FIRE-RESISTANCE STUDIES OF THE CONVAIR-340 POWER PLANT

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SUMMARY

During the period that fire-detection and extinguishing tests of the CV-340 power plant were in progress, the installation was also studied with respect to its fire resistance. Air flow and leakage in the power and accessory sections were studied with the aid of a dye introduced into the air stream upwind of the nacelle under simulated flight conditions. The dye technique proved to be a practicable means of detecting loose fits between mating parts. Test fires in the nacelle revealed which materials and components are most likely to fail during a power-plant fire. In many respects, the nacelle was exceedingly well constructed from the standpoint of fire safety. This was due in part to the unique design and to the generous use of stainless steel. However, the sealing materials used between mating surfaces were found to be vulnerable with the result that the confinement of fires was not successful. The destruction of certain seals permitted some fires to extend to the outside of the nacelle, a fact which complicated the extinguishment problem. A change in fabricating materials of one or two items of equipment are recommended.

INTRODUCTION

Throughout the full-scale fire tests including special tests involving fire detection and fire extinguishment, the fire resistance of the CV-340 nacelle was studied. The studies were made at the Technical Development and Evaluation Center of the Civil Aeronautics Administration, Indianapolis, Indiana. Co-operating with the TDEC in the studies were United Air Lines, which supplied an operable engine-and-propeller assembly, and Consolidated Vultee Aircraft Corporation, which supplied the nacelle and assistance in assembling the equipment. The studies were initiated in November 1952 and were completed July 1954. During this period, approximately 1000 fires were started in the nacelle.

DESCRIPTION OF TEST EQUIPMENT

The facilities used in this study are described in two previously published reports. [1,2] Additional equipment consisting of an extinguishing agent container charged with a mixture of powdered oil-soluble orange dye (Dye No. S-27 manufactured by the Indianapolis Paint and Color Company) and carbon tetrachloride, pressurized with nitrogen, was used in the study of the air flow. The container was fitted with a manually controlled valve and 1/4-inch-diameter tubing of sufficient length to reach any desired point immediately forward of the nacelle air-inlet openings.

TEST PROCEDURE

Before any fire tests were conducted and while the nacelle was still in an undamaged condition, a study was made of the air flow through the nacelle with the aid of dye released into the air stream directly ahead of the nacelle. The dye was prepared prior to the tests by mixing powdered dyestuff and carbon tetrachloride and then stirring the mixture thoroughly to keep the dye in a state of suspension. To conduct a dye test, simulated flight conditions were first established for the CV-340 by operating the engine in an air blast of 120 mph furnished by the mobile blower. See Fig. 1. The air blast carried the dye into the nacelle and deposited it on the inside surfaces. After each discharge of dye, the engine and the mobile blower were shut down and the dispersion of the dye inside the nacelle was noted. In the Zone 1 tests, the dye was introduced just ahead of each cylinder of the engine. In the Zone 2 tests, the dye was released at the entrance to the air scoop.

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*Manuscript submitted for publication February 1955.

[1] L. A. Asadourian, "Fire-Detection Studies in the Convair-340 Power Plant," CAA Technical Development Report No. 250, November 1954.

[2] L. A. Asadourian, "Fire-Extinguishment Studies of the Convair-340 Power Plant," CAA Technical Development Report No. 265, May 1955.

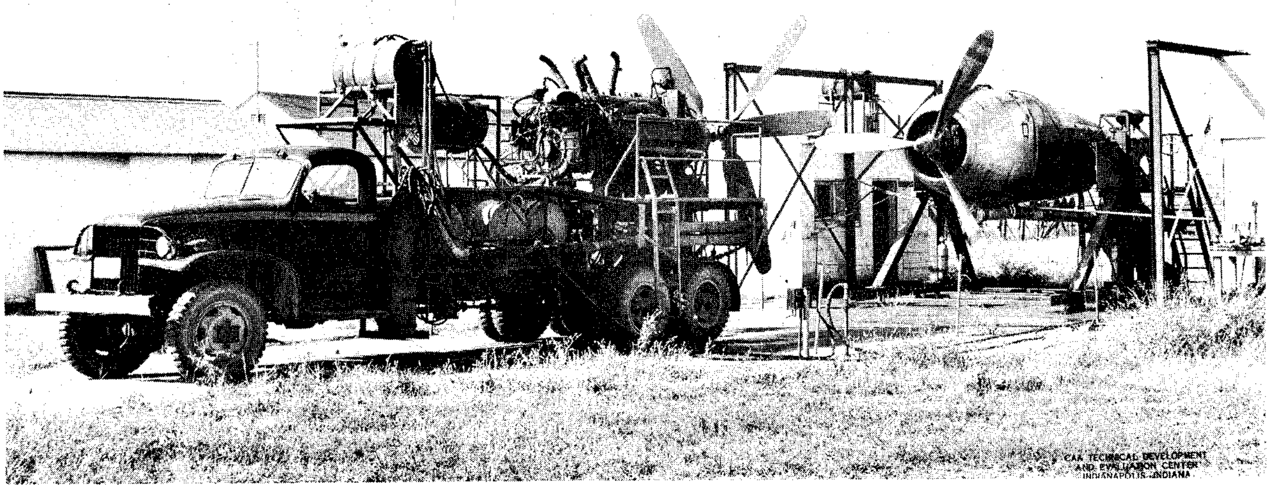

Fig. 1 General View of Fire-Test Facilities

Throughout the fire-detection and fire-extinguishment programs, particular attention was paid to the effectiveness of the compartmentation in preventing the spread of fire from zone to zone; the effectiveness of stainless steel, which was widely used in place of aluminum inside the nacelle; and the effectiveness of certain design features such as the top-wing exhaust system. This arrangement of the exhaust system in the CV-340 nacelle is in accordance with recommendations made in previous reports issued by this Center; that is, that the exhaust system be located high in the nacelle out of the path of leaking fuel and oil. The safety of the arrangement was apparent during the tests when gasoline and oil were repeatedly released in the vicinity of the engine without being ignited by the hot exhausts. During the fire tests, all of the conventional MIL-H-5511 rubber hoses in Zone 2 were replaced with flexible metal hoses supplied by Flexonics Corporation, Maywood, Illinois.

A few test fires were started in Zone 1 forward of the top cowl-flap openings in order to determine what damage would be inflicted on the cowl-flap ports and on the nacelle skin downstream of the ports by fires emerging from the openings. Test fires were also started close to the engine crankcase to determine whether such fires would enter Zone 2. Fires on the outer periphery of the engine were used to test the cowling seals. When detector fire tests were being conducted, small gasoline fires of 1/3 gpm were used. For the extinguishing tests, larger gasoline fires of 1 1/2 gpm and combination gasoline-and-oil fires were used. In the latter instance, gasoline was supplied at 1 1/2 gpm while heated oil was simultaneously supplied at 2 gpm. The duration of fires ranged between 15 and 75 seconds.

RESULTS AND DISCUSSION

The use of dye injected into the air stream ahead of the test nacelle was first considered in connection with the fire-detection studies. It was thought that the dye deposits might be helpful in tracing fire patterns and consequently in determining where fire detectors should be located. The liquid vehicle in which the dyestuff was suspended was heavier than the burning gases and therefore was not able to follow the circuitous path of the flames through the nacelle. Consequently, the dye precipitated out of the air stream at places where the paths changed directions abruptly. However, the dye-injection technique did provide an approximate indication of air and probable flame flow through the nacelle.

There were indications that the air flow reversed in direction under certain conditions and indications that leakage occurred through seals which were designed to be leak-proof. Color photographs of the dye deposits facilitated this study. The sketches in Fig. 2 are reproduced from the photographic indications of dye deposition. Figure 2A shows the inside surface of the left side-cowl panel. The pattern was produced when the dye was introduced forward of the engine cylinders on that side. This pattern indicates that part of the air passing between the cylinders reversed, came forward, and spilled over the front of the lower left portion of the cowling. Figure 2B shows the dye pattern on the outside surface of the nacelle as viewed from the right, near the propeller. This test was conducted with closed cowl flaps. The dye stain at the upper right corner, X, of the sketch was not caused by leakage through the seals between the horizontal mating surfaces. This stain was produced by the dye which first entered Zone 1, then passed between the inner and outer skin of the bottom cowl panel by leaking around the scupper drainpipe in the bottom of the cowling. The dye traveled thence to a hole in the horizontal mating surface, where it emerged at the outside surface. The loose fit of the scupper drain at the inner liner of the cowling would have gone unnoticed except for the dye. Such a loose fit is a potential hazard because flammable fluids and explosive gases can collect in the interior space of the cowl panel. The dark stain immediately below, at Y, was produced by the dye which passed through the scupper drain itself. Although the dye adhered to the skin that encloses Zone 3, there is little reason to believe that fire at the exit of the scupper drain would cause damage in this area. Tests have indicated that such a fire would be wiped off immediately by the air stream.

In dye tests with the cowl flaps open, deposits were also made on the Zone 3 skin by dye leaving the cowl-flap ports. Since fire will continue to burn when the slip stream is diverted by the extended cowl flaps, there is a real danger that fire will destroy the downstream skin under such conditions.

Inside Zone 1, dye was deposited on the bell-mouths of the augmenter tubes and on the closed cowl flaps. There was also a heavy deposit on the forward side of the carburetor intake duct, as shown in Fig. 2C.

Dye introduced at the intake to Zone 2 was deposited mainly at the lower right side, as shown in Fig. 2D. The left interior of Zone 2 was comparatively free from dye deposits. There was a large deposit of dye on the right side of the Zone 2 access door but no penetration of the seal around this door into Zone 3.

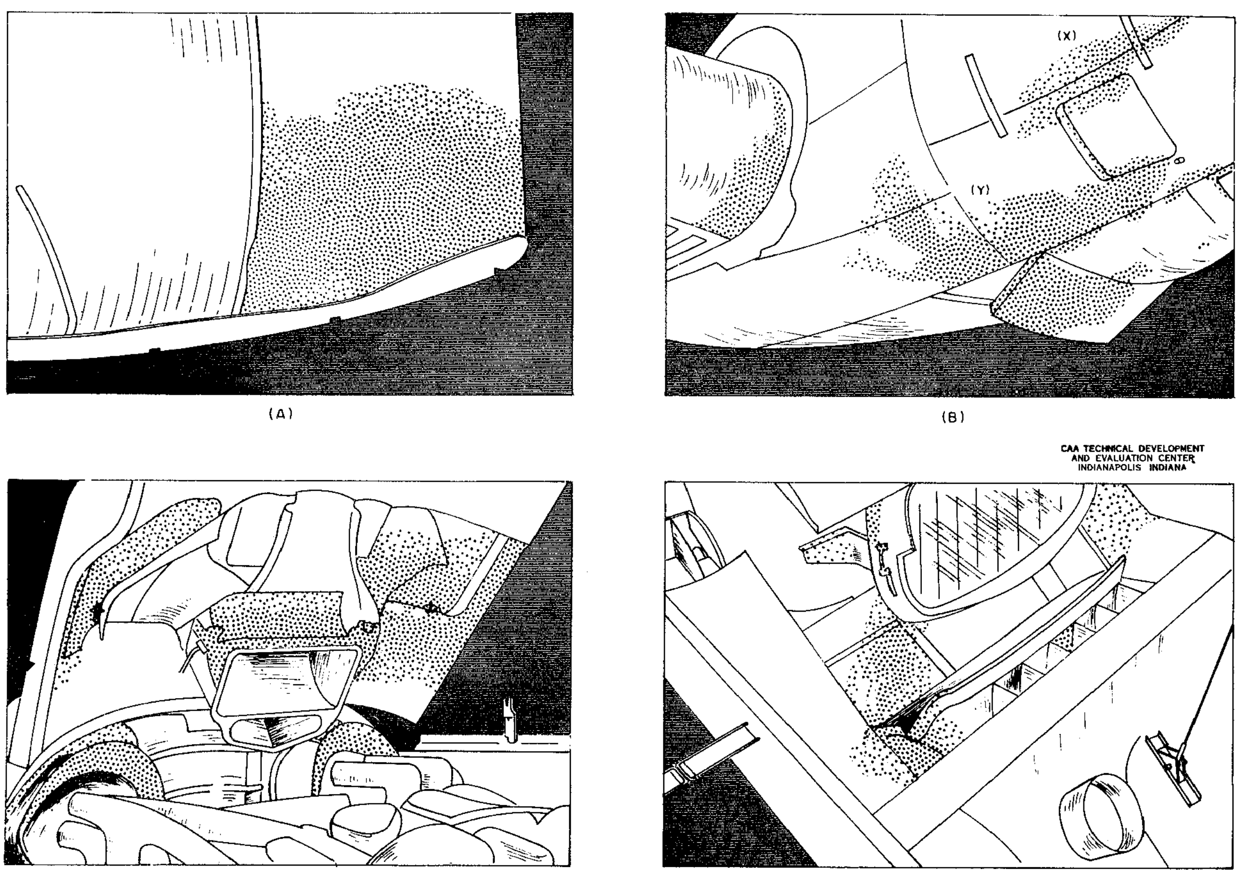

Fig. 2 Dye Deposition on Internal and External Surfaces of the Nacelle During Air-Flow Studies

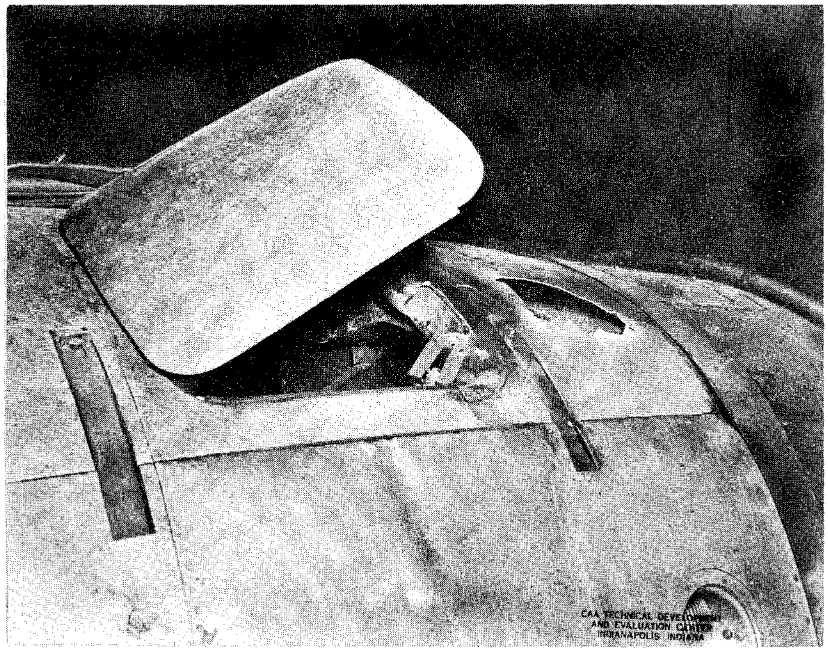

Fig. 3 Hole Burned in Cowling by Fire Leaving Cowl-Flap Port

The chief value of the tests described was to indicate the areas where sealing was ineffective and to reveal unsuspected air flows within the zone. The need for tight sealing in the control of fire is generally recognized, but it is difficult in many cases to be sure that a tight seal has been effected. The dye method provides one means for determining the degree of success that has been achieved in this connection.

When a fire of 20 seconds duration was started high in Zone 1 near the partially open cowl flaps, the flames hugged the skin aft of the flaps and burned through the duraluminum outer skin. The damage is shown in Fig. 3. The port was also damaged, but the inner skin of the cowling remained intact because it was fabricated of stainless steel. The flames extended beyond the cowl hinge line, which marks the location of the fire wall, and impinged on the duraluminum skin covering Zone 3. Since there is no protective inner lining for Zone 3, stainless steel was used during the tests to cover this area to prevent its being penetrated by fires.

After many fires had been ignited in Zone 1, the inner stainless steel linings of the two side-cowl panels were buckled and cracked to such an extent that they had to be replaced. The cracks permitted flammable fluids to enter the panels; and, in one instance, an explosion occurred in one of the panels when a fire was started inside of the zone.

The fires originating close to the crankcase of the engine caused the engine shroud to warp along the line where it butts against the engine fire seal. This made it possible for fire to gain entrance to Zone 2. The fires inside Zone 2 were well contained until the seals started to burn out. The destruction of the original seals was progressive and required several small fires and a few large fires to create a critical condition. When the seals around the oil cooler failed, fires extended outside the nacelle and lodged behind the oil-cooler flap. This development complicated the extinguishment problem.

Although they became brittle after exposure to fire, the seals at the cowl hinge line continued to be effective barriers for several tests. Even when failure occurred at different points, the flames which emerged to the outside of the nacelle were comparatively small and harmless to downstream skin. The rubber cushion in the cowl hinges eventually burned out completely.

Early in the program the test fires found their way from Zone 2 into Zone 3 through the fire wall at the lower left side of the oil-cooler air-exit duct. The flames burned insulation off some of the wires in Zone 3. Sealing compound was used to prevent further leakage at this point during the remaining tests.

The aluminum alloy junction box in Zone 2 to which the fire-detection system as well as other wiring is connected was protected during the fire tests by a coating of asbestos impregnated with water glass. This was necessary because its destruction would have an effect on the detection system and on the governor solenoid by which unfeathering is accomplished. It would seem desirable to construct this box of a material having greater fire resistance than aluminum alloy has.

In some of the tests, the accordion rubber-hose coupling in the generator blast tube continued to burn and to cause reignition of the fires. The flexible metal hoses used in place of the other conventional rubber hoses in Zone 2 were only slightly damaged by the prolonged exposure to fires.

CONCLUSIONS

It is concluded that:

1. Dye, in suspension, injected into the air stream ahead of the nacelle in such a manner that it enters Zones 1 and 2, is helpful in determining flow patterns and in testing the effectiveness of compartment seals.
2. The dye deposit indicated a reverse air flow in Zone 1 between the 4-and 6-o'clock positions as viewed from the propeller end and indicated an unsymmetrical flow in Zone 2.
3. A loose fit between the inner liner of the bottom cowl panel and the scupper drain or any small opening into the interior of any of the cowl panels is hazardous and, therefore, should be avoided.
4. Fire passing through cowl flaps which are partially open will impinge on the metal ports and on the downstream skin.
5. The top-wing exhaust arrangement reduces fire-ignition hazards.
6. The seal around the Zone 2 access door is effective.
7. Fires in Zone 1 near the crankcase of the engine can warp the engine shroud sufficiently to let fire enter Zone 2.
8. The seals near the hinge line of the cowling are fairly effective in the retention of fire.
9. The integrity of the seals around the oil cooler is of paramount importance in preventing Zone 2 fires from extending overboard and lodging behind the oil-cooler flap, where they are difficult to extinguish.
10. The fire wall must be carefully fitted or sealed in the region near the oil-cooler duct to preclude the passage of flammable fluids from Zone 2 into Zone 3.
11. The accordion rubber-hose coupling in the generator blast tube supports combustion and can cause reignition of a fire.
12. The flexible metal hoses were only slightly damaged from exposure to approximately 1000 fires.

RECOMMENDATIONS

It is recommended that:

1. The injection of liquid dye mixture into the stream of air entering the various nacelle zones be given consideration as a practical method of determining the effectiveness of seals and the tightness of fire walls in new or reworked nacelles and as an aid in the study of air flows through nacelles.
2. In cowl panels having an enclosed air space, (1) the inner surface be tightly sealed and carefully maintained to prevent flammable fluids from entering the interior of the panels; and (2) means be provided to drain and ventilate the interior.
3. Exterior nacelle surfaces downstream of flaps be protected with materials which are more fire-resistant than aluminum alloy.
4. The seals around the oil cooler be fabricated of materials having a maximum of fire resistance together with the necessary degree of flexibility.
5. In fitting the fire wall around the engine and around the oil cooler, care be taken to eliminate all small openings which would impair the tightness of the fire wall.

6. The engine shroud be redesigned to prevent excessive buckling induced by exposure to fire.

7. The flexible rubber-hose coupling in the generator blast tube be replaced with a flexible metal coupling.

8. The junction box in Zone 2 be fabricated of stainless steel.