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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
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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, other 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 non-existent, 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 flame 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.

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 are 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 Figs. 1 and 2. In Fig. 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.

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 degrees F.
Diesel oil: Flash point 250 degrees F.

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

Physical Characteristics of Airfoil:

N.A.C.A. M-3 section
Chord: 50 inches
Span: 8 feet, 9 inches
Flap Chord: 25% of airfoil chord

Wooden interior covered with 20 gauge galvanized iron.

Leading edge of airfoil 26 feet behind fuel outlet.

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 Figs. 3, 4, 5, and 6. The tests were conducted in the following manner:

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. Fig. 6 shows the flame leaving the sprayed gasoline immediately after the ignitor was removed. Fig. 5 shows the condition just prior to that shown on Fig. 6.

Run No. 2:

The ignitor was applied at the point of the gasoline outlet. In the first part of this run an auxiliary 1/4 inch internal diameter copper tube supplied the gasoline in place of the regular two-inch diameter pipe. See Fig. 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.

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 6. An airfoil with flap was used to simulate an external surface of an airplane.

Test Procedure and Results:

See Figs. 1 and 2 for a general view of the set-up. See page 9 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 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 x 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 Fig. 16. In three of the runs a .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 degrees F.) diesel oil (flash point 250 degrees F.), and gasoline (Domestic aviation, 73 octane).

The results of the tests are given in table form on pages 14, 15, 16, 17, 18, and 19. 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.

TEST RESULTS

PART II

Run No.	*Quan. Type of Fuel	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. Fig. 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.

*The number is fuel quantity in gallons per minute. G: Gasoline F: Furnace Oil D: Diesel Oil

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TEST RESULTS

PART II (Cont'd)

Run No.	*Quan. and Type of Fuel	Airfoil, Angle of Attack to Air-stream	Flap, Angle to Airfoil	Point of Ignition	Spoiler Strip	Remarks
9	G-23	0	30	LE	off	Figure 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.
(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.

*The number is fuel quantity in gallons per minute. G: Gasoline F: Furnace Oil D: Diesel Oil

(Continued on next page)

TEST RESULTS

PART II (Cont'd)

Run No.	*Quan. and Type of Fuel	Airfoil Angle of Attack to Air-stream	Flap, Angle to Airfoil	Point of Ignition	Spoiler Strip	Remarks
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.

*The number is fuel quantity in gallons per minute. G: Gasoline. F: Furnace Oil. D: Diesel Oil.

(Continued on next page)

TEST RESULTS

PART II (Cont'd)

Run No.	*Quan. and Type of Fuel	Airfoil Angle of Attack to Airstream	Flap, Angle to Airfoil	Point of Ignition	Spoiler Strip	Remarks
19 (a)	G-23	20	0	Slot	on	Fuel ignited readily and continued in the slot and below the flap.
(b)	G-23	20	0	Slot	on	Results same as for Run No. 19 (a).
(c)	G-23	20	0	Slot	on	Results same as for Run No. 19 (a).
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.
(b)	G-23	20	30	LE	on	
(c)	G-23	20	30	LE	on	

*The number is fuel quantity in gallons per minute. G: Gasoline F: Furnace Oil D: Diesel Oil

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TEST RESULTS

PART II (Cont'd)

Run No.	*Quan. and Type of Fuel	Airfoil Angle of Attack to Air-stream	Flap, Angle to Airfoil	Point of Ignition	Spoiler Strip	Remarks
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.
(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.

*The number is fuel quantity in gallons per minute. G: Gasoline F: Furnace Oil D: Diesel Oil

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TEST RESULTS

PART II (Cont'd)

Run No.	*Quan. and Type of Fuel	Airfoil Angle of Attack to Air-stream	Flap, Angle to Airfoil	Point of Ignition	Spoiler Strip	Remarks
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.
(b)	G-23	-5	0	TE	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.
(b)	G-23	-5	30	LE	on	Same results as for Run No. 30 (a).

*The number is fuel quantity in gallons per minute. G: Gasoline F: Furnace Oil D: Diesel Oil

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 pre-arranged 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 tests 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 .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 degrees 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 (1/4 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 were 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" (Column 7, page 26) 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 per cent of gas vapor, by volume, in the total mixture.)

TEST RESULTS

PART III

1	2	3	4	5	6	7	Remarks
Run No.	Fuel	Air-foil	Flap	Inlet	Location	Mixture	
1	33	0	10	For'd	30	0	The "wedge" 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	.14	The fuel occasionally wet the lower surface.
3	40	0	10	For'd	19.5	.15	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	.20	Approx. 10 per cent 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	.21	Considerable fuel passed over the top of the airfoil.

- 2 - Gasoline quantity in gallons per minute.
3 - Angle of attack of airfoil to airstream.
4 - Angle of flap to airfoil.
5 - Location gas inlet. See page 24.

- 6 - Location of centerline of gasoline stream with respect to lower airfoil surface.
7 - Percentage of gas vapor in total mixture. See page 25.

(Continued on next page)

TEST RESULTS

PART III (Cont'd)

1	2	3	4	5	6	7	Remarks
Run No.	Fuel	Air-foil	Flap	Inlet	Location	Mixture	
8	40	-20	-30	For'd	13.5	.17	Same as for Run No. 7.
9	40	-20	-30	None	23.5	(see re-marks)	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	(see re-marks)	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 per cent of the fuel passed over the airfoil.
11	40	-20	-30	For'd	9	1.0	Approx. 25 per cent 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	.16	Approx. 25 per cent of the fuel passed over the airfoil.
13	40	0	-30	(See re-marks)	30	0	Gas sample line placed inside of flap. Occasional waves of fuel practically contacted the lower surface of the airfoil.

- 2 - Gasoline quantity in gallons per minute.
3 - Angle of attack of airfoil to airstream.
4 - Angle of flap to airfoil.
5 - Location gas inlet. See page 24.

- 6 - Location of centerline of gasoline stream with respect to lower airfoil surface.
7 - Percentage of gas vapor in total mixture.
See page 25.

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.

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.

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.

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.

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 Figs. 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 Fig. 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 Fig. 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 degrees angle of attack and the flap at 30 degrees to the airfoil. The fuel quantity was 40 gallons per minute and the airspeed 70 miles per hour for all runs.

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.

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.

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.

Conclusions:

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

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.

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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	0.100	130	2-smooth	Brass with galv. iron elbows
C	0.976	0.012	65	none	Annealed copper
D	0.976	0.012	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.

Fig. 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.

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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
<u>Tube:</u>					
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 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 inches 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 .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 degrees 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.

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FIGURE 1

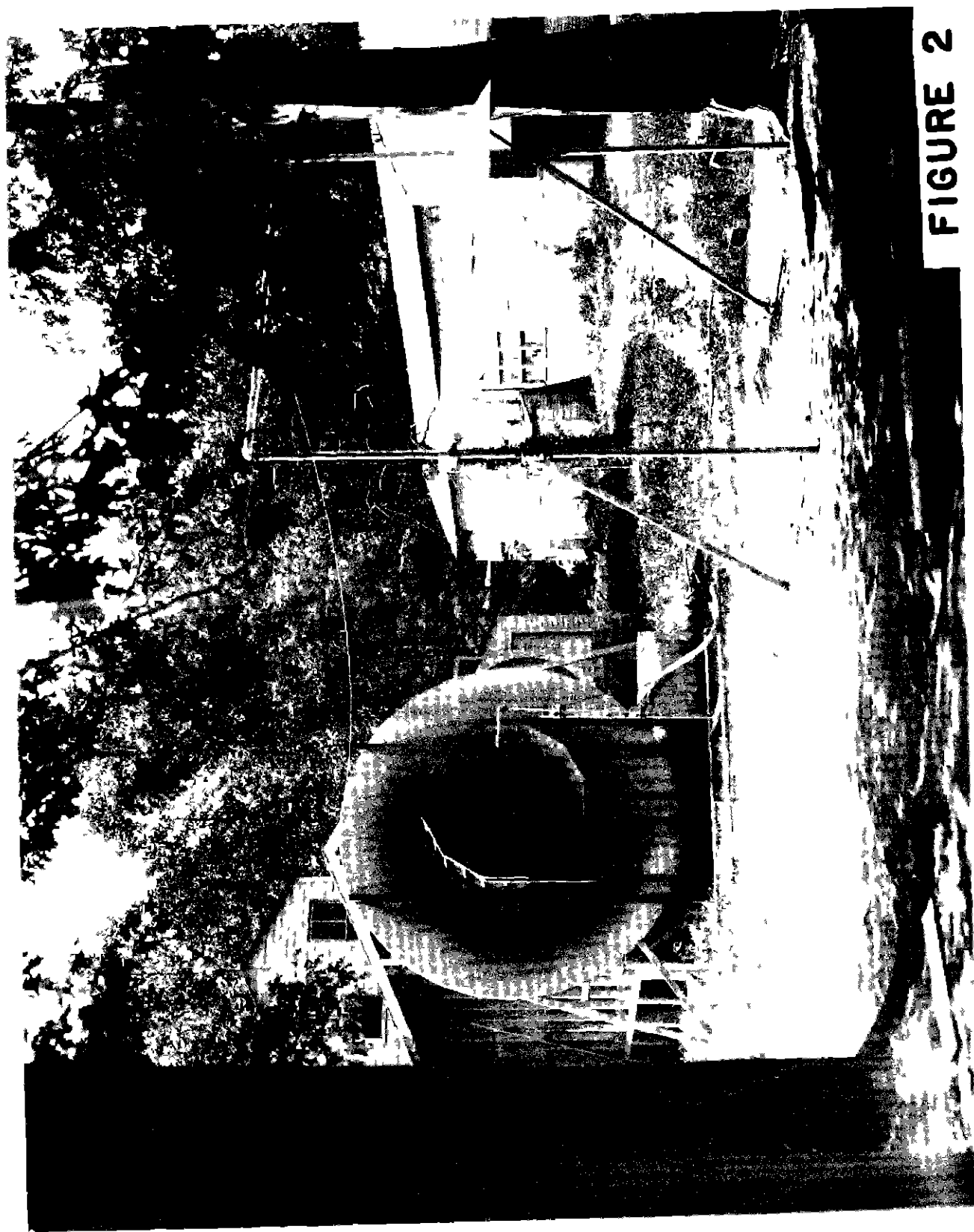


FIGURE 2

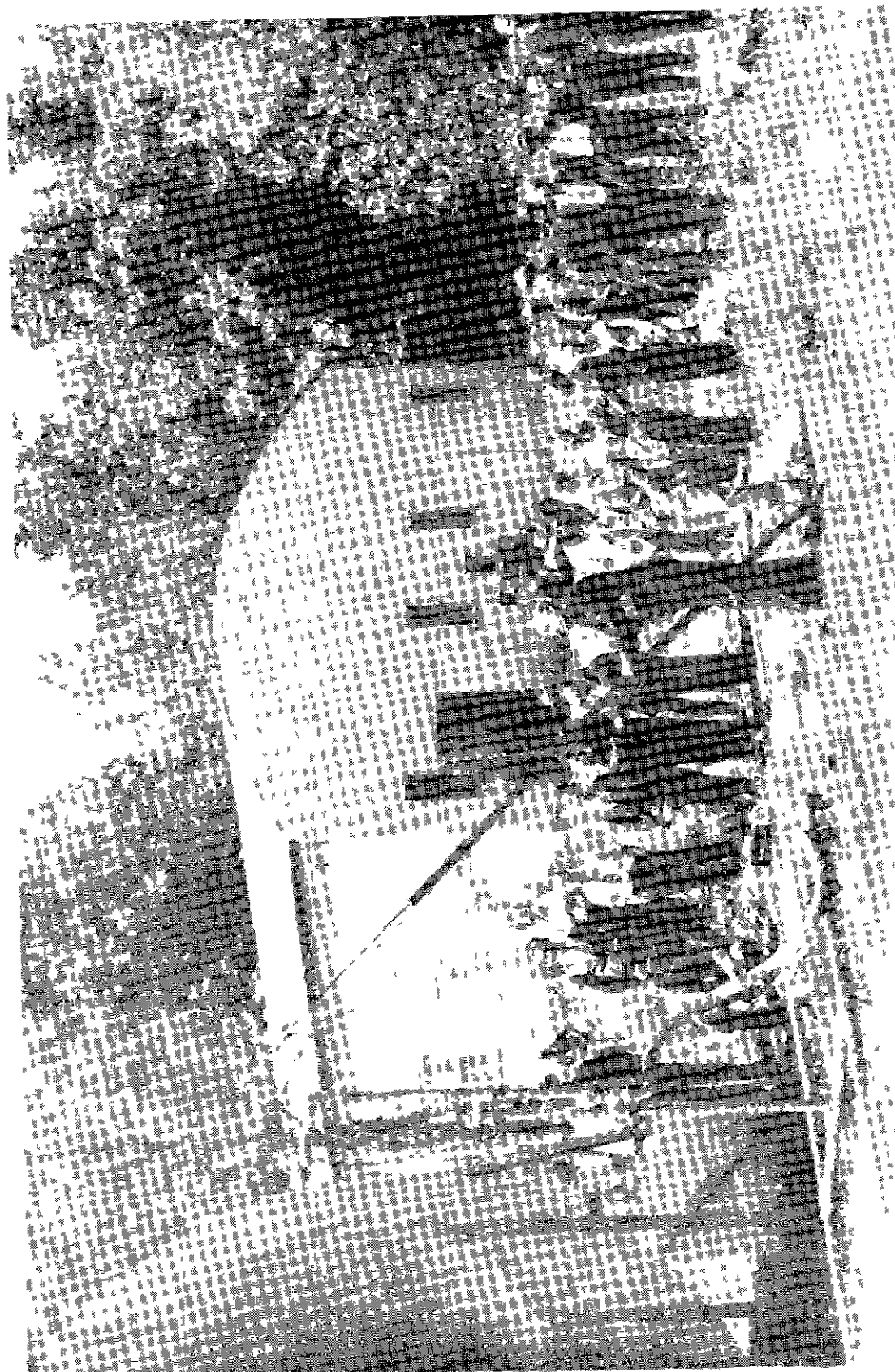


FIGURE 3



FIGURE 4



FIGURE 5

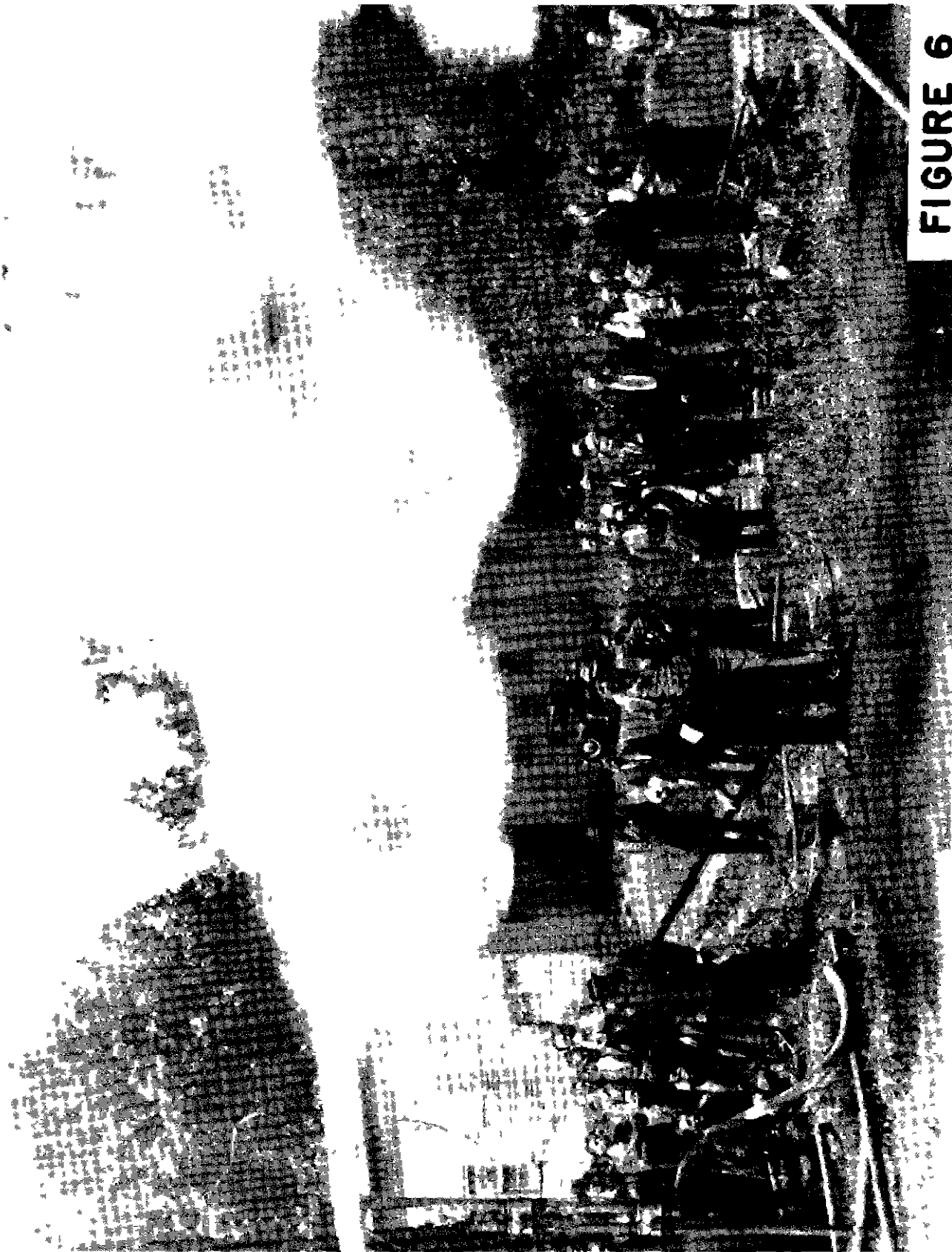


FIGURE 6

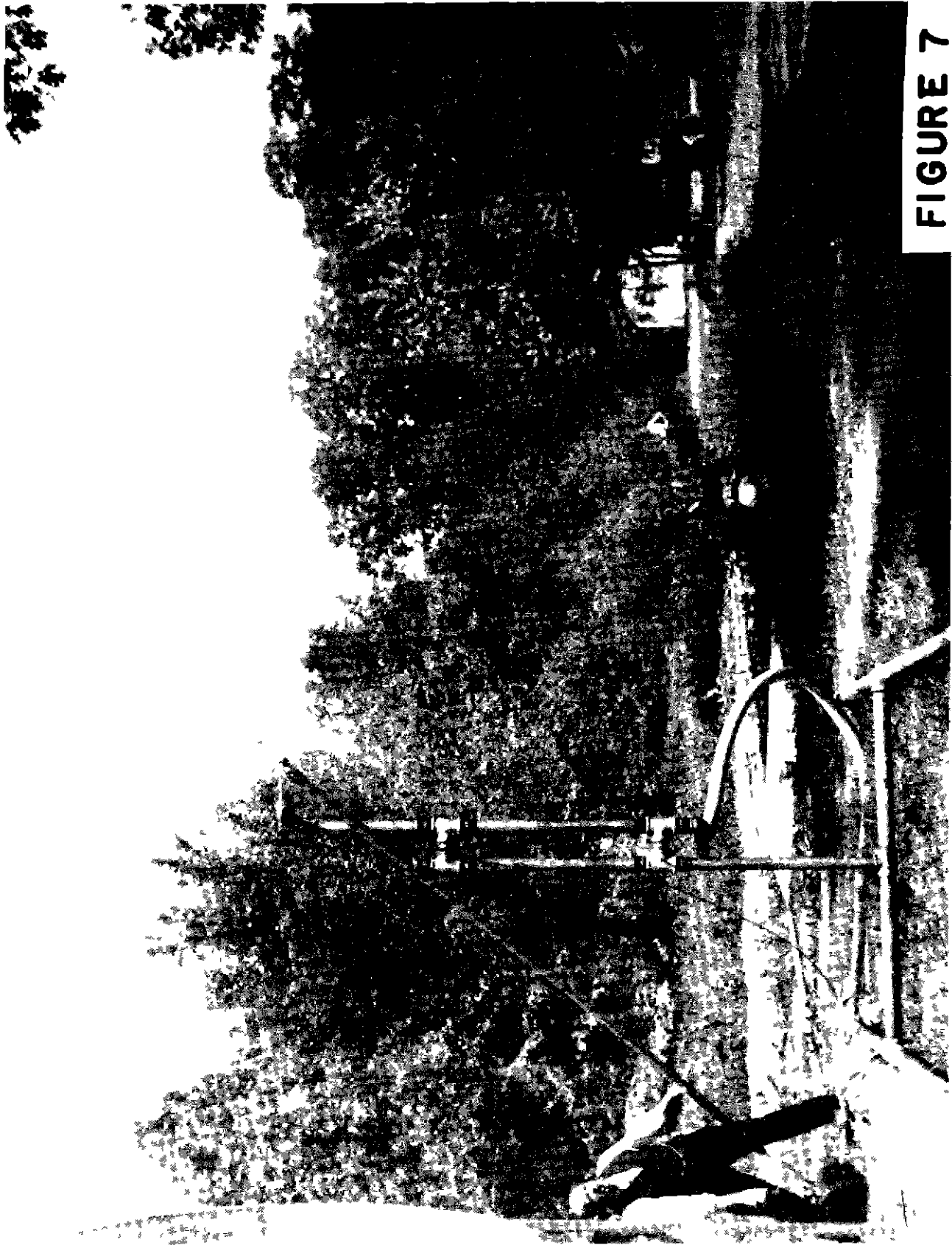


FIGURE 7

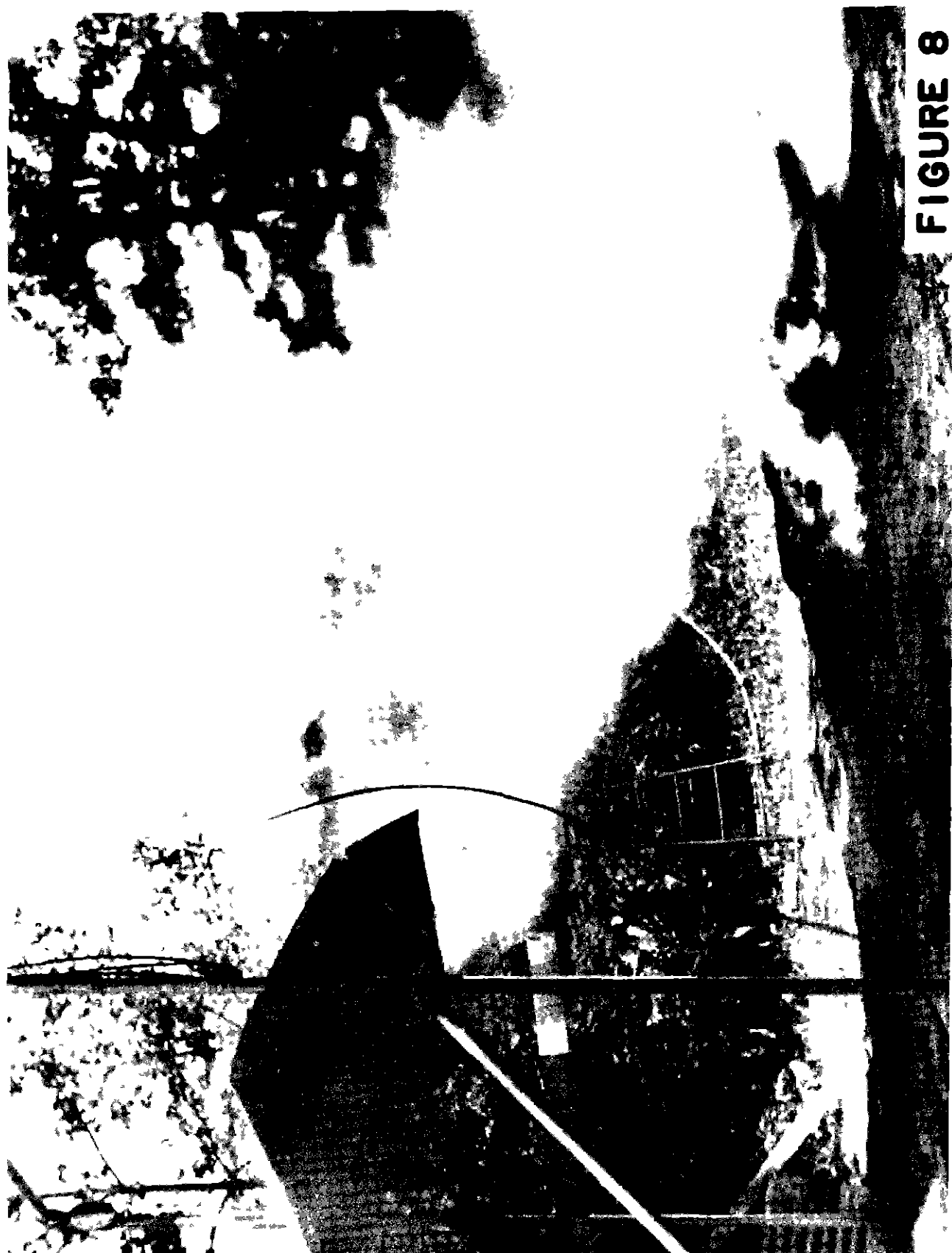


FIGURE 8



FIGURE 9



FIGURE 10



FIGURE II



FIGURE 12





FIGURE I4



FIGURE 15

FIGURE 16





FIGURE 17



FIGURE 18

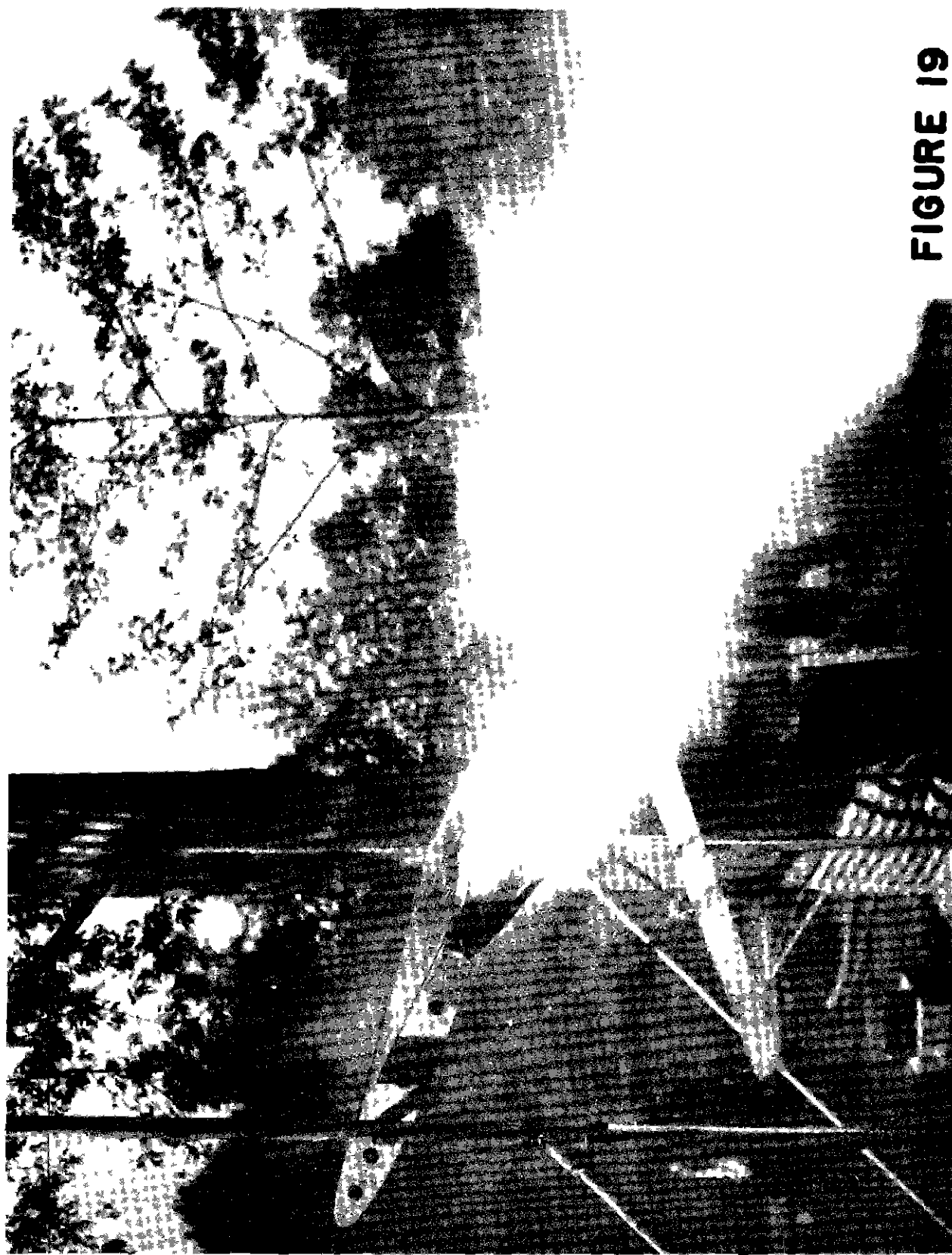


FIGURE 19

FIGURE 20





FIGURE 21

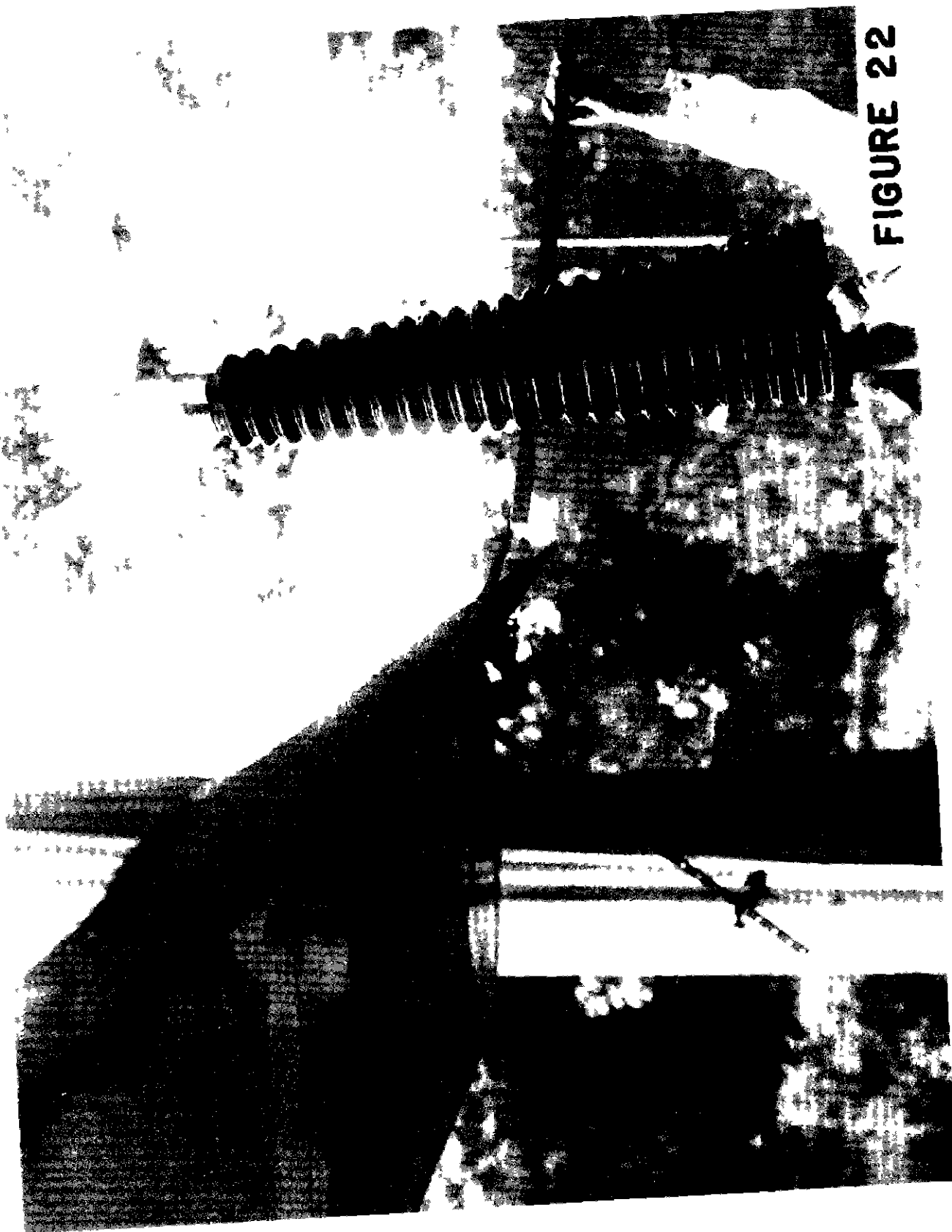


FIGURE 22

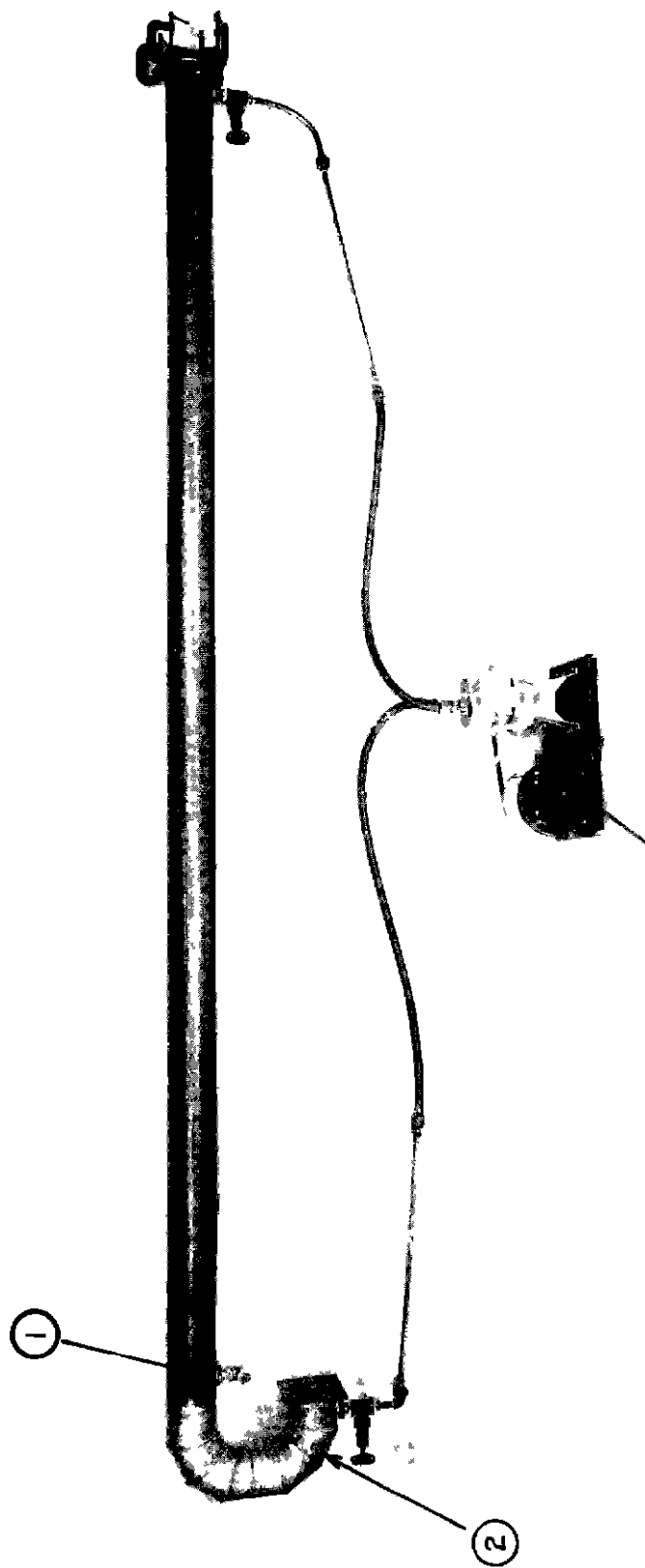


FIGURE 23 TUBE B

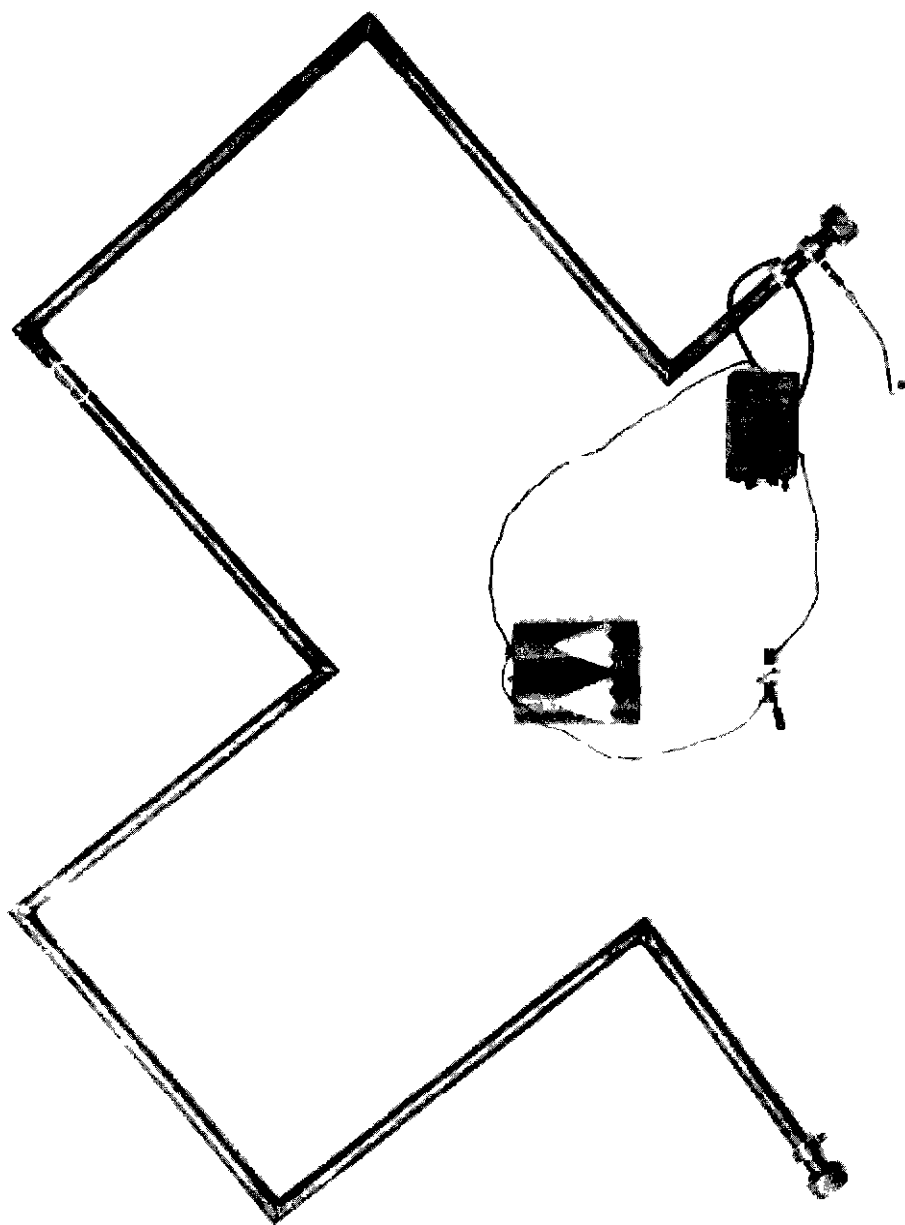


FIGURE 24 TUBE D

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

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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.

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