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Evaluation of the Resetting Continuous Fire-Detection System for the B-36 Aircraft Nacelle

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UNITED STATES DEPARTMENT OF COMMERCE
OFFICE OF TECHNICAL SERVICES

Evaluation of the Resetting Continuous Fire-Detection System for the B-36 Aircraft Nacelle

by
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Aircraft Division

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EVALUATION OF THE RESETTING CONTINUOUS FIRE-DETECTION SYSTEM FOR THE B-36 AIRCRAFT NACELLE*

SUMMARY

A continuous type of fire-detection system for the B-36 aircraft nacelle was designed jointly by qualified personnel of the Department of the Air Force, Civil Aeronautics Administration, and detector manufacturers. Two manufacturers, using their own equipment, then made similar installations of the system in the B-36 test nacelle at the CAA Technical Development Center. The system was evaluated by fire tests under simulated flight conditions and was found to be effective. Only minor changes were recommended as a result of the tests. Shortly thereafter, the company which submitted the lowest bid was awarded a contract to supply fire-detection equipment for installation on all operational B-36 aircraft.

At the time the award was made the forward portion of the nacelle was, for all practical purposes, a portion of the wing. Subsequent modifications to the nacelle, however, created a new zone in this region. Because the protection afforded by the original detection system was limited to the engine and lower accessory compartments, further tests were conducted to contrive an effective arrangement of the system in the new zone. The system described in this report is recommended for protection of the entire revised B-36 aircraft nacelle.

INTRODUCTION

The need for a more effective and reliable fire-detection system has been repeatedly expressed by military personnel concerned with the operation and maintenance of the B-36 airplane. The system which they desired to replace was one employing unit-type detectors. Improvement of such a system usually requires the use of additional units and additional circuits. Such additions, however, increase maintenance and operational problems.

Because fire-detector development in recent years has been directed toward the resetting continuous type, the Department of the Air Force was interested in learning whether such a detection system could replace the unit type of system successfully. A program of testing was planned to evaluate a continuous system under both normal flight and fire-in-flight conditions.

The Department of the Air Force requested TDC to conduct simulated flight-fire investigations concurrently with its tests on operational B-36 aircraft based at Ellsworth Air Force Base, Rapid City, South Dakota. A conference attended by representatives of industry, the Air Force, and TDC was held in September 1952, at Ellsworth AFB to determine the design of a system which was to be flight and fire tested. Immediately afterward, two manufacturers who were able to supply this new type of detector made installations in two operational B-36 airplanes and in the fire-test nacelle at TDC. The program carried out by TDC included a study of fire behavior in the B-36 nacelle, an evaluation of the detection systems, and development of an effective detector arrangement for the nacelle, including Zone 3 which was established after the program had started. This report is confined to that program.

PROCEDURE

The facilities available at TDC included a full-scale B-36 aircraft nacelle, equipped with a Pratt & Whitney R4360-41 engine, and a wind tunnel which provided a stream of air to simulate flight conditions. Two continuous-type fire-detection systems were installed in this nacelle by their manufacturers, Thomas A. Edison, Inc., West Orange, New Jersey, and Walter Kidde & Company, Inc., Belleville, New Jersey. Figures 1 and 2 show the major components comprising each system. Both systems were arranged in approximately the same pattern to

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*Manuscript submitted for publication October 1956.

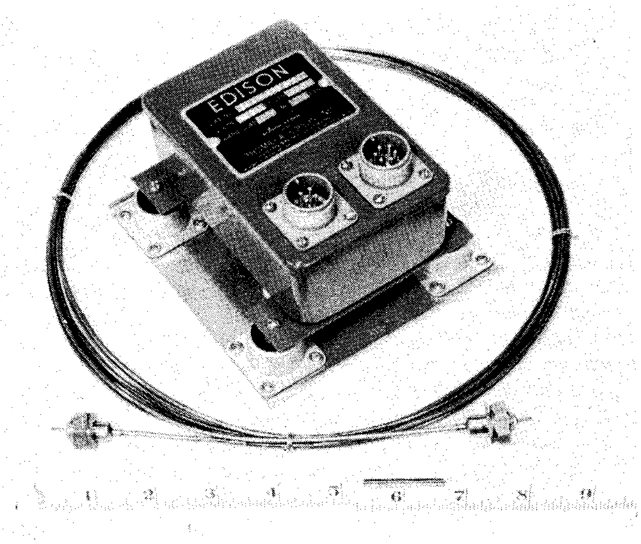

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Fig. 1 Major Components of the Edison Resetting Continuous Fire-Detection System

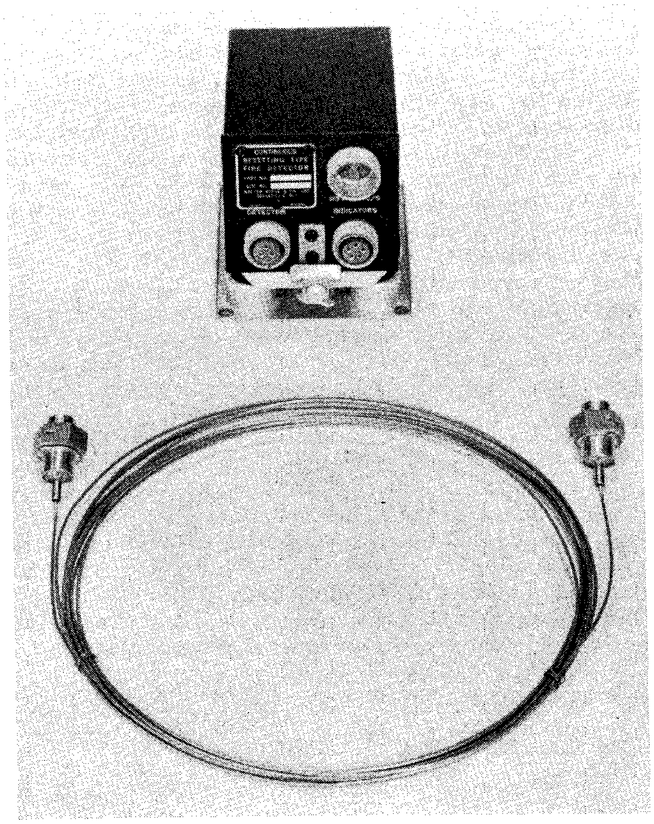

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Fig. 2 Major Components of the Kidde Resetting Continuous Fire-Detection System

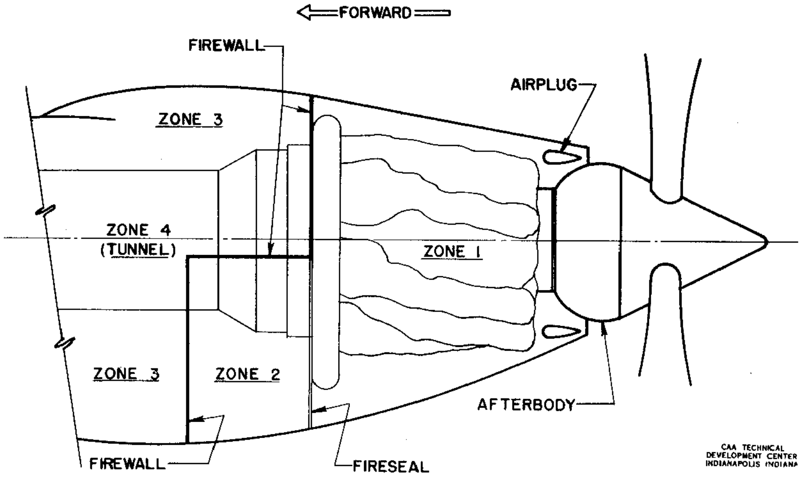

Fig. 3 Major Zones in the B-36 Nacelle

provide protection for the engine and lower accessory compartments, designated as Zones 1 and 2 in Fig. 3. The pattern in Zone 1 consisted of three connected loops. One loop was attached to the afterbody which is the stationary part of the propeller-hub housing, immediately forward of the propeller. A second loop, located between the air plug and the cowling, was attached to the rear cowl-support ring. A third loop encircling the engine was attached to the middle cowl-support ring. For the protection of Zone 2, the lower accessory section, one loop was attached to the louvered access door at the bottom of the nacelle; other loops followed nacelle formers and tubular engine-mount members. The Zone 1 and Zone 2 portions of each system were connected together and to the proper control box or amplifier. As installed, each system afforded practically no protection for the wing space and none whatsoever for Zone 4, which is the duct through which ram air reaches the engine and coolers. This was the extent of each system when the original series of tests was conducted. Subsequently, however, a new zone was created by installation of a fire curtain in the forward part of the nacelle, and protection was extended into it. In the final series of tests, the proper arrangement of loops for this new zone (Zone 3) was determined. The final arrangement developed for the whole nacelle is illustrated schematically in Fig. 4. In addition to the two complete test systems, other independent detector circuits were employed from time to time to study alternate arrangements.

Prior to the detector tests a survey was made of the airflow, pressures, and temperatures normally existing in the various zones of the nacelle during selected representative operating conditions. The airflow and pressure measurements were obtained by means of Pitot-static tubes connected to water manometers. The temperatures were measured by means of thermocouples connected to recording potentiometers.

In the original testing program, more than 800 fires were started in Zones 1 and 2 of the test nacelle. The majority of these were in Zone 1, which is a large zone with several possible ignition sources. Later, when Zone 3 was created and the original detection system was extended to protect it, more than 100 additional fire tests were conducted to assure that the extension was located effectively and to coordinate all parts of the system. The fires were produced by burning gasoline sprayed from a nozzle at a rate of approximately one-third gallon per minute (gpm) under a pump pressure of 20 pounds per square inch (psi). Gasoline was supplied to the fires until both detection systems operated, but not longer than ten seconds per test.

During the tests specific aircraft operating conditions were simulated. These included ground operation, takeoff, climb, and three conditions in the cruise range arbitrarily called minimum, medium, and maximum cruise.

RESULTS AND DISCUSSION

The preliminary study of static pressures, airflow, and normal ambient temperatures in the major zones of the nacelle was of considerable assistance in determining what measures

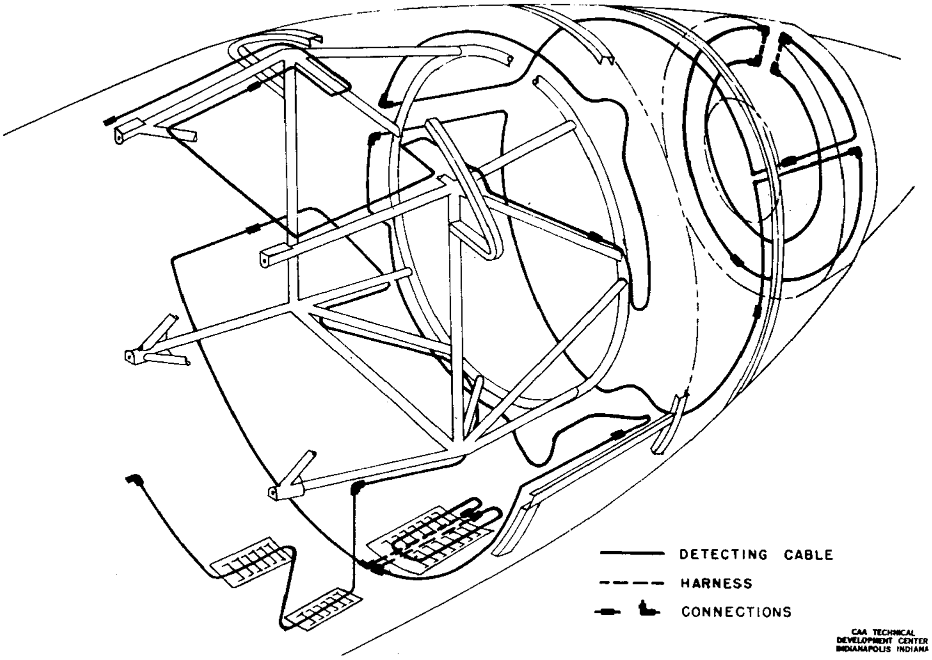

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Fig. 4 Final Arrangement of Continuous Fire-Detection System in the B-36 Nacelle

could be employed to make the nacelle safer. For instance, the static pressure results confirmed the belief that fires originating in Zone 1 have a tendency to move forward through the nacelle; this knowledge influenced the decision to create Zone 3.

The magnitude of the pressure differentials between Zone 1 and the further forward zones was significant and was influenced by the position of the air plug. This fact is most clearly demonstrated by data compiled during a test in which flight conditions were simulated with the engine operating at maximum cruise power. See Table I.

TABLE I

STATIC PRESSURES IN NACELLE ZONES FOR DIFFERENT AIR PLUG POSITIONS

Air Plug Position	Static Pressures (inches of water)		
	Zone 1	Zone 2	Wing Space
Open	4.60	1.30	0.25
One-half open	9.00	2.15	0.20
Closed	19.00	3.25	0.20

It will be noted that the pressure differential between any two zones increased as the air plug closed. The space within the wing experienced practically no pressure change. Under these conditions, a strong tendency existed for fire to move forward from Zone 1 into Zone 2 or the wing, or even from Zone 2 into the wing, if the seal between zones was imperfect or became imperfect due to heat buckling. Static pressure measurements made after the creation of Zone 3 showed the differential pressures between zones to be substantially unchanged. The pressure in Zone 3 was slightly higher than the pressure in the wing space but lower than in Zone 2.

The wing interior is a critical region because of the electrical harness concentrated there. In the event that fire should enter this region at an inboard nacelle and destroy the harness, a complete power loss could occur in that wing. The creation of Zone 3, with adequate protection therein, was a major contribution to the safety of the whole aircraft.

In addition to the measurements of static pressure in Zone 1, measurements were made of the airflow at the rear end of the zone. With the air plug open, the highest airspeed was observed in the annular opening between the air plug and the cowl. It was much higher than between the air plug and the afterbody. Also, the air passing between the air plug and the cowl tended to continue straight out, whereas the air between the air plug and the afterbody tended to follow the contour of the afterbody in a layer approximately 1 1/2 inches thick. Later, during fire tests, flames were observed to follow both of these paths as they left the zone. Closure of the air plug decreased the space through which the air could exit. In the completely closed position, no space remained between the air plug and the cowl through which air could pass, and a space only three-fourths-inch wide remained between the air plug and the afterbody.

The temperature survey revealed no extreme temperatures in any of the three zones during normal engine operation on a 65° F. day. The maximum air temperature recorded in the entire nacelle was 400° F. This was recorded at the base of the right-hand turbosupercharger during single turbosupercharger operation. The air temperature at all other points was 250° F. or less. During engine operation at a cylinder-head temperature of 375° F., with the air plug closed, the temperature of the ambient air in the space between the engine and the skin in Zone 1 reached 250° F., while the temperature of the cooling air leaving the cylinder baffles reached 190° F. An air temperature of 400° F. was recorded at the downstream side of the flange where the exhaust is connected to Row D cylinder. The average ambient air temperature in Zones 2 and 3 was 150° F., and in Zone 4 the temperature ranged from 75° F. to 175° F. The temperature measured at several points around the circumference of the afterbody near the continuous detector did not exceed 250° F. The temperature of the air leaving the exhaust-shroud exit ducts on the afterbody was 325° F.

As soon as the pressure and temperature surveys were completed, the detector fire-testing program was begun. Initially the fires were intended to resemble those which might originate near the exhaust-stack flanges at the cylinder heads. With the engine idling and the engine cooling fan turning at slow speed, the fires usually were detected within 3 seconds. Detection occurred in less time when the fan was turning at high speed. At simulated cruise-power settings and a simulated flight speed of 120 mph produced by the wind tunnel, there was a tendency for fires to reduce in size and occasionally to blow out. As a result, detection usually occurred 5 to 8 seconds after the start of the fires. The detector loops mounted on the afterbody and on the rear cowl-support ring were best situated to intercept these fires.

Test fires originating on the crankcase were even more difficult to keep burning, and detection time increased. In general, the response time of the detection system increased as the engine power increased from idle to cruising and as the fan speed increased from low to high. Undoubtedly this can be attributed to the lower intensity of the fire in the faster moving air. Figure 5 shows such a fire. Detection was accomplished by the loop attached to the afterbody.

Fires which originated near the exhaust-collector ring were relatively large when the engine was idling, and they were somewhat reduced in size under cruising conditions. The detection record was poor. The fires should have been detected by the loop attached to the middle cowl-support ring; however, this loop as installed by the manufacturers was buried in the channel of the ring to protect it from mechanical damage, with the result that it also was protected from the fires. The two loops farther aft, therefore, were mainly responsible for any detection which occurred.

Under normal conditions there was relatively little air movement within Zone 2 and, as a consequence, fires in this zone tended to billow. In particular locations, fires which were large enough emerged to the outside through openings around the exhaust ducts and through the louver openings in the bottom access door. In making the installations of elements in Zone 2, the two manufacturers used different routings. No particular importance was attached to this fact prior to the tests because the coverage appeared to be adequate in both cases. When a variation in performance was noted between the two installations, however, the layouts of the systems were studied in detail. The principal deficiency in the slower acting system was judged to be lack of sufficient element near the firewall at the front of the zone. In those instances where fires escaped through the louvers, the flames appeared to be concentrated in the center of the openings. The original loops of element attached to the access door passed over the outer edges of the openings rather than over the center.

From observation of the fires during this phase of the program, the original system seemed to be fairly effective. Only a few areas seemed to require more detailed study;

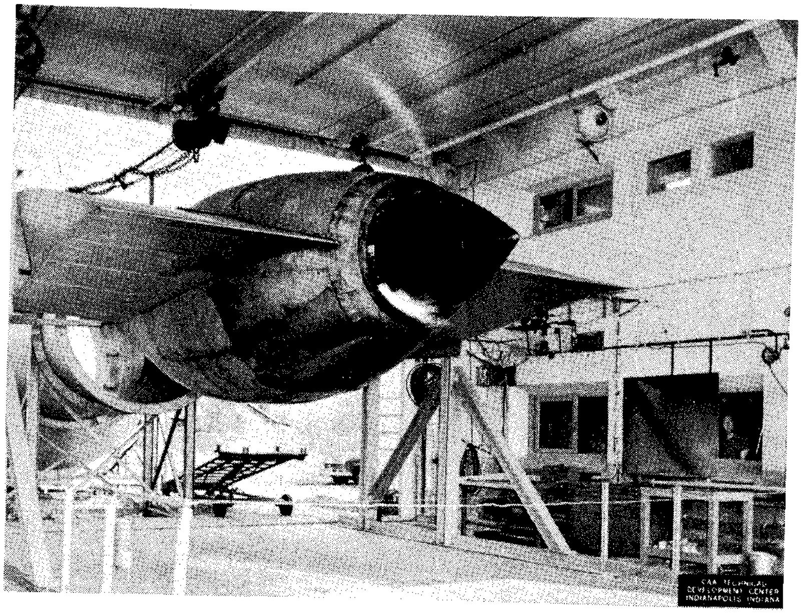

Fig. 5 Typical Zone 1 Detection Test Fire

however, each loop received some attention. After a few experimental changes in location, the loop on the afterbody was found to be located most effectively in its original position. Because it already was mounted on one-inch standoff brackets, there was no need for any change. It was particularly well situated for detection of crankcase fires. The loop between the air plug and the cowl was limited in effectiveness when retained in its original position, which was influenced partially by the comparatively large connectors used to join elements together. When size of the connectors was reduced, it became possible to move the loop aft and separate it by two inches from the cowl on which it was mounted, thus bringing it more fully into the airstream. The bulk of the flames produced by fires on the outer periphery of the engine followed this stream.

Because of the length of Zone 1 and the comparatively still air surrounding the engine, fires originating in the forward part of the zone could not be detected satisfactorily by the loops on the afterbody and near the air plug; therefore, retention of the loop at the middle cowl-support ring was found necessary. It was desirable, however, to move it radially inward away from the ring for three reasons: (1) to separate it from electrical cables also attached to the ring; (2) to bring it closer to the center of the large space between the engine and cowling, especially at the sides and bottom of the zone; and (3) to route it over the hot deicing duct in the bottom of the zone. The loop was fixed in this improved position by supporting it on two-inch standoff brackets which were attached to the cowl ring.

Although there is a natural reluctance to locate loops in exposed positions because of their vulnerability to mechanical damage, it is essential that any heat-actuated detector be placed in the flame paths. Mounting detectors directly on or behind structural members or power plant components can make them completely ineffective as fire detectors.

Bearing in mind the hazards associated with mounting element in such an exposed position, and the fact that some of the early fires originating in Zone 1 progressed forward into the wing area, an investigation was conducted to determine whether this loop could be eliminated if a new loop was added to the system near the firewall. It was believed that such a loop mounted concentric with the exhaust-collector ring might be as effective as the middle loop for average fires and more effective for detecting fires threatening to progress into the wing. Unfortunately, the new loop did not prove to be capable of replacing the original loop; moreover, no practical method was found to mount it on the firewall where it would not interfere with an engine change.

A series of tests was conducted to determine whether the double loop of element attached to the access door on the bottom of Zone 2 could be eliminated, or at least simplified. This loop was disconnected from the remainder of the Zone 2 system and was monitored separately. It was found that certain fires did not cause this element to alarm but that certain other fires were detected by this element only. It was apparent that this loop could not be eliminated, but it was more elaborate than necessary. Instead of the double loop, one loop was routed directly over the center of each row of louvers, because it was unnecessary to have a separation in order to intercept fires emerging from the zone. Other elements attached to the engine mounts and structural formers in Zone 2, however, were separated by one inch from those surfaces.

There was no Zone 3 at the time the original tests were conducted; therefore, no attempt was made to find an effective routing forward of the firewall.

The Kidde and Edison systems operated with equal efficiency. Both experienced the same types of troubles at different times. Both required replacement of elements which developed short circuits, broke at connectors, or were damaged as a result of careless handling. Considering the large number of fires to which the systems were subjected and the amount of handling they received, the number of failures was not exceptional. The manufacturers were kept informed of the performance of their respective systems, and they continually improved their products during the course of the program.

The elements mounted on the afterbody were affected adversely by the vibration to which they were subjected. To minimize the number of failures resulting from this cause, the manufacturers reduced the sizes of the connectors, thus decreasing the differences in mass between the connectors and the elements. Firm support for the connectors was provided. As for the rest of the element, the spacing of supports was determined by circumstances. Tests conducted on a vibrating table gave no indication that a spacing of 8 inches was excessive for frequencies up to 50 cycles per second (cps).

Upon completion of the tests with the two original systems, all element was removed from the nacelle and a completely new installation was made. The Kidde system, which had undergone important developmental changes in the meantime, was used for this purpose. It was arranged in the nacelle to reflect all of the changes found desirable; consequently, it served as a guide in writing specifications for the installation of production kits. Spot checks showed that the system operated satisfactorily in the two zones where it was installed. Subsequently, the contract to supply production kits for all operational B-36 aircraft was awarded through competitive bidding to Thomas A. Edison, Inc. Zone 3 was not yet a reality but had been proposed; therefore, in supplying the kits, the manufacturer added a small amount of element to be used for the protection of that zone.

The recommendations for installing the element in Zone 3 were, to mount one semicircular loop on the forward side of the firewall (attached directly to radial members supporting the firewall) and a second loop on the diagonal engine-mount tubes so that two sides of the loop extended forward and upward from the firewall to the cowl former, then across the top of the zone under the former. In the final series of tests, this arrangement was evaluated and found ineffective, and a new arrangement was developed. It consisted of three loops; one was mounted on the firewall, a second at the top, and a third in the bottom of the zone. The loop on the firewall was retained without change. The upper loop extended along the diagonal engine tubular mounts in a manner similar to that described previously except that at the cowl former it extended only part way, returned, and continued along longitudinal engine mounts to the forward fire curtain, then across the upper forward part of the zone. The lower loop passed over the center of each of the two louvered areas in the bottom of the zone. The arrangement of loops in the other zones was in accordance with the previously developed pattern.

A final test program, consisting of a number of simulated flight fires with a variety of possible points of origin, indicated that the arrangement of the system in all zones was satisfactory. No false alarms or other serious troubles were experienced during this test program.

The final and recommended layout for a continuous fire-detection system for the B-36 airplane is shown in Fig. 4. It will be noted that element is used in many places where an electrical wire harness would suffice; and that the use of harness is limited to those areas where there is likely to be considerable relative movement between loops, as at the bottom access door and and at the afterbody. Such a layout is an improvement over the basic system which was developed, because the additional element extends the coverage and the use of fewer connectors results in a simpler arrangement.

A better comprehension of the system as it was installed in the test nacelle can be obtained from photographs. Because the system is rather complicated, each photograph portrays only small portions of it. Figure 6 is a general view showing portions in Zones 1 and 2; Figs. 7 and 8 are concerned with the afterbody loop; Figs. 9 and 10, with the loop between the air plug and the cowl; and Fig. 11, with the loop on the middle cowl-support ring. The five-foot length used on the louvered access door in Zone 2 is shown in Fig. 12. Other five-foot lengths, symmetrically mounted on opposite sides of the zone, started at the hinge line of the access door, followed the contour of the nacelle former outward to longerons, then followed the

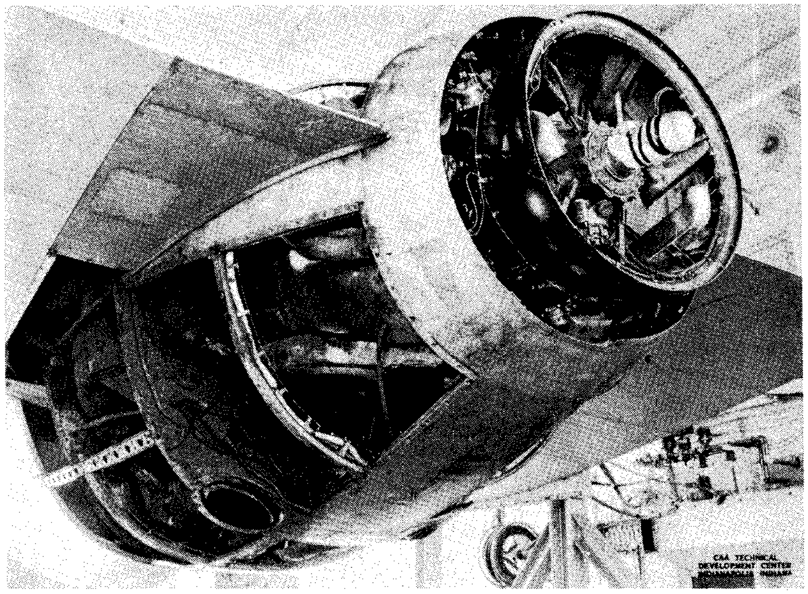

Fig. 6 General View of Test Nacelle with the Continuous Detection System Installed

longerons aft. One of these lengths is shown in Fig. 13. Another length of element in the zone followed tubular engine mounts, and a third followed the lower half of the engine-mount ring close to the fire seal. Portions of these loops are shown in Fig. 14. The loops in the upper part of Zone 3 and on the firewall are partly visible in Fig. 15. The loop in the bottom of Zone 3 could not be photographed effectively.

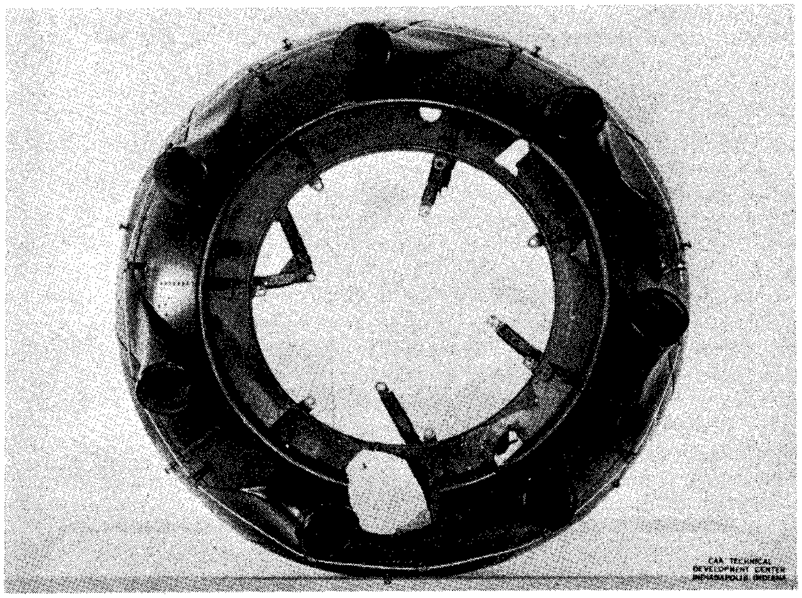

Fig. 7 Over-all View of Loop on Afterbody

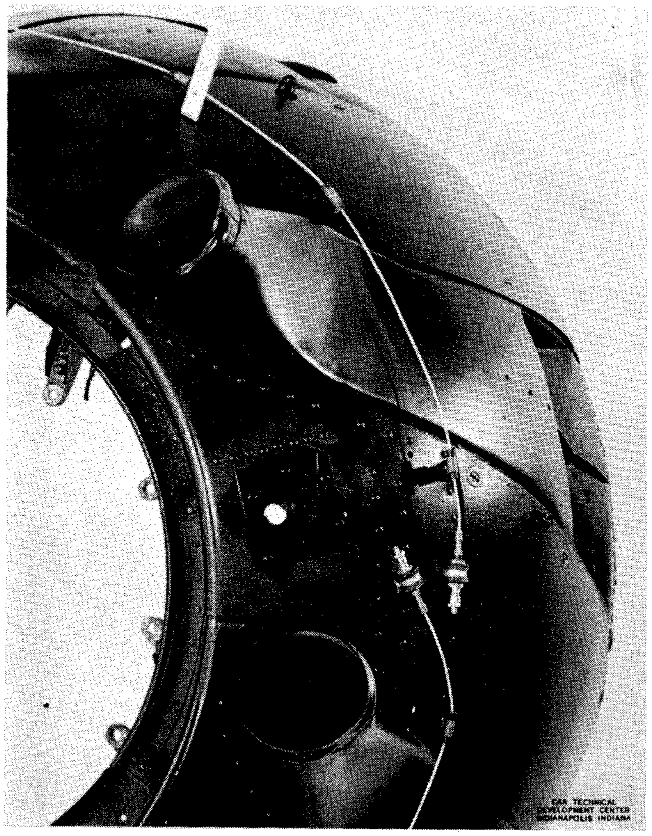

Fig. 8 Mounting Details for **Afterbody** Loop

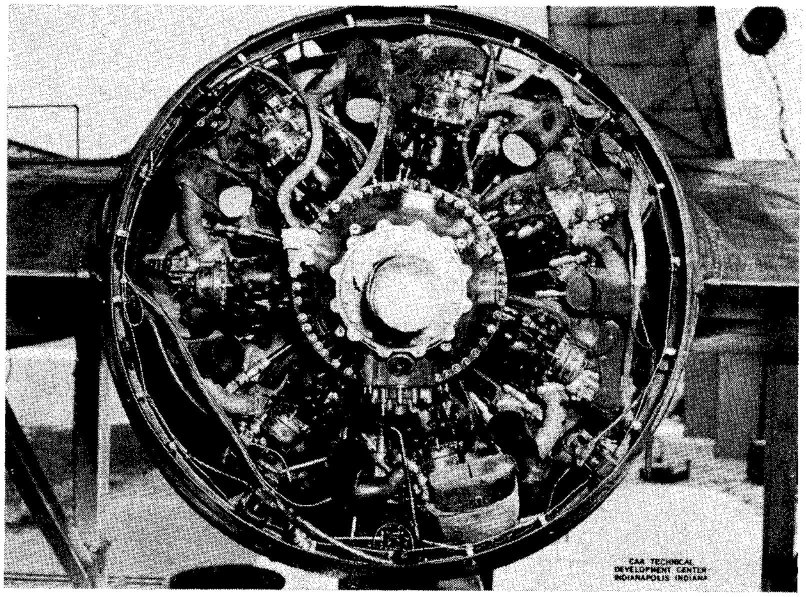

Fig. 9 Over-all View of Loop Between the Air Plug and the Cowl

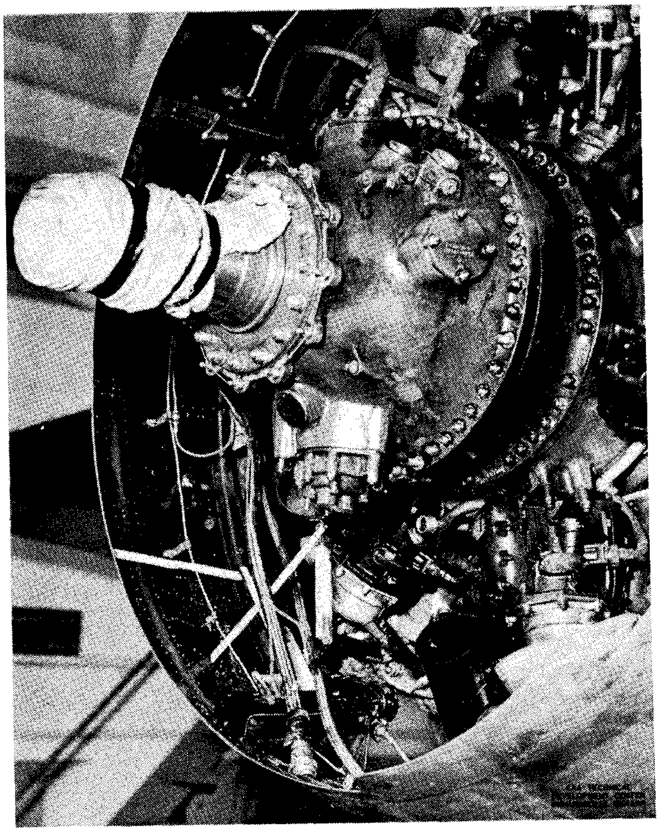

Fig. 10 Supplemental View of Loop Between the Air Plug and the Cowl

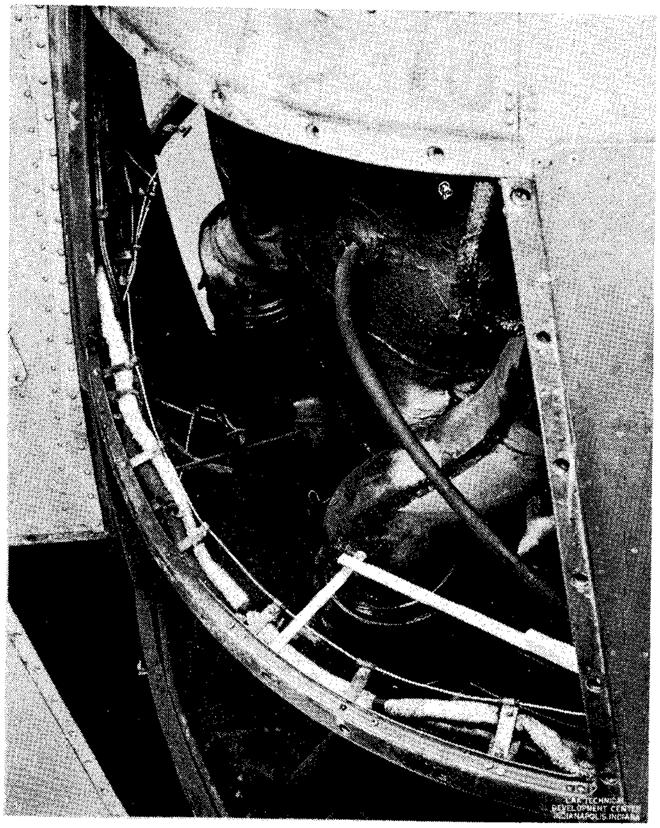

Fig. 11 Mounting Details for Loop on Middle Cowl-Support Ring

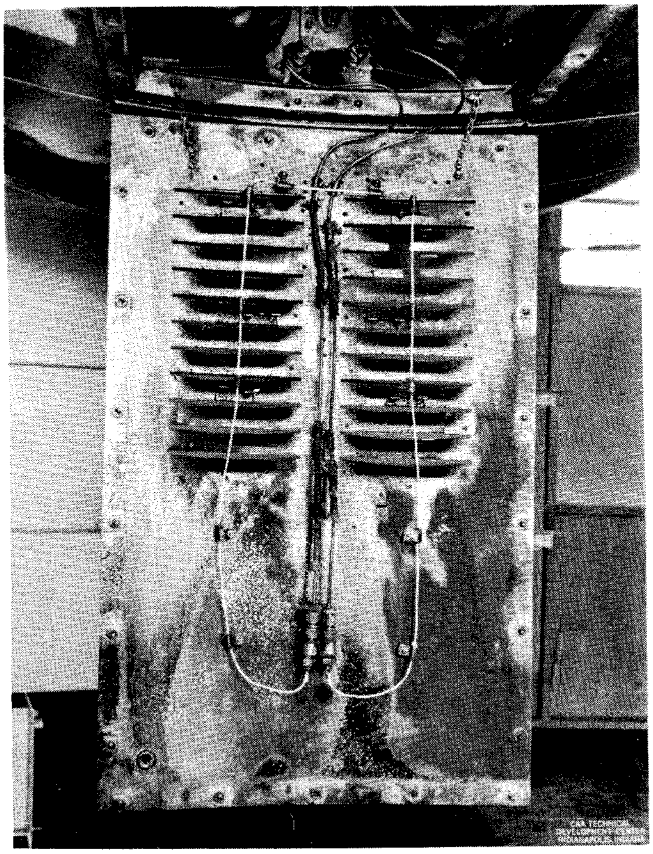

Fig. 12 View Showing Loop on Zone 2 Access Door

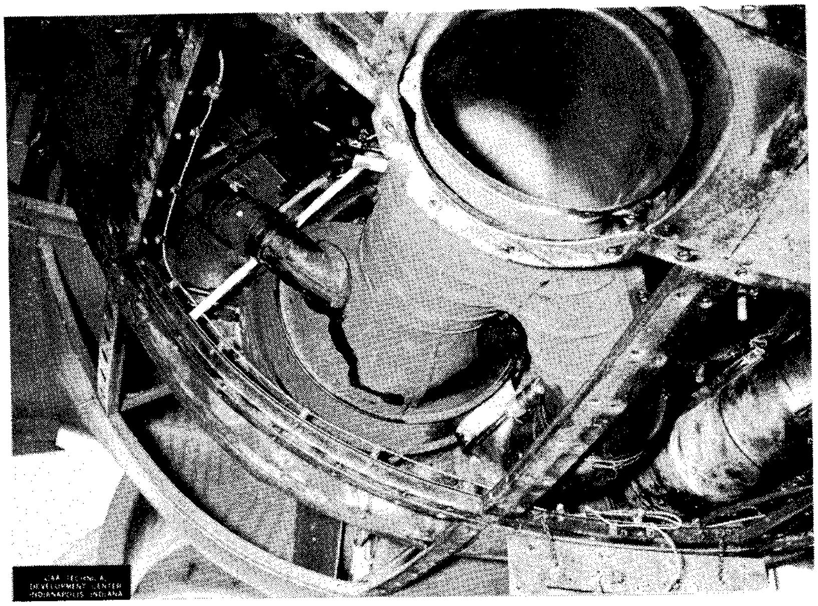

Fig. 13 View Showing Loop Attached to Lower Formers

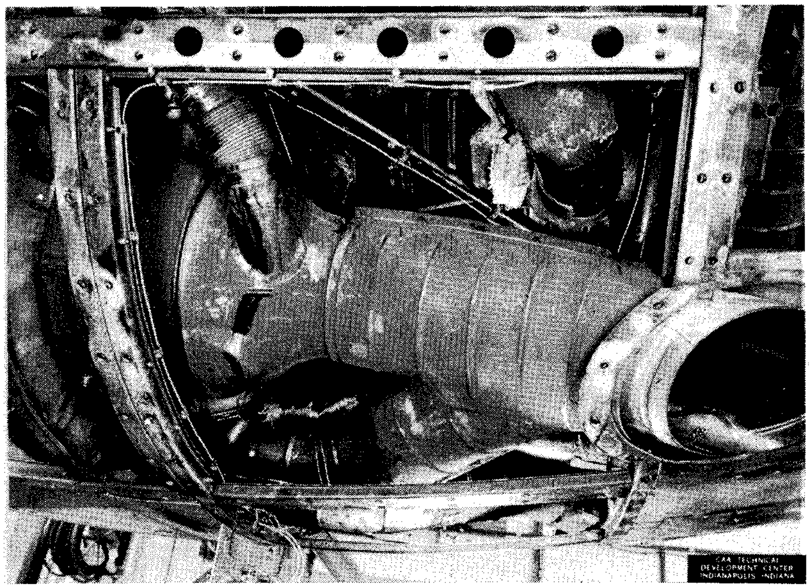

Fig. 14 View of Zone 2 Showing Portions of Various Loops

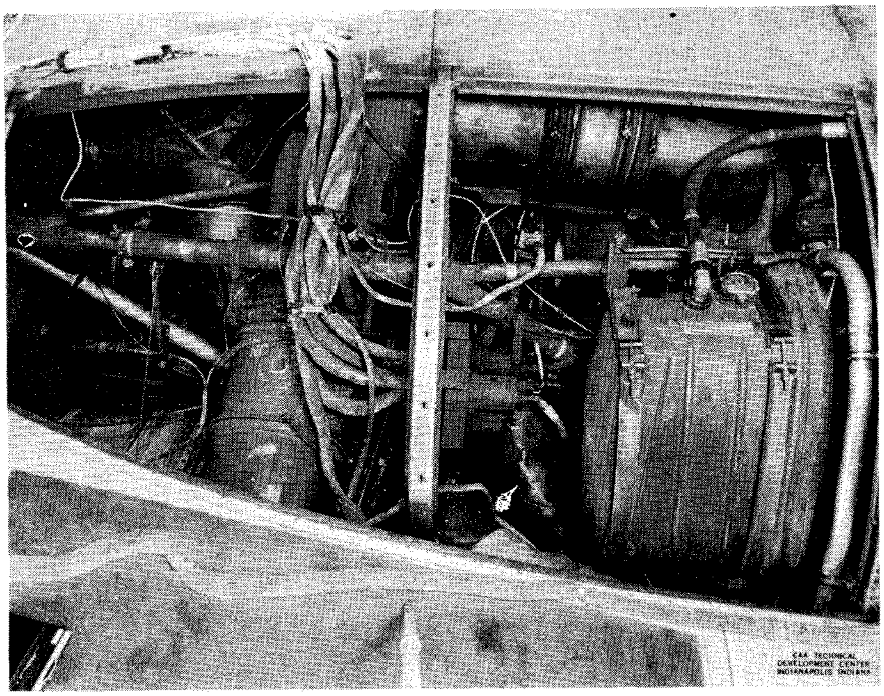

Fig. 15 . View Showing Loops in Upper Part of Zone 3 and on the Firewall

CONCLUSIONS

1. Under simulated flight conditions, the static pressure in Zone 1 is of greater magnitude than the static pressure in Zones 2 or 3, and the static pressure in Zone 2 is of greater magnitude than the static pressure in Zone 3.
2. The pressure differential between any two zones increases as the air plug closes.
3. Due to the pressure differential between zones, fire has a tendency to progress forward in the nacelle from Zone 1 into Zones 2 and 3 and from Zone 2 into Zone 3.
4. Zone 1 crankcase fires are detected effectively by the continuous fire-detecting element mounted on the afterbody.
5. Fires originating in the rear half of Zone 1 are detected effectively by elements mounted on the afterbody and between the air plug and the cowl.
6. Fires originating in the forward half of Zone 1 are detected effectively by a loop of element surrounding the engine in the same plane as the middle cowl-support ring.
7. The loop attached to the middle cowl-support ring must pass over rather than under the hot air deicing duct on the bottom of Zone 1.
8. It is impractical to mount element on the firewall or fire seal in Zone 1.
9. For adequate detection coverage in Zone 2, element is required in four general areas: (a) along the engine tubular mounts, (b) along the longerons and nacelle formers at the sides and lower forward part of the zone, (c) traversing the louvers in the bottom access door, and (d) on the fire seal.
10. Fires in the top of Zone 3 are detected effectively by a large horizontal loop attached to upper tubular mounts.
11. Fires in the bottom of Zone 3 are detected effectively by a loop which traverses the center of the louvers in the lower part of the zone.
12. In order to be effective, element must be placed where it will be exposed to flames, even at the risk of being exposed to mechanical damage.
13. The performance records of the Edison and Kidde detector systems used in the tests were comparable, and the response times of both were satisfactory.
14. In mounting the detecting element, support must be provided at the connectors and at intervals of approximately eight inches along the remainder of the element.

RECOMMENDATIONS

1. In making an installation of a continuous fire-detection system in the B-36 nacelle, the system described in the text and shown in Figs. 4 and 6 through 15 is recommended.
2. To improve the effectiveness of the production kit, element should be added to the system as follows: (a) in the top of Zone 3 so that the loop may extend farther forward, and (b) across the louvers of Zone 3.
3. Detecting element should be used instead of harness, wherever feasible, to reduce the number of connectors to a minimum.
4. Detecting element should be attached to any surface on which it is mounted so that flames in their most normal course will impinge on the element.
5. Terminal fittings should be located where they are easily accessible to facilitate maintenance.
6. Disconnect points should be located where they are accessible to facilitate quick engine changes.
7. To simplify manufacturing, supply, and maintenance problems, the continuous detection system should be arranged so that its assembly will require element in no more than two different lengths (preferably five and ten feet).