DETERMINATION OF MEANS TO SAFEGUARD AIRCRAFT FROM POWERPLANT FIRES IN FLIGHT

PART II

By

George L Pigman
Aircraft Development Section

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SAFEGUARD AIRCRAFT FROM POWERPLANT FIRES IN FLIGHT

PART II

SUMMARY

The problem of providing adequate fire protection in flight for modern, tightly cowled, air-cooled radial aircraft powerplant installations, as previously discussed in Technical Development Report No. 33, "Determination of Means to Safeguard Aircraft from Powerplant Fires in Flight, Part I", for the conventional type cowling arrangement represented by the DC-3 airplane, was extended to cover another general type of cowling design represented by the Curtiss-Wright CW-20 airplane. A full scale, operating engine nacelle set-up, similar in general arrangement but not in size or detailed construction to the Curtiss-Wright CW-20 airplane, was constructed and placed in a controlled air blast from a wind tunnel to simulate actual flight conditions. Various quantities of gasoline and oil were ignited at locations throughout the powerplant installation where fire might occur as a result of failure of the engine or of the fuel or oil systems. As in the tests of the DC-3 type installation, the procedure consisted of four phases of investigation: (1) Fire extinguishment, (2) sources of ignition, (3) fire detection, and (4) effect of fire on materials.

In the fire extinguishment tests, a variety of different types of extinguisher nozzle arrangements were investigated and the effect of different quantities and rates of application of various extinguishing agents was determined. In addition, information was obtained on the effect of different operating conditions during fire extinguishment. With regard to sources of ignition, the possibility of ignition from the exhaust system, from electric sparks, or from the collection of explosive vapors was investigated for this type cowling. Tests were made of improved fire detectors and the optimum locations for installations of the various types were determined. Temperature readings were obtained throughout the nacelle and observations were made of the effect of the fire on different structural materials at various locations. The effect of fire on the rubber tire, the oil and gasoline systems, the engine mount, the oil tank and oil cooler, and other miscellaneous accessories, was determined. A comparison also is given between the DC-3 type cowling tested previously and the CW-20 type cowling with regard to the various aspects of the fire protection problem.

In general, it was found that adequate fire detection and extinguishment could be obtained for installations of the CW-20 type and that the rates and quantities of extinguishing agent necessary were approximately the same as for the DC-3 type. It was also found that the absence of a diaphragm between the power and the accessory regions resulted in higher temperatures in the accessory region.

INTRODUCTION

The series of tests on the CW-20 type cowling is a continuation of a general fire protection program started by the Technical Development Division in November 1939 at the request of the air transport industry. Previous tests on the DC-3 type cowling were covered in Part I of this report. Reports covering other types of engine installations will be published in the future as the program progresses.

During the course of the tests on the DC-3 type installation, the need was expressed by the industry for similar tests on other types of nacelle and cowling arrangements now being used or introduced. Accordingly, tests were started on the CW-20 type cowling in June 1941 and were completed in February 1942. This type of cowling represents the most distinctive variation from the conventional or DC-3 type arrangement. It was intended in these tests to determine the fire characteristics of the general type of cowling arrangements of which the CW-20 is representative and in which no separating diaphragm is present between the power and the accessory regions. In this type of installation as tested, the cooling air was exhausted through a rear exit gill on the lower side of the cowl, and the exhaust stack extended through the side of the cowling in line with the collector ring without passing rearward through a well in the accessory region. The test installation varied considerably in size and in detailed arrangement from the actual Curtiss-Wright CW-20 installation, but was of the same general type.

As in the series of tests on the DC-3 arrangement, the tests on the CW-20 installation concerned:

1. Fire Extinguishment
It was desired to determine the optimum type of extinguishment system for the CW-20 arrangement and the effect of various types, quantities, and rates of application of extinguishing agents in this installation. It was also desired to obtain knowledge of the general fire extinguishing problem in this type of cowling.

2. Sources of Ignition
Determination was desired of the most probable sources of ignition in the CW-20 type cowling and the probability of ignition in such an arrangement as compared with the DC-3 type.

3. Fire Detection
It was desired to carry out further development of the most promising types of detectors which previously were tested and of new types which have been suggested. Information was also desired concerning the optimum location of the fire detectors in the nacelle of the CW-20 type arrangement to obtain rapid and positive indication of fire.

4. Materials
Further information was desired on the relative fire-resistant properties of various materials and components comprising powerplant installations, and on the temperatures encountered in the cowling, firewall, nacelle, and wing during typical oil and gasoline fires for the CW-20 type arrangement.

All of the tests were made at the National Bureau of Standards where test equipment and test facilities were provided.

TEST EQUIPMENT AND GENERAL TEST PROCEDURE

The test equipment used, except for the engine cowling, was identical to that used in the tests on the DC-3 cowling as reported in Part I of this report. A diagram of the complete test layout is shown in figure 1 and a diagram of the nacelle unit in figure 2. A view of the test set-up is shown in figure 3. The wing-nacelle-powerplant set-up was the same as that used in the DC-3 tests except that the cowling arrangement was changed to simulate the Curtiss-Wright CW-20 type cowling. The same Pratt and Whitney 1830-B engine installation and engine mount were used. The same aluminum alloy oil tank was mounted forward of the firewall. All engine accessories, fuel lines, and the outside of the oil cooler were protected against fire by a lagging consisting of asbestos cloth soaked in waterglass. The oil tank, oil lines, firewall, and engine mount were unprotected and were exposed to the fires. The engine was equipped for remote control operation during the tests.

The test equipment consisted of:

1. Engine
Pratt and Whitney 1830-SB3G, Wasp - 14 cylinders, twin row, radial, air-cooled aircraft engine; rated at 1000 hp. at 2650 r.p.m. (take-off power), and 900 hp. at 2450 r.p.m. (maximum except take-off power).

2. Propeller
Hamilton Standard, three-blade, metal, constant speed, controllable pitch, 11-1/2 feet in diameter, type 3E50.

3. Engine Cowling
Standard DC-3 aluminum alloy, NACA cowling, modified on the lower side with a stainless steel adjustable gill to simulate the CW-20 type cowling, and with an air duct for the oil cooler. The general arrangement of this cowling is shown in figures 4, 5, and 6.

4. Accessory Section Cowling
Reinforced panels of 0.049-inch aluminum alloy which later were replaced with panels of 0.018-inch stainless steel.

5. Nacelle and Wing Section

The external dimensions were identical to those of the DC-3 installation. The 0.012-inch stainless steel nacelle and wing skin carried no load, with the engine loads being supported by an internal welded steel tube truss. The wheel well and nacelle were fitted to receive a standard DC-3 landing wheel, but in some tests the wheel well was covered with a 0.018-inch stainless steel skin.

6. Firewall

A welded 0.040-inch sheet of low carbon steel was used as the firewall material.

7. Fire Nozzle

The fire nozzle shown in figure 7 was attached to flexible tubing to permit application at any point within the powerplant installation. A small auxiliary gasoline supply line was attached to the main nozzle to supply small quantities of gasoline to facilitate the ignition of the oil. An aircraft spark plug for producing a high tension ignition spark was provided at the nozzle outlet.

8. Miscellaneous Equipment

An engine control house, extinguisher system house, and a tower for supporting the fuel and oil tanks were used. These are described in Part I of this report and are shown in figure 1.

9. Wind Tunnel

Maximum air speed at the outlet of the tunnel was 70 m.p.h. The outlet was 7 feet in diameter and was located 5 feet forward of the propeller.

As was pointed out in the DC-3 report, the volume of air passing through the engine cowling is of primary importance in the tests and is affected by cylinder baffling, wind tunnel air speed, engine speed, and the degree of cowl flap or gill opening. As the maximum wind tunnel outlet air speed attainable with the present equipment was approximately 70 m.p.h., a portion of the standard inter-cylinder baffles was removed to simulate higher air speeds by allowing a greater volume of air to pass through the cowling. The approximate quantities of air passing through the engine cowling under various conditions, as measured by means of a pitot static tube, are shown in Table I.

Table I

Quantity of Air Flow Through CW-20 Type Cowl
(70 m.p.h. wind tunnel speed, 2000 r.p.m. of engine)

Flaps	Gill	Air Flow - Lbs./hr.
No flaps	Closed	45,000
With flaps	Closed	55,000
No flaps	Open	55,000
With flaps	Open	75,000

Practically all of the tests were run at 70 m.p.h. wind tunnel speed, at 2000 r.p.m. of the engine, and with the exit gill completely open. A preliminary series of tests was run without cowling flaps and a later series of tests was run with cowling flaps installed.

As in the tests on the DC-3 installation, SAE 10 oil was used for the fires with the oil being preheated to 145°C. to simulate the release of hot oil from an overheated engine, and 87-octane aviation gasoline was used for the gasoline fires in the accessory region. As established during the tests on the DC-3 type cowling, the rate of oil flow used to feed power section oil fires was standardized at 5 gallons per minute. However, some tests were made with rates of oil flow as low as 2 gallons per minute and as high as 8 gallons per minute. The rate of 5 gallons per minute was used for accessory region oil fires and for accessory region gasoline fires.

In the power region, fires resulting from cylinder failures were simulated by placing the fire nozzle on or between the various engine cylinders with the nozzle direction and location varied to cover all probable fire conditions. In the accessory region, fires resulting from oil and fuel line failures were simulated by placing the fire nozzle outlet just inside the accessory region cowling and on the front of the firewall, and also at various locations on the lagging covering the engine accessories. The fire duration in most of the tests was 30 seconds, as it was assumed that an airplane crew could apply the fire extinguisher within this time. The test fires were ignited by an electric spark. In the case of oil fires, a small stream of gasoline was first ignited by the spark to facilitate the ignition of the oil, the gasoline then being shut off.

FIRE EXTINGUISHMENT TESTS

Purpose

The purposes of the extinguishment tests were: (1) To determine the properties of the CW-20 type cowling arrangement with respect to ease of fire extinguishment; (2) to determine the efficacy of various fire extinguishing agents when applied to gasoline and oil fires in both the power and the accessory regions of the CW-20 type installations; (3) to determine for the various extinguishing agents the quantity required, the necessary rate of application, and the optimum methods of agent distribution in the nacelle.

Procedure

A total of 552 fire extinguishing tests were conducted using various distribution methods, extinguishing agents, and quantities and rates of application of agent.

As in the tests described in Part I of this report, the general procedure consisted of applying extinguishing agents with various rates and durations of discharge through various distribution systems to gasoline and oil fires at all possible locations throughout the powerplant installation. A typical fire nozzle location in the power region is shown in figure 8. Figure 9 shows a typical nozzle location in the accessory region. Seven different fire extinguishing agents, as listed below, were included in the tests:

1. Methyl bromide
2. Carbon dioxide
3. Carbon tetrachloride
4. Ethylene dichloride
5. Ethylene dibromide
6. Ethylene chlorobromide
7. Propolene dibromide

Most of the tests were limited to the use of methyl bromide, carbon dioxide, and carbon tetrachloride. The properties of these extinguishing agents are given in the previous report. The other agents listed did not prove satisfactory for this application.

As in the DC-3 tests, the development of satisfactory distribution systems for the powerplant installation was accomplished by the trial and error method involving a large number of tests. A number of different extinguisher nozzle arrangements were installed and tested before the optimum arrangements were determined.

The effect of rate and duration of application of the agents on extinguishment was determined. The extinguishing agent was applied to the entire powerplant installation and the rate was varied from approximately 5 to 15 pounds of agent per second by changing feed line dimensions and by regulating the pressure within the extinguishing agent containers. The duration of agent application was varied from about 1/2 second to 4 seconds. The quantity of agent depended upon rate and duration of application and was varied from approximately 10 to 35 pounds. The pressure containers used for measuring and applying the extinguishing agents are shown in figure 10.

The general method of determining the rate of discharge of liquid extinguishing agents from the extinguishing nozzles was the same as described in the report on the DC-3 tests. This consisted of trapping the discharge from a single nozzle over different time intervals during the discharge and measuring the time intervals with a motion picture camera operating at 32 frames per second. However, this can be done only with liquids having reasonably low volatility.

It is impractical to obtain similar measurements for carbon dioxide gas and for methyl bromide because of their high volatility. The discharge rate for carbon dioxide was determined from the total amount used and the time required to discharge it, as determined through the use of a motion picture camera. For a given nozzle, discharge rates for methyl bromide were assumed to be substantially the same as for carbon tetrachloride, since both have approximately the same specific gravity.

Results and Discussion

Because of the large number of tests, no attempt is made in this report to present the particular conditions and results of each individual fire extinguishing test. Difficulty would be experienced in interpreting the results of individual tests as the main conclusions were obtained from observation and general consideration of a large number of tests pertaining to each particular phenomenon studied.

As in all tests concerning fire protection of aircraft engine installations, the type and degree of air blast present are of primary importance. In the CW-20 type cowling, the flow of cylinder cooling air is through the cylinder baffles, over and around the engine accessories, and out through the lower rear exit gill. This type of air flow is considerably different from that in the DC-3 nacelle arrangement. In the CW-20 cowling, the fire from a source in the power region is concentrated mainly inside the nacelle and in the accessory region. In the DC-3 type cowling, fires originating in the power region tend to burn more outside of the cowling, spreading gradually to the accessory region through leaks and openings in the separating diaphragm. For fires originating in the accessory region, the type of air flow is also considerably different in the two cases, and it is therefore necessary to consider such differences in the arrangement of the extinguishing agent distribution system.

In the CW-20 tests, two quantities of air flow through the cowling were utilized. In the first case, a flow of approximately 55,000 pounds of air per hour was used, which approximately simulates the amount of air obtained in a DC-3 type cowl using the Pratt and Whitney 1830-SB3G engine under climbing conditions. In a second series of tests, flaps were mounted along the side of the rear exit gill. Under this condition, a rate of air flow of approximately 75,000 pounds per hour was obtained, which is about the quantity necessary for cooling that engine under cruising conditions.

It was found that with the higher air flow of 75,000 pounds per hour passing through the cowl, difficulty in fire extinguishment was considerably increased. However, with the lower quantity of 55,000 pounds per hour passing through the cowl, the fires tended to burn much hotter and more completely inside the nacelle. This accelerated and aggravated the destructive effect of the fire on the cowling structure. It is indicated that if a larger engine were used, requiring a greater amount of air for cooling, the difficulties of extinguishment would be increased in proportion to the amount of cooling air required, and the quantities and rates of application of extinguishing agents would also be increased approximately in the same ratio.

Some tests were run in which the exit gill was partially closed. Again it was found that decreasing the cooling air tended to cause more complete burning inside the cowling, resulting in higher temperatures of the structure. With the gill partially closed, the air flow behind the gill tended to lie closer to the skin on the rear part of the nacelle. In the series of tests in which no flaps were used, it was noted that all of the air tended to pass out of the main gill opening and that none came out of the side openings in the cowl at the top of the gill. However, when flaps were placed in front of the side openings, considerable air and flame were drawn out at these points and concentrated more on the lower surface of the wing.

Fire tails tended to hang at a number of points around the gill opening and nacelle. In particular, such tails tended to hang on the outside and on the rear edge of the oil cooler which was set in the center of the gill opening. Fire tails also would hang onto any protuberances, such as stiffeners, around the edge of the opening or on the inside of the gill, and could be avoided to a large degree by eliminating such protuberances on the surfaces at these points. Fire tails also were observed lying close to the nacelle skin behind the flaps which were placed at the upper side openings of the gill. Such flaps caused an extremely turbulent region on the nacelle skin to the rear, with a considerable mixing of fresh outside air with the burning fuel at this point. For certain fire locations, fire tails in that region were extremely difficult to extinguish and required a highly efficient "wiping-off" action of the extinguishing agent. Burning oil and gasoline also tended to whip up into the wheel well on many occasions and continued burning for a short time after the main fire was extinguished. However, no cases of relighting were observed from such fires in the wheel well.

Two types of fuel were used for the fires in the tests. SAE 10 oil was used for both the power and the accessory region fires, and 87-octane gasoline was used for accessory region fires. Gasoline fires in the accessory region were the most difficult to extinguish. Oil fires in the accessory region, in general, burned poorly and tended to blow out. However, accessory region oil fires in which the oil was sprayed directly onto the exhaust collector ring were extremely hot and destructive.

As discussed in the report on the DC-3 tests, over an appreciable range the size of the fire had little relation to the ease of extinguishment. Proper and even distribution of extinguishing agent which extinguished small fires at any location also extinguished larger fires. In general, the effect of the larger fires was to cause more rapid and greater heating of the structure and to produce more fire tails.

The duration of the fires was standardized at 30 seconds. In the DC-3 tests it was found that oil fires reached their maximum intensity before such time and that continuing the fire longer made little difference in the ease of extinguishment. The gasoline fires reached their maximum intensity within a few seconds after starting. During the tests, the source of the fire was varied over all probable fire locations by moving the fire nozzle. It was found that the most severe power region oil fires occurred when the fire nozzle was located on the side and upper cylinders, while relatively small fires were produced when the nozzle was located on the lower cylinders. In general, the most intense fires occurred when the fire nozzle was placed on the cylinder head. As stated previously, oil fires of appreciable intensity in the accessory region could be produced only when the oil was directed onto the exhaust collector, because of the more rapid and complete vaporization of the oil. The most intense fires in the accessory region for both oil and gasoline were produced when the fire originated in the upper part of the nacelle.

In the development of a satisfactory extinguishing agent distribution system for the CW-20 type cowl, the same nozzle arrangement in the power region as was used in the DC-3 tests was found satisfactory as a basic system. This is shown in figure 11. In consideration of the type of air flow found in the CW-20 type cowl, where the cylinder cooling air is carried through the accessory region, tests were conducted in which power region nozzles only were used. The objective was to determine whether the extinguishing agent thus released in this region and carried back through the accessory region would extinguish fires throughout the entire nacelle. In general, it was found that this could be accomplished but that the distribution of the extinguishing agent was inefficient. It was later determined that the distribution of agent into the accessory region, as well as into the power region, considerably decreased the total quantity and rate of application required. Accordingly, a variety of extinguisher nozzle arrangements in the accessory region (in addition to the power region distribution system) were tried, some of which are shown in figures 12 to 19 inclusive. The accessory region distribution system which was found to be most efficient consisted of a set of five nozzles distributed around the upper half of the engine mount ring as shown in figure 12. These nozzles direct one fan spray radially outward and forward from the ring and another spray radially inward and to the rear of the ring over the top of the engine accessories. The tests showed that through the use of these nozzles in the accessory region, in addition to those in the power region, the total quantity of extinguishing agent could be decreased approximately 8 to 10 pounds and that more positive fire extinguishment is obtained. In general, the release of extinguishing agent in the upper portion of the accessory region is the most efficient, and nozzles in the lower part of the accessory region are extremely inefficient because the extinguishing agent released from them is immediately carried out of the gill.

The various types of nozzles used for releasing the extinguishing agent in the CW-20 tests are shown in figure 20. For the power region system, the most satisfactory types of nozzles were as determined in the DC-3 tests. These are shown as types T-1 and T-3 in figure 20. For the accessory region nozzles, the slot arrangement shown as type T-5 was found most satisfactory. For the nozzle over the oil cooler, the arrangement shown as type T-4 was satisfactory. The detailed design and dimensions of the nozzles are not critical, but the location of the nozzle in the nacelle and the general direction of agent application are important factors.

As in all of the previous extinguishment tests, the rate of application of agent is the most important factor affecting the ability of an agent to extinguish fires. Because of the high air blast velocity, the agent is rapidly dissipated and the penetration of the agent into the fire with adequate force and concentration is possible only through the use of an adequate discharge rate. The minimum rates of application of methyl bromide and carbon dioxide necessary to insure extinguishment in the CW-20 type cowl when discharged in the power region only, and when discharged in both the power and the accessory regions, are given in table II.

Table II

Necessary Minimum Rates of Application of Extinguishing Agents and Time of Discharge

	Basic Type System Shown in Figure 11			Type A System Shown in Figure 12		
	Methyl Bromide		Carbon Dioxide	Methyl Bromide		Carbon Dioxide
	Qts/sec	Lbs/sec	Lbs/sec	Qts/sec	Lbs/sec	Lbs/sec
Power Region	3.0	10.5	8.1	1.6	5.5	5.7
Accessory Region	–	–	–	0.7	2.8	2.6
Oil Cooler	0.2	0.7	0.5	0.2	0.7	0.5
Effective Time of Discharge	2.5 sec.		3.5 sec.	2.0 sec.		2.5 sec.

The rates shown in table II are the average rates over the effective time of discharge listed. The rate of discharge of methyl bromide is assumed to be substantially equal to the rate of discharge of carbon tetrachloride, shown by the curve in figure 21, as both liquids have approximately the same density. It should be noted that the initial rate of discharge as shown in figure 21 is much higher than the average rate given in table II. Such a curve could not be obtained for carbon dioxide because of its volatility. Its average rate of discharge, however, was determined by the amount used and the total time required for discharge.

As pointed out in the report on the DC-3 tests, many fires can be extinguished at lower rates of application than are shown in table II. However, the values shown are the minimum rates of application of extinguishing agent which were found to be necessary in the tests for positive extinguishment of any fire tried in any location.

In the report on the DC-3 tests, it was indicated that a minimum of 2 seconds is required for the agent to extinguish fire tails, although the main part of each fire was extinguished within a fraction of a second. This, of course, is true only when an adequate rate of application is used. In the tests on the CW-20 set-up, a duration of application of extinguishing agent of from 2 to 3.5 seconds was necessary in order to extinguish all fire tails. This is shown in Table II. If rates of application of agent are inadequate, increasing the duration of application has no effect in extinguishing the fire, as the extinguishing agent is carried away by the air blast as rapidly as it is released.

The quantities of extinguishing agent found necessary for positive extinguishment are shown in table III. These quantities are based upon the rates of application and discharge durations shown in table II. The quantities necessary for adequate extinguishment with both types of distribution systems used are indicated. The distribution system utilizing nozzles in both the power and the accessory regions is of much higher efficiency.

Table III

Necessary Minimum Quantities of Extinguishing Agents Determined by Tests.

	Basic Type System Shown in Figure 11			Type A System Shown in Figure 12		
	Methyl Bromide		Carbon Dioxide	Methyl Bromide		Carbon Dioxide
	Quarts	Pounds	Pounds	Quarts	Pounds	Pounds
Power Region	7.5	26.2	28.2	3.2	11.2	14.3
Accessory Region	-	-	-	1.4	5.6	6.5
Oil Cooler	0.5	1.8	1.8	0.4	1.4	1.2
Total	8.0	28.0	30.0	5.0	18.0	22.0

Seven different extinguishing agents were used in the CW-20 tests. As in the tests on the DC-3 type cowling, methyl bromide and carbon dioxide were the only fire extinguishing agents of those used which proved satisfactory for use in the CW-20 type installation. Of these two agents, methyl bromide was again found to be more positive and efficient in action, requiring less care and exactness in application. Carbon tetrachloride was found to be satisfactory for extinguishing oil fires throughout the nacelle but unsatisfactory for extinguishing gasoline fires without utilizing time delays of 15 to 30 seconds between the time of cutting off the gasoline and releasing the extinguishing agent. The other extinguishing agents tested were similar in action to carbon tetrachloride.

In order to obtain adequate extinguishment in the CW-20 type cowling tests, tightness of the firewall was found essential. Holes or cracks existing in the firewall allowed burning oil or gasoline to run through and burn on the rear face, and relighting from these sources occurred forward of the wall after apparent extinguishment was obtained. For similar reasons it was necessary to have maximum tightness of the accessory region cowling to insure that no liquid would leak through cracks in the cowling and burn outside, thus causing relighting. This condition for the cowling, however, was not as critical as in the case of the firewall.

It was observed that flames tended to concentrate in the well around the air duct leading to the oil cooler in the lower part of the cowling. Fire in this region could not be extinguished with the power region nozzles or the upper accessory region nozzles A single extinguishing nozzle placed above the air duct leading to the oil cooler and spraying into this region, however, provided adequate extinguishment.

The engine installation used in the CW-20 tests utilized an exhaust stack extending radially outward on the right-hand side and passing through the cowling in line with the collector ring. This is shown in figure 6. This exhaust system installation was relatively clean and contains no pockets or wells from which relighting might occur. However, for test purposes a heating shroud, as shown in figure 22, was placed over a portion of the collector ring with the opening to the shroud located behind the cylinders. With such a shroud forming a pocket around the hot collector ring, it was found that relighting occurred from fires inside the shroud which could not be extinguished during the release of extinguishing agent. As discussed in the report on the DC-3 type installation, this in general has been found to be true for any type of closed pockets inside the nacelle.

In Part I of this report considerable design information for extinguishing systems was provided and discussed. The same information and discussion will apply to the extinguisher distribution system used for the CW-20 type installation. In general, the same problems of obtaining equal distribution of extinguishing agent were found and the same precautions were observed with regard to nozzle arrangement and location of nozzle feed lines. Typical gasoline and oil fires in both the power and the accessory regions are shown in figures 23 to 27, inclusive.

Conclusions

1. In the CW-20 tests, as in the tests on the DC-3 cowling, extinguishment of aircraft powerplant gasoline and oil fires occurring in flight can be accomplished within reasonable weight limitations, provided adequate rates of extinguishing agent application and optimum distribution methods are used and provided the gasoline flow is shut off before extinguishment is attempted.

2. Extinguishment of oil fires occurring in flight in the CW-20 installation can be accomplished without stopping the oil flow, but oil shut-off is important to prevent recurrence of the fire.

3. Gasoline fires were found more difficult to extinguish than oil fires.

4. Adequate fire extinguishment can be obtained in the CW-20 type installation with extinguishing agent nozzles in the power region only. However, by employing additional nozzles in the upper part of the accessory region, more positive and efficient extinguishment can be obtained.

5. In the CW-20 type installation there exists a tendency for fire tails to occur on the outside of the oil cooler, the inside of the gill, and on the nacelle skin behind the flaps. Minimum obstructions to the air flow are desirable in these regions to minimize fire tails and to aid the "wiping-off" action by the extinguishing agent.

6. The well in the lower part of the cowl around the air inlet to the oil cooler must be separately protected against fire.

7. The tests showed that wheel well protection is unnecessary provided the firewall is tight against fuel and flame leakage.

8. Reasonable flame tightness of the accessory region cowling and firewall is necessary to prevent relighting of fires. This is particularly true of the opening through the cowling around the exhaust stack.

9. The presence of pockets, such as exist in a heating shroud around the collector ring, will result in relighting of fires.

10. With an increase of air flow through the cowling from 55,000 pounds of air per hour to 75,000 pounds of air per hour, difficulty of extinguishment was increased considerably, although the fires did not burn as intensely inside the cowl with the greater air flow.

11. The tests showed that methyl bromide and carbon dioxide are the only extinguishing agents of those tested which are satisfactory for general protection against aircraft powerplant fires in flight for the CW-20 type installation. Methyl bromide is the most satisfactory agent from the fire extinguishment standpoint for the installation tested.

12. The rate of extinguishing agent application is the most important factor in fire extinguishment. For the entire engine installation in the CW-20 type arrangement, a rate of application of 9.0 pounds per second of methyl bromide or 8.8 pounds per second of carbon dioxide is required for adequate extinguishment with the most efficient distribution system tested.

13. The minimum duration of extinguishing agent application found to be satisfactory was approximately 2 to 2.5 seconds for the most efficient extinguishing system tested.

IGNITION TESTS

Purpose

The purposes of the ignition tests were: (1) To study the possible causes of gasoline and oil ignition in the CW-20 type installation in flight; and (2) to determine methods whereby the ignition hazard may be reduced.

Procedure

The majority of the data on fire ignition were obtained incidental to the other tests on extinguishment, detection, and materials.

Certain special tests were carried out concerning the ignition hazard of faults in the exhaust system when such openings or cracks were observed during the tests.

The possibilities of ignition of oil and gasoline from an electric spark were determined using a 15,000 volt spark deliberately produced with a spark plug.

Results and Discussion

Since it was definitely concluded from the tests on the DC-3 type installation that the most probable source of ignition of an aircraft powerplant fire lies in enclosed pockets, heating shrouds, or wells around the exhaust system, no tests of this nature were attempted in the CW-20 type arrangement. There were no pockets in connection with the exhaust system in this test set-up, and no ignition from explosive vapors was observed in any of the tests. However, it is to be noted that this source of fire ignition is generally considered the most dangerous in a powerplant installation.

Ignition of both gasoline and oil can readily be obtained through cracks or openings in the exhaust system. This is particularly true of oil released in the power region, but it is also true for either oil or gasoline released in the accessory region of the CW-20 type installation because of the absence of a separating diaphragm and because of the turbulent air flow existing inside the cowl. As a result of the tests it is believed that where no pockets or wells are present, the possibilities of ignition of gasoline or oil through faults and cracks in the exhaust stack and collector ring constitute the most probable source of ignition. As discussed in the DC-3 report, stopping the engine before extinguishing the fire prevents relighting of fires ignited from such sources.

In none of the tests conducted with the CW-20 cowling arrangement was ignition of gasoline or oil from contact with the hot exhaust system or other hot or glowing parts observed.

As in the DC-3 tests, gasoline could be readily ignited from a high-voltage electric spark, but oil could be ignited from such a source only with great difficulty. It is to be noted that the absence of the separating diaphragm between the power and the accessory regions in the CW-20 type arrangement makes it possible for the gasoline released in the accessory region to reach the engine ignition system.

Conclusions

1. In the tests with the CW-20 type installation, no attempt was made to investigate the probability of explosive ignition of gasoline or oil collecting in pockets or wells around the exhaust system. However, previous tests on the DC-3 type installation have indicated this to be the most probable source of ignition in a powerplant installation.

2. A faulty exhaust system with cracks or openings constitutes a probable source of ignition for either gasoline or oil released in either the power or the accessory region.

3. In the tests of the CW-20 type installation, no ignition was obtained with either gasoline or oil in contact with metal surfaces at high temperature.

4. It was found that gasoline can be readily ignited by high-voltage electric sparks, but that oil is ignited from this source only with difficulty.

5. It is concluded from the tests that stopping the engine before attempting to extinguish the fire considerably reduces the possibility of re-ignition of the fire after extinguishment.

FIRE DETECTOR TESTS

Purpose

The purposes of the tests on fire detectors were: (1) To continue development of various types of fire detectors for detecting gasoline and oil fires occurring in aircraft powerplant installations in flight; and (2) to determine for each type of detector the number required and the optimum location in the CW-20 type installation.

Procedure

A standard gasoline fire of 0.33 gallons per minute was utilized for both power and accessory region detector tests. This standard was established in the tests of the DC-3 type installation. A fire of this type in the accessory region is shown in figure 28. It is considered that a fire of this size represents a minimum size of fire which should be rapidly detected and would not be of immediate danger to the aircraft structure.

In the tests the detectors were connected electrically to signal lights in the control shed, and the time between the start of the fire and the time the light signals first were observed was recorded.

In conducting the detector tests, the standard gasoline fire was started at various locations throughout the power and the accessory regions. For each location of fire, the detectors were located so as to obtain the most rapid indications of fire and the spacing of the detectors was decreased until a time lag in detection of 3 seconds or less was observed. By continuing this process with a large variety of fire locations, the optimum location and spacing of detectors were determined.

In the case of continuous detectors, the detectors were placed at the same location as determined for the unit types, but in this case there was no necessity for determining detector spacing.

In order to determine the effect of rain on the operation of the fire detectors, a stream of water at the rate of 15 gallons per minute was introduced into the air stream from the wind tunnel forward of the propeller during the detector fires.

During these tests, observations were made of the time required for the detectors to operate under the actual fire conditions in the nacelle. In order to obtain a more accurate comparison of the time of operation of the various detectors, a laboratory set-up was made in which this could be determined. This set-up is shown in figure 29. The laboratory arrangement consisted of a gasoline burner in conjunction with an electric timing clock. The detector was placed in the gasoline flame at the time the clock was started, and the action of the detector stopped the clock to give a measure of the time of operation. The flame of the gasoline burner was spread evenly by the use of a wire screen in the flame, and a thermocouple was utilized to indicate when a standard flame temperature of 1900°F. was obtained before each test was conducted.

It was found that the time of operation of the various detectors with this laboratory set-up was essentially the same as that obtained in the nacelle with the standard gasoline fire.

Types of Detectors Tested

Four types of fire detectors were included in these tests. The Walter Kidde & Company unit flame type detector and the American-LaFrance-Foamite Corporation unit metal expansion type, as described in detail in the DC-3 report (see figures 30 and 31), were included for determining optimum unit type detector locations.

The continuous fusible alloy type detector manufactured by Fenwal, Inc., as described in the DC-3 report and as shown in figure 32, was also included in the CW-20 tests. However, this detector has undergone additional development including the use of a new tin alloy and the substitution of a rough copper plating in place of the nickel plating previously used. The tin alloy used in the latest type of Fenwal detector has a melting point of 360°F.

Also included in the tests was a continuous ionization type detector developed by the Minneapolis-Honeywell Regulator Company. The detecting element of this unit consists of a continuous bare conductor mounted on ceramic or pyrex glass insulators, as shown in figure 33. The conductor was connected to a sensitive electronic indicator. The operation of this detector system depends upon the conducting and rectifying properties of the gasoline or oil flame, and this detector will operate whenever a turbulent flame contacts both the main aircraft structure and the conducting electrode.

Results and Discussion

The continuous type detectors included in the present series of tests are still in a state of development, and it is considered that further development is necessary before they will be suitable for use in actual aircraft installations. Results of such development will be covered in future reports of the fire test program. The CW-20 tests indicate the proper location of the continuous as well as the unit type detectors in this installation and further establish the necessary design criteria for future development of such detectors.

As in the DC-3 tests, the tests on the CW-20 type installation showed that the effect of the flame stratification in the cowling is extremely important in determining satisfactory detector action. In both the power and the accessory regions a high degree of stratification occurs, and a stream of cold air may be passing directly over a detecting element to keep it from operating when a very intense strata of flame may be passing within several inches of the unit. As was found in the previous tests, heat radiation from a flame to a detector cannot be depended upon for detector operation, and it is essential that the flame pass directly over the detecting units. For this reason, the proper locations and spacing for the unit detectors were determined so that, for the standard 0.33 gallons per minute gasoline fire, the flame would come in contact with one or more detecting elements for any possible fire location. The proper locations and spacing for unit detectors are given in figure 34, and the proper locations of continuous type detectors are given in figure 35. It is to be noted that a spacing of 18 inches or less for unit detectors is required around the engine mount ring where detection for power region fires is obtained, and that a spacing of 8 inches or less is required on the firewall and in the gill opening where a higher degree of flame stratification occurs. At all locations it is necessary that the detector project out from the supporting structure so that it may be completely surrounded by flame.

The time of operation of the various detectors as determined in the nacelle and in the laboratory set-up is shown in table IV.

Table IV

Time of Operation of Detectors

Detector Manufacturer	Detector Type	Temperature Setting	Operating Time (Seconds)
American-LaFrance-Foamite Corporation	Metal Expansion	400° F.	3.5
Fenwal, Inc.	Fusible Alloy	360° F.	3.2
Minneapolis-Honeywell Regulator Company	Flame Ionization	-	0.0
Walter Kidde & Company	Flame	-	0.0

It is seen that the flame type detectors provide more rapid detection than the detectors which depend upon the heating of a disc or fusible alloy, although satisfactory operation may be obtained with any of these types.

Of the detectors included in the present tests, the Minneapolis-Honeywell ionization type was the only one which was affected to any degree by rain water. With this type it was found that there was a tendency for the insulators to become wet and to "ground out" the indicating circuits, causing the detector to become inoperative and to give occasional false alarms. However, further development with this detector is now being carried out to eliminate this difficulty.

From these tests it was determined that the design criteria for adequate detector operation which were established in the DC-3 tests, and as discussed in the DC-3 report, still are valid for the CW-20 installation and require no modification.

Conclusions

1. Adequate detection of aircraft powerplant gasoline and oil fires can be obtained in the CW-20 type installation when proper detectors and detector locations are utilized.
2. The proper locations for fire detectors in the CW-20 type installation are around the engine mount ring, on the center and bottom of the firewall, and on structural members in the center of the exit gill.
3. The spacing of unit type detectors in this installation should not exceed 18 inches around the engine mount ring and should not exceed 8 inches on the firewall and in the gill opening.
4. The need for further development of continuous type fire detectors is indicated by the tests.

MATERIALS

Purpose

The purpose of the tests on materials was to determine the effect of gasoline and oil fires on the various materials and equipment commonly used in aircraft powerplant installations and structures.

Description of Materials Tested

The materials used in the CW-20 installation were as follows:

Engine mount - SAE 4130 steel tubing of 0.065-inch wall thickness.

Accessory cowl - both 0.049-inch aluminum alloy and 0.018-inch stainless steel.
Firewall - 0.040-inch low carbon steel.
Wing and nacelle skin - 0.012-inch stainless steel sheet.
Engine fuel system - standard aluminum tubing installation lagged with asbestos. Also, special auxiliary unlagged fuel system with standard fuel pump and 5/8-inch O.D. aluminum alloy tubing.
Engine oil system - aluminum alloy oil tank and oil lines with standard AN (neoprene) hose connections. Standard soldered construction oil cooler lagged externally with asbestos.
Tire - standard DC-3 tire.
Test panels of substitute firewall material - 27 panels of various materials suggested as substitutes for stainless steel in firewalls. A description of these panels is given in table V.

Table V

Substitute Materials for Firewalls (9" x 12" Panels)

Sample No.	Thickness of Sheet (Inches)	Thickness of Coating (Inches)	Description
1	0.010	0.00016	Coronite coating of alternate Zn and Ni dipping on mild steel sheet heat treated.
2	0.010	0.00020	" "
3	0.010	0.00023	" "
4	0.010	0.00030	" "
5	0.010	0.00032	" Non-heat treated
6	0.010	0.00032	" "
7	0.010	0.00040	" "
8	0.010	0.00040	" "
9	0.010	0.00040	" ")Different
10	0.010	0.00040	" ")ratio of plating from 7 & 8
11	0.017		Aluminum dipping on mild steel
12	0.023		" "
13	0.021		" "
14	0.015		" "
15	0.018		4 - 6 Cr. - Mo.
16	0.025		" "
17	0.040		Special aluminum coating on mild steel sheet heat treated.
18	0.040		" "
19	0.039		" "
20	0.037		" "
21	0.040		Special aluminim coating on mild steel sheet, non-heat treated.
22	0.055		" "
23	0.033		Special aluminum coating on mild steel sheet, sand blasted.
24	0.020		Stainless-clad mild steel
25	0.020		" "
26	0.027		" "
27	0.027		" "

Procedure

Most of the tests on materials were conducted in conjunction with the fire extinguishment and detector tests, observations being made of the effect of the fire on the different components. In a separate series of tests, 25 chromel-alumel thermocouples were mounted at different locations throughout the nacelle to obtain temperatures of the various parts of the structure under typical fire conditions. A bank of 25 pyrometers and a slow speed camera, as described in Part I of this report, were used to record the temperatures during the fires. The thermocouple locations are shown in figure 36, and thermocouples on the outside of the cowling are shown in figure 37.

Tests of the rubber tire were conducted with the wheel and the tire in both the retracted and extended positions. Observations were made to determine the effect of the fire on the tire and the ease with which this fire could be extinguished. Tests were made of a standard aluminum alloy gasoline system in which an auxiliary pump and gasoline lines were mounted in the nacelle forward of the firewall without asbestos lagging on the aluminum tubing. Gasoline was pumped through this system at the same rate as in the standard fuel system in the engine, and the effect of fire on the aluminum lines and the tendency to vapor lock were observed. In addition, the effect of the fire on the various ducts, brackets, straps, and miscellaneous equipment in the nacelle was noted.

Results and Discussion

As noted previously, most of the engine accessories were covered with a lagging consisting of asbestos and waterglass. However, the engine mount, the firewall, the engine oil system, and the main nacelle structure were left exposed to the fire. The maximum temperatures at various locations on the cowling, nacelle, wing, and firewall are shown in figure 38. At many locations temperatures in excess of the melting point of aluminum alloy were reached, and temperatures which would seriously decrease the strength of stainless steel structures were measured. The data given are for fires of 30 seconds duration. Figures 39 to 48 show the rate of increase of temperature at these various locations for typical gasoline and oil fires. It is seen that a maximum temperature is reached 20 to 30 seconds after the fire is started.

At the beginning of the tests, aluminum alloy cowling was used around the accessory region. As the tests were continued and the location of the fires varied, sections of this cowling were melted off and were replaced with stainless steel. It was found that aluminum alloy accessory cowling might withstand a considerable number of intense fires without failure because of the cooling effect of the air blast on the outside of the cowl, but a single fire in a critical location might cause failure. Failure of the accessory region cowling generally occurred close to internal stiffeners, apparently where there was a turbulent air flow on the inside surface. Aluminum alloy cowl flaps used in some of the tests showed rapid failure and were replaced with steel flaps. The entire gill structure was made of stainless steel, and it was indicated from the temperature data that aluminum alloy would fail rapidly at this location.

As in the tests of the DC-3 type installation, no tendency for melting or failure of the NACA engine cowling was observed. The standard steel engine mount used in the DC-3 tests was utilized in the CW-20 type set-up. At the completion of these tests, this engine mount had undergone approximately 2,200 fires without appreciable damage except for corrosion and scaling, (see figure 5). However, it should be noted that most of the fires lasted for only 30 seconds and that the engine mount sustained only the weight of the powerplant without additional acceleration loads. No estimate can be given concerning the probable time of failure of such an engine mount for fires of longer individual duration and with acceleration loads applied.

The aluminum alloy oil tank and oil lines used in the previous tests also were utilized in the CW-20 test set-up. No appreciable damage to the engine oil system occurred as long as the oil tank and lines contained flowing liquid. The tendency for the neoprene hose connections to char and fail after a number of fires was observed, although there seemed to be no tendency to approach failure in any single 30-second fire. The oil cooler used in the DC-3 tests, shown in figure 6, was used in the CW-20 set-up and was undamaged in any of the fires in spite of the fact that nearly all of the fires in the CW-20 type installation passed directly around the oil cooler, completely enveloping it in flame. It was apparent that as long as the blast of cooling air was maintained through the oil cooler, no damage to the cooler would occur.

In the present set-up a steel air duct was used to conduct the cooling air from the front of the cowling to the oil radiator. It was indicated that the use of an aluminum duct for this purpose would probably result in burning through of the duct and entrance of flame into the front of the oil cooler, with resultant failure of soldered joints. No actual test of this condition was made.

Tests were made of a gasoline system utilizing aluminum alloy tubing in which an auxiliary gasoline pump and lines were mounted ahead of the firewall without asbestos lagging. The effect of a 30-second gasoline fire on the aluminum alloy gasoline lines is shown in figure 49. Vapor lock was found to occur in this system in less than 15 seconds, with resultant burning through of the aluminum alloy lines and the release of large quantities of gasoline to feed the fire. Thus, it is indicated that aluminum alloy lines are unsatisfactory from a fire protection standpoint for conducting gasoline, although such lines are satisfactory for the oil system.

The tests on the rubber tire in both the retracted and the extended positions showed that the tire would ignite in less than 30 seconds and that the resultant fire would not be completely extinguished by application of the extinguishing agent. Smouldering in the tire continued for some time after the main fire was extinguished but eventually ceased without burning completely through the tire. In general, the smouldering continued until the fabric in the tire was reached.

The test panels of the various substitute firewall materials listed in table V were mounted in an opening in the nacelle skin directly behind the gill opening in what was found to be a region of maximum skin temperature. Each panel was left in place during two or three intense fires in this region, and the effect of the fire on the panels and the maximum temperature reached by the panels were observed. An aluminum panel of 0.030-inch thickness at this location was observed to burn completely through in 10 to 15 seconds, but none of the firewall materials showed serious signs of failure. In some cases with the thinner gauge materials warping, discoloration, and burning of the surface coatings occurred. The appearance of several of these panels after test is shown on figure 50. In general, it was found that any of these materials would withstand an intense gasoline or oil fire for 30 seconds without burning through, and that they are comparable to stainless steel in this respect.

Conclusions

1. The structure of a CW-20 type nacelle and, in particular, the accessory cowling, firewall, and nacelle skin behind the firewall, can be seriously affected by an engine fire within 15 seconds from the start of such a fire.

2. Temperatures as great as 1700°F. were observed on the cowling, firewall, and nacelle skin during typical gasoline and oil fires. Such temperatures will result in the melting of aluminum alloy and will seriously reduce the strength of stainless steel.

3. The conventional welded steel tube engine mount used in the tests has suffered no serious damage during approximately 2200 fires, most of which were of 30 seconds duration.

4. The firewall of 0.040-inch low carbon steel was not appreciably damaged by approximately 800 gasoline and oil fires, each of 30 seconds duration.

5. The aluminum alloy oil tank and oil lines were not appreciably affected after approximately 2200 gasoline and oil fires, each of 30 seconds duration. However, the AN (neoprene) hose connections in the oil system were damaged after a smaller number of fires.

6. Aluminum alloy gasoline lines will burn through from an intense gasoline or oil fire in approximately 15 seconds as a result of vapor locking of the gasoline system. Other aluminum alloy tubing in which there is no liquid is damaged in a similar manner.

7. The oil cooler was not appreciably damaged by fire after approximately 2200 fire tests. The oil cooler air intake, however, must be arranged so as to preclude the entrance of fire into the air stream forward of the cooler.

8. The landing gear tire will ignite and will continue to smoulder for some time after fire extinguishment, but such smouldering will cease before complete penetration of the tire is obtained.

9. Aluminum alloy cowl flaps were found to burn off readily from gasoline or oil fires in critical locations.

10. The aluminum alloy NACA cowl was not seriously damaged by any of the fires.

11. Substitute firewall materials consisting of a low carbon steel base or low nickel content stainless steel withstood penetration by fire in a manner comparable to stainless steel.

COMPARISON OF CW-20 AND DC-3 TYPE COWLINGS

The essential structural characteristics of the CW-20 type cowling, as compared with the DC-3 type cowling, are the absence of a diaphragm cowl separating the power and the accessory regions and the exhausting of the engine cooling air through a single lower exit gill at the bottom of the accessory region. In addition, the CW-20 arrangement as tested includes an exhaust stack through the side of the cowling in line with the collector ring rather than rearward through a well in the accessory region. The effects of these design features upon the fire characteristics of the CW-20 type cowling as noted in the present tests are as follows:

1. The absence of the separating diaphragm causes power region fires to burn more completely in the accessory region and on the firewall rather than on the outside of the cowl. Power region fires in the DC-3 type installation spread to the accessory region through openings in the diaphragm and cowling. In the CW-20 type installation, however, they immediately occupy the accessory and firewall region and are larger and hotter in that region. Also, for many fire locations, little or no outside fire tail is obtained. As a result, more complete burning of the fire occurs inside the cowling with a more destructive effect on the structure forward of the firewall. The maximum temperatures measured on the firewall in the CW-20 type arrangement, as shown in figure 38, are considerably higher than the maximum firewall temperature of 500°F. measured with the DC-3 type installation.

2. The exit of the engine cooling air through the lower gill results in a concentration of flame over the lower part of the nacelle skin and wheel but eliminates all flame from the upper part of the nacelle skin back of the firewall and from much of the wing skin adjacent to the nacelle. As a result, the fire is concentrated more intensely over a smaller portion of the nacelle and wing, and higher temperatures are reached along the bottom nacelle skin back of

the firewall.

3. In many fires around the lower cylinders in the power region and in the lower accessory region with the gill completely open, a long fire tail may be formed which has no contact with the main nacelle structure. This is not likely to occur in the conventional type cowling.

4. The absence of the diaphragm cowl greatly increases the possibility of flames from cracks or openings in the exhaust system igniting gasoline or oil released in the accessory region. In the conventional cowling arrangement the gasoline or oil cannot readily work forward through the diaphragm to come in contact with the exhaust collector ring but can readily do so in the CW-20 arrangement.

5. The type of exhaust system in the CW-20 type installation with the short stub tail pipe extending directly through the side cowling is less hazardous from the fire ignition standpoint than the conventional shrouded tail type. The CW-20 installation apparently offers no possibility for explosive ignition of gasoline or oil vapors around the exhaust system if no heating shroud or muff is placed on the collector ring.

6. From the standpoint of fire extinguishment, both the CW-20 and the conventional type cowlings offer about the same difficulty of extinguishment and required approximately the same quantities and rates of application of extinguishing agent. The optimum types of extinguishing agent distribution systems in the two cowling arrangements are of about equal complexity.

7. The fire detection problem appears to be of about equal difficulty and requires installations of equal complexity in the two types of cowling.

In general the tests showed that adequate extinguishment and detection can be obtained with the CW-20 as well as with the conventional type of cowling arrangement, with each type possessing particular advantages and disadvantages from the fire protection standpoint.

Table VI

Fire Test Statistics

Extinguishing Agents	Number of Tests Conducted			Quantity of Agents Used		
	Fire Tests	Rate Tests	Total Tests	Fires	Rate Tests	Total Tests
Carbon Dioxide	151	19	170	3281 lbs.	227 lbs.	3508 lbs.
Carbon Tetrachloride	262	236	498	465 gal.	179 gal.	644 gal.
Methyl Bromide	135	0	135	168 gal.	0	168 gal.
Other Extinguishing Agents	10	0	10	9 gal.	0	9 gal.
Total Number of Tests on Extinguishing Agents	558	255	813			
Detector Tests	152	0	152			
Material Tests	89	0	89			
Total Tests	799	255	1054			

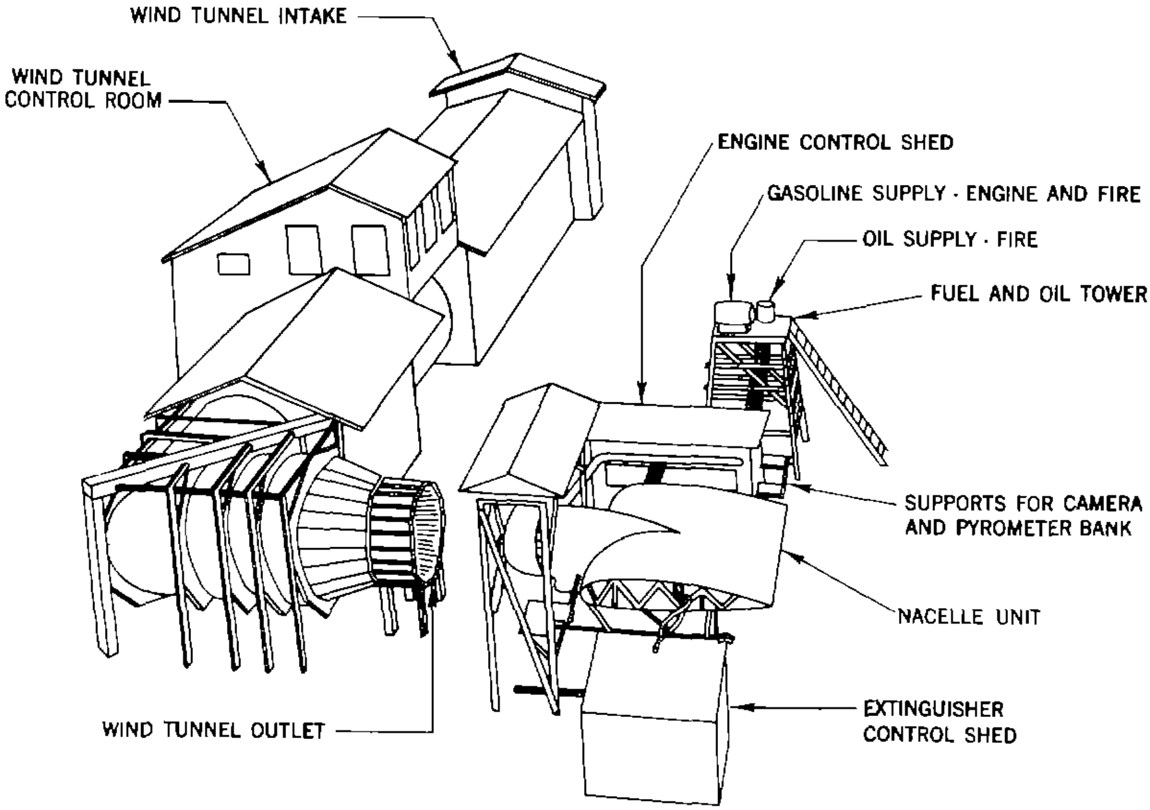

Figure 1. Test Layout

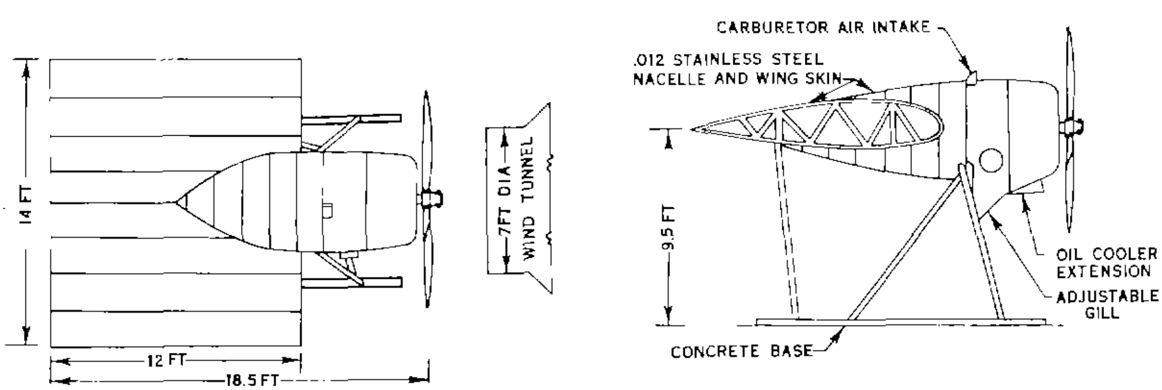

Figure 2. Nacelle Unit

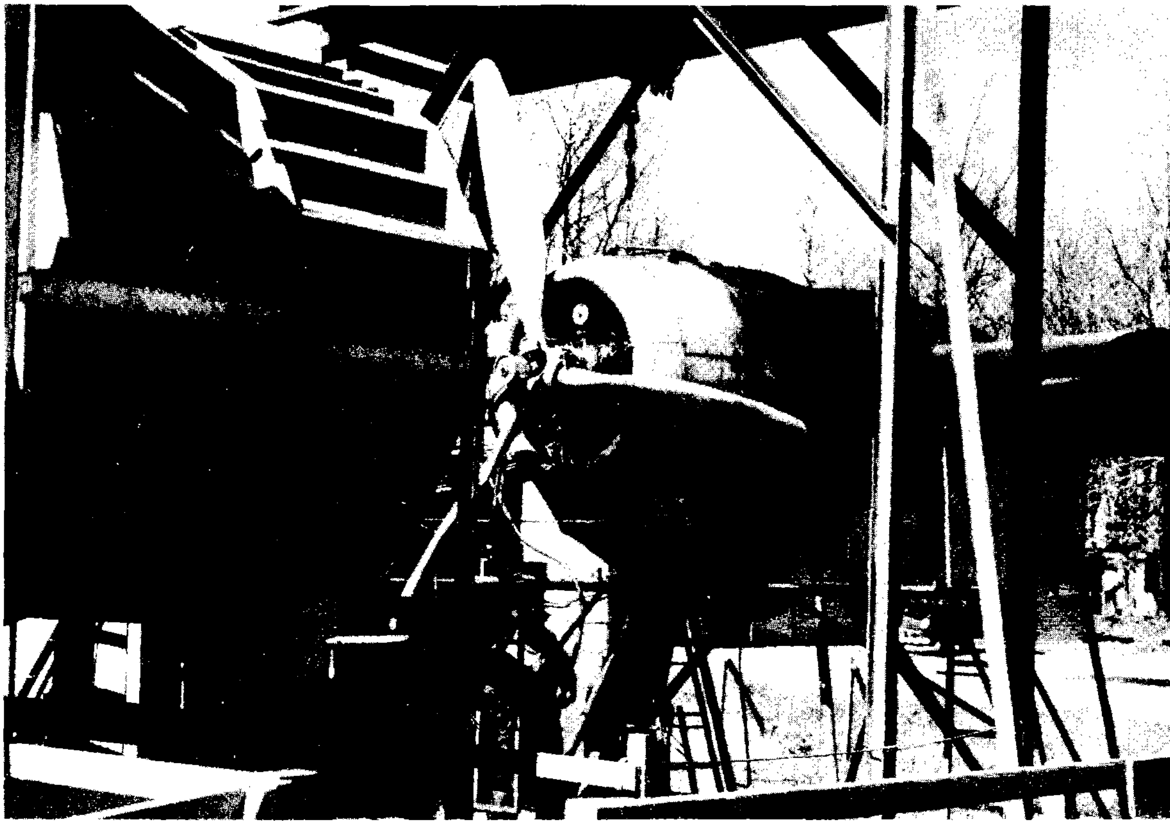

Figure 3. 3/4 Front View of Nacelle Unit

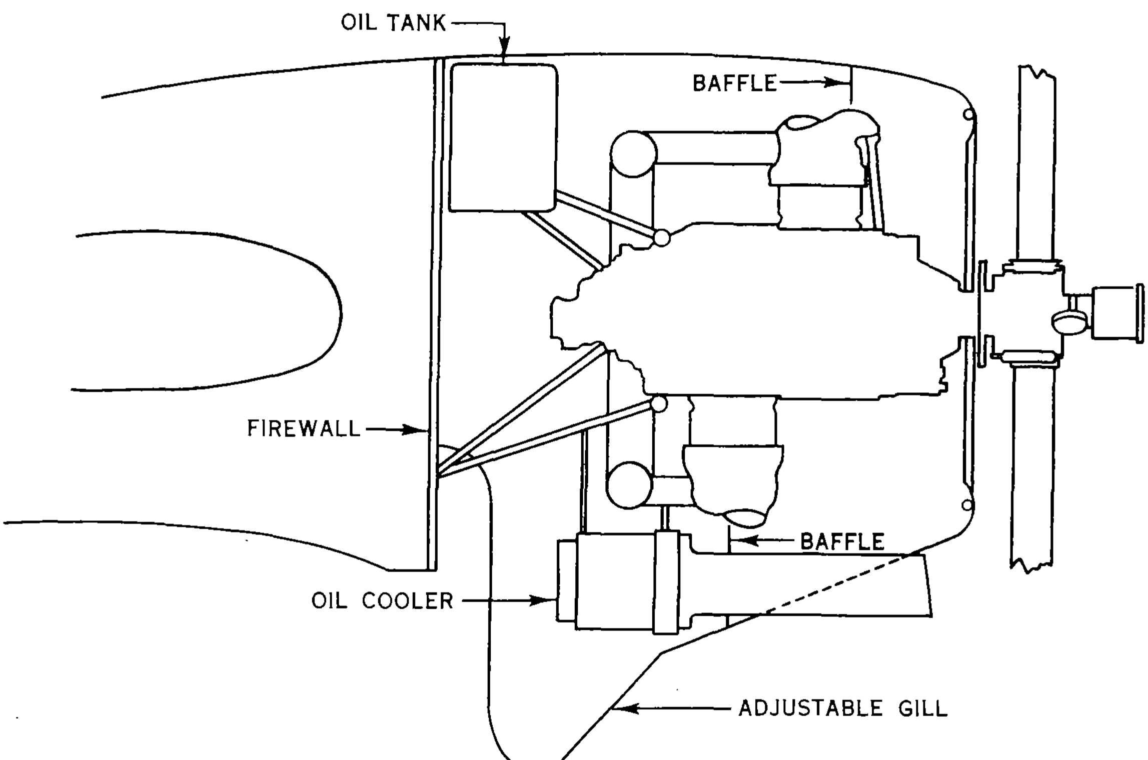

Figure 4. Cross Section Thru Cowl of CW-20 Type

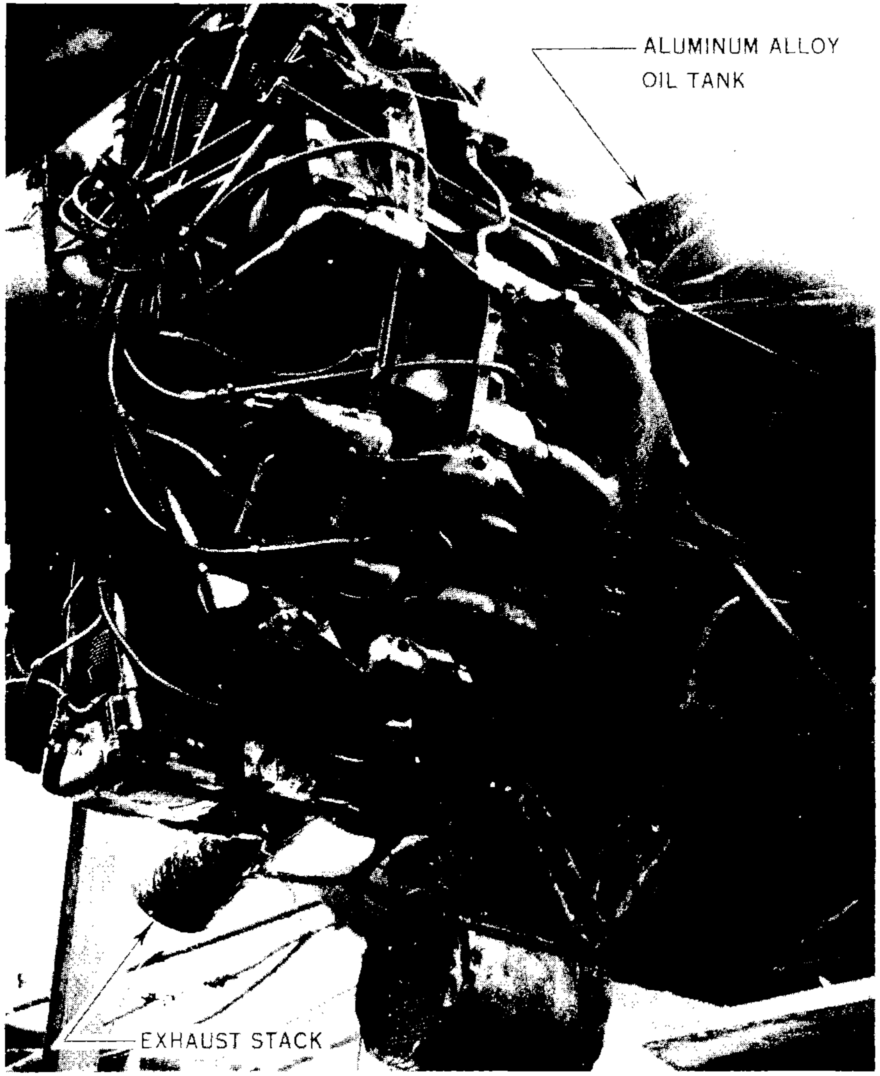

Figure 5. Power Plant Installation (Left Side) After 800 Fires.

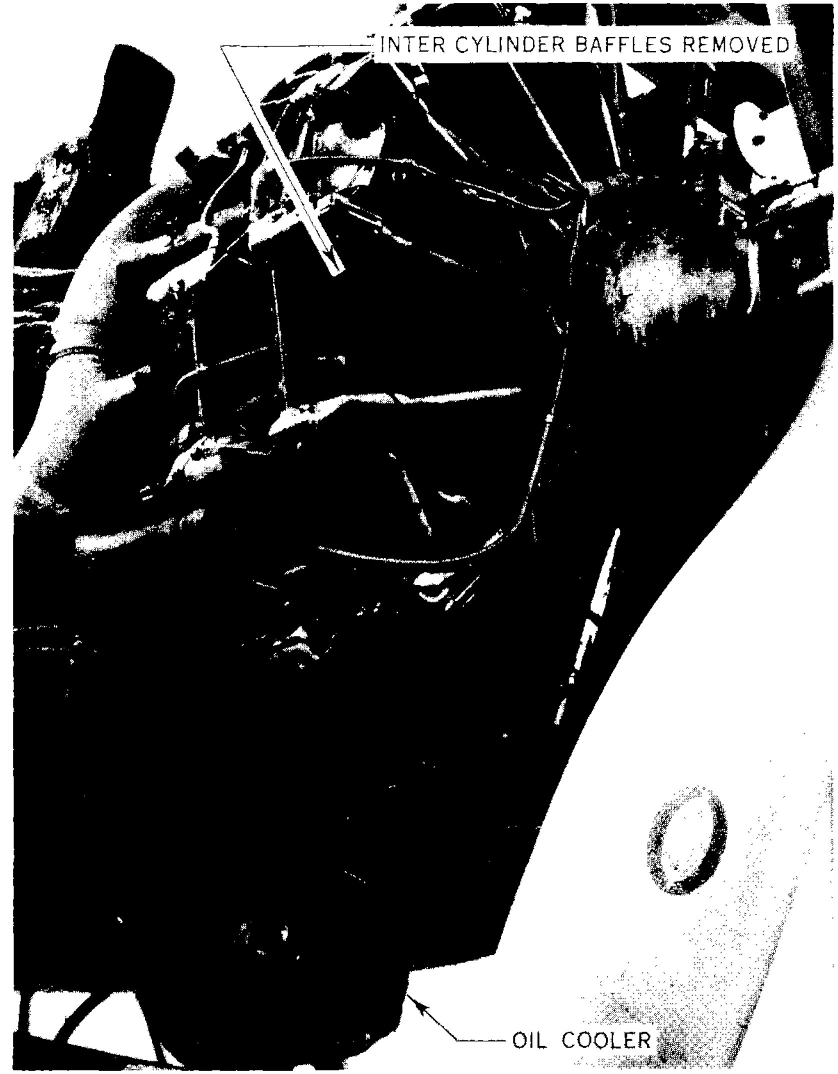

Figure 6. Power Plant Installation (Right Side) After 800 Fires

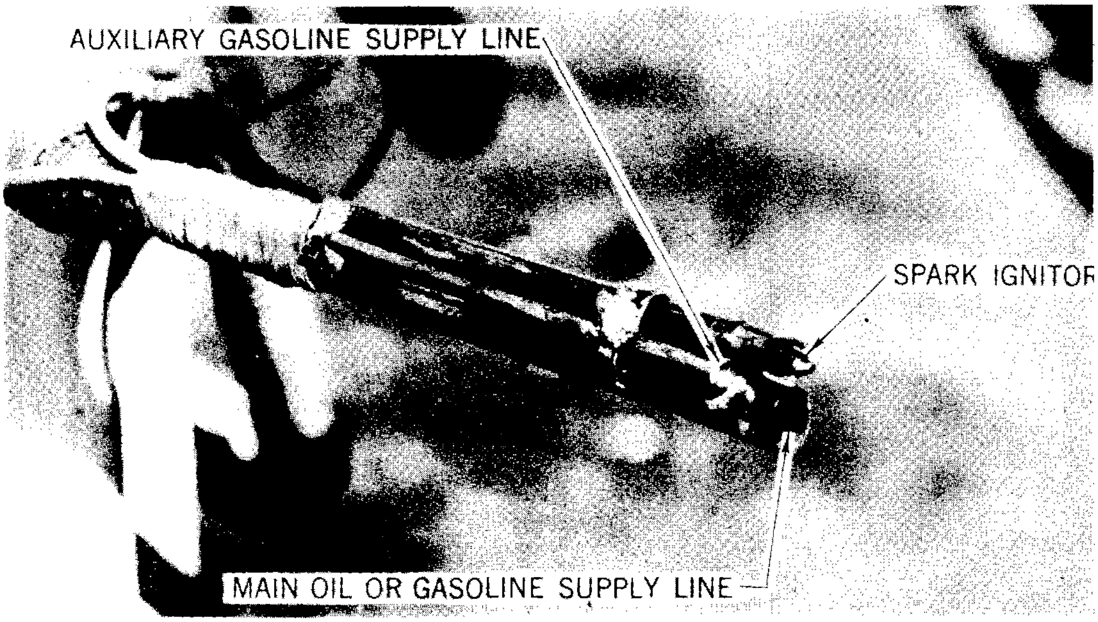

Figure 7. Fire Nozzle

Figure 8. Fire Nozzle in Position in Power Region

Figure 9. Fire Nozzle in Position in Accessory Region
(Before Installation of Flaps)

Figure 10. Interior of Extinguisher Control Shed

A. ONE NOZZLE AFT OF EACH CYLINDER-ON CRANKCASE-DISCHARGED AWAY FROM CRANKCASE-EACH NOZZLE FED INDEPENDENTLY BY FEED LINE FROM DISTRIBUTOR AT EXTINGUISHER. EACH NOZZLE DISCHARGES TWO SPRAYS-ONE AFT OF THE OTHER. ONE NOZZLE ABOVE AND FORWARD OF OIL COOLER.

B. SAME AS A. EXCEPT EACH CYLINDER NOZZLE DISCHARGED ONE SPRAY.

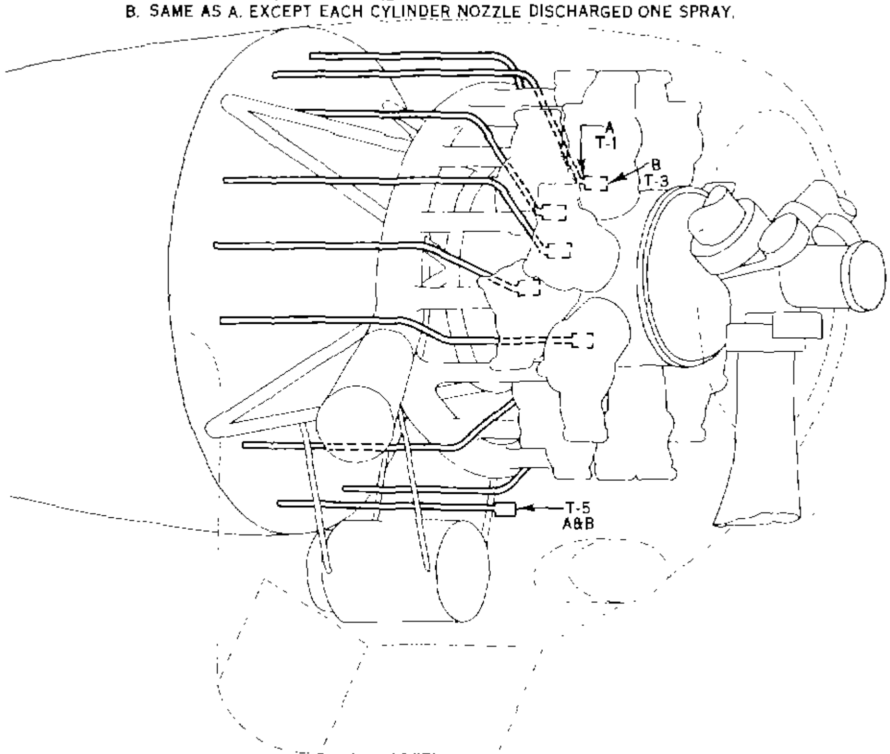

Figure 11. Distribution System-Basic Type

14 NOZZLES-ONE AFT OF EACH CYLINDER-DISCHARGED AWAY FROM CRANKCASE

5 NOZZLES AROUND UPPER HALF OF ENGINE MOUNT RING

1 NOZZLE ABOVE AND FORWARD OF OIL COOLER

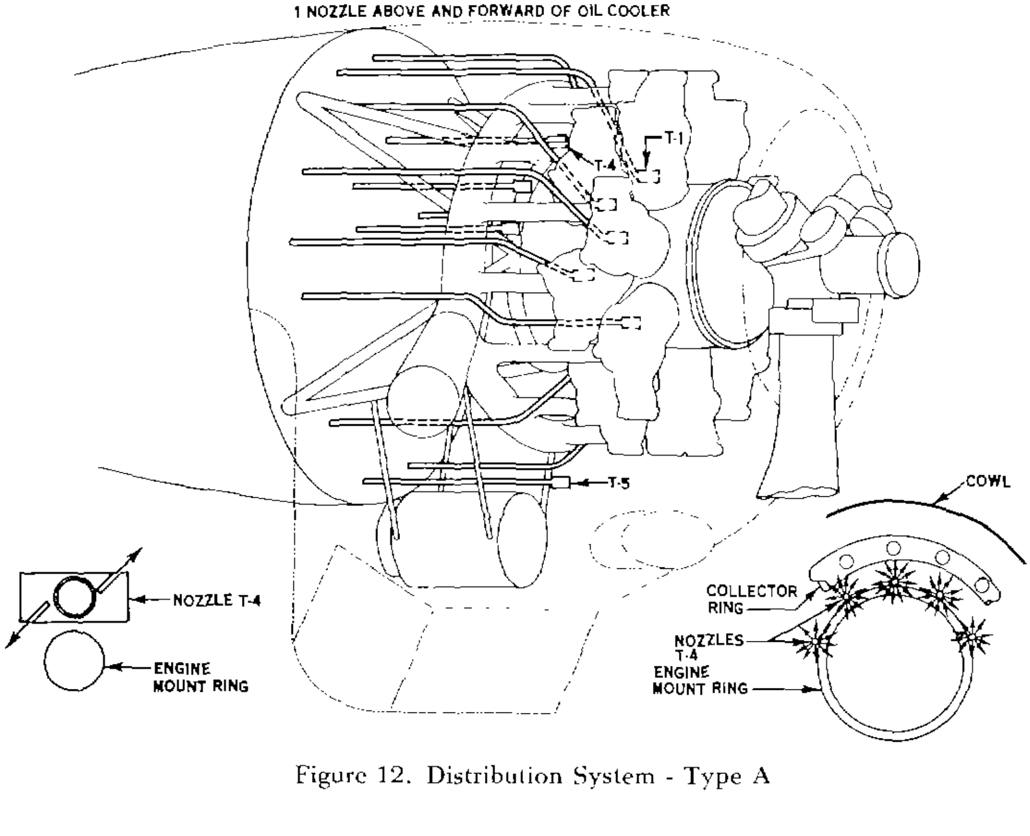

Figure 12. Distribution System - Type A

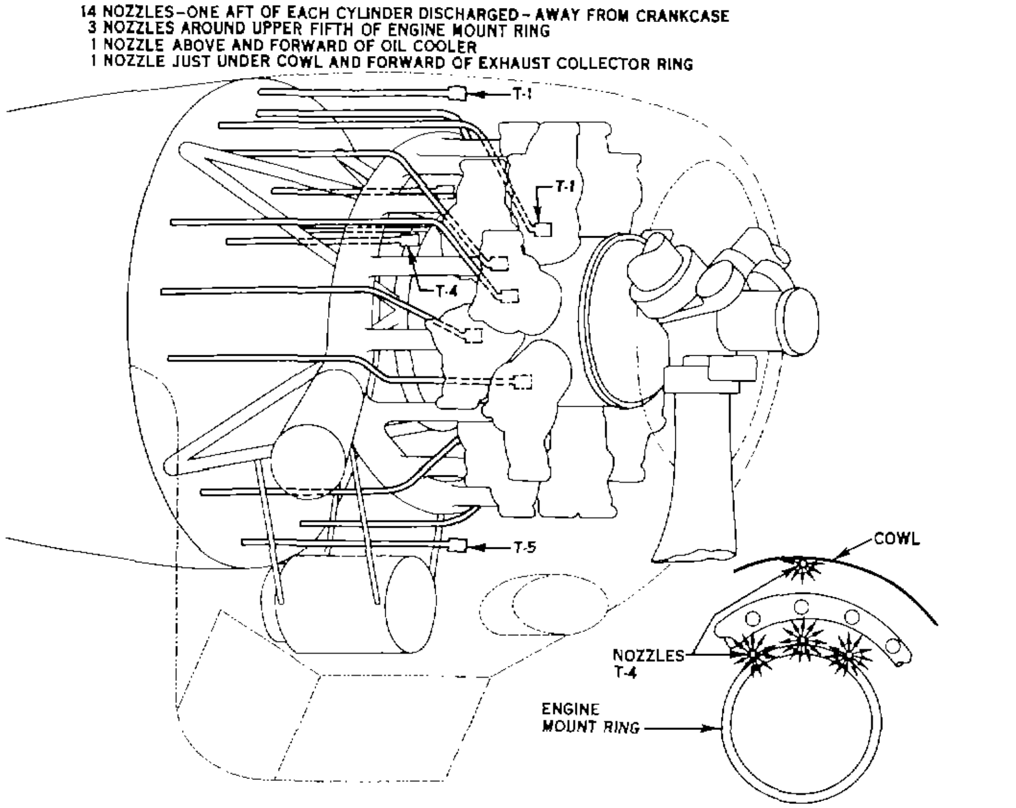

Figure 13. Distribution System - Type B

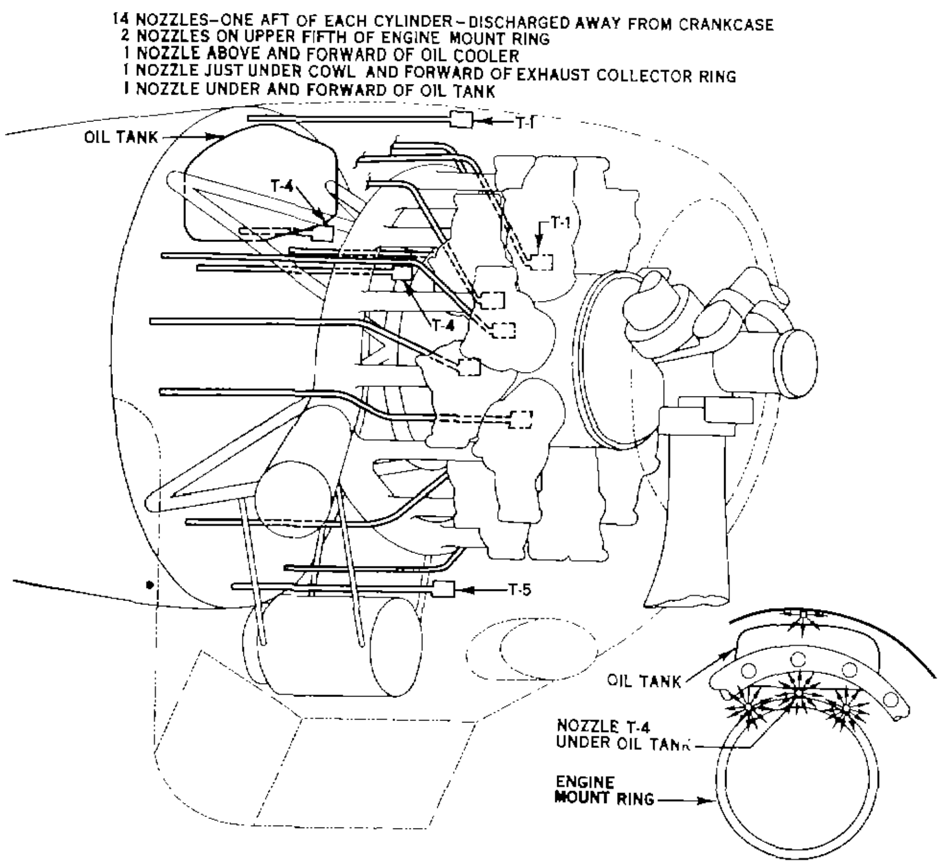

Figure 14. Distribution System - Type C

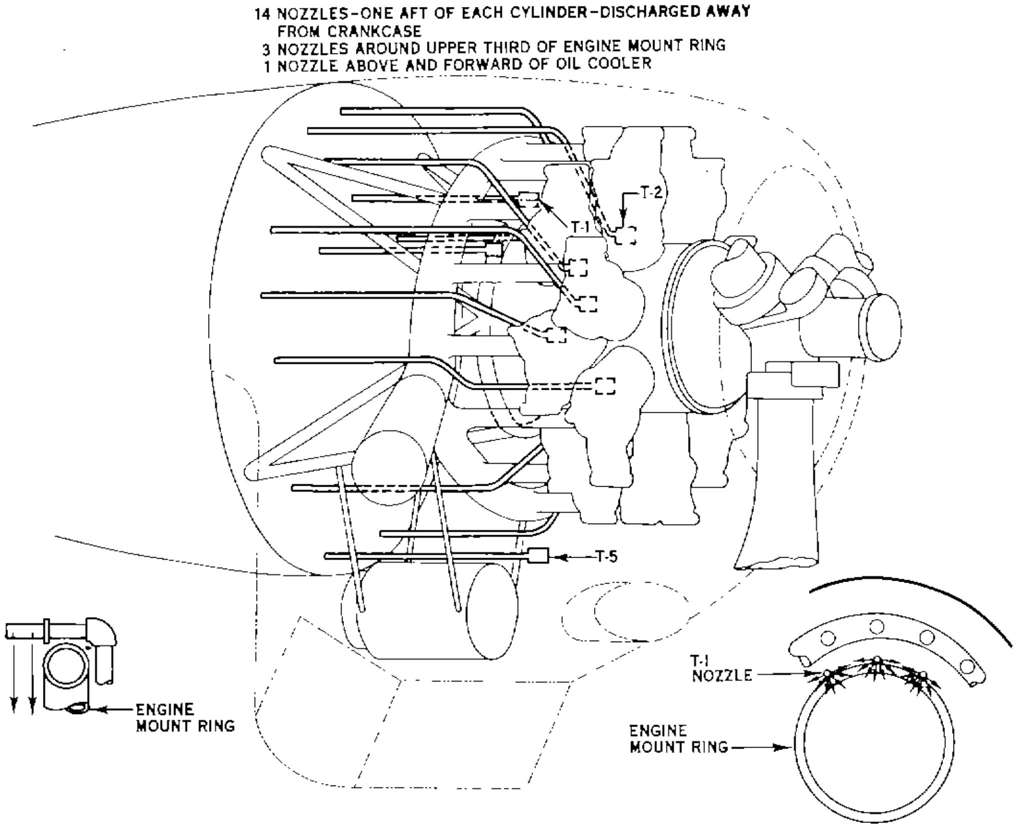

Figure 15. Distribution System - Type D

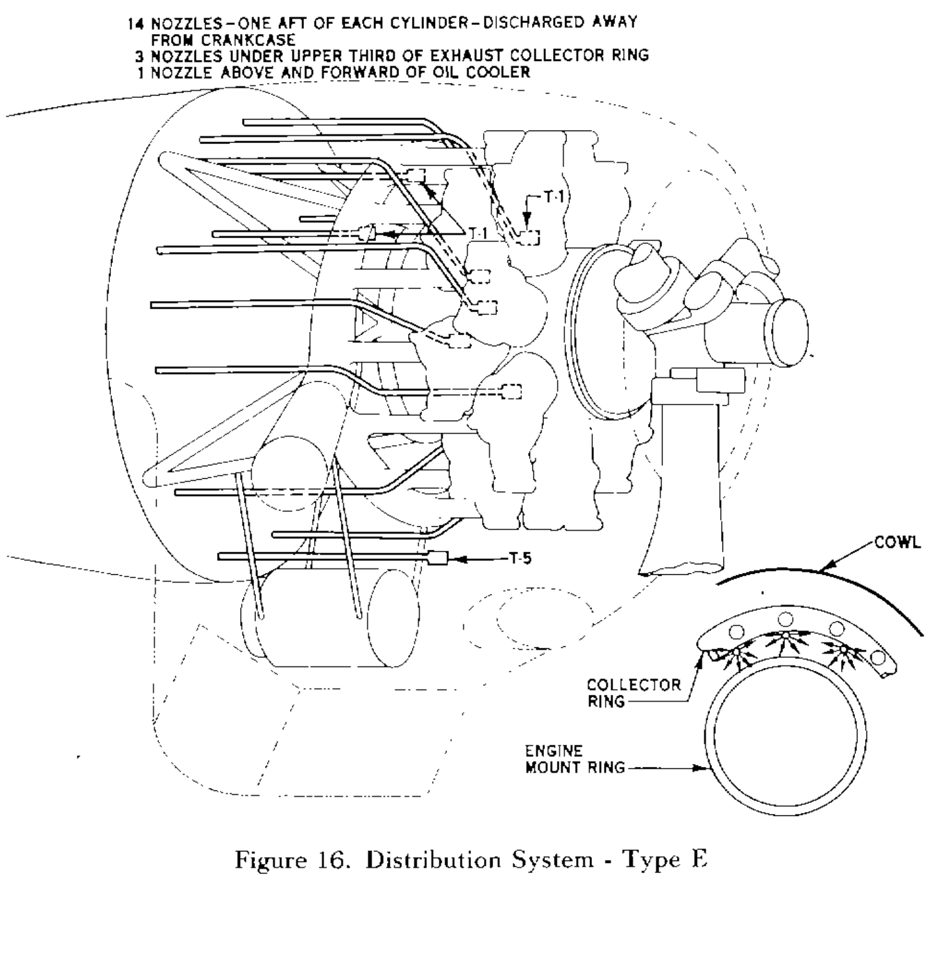

Figure 16. Distribution System - Type E

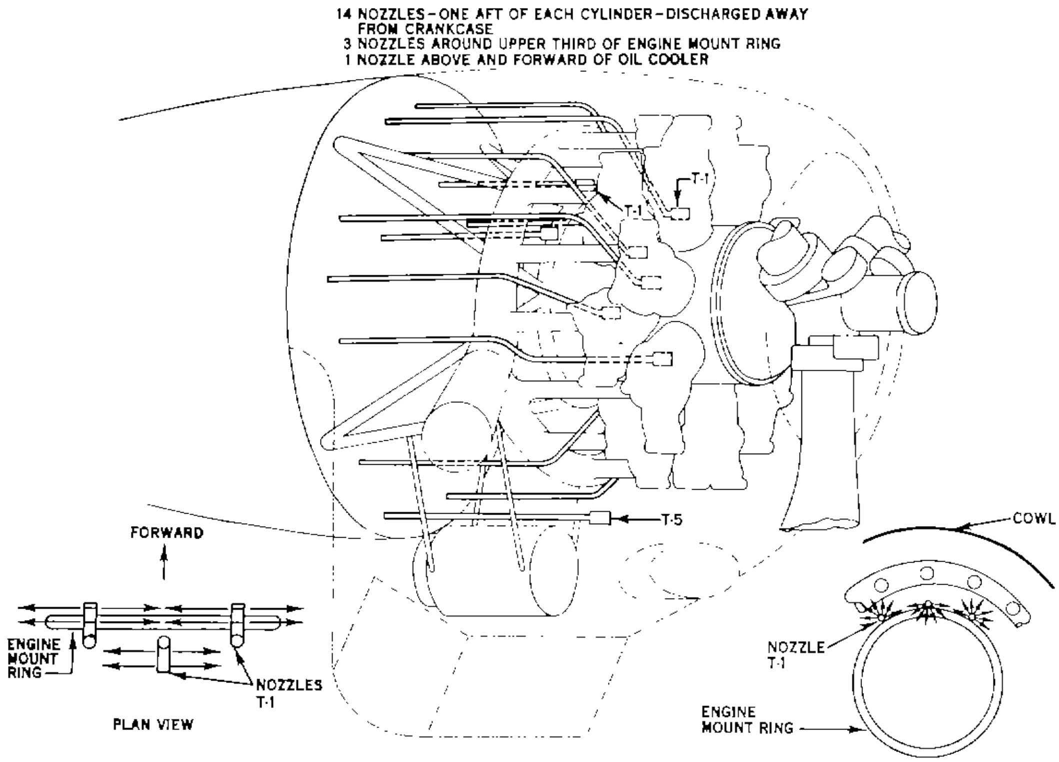

Figure 17. Distribution System - Type F

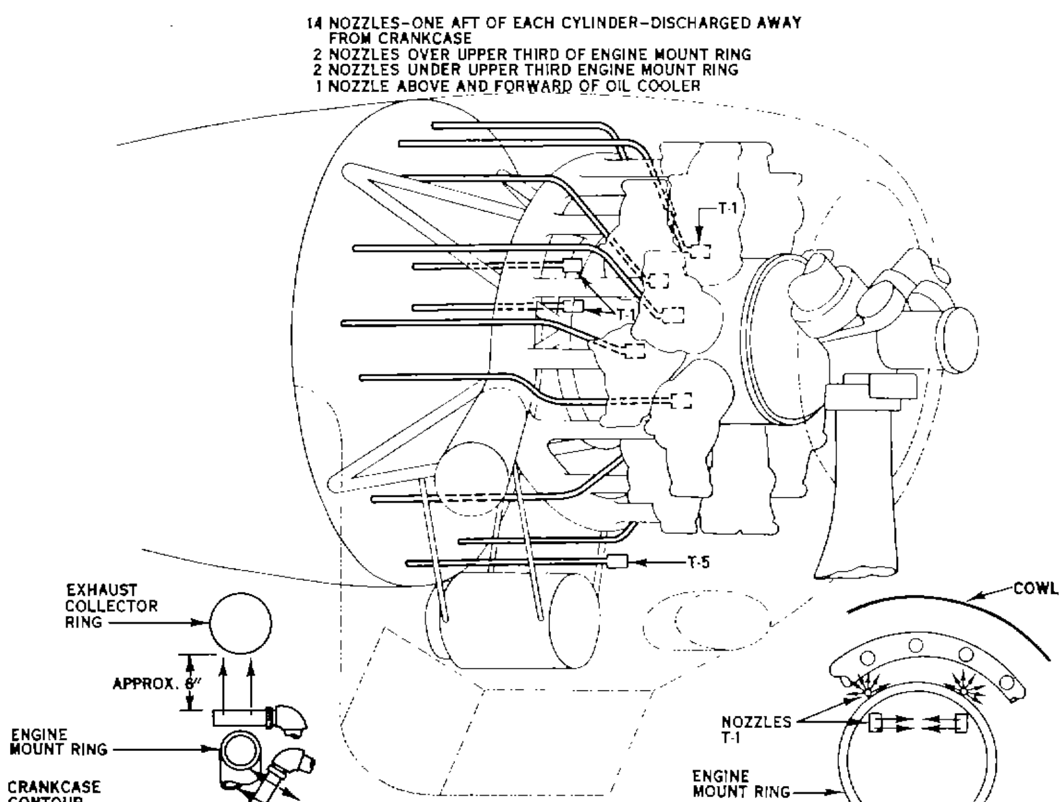

Figure 18. Distribution System - Type G

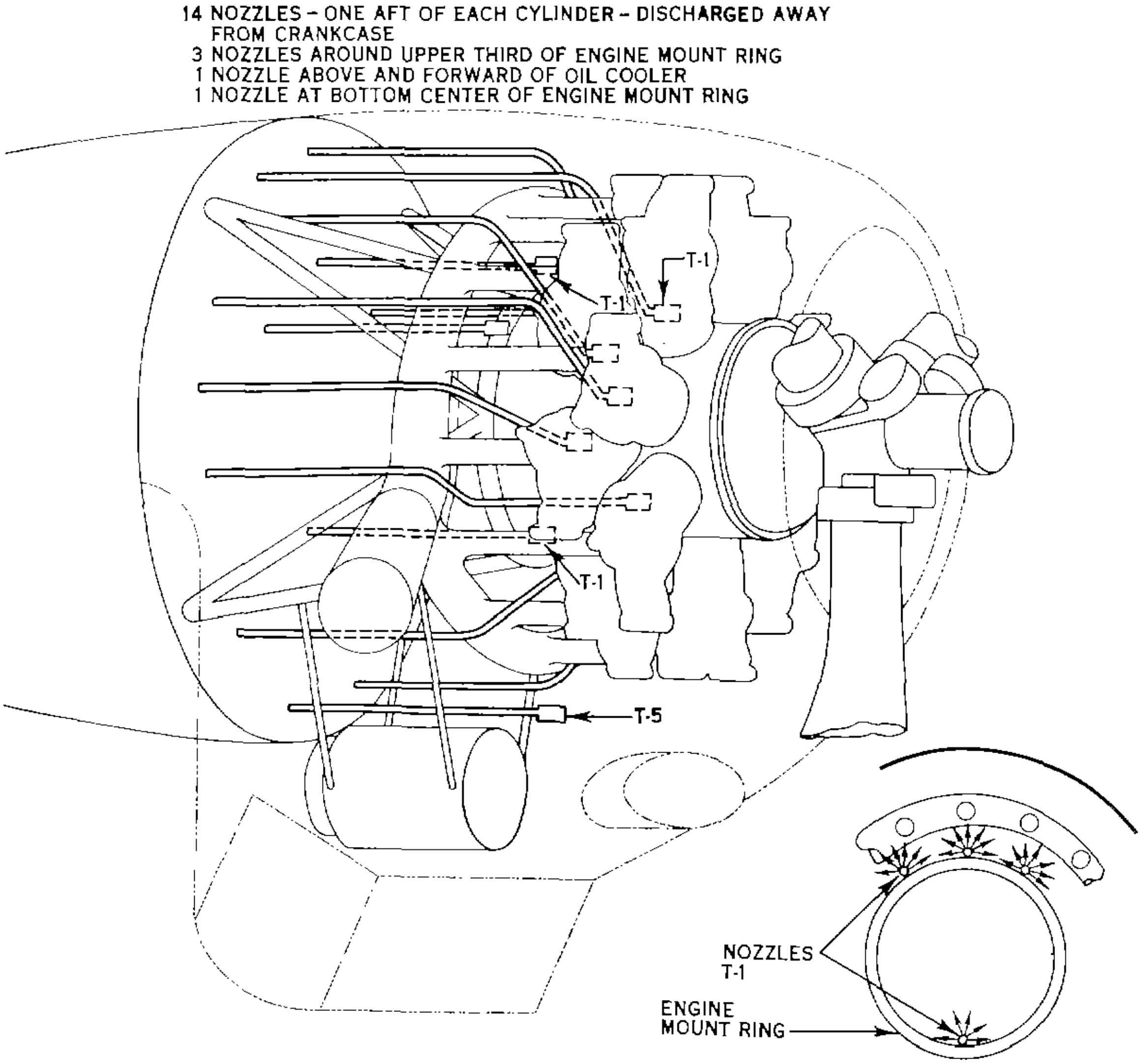

Figure 19. Distribution System - Type H

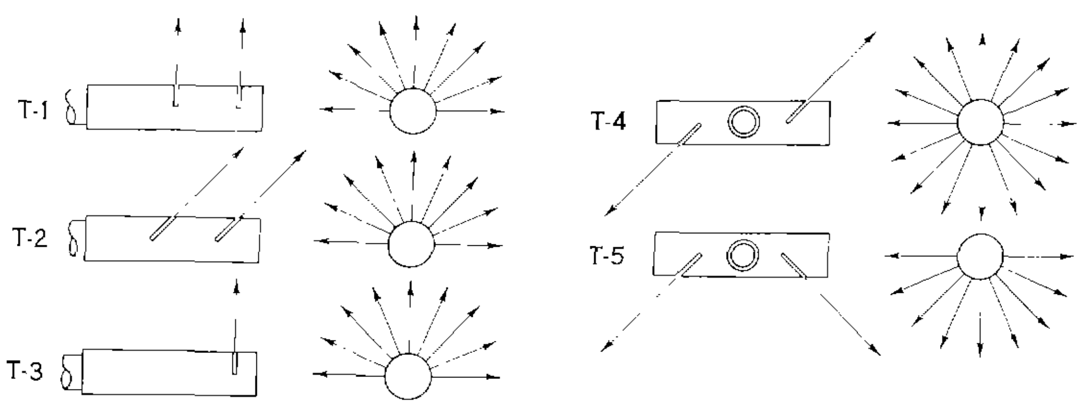

Figure 20. Nozzle Types Used in Tests
(Arrows Indicate Spray Direction)

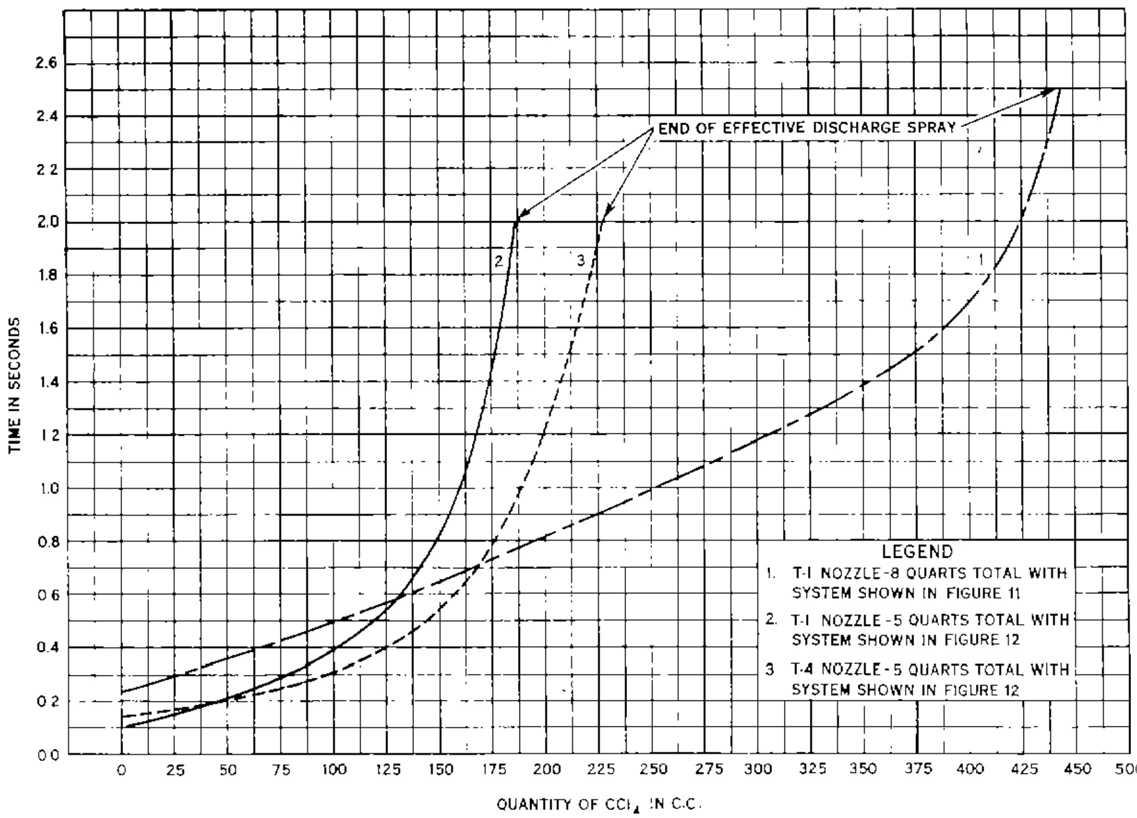

Figure 21. Rates of Carbon Tetrachloride Discharge from T-1 and T-4 Type Nozzles

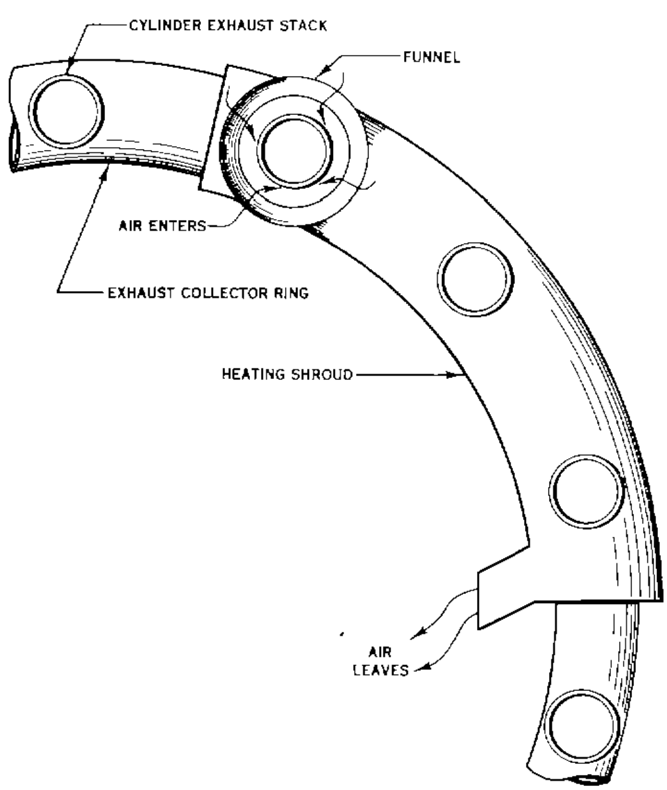

Figure 22. View of Heating Shroud from Front

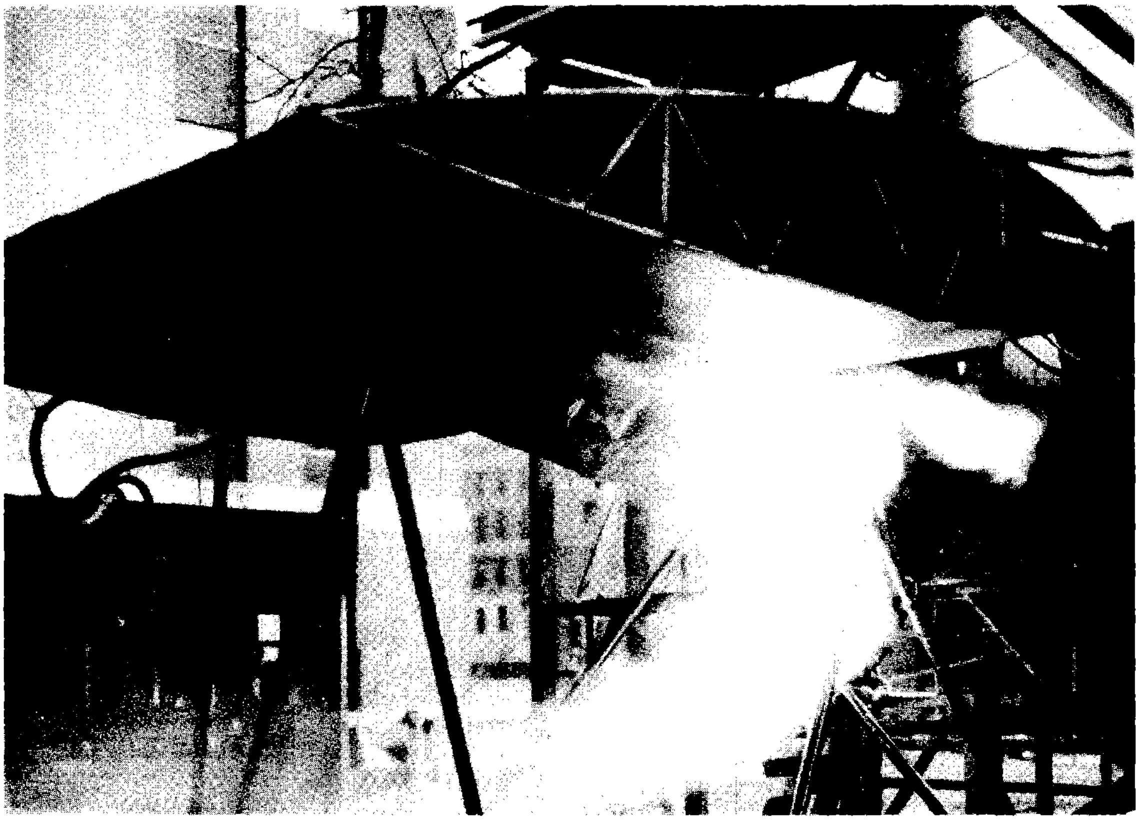

Figure 23. 5 Gallons Per Minute Oil Fire in Power Region

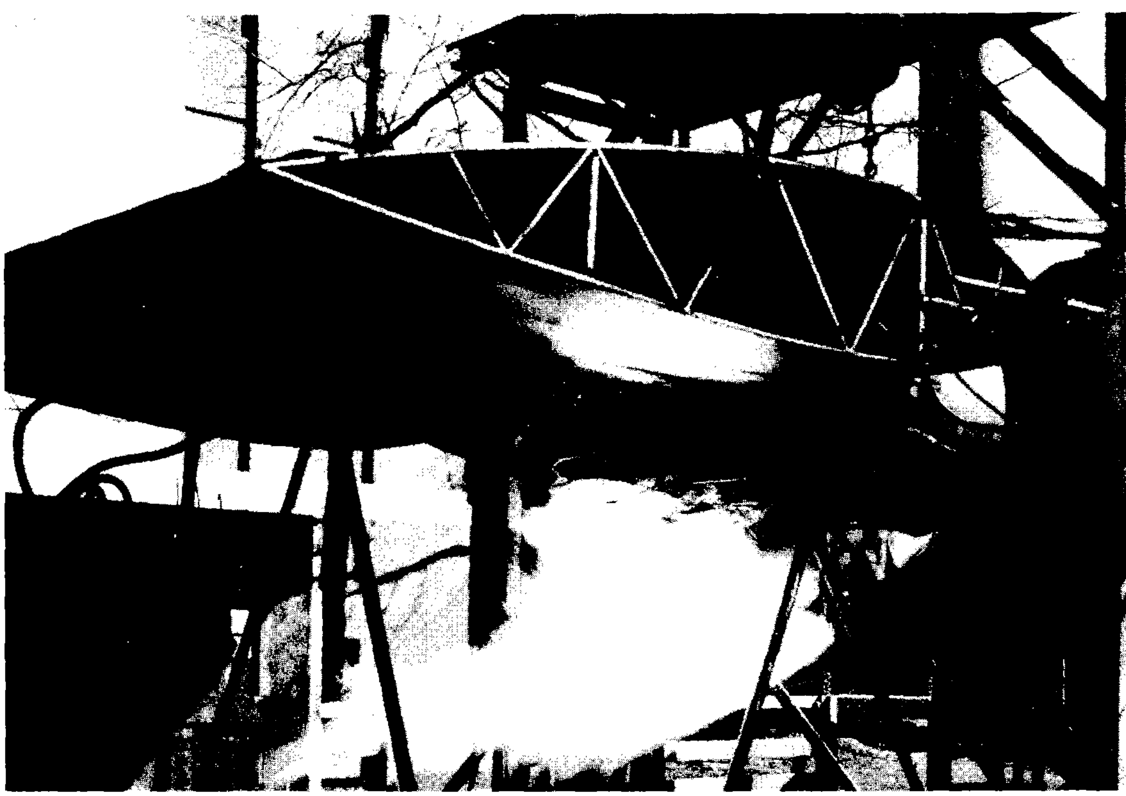

Figure 24. 5 Gallons Per Minute Oil Fire in Power Region

Figure 25. 5 Gallons Per Minute Oil Fire in Accessory Region

Figure 26. 5 Gallons Per Minute Gasoline Fire in Accessory Region

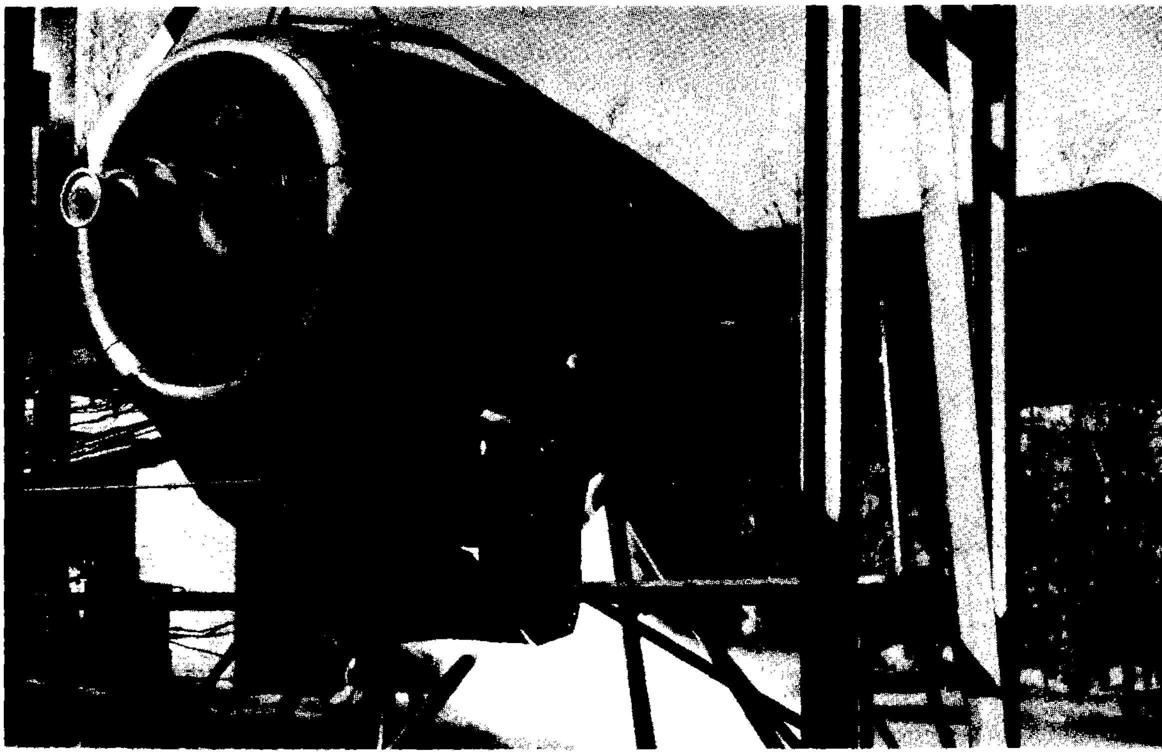

Figure 27. 5 Gallons Per Minute Gasoline Fire in Accessory Region

Figure 28. Standard Fire for Location of Fire Detectors
(One Third Gallons Per Minute Gasoline Fire in Accessory Region)

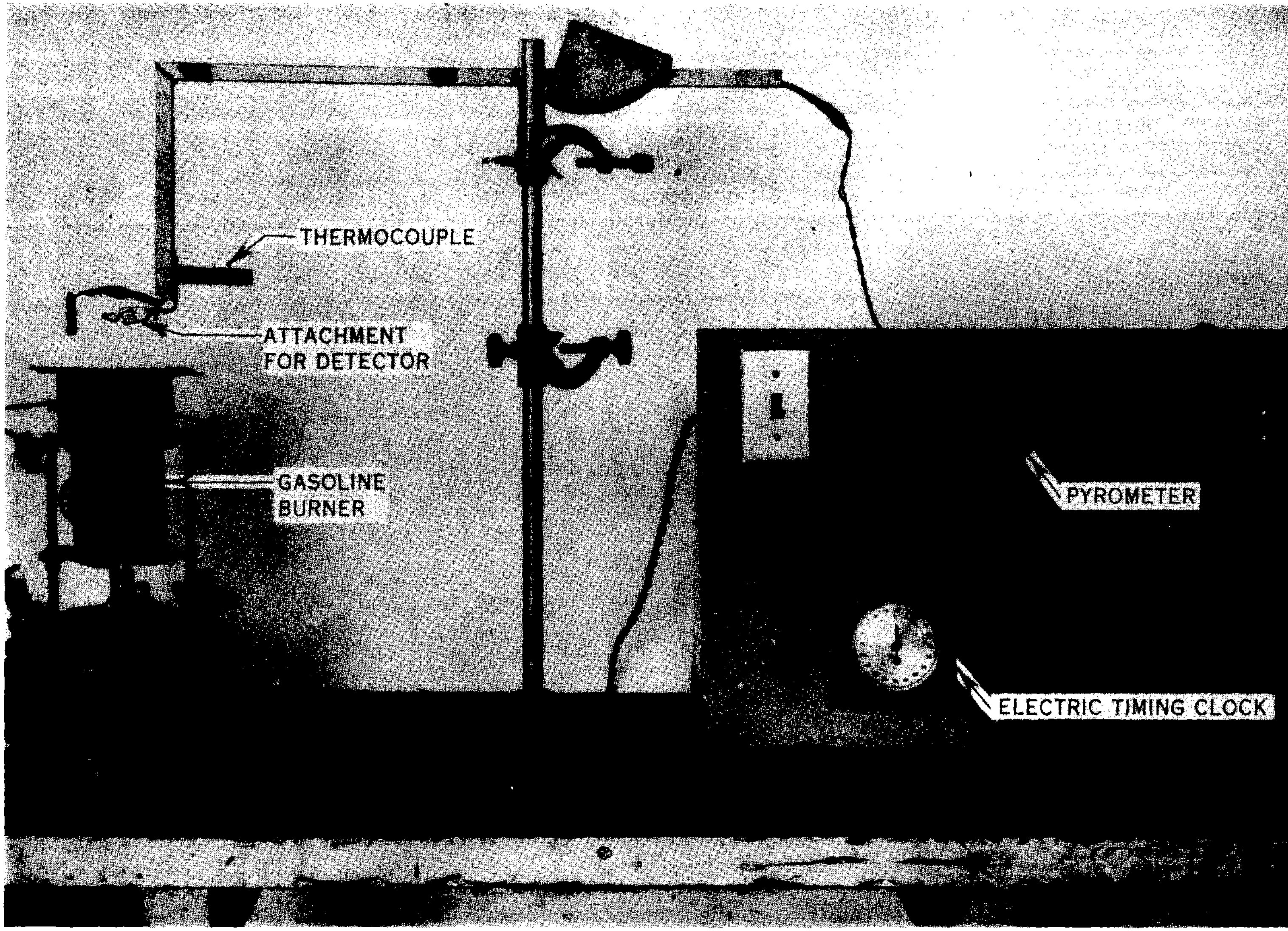

Figure 29. Set-Up for Determining Detector Operating Time

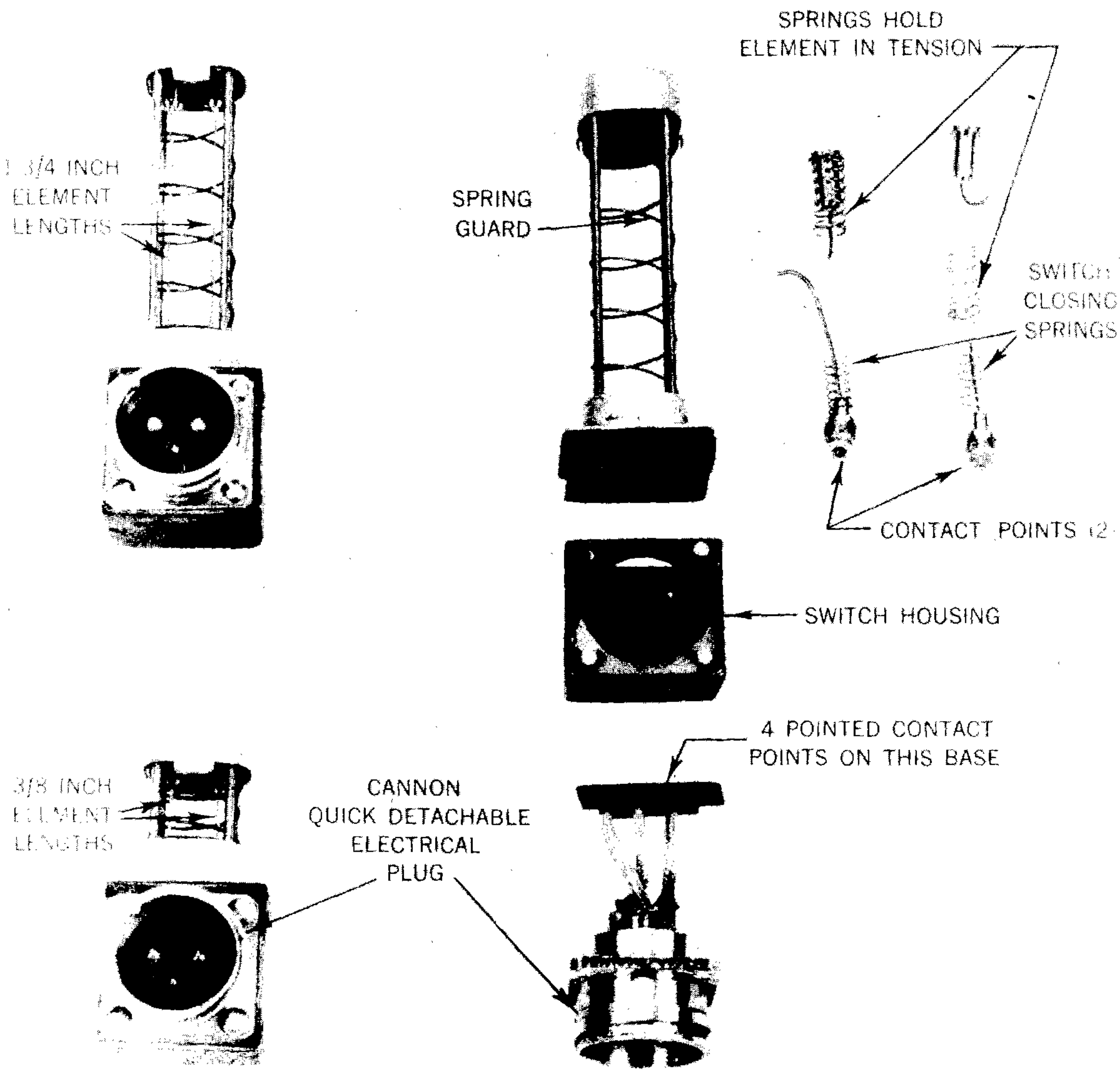

Figure 30. Flame Type Detector - Walter Kidde & Company

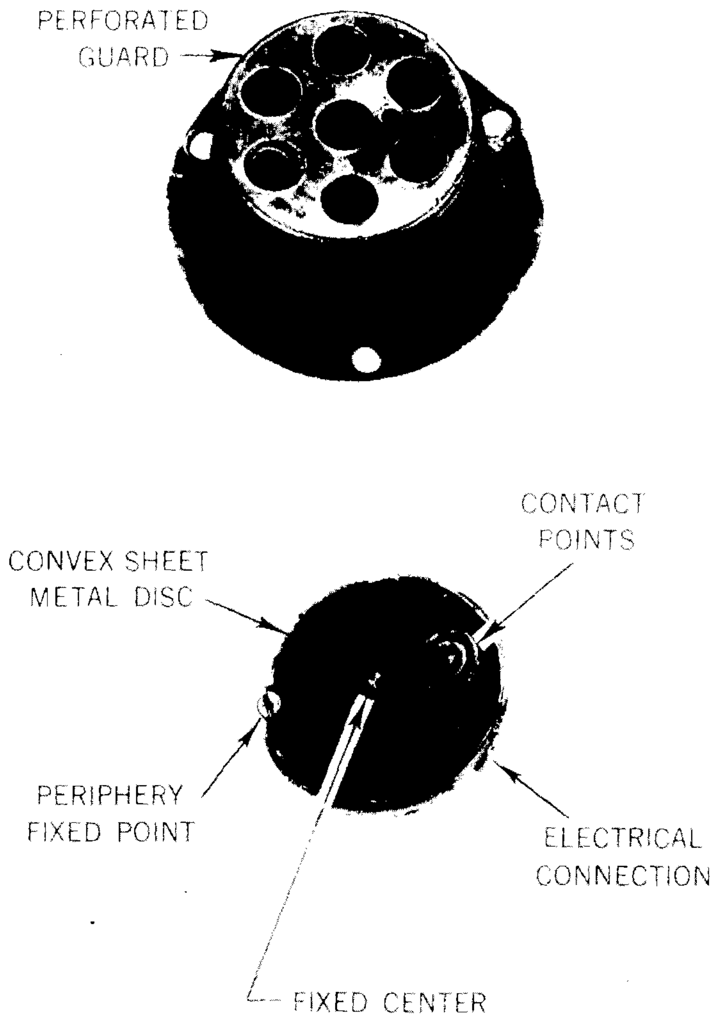

Figure 31. Metal Expansion Type Detector - American Lafrance Foamite Corporation

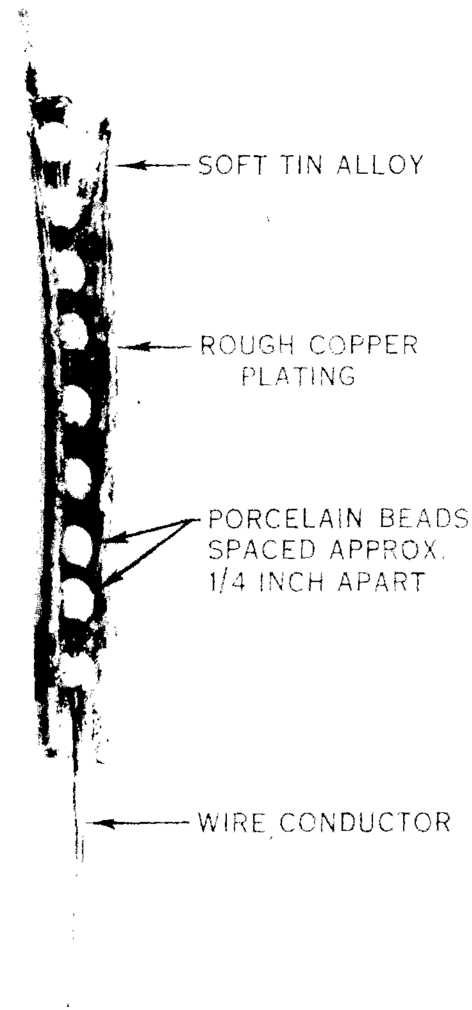

Figure 32. Fusible Alloy Type Detector - Fenwal, Incorporated

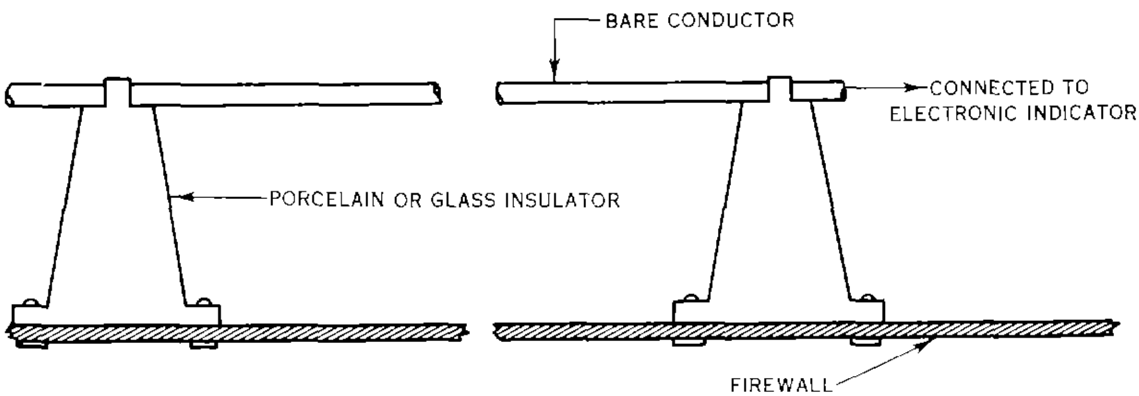

Figure 33. Ionization Type Continuous Detector - Minneapolis Honeywell Regulator Company

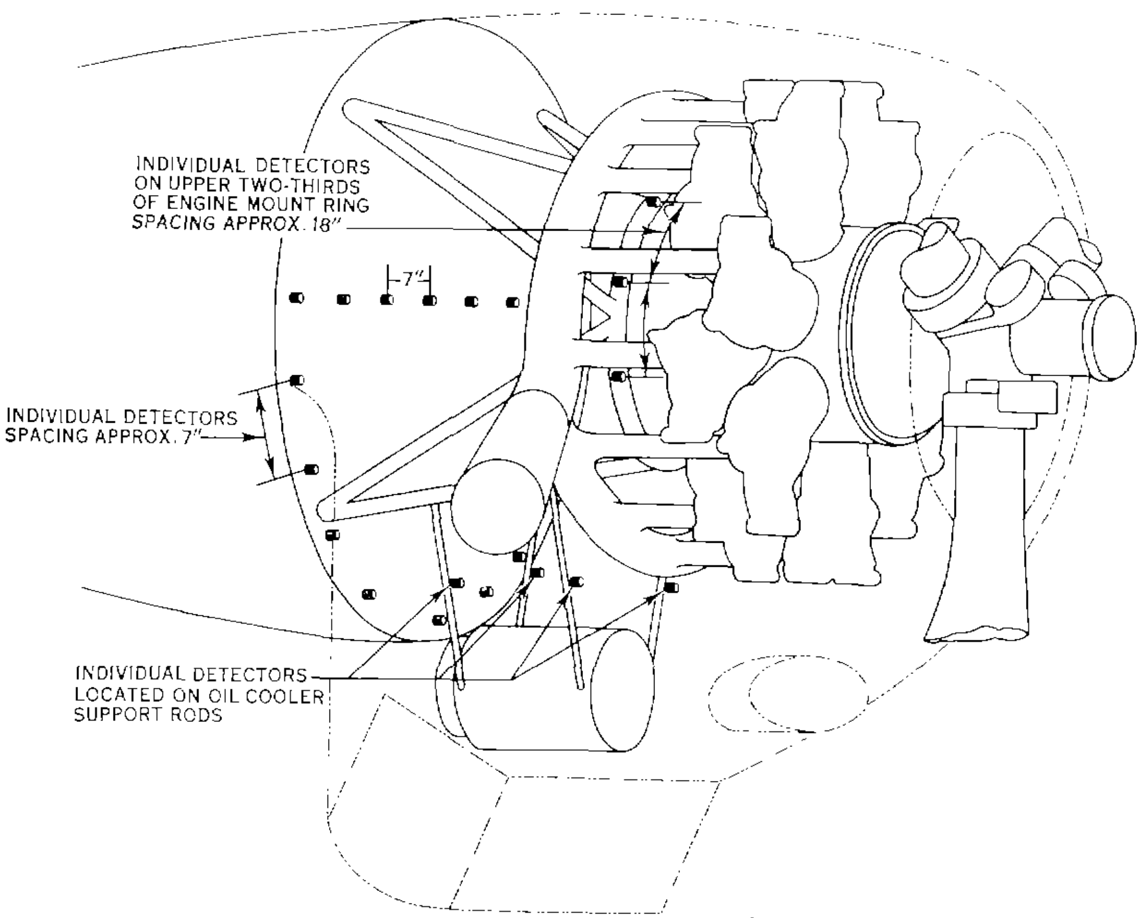

Figure 34. Optimum Locations for Unit Type Detectors

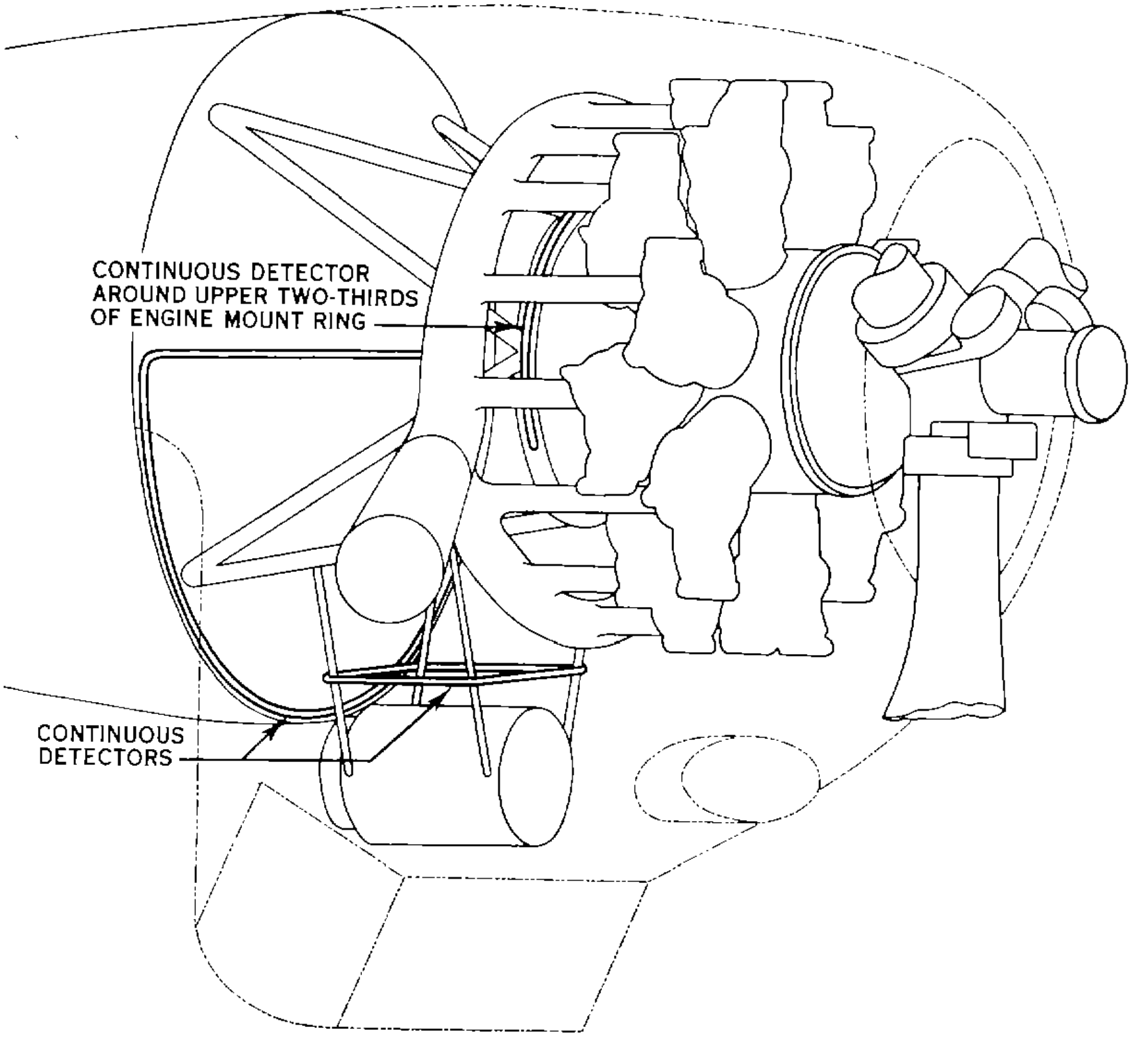

Figure 35. Optimum Locations for Continuous Type Detectors

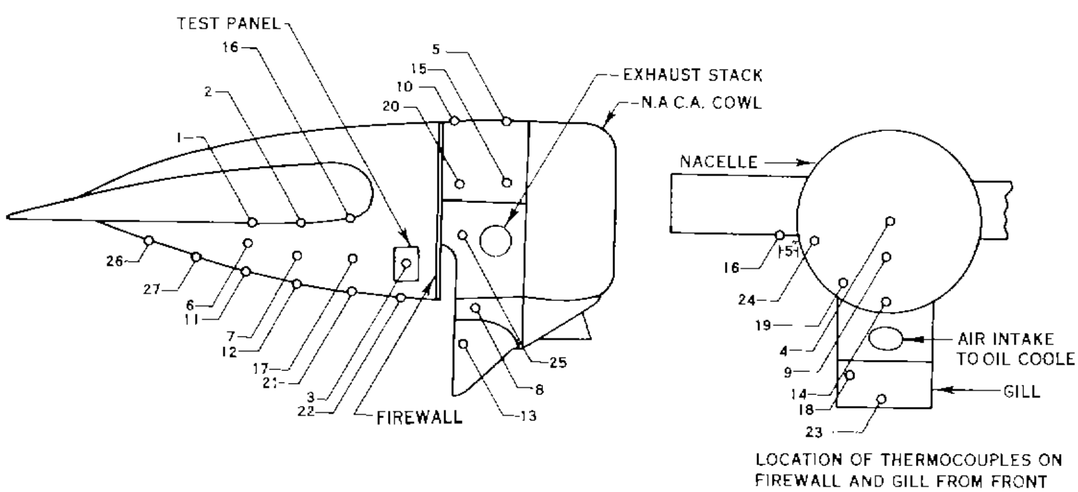

Figure 36. Locations of Thermocouples for Determination of Skin Temperatures under Various Fire Conditions

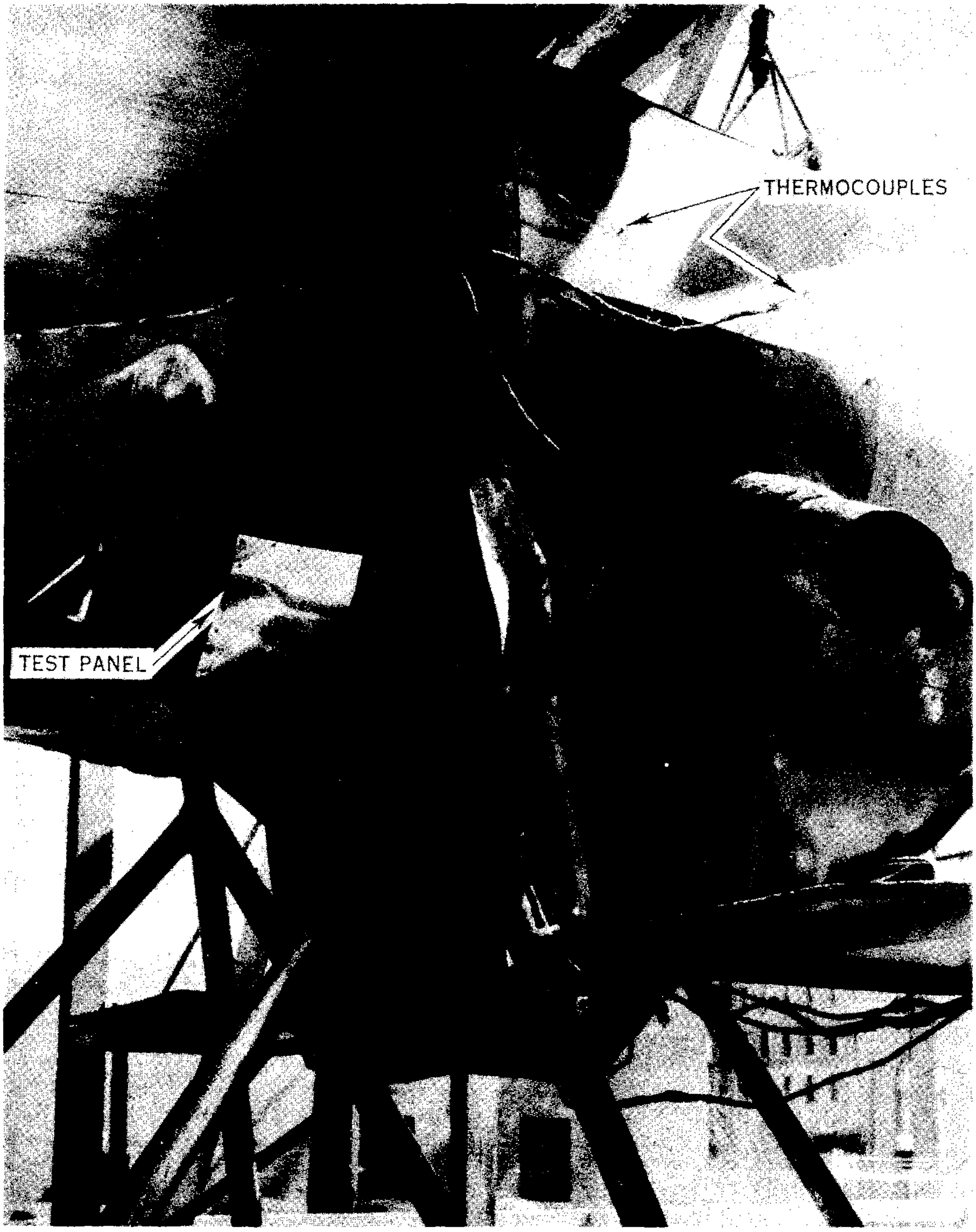

Figure 37. View of Nacelle Showing Test Panel,
Aluminum Cowl Flap and Thermocouple Installations

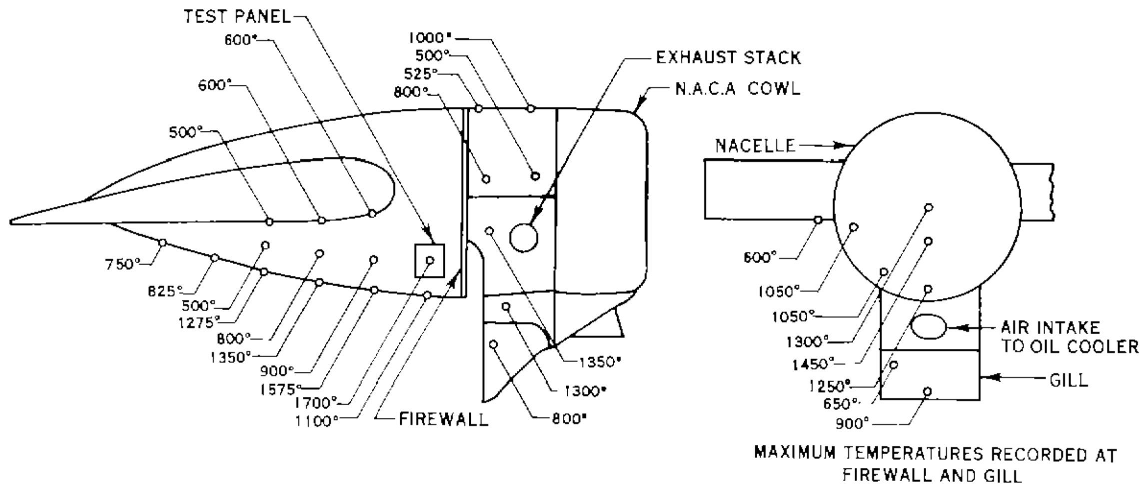

Figure 38. Highest Temperatures (°F) Recorded at Thermocouples Located as shown on Figure 36.

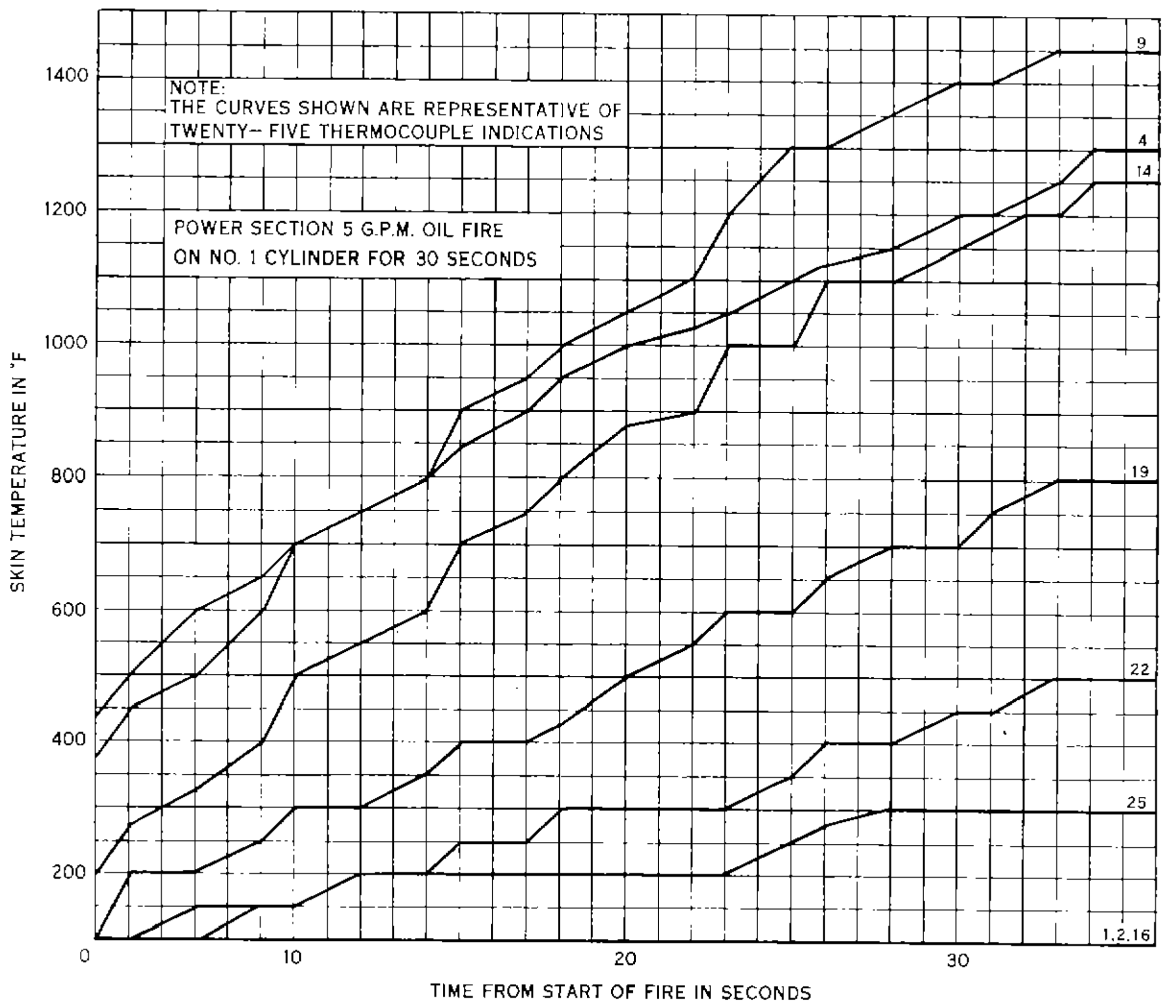

Figure 39. Skin Temperature Versus Time - Oil Fire on No. 1 Cylinder (Thermocouple Locations Shown on Figure 36)

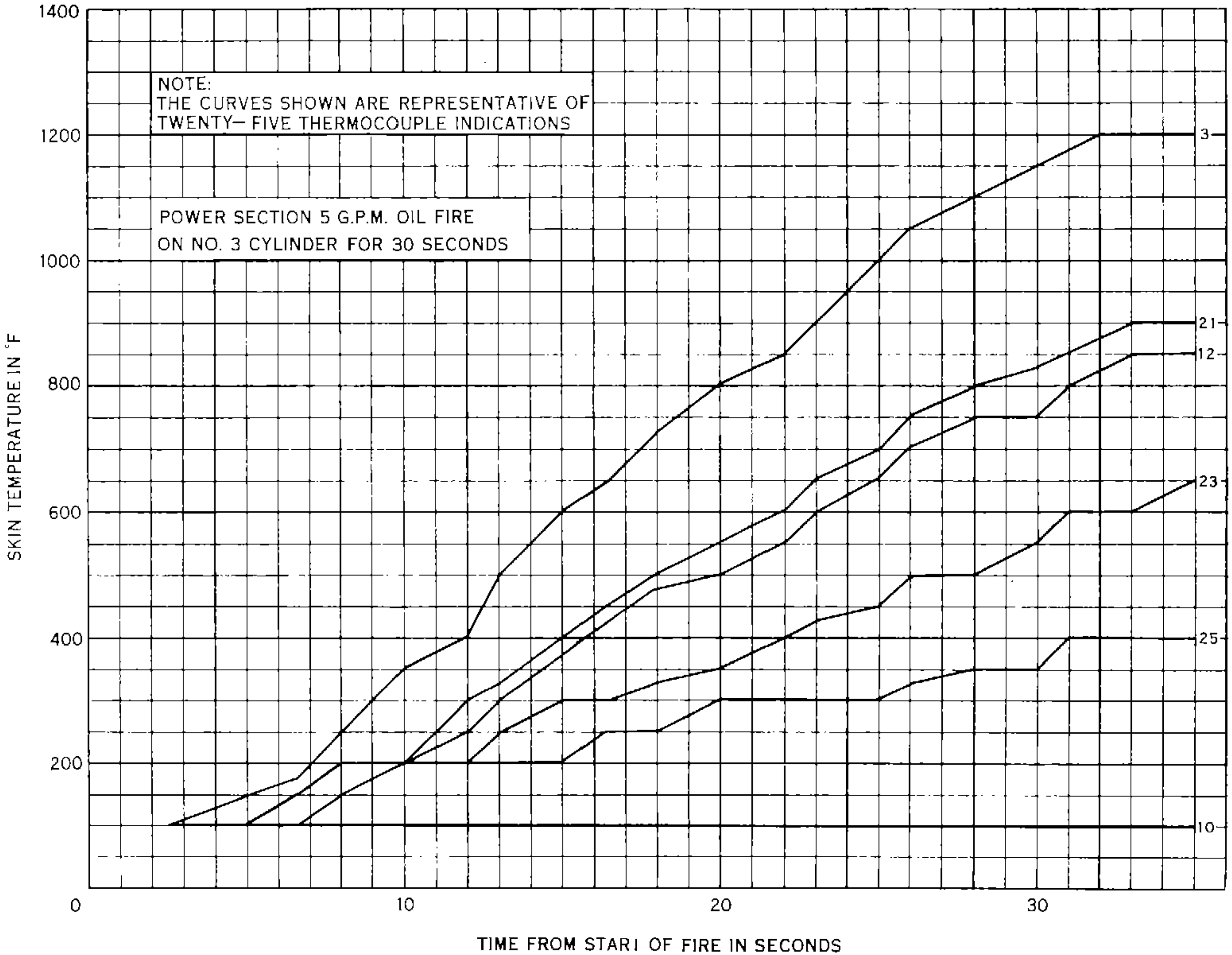

Figure 40. Skin Temperature Versus Time - Oil Fire on No. 3 Cylinder
(Thermocouple Locations Shown on Figure 36)

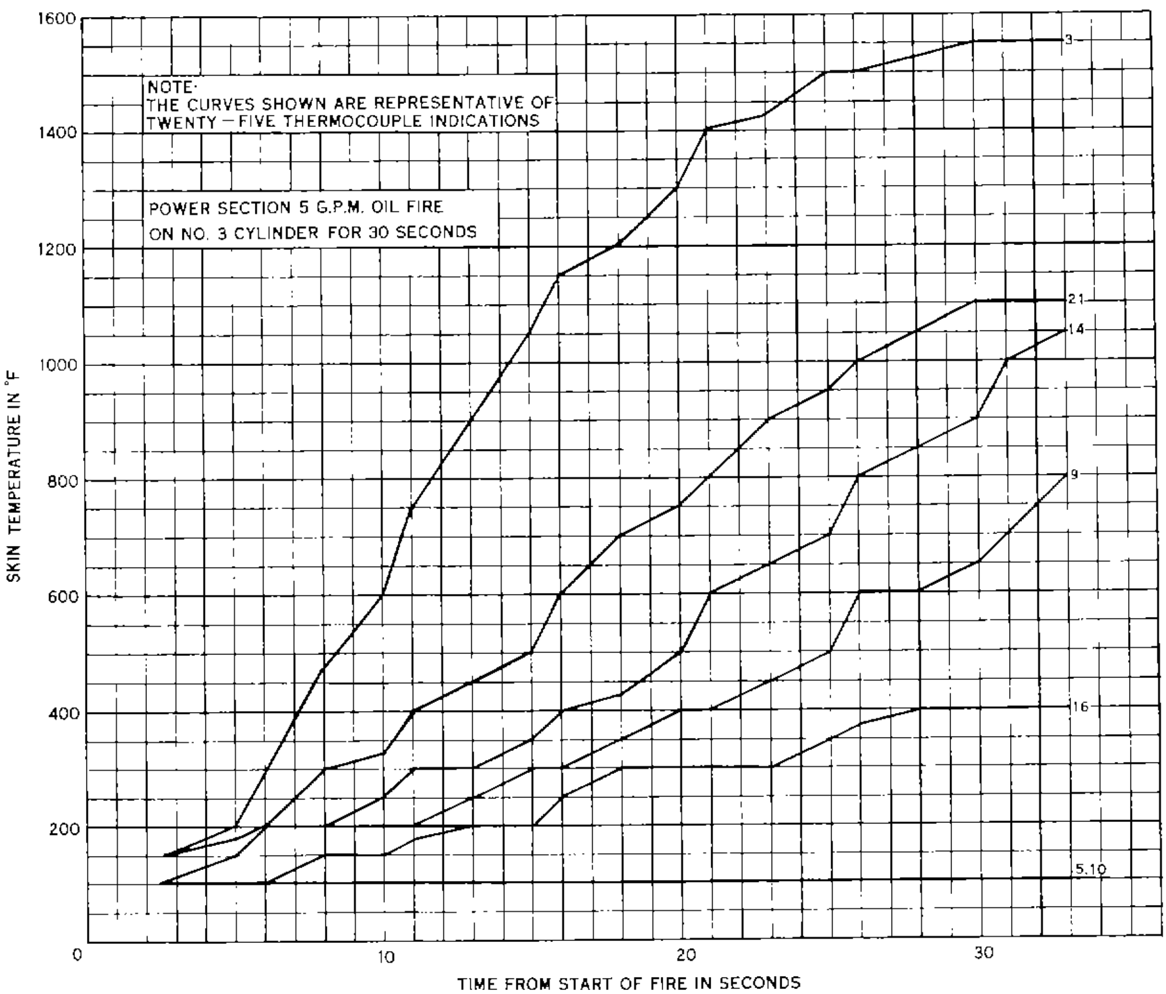

Figure 41. Skin Temperature Versus Time - Oil Fire on No. 3 Cylinder (Thermocouple Locations Shown on Figure 36)

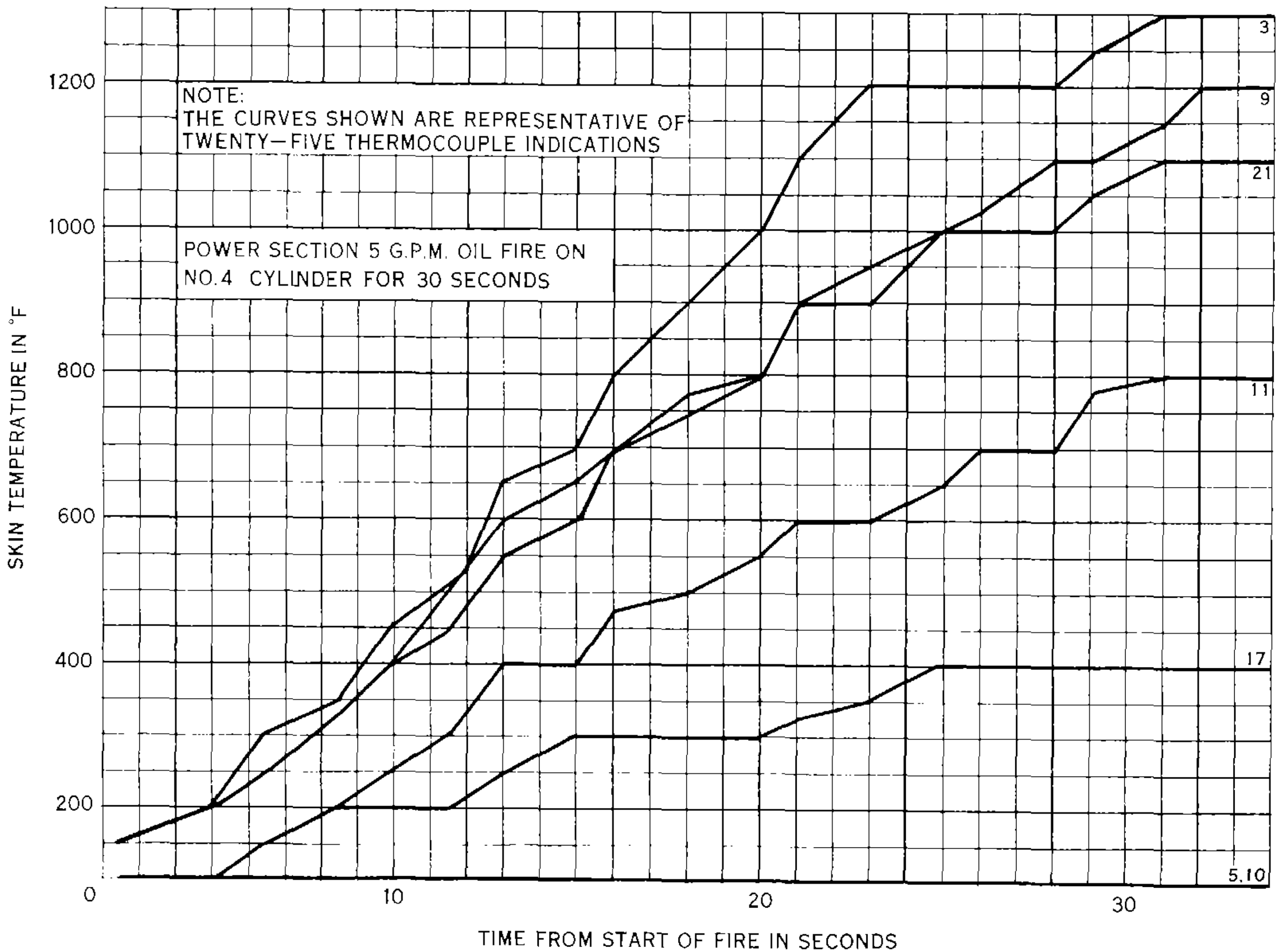

Figure 42. Skin Temperature Versus Time - Oil Fire on No. 4 Cylinder
(Thermocouple Locations Shown on Figure 36)

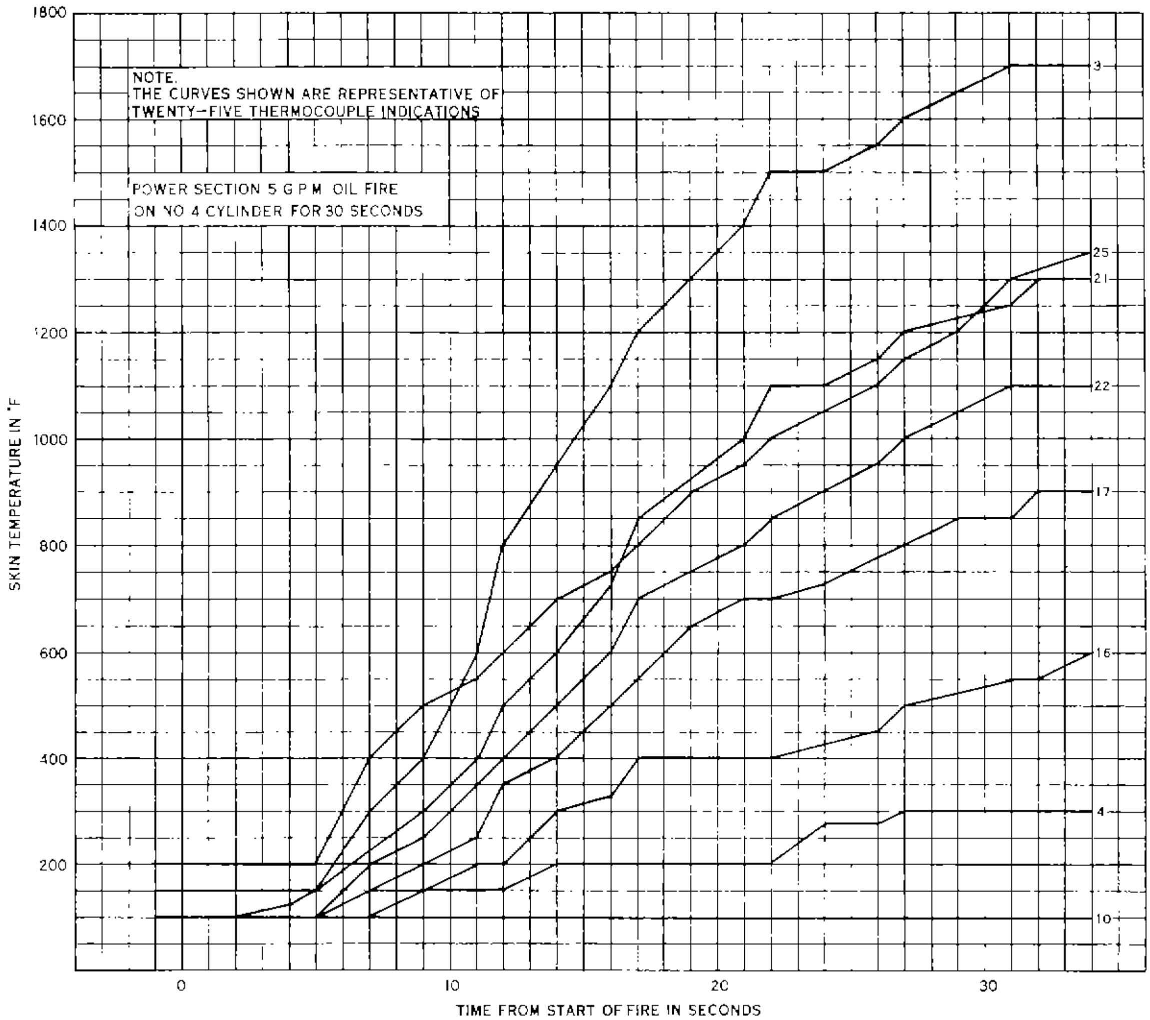

Figure 43. Skin Temperature Versus Time - Oil Fire on No. 4 Cylinder (Thermocouple Locations Shown on Figure 36)

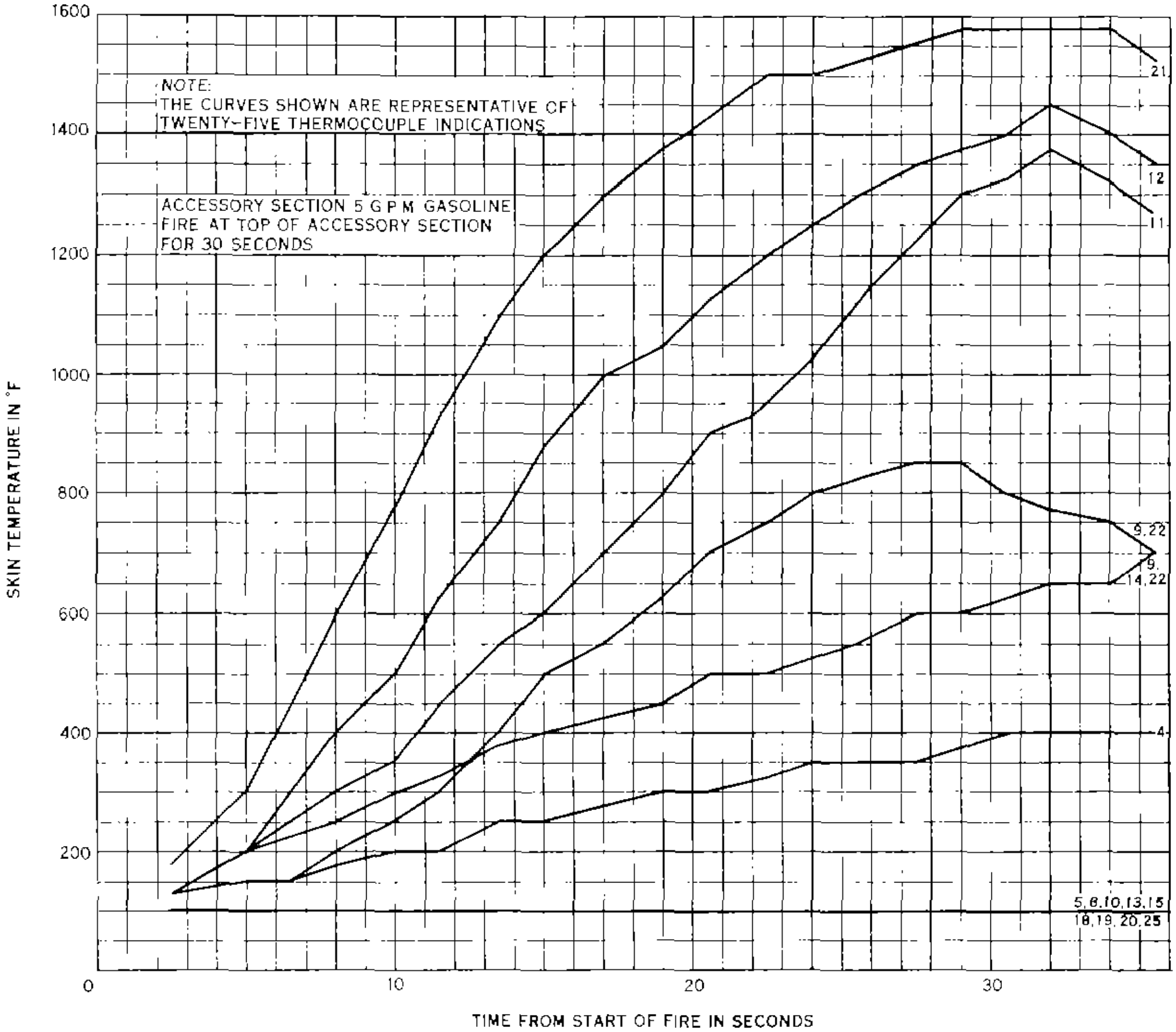

Figure 44. Skin Temperature Versus Time - Gasoline Fire at Top of Accessory Region (Thermocouple Locations Shown on Figure 36)

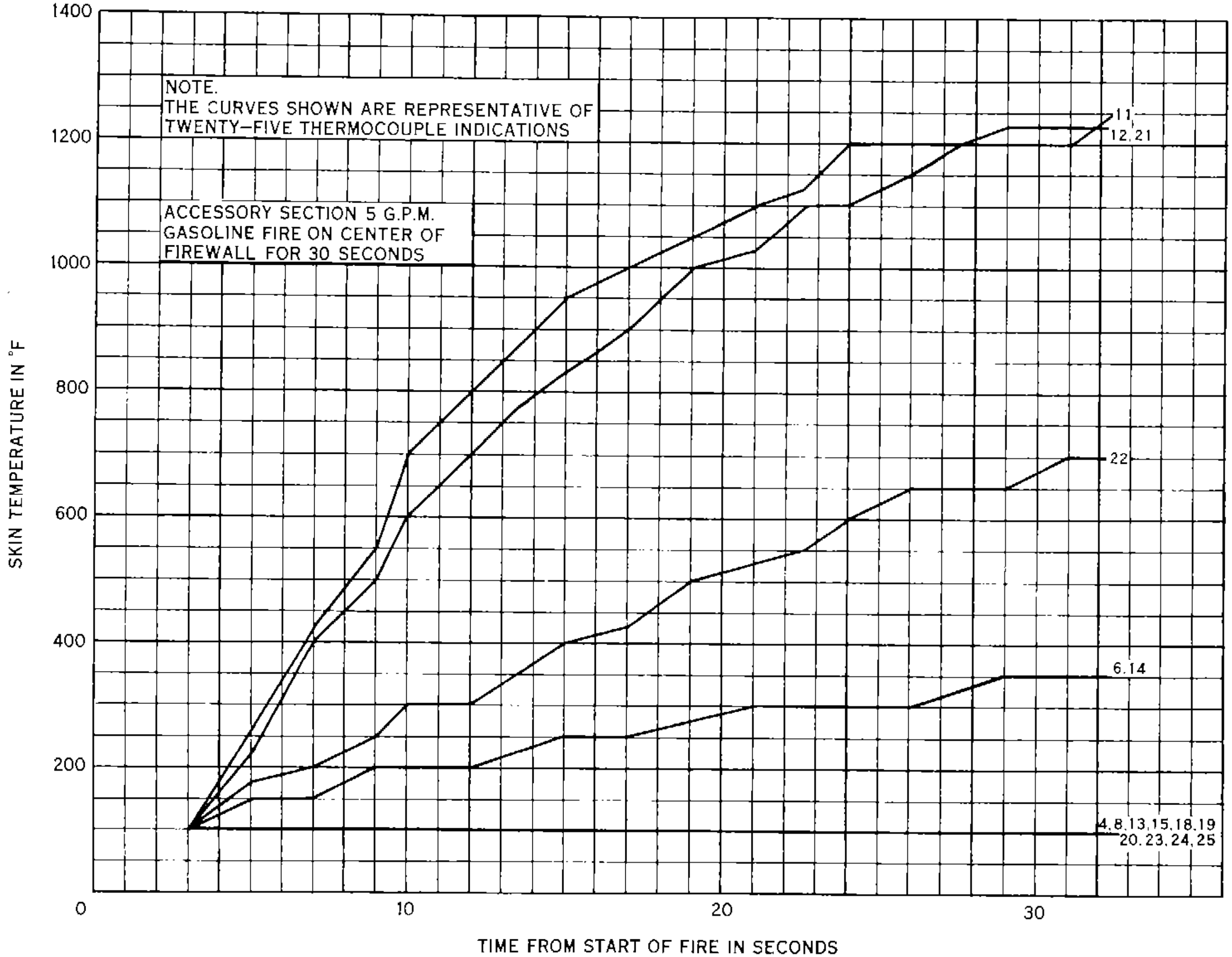

Figure 45. Skin Temperature Versus Time - Gasoline Fire on Center of Firewall
(Thermocouple Locations Shown on Figure 36)

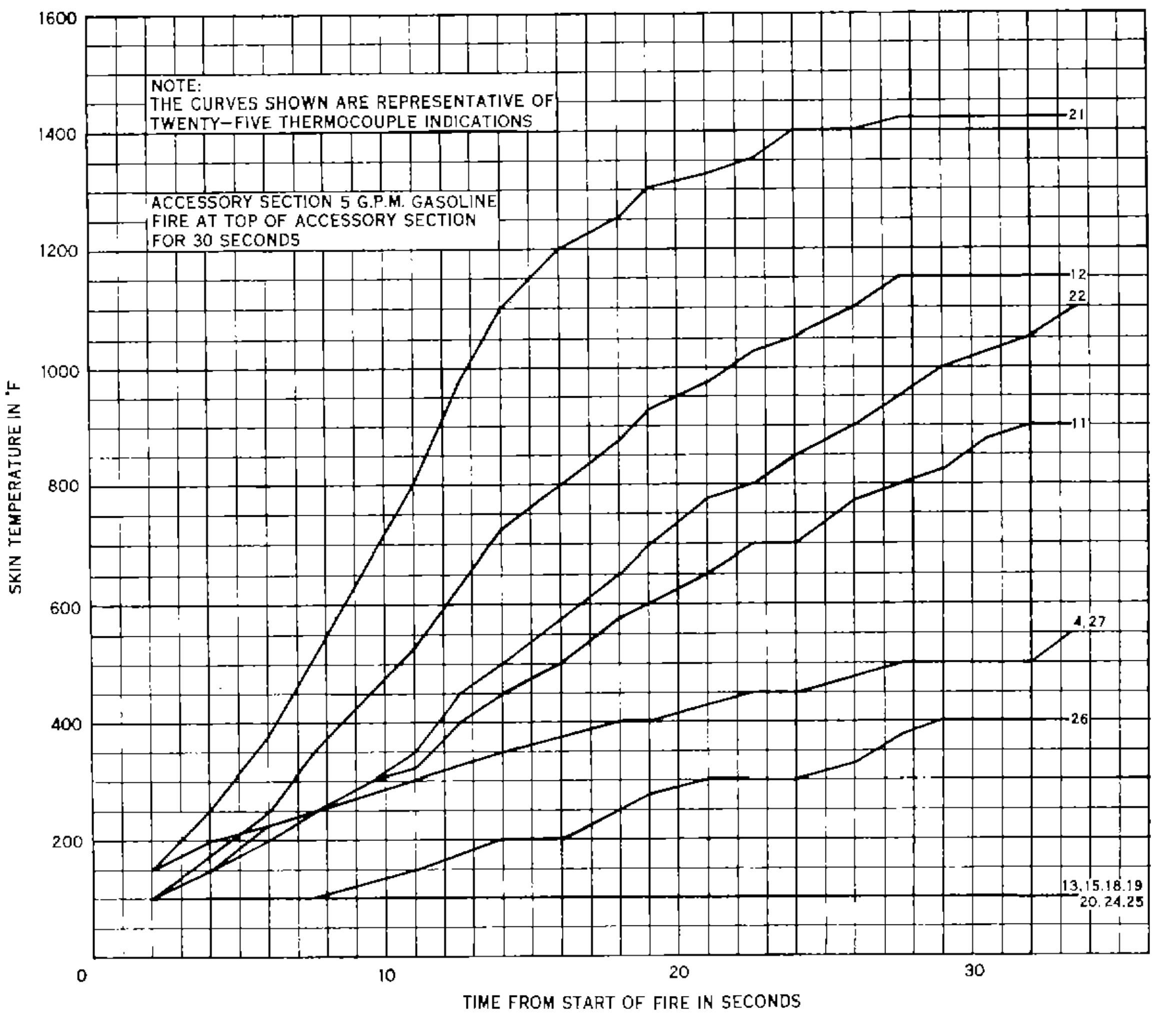

Figure 46. Skin Temperature Versus Time - Gasoline Fire at Top of Accessory Region (Thermocouple Locations Shown on Figure 36)

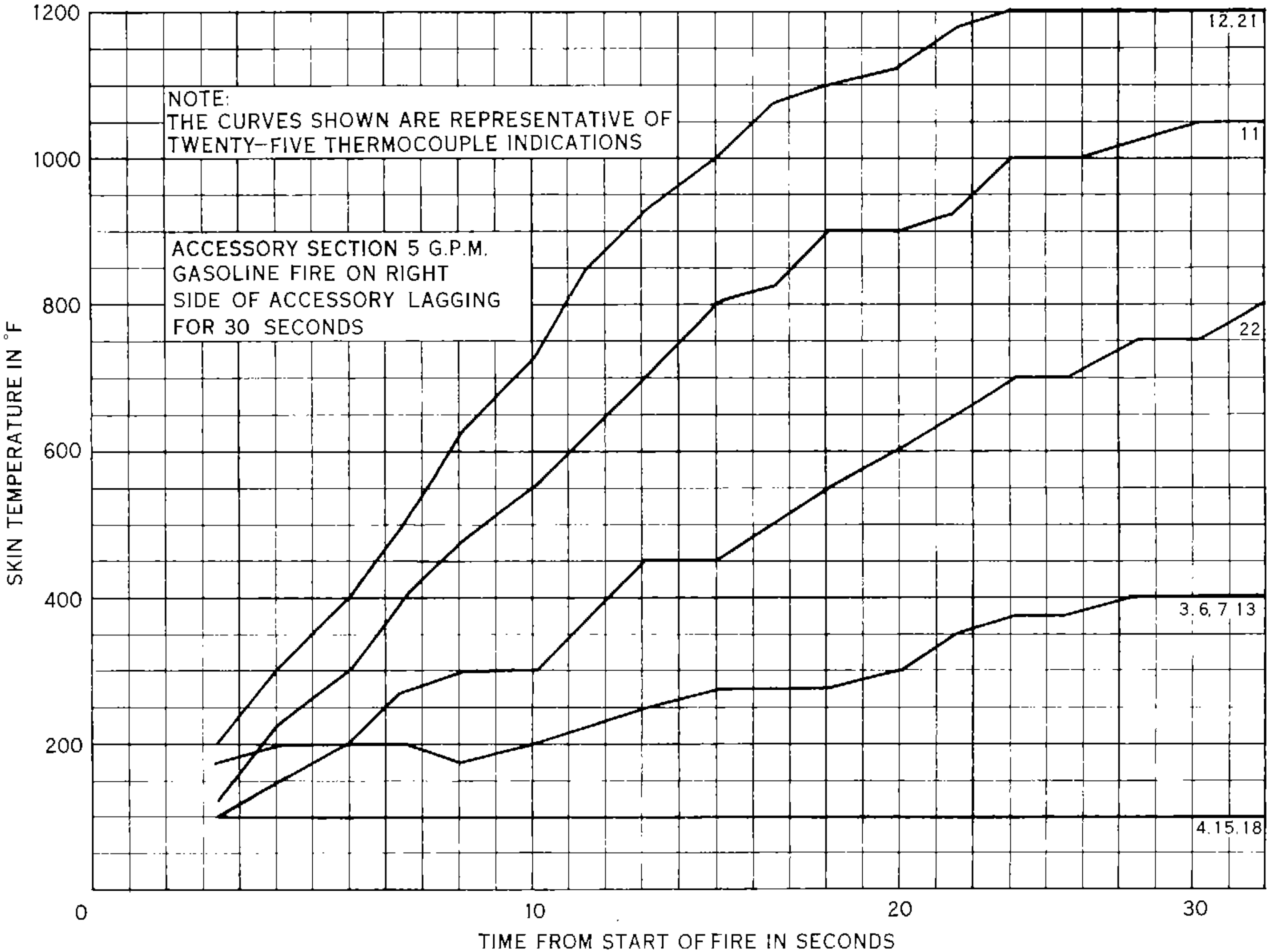

Figure 47. Skin Temperature Versus Time - Gasoline Fire on Right Side of Accessory Lagging
(Thermocouple Locations Shown on Figure 36)

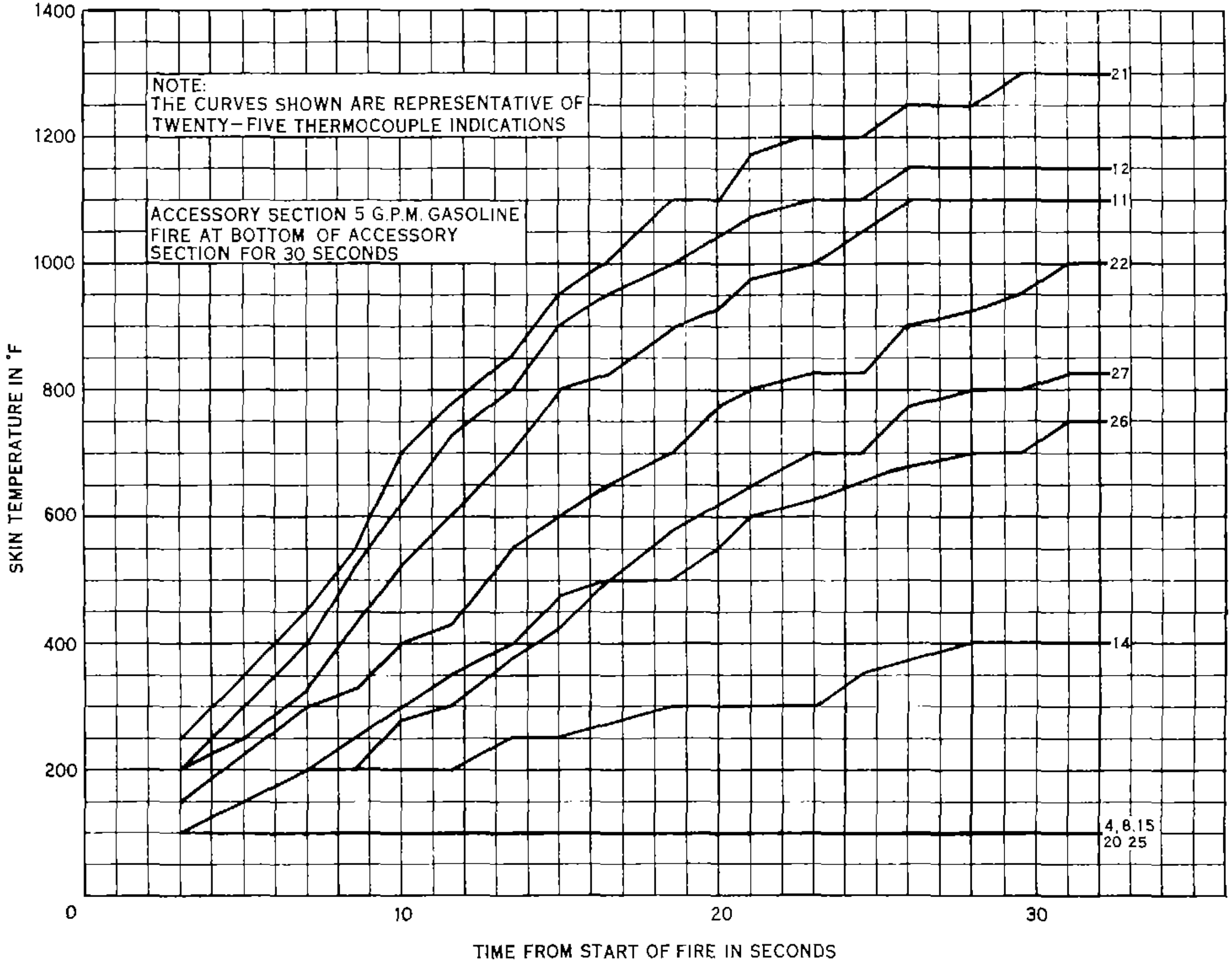

Figure 48. Skin Temperature Versus Time - Gasoline Fire at Bottom of Accessory Region
(Thermocouple Locations Shown on Figure 36)

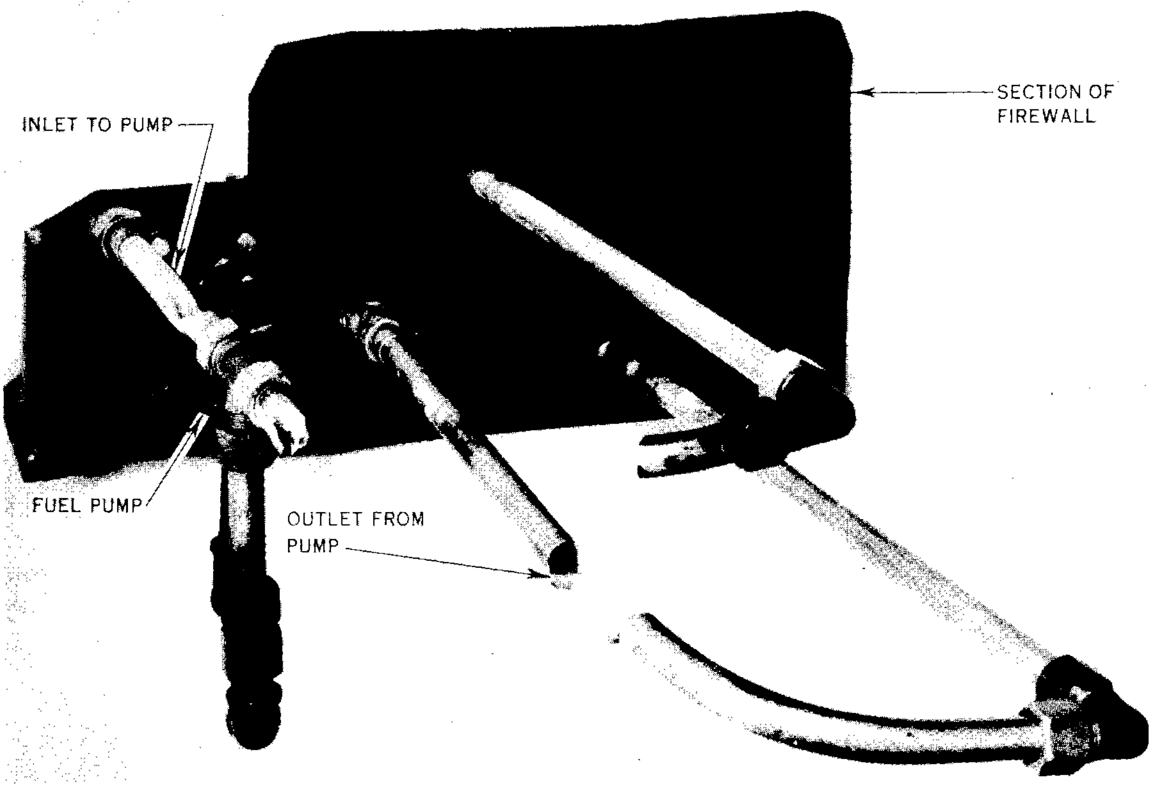

Figure 49. Auxiliary Aluminum Alloy Gasoline System After Test in 30 Second Fire

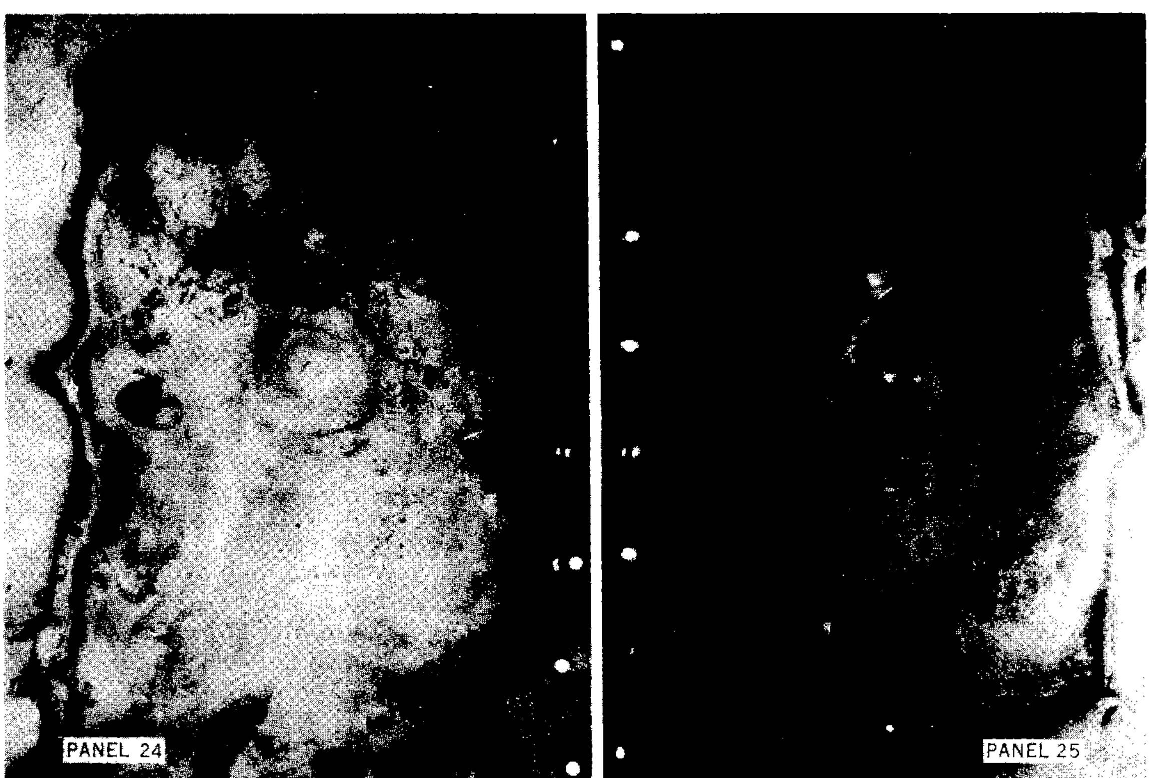

Figure 50. Test Panel of Stainless-Clad Mild Steel Substitute Firewall Material after Fire Test (Samples 24 and 25 of Table 5)