE 18. COMPARISON OF JP-4 AND JP-8 EXTERNAL FIRES

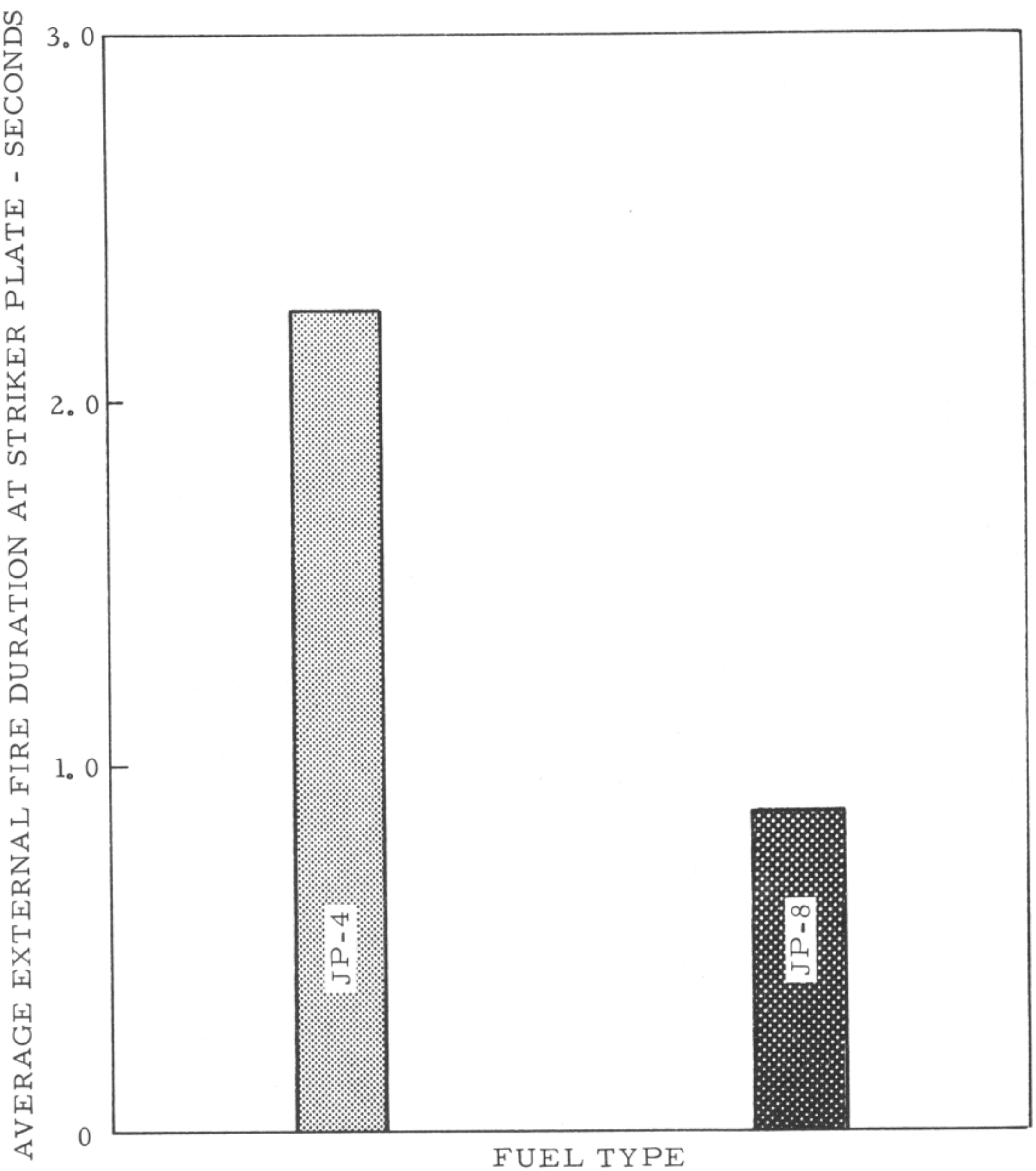


FIGURE 19. AVERAGE EXTERNAL FIRE DURATION, JP-4 vs JP-8

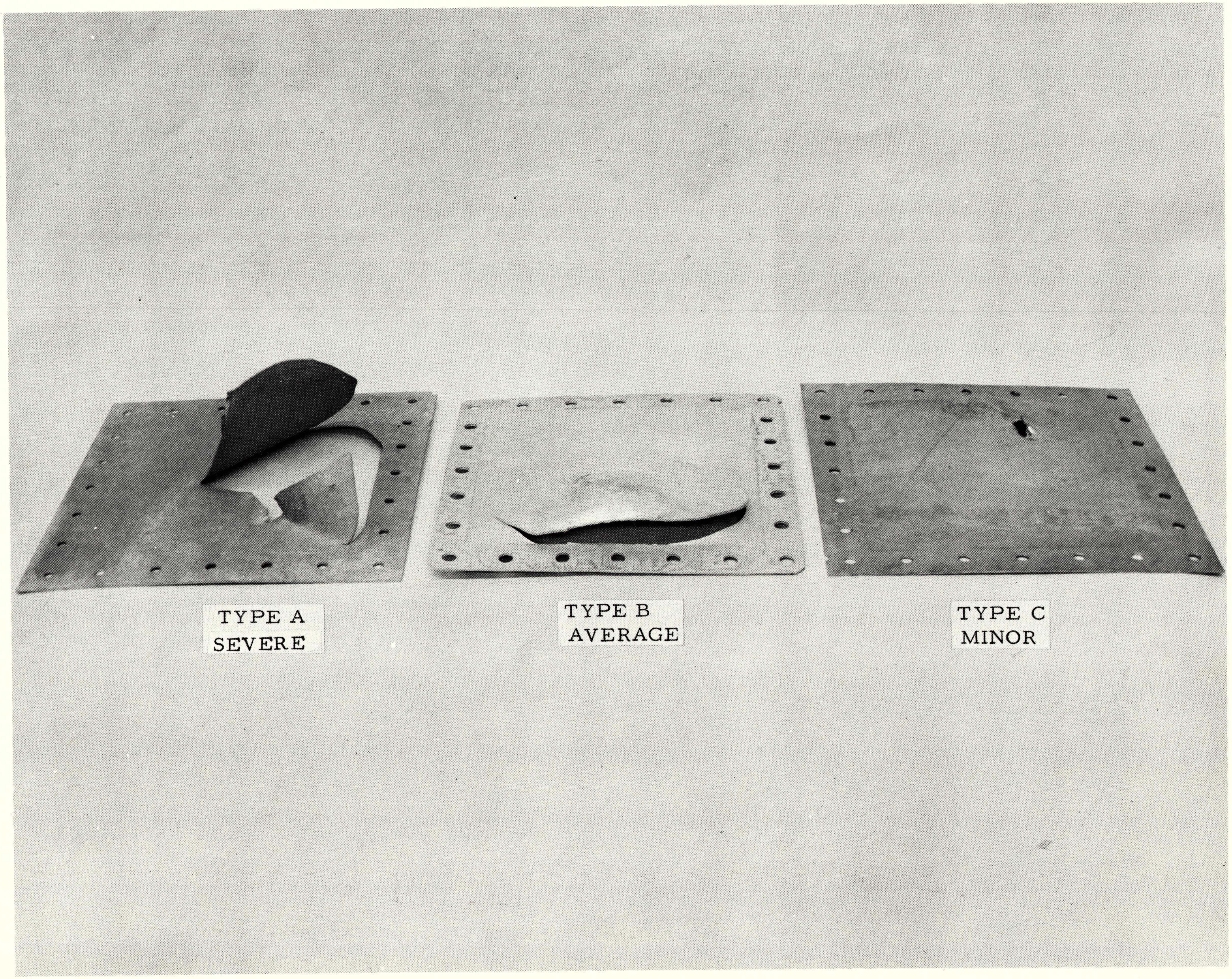


FIGURE 20. STRIKER PLATE DAMAGE

REFERENCES

1. AFAPL-TR-70-93 (FAA-NA-71-6), "AFAPL Aircraft Fire Test Program With FAA," 1967 - 1970, June 1971.

2. AFAPL-TR-72-83, "Vulnerability of Dry Bays Adjacent to Fuel Tanks Under Horizontal Gunfire."

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13. ABSTRACT

Fire tests were conducted in a turbojet powerplant installation to determine the effectiveness of an Edison and a Honeywell Ultraviolet Fire Detection System. The four sensor units for each system were installed on the forward bulkhead of the engine nacelle's accessory and compressor compartment (Zone II) and provided surveillance aft to the firewall. Fires having fuel-flow rates of 0.04 and 0.13 gallons per minute were initiated about 12 inches forward of the firewall at several locations around the periphery of the engine.

Both systems provided adequate detection of the 0.13 gallon per minute fires, but generally there was limited detection of the small 0.04 gallon per minute fires, depending on the fire location. Both systems provided rapid response time to fires, within the range of 0.2 to 1.0 seconds after the fuel-to-fire was released. In this test installation the peripheral disposition of the sensor units on the forward bulkhead provided overlapping coverage by most units.

A study of flammability and smoke generation characteristics was performed on different types of litter pads and pillows. These items were subjected to the following tests; Horizontal Test Method No. 5906, Vertical Test Method No. 5903, Radiant Panel Test Method, ASTM E-162, and Smoke Measurement Test Method, ASTM STP No. 442.

(Cont'd on Atched Sheet)

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Ultraviolet Radiation Detectors						
Fire Detectors						
Aircraft Engine Fire Tests						
Materials Flammability						
Smoke generation						
Fire Resistant materials						
Aviation Fuels, JP4 & JP8						
Gunfire						
Fuel System Vulnerability						
Aircraft Safety						