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TESTS CONDUCTED TO DETERMINE SAFE METHODS OF DUMPING FUEL FROM AIRPLANES IN FLIGHT

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Tests Conducted to Determine Safe Methods of Dumping Fuel From Airplanes in Flight

SUMMARY

In order that the Bureau of Air Commerce might determine safe methods of dumping fuel from airplanes in flight, a series of tests was conducted to evaluate the fire hazard present in such an operation.

Ignition of discharged fuel may be caused by the various forms of static electricity, lightning, or by exhaust flames, and burning carbon from the engines.

While some types of dump installations discharge the fuel practically clear of any external component of the airplane, others discharge in such a manner that the external surfaces are soaked with the fuel.

Considering the present types of fuel dump installations and the possibility of ignition, the fire hazard was classified into three parts for investigation.

(1) The hazard due to flame propagation forward against the airstream, if ignition occurs at some point aft of the outlet valve.

(2) The hazard due to fuel contacting an external surface if ignition occurs forward of, or on, the surface.

(3) The hazard due to explosions occurring in dump ducts or chutes.

The tests, which were divided into five parts, included the deliberate ignition of gasoline in a free airstream, and the deliberate ignition of gasoline and fuel oils on an airfoil placed in an airstream, an investigation of the combustible gas envelope surrounding dumped gasoline in an airstream, the ignition of gasoline in an airstream by static discharge from an airfoil, and the deliberate ignition of combustible gases in dump ducts.

The tests in the free airstream showed conclusively that flame resulting from the ignited fuel in an airstream will not propagate forward against an airstream of a velocity as low even as 25 miles per hour. Hence, fuel dumped from an airplane free from an external component of the airplane does not constitute a hazard although ignition occurs.

The tests with an airfoil in the airstream indicate strongly that dumped fuel which contacts an external component of an airplane constitutes a serious hazard, since burning may continue once the fuel is ignited. This applies to fuel oils as well as to gasoline, but to a lesser degree.

The investigation of the combustible gas envelope surrounding the liquid fuel spray revealed that the envelope is so confined to the liquid fuel that it is practically nonexistent, and therefore presents no hazard.

The tests dealing with the ignition of gasoline in an airstream by static discharge from an airfoil showed that static discharges of the corona or brush type quite probably would ignite sprayed or atomized gasoline.

Explosion tests with dump ducts or chutes revealed that the explosion pressures are so low that open end ducts, constructed of practicable materials and of appropriate size would not be damaged although explosions occurred within them.

The general conclusion reached from all of the tests is that fuel may be dumped safely if it discharges clear of the aircraft structure.

INTRODUCTION

Practically all large transport airplanes are equipped with fuel dump valves, which provide a means for the rapid discharge of fuel to decrease the load in cases of emergency.

The ever increasing number of transport airplanes, the expansion and development of airways, and the utilization of provisional gross weights, indicate that fuel will be dumped more often than in the past, and hence the safety of the operation becomes of paramount importance

Analysis of the problem

The obvious matter to be investigated in connection with the dumping of fuel from airplanes in flight is that of fire resulting from the ignition of the fuel There are several sources of ignition which present possibilities of having sufficient intensity to ignite atomized fuel or combustible mixtures of air and gasoline They are any one or a combination of the following

1 Static discharge from the fuel to the dump valve or duct
2 Static discharge from an airplane to the air
3 Lightning strokes
4 Sparks originating within the airplane from auxiliary electrical devices, or from improper or defective bonding (This source constitutes a hazard when combustible mixtures enter the interior of airplane structures due, for example, to the outside surfaces being soaked with fuel)
(5) Burning carbon or flames from the engine exhaust stacks

The possibility of ignition is realized when it is considered that the fuel upon leaving the airplane and entering a high velocity airstream, becomes atomized immediately The degree of atomization depends upon the type and location of the fuel outlet

The variety of types of fuel-dump installations found on modern airplanes indicates a difference of opinion on the part of designers as to the existence of a hazard and as to the degree of such hazard if existent It is reasonable to assume that the most hazardous type of fuel outlet is the one so designed that large areas of the external surfaces of the airplane become soaked with the dumped fuel, and that the least hazardous is one so designed that all of the dumped fuel passes entirely clear of any component of the airplane Types of modern fuel-dump installations vary to such an extent that all degrees of conditions between the two described above, may be encountered

In view of the possibility of ignition and the types of fuel-dump installations now in existence, there appear to be three distinct problems to be considered, as follows

1 The possibility of forward propagation of flames resulting from the ignition of fuel in a free airstream

Whether or not this presents a hazard depends upon the propensity of flame from burning fuel to propagate forward in an airstream of a velocity equal to, or greater than the minimum flying speed of the airplane concerned

2 The danger which might be present if fuel spray or combustible mixtures contacted any external surface of an airplane

This circumstance might present a hazard because of boundary layers, eddy currents, etc This implies that air velocities may be very low in the vicinity of window and door mouldings, metal lap joints, inspection doors or openings, hinges, control surface openings or slots corners formed by the junction of control surfaces with wings or fuselage, and therefore dumped fuel contacting such parts constitutes a hazard, since burning might continue regardless of the speed of the airplane, once the fuel is ignited

3 The danger from explosions occurring within dump chutes

In several designs, metal ducts are provided below the wings or fuselage to guide the fuel away from the airplane Immediately after the fuel-dumping operation, or due to a slight leak in the dump valve, these ducts may contain a combustible mixture which might be ignited by a static spark

Recognizing the importance of these possible hazards, the Bureau of Air Commerce determined to conduct tests to evaluate them The possible hazard of an explosion occurring within the structure is neglected for the simple reason that any fuel-dumping system which permits fuel or combustible mixtures to enter the interior of an airplane structure is considered, without argument, to be dangerous.

The tests were conducted at the National Bureau of Standards. The decisions as to the general course of action for the tests were agreed upon by an informal committee representing the National Bureau of Standards, the U. S. Navy, the U. S. Army, the National Advisory Committee for Aeronautics, and the Bureau of Air Commerce; and the helpful cooperation of these other agencies proved exceedingly valuable.

Helpful suggestions also were received from the Underwriters' Laboratories of Chicago and from the University of Detroit.

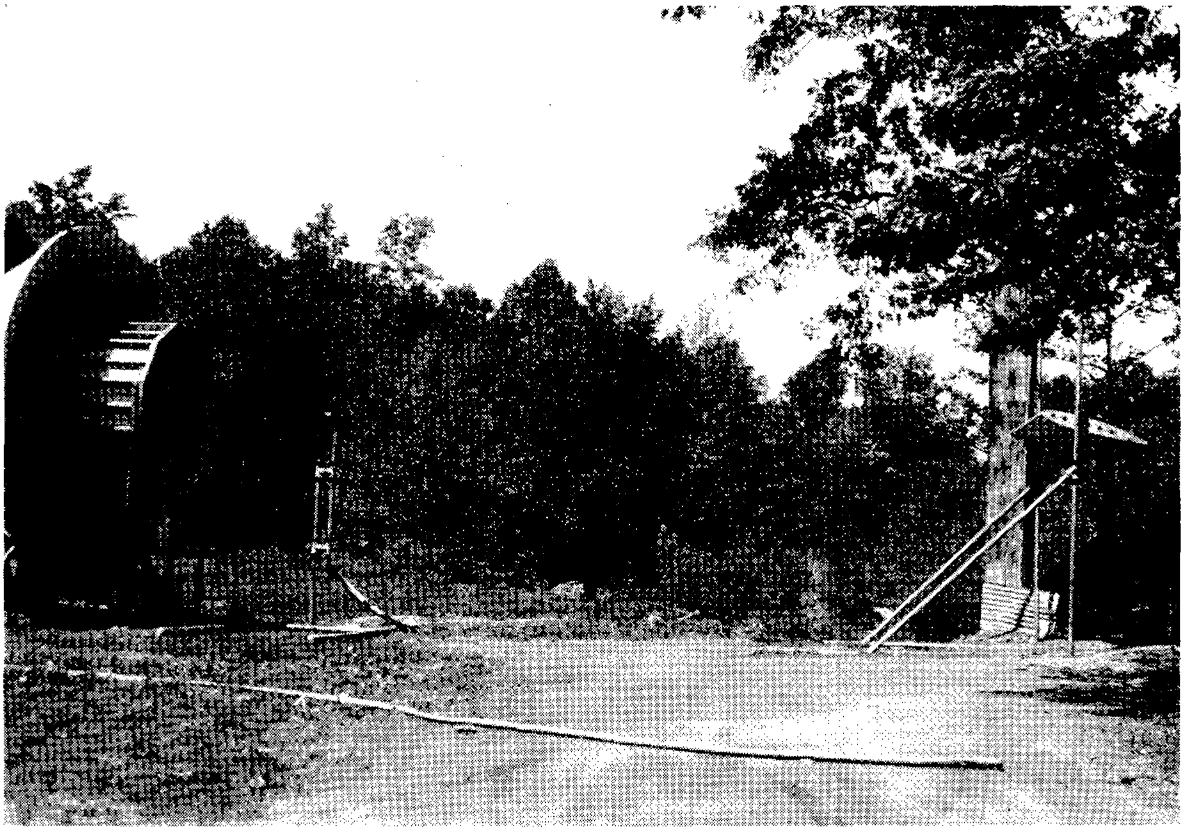

Figure 1.—General view of test set-up.

TEST PROCEDURE

The tests were conducted in five parts as follows:

I. Experiments in Free Airstream.

II. Experiments with an Airfoil in an Airstream.

III. Experiments with the Combustible Gas Envelope Surrounding the Liquid Gasoline Spray.

IV. Experiments on the Ignition of Gasoline by Static Discharge from the Trailing Edge of an Airfoil.

V. Experiments with Combustible Mixtures in Dump Ducts.

Each of these five parts is described independently herein.

An airstream was produced by an outside wind tunnel located at the National Bureau of Standards. For Parts Nos. II, III, and IV (see above) an adjustable airfoil with a flap was mounted in the airstream. The fuel supply was provided by a 20-gallon tank connected to a two-inch diameter pipe which led to the center of the airstream at the open end of the tunnel. The supply line was equipped with a quick acting shut-off valve in combination with an adjustable gate valve to regulate the rate of flow. See figures 1 and 2. In figure 2 note the supply tank mounted in the tree.

In all of the tests, with the exception of Part IV, the fuel was deliberately ignited by means of spark gaps.

Physical characteristics of airfoil:

N. A. C. A. M-3 section.

Chord	50 inches.
Span	8 feet, 9 inches.
Flap Chords	25% of airfoil chord.

Wooden interior covered with 20-gauge, galvanized iron. Leading edge of airfoil 26 feet behind fuel outlet.

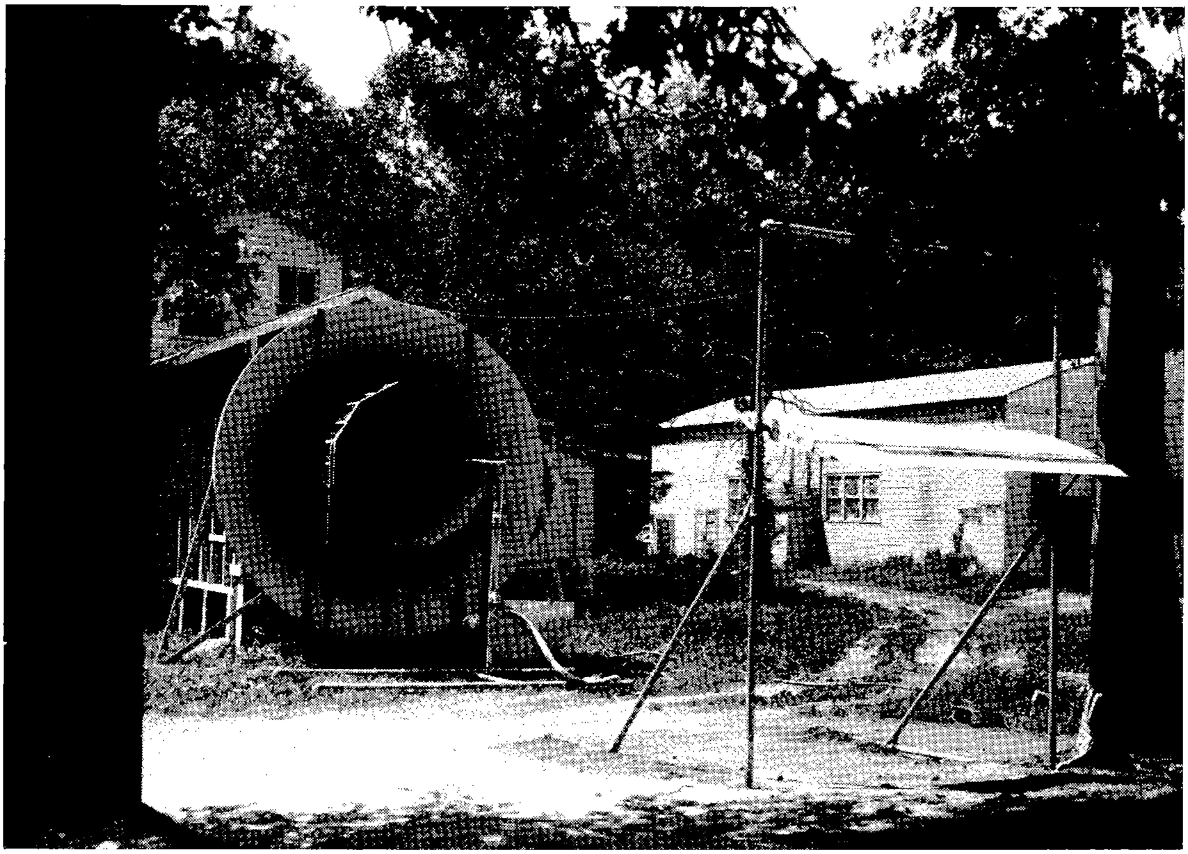

Figure 2.—General view of test set-up.

The following are general data pertaining to the test set-up and procedure.

GENERAL DATA

Diameter of tunnel at open end	7 ft.
Maximum airspeed (in vicinity of airfoil)	70 m. p. h.
Maximum rate of fuel flow	40 gal. per min.

Grades of fuel used:

Gasoline: Domestic Aviation	73 Octane
Fuel oil (furnace): Flash point	140° F.
Diesel oil: Flash point	250° F.

(The viscosity of the oils was slightly higher than that for kerosene.)

Part I.—EXPERIMENTS IN FREE AIRSTREAM

(*Without Airfoil in Place*)

Purpose.

To evaluate possible hazards resulting from the ignition, at a point behind the outlet, of dumped gasoline in a free airstream.

Introduction.

These tests are confined to those hazards involved when gasoline does not contact any component of the airplane after leaving the dump valve or chute. Assuming ignition to occur after the gasoline has left the outlet, it is desired to investigate the possibility of flame propagation forward against an airstream of a velocity equal to or greater than minimum flying speeds.

Test procedure and results.

Ignition was produced by means of a spark gap located on the end of a long pole. See figures 3, 4, 5, and 6. The tests were conducted in the following manner:

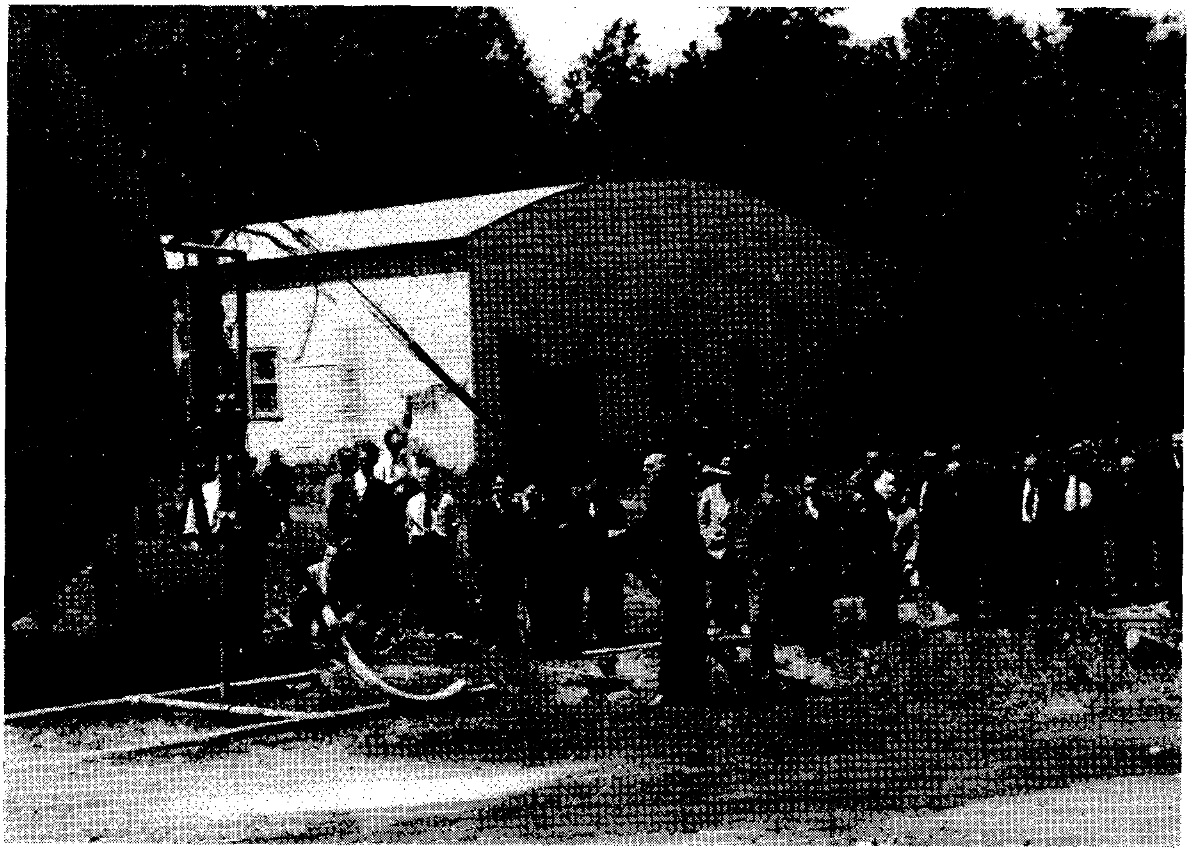

Figure 3.—Test setup for investigating flame propagation in free airstream with pole ignitor in place.

Run No. 1.

The ignitor was held approximately four feet aft of the outlet pipe. The gasoline was turned on and the quantity increased in stages from zero to 40 gallons per minute. The airspeed was 70 miles per hour. There was no tendency at any time for the flame to propagate forward against the airstream, and in all instances when the ignitor was removed the flame was blown aft by the airstream. Figure 6 shows the flame leaving the sprayed gasoline immediately after the ignitor was removed. Figure 5 shows the condition just prior to that shown on figure 6.

Run No. 2.

The ignitor was applied at the point of the gasoline outlet. In the first part of this run an auxiliary ¼-inch internal diameter copper tube supplied the gasoline in place of the regular two-inch diameter pipe. See figure 7. The airspeed was varied between 25 and 70 miles per hour, and in no instance would the flame persist once the ignition was turned off. In the second part of this run, the regular fuel supply pipe was used, and the quantity was increased in stages to 40 gallons per minute. The results were identical to those described in Run No. 1.

Figure 4.—Gasoline spray being ignited 4 feet aft of outlet.

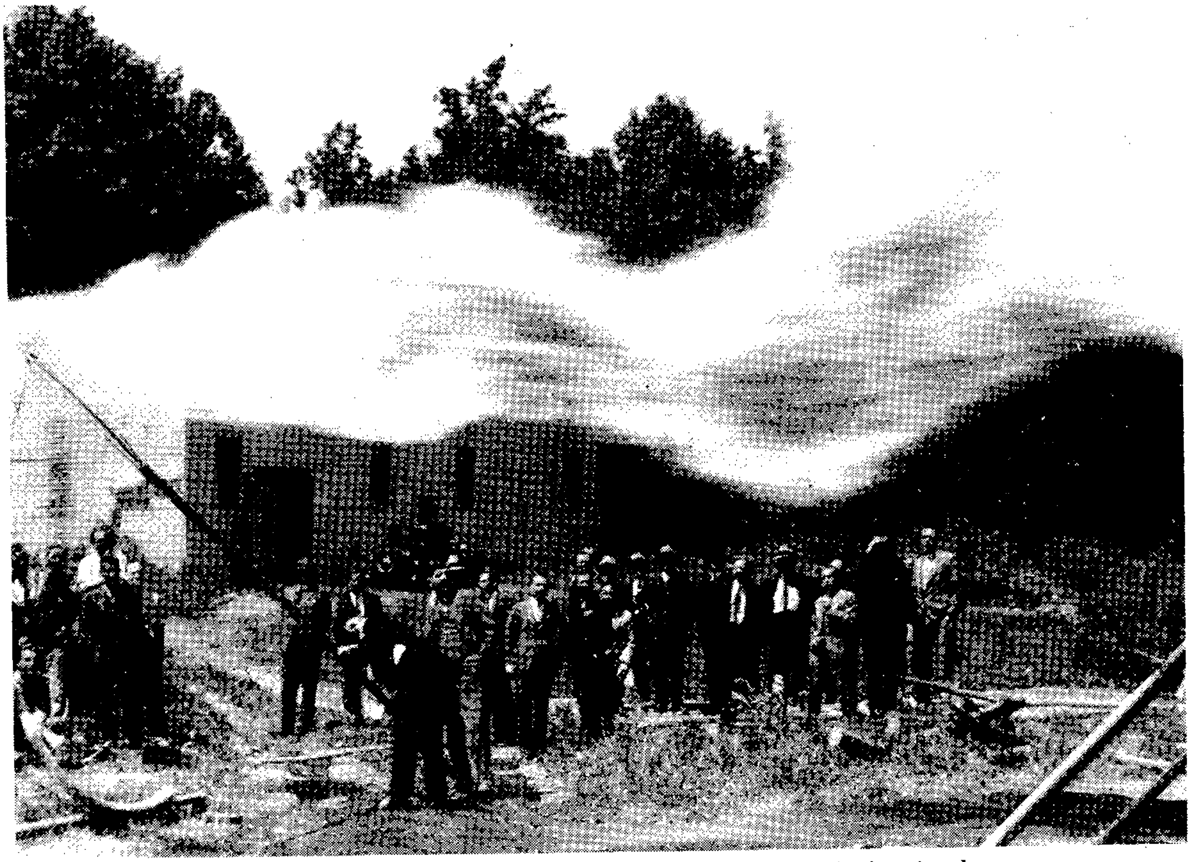

Figure 5.—Gasoline spray burning in free airstream with ignitor in place.

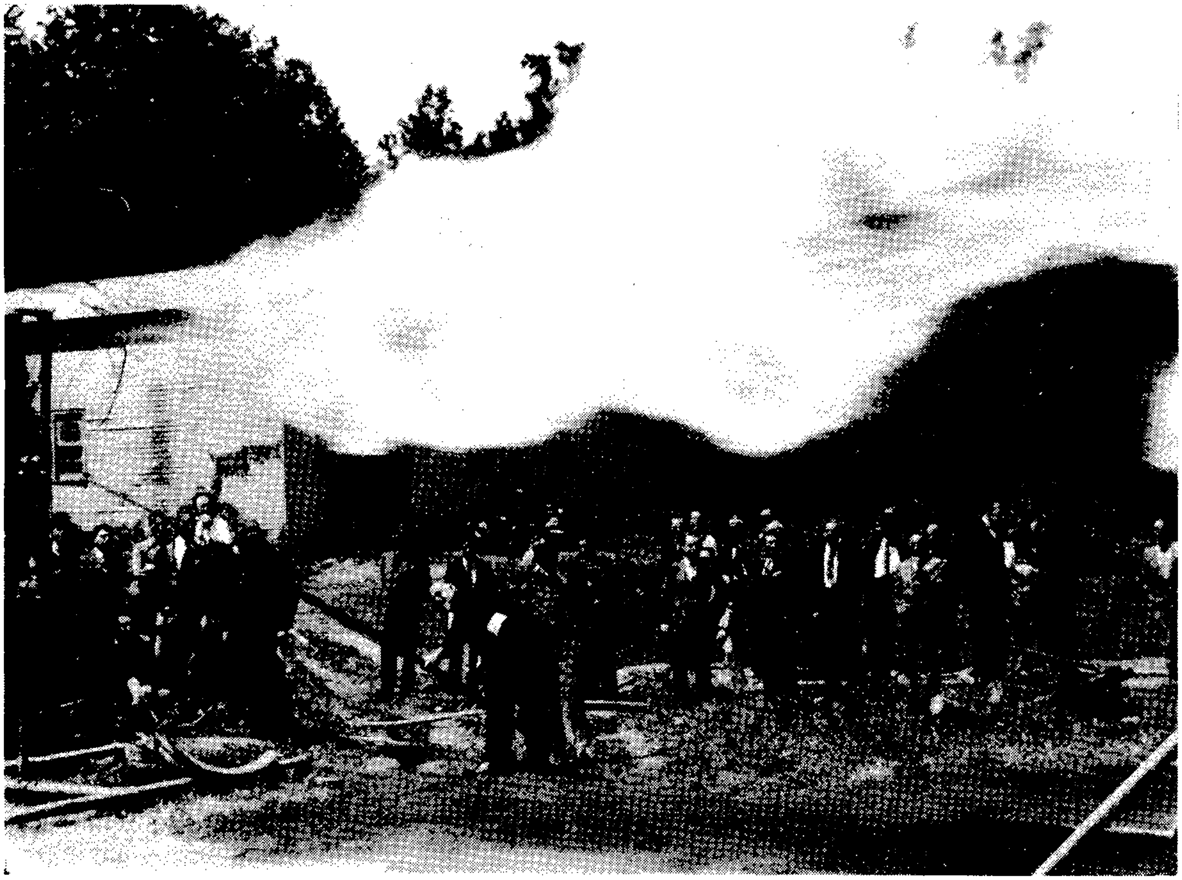

Figure 6.—Gasoline spray immediately after removing ignitor. Flame is being blown downstream.

Run No. 3.

This run was identical to Run No. 1, except that the ignitor was held approximately 10 feet aft of the outlet pipe. The results were identical to those described in Run No. 1.

Conclusions.

Dumped fuel which does not contact any component of an airplane after leaving the outlet valve or chute does not constitute a hazard to the airplane even if ignition of the fuel should occur.

Part II.—EXPERIMENTS WITH AN AIRFOIL IN AN AIRSTREAM

Purpose.

To evaluate the hazards involved when dumped fuel contacting an external surface of an airplane, is ignited.

Introduction.

A discussion of the hazards involved under these conditions is given on page 2. An airfoil with flap was used to simulate an external surface of an airplane.

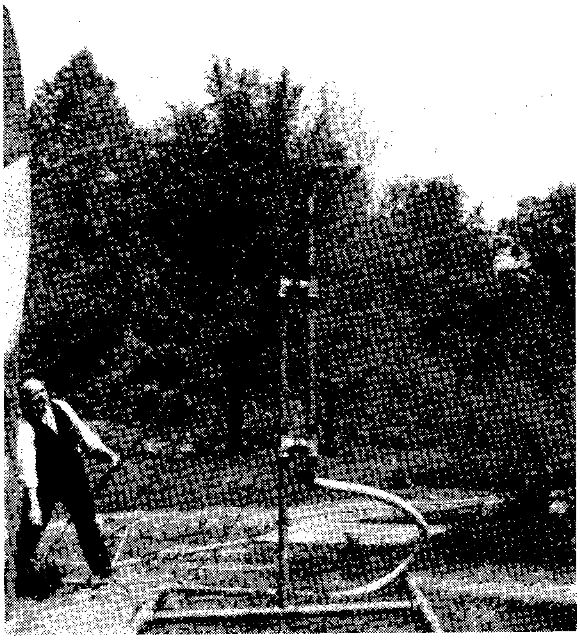

Figure 7.—Free airstream test with ignitor at point of gasoline outlet.

Test procedure and results.

See figures 1 and 2 for a general view of the set-up. See page 4 for the physical characteristics of the airfoil. Ignition was deliberately provided by the pole ignitor as used in Part I except in isolated cases where ignition

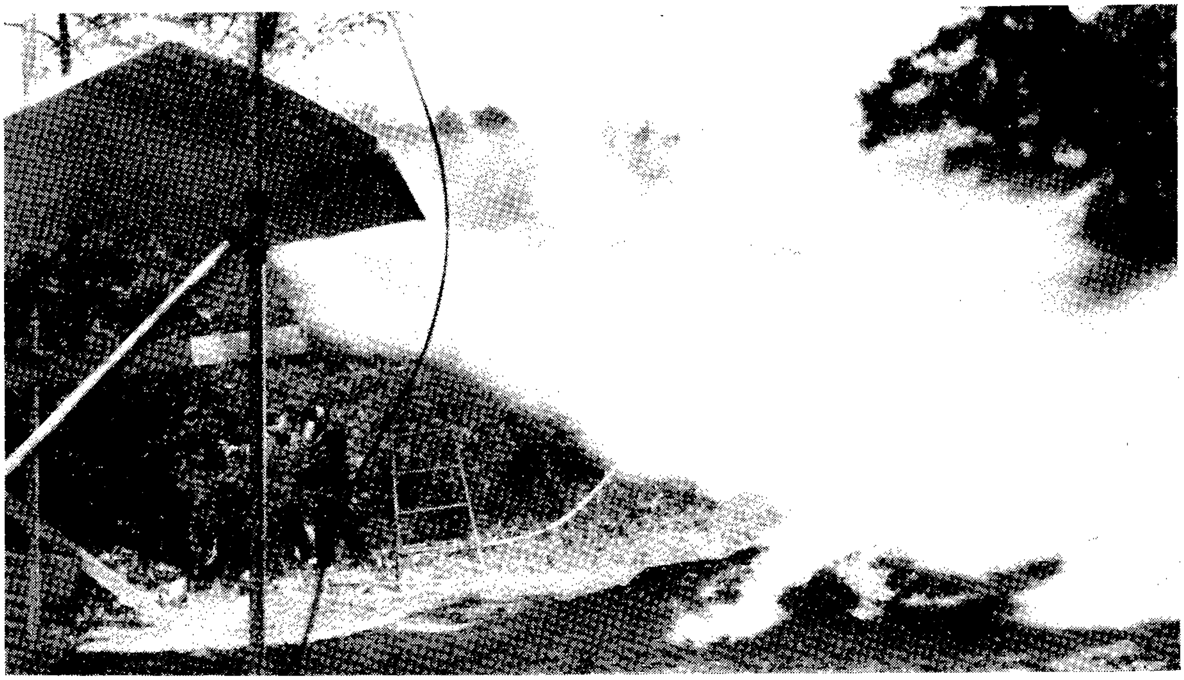

Figure 8.—Airfoil with flap deflected, ignitor at leading edge.

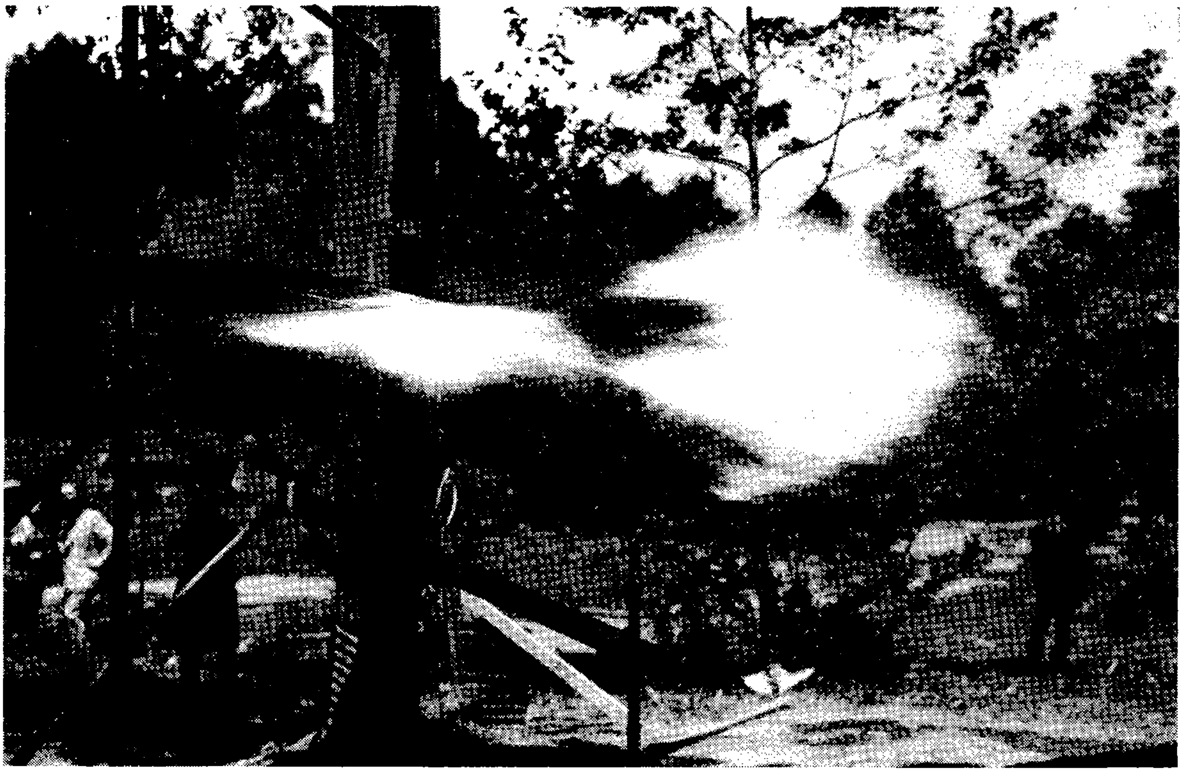

Figure 9.—Airfoil with zero flap deflection, ignitor at leading edge.

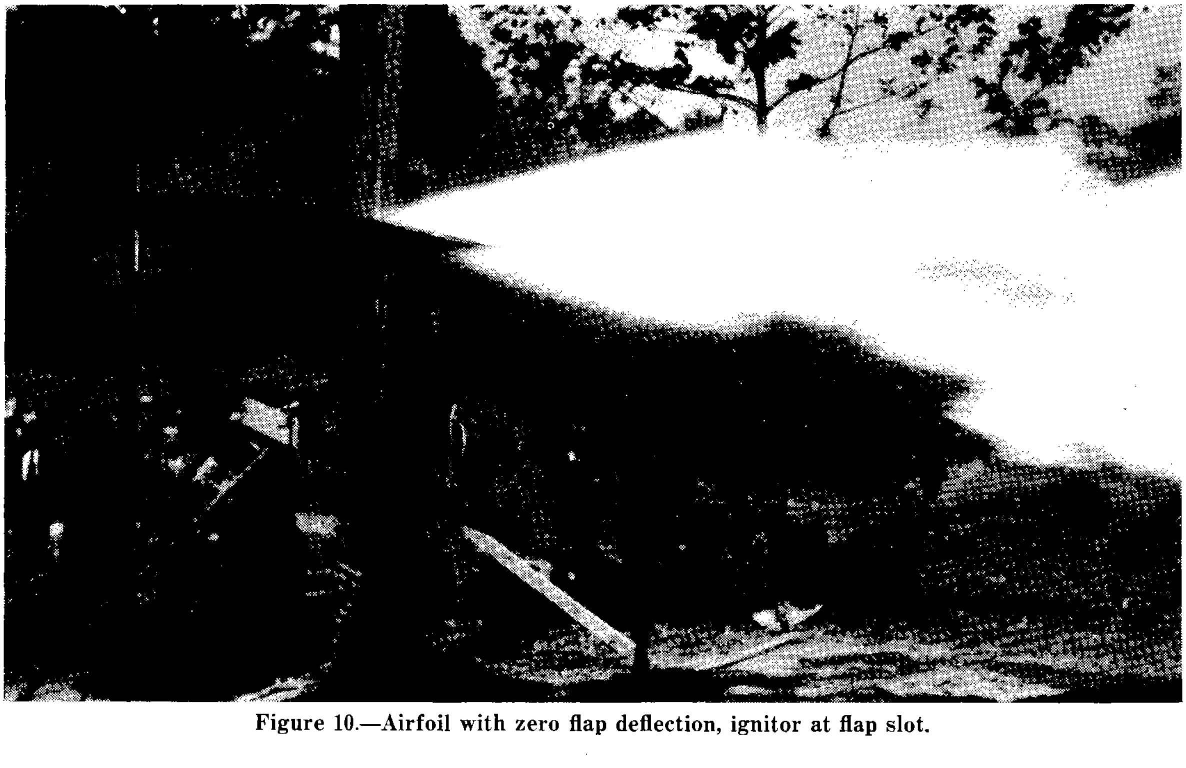

Figure 10.—Airfoil with zero flap deflection, ignitor at flap slot.

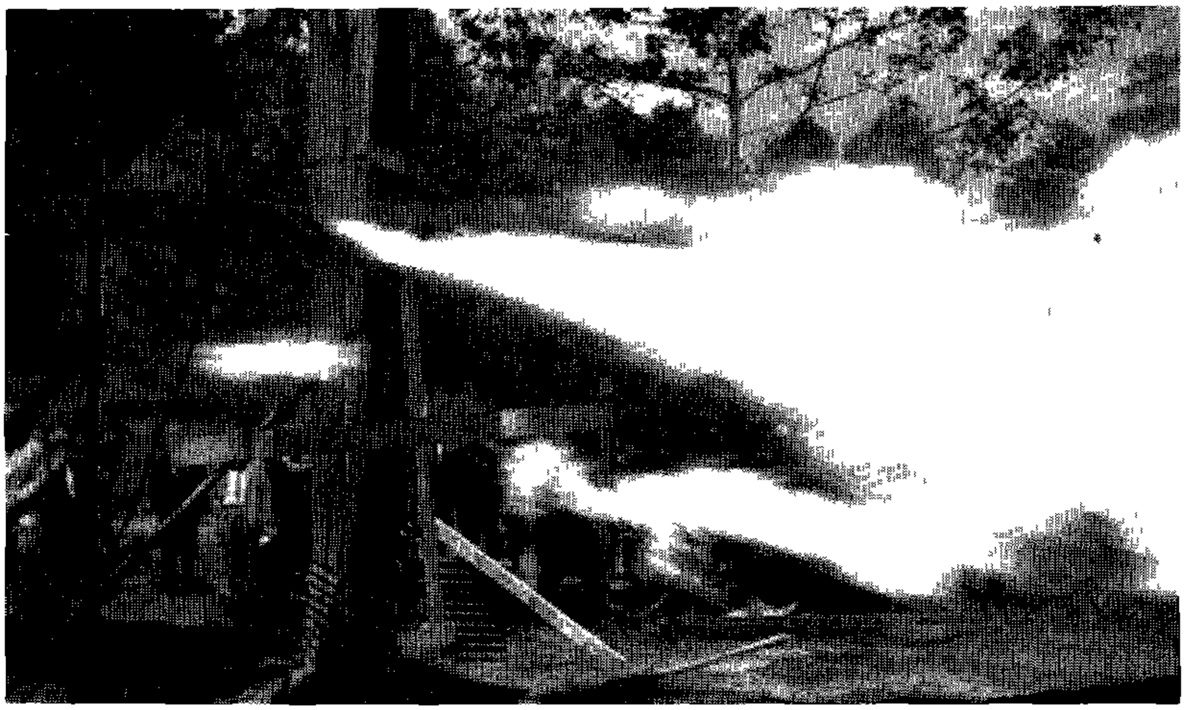

Figure 11 —Airfoil with flap deflected, ignitor at leading edge Flame pattern immediately after ignition

Figure 12 —Airfoil with flap deflected, ignitor at trailing edge Flame pattern immediately after ignition

Figure 13—Airfoil with zero flap deflection, spoiler on ignitor at leading edge

Figure 14—Airfoil with flap deflected, spoiler on, ignitor at leading edge

was provided by spark gaps located in the flap slot All runs were made at 70 miles per hour airspeed In all runs the fuel was directed so that it contacted the airfoil and ignition was made at some point on the airfoil or flap Fuel quantity, point of ignition, and attitude of airfoil and flap were varied over a series of runs In several of the runs a 1/8-inch thick by 1/2-inch wide steel spoiler strip was attached span-wise along the upper surface of the airfoil at approximately one-third of the airfoil chord This strip may be seen on figure 16 In three of the runs a 0 032-inch thick aluminum alloy sheet was attached to the flap to determine the effect of the heat on the aluminum alloy The tendency to ignite and the behavior of the flame after ignition was noted for all runs These tests include the use of furnace fuel oil (flash point 140° F) diesel oil (flash point 250° F), and gasoline (Domestic aviation, 73 octane)

The results of the tests are given in table form on pages 14 and 15 All references made in the Remarks column to the "flame continued" or "persisted" mean that the flame continued or persisted AFTER the ignitor was removed or shut off

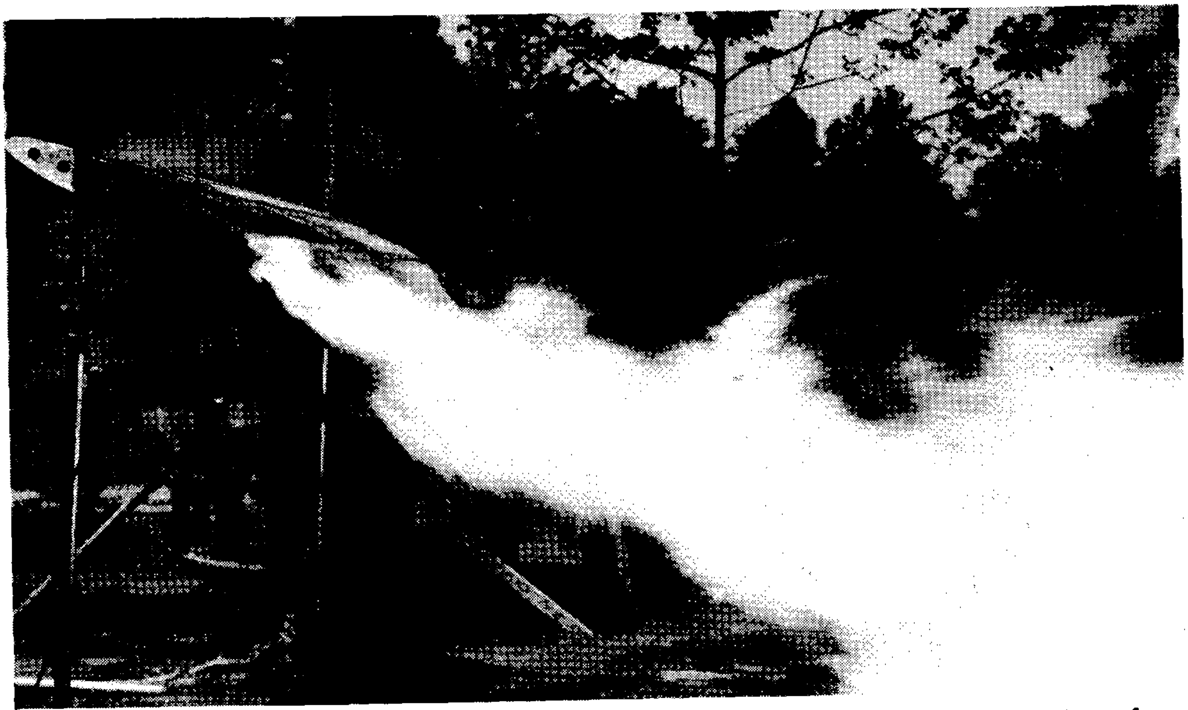

Figure 15.—Airfoil with flap deflected, spoiler on, ignitor at flap slot. Flame pattern at late stage of run.

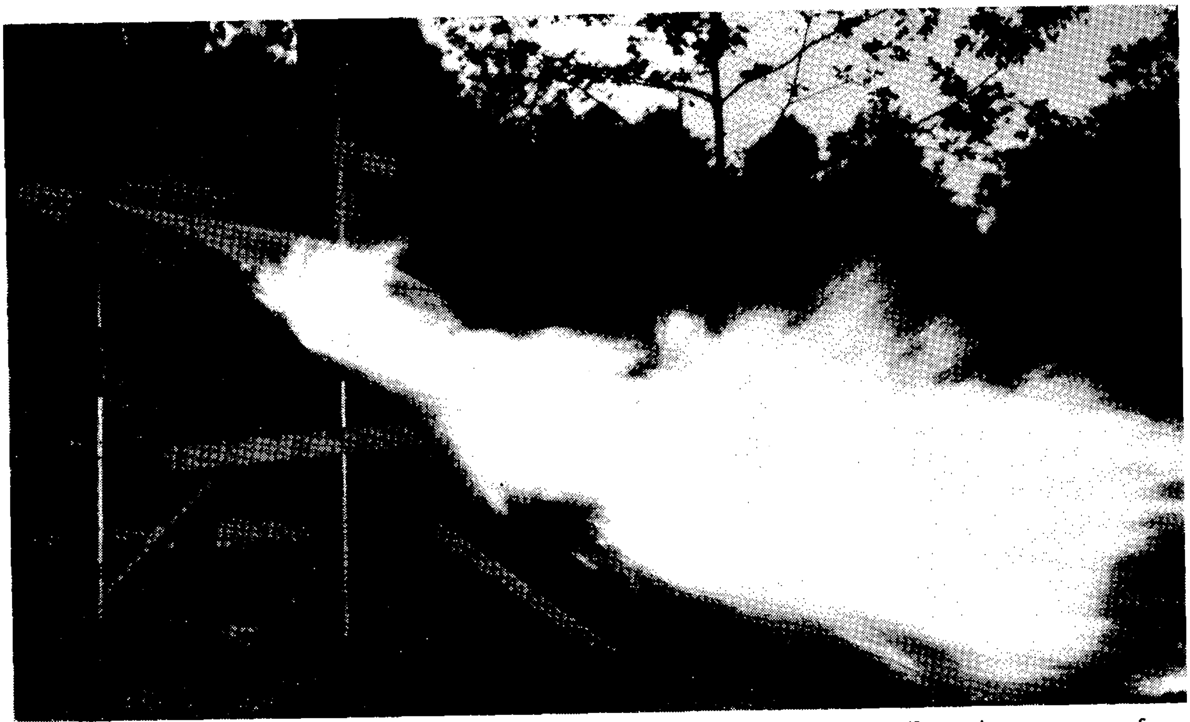

Figure 16.—Airfoil with flap deflected, spoiler on, ignitor at trailing edge. Note spoiler strip on upper surface.

Test Results

Part II

Run No	Quan and type of fuel [1]	Airfoil angle of attack to airstream	Flap angle to airfoil	Point of ignition	Spoiler strip	Remarks
1	G-23	0	0	LE	Off	Ignition slightly difficult but the fuel once ignited continued burning violently from the flap slot to the T E figure 9 shows the first attempt at ignition
2	G-23	0	0	LE	On	After ignition the flame clung just aft of the spoiler strip and continued violently above the airfoil See fig 13
3	G-23	0	0	Slot	Off	The flame continued violently above and moderately below the flap and in the flap slot The flame persisted in the flap slot after the fuel had been shut off See fig 10
4	G-23	0	0	Slot	Off	Practically same results as for Run No 3
5	G-23	0	0	Slot	On	The flame continued above and below the flap and in the slot but did not progress forward of slot
6	G-23	0	0	TE	Off	T E traversed spanwise with ignitor Flame would not continue or progress forward over the flap from the T E
7	G-23	0	0	TE	Off	Practically same results as for Run No 6
8	G-23	0	0	TE	On	Practically same results as for Runs No 6 and 7 Spoiler strip had no effect
9	G-23	0	30	LE	Off	Fig 11 shows flame pattern immediately after ignition The flame continued in various patterns over the flap until the fuel supply was shut off
10	G-23	0	30	Slot	Off	Flame continued on top of the flap and in the slot
11	G-23	0	30	TE	Off	Fig 12 shows the flame pattern immediately after ignition Flame progressed forward to the slot and continued
12	F-23	0	20	LE and Slot	On	Fuel would not continue burning when ignitor was removed Fig 18 shows attempted ignition at slot
13	D-40	0	20	LE and Slot	On	Practically same results as for Run No 12
14 (a)	G-23	8	0	TE	Off	Ignition difficult Flame clung to upper flap surfaces a distance of approx 2 inches forward of T E
14 (b)	G-23	8	0	TE	Off	Same behavior as for Run No 14 (a) except that a lap joint (in longitudinal direction) made by two sheets of 20 gauge galvanized iron which covered the flap provided an irregularity which caused the flame to cling to the flap at this point
15	G-23	8	10	TE	Off	Flame progressed forward on top to slot and continued on top and in slot
16	G-23	8	10	LE	Off	Aluminum alloy sheet on flap Flame continued violently below and moderately above the flap and in the slot Sheet broke into small pieces and fused slightly These pieces were very brittle
17	G-40	20	25	Slot	On	Run No 16 repeated with 40 gal per min See fig 17 for flame pattern at one stage of the run The flame existed for approximately 25 seconds Small particles of the sheet completely fused were found on the ground after the run
18	G-23	8	10	LE	Off	Aluminum alloy sheet attached to TE and extended beyond T E This was an attempt to eliminate the cooling effect of the flap which possibly existed when the sheet was attached as in Run No 16 The results were the same as for Run No 16 except that the sheet did not break but fused slightly and became exceedingly brittle A minor explosion occurred within the flap approximately one minute after the run was completed
19 (a)	G-23	20	0	Slot	On	Fuel ignited readily and continued in the slot and below the flap
19 (b)	G-23	20	0	Slot	On	Results same as for Run No 19 (a)
19 (c)	G-23	20	0	Slot	On	Results same as for Run No 19 (a)

[1] The number is fuel quantity in gallons per minute G Gasoline F Furnace Oil D Diesel Oil

Test Results—Continued

Part II—Continued

Run No	Quan and type of fuel	Airfoil angle of attack to air-stream	Flap angle to airfoil	Point of ignition	Spoiler strip	Remarks
20	G–40	20	25	LE	On	Fuel ignited readily and continued violently See fig 14 for flame pattern
21	G–23	20	25	Slot	On	Flame continued violently above and below flap but did not progress forward of slot See fig 15 for flame pattern at late stage of run
22	G–23	20	25	TE	On	Flame progressed to slot and continued See fig 16 for flame pattern
23 (a)	G–23	20	30	LE	On	Flame ignited readily and continued violently on top of the flap, in the slot, and slightly forward of slot on top of airfoil Fig 8 although not a photograph of this particular run shows the approximate flame pattern
23 (b)	G–23	20	30	LE	On	
23 (c)	G–23	20	30	LE	On	
24	F–23	20	30	LE	On	Ignition more difficult than for gasoline The flame continued in the vicinity of the flap as shown on fig 20 Fig 19 shows the flame pattern just before the ignitor was removed
25	F–23	20	30	Slot	On	Same results as for Run No 24 Fig 20 shows the approximate flame pattern
26	D–40	20	30	LE	On	Same results as for Run No 24 except that ignition was slightly more difficult than for the furnace oil
27 (a)	G–23	−5	0	LE	On	The flame persisted only momentarily behind the spoiler strip but continued violently in the vicinity of the slot and flap
27 (b)	G–23	−5	0	LE	On	Same results as for Run No 27 (a) except that the flame persisted behind the spoiler strip for a longer period of time
28 (a)	G–23	−5	0	TE	On	The flame progressed forward to the flap slot and continued violently above and moderately below the flap and in the flap slot
28 (b)	G–23	−5	0	LE	On	Same results as for Run No 28 (a)
29	G–23	−5	0	TE	Off	Same results as for Run No 28 (a)
30 (a)	G–23	−5	30	LE	On	The flame continued violently above and below the flap and in the slot
30 (b)	G–23	−5	30	LE	On	Same results as for Run No 30 (a)

Discussion of results

After a few trial runs at the beginning of the tests, it was evident that it would be exceedingly difficult to obtain quantitative results by varying fuel quantity, airspeed, attitude of airfoil and flap, and points of ignition in a regular prearranged sequence The tests were therefore confined to obtaining qualitative results only and the limitations on the procedure were

(1) No runs were made at less than 70 miles per hour airspeed since this is probably the lowest speed at which fuel would be dumped in actual operation

(2) The fuel quantity was limited to two values, 40 and 23 gallons per minute The former value was the maximum obtainable The latter represented two turns on the control valve and was used in the majority of runs instead of the maximum to prevent the test airfoil from becoming seriously damaged by heat before the tests were concluded

(3) The attitudes of the airfoil and flap and the points of ignition as shown in the test results were purely arbitrary selections intended only to show the qualitative effect of change

Runs No 1 through No 8 were conducted with the airfoil and flap at zero degrees to the airstream with the spoiler strip first on and then off for all three points (L E, flap slot, and T E) of ignition From these runs it is significant to note

(1) That the flame would not progress forward when the fuel was ignited at the trailing edge
(2) That the flame would continue in and aft of the slot when ignition was made either at the leading edge or at the slot
(3) That the spoiler strip was ineffective in maintaining the flame behind it except when ignition was made at the leading edge

In all subsequent runs, with the exception of those with the fuel oils, where the attitude of the airfoil or flap varied from zero degrees to the airstream, the flame would continue regardless of point of ignition and would progress forward when ignition was made at the trailing edge In general ignition became easier and flame violence greater as the angle of the flap and airfoil increased with respect to the airstream

In the runs using fuel oils considerable angle of the airfoil and flap to the airstream was required to permit the flame to continue In general, the fuel oils were more difficult to ignite and were extinguished more easily than the gasoline, but while burning, they appeared to observers to produce more heat than gasoline for equal quantities

The effect of the spoiler strip was very noticeable, in that it permitted the flame to cling to the airfoil just aft of the strip A lap joint on the flap produced a similar effect as described in Run No 14 (b) In many of the runs the flame continued quietly in the flap slot after the fuel supply was shut off

Runs No 16, 17, and 18 showed the effect of the intense heat on aluminum alloy sheets In all three runs the flame existed for less than 30 seconds and changed the physical properties of the sheets to such an extent that they would be entirely incapable of supporting a load

In many of the runs the important effect of fuel quantity on ease of ignition and flame violence was particularly noticeable The less the fuel quantity the more difficult the ignition became and the less violent the flame

Although the maximum airspeed possible in the test was 70 miles per hour, there is reason to believe that similar conditions would exist at a much higher airspeed The continuance of the flame on the airfoil after the ignitor is removed is caused by local regions of low air velocity resulting from boundary layers, protuberances and eddy currents These would not necessarily be eliminated by an increase in airspeed

Conclusions

1 The dumping of gasoline from an airplane in flight in such a manner that it contacts an external surface of the airplane is considered hazardous since, if it were accidentally ignited, burning on the surface might continue after the source of ignition had disappeared

2 The hazard is increased by the presence of protuberances and irregularities on the surface and by deflection of control surfaces or increase of angle of attack of the fixed surfaces

3 Aluminum alloy surfaces, constructed of sheets of 0 032 inch or less in thickness and subjected to burning gasoline in quantities of 40 gallons per minute or greater, and in a 70 mile per hour airstream would be seriously damaged in less than 30 seconds

4 Fuel oils having flash points up to 250° F are more difficult to ignite than gasoline but, once ignited, appear to produce more heat for equal quantities Such oils are considered less hazardous than gasoline

Part III—EXPERIMENTS WITH THE COMBUSTIBLE GAS ENVELOPE SURROUNDING THE LIQUID GASOLINE SPRAY

Purpose

To determine the extent of the combustible gas envelope surrounding the liquid gasoline spray

Introduction

While dumping gasoline, the possibility of combustible gases contacting an external surface of an airplane, although the liquid gasoline passes clear of the surface, is considered of importance These gases may be dangerous if they enter the interior of the airplane structure through vents, drains, etc

Test procedure and results

The location of the airfoil used in Part II was varied vertically with respect to the centerline of the gasoline stream. Detection of possible gasoline vapors was made by the use of a combustible gas indicator (Mines Safety Appliance Company Type W–5) and by spark gap ignition. Two gas vapor inlet tubes (¼ inch, inside diameter, copper) were attached to the lower surface of the airfoil. One was placed 12 inches aft of the leading edge at the center of the airfoil and the other four inches aft of the leading edge of the flap at the center of the flap. These tubes were run to the gas indicator.

The attitude of the airfoil and flap was arbitrarily varied over a series of runs. Gas samples were taken and ignition attempted at various relative locations of the airfoil and centerline of the gasoline stream. All runs were made at 70 miles per hour airspeed.

The "mixture" in the test results gives the percentage of gas vapor, by volume, in the total mixture. (NOTE.—The lower limit of the explosive range for gasoline vapor and air mixtures is approximately 1.4 percent of gas vapor, by volume, in the total mixture.)

Discussion of results

The test results indicate that the combustible gas envelope around the fuel spray is confined exceedingly close to the liquid fuel. In none of the runs were combustible gases indicated even though "waves" of fuel contacted the airfoil.

The attempts at ignition failed due, probably, to the high dilution of the fuel by air at the "edges" of the fuel spray. The test results indicate that, when dumping fuel from an airplane, if the fuel spray just clears an external component of the airplane no hazard need be expected from the combustible mixture surrounding the liquid fuel.

Test Results

Part III

Run No	Fuel [1]	Airfoil [2]	Flap [3]	Inlet [4]	Location [5]	Mixture [6]	Remarks
1	33	0	10	For'd	30	0	The "edge" of the fuel stream passed approx. 2 feet below the airfoil but occasional "waves" practically contacted the lower surface
2	33	0	10	For'd	19.5	1.4	The fuel occasionally wet the lower surface
3	40	0	10	For'd	19.5	1.5	Same as for Run No. 2
4	40	0	10	Aft	10.5	0	Same as for Run No. 2
5	40	0	10	Aft	13.5	2.0	Approx. 10 percent of the fuel passed over the top of the airfoil
6	40	0	−30	Aft	13.5	0	Same as for Run No. 5
7	40	−20	−30	Aft	13.5	2.1	Considerable fuel passed over the top of the airfoil
8	40	−20	−30	For'd	13.5	1.7	Same as for Run No. 7
9	40	−20	−30	None	23.5	(7)	Spark ignition was attempted at the flap lower surface and at the leading edge of the airfoil with no success. A slight quantity of fuel passed over the airfoil
10	40	−20	−30	None	9	(7)	Spark ignition was attempted at the leading edge and intermittent ignition was attained by holding the ignitor continually in the spray. Very little tendency for the flame to cling to any part of the airfoil was noted. Approx. 25 percent of the fuel passed over the airfoil
11	40	−20	−30	For'd	9	1.0	Approx. 25 percent of the fuel passed over the airfoil. The lower surface of the airfoil was wet in the vicinity of the inlet tube
12	40	−20	−30	Aft	9	1.6	Approx. 25 percent of the fuel passed over the airfoil
13	40	0	−30	See remarks	30	0	Gas sample line placed inside of flap. Occasional waves of fuel practically contacted the lower surface of the airfoil

[1] Gasoline quantity in gallons per minute.
[2] Angle of attack of airfoil to airstream.
[3] Angle of flap to airfoil.
[4] Location gas inlet.
[5] Location of centerline of gasoline stream with respect to lower airfoil surface.
[6] Percentage of gas vapor in total mixture.
[7] See remarks.

Conclusions.

When dumping gasoline from an airplane in flight the combustible gas envelope surrounding the liquid fuel spray presents practically no hazard to external or internal components of the airplane.

Figure 17.—Airfoil with flap deflected, spoiler on, ignitor at flap slot.

Part IV.—EXPERIMENTS ON THE IGNITION OF GASOLINE BY STATIC DISCHARGE FROM THE TRAILING EDGE OF AN AIRFOIL

Purpose.

To investigate the possibility of ignition of gasoline, when being dumped from an airplane in flight, by static discharge from the airplane.

Introduction.

In all of the tests described in Parts I, II, and III, ignition was deliberately produced by means of spark gaps and, therefore, those tests pertain only to the hazards involved after the fuel is ignited and have no direct bearing on the probability of accidental ignition in flight.

This section of the Report (Part IV) deals with tests planned to ignite gasoline by static discharge from the trailing edge of an airfoil, thus simulating a static phenomenon which occurs regularly on airplanes in flight. Since it was observed from the previous tests, described in Parts I, II, and III, that sparks would ignite dumped gasoline, these tests were restricted to an attempt to produce a corona or brush discharge from the trailing edge rather than a spark, and to determine if these types of static discharge would ignite the gasoline.

Test procedure and results.

The final test set-up is shown on figures 21 and 22. The airfoil and supporting structure were insulated from the ground and charged with alternating current of high potential (225,000 volts). A triangular sheet metal plate (See figure 21) was attached to the trailing edge of the flap to localize the point of discharge. A ground was provided by means of a vertical pipe mounted as shown on figure 21. The insulator shown on the ground pipe was found to be necessary in order to provide a long leakage path from the ground pipe to the flap and thus prevent excessive sparking. The airfoil was set at 0° angle of attack and the flap at 30° to the airfoil. The fuel quantity was 40 gallons per minute and the air-speed 70 miles per hour for all runs.

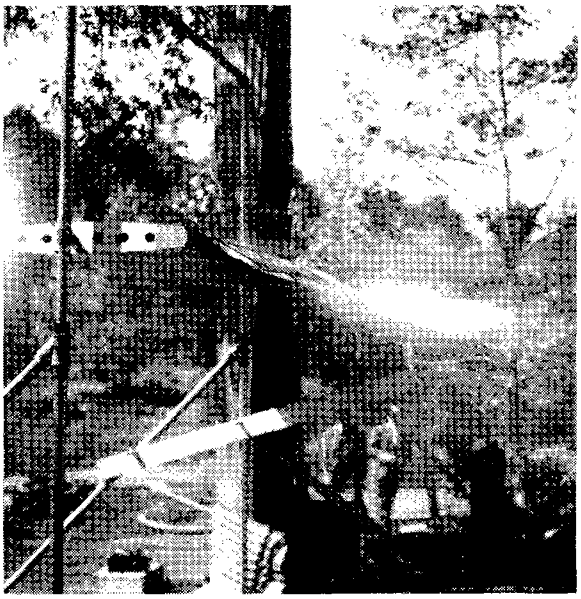

Figure 18.—Test using furnace oil, ignitor at flap slot. Fuel would not continue burning when ignitor was removed.

Forty-one runs were made under the above conditions and all were recorded on 16 mm. kodachrome motion picture film. The film when projected was stopped for close examination at the points where ignition occurred.

In nine of the runs sparks were visible and apparently caused the ignition. Attention is here directed to the use of the word "sparks." In only two or three of the runs (before ignition occurred) was the visual definition such that the phenomena could be called sparks in the true meaning of the word. In the other six or seven runs (of the nine) the "sparks" resembled, in various degrees, faint, hazy edged ribbons or streamers which in two of the runs were barely visible.

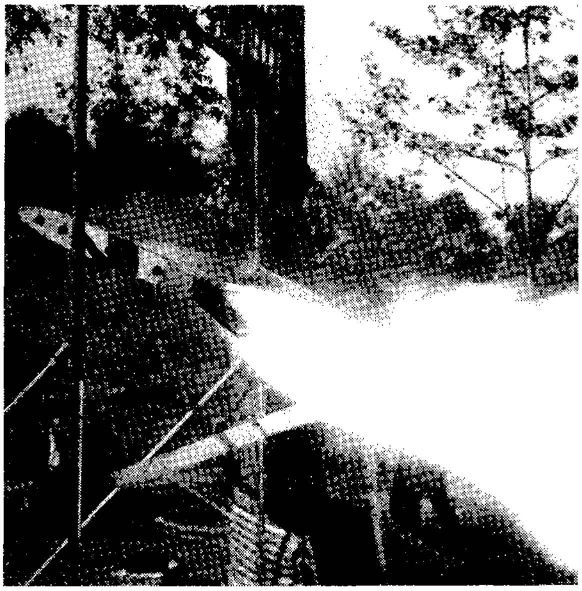

Figure 19.—Test using furnace oil, ignitor at leading edge.

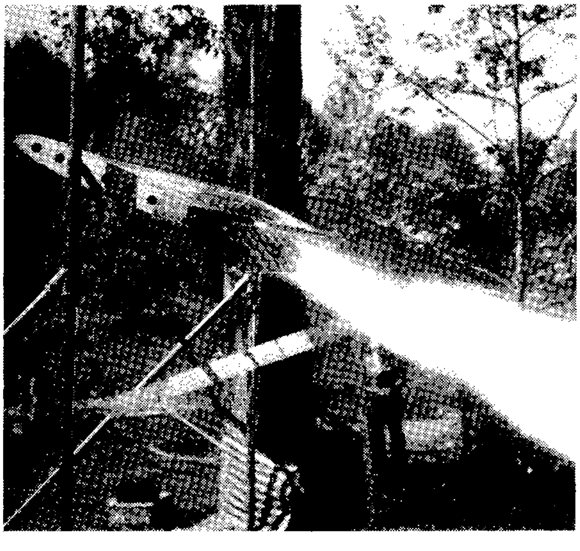

Figure 20.—Test using furnace oil, ignitor at flap slot.

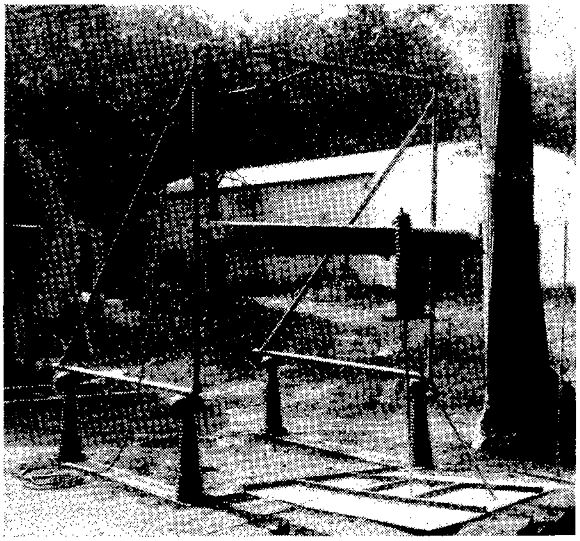

Figure 21.—General view of test set-up for investigating ignition of gasoline by static discharge from trailing edge of airfoil.

In four or five of the runs, ignition was caused by sparks at the lower end of the insulator and, therefore, these runs are irrelevant.

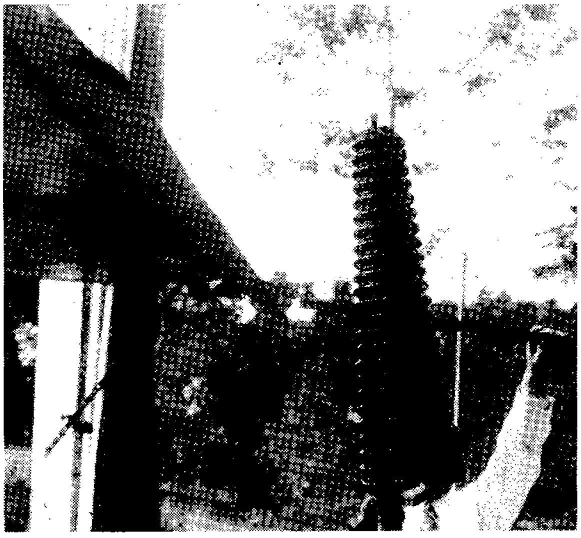

Figure 22.—Close-up view of test set-up for investigating ignition of gasoline by static discharge from trailing edge of airfoil.

In the remaining twenty-six or twenty-seven runs, ignition occurred although no sparks of any description were observed beforehand.

Discussion of results

The test results as observed do not definitely prove that ignition was caused by corona or brush discharge rather than by sparks. The maximum camera speed was only 64 frames per second and it is possible, in the runs where no sparks were observed, that they could have occurred between film frames and therefore not be visible on projection of the film. However, the fact that sparks were observed in only nine out of thirty-seven runs indicates the improbability of sparks being present in all of the runs where they were not observed.

The observed results of these tests indicate that the gasoline was ignited by corona or brush discharge. The intensity of the corona when observed at night was, in the opinion of airline inspectors, very low in comparison to the intensities usually observed on airplanes in flight.

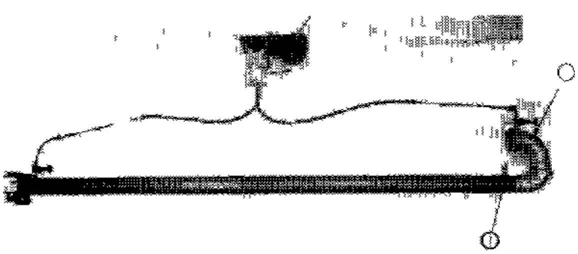

Figure 23.—Tube B used to simulate dump duct

Conclusions

It is quite probable that static discharges of the corona or brush type will ignite sprayed or atomized gasoline in an air stream.

Part V.—EXPERIMENTS WITH COMBUSTIBLE MIXTURES IN DUMP DUCTS

Purpose

The primary purpose of these tests was to evaluate the hazards of explosions of the most dangerous mixtures of gasoline and air in tubes simulating the gasoline dump ducts of transport aircraft.

Introduction

Since there is great variation in the size and shape of dump ducts currently in use, and since no actual duct was readily available, these tests were conducted in cylindrical tubes of such diameters and configurations that the most hazardous conditions likely to exist in aircraft were represented. The actual ducts are always open at the end farthest from the dump valve where ignition would be most probable so long as the dump valve is closed. Hence, the experimental tubes were always fired at a point near an open end, while the other end was always closed by a metal diaphragm. The total pressure of the explosive mixture at firing was thus equal in each test to that of the surrounding atmosphere. These tests were conducted and reported by the National Bureau of Standards.

Test procedure and results

Tests were conducted in four different tubes whose dimensions are as follows:

	Inside diameter (in.)	Wall thickness (in.)	Total length (in.)	Number and type of bends	Material of tube
A	3.800	0.100	112	None	Brass
B	3.800	.100	130	2 smooth	Brass with galv. iron elbows
C	.976	.012	65	None	Annealed copper
D	.976	.012	157	7 right angle	Annealed copper

Ignition at or near the open end was accomplished with a spark or flame. The other end, where peak pressures were expected to occur, was closed by a comparatively weak sheet of rolled aluminum 0.002 in. thick.

Mixtures in Tubes A and B were made by introducing selected volumes of liquid fuels, closing temporarily the open end of the tube, and circulating for previously determined times with a diaphragm type circulating pump.

Figure 23 is a photograph of Tube B, including the circulating pump and lines. The arrangement of Tube A was the same except that the U-bend was removed and the spark plug was at Position 1 instead of Position 2.

Mixtures in Tube C were made by introducing selected quantities of liquid fuel, closing both ends, and allowing the mixture to become uniform by standing. The diffusion process was hastened by frequent changes in the position of the tube.

Previously prepared mixtures were admitted to Tube D after the latter had been evacuated Fig 24 is a photograph of Tube D showing the shape, spark plug location, tube for evacuation and introduction of the mixtures, and the ignition system

For each mixture, both ends of the tube were closed during the preparation or introduction of the charge, and the end nearest the spark plug was opened just prior to firing

The following table lists the mixtures that were fixed in the various tubes The symbols R, L, and M stand for rich (in fuel), lean, and maximum power, respectively

Fuel	Normal heptane	Reference octane	Aviation gasoline	Ethyl alcohol (absolute)	Motor benzol
Octane No	*0*	*100*	*37*	*91*	*107*
Tube					
A	R-L-M	R-L-M	R-L-M	M	M
B	-	-	R-L-M	-	-
C	-	M	-	-	-
D	-	R-L-M	R-L-M	-	-

In no explosion in any of the tubes did the pressure at the closed end of the tube become sufficiently great to blow out the 0 002-in aluminum diaphragm In each tube the explosion of a maximum power mixture produced a roar and a simultaneously audible vibration of the thin aluminum diaphragm In Tubes A and B this vibration was, in some cases, of sufficient amplitude to produce permanent deformations (the pattern being roughly concentric corrugations) in a small central portion, and in four cases out of 21 there were small fatigue cracks at the centers With Tubes C and D no diaphragm was permanently distorted

There was no noticeable difference in the explosions whether initiated by a spark or by a flame In a few cases of very rich or very lean mixtures the charge failed to ignite with continuous sparking, but burned quietly when ignited by a flame

In Tube A explosions of maximum power mixtures did not vary greatly for the different fuels either as to noise or effect upon the aluminum diaphragms Several observers agreed that the alcohol gave a little greater noise, and the heptane the least

In Tubes A and B, from two to three seconds were required for the flame front to move from the spark plug to the closed end in a maximum power mixture During roughly half of this time, visible flame was projected from the open end of the tube for a distance of a few inches

The roaring noise in Tubes A and B was much louder than for corresponding mixtures in Tubes C and D

A 0 002-in aluminum diaphragm of 3 8 in effective diameter (i e, such as was used on

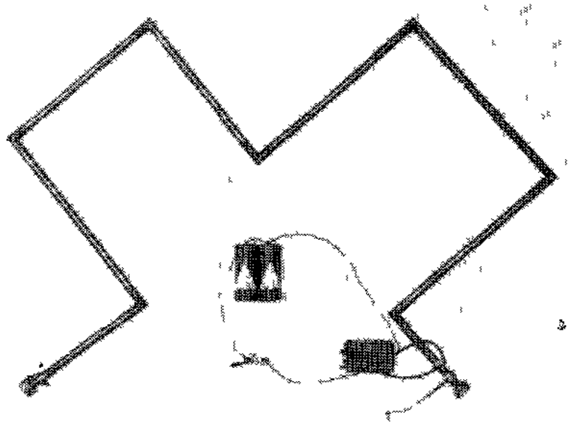

Figure 24 —Tube D used to simulate dump duct

Tubes A and B) was blown out by a static pressure of 13 5 lbs per sq in It broke at the circumference, as is characteristic of a diaphragm loaded excessively, by either static pressure or rapidly rising pressure such as prevails during an explosion in a closed container No break of this character was produced by any explosion

Discussion of results

The roaring noise observed in each test was distinctly different from the sharp report commonly connected with an explosion In these tubes the flame begins to move at a uniform rate, but is soon disturbed by pressure waves reflected from the closed end Thus during most of its travel the flame becomes vibratory and its progress is accompanied by the sound waves which produce the only observed distortions of the thin closure at the end of the tube

The pressure at the closed end of a tube, fired at the open end, rises from two principal causes first, the resistance furnished by the tube to the escape of the burned gas through the open end, and second, the resistance which the atmosphere at the open end of the tube offers to the escape of the burned gas Even when it is assumed that there is no loss of heat to the tube by the burned gas, these two resistances are low for large tubes and for mixtures which burn as slowly as hydrocarbons and air at atmospheric conditions The values of the peak pressures at the closed ends of the tubes were calculated to be extremely low, and the tests furnish a qualitative confirmation of the computed values, since the very thin aluminum diaphragms were not blown out

The peak pressures in the smaller tubes (C and D) should be higher than those in Tubes A and B, were it not for the fact that the burned gas has a better opportunity to lose heat to the walls of the small tube before it reaches the open end Since this heat loss does occur to a considerable extent in tubes as small as C and D it seems doubtful that the peak pressures in these tubes were much, if any, greater than in A and B

The introduction of bends and angles tends to increase the resistance which the burned gas encounters in its passage to the open end Again, however, particularly in the case of Tubes C and D, it seemed that the angles were more effective in cooling the burned gas than in preventing its escape This conclusion is based upon the extreme mildness of explosions in Tube D as compared with any of the others

It is emphasized that the tests described herein were confined to ducts only, assuming that the dump valve between the duct and tank would be tightly and securely closed An explosion in a dump duct would be extremely dangerous if its dump valve were open enough to provide a gaseous connection with the nearly empty gasoline tank To prevent this condition particular thought and study should be given to the design of the dump valve and to the operating mechanism, which might be so controlled that the valve would close automatically before all of the fuel was dumped As an alternative safety precaution an inert gas might be introduced into the tank to replace the fuel as it leaves the tank and duct Thoroughly tested flame arresters placed within ducts also would give adequate protection but these might seriously retard the flow of fuel

Conclusions

1 The results of these experiments are in agreement with previous calculations which indicated that only very low pressures are developed by explosions of maximum power mixtures of gasoline and air in tubes of uniform cross section, open at one end

2 Although decreasing the diameter, increasing the length or inserting bends in the tube will increase the resistance to the escape of the burned gases, these changes will also increase heat loss from the gas behind the flame front

3 In small tubes, the cooling effect may predominate, and flame may, in some cases, be extinguished before traversing a long tube with numerous bends

4 In large tubes, the peak pressures may increase with length or the number of bends, but destructive peak pressures are not to be expected in any tubes of dimensions appropriate for gasoline dump ducts on aircraft

5 The effects which may result from the vibratory motion of the flame depend on the configuration of the duct It is possible that very weak sections might be caused to vibrate violently during an explosion, with the result that a fatigue fracture might occur For this reason it is suggested that dump ducts should be circular, rather than rectangular in section, and free of weak, flat areas

6 The present tests indicate conclusively that a cylindrical duct of aluminum alloy, having a wall thickness of 0 020 inch or more, an inside diameter of 4 inches or less, and a length of 11 feet or less, will not be damaged in any way by the explosion of any mixture of gasoline and air, initially at the pressure of the atmosphere surrounding the open end

7 A hazardous condition may result if the duct is constricted at some point along its length

8 An explosion in a dump duct would be extremely dangerous if its dump valve were open enough to provide a gaseous connection with the nearly empty gasoline tank

SUMMARY OF CONCLUSIONS

Part I

Dumped fuel which does not contact any component of an airplane after leaving the outlet valve or chute does not constitute a hazard to the airplane even if ignition of the fuel should occur

Part II

1 The dumping of gasoline from an airplane in flight in such a manner that it contacts an external surface of the airplane is considered hazardous since, if it were accidentally ignited, burning on the surface might continue after the source of ignition had disappeared

2 The hazard is increased by the presence of protuberances and irregularities on the surface and by deflection of control surfaces or increase of angle of attack of the fixed surfaces

3 Aluminum alloy surfaces, constructed of sheets of 0 032 inch or less in thickness and subjected to burning gasoline in quantities of 40 gallons per minute or greater and in a 70 mile per hour airstream would be seriously damaged in less than 30 seconds

4 Fuel oils having flash points up to 250° F are more difficult to ignite than gasoline but, once ignited appear to produce more heat for equal quantities Such oils are considered less hazardous than gasoline

Part III

When dumping gasoline from an airplane in flight the combustible gas envelope surrounding the liquid fuel spray presents practically no hazard to external or internal components of the airplane

Part IV

It is quite probable that static discharges of the corona or brush type will ignite sprayed or atomized gasoline in an airstream

Part V

1 The results of these experiments are in agreement with previous calculations which indicated that only very low pressures are developed by explosions of maximum power mixtures of gasoline and air in tubes of uniform cross section, open at one end

2 Although decreasing the diameter, increasing the length or inserting bends in the tube will increase the resistance to the escape of the burned gases, these changes will also increase heat loss from the gas behind the flame front

3 In small tubes, the cooling effect may predominate, and flame may, in some cases, be extinguished before traversing a long tube with numerous bends

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