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PROPOSED INITIATING SYSTEM FOR CRASH-FIRE PREVENTION SYSTEMS

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SUMMARY

The initiating system described in this report was designed to meet the requirements of such a system as determined by a study of data obtained from full-scale experimental and accidental airplane crashes. An example of the application of these requirements in the design of an initiating system for a twin-engined piston-powered airplane is given.

The proposed system can be designed so that it acts rapidly and so that accidental operation is improbable. In addition, if the system should operate accidentally, catastrophic results are also improbable. This system is selective in that it inerts only those damaged zones where combustibles are spilled. The system can be used on all airplanes whether they are powered by reciprocating, turboprop, or turbojet engines.

INTRODUCTION

Research has shown (ref. 1) that many airplane crash fires can be prevented by a crash-fire prevention system. Such a system includes an initiating system, which detects that conditions for crash fire exist and turns on an inerting system, which suppresses the ignition sources that can ignite spilled combustibles. Suppression of the ignition sources is accomplished by cooling the hot metal of the engine exhaust system, discharging a fire-extinguishing agent into the engine induction system, shutting off the flow of fuel and oil to the engines, and deenergizing the electrical system of the airplane. The inerting system is described in detail in references 1 and 2. This report discusses a proposed initiating system for crash-fire-prevention systems.

An initiating system may be designed so that the pilot must initiate its action or such that it is completely automatic with a manual override. The system also may be designed to react only to crash damage that can lead to fire or to react to any impact. Finally, the system may be designed to select and inert only the zone adjacent to the damage in which fire may occur or to inert all zones carrying potential ignition sources however remote from the damage.

From the study of a variety of approaches to the design of initiating systems, the form proposed in this report is considered to meet the requirements of rapid and reliable actuation while largely avoiding the hazards associated with accidental functioning. These hazards stem from the fact that one step in the inerting procedure for nacelle ignition sources involves shutting off fuel flow to the engine. Therefore, the proposed initiating system activates only that part of the fire-prevention system that inerts ignition sources local to crash damage where fire is likely. The remainder of the airplane can function in the normal way.

An alternate approach to the design of initiating systems would be to cause all elements of the fire-prevention system on the airplane to function simultaneously in the event of crash damage anywhere on the airplane. However, in view of the fact that power is lost from all engines in such a system, accidental operation of the fire-prevention system raises the danger of a serious accident. For this reason detailed study of initiating systems of this type was not made.

Because the proposed system actuates the inerting system only in those zones where fire may occur, it allows the airplane to fly with the benefit of fire protection after striking an obstacle on takeoff or landing. In addition, after the airplane makes a belly landing and there is no need for further flight, then the entire inerting system could be actuated either automatically or manually.

Several requirements must be met in the design of an initiating system. These requirements are dictated by the speed with which a fire can occur after a crash, the sequence of events that lead to a fire, and the fact that the fire-prevention system must not hinder either the normal or emergency operation of the airplane. These requirements will be similar for all airplanes whether they are powered by reciprocating, turboprop, or turbojet engines.

REQUIREMENTS

An initiating system for a crash-fire-prevention system must be able to detect the presence of airplane damage that may lead to fire. It must then actuate that portion of the prevention system that suppresses the potential hazard in time to prevent the fire.

The requirements of this initiating system are discussed in the following paragraphs.

Detecting Damage Leading to Combustible Spillage

The initiating system should detect only crash damage that creates combustible spillage since a crash fire cannot occur if a combustible is not spilled. Combustible spillage may occur when an engine breaks out of its mounts and ruptures fuel and oil lines, when the propeller-reduction-gear housing of the engine is broken as the propeller strikes obstacles, and when the fuel tanks are penetrated, for example, by trees, buildings, or the airplane landing gear. The initiating system should not, therefore, detect crash damage that will not lead to combustible spillage. For example, minor collisions that may damage a wing tip, dent a wing leading edge, or wrinkle the belly skin should not be sensed.

Inerting Selected Parts of Airplane

The initiating system should trip the inerting system only in those airplane zones where combustibles have been spilled. This selective inerting of damaged zones allows the airplane to fly with the benefit of fire protection after striking an obstacle. For example, if an airplane strikes an obstacle that penetrates the fuel tanks in one wing, that part of the electrical system in the wing not needed for emergency airplane operation should be shut off at once to prevent arcs, sparks, and hot wires from starting a fire. However, the engine adjacent to the damaged fuel tanks need not be stopped at this time. Fuel from the ruptured wing will not spread spanwise outside the wing during flight, and there is little chance that the fuel will reach an ignition source in the nacelle if the wing is properly bulkheaded.

In some airplanes, however, fuel may travel through hot-air ducts or passageways in the wing to ignition sources in the engine nacelle or fuselage (combustion heaters or heat exchangers). Shutoff systems must be installed in these hot-air ducts or passageways to prevent this flow, or the ignition sources must be suppressed.

If, on the other hand, an engine is so damaged that combustibles are spilled in the nacelle, this engine should be shut down and the ignition sources in this nacelle suppressed. Other engines need not be shut down, but can provide power for continued flight.

Actuation of Entire Fire-Prevention System When Airplane Is No Longer Flying

If, subsequent to an accident, the airplane makes a wheels-up crash landing and there is no further need for engine power, the entire fire-prevention system should act. This step is necessary because fuel spilling from ruptured wing tanks can spray forward and spread spanwise as the airplane slows down and may reach ignition sources in an engine nacelle.

Deenergizing of Electric Power Circuits of Fire-Prevention System After Actuation

The fire-prevention system should not in itself become an ignition source. It is desirable after fire-prevention measures have been started to remove electric power from all fire-prevention-system circuits that have been actuated, since these electric wires may also be damaged or broken in the crash and thus become ignition sources.

Immediate and Automatic Action

A requirement equally as important as those already described is that the initiating system should act immediately and automatically because fire can occur quickly under certain circumstances. Immediate actuation is necessary because of the proximity of combustibles to the many ignition sources in the engine nacelle of all present-day airplanes, regardless of the type of powerplant used. These ignition sources must be suppressed before they have been reached by fuel, oil, hydraulic fluid, or alcohol spilling from broken tubing or storage tanks if fire is to be prevented.

Automatic actuation is necessary because many of the ignition sources in the engine nacelles and wings can start a crash fire faster than the crew can sense that combustibles have been spilled and trip the inerting system. The inclusion of human reaction time would allow some ignition sources time to start a fire.

The need for rapid automatic action of the fire-prevention system has been shown by the experimental crashes. In these crashes, some fires started within 0.1 second after impact (ref. 2). For example, fires occurred when the engine induction system was torn open exposing the enclosed fuel-air mixture to the ignition sources in the nacelle. During the course of this crash-fire study, the induction system was torn open in 6 of the 42 engines involved. The frequency with which the induction systems were damaged indicated that this potential source of crash fires cannot be ignored.

Breaking the propeller-reduction-gear housing away from the power section is another crash event that can result in fire almost immediately. In a piston-engine-airplane crash, for example, the lubricating oil from a damaged propeller-reduction-gear housing can be carried by the airstream over the outside of the engine to the exhaust system. In the experimental crashes, the reduction-gear housings on the piston engines were ruptured in 8 of the 42 engines involved.

Similar circumstances can occur in turboprop nacelles. For example, all four propeller-reduction-gear housings were broken during a crash of a turboprop airplane at London, England. In another crash of a similar airplane at Chicago, Illinois, the propeller-reduction-gear housings were broken in two of the four engines. Tearing open the reduction-gear housing spills oil into the engine inlet of some turbopropeller engines where it can be carried into the engine to start a fire.

The initiating system must also act rapidly when an obstacle penetrates the wing, breaking the electric wiring and tearing open the fuel tanks. When fuel tanks are torn open, fuel is released in the immediate vicinity of electric arcs or sparks that are formed when the electric wiring is broken or grounded. Consequently, fire can occur very quickly.

The incandescent filaments of landing lights that are normally present during a landing or takeoff at night can also ignite spilled fuel if the surrounding bulb is broken. Ignition of fuel spilled in the wing by the incandescent filaments of a landing light was observed in an experimental crash (ref. 2).

Prevention of Accidental Operation

The fire-prevention system should not be actuated accidentally by a malfunctioning switch or short circuit in the initiating system. Accidental operation could easily cause a crash by stopping the engine of an airplane at a critical time during takeoff or landing. The initiating system can be so designed that a short circuit developing in a switch or in the electric wiring would not actuate the entire inerting system or any part of it.

The Air Transport Association of America as well as others is concerned about the hazard that can result from the accidental operation of any crash-fire-prevention system that can shut down all engines at the same time. The proposed initiating system was planned to take this hazard into account.

Manual Control and Monitoring

Provisions should be made for manual actuation of the fire-prevention system. The system should be so arranged that it can be actuated manually, because not all situations that lead to fire can be detected automatically without making the initiating system unduly sensitive and, hence, subject to potential accidental operation. For example, if a fuel tank is torn open in flight, the initiating system trips only the inerting system in this fuel-tank zone. All engines would continue to run. Subsequently, when the pilot makes a normal landing, the initiating system will not trip the rest of the inerting system since no other damage has occurred.

Fuel escaping from the ruptured fuel tank can move forward and spanwise as the airplane slows down, however, and reach ignition sources in an operating engine nacelle. Because the fuel will not reach these ignition sources for a few seconds after touchdown, the crew can trip the entire fire-prevention system after a safe landing is assured. Also, while the airplane is in normal flight, there may be times when the crew would want to turn off electric power to the crash-fire-prevention system. This action reduces the possibility of accidental operation during normal flight.

Means for monitoring the system are desired to inform the crew when switches have closed or portions of the system are malfunctioning. An indication on the monitoring system that a switch has closed tells the crew that dangerous damage has occurred or that a switch is malfunctioning. A crew check can then determine whether a malfunction is involved. If malfunctioning is involved, this portion of the system can be isolated while protection is still provided by the remainder of the system. The monitoring system should also be able to detect an imminent short circuit so that this part of the system can be isolated. Methods for providing this degree of monitoring and control have been devised without undue complexity.

EXAMPLE OF APPLICATION TO A TWIN-ENGINED AIRPLANE

In this example, it is assumed that the airplane is powered by two reciprocating engines, the fuel is stored in the wings, part of the wing fuel tanks are located above or near the main landing gear, and the landing gear, when broken in a crash, can rupture these fuel tanks.

The proposed initiating system is shown diagrammatically in figure 1. This block diagram shows how the various initiating switches are incorporated into the fire-prevention system and indicates the electric interconnections necessary to satisfy the requirements for the initiating system. The monitoring, manual control, and inerting power cut-off circuits have been deleted to simplify the diagram.

In order to satisfy the requirement that the initiating system detect crash damage that will cause combustible spillage, switches would be located as follows: a switch in each nacelle to detect engine breakout, a switch to detect when the propeller-reduction-gear housing is broken out of the nose section of each engine, a switch to detect when each main landing gear is torn out, and a switch in front of each fuel-tank zone to detect when a fuel tank might be damaged.

The engine-breakout switch indicates when the crash impact has moved the engine enough that the fuel and oil plumbing lines are liable to be broken. Because there is usually some slack in the flexible fuel and oil lines, the engines will have considerable movement before these lines are broken. The designer thus has considerable freedom in selecting the value of the engine movement that will actuate such a switch.

The switch should not operate during either normal or rough engine operation. Further, it should not operate upon minor impact of the propeller blades with the ground. It should operate, however, before sufficient engine movement has occurred to break the fuel and oil lines.

A switch similar in principle to the engine-breakout switch proposed above was installed between the mounting ring and the engine for an experimental crash as shown in figure 2. This switch actuated with a forward or aft engine movement of 0.17 inch. The switch consisted of a microswitch operated by a notched spring-loaded shaft. The entire assembly was mounted in a box. The engine movement was detected by installing the switch body on the engine mounting ring with the spring-loaded shaft bearing on a plate which was fastened to the engine. Excessive foreward or aft engine movement would move the shaft far enough away from its center position that the slant sides of the notch would move the lever of the microswitch and close it.

In tests with this switch, fore and aft engine movements up to 0.03 inch were recorded during normal engine operation. With rough engine operation, the fore and aft engine movement was no more than that during normal engine operation. During rough engine operation, the engine movement increased in a rotary direction instead of fore and aft. During these crash tests, fore and aft engine movements from 0.25 to 0.29 inch were measured when the propeller blades struck an abutment of railroad ties and dirt. This propeller impact was fairly severe and produced incipient failure of the engine mounts but did not break oil and fuel lines. It appears, then, that a switch setting of 0.25 inch would be adequate for this specific engine installation.

The propeller-reduction-gear switch, shown on the block diagram (fig. 1), indicates when the propeller-reduction-gear housing of the engine breaks away from the power section. A switch similar to that used to detect engine movement could be used for this purpose. A proposed method of installing such a switch on the reduction-gear housing is shown in figure 3. The switch body would be fastened to the flange on the power section of the engine with the spring-loaded shaft resting on the reduction-gear housing. This location was chosen because, in the experimental crashes, the reduction-gear housings always broke away from the power section at this flange.

The landing-gear switch (fig. 1) indicates when the landing gear is torn out and fuel may spill into the wheel well. One method of installing such a switch is shown in figure 4. This switch assembly consists of a cable attached to the landing gear in such a way that it actuates the switch when the landing gear is torn off.

The fuel-tank-penetration switch (fig. 1) indicates when the wing has been penetrated, thus indicating that a fuel tank may be torn open spilling fuel and breaking electric wiring. This switch is essentially the same as the engine-breakout switch except that a cable is attached to the notched spring-loaded shaft as shown in figure 5. The complete switch was installed inside the wing. The cable was supported at intervals along the spar in front of the fuel tanks as shown in figure 6. Crash tests of this switch showed that this cable should be located far enough ahead of the front spar to allow the cable to close the switch before the obstacle has reached the spar. However, the cable should be far enough behind the leading edge of the wing so that minor impacts such as a bird striking the wing will not close the switch. The switch should also be located close to the bottom of the wing to detect a penetration that could be produced by a slanted obstacle or one that does not pierce the entire leading edge of the wing. It is very important that the wing fuel-tank-penetration switch be cable operated so that electric wiring for the switch need not be carried in front of the fuel tanks. Eliminating the wiring prevents the sparks or arcs that would occur if this wiring were broken.

The electric wiring normally carried in the wing in front of the fuel tanks may also be an ignition source when it is broken. Even after the inerting system has disconnected the wiring from power sources and grounded the circuits, an interval of about 0.1 second is needed to deenergize these electric circuits (ref. 1). The distance between the leading edge of the wing and the fuel tanks in most airplanes is too small to allow this much time, even if electric circuits were deenergized at the moment the leading edge strikes an obstacle. Therefore, it is recommended that, whenever possible, this electric wiring be moved to the rear of the wing behind and near the top of the rear spar. It is also suggested that this wiring be sheathed. The sheathing can consist in placing the electric wiring in loose, elastic, heat-resisting sleeves that would remain intact under tension until the wiring inside breaks. In this way, any arc resulting from a break in the electric wiring will be shielded from combustibles until the arcing has subsided.

These four switches, then, detect the various ways in which damage can occur and result in combustible spillage, if an airplane of the type assumed crashes.

In order to obtain selective inerting, the second requirement, the initiating switches are electrically connected to the fire-prevention system in such a way that only the inerting system local to the airplane damage is actuated. In figure 1, the line from the engine-breakout and reduction-gear-housing switches indicates that the switches actuate the inerting system for that nacelle in which these switches have been installed and send a signal to the arming control box. Likewise, if the landing gear is damaged, the landing-gear switch inerts the nacelle into which the landing gear retracts and also sends a signal to the arming control box. The landing-gear switch is provided only in those airplanes where landing-gear damage is likely to produce combustible spillage. The fuel-tank-penetration switch deenergizes, in the damaged wing, those electric circuits not needed for emergency operation of the airplane. This selective inerting protects the zones adjacent to the crash damage.

The next requirement is to actuate the entire inerting system after the pilot has flown the airplane to a landing area, a wheels-up crash landing has been made, and engine power is no longer needed. This ground contact can be sensed by contact pressure switches, which are commercially available. The switches are in strip form and can be fastened to the underside of the airplane at any location. A contact pressure of 150 pounds per square inch any place on the strip closes the electric circuit.

A signal in the arming control box from one of the four initiating switches previously described can be combined with signals from two ground-contact switches (fig. 1). These combined signals, when recieved in the total-inerting control box (fig. 1), activate the entire fire-prevention system which then suppresses all remaining ignition sources on the airplane. For example, if an engine-breakout switch, propeller-reduction-gear switch, landing-gear switch, or a wing fuel-tank-penetration switch, and any two ground-contact switches have been closed, the entire inerting system will act.

The requirement for simultaneous signals from two ground-contact switches in conjunction with a signal from one other initiating switch prevents the entire inerting system from functioning while the airplane is still in the air. "Bird strikes," minor collisions with trees, flying debris from the runway, and so forth, may close a single ground-contact switch, but it is extremely unlikely that two switches would be closed simultaneously if these switches are located properly.

The proper positions of the contact pressure switches on an airplane and the number needed depend upon the airplane configuration. On any airplane, however, the switches must be located in such a way that two of the switches will close when the airplane is on the ground. This must occur when any one or any combination of landing gear is retracted or torn off. In addition, these switches should be placed so that impact with a pole or tree will not close two switches at the same time. Placing the switches near each other, either laterally or longitudinally, would allow a single pole to close both switches before the airplane landed.

The contact pressure switches should also be installed with the electric leads entering the fuselage behind the switch instead of in front of it. Installed in this way, there will be time for the switch to close and send a signal before the switch is torn completely away from the airplane.

How these conditions would fix the position and number of ground contact switches is shown by the airplane chosen as an example. The switch positions chosen are shown schematically in figure 7. The two contact pressure switches A on the underside of each nacelle would close if the airplane landed with the entire landing gear retracted or torn off. To satisfy the condition of two ground-contact switches being closed when one main landing gear is retracted or torn off, a nacelle switch and a switch on one side of the belly at the rear B form the pair. In a similar way, if one main landing gear and the nose gear have been torn out, a nacelle switch and a switch on the fuselage nose C make up the pair.

CONCLUDING REMARKS

The initiating system proposed in this report meets the requirements for rapid and reliable actuation of the inerting system while largely avoiding the hazards associated with accidental functioning. The initiating system discussed in this report is based upon the use of mechanically simple switches that detect linear movement or contact pressure and avoids the use of inertia and frangible switches. Switches of these types were tested in experimental crashes. Experience showed that in order for inertia switches to operate rapidly enough to trip the inerting system within the allowable time, the sensitivity to acceleration must be high. With high sensitivity, the switches may be operated accidentally by minor accelerations. Also, the experimental crashes showed that frangible switches may not function even though the structure adjacent to the switch was heavily damaged.

The proposed system can be modified from the arrangement shown in this report to meet the special needs of various airplane configurations. The method used to detect dangerous damage in each of the airplane components described here can be employed for the corresponding components in any airplane. However, the number of damage detector elements and their position on the airplane can vary according to the airplane design.

In order to provide an extra margin of safety in airplanes carrying crash-fire protection, it would be desirable to have means for restoring the fuel and oil flow to the engines after the crash-fire system has functioned. In this way, the crew can restart any engine, if in their opinion the degree of engine damage and the nature of the emergency warrant a restart.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
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2. Pinkel, I. Irving, Preston, G. Merritt, and Pesman, Gerard J.: Mechanism of Start and Development of Aircraft Crash Fires. NACA Rep. 1133, 1953. (Supersedes NACA RM E52F06.)

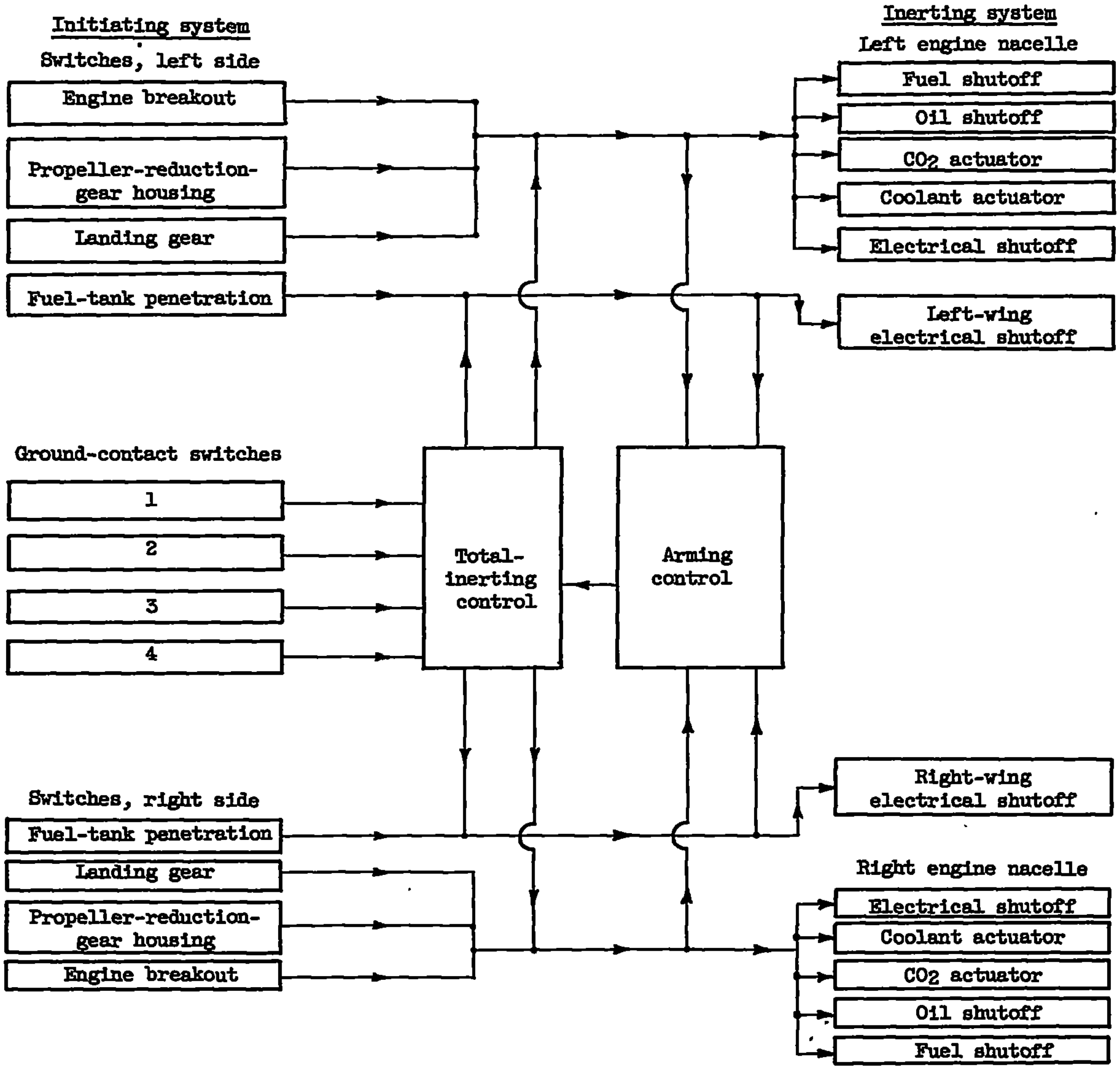

Figure 1. - Block diagram showing how initiating switches are incorporated into crash-fire-prevention system for twin-engined airplane.

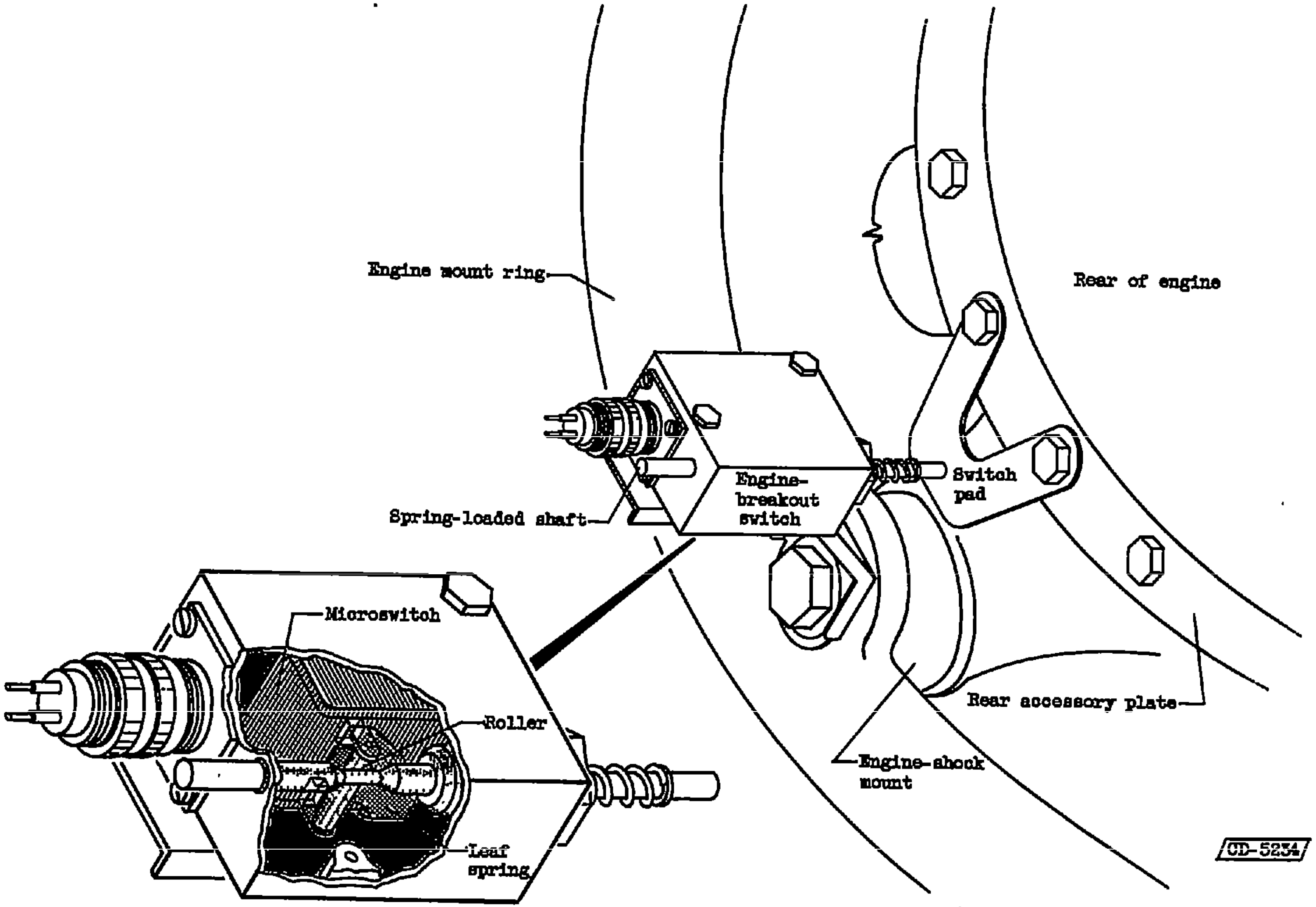

Figure 2. - Switch installed between engine mounting ring and engine to detect engine breakout.

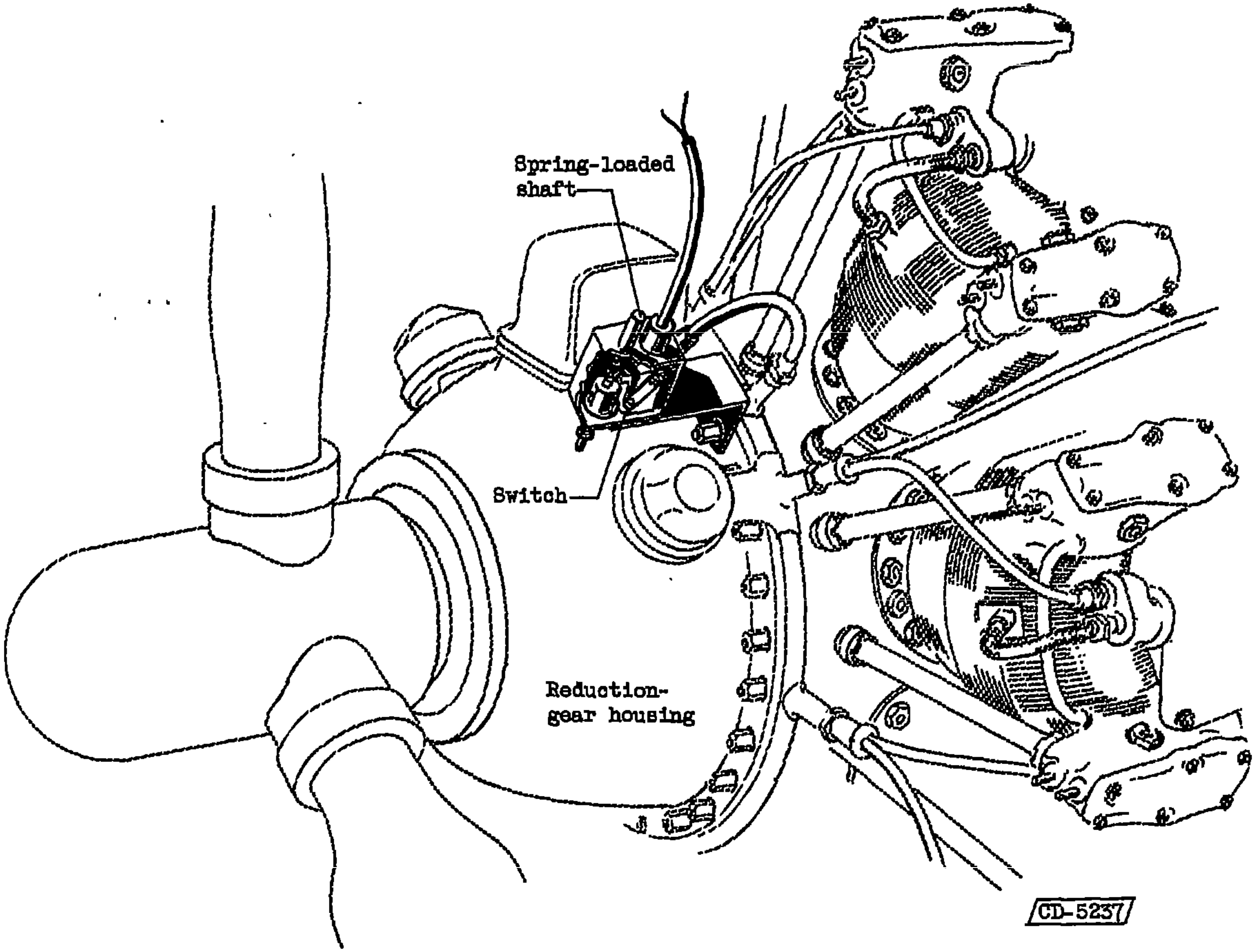

Figure 3. - Switch installed on reduction-gear housing to detect breaking away of nose section from engine power section.

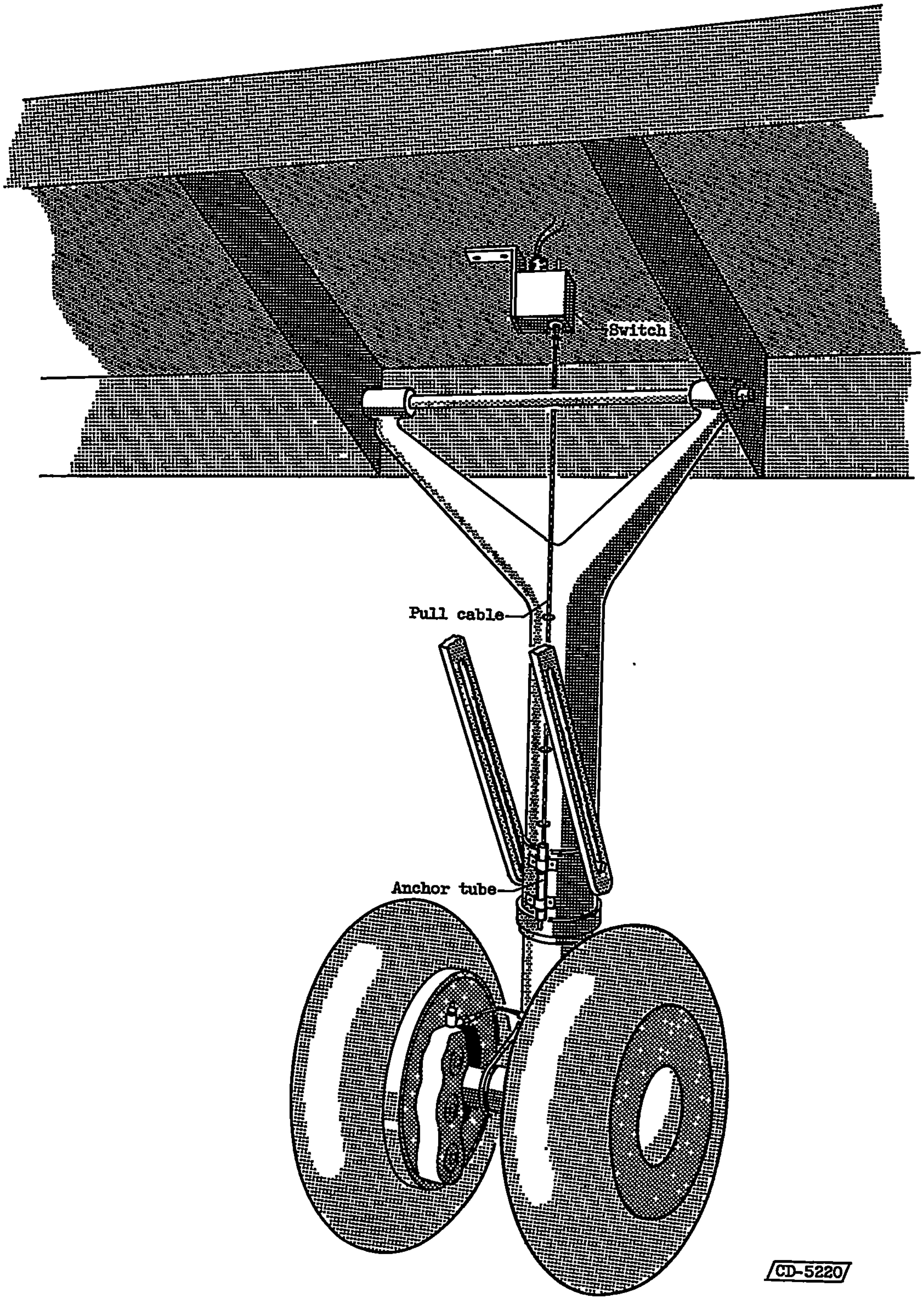

Figure 4. - Switch installed on main landing gear to detect tearing out of landing gear from airplane.

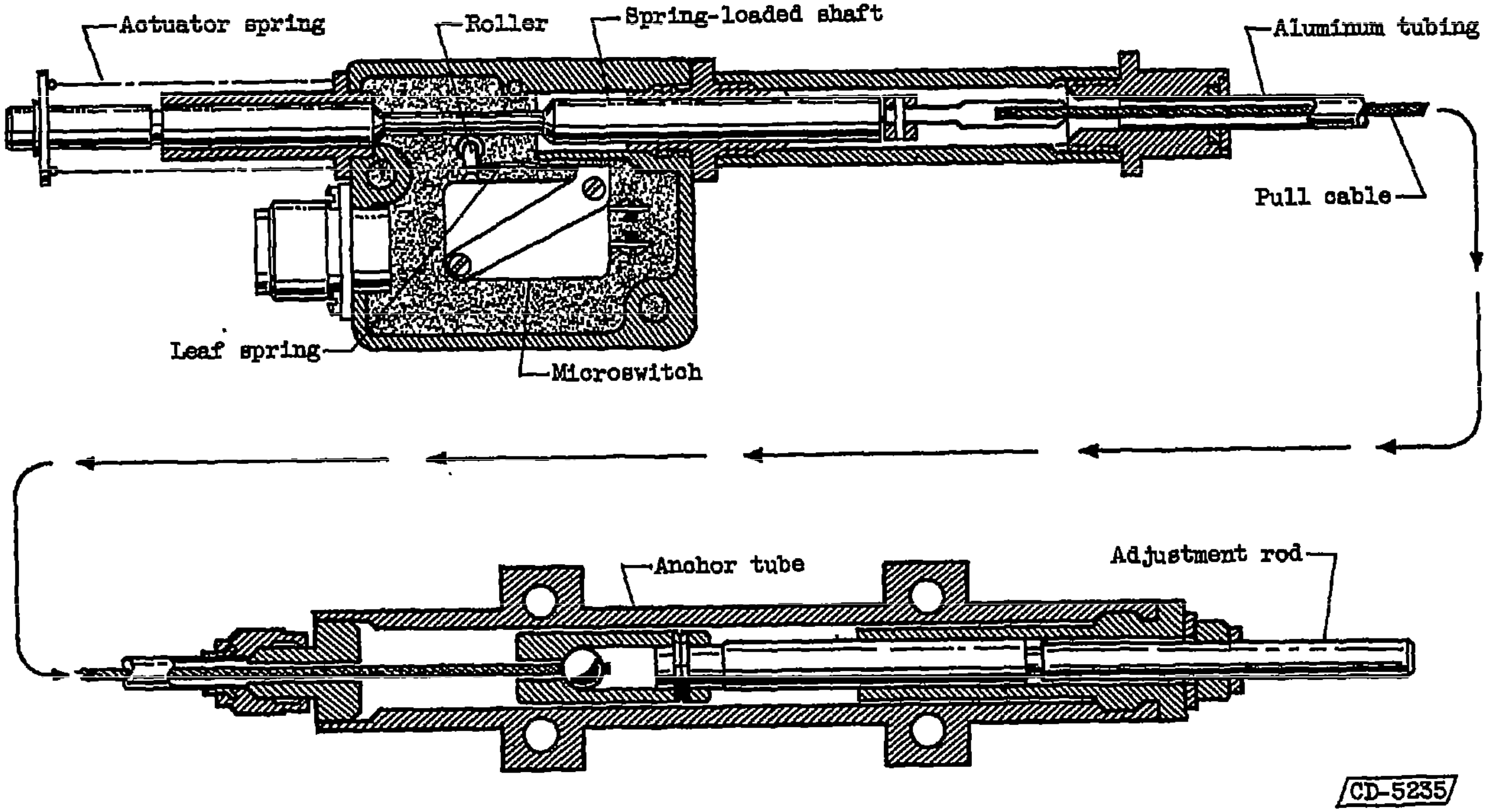

Figure 5. - Fuel-tank-penetration switch.

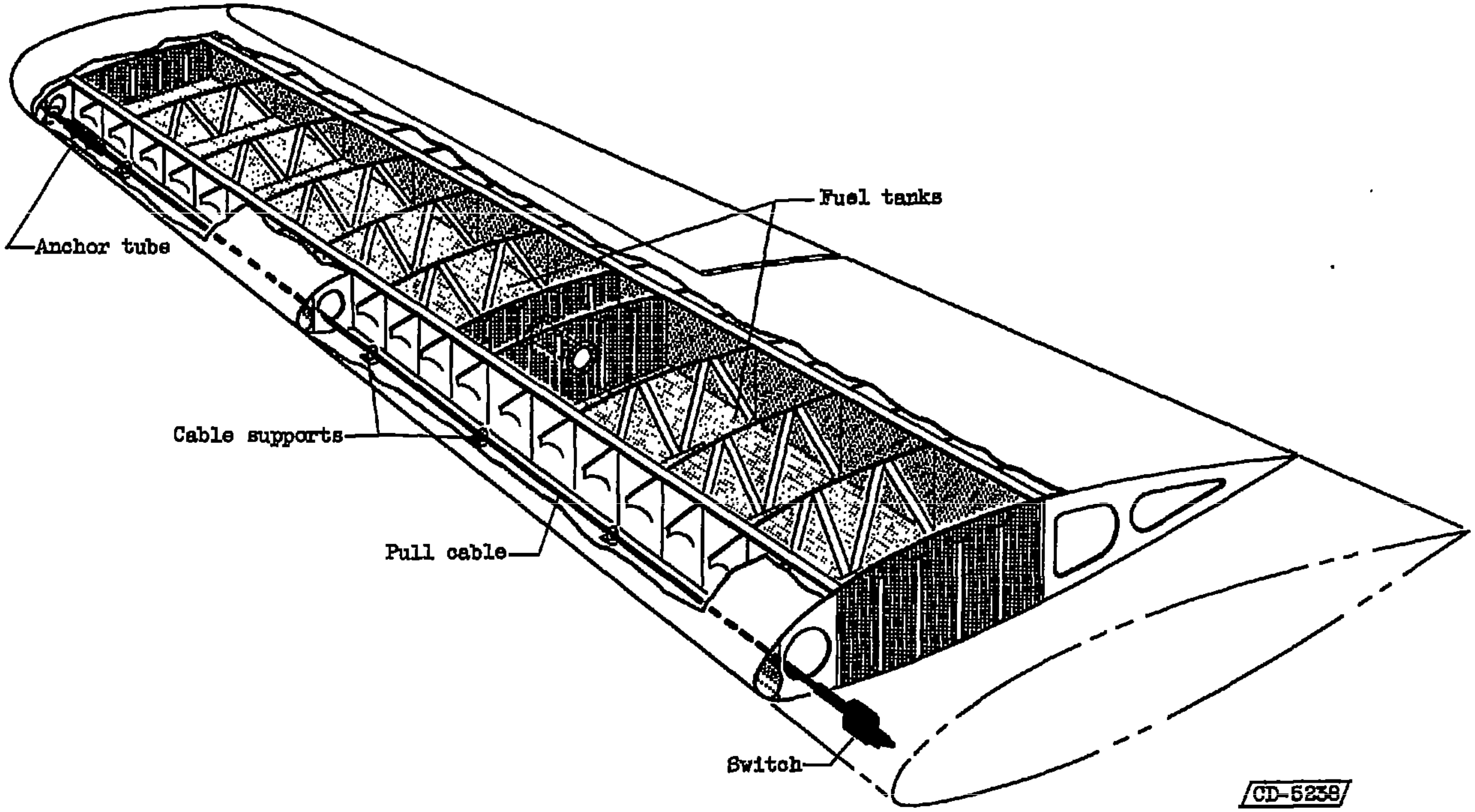

Figure 6. - Fuel-tank-penetration switch installed inside wing.

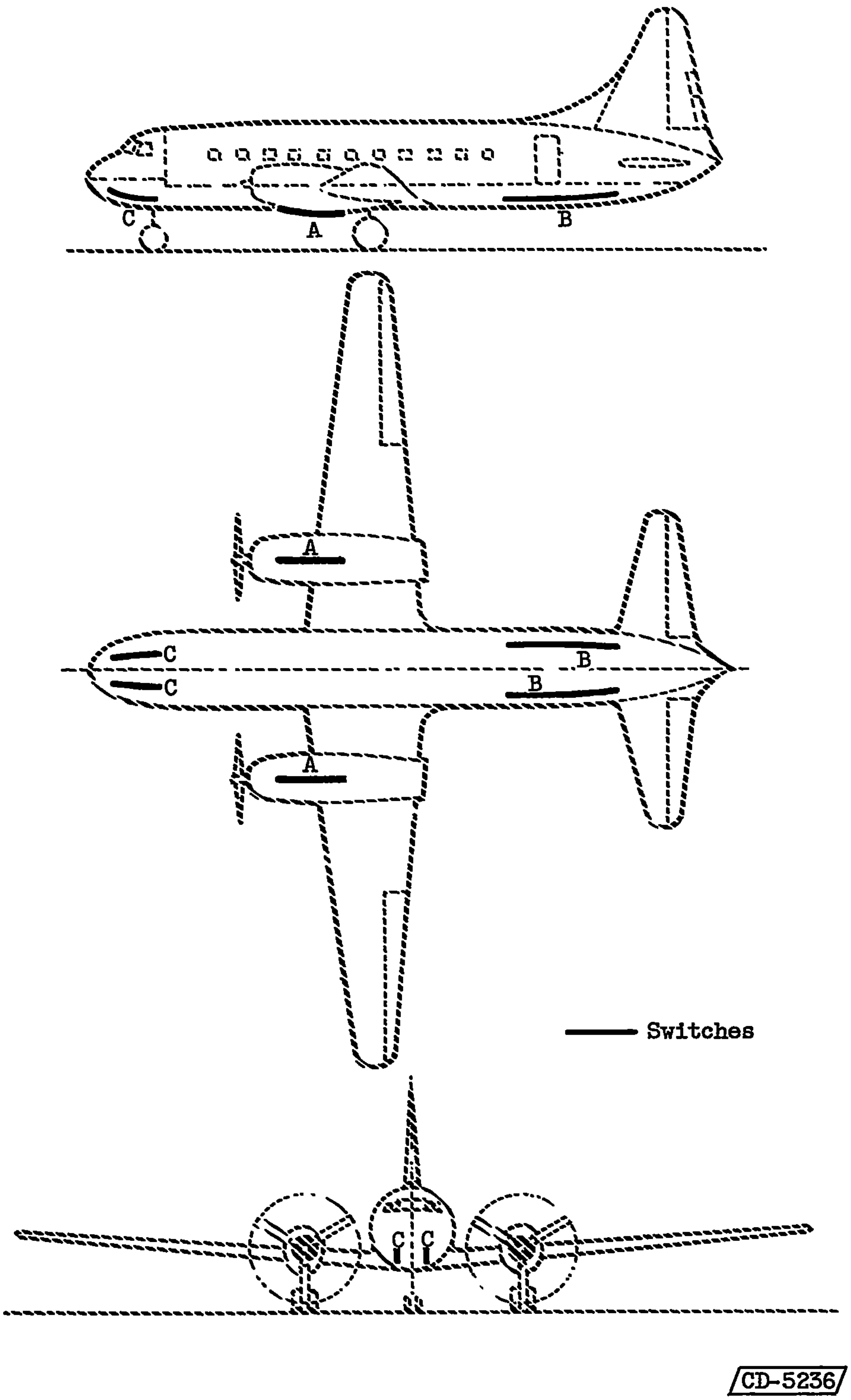

Figure 7. - Location of fuselage-belly-contact switches on twin-engined airplane.

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