

RESEARCH MEMORANDUM

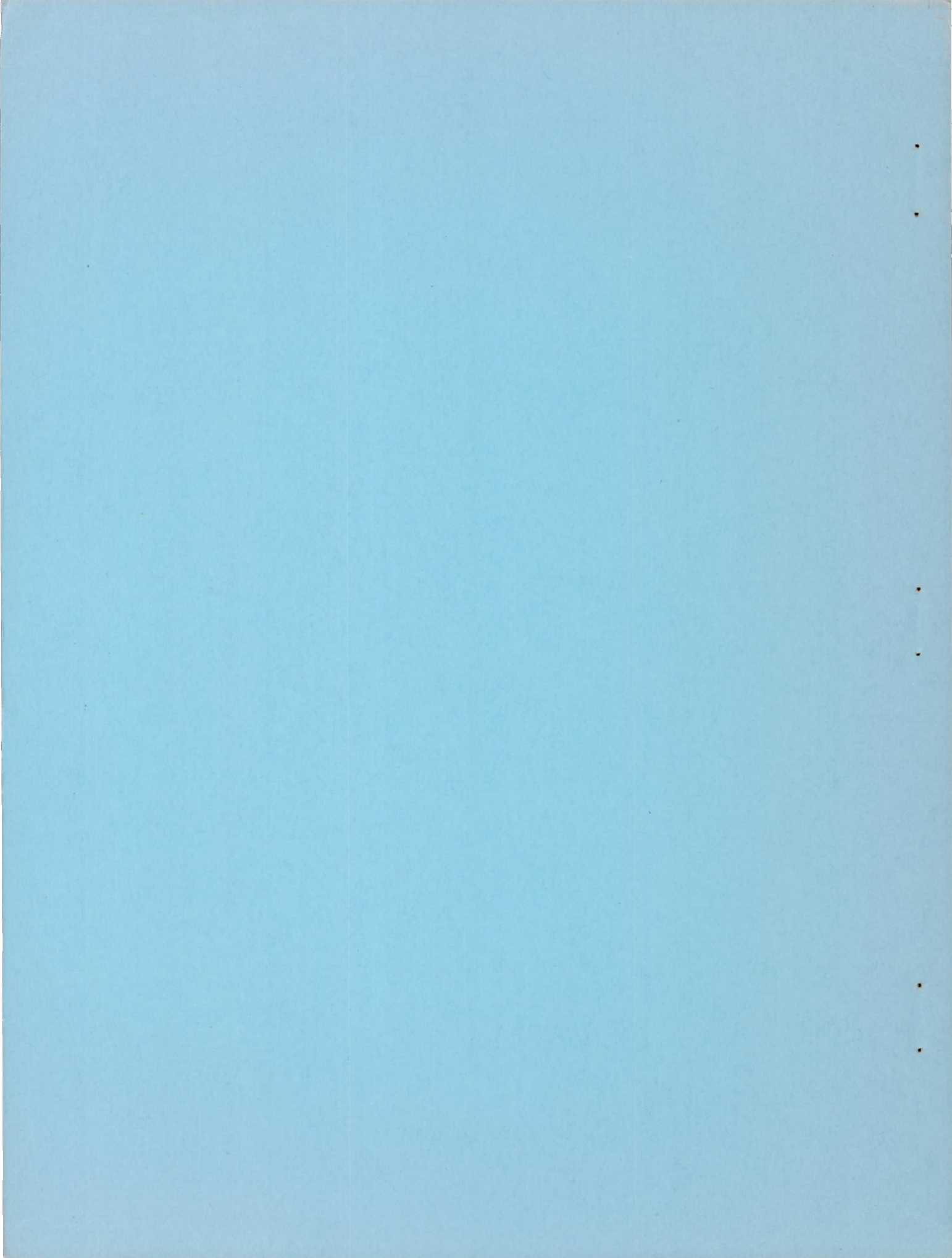
FULL-SCALE PERFORMANCE STUDY OF A PROTOTYPE CRASH-
FIRE PROTECTION SYSTEM FOR RECIPROCATING-
ENGINE-POWERED AIRPLANES

By Dugald O. Black and Jacob C. Moser

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NATIONAL ADVISORY COMMITTEE
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FULL-SCALE PERFORMANCE STUDY OF A PROTOTYPE CRASH-FIRE PROTECTION
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SUMMARY

An airplane was experimentally crashed to study the performance of a prototype crash-fire inerting system for reciprocating-engine-powered airplanes. The results of previous experimental crashes indicate that the crash conditions imposed almost always result in fire. The inerting system was therefore exposed to conditions that would adequately test its ability to inert and de-energize the various ignition sources known to cause crash fires.

The fact that fire did not occur during this crash indicated that the crash-fire inerting system functioned satisfactorily as a complete unit. The prototype inerting system functioned with a rapidity equal to or greater than that of the experimental system used in the NACA crash-fire studies.

INTRODUCTION

A commercial version of an NACA crash-fire prevention system for reciprocating-engine-powered airplanes, based on results of the crash-fire program reported in reference 1, has been built for the U. S. Air Force by Walter Kidde & Company, Inc. The performance of this prototype system was studied by the NACA in a full-scale experimental crash. This crash-fire prevention system includes an "initiating system" which senses that a crash has occurred, and an "inerting system" which inertes the various ignition sources that can start a crash fire. Only the performance of the inerting system is described in this report.

The performance of the inerting system was studied by installing it in a properly instrumented C-82 airplane that was subsequently crashed. The crash conditions imposed almost always resulted in fire when no fire-prevention system was used. The inerting system was therefore exposed to conditions that would adequately test its ability to inert and de-energize the various ignition sources known to cause crash fires.

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CRASH-FIRE IGNITION-SOURCES INERTING SYSTEM

The crash-fire ignition-sources inerting system is composed of four main components arranged to function automatically upon airplane crash:

- (1) A fuel shut-off valve on each fire wall and in the tubing between each carburetor metering section and fuel injection nozzle; an oil shut-off valve on each fire wall
- (2) A storage and plumbing system in each nacelle for discharging carbon dioxide into the diffuser housing of the engine induction system
- (3) A storage and plumbing system in each nacelle for spraying a coolant on the hot exhaust collector ring and heat exchangers
- (4) A switching arrangement for disconnecting the airplane batteries and generators from the electrical power system

The crash-fire study reported in reference 1 shows that all these components are required to inert and de-energize the ignition sources that may start a crash fire.

The fire-wall fuel and oil valves stop the flow of combustibles into the nacelles. This action limits the possibility of spread of fire if the fuel or oil tubing is broken.

The fuel shut-off valve between the carburetor and the fuel-injection nozzle stops the engine and prevents the further production of hot exhaust gases, exhaust torching, and backfires. Carbon dioxide is injected into the diffuser housing to inert the combustible mixture remaining in the engine induction system while the fuel valve is closing, and the engine is purged with air. The carbon dioxide discharges with sufficient velocity to mix uniformly and rapidly with the induction-system fuel-air mixture.

The coolant spray system cools the hot metal of the collector ring and the heat-exchanger assemblies so that they are eliminated as potential ignition sources. This coolant is a solution of water and chemicals. The chemicals are used to depress the freezing point to -40° F. The steam from this coolant solution inerts the atmosphere surrounding the exhaust disposal system while cooling occurs.

The switching arrangement de-energizes the electrical power circuits so that arcs and sparks that would act as ignition sources are not created during the crash. Three components are needed in this system: (a) a relay that disconnects the electrical power circuits from the generators and battery; (b) a second relay that connects the power circuit directly

to ground, thus rapidly decreasing the potential to zero; and (c) a time delay switch that de-energizes the initiating and inerting circuits after the inerting system has been actuated. For this crash, the airplane battery was moved to the cockpit floor from the nose-belly area where it is normally located to protect it against crash damage. This assured that power for actuating the fire-prevention system would be available for a longer time.

These components of the inerting system are installed in an engine nacelle at the locations shown by the schematic diagram in figure 1. This crash-fire ignition-source inerting system is completely automatic, since the inerting system is actuated at the time of impact with the crash barrier by the crash-actuated initiating system. All components of this crash-fire prevention system are described completely in reference 2.

DESCRIPTION OF CRASH

The procedure for such experimental crashes is fully described in reference 3. Briefly, however, the crash was conducted in the following manner. The unmanned airplane was guided by a rail along a 1700-foot paved runway at full power until it crashed into a series of obstacles at take-off speed (fig. 2). The first obstacles were two abutments, made of railroad ties and earth, placed in the path of the main landing wheels. These barriers removed the landing gear and damaged the propellers and engines. Four poles then ripped open the fuel tanks in the wings. After being damaged, the airplane slid across an open area on its belly. The sliding airplane was enveloped by a large volume of fuel mist formed by the fuel spilling from the wings while the airplane was in motion. Because the fuel in vapor, mist, and liquid form was extensively distributed, this crash was a severe test of the inerting system.

INSTRUMENTATION AND DATA RECORDING

Instruments were installed to measure the airplane acceleration after impact, the time to open or close each valve or relay, and the time each inerting-system component took to function. These data were recorded by one or more of the following recording systems:

- (1) Cameras photographing an instrument panel
- (2) Magnetic tape recorders
- (3) Telemetering equipment
- (4) Cameras installed around the crash area

Of the four data-recording systems described, the most complete record of time histories was obtained by photographing an instrument panel in a fireproof box that was carried in the airplane. The instrument panel held lamps that indicated the functioning time of switches, valves, and relays. Because of the low film speed (about 29 frames/sec), and also because of the lag in changes of light intensity of the lamps on the instrument panel, it was necessary to devise an interpolation method of reading these data. By this method it was possible to interpret the photographic record of a particular event within ± 0.004 second.

The data obtained by photographing the instrument panel included

- (1) Time
- (2) Backfire indication
- (3) Exhaust-disposal-system temperatures
- (4) Fuel flow
- (5) Fuel pressure
- (6) Time of airplane impact with barrier
- (7) Functioning time of the various inerting-system components
- (8) Fuel and oil shut-off time
- (9) Carbon dioxide pressure in lines from reservoir to engine inlet
(Used to determine when CO₂ flow was fully established)
- (10) Coolant pressure in distribution line serving the hot exhaust-disposal-system metal

The magnetic-tape recorders obtained a time history of the inerting-system operation. The telemetering equipment recorded impact accelerations and engine displacement. Cameras installed around the crash area photographed the airplane as it progressed through the crash.

Duplicate time histories of the inerting-system operation were obtained by the cameras photographing the instrument panel and by the magnetic-tape recorders. These duplicate records were obtained to reduce the possibility of losing the data because of failure in one of the recording systems. The methods of obtaining these data are described in reference 3.

RESULTS AND DISCUSSION

Crash Damage

In this experimental crash, initial impact with the wheel barrier occurred at a speed of 86 miles per hour. The airplane was damaged severely by the succession of crash events. The airplane slid 297 feet from the point of initial impact. The time after impact at which each of the crash events occurred was determined from the high-speed photographs taken from the camera stations and was checked by other data such as telemetered acceleration records. The crash events and the time after first impact at which they occurred is given in the following table:

| Crash event | Time after impact, sec |
|---|---------------------------|
| Propellers strike crash barrier (time zero) | 0 |
| Main landing wheels strike crash barrier | .095 |
| Wings strike first poles | .273 |
| Belly strikes ground | .380 |
| Wings strike second poles | .758 |
| Airplane stops sliding | 4.6 |

The propellers of both the right and the left engines were bent from impact with the crash barrier as shown by photographs in figures 3(a) and (b), respectively.

Fuel tanks 2 and 5 in both wings were pierced by the pole barriers. The extent of the damage to the left and right fuel tanks and wings is shown in figures 4(a) and (b), respectively.

The engine nose-gear accessory housings were not damaged during the crash. Tubes in the right engine mount were slightly bent but not broken. Figure 5 shows the broken generator housing in the right engine nacelle. On the right engine the exhaust-stack connecting sleeves were pulled out of cylinder 14 (fig. 6(a)) and cylinder number 2 (fig. 6(b)). Two of the right-engine exhaust collector-ring mounting brackets were broken away from their support when their mounting bolts were sheared. Figure 7 shows one of these brackets broken from the support. The disruption of the exhaust stacks and shearing of the bolts were caused by the engine's twisting during the crash. The exhaust system on the left engine was not damaged.

The fuel and oil plumbing systems on both engines remained intact. Post-crash examination showed, however, that large amounts of fuel had reached the nacelles and exhaust stacks from the ruptured wing fuel tanks. The fuel path from the ruptured tanks could be traced by the dye that had been added to the fuel. The fuel ran along the bottom of the wing, down

the nacelle to the bottom of the fire wall near the fuel strainer. Fuel also ran into the wheel well and onto the landing gear retracting mechanism, inside the wheel well doors, and on the rear of the fire wall.

The amount of fuselage crushing that occurred during the crash is shown in the photographs of the right and left sides of the airplane in figures 8(a) and (b), respectively. The dotted lines in each figure define the original contour of the fuselage before the crash. In order to determine the extent of the crash damage to the skin and structure on the belly of the airplane, the fuselage was jacked up and examined. Figure 9 is a front view of the fuselage belly showing the damage to the skin and structure. The large opening in the center of the fuselage belly is the nose-gear well. The damage directly behind this opening was caused by the nose-gear strut's being driven rearward by impact with the ground and by the subsequent slide of the airplane. The skin and structure on each side of this opening was twisted and ripped. A front view of the nose gear and front bulkhead in figure 10 shows the structural damage to the bulkhead to which the nose-gear assembly was attached. This entire bulkhead was torn loose by the nose gear as it was driven rearward for approximately 9 feet by the force of the crash. Figure 11(a) shows the buckled floor and the structural damage in the left front portion of the cargo compartment. Damage to the structure in the right front portion of the cargo compartment is shown in figure 11(b).

The results of previous experimental crashes such as described in reference 1 indicate that the conditions just described almost always result in fire when no crash-fire prevention system is employed. The inerting system was therefore exposed to conditions that would adequately test its ability to inert and de-energize the various ignition sources known to cause crash fires. The fact that fire did not occur during this crash indicated that the crash-fire prevention system functioned satisfactorily as a complete unit.

Performance of Fire-Prevention System

The performance of individual components of the fire-prevention system is described in the following paragraphs. The switching arrangement that disconnects the airplane batteries and generators from the airplane power distribution system is described first. This sequence in presentation is necessary because short circuits in the airplane electrical system affected the performance of various parts of the inerting system.

Electrical system de-energizing. - The variation of voltage in the airplane electrical system during the crash is presented in figure 12. Impact of the airplane with the first crash barriers occurred at time zero. Two sharp reductions in voltage occurred at approximately 0.05

and 0.11 second after impact. These reductions in voltage were caused by short circuits when the generators were torn from their mountings. The relays in the inerting system that disconnect the generators and battery from the airplane electrical system opened at 0.12 second after impact. The airplane voltage began to drop immediately thereafter. Part of the voltage drop after 0.12 second was the result of this relay action. Closing of a relay that grounds the power circuit (shortly after the batteries and generators are disconnected) hastened this voltage reduction. The grounding relay is actuated by the inerting system.

The electrical de-energizing action was complete when the voltage (fig. 12) reached zero at 0.178 second after impact. The 2-volt rise in potential thereafter could have been caused by the generator effect of coasting motors. Although the energy represented by this resurgence of voltage may be marginal as an ignition source, it should be prevented by means of a better grounding system, as discussed in the following paragraph.

The effect of the grounding relay in the fire-prevention system on the airplane electrical system voltage is shown in figure 13. The voltage variations recorded during this crash are compared with those obtained in precrash trials of the electrical inerting system with and without a grounding relay. It can be seen from this figure that zero potential is obtained in a much shorter time with a grounding relay. The grounding relay used in the crash study had smaller contacts and lighter contact pressure than the relay used in the precrash studies. Because of these differences, the voltages in the precrash studies reached zero 0.25 second sooner than in the crash. In figure 13 "zero" on the time coordinate is defined as the moment at which voltage was applied to the inerting system.

Short circuits, such as occurred in this crash, could prevent proper functioning of the fire-prevention system. For this reason, a suitable method should be devised to prevent short circuits in the airplane electrical system from influencing the output of the battery to the inerting system. If the battery is disconnected from the airplane electrical system before take-off or landing, short circuits in the airplane electrical system could not damage the battery. Therefore, the battery will have full potential to operate the fire-prevention system. Disconnecting the battery would not appreciably affect the airplane electrical system because the generators are generally large enough to meet all electrical requirements.

Inerting-system voltage. - The effect of the short circuits in the airplane electrical system on the voltage applied to the inerting-system components is presented in figure 14. The initiating system first applied voltage to the inerting-system components 0.09 second after impact. The second short circuit in the airplane electrical system occurred immediately thereafter and reduced the inerting voltage to zero, which delayed

the action of part of the inerting system. However, this short circuit quickly disappeared and both the airplane-electrical-system and the inerting-system voltage increased to battery potential (23 volts). The inerting-system voltage then remained at 23 volts from approximately 0.12 to 0.26 second after impact. At 0.26 second after impact the time-delay switch opened the circuit from the battery to the inerting system. The inerting voltage reached zero 0.27 second after impact and the inerting system wiring could then no longer act as a potential ignition source. The varying voltage after 0.27 second was due to inductive effects in valve and relay coils.

Although the first pulse of inerting voltage 0.09 second after impact contained enough energy to actuate the explosive cartridge coolant valves, it only partially energized the coils in the other valves and relays. The coolant valves require little energy to operate because the explosive is ignited by a wire filament that heats rapidly. The other valves and relays require an electrical impulse of at least 0.02-second duration at full battery voltage to open or close. This value was obtained from precrash trials.

Oil and fuel shut-off valves. - In order to evaluate the effect of crash acceleration on the operation of the oil and fuel valves, it was necessary to compare their functioning time during crash with those obtained when the airplane was stationary. The effects of voltage variations can be eliminated by converting the interrupted voltage to a single impulse of equal energy. This approximate conversion (fig. 15) was obtained by replacing areas A and A₁ by a rectangular pulse of the same area. The new area B represents a single uninterrupted pulse starting at 0.10 second rather than at 0.09 second as recorded. Therefore, voltage will be considered as having been applied at 0.10 second after impact, thus giving functioning-time data independent of the influence of the short circuit.

The following table shows the time the oil and fuel shut-off valves took to function, after application of voltage, under crash conditions in which accelerations were experienced:

| Shut-off valve | Functioning time, sec | |
|------------------|-----------------------|--------------|
| | Left engine | Right engine |
| Oil | 0.02 | 0.02 |
| Fuel (fire wall) | .02 | Unknown |
| Fuel (engine) | .06 | .02 |

Four of the valves closed with the same speed under crash conditions as in precrash trials. This indicates that these valves are insensitive to accelerations of the magnitude obtained in this crash. All these valves were found closed after the crash, including the one for which the closing

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time was not obtained because of failure in the indicating system. The recorded data for the left-engine fuel valve at the carburetor showed that it took 0.04 second longer to function than the other valves. This delay is also believed to have been caused by failures in the indicating system. The values of 0.02 second listed for the four valves are considered to be correct and representative.

Because the fuel and oil shut-off valves can be actuated by an electrical impulse enduring for at least 0.02 second, an additional electrical pulse, such as that resulting after a short circuit, could reopen a valve if it were closed by the first pulse. Fortunately, the first pulse of inerting voltage in this crash was too short to close these valves; thus, the second pulse helped to close instead of open them. Eliminating short circuits would prevent the possibility of reopening such valves.

Induction-system inerting. - Carbon dioxide discharged into the diffuser housing inerts the fuel-air mixture in the engine induction system while the fuel valve is closing and the engine is purging itself with air. Purging the engine with air takes about 0.2 second at normal take-off power. The carbon dioxide pressure in the distribution line to the right-engine diffuser housing started to build up at 0.02 second after the carbon dioxide cylinder solenoid valve was energized, and reached its maximum operating pressure of 550 pounds per square inch gage in an additional 0.21 second. The carbon dioxide in the left engine was not discharged because the electrical connector had been inadvertently left off the operating head. Fortunately, in this instance, flames at the engine inlet and exhaust did not appear at the left engine and no fire occurred.

It must be recognized, however, that crash circumstances can occur in which some part of the induction system is torn open at the same time that the carbon dioxide system is being energized and the valve is opening. The combustible mixture in the induction system can then be spilled in the vicinity of the collector ring and be ignited while the carbon dioxide system is filling the distribution lines and beginning to discharge into the diffuser housing. The carbon dioxide system cannot be expected to prevent such fires. Crash circumstances similar to those just described, however, apparently do not occur frequently. Induction systems were torn open in only 3 of the 42 engines involved in the experimental crashes conducted by the NACA.

Exhaust-disposal-system cooling and inerting. - The exhaust-disposal-system coolant flow for the right and left engines started at 0.23 and 0.27 second, respectively, after the inerting voltage was applied to the valve. The steam and other gases from the evaporating coolant inerted the atmosphere around the collector ring soon after the coolant flow started. The full coolant flow on both engines lasted for 22 seconds. Mixed coolant and driving gas continued to flow for an additional 14 seconds.

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Both left and right exhaust disposal systems were cooled at essentially the same rates as the experimental systems studied in previous crashes, indicating that these systems functioned properly. The lag of about 0.25 second before the coolant flow starts introduces the possibility of fire starting from fuel or oil spilled on the collector ring during this interval. The fuel or oil plumbing would not provide such combustibles, however, because the rapid actuation of the fuel and oil shut-off valves prevents fuel or oil from being sprayed on the collector ring from either of these systems during this 0.25-second interval. Fuel-air mixture spilled from a broken induction system, as described in the preceding paragraph, could reach the exhaust collector ring and be ignited before the collector-ring cooling system can function. Oil from a broken propeller reduction gear housing could conceivably reach the collector ring during this interval. A study of the crashes in which the experimental inerting system was used shows, however, that fire did not result during this 0.25-second interval, apparently because the time required for the oil to reach the collector ring plus the residence time required for ignition is equal to or greater than the 0.25 second lag in the action of the coolant system. The reduction gear housing was ruptured in 8 of the 28 engines involved in these crashes. Oil spilling from the ruptured reduction gear housing did not ignite on any of these 8 engines.

The temperature history of the right-engine exhaust collector ring (fig. 16) indicates that it took 17.5 seconds for the hottest portion of the exhaust collector ring to cool to 950° F, the lowest temperature at which gasoline will ignite readily on the external surfaces of the exhaust system, and 24 seconds to cool to 760° F, the lowest temperature at which lubricating oil was observed to ignite readily. The temperatures continued to fall well below these critical values, indicating that the cooling system cooled the exhaust collector ring enough so that it was no longer an ignition source.

The temperature history of an exhaust heat exchanger (fig. 17) shows that the hottest part of the heat exchanger had been cooled to 850° F by the time the flow of coolant and driving gas stopped. Precrash studies showed that neither gasoline nor oil would ignite on these heat-exchanger surfaces at this temperature. The relatively stagnant atmosphere of inert gases within the heat exchanger evidently continued to protect this zone while the heat exchanger continued to cool by radiation and conduction. The data presented in figure 16 were taken from the right engine; the data from the left engine are essentially similar.

The coolant used in the earlier experimental inerting systems (ref. 1) was water, whereas in this prototype system the coolant was a mixture of water and chemicals. Figure 18 compares the cooling effectiveness of water and the coolant solution for the exhaust collector ring. These data were obtained from a preliminary study made before the airplane was crashed. The results indicate that the rate of temperature decrease was approximately the same for water and the coolant solution.

GENERAL DISCUSSION

This prototype inerting system functions with a rapidity equal to or greater than that of the experimental system used for the NACA crash-fire studies (ref. 1). The following table gives a comparison of the functioning times for the experimental and the prototype inerting-system components:

| Inerting-system components | Functioning time, sec | |
|---|-----------------------|--------------|
| | Experimental | Prototype |
| Fuel shut-off valves | (a) | 0.02 |
| Oil shut-off valves | (b) | 0.02 |
| Carbon dioxide induction inerting system pressure | 0.06 | 0.05 |
| Coolant spray system | 0.19 to 0.40 | 0.23 to 0.27 |
| Airplane electrical system de-energizing | 0.10 | 0.08 |

^aNot measured in same manner; no comparison possible.

^bNot used.

The "functioning time" for the carbon dioxide systems is the time required for the pressure to reach 75 pounds per square inch gage at the nozzle of the injection system.

The functioning times for the carbon dioxide systems that inert the engine induction system are about equal, which could be expected because the equipment was essentially the same. The coolant spray systems were also similar, although refinements decreased the functioning time of the prototype system. The airplane electrical system was de-energized somewhat more rapidly by the prototype system, which used faster relays and an improved grounding system. On the basis of the test results, it is concluded that the prototype crash-fire prevention system is generally more effective than the experimental system.

Further improvements, however, can be made in the prototype system. These improvements should decrease the time interval between the instant of first impact and the full operation of the complete fire-prevention system. In other words, the functioning speed of both the initiating and the inerting components of the system should be increased.

As an example of the need for rapid component actuation, a pole passing through the wing of a crashed airplane can tear through the wing electrical wiring and fuel storage, placing spilled fuel in contact with electrical sparks before the protection system is actuated. It appears essential, then, that the crash-sensing switch in the wing be arranged to immediately switch off all electrical power in the wing circuits not needed for airplane control at the instant the wing is penetrated.

As a means of providing more time for the fire-prevention system to function, the airplane electrical wiring in the wing should be moved to the trailing edge. This would give the electrical grounding system a longer time to decrease the power-circuit voltage to zero. Electrical wires can also be sheathed in loose elastic sleeves that would remain intact until the wires break. In this way any arc resulting from a break will be shielded from combustibles until the arc is quenched.

CONCLUSIONS AND RECOMMENDATIONS

This experimental crash study shows that the prototype inerting system was exposed to conditions that would adequately test its ability to inert and de-energize the various ignition sources known to cause crash fires.

The fact that fire did not occur indicates that the crash-fire prevention system functioned satisfactorily as a complete unit.

The study also shows that further improvements can be made in the crash-fire inerting system if the following recommendations are adopted:

- (1) Devise a method to prevent short circuits in the main airplane electrical system from diverting the power needed for inerting-system actuation and from reopening the solenoid fuel valves.
- (2) Provide a means of disconnecting noncritical wing power circuits from power sources as soon as a wing is penetrated.
- (3) Where possible, install wing wiring in the wing trailing edge. This wire should be of the shielded type so that it will break inside the shield. In this way any arc resulting from a break will be shielded from combustibles until the arc is quenched.

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National Advisory Committee for Aeronautics
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3. Black, Dugald O.: Facilities and Methods Used in Full-Scale Airplane Crash-Fire Investigation. NACA RM E51106, 1952.

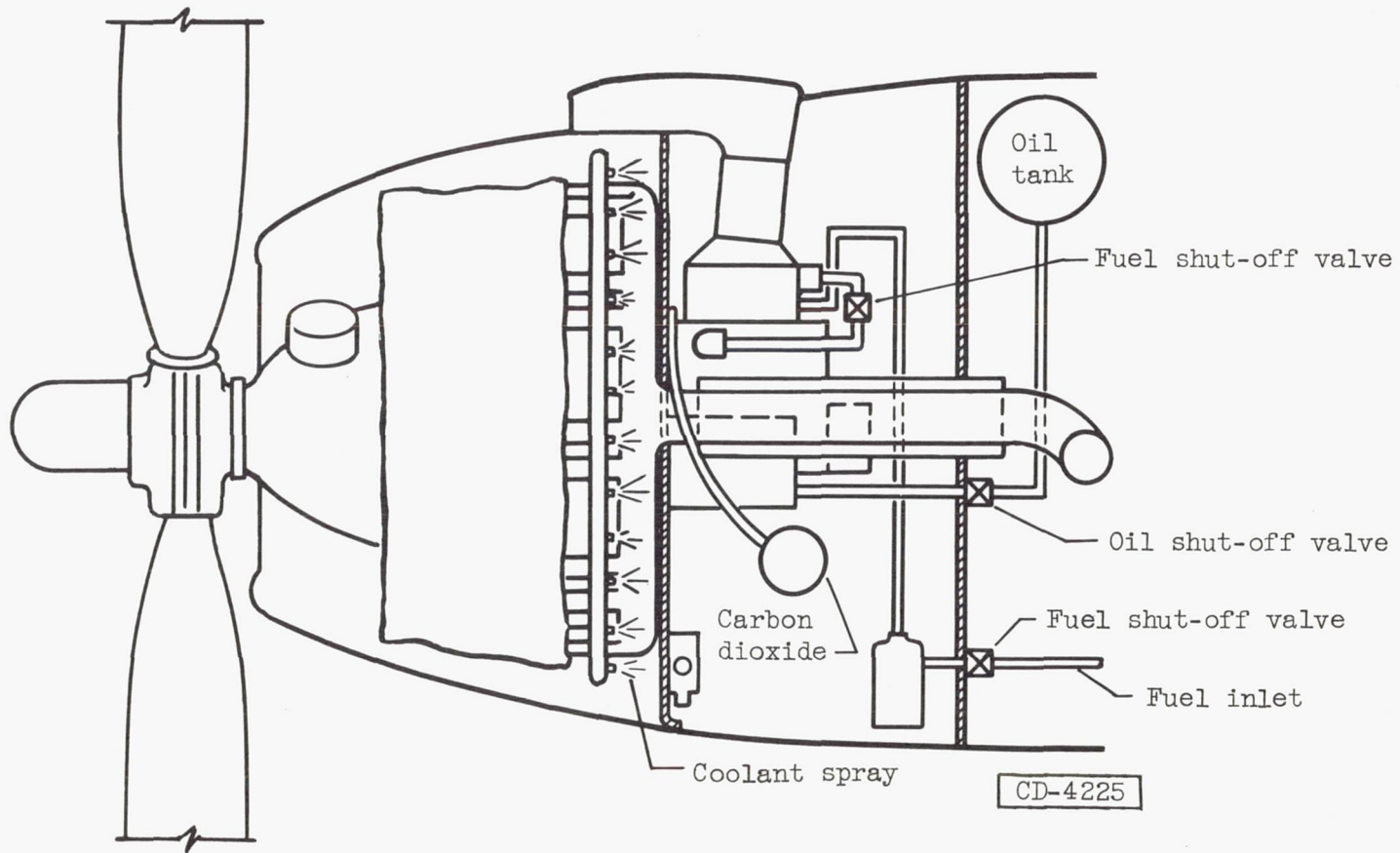


Figure 1. - Schematic diagram of inerting-system components on engine.

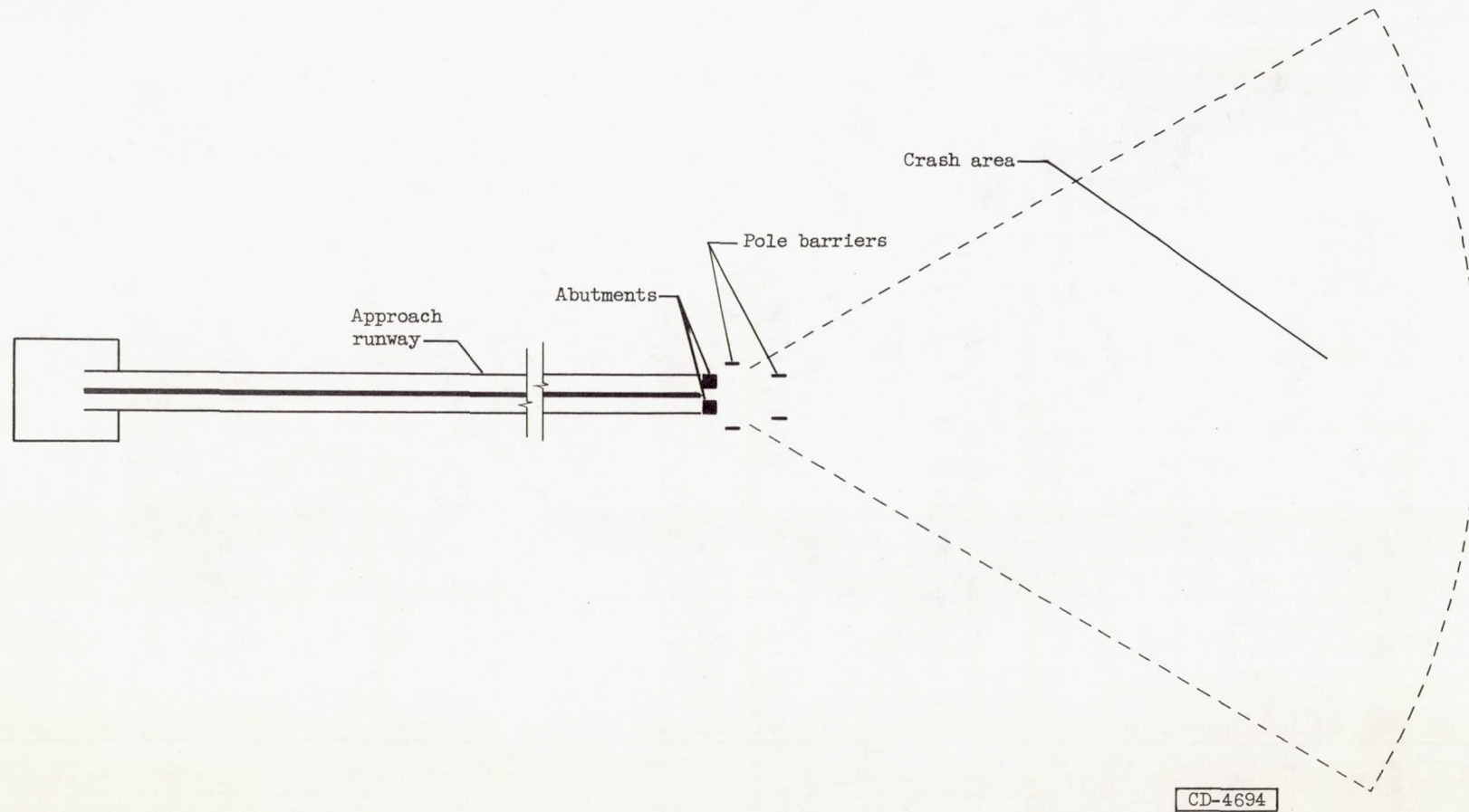
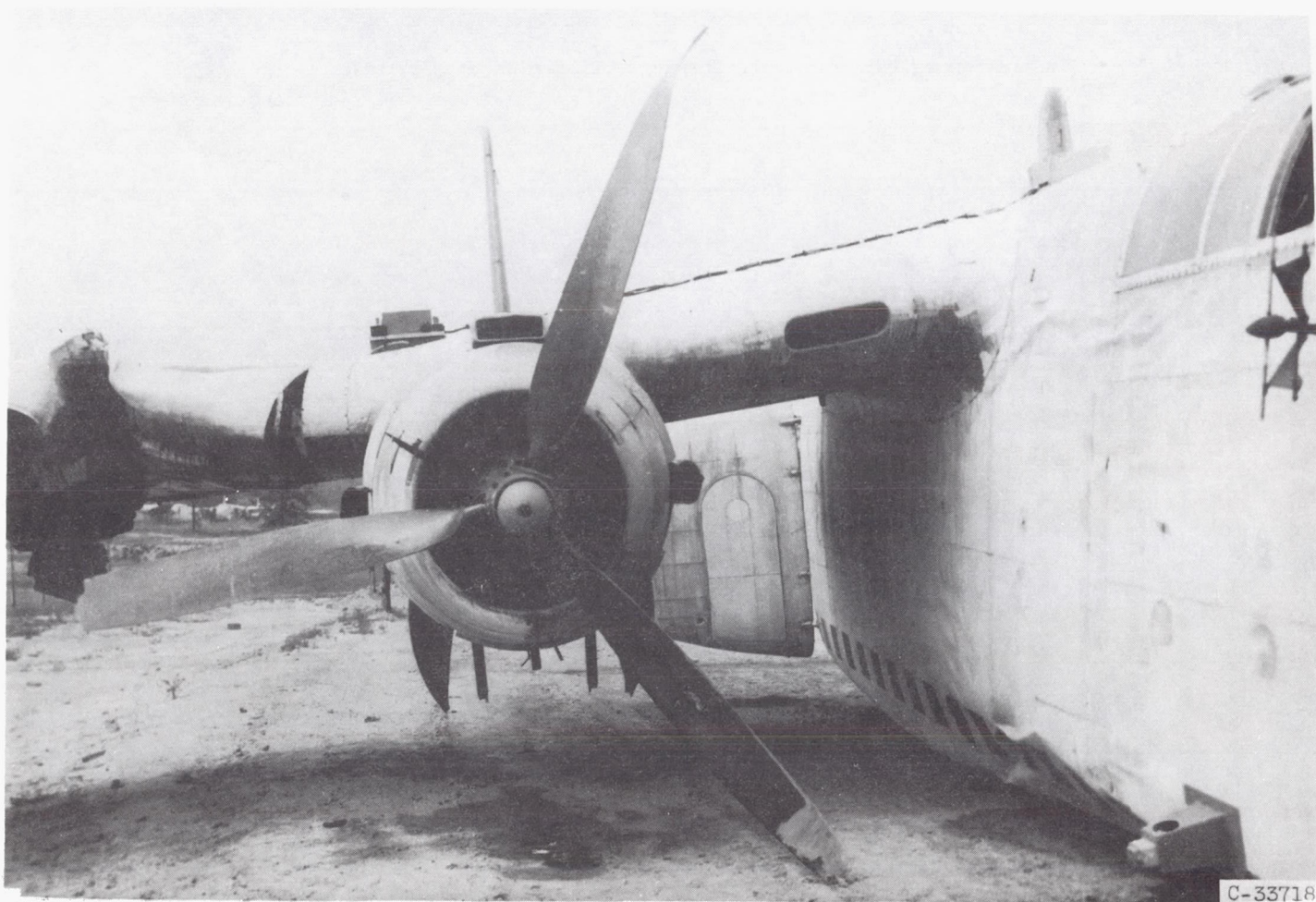
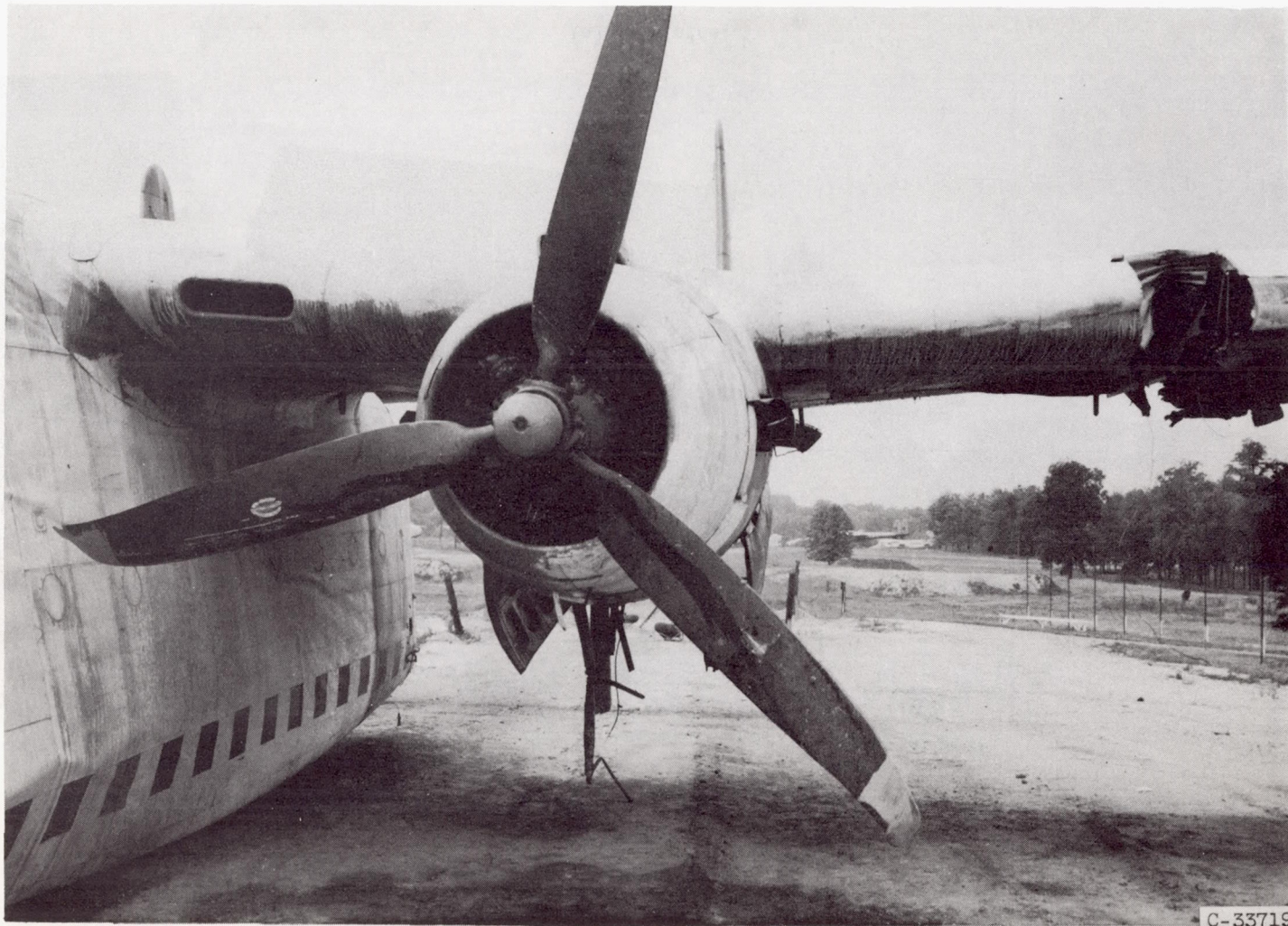


Figure 2. - Schematic drawing of crash site for conducting experimental crashes.



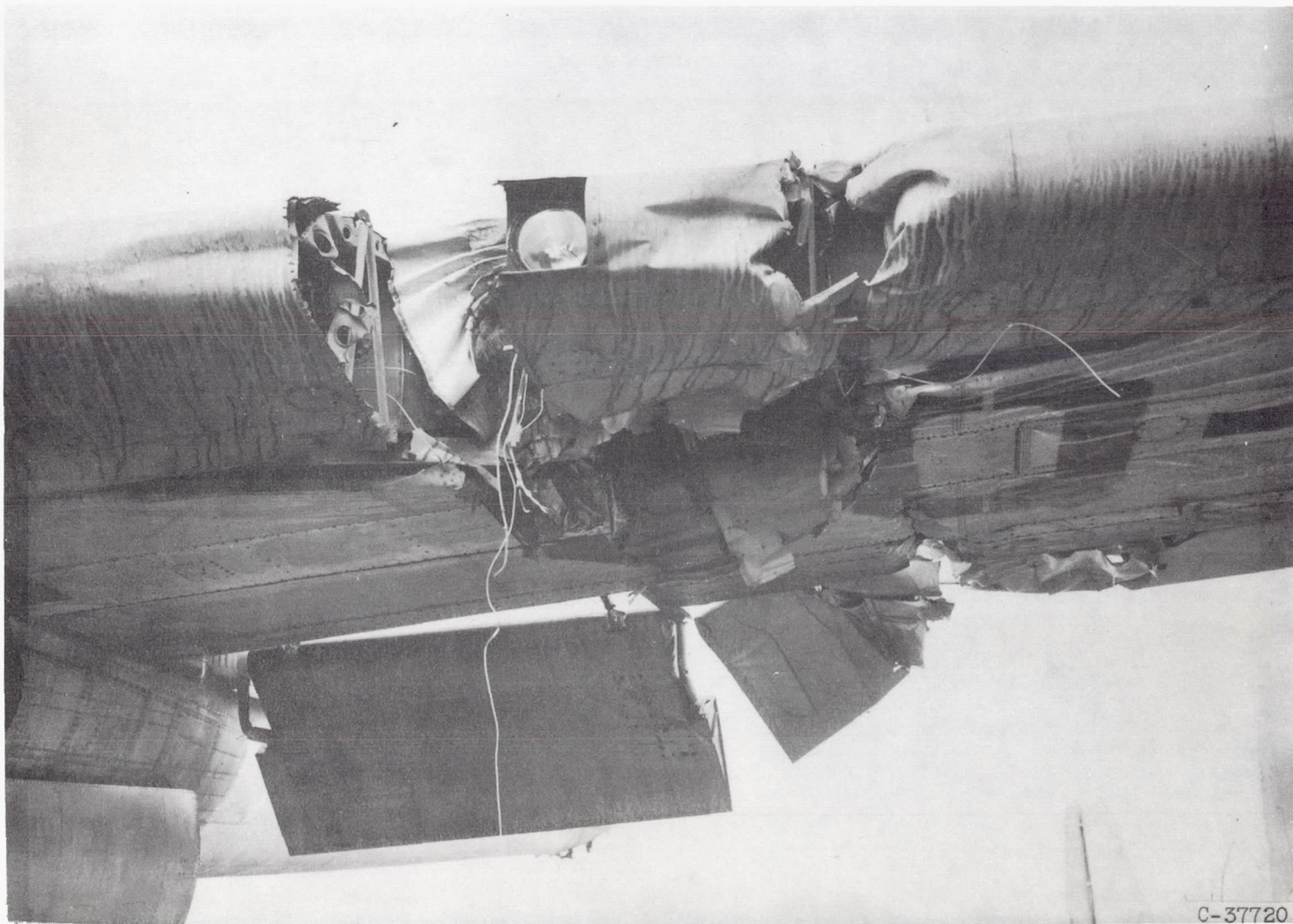
(a) Right engine.

Figure 3. - Propeller damage produced by crash barriers.



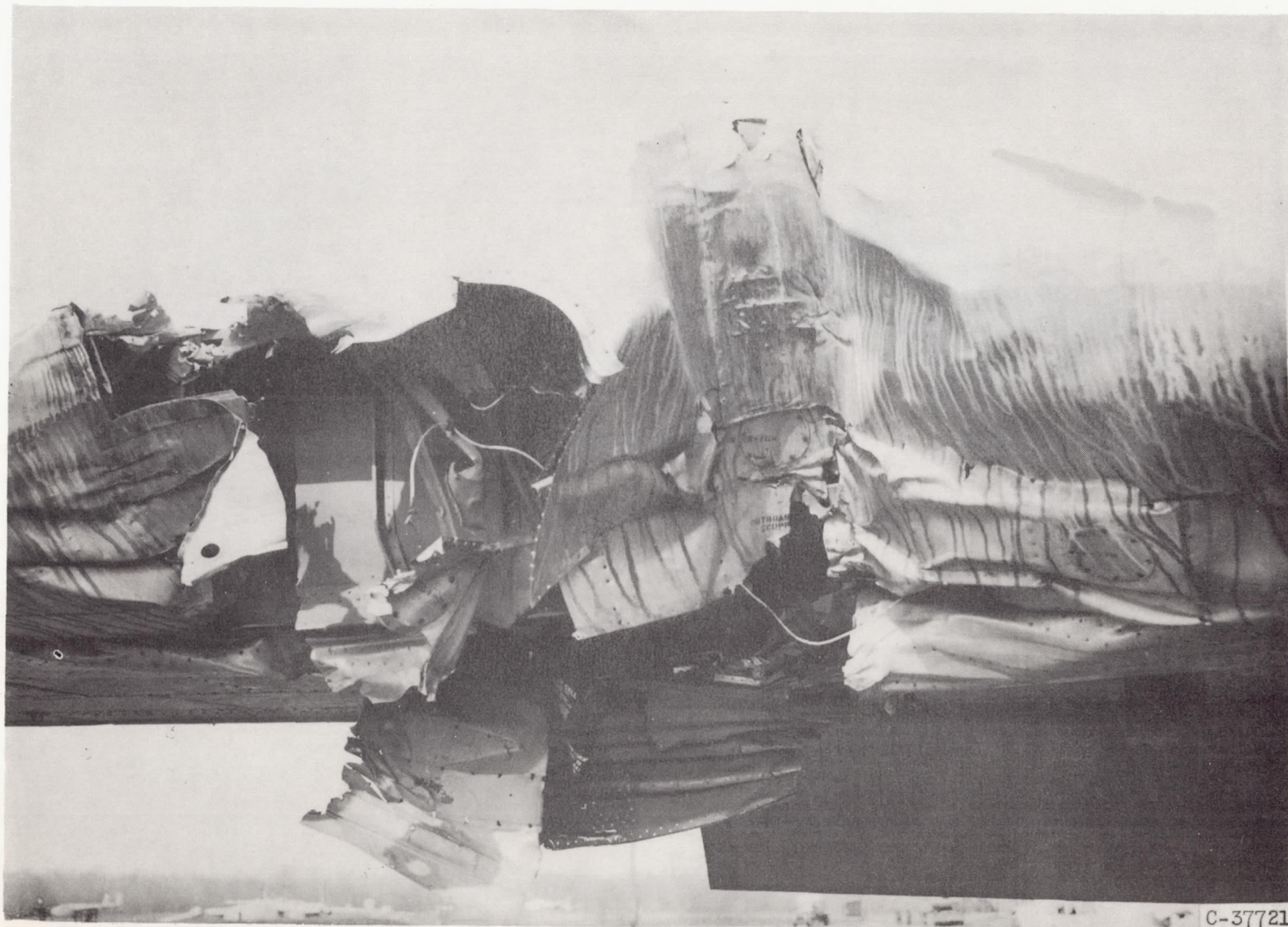
(b) Left engine.

Figure 3. - Concluded. Propeller damage produced by crash barriers.



(a) Left side.

Figure 4. - Damage to wing and fuel tanks produced by pole barriers.



(b) Right side.

Figure 4. - Concluded. Damage to wing and fuel tanks produced by pole barriers.

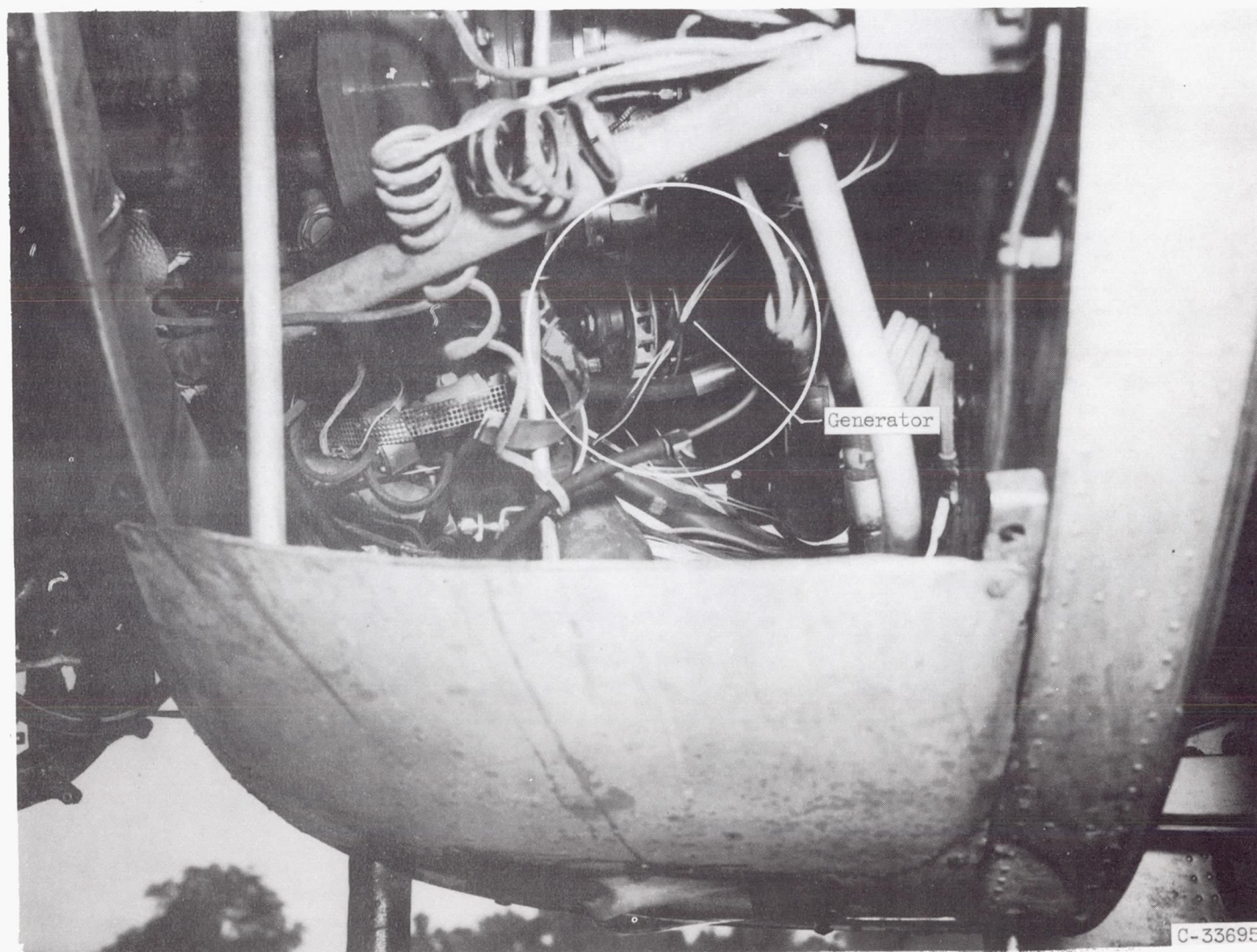
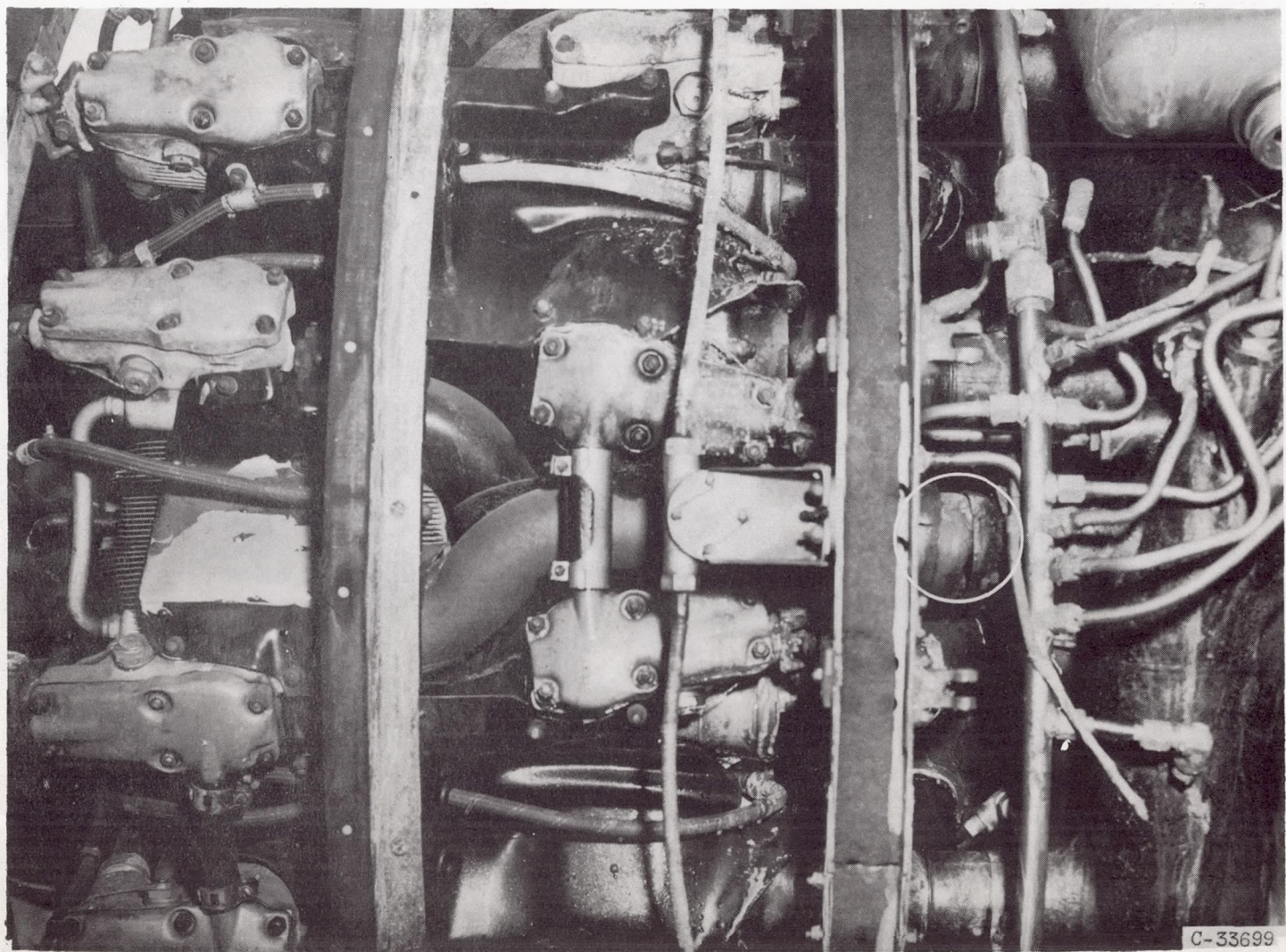
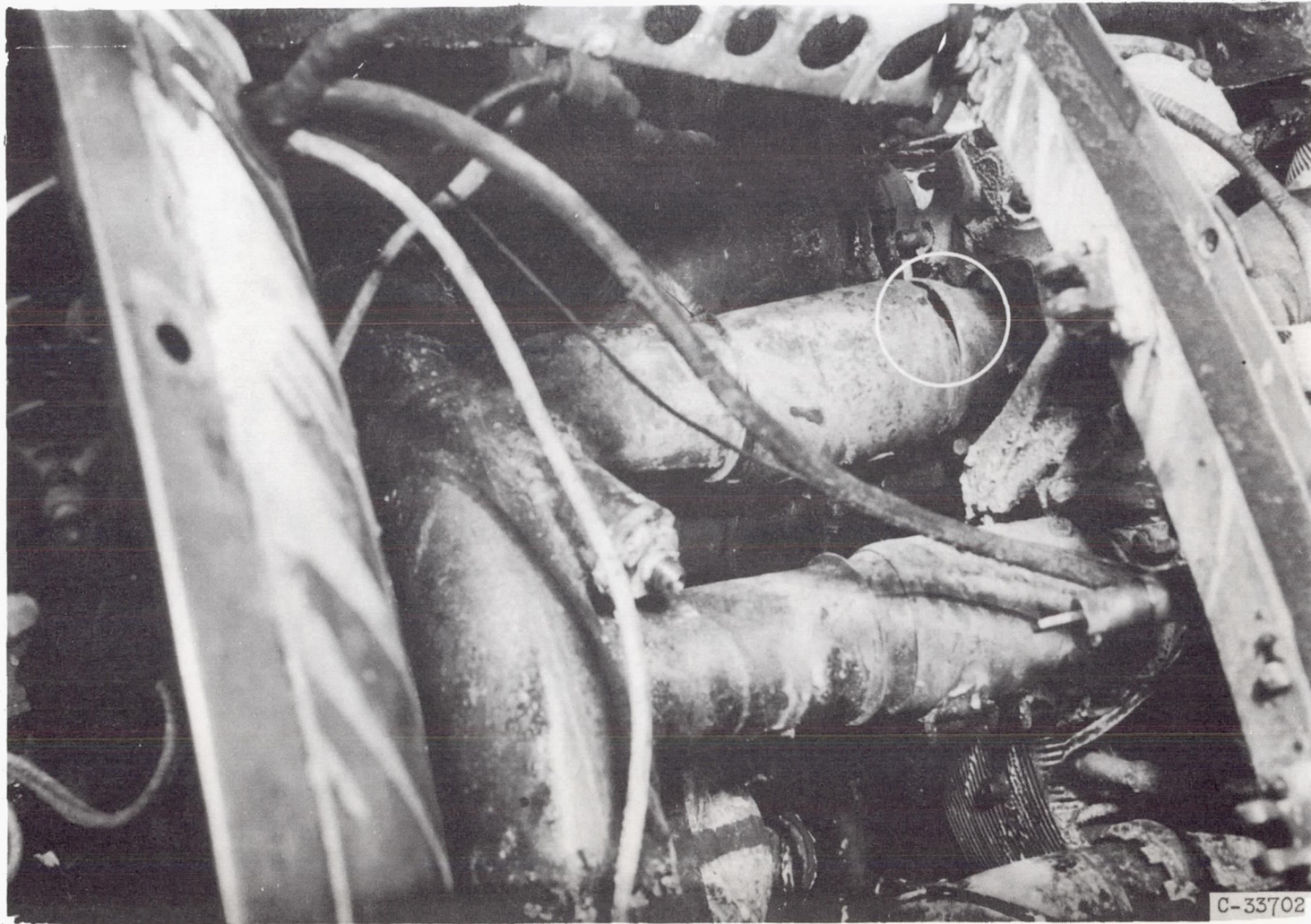


Figure 5. - Broken generator mounting flanges in right-engine nacelle.



(a) Cylinder 14.

Figure 6. - Gap in right-engine exhaust-stack connecting sleeve.



(b) Cylinder 2.

Figure 6. - Concluded. Gap in right-engine exhaust-stack connecting sleeve.

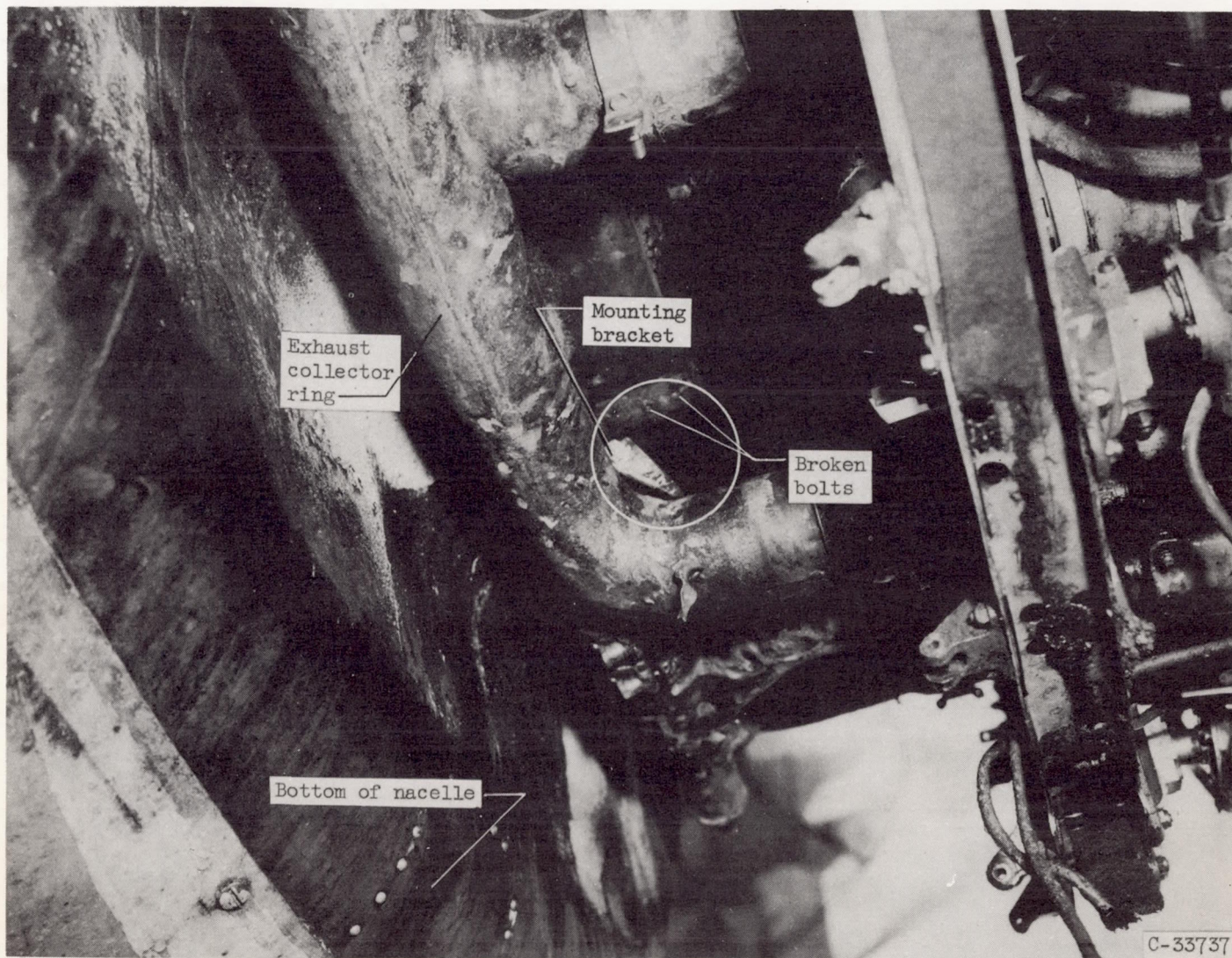
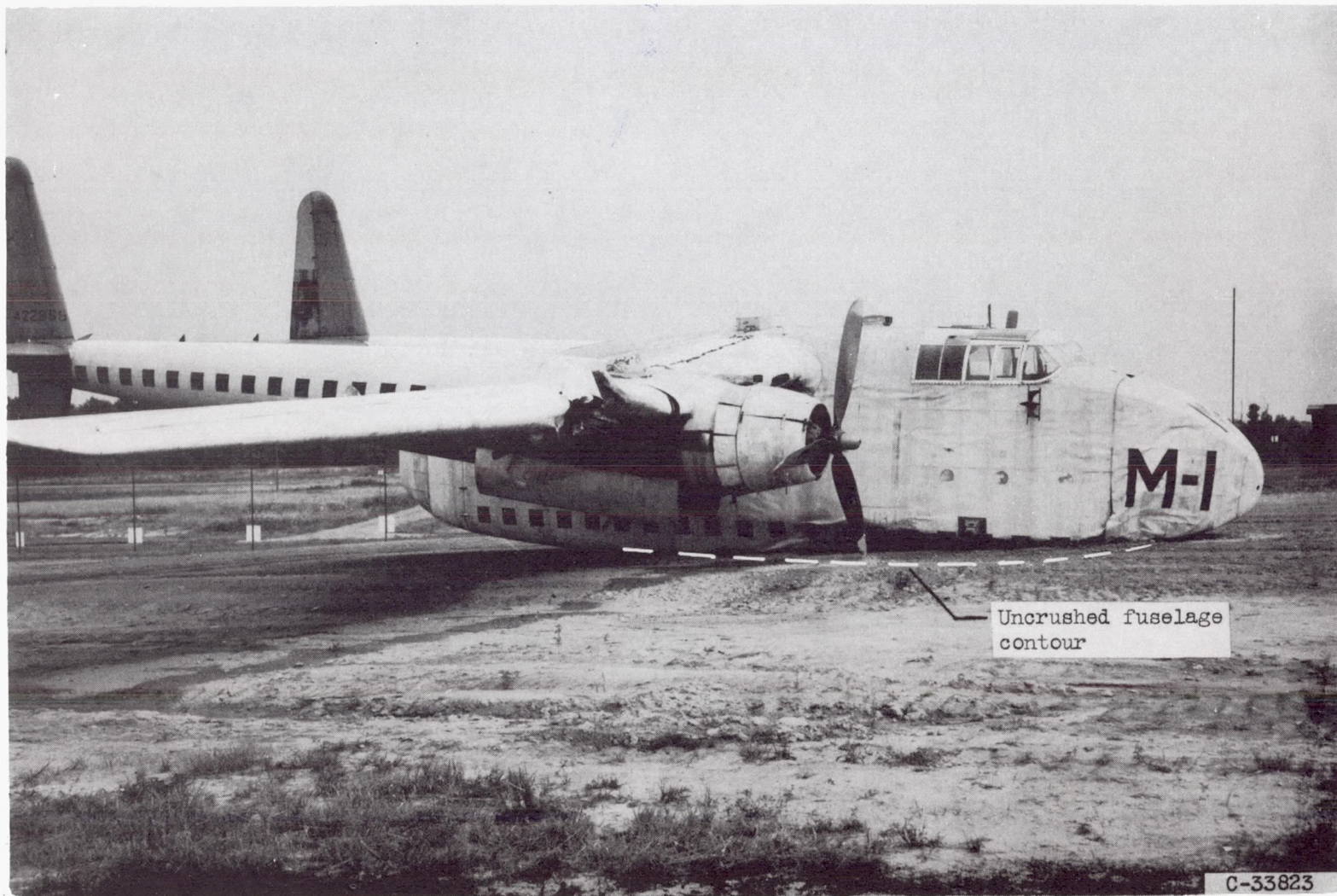


Figure 7. - Exhaust-collector-ring mounting bracket broken from its support.



(a) Right side.

Figure 8. - Crash-damaged fuselage of airplane.



(b) Left side.

Figure 8. - Concluded. Crash-damaged fuselage of airplane.



Figure 9. - Crash-damaged belly of airplane.

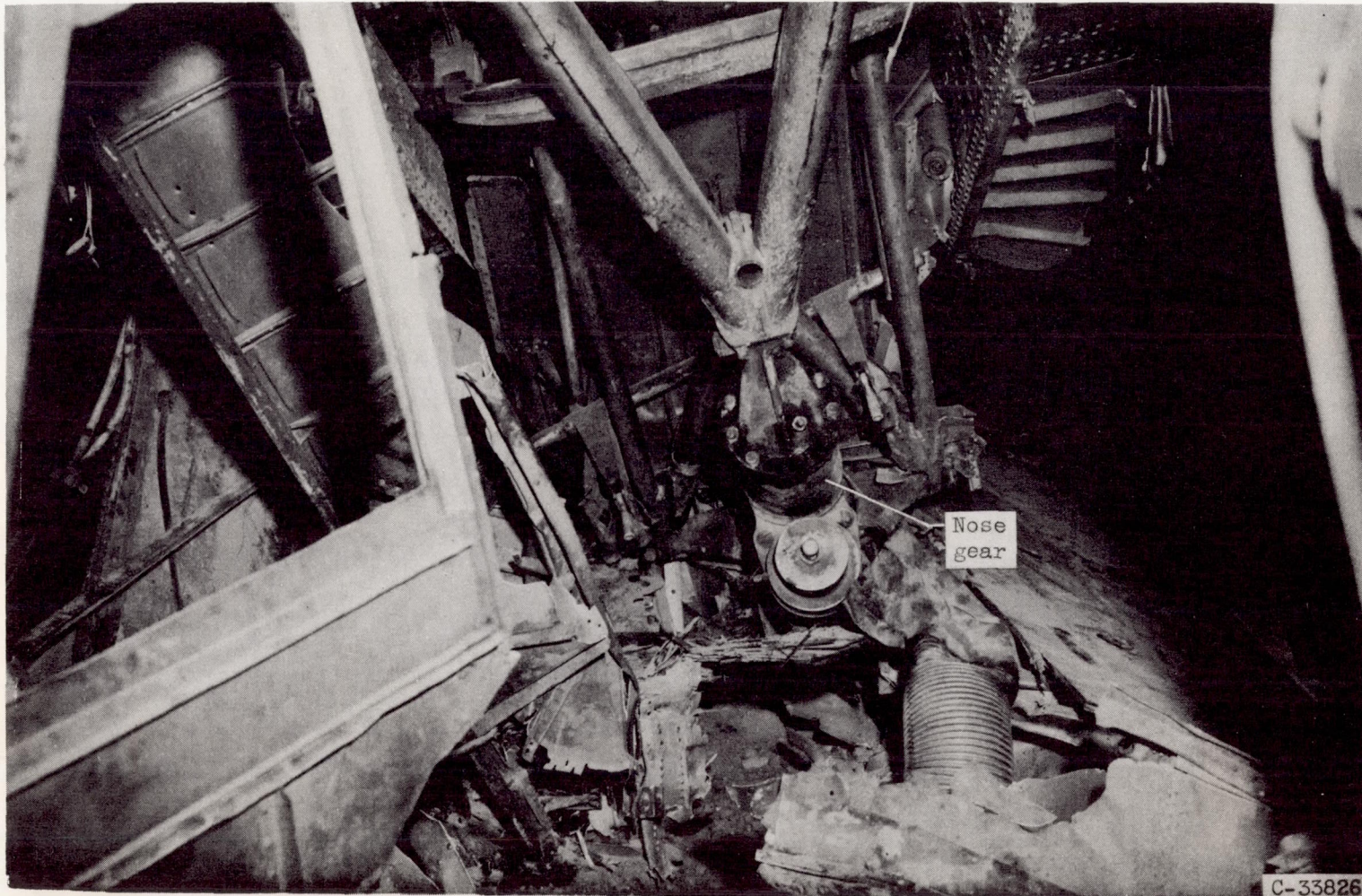


Figure 10. - Crash-damaged interior of nose-gear well.



(a) Left front.

Figure 11. - Crash-damaged interior of cargo compartment.



(b) Right front.

Figure 11. - Concluded. Crash-damaged interior of cargo compartment.

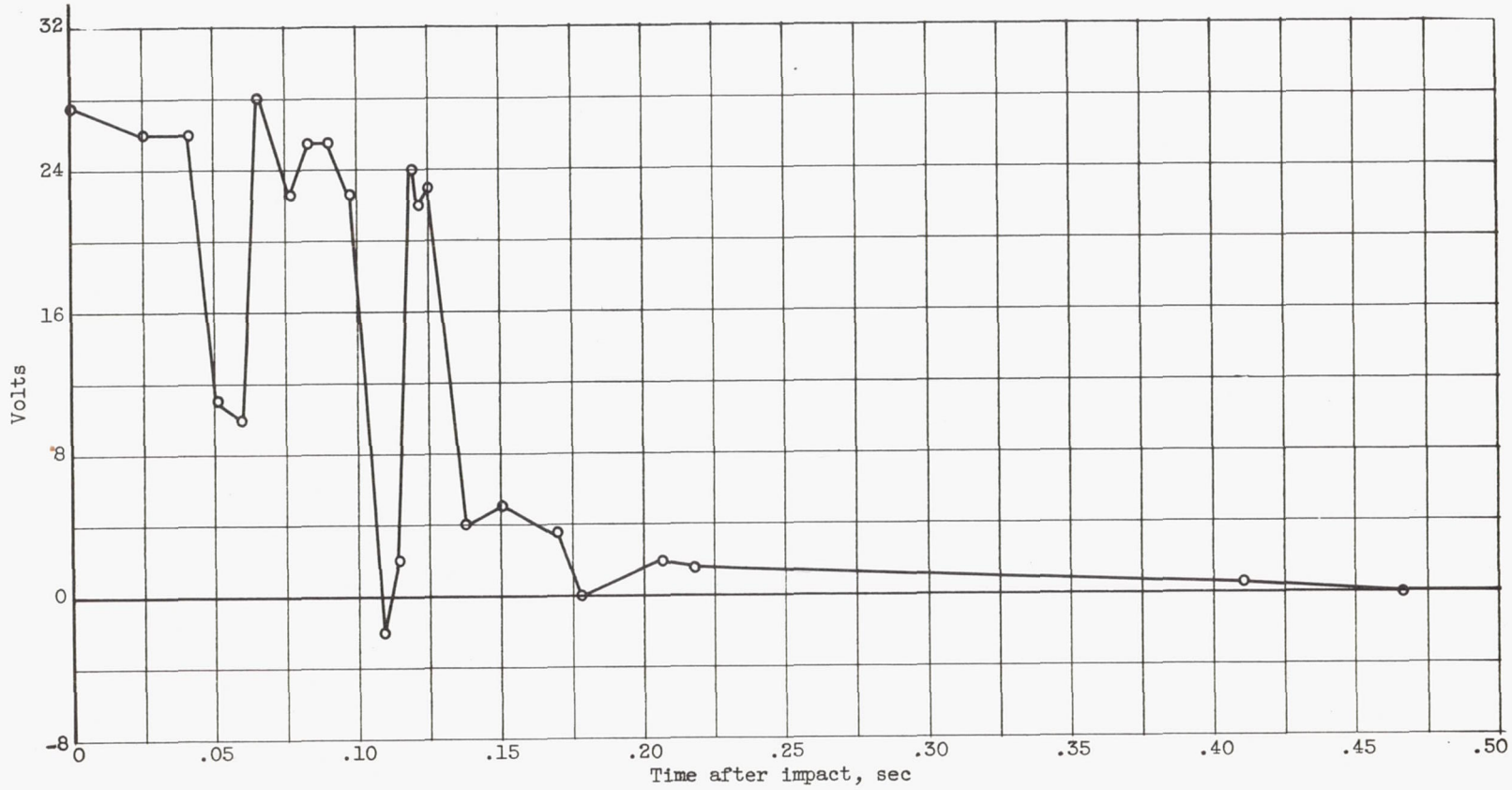


Figure 12. - Variation of voltage in airplane electrical system.

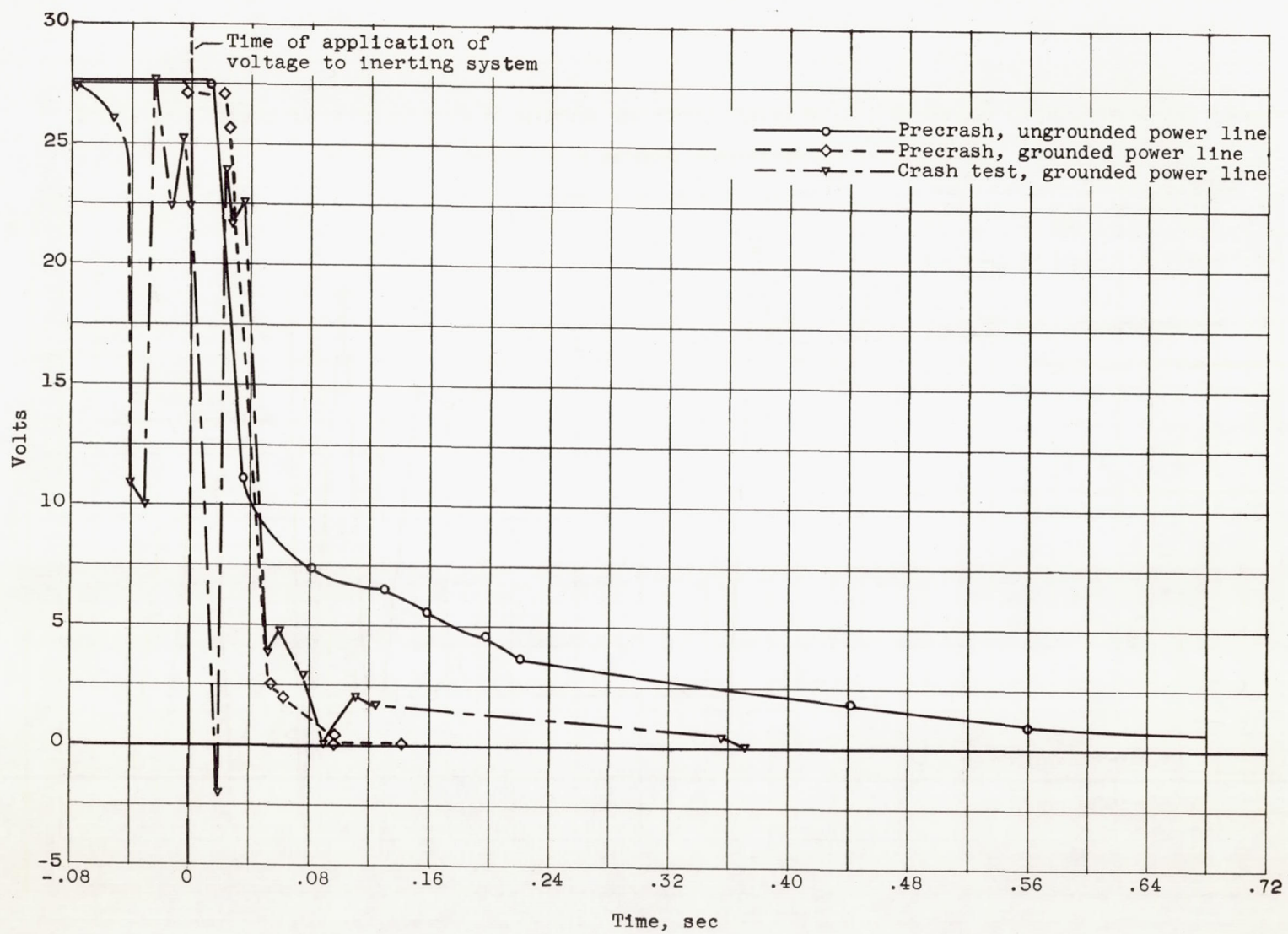


Figure 13. - Effect of grounding on airplane electrical system voltage.

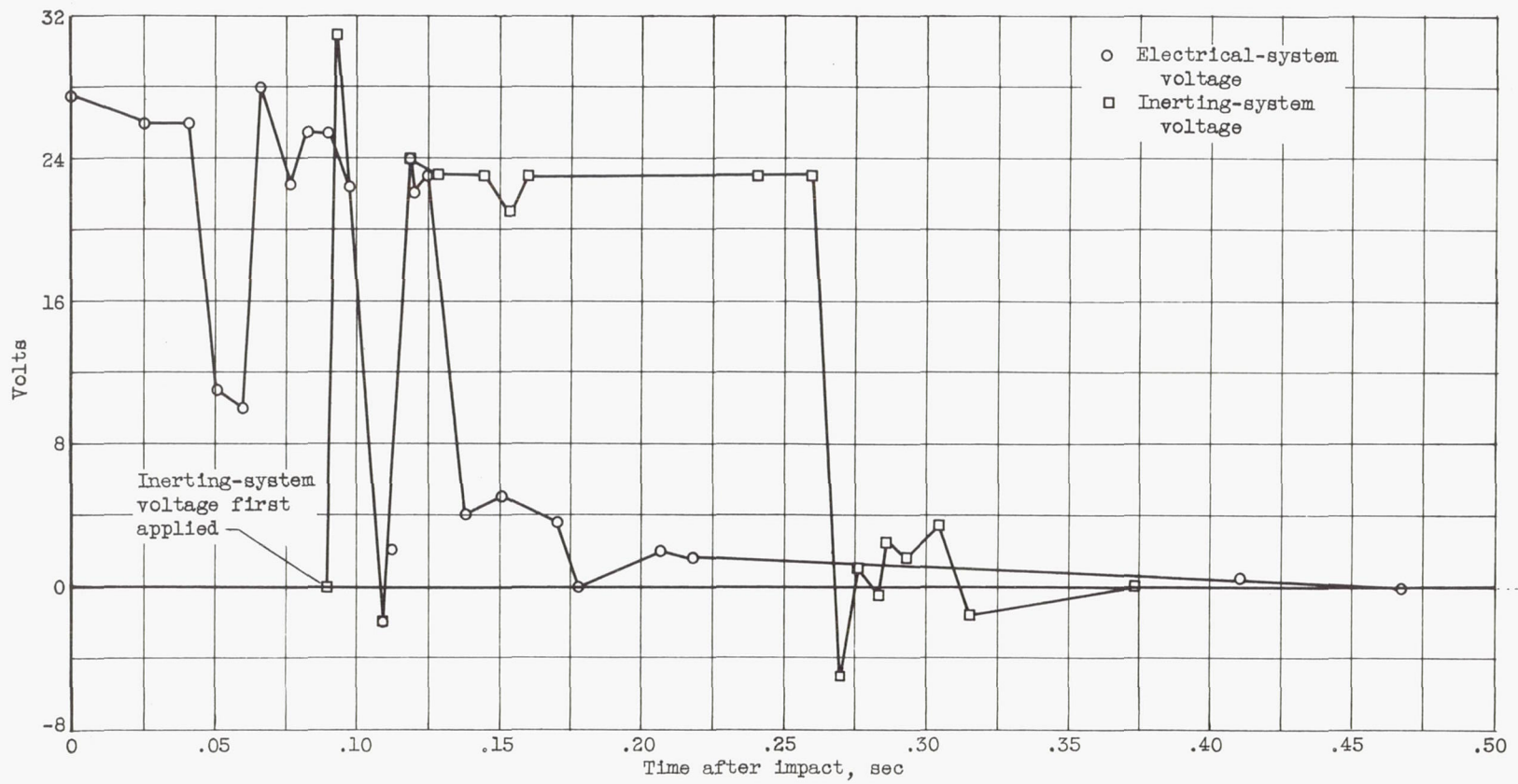


Figure 14. - Effect of short circuits in airplane electrical system on voltage applied to inerting-system components.

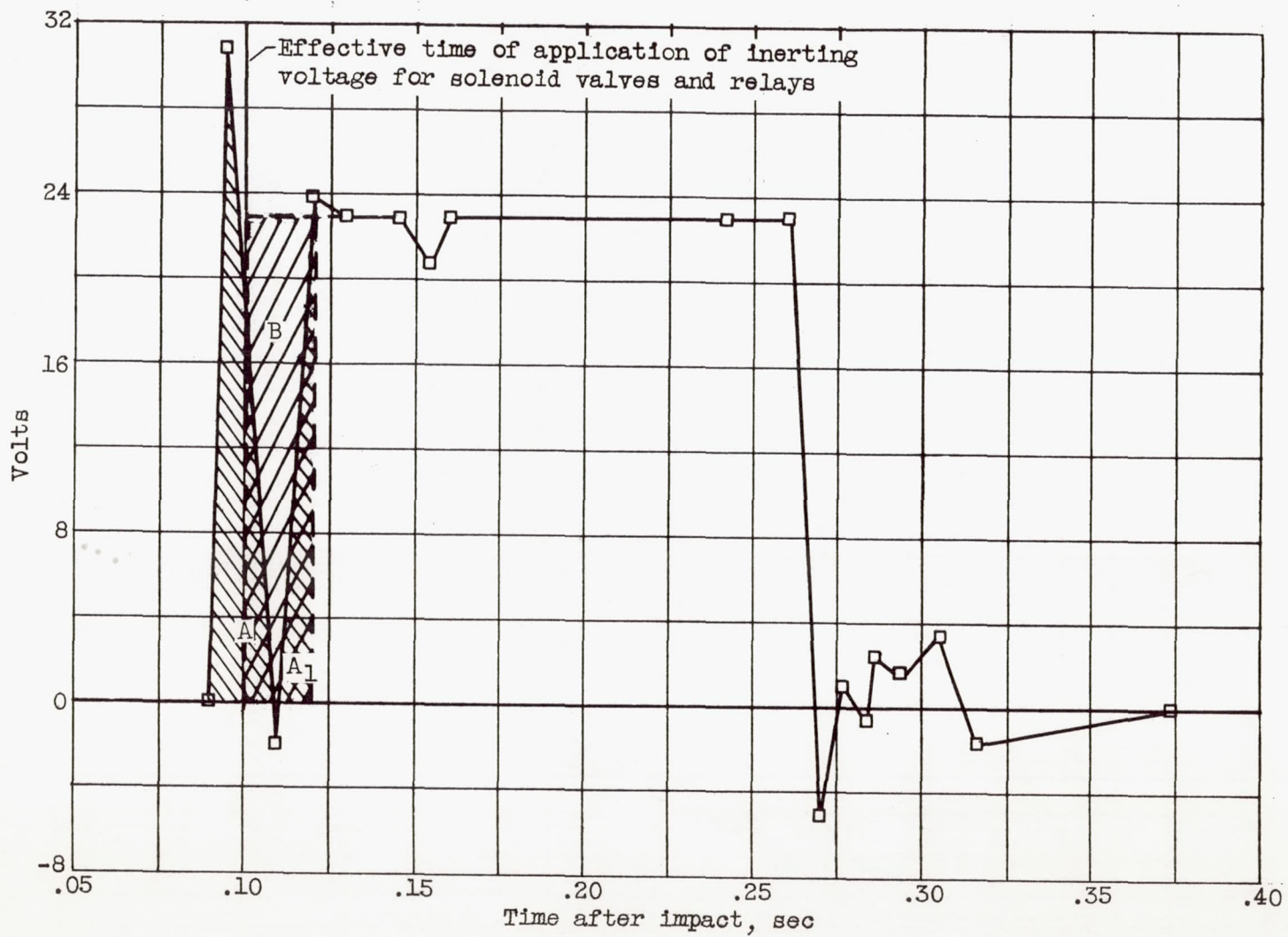


Figure 15. - Voltage applied to inerting system components.

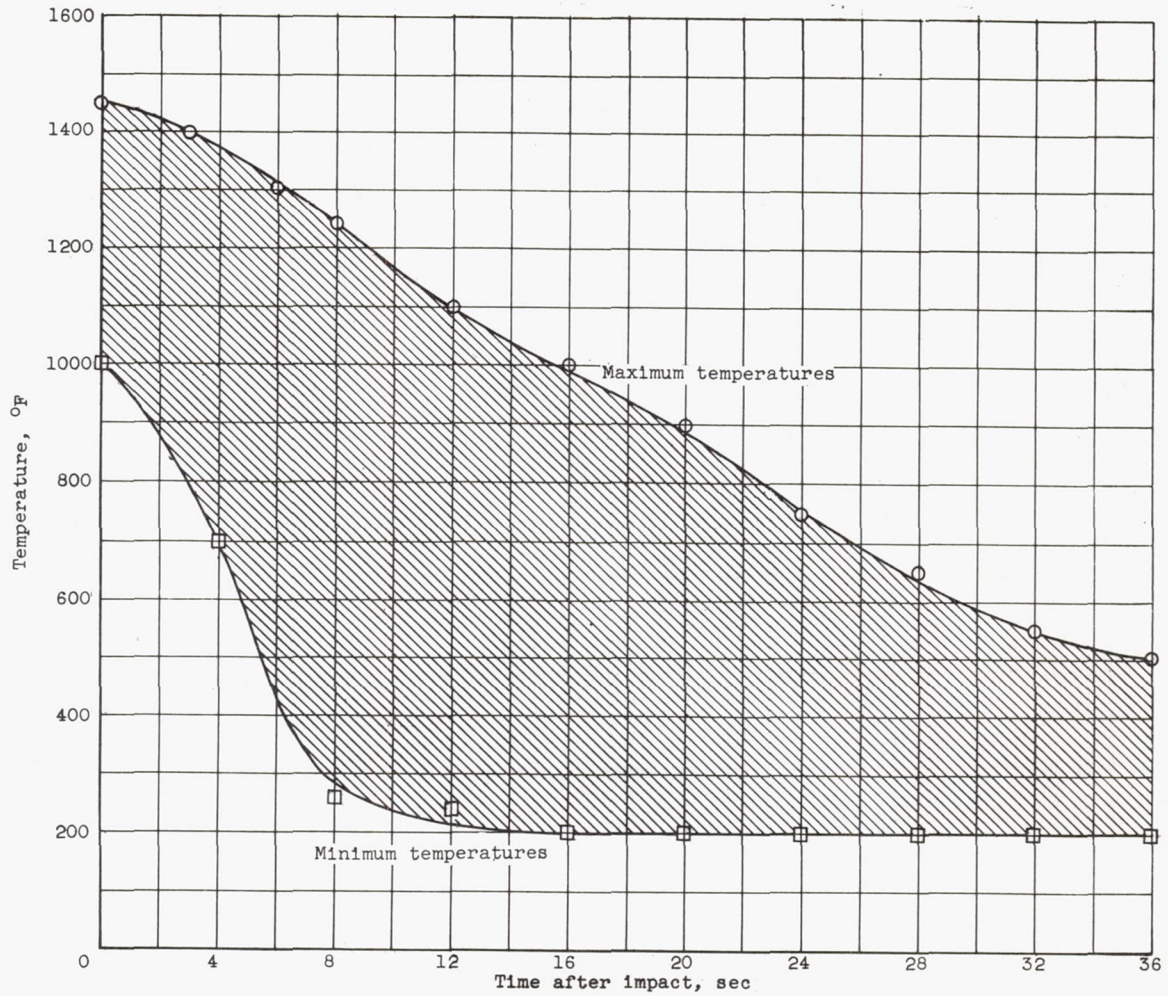


Figure 16. - Temperature history of right-engine exhaust collector ring.

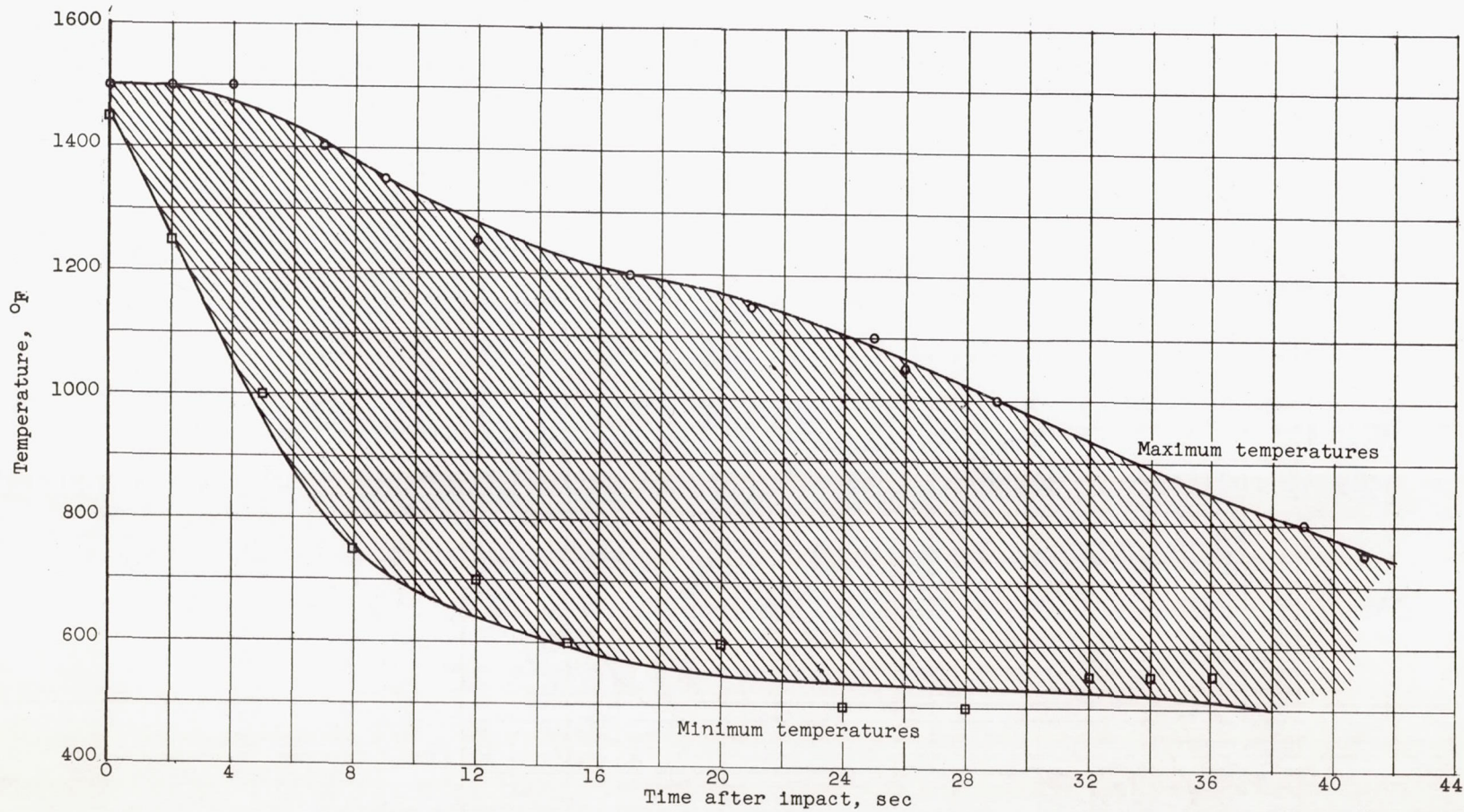


Figure 17. - Temperature history of right-engine exhaust heat exchanger.

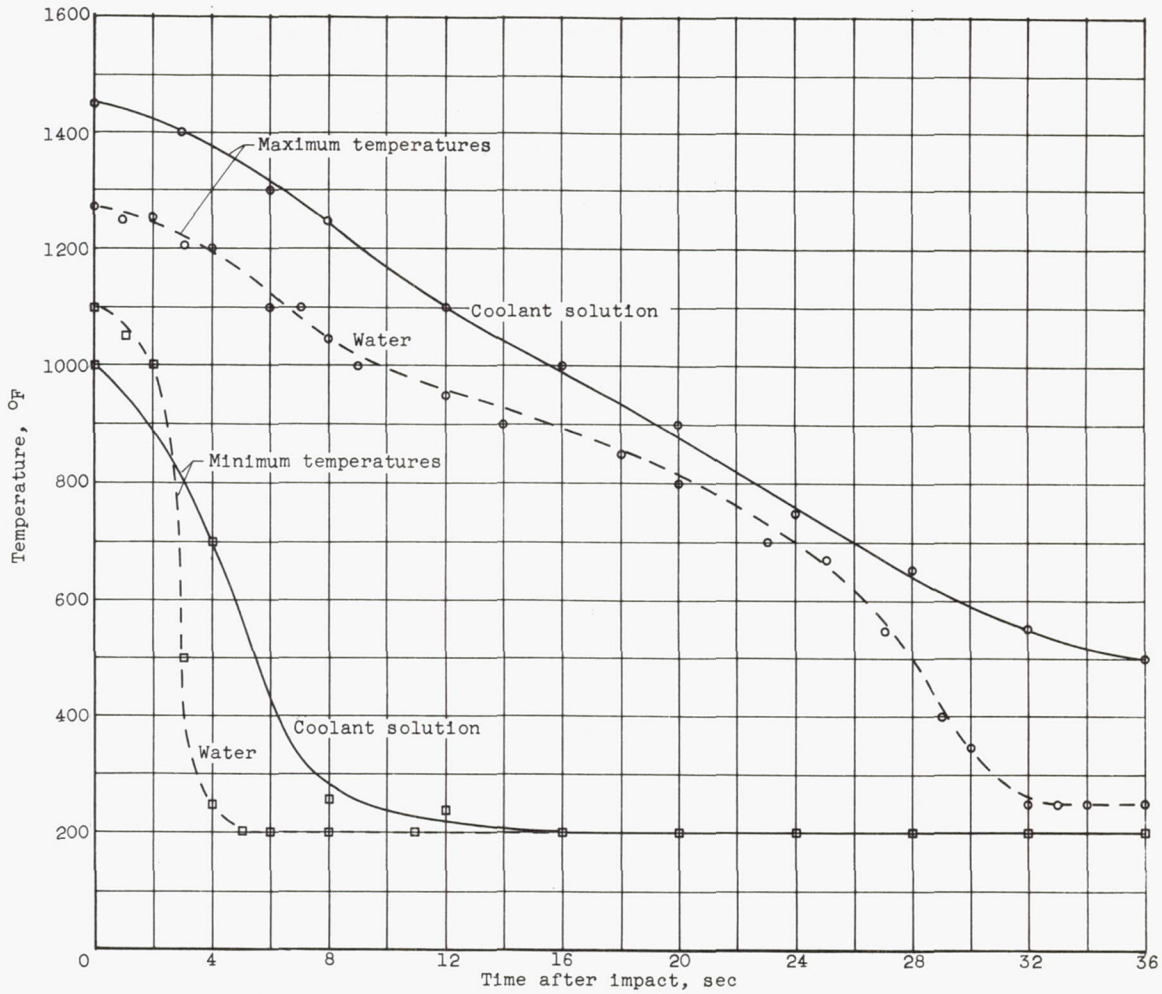


Figure 18. - Cooling effectiveness of water and coolant solution as indicated by temperature of exhaust collector ring.