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FIRE TEST OF R-4360 ENGINE NACELLE AS USED IN AN INSTALLATION SIMILAR TO THE B-50

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INTRODUCTION

A program of fire testing was undertaken at the Technical Development and Evaluation Center using a power plant and nacelle of the XR60-1 Constitution. Because of the similarity between this power plant installation and that of the B-50 airplane, such conclusions and recommendations as are applicable are made available for consideration and use in the B 50 installation.

In order to make this report concise, no attempt has been made to describe the facilities and equipment used during the test program or to explain precisely the test procedure. Reports[1,2] have been published previously which give a detailed picture of the test facilities and outline the procedure usually followed in conducting an investigation. The final report covering all the studies made on the Constitution power plant will include sections pertaining to these subjects.

FIRE DETECTION

Power Zone

A large part of the investigation was devoted to the study of fire detectors and fire-detector systems in the power section The study centered particularly around the cowl-flap region through which power-section fires tend to pass. Fig. 1 shows the comparable views of this region in the two installations. The conclusions based on this study indicate that the present practice of locating the fire-detector system on the air-seal diaphragm of the B-50 has merit. Other locations were found which were as good or better for a wider range of conditions, but, considering the problems of installation and maintenance, as well as the efficiency during the most critical period of aircraft operation, i.e , in flight, a detector system located on the diaphragm constitutes a practical solution to the detector problem in the power zone for this airplane.

To assist in the determination of the type of detectors which could

[1]H. L. Hansberry, "Test Facility Aircraft Fire Protection Program," Technical Development Report No 54, February 1947.

[2]Lyle E. Tarbell and H. R. Keeler, "Determination of Means to Safeguard Aircraft from Power Plant Fires in Flight," Part IV, The Boeing B-29, Technical Development Report No. 107, April 1950.

be considered for use, and the setting of such detectors, records were made of the temperatures and rates of temperature rise encountered during the tests. The maximum rate of temperature rise of the air, observed during the tests, was 1,080 degrees F per minute at the top and sides of the nacelle in the region of the cowl flaps. This occurred during a simulated ground maneuver in which the propeller was reversed. A high temperature of 275 degrees F was achieved during this maneuver. During simulated forward movement on the ground, the maximum rate of temperature rise of the air in the same region was 480 degrees F per minute, and the highest temperature of the air during this period was 290 degrees F Metal temperatures in the same region reached a maximum of 360 degrees F from engine heat only.

Certain types of detectors which are of particular interest to the Department of the Air Force, because they were designed in accordance with USAF specifications or because their development has been encouraged by that branch of the Military Establishment, were subjected to tests. For instance, to meet the need for an overheat detector, Fenwal Inc. developed the Model No 17343-16 which complies with USAF Specification 41379. When installed as a system in the test installation and observed under simulated flight and fire conditions, this overheat detector performed well, giving warning within a reasonable time and displaying comparative freedom from false alarms.

Another detector system which was of particular interest to the Department of the Air Force was the visual type developed by Photoswitch Inc. in accordance with AMC Exhibit MCREXE53-28. Commercially, it is known as Fireye Model FD-2. One of the objectives of the tests was to determine whether the sensitivity of the system had been suitably specified. It was considered axiomatic that the minimum sensitivity which would give the necessary protection was all that was required for any specific type of airplane. With this as a basis for the determination, the tests in the power section indicated that a degree of sensitivity on the order of one-seventh to one-tenth of the original maximum specified in the exhibit was sufficient and desirable Greater sensitivity needlessly tended to make the system more susceptible to false alarms from extraneous light.

A suitable arrangement of Fireye units in the power section involved the use of only five units mounted on the cowl-support ring so that each eye was offset slightly from a direct radial line through an exhaust manifold by moving it around the ring toward the next manifold (approximately one fourth to one third of the distance). The scheme followed was for each eye to be slightly removed from the proximity of an exhaust stack to minimize radiant heating effects and at the same time to maintain a considerable distance between the eye and the next stack to minimize the strength of the infrared radiation. The eyes were directed to view 45 degrees away from the radial line directly into the engine.

No units were used between the exhaust stacks connected to the lower cylinders. The reason for this was that fires originating near the bottom of the engine tend to emerge through the lower cowl-flap openings on either side of the nacelle and, in doing so, come under the surveillance of other units. Five units located in the general region encompassed by the cowl flaps were considered sufficient. Naturally, no harm is done by the addition of units under the engine if the added protection is felt to be desirable. Fig. 2 illustrates the arrangement in the power section and also suggests other possible locations for the remaining units to complete a system for one nacelle.

Power supply variation considerably in excess of the Fireye design specifications (110 to 120 volts) caused false indications. Rapid and repeated dips to 80 volts, or lower, were traced to specific items of test equipment, but this source of trouble was eliminated in the tests by use of a separate power supply for the detector system only. Actually, the system was able to operate with variations of input voltage from 100 to 130 volts, and, if the B-50 or other flying aircraft voltages are maintained within this range, little difficulty should emanate from this source.

According to design specifications, the equipment was suitable for operating in ambient temperatures up to 220 degrees F. Temperatures in excess of this resulted in reduced sensitivity, which was manifest whenever an attempt was made to test units which happened to be located in regions of high temperature. Such units occasionally failed to respond to the test light until the temperature was reduced. This did not mean that the system became inoperative, it simply meant that more energy in the form of light or fire was required to produce an equivalent effect.

In addition to the fire tests which were conducted in connection with the Fireye system, a study was made of the effect produced by water passing through the engine, a condition experienced whenever rainstorms are encountered in flight With certain arrangements of the detector units, false alarms were produced during the simulated rain tests. It was believed that the rain droplets passed between the unshrouded exhaust manifolds and the eyes producing the effect of modulated light of the critical frequency. With the configuration described in this report, however, the false alarms from this source ceased to be a problem.

Accessory Zone

The accessory section in the test installation differed considerably from that in the B-50. In the latter installation, the space aft of the air-seal diaphragm is filled to a large extent with ducts, the engine lubricating oil tank and other equipment In the test installation, however, considerable open space has been provided, as in the flying counterpart, into which a mechanic can crawl via the wing during flight if necessary. This space is divided into two parts by an auxiliary fire wall through which passage is afforded by a folding door. The space forward of this fire wall would correspond roughly to the accessory section of the B-50 in purpose, but there is no space in the B-50 comparable to the space aft of the auxiliary fire wall

For a clearer understanding of the regions involved, Fig. 3 has been included.

It is evident from the sketch that the accessory section is much more congested in the B-50 than in the Constitution. The results of the tests conducted in this region, therefore, may not be directly applicable, but may be used as a general guide to detector installation where specific information is lacking.

When small fires were started at various points within the accessory section, it was observed that

1. Temperatures were higher with partly closed cowl flaps than with flaps 100 per cent open.
2. Temperatures near the top of the zone decreased as the engine speed increased.
3. Temperatures near the sides of the zone tended to increase slightly as engine speed increased.
4. Lowest temperatures were near the sides of the zone.
5. Highest temperatures were near the top of the zone.

FIRE EXTINGUISHMENT

Power Zone

A number of tests were conducted in the study of power-zone, fire extinguishing systems. One system consisted of nozzles located behind each cylinder, an arrangement which has proved most successful on conventional twin-row engines. Such a system was very difficult to install on this engine and was no better, apparently, than a much simpler system consisting of seven nozzles located at the front hood, symmetrically spaced so as to discharge fluid in a fan shape toward the crankcase between cylinder banks. Neither of these systems were satisfactory, however. Various quantities of extinguishing fluid, up to 50 pounds per charge were used and at pressures from 300 to 500 psi. This study is continuing, and will be reported in connection with the XR60-1, rather than with the B-50.

In view of the fact that no fire-extinguishing system is used in the power zone of the B-50 on the theory that power-zone fires can be blown out, it was felt that a study of the "blow-out" theory would be much more to the point in this particular report.

Therefore, tests were conducted to determine the feasibility of controlling power-section fires without the use of an extinguishing fluid. The procedure was to start a fire at some point within the section. When the fire appeared to have reached its maximum intensity, the engine was shut down, the flammable-fluid valves were closed and the propeller was brought to the feather position. In some of the tests, the cowl flaps were allowed to open, and in others they were allowed to close. In any event, all of the actions, after engine shutdown was initiated, were controlled by a single switch on the emergency panel. As the propeller began to feather, the oil flow to the fire was gradually reduced and was completely shut off when full feather was achieved. The wind tunnel was continued in operation to simulate continued forward flight.

Control of Zone 1 fires without the use of extinguishing fluid has been known in the past as control by "blow-out," but the term is a misnomer. The results of the tests indicated that oil fires are not blown out by the air blast due to forward flight after the engine and propeller have stopped turning. If the lack of rotation by the engine has effectively reduced the quantity of flammable fluid available for burning, the fire will diminish in size and intensity until the supply of fluid has been consumed or drained away, whereupon the fire will go out. A more appropriate term for this type of control would be "burn-out." Opening the cowl flaps during this procedure appears to reduce the intensity of the fire and to shorten the time required for the fire to burn out. Closing the cowl flaps, besides holding the fire within the power section and, thus, increasing the possible damage to the engine, has the added disadvantage of tending to force the burning fuel into the accessory section and spreading the fire. As an example of the time involved, an initial 4-gallons-per-minute oil fire burned out in approximately one minute in the power section, but not before fire had entered the accessory section.

Adequate drainage in the power zone is essential to the control of fires by this method. Several damaging fires occurred during the tests because of the lack of drainage until this undesirable feature was corrected in the test installation.

The skin of the test installation aft of the cowl flaps is stainless steel, which has remained intact through thousands of fires. The only means, therefore, by which fire could have gained entrance to the accessory section was through tiny cracks or holes in the air-seal diaphragm. A close examination of the diaphragm revealed openings of this nature.

Since an advantage is gained by immediate shutdown of the engine in case of fire, a short series of runs was made to determine which action or combination of actions would be most effective in stopping the engine. For each run in the series, the engine was operated at 1,450 rpm, and the cowl flaps were held at 25 per cent opening. Shutdown measures were initiated in each case at the instant when the cylinder-head temperature reached 350 degrees F, and all actions involved in any one test were simultaneous. The various measures included putting the mixture control in idle cutoff, closing the throttle and closing the solenoid-operated fuel shut-off valve. The results of the runs are given in Table I.

TABLE I

Test	Idle Cutoff	Throttle Closed	Shut-Off Valve	Feather	Time (Secs)
1	X				15
2	X	X			14
3	X			X	9
4	X	X		X	8
5			X		41 1/2
6	X		X		14 1/2
7	X		X	X	8
8	X	X	X	X	8
9			X		41 1/2

The table shows that simply putting the mixture control in idle cutoff, or this action plus closing the throttle, will cause the engine to stop turning in 14 or 15 seconds under the conditions mentioned. When the propeller is feathered in addition, the engine stops in 8 or 9 seconds. Closing the fuel shut-off valve, only, stops the engine in 41 1/2 seconds, which is a relatively long period. Moreover, during this period, the engine operates very unevenly and backfires frequently The time involved when both the valve is closed and the mixture is placed in idle cutoff shows no improvement over the latter action alone. Feathering the propeller, in addition to these two actions, stops the engine in eight seconds, which is the shortest time recorded in any of the tests, including Test No. 8, in which all actions, plus feathering, were initiated together. When the mixture control is adjusted to idle cut-off position, the engine responds immediately In contrast to this, when the fuel shut-off valve is closed, very little effect, if any, is noticeable immediately in the functioning of the engine. After a few seconds, the engine slows down abruptly, backfires and then surges back to approximately the original power. This process is repeated at increasingly frequent intervals until the engine is finally starved completely Because of this erratic surging of power, it was considered inadvisable to attempt feathering of the propeller, which could have resulted in irreparable damage to the engine As far as the time element is concerned, the assumption can be made that closing the valve, plus feathering, will require something more than 8 seconds and something less than 41 1/2 seconds if no untoward complications result from this procedure. The most positive and most rapid procedure still involves the manipulation of the mixture control.

The wind tunnel was not used in these tests because the air blast furnished by the tunnel would have caused the engine to "windmill," except in those tests where the propeller was feathered, making it impossible to compare the various methods.

CONCLUSIONS

The conclusions based on this study are as follows

1. In an installation using the Pratt and Whitney R-4360 engine, the path followed by crankcase fires differs from the path followed by cylinder-head fires.

2. When the cowl flaps are open only moderately, as in flight, crankcase and cylinder-head fires are constrained to pass through a common region prior to emerging to the outside.

3. Heat-actuated fire detectors located on the outer periphery of the air-seal diaphragm, concentric with the exhaust-collector ring, will detect both crankcase and cylinder-head fires occurring in flight, provided the cowl flaps are open no wider than the recommended amount for flight.

4. The maximum rate of temperature rise recorded for air passing through the engine section in simulated ground operation with no fire involved was 1,080 degrees F per minute, and the maximum temperature attained was 290 degrees F. The maximum metal temperature under the same conditions was 360 degrees F, which was the temperature of the shell of a detector located in the lower cowl-flap opening.

5. The Fenwal Model 17343-16 detector which complies with USAF Specification 41379, operated satisfactorily in detecting fires, although it was intended for use as an overheat detector, rather than a fire detector.

6. No false alarms resulted from simulated rain tests or as a result of accumulations of oil or dirt on the Fenwal units during the test program.

7. The sensitivity of the Fireye FD-2 detector system can safely be reduced by a factor of ten from the original specification when used in the power section of an installation such as the B-50.

8. Variations of input voltage must be maintained within the range of 100 to 130 volts to prevent false alarm of the FD-2 detector.

9. Ambient temperatures in excess of the design-operating maximum of 220 degrees F result in reduced sensitivity of the Fireye system.

10. One possible condition which might induce false alarms in the Fireye system is the presence of rain in combination with hot exhaust stacks. Flight tests may reveal other possible sources of modulated light.

11. The best general location for detectors requiring flame contact to operate is at the top of the accessory section

12. The best general location for detectors which do not require flame contact to operate is at the sides of the accessory section.

13. Power-zone fires are not blown out by the air blast due to forward flight after the engine and propeller have stopped turning. Such fires may burn out if the lack of rotation of the engine has effectively reduced the quantity of flammable fluid available for burning.

14. Good drainage underneath the engine will reduce the fire hazard in the power zone, and will aid considerably in the extinguishment or control of power-zone fires.

15. A tight seal must be maintained between the power and accessory

sections to prevent the spread of fire between zones.

16. Stainless-steel skin immediately behind the cowl flaps will prevent fire from entering the accessory section through the skin.

17. To consummate rapid shutdown of an engine, two actions are necessary (a) adjust the mixture to the idle cut-off position, and (b) feather the propeller. Closing the throttle or solenoid shut-off valve in the fuel line will not materially reduce the shut-down time.

18. Closing the solenoid fuel shut-off valve is a desirable part of the shut-down procedure, because it will reduce the fuel available for burning in the accessory section.

RECOMMENDATIONS

It is recommended that

1. The present practice of mounting heat-actuated fire detectors on the air-seal diaphragm be continued for practical reasons. Spacing of unit detectors should not exceed eight inches, center to center.

2. The preset temperature of heat-actuated fire detectors be between 450 degrees F and 550 degrees F.

3. Fireye flame detectors, if contemplated for use in the power section of the B-50, be located on the cowl-support ring and spaced circumferentially between banks of cylinders. The units should be twisted to view approximately 45 degrees away from a line toward the engine and to avoid a direct view of the hot exhaust stacks. See Fig 2.

4. Fireye units, if contemplated for use in Zone 2 or Zone 3 of the B-50, be installed to observe as much open space as possible within the zones and, also, the areas where flames may tend to enter or leave the zones. See Fig. 2.

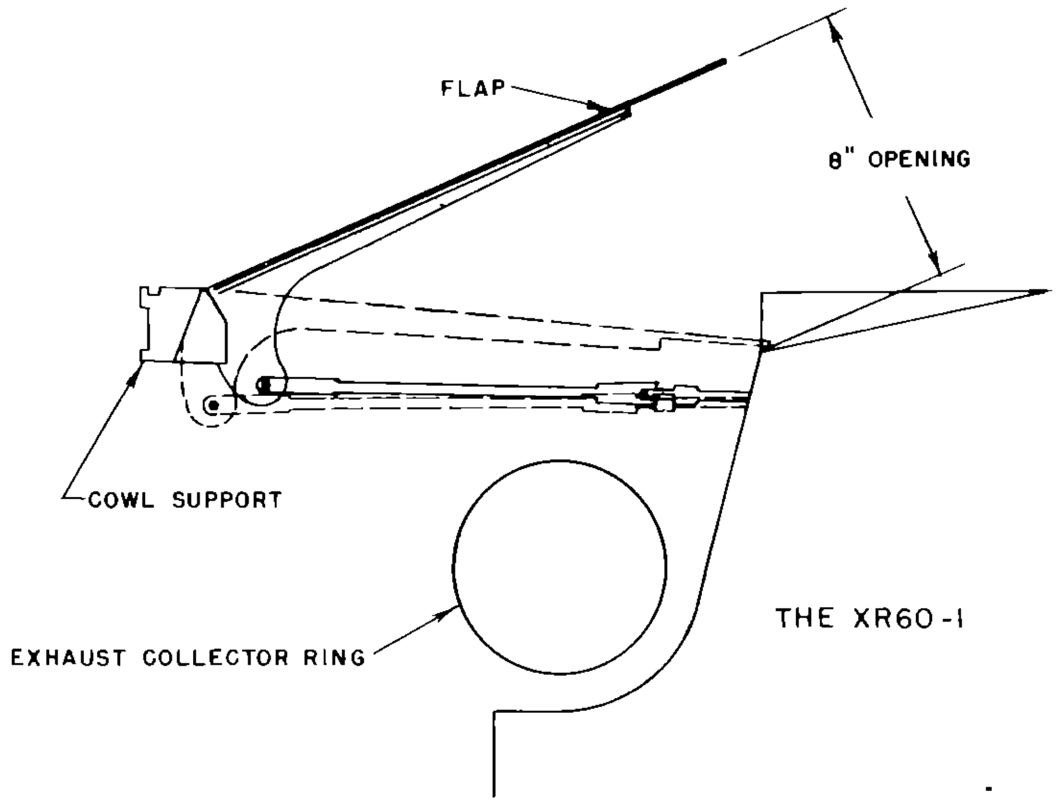
5. The sensitivity of the Fireye FD-2 system, as determined in this test installation, be compared with the sensitivity in other test installations for the purpose of standardizing at some reasonable value.

6. Heat-actuated fire detectors be mounted near the top of the accessory section for general coverage and near louvers or other openings to the outside.

7. Visual-type flame detectors be located near the sides of the accessory section in such a manner as to view as much of the open space within the zone as possible. A sufficient number of units should be used to provide supplemental coverage and to monitor adequately all openings to the outside.

8. The top and side panel assemblies be fabricated of stainless steel.

9. The emergency shut-down procedure consist of two steps (a) set the mixture in idle cut-off position, close flammable-fluid valves, open cooling flaps, feather propeller, adjust extinguishing fluid valves to proper engine, all in one operation, and (b) discharge extinguishing fluid at the discretion of the operator after the propeller has stopped turning.



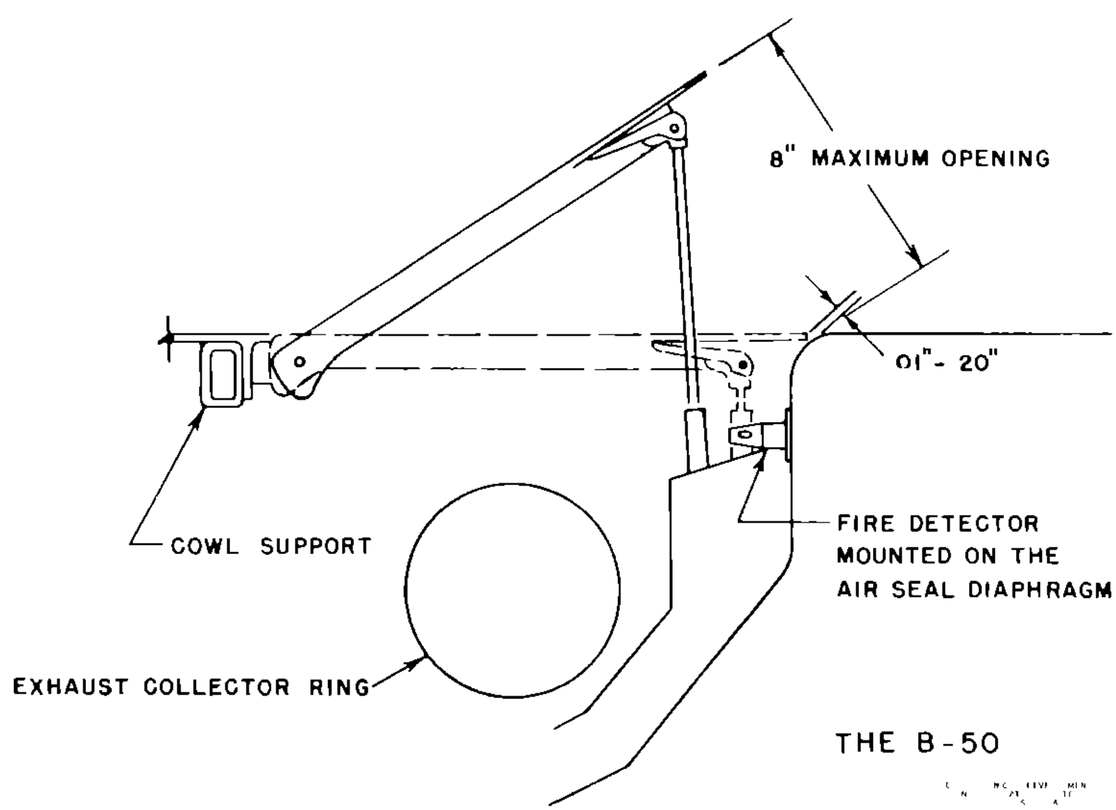


FIG 1 SKETCH SHOWING THE COWL FLAPS OF THE TWO TYPES OF AIRCRAFT IN EXTREME POSITIONS

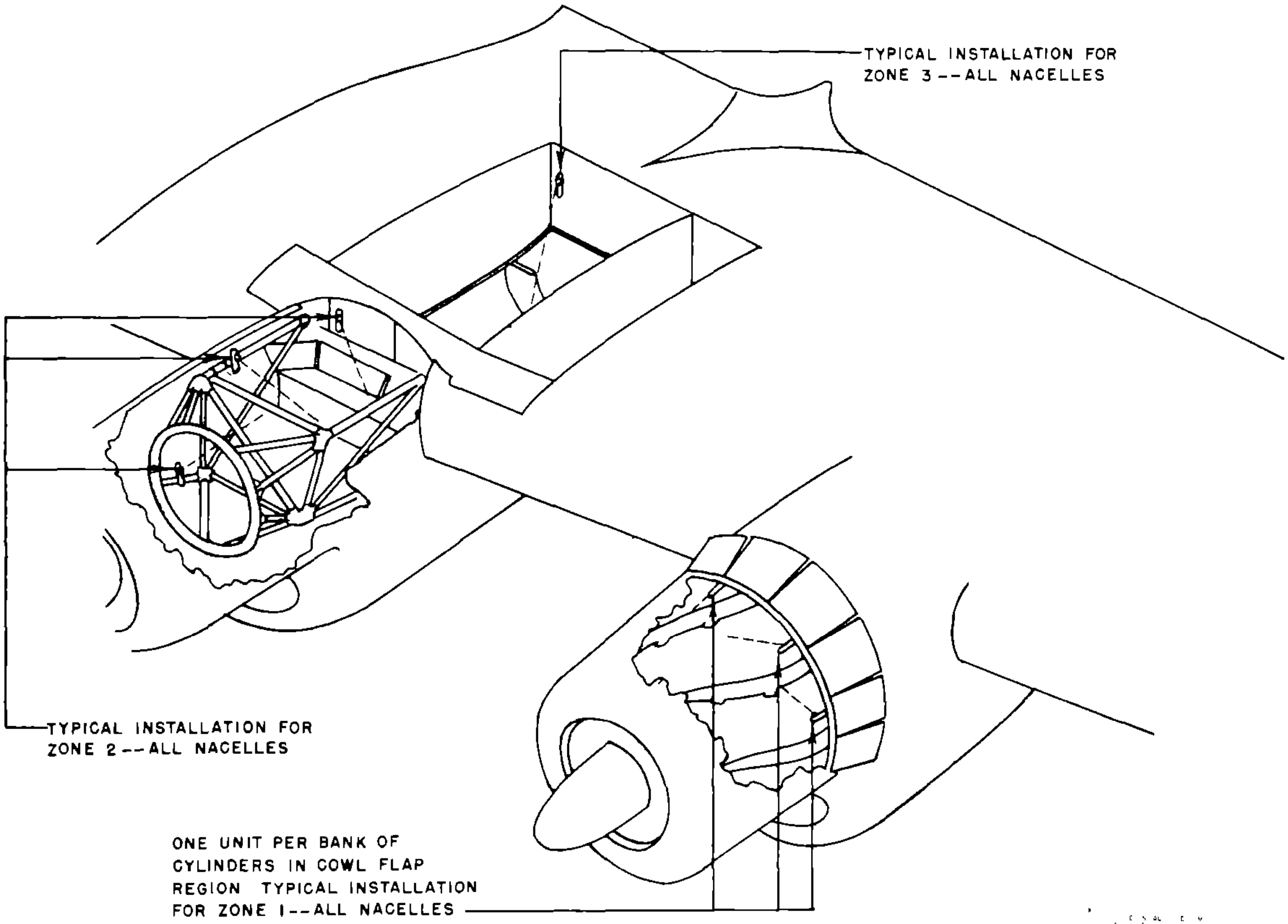


FIG 2 SUGGESTED LOCATIONS FOR FD-2 FIREYE UNITS

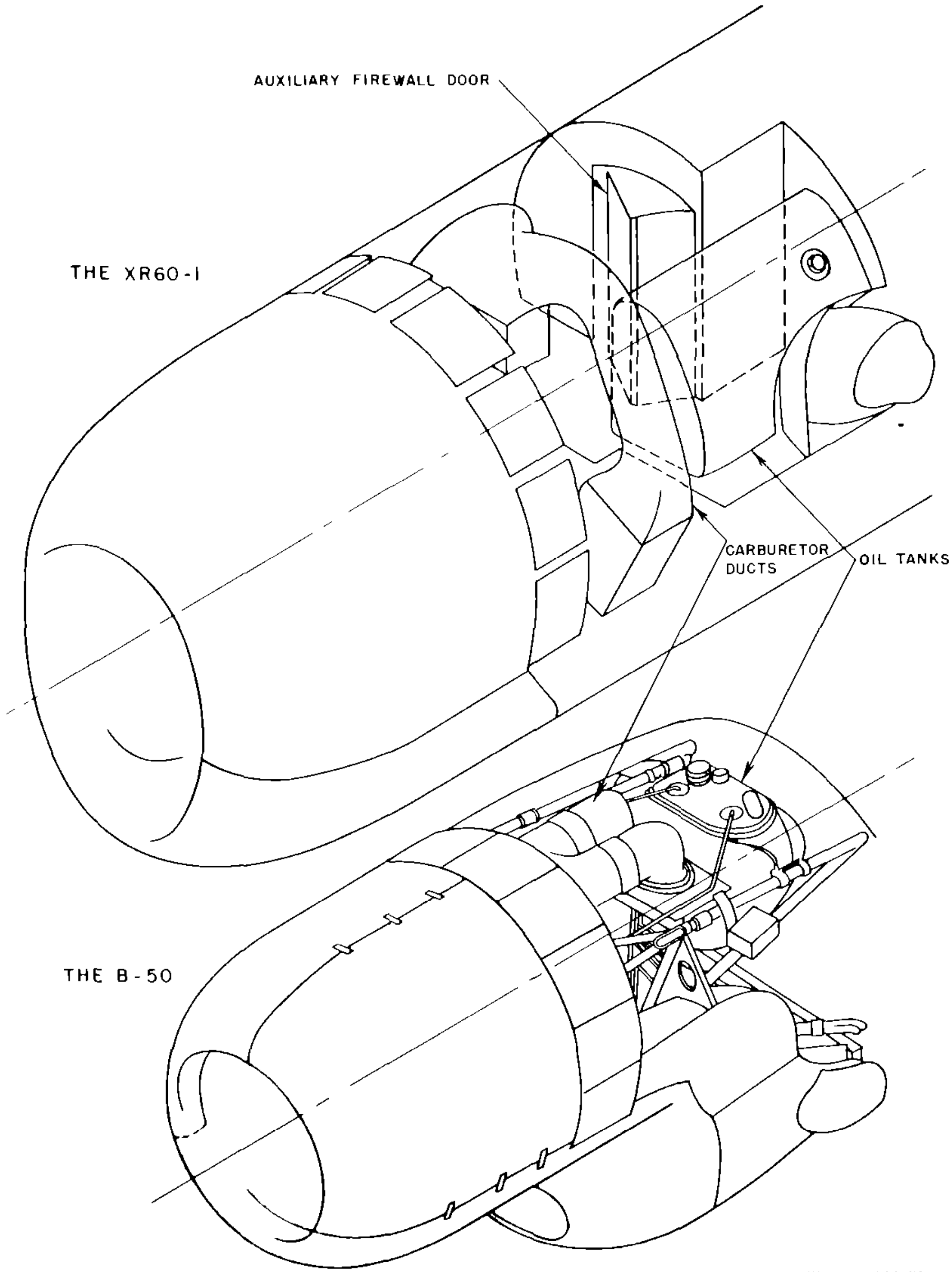


FIG 3 SKETCH SHOWING ARRANGEMENT OF DUCTS AND OIL TANKS IN THE ACCESSORY SECTIONS