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Flammability of Fire Resistant, Aircraft Hydraulic Fluid

David Blake

April 1990

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16. Abstract

This study was undertaken following a wheel-well fire in a 737 aircraft. Hydraulic fluid appeared to be the fuel for this fire. Twenty-six tests were conducted with Monsanto Skydrol 500B-4 and Chevron Hy-Jet IV-A fire resistant phosphate ester-based hydraulic fluid. The testing was conducted to determine the conditions necessary for ignition and self-sustained burning of these fluids and to attempt to simulate what probably happened in the wheel-well fire. The testing determined that under certain conditions these fluids will ignite and continue to burn after the ignition source is removed.

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

EXECUTIVE SUMMARY

This study was undertaken following a wheel-well fire in a 737 aircraft. The aircraft made an emergency landing but was unable to stop due to the loss of hydraulic system pressure. The plane overran the end of the runway, and nine people received minor injuries during the emergency evacuation. In this incident a chafed wire arced a hole into a low pressure aluminum hydraulic line. The National Transportation Safety Board has not yet reported the probable cause of the fire but hydraulic fluid appeared to be the fuel. The fluid used in this aircraft was Chevron Hy-Jet IV-A. Twenty-six tests were conducted with Chevron Hy-Jet IV-A and Monsanto Skydrol 500B-4 fire resistant phosphate ester-based hydraulic fluid. The testing was done to determine the conditions necessary for ignition and self-sustained burning of these fluids and to attempt to simulate what probably happened in the wheel-well fire. The testing determined that under certain conditions these fluids will ignite and continue to burn after the ignition source is removed.

INTRODUCTION

PURPOSE.

The purpose of this study was to determine the flammability characteristics of fire resistant, aircraft hydraulic fluid.

BACKGROUND.

This study was undertaken following a fire in the main gear wheel-well of an American West Airlines 737 in Tucson, Arizona on December 30, 1989. The aircraft lost the A, B, and standby hydraulic systems and had a wheel-well overheat warning while on approach to Tucson International Airport. The crew made an emergency landing; but they were not able to stop the aircraft, and it overran the end of the runway. The nose gear was sheared off and nine people received minor injuries during the emergency evacuation. The fire in the wheel-well was extinguished by crash, fire, and rescue personnel.

The 737 is equipped with two engine driven pumps for the A hydraulic system, two electrically driven pumps for the B hydraulic system, and an electrically driven standby pump. The investigation of this incident revealed a chafed 115- volt power wire for the number 2 B pump adjacent to a low pressure aluminum hydraulic return line from the A hydraulic system. The wire had arced a hole into the hydraulic line. The subsequent fire melted through an aluminum hydraulic return line from the B system and burned away the insulation on wires for the standby hydraulic pump. When the standby pump was activated following the loss of the A and B systems, the bare wires shorted to aircraft structure and tripped the standby pump circuit breaker. The fluid used in the aircraft was Chevron Hy-Jet IV-A fire resistant phosphate ester-based aircraft hydraulic fluid. This fluid has a flash point of 360 degrees F (^{o}F) and an autoignition temperature of 965 ^{o}F.

The Federal Aviation Regulation (FAR) for the flammability of hydraulic fluid is covered by FAR 25.1435(c) which states "FIRE PROTECTION. Each hydraulic system using flammable hydraulic fluid must meet the applicable requirements of FAR 25.863, 25.1183, 25.1185 and 25.1189." These FARs do not require any specific flammability tests and are listed in the appendix.

The hydraulic fluid in use in commercial transport category airplanes today is commonly known as Type IV fluid. This label comes from the material specifications of the airframe manufacturers. These specifications contain limits on flash and fire points, autoignition temperature, a wick flammability test, a mist ignition test, and a hot manifold flammability test. In addition to these tests, the manufacturers of hydraulic fluid label their fluid as fire resistant after the fluid meets the American Materials Society (AMS) 3150 specification. This specification subjects the fluid to the following flammability tests: high temperature/high pressure spray test, hot manifold test, low pressure spray test, wick flammability test, hot compartment spray test, hot manifold spray test, hot brake flammability test, spontaneous ignition temperature, autoignition temperature, and flash and fire temperature points.

TEST CONDITIONS AND RESULTS

A total of twenty-six tests were conducted with Monsanto Skydrol 500B-4 and Chevron Hy-Jet IV-A hydraulic fluids. Both of these fluids are phosphate ester-based Type IV fire resistant, aircraft hydraulic fluids. Table 1 gives a brief description of the test conditions and results. Nine of the tests involved arcing a 115-volt wire onto a 3/8-inch low pressure aluminum hydraulic tube. The wire arced a hole into the tube in every case. The holes were irregularly shaped and ranged in size from less than 1 millimeter to approximately 4 millimeters in diameter. The tube was attached to a reservoir containing 1/2 quart of either Skydrol or Hy-Jet hydraulic fluid at pressures of 50 or 100 pounds per square inch (psi). In the majority of these tests the fluid mist was ignited very briefly by the arc and then self-extinguished. In one test the fluid did not ignite at all. Ignition of the fluid was not sustained in tests 1, 2, 3, 16, 17, 18, and 19 where an arcing wire was the sole ignition source. Tests 24 and 26 used an arcing wire and electrodes as ignition sources. In test 24 the fluid was ignited very briefly by the initial arc and then self-extinguished. The electrodes reignited the fluid in this test which burned for several seconds before self-extinguishing again. In test 26 the electrodes did not reignite the fluid after the initial arc.

There were three scenarios where sustained burning of the fluid was achieved after the ignition source was removed. Two of these scenarios involved spraying the fluid through an oil burner nozzle to produce a fine mist. In test 4, Skydrol at 100 psi was sprayed through the nozzle into open air. The mist was ignited with a propane torch but would immediately self-extinguish when the torch was removed. Figure 1 shows the ignited mist when in contact with the torch. Figure 2 shows the mist after the torch was removed. Sustained burning first occurred in test 5 when Skydrol at 100 psi was sprayed into a capped section of a 10-inch-diameter duct. The mist was ignited with a propane torch and continued to burn after the torch was removed. Figure 3 shows the ignited mist when in contact with the torch. Figure 4 shows the mist still burning after the torch was removed. This scenario was repeated in test 22 with Hy-Jet fluid at 50 psi with similar results.

The second scenario where sustained burning occurred was when the hydraulic fluid was sprayed into small metal pans measuring 8 inches high by 4 inches wide by 1.5 inches deep, representative of aircraft structure such as bulkheads. In test 6, these pans were placed 3 inches from the oil burner nozzle. The fluid was sprayed into these pans and ignited with the propane torch. The fluid would only burn when the torch was in contact with the spray. In test 7 the pans were moved approximately 12 inches away from the nozzle. The fluid was sprayed into the pans and ignited with the propane torch. This time the mist continued to burn after the torch was removed. Figure 5 shows the ignited mist when in contact with the torch. Figure 6 shows the mist still burning after the torch was removed. This scenario was repeated in test 23 with Hy-Jet fluid at 50 psi with similar results. Test 8 used the same nozzle and pans position as test 7 but with a different ignition source. Electrodes were placed directly in front of the nozzle and energized. The fluid did not ignite. Figure 7 shows the configuration for test 8. Test 9 used the same nozzle and pans position as the previous two tests. However in this test the electrodes were moved away from the nozzle and placed in the bottom of one of the pans, approximately 12 inches from the nozzle. The fluid ignited and continued to burn after the electrodes were turned off. Figure 8 shows the configuration for test 9.

The third scenario where sustained burning occurred used a section of aluminum tubing with a hole arced into it from a previous test. The stream exiting the hole was directed 45 degrees downward, against a wire, and then into the vertically mounted pans. The wire was positioned to just contact the edge of the fluid stream. The ignition source was electrodes placed in one of the pans. During test 12, the fluid ignited as soon as the flow was started and burned for approximately 15 seconds after the electrodes were turned off. The fluid self-extinguished and was then reignited with the electrodes. The fluid burned for several more seconds before self-extinguishing. This occurred several times in this test. In test 13, the pans and electrodes were moved lower. All other conditions were the same as test 12. Figure 9 shows the configuration used for tests 13, 14, 15, 20, 21, and 25. In test 13, the fluid ignited immediately and continued burning after the electrodes were turned off. The fire grew relatively large as pooled fluid on the bottom of the test fixture ignited. The flow of Skydrol was then stopped and the fire self-extinguished. Test 14 used the same configuration as test 13 except Hy-Jet fluid was used. In this test the fluid ignited briefly and then self-extinguished. The same configuration was repeated in test 15. In this test the wire was adjusted while the fluid was flowing out of the hole until it just contacted the edge of the fluid stream causing it to mist and ignite. The electrodes were turned off and the fluid continued to burn until the reservoir was empty. Tests 20, 21, and 25 were repeats of this same scenario. In test 20, the fluid ignited and burned for several seconds after the electrodes were turned off and then self-extinguished. This occurred several times during the test. In test 21, a 6-mile-per-hour airflow was directed onto the area of escaping fluid. The fluid ignited briefly and then self-extinguished. The airflow seemed to inhibit ignition of the fluid. In test 25, the fluid ignited and burned for several seconds after the electrodes were turned off and then self-extinguished. The electrodes were turned back on and the fluid immediately reignited and continued to burn with the electrodes off for 38 seconds until the reservoir was empty.

CONCLUSIONS

1. When fire resistant Type IV hydraulic fluid spray was not contained, it self-extinguished as soon as the ignition source was removed.

2. In some cases, when the same fluid spray was contained it continued to burn after the ignition source was removed.

3 There are many factors which affect the ability of fire resistant Type IV hydraulic fluids to support combustion. Some of these are the size and shape of the leak, fluid pressure, size and shape of structure surrounding the leak, location and energy of ignition source, flammability of surrounding materials (for reignition of the fluid), and air velocity in the area of the ignition source.

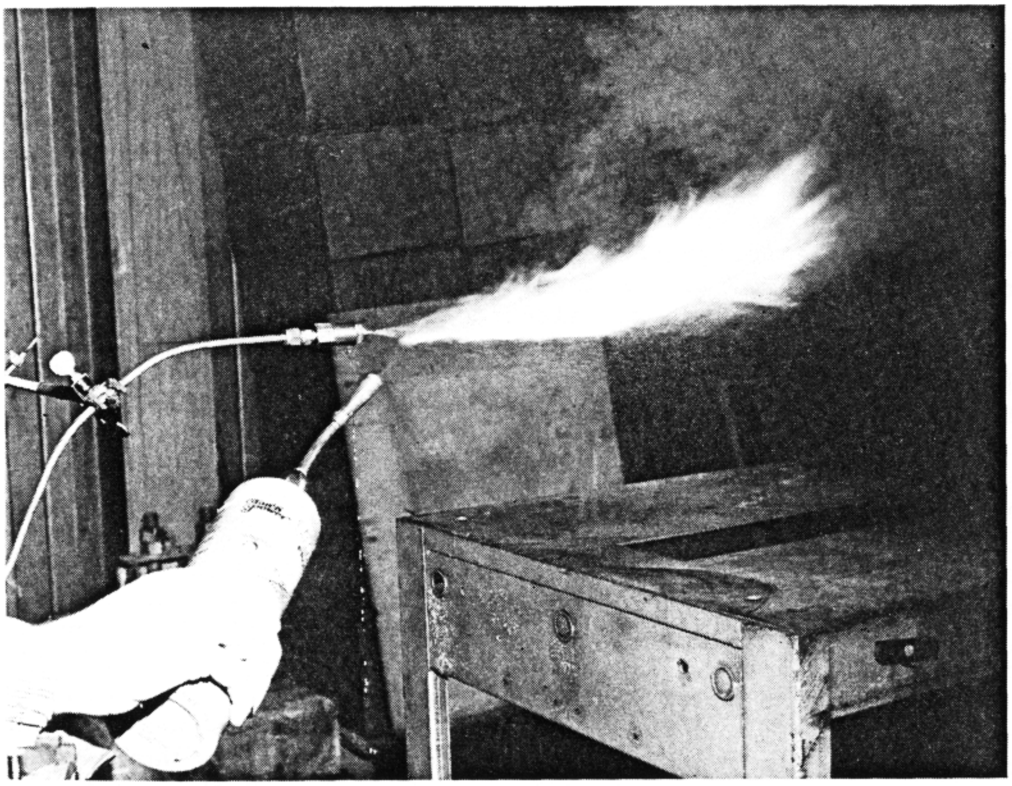

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FIGURE 1. HYDRAULIC FLUID MIST IGNITED WITH PROPANE TORCH, TEST 4

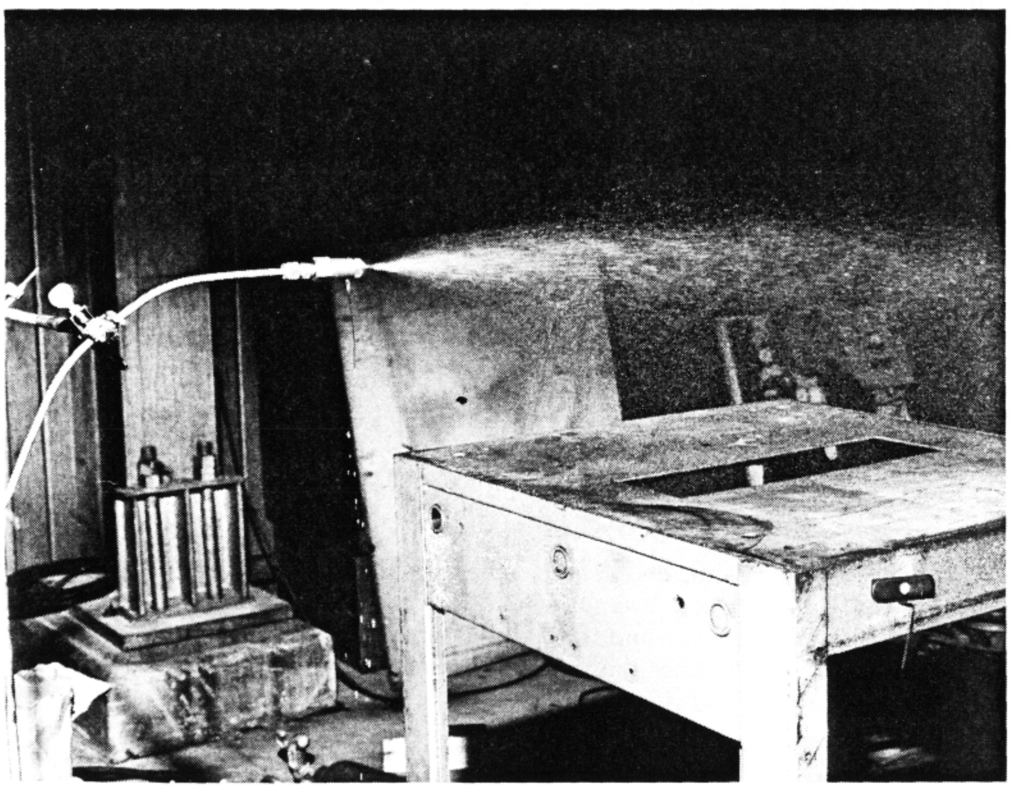

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FIGURE 2. HYDRAULIC FLUID MIST SELF-EXTINGUISHED, TEST 4

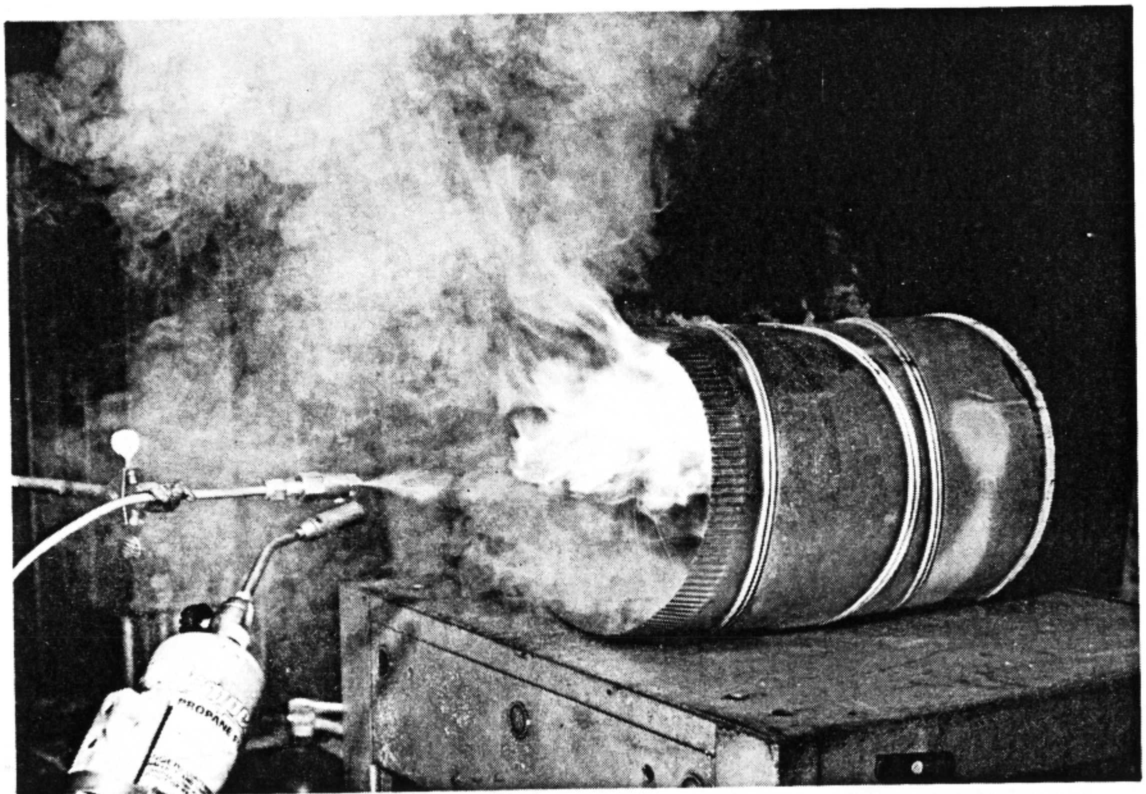

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FIGURE 3. HYDRAULIC FLUID MIST SPRAYED INTO DUCT AND IGNITED, TEST 5

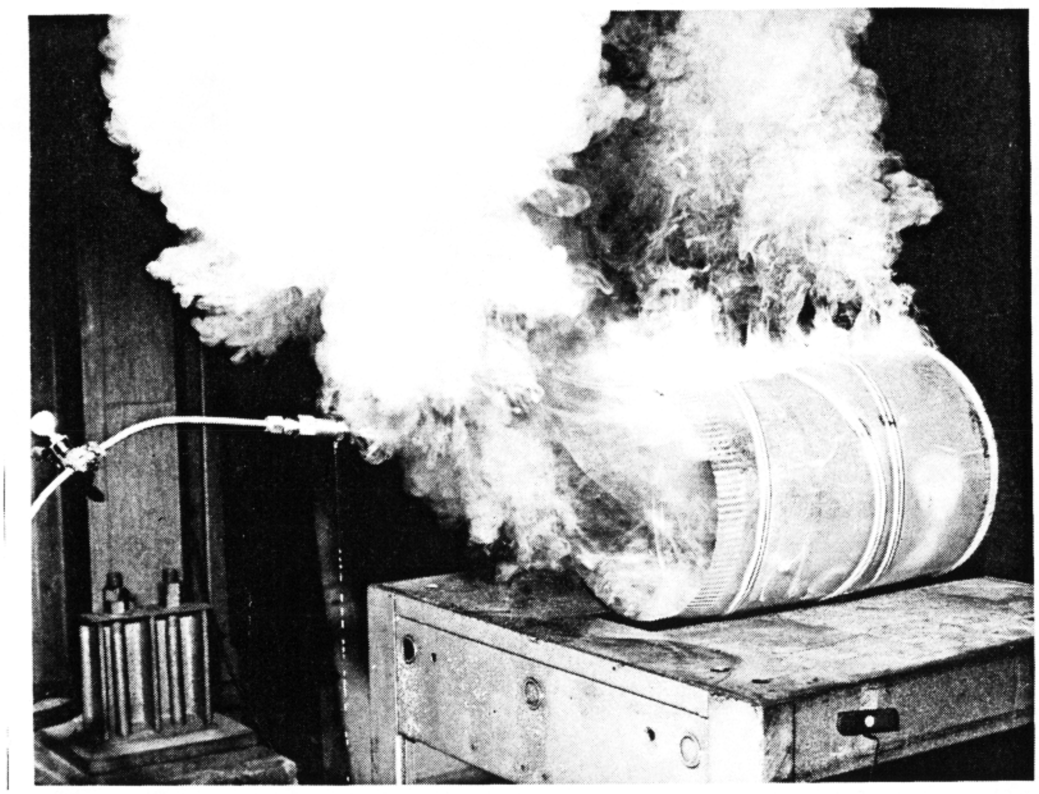

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FIGURE 4. HYDRAULIC FLUID MIST BURNING AFTER TORCH REMOVED, TEST 5

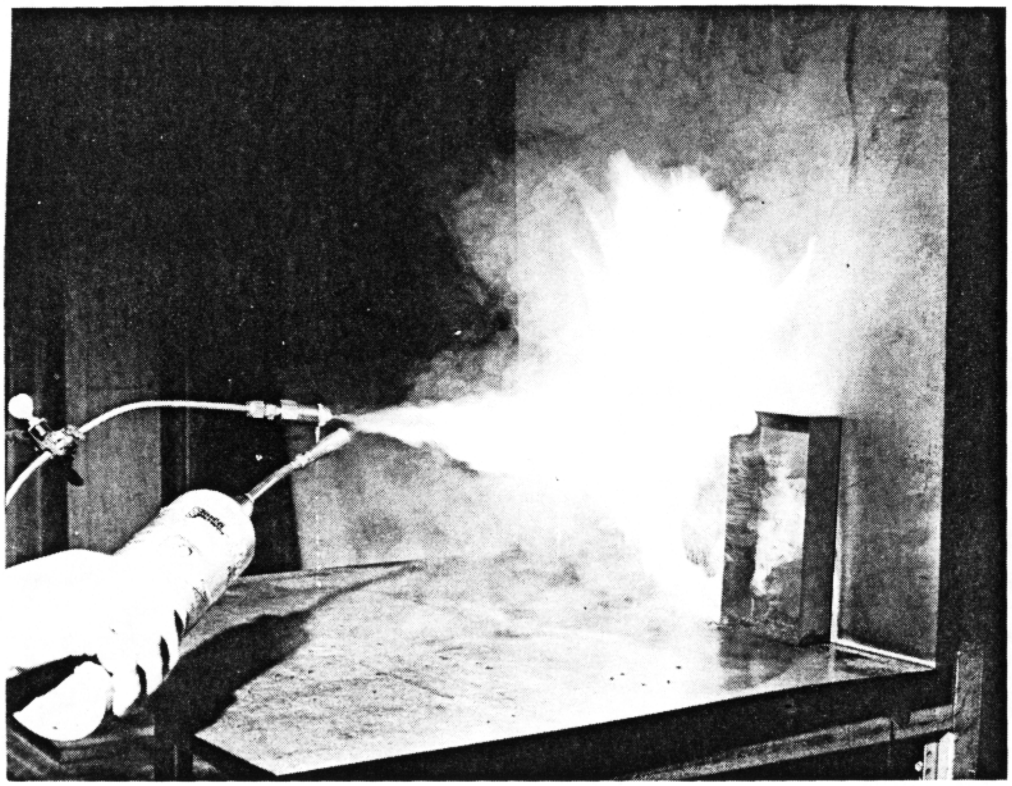

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FIGURE 5. HYDRAULIC FLUID MIST SPRAYED INTO PANS AND IGNITED, TEST 7

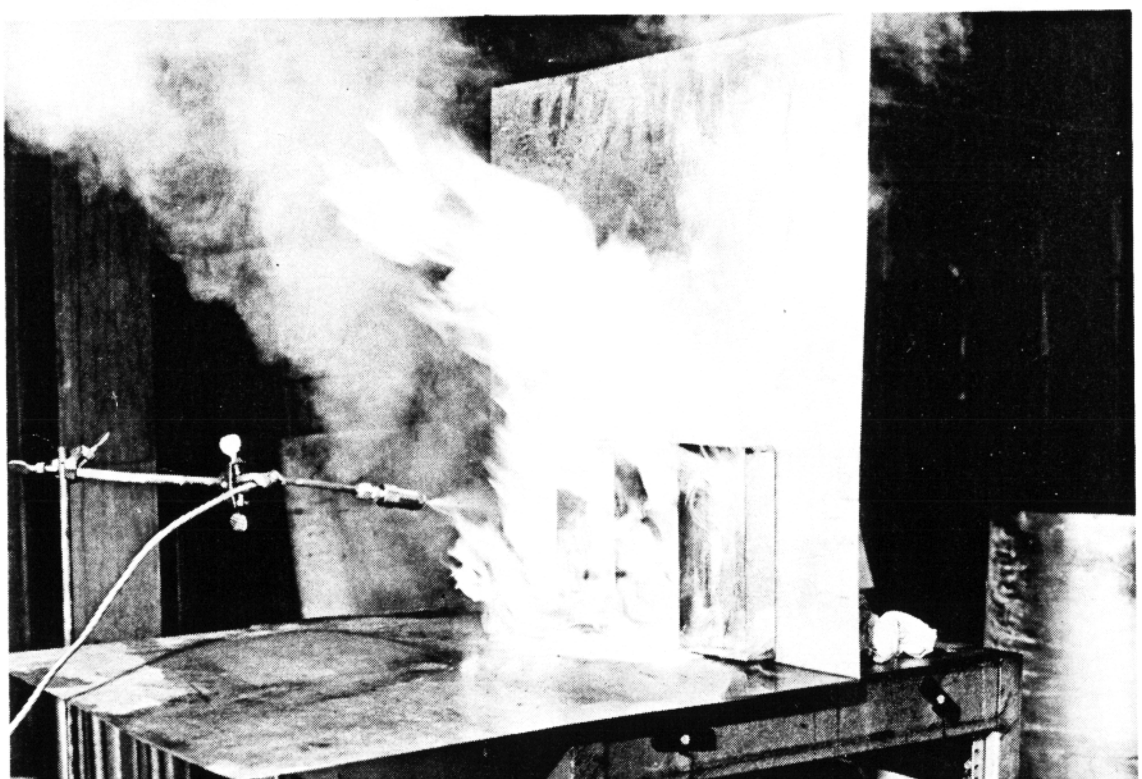

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FIGURE 6. HYDRAULIC FLUID MIST BURNING AFTER TORCH REMOVED, TEST 7

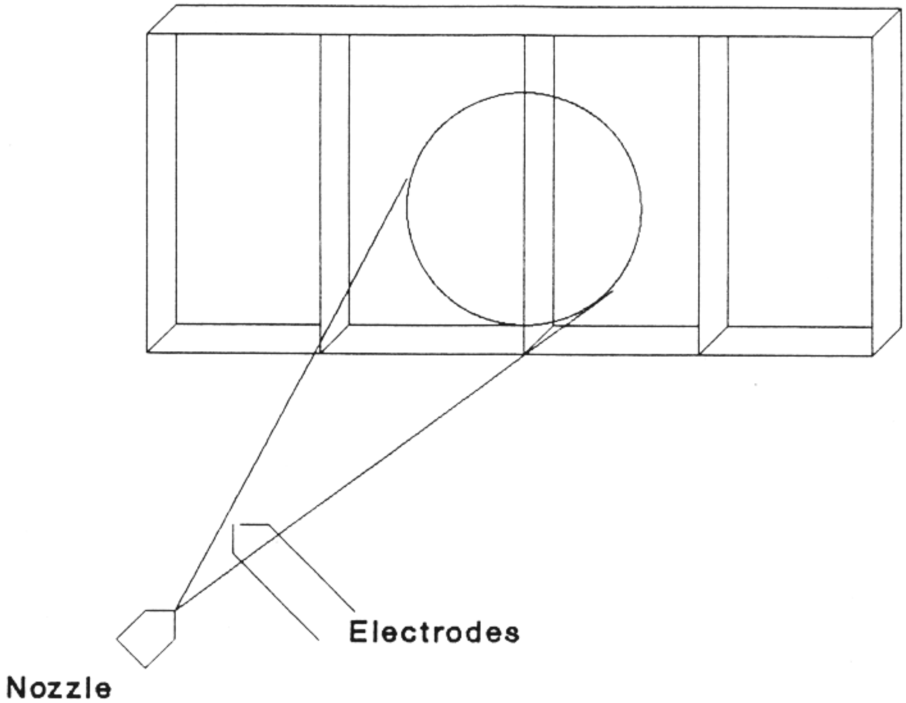

FIGURE 7. CONFIGURATION FOR TEST 8

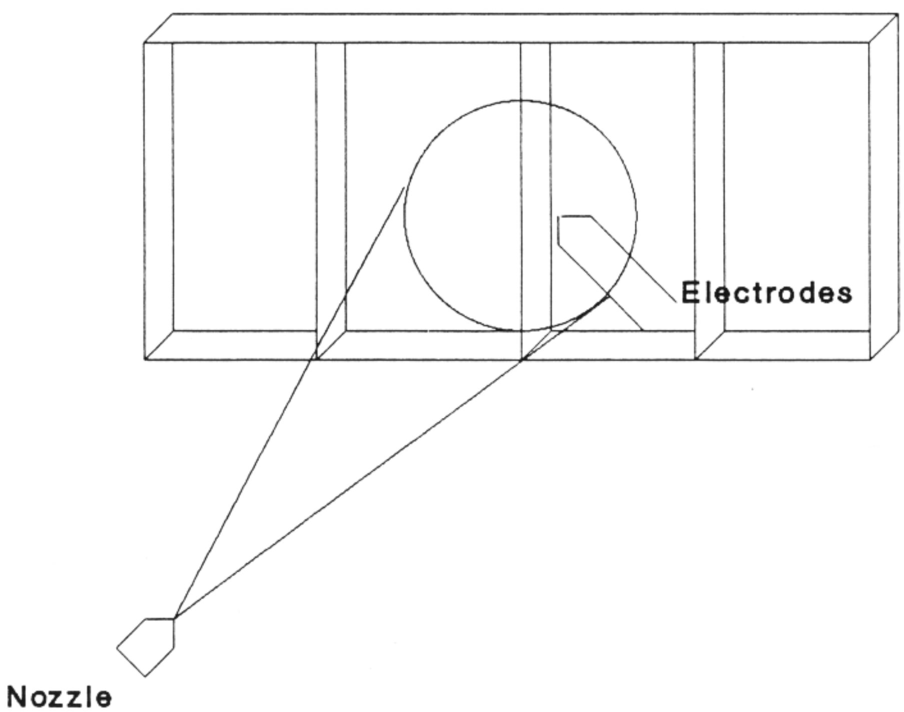

FIGURE 8. CONFIGURATION FOR TEST 9

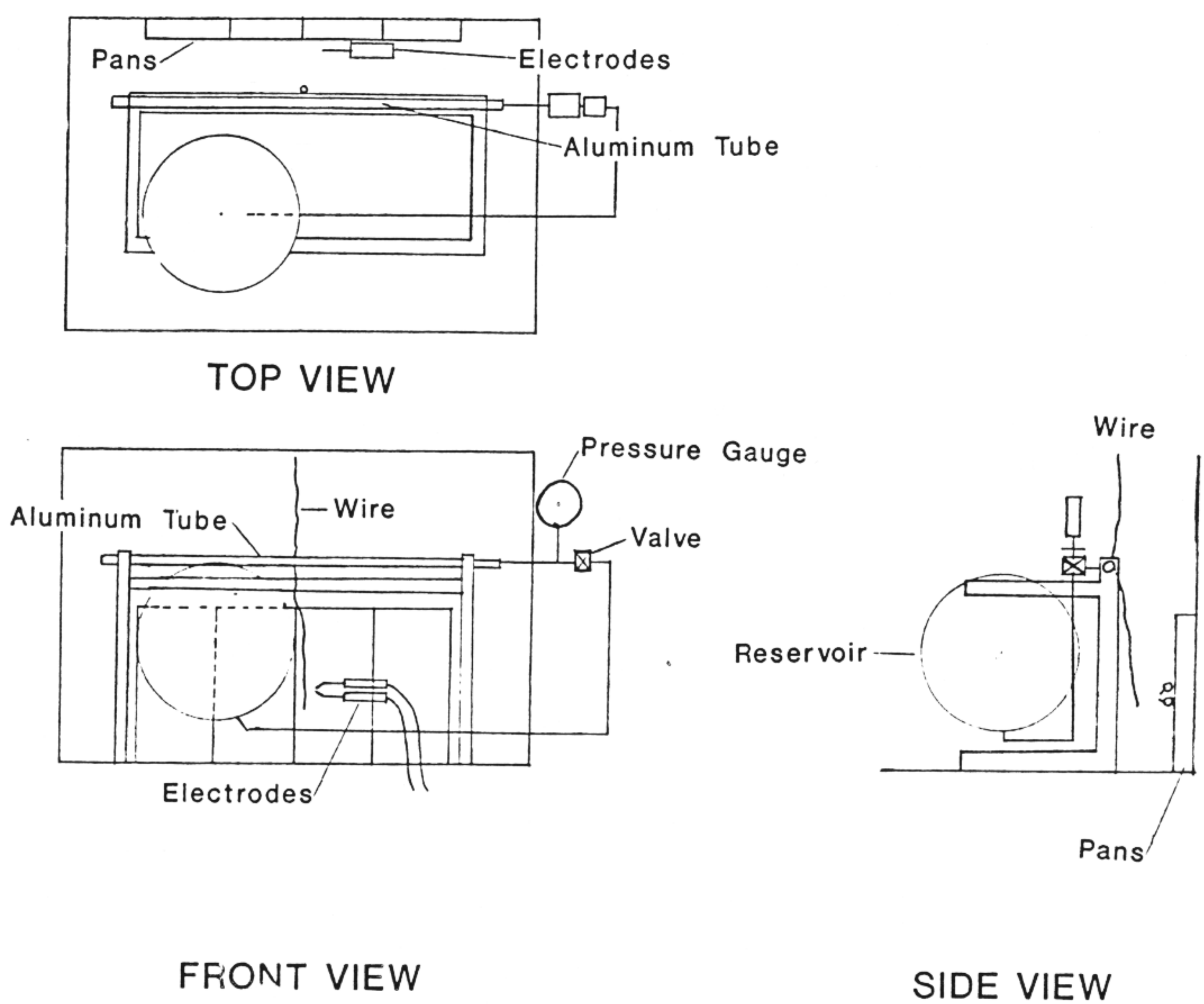

FIGURE 9. CONFIGURATION FOR TEST 13, 14, 15, 20, 21, AND 25

Table 1. Hydraulic Fluid Fire Test Results

Test	Fluid	Pressure	Ignition Source	Source of Fluid	Result
1	Monsanto, Skydrol	100 psi	Arcing Wire, 115 VAC - 30 amp	Hole arced into aluminum tube	Fluid ignited briefly then self-extinguished.
2	Skydrol	100 psi	Arcing Wire, 115 VAC - 30 amp	Hole arced into aluminum tube	Fluid ignited briefly then self-extinguished.
3	Skydrol	100 psi	Arcing Wire, 115 VAC - 30 amp	Hole arced into aluminum tube	Fluid ignited briefly then self-extinguished.
4	Skydrol	100 psi	Propane Torch	Oil burner nozzle	Fluid sprayed into open air. Fluid burned only while torch was in contact with spray.
5	Skydrol	100 psi	Propane Torch	Oil burner nozzle	Fluid sprayed into capped off duct. Fluid ignited immediately & continued to burn after torch was removed.
6	Skydrol	100 psi	Propane Torch	Oil burner nozzle	Fluid sprayed into vertical pans 3 inches from nozzle. Fluid burned only while torch was in contact with spray.
7	Skydrol	100 psi	Propane Torch	Oil burner nozzle	Fluid sprayed into vertical pans 12 inches from nozzle. Fluid continued to burn after torch was removed.
8	Skydrol	100 psi	Electrodes	Oil burner nozzle	Fluid sprayed into vertical pans 12 inches from nozzle. Electrodes placed directly in front of nozzle. No ignition.
9	Skydrol	100 psi	Electrodes	Oil burner nozzle	Fluid sprayed into vertical pans 12 inches from nozzle. Electrodes placed directly in front of pans. Fluid ignited and continued to burn after electrodes were turned off.
10	Skydrol	100 psi	Electrodes	.052" diameter hole drilled in aluminum tube	Fluid stream directed against a wire and then into vertically mounted pans. Electrodes placed in front of pans. Fire ignited briefly then self-extinguished.
11	Skydrol	50 psi	Electrodes	.052" diameter hole drilled in aluminum tube	Fluid stream directed against a wire and then into pans. Fire ignited briefly several times then self-extinguished.
12	Skydrol	50 psi	Electrodes	Aluminum tube with hole arced from a previous test	Fluid stream directed against a wire and then into pans. Fire ignited immediately & burned for 15 seconds after electrodes turned off. Electrodes were turned on and off several more times. This would reignite the fluid which would burn for between 5 and 20 seconds before self-extinguishing.
13	Skydrol	50 psi	Electrodes	Aluminum tube with hold arced from a previous test	Fluid stream directed 45 degrees downward against a wire & into pans. Pans were moved lower on the wall for this test. Fluid ignited immediately & continued to burn when electrodes turned off. Fluid continued to burn until flow was stopped.
14	Chevron Hy-Jet IVA	50 psi	Electrodes	Aluminum tube with hole arced from a previous test	Fluid stream directed 45 degrees downward against a wire and into pans. Fluid ignited briefly then self-extinguished.
15	Hy-Jet	50 psi	Electrodes	Aluminum tube with hole arced from a previous test	Fluid stream directed 45 degrees downward against a wire and into pans. The wire was adjusted until it just contacted edge of stream. Fluid then ignited and continued to burn after electrodes turned off.
16	Hy-Jet	50 psi	Arcing Wire, 115 VAC - 30 amp	Hole arced into aluminum tube	Fluid did not ignite.
17	Hy-Jet	50 psi	Arcing Wire, 115 VAC - 30 amp	Hole arced into aluminum tube	Fluid ignited briefly then self-extinguished.
18	Hy-Jet	50 psi	Arcing Wire, 115 VAC - 30 amp	Hole arced into aluminum tube	A fan was directed onto the area of arcing. Fluid ignited briefly then self-extinguished.
19	Hy-Jet	50 psi	Arcing Wire, 115 VAC - 30 amp	Hole arced into aluminum tube	Fluid ignited briefly then self-extinguished.
20	Hy-Jet	50 psi	Electrodes	Aluminum tube with hole arced from a previous test	Fluid stream directed 45 degrees downward against a wire and into pans. Fluid ignited and burned for several seconds after electrodes turned off. This was repeated several times during test.
21	Hy-Jet	50 psi	Electrodes	Aluminum tube with hole arced from a previous test	Fluid stream directed 45 degrees downward against a wire and into pans. A fan was directed into area of escaping fluid. Fluid ignited briefly then self-extinguished.
22	Hy-Jet	50 psi	Propane Torch	Oil burner nozzle	Fluid sprayed into capped off duct. Fluid ignited after distance from nozzle to duct was adjusted. Fire continued to burn after torch was removed. Pooled fluid continued to burn for several minutes after spray through nozzle was stopped.
23	Hy-Jet	50 psi	Propane Torch	Oil burner nozzle	Fluid sprayed into vertical pans. Fluid ignited after distance from nozzle to pans was adjusted. Fire continued to burn after torch was removed. Pooled fluid continued to burn for several minutes after spray through nozzle was stopped.
24	Hy-Jet	50 psi	Arcing Wire and Electrodes	Hole arced into aluminum tube	Fluid ignited briefly from initial arc and then self-extinguished. Fluid reignited twice from electrodes and burned for several seconds before self-extinguishing.
25	Hy-Jet	50 psi	Electrodes	Aluminum tube with hole arced from a previous test	Fluid stream directed 45 degrees downward against wire and into pans. Fire ignited then self-extinguished several times. Fire then ignited and continued to burn when electrodes were turned off until reservoir was empty.
26	Hy-Jet	50 psi	Arcing Wire and Electrodes	Hole arced into aluminum tube	Used the tube and wire from the incident airplane. Tube was placed adjacent to vertical pans with electrodes below tube near pans. Fluid ignited briefly from initial and subsequent arc then self-extinguished.

FAR 25.863 Flammable fluid fire protection.
(a) In each area where flammable fluids or vapors might escape by leakage of a fluid system, there must be means to minimize the probability of ignition of the fluids and vapors, and the resultant hazards if ignition does occur.
(b) Compliance with paragraph (a) of this section must be shown by analysis or tests, and the following factors must be considered:
(1) Possible sources and paths of fluid leakage, and means of detecting leakage.
(2) Flammability characteristics of fluids, including effects of any combustible or absorbing materials.
(3) Possible ignition sources, including electrical faults, overheating of equipment, and malfunctioning of protective devices.
(4) Means available for controlling or extinguishing a fire, such as stopping flow of fluids, shutting down equipment, fireproof containment, or use of extinguishing agents.
(5) Ability of airplane components that are critical to safety of flight to withstand fire and heat.
(c) If action by the flight crew is required to prevent or counteract a fluid fire (e. g., equipment shutdown or actuation of a fire extinguisher) quick acting means must be provided to alert the crew.
(d) Each area where flammable fluids or vapors might escape by leakage of a fluid system must be identified and defined.

FAR 25.1183 Flammable fluid-carrying components.

(a) Except as provided in paragraph (b) of this section, each line, fitting, and other component carrying flammable fluid in any area subject to engine fire conditions, and each component which conveys or contains flammable fluid in a designated fire zone must be fire resistant, except that flammable fluid tanks and supports in a designated fire zone must be fireproof or be enclosed by a fireproof shield unless damage by fire to any non-fireproof part will not cause leakage or spillage of flammable fluid. Components must be shielded or located to safeguard against the ignition of leaking flammable fluid. An integral oil sump of less than 25 quart capacity on a reciprocating engine need not be fireproof nor be enclosed by a fireproof shield.
(b) Paragraph (a) of this section does not apply to-
(1) Lines, fittings, and components which are already approved as part of a type certificated engine; and
(2) Vent and drain lines, and their fittings whose failure will not result in, or add to, a fire hazard.

FAR 25.1185 Flammable fluids.

(a) Except for the integral oil sumps specified in 25.1013 (a), no tank or reservoir that is a part of a system containing flammable fluids or gases may be in a designated fire zone unless the fluid contained, the design of the system, the materials used in the tank, the shut-off means, and all connections, lines, and control provide a degree of safety equal to that which would exist if the tank or reservoir were outside such a zone.
(b) There must be at least one-half inch of clear airspace between each tank or reservoir and each firewall or shroud isolating a designated fire zone.

(c) Absorbent materials close to flammable fluid system components that might leak must be covered or treated to prevent the absorption of hazardous quantities of fluids.

FAR 25.1189 Shutoff means.

(a) Each engine installation and each fire zone specified in 25.1181(a)(4) and (5) must have a means to shut off or otherwise prevent hazardous quantities of fuel, oil, deicer, and other flammable fluids, from flowing into, within, or through any designated fire zone, except that shutoff means are not required for-

(1) Lines, fittings, and components forming an integral part of an engine: and

(2) Oil systems for turbine engine installations in which all components of the system in a designated fire zone, including oil tanks, are fireproof or located in areas not subject to engine fire conditions.

(b) The closing of any shutoff valve for any engine may not make fuel unavailable to the remaining engines.

(c) Operation of any shutoff may not interfere with the later emergency operation of other equipment, such as the means for feathering the propeller.

(d) Each flammable fluid shutoff means and control must be fireproof or must be located and protected so that any fire in a fire zone will not affect its operation.

(e) No hazardous quantity of flammable fluid may drain into any designated fire zone after shutoff.

(f) There must be means to guard against inadvertent operation of the shutoff means and to make it possible for the crew to reopen the shutoff means in flight after it has been closed.

(g) Each tank-to-engine shutoff valve must be located so that the operation of the valve will not be affected by powerplant or engine mount structural failure.

(h) Each shutoff valve must have a means to relieve excessive pressure accumulation unless a means for pressure relief is otherwise provided in the system.