# DETERMINATION OF MEANS TO SAFEGUARD AIRCRAFT FROM POWERPLANT FIRES IN FLIGHT

## PART III

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## PART III

## SUMMARY

A full scale, operating Waco YKS-37 engine-fuselage-wing combination was fire tested in a controlled air blast to simulate actual flight conditions Quantities of gasoline and oil were ignited at locations throughout the powerplant installation where fire might occur as a result of failures of the engine or the fuel or oil systems

Four separate investigations were conducted concerning (1) fire extinguishment, (2) fire detection, (3) effect of fire on materials, and (4) sources of ignition

Fire extinguishing systems of reasonable size and weight proved capable of extinguishing fuel and oil fires within limitations of fire size and duration under simulated flight conditions These tests resulted in determinations of optimum agent distribution systems, minimum agent quantities, and minimum agent application rates necessary for protection of the engine installation tested

The fire detection tests proved that quick, positive fire detection is practical and that wire type fire detectors are considerably superior to unit detectors in installations of this type

Tests on materials included the development of methods for making fabric and doped aircraft covering more resistant to flame, and investigations into the use of non-metallic firewalls During oil and gasoline fires of various sizes and in various locations, temperatures of cowling, wing and fuselage skin, and the firewall were recorded The general effect of fire on the entire powerplant installation was observed throughout the tests

Ignition tests were conducted to determine the possibility of spontaneous ignition of gasoline, lubricating oil, and diesel fuel oil The tests showed that ignition sparks, the carburetor air heating system, and cracks or openings in the exhaust system can be ignition sources

## INTRODUCTION

Following the fire tests on the DC-3 type[1] and the CW-20 type[2] powerplant installations, a questionnaire was circulated through the organizations which were actively interested in these tests to determine the next installation to be tested A four or five-place private-owner type aircraft in the 200- to 400-horsepower class was chosen Accordingly, a Waco YKS-37 airplane powered by a Jacobs L-4M engine (225 horsepower) was obtained and made suitable for fire testing

The control of fires burning fuel or oil, released by fuel or oil system failures or by engine structural failures and ignited by sparks or faulty exhaust systems, is of primary importance

Most private-owner type aircraft are not equipped with fire detectors, fire extinguishing systems, or with means for stopping the engine oil flow in flight Aluminum alloy bulkheads

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[1] A W Dallas and H L Hansberry, "Determination of Means to Safeguard Aircraft from Powerplant Fires in Flight - Part I," CAA Technical Development Report No 33, September 1943

[2] G L Pigman, "Determination of Means to Safeguard Aircraft from Powerplant Fires in Flight - Part II," CAA Technical Development Report No 37, October 1943

separate power sections from accessory sections, and accessory sections from the fuselage In addition, aluminum alloy is used extensively throughout the powerplant installation

Fire protection of large air-cooled radial engines was discussed in references 1 and 2, but no information was available on fire protection of air-cooled radial engines of the 200- to 400-horsepower class Therefore, information was desired as follows

1 Fire Extinguishers Methods of application of the three extinguishing agents which proved most effective in previous tests Information on their rates and times of discharge in power and accessory sections, on the weights of the agents, and the design of necessary piping and controls
2 Fire Detectors: Information on the time of operation, ability to withstand severe operating conditions, proper locations, and proof against false alarm of the detectors most suitable for the type of installation tested
3 Materials and Equipment: Determination of relative resistance of all parts of the powerplant installation to test fires Data on temperatures around and in the vicinity of the powerplant installation Also development of dope and fabric combinations capable of withstanding fires of 30 seconds duration
4 Fire Ignition Possibilities. Information on ignition sources and means to reduce the hazards of such ignition

The conditions existing in a powerplant installation during flight were reproduced by subjecting a remotely controlled, full scale engine-fuselage-wing combination to an air blast from a wind tunnel, which simulated forward motion of the airplane

As the engine installation was basically similar to that of the DC-3 previously tested, it was felt that the test results would be of value from a comparative standpoint and would make the results of both tests more applicable to other installations Material from this report and from references 1 and 2 has already been summarized in a separate note[3].

An outside wind tunnel and other necessary facilities were made available by the National Bureau of Standards where all the tests were conducted

Excellent cooperation was received from and acknowledgment is given to the following organizations which supplied the personal services of their engineering staffs, test materials, and equipment

1 American-LaFrance-Foamite Corporation
2 C-O-Two Company
3 Empyre Extinguishing Company
4 Fenwal, Inc
5 Minneapolis-Honeywell Regulator Company
6 National Bureau of Standards
7 Panelyte Division, St Regis Paper Company
8 Phister Manufacturing Company
9 Pyrene Manufacturing Company
10 United States Navy Department
11 Walter Kidde & Company, Inc

## DESCRIPTION OF TEST EQUIPMENT

The complete test layout is essentially the same as that shown in figure 1 of reference 1, except for the replacement of the DC-3 nacelle unit by the Waco fuselage unit A sketch of the test unit is shown in figure 1 of this report, and figures 2 and 3 are photographs of the test set-up

The test set-up was a Waco YKS-37 airplane with a Jacobs L-4M engine installation obtained for these tests Several modifications in the set-up were made, including

1 The aluminum alloy accessory section cowling (diaphragm) was replaced by a black iron diaphragm
2 The aluminum alloy firewall was replaced by a black iron firewall

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[3] H L Hansberry, "Design Recommendations for Fire Protection of Aircraft Powerplant Installations," CAA Technical Development Note No 31, September, 1943

3 The fabric covering of the airplane was replaced by 0 012-inch stainless steel sheet

4 The engine oil tank was removed from the accessory section and installed in the fuselage

5. The engine oil cooler was replaced by a dummy cooler

6 The engine accessories and fuel system in the accessory section were protected from fire by lagging consisting of asbestos cloth soaked in waterglass Figures 4 and 5 are photographs of the accessory section

The engine was operated by remote control during the tests The test equipment consisted of

Engine: Jacobs L-4M, seven cylinders, single row, radial air-cooled aircraft engine rated at 225 h p. at 2,000 r p m

Propeller: Two-bladed, adjustable pitch, metal propeller, 8 feet, 3 inches in diameter

Engine Cowl: Standard aluminum alloy N A C A cowl

Accessory Section Cowling Standard 0 049-inch aluminum alloy cowling and 0 030-inch black iron cowling

Engine Air Induction System Carburetor air intake system as shown in figure 6

Fuselage: Steel tubing structure of the original airplane was used. Wooden formers were replaced by SAE #1025 steel strips Fabric was replaced by 0 012-inch stainless steel The test unit was supported at the landing gear support connections

Wing Stubs: Built up of 0 012-inch stainless steel skin on SAE #1025 strap steel structure.

The engine control shed, oil and fuel tower, extinguishing shed, wind tunnel, and fire nozzle used in these tests were as described in reference 1

## GENERAL TEST PROCEDURE

Three different types of installations were tested in this program In the first type the inter-cylinder and head baffles, as well as the N A C A ring cowl, were installed as shown in figure 7A The approximate air volume passing through the power section, measured by means of a pitot static tube, was 33,000 pounds per hour, with the engine running at 2,000 r p m and 21 inches manifold pressure, and the tunnel producing an air flow of 70 miles per hour

In the second type of installation the inter-cylinder and head baffles were removed, but the N A C A ring cowl was installed as shown in figure 7B The approximate air volume passing through the power section, measured by a pitot static tube, was 49,000 pounds of air per hour with the engine running at 2,000 r p m and 21 inches manifold pressure and the wind tunnel developing an air speed of 70 miles per hour

The engine, without inter-cylinder or head baffles and without the N A C A ring cowl, was tested as the third type of installation shown in figure 7C No attempt was made to check the air flow through this type of powerplant installation

The factors affecting fire conditions were the type of fuel burned, the fuel flow rate, and the fire location and duration

Number 10 SAE oil, preheated to 300° F to simulate effect of an overheated engine, was used in the oil fire tests to facilitate handling and ignition Tests were also conducted using diesel fuel oil to determine the hazards involved in the use of such oil In the accessory section gasoline fires, 73-octane aviation gasoline was burned

The rate of oil flow used to feed a majority of the power section oil fires was 1 5 gallons per minute If the engine were stopped and the oil flow shut off at the tank immediately following a fracture of the crankcase or a cylinder, the 1 5 g p m. oil flow used in the tests would result from three quarts of residual oil being uniformly jettisoned for 30 seconds In addition, the total oil flow through the engine would be approximately 1 5 g p m Tests were conducted using flow rates of 1 0 g p m to 3 g p m for comparative results Figures 8, 9, and 10 show typical power section oil fires

The maximum rate of oil flow used to feed accessory section oil fires was 4 0 g p m Such a quantity of oil could be released in the accessory section because of failure of the oil tank or of the oil lines between the engine, oil cooler, and oil tank Figure 11 shows a typical accessory section oil fire

The rate of gasoline flow used to feed accessory section gasoline fires was varied from 0 2 g.p m to 3 g p m. An accessory section gasoline fire is shown in figure 12

Power section fires, resulting from cylinder failures, were simulated by introducing a burning stream of oil between the engine cylinders. The radial range of fire nozzle locations extended from the crankcase to the cylinder heads, and the fore and aft range extended from the forward edge of the cylinders to the rear edge. The nozzle direction was varied at the various inter-cylinder locations.

Accessory section fires resulting from fuel and oil line failures were simulated by placing the fire nozzle outlet just inside the accessory section cowl (diaphragm). This procedure was followed at five locations around the cowl, and at each location the nozzle angle with respect to the cowl was varied.

The fire duration in all tests was 30 seconds, since it was assumed that fire detection would occur within 3 seconds of a fire start and that an airplane crew could apply the extinguishing agent well within the remaining 27 seconds.

Gasoline fires were ignited by an electric spark. Oil fires were ignited by a small stream of burning gasoline.

## EXTINGUISHING TESTS

Purpose

The purposes of the extinguishing tests were:

1. To determine the efficacy of various fire extinguishing agents when applied to gasoline and oil fires occurring in the power and accessory sections of the aircraft powerplant installation tested under simulated flight conditions.
2. To determine for each extinguishing agent the quantity required, rate of application necessary, and the optimum method of distribution in both the power and accessory sections.

Procedure

A total of 648 fire extinguishing tests were conducted, using various extinguishing agents, under the test conditions as described on pages 3 and 4. In general, extinguishing agents were applied, at various rates and durations of discharge, through various distribution systems to gasoline and oil fires occurring throughout the powerplant installation. Three fire extinguishing agents were included in the tests. These agents and their properties appear in table I.

Table I

EXTINGUISHING AGENTS TESTED AND PROPERTIES

| Extinguishing Agent | Methyl Bromide $CH_3Br$ | Carbon Dioxide $CO_2$ | Carbon Tetrachloride $CCl_4$ |
|---|---|---|---|
| Molecular weight | 94.94 | 44.00 | 153.84 |
| Specific gravity | 1.732 (1) | 0.77 (1) | 1.6326 (1) |
| Boiling point | 4.6° C (2) | -78.5°C (2) | 76.8°C (2) |
| Melting point | -93°C (1) | | -23°C (1) |
| Cu. ft. per lb. of gas or vapor at 20°C - 760 mm | 4.05 (2) | 8.75 (2) | 2.50 (2) |
| Specific gravity of gas or vapor at 0°C - 760 mm (air = 1.0) | 3.27 (2) | 1.52 (2) | 5.31 (2) |
| Vapor pressure at 20°C lb. per sq. in. | - | 817 (2) | 1.76 (2) |

(1) International Critical Tables

(2) "The Comparative Life, Fire and Explosive Hazards of Common Refrigerants" - Underwriters Laboratories.

(3) In addition, two experimental extinguishing agents, produced by the J-T Laboratories, Plainfield, New Jersey, were tested. However, only 1 gallon of each of these agents was used, and no conclusions concerning their relative merits could be substantiated.

The systems used for distributing the extinguishing agents to the power and accessory sections were basically the same as the satisfactory systems developed in reference 1

The effects of rate and duration of application of the agents on extinguishment were determined using each of the three installation conditions shown in figure 7 Rates were varied from 1 to 5 pounds per second, as applied to the entire powerplant installation, by varying dimensions of lines and nozzles and by regulating pressures in the extinguishing agent containers Durations were varied from 1/2 second to 5 seconds The quantity of agent used in each test, as determined by the rate and duration of the application, varied from approximately 2 to 10 pounds

A short series of fire tests was conducted in which the power section outlet area was completely covered with asbestos cloth to ascertain the reduction in the quantity, rate, and duration of extinguishing agent application which would result from complete closure of the rear of the power section. Additional tests were conducted in which extinguishing agent was applied without fire, with and without the power section outlet closure, to compare the concentration of agent under the two conditions

Results and Discussion

Individual fire extinguishing tests are not discussed in this report as such data would be confusing because of their volume and would serve no useful purpose Tests were conducted on each point until such point could be substantiated or discarded Accordingly, it was necessary to conduct a great number of tests in order for the test results to prove reliable

The three test variables which had the greatest effect on fire extinguishment were air blast, fire conditions, and extinguishing agent conditions The degree of air blast was dependent upon the propeller slip stream and the wind tunnel air speed Fire conditions included the type of fuel and the size, location, and duration of the fire The factors affecting extinguishing agent involved the type and quantity of agent, the distribution system, and the rate and duration of agent application

The effects of air blast on extinguishment were as follows

As discussed in reference 1, extinguishing agent applied forward of the cylinders is wasted by overflowing around the outside of the ring cowl Figure 8 shows the effect of this spillage of fire from a source between the cylinders In this instance the fire nozzle was located between the cylinders, at the crank case The resulting flame extended several inches behind the cylinders, then radially outward from the crank case and forward just inside the ring cowl The flame swirled around the propeller hub and spilled over the ring cowl

The quantity of cooling air passing through the power section rapidly removes extinguishing agent applied near the fire source Consequently, quick application and proper distribution and placement of the agent are necessary for extinguishment

The air blast forced power section fires back into the accessory section and carried accessory section fires from the air outlet at the bottom of the section to within a few feet of the tail assembly In general, fires in the air blast were very severe, being similar in nature to a blow torch flame

The fire tests in which the power section air blast was eliminated by closure of the outlet area indicated that such a design would reduce the extinguishment problem, if the closure were absolutely leak-proof Extinguishing agent concentration tests showed that the agent concentration with full closure was approximately 100 percent higher than with the power section outlet area open, all other conditions of air blast and extinguishing agent remaining the same

Agent concentrations in the power section, with the section outlet area open, were generally so low that the smothering action of the agent could not have been sufficient to extinguish power section fires Apparently, the successful extinguishment of power section fires is dependent on the force with which the agent cuts through the air blast and fire in the proximity of the fire source The degree of cutting force attained is a function of the rate of agent application

The tests proved that data on the mass air flow through a power section are not sufficient to determine the rate of agent application necessary for extinguishing power section fires Successful extinguishment of fires in the installation incorporating inter-cylinder and head baffles and ring cowl, through which the air flow was 33,000 pounds per hour, required a higher rate of agent application than was necessary in the installation without the head and inter-cylinder baffles, through which the air flow was 49,000 pounds per hour Apparently, a small quantity of air moving at high velocity between cylinders and baffles is more critical from the fire extinguishing standpoint than a greater quantity of air moving between the cylinders at a lower velocity A higher rate of agent application, or force applied, was required in order for the high speed air flow and fire to be cut off and the fire extinguished

The fire fuels burned during the tests were #10 SAE oil, diesel fuel oil, and 73-octane aviation fuel  Oil and diesel fuel only were burned in the power section as no appreciable quantities of gasoline can be released in an actual power section

In the power section, the extinguishment of diesel fuel fires was much more difficult than the extinguishment of fires burning similar quantities of #10 SAE oil  Fires burning diesel fuel reached maximum intensity within a few seconds of the fire start, whereas fires burning #10 SAE oil gradually increased in intensity until 20 seconds after the fire start  A great percentage of the diesel oil released in the power section burned within the power section, whereas only a small percentage of the #10 SAE oil released actually burned within the section  The diesel oil fires were much more severe and difficult to extinguish than fires burning #10 SAE oil

The types of accessory section fires tested were:

#10 SAE oil)  Fires entering the accessory section from fire source in the power section
Diesel oil )

#10 SAE oil)  Fire source in the accessory section  No fire in the power section
Diesel oil )

73-octane aviation)  Fire source in the accessory section  No fire in the power section
gasoline )

Extinguishment comparisons between #10 SAE oil fires and diesel fuel fires in the accessory section with the fire source in the accessory section, or with fire leakage from a power section fire source, were as explained for the power section fires

Of the three types of fires with the source in the accessory section, gasoline fires and diesel fuel fires were the most difficult to extinguish  There was little difference between the two fire fuels as far as extinguishment was concerned  Fires burning #10 SAE oil were appreciably easier to extinguish than those burning gasoline or diesel oil  However, in no instance was extinguishment of fire from a source in the accessory section difficult  This was due to the small volume of the section and to the fact that very small quantities of the fire fuels released actually burned within the section  A major part of the fuel released burned in a long tail of flame under the fuselage, leaving the accessory section through the air outlet opening at the bottom of the section

In most of the fires with the source in the accessory section, liquid gasoline and oil ran out of the section and burned outside because of the lack of air for combustion within the section proper  All of these liquids escaped at the bottom of the section and resulted in one large tail of flame with no tails around the rest of the section  Thus, all the extinguishing agent and fire escaped through the same opening, which reduced the extinguishment problem  This fact also made possible the extinguishment of gasoline fires with the gasoline flowing, which was not possible in the DC-3 type of installation because of the many fire tails which escaped in that installation  Figure 13 shows a comparison of the accessory section cowling attachment methods used on the Waco and DC-3 airplanes  Of these two methods, that of the Waco is more advantageous from the standpoint of fire extinguishment  In the case of the Waco installation the lack of a great number of fire tails from accessory section fires made possible the extinguishing of accessory section fires without the overflow of power section agent which was necessary in the DC-3

Gasoline and diesel fuel fires generally appeared much larger than oil fires of the same quantity of flow  This was due to the fact that much of the oil released for the fires did not burn but was carried away in the air blast, and oil fires in general required considerable time to reach maximum combustion  Gasoline and diesel fuel reached maximum combustion immediately after ignition, and the entire quantities of each fuel released burned instead of being carried away by the air blast in the liquid state

When adequate rates of agent application and proper distribution methods were used, large and small oil fires within the power section proper were extinguished with the same ease  Conversely, when inadequate rates of agent application and improper distribution methods were used, large and small oil fires within the power section were equally difficult to extinguish  For the remainder of the fire, or fire tail, larger fires were somewhat more difficult to extinguish than smaller fires  However, the difference between large and small fires in the Waco was not nearly so great as in the DC-3 because of the smaller quantities of oil necessarily burned in the smaller installation and the resultant shorter fire tails

Because of air blast variations behind the various cylinders in the power section fire extinguishment was simple or difficult, depending upon the particular fire source location. The rate of application was increased until the fires could be extinguished repeatedly regardless of the fire source location

The oil cooler on this installation was located in a small tunnel between cylinders #6 and #7 shown in figures 4 and 5 The inlet opening to the cooler extended several inches forward of the cylinders This design precluded the entrance of oil or flame and made any special distribution of agent to this location unnecessary as there were no instances in which reignition occurred from this source

The exhaust stack on the installation (see figures 4 and 5) was a double outlet type comprising two half circles, one exhausting on either side of the installation at the bottom Although the stacks projected only approximately one-half inch through the ring cowl and no attempt had been made to provide seals between the ring cowl and the exhaust stacks, there were no instances of ignition or reignition from this source Tests were conducted, with and without previous oil fires, in which the engine was caused to backfire at various engine speeds, air blast velocities, and rates of oil flow In a very few instances there were evidences of flame at the exhaust stack outlets, but such flames were so small and of such short duration that it could not be determined whether the flames were due solely to the backfire or partly to ignition of the oil vapor at that location However, all such fires went out immediately and never became hazardous

A discussion of the carburetor air heating system is included in the latter part of this report which deals with ignition possibilities

All the fires tested were permitted to burn 30 seconds before extinguishing agent was applied Although fires of shorter duration might be slightly easier to extinguish, the difference is not sufficient to warrant the use of smaller agent quantities or lower rates of agent application

The methods used to distribute the extinguishing agents to the powerplant installation were basically the same as those developed in the tests of the DC-3 type installation It was found necessary to distribute agent simultaneously to the power and accessory sections only, as no other volumes of the installation were separated from those two sections Table 2 shows the optimum methods of agent distribution in the two sections for the three agents tested

Table II

OPTIMUM DISTRIBUTION METHODS FOR FIRE EXTINGUISHING AGENTS
(See figures 14, 15, and 16)

| Extinguishing Agent | Power Section | Accessory Section |
|---|---|---|
| Methyl Bromide and Carbon Tetrachloride | Double slot nozzle at the rear of the base of each cylinder | Nozzles or perforated ring around the engine rear case |
| Carbon Dioxide | Double or single slot nozzle at the rear of the base of each cylinder | Perforated ring around the engine rear case |

From experience gained during tests on the DC-3 type powerplant installation, the first power section distribution system installed consisted of a double slot spray nozzle located at the rear of the base of each cylinder, each nozzle fed by an individual lead from a distributor which was directly connected to the agent container (see figure 14) Because of the restricted area behind the cylinders it was necessary to provide a tee nozzle with the inlet on the side and outlets on the forward and rear ends The same power section distribution system was used in the three installation conditions shown in figure 7

In the accessory section, the first system installed consisted of perforated tubing, as shown in figure 15 This system proved very effective for all three extinguishing agents tested In later tests a system of nozzles was installed as shown in figure 16 This system proved slightly superior to the perforated ring when liquid agents, methyl bromide and carbon tetrachloride, were used but proved somewhat inferior to the perforated ring for use with carbon dioxide

No protection other than that of the power and accessory sections was required as there were no other isolated volumes in the powerplant installation However, carburetor protection, as already provided in many airplanes, is considered of great value

The rate of agent application proved to be the most important factor affecting the ability of an agent to extinguish fires, particularly power section fires The rapid dissipation of the agent from the power section by the air blast made extinguishment of fires in that section possible only when agent was discharged at a sufficiently high rate Although the discharge rate was not so critical in the accessory section as in the power section, because of the reduced air blast, it was still the most important factor affecting extinguishment

In the three installation conditions tested, the rates of agents discharged were gradually increased in both the power and the accessory sections until all fires, regardless of the location of the fire sources, could be extinguished This rate at which all fires could be extinguished is known as the minimum necessary rate The rates for the various agents in the two sections, for the three installation conditions tested, are given in table 3 In the DC-3 tests, it was possible to determine the end of effective discharge of the liquid agents with some accuracy However, in the Waco tests, because of the small quantities of the agents which were required and the comparatively low discharge rates, the determinations of exact rates and/or durations of discharge of liquid agents were not practical Accordingly, the actual discharge curves of the agents are given since it is believed that such curves may be more accurately and more easily checked in the development of actual aircraft powerplant fire extinguishing systems

Table III

NECESSARY MINIMUM APPLICATION RATES OF EXTINGUISHING AGENTS
AS DETERMINED BY THE TESTS

| Installation Condition | Engine Section | Methyl Bromide | Carbon Dioxide | Carbon Tetrachloride |
|---|---|---|---|---|
| Included head and inter-cylinder baffles, ring cowl (see fig 7A) | Power | Figure 18 | 4 pounds<br>1 5 seconds | Figure 17 |
| | Accessory | 2 53 lbs<br>0 6 seconds | 2 pounds<br>1 5 seconds | 2.33 pounds<br>0 5 seconds |
| Included ring cowl only (see fig 7B) | Power | Figure 20 | 2 5 pounds<br>1 0 seconds | Figure 19 |
| | Accessory | 1 50 pounds<br>0 6 seconds | 1 5 pounds<br>1 0 seconds | 2 33 pounds<br>0 75 seconds |
| No cowl or baffles (see fig 7C) | Power | Figure 19 | 5 5 pounds<br>1 5 seconds | Figure 21 |
| | Accessory | 2 50 pounds<br>0 75 seconds | 1 5 pounds<br>1 5 seconds | 2 75 pounds<br>0 75 seconds |

The short durations of agent discharges and the small quantities of agents involved made the resulting discharge rates most difficult to determine Therefore, the means by which the rates were measured are described

In every case, the system to be tested was removed from the airplane and re-assembled exactly as it had been installed Motion pictures were taken in all rate tests at a rate of 20 frames per second

All carbon dioxide tests were timed from the first appearance of the liquid until the last trace of liquid It is believed that these points are sufficiently definite for reproducing results This procedure for carbon dioxide was used for both power and accessory section systems

Because of the volatility of methyl bromide, carbon tetrachloride was used for the rate tests of both liquid agents As the specific gravities of the two liquids are approximately equal, this method was deemed advisable Thus, when equal volumes of the liquids were used, the rates were slightly different because of the difference in weight shown in table 1

Liquid agent discharges from the accessory section system were timed from the first appearance of the liquid until the first point at which the spray pattern began to deteriorate This point was the last definite point before the absolute end of discharge, generally occurring after 4 or 5 seconds Observations of actual fire extinguishments showed such discharge times as 4 or 5 seconds to be highly inaccurate as fires were extinguished within 1 5 seconds Obviously, agent vapors and small quantities left in the lines are carried out along with the escaping propulsive air long after the useful discharge has stopped

For checking the rate of liquid agent discharges from the power section system, the method used was more involved and more accurate than any of the methods discussed above In this case, motion pictures taken at a rate of 20 frames per second were made of two nozzles only, the remaining five nozzles having been cut off from view One nozzle was used to determine the starts of successive tests In these tests, the discharge from the other nozzle was collected during various time intervals from the test starts When, for any one set of agent conditions, the quantities of agent discharged in the various time intervals from the start were plotted against the time intervals as determined from the motion pictures, the discharge curves shown in figures 17 to 21 resulted The slope of these curves at any point is the rate of agent discharge at that point Approximately 40 points were plotted for each curve, each point requiring a rate test as described above

Figures 17 to 21 show the actual rates of agent discharges from one nozzle of the seven-nozzle power section system Inspection of these curves will indicate the difficulties of determining the exact duration of effective discharge Such curves could not be determined for carbon dioxide because of the difficulty of collecting the gas in increments during the discharge

Lower air blast velocities in the accessory section did not require the high agent rates of application which were necessary in the power section

During the tests many fires were extinguished, in both sections of the installation, at agent rates much lower than those given in table 3 and in figures 17 to 21 However, it was necessary to increase the rate until all fires could be extinguished, regardless of the prevailing conditions at the particular fire location

The DC-3 tests proved that the duration of agent discharge should not be less than 2 seconds for that installation The agent discharge durations in the case of the Waco varied, for the particular condition of installation, between 0 5 and 1 5 seconds This difference probably results from the fact that the fire "tails", so common to the DC-3, were not encountered with the Waco Thus, in each installation, the bulk of fire within the installation was extinguished within approximately 1 second, but extinguishment of the numerous fire tails of the DC-3 required additional time Long durations of extinguishing agent discharge are beneficial, but tests proved that such long durations are unnecessary Longer durations require proportionately greater quantities if the rate is to be maintained since rate, not quantity, is the criterion governing extinguishment

Table IV

NECESSARY MINIMUM EXTINGUISHING AGENT QUANTITIES
DETERMINED BY THE TESTS

| Installation Condition | Engine Section | Methyl Bromide (pounds) | Carbon Dioxide (pounds) | Carbon Tetrachloride (pounds) |
|---|---|---|---|---|
| Included head and inter-cylinder baffles and ring cowl (see fig 7A) | Power<br>Accessory<br>Total | 3 3<br>2 5<br>5 8 | 4 0<br>2 0<br>6 0 | 4 0<br>2 3<br>6 3 |
| Included ring cowl only (see fig 7B) | Power<br>Accessory<br>Total | 1 5<br>1 5<br>3 0 | 2 5<br>1 5<br>4 0 | 2 3<br>2 3<br>4 6 |
| No cowl or baffles (see fig 7C) | Power<br>Accessory<br>Total | 2 5<br>2 5<br>5 0 | 5 5<br>1 5<br>7 0 | 2 7<br>2 7<br>5 4 |

The actions of extinguishing agents found to be most effective in the Waco powerplant installation were the mechanical and smothering actions Mechanical action, which results when agent is directed across the fire with sufficient force to cut the flame away from the fuel, is most effective in extinguishing power section fires Smothering action, which renders air incapable of supporting combustion, was of most importance in extinguishing fires in the more confined accessory section Blanketing action, which prevents air from reaching fire tails, was not nearly so important in the Waco tests as in the DC-3 tests because of the single fire tail resulting from the Waco powerplant fires In the Waco tests, fires burning outside the installation proper were concentrated into one large tail rather than into numerous smaller tails as in the DC-3 tests Cooling action had a negligible effect on extinguishment because of the small quantities of agents necessarily used

A comparison of the three extinguishing agents tested in this particular type of powerplant installation is given in order of merit in table 5 and is based on the extinguishing ability of the agent only, assuming proper distribution methods, rate, and quantities exist for each agent

Table V

FIRE EXTINGUISHING AGENTS IN ORDER OF MERIT FOR USE IN AIRCRAFT POWERPLANT INSTALLATIONS OF THE TYPE TESTED

| Order of Merit | Power Section Oil Fires | Accessory Section | | Overall |
|---|---|---|---|---|
| | | Oil Fires from Power Section Source | Gasoline Fires from Accessory Section Source | |
| 1 | Methyl Bromide | Methyl Bromide | Methyl Bromide | Methyl Bromide |
| 2 | Carbon Tetrachloride | Carbon Dioxide | Carbon Dioxide | Carbon Dioxide<br>Carbon Tetrachloride |
| 3 | Carbon Dioxide | Carbon Tetrachloride | Carbon Tetrachloride | |

This comparison of agents is purely qualitative because of the many variables involved and the necessity for limiting the number of tests conducted Such factors as complexity and weight of distribution systems, containers, line sizes, pressures required, agent operating and handling conditions, toxicity, and corrosion, were considered design problems having no bearing on the relative merits of the extinguishing agents

All three agents tested were capable of extinguishing power section oil fires and accessory section oil and gasoline fires with the liquids being burned flowing during extinguishment. In addition, these agents extinguished accessory section diesel oil fires in which the oil continued to flow during extinguishment However, none of the agents, applied at the rates given in table 3, were capable of extinguishing power section fires burning diesel fuel oil The few tests conducted on power section diesel oil fires indicated that a specific series of tests should be conducted on an actual diesel engine if the test results were to be of any value

Although methyl bromide, carbon dioxide, and carbon tetrachloride each proved capable of extinguishing all lubricating oil and gasoline fires tested, methyl bromide proved superior to the other agents in extinguishing ability

For all agents, stoppage of flows of gasoline and oil before extinguishment is attempted reduces the extinguishment problem, particularly in the case of burning gasoline

It is repeated that the comparison between the agents given above applies only to their ability to extinguish fires in flight in the type of powerplant installation tested

Design Information for Extinguishing Systems

The basic distribution systems used in these tests resulted from the systems developed on the DC-3 type powerplant installation discussed in reference 1

The power section system tested consisted of one twin-slot spray nozzle behind the base of each cylinder, as shown in figure 14 Each such nozzle was fed by an individual line from a distributor which was connected by a large single line to the agent container Although this arrangement facilitated testing, it was indicated that a large feed line leading to a tube around the crankcase, then through short feed lines to each nozzle might be more advantageous in practice However, any system making use of a ring around the crankcase will involve considerable work to insure that the spray nozzles receive equal quantities of agent within plus or minus 10 percent, which was required in the distributor type installation tested

In the accessory section, the systems shown in figures 15 and 16 were tested The system comprising a ring of perforated tubing around the engine rear case proved satisfactory for use with all agents tested However, for liquid agents the system comprising the ring and nozzles proved somewhat superior to the perforated tube, but the difference was not great enough to warrant use of lower rates. The required distribution from the accessory section system is not nearly so critical as in the case of the power section. In the accessory section no nozzles should discharge less than 50 percent of the quantity which would be discharged if the quantities distributed to the various nozzles were equal. Distribution tests of accessory section systems showed that the greatest agent quantities are discharged from the ring at a point diametrically opposite the feed line connection. For this reason, in the case of the Waco installation it was advantageous to locate the inlet to the ring at the bottom of the section. This arrangement provided the greatest quantities of agent at the top of the section, and this agent had to drop through the entire section in order to escape through the outlet opening at the bottom. If the inlet to the ring had been made at the top of the accessory section, higher rates and greater quantities of the agents would have been necessary.

The discharge rates for extinguishing agents in the two sections should be determined as discussed on pages 7, 8, and 9. For power section systems an effort should be made to reproduce the curves shown in figures 17 to 21 as the establishment of the end point of the effective spray is extremely difficult. Means for determining this end point are not sufficiently accurate, and the equipment to determine the entire curve is the same as that required to obtain the approximate end point. More time is required and more tests are necessary to obtain the curve, but the results are more accurate and dependable.

Separate agent containers were used for the two sections in the tests, but in actual practice a single container with devices for metering agent to the individual sections may be more practicable. This problem may be similar to that of obtaining equal distribution, as discussed above. Tolerances on quantities metered to the various locations could not be determined, and quantities shown in table 4 should be adhered to as nearly as possible.

To minimize the effect of heating, distribution rings should be located as near the crankcase as possible, and lead lines should follow other parts as this permits transfer of heat away from the lead line and prevents fire from entirely encircling such lines.

During the tests, rates of agent discharge were varied by changing lengths and diameters of feed lines, numbers and sizes of holes in perforated tubing, bore and slot sizes of nozzles, and agent container pressures. The twin-slot nozzle proved superior in the power section for use with liquid agents and, in addition, proved to be as successful as the single-slot nozzle for use with carbon dioxide. Accessory section liquid spray nozzle design is not critical, but the cone type spray pattern appears most satisfactory when located as shown in figure 16. All spray nozzles used in the tests were made of brass. All tubing used was copper, with the exception of the perforated tubing used in the accessory section, which was stainless steel. Nozzles should be tested for their tendency to plug, particularly if carbon dioxide is to be used. The design of nozzles to prevent oil and dirt from plugging outlets in actual installations is advisable.

Power section nozzles should be located as shown in figure 14, preferably with the forward spray impinging on the rear edges of the cylinder head fins and the rear spray discharging outward past the top of the cylinder head. Accessory section spray nozzle locations are not critical, and such nozzles should be located to avoid as many obstructions as possible. The number and sizes of nozzles or outlet holes in the accessory section system are dependent on metering tests for determining the rate of agent discharge and equality of distribution. Obviously, the greater the number of nozzles or outlet openings used, the greater will be the coverage. Eight nozzles or twenty three 1/16-inch diameter holes were used in the tests, the total outlet areas of the holes and nozzles being equal.

Release valves should be quick opening in order to obtain the high discharge rates necessary over the short durations from 0.5 to 1.5 seconds.

The location of agent containers may be critical, particularly with respect to carbon dioxide systems, because of the rapid decrease of pressure in agent containers with a temperature decrease. Figures 80 and 81 of reference 1 show the increased length of discharge time for equal quantities of carbon dioxide as the temperature of the containers was lowered.

## Conclusions

1. Extinguishment of powerplant gasoline and oil fires in flight in the type of installation tested can be accomplished within reasonable weight limitations, provided adequate agent application rates and distribution methods are used.
2. Extinguishment of gasoline and oil fires in flight can be accomplished without stopping the flows of the burning liquids, but shut-off of both gasoline and oil is advisable to prevent recurrence of the fire.
3. Air blast is the most serious factor to be overcome in extinguishing aircraft powerplant fires, and it can be overcome by the use of adequate rates of agent application.

4 Adequate rate of agent application is not dependent solely on the mass flow of cooling air, it is also a function of the air velocity through the powerplant installation Small masses of air moving at high speed require a higher rate of agent application than greater masses of air moving at lower speeds

5 In the accessory section of the installation tested, gasoline fires were only slightly more difficult to extinguish than oil fires

6 An accessory section air outlet consisting of a single area at the bottom of the section simplifies the extinguishment problem by concentrating escaping fire into one large fire tail which is acted upon by all the agent released in that section

7 Within limits, large fires are no more difficult to extinguish than small fires

8 Sections of any installation which are separated by bulkheads, such as the power and accessory sections, must be individually protected against fire

9 Extinguishing agent, applied to the power and accessory sections, should be discharged simultaneously

10 Methyl bromide, carbon dioxide, and carbon tetrachloride are satisfactory for general protection against aircraft powerplant fires in flight in the type of installation tested Methyl bromide was found to be the most satisfactory agent tested for extinguishing such fires

11 The rate of extinguishing agent application is the most important factor in applying agent to powerplant fires in flight

12 In the type of installation tested, fires within the sections proper are extinguished within 1 second, but agent discharge durations up to 1 5 seconds may be required to extinguish the short fire tails outside the power section and the one large fire tail emanating from the accessory section

13 Although the tests conducted to date make possible the design of extinguishing systems for most radial engine installations, the required rate of agent application can be proved only by test

## DETECTORS

### Purpose

The purposes of the tests on fire detectors were

1 To develop, test, and compare fire detectors suitable for use in detecting gasoline and oil fires occurring in both the power and the accessory sections of the aircraft powerplant installation type tested, under simulated flight conditions

2 To determine for each detector the number required, optimum locations, and the time necessary for operation

### Description of Detectors Tested

The detectors tested were of two general types, unit and continuous A unit detector is an individual type capable of detecting heat or flame in the immediate vicinity of the detector, whereas a continuous detector may be in the form of a wire capable of detecting heat or flame anywhere along its length Descriptions of many types of fire detectors are given in reference 1

The four detectors used in a majority of the Waco tests are described in the following paragraphs

The operation of one unit detector used in the tests was due to the burning of combustible material In the detector two nylon strands held open two electrical switches Burning of the strands allowed the switch to close Two strands were provided to prevent operation if one strand were broken accidentally This detector is a product of Walter Kidde & Company, Inc , and is shown in figure 22

The unit detector used in most of the tests operated on the principle of expansion of metals due to temperature increases This detector consisted of a convex sheet metal disc, fixed to a base at its center and at one point on its periphery A sufficient increase in temperature caused the disc to "oil can," making electrical contact between a point on the disc periphery opposite the fixed point and a corresponding contact built into the detector base This detector is a product of the American-LaFrance-Foamite Corporation and is shown in figure 23

One continuous type detector used in the tests was a wire type, the operation of which was due to the melting of a soft metal alloy It consisted of an inner conductor (wire) upon which were strung porcelain bead insulators These insulators were sheathed with a soft tin alloy which was plated with copper When the melting point of the tin alloy was reached, the alloy fused and made contact between the copper plating, which remained in tubular form, and the inner conductor This detector is a product of Fenwal, Inc , and is shown in figure 24

The fourth detector tested was used as both a continuous and a unit detector  Its operation was due to the ability of flame to rectify an alternating current  An a-c voltage was impressed across a gap between a metal section of the airplane (firewall) and a wire conductor, supported on but insulated from the firewall  Passage of flame between the firewall and the conductor rectified the current and, by means of an electronic circuit, operated a warning signal  This detector was used as a continuous wire type and, by using numerous short conductor lengths connected to the electronic circuit in parallel, it was also used as a series of unit detectors  This detector is a product of the Minneapolis-Honeywell Regulator Company

Procedure

A basic size gasoline fire of 0 2 g p m  was arbitrarily established for power section detection tests  The spread of such a fire as it emerged from the power section is shown in figure 25  It was considered that fires smaller than 0 2 g p m  would not be immediately damaging to the aircraft primary structure but fires of that size or larger should be detected within 3 seconds  Although the rapidity of power section fire detection depended on the fire size, this relationship did not exist in the accessory section, therefore, accessory section gasoline detector fires were varied from 0 2 g p m  to 3 g p m

All detectors were electrically connected to signal lights in the control shed, and the time lags between the starts of fires and the operations of the warning lights were observed

For power section tests the basic detector fire spread on the diaphragm was observed  In successive fires a unit type detector was moved closer to the fire until the time from the fire start to the detector signal did not exceed 3 seconds or until the detector was actually in the flame  At various locations the spread of the detector fire changed, making it necessary to conduct tests completely around the diaphragm  This variation of fire spread made useful another test method  In this instance the Minneapolis-Honeywell detector was used in connection with 12 short conductor lengths  If any of the 12 conductors were affected by fire the warning light operated, and by switching the various segments on and off it was possible to determine which segments were covered by fire and the approximate width of the fire  These segments were installed completely around one side of the diaphragm so that tests could be conducted with the fire located at any point on that side without shifting the detector locations

Continuous detectors were arranged to pass through the unit detector locations, and the time lag was noted as in the tests of the unit detectors

In the accessory section, detectors were placed around the firewall edge as far from the fire source as possible to determine the required proximity of the detector to the flame source in this section of relatively low air flows  Detectors were also located around the outlet opening of the accessory section

From experience gained on the DC-3 type installation, power section detectors were located on the diaphragm only, and accessory section detectors were located on the firewall and around the section outlet opening

The effect of rain on the operation of detectors was simulated by introducing water at a rate of 20 g p m  into the air stream forward of the propeller, before and during detector fires

Results and Discussion

The tests showed that the basic power section detector fires, because of the high velocity turbulent air blast conditions, varied in spread over the diaphragm depending on the location and direction of the fire nozzle  The width of this spread varied from 5 inches to 20 inches  As in the DC-3 tests, it was proved that power section detectors had to be actually contacted by flame for rapid detection or for any detection at all  Although the flame temperature approximated 2000° F , the air adjacent to the flame was of much lower temperature and could not be depended upon to operate the detectors

Temperatures in the accessory section during fires varied from 200° F  to 2000° F  regardless of the quantity of gasoline used to feed the fires  These temperature variations were probably due to fire stratification caused by air blast entering the section through blast tubes, cowl cracks, and similar openings, as well as to the cooling effect of unburned gasoline  However, due to the fact that the only sizable opening in the accessory section cowl existed at the bottom of the cowl, and because of the small volume of the accessory section, it was proved that even the smallest fires in the accessory section emerged through that outlet opening  Thus, by proper placement of detectors around this opening, fires of any size were rapidly detected  As in the power section, radiation of heat from a flame to a detector could not be depended upon for rapid fire detection

Tests showed that the optimum detector locations were the points of flame egress from the powerplant installation  Flame emerged from the power section between the ring cowl rear edge and the diaphragm, and from the accessory section outlet area at the bottom of that section The spacings for unit type detectors are given in figure 26 As the flame types were sensitive to small tails of flame it was possible to space them approximately 8 inches apart, whereas the metal expansion types, which had to be actually enveloped in flame, could not be spaced at distances greater than 6 inches

The optimum locations for continuous detectors are shown in figure 26 A single loop of the continuous type detector is sufficient for both power and accessory section detection

The detectors tested were designed to operate between 350°F and 400°F This setting precluded the possibility of false alarm as the powerplant installation air temperatures, with the engine operating but without fire, varied between 250°F and 300°F

The laboratory tests conducted on detectors consisted of plunging a detector into a Bunsen burner flame of 2050°F (determined by a chromel-alumel thermocouple of #18 gage wire) and observing the time required for detector operation from the first contact with flame

The operating times required for the fire detectors tested are given in table 6

Table VI

TIME REQUIRED FOR DETECTOR OPERATION

| Detector Manufacturer | Detector Type | Temperature Setting (°F) | Operating Time (secs ) | Remarks |
|---|---|---|---|---|
| American-LaFrance-Foamite Corporation | Metal Expansion | 400 | 3 5 | Unit type |
| Fenwal, Inc | Fusible Alloy | 375 | 2 2 | Continuous type |
| Minneapolis-Honeywell Regulator Company | Electronic | - | 0 0 | Continuous type |
| Walter Kidde & Company, Inc | Flame | - | 0 0 | Unit type |

Tests in which water was sprayed into the wind tunnel forward of the propeller to simulate rain indicated that the electronic detector would short out of operation or give false alarms With the cooperation of the Minneapolis-Honeywell Regulator Company, considerable testing and reviewing of the equipment proved that the system could be made to operate properly under simulated rain conditions The revisions consisted mainly of obtaining proper insulators and balancing the circuit to preclude short-circuiting and false alarming However, at the completion of the Waco tests no complete electronic detector was available A final series of tests should be conducted on this type of detector when suitable insulators and detecting units have been fabricated for use in actual installations At that time, the entire system should be checked for operating characteristics and susceptibility to simulated rain

In general, the tests did not involve considerations of mechanical construction, resistance to corrosion, fatigue, vibration, and other conditions which would exist in an actual powerplant installation However, as the Fenwal fusible alloy detector appeared to be the most highly developed of the detectors tested, a few vibration tests were conducted to determine the allowable spacing between the detector supports The optimum spacing between supports using the detecting wire alone was 12 5 inches The connectors used in combination with this detector should be individually supported

The Waco tests indicated the superiority of the continuous type detector over the unit type detector The number of unit type detectors which would be required, the number of necessary lead wires to these detectors, and the fact that the coverage of such detectors is not nearly so complete as that which can be obtained by using the continuous type detector, made the continuous detector appear more suitable for this particular purpose

The design criteria as stated in reference 1 were substantiated by the tests conducted on the Waco powerplant installation

Conclusions

1 Rapid detection of aircraft powerplant fires can be obtained within reasonable weight limitations if suitable detectors and detector locations are used

2 The proper fire detector locations are the points of flame egress from the powerplant installation

3 Spacing between flame type unit detectors in the power and accessory sections of the installation tested should not exceed 8 inches The spacing between metal expansion type detectors in this installation should not exceed 6 inches

4 The continuous type detector is superior to the unit detectors from the standpoints of area covered and simplicity of installation

5 The Fenwal fusible alloy continuous detector is considered the most highly developed of the detectors tested for use on aircraft powerplant installations

## MATERIALS

Purpose

The purpose of the tests on materials was to study under flight conditions the effects of gasoline and oil fires on materials and equipment commonly used in aircraft powerplant installations

Description of Materials Tested

The materials used in the components of the powerplant-fuselage-wing stub unit were as follows

Engine Mount Standard Waco YKS-37 engine mount Rubber engine mount bushings were installed on four of the eight supports The remaining four supports were solidly connected

Accessory Section Cowl (Diaphragm) Both 0.031-inch black iron and 0.049-inch aluminum alloy

Wing and Nacelle Skin. 0.012-inch stainless steel sheet

Firewall: 0.050-inch black iron

Engine Fuel System Copper tubing lagged with asbestos

Engine Oil System: Copper tubing lagged with asbestos The oil cooler of this installation was mounted between cylinders #6 and #7 and so shrouded as to prevent entrance of fire

Engine Accessories As described under "General Test Procedure," the engine accessories were protected from fire by an asbestos lagging

Procedure

A majority of these tests were conducted in conjunction with the extinguishing and detector tests under the air blast and fire conditions described under "General Test Procedure "

Under various fire conditions, temperatures throughout the powerplant installation, fuselage, and wing stubs were recorded by means of 25 chromel-alumel thermocouples connected to a bank of 25 pyrometers A slow speed camera, taking pictures at a rate of one frame every 3 seconds, was used to record the pyrometer readings The thermocouple locations used in the tests are shown in figure 27

Tests were conducted in which copper tubing, carrying flows of gasoline, was subjected to accessory section gasoline fires

Copper and stainless steel were used in fabricating extinguishing systems, but, in a few tests, heavy walled aluminum fittings were incorporated in the systems for test purposes

In general, the effects of fire were noted on all the materials and equipment described as well as on blast tubes, aluminum alloy brackets, clips, straps and intake ducts

Results and Discussion

The standard Waco YKS-37 engine mount supported the engine throughout the 812 fire tests conducted At the end of the test program the mount was in very poor condition because of continued exposure to flames and the corrosive effects of the extinguishing agents tested The rubber engine mount bushings, which were protected from flame contact, were hard and brittle but otherwise intact Obviously, shock units, designed to support an engine after destruction of the rubber components, would be advantageous

Figure 27 shows the maximum temperatures recorded on the skin, cowling, and firewall in a series of 30 fires at various locations The maximum temperatures shown are not those reached during any one fire but are the maximum temperatures attained at each thermocouple location during the 30 fires

Continuous temperatures were recorded during many fire tests and, in general, the results of temperature surveys of the Waco installation are not materially different from those of the DC-3 installation. The hottest areas are the diaphragm, the firewall, and the fuselage skin immediately behind the firewall. The leading edge of the lower wing remained cool, but the temperatures increased toward the trailing edge. The upper part of the fuselage, above the lower edge of the windshield, and the upper wing were not affected by any of the test fires. However, the sides and bottom of the fuselage were subjected to considerable fire. Many of the fires extended past the tail of the fuselage.

In revising the Waco airplane for the fire tests, the fuselage was covered to within 6 feet of the tail with stainless steel sheet (see figure 2). The fabric covering was left on the rear of the fuselage as it was believed that the relatively small fires which might occur in the Waco powerplant installation would not extend so far aft. However, the second fire tested, burning oil applied at a rate of 2 gallons per minute, destroyed this fabric. Accordingly, preliminary investigations were begun in which panels of fabric and dope were covered with solutions of chlorinated rubber, installed in the belly of the fuselage, and subjected to typical powerplant fires. This coating proved to have considerable resistance to fire and made necessary a more thorough investigation, which is in progress. Results of these tests will be published in a separate report.

Tests were conducted on non-metallic firewall materials as described in a separate note[4].

The aluminum alloy N.A.C.A. ring cowl remained intact at the end of the test program. As in the case of the DC-3 fire tests, aluminum alloy proved sufficiently fire-resistant for use in such ring cowls. After the first dozen fire tests it was found necessary to reinforce the trailing edge of the Waco ring cowl with 0.012-inch stainless steel sheet. However, no one fire damaged the cowl enough to warrant a change of material.

The 0.049-inch aluminum alloy diaphragm (accessory section cowl) was installed during several power section fires as such fires proved most damaging to this cowl. This cowling on the Waco was not damaged to the extent that the DC-3 accessory section cowling was damaged under comparable fire conditions. This was probably due to the fact that the fire which could actually burn within the accessory section was so small. In each of these fires several square inches of cowling were destroyed, but this was not enough to seriously affect the extinguishing problem. However, stainless steel sheet appears advantageous for fabricating such cowl sections.

The firewall used throughout the test program was fabricated of 0.050-inch black iron because of the irregular firewall shape and the necessity for working the firewall material by hand. Although stainless steel sheet is considered the best firewall material, the black iron used in the tests proved adequate.

As discussed in the report of tests on the DC-3 type engine installation, materials such as steel or copper should be used in all tubing forward of the firewall. The only exception is in the case of tubing carrying a flow of oil, in which instance aluminum alloy is adequate. In the tests, copper fuel lines were exposed to accessory section gasoline fires for periods in excess of 1 minute. Although vapor lock occurred <u>within</u> 10 seconds of the fire starts, there was no instance in which the copper tubing failed.

In a few instances heavy walled aluminum alloy fittings were used in fire extinguishing systems. When subjected to fire, such fittings were so weakened that they were destroyed when extinguishing agent (under pressure) was released.

Standard AN (neoprene) hose connections proved capable of withstanding numerous fires of 30 seconds duration.

The oil cooler of this installation was so located as to preclude the entrance of any appreciable quantities of burning fluids or fire and therefore required no protection. The oil cooler, located as shown in figures 4 and 5, was housed in a small tunnel between cylinders #6 and #7 and the tunnel inlet was sufficiently forward of the cylinders to maintain a reasonable quantity of cooling air through the cooler at all times. A butterfly valve, located in the tunnel ahead of the cooler in the original installation, was removed to assure this flow of cooling air.

Aluminum alloy ducts, carrying air into the carburetor air heater, were damaged early in the tests and the air heating arrangement was plugged during a majority of the tests. However, tests were conducted with the damaged inlets installed as described later in this report.

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[4] H. L. Hansberry, "Fire Resistance Characteristics of Asbestos Base Phenolic Impregnated Materials for use in Aircraft Firewalls," CAA Technical Development Note No. 27, January, 1943.

Observations made during all the tests indicated that no powerplant fire would impinge on the tires or wheels of aircraft of this type However, the landing gear struts would be surrounded by such fires

Conclusions

1 The integrity of conventional welded tube fuselage structures is not seriously jeopardized within several minutes of the start of engine fires However, aircraft covered with doped fabric can become unairworthy within a few seconds of the start of such fires

2 The aluminum alloy accessory section cowling (diaphragm) of the test installation was not sufficiently damaged in any one fire to necessitate a change of material

3 Flame temperatures within the accessory section reached values of approximately 2000°F However, the small volume of the section and the air stratification present prevented fires in this installation from being as severe as those encountered in the DC-3 and CW-20 installations

4 The conventional welded steel tube engine mount, which was an integral part of the fuselage structure, successfully withstood 148 fires of 30 seconds or more duration

5 The firewall, 0 050-inch black iron, was undamaged by the first 400 fires However, the high temperatures, in addition to the corrosive effects of the extinguishing agents, led to gradual deterioration and eventually to destruction of the firewall

6 Copper, or material of greater fire resistance, should be used in all tubing systems forward of the firewall, with the exception of tubes carrying flows of oil Such tubes can be aluminum alloy

7 Neoprene hose connections withstood many fires in the tests and in no instance were such hoses seriously damaged by any one fire

8 The oil cooler arrangement in the test installation was so located as to preclude entrance of fire or burning liquids and did not require any special fire protection

9 In the type of installation tested, the landing gear tires would not be subjected to powerplant fires, but landing gear struts and supports could be enveloped by flame

10 The aluminum alloy N A C A ring cowl was not seriously damaged by fires

## IGNITION

Purpose

The purposes of the ignition tests were to study the causes of gasoline and oil ignition in an aircraft powerplant installation in flight and to determine methods whereby these hazards might be reduced

Procedure

A majority of the data on ignition was obtained during tests of extinguishers, detectors, and materials

Early in the extinguishing tests it was observed that the aluminum alloy cold air inlet ducts to the carburetor air heating system shown in figure 6 were damaged by the test fires It was believed that failure of these ducts would allow oil vapors to enter the confined high temperature regions of the system and that "flashback" or reignition might occur In order to prevent complication of the extinguishing tests by such reignition, the cold air inlet ducts were removed and the remainder of the system plugged At the beginning of the ignition tests, these plugs were removed and the aluminum alloy cold air inlet ducts were replaced Tests were then conducted in which oil was allowed to flow in the area of the inlets after fires at that location had been extinguished

Other ignition sources which became evident during the extinguishing and detector tests were due to deterioration and failure of the exhaust system

Accidental spark ignition of gasoline and oil was simulated by spraying these liquids over electric sparks (15,000 volts, 30 milliamperes) deliberately produced

Results and Discussion

Tests proved that reignition of power section oil fires could occur as a result of damage to the aluminum alloy cold air inlet ducts, shown in figure 6 However, tests also proved that as long as those ducts remained intact flashback would not occur This was due to the fact that the inlets to the cold air ducts were well located on either side of #1 cylinder ahead of the cylinder This location, at the top of the engine and forward of the cylinders, prevented the entrance of any appreciable quantities of oil, oil vapor, or flame Conversely, when the ducts were pierced by flame behind the cylinders, sufficient quantities of oil vapor entered the air heating system to provide reignition after the fire had been extinguished This reignition occurred in tests in which both #10 SAE oil and diesel oil were burned As appreciable quantities of gasoline could not be released in the power section of an actual installation, gasoline was not used in the flashback tests However, tests on the DC-3 installation, in which the design allowed gasoline to enter the hot air heating system in the vicinity of the accessory section, proved that gasoline was not susceptible to the flashback type of reignition because of its relatively narrow explosive range as compared to that of oil

The tests proved that the Waco carburetor air heating system was an excellent design with the single exception of the aluminum alloy cold air inlet ducts Substitution of stainless steel ducts would provide the only necessary change to preclude the flashback possibility Such a change would be required with or without N A C A cowl and inter-cylinder baffles

During the ignition tests, the exhaust stack and flange parted from the exhaust port of #2 cylinder, allowing a 1/8-inch gap Under this condition, oil fires with the source in the vicinity of #2 cylinder could not be extinguished while the oil continued to flow Oil (#10 SAE or diesel) or gasoline can be ignited easily by this exhaust flame

Deterioration of the exhaust manifold also proved to be a source of ignition as indicated in several tests in which engine exhaust, escaping through small holes in the manifold, prevented extinguishment of power section oil fires with the oil flowing during extinguishment

The exhaust stack outlets, located as shown in figures 4 and 5, did not prove a source of ignition as long as the outlets were outside the N A C A cowl At the beginning of the tests, these outlets projected about one-half inch outside the cowl and no troubles were experienced Late in the tests, however, the N A C A cowl sagged sufficiently to allow the cowl to drop below the exhaust stack outlets This resulted in the outlets becoming sources of oil ignition and reignition

Both #10 SAE oil and diesel oil were tested in the power section ignition tests Of the two oils, the diesel oil appeared more dangerous as far as ease of ignition was concerned The volatility of the diesel oil also made possible its ignition by an electric spark operating on 15,000 volts and 30 milliamperes, artificially produced

In all instances, stoppage of the engine and the flows of fuel and oil before extinguishment is attempted would eliminate sources of fire reignition

Conclusions

1 The most dangerous sources of oil ignition in an aircraft powerplant installation are stagnant volumes of air and oil vapors at high temperatures

2 In the tests gasoline was easily spark-ignited, diesel oil could be ignited by spark, but oil could not be spark-ignited

3 Ignition hazards can be reduced by locating carburetor air heating systems and carburetors high in the powerplant installation, making the systems leakproof, using proper fire-resistant materials, and so locating air inlets that flame or inflammable fluids or vapors cannot enter the systems

4 Stopping of the engine and the flows of fuel and oil before attempting extinguishment of fire obviously reduced the possibility of fire reignition

5 Cracks, holes, or other openings in exhaust systems are dangerous ignition sources, particularly when they occur in stagnant volumes of air and oil vapor

Table VII

FIRE TEST STATISTICS

| | | NUMBER OF TESTS CONDUCTED | | | QUANTITIES OF AGENTS USED | | |
|---|---|---|---|---|---|---|---|
| | | FIRE TESTS | RATE TESTS | TOTAL TESTS | FIRES | RATE TESTS | TOTAL TESTS |
| EXT AGENTS | Carbon Dioxide | 212 | 108 | 320 | 1192 lbs | 381 lbs | 1573 lbs |
| | Carbon Tetrachloride | 359 | 325 | 684 | 560 qts | 240 qts | 800 qts |
| | Methyl Bromide | 77 | - | 77 | 120 qts | | 120 qts |
| | Total Number of Tests on Extinguishing Agents | 648 | 433 | 1081 | | | |
| | Detector Fires | 103 | 17 | 120 | | | |
| | Ignition Fires | 34 | - | 34 | | | |
| | Materials Fires | 27 | - | 27 | | | |
| | TOTAL TESTS | 812 | 450 | 1262 | | | |

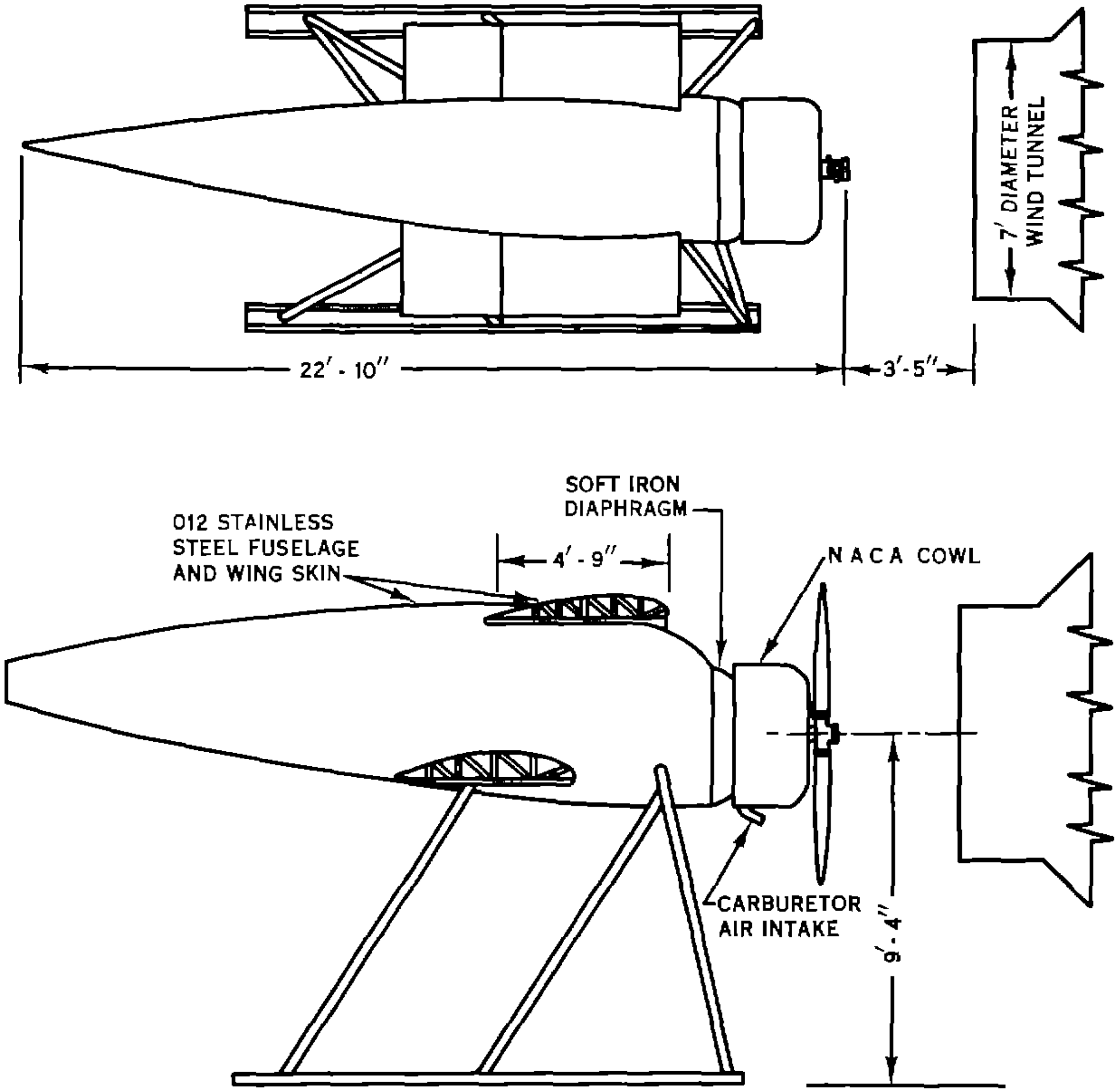


Figure 1 Test Unit

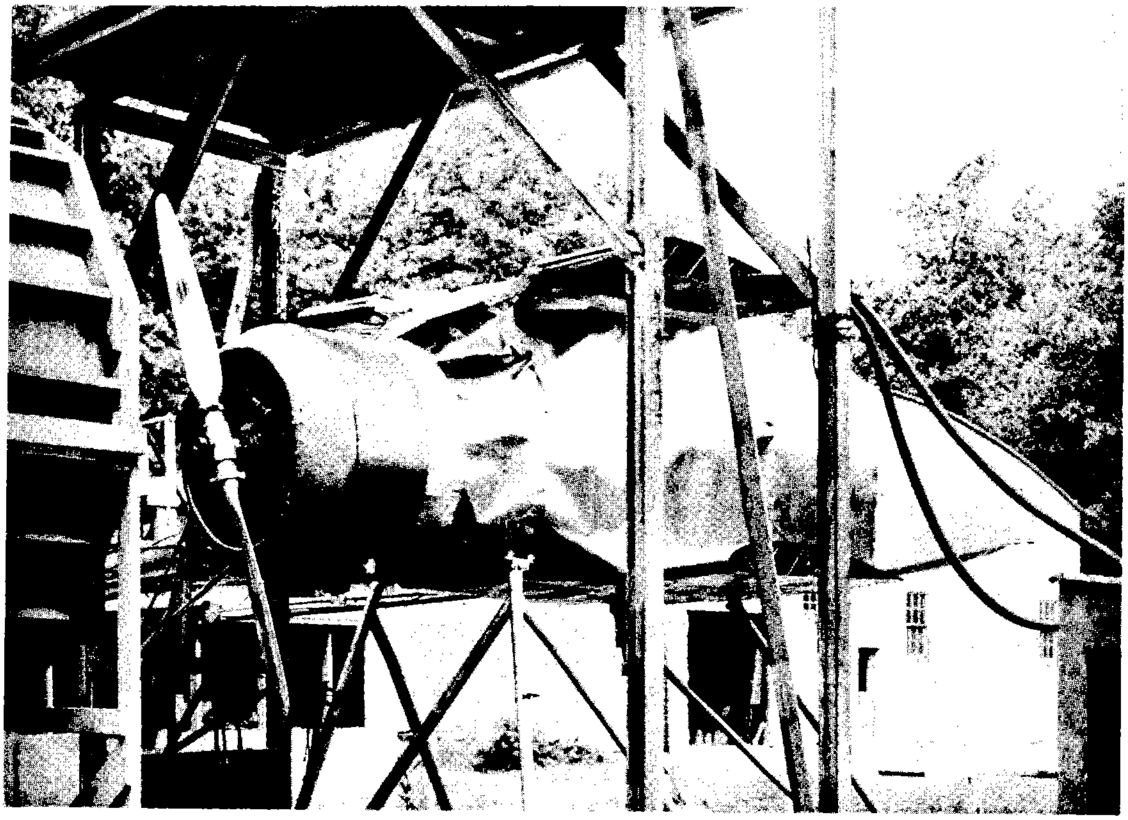


Figure 2. Test Set-Up

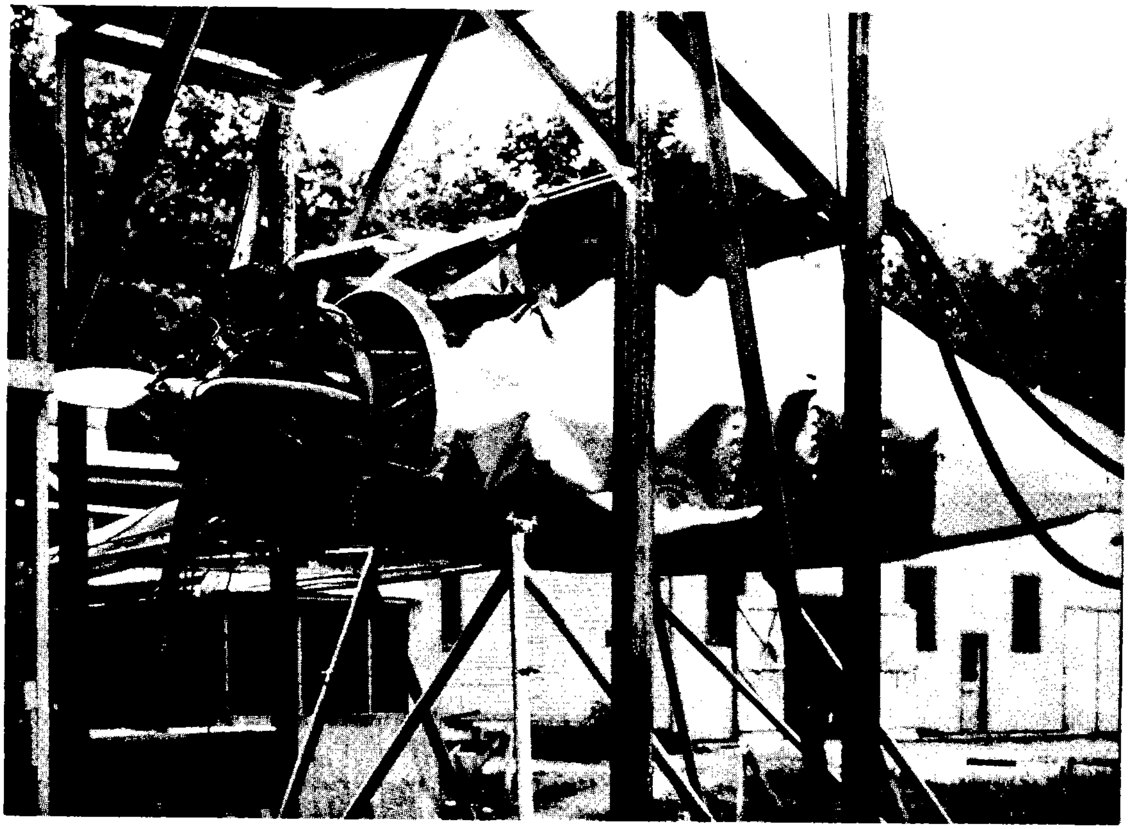


Figure 3. Test Set-Up

Figure 4. View of Accessory Section

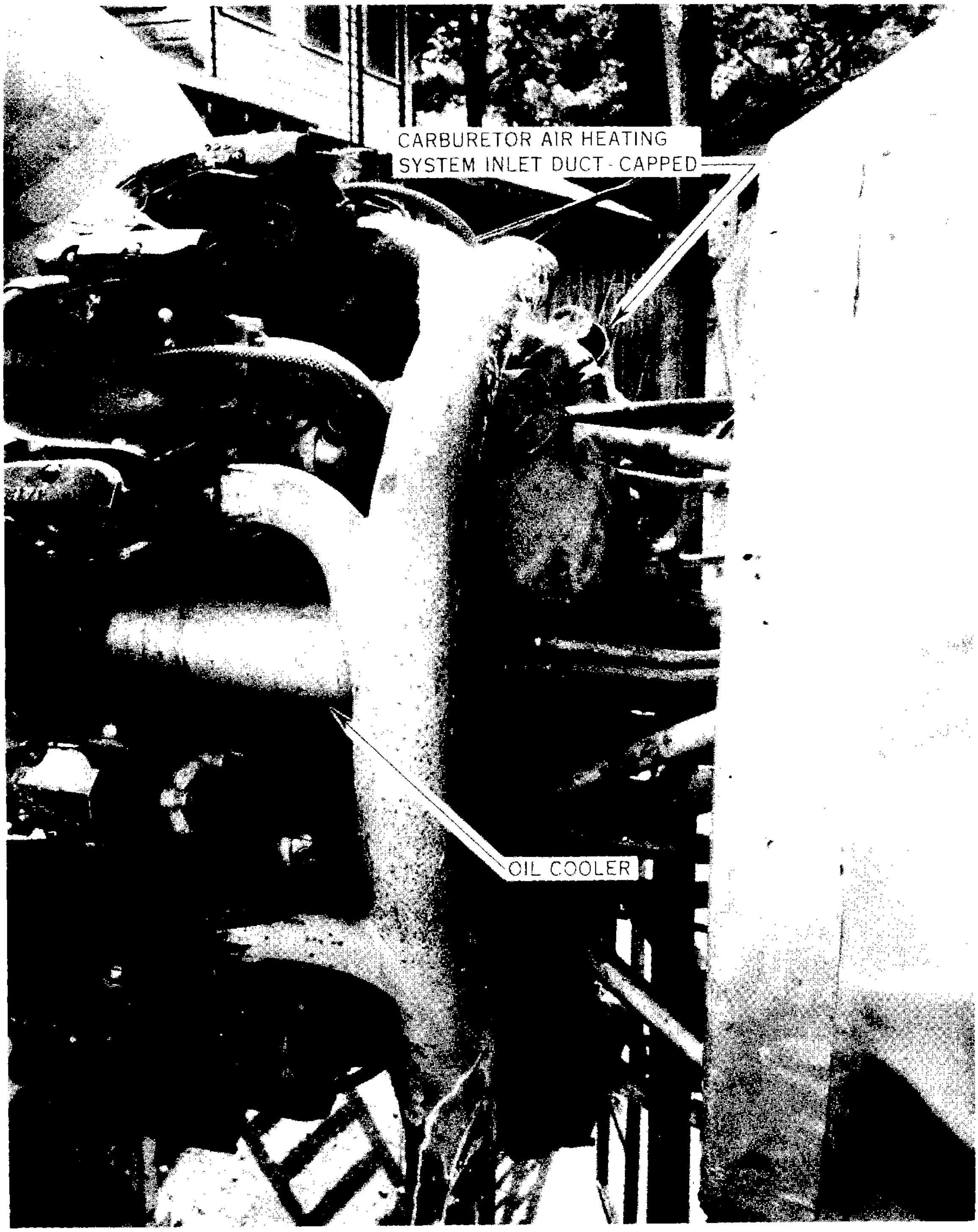


Figure 5. View of Accessory Section

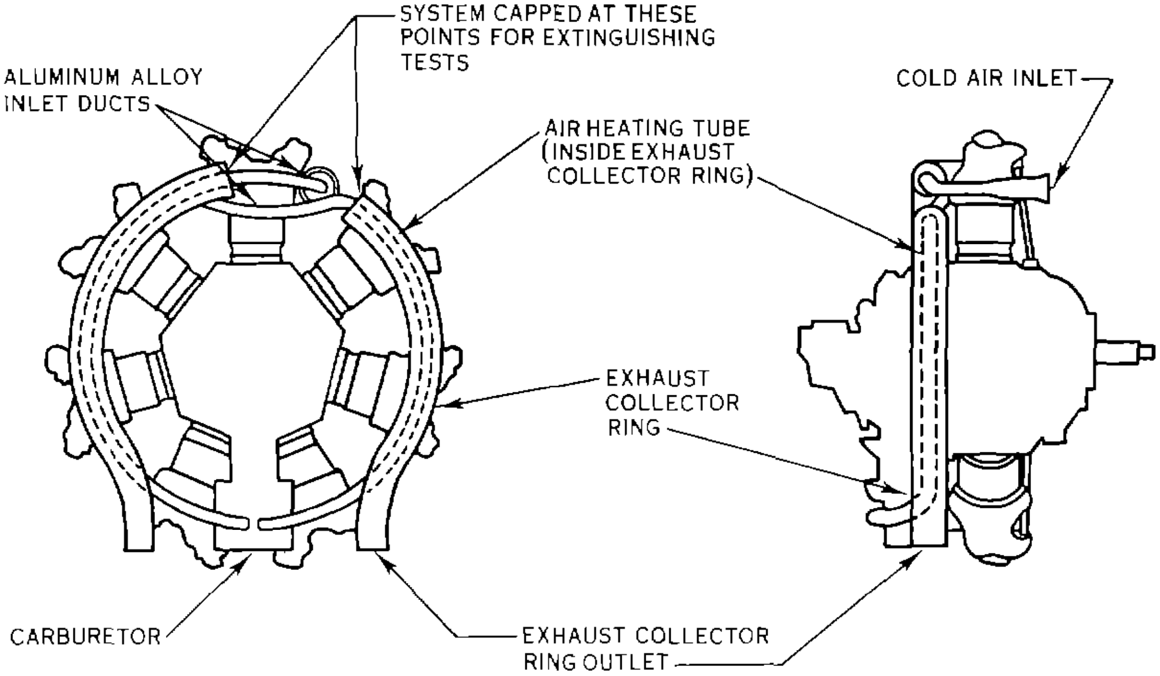


Figure 6 Carburetor Air Intake System

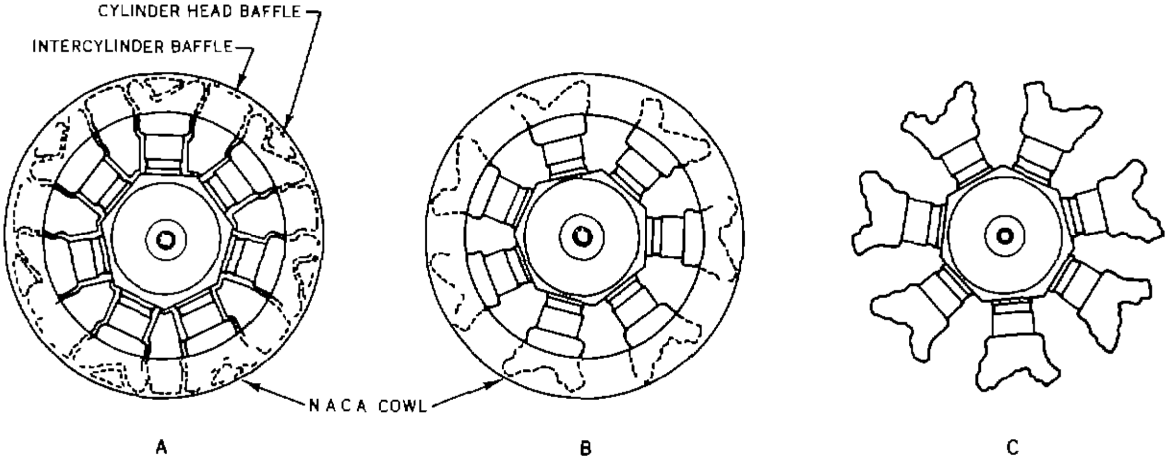


Figure 7 Three Installation Types Tested

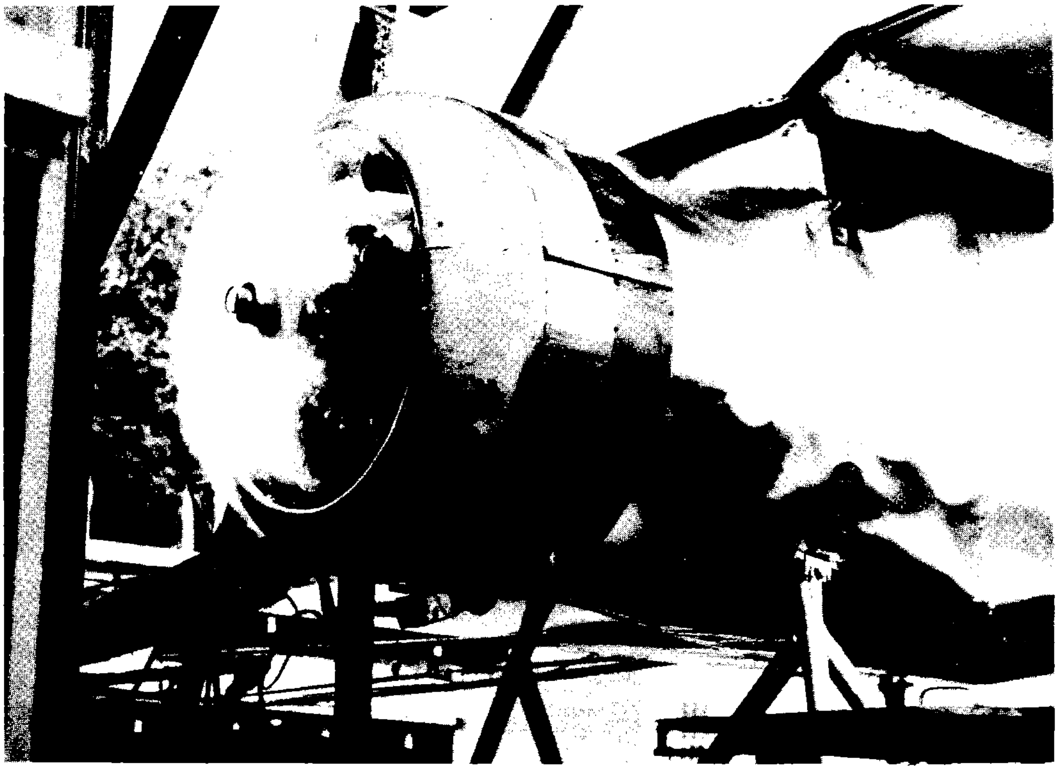


Figure 8. Typical 1.5 Gallons Per Minute Power Section Oil Fire

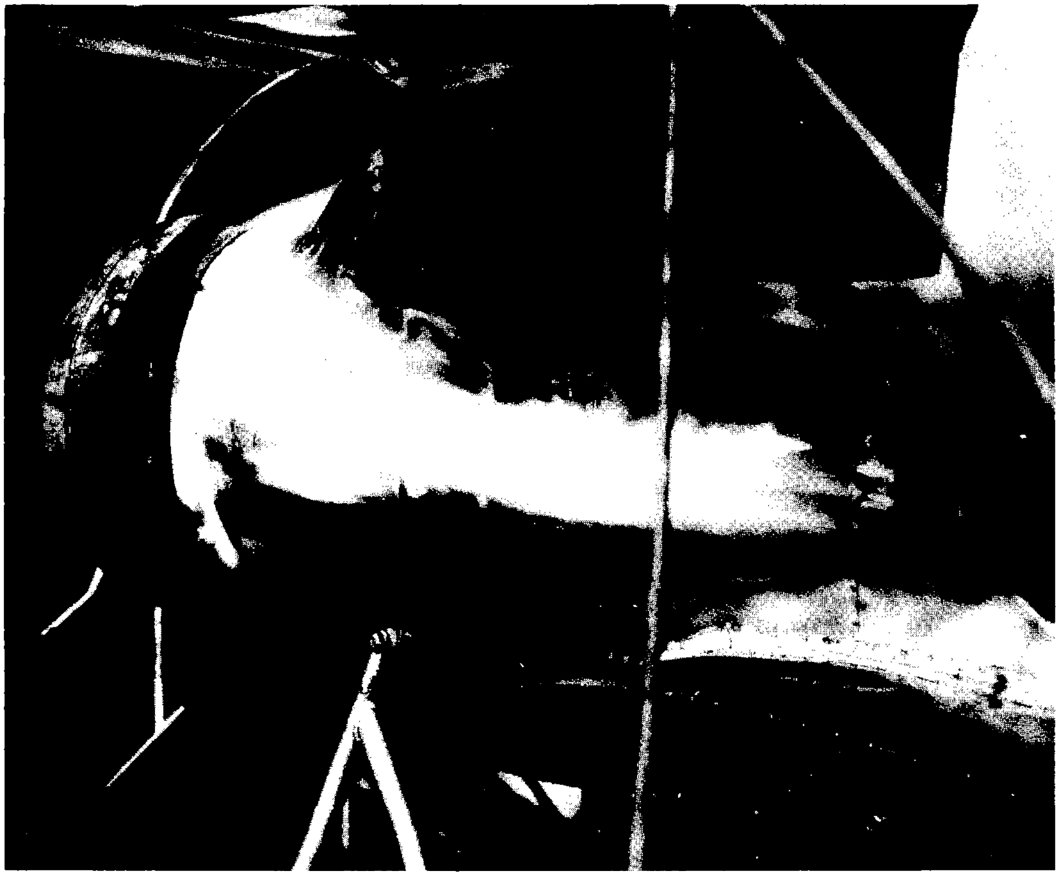


Figure 9. Typical 1.5 Gallons Per Minute Power Section Oil Fire

Figure 10. Typical 1.5 Gallons Per Minute Power Section Oil Fire

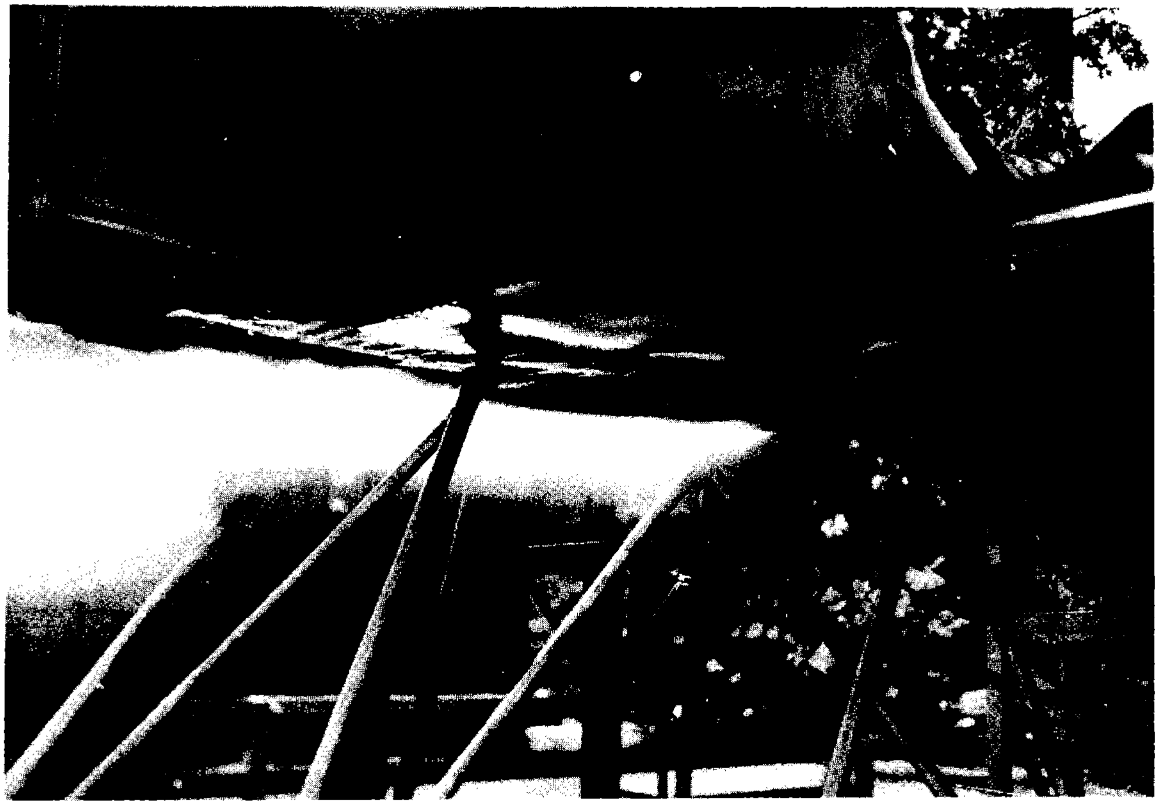


Figure 11. Typical 4.0 Gallons Per Minute Accessory Section Oil Fire

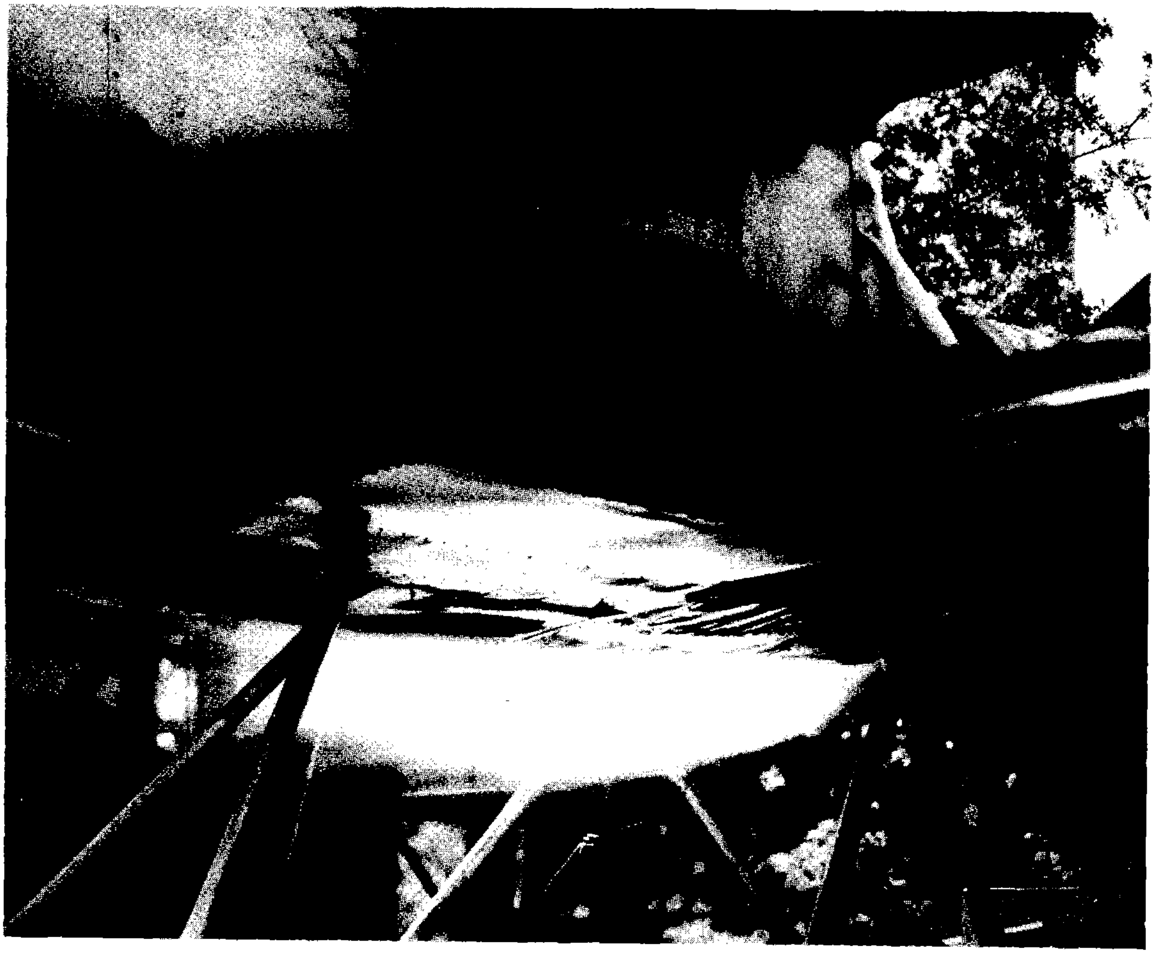
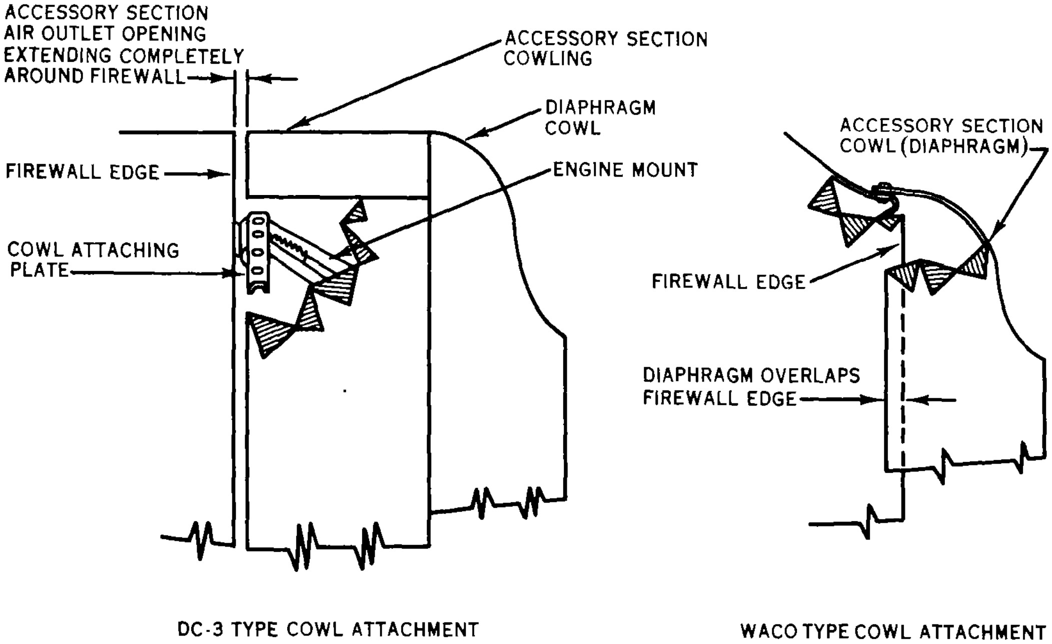


Figure 12. Typical 4.0 Gallons Per Minute Accessory Section Gasoline Fire



DC-3 TYPE COWL ATTACHMENT

WACO TYPE COWL ATTACHMENT

Figure 13. Comparison of DC-3 and Waco Cowl Attachments

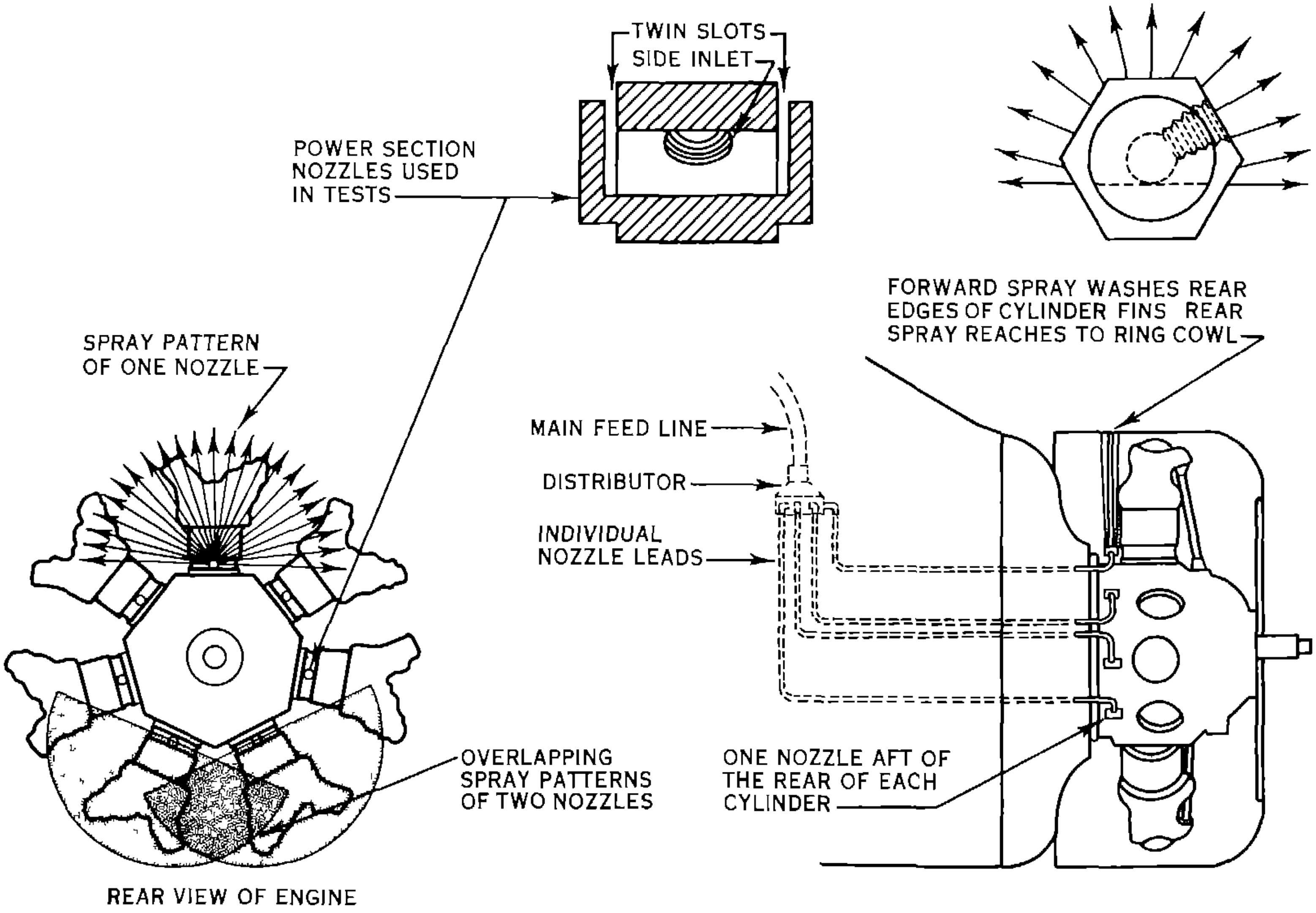


Figure 14 Power Section Distribution System

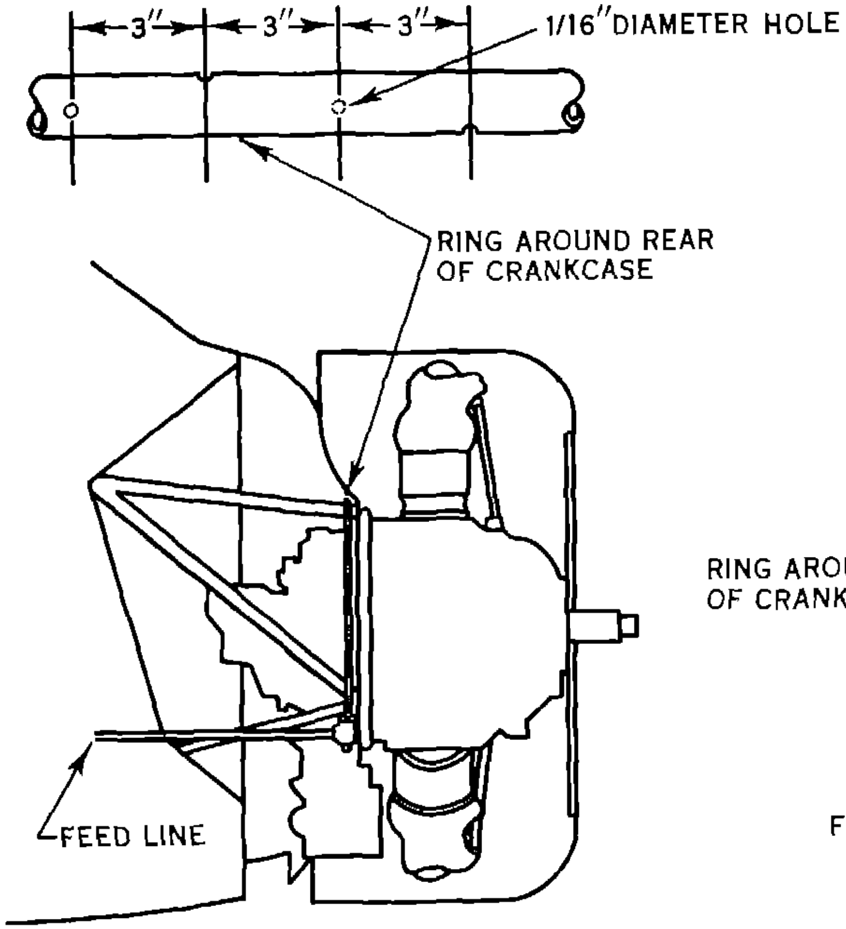


Figure 15 Accessory Section Distribution System for Gaseous Extinguishing Agents

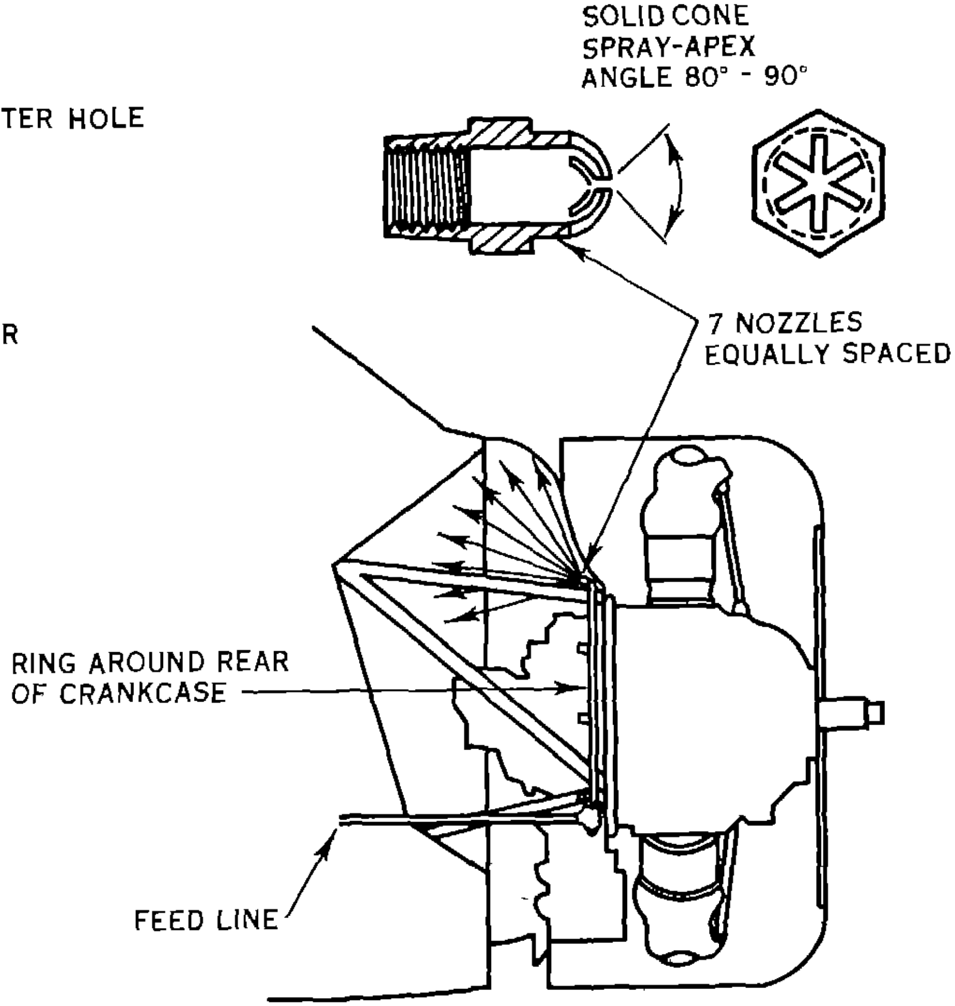


Figure 16 Accessory Section Distribution System for Liquid Extinguishing Agents

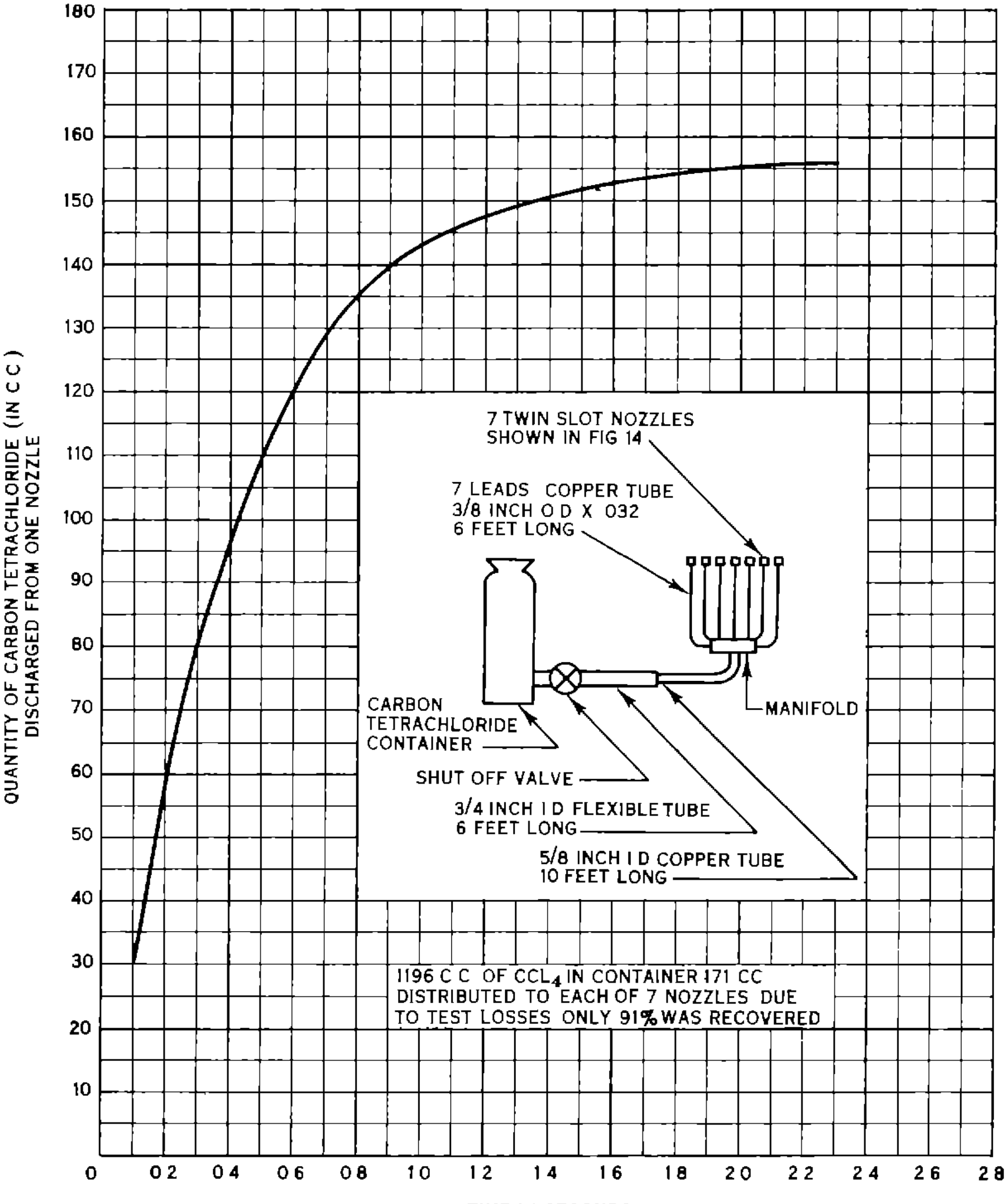
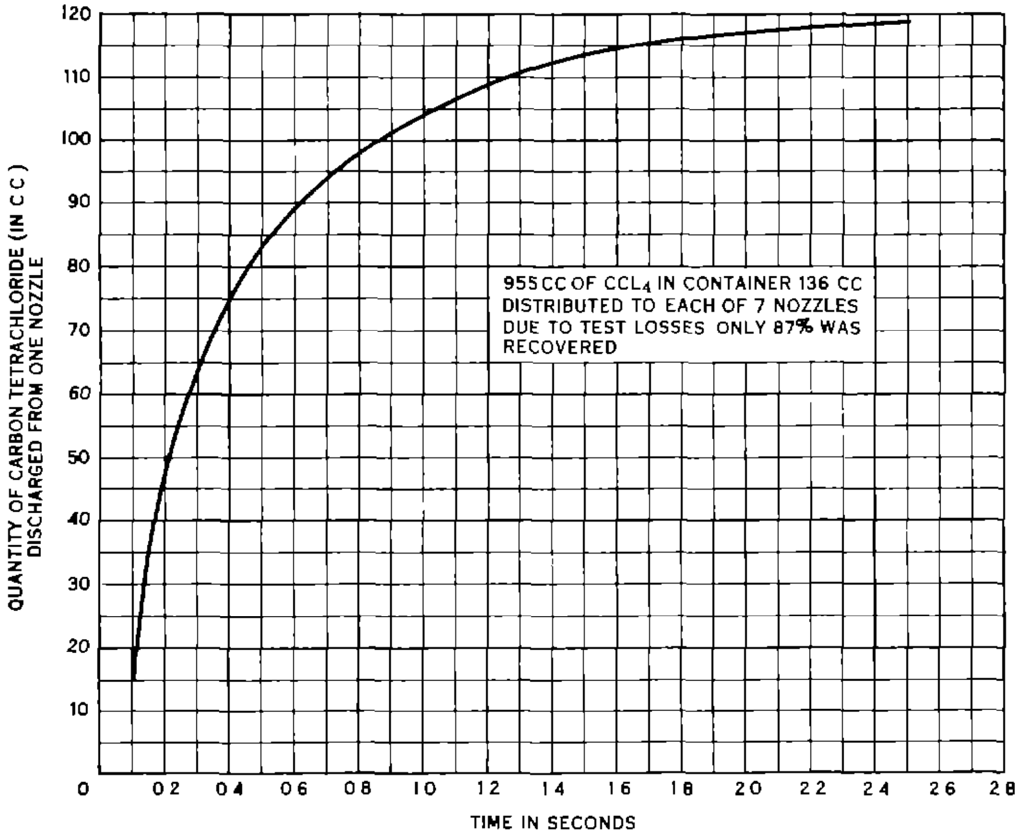
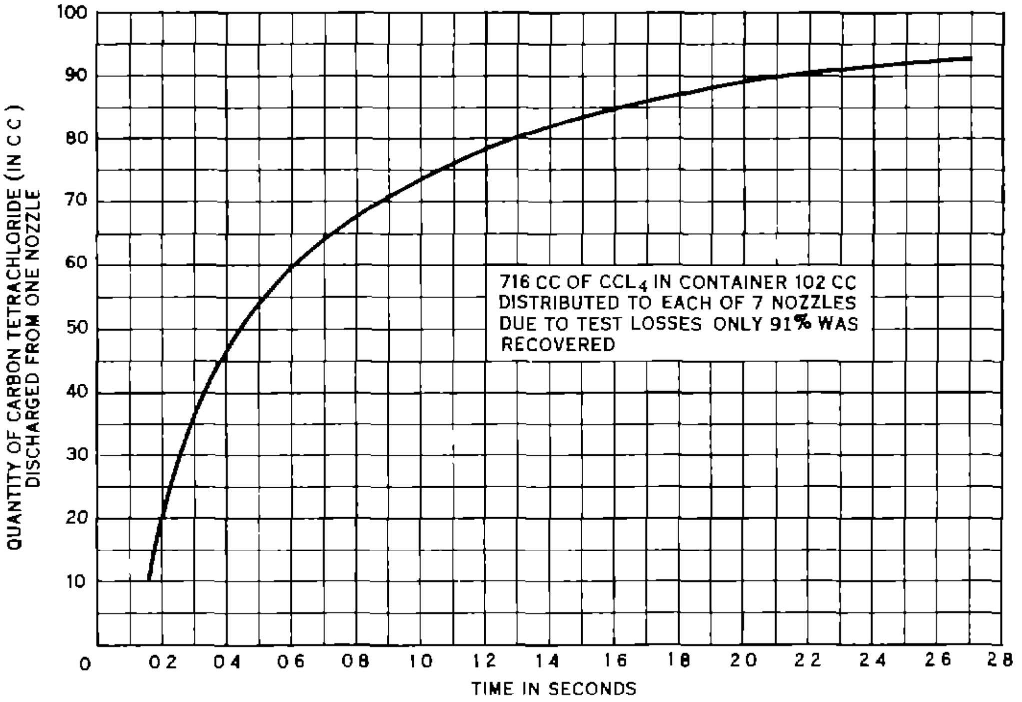


Figure 17 Necessary Minimum Rate of Carbon Tetrachloride Discharge for Extinguishing Fires in Power Section Shown in Figure 7A



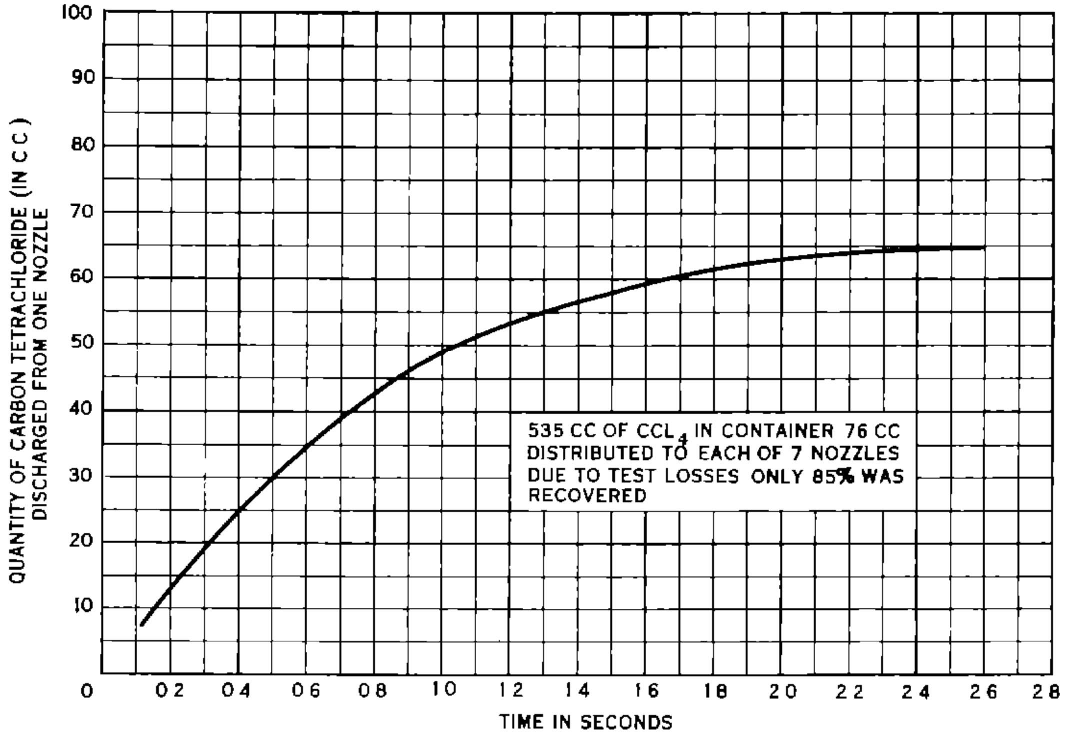
955 CC OF $CCL_4$ IN CONTAINER 136 CC DISTRIBUTED TO EACH OF 7 NOZZLES DUE TO TEST LOSSES ONLY 87% WAS RECOVERED

Figure 18 Necessary Minimum Rate of Methyl Bromide Discharge for Extinguishing Fires in Power Section Shown in Figure 7A



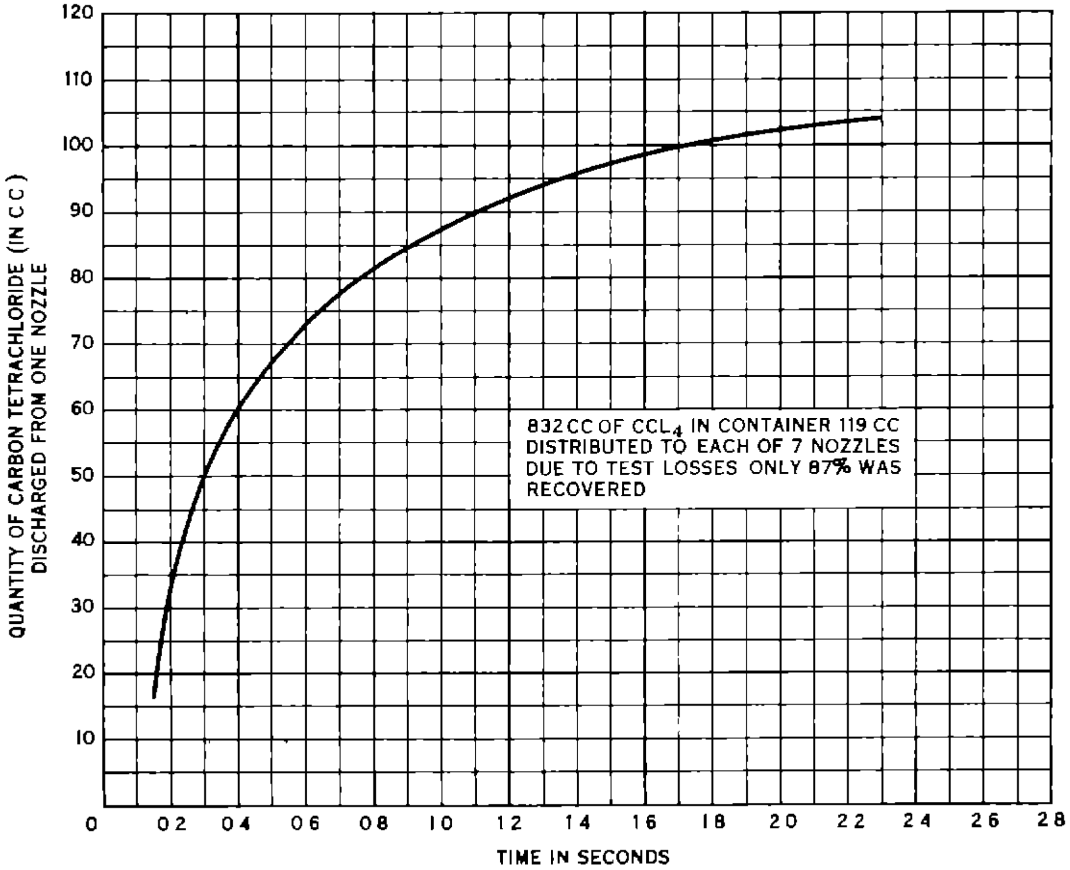
716 CC OF $CCL_4$ IN CONTAINER 102 CC DISTRIBUTED TO EACH OF 7 NOZZLES DUE TO TEST LOSSES ONLY 91% WAS RECOVERED

Figure 19 Necessary Minium Rate of Agent Discharge for Extinguishing Fires in Power Section Shown in Figure 7B Using Carbon Tetrachloride or for Extinguishing Fires in Power Section Shown in Figure 7C Using Methyl Bromide



535 CC OF $CCL_4$ IN CONTAINER 76 CC DISTRIBUTED TO EACH OF 7 NOZZLES DUE TO TEST LOSSES ONLY 85% WAS RECOVERED

Figure 20 Necessary Minimum Rate of Methyl Bromide Discharge for Extinguishing Fires in Power Section Shown in Figure 7B



832 CC OF $CCL_4$ IN CONTAINER 119 CC DISTRIBUTED TO EACH OF 7 NOZZLES DUE TO TEST LOSSES ONLY 87% WAS RECOVERED

Figure 21 Necessary Minimum Rate of Carbon Tetrachloride Discharge for Extinguishing Fires in Power Section Shown in Figure 7C

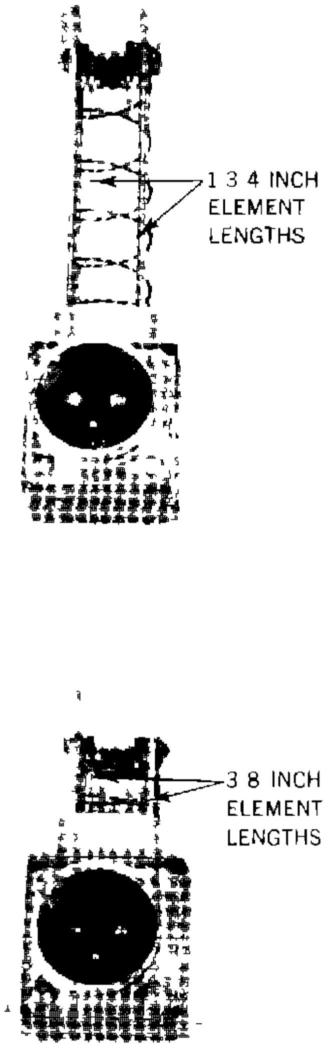


Figure 22 Flame Type Detector Walter Kidde & Company, Incorporated

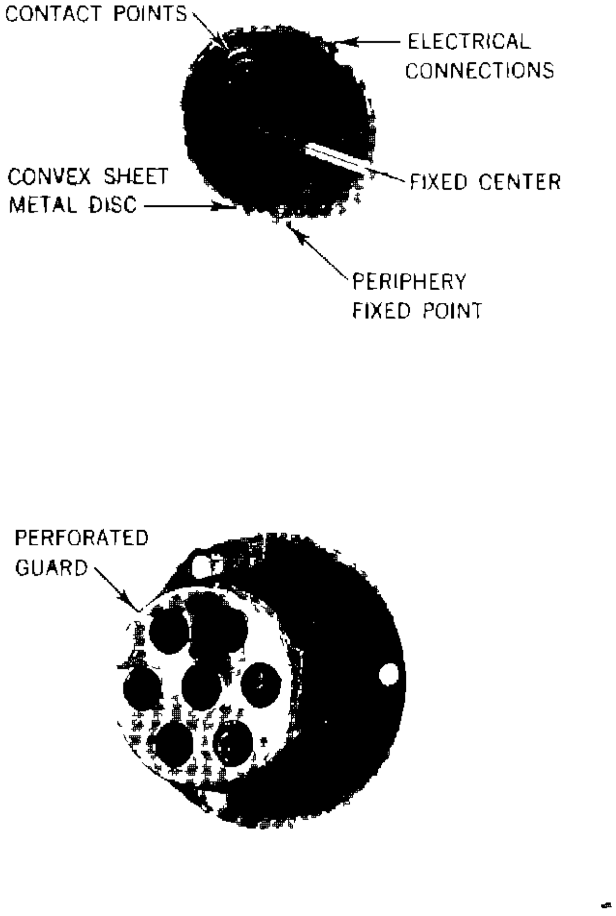


Figure 23 Metal Expansion Type Detector American La France Foamite Corporation

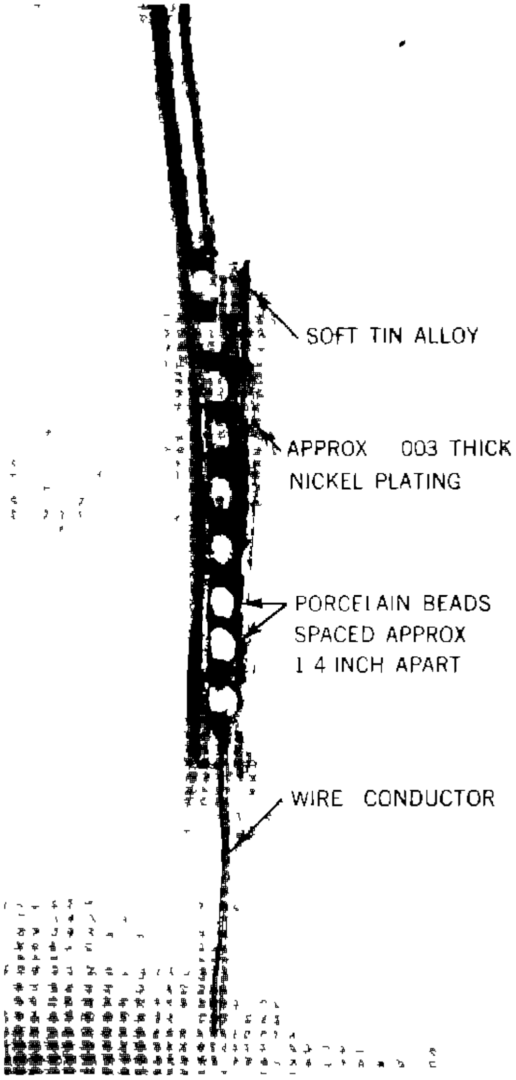


Figure 24 Fusible Alloy Type Detector Fenwal, Incorporated

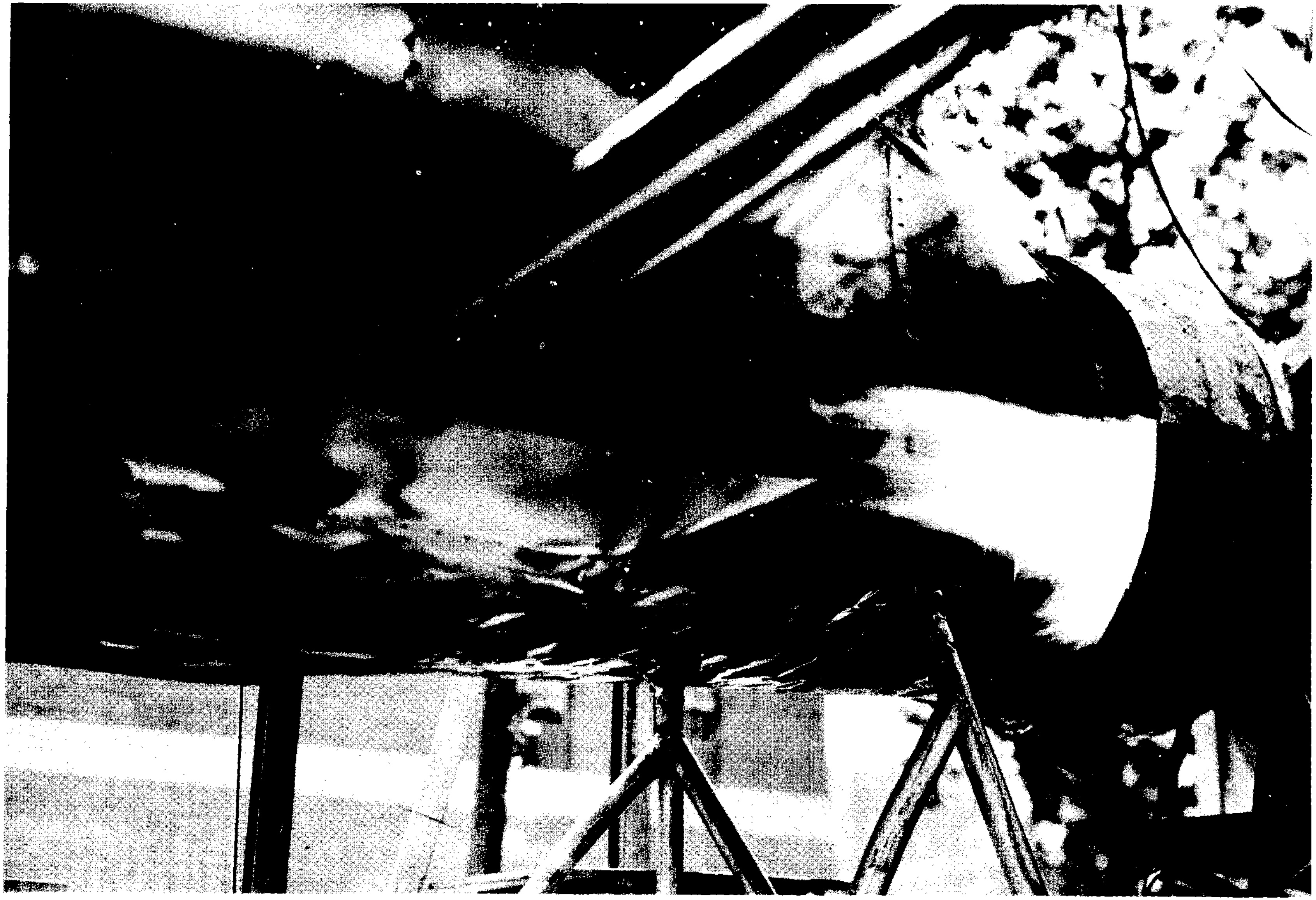


Figure 25. Basic Power Section Detector Fire

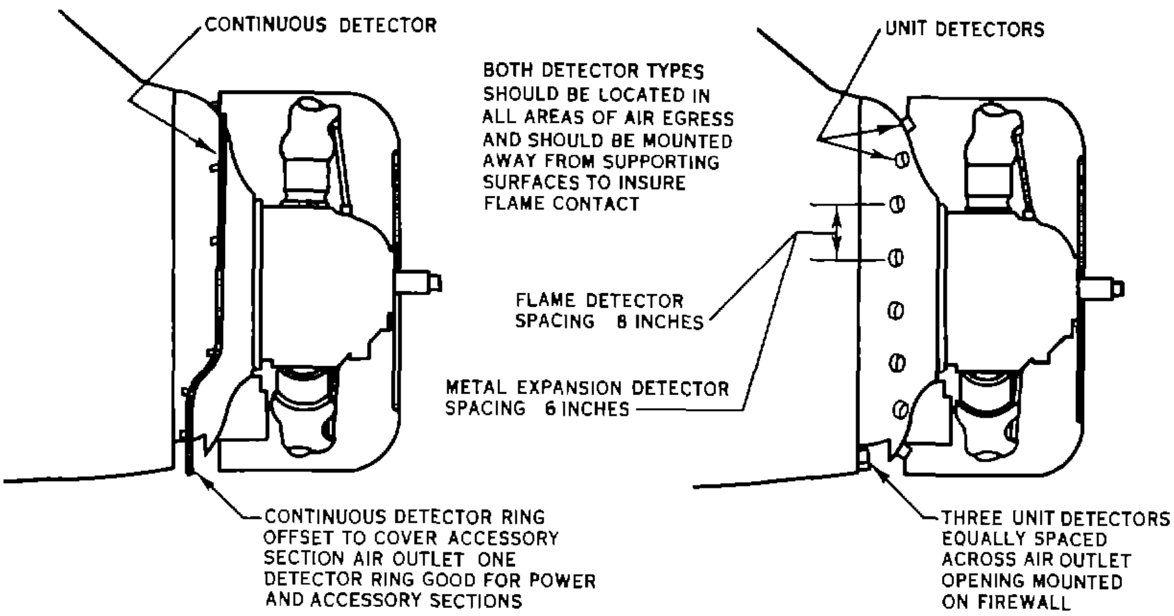


Figure 26 Optimum Detector Locations in the Type of Powerplant Installation Tested

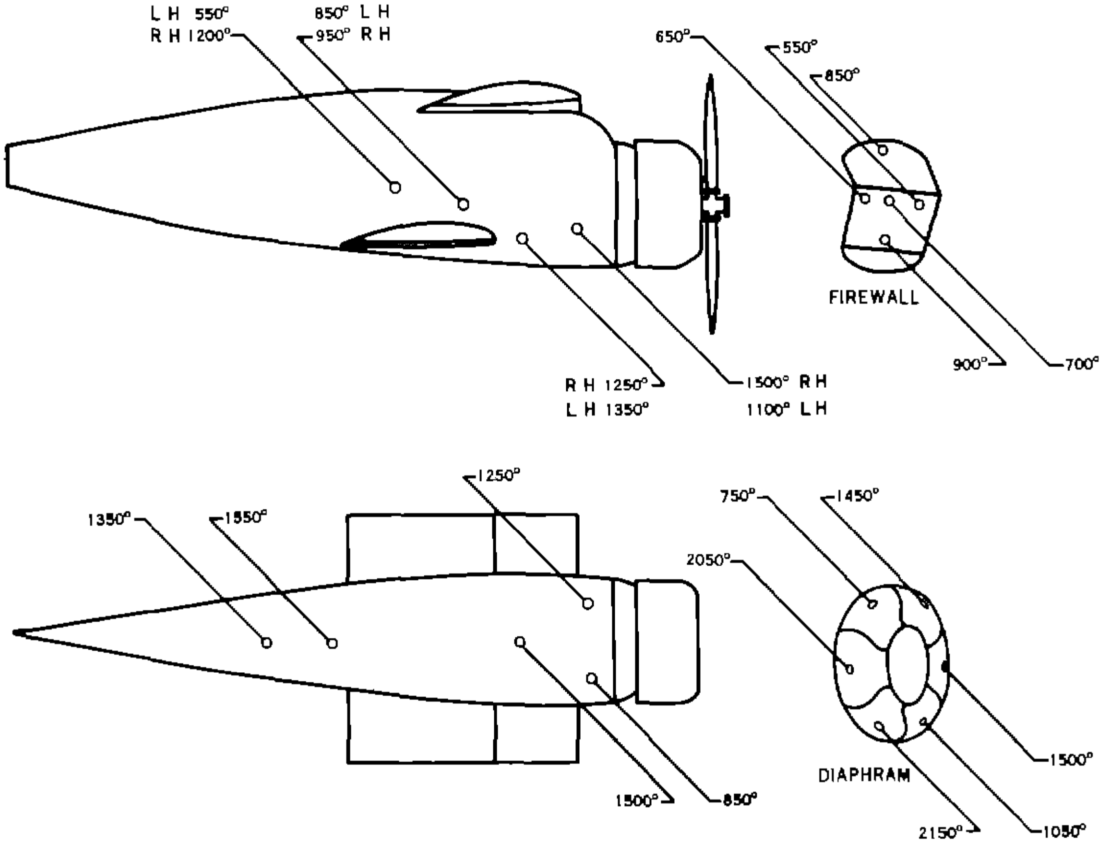


Figure 27 Highest Temperatures (°F) Recorded on Fuselage Skin, Cowling, and Firewall under Various Fire Conditions