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FIRE PROTECTION TESTS IN A SMALL FUSELAGE-MOUNTED TURBOJET ENGINE AND NACELLE INSTALLATION

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FINAL REPORT

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16. Abstract

Tests under simulated flight conditions were conducted on a small fuselage-mounted turbojet engine and nacelle installation to investigate the potential explosion and fire hazards and detection and fire control methods.

Hot-surface ignition of flammables did not occur during simulated flight operating conditions until a change to the normal nacelle configuration reduced cooling airflow to the hot section of the engine (Zone I) below 0.15 pound per second.

The installed detection system did not provide for prompt detection of all fires originated in the lower forward portion of the compressor compartment (Zone II). Both the Zone II fire detection and the Zone I overheat detection system, a portion of which traversed the aft inboard section of Zone II, were sensitive to fires originated in the inboard portion of Zone II.

The installed extinguishing system provided rapid extinguishment of all Zone II fires until extensive accumulative damage from fires destroyed the integrity of the zone. Fireproof protection incorporated in the nacelle was very effective in performing its intended function. Most susceptable to damage by fire was the aluminum portion of the nacelle, especially aluminum receptacles for camlock-type fasteners, an aluminum ventilation louver panel in the top aft portion of Zone II, and aluminum ribs, formers, and baffles inside the nacelle in the path of fire. The fire damage to the engine and accessories was insignificant in regard to engine operation.

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INTRODUCTION

Purpose

The purpose of this project was to obtain, through full-scale fire tests on a small fuselage-mounted turbojet engine and nacelle installation, general design criteria which would enhance in-flight fire safety of this and similar installations. The scope of the project encompassed the determination of flammable fluid ignition hazards on engine hot surfaces, flame paths, fire detection, fire extinguishment, and fire resistance aspects of the installation.

Background

The program was originated at the request of the Federal Aviation Administration's Flight Standards Service, through the Aircraft Development Service. Uninterrupted testing began July 1, 1967, and was completed June 30, 1968.

Description of Equipment

The National Aviation Facilities Experimental Center's (NAFEC) Five-Foot Fire Test Facility was utilized for the full-scale test work. This facility had a 20-foot-long by 5-foot-diameter cylindrical test section. Airflow through the test section was induced by ejector pumping of two Pratt and Whitney J-57 turbojet engines whose exhausts were directed into a mixing section downstream of the test section. The test facility is shown in Figure 1.

The test article was the left inboard fuselage-mounted engine and nacelle of the Lockheed C-140 (Jet Star) airplane. This installation was normally a twin-engine siamese nacelle; however, limitation of the fire test facility's test section size necessitated cutting off the outboard portion of the siamese nacelle and installing only the inboard portion with its engine in the test section.

Each nacelle was divided into two fire zones by a vertical transverse stainless steel fire seal at Nacelle Station 117 (the main engine mount location in the nacelle was designated as Nacelle Station 100). Part of this fire seal was attached to the engine and consisted of an engine combustor shroud which extended aft 12.5 inches to the vertical section. The vertical section was mated with a vertical firewall collar built into the nacelle and was sealed by means of a fire-resistant tadpole tape compression seal. Also, for each twin-engine pod there were two vertical stainless steel firewalls extending longitudinally the length of Fire Zones I and II. One was on the inboard side of the nacelle isolating the pylon and fuselage from the nacelle fire zones, and the other was on the outboard side of the inboard nacelle isolating the outboard nacelle fire zone areas from the inboard nacelle areas.

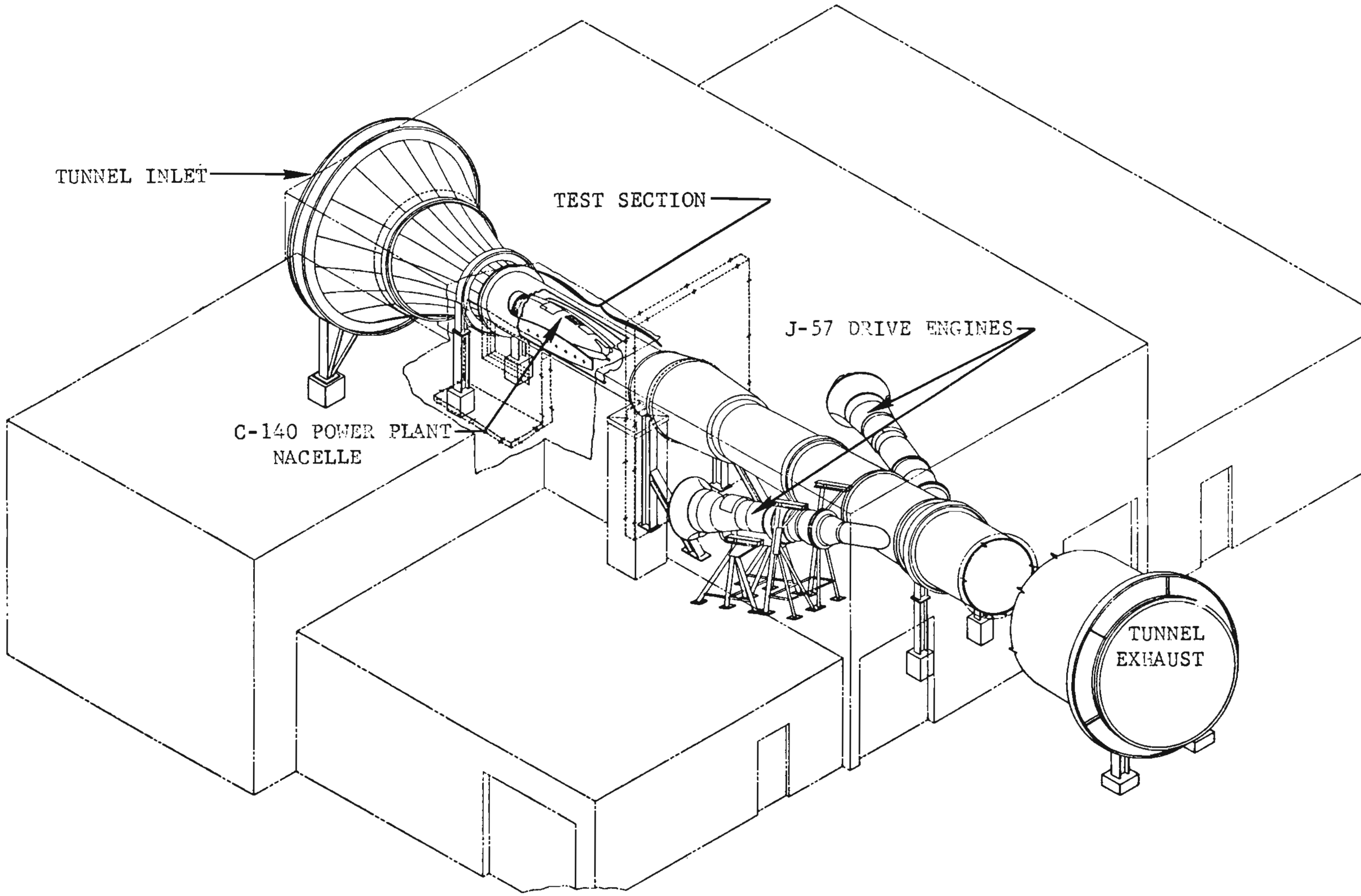


FIG. 1 FIVE-FOOT FIRE TEST FACILITY

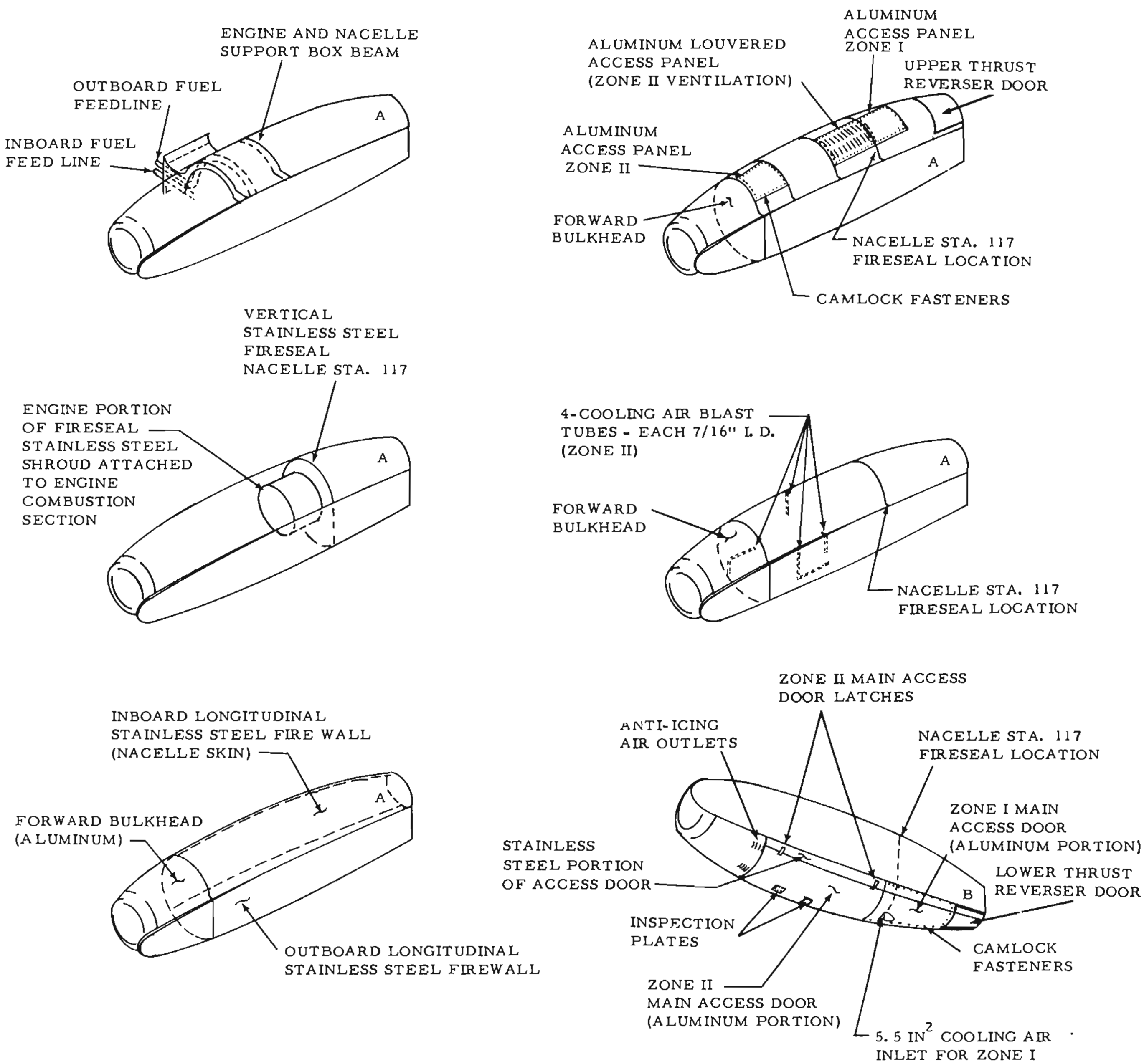
Zone I, with a 10.0-cubic-foot free volume, encompassed the aft portion of the engine including the combustor, turbine, and tailpipe sections. Zone II, with a 12.6-cubic-foot free volume, encompassed the engine compressor and accessory sections.

A continuous-type fire detection system was provided for Zone II, and a separate continuous-type overheat detection system was provided for Zone I of each nacelle. The powerplant fire-extinguishing system provided extinguishment capability for Zone II of each nacelle only. Isolation of flammable fluid systems from the hot section of the engine (Zone I) by a vertical fire seal was a design feature of each nacelle.

Airflow into Zone II was provided by four 7/16-inch ID ram air tubes for cooling specific engine parts such as ignitor transformers and the main engine mounts. The outlet from Zone II for both ram air and engine bleed air (dumped into Zone II at and below approximately 81 percent of rated rpm (N_1) as observed during test operating conditions) was a louvered access panel located in the top aft portion of the zone. A captive air-cooling system was provided for cooling the starter/generator unit in Zone II. Cooling air was taken from the compressor inlet, ducted to a housing encasing the starter/generator, then ducted overboard. Cooling airflow to Zone I was provided through a 5.5-square-inch ram air duct located at Station 117, 5 o'clock position on the Zone I main access door. Air moving through this duct was directed onto the engine turbine case and expelled around the periphery of the engine exhaust nozzle assisted by ejector pumping action of the engine exhaust. A small spring-loaded flush air inlet door located just aft of the firewall on the inboard upper portion of Zone I was also provided for ventilation of this zone. This door was closed and sealed during this test program. The general features of the nacelle are shown in Figure 2.

The test engine was a Pratt and Whitney JT-12A-6 rated at 3,000 pounds maximum thrust. This turbojet engine has a nine-stage axial flow compressor and a two-stage axial flow turbine. It has interstage bleed ports at the fourth compressor stage which prevent compressor stall during engine acceleration. These ports were open from engine start to approximately N_1 = 81 percent rated rpm. Also, bleed air was supplied from the compressor ninth stage through a closed duct system for engine and nacelle inlet anti-icing and for fuselage pressurization.

The engine controls, fire detection indicators, extinguishing system controls, fuel-to-fire and ignitor controls as well as data collection equipment were centrally located in a test control room adjacent to the test section. A listing of the instrumentation used to monitor and record test data is provided in Table 1.



LEGEND
A = TOP THREE-QUARTER VIEW OF NACELLE LOOKING AFT
B = BOTTOM THREE-QUARTER VIEW OF NACELLE LOOKING AFT

FIG. 2 GENERAL FEATURES OF THE TEST NACELLE

TABLE 1

SUMMARY OF INSTRUMENTATION

	Parameter	Location	Sensor	Transducer	Indicator	Record
1.	Nacelle Cooling Air Temperatures	Zone II - 24 Positions Zone I - 24 Positions Main Structural Beam Void Space - 4 Positions	30 Gauge Wire Probes	Type K Thermocouple Range: 0-2300^{o}F	Self-balancing Potentiometers	Strip Chart
2.	Engine Metal Temperatures	Zone II - 3 each Diffuser and Combustor Fire-Seal Shroud Zone I - 3 each Combustor, turbine Outlet, tailpipe Sections	20 Gauge Wire Probes	Type K Thermocouple Range: 0-2300^{o}F	Self-balancing Potentiometers	Strip Chart
3.	Other Metal Temperatures	Main Structural Beam - 4 Positions	20 Gauge Wire Probes	Type K Thermocouple Range: 0-2300^{o}F	Self-balancing Potentiometers	Strip Chart
4.	Overpressure	Zone I	Pressure Transducer	C.E.C. Type 4-312-0002 Range: 0-25 psi ABS	Oscillograph	Strip Chart
5.	Nacelle Airflow	Zone I	Pitot-static Pressure Probe	Manometer Range: 0-60 inches HG ABS	Column of Mercury	Visual

TABLE 1 (continued)

SUMMARY OF INSTRUMENTATION

	Parameter	Location	Sensor	Transducer	Indicator	Record
6.	Test Fluid Pressure		Pressure Transducer	Teledyne Type 217-SA Range: 0-600 psig	Teledyne 237R Indicator	Visual
7.	Test Fluid Temperature		Thermal Electric Probe Model # 5D2711E	Type T Thermocouple Range: -300 to +700°F	Potentiometer Type Indicator	Visual
8.	Engine rpm N_1	Engine Accessory Section	Tach-generator	G.E. 2CM14AAB-1 Range: 0-108% rated rpm	G.E. 8DJ81CAA Indicator	Visual
9.	Engine Exhaust Gas Temperature	Engine Exhaust Section	Engine Probe (4 probes)	Type K Thermocouple Range: 0-2300°F	Potentiometer Type Indicator	Visual
10.	Tunnel Airflow		Tunnel Wall Static Ports	Manometer Range: 0-60 inches HG ABS	Column of Mercury	Visual

DISCUSSION

Hot-Surface Ignition Hazard

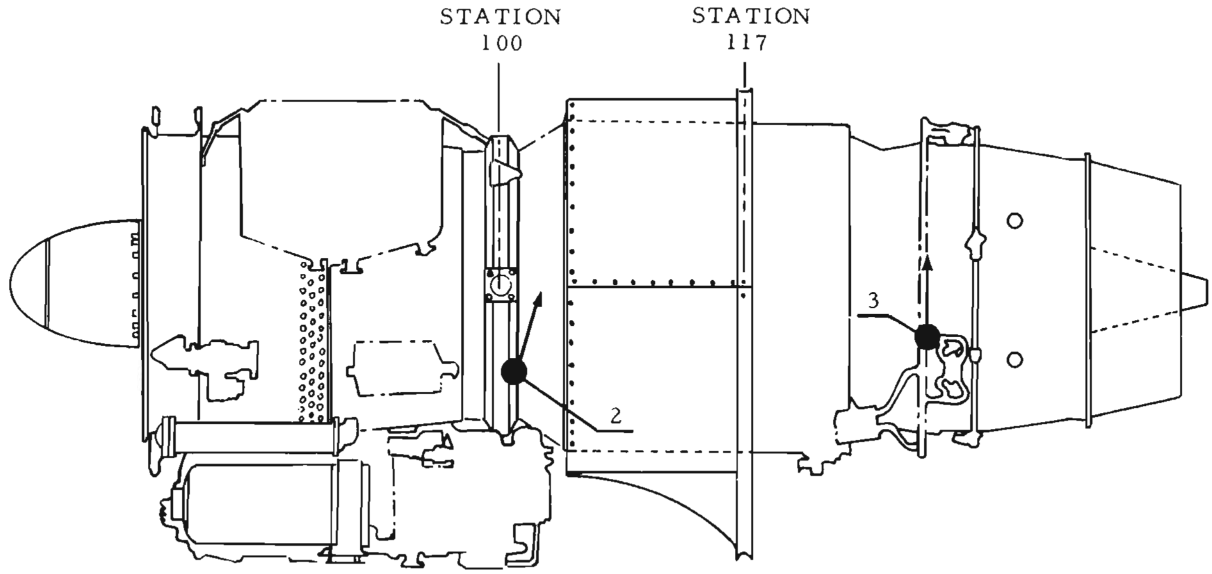
The hazard of igniting jet engine fuels and aircraft hydraulic fluids on the surfaces of an operating engine was investigated. The investigation was limited to two jet engine fuels (JP-4 and Jet A-1) and one hydraulic fluid (Military Specification 5606) in Zones II and I, with the normally configured Zones II and I, and one fuel (Jet A-1) in Zone I with a modified Zone I configuration. The fuel was heated and released as a spray at two locations in both Zone II and Zone I of the nacelle. Figure 3 shows these fuel release locations and contains a description of each release location. The fuel spray was directed so as to impinge on the engine diffuser case just ahead of the combustor section in Zone II and on the turbine outlet case in Zone I. These were areas where maximum engine surface temperatures were known to exist in each zone.

The test procedure for each test was essentially the same. The test engine was operated at military rated thrust (MRT), and the test facility airflow was adjusted to the desired Mach number. When all temperatures (engine case and ambient air temperature within the fire zone) were stabilized, fuel was released on the engine case for 2 to 3 minutes followed by engine speed reduction to idle. Fuel release was continued for 1 minute after power reduction to idle to investigate the possibility of hot-surface ignition during or after this transient power operation. Other tests were conducted in which the procedure was changed to include power reduction from MRT to a cruise setting for 1 minute, followed by a power increase to MRT for 1 minute, and finally a reduction in power to idle for 30 seconds before shutdown. Fuel release was continued throughout this procedure.

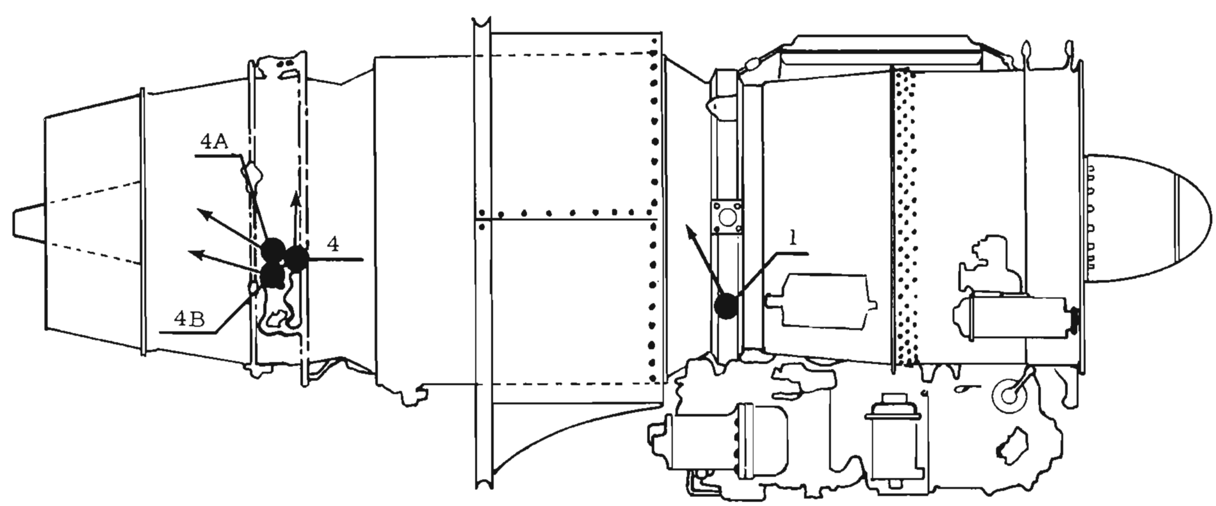
Figure 4 shows the engine operation and fuel release schedules for the hot-surface ignition tests.

Table 2 provides the environmental conditions and results of all hot-surface ignition tests conducted in Zones II and I of the normal nacelle configuration. Table 3 provides the environmental conditions and results of all hot-surface ignition tests conducted in Zone I when the normal configuration of Zone I was changed by reducing the size of the ram air inlet to this zone. Table 4 provides the environmental conditions and results of hot-surface ignition tests conducted in Zone I when the ram air inlet to this zone was closed completely.

Table 2 shows that there was no ignition of the flammable fluids (JP-4, Jet A-1, and Military Specification 5606 Hydraulic Fluid) released in Zones II and I, when the normal nacelle configuration was maintained. During the tests in which the flammable fluids were released in Zone II (the forward engine compartment), excess fuel was observed to leak out at the aft mating surface of the main access door to Zone II, run along



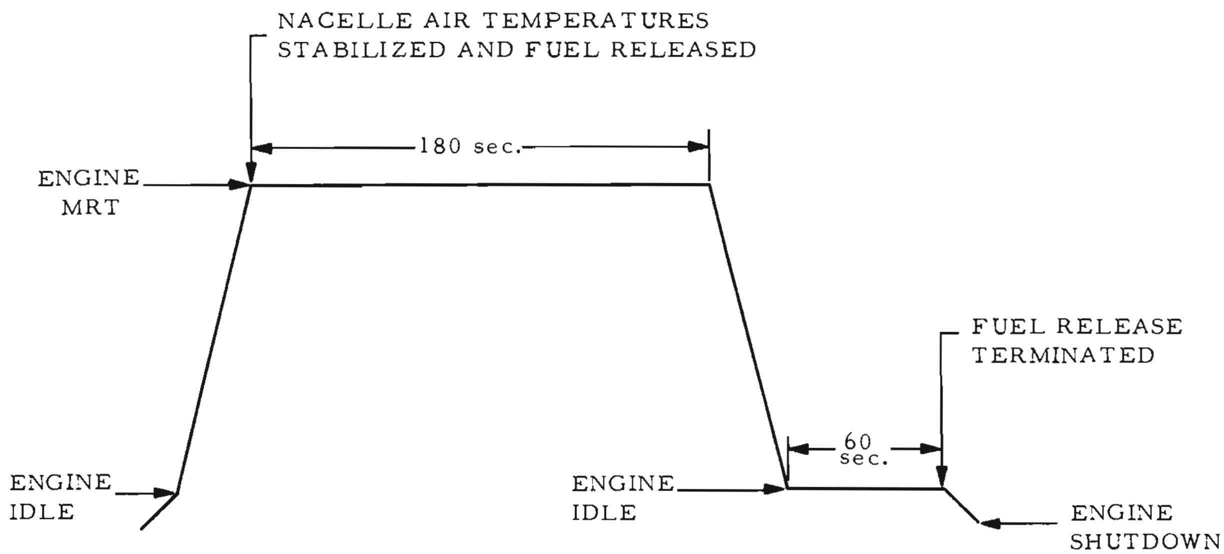
Nozzle Location:
2- Zone II, Nacelle Sta. 102.5, 7 o'clock; directed to spray fuel on the diffuser case at 9 o'clock
3- Zone I, Nacelle Sta. 128.5, 7 o'clock; directed to spray fuel on the turbine case at 9 o'clock



Nozzle Location:
1- Zone II, Nacelle Sta. 100, 4 o'clock; directed to spray fuel on the diffuser case at 3 o'clock
4- Zone I, Nacelle Sta. 128.5, 3:30 o'clock; directed to spray fuel on turbine case at 3 o'clock
4A- Same as 4 except that nozzle was directed to spray fuel on exhaust case at 3 o'clock 3" aft of turbine case
4B- Same as 4 except that nozzle was directed to spray fuel on horizontal centerline at the mating flange of the exhaust and tailpipe case

FIG. 3 FUEL RELEASE LOCATIONS FOR HOT-SURFACE IGNITION TESTS

SCHEDULE I



SCHEDULE II

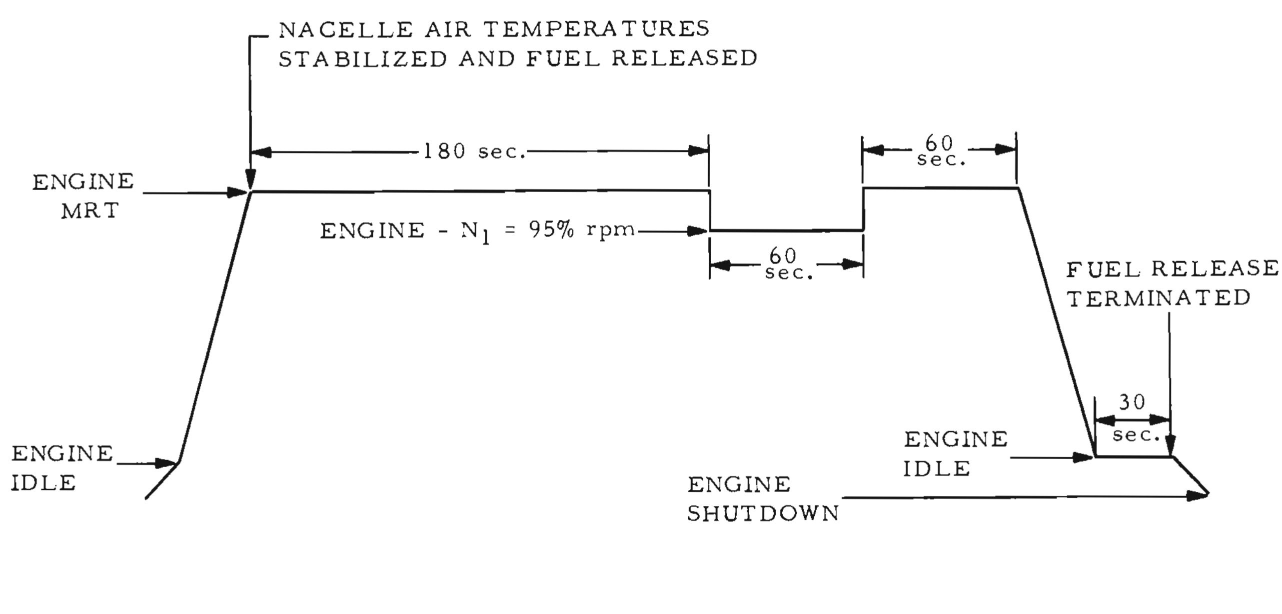


FIG. 4 TEST ENGINE POWER AND FUEL RELEASE SCHEDULES FOR HOT-SURFACE IGNITION TESTS

TABLE 2

SUMMARY OF HOT-SURFACE IGNITION TESTS CONDUCTED IN ZONES II AND I WITH THE NORMAL NACELLE CONFIGURATION

Run Nos.	Fluid	Nozzle Location (1)	Fluid Flow Rates (gpm)	Fluid Pressure Range (psi)	Fluid Temp. Range (°F)	Exhaust Gas Temp. Range @ MRT (°F)	Case Temp. @ MRT (2) (Min/Max °F)	Cooling Air (3) Temp. @ MRT (Min/Max °F)	Nacelle Air-flow @ MRT (lb/sec)	Results and Remarks
1 thru 6	JP-4	1, Zone II	0.1, 0.3, 0.56	345 - 570	122 - 195	---	455/485	95/200	0.2 (4)	No ignition (6)
7 thru 10	Jet A-1	1, Zone II	1.1, 0.3, 0.56, 0.1	320 - 565	186 - 234	1148 - 1157	420/510	110/220	0.2	No ignition (6)
11 thru 14	Jet A-1	2, Zone II	0.1, 0.3, 0.56, 1.1	340 - 660	195 - 263	1148 - 1157	440/515	100/180	0.2	No ignition (6)
15 thru 17	5606 Hyd. Fluid	2, Zone II	0.1, 0.3, 0.56	350 - 385	144 - 183	1157 - 1175	440/500	100/210	0.2	No ignition (6)
18 thru 20	5606 Hyd. Fluid	1, Zone II	0.1, 0.3 0.56	395 - 580	138 - 176	1175 - 1184	420/505	100/200	0.2	No ignition (6)
21 thru 23	5606 Hyd. Fluid	3, Zone I	0.1, 0.3, 0.56	385 - 575	136 - 176	1094 - 1175	830/1065	140/230	1.3 (5)	No ignition (6)
24 thru 27	Jet A-1	3, Zone I	0.1, 0.3, 0.56, 1.1	325 - 550	198 - 230	1130 - 1166	844/1085	125/250	1.3	No ignition (6)
28 thru 31	JP-4	3, Zone I	0.1, 0.3, 0.56, 1.1	260 - 485	194 - 244	1157 - 1175	825/1085	125/250	1.3	No ignition (6)
32 thru 33	Jet A-1	3, Zone I	0.3, 0.1	495 - 580	192 - 216	1148	830/1055	135/225	1.3	No ignition (6)

NOTES:
(1) See Figure 3 for description of location.
(2) Case temperature Zone II at Nacelle Station 103 in impingement area and Zone I at Nacelle Station 128.2 in impingement area.
(3) Cooling air temperature Zone II at Nacelle Station 98 close to impingement area and Zone I at Nacelle Station 129 close to impingement area.
(4) Calculated airflow to Zone II for facility Mach No. 0.5 and engine at MRT.
(5) Measured airflow to Zone I through the 5.5-square-inch ram air inlet duct for Facility Mach No. 0.5 and engine at MRT.
(6) See engine power Schedule I Figure 4.

TABLE 3

SUMMARY OF HOT-SURFACE IGNITION TESTS CONDUCTED IN ZONE I WITH JET A-1 FUEL AND REDUCTION IN AREA OF SECONDARY AIR INLET

Run Nos.	Nozzle Location (1)	Fluid Flow Rates (gpm)	Fluid Pressure Range (psi)	Fluid Temp. Range (°F)	Exhaust Gas Temp. Range @ MRT (°F)	Case Temp. @ MRT (2) (Min/Max °F)	Cooling Air Temp. @ MRT (3) (Min/Max °F)	Nacelle Air-flow Zone I (4) (lb/sec)	Inlet Air Duct Size Zone I (in.^{2})	Results and Remarks
34 thru 37	3	0.1, 0.3 0.56, 1.1	300 - 580	207 - 214	1175 - 1184	975/1180	145/280	0.6	2.75	No ignition (5)
38 thru 41	3	0.1, 0.3, 0.56, 1.1	360 - 585	167 - 228	1157 - 1220	1035/1160	150/260	0.3	1.35	No ignition (5)
42 thru 45	3	0.1, 0.3 0.56, 1.1	370 - 585	186 - 241	1202	1080/1225	155/380	0.15	0.65	No ignition (5)
46 thru 49	4	0.1, 0.3 0.56, 1.1	380 - 590	185 - 219	1193 - 1202	1095/1225	180/390	0.15	0.65	No ignition (5)

NOTES:
(1) See Figure 3
(2) Case temperature Zone I is at Nacelle Station 128.2 in impingement area.
(3) Cooling air temperature in Zone I at Nacelle Station 129 close to impingement area.
(4) Measured airflow to Zone I for Facility Mach No. 0.5 and engine at MRT.
(5) See engine power Schedule I Figure 4.

TABLE 4

SUMMARY OF HOT-SURFACE IGNITION TESTS CONDUCTED IN ZONE I WITH JET A-1 FUEL AND COMPLETE CLOSURE OF SECONDARY AIR INLET

Test No.	Nozzle Location(1) Type Release	Fluid Flow Rate (gpm)	Fluid Pressure/Temp. (psi/°F)	Exhaust Gas Temp. @ MRT (°F)	Case Temp. @ MRT (2) (°F) (Min/Max)	Cooling Air Temp. @ MRT (3) (°F) (Min/Max)	Air Temp. in Impingement Area Before Ignition (°F)	Case Temp. in Impingement Area at Fuel Release (°F)	Overpressure (psi)	Tunnel Velocity at Ignition (Mach No.)	Results
50	4/Spray	0.1	500/192	1166	1045/1205	180/440					No ignition (4)
51	4/Spray	0.3	595/207	1184	1050/1205	180/420					No ignition (4)
52	4/Spray	0.56	410/196	1184	1060/1220	180/370					No ignition (4)
53	4/Spray	1.1	400/216	1193	1070/1225	190/420					No ignition (4)
54	3/Spray	0.1	500/182	1184	1035/1220	180/					No ignition (4)
55	3/Spray	0.3	600/203	1175	1045/1220	180/					No ignition (4)
56	3/Spray	0.56	390/214	1175	1040/1225		235	1225	3.2	0.4	Ignition occurred 1.25 seconds after power reduction to idle (4).
57	3/Spray	0.56	385/212	1202	1030/1240	160/475					No ignition (4)
58	3/Spray	0.1	500/185	1229	1090/1250	180/530					No ignition (4)
59	3/Spray	0.3	600/210	1220	1040/1240	180/530					No ignition (4)
60	3/Spray	1.1	395/219	1202	1040/1230	180/540					No ignition (4)
61	4/Spray	0.56	400/216	1211	1040/1240	190/500	220	1235	1.2	0.3	Ignition occurred 9 seconds after power reduction to idle (4).
62	4/Spray	0.3	595/204	1202	1070/1230	190/500	230	1225	3.2	0.35	Ignition occurred 8.3 seconds after power reduction to idle (4).
63	4/Spray	0.1	490/176	1184	1100/1240	190/480					No ignition (4). Sealed Zone I cowl panels and thrust reverser.
64	4/Spray	0.3	600/187	1193	1060/1230	225/510	275	1230		0.5	Ignition occurred 30 seconds after acceleration from 95% to MRT, fuel shutoff (5).
65	4/Spray	0.1	485/203		1055/						No ignition (5)
66	4A/Spray	0.3	600/160	1202	1060/1150	220/490			1.0	0.5	Ignition 142 seconds after fuel release at MRT power (5) and (6)
67	4A/Spray	0.3	600/165	1202	1010/1165	225/460			0.75	0.5	Ignition directly after fuel release initiated (5) and (6).

TABLE 4 (CONTINUED)

SUMMARY OF HOT-SURFACE IGNITION TESTS CONDUCTED IN ZONE I WITH JET A-1 FUEL AND COMPLETE CLOSURE OF SECONDARY AIR INLET

Test No.	Nozzle Location(1) Type Release	Fluid Flow Rate (gpm)	Fluid Pressure/Temp. (psi/°F)	Exhaust Gas Temp. @ MRT (°F)	Case Temp. @ MRT (2) (°F) (Min/Max)	Cooling Air Temp. @ MRT (3) (°F) (Min/Max)	Air Temp. in Impingement Area Before Ignition (°F)	Case Temp. in Impingement Area at Fuel Release (°F)	Over-pressure (psi)	Tunnel Velocity at Ignition (Mach No.)	Results
68	4A/Spray	0.3	610/172	1067					0.5	0.5	Ignition 87.7 seconds after increase power from 95% to MRT (5) and (6).
69	4/Spray	0.3	600/203	1211	1060/1150	245/490					No ignition (5)
70	4/Spray	0.3	600/194	1211	1060/1145	230/480	305	1145	0.5	0.35	Ignition 5.8 seconds after power reduced to idle (5).
71	4/Spray	0.3	580/207	1220	1090/1150	310/580					No ignition (5). Exhaust case insulation blanket removed.
72	4/Spray	0.3	580/203	1211	1085/1140	290/530					No ignition (5).
73	4B/Running	0.26	25/214	1202	1090/1210	300/525					No ignition (5).
74	4B/Running	0.13	25/199	1202	1095/1220	270/470					No ignition (5)
75	4B/Running	0.13	25/214	1202	1090/1195	235/520					No ignition (5)
76	4B/Running	0.26	25/219	1184	1090/1200	260/550					No ignition (5)
77	4B/Running	0.5	25/225	1184	1080/1185	270/500					No ignition (5)
78	4/Spray	0.1	505/212	1193	1085/1195	280/590					No ignition (5)
79	4/Spray	0.3	600/253	1166	1070/1185	270/565					No ignition (5)
80	4/Spray	0.3	600/226	1202	1085/1220	260/580					No ignition (5)
81	4A/Spray	0.3	600/230	1202	1100/1220	270/590					No ignition (5)
82	4A/Spray	0.3	600/239	1202	1100/1230	290/580					No ignition (5)
83	4/Spray	0.56	400/212	1202	1110/1235	280/570					No ignition (5)
84	4A/Spray	0.56	385/248	1220	1105/1220	280/590	255		2.5	0.3	Ignition occurred 14.9 seconds after power reduction to idle from MRT. (5)
85	4A/Spray	0.56	400/216	1220	1110/1230	280/500	255		2.8	0.3	Ignition occurred 16.2 seconds after power reduction to idle from MRT. (5)
86	4/Spray	0.56	405/234	1202	1090/1200	260/460					No ignition (5)
87	4/Spray	0.56	400/226	1220	1090/1200	250/485					No ignition (5)

TABLE 4 (CONTINUED)

SUMMARY OF HOT-SURFACE IGNITION TESTS CONDUCTED IN ZONE I WITH JET A-1 FUEL AND COMPLETE CLOSURE OF SECONDARY AIR INLET

Test No.	Nozzle Location[1] Type Release	Fluid Flow Rate (gpm)	Fluid Pressure/Temp. (psi/°F)	Exhaust Gas Temp. @ MRT (°F)	Case Temp. @ MRT (2) (°F) (Min/Max)	Cooling Air Temp. @ MRT (3) (°F) (Min/Max)	Air Temp. in Impingement Area Before Ignition (°F)	Case Temp. in Impingement Area at Fuel Release (°F)	Overpressure (psi)	Tunnel Velocity at Ignition (Mach No.)	Results
88	4/Spray	0.56	395/226	1211	1100/1190	270/520	275	1190	1.5	0.3	Ignition occurred 20 seconds after power reduction to idle from MRT. (5)
89	4/Spray	0.56	400/241	1202	1080/1180	265/460					No ignition (5)
90	4A/Spray	0.56	405/230	1202	1090/1190	270/590					No ignition (5)
91	4A/Spray	0.56	370/235	1211	1085/1190	270/580	255		2.0	0.3	Ignition occurred 10.9 seconds after power reduction to idle from MRT. (5)
92	3/Spray	0.56	385/250	1202	1070/1180	270/585					No ignition (5)
93	3/Spray	0.56	390/216	1202	1090/1195	280/600					No ignition (5)
94	3/Spray	0.56	/216	1211	1070/1190	260/510					No ignition (5)
95	3/Spray	0.56	405/226	1193	1070/1190	250/570	200	1070	4.5	0.5	Ignition occurred 51.7 seconds after fuel release at MRT (steady-state). (5)
96	3/Spray	0.56	405/241	1184	1050/1165	250/550	205	1050	3.6	0.5	Ignition occurred 182 seconds after fuel release at MRT (ateady-state). (5)
97	3/Spray	0.56	400/243	1202	1040/1170	260/540					No ignition (5)

NOTES:
(1) Location of nozzles are shown in Figure 3.
(2) Case temperature in Zone I is at Nacelle Station 128.2 in fuel impingement area.
(3) Cooling air temperature in Zone I is at Nacelle Station 129 in fuel impingement area.
(4) See engine power Schedule I (Figure 4).
(5) See engine power Schedule II (Figure 4).
(6) Fuel nozzle was positioned so that the spray was directed toward the insulator blanket which covered the exhaust case section of the engine.

lower outside surface of Zone I and enter Zone I through the 5.5-square-inch secondary air inlet to this zone. An inspection of Zone I after a test in which hydraulic fluid was released in Zone II, indicated that the excess fluid which entered Zone I through the air inlet impinged directly on the turbine outlet case, the hottest surface area in Zone I. However, there was no occasion where this caused ignition of the fuel. An inspection of Zone II, after each test, revealed that the fluid did not completely drain out of the zone and puddled in the lower aft portion of the main access door.

Table 3 shows that hot-surface ignition of Jet A-1 fuel released on the turbine outlet in Zone I did not occur when the secondary air inlet to Zone I was reduced to 2.75, 1.35, and .65 square inches. Table 4 shows that hot-surface ignition of Jet A-1 fuel released on the turbine outlet surface occurred under steady-state operating conditions and under transient operating conditions when the ram air inlet to Zone I was completely blocked off. In many cases an attempt to repeat the ignition under similar conditions was unsuccessful. On two occasions hot-surface ignition of released Jet A-1 fuel occurred soon after the fuel flow was initiated. Investigation of the fuel nozzle position after these tests indicated the nozzle which was originally directed toward the turbine outlet case had slipped so that the fuel spray was directed toward the heat blanket which covered the turbine exhaust case aft of the turbine outlet case. Therefore, it was surmized that this hot-surface ignition of the sprayed fuel was caused by the leaking of fuel on the exhaust case underneath the blanket.

Hot-surface ignition resulted in overpressures of 0.5 to 4.5 psi in Zone I of the nacelle. Damage to Zone I due to these overpressures was small. Camera coverage of these tests and inspection of the installation after ignitions showed that overpressures were relieved through (1) the closed-off ram air inlet to Zone I, (2) two pressure relief panels which were fabricated for the bottom access door, (3) the mating surfaces of this access door and a top access panel, and (4) the opening between the engine tailpipe and the nacelle. Slight deformation of the access panel and door between the camlock-type fasteners occurred during these tests.

Fire Detection and Fire Paths

The fire detection aspects in this powerplant installation were investigated looking towards general ways improvements could be made that would be applicable to similar installations.

The continuous-type fire detection system in nacelle fire Zone II and the separate overheat continuous system in Zone I are shown in Figure 5. In the aircraft, a single warning light for the two systems in each nacelle is provided in the cockpit. A steady warning light indicates a fire in Zone II, and an intermittent light indicates an overheat situation in Zone I. However, as part of the test setup a separate warning

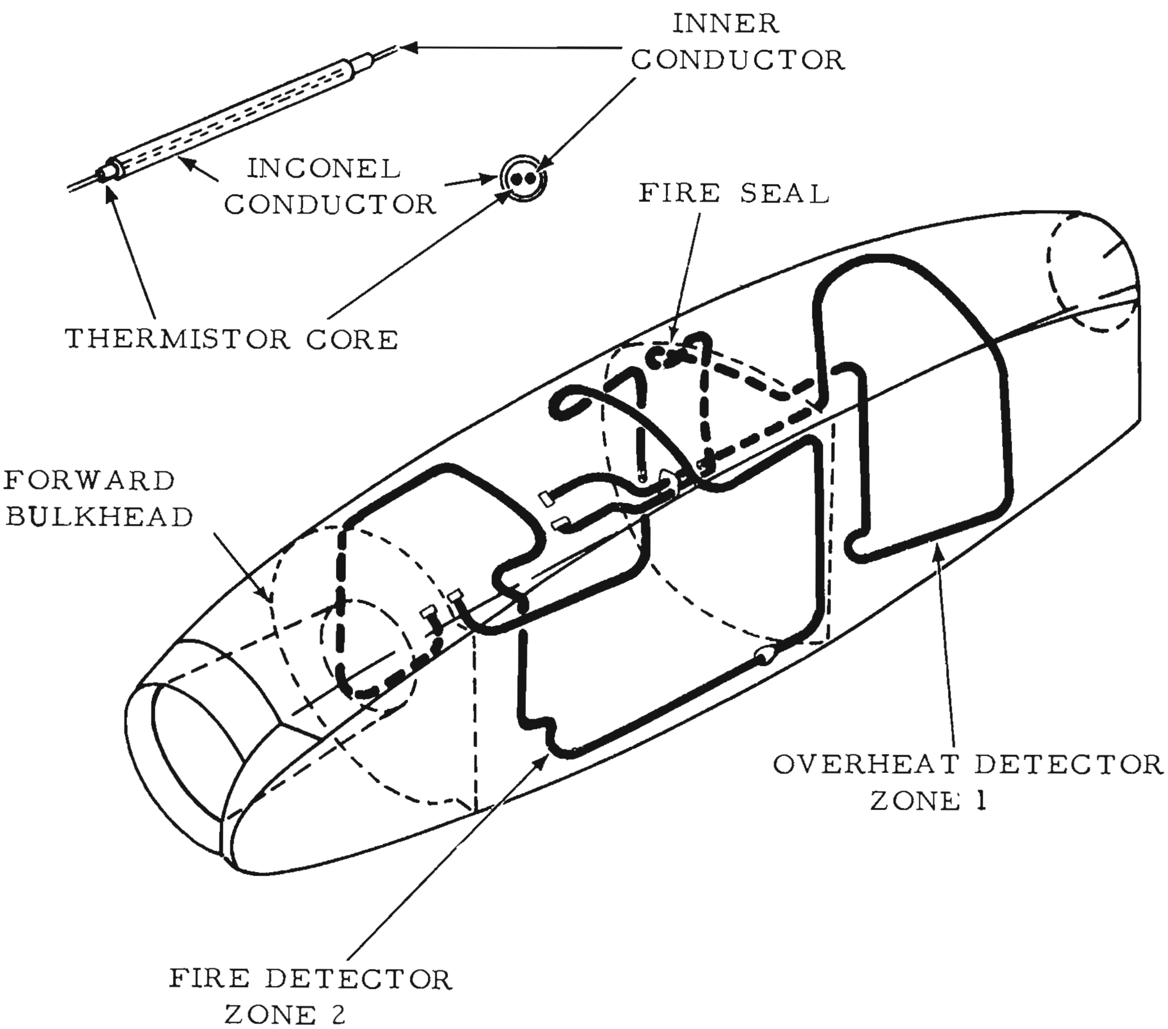


FIG. 5 NACELLE CONTINUOUS TEMPERATURE-SENSITIVE FIRE AND OVERHEAT DETECTION SYSTEMS

light for each of the two nacelle detection systems was provided and monitored. Fire detection tests were conducted within fire Zone II only.

The general test procedure for fire detection tests consisted of establishing the engine power setting in combination with facility Mach number, operating the engine until Zone II ambient air temperatures were stabilized, initiating a fire at one of five locations in Zone II shown in Figure 6, and recording detector response time.

Table 5 provides the test conditions and results of the fire-detection testsconducted utilizing a 0.3-, 0.46-, and 1.0-gpm fuel-to-fire source. Most of the test fires were promptly detected. The exceptions were- (1) those test fires conducted at 6 and 7:30 o'clock in the forward part of Zone II and (2) those fires conducted at 4:30 o'clock in the aft portion of Zone II when the engine power was at N_1 = 78 percent of rated rpm (compressor bleed valves open). When engine power was maintained above N_1 = 81 percent rpm (compressor bleed valves closed) and test fires were located at 4:30 o'clock in both the forward and aft portion of Zone II (Locations 5 and 6 shown in Figure 6), both the Zone I overheat-detection system and the Zone II fire detection system alarmed. When engine power was maintained below N_1 = 81 percent rpm (compressor bleed valves open) and the test fires were located at 4:30 o'clock in the aft portion of Zone II (Location 6 shown in Figure 6), only the Zone I overheat-detection system alarmed. Alarm of the Zone I detection system occurred in both of these cases because the terminal portions of the overheat system were found to be routed through Zone II on the inboard side from the nacelle's main structural box beam which is about midway in Zone II to the fire seal where they enter Zone I.

The Zone II continuous-type heat-sensitive fire detection system shown in Figure 5 was not routed in the lower portion of the zone. For this reason, fires which were originated at 7:30 and 6 o'clock in the lower forward portion of Zone II either were not detected or usually required a longer time for detection.

Figure 7 is an isothermalplot of the normal ambient air temperature in Zone II prior to ignition of fuel. The outside ambient air temperature during this test was 21^{o}F.

Isothermalplots of the increase in temperature above normal, resulting from 0.46-gpm JP-4 fires originated in Zone II at Locations 5A, 6A, 7A, 8A, and 9A (Figure 6), are shown in Figures 8, 9, 10, 11, and 12. These indicated the path of heat and flame from each fire location in Zone II. Flames from fires originating in the lower forward portion of Zone II propagated aft along the lower center portion of the nacelle. The flames then spread out forward of the vertical fire seal at Nacelle Station 117 and moved up and around the engine favoring the outboard side of the nacelle and egressed out the louvers in the top aft section

TABLE 5

SUMMARY OF FIRE DETECTION TESTS IN ZONE II

Test	Test Engine Power	Facility(4) Mach No.	Fire(1) Location	Zone II Fire Detector Alarm Time (sec.)	Zone I Over-heat Detector Alarm Time (sec.)	Fire Duration (sec.)
			FUEL FLOW TO FIRE - 0.3 GPM			
1	T.O.	0.5	5	4.2	6.2	12.5
2	T.O.	0.5	6	3.1	3.2	8.2
3	T.O.	0.5	7	3.7		7.3
4	T.O.	0.5	8	2.3		11.4
5	T.O.	0.5	9	7.9		12.3
6	Cruise	0.5	5	4.3	5.7	8.3
7	Cruise	0.45	5	4.9	6.5	8.6
8	Cruise	0.5	6	3.5	3.0	7.4
9	Cruise	0.45	6	3.1	3.3	6.7
10	Cruise	0.5	7	3.7		8.9
11	Cruise	0.45	7	1.7		4.2
12	Cruise	0.5	8	2.3		11.4
13	Cruise	0.45	8	2.7		7.1
14	Cruise	0.5	9	No alarm		8.5
15	Cruise	0.46	9	No alarm		5.8
16	Cruise	0.5	7A	3.2		9.2
17	Cruise	0.5	9A	3.1		9.1
18	N_1= 78% rpm (2)	0.5	5	2.8	3.8	8.0
19	N_1= 78% rpm (2)	0.32	5	2.6	3.7	6.6
20	N_1= 78% rpm (2)	0.5	6	3.8	3.1	7.3
21	N_1= 78% rpm (2)	0.3	6	No alarm	5.3	8.0

TABLE 5 (CONTINUED)

SUMMARY OF FIRE DETECTION TESTS IN ZONE II

Test	Test Engine Power	Facility Mach No. (4)	Fire Location (1)	Zone II Fire Detector Alarm Time (sec.)	Zone I Over-heat Detector Alarm Time (sec.)	Fire Duration (sec.)
			FUEL FLOW TO FIRE - 0.3 GPM			
22	N_1= 78% rpm (2)	0.3	6	No alarm	4.0	11.4
23	N_1= 78% rpm (2)	0.5	7	4.4		6.5
24	N_1= 78% rpm (2)	0.3	7	4.6		6.9
25	N_1= 78% rpm (2)	0.5	8	3.7		6.5
26	N_1= 78% rpm (2)	0.3	8	2.4		6.6
27	N_1= 78% rpm (2)	0.5	9	5.0		8.0
28	N_1= 78% rpm (2)	0.3	9	6.4		7.9
			FUEL FLOW TO FIRE - 0.46 GPM			
29 (3)	T.O.	0.52	5A	8.5		12.0
30 (3)	T.O.	0.55	6A	5.3	4.1	10.7
31 (3)	T.O.	0.5	7A	2.5		7.0
32 (3)	T.O.	0.53	8A	No alarm		9.6
33 (3)	T.O.	0.54	9A	No alarm		9.0
34	T.O.	0.5	5	3.2	4.4	9.0
35	T.O.	0.5	6	2.0	2.0	6.9
36	T.O.	0.5	7	1.5		5.0
37	T.O.	0.5	8	2.4		6.4
38	T.O.	0.5	9	No alarm		10.0
39	Cruise	0.5	5	4.5	8.3	11.4
40	Cruise	0.5	5A	6.6	14.4	15.9

TABLE 5 (CONTINUED)

SUMMARY OF FIRE DETECTION TESTS IN ZONE II

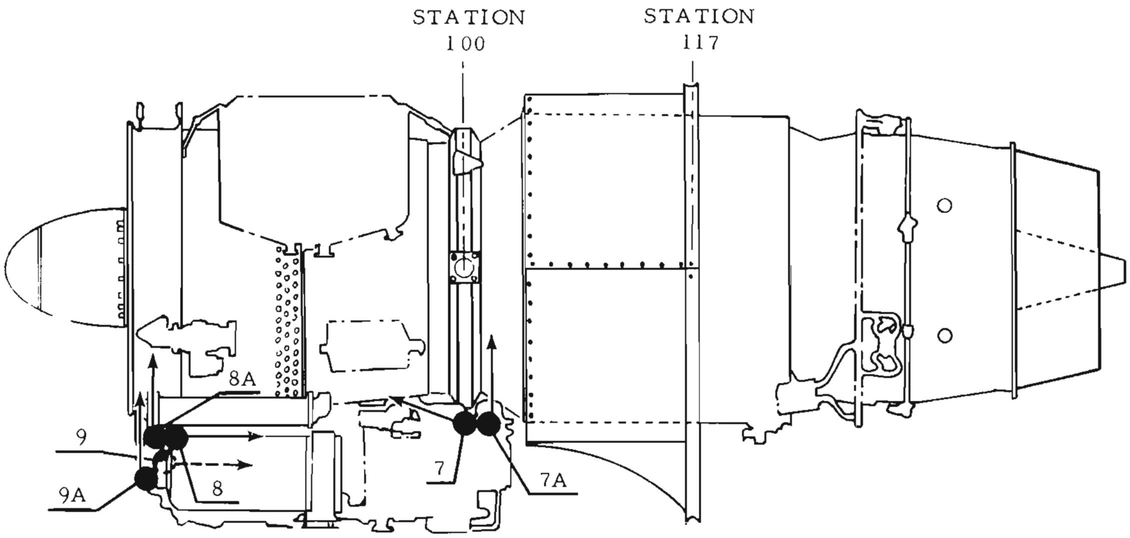
Test	Test Engine Power	Facility Mach No. (4)	Fire(1) Location	Zone II Fire Detector Alarm Time (sec.)	Zone I Overheat Detector Alarm Time (sec.)	Fire Duration (sec.)
41	Cruise	0.5	6	2.7	3.5	8.8
42	Cruise	0.5	6A	3.2	6.7	10.1
43	Cruise	0.5	7	1.0		4.6
44	Cruise	0.5	7A	2.7		7.5
45	Cruise	0.5	8	4.4		15.8
46	Cruise	0.5	8A	3.3		7.0
47	Cruise	0.5	9	5.8	9.6	11.6
48	Cruise	0.5	9A	4.7	9.7	13.2
49	N_1= 78% rpm (2)	0.3	5	3.9	5.0	7.3
50	N_1= 78% rpm (2)	0.5	5	2.8	4.1	7.1
51	N_1= 78% rpm (2)	0.3	6	No alarm	4.8	7.5
52	N_1= 78% rpm (2)	0.5	6	No alarm	4.7	6.1
53	N_1= 78% rpm (2)	0.3	7	4.3		9.0
54	N_1= 78% rpm (2)	0.5	7	3.2		7.0
55	N_1= 78% rpm (2)	0.3	8	3.6		7.0
56	N_1= 78% rpm (2)	0.5	8	2.6		6.1
57	N_1= 78% rpm (2)	0.3	9	No alarm		6.2
58	N_1= 78% rpm (2)	0.5	9	4.2		8.3

TABLE 5 (CONTINUED)

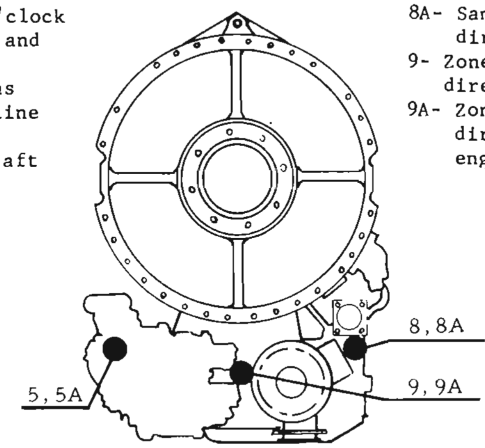
SUMMARY OF FIRE DETECTION TESTS IN ZONE II

Test	Test Engine Power	Facility(4) Mach No.	Fire(1) Location	Zone II Fire Detector Alarm Time (sec.)	Zone I Over-heat Detector Alarm Time (sec.)	Fire Duration (sec.)
			FUEL FLOW TO FIRE 1.0 GPM			
59	Cruise	0.5	5	1.0	4.1	7.0
60	Cruise	0.5	5A	3.7	6.1	8.7
61	Cruise	0.5	7	2.7		9.0
62	Cruise	0.5	7A	3.0		10.2
63	Cruise	0.5	8	4.9		11.7
64	Cruise	0.5	8A	No alarm		30.8
65	Cruise	0.5	9	3.3	4.2	9.8
66	Cruise	0.5	9A	3.3		9.9

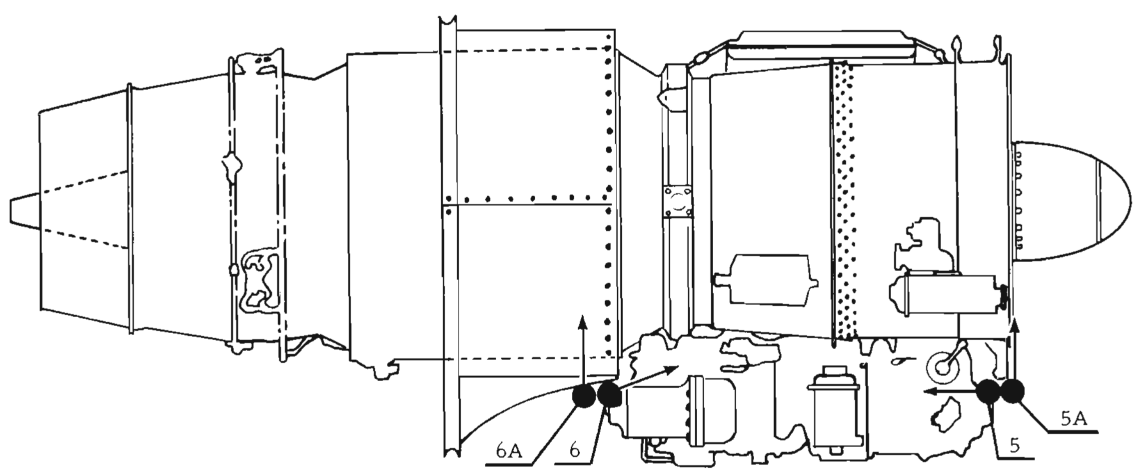
NOTES:
(1) Description of fire locations are provided in Figure 6.
(2) At N_1= 78% rated rpm, the engine compressor interstage bleed valves were open and compressor air was released into Zone II.
(3) The increase in Zone II air temperature above normal for these detection tests are presented as Figures 8, 9, 10, 11, and 12.
(4) Facility Mach number (M_N) represents an average Mach number which was obtained from the average of five static pressure measurements along the tunnel wall. These five measurement positions relative to the test nacelle were at Nacelle Stations 43.75, 67.75, 91.75, 115.75, and 139.75.



Nozzle Location:
7- Zone II, Nacelle Sta. 101, 8 o'clock directed to spray fuel forward and up 10°
7A- Same as 7 except fuel spray was directed towards engine centerline
8- Zone II, Nacelle Sta. 78, 7:30 o'clock directed to spray fuel aft



Nozzle Location:
8A- Same as 8 except fuel spray was directed towards engine centerline
9- Zone II, Nacelle Sta. 77, 6 o'clock, directed to spray fuel aft
9A- Zone II, Nacelle Sta. 75, 6 o'clock, directed to spray fuel towards engine centerline



Nozzle Location:
5- Zone II, Nacelle Sta. 76, 4:30 o'clock, directed to spray fuel aft
5A- Same as 5 except fuel spray was directed towards engine centerline
6- Zone II, Nacelle Sta. 104.5, 4:30 o'clock, directed to spray fuel forward and up 10 degrees
6A- Same as 6 except fuel spray was directed towards engine centerline

FIG. 6 FUEL RELEASE LOCATIONS FOR FIRE DETECTION AND FLAME PATTERN STUDY

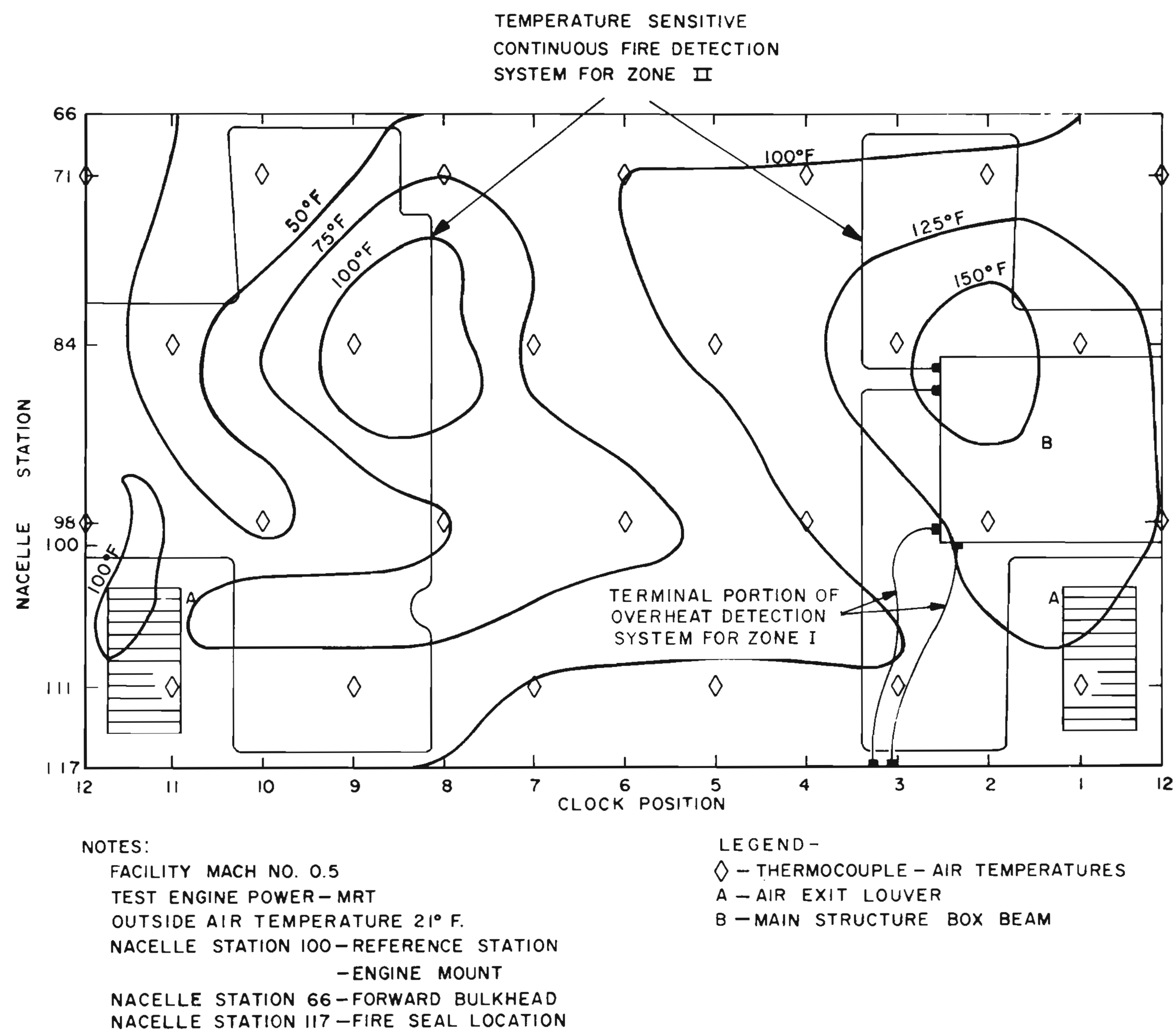
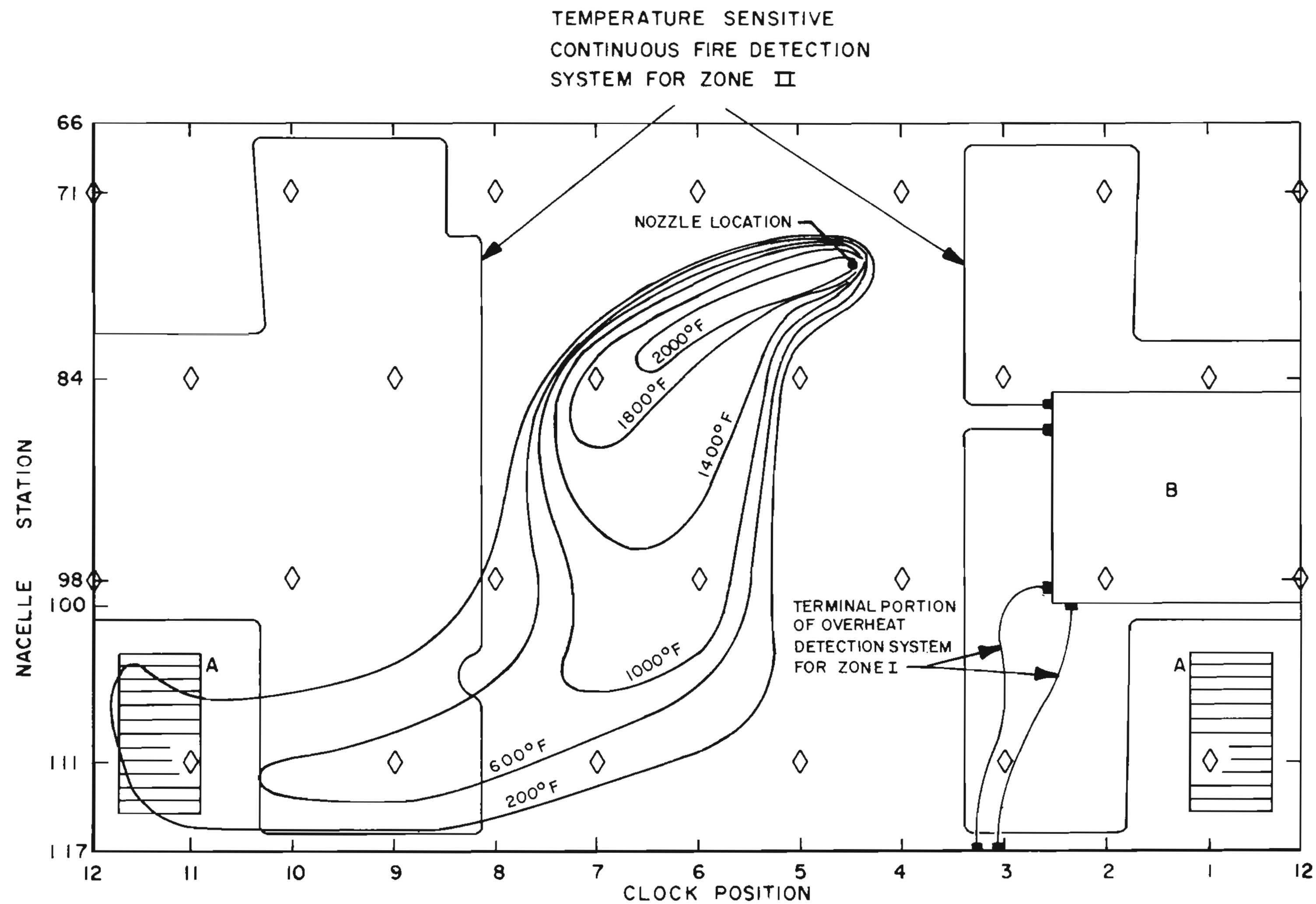


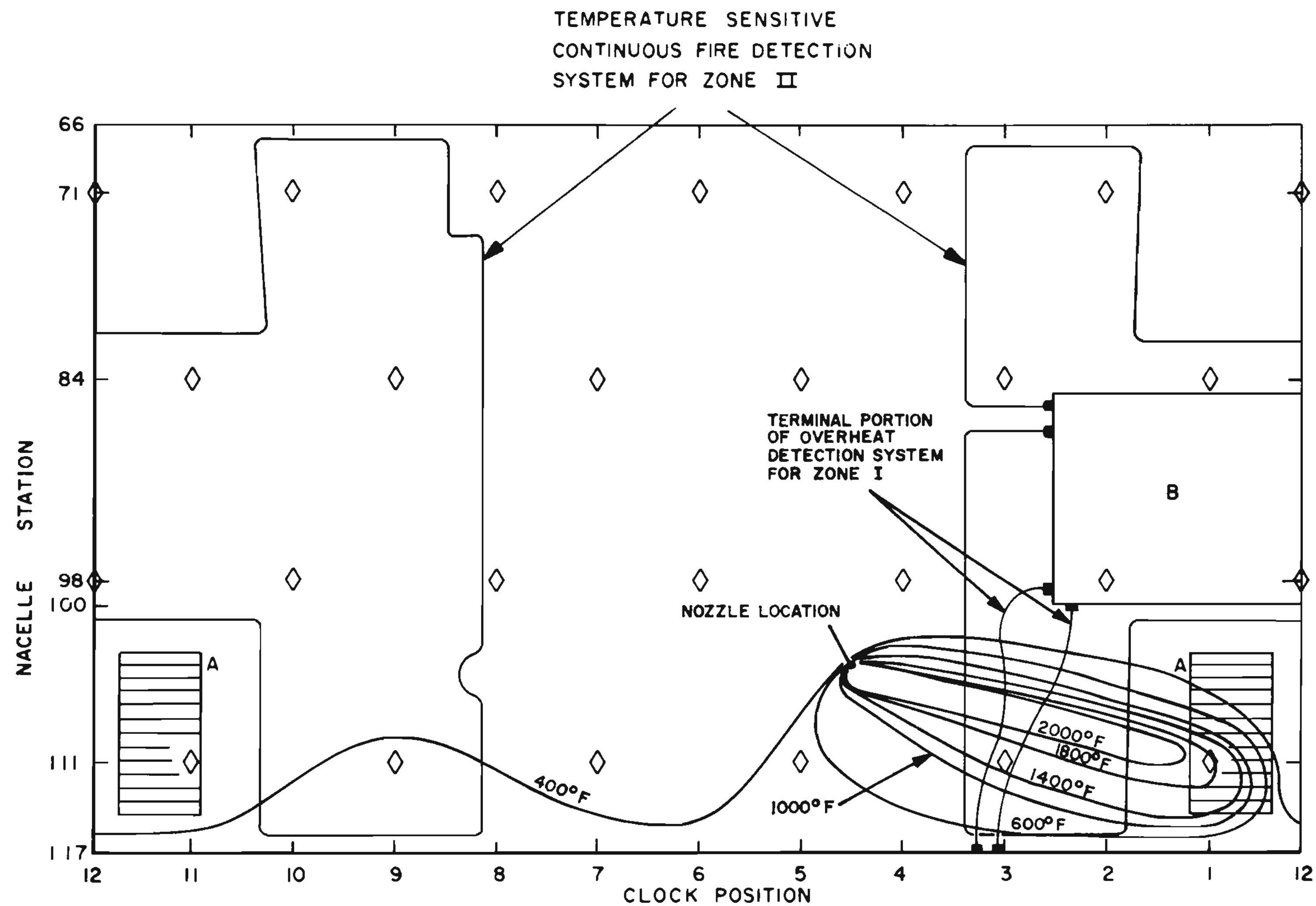
FIG. 7 ISOTHERMALPLOT OF AMBIENT AIR TEMPERATURE IN ZONE II



NOTES:
FACILITY MACH NO. 0.5
TEST ENGINE POWER – MRT
FUEL FLOW TO FIRE – 0.46 gpm.
NACELLE STATION 100 – REFERENCE STATION
– ENGINE MOUNT
NACELLE STATION 66 – FORWARD BULKHEAD
NACELLE STATION 117 – FIRE SEAL LOCATION

LEGEND –
◊ – THERMOCOUPLE – AIR TEMPERATURES
A – AIR EXIT LOUVER
B – MAIN STRUCTURE BOX BEAM

FIG. 8 INCREASE IN AIR TEMPERATURE ABOVE NORMAL FROM FIRE AT LOCATION 5A



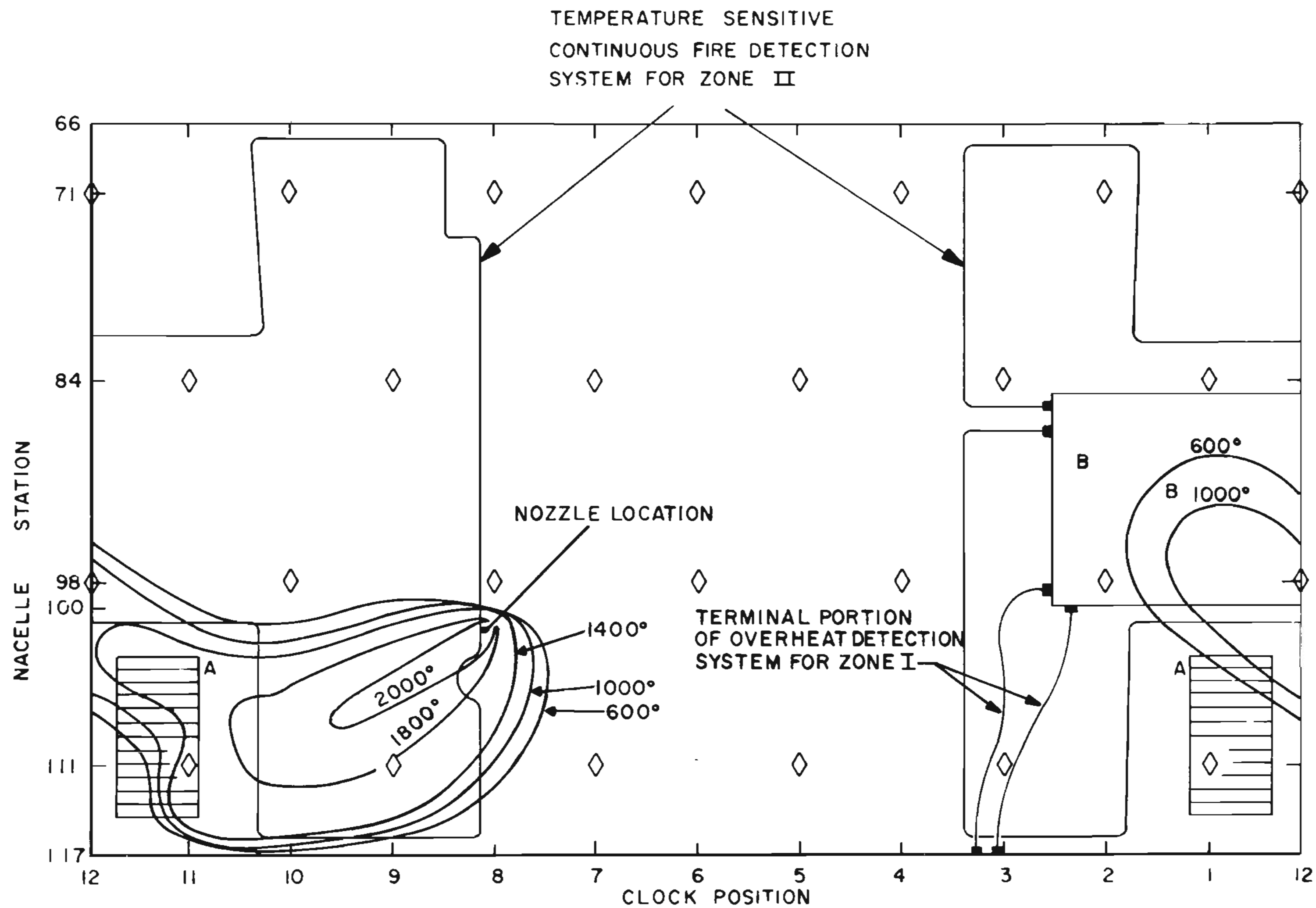
NOTES:

FACILITY MACH NO. 0.5
TEST ENGINE POWER – MRT
FUEL FLOW TO FIRE – 0.46 gpm.
NACELLE STATION 100 – REFERENCE STATION
– ENGINE MOUNT
NACELLE STATION 66 – FORWARD BULKHEAD
NACELLE STATION 117 – FIRE SEAL LOCATION

LEGEND –

◇ – THERMOCOUPLE – AIR TEMPERATURES
A – AIR EXIT LOUVER
B – MAIN STRUCTURE BOX BEAM

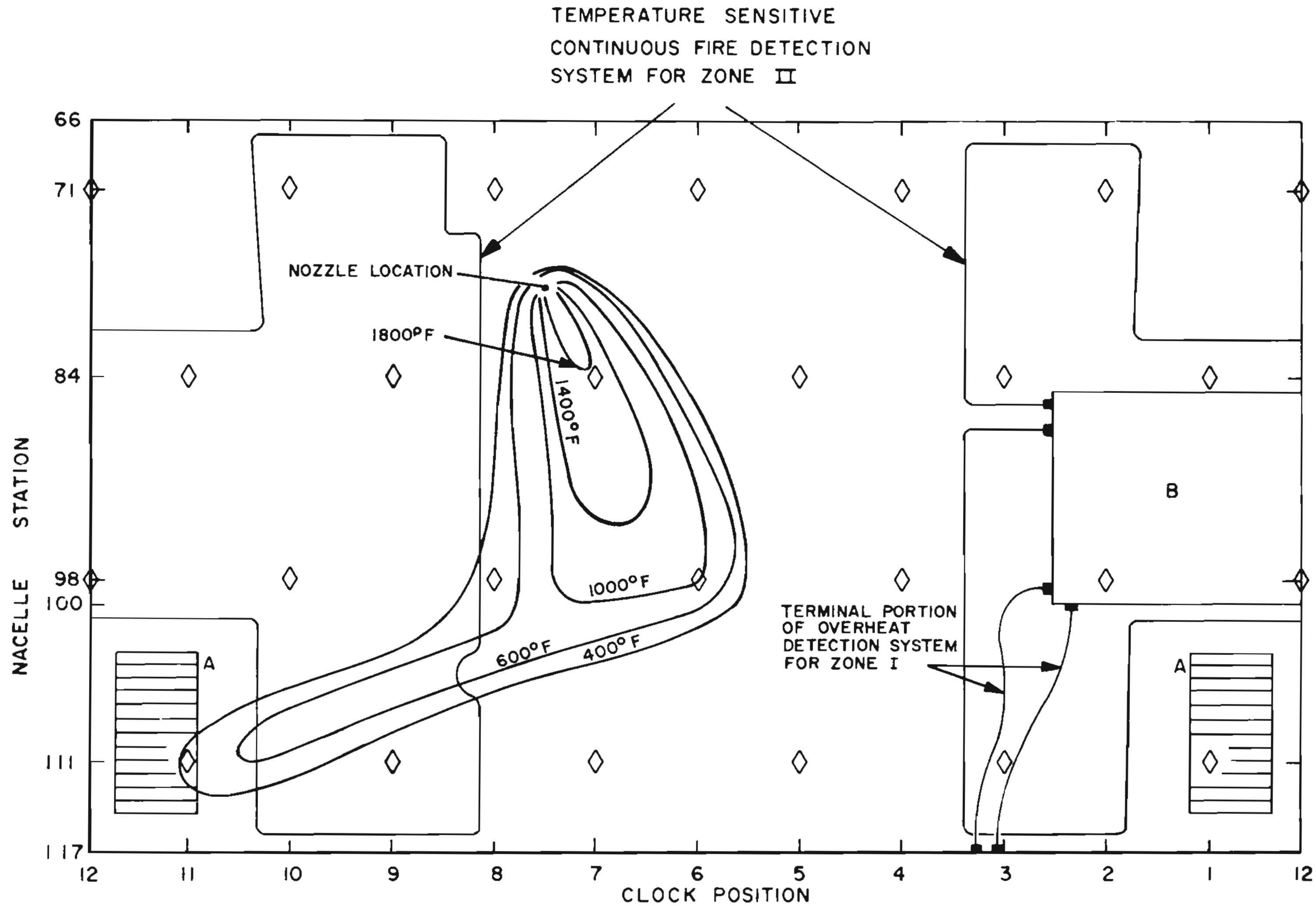
FIG. 9 INCREASE IN AIR TEMPERATURE ABOVE NORMAL FROM FIRE AT LOCATION 6A



NOTES:
FACILITY MACH NO. 0.5
TEST ENGINE POWER – MRT
FUEL FLOW TO FIRE – 0.46 gpm.
NACELLE STATION 100 – REFERENCE STATION
– ENGINE MOUNT
NACELLE STATION 66 – FORWARD BULKHEAD
NACELLE STATION 117 – FIRE SEAL LOCATION

LEGEND-
◇ – THERMOCOUPLE – AIR TEMPERATURES
A – AIR EXIT LOUVER
B – MAIN STRUCTURE BOX BEAM

FIG. 10 INCREASE IN AIR TEMPERATURE ABOVE NORMAL FROM FIRE AT LOCATION 7A

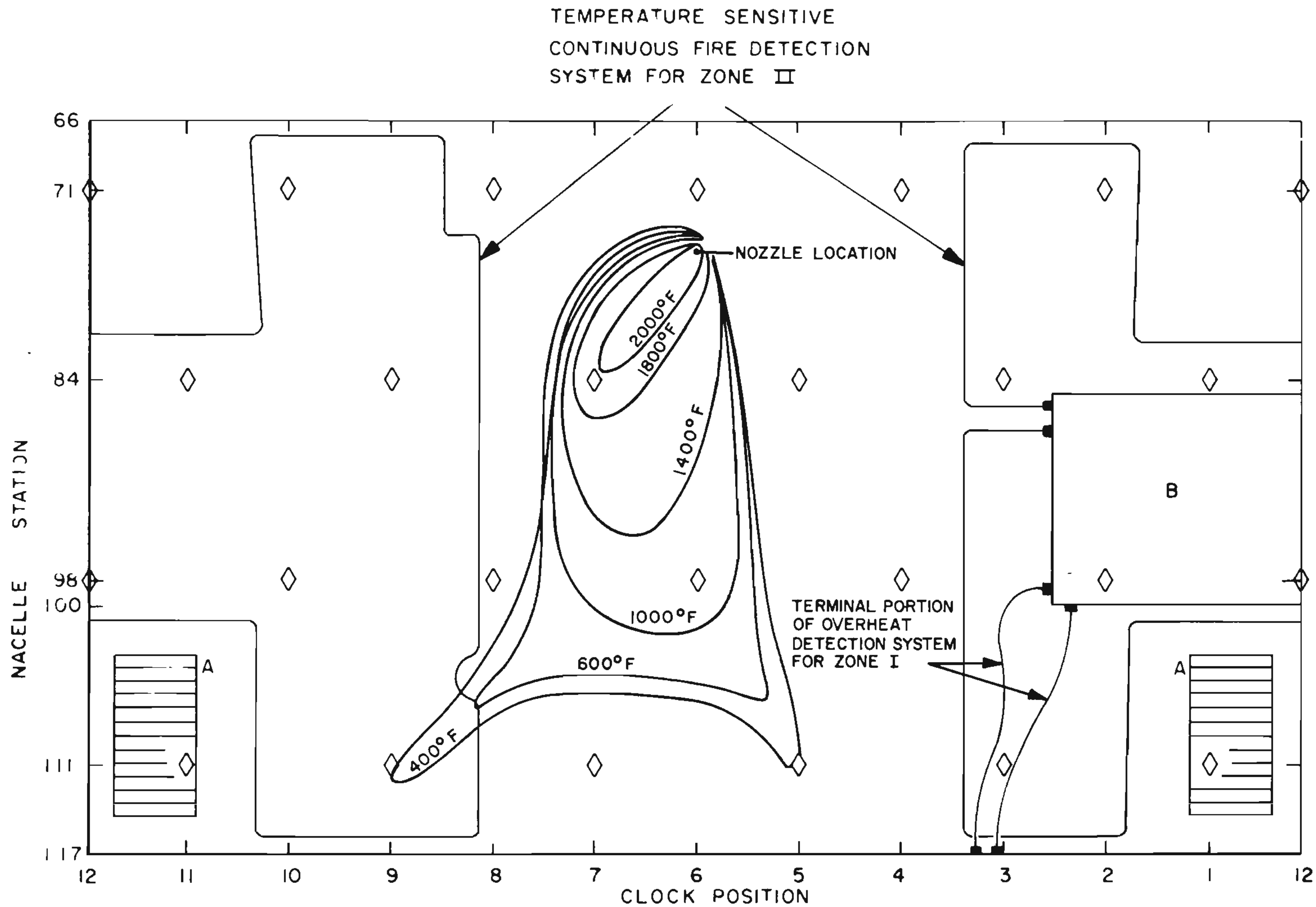


NOTES:

FACILITY MACH NO. 0.5
TEST ENGINE POWER – MRT
FUEL FLOW TO FIRE – 0.46 gpm.
NACELLE STATION 100 – REFERENCE STATION
– ENGINE MOUNT
NACELLE STATION 66 – FORWARD BULKHEAD
NACELLE STATION 117 – FIRE SEAL LOCATION

LEGEND –
◇ – THERMOCOUPLE – AIR TEMPERATURES
A – AIR EXIT LOUVER
B – MAIN STRUCTURE BOX BEAM

FIG. 11 INCREASE IN AIR TEMPERATURE ABOVE NORMAL FROM FIRE AT LOCATION 8A



NOTES:
FACILITY MACH NO. 0.5
TEST ENGINE POWER – MRT
FUEL FLOW TO FIRE – 0.46 gpm.
NACELLE STATION 100 – REFERENCE STATION
– ENGINE MOUNT
NACELLE STATION 66 – FORWARD BULKHEAD
NACELLE STATION 117 – FIRE SEAL LOCATION

LEGEND –
◇ – THERMOCOUPLE – AIR TEMPERATURES
A – AIR EXIT LOUVER
B – MAIN STRUCTURE BOX BEAM

FIG. 12 INCREASE IN AIR TEMPERATURE ABOVE NORMAL FROM FIRE AT LOCATION 9A

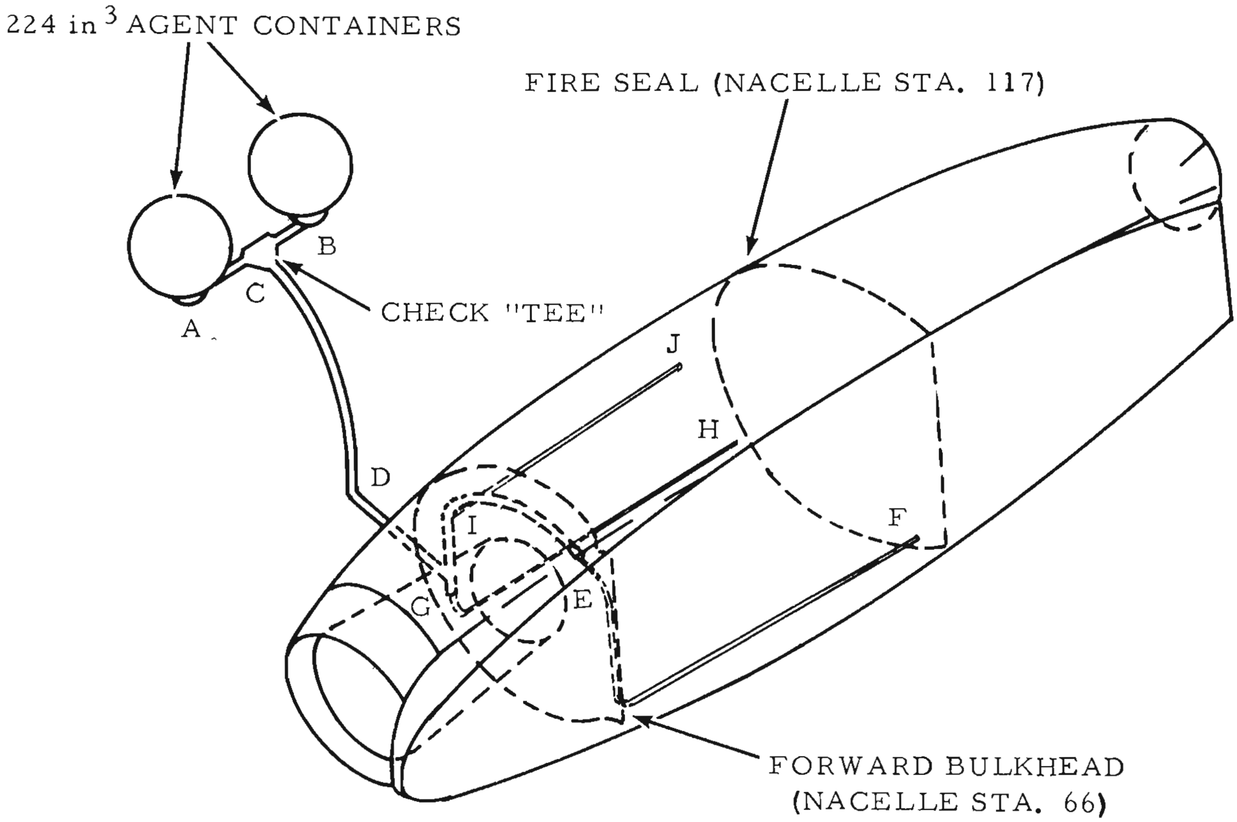
of Zone II. Flames from fires originating in the lower aft portion of Zone II propagated directly up and around the engine and out the louvers favoring that side of the nacelle where the fire originated.

Fire Extinguishment

Fire-extinguishing tests were conducted in a powerplant installation to obtain general extinguishing system design criteria as well as factors which adversely affect the capability of the system.

The powerplant fire-extinguishing system, which provided a two-shot capability for each nacelle, consisted of (1) two 224-cubic-inch containers each containing 6.5 pounds of bromotrifluoromethane ($CBrF_3$) extinguishing agent pressurized with nitrogen to 525 psig at room temperature (70°F), (2) associated valving and lines to route agent from each container to Zone II of each nacelle, and (3) a three-prong perforated-tube distribution system for Zone II of each nacelle. Figure 13 shows the fire-extinguishing system for the left hand inboard nacelle of the Jet Star.

Zone II had a void volume of 12.6 cubic feet. Four 7/16-inch ID ram air tubes (Figure 2) provided air to cool specific areas in Zone II. During engine operation below 81 percent rated rpm, additional air was expelled into Zone II from fourth stage compressor bleed ports on the engine. Airflow through Zone II during extinguishing system tests was a function of engine compressor speed and test section Mach number. In all extinguishing system tests, the system was activated after the engine was stopcocked (windmilling at 17 percent rpm), and the facility test section nominal Mach number was 0.5. Airflow provided by the blast tubes was calculated to be 0.2 pound per second at a test section Mach number of 0.5. Airflow provided by bleed air at the engine windmilling speed of 17 percent rpm and the test section Mach number of 0.5 was calculated to be 2.3 pounds per second from information contained in the Pratt and Whitney JT-12 engine handbook. Therefore, the total airflow rate through Zone II was 2.5 pounds per second when the extinguishing system was activated. A comparison was made of the actual agent quantity of 6.5 pounds of $CBrF_3$ used with the installed system to a required quantity based on the Air Force Specification MIL-E-5352A for a conventional perforated tubing discharge system. Although the Air Force requirement was based on the use of bromochloromethane (CH_2BrCL) only, test results contained in the Civil Aeronautics Administration's Technical Development Reports Nos. 205 and 206 indicated that $CBrF_3$ was more effective as an extinguishant on a weight basis than CH_2BrCL. Therefore, the use of the Air Force specification in calculating the quantity of $CBrF_3$ extinguishing agent for a particular aircraft powerplant installation utilizing a perforated tube extinguishing system was considered a conservative approach. The factor which was contained in the Air Force specification for calculating the extinguishing weight requirement was $.16V + .56\ Wa$ where V is the void volume of the fire zone compartment in cubic feet, and Wa is the airflow rate through the compartment in pounds of air per second. Substituting



	LINE LENGTH (INCHES)	LINE I. D. (INCHES)	NO. OF ORIFICES	ORIFICES DIA. (INCHES)
A - B	19	0.726	NONE	NONE
C - D	88	0.726	NONE	NONE
D - E	34	0.726	5 (G-E)	0.095 - 0.100
E - F	64.5	0.476	20	0.080 - 0.085
G - H	51	0.476	18	0.080 - 0.085
I - J	30	0.476	14	0.080 - 0.085

FIG. 13 NACELLE FIRE-EXTINGUISHING SYSTEM

12.6 cubic feet for V and 2.5-pounds-per-second airflow rate for Wa in the factor .16V + .56 Wa, 3.4 pounds of $CBrF_3$ extinguishing agent was calculated to satisfy agent quantity requirement for the test installation during a fire emergency situation at a cruise flight condition. Also, a calculation of agent quantity was made for a more severe aircraft operating condition than would be encountered during an emergency situation. This condition was one in which the engine was operated at N_1 = 78 percent rated rpm (compressor bleed valves open), and the airflow around the nacelle was maintained at 0.5 Mach number. This increased the nacelle secondary airflow from 2.5 pounds per second to 5.1 pounds per second. The required agent quantity for this flight operating condition was calculated to be 4.9 pounds of $CBrF_3$. The fact that the actual amount of agent provided for in the design of the installed perforated tubing extinguishing system was 6.5 pounds of $CBrF_3$, indicated that a conservative approach was used in the design of the system. Actual fire tests as well as tests in which extinguishing agent concentrations were measured in the nacelle during the two airflow conditions of 2.5 and 5.1 pounds per second, indicated the agent quantity provided was in excess of actual requirements.

Initial tests were conducted to determine the agent concentration within Zone II using agent concentration measuring equipment described in the Federal Aviation Administration's Technical Development Report No. 403, entitled "Aircraft Installation and Operation of an Extinguishing Agent Concentration Recorder," dated September 1959. Gas sampling probes were placed in Zone II of the nacelle at locations shown in Figure 14.

Figures 15 and 16 show the conditions and results of the two agent concentration tests conducted. Results indicated that the installed extinguishing system exceeded by a substantial margin the recommended minimum of 15-percent relative concentration at all sampling locations simultaneously for at least a one-half second period when the extinguishing agent was released in Zone II of the nacelle under a normal simulated emergency condition (engine windmilling with a compartment airflow of 2.5 pounds per second). The extinguishing system also provided adequate concentration with respect to the recommended minimum when the agent was released in Zone II at an engine operation condition of N_1 = 78 percent rpm when the total compartment airflow was increased to a rate of 5.1 pounds per second.

Actual fire-extinguishing tests were confined to Zone II of the nacelle since this zone of each nacelle was the only compartment protected by the extinguishing system. Fire locations were the same as for the detection test phase.

The general procedure for fire-extinguishing tests was to stabilize engine power at 95 percent rpm and Facility Mach Number of 0.5, initiate the test fire and upon fire detection plus 5 seconds initiate the fire emergency procedure (stopcock the engine, increase the tunnel power to maintain Mach number and release the extinguishing agent).

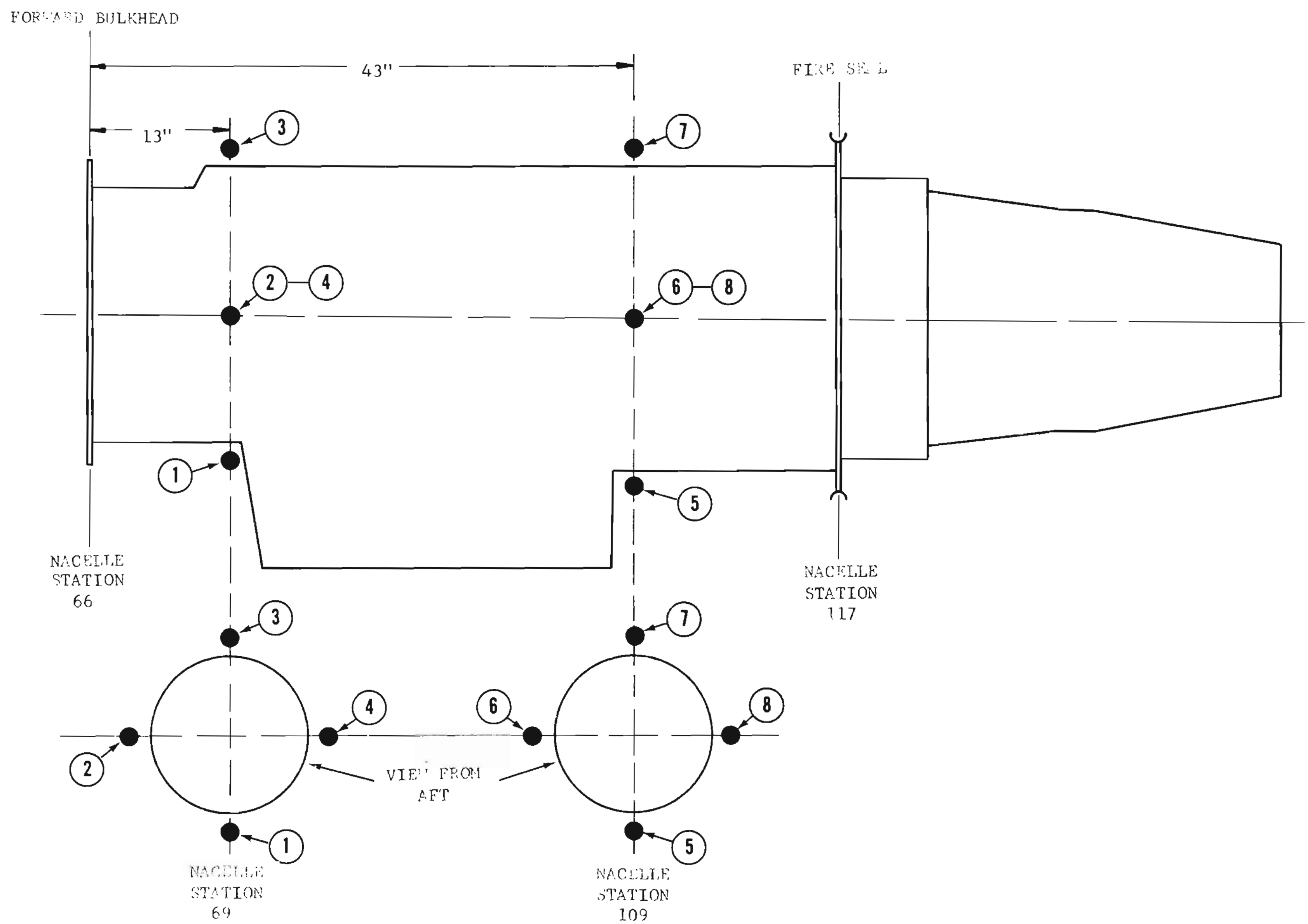


FIG. 14 LOCATION OF EXTINGUISHING AGENT SAMPLING PROBES IN ZONE II

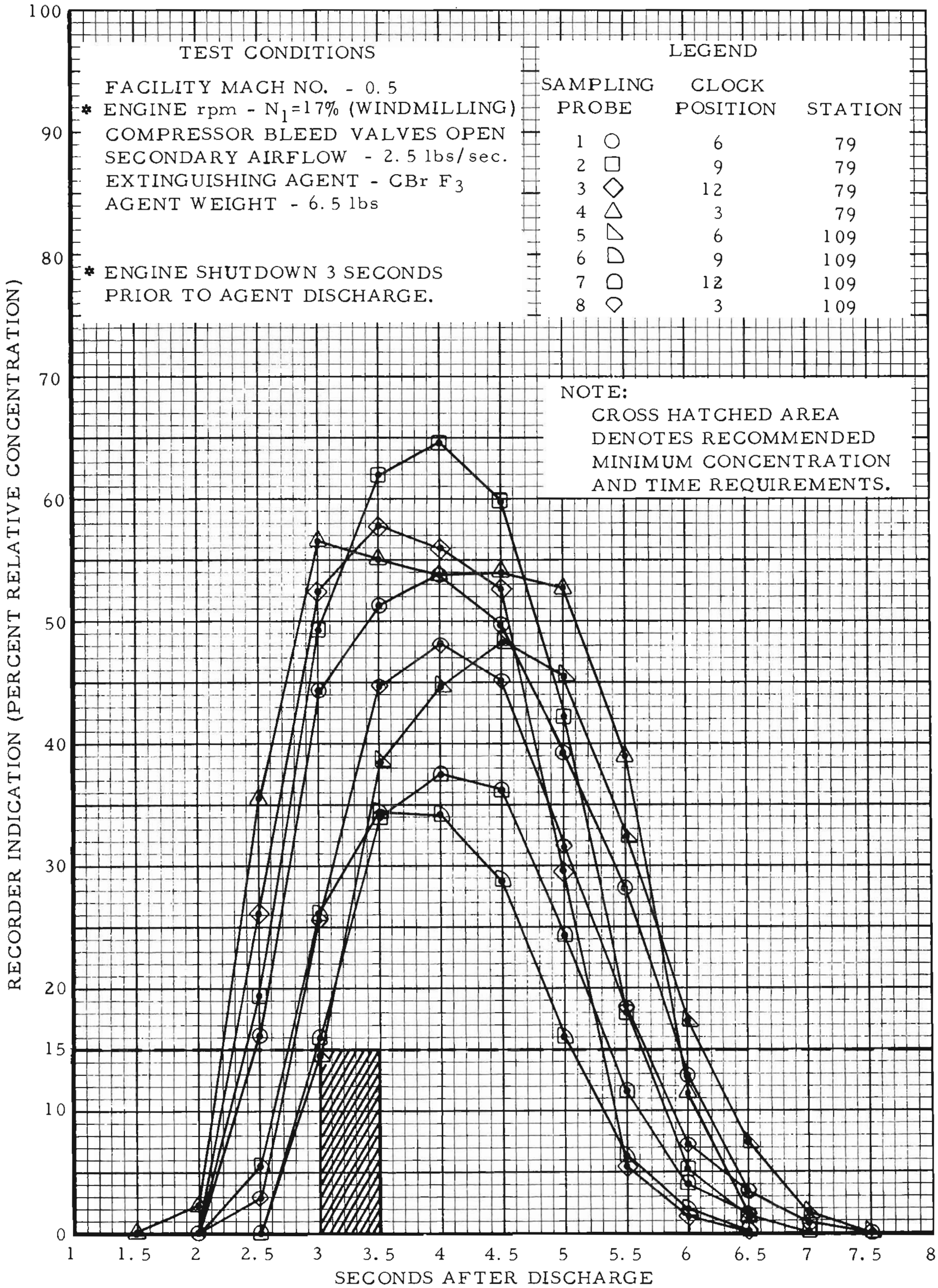


FIG. 15 EXTINGUISHING AGENT CONCENTRATION WITH 2.5-POUNDS-PER-SECOND SECONDARY AIRFLOW RATE IN ZONE II

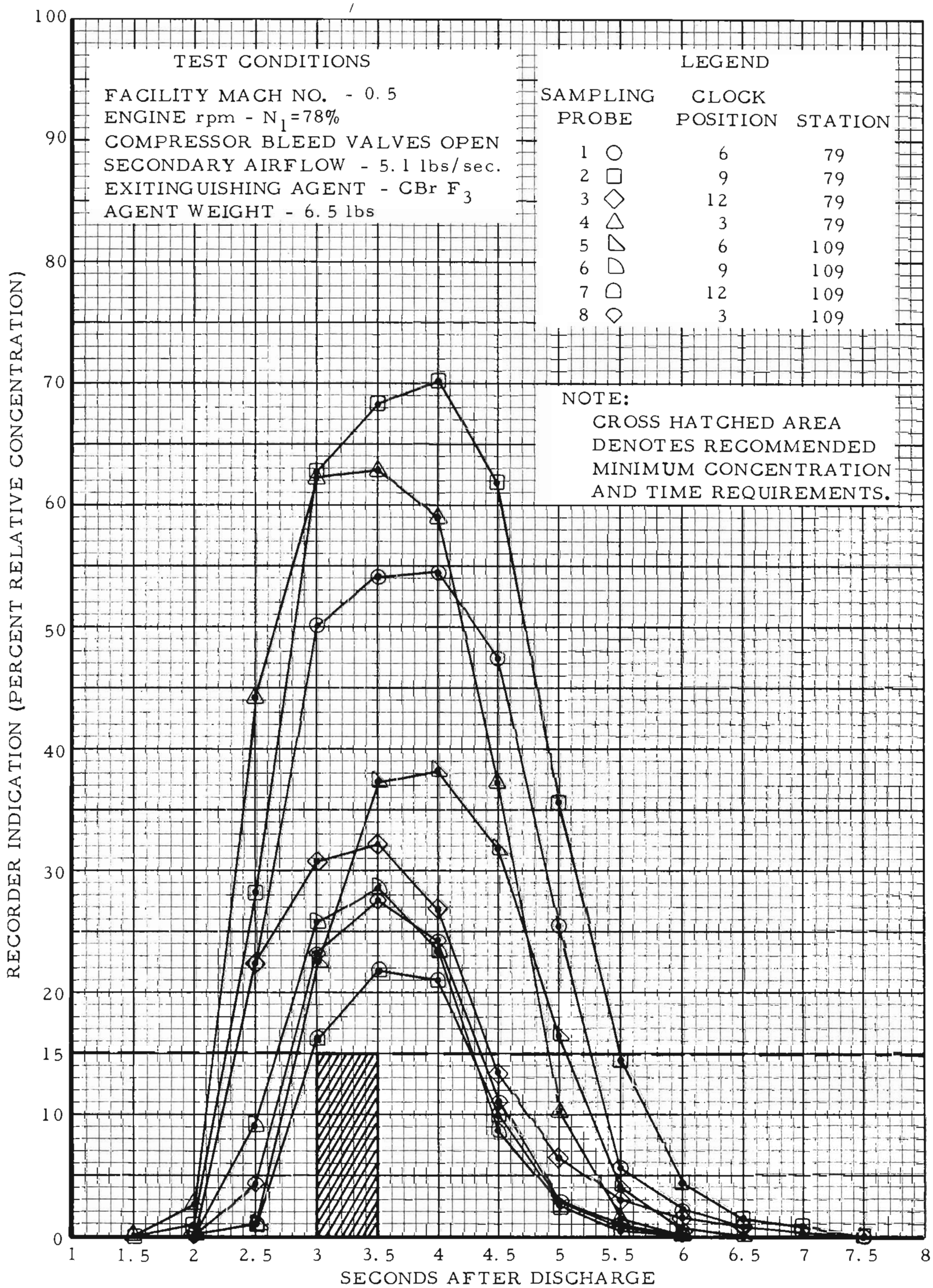


FIG. 16 EXTINGUISHING AGENT CONCENTRATION WITH 5.1-POUNDS-PER-SECOND SECONDARY AIRFLOW RATE IN ZONE II

For the 45-second duration fires, the engine was stopcocked at 30 seconds and the tunnel power was increased, and 15 seconds later the extinguishing system was initiated. The fuel to the test fire was allowed to flow at least 30 seconds after the fire was extinguished during all extinguishing system tests.

The first 24 fire-extinguishing tests were either 0.42- or 1.0-gpm JP-4 fires of 10 to 15 seconds duration each. At the time, fire produced by these fuel-to-fire flow rates was considered to provide a most severe test of the installed extinguishing system. The duration of these fires was limited to reduce damage to the nacelle secondary structure and increase the fire test life of the installation. All the fire locations in Zone II of the nacelle indicated in Figure 6 were covered in this series of tests. The normal amount of extinguishing agent, which is 6.5 pounds of $CBrF_3$, provided immediate extinguishment of each fire.

The next 44 fire-extinguishing tests were either 0.3- or 0.42-gpm JP-4 fires of 10 to 20 seconds duration each. The 1.0-gpm JP-4 fire was eliminated during these and subsequent tests, since the preceding tests showed that this fuel flow produced fires which were most damaging during the engine shutdown phase of the test. Fires were originated at Locations 7A and 9A (Figure 6) in Zone II. The fire locations selected were considered most remote from the effect of the extinguishing agent in the aft and forward portion of the nacelle under the test conditions (Figure 15). The amount of extinguishing agent was reduced from 6.5 pounds to less than 1.0 pound during these tests. The minimum amount of agent required to consistently extinguish these short-duration fires was 1.0 pound of $CBrF_3$.

The last 24 fire-extinguishing tests were 0.14-, 0.3-, and 0.46-gpm JP-4 fires of 44 to 45 seconds duration. These fires were originated at Location 7A in Zone II. The minimum amount of agent required to extinguish 45-second duration fires with fuel flow rates up to 0.3 gpm of JP-4, was 3.5 pounds of $CBrF_3$. None of the final six fires, in which fuel-to-fire was increased to 0.46 gpm, were extinguished as agent ($CBrF_3$) quantity was increased to 3.5 pounds for two tests; then, 4.0 pounds for one, 5.0 pounds for the next, and 6.5 pounds for the last two tests. This was mainly due to the increasing deterioration of aft portion of the Zone II main access door and fire seal between Zones II and I during the 18 fire tests preceding the initial 0.46-gpm JP-4 fire tests as well as the final six 0.46-gpm fire tests. The aft edge of the access door tended to warp and weaken, allowing egress of fire. The fire seal also weakened allowing egress of fire into Zone I and out the aft edge of an aluminum access panel located in the top forward portion of the Zone I nacelle skin.

There was no instance of reignition of the flammable fluids during these tests. Apparently the compressor bleed air of approximately

2.3 pounds per second, which was expelled into Zone II of the nacelle when the engine was shut down, provided adequate ventilation and cooling and prevented reignition.

The extinguishing capability of the installed system was not affected by the addition of cooling airflow to Zone II when failure of the closed air cooling system for the starter/generator unit was simulated. The extinguishing system which was installed in Zone II and was constructed from stainless steel tubing did not sustain fire damage and functioned properly throughout the test program.

An analysis of isothermalplots for 0.14-, 0.3-, and 0.46-gpm JP-4 fires conducted at Location 7A under similar test conditions before and after initiation of the fire emergency procedure was made. Under the conditions of low airflow in Zone II (approximately 0.2 pound of air per second), before emergency shutdown of the engine when the compressor bleed valves were closed, there was a noticeable increase in fire intensity and area which the fire covered when the fuel-to-fire flow was increased from 0.14 to 0.3 gpm. Under the same conditions when the fuel-to-fire flow was increased from 0.3 to 0.46 gpm the intensity of the fire as well as the area which the fire covered remained about the same. Under the emergency engine shutdown condition, when the compressor bleed valves were open causing an increase in secondary airflow in Zone II up to approximately 2.5 pounds per second, the 0.14-gpm fire was less intense, the 0.3-gpm fire intensity remained approximately the same, and the 0.46-gpm fire intensity increased. This analysis indicated that the 0.3- and 0.46-gpm fuel flows produced the most intense and severe test fires in Zone II under the low airflow condition of 0.2 pound per second. Also fuel-to-fire flows of 0.46 gpm and above produced the most intense and severe fires when conducted under the 2.5-pounds-per-second airflow condition.

Fire Resistance

Factors which directly affected the extent of damage to the nacelle from fire were the location of the fire, the duration of the fire, and the secondary airflow rate when the engine was windmilling combined with the fuel-to-fire flow rate.

Fire damage to Zone II of the Jet Star powerplant installation was of an accumulative nature. The aluminum structure (secondary structure), especially camlock-type receptacles for inspection and access panels, seam lines of access doors, mating surfaces of access doors and panels as well as edges of aluminum formers and stiffeners, sustained damage initially.

The primary structure was a steel box beam extending over the top of the nacelle at the midpoint of Zone II ahead of the louvered air exit in the top aft portion of this zone. Fuel and electrical lines routed to the outboard engine were housed in this beam. Because of the box beam's location in relation to the Zone II air exit and the test fire paths, it was never in the path of fire; consequently never sustained any damage. Metal temperature rise and internal void area ambient temperature rise in the beam were insignificant.

The longitudinal vertical stainless steel firewalls on the inboard and outboard portion of the nacelle were not penetrated by fire.

The initial damage of significance was fire penetration of the main Zone II bottom access door at the aft edge of two small inspection plate locations. This was obtained during the initial fire detection test originating at a 4 o'clock forward position in Zone II (Location 5 shown in Figure 6). A 0.07-gpm 10-second duration fire melted aluminum camlock fastener receptacle on the aft corner of each plate. This allowed the aft inboard edge of each plate to pop open, and fire egressed from these openings. Fire started to erode the edge of the aluminum doubler to which these panels were secured. This damage is shown in Figures 17 and 18. To prevent continual repair of this area during subsequent fire test originating in the forward inboard portion of Zone II, the inspection panels were replaced by flush aluminum patches. This modification eliminated any further fire damage to this area during the remaining test program.

Rapid fire deterioration of the aft section of the Zone II aluminum-louvered panel located at the aft top portion of the zone occurred especially when fires were originated in the aft portion of this zone. Figure 19 shows the damage that occurred after 19 seconds total exposure time to two 0.42-gpm fires originated at the 4:30 o'clock position in the aft inboard portion of Zone II (Location 6 shown in Figure 6). Since the louvered panel was particularly susceptible to damage, a stainless steel slotted panel was fabricated to replace it. This stainless steel panel lasted the remainder of the program.

The hinge line neoprene seal on the inboard side of the Zone II access door was initially damaged after a total of 2 minutes 10 seconds exposure to fires. These fires consisted of three 0.07-gpm, five 0.3-gpm, and two 0.14-gpm JP-4 fires originated at the 4:30 o'clock forward position (Location 5 shown in Figure 6) in Zone II. The seal was penetrated and fire egressed through the hinge line. For subsequent tests, the seal was replaced by room temperature vulcanizing (RTV) rubberized compound to reduce fire deterioration along the hinge line and to provide maintenance of similar environmental conditions within the nacelle from test to test.

In addition to the above described damage, Table 6 is presented as a summary of the fires by number, location, fuel-to-fire rate, and fire duration as related to the fire deterioration of other specific areas in Zone II. These include the Zone II main access door's rear hinge aluminum support bracket, the fire barrier's upper aluminum frame, and the engine portion of the fire seal. Fire location in respect to the

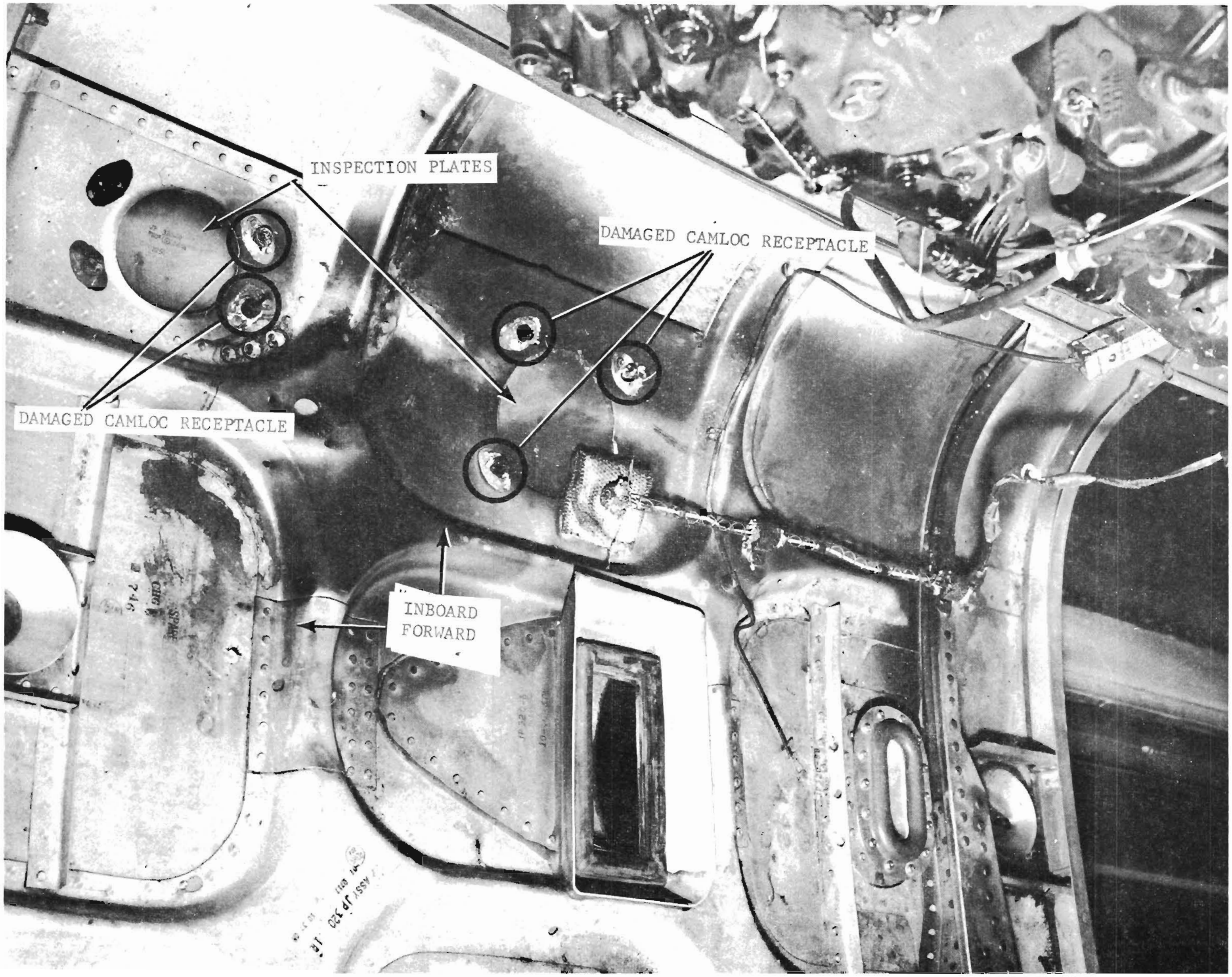


FIG. 17 DAMAGE TO SMALL INSPECTION PLATE

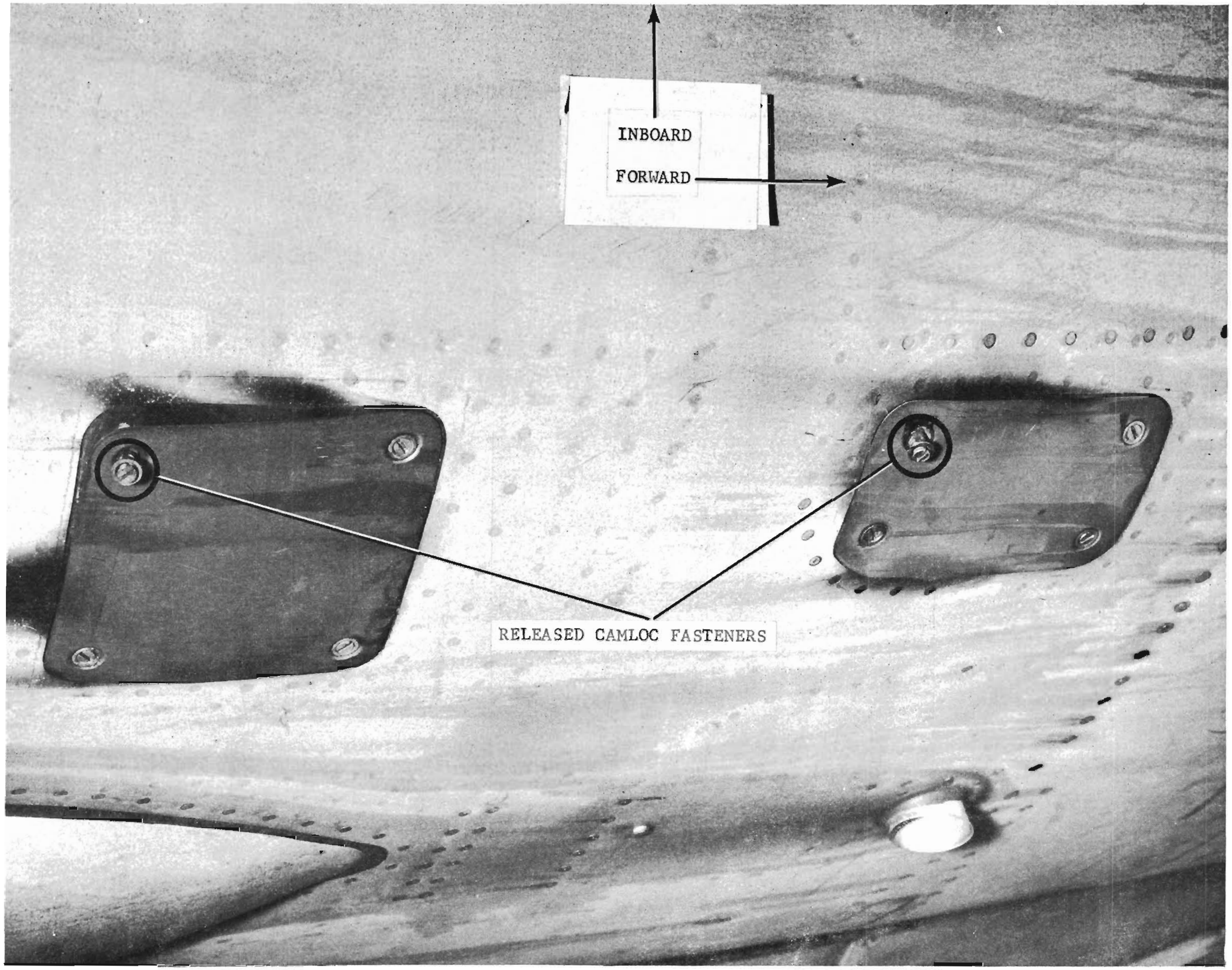


FIG. 18 EXTERNAL VIEW OF DAMAGE IN INSPECTION PLATE AREA

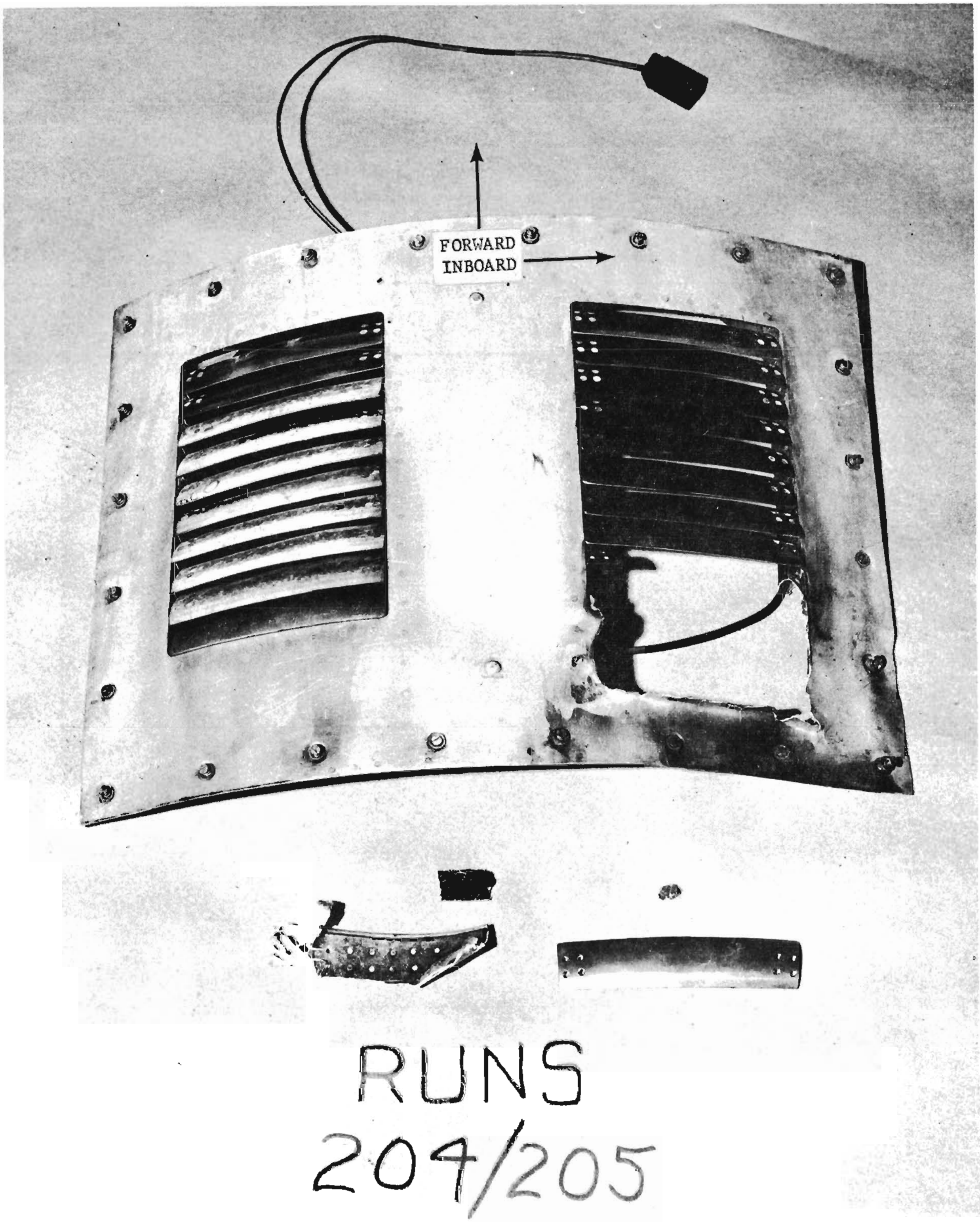


FIG. 19 DAMAGE TO TOP AFT LOUVERED PANEL IN ZONE II

TABLE 6

EXPOSURE TIME TO FIRE FOR SIGNIFICANT DAMAGE

Damage to Nacelle	Fuel to Fire Flow (gpm)	Fire Location 5 No. of Fires	Fire Location 5 Fire Duration (sec)	Fire Location 6 No. of Fires	Fire Location 6 Fire Duration (sec)	Fire Location 7 No. of Fires	Fire Location 7 Fire Duration (sec)	Fire Location 8 No. of Fires	Fire Location 8 Fire Duration (sec)	Fire Location 9 No. of Fires	Fire Location 9 Fire Duration (sec)	Total Number of Fires	Total Exposure Time (Min:Sec)
Main	0.07	3	31.8										
Access Door	0.14	6	41.8	8	90.9	5	37.2	5	53.5	5	44.8		
Aft Hinge	0.3	5	42.6	6	70.3	5	33.8	5	45.8	5	42.5		
Support	0.4	2	27.4			2	11.9	2	18.1			99	15:05
Bracket -	0.46	5	41.2	6	60.0	6	41.9	6	40.3	6	52.3		
Zone II	1.00	2	15.8			2	19.2	2	42.6				
	Total	23	200.6	20	221.2	20	144.0	20	200.3	16	139.6		
Upper	0.07	3	31.8										
Nacelle	0.14	6	41.8	8	90.9	5	37.2	5	53.5	5	44.8		
Former at	0.3	5	42.6	6	70.3	5	33.8	5	45.8	5	42.5		
Fire Seal -	0.4	3	36.8	3	23.7	3	21.4	3	28.1	5	58.9	113	17:33
Zone II	0.46	5	41.2	6	60.0	6	41.9	6	40.3	6	52.3		
	1.00	2	15.8			2	19.2	2	4				
	Total	24	210.0	23	244.9	21	153.5	21	210.3	24			
Penetration	0.07	3	31.8										
of Fire	0.14	6	41.8	8	90.9	11	327.1	5	53.5	5	44.8		
Seal at	0.3	5	42.6	6	70.3	34	779.9	5	45.8	8	86.5		
Combustor	0.4	3	36.8	3	23.7	13	123.0	3	28.1	17	197.9	179	43:52
Shroud -	0.46	5	41.2	6	60.0	12	300.0	6	40.3	6	52.3		
Zone II & I	1.00	2	15.8			2	19.2	2	42.6	3	36.6		
Damage													
	Total	24	210.0	23	244.9	72	1549.2	21	210.3	39	418.1		

damage area, as well as fuel-to-fire flow rate and fire duration, have to be considered in analyzing how long it took a specific area to deteriorate to failure.

The aft inboard aluminum hinge anchor bracket for the Zone II main access door separated from its attachment point after a total of 99 fire tests in Zone II. The aluminum rib to which the bracket was attached deteriorated and the bracket broke away, allowing the aft inboard portion of the Zone II main access door to drop open. The fire then egressed from Zone II to the outside at this opening. The fires originated in the inboard portion of Zone II and especially those at the 4:30 o'clock aft position in the zone (Location 6 shown in Figure 6) as well as those fires which had fuel flow rates in excess of 0.4 gpm had the most damaging effect on this bracket attachment point. The attachment point failed during a 1.0-gpm JP-4 fire originated at the 4:30 o'clock position in the forward portion of Zone II (Location 5A shown in Figure 6). The duration of this fire was 8.8 seconds. The damage to this area is shown in Figure 20.

The upper "T" aluminum former attached to the nacelle portion of the Zone I/Zone II separating seal deteriorated to a point that it had to be replaced after 112 fire tests. The Zone II louvered panel as well as the forward top Zone I access panel were attached to this former by camlock-type fasteners. The camlock receptacles riveted to the inside of this former as well as a good portion of the former on the Zone II side of the fire barrier were destroyed. Figure 21 shows the fire damaged aluminum former and the stainless steel former which was used to replace it. Fires which originated in the aft portion of Zone II at the 4 and 8 o'clock positions (Locations 6 and 7 as shown in Figure 6), as well as those fires in the nacelle with fuel flow rates greater than 0.4 gpm, had the most damaging effect on the former. The last fire to which this former was subjected before replacing it was a 0.42-gpm JP-4 fire originated at the 6 o'clock position in the forward portion of Zone II (Location 9A as shown in Figure 6). The duration of this fire was 9.0 seconds.

The lower outboard side of the fire barrier was penetrated by fire during Fire Tests Nos. 155 through 157. These were the first three 45-second duration fire tests. Penetration of fire occurred through the tadpole tape compression seal which is located between the engine and nacelle portions of the fire barrier. A considerable portion of the Zone I access door strengthening baffle which extended into Zone II was destroyed during these three fire tests. Figure 22 shows this damage. The fire-barrier seal was replaced for subsequent tests. The fire tests in which this damage occurred were 0.3-gpm JP-4 fire tests. The total fire duration was 2 minutes and 15 seconds; 45 seconds for each test. The fire location in Zone II was at 8 o'clock in the aft portion of the zone (Location 7A shown in Figure 6). However, preceding these 45-second duration fire tests there were 18 fire tests which were originated at Location 7A. These were short-duration fires of 10 to 20 seconds fed by

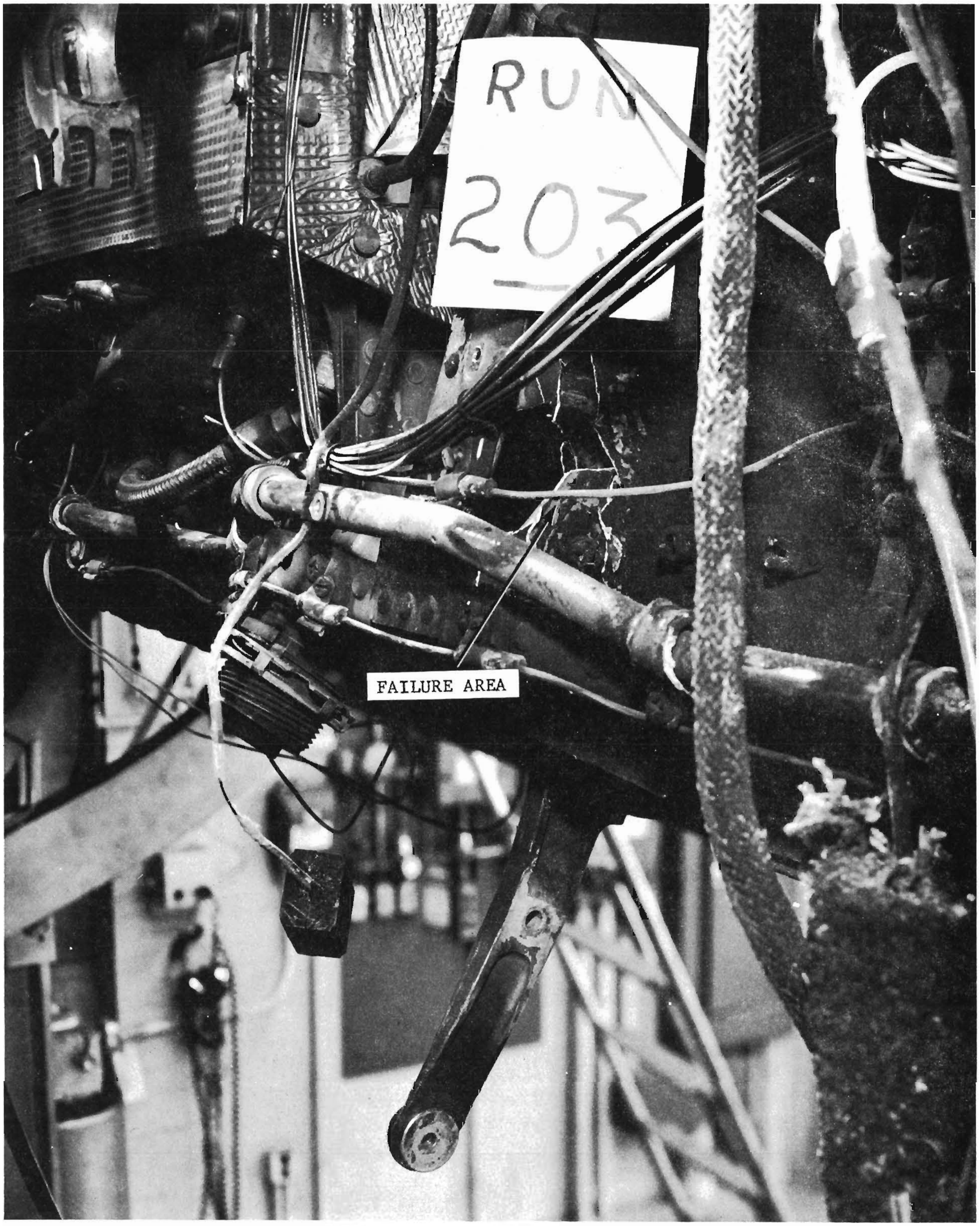


FIG. 20 DAMAGE TO ZONE II MAIN ACCESS DOOR AFT HINGE SUPPORT BRACKET

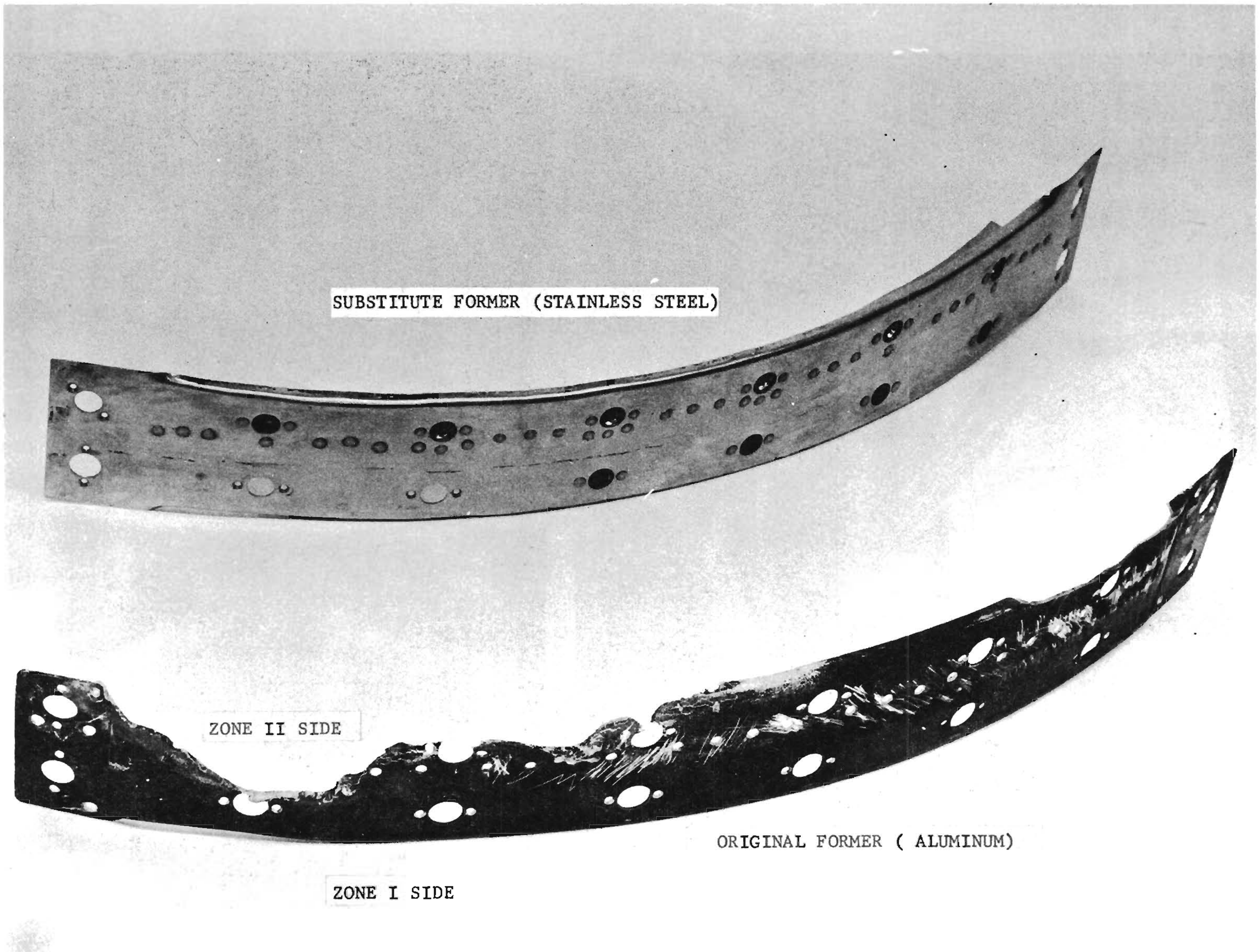


FIG. 21 DAMAGE TO NACELLE UPPER FORMER AT THE ZONE II/ZONE I SEPARATING FIRE SEAL

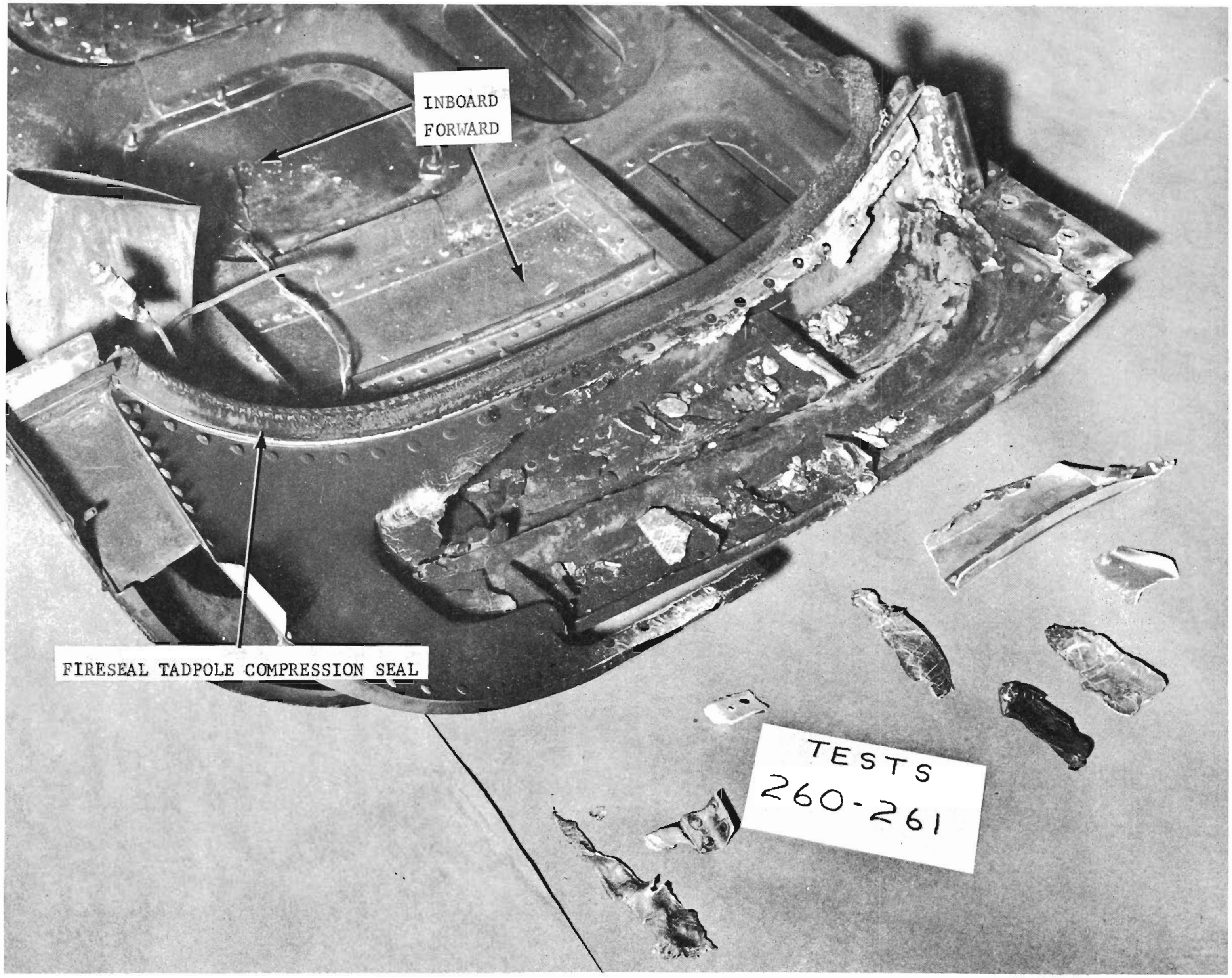


FIG. 22 DAMAGE TO FIRE SEAL TADPOLE COMPRESSION SEAL AND ZONE I ACCESS DOOR BAFFLE SECTION

JP-4 fuel at flow rates of either 0.3 or 0.42 gpm. These fires most likely contributed to the deterioration of the tadpole tape compression seal prior to the 45-second fires.

During the Fire Tests Nos. 178 and 179, which were the last two conducted in Zone II, fire again penetrated the fire barrier. The tadpole tape compression seal between the engine and nacelle sections of the fire barrier was burned through on the outboard side of the nacelle. Warpage of the engine combustor stainless steel shroud occurred causing the shroud to pull away from the "U"-shaped peripheral collar to which it was riveted. The fire egressed through these openings and into Zone I. Then the fire progressed toward the top of Zone I, burning out the aft outboard edge of the Zone I top aluminum access panel where it mated with the nacelle skin. It burned away a section of the aluminum former to which the aft portion of the panel was attached and burned away a portion of skin directly behind the outboard aft edge of the panel. Figures 23, 24, and 25 show this damage. The two fires during which this damage occurred were 0.46-gpm JP-4 fires conducted at 8 o'clock in the aft portion of Zone II (Location 7A shown in Figure 6). The combined fire duration time for these two tests was 1 minute and 18 seconds.

There was never a direct penetration of the aluminum skin portion of the nacelle. Penetration of the nacelle by fire was limited to those areas where there was discontinuity in the skin. This included the louvered area in the top of Zone II, hinge lines of the main access doors, and the downstream edges of access doors and panels. After numerous fires, the Zone II main access door warped allowing egress of fire out the aft edge of the door. This door mated metal to metal with the Zone I main access door at this edge.

Electrical cable and wire insulation were burned off during the initial 90 fire tests. These were replaced and protected with asbestos covering. During the last 25 tests which were 45-second duration fires, damage to the engine accessories consisted of the following:

1. The hydraulic pump overboard aluminum drain line was burned off.

2. The fuel pressure differential switch failed allowing JP-4 fuel to leak into Zone II at about 0.1-gpm flow rate. This switch was replaced.

3. The fuel pressure switch began to leak so it was blocked off. It was destroyed in subsequent tests.

4. The fuel pressure switch aluminum drain line was burned away.

5. The stainless steel thrust reverser hydraulic line in the outboard aft portion of Zone II burst. This line had hydraulic fluid in it.

None of this damage interfered with the normal operation of the engine.

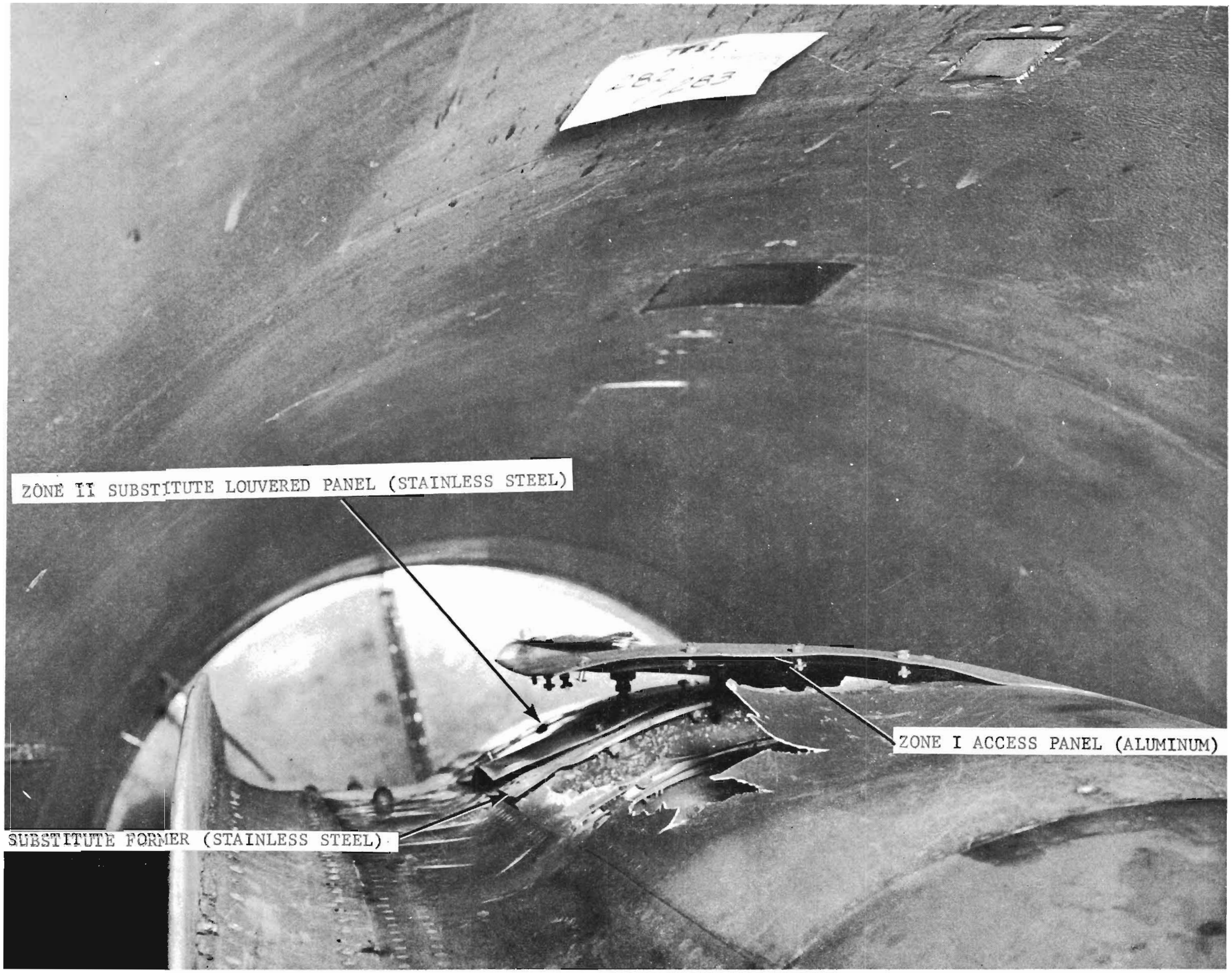


FIG. 23 EXTERNAL VIEW OF DAMAGE TO ZONE I ALUMINUM ACCESS PANEL, NACELLE FORMER, AND SKIN

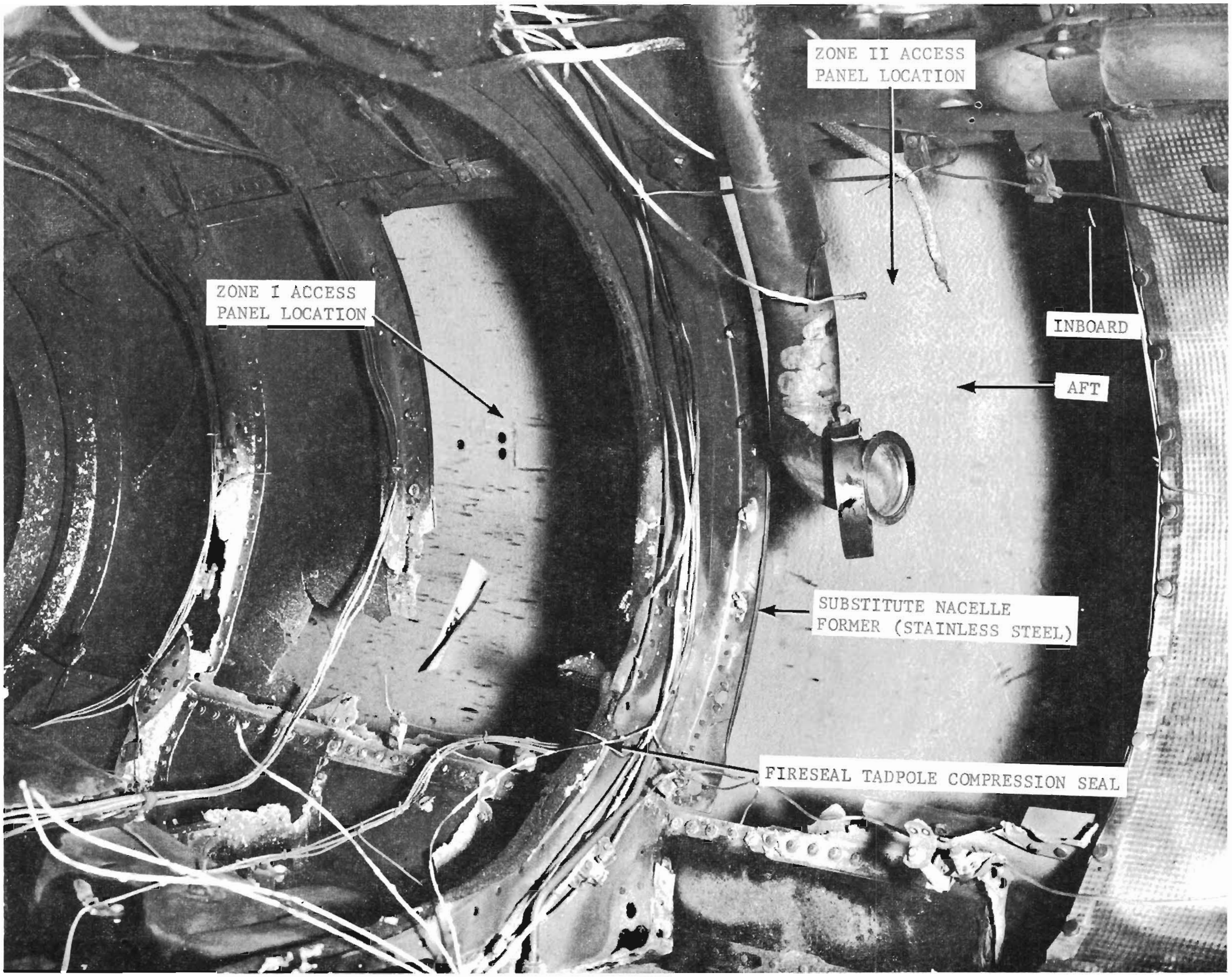


FIG. 24 INTERNAL VIEW OF DAMAGE IN THE TOP OF THE NACELLE FORWARD AND AFT OF THE FIRE SEAL

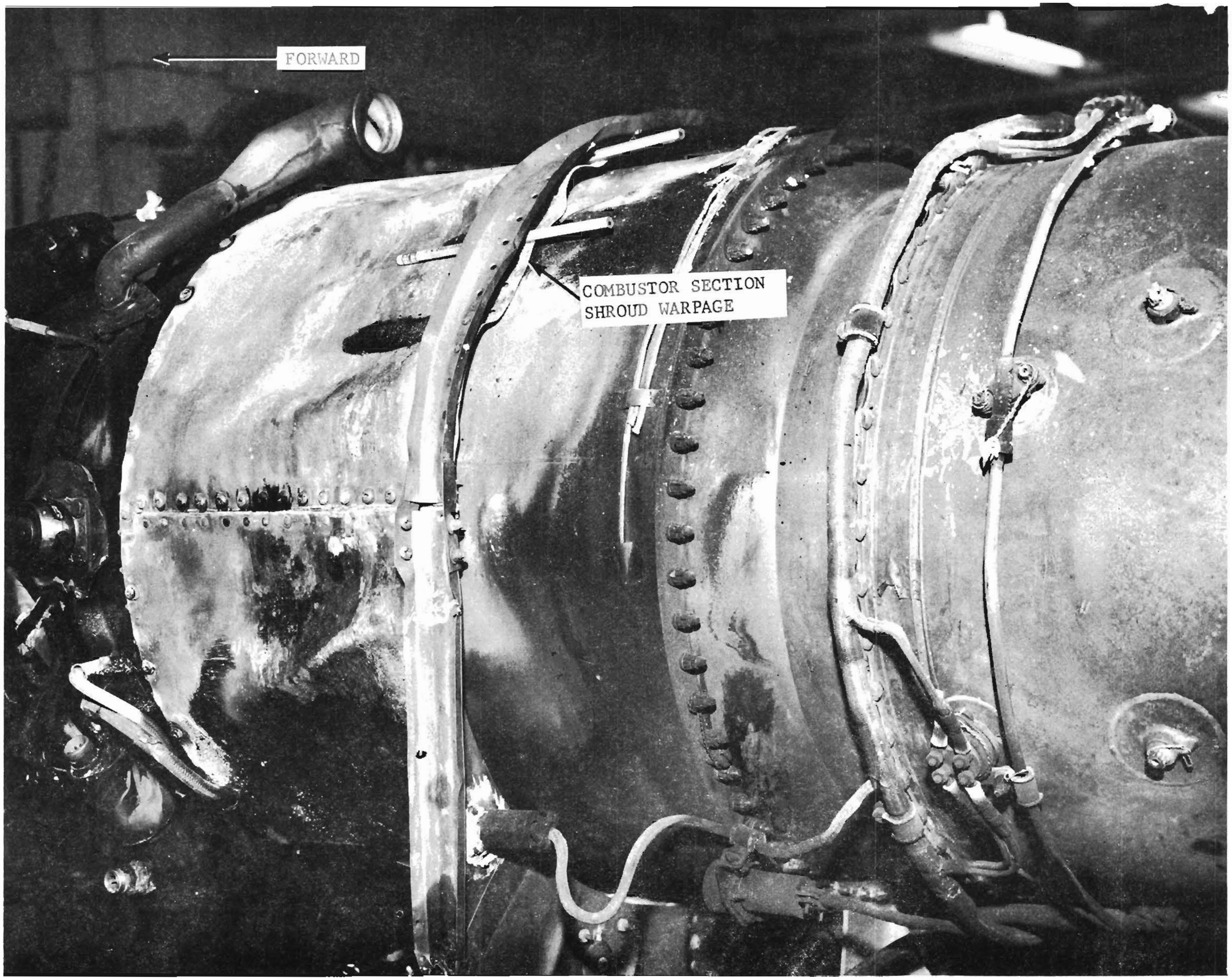


FIG. 25 DAMAGE TO STAINLESS STEEL ENGINE COMBUSTOR SHROUD AND ATTACHED "U" FRAME

SUMMARY OF RESULTS

Hot-Surface Ignition

The significant findings obtained during the Hot-Surface Ignition Tests are as follows:

1. Ignition of JP-4 fuel, Jet A-1 fuel, and Military Specification 5606 Hydraulic Fluid by hot-engine surfaces in Zone I (aft portion of the nacelle which houses the engine combustor, turbine, and tailpipe sections), and Zone II (the forward portion of the nacelle which houses the engine compressor and accessory sections) did not occur under normal engine operating conditions, either with steady-state or transient power, when the normal nacelle configuration was utilized.

2. Ignition of Jet A-1 fuel on the hot-engine surface in Zone I occurred during four of 48 tests under conditions of maximum steady-state engine power, when the ram cooling air inlet to Zone I was covered, allowing air leakage only at the mating surfaces of three nacelle panels. Two of these were access panels held by camlock-type fasteners, and the third was a small spring-loaded flush air inlet which was fastened shut. These doors provided discontinuity in the nacelle exposed to some air leakage of approximately 157 inches linearly.

3. With the ram cooling air inlet to Zone I covered, ignition of Jet A-1 fuel on the hot-engine surface in Zone I occurred during 10 of 48 tests when a power change was made.

4. The ignitions that occurred resulted in overpressure from 0.5 to 4.5 psi. This type of ignition was difficult to repeat under the same test conditions. Damage from overpressure was not extensive.

5. During two of the four hot-surface ignitions which occurred under the steady-state power conditions, a heat blanket on the turbine exhaust case was believed to have contributed to ignition of the Jet A-1 fuel. Apparently, fuel leaked underneath the blanket and ignited on the case surface. Ignition occurred soon after fuel release was initiated. When the blanket was removed and tests were repeated, ignition of the fuel did not occur.

6. The construction of this installation was intended to provide separation of all flammable fluid systems from Zone I (the hot section) by a fire seal. However, when fuel was released in Zone II in quantities in excess of 0.3 gpm, leakage was observed at the circumferential mating surfaces of the lower nacelle access doors. This mating surface was forward of the firewall. The fuel flowed aft on the external nacelle surface and into Zone I through a 5.5-inch-square ram air scoop used to direct cooling air onto the engine turbine case. The fluid impinged directly on the engine turbine case. However, no ignition occurred. Also, inspection of the Zone II compartment after each test revealed accumulation of fuel in the lower portion of the zone especially during those tests in which the fuel flow rate was 0.3 gpm or greater.

Fire Detection and Flame Paths

The significant findings obtained during the Fire Detection and Flame Paths Tests are as follows:

1. The continuous-type temperature-sensitive fire detector system in Zone II provided prompt detection of most fires during tests conducted at takeoff and cruise operating conditions. However, many of the fires originated at the 7:30 and 6 o'clock positions in the forward portion of Zone II were either undetected or were slower to provide alarm than fires at other locations in Zone II.

2. The Zone I overheat-detection system in the powerplant was noted to include two segments (terminal segments) of sensing element in Zone II. These segments were routed through Zone II on the inboard side from terminal points at the main nacelle structural overhead box beam in Zone II to the zone-separating fire seal where they entered Zone I.

3. As a result of Item 2, the majority of the fires originated in Zone II on the inboard side, both forward and aft, alarmed both the Zone II fire detection and the Zone I overheat-detection systems during normal cruise operating conditions.

4. Also, as a result of Item 2, some fires that were originated at the lower aft inboard portion of Zone II caused alarm of the Zone I overheat-detection system only. This happened during a condition in which the engine was operated at N_1 = 78 percent rpm (compressor interstage bleed valves open).

5. Fires that were originated in the forward part of Zone II tended to travel along the lower portion of the nacelle toward the fire seal, then up and around the engine, favoring the outboard side of the nacelle. They then exited at the ventilation louver located in the top aft portion of the zone. Fires that were originated in the lower inboard and outboard aft portion of Zone II traveled up around the engine to the ventilation louver, favoring that side of the engine where the fire was initiated.

Extinguishment

The significant findings obtained during the Extinguishment Tests were as follows:

1. The installed extinguishing system incorporating 6.5 pounds of $CBrF_3$ extinguishing agent provided more than adequate effectiveness as long as the integrity of the fire zone remained substantially intact.

2. Ten- to 20-second fires fed by JP-4 fuel at a rate up to 0.46 gpm were extinguished with a minimal amount of $CBrF_3$ of 1 pound.

3. Forty-five-second fires fed by JP-4 fuel at a rate up to 0.3 gpm were extinguished with a minimal amount of $CBrF_3$ of 3.5 pounds.

4. There was no occasion of reignition of fuel after the fire was extinguished even though fuel-to-fire was allowed to flow at least 30 seconds after extinguishment. This was attributed to the ventilation and cooling effect provided by the total airflow through Zone II of approximately 2.5 pounds per second during and after extinguishing system activation. During this time the engine was shut down and windmilling and the engine compressor interstage bleed values were open, expelling approximately 2.3 pounds of air per second into this zone.

5. Simulation of a failure of the starter/generator air-cooling system provided no significant change in extinguishing system effectiveness.

6. The installed extinguishing system, with 6.5 pounds of $CBrF_3$, produced extinguishing agent relative concentrations above the recommended minimum of 15 percent for 2.0 seconds with a Zone II airflow of 2.5 pounds per second and 1.25 seconds with a Zone II airflow of 5.1 pounds per second. The recommended minimum duration for the 15 percent relative concentration is 0.5 seconds.

Fire Resistance

The significant findings obtained during the Fire Resistance Tests were as follows:

1. The two locations in the nacelle that were highly susceptible to damage by fire were the area of the two small inspection panels in the left forward portion of the Zone II main access door and the area of the louvered ventilation panel located at the top aft portion of Zone II. Fires in the inboard lower forward portion of Zone II quickly destroyed the aluminum camlock-type receptacles that held these panels to the nacelle skin and allowed egress of fire from the nacelle. Fires in the lower aft portion of Zone II quickly burned out the Zone II top aluminum louvers and the skin directly aft of the louvers.

2. The fire damage to the installation was generally of an accumulative nature since initial fires were limited in duration. Aluminum formers, ribs, hinge supports, camlock-type receptacles for panels, drain lines, as well as hinge line seals, neoprene gaskets, neoprene impregnated fiberglas air ducts, and electrical wires incurred damage from repeated exposure to fire.

3. There was no damage to the nacelle's main overhead box beam support through which fuel lines and electrical wiring were routed to the outboard engine, since it was not in the direct path of fire. Also, there was no significant damage to the two vertical longitudinal stainless steel firewalls on either side of the inboard nacelle which isolated the nacelle from the pylon and fuselage and from the outboard engine/nacelle area.

4. Deterioration and egress of fire occurred at the downstream mating surfaces of access doors and panels as well as at butt and hinge lines of access doors. Burn-through of the aluminum cowl, except at these joints, did not occur.

5. Failure of the aft inboard hinge anchor bracket which supports the hinge for the Zone II main access door occurred after exposure to 99 short-duration (5 to 15 seconds) fire tests of which 43 originated on the inboard side of the nacelle. The aluminum "T" frame, which is attached to the upper ZoneI/Zone II separating fire seal, deteriorated to a point it had to be replaced after exposure to 112 short-duration fire tests. The engine portion of the firewall separating Zone II from Zone I failed after 178 fire tests of which 21 were 45-second duration fires. Also, the tadpole tape fire-resistant seal between the engine portion and the nacelle portion of the fire barrier burned through.

6. Fire which egressed either to the outside of Zone II or through the fire barrier into Zone I deteriorated aluminum cowl aft of the initial point of egress. The last six 45-second fires (JP-4 fuel-to-fire rate of 0.46 gpm) were not extinguished with increasing amounts of agent from 3.5 to 6.5 pounds of $CBrF_3$. It was during these fires that increasing deterioration of the Zone I/Zone II separating fire barrier occurred allowing penetration of fire into Zone I from Zone II.

7. Damage to the engine and engine accessories was limited and did not affect operation of the engine. Such items as the fuel pressure switch drain line, engine fuel pressure switch, fuel pressure differential switch, and hydraulic pump overboard drain line were destroyed during the twenty-four 45-second duration fire tests.

CONCLUSIONS

Within the limits of the tests conducted, the following is concluded with respect to the C-140 powerplant installation:

1. Ignition of JP-4 and Jet A-1 fuels and Military Specification 5606 hydraulic fluid on the engine hot surfaces of the normally configured powerplant installation is improbable under flight operating conditions.

2. Ignition of Jet A-1 on the engine hot surfaces can occur in Zone I during maximum steady-state engine power condition and transient power conditions when the Zone I configuration is changed to reduce the secondary airflow to less than 0.15 pound per second.

3. The drainage provisions in Zone II does not prevent accumulation of flammables, in the lower portion of the zone, from leaks in excess of 0.3 gpm.

4. The ram air scoop which is located in the bottom aft portion of the nacelle to provide cooling air for the hot section of the jet engine housed in Zone I can act as a passage through which flammables which leak out of Zone II can enter Zone I and possibly impinge on the hot section.

5. The installed continuous-type detection system provides prompt detection of fires originating at all locations except the forward lower portion of Zone II.

6. Erroneous Zone I overheat indication can occur from a fire in Zone II since the heat sensing continuous-type detection system for fire in Zone I is routed through Zone II which has a separate detection system.

7. The extinguishing system and quantity of extinguishing agent in this powerplant installation provide more than adequate extinguishment capability as long as severe deterioration of the nacelle skin or the fire seal by fire does not occur prior to system activation.

8. A perforated tube extinguishing system which is similar in design to the system in this powerplant installation can provide very effective distribution of extinguishing agent in fire zone compartments which have low-to-moderate airflow rates.

9. Reignition of fuel on overheated surfaces in Zone II of the nacelle after fire extinguishment is improbable.

10. Fire penetration and deterioration of the aluminum portion of the nacelle will initially occur at the downstream edges of airflow exits constructed in the nacelle, at access door hinge lines and mating surfaces, and at access panel mating surfaces which are in close proximity to the origin of the fire.

11. The small aluminum receptacles for the camlock-type fasteners which secure access panels to the aluminum portion of the nacelle are highly susceptable to fires, which are in close proximity to them. Rapid destruction of these receptacles by fire can occur allowing separation of the panels from the nacelle, egress of fire at the separation location, and deterioration of the aluminum skin downstream of the egress location.

12. Penetration of or major damage to the inboard and outboard longitudinal firewall, as well as the main structural beam, by fire in the inboard portion of the C-140 siamese nacelle installation is improbable prior to severe fire damage and deterioration of the aluminum portion of the nacelle and the zone separating fire seal within the nacelle.