A Study of Ignition Hazards and Fire-Resistance of the Boeing 707 Powerplant

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TECHNICAL DEVELOPMENT REPORT NO. 357

CIVIL AERONAUTICS ADMINISTRATION

TECHNICAL DEVELOPMENT CENTER

INDIANAPOLIS, INDIANA

August 1958

U S. DEPARTMENT OF COMMERCE
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CIVIL AERONAUTICS ADMINISTRATION
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A STUDY OF IGNITION HAZARDS AND FIRE-RESISTANCE OF THE BOEING 707 POWERPLANT*

SUMMARY

A study was made of the characteristics of powerplant fires in the Boeing 707 pod-type turbojet engine installation and of the ignition hazards and fire-resistance characteristics of this installation

The powerplant under investigation employed a tightly sealed nacelle with a low rate of ventilation The early phases of this study indicated that the flammable fluids used in the powerplant would not ignite from contact with the hot surfaces of the engine under normal operating and nacelle airflow conditions. However, the particular type of fuel-air starter employed in this test article would ignite JP-4 fuel and MIL-O-5606 hydraulic fluid readily when either was sprayed on the starter during the starting cycle

In order to study external flame paths, a prolonged uncontrolled in-flight fire was simulated It was observed that the strut dimensions for this design were adequate to prevent flame impingement on the wing although considerable damage was done to the nacelle doors with lesser damage to the strut skin An uncontrolled powerplant fire of the size and intensity used in these tests should not damage any portion of the wing.

INTRODUCTION

The United States Air Force's aerial jet tanker, the KC-135, and its commercial counterpart, the Boeing 707, are representative of a new concept in multiengine turbojet transport design which uses pod-mounted engines on struts underneath the wing This resulted in the necessity to reconsider the means for providing fire safety established from years of experience with reciprocating engine transports. For this reason, a test program was carried out and the fire characteristics of this design were studied under controlled conditions The KC-135 was chosen for this purpose because it was representative of this general design and was in an advanced stage of production

The testing was accomplished at the CAA Technical Development Center (TDC), Indianapolis, Indiana, during the period April through June, 1957 This is the first of a series of reports on these studies and deals specifically with the ventilation characteristics of this powerplant, the ignition hazards present in the nacelle when combustible fluids contact the hot engine surfaces, and the effect of uncontrolled powerplant fires on the structural integrity of the airplane.

Included in these major divisions of the fire studies were investigations into the external flame paths after nacelle burn-through, resistance of the structure and engine mounts to continued fire exposure, and a study of the likelihood of ignition of the various flammable fluids used in the powerplant.

While the tests were conducted on the KC-135 powerplant installation, the information and design criteria obtained from these tests may apply in general to similar design configurations.

This project was made possible and was supported jointly by the Boeing Airplane Company, Wright Air Development Center, Department of the Air Force, and the CAA Technical Development Center

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*Manuscript submitted for publication June 1958

DESCRIPTION OF TEST EQUIPMENT

Test Article.

The test article consisted of the No 2 engine, pod, strut, and 12 feet of the wing section of the KC-135 airplane, mounted on a supporting structure in a test cell The wing section was mounted at a 7° angle of dihedral and an 8° angle of attack, with the centerline of the engine intersecting the centerline of the wind tunnel at the opening of the nose cowl air intake The 8° angle of attack was considered to be the worst condition for external flame travel from nacelle to strut to wing The engine was a Pratt and Whitney J57-P-1 modified slightly so that it could be adapted to the nacelle The test installation differed slightly from the standard No 2 engine installation in that a fuel-air starter was installed and supplied with an external source of compressed air in place of the pneumatic starter The compressed-air storage bottle used in the airplane in conjunction with the fuel-air starter was not installed, nor was the bleed air duct which is a part of the pneumatic starter installation

The entire series of tests was run without the use of nose cowl anti-icing air which, when operating, is exhausted into the compressor section A Walter Kidde continuous detector system and the KC-135 Fenwal unit detector system had been installed in the test article prior to receipt at TDC and were operative during the fire-resistance tests

Facility

Airflow over the outside surfaces of the test article was supplied by an electrically driven, four-bladed fan which forced air through an eight-foot-diameter tunnel directed at the test article This fan was capable of providing an air velocity of up to 165 mph

Compressed air for the fuel-air starter was supplied by eight 1 1/2-cubic-foot nitrogen cylinders pressurized with air to 2,000 psi and connected to the starter air inlet This provided enough air for an average of five starts before recharging the cylinders

Control of the powerplant, the wind tunnel, and the fires was maintained from operating stations inside a control room adjacent to the test cell The engine and wind tunnel were operated from the engine operator's panel located at one of the two observation windows in the control room The flow and ignition of fluids, operation of recording instruments, and the discharge of fire-extinguishing agents were controlled from the fire-control console located at a second observation window These windows consist of 4 layers of high-tempered glass totaling 2 1/4 inches in thickness They permitted observation of the test article and the taking of color motion pictures of the tests Communication between members of the test crew was achieved with an aircraft intercommunications system

An Esterline-Angus operation recorder was used to record the sequence of the various phases of the tests, and temperatures were recorded on Brown temperature recorders The agent concentrations during the ventilation tests were obtained with a Statham agent concentration recorder developed by TDC [1]

As many as three different cameras were focused simultaneously on the test article during the conduct of tests to obtain complete photographic coverage from all vantage points The analysis of the color film provided evidence from which many conclusions were reached

VENTILATION STUDIES

Purpose

The purpose of the ventilation studies was to determine the rate of dissipation of combustible vapors in the nacelle and the leakage of vapors from one nacelle compartment to another

Procedure

The method of test consisted of releasing CO_2 within both the compressor compartment and the burner compartment of the nacelle at various engine power settings and measuring the rate of dissipation resulting from nacelle ventilation The concentrations were

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[1] James D New and Charles M Middlesworth, "Aircraft Fire Extinguishment, Part III, An Instrument for Evaluating Extinguishing Systems," CAA Technical Development Report No. 206, June 1953

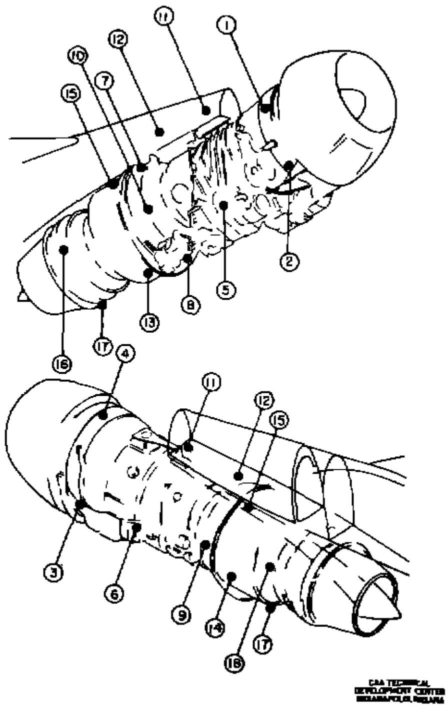

Fig 1 Locations of Sampling Probes for Ventilation Tests

obtained using a Statham agent concentration recorder with 18 gas sampling probes mounted at various locations in the test article, 10 in the compressor compartment, 6 in the burner compartment, 1 above the vapor barrier in the strut, and 1 below the vapor barrier and above the horizontal firewall in the strut The locations and numbers of these sampling points are shown in Fig 1 After the nacelle volume was saturated with CO_2, the CO_2 supply line was shut off, and continuous samples of the air-CO_2 mixture were extracted at each of the 18 sampling points by the concentration recorder The concentrations were shown as traces on a recording oscillograph This sampling continued until the CO_2 disappeared Gas samples were taken simultaneously from all 18 locations during each test

The tests were divided into three phases (1) the CO_2 released into both the compressor and burner compartments simultaneously, (2) the CO_2 released into the compressor compartment only, and (3) the CO_2 released into the burner compartment only Readings were obtained under each of the above conditions at five engine power settings and air velocities as follows

1 Static, no engine power, and no air velocity
2 Fifty-eight per cent maximum engine rpm, 25-mph air velocity
3 Ninety per cent normal rated thrust (NRT), 165-mph air velocity
4. One hundred per cent NRT, 165-mph air velocity
5 Engine windmilling, 165-mph air velocity

Various airflows were obtained by means of the wind tunnel which directed the airflow over the test article Duplicate runs were made of each test

Results

The dissipation of the CO_2 under various conditions of test are summarized in the following outline These are general trends indicated from a study of extensive data

1 CO_2 released into both the compressor and burner compartments

a Static conditions, no engine power, no air velocity
Dissipation of the CO_2 in the compressor compartment was very gradual and exceeded 374 seconds In the burner compartment, the dissipation was more rapid and was completed in 40 to 50 seconds, due probably to the annular opening around the engine exhaust nozzle

b Fifty-eight per cent maximum engine rpm, 25-mph air velocity
The dissipation of the gas was gradual in both compartments and required up to 120 seconds

c One hundred per cent NRT, 165-mph air velocity
Dissipation in the compressor compartment was more rapid and was completed within 30 seconds In the burner compartment, the CO_2 was dissipated in 20 to 30 seconds

d Ninety per cent NRT, 165-mph air velocity
Dissipation in the compressor compartment was completed in 30 to 40 seconds, and in the burner compartment in 20 seconds

e Windmilling, no engine power, 165-mph air velocity
In the compressor compartment, the dissipation was complete in 20 to 30 seconds In the burner compartment, 40 to 45 seconds were required for gas dissipation

2 CO_2 released into the compressor compartment only

a Static conditions, no engine power, and no air velocity
The dissipation rate was 2 to 4 minutes in the compressor section with little variation between the upper and lower areas of the engine In the burner section the upper locations dissipated in 25 to 30 seconds, with the low areas requiring 40 to 60 seconds The leakage of CO_2 into the burner section resulted in local concentrations of 80 per cent in that section

b Fifty-eight per cent maximum engine rpm and 25-mph air velocity
The dissipation rate was 5 to 6 minutes in the compressor section with little variation from the high to the low areas of the engine In the burner section, the dissipation rate was 3 to 3 1/2 minutes with no variation between sampling locations The leakage of CO_2 into the burner section resulted in a local concentration of 80 per cent in that section

c One hundred per cent NRT and 165-mph air velocity
The dissipation rate was 40 to 50 seconds for both compartments A local concentration of 50 per cent in the burner compartment resulted from CO_2 leaking from the compressor compartment

d Ninety per cent NRT and 165-mph air velocity
The dissipation rate was 50 to 60 seconds for both compartments with little variation between sampling locations The leakage of CO_2 into the burner compartment resulted in a local concentration of 50 per cent in that compartment

e Windmilling, no engine power, and 165-mph air velocity
In the compressor compartment, the dissipation rate was 50 to 60 seconds with little variation with respect to location inside the nacelle In the burner compartment, the dissipation rate was from 5 to 20 seconds The concentration due to leakage of CO_2 from the compressor compartment decreased rapidly toward the aft areas of the burner compartment

3 CO_2 released into the burner compartment only

a Static conditions, no engine power, and no air velocity
A concentration of 20 per cent occurred just forward of the fire seal in the compressor compartment due to leakage of CO_2 from the burner compartment This lagged the introduction of CO_2 in the burner compartment by 30 seconds and required 4 minutes to dissipate In the burner compartment, the dissipation was similar for all locations regardless of position inside the nacelle and required 6 minutes

b Fifty-eight per cent maximum engine rpm and 25-mph air velocity
There was no leakage of CO_2 into the compressor compartment In the upper areas of the burner compartment, the CO_2 dissipated within 30 to 60 seconds, and at the lower locations, the CO_2 dissipated in 90 to 100 seconds

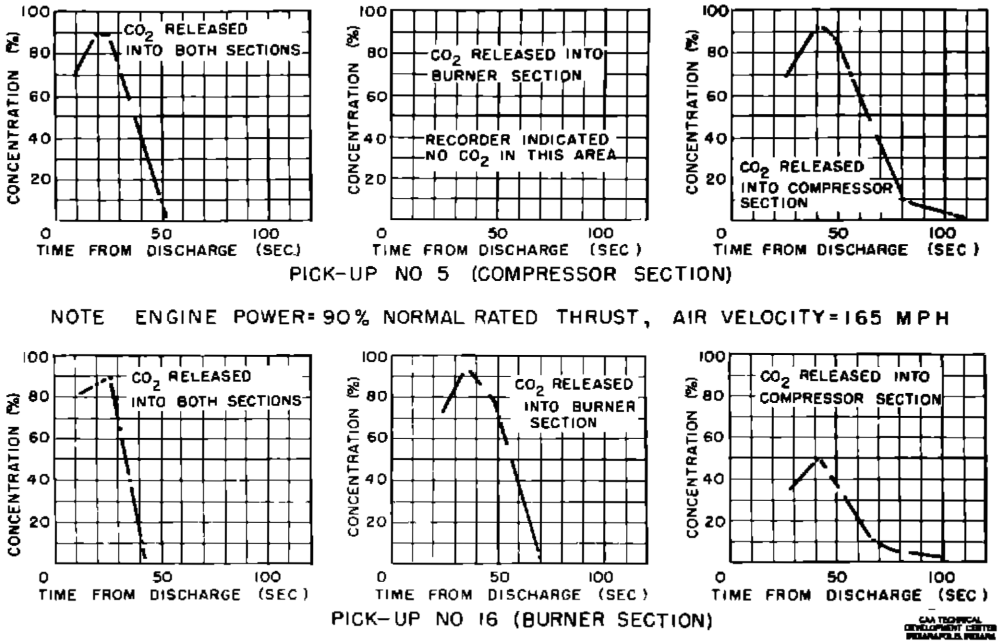

Fig 2 Typical Curves Showing the Rate of CO_2 Dissipation Within the Nacelle From Normal Ventilation

c One hundred per cent NRT and 165-mph air velocity
There was no leakage of CO_2 into the compressor compartment In the burner compartment, the dissipation of CO_2 required from 20 to 40 seconds and was similar for all sampling locations

d Ninety per cent NRT and 165-mph air velocity
There was no leakage of CO_2 into the compressor compartment The dissipation of CO_2 in the burner compartment required 30 to 60 seconds and was similar for all pickup locations.

e Windmilling, no engine power, and 165-mph air velocity
There was no leakage of CO_2 into the compressor compartment In the burner compartment, CO_2 dissipation required 35 to 45 seconds and was similar for all sampling locations

Figure 2 shows the dissipation curves for a representative pickup in each compartment These are typical of the time-versus-concentration curves for the majority of the sampling locations

FLAMMABLE FLUID IGNITION TESTS

Purpose

The purpose of these studies was to determine the probability of hot-surface ignition of engine oil, hydraulic fluid, and JP-4 fuel when these fluids are released in the engine compartments simulating failure of some component of the fluid-carrying systems

Oil Ignition Tests

Procedure

Varying degrees of failure of the outlet of the main oil tank were simulated, and the total quantity of oil contained in the tank was released in a solid stream into the compressor compartment In all instances in simulating compressor section oil leaks, the quantity of oil was 6 8 gallons of MIL-L-7808, preheated to engine operating temperature, 250° F , but released over various lengths of time to represent varying degrees of line failure An external oil supply separate from the engine oil system was used A control valve, flowmeter, and pressure gage in the control room provided control of the oil flow

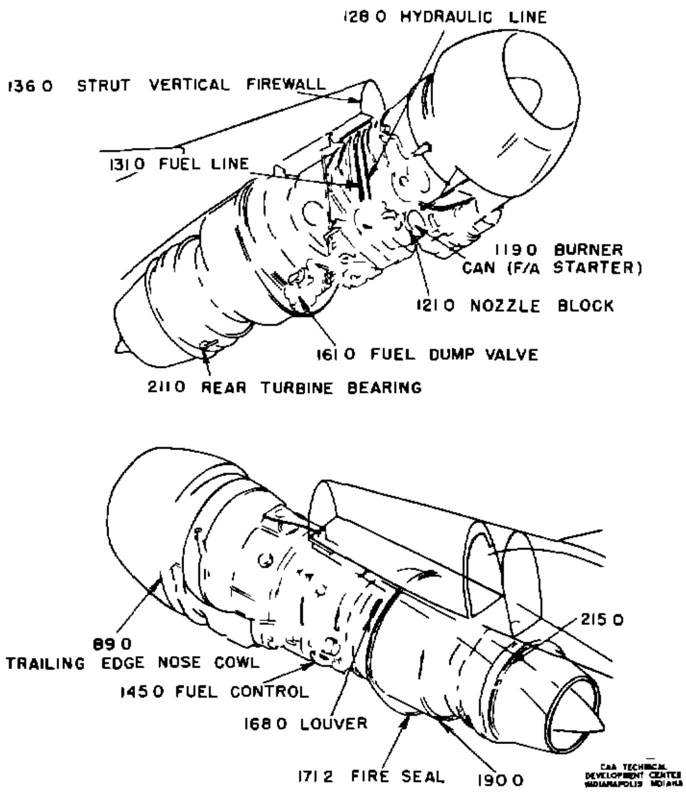

Fig 3 Nacelle Stations

The test procedure was the same for all tests The engine was started and allowed to warm up for 5 minutes at 58 per cent maximum rpm and then the engine power was increased to 90 per cent NRT After the engine had stabilized at this thrust rating and operated for 5 minutes, the oil was released at the desired rate and allowed to continue flowing until the total quantity of 6 8 gallons of oil was released The engine power continued at this setting for an additional two minutes before being reduced to idle power and shut off

In additional tests simulating failure of the engine oil pressure line to the rear turbine bearing, the engine was operated for 3 minutes at 90 per cent NRT and then windmilled at 8 per cent maximum rpm for 3 minutes Oil was released continuously from a separate supply line during both conditions of engine operation, and pressure in this line was varied to represent oil pressures in the bearing supply line for each engine power setting Oil-line breaks were simulated at nacelle stations 179 and 211 These station locations and others referred to in the report are shown in Fig 3 During these tests the wind tunnel was providing an airstream of 165 mph over the test article

The locations of oil release are indicated on Fig 4 and are described as follows

Location A This leak was at the lower portion of the oil tank to simulate partial or complete rupture of the oil supply line

Location B This location represented a leak of the low pressure return oil and of scavenge oil in the gear box A flow rate of five pounds of oil per minute was considered representative of the type of leak which could occur at this point

Location C This leak was at the bottom of the housing for the angular accessory drive Oil is scavenged through this housing to the gear box

Location D This represented total failure of the oil return line at the top rear corner of the oil tank. An amount of oil equal to the total capacity of the oil tank, 6 8 gallons, was released in 30 seconds in a solid stream allowing the oil to cover the compressor bleed air collector and diffuser case completely The measured surface temperature of the diffuser case prior to oil discharge was 500° F During oil discharge this temperature was 450° F

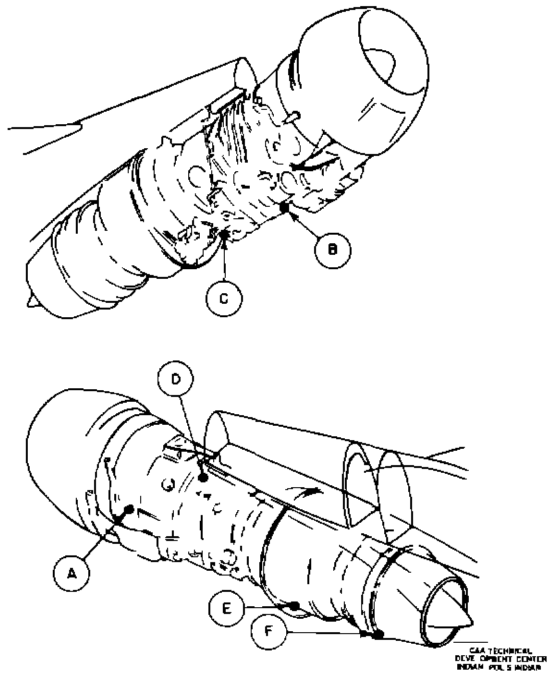

Fig 4 Location of Engine Oil Release Points

Location E This leak was in the rear turbine bearing oil pressure line and represented a break of the line which would permit some oil to leak and the remainder to continue flowing through the line The line was cut halfway through with a hacksaw blade on the engine side to cause oil to be sprayed on the combustion chamber outer front case at nacelle station 179 in a flat, fan-shaped pattern The pressure was varied in accordance with the engine power setting as shown in Table I

Location F This leak was in the rear turbine bearing oil pressure line at nacelle station 211 The other details are identical with E above

The rates and quantities of oil discharged are shown in Table I Ambient air temperatures at the points of fluid discharge were obtained by the use of chromel-alumel thermocouples at those locations and also are included in Table I

Results

Table I gives a summary of test results Considerable smoke and oil vapors were observed, but at no time during the entire survey was there any ignition of MIL-L-7808 engine oil from any of the hot surfaces of the engine

Hydraulic Fluid Ignition Tests

Procedure

To determine whether hot-surface ignition of hydraulic fluid would occur, MIL-O-5606 hydraulic fluid under 3,000-psi pressure was sprayed on the engine surfaces in the proximity of the hydraulic pump and lines The locations of the point of discharge are shown in Fig 5 The hydraulic fluid was released in a thin stream to simulate a loose or cracked fitting and was distributed over a considerable area in the compressor compartment due to the high velocity of release An external supply of fluid and a separate pump were used to supply the fluid under pressure to the proper location in the nacelle Thermocouples were mounted at the test area to record ambient air temperatures and to give an indication of fire, should one occur

During the hot-surface ignition tests, the engine was operated at 90 per cent NRT and after the engine surfaces had reached their saturation temperature, hydraulic fluid was released onto the test area The wind tunnel provided an airstream of 165 mph over the test article during tests The quantities and durations of fluid discharge are shown in Table II

TABLE I

CONDITIONS AND RESULTS OF OIL IGNITION TESTS

Engine Power 90 Per Cent NRT (except as noted) Simulated Airspeed 165 mph

Location of Oil Release	Rate of Oil Release	Duration of Oil Release	Quantity of Oil Released	Oil Pressure (psi)	Ambient Air Temperature (°F)	Results
A - Lower forward portion of engine oil tank	15 10 gpm	27 0 sec	6 8 gal		110	No ignition
	12 25 gpm	33 5 sec	6 8 gal		110	No ignition
	6 66 gpm	61 0 sec	6 8 gal		110	No ignition
	3 87 gpm	105 0 sec	6 8 gal		110	No ignition
	1 76 gpm	229 5 sec	6 8 gal		110	No ignition
B - Gear box	5 0 ppm*	10 0 min	50 0 lb		130	No ignition
C - Angular accessory drive housing	5 0 ppm	10 0 min	50 0 lb		130	No ignition
D - Top rear corner of engine oil tank	13 60 gpm	30 0 sec	6 8 gal		275	No ignition
E - Rear turbine bearing oil pressure line, Nacelle sta No 179	1 16 gpm	3 0 mir	3 48 gal	45	350	No ignition
	0 62 gpm**	3 0 min	1 86 gal.	10	350	No ignition
F - Rear turbine bearing oil pressure line Nacelle sta No. 211	1 16 gpm	3 0 min	3 48 gal	45	300	No ignition.
	0 62 gpm**	3 0 min	1 86 gal	10	300	No ignition

* Pounds per minute

** Engine windmilling at 8 per cent maximum rpm with simulated airspeed of 165 mph

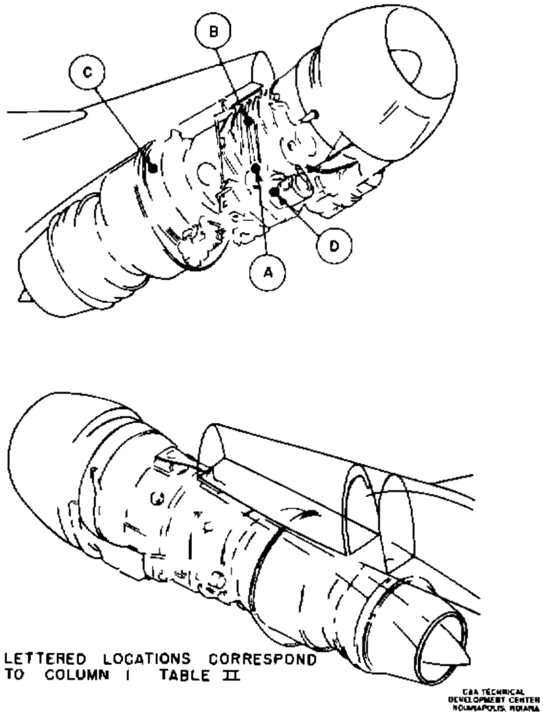

Fig 5 Location of Hydraulic Fluid Release Points

The only deviation from the above procedure was for hot-surface ignition tests involving the fuel-air starter In these tests, hydraulic fluid was released on the starter just prior to a normal starting attempt The starter on the test article was manufactured by the Hamilton Standard Division of United Aircraft Corp , Model No FAS 450-3, Assembly No 506270, Serial No 4632

Results

Table II gives a summary of the results for each test At no time under conditions of testing was there any hot-surface ignition from the engine surfaces During discharge of hydraulic fluid on the diffuser section, dense clouds of smoke were created indicating an approach to ignition temperature During a normal start cycle, ignition of the hydraulic fluid did occur from hot surfaces of the blast tube and nozzle block of the fuel-air starter

JP-4 Ignition Tests

Procedure

JP-4 fuel was sprayed on various hot surfaces of the engine to determine whether ignition would occur under normal flight conditions The locations of fuel release are shown in Fig 6 and are described below

Location A A leak of the fuel dump valve was simulated and JP-4 fuel was sprayed on the diffuser section at the 6 o'clock position The engine was operated at 90 per cent NRT for 5 minutes prior to fuel release, with the wind tunnel forcing air past the nacelle at a velocity of 165 mph

Location B A leak of the fuel line to the fuel-air starter during a normal start cycle was simulated To give the worst conditions under normal operations, the first start cycle was initiated up to engine light-off rpm and then purposely aborted After a 30-second interval, the second start cycle was initiated with JP-4 fuel being sprayed on the starter assembly. The starter continued through its normal cycle ending with engine light-off In this manner, the metal surfaces of the starter reached a maximum temperature for routine operation

TABLE II

CONDITIONS AND RESULTS OF HYDRAULIC FLUID IGNITION TESTS

Engine Power 90 Per Cent NRT
Hydraulic Fluid Pressure 3,000 psi

Simulated Airspeed 165 mph

Location of Fuel Release*	Rate of Fuel Release (gpm)	Duration of Fuel Release (min -sec)	Quantity of Fuel Released (gal)	Temperature Ambient (°F.)	Temperature Surface (°F)	Results
Location A Nacelle station 128, 5 o'clock	0 3	5-0	1 5	175	175	No ignition
Location B Nacelle station 128, 2 o'clock	1 9	2-0	3 8	150	200	No ignition
Location C Nacelle station 157, 2 o'clock	1 9	1-43	3 3	285	500	Ignition did not occur Heavy dense vapor filled nacelle, indicating approach to ignition temperature
Location D Nacelle station 119, blast tube and nozzle block of combustion starter	Sprayed prior to normal engine starting cycle			100	1400	Ignition occurred during normal starting cycle

* See Fig 5

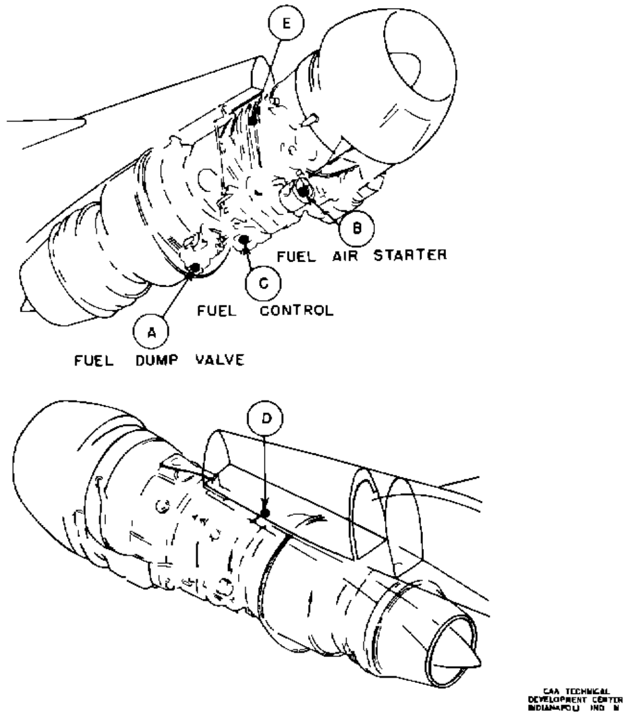

Fig 6 Location of JP-4 Fuel Release Points

Location C A leak of the seals around the control shaft of the fuel control was simulated The fuel nozzle was placed at the 6 o'clock position under the fuel control and fuel released in a low-pressure spray pattern During the release of fuel, the engine was operating at 90 per cent NRT with an air velocity of 165 mph over the nacelle Thermocouples were mounted in test areas and connected to Brown temperature recorders to record ambient air temperatures and any indications of fire

Results

No ignition of JP-4 fuel occurred during tests on the fuel dump valve or fuel control even though fuel was released for an extended period of time and allowed to accumulate in the bottom of the nacelle

During the period when fuel was being released on the fuel-air starter during a normal start cycle, ignition occurred an average of 10 seconds after initiating the start cycle The nozzle block on the starter turbine housing was the hottest part of the starter assembly, glowing bright red with a measured surface temperature of 1,400° F 12 seconds after initiation of the start cycle Figure 7 shows the time-temperature history of four thermocouples which measured the surface temperature of the nozzle block during a normal start cycle Viewing the starter from the combustion chamber end, and with the chamber in an upright position, the four thermocouples were positioned on the inner diameter of the starter nozzle block in the lower right-hand quadrant This was determined to be the hottest area by visual observation and by a number of temperature measurements on various parts of the starter assembly Table III shows test conditions and results for this phase of testing

FLAMMABLE FLUID FIRE TESTS

Purpose

The purpose of the flammable fluid fire studies was to determine the intensity of fires resulting from ignition of MIL-L-7808 engine oil MIL-O-5606 hydraulic fluid, and JP-4 fuel, the external flame path characteristics, and damage suffered by the powerplant installation after exposure to these fires

TABLE III

CONDITIONS AND RESULTS OF JP-4 IGNITION TESTS

Location of Fuel Release*	Rate of Fuel Release (gpm)	Duration of Fuel Release (min -sec)	Quantity of Fuel Released (gal)	Test Conditions	Temperature Ambient (°F.)	Temperature Surface (°F.)	Results
Location A Fuel dump valve, nacelle station 161, 6 o'clock	0 3	3-0	0 9	A**	220		No fire Some discharge of fuel vapors through cowl vents and drain holes
Location B Fuel-air starter, nacelle station 121, 6 o'clock	0 75	0-15	0 19	Starting cycle		1400	Starter nozzle block glowed red during start cycle Fuel ignited 10 seconds after initiation of start cycle
Location C Fuel control shaft seals, nacelle station 145, 6 o'clock	0 3	6-4	1 82	A	225		No fire Fuel drained through drain holes in nacelle doors

* See Fig 6.
** A - 90 per cent NRT, simulated airspeed of 165 mph

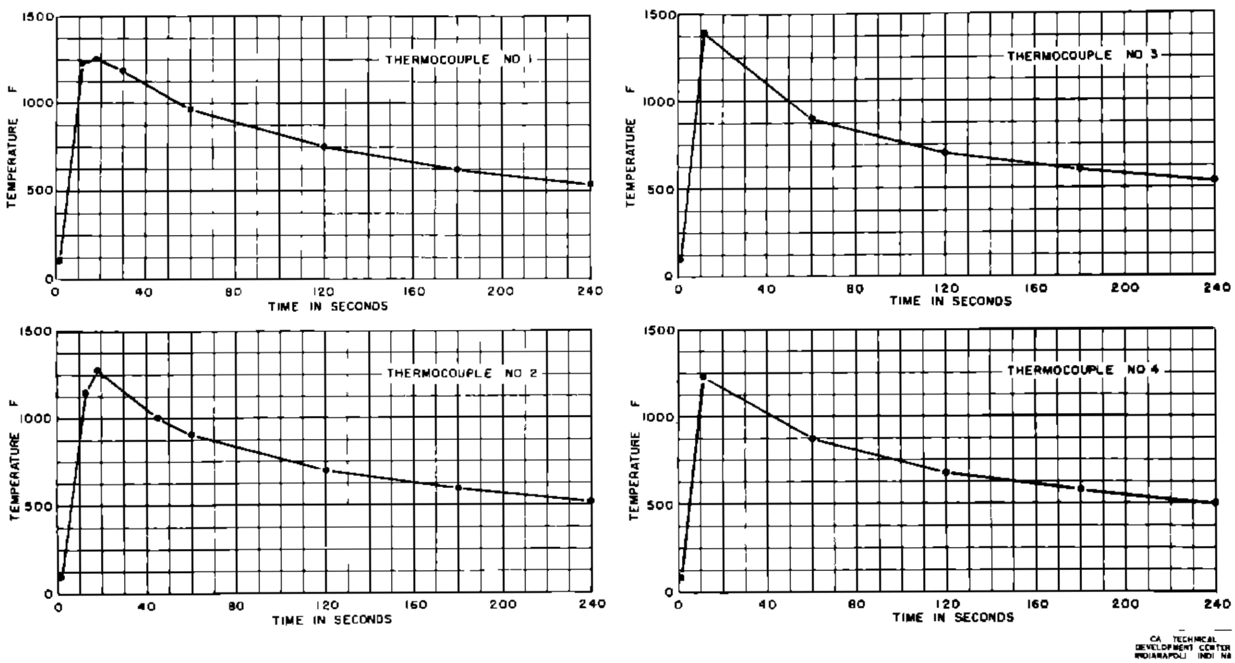

Fig 7 Time-Temperature History for the Hamilton-Standard FAS 450-3 Fuel-Air Starter

Oil Fire Tests

Procedure

An external supply of MIL-L-7808 engine oil was preheated to 250° F and piped into the engine nacelle to locations where various oil-system failures were to be simulated After a study of the results of oil ignition tests, three locations were decided upon as being the most likely source areas which could result in severe damage should a fire be ignited These were

1 The area around and under the oil supply tank in the compressor section At this location, the oil could puddle in nacelle doors for the entire length of the compressor section and flames could totally envelop this area See Location A, Fig 4 The oil was released in a solid stream for these tests

2 The oil pressure line to the rear turbine bearing just aft of the firewall bulkhead fitting at nacelle station 179 See Location E, Fig 4 The oil was released in a fan-shaped pattern and directed against the combustion chamber outer front case

3 The oil pressure line to the rear turbine bearing at nacelle station 211 The oil was released in a fan-shaped pattern and directed against the turbine exhaust case See Location F, Fig 4

The oil was released at these various locations at the rates and pressures indicated in Table IV For all tests the engine was started and allowed to warm up for 5 minutes at 58 per cent maximum rpm After warm up, the power was increased to 90 per cent NRT and operated for 5 minutes After the required engine power conditions had been set up, the wind tunnel was started and heated oil was released at the test location To accomplish ignition of the oil, a 20-second primer fire of JP-4 fuel, released at a rate of 0 75 gallons per minute (gpm), was spark-ignited intermittently before and during oil release until either the oil ignited or it was determined that ignition of the oil could not be accomplished Indications of fire were provided by several chromel-alumel thermocouples mounted in the test area and connected to Brown temperature recorders

TABLE IV

CONDITIONS AND RESULTS OF OIL FIRE TESTS

Run No	Ignitor and Preheated MIL-L-7808 Discharge Location*	Test Condition	Oil Flow to Fire: Rate (gpm)	Duration (min -sec)	Quantity (gal)	Line Pressure (psi)	Results and Observations
1	Lower, forward corner of engine oil supply tank See Location A, Fig 4	A	15 1	0-27	6 8	45	No oil sustained fire Damage confined to sooting of cowling and engine case from primer fires
2	Same as run no 1	A	12 25	0-33	6 8	45	Same as run no 1 Also, pressure ratio transducer became inoperative
3	Same as run no 1	A	3 87	1-45	6 8	45	Same as run no 1
4	Same as run no 1	A	1 76	3-50	6 8	45	Several attempts to ignite failed to give an oil sustained fire
5	Nacelle station 179 Rear turbine bearing oil pressure line See Location E, Fig 4	A B C		1-0 0-30 4-25	7 4 Total	45 20 10	Required several attempts with primer fire to ignite Low-intensity fire, lazy flame Minor distortion of nacelle door latch line
6	Nacelle station 211 Rear turbine bearing oil pressure line See Location F, Fig 4	A B C		2-0 1-0 5-0	7 35 Total	45 20 10	Primer fire energized five times before oil ignited Low-intensity fire, lazy flame Discharged oil flowed to low point of nacelle at firewall carrying the flame with it

* - MIL-L-7808 oil preheated to 250° F used in this study
A - 90 per cent NRT and simulated airspeed of 165 mph
B - 58 per cent maximum N_2 rotor rpm, simulated airspeed of 165 mph
C - Windmill or engine power lever "off", simulated airspeed of 165 mph

In tests involving simulated failure of the pressurized oil line to the rear turbine bearing, the engine was operated at 90 per cent NRT, then reduced to idle for a short period of time Then the power was cut off completely, allowing the engine to windmill in the airstream During each of these three phases of operation, the oil pressure in the test line was adjusted to correspond to the simulated flight condition The primer fire was operated intermittently until the heated engine oil ignited The engine then was shut down by following the above procedure, remaining at the various power settings for the times shown in Table IV

Results

During tests in the compressor section simulating failure of the oil supply line from the oil tank, MIL-L-7808 oil could not be ignited Attempts were made to ignite the oil at various flow rates but all attempts were unsuccessful The only fires were primer fires and were of 20 seconds duration The released oil accumulated in the bottom of the nacelle and slowly drained out through the drain holes provided in the doors

During the discharge of oil simulating failure of the oil pressure line to the rear turbine bearing at both locations in the burner section, ignition of MIL-L-7808 oil occurred after several attempts with the JP-4 primer fire. When oil was released at Location E, Fig 4, nacelle station 179, it puddled and burned in the bottom of the nacelle just aft of the firewall causing minor distortion of the nacelle latch line Several short bursts of flame escaped from the nacelle and were carried away in the external airstream The fire at nacelle station 211 burned in the annular opening around the tailpipe for 55 seconds and then was carried forward by the oil as it drained to the lower part of the nacelle just aft of the firewall It continued to burn in this location for the duration of the test

The only damage which resulted from these fires was some minor distortion of the door latch line just aft of the firewall

Hydraulic Fluid Fire Tests

Procedure

MIL-O-5606 hydraulic fluid was supplied at 3,000-psi pressure to the test location from an external reservoir and separate pump The test location selected was at the fitting of the high-pressure hydraulic line on the plumbing shelf at the 2 o'clock position and at nacelle station 128 See Location B, Fig 5 The end of the test line was restricted, allowing only a small stream of hydraulic fluid to escape to simulate a loose fitting or a cracked line Due to the high release pressure, the small stream of fluid sprayed over most of the right side of the compressor section

During the test, the engine was operated at 90 per cent NRT with the wind tunnel set at 165 mph The primer fire, burning 0 3 gpm of JP-4 fuel, was started and the hydraulic fluid under pressure was released at the test location Ignition of hydraulic fluid was almost instantaneous, and the fuel to the primer fire was shut off after eight seconds Two identical tests were made under the conditions shown in Table V Indications of fire were provided by thermocouples mounted in the test area and connected to Brown temperature recorders, and by observation through a window installed in the right nacelle door ground-extinguisher access panel

Results

The fire which resulted from ignition of the hydraulic fluid was a lazy flame which produced dense clouds of vapor and smoke The vapor and smoke escaped from both louvers and the door latch line with considerable fluid drainage from the bottom of the nacelle As the fire intensity increased, the engine exhaust gas pressure (P_{t7}) decreased and exhaust gas temperature (EGT) increased Portions of the seals around the surge bleed valves were destroyed, and considerable distortion of the nacelle skin occurred in the vicinity of the fire

Ignition of hydraulic fluid was accomplished easily and its lazy flame characteristics were due to the low ventilation rate which existed in the nacelle with no anti-icing air

JP-4 Fire Tests

Procedure

Three locations were chosen for JP-4 fuel fire tests on the basis of the proximity of fuel sources to ignition sources and on operational reports of leaks occurring during flight operations of this jet engine The procedure generally followed was to release JP-4 fuel in the area to be investigated in quantities commensurate with the possible leakage source and ignite the fuel by means of a spark ignitor The fuel for test fires was plumbed in from an external source to the area under investigation The locations used are described below and shown in Fig 6 Table VI gives the test conditions for all tests

TABLE V

CONDITIONS AND RESULTS
OF MIL-O-5606 HYDRAULIC FLUID FIRE TESTS

Engine Power 90 Per Cent NRT

Simulated Airspeed 165 mph

Location of Fluid Release	Rate of Fluid Release (gpm at 3000 psi)	Duration of Fluid Release (min -sec)	Quantity of Fluid Released (gal)	Air Temperature During Fire (°F. Max)	Results
Nacelle station 115, 2 o'clock position	1 8	1-50	3 3	1140° F. at station 128, - 2 o'clock position	Total fire time 2 minutes, 40 seconds, considerable drainage overboard Some skin warping between stations 133 and 162
Same as above	1 8	1-50	3 3	Same as above	Same as above

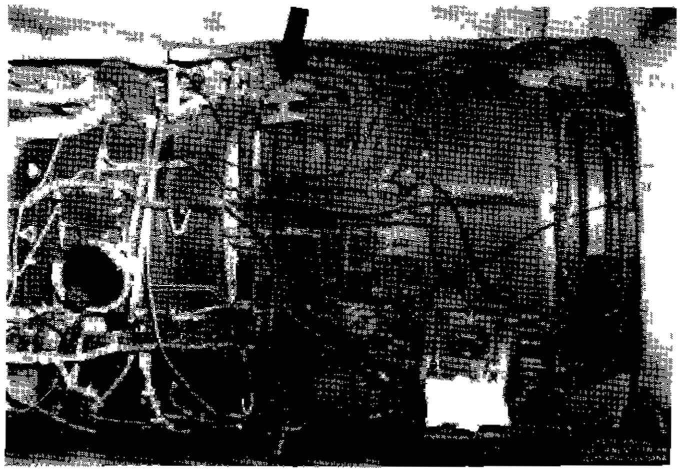

Fig 8 Location and Direction of JP-4 Fuel Release for Uncontrolled Fire

Location C A leak of the seals around the control shaft of the fuel control was simulated The fuel nozzle was placed at the 6 o'clock position under the fuel control, and fuel was released in a spray pattern The fuel was released for one minute prior to ignition, simulating existence of a leak for a short time and allowing fuel to puddle before ignition

Location D Fuel was sprayed on the diffuser section at the 12 o'clock position and ignited to determine the effects of a fire in this area on the engine and nacelle. The engine was operated at 90 per cent NRT for 5 minutes prior to ignition of fuel The power settings during the fire are itemized in Table VI

Location E A leak of the main fuel line at the plumbing shelf on the right side of the engine was simulated This test was to represent an uncontrolled fire resulting from the burning of a large quantity of fuel in the nacelle, and was designed to determine the fire-resistance of the nacelle skin, external flame paths, the effect on engine operation of a prolonged uncontrolled fire, and whether the strut dimensions were adequate to prevent flame impingement on the wing

An open line from an external source of JP-4 fuel was routed to the location on the plumbing shelf, indicated by the arrow in Fig 8, so that fuel was directed against the shelf This caused the fuel to splash in all directions, resulting in considerable dispersion A spark ignitor and primer fire were located at that point to provide ignition of the primary fuel The engine power was stabilized at 90 per cent NRT and held at this power setting during the discharge of fuel and ensuing fire The velocity of the airstream around the outside of the nacelle was 165 mph When the discharge of fuel was stopped, the engine power was reduced to idle and then cut off to allow the engine to windmill in the airstream while the fire continued to burn No attempt was made to extinguish the fire until the engine was ready to be shut down Table VI shows the conditions during the test

Results

In the test simulating a leak of the seals around the fuel control shaft, there was no explosion when the fuel was ignited even though fuel had been allowed to puddle before being ignited The flame was not intense after ignition and the released fuel was completely burned Some flames appeared through drain holes in the bottom of the nacelle doors, and additional flames were carried into the burner section by the seepage of fuel past the firewall No damage was done to the structure of the nacelle

Within 2 minutes after the fire was ignited at Location D, a hole approximately 5 inches in diameter appeared in the left-hand door just below the hinge line and at nacelle station 151 The cowl formers in this area were partially destroyed, and the cowl seal for the left-hand engine bleed overboard vent was destroyed

TABLE VI

CONDITIONS AND RESULTS OF JP-4 FIRE TESTS

Run No	Ignitor and JP-4 Fuel Discharge Location	Engine Power Setting	Engine Power Time (min -sec)	Fuel Flow to Fire Rate (gpm)	Fuel Flow to Fire Time (min.-sec)	Fuel Flow to Fire Total (gal)	Results and Observations
1	6 o'clock position, under fuel control, nacelle station 145, Location C, Fig 6	A B C	0-22 1-0 3-24	0 3	1-40	0 5	Small low-intensity fire caused very minor cowling damage, very small flames at nacelle door latch line
2	12 o'clock position, nacelle station 159, Location D, Fig 6	A B C	2-0 1-0 2-2	2 2	3-15	7 15	Low-intensity fire burned a 4- to 5-inch diameter hole in left cowl near hinge line and 20 inches forward of firewall Left air bleed duct seal destroyed
3	2 o'clock position, nacelle station 129, Location E, Fig 6	A B C	6-32 0-30 2-32	5 0 0 3	5-59 0-22	29 80 0 12	Intense fire destroyed 50 per cent of right nacelle door Several engine accessories made inoperative Some pylon skin burned through No flame damage other than discoloration observed in pylon No flames impinged on wing surfaces Total fire time 9 minutes - 1 second

A - 90 per cent NRT and simulated airspeed of 165 mph
B - 58 per cent maximum N_2 rotor rpm and simulated airspeed of 165 mph
C - Windmill or engine power lever "off" and simulated airspeed of 165 mph

Fig 9 Engine Nacelle Showing Location of Inboard Vent

As a result of the simulated uncontrolled fire at Location E (see Fig 6), approximately 50 per cent of the right-hand door was destroyed Photographs of the nacelle taken before and after the fire are shown as Figs 9 and 10 The area of destruction was located between nacelle stations 136 and 225 This fire, when first ignited, filled the entire compressor section with considerable flames shooting from the right-hand louver at nacelle station 16 8 The hinge line distorted at stations 155 and 163, allowing small jets of flame to escape and burn a hole of about two square inches' area in the strut skin at each of those stations The nacelle contained the flames for two minutes after which time the right louver burned away Disintegration began with the sharp edge of the louver and progressed rapidly into the nacelle skin just aft of the firewall When the burner section was opened up to the airstream, the fire increased in intensity rapidly and a large portion of the door burned away The fire balled up behind the exposed firewall and shot up to the strut and toward the under surface of the wing None of the flames could penetrate the layer of air around the airfoil section and were carried away by the airflow The flames burned through the strut skin in several areas, as shown in Fig 10 but flames did not enter the strut structure

The flames struck the strut only during the early stages of the fire As the hole next to the hinge line enlarged, flames ceased striking the strut and reached upward toward the wing Considerable fuel was draining from the engine pod during the fire, being ignited and carried away in the airstream in trailing streamers

Most of the fire was concentrated on the right-hand side of the nacelle where the fuel-line break was simulated, consequently, there was minor damage done to the outboard,

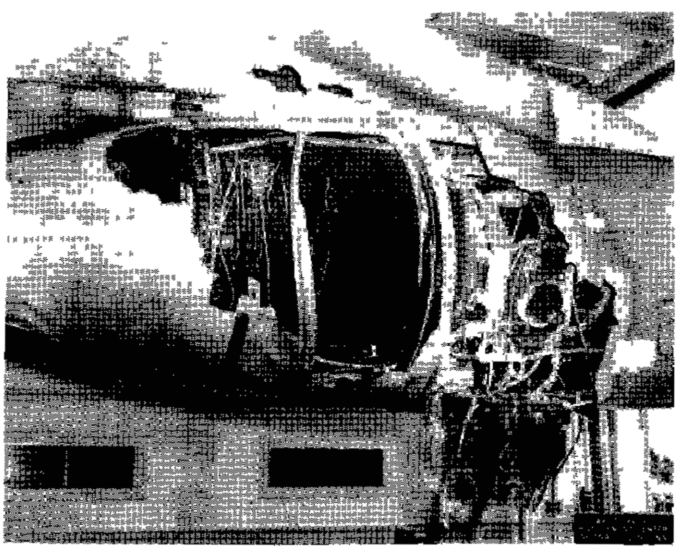

Fig 10 Damage to Right-Hand Door and Strut as a Result of Simulated Uncontrolled Fire

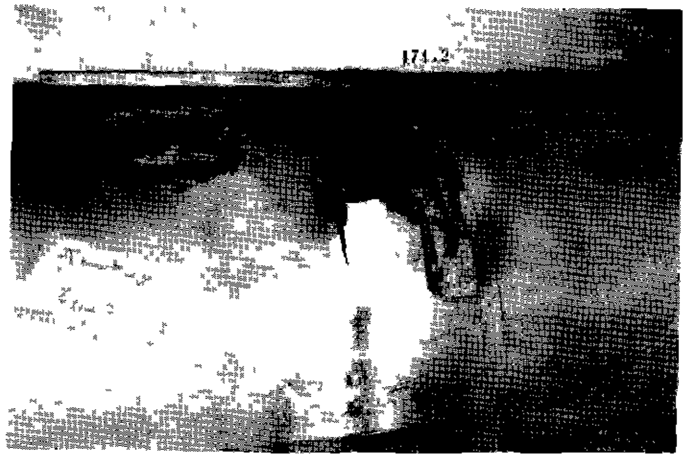

Fig 11 Damage to Left-Hand Nacelle Door as a Result of Louver Burn-Through

or left, door One hole about 12 inches in diameter burned through at the location of the outboard louver Figure 11 shows the hole in the skin resulting from the louver burnout On this side, as on the right side, the louver created a chimney effect which caused flames to torch out of the louver, resulting in early failure of the louver and metal surrounding it

In this fire, flames were very intense and destructive after the initial burn-through of the nacelle as they were then fed by large quantities of both fuel and air Control of the engine was maintained during the entire test even though the P_{t7} decreased during the height of the fire intensity This was due to the temperature-compensating action of the fuel control

The following powerplant components were destroyed or made inoperative as a result of the fire· the entire engine ignitor system, tachometer generator, oil pressure transmitter, fuel pressure transmitter, nacelle elements of the Kidde continuous detector system , one 675° F Fenwal unit-detector, right-hand engine bleed overboard vent, all electrical and control wiring mounted on the engine, left-hand engine bleed overboard vent seal, right-hand nacelle door, all grommets and clip cushions, and the oil breather line tee on the diffuser case

GENERAL OBSERVATIONS

Based on visual observations, motion pictures, and data recorded during test runs, the following were noted

1 MIL-L-7808 engine oil did not ignite from any of the engine surfaces and was very difficult to ignite with a primer fire

2 Hydraulic fluid, MIL-O-5606, did not ignite from any of the hot surfaces of the engine, however, the dense vapors given off by contact with hot surfaces indicated that the fluid was approaching ignition temperature

3 When ignition of hydraulic fluid was stimulated with a primer fire, it ignited readily

4 JP-4 fuel did not ignite from any hot surfaces of the engine in the compressor compartment

5 The fuel-air starter was the only source of hot-surface ignition observed in the nacelle in the tests conducted

6 The fires which were ignited inside the engine nacelle were low-intensity fires as long as the nacelle remained intact

7 Due to the low ventilation rate in the nacelle with no anti-icing air, only a small quantity of fuel could be burned

8 Continued exposure to flame and heat caused the hinge line to distort, allowing small flames to impinge on the strut

9 The louvers in the nacelle doors created a chimney effect during a fire and failed when exposed to flames for more than two minutes

10. The aluminum skin on the nacelle doors resisted burn-through for two minutes under severe fire conditions
11 After a burn-through of the nacelle doors, fire reached the strut and burned through the strut skin However, flame penetration into the strut did not occur
12 Under the most severe fire conditions, flames did not reach or come close to the under surfaces of the wing
13 After disintegration of the nacelle door skin, the engine firewall acted as a flame barrier
14 The engine mounts apparently were unaffected by exposure to a severe fire

CONCLUSIONS

As a result of the analysis of data obtained during the foregoing tests, it is concluded that

1 With no anti-icing air, a low ventilation rate exists in the nacelle
2 The engine power setting has little or no effect on the rate of fuel vapor dissipation within the nacelle
3 Increasing airspeed around the outside of the nacelle decreases the time required to clear the nacelle volume of fuel vapors
4. The data indicated that some flow of vapor from the compressor compartment to the burner compartment will occur
5 Ignition of MIL-L-7808 engine oil, MIL-O-5606 hydraulic fluid, or JP-4 fuel from the engine hot surfaces is not probable This does not apply to JP-4 fuel in the aft engine compartment since the tests conducted did not include this condition
6 During the starting cycle, the fuel-air starter is an ignition hazard and will cause free fuel to ignite
7. The strut supporting the engine pod is of adequate length to prevent external flames from contacting the wing surfaces
8 Flammable fluids released inside the nacelle will accumulate in the bottom of the nacelle and will not be drained away rapidly enough