DETERMINATION OF IGNITION CHARACTERISTICS OF HYDRAULIC FLUIDS

PART I

SIMULATED FLIGHT AND CRASH CONDITIONS

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SUMMARY

The relative ignitability of various hydraulic fluids has been determined qualitatively under simulated flight and crash conditions The ignition characteristics of the fluids, under practical aircraft conditions, were the only properties investigated in this test program

Flight conditions were simulated in a full-scale operating B-29 engine installation in which the fluids, released at pressures of 1,000 and 3,000 psi, were exposed to four typical sources of ignition (1) exhaust flame, (2) hot exhaust stack, (3) ignition spark and (4) burning gasoline

Crash conditions were simulated by bench tests in which the fluids were ejected at 3 000 psi through a strong electric arc and an oxy-acetylene flame Wick fires were simulated by using horizontal and vertical wick test conditions

Seven different fluids were tested In the order of increasing ignitability as determined by these tests, they were

Hydrolube (Union Carbide and Carbon Corp) Navy 51F-22

Type A Fluid (California Research Corp) No 50743-R

Type B Fluid (California Research Corp) No 50744-R

909 (Cook Electric Co)

Silicone Oil (General Electric Co) No 998ILTNV-70

WS-804 (Standard Oil Co of New Jersey)

Standard Hydraulic Fluid (Specifications AAF-3580D and AN-VV-O-366b)

All of the experimental fluids submitted for test, except WS-804, proved more difficult to ignite than the standard hydraulic fluid Under the simulated flight and crash conditions, all except Hydrolube could be made to burn under some conditions of ignition Under the simulated wick conditions, all the fluids could be made to burn

PURPOSE

The purpose of these tests was to compare, under simulated flight and crash conditions, the ignition characteristics of several hydraulic fluids, both standard and proposed less flammable types

INTRODUCTION

A number of aircraft fires have resulted from the use of flammable hydraulic fluids As a result, an effort has been made to develop hydraulic fluids which are less flammable than those currently used, or nonflammable The new fluids have been, and are being, subjected to standard tests in other laboratories to determine Flash point, fire point, lubricity, viscosity, effect on packing materials and the like

The transition from the standard laboratory tests to general use in aircraft seemed too great a step without some intermediate full-scale fire testing Quiet laboratory conditions with the fluid applied to ignition sources at very low pressures were not believed to be comparable with flight conditions of high air blast in which the fluid

Please note that with the exception of the standard hydraulic fluids, the test fluids are either of a development nature or are primarily intended for other purposes and have been tested here only for the purpose of obtaining information might be released near an ignition source at pressures up to 3,000 psi Accordingly, the Civil Aeronautics Administration Technical Development and Evaluation Center undertook the determination of hydraulic fluid-ignition characteristics on a B-29 engine installation under simulated flight conditions, and in bench tests under simulated crash and wicking conditions

DESCRIPTION OF TESTS

Simulated Flight Conditions

Pressures Used

The hydraulic systems of the majority of modern transport aircraft operate at 1,500 psi pressure, and many of the newer and larger types of aircraft are using 3,000 psi pressure Assuming a break in such a system, fluid would be discharged at any pressure up to 3,000 psi, therefore, the fluids were fire tested within that pressure range The fluids were released at flow rates between one-half and one gpm

Ignition Sources

During normal aircraft operation, escaping hydraulic fluid could be ignited by hot exhaust gases, hot metal surfaces and electric sparks If, for some reason, a fire already existed in the aircraft, this fire could be a source of ignition of the fluid

The exhaust gas ignition test was arranged by removing the short stub exhaust stack between a cylinder and the exhaust collector ring The fluid being tested was sprayed through a nozzle into the exhaust gases The portion of the exhaust stack which lies in the louvered exhaust stack well was used in making the hot surface test The nozzle was inserted into the exhaust stack well through a louver and directed so the fluid sprayed directly on the stack

For the tests simulating an electric spark, a standard aircraft spark plug was used The spark of 15 000 volts was protected from the propeller air blast by a cone which surrounded the plug Fluid was sprayed through a nozzle into the cone, which further broke up the fluid to facilitate ignition

The same location and the same apparatus, with the addition of a gasoline feed line, were used in the gasoline fire ignition tests Gasoline flowing from the feed line was ignited by the spark The fluid being tested was then sprayed through the burning gasoline See Fig 1

Fluids Tested

The fluids tested, and their physical properties, are listed in Table I

Test Procedure

For the early tests, the variables were the nozzle size, metering valve setting, fluid pressure at the nozzle, engine speed and location or type of ignition Experience showed, however, that changing the nozzle and the valve setting yielded no additional data of value, so the metering of the fluid was eliminated and the nozzle was changed only when the pressure was changed, to keep the rate of flow within reasonable limits (from one-half to one gpm) The test procedure eventually resolved itself into testing each fluid in the four types of ignition sources at three different engine speeds (800, 1,600 and 2,400 rpm) at 1,000 and then at 3,000 psi pressure at the discharge nozzle

Simulated Crash Conditions

In a welded iron box having one side open, fluids were sprayed into an electric arc or a torch flame to subject them to what was considered as severe ignition conditions as could be devised This was set up as a bench test, separate from the tests on the B-29 engine No induced air flow was employed See Fig 2 The fluid to be tested was pressurized to 3,000 psi and then ejected into either the arc or the torch flame Various arrangements of straight jet discharge (the jet impinging on an electrode surface) and a dispersed spray, were used

Simulated Wick Conditions

Two types of wick fires were investigated by (1) The vertical wick test, in which 3 cc of fluid were allowed to soak into a piece of 1 1/2-inch wide asbestos tape, 6 inches long The wick was then supported vertically and ignited at the bottom by means of 1,500°F flame produced by the standard burner used in testing heat detectors (2) The horizontal wick test, in which a similar wick was supported horizontally and half submerged in fluid One of the exposed corners of the wick was ignited by means of a small oxy-acetylene flame

DESCRIPTION OF TEST EQUIPMENT

Simulated Flight Conditions

Engine

The engine used for these tests was a

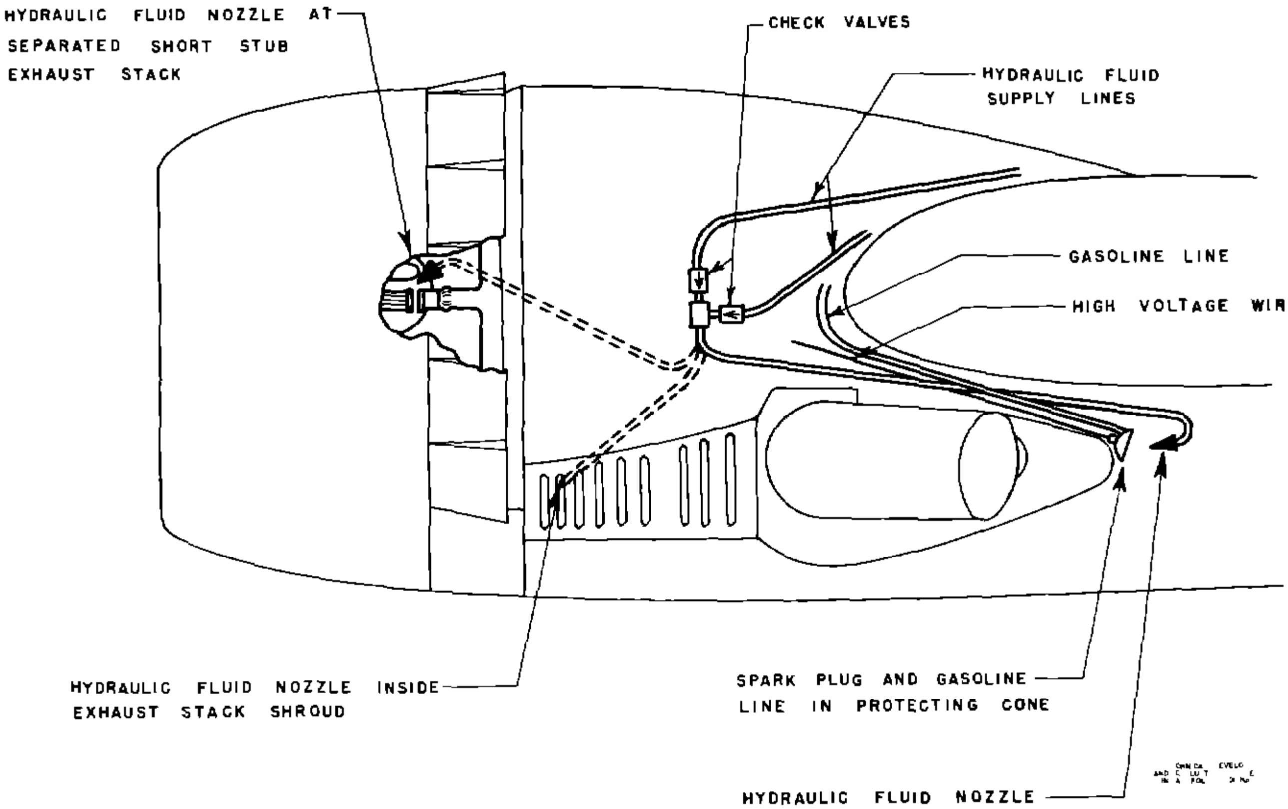

Fig 1 Diagram of Nozzle Locations on Engine and Nacelle

Wright R-3350 of 2,200 horsepower maximum, installed in a standard B-29 inboard nacelle The nacelle was in a special wing section mounted in the test cell, and the engine was in normal operation during all tests

Pumping Equipment

Several different pumps were used during the test program to produce the pressures and the flow rates desired For pressures up to 1,000 psi, aircraft propeller feathering pumps were used These were connected through 1/4-inch OD tubing to a discharge nozzle located, as desired, at an ignition source in the nacelle A Y-connection about three feet from the nozzle allowed both pumps to discharge through the same nozzle, and made it possible to test two fluids alternately, and thus to compare them directly under identical conditions Ball check valves in each line ahead of the Y prevented reverse flow in the unused line See Fig 1

Because of the small quantity of Silicone Oil available for test purposes, it was considered necessary to develop a different means of pressurizing this liquid A high-compression cylinder was fabricated from spare aircraft hydraulic parts, and was operated by a hydraulic jack The jack was operated by hand Pressure was maintained at any desired level by watching the gauge and manipulating the jack handle accordingly This unit is shown at the right end of the test bench in Fig 3

Some of the tests at the higher pressures were run with a portable 3,000 psi hydraulic test rig loaned by Greer Hydraulics, Inc The unit proved impractical for this work, since several gallons were required to fill the system, and it was replaced by Greer with a 3,000 psi pump, manufactured by the New York Air Brake Co , which had a capacity of 2 gpm at 1,500 rpm A 20-horsepower, 3,500-rpm motor was used to operate it A bypass valve returned excess fluid to the supply container and was set to maintain the nozzle pressure at 3,000 psi This is shown in Fig 3

After a few tests with this equipment, the pump became inoperable because of excessive scoring of some of the parts, espe-

TABLE I

General Physical Characteristics Of The Fluids Tested
(Data Obtained From Manufacturers)

Fluid	Manufacturer	Specific Gravity	Flash Point (°F)	Fire Point (°F)	Viscosity Index	Viscosity (C S) 100°F	130°F	210°F	Pour Point (°F)	Color
Mobil Aero Hydrol HFD (AAF-3580-D)	Socony Vacuum Oil Co	0 8849	280	320	125	91 2	62 0	39 4	-50	Red
Silicone Oil (998ILTNV-70)	General Electric Co	0 97	600	600	158	74 0	55 0	30 0	-125	Clear
Hydrolube (Navy 51F-22)	Union Carbide and Carbon Corp	1 0575	None[1]	None[1]		16 5	9 97		Below -65	Clear
Aircraft Hydraulic Fluid "909"	Cook Electric Co	1 105	None[2]	None[2]			4 4		-89	Clear
Lubricant WS-804	Standard Oil Co of New Jersey	0 917	425		149	12 65		4 47	-90	Yellow-Brown
Fluid "A" 50743-R	California Research Corp	1 550	No True		224	7 72	5 49	2 87	Below -70	Dark Amber
Fluid "B" 50744-R	California Research Corp	1 237	No True		129	11 04	6 92	2 91	Below -70	Light Amber

[1]Flashes at 295°F after expulsion of water
[2]Flashes at 300°F after expulsion of water

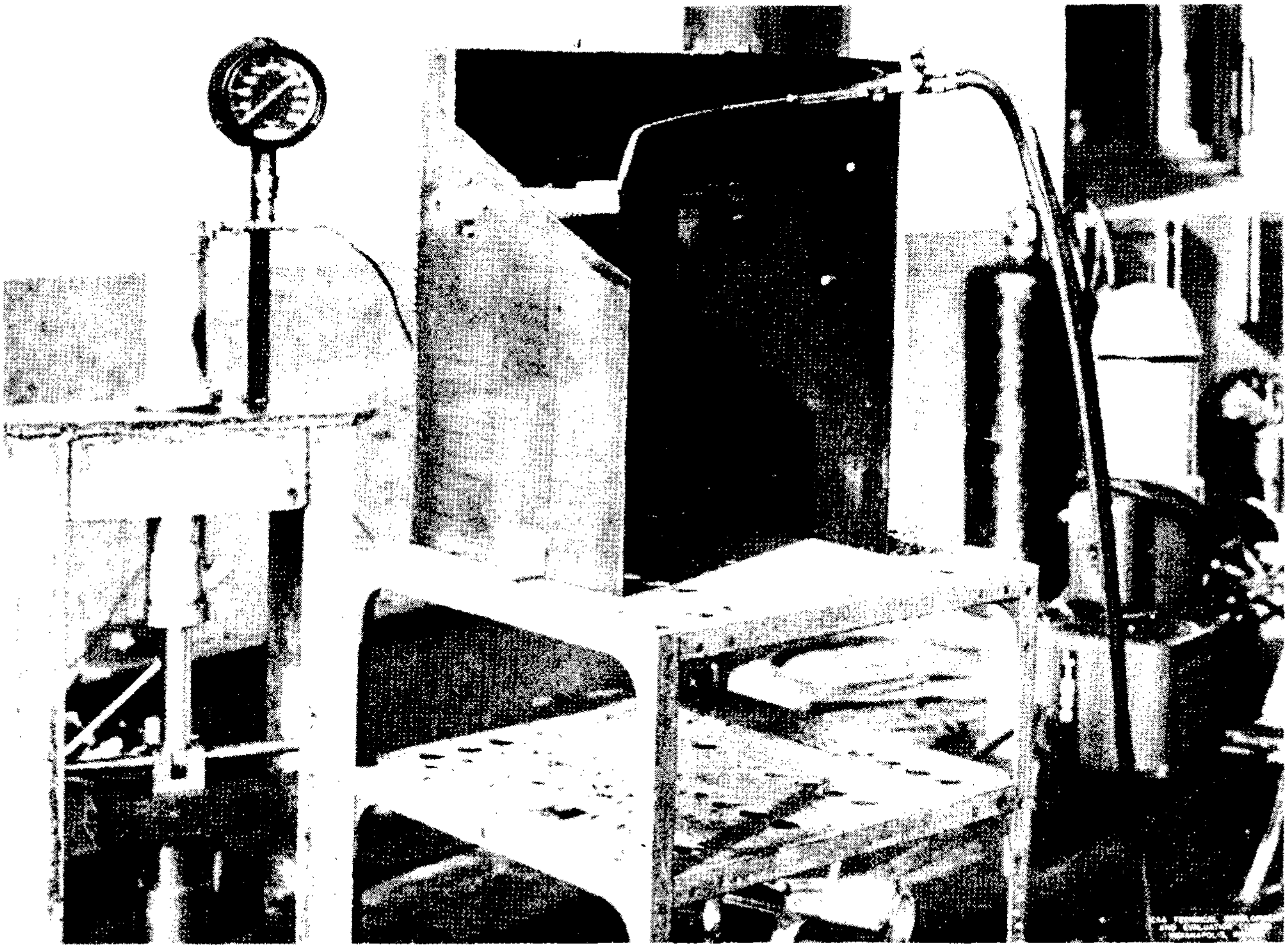

Fig. 2 Equipment for Ignition Tests in Electric Arc and Torch Flame

cially the steel wobble plate and mating bronze pieces. Although the pump was rated for a maximum speed of 4,500 rpm (well above that used) it was considered that the combination of high speed, high pressure and probably poor lubricity of some of the fluids pumped caused the failure. The pump parts were re-machined, the driving motor changed to a 1,750 rpm and the pressure system revised so that only a good lubricating oil passed through the pump. This was accomplished by using two hydraulic cylinders, the pistons of which were linked together. When pressurized oil was introduced into one cylinder, the piston linkage transferred the pressure to the hydraulic fluid contained in the other cylinder and forced it out of the discharge nozzle under this pressure. The first piston was made double-acting to facilitate drawing a new supply of fluid into the second cylinder.

Since it was necessary (using this high-pressure equipment) to run a complete series of tests on one fluid, then repeat the series with another fluid, similar conditions were maintained from series to series as nearly as possible.

Nozzles

The rates of fluid flows and, to some extent, the pressures, were varied by changes in nozzle design. In general, two nozzle types were used — straight jet discharge and jet discharge through a dispersing screen. Flow rates were determined by timing and measuring the quantities of fluids discharged.

The first nozzles were simply plugs with 3 to 5 No. 70, No. 75 and No. 80 holes drilled in the end so that the jets diverged slightly from each other. Later, these were replaced with a nozzle having a single No. 60 hole and with a 50 by 50 mesh screen over it to disperse the jet into a more ignitable spray. For some of the high-pressure tests,

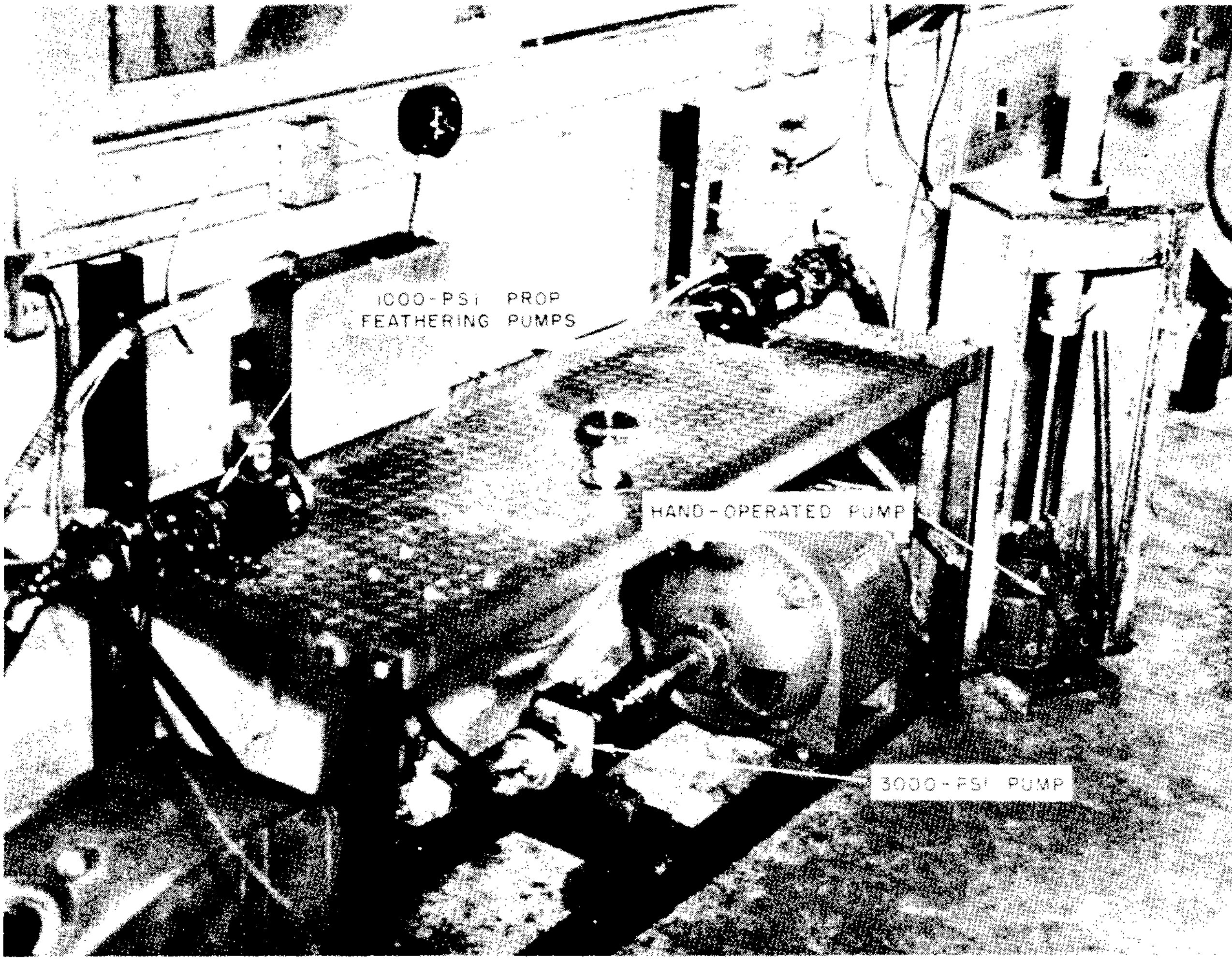

Fig. 3 General View of Pumping Equipment

the nozzle used was formed from a 1/8-inch pipe nipple by flattening out one end until, by trial and error, a suitable rate of flow was obtained. This was used because a straight drilled hole of comparably small area (approximately No. 80 drill) could not be kept clear of dirt particles.

Simulated Crash Conditions

The pump used for these tests was the hand-operated pump described previously. In order to get a short burst of fluid at the full 3,000 psi pressure desired, a spring-loaded relief valve set to open at 3,000 psi was used in the discharge line just ahead of the nozzle. Two different nozzles were used, both having a single No. 80 hole, but one with a 50 by 50 mesh dispersing screen which broke up the jet into a fine spray.

The igniting arc was produced between two 1/2-inch diameter carbon electrodes with a potential of 60 volts at 200 amperes. The electrodes could be adjusted so that the fluid jet either passed directly between them or impinged on the end of one.

The igniting flame was that of a standard oxy-acetylene torch mounted so that the fluid jet passed through the hottest part of the flame.

Simulated Wick Conditions

No special test equipment was used for conducting the wick tests other than a simple means for supporting the wick.

DISCUSSION OF TEST RESULTS

Simulated Flight Conditions

The significant test data are presented in Table II, enabling quick and direct com-

TABLE II

Tabulation Of Simulated Flight Test Results

Legend X - Test in Which Fluid Ignited
O - Test in Which Fluid Did Not Ignite

Fluid	Gasoline Fire	Spark	Exhaust Stack	Exhaust Flame
Hydrolube	OOOOOOOOO OOOOOOOOO	OOOOOO	OOOOOOOO OOOOOOOO	OOOOOOOOOO OOOOOOOOO
Type A	OOO	OOO	X OOOOOOOOOOO	OOOOOOOOOO
Type B	OO	OOO	X OOOOO	XX OOOOOOOO
909	XXXXX OOOOOOOOOO OOOOOOOOO	OOOOOOOO OOOOOOOO	X OOOOOOOOOO OOOOOOOOOO OOOOOOOOO	XXXXXX XXXXX OOOOOOO OOOOOO
Silicone	XXX OOOOOOOO	X OOOOOOOOOO	XXXX OOOOOOO	XX OOOOOOO
WS-804	XXXXXXXXXX OO	XXXXXXXX OOOOOO	XXXXXXX OOOOOOOOOOOO	XXXXXXXXX XXXXXXXXX OOOOOOO OOOOOOO
Standard Fluid	XXXXXXXX XXXXXXXX XXXXXXXX OOOO	XXXXXXXXX XXXXXXXXX XXXXXXXXX OOOOOOOOO OOOOOOOOO	XXXXXXXXXXXXX OOOOOOOOOOOOO OOOOOOOOOOOOO OOOOOOOOOOOOO	XXXXXXX XXXXXX OOOOOOOO OOOOOOOO

parisons of the general performances of the fluids tested Each mark, X or O, represents a single test, X being one in which ignition occurred, and O one in which ignition did not occur The variations in engine speed and in fluid pressure are not shown, to simplify the table and because no important or consistent effects of these variations on the test results were discernible Thus, the over-all performance of each fluid is shown in each of the four types of ignition to which they were exposed

Fluid meeting Specification AAF-3580D and another meeting Specification AN-VV-O-366b were tested separately, but no difference in their ignitability was apparent, and they are grouped together in the tabulation as "Standard Fluid " Figs 4 and 5 illustrate typical fires with these fluids

The ignitability of WS-804 is roughly the same as that of the standard fluids In fact, a strict calculation of the data shows it to be slightly more readily ignited, but such close figuring is not considered warranted in view of the necessarily rough nature of the tests Comparison of the fires that resulted from ignition of each of these fluids, especially in the bench tests, indicated that, although WS-804 is as easily ignited, it does not burn with as large and severe a fire as does the standard fluid

Silicone and 909 were much less ignitable than the first two, but could be ignited under certain conditions quite consistently Of the two, 909 appeared to be somewhat less easily ignited

Both fluids of the California Research Corp were less ignitable than those mentioned previously, but Type B proved, as expected, to be noticeably more easily burned than Type A The one fire which is recorded for Type A was unusual, but there could be little doubt that it was this fluid burning It occurred at the exhaust stack (forward of the turbo) immediately after the engine speed had been reduced from 2,400 to 800 rpm The fire could not be repeated, however, in several trials

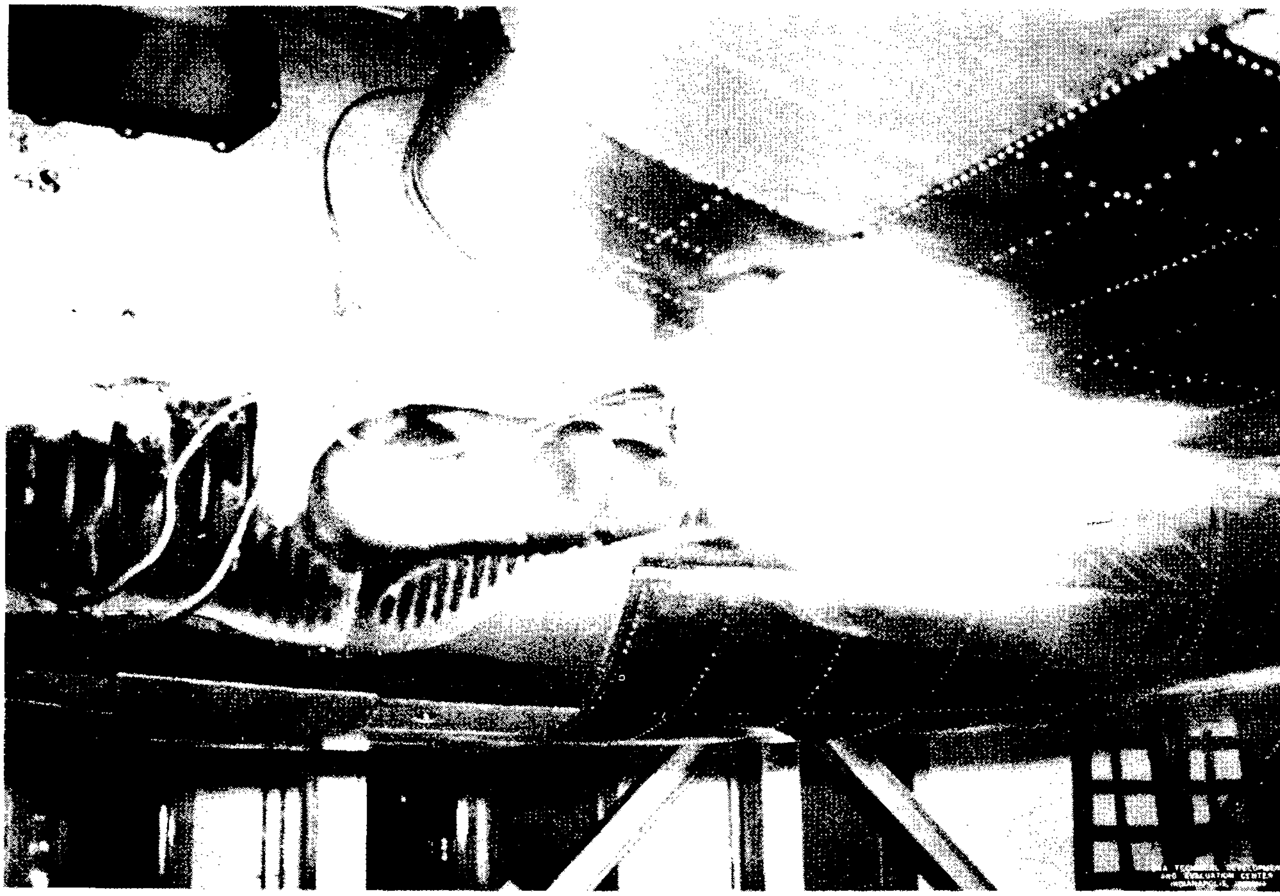

Fig. 4 Typical Fire After Spark Ignition — Standard Hydraulic Fluid

Hydrolube gave no evidence of burning under any conditions.

The order of ignitability of the fluids tested, therefore, is that in which they are listed in Table II.

Of the sources of ignition used, the most severe were the hot exhaust stack (inside the exhaust-stack shroud) and the exhaust gases themselves issuing directly from a cylinder exhaust port.

Variations of engine speed affected ignition in two ways; by changing air flow and by changing the heat emitted by the exhaust and exhaust system. Generally, ignition would be aided by low air flow and more heat, and since these varied oppositely as the engine speed was changed, their effects were commonly nullified. It was possible, however, to combine to some extent the more severe effects of both by sharply reducing engine speed, say from 2,400 to 800 rpm, then immediately ejecting a charge of the test fluid. This was especially severe at the exhaust stack, and frequently resulted in ignition when other conditions did not provide ignition.

Changing the fluid pressure at the discharge nozzle from 1,000 to 3,000 psi had no apparent influence on the occurrence of ignition, unless the nozzle was such that the high pressure caused dispersion of the stream which at low pressure remained a straight jet.

Simulated Crash Conditions

In simulated crash conditions, as determined by bench tests with the equipment shown in Fig. 2, the order of ignitability differed to no great extent from that determined by the tests on the B-29 engine. The results of the bench tests are summarized in Table III, in which the fluids are listed in order of preference from the standpoint of ignitability as determined by these tests. The only change from the order as determined by the engine tests is the position of Type B fluid of the California Research Corp. (No. 50744-R),

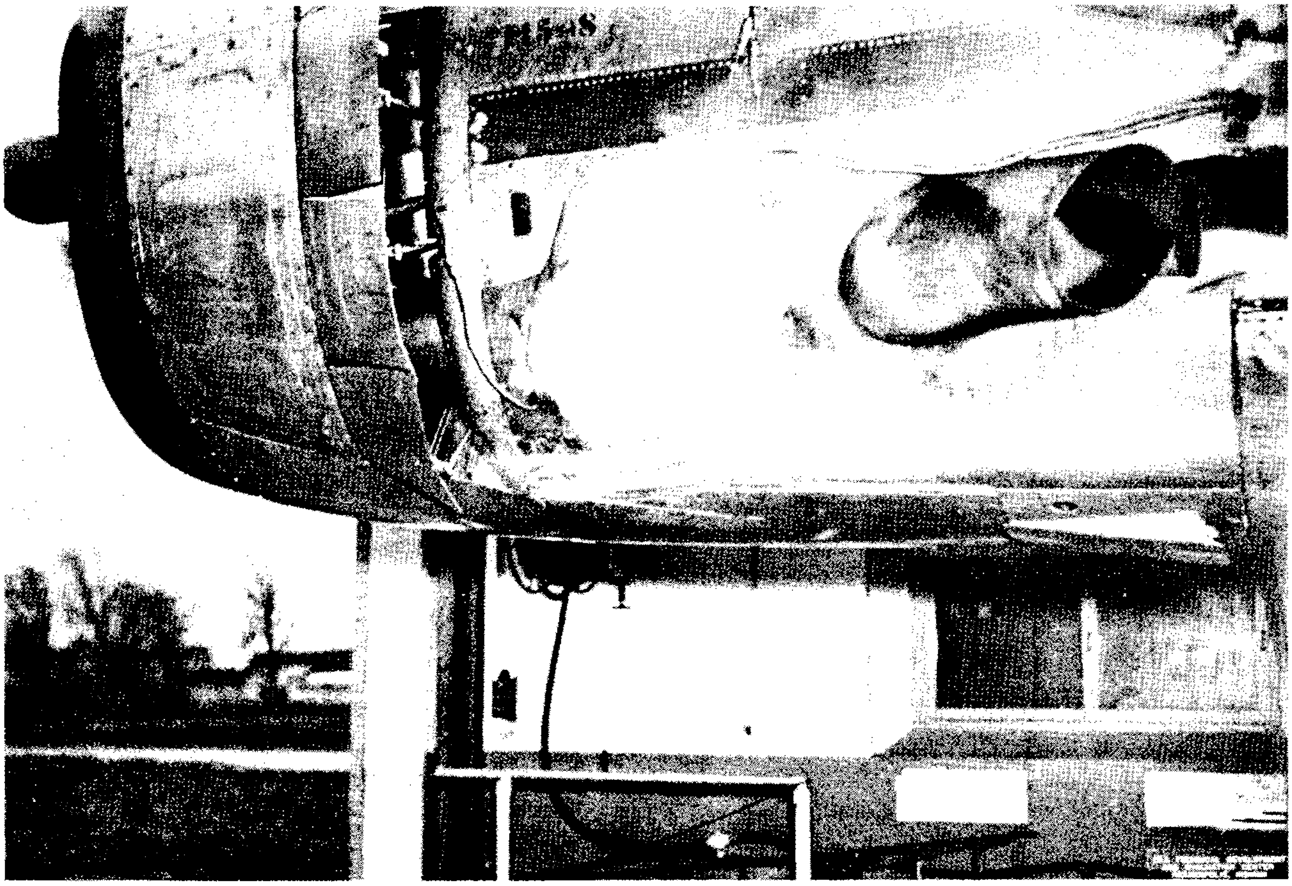

Fig. 5 Typical Fire After Ignition at Exhaust Stack — Standard Hydraulic Fluid

which appeared more easily ignited in the bench tests than did 909 or Silicone.

Simulated Wick Conditions

In the vertical wick tests, the more flammable fluids produced larger flames than the less flammable fluids. In the horizontal wick tests, the flames produced by the more flammable fluids were large and traveled the 6-inch horizontal distance of the wick in a short time, while the flames produced by the less flammable fluids were small, unstable and generally went out before traveling the complete length of the wick.

CONCLUSIONS

1. All the new fluids tested except WS-804 are less easily ignited, under practical aircraft conditions, than the standard aircraft hydraulic fluid.
2. WS-804 would not be appreciably safer for aircraft use than the standard fluid.
3. All the fluids tested except Hydrolube are ignitable under some conditions. Hydrolube is, for practical purposes, not ignitable. Type A fluid of the California Research Corp. (No. 50743-R) is non-ignitable under almost all conditions, and would be very nearly as safe as Hydrolube in aircraft.
4. A practical and standardized testing procedure not requiring the use of an aircraft engine, by which any laboratory could determine the relative ignitability of hydraulic fluids, and possibly other aircraft fluids, is apparently a possibility and would be desirable.
5. Little could be learned of the relative flammabilities of various fluids from the wick tests. The discharging of fluids under pressure through an oxy-acetylene flame seems to be a more accurate and easily observed method for determining the flammability of fluids.

RECOMMENDATIONS

It is recommended that:

1. Silicone, Fluid 909 of the Cook Elec-

TABLE III

Tabulation Of Simulated Crash Test Results

	Electric Arc			Acetylene Flame	
	Stream Between Electrodes	Stream Impinging on Electrode	Spray	Stream Through Flame	Spray
Hydrolube	No Fire	No Fire	No Fire	No Fire	No Fire
Type **A**	No Fire	Very Small Fire	Very Small Fire	No Fire	Very Small Fire
909	No Fire	Small Fire	Small Fire	No Fire	Small Fire
Silicone	Short Flash At Instant of Release of Fluid	Fire	Fire	Short Flash At Instant of Release of Fluid	Fire
Type B	Fire of Short Duration	Fire	Fire	Fire of Short Duration	Fire
804	Fire	Fire	Fire	Fire	Fire
Standard Fluid	Fire	Violent Fire	Violent Fire	Fire	Violent Fire

tric Co , Type A and Type B of the California Research Corp and Hydrolube be investigated further to determine their suitability, from other viewpoints than ignitability, as practical aircraft hydraulic fluids Among these other investigations should be determination of surface tension, since this appears to influence the tendency of the fluid to leak under pressure

2 The standard aircraft hydraulic fluid be replaced as soon as possible with any of the fluids mentioned in Recommendation 1, which is found entirely suitable for this use

3 Further research be applied to the improvement of the experimental fluids tested, especially Hydrolube and the fluids of the California Research Corp and the development of new ones

4 Further study be applied to the development of a simple and standardized testing procedure, not requiring the use of an aircraft engine, but equivalent to practical aircraft conditions, by which any laboratory could test, qualitatively, the ignitability or flammability of hydraulic or other aircraft fluids

5 Cognizance be taken of the serious need for a lubricating fluid which is less flammable than that now used in aircraft engines and accessories, and that any program of hydraulic fluid development include equal attention to lubricating fluids

ACKNOWLEDGMENT

The author wishes to acknowledge the excellent co-operation of the Union Carbide and Carbon Corp , California Research Corp , Cook Electric Co , General Electric Co and Standard Oil Co of New Jersey, which submitted the various fluids for use in this test program Throughout the report, the names of these organizations are used only as a means of identifying the test fluids, because their precise composition is not known to the author and because incomplete identification of the fluids would represent a considerable decrease in the usefulness of this report It should be pointed out that, with the exception of the standard hydraulic fluids, the test fluids are either of a development nature or are primarily intended for other purposes, and have been introduced into this test program for the purpose of obtaining information only

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