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# TECHNICAL NOTE

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A COMBINED WATER-BROMOTRIFLUOROMETHANE

CRASH-FIRE PROTECTION SYSTEM FOR

A T-56 TURBOPROPELLER ENGINE

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# A COMBINED WATER-BROMOTRIFLUOROMETHANE CRASH-FIRE PROTECTION SYSTEM FOR A T-56 TURBOPROPELLER ENGINE

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## SUMMARY

A crash-fire protection system is described which will supress the ignition of crash-spilled fuel that may be ingested by a T-56 turbopropeller engine. This system includes means for rapidly extinguishing the combustor flame, means for cooling and inerting with water the hot engine parts likely to ignite engine ingested fuel, and means for blanketing with bromotrifluoromethane massive metal parts that may reheat after the engine stops rotating.

Combustion-chamber flames were rapidly extinguished at the engine fuel nozzles by a fuel shutoff and drain valve.

Hot engine parts were inerted and cooled by 42 pounds of water discharged at seven engine stations.

Massive metal parts that could reheat were inerted with 10 pounds of bromotrifluoromethane discharged at two engine stations.

Performance trials of the crash-fire protection system were conducted by bringing the engine up to takeoff temperature, actuating the crash-fire protection system, and then spraying fuel into the engine to simulate crash-ingested fuel. No fires occurred during these trials, although fuel was sprayed into the engine from 0.3 second to 15 minutes after actuating the crash-fire protection system.

## INTRODUCTION

Fuel spilled in an airplane crash may be ingested by turbine engines and ignited by either the flame in the combustors or by some of the hot metal parts inside the engine. The resulting flames can issue from the tailpipe or inlet and ignite other fuel spilled around the aircraft. A general crash fire then results.

Such fires may be prevented by quickly extinguishing the flame in the combustors and spraying the hot metal parts with water. The water inerts and cools these metal parts. These principles and their application to turbojet engines are described in reference 1. An extension of these principles is the basis for the all-water crash-fire protection system for the T-56 turbopropeller engine described in reference 2.

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Additional studies were made to determine whether the weight and compexity of the T-56 crash-fire protection system using water could be reduced by replacing some of the required inerting and cooling water with the flight fire extinguishing agent already carried in the aircraft. The fire extinguishing agent bromotrifluoromethane, $CBrF_3$, was used for these studies.

Although the physical properties of water and $CBrF_3$ are quite different, $CBrF_3$ can be substituted for water in some applications in a crash-fire protection system. When added to combustible fuel-air mixtures, $CBrF_3$ can inert the mixture; that is, make it unignitible. Therefore, $CBrF_3$ can be used to inert the atmosphere around hot surface ignition sources in a turbine engine. Since under atmospheric temperature and pressure $CBrF_3$ is a gas, it diffuses easily and can be used to inert areas that cannot be easily sprayed with water. However, because of its low heat of vaporization, $CBrF_3$ cannot be used instead of water as a cooling agent. Its heat of vaporization is only 28 Btu per pound (ref. 3), compared with 970 Btu per pound for water. Since $CBrF_3$ will not appreciably cool hot surface ignition sources, an inert atmosphere must be kept around these surfaces until they cool normally. The concentration required to inert a fuel-air mixture will vary, depending on such factors as the type of fuel, the fuel-air ratio, the temperature and pressure of the fuel-air mixture, and the ignition source. The volume of air to be inerted will depend on the airflow through the engine.

The use of $CBrF_3$ in a portion of a crash-fire protection system for a turbopropeller engine is practical because there is no measurable airflow through the engine after it has stopped rotating. After the normal fuel flow to the combustors is cut off, the T-56 turboprop engine coasts to a stop in 45 seconds if the propeller is in flat pitch or 13 seconds if it is feathered. In experimental studies an anemometer indicated no airflow through the engine at wind speeds of 30 miles per hour after the engine stopped rotating. However, there was a slight circulation of air inside the inlet with a 30-mile-per-hour headwind, and there was slight air circulation inside the tailpipe with a 30-mile-per-hour tailwind. Winds higher than 30 miles per hour are extremely rare; for example, in Cleveland, Ohio, the wind speed is above 30 miles per hour only 2 percent of the time. Since there is no significant airflow through the engine, a small amount of $CBrF_3$ can be used to blanket hot metal parts with an inert atmosphere. This prevents the ignition of fuel vapors on these parts while their heat is slowly dissipated to adjoining cooler metal parts and to the atmosphere.

A crash-fire protection system was built for the interior of the T-56 engine using both $CBrF_3$ and water as inerting agents. This system was based on the all-water crash-fire protection system described in reference 2. However, $CBrF_3$ was substituted for part of the water and used to protect the engine after the airflow through the engine had stopped. Most of the components of the combined water-$CBrF_3$ crash-fire protection system were also used in the all-water crash-fire protection system described in reference 2. However, for the convenience of the reader, a complete description of the water components is included in this report.



## DESCRIPTION OF SYSTEM

The interior crash-fire protection system is divided into three main parts: an engine fuel manifold shutoff and drain system, a water spray system, and a $CBrF_3$ system. These basic parts are illustrated in figure 1. The fuel shutoff and drain system shuts off the fuel to the engine and quickly extinguishes the normal flame in the combustors. The water spray system inerts and cools hot metal parts during the time when the engine can be coasting to a stop. The $CBrF_3$ system blankets with an inert atmosphere massive metal parts which may reheat after the engine stops rotating.

### Fuel Shutoff and Drain System

A fuel shutoff and drain valve (fig. 1) simultaneously stops the flow of fuel into the engine fuel manifold and vents the manifold overboard. The combustion-chamber pressure reverses the fuel flow in the nozzles, and the residual fuel in the manifold is discharged overboard. The normal flame in the combustors, which lingers for 0.5 second after actuation of the standard engine fuel shutoff valve, was extinguished in 0.07 second by the additional fuel shutoff and drain valve.

### Water Spray Systems

Because the heat dissipation of engine parts will vary as their surface to mass ratios, two types of water spray systems were used. A high-flow, short-duration discharge of water suppressed ignition on thin metal parts around the main gas stream such as combustor liners, turbine blades, and exhaust ducts. Since these metal parts have high surface-to-mass ratios, they cooled quickly. This short-duration discharge system sprayed water into the combustor zone and is subsequently referred to as the combustor system. A slow-flow, long-duration discharge of water cooled the turbine rotor faces and the rear-bearing support struts. These massive metal parts have low surface-to-mass ratios and can only be cooled slowly. This long-duration discharge system is located in the turbine zone and is subsequently referred to as the turbine system.

A schematic diagram of the water spray systems is shown in figure 1. The similarity between this water spray system and the water spray system described in reference 2 can be seen by comparing figure 1 with figure 2, which shows the all-water system. The combustor system is identical in both the all-water and the combined water-$CBrF_3$ crash-fire protection systems. However, the turbine system on the combined water-$CBrF_3$ system uses less water, has a shorter discharge time, and one less subsystem than on the all-water system.

The details of the water spray system and subsystems used in the combined water-$CBrF_3$ crash-fire protection system are described in the following paragraphs. Those details which are discussed in reference 2 are repeated in order to provide a complete description of the crash-fire protection system in this report.

Combustor system. - The combustor water system consisted of three subsystems. Two of the subsystems were located in front of the combustion chambers. The water from these subsystems inerted and cooled the combustor liners and structures enclosing the main airstream. The third combustor subsystem sprayed water on the outer surface of the transition liners joining the combustors to the turbine.

Compressor-outlet subsystem: Twelve nozzles spaced 30° apart in a circumferential direction at the compressor outlet sprayed 23.0 pounds of water into the compressor-outlet airflow (fig. 3(a)). In order to make use of the revolving rotor and the airflow to distribute the water over the diffuser and the combustor liner surfaces, each nozzle was placed so that the water jet discharged upstream of and parallel to the 14th-stage compressor stator vanes. The nozzles were aimed so that the water jets would strike the bases of the rotating 14th-stage blades and be dispersed circumferentially. The airflow through the diffuser straightening vanes would then tend to carry the water droplets over the diffuser struts and the combustor liners. Each nozzle orifice was 0.089 inch in diameter.

A cold-air-flow model of the diffuser and combustor sections of the engine indicated that the water from these nozzles wets the two-thirds of the surfaces of the combustor liners farthest from the engine centerline. The cumulative water discharge of the compressor-outlet subsystem is plotted against time in figure 3(b). To facilitate the measurement and future duplication of the water discharge, the data shown in figure 3(b) were obtained with the system discharging to atmospheric pressure rather than to the declining combustor pressure of the coasting engine. Therefore, the initial flow rate shown in figure 3(b) is somewhat higher than those obtained in the engine. The cumulative water discharge with time of all the subsystems and systems to follow were also measured in this manner.

Inner-diffuser-fairing subsystem: To spray water on the liner surfaces not protected by the compressor-outlet subsystem, the inner-diffuser-fairing subsystem directed 10.3 pounds of water at the surfaces of the liners nearest the axis of the engine. Six 0.117-inch-inside-diameter tubes, centered in the support fairings, directed water at the inner cone of the diffuser as shown in figure 4(a). A 0.060-inch (±0.020-in.) gap between the end of each tube and the inner cone dispersed the water radially from the inner ends of the tubes. The cumulative water discharged with time is shown in figure 4(b). The water washed over the cone surface and traveled through the gaps between the fairings and the cone into the portion of the main airstream closest to the engine centerline.

Outer-rear-liner subsystem: The outer rear areas of the liners with their reinforcing "hat" section (fig. 5(a)) are made of thin metal. The hat sections are not located in the main gas stream. The liner surfaces and hat sections were inerted and cooled by a spray of water from nozzles installed in the turbine-inlet casing as shown in figures 5(a) and (b). One pound of water was widely distributed over the surfaces of the liners by very flat 160° hollow-cone-pattern nozzles. These nozzles had internal cores to meter and swirl the water and thus produce a conical pattern. They were satisfactory for this application, but are not recommended for hotter locations. When these core-type nozzles become too hot and are quenched, the cores loosen and the spray pattern becomes erratic. The cumulative water discharge with time of this subsystem is plotted in figure 5(c).

These hat sections enclose a space where the airflow is negligible and combustible mixture may reside long enough to ignite. To reduce the interval that the mixture may reside in the hat sections, ventilation holes were drilled in all the hat sections (but not through to the main gas stream) as shown in figure 6. Water spray and steam circulation through the hat sections was increased by these holes.

The three combustor subsystems just described discharged a total of 34.3 pounds of water from a single nitrogen pressurized tank as shown in figure 7(a). The pressure and volume of propelling nitrogen gas, and the discharge nozzle orifice areas were selected to give the desired fast-flow, short-duration discharge. The pressure decay and total cumulative water discharge for the entire combustor system are shown in figure 7(b).

Although a 700-pound-per-square-inch-gage propelling nitrogen pressure was used as an experimental expedient in the final trials of this system, a lower pressure could be desirable in a commercial installation. In preliminary experiments, the use of a propelling pressure as low as 400 pounds per square inch gage and an increased volume of propelling nitrogen, with larger and slightly different orifices was satisfactory. Nitrogen pressures lower than 400 pounds per square inch gage may appear to produce the desired discharge timing when the water is discharged through much larger orifices to atmospheric pressure, but may not give satisfactory results when the water is discharged into the airstream against the engine pressure during the initial period of coastdown.

Some of the initial propelling nitrogen pressure is expended in filling the dry passage volumes from the water supply tank valve to the metering discharge orifices. Large, dry passage volumes thus reduce the water pressure available at the nozzles and also increase the time taken to fill the lines. Because the propelling pressure and water discharge history depend upon both the volume of propelling gas and the volume of air that must be expelled from the line between the valve and the nozzles, the dry volumes of this system are shown in figure 7(a).

These experimental systems were not built with as small, dry volumes as may be achieved on a production-engine system. The dry volumes in the supply lines and manifolds of the commercial version should not be greater than those shown. Reducing the dry volumes would be preferable. The commercial version would then begin to spray water sooner than the experimental system, and the hot surface ignition sources would be inerted more rapidly.

Turbine system. - The turbine system consisted of four subsystems. Two of the subsystems sprayed water on the front and rear surfaces of the massive rotor assembly. The other two subsystems sprayed water on the heavy, rear turbine-bearing-support assembly.

Surfaces of the turbine section that were not sprayed directly by these subsystems were inerted by excess steam generated from water sprayed on adjacent and upstream surfaces. Figure 1 shows the arrangement of these subsystems, which are designated front rotor, rear rotor, inner-rear-support, and outer-rear-support subsystems.

Front rotor subsystem: Six 95° flat spray nozzles discharged 3.5 pounds of water onto the forward surface of the first turbine wheel. These nozzles had an equivalent orifice of 0.026-inch diameter and a rated discharge of 0.16 gallon per minute at a pressure of 100 pounds per square inch. The installation of these nozzles is shown in figures 8(a) and (b). The water was sprayed against the direction of turbine rotation at a 15° angle of incidence on the forward surface of the first turbine wheel. The spray patterns overlapped to provide spray on most of the forward face of the wheel even after engine rotation stopped. In addition to cooling and inerting the forward face of the first rotor, the turbine cooling air carried water mist and steam to spaces between the turbine wheels and helped to inert these zones. The cumulative water discharge with time is shown in figure 8(c).

Rear rotor subsystem: Three 95° flat atomizing spray nozzles covered most of the rear face of the fourth-stage turbine wheel with 1.6 pounds of water. These nozzles had an equivalent orifice of 0.026-inch inside diameter and a rated discharge of 0.16 gallon per minute at a pressure of 100 pounds per square inch. Their installation is shown in figures 9(a) and (b). These nozzles were located next to the rim of the wheel and sprayed toward the disk and hub. The cumulative discharge of water to atmospheric pressure is shown in figure 9(c).

Rear support subsystems: Two water spray subsystems cooled and inerted the exterior and interior of the rear turbine-bearing-support-strut assembly. This strut assembly is composed of six struts and an interconnecting ring structure. The six struts cross the hot turbine exhaust gas stream. One subsystem, the inner-rear-support subsystem, cooled and inerted the interior of the struts and interconnecting ring structure; the other subsystem, the outer-rear-support subsystem, cooled the exterior of that assembly:

(1) Inner-rear-support subsystem: The inside of the tubular strut-ring structure supporting the rear turbine bearing was sprayed with 1.0 pound of water through the open strut ends. Six nozzles, each producing an 80° semihollow-cone-pattern spray, were located outside the engine as shown in figure 10(a). These nozzles had a 0.040-inch orifice and a rated discharge of 0.1 gallon per minute at 100 pounds per square inch. The cumulative water discharge from this subsystem is shown in figure 10(b).

(2) Outer-rear-support subsystem: Six 95° flat spray nozzles, mounted in the inner rear exhaust cone, sprayed 1.2 pounds of water on the outside of the bases of the struts and the interconnecting ring assembly. These nozzles had an equivalent orifice of 0.026-inch inside diameter and a rated discharge of 0.16 gallon per minute at 100 pounds per square inch. Details of their installation are shown in figure 11(a). The cumulative water discharge is shown in figure 11(b).

The four turbine subsystems described above were supplied from a single tank containing 7.3 pounds of water as shown (fig. 12(a)). The volume and pressure of propelling nitrogen, and the nozzle orifice areas were selected to give the desired discharge time. To prevent the flow of turbine gases from the front rotor nozzles to the rear rotor nozzles during engine operation, a check valve was installed in the tube supplying the front turbine subsystem. Less water was needed to cool the rear-bearing support struts than to cool the rotor because of the difference in mass and heat capacity. For this reason, a relief valve was installed as a pressure-operated variable orifice. This relief valve began to close about 20 seconds after the system was actuated and thereby reduced the flow rate to the inner and outer support subsystem (figs. 10(b) and 11(b)).

The total cumulative water discharge with time by these four turbine subsystems is shown in figure 12(b), along with the propelling nitrogen pressure decay in the tank. Less initial propelling pressure was used for these turbine subsystems than in the combustor system (150 as compared with 700 lb/sq in. gage), because smaller initial discharge rates were needed.

## Bromotrifluoromethane System

Ten pounds of bromotrifluoromethane ($CBrF_3$) was discharged during a period from 45 seconds to 10 minutes after fuel shutoff to inert the atmosphere around the turbine rotor until the rotor had cooled sufficiently so that it was no longer a possible crash-fire ignition source. A schematic diagram of the $CBrF_3$ system is shown in figure 13. The $CBrF_3$ was discharged onto the front and rear surfaces of the turbine rotor through the front and rear rotor subsystems of the turbine water spray system. To provide an approximately equal discharge out of each subsystem, a 0.0040-square-inch orifice metered the flow of $CBrF_3$ into each of the water spray manifolds. Check valves were used to prevent the flow of $CBrF_3$ into the turbine water spray system supply tank.

The $CBrF_3$ was stored as a liquid and discharged by its own vapor pressure. As it flowed through the metering orifice, it expanded and cooled, becoming a liquid-vapor mixture. It expanded more at the nozzle and was discharged as a liquid-vapor mixture. However, the liquid quickly vaporized after passing through the nozzles. The vapor then mixed with the air around the turbine rotor and inerted the atmosphere. Ten minutes after fuel shutoff, the internal heat in the rotor had been dissipated to surrounding cooler metal and to the atmosphere, and the rotor was no longer a crash-fire ignition source.

Although the $CBrF_3$ was discharged through a water spray manifold after the water was expended, a separate $CBrF_3$ manifold might be desirable for a production system. The $CBrF_3$ valve could then be actuated at the same time as the water spray valves. This would be simpler than delaying the $CBrF_3$ valve actuation for 45 seconds. Less than 1 pound of $CBrF_3$ would be required for the additional 45 seconds of discharge.

## TRIAL PROCEDURE AND CONDITIONS

The combined water-$CBrF_3$ crash-fire protection system was evaluated in a similar manner to that described in reference 2 for the all-water system. Because of the way fuel spills in a crash (ref. 4) crash fuel spillage could be simulated on a test stand. The engine was mounted on a movable test stand consisting of a stripped C-82 airframe (fig. 14). The engine was fastened to one of the reciprocating-engine fire-wall structures. The cargo compartment was used to house the control room. This three-wheeled test stand allowed the engine to be oriented to various wind directions and to be hangared for experimental modifications.

In trials of this protection system, engine operating conditions were established which corresponded to those that would exist in a crash on takeoff. This represents the most severe crash-fire hazard because the engine temperatures are highest under these conditions.

To simulate takeoff conditions, the engine was operated at maximum power and maximum turbine-inlet temperature (1780° F) until the temperatures of massive metal parts, such as the turbine rotor, reached equilibrium. At a moment that corresponded to airplane crash, the fuel flow to the engine combustors was stopped and the crash-fire protection system was actuated. The engine was then exposed to simulated crash-spilled JP-5 fuel mist 0.3 second after normal fuel to the combustors was cut off; JP-5 fuel was sprayed into the engine inlet duct to match the initial airflow, which had a fuel-air ratio of approximately twice stoichiometric. This fuel-air ratio was used because it is about the most easily ignited. As the engine slowed, this spray was replaced by a 4- to 5-second pulsed atomized fuel spray. The pulsed atomized fuel spray was directed into both the inlet and the exhaust. Fuel sprayed into the exhaust impinged on the rear turbine-bearing-support assemblies and the last-stage turbine rotor. The pulsing of the fuel spray covered a range of fuel-air ratios from too lean for ignition up to too rich for ignition. During the later portion of engine coastdown, the pulsed spray was actuated at 10-second intervals. After the engine had stopped rotating, the spray was actuated at 15-second intervals until 3 minutes after normal fuel shutoff. From 3 until 7 minutes after fuel shutoff the pulsed spray was actuated every 30 seconds, and from 7 to 15 minutes it was actuated every 60 seconds.

JP-5 grade fuel was selected for the performance-trial fuel sprays because it represented the kerosene-type fuel that is intended for commercial use. The spontaneous-ignition temperature of this fuel is one of the lowest for a combustible liquid carried in a turboprop airplane.

Because of the high cost of $CBrF_3$, the initial experiments were made using only the fuel shutoff and drain system and the water spray system. Fuel was sprayed in from 0.3 to 45 seconds after actuation of the crash-fire protection system. After the water spray system had been evaluated, the $CBrF_3$ system was added and evaluation experiments were made using the full crash-fire protection system.

These initial experiments showed that the water spray system alone adequately protected the engine for 45 seconds. Therefore as an experimental convenience the combined water-$CBrF_3$ system was evaluated by spraying fuel in from 15 seconds to 15 minutes after normal engine fuel shutoff. The overlapping period of fuel sprays ensured that the combined water-$CBrF_3$ system was adequately evaluated over the entire period from 0.3 second to 15 minutes after normal engine fuel shutoff.

The twice-stoichiometric fuel spray and the pulsed atomized fuel sprays simulated extremely severe crash-fuel-spilled conditions. Descriptions of experimental crashes in reference 4 indicate that the fuel mist is unlikely to persist for more than 17 seconds after crash impact. However, a reduced fire hazard still exists after the fuel mist has subsided because considerable liquid fuel may be present. Since kerosene-type fuels, such as JP-5, will not produce an ignitible quantity of vapor at normal atmospheric temperatures, the liquid fuel must first be vaporized before it can be ignited. Such vaporization may occur if liquid fuel flows through the engine or onto hot exhaust ducts. Even though metal parts which liquid fuel can easily reach may not be hot enough to ignite the fuel, they may be hot enough to vaporize it. Combustible fuel-air mixtures may thus be present inside and around an engine long after the fuel mist subsides. The combustible vapors can reach hot surface ignition sources inside an engine more readily than liquid fuel. The fuel sprays in these trials simulated extremely severe conditions of both crash-generated fuel mist and liquid fuel spillage.

In a normal engine shutdown, the fifth- and tenth-stage compressor bleed valves reopen for the next start. In these trials the compressor bleeds were kept closed to prevent inlet-ingested fuel from entering the nacelle through these compressor bleed valves. In preliminary experiments fuel sprayed directly into the YC-130 nacelle did not ignite. However, passage through the compressor atomizes and heats the fuel. Fuel so mixed and heated in the compressor becomes much more easily ignited, and it is believed that such fuel should be excluded from the nacelle if practicable.

The propeller pitch was selected to give the two extremes of a 45-second normal flat-pitch coastdown and a 13-second feathered coastdown. If in a crash the propellers were to drag the ground to impose the maximum torque within the stress limits of the gearing, it is estimated that the rotation and air pumping could stop in about 1 second. Such short coastdowns are considered unlikely in a crash, and no attempt was made to duplicate these conditions in this test-stand study. However, it is believed that these previously described water-$CBrF_3$ systems would prevent a crash fire even if such a short coastdown should occur. If the engine coastdown is of short duration, the large amount of steam produced by the water systems will not be carried out of the engine by the airflow. This steam fills the interior of the engine and inerts and cools the hot metal parts. The smaller amount of combustor water that reaches the turbine should be balanced by the increased amount of steam that will remain around the turbine to inert and cool the hot rotor assembly. After the engine has stopped, the $CBrF_3$ inerts the atmosphere around the turbine and prevents ignition of spilled fuel.

## FIRE DETECTION

Visual or audible propagation of fire out of the inlet or exhaust ducts provided the most positive indication of fire resulting from inadequacies of the preliminary crash-fire protection system. However, as described in reference 2, fires can occur in the engine without a visual flame or audible explosion propagating out of the engine. To detect these internal fires, motion pictures were taken through windows in the combustor-chamber housing. These windows are shown in figure 15. The longitudinal row of three windows, when photographed at 50 frames per second, also indicated the direction of propagation, and thus, pointed to the sources of ignition. Weak flames of less than 0.1-second duration could be photographed.

Although fires which remain in the engine are not a hazard, the objective that even nonpropagating flames within the engine also be prevented by the crash-fire protection system was set and realized. Flames within the engine, even though they do not propagate, were taken to indicate marginal fire suppression.

## RESULTS OF TRIALS

This crash-fire protection system prevented ignition of ingested fuel in a series of severe performance trials. The most hazardous condition of engine operation and exposure to simulated fuel spillage was duplicated or exceeded.

Ten performance trials were used to simulate engine exposure to crash fuel spillage during the interval from 0.3 to 45 seconds after fuel shutoff. Another ten performance trials were used to simulate engine exposure to crash fuel spillage during the interval from 15 seconds to 15 minutes after fuel shutoff. The overlapping of these time intervals ensured that the engine had been exposed to simulated crash fuel spillage from 0.3 second to 15 minutes after fuel shutoff. Five of the trials for each time interval were made using a feathered propeller and a short coastdown time (13 sec). The other five trials for each time interval were made using a flat-pitched propeller and a longer coastdown time (35 to 45 sec).

## GENERAL REMARKS

The mass discharge rate of liquid $CBrF_3$ that is expelled by its own vapor pressure can vary considerably depending on the temperature of the $CBrF_3$. Both its liquid density and vapor pressure change with temperature. For example, at -20° F its density is 109 pounds per cubic foot and its vapor pressure 35 pounds per square inch, while at 120° F its density is 81 pounds per cubic foot and its vapor pressure 425 pounds per square inch (ref. 3). Therefore, the mass discharge rate of $CBrF_3$ will depend greatly on its temperature when expelled under its own vapor pressure through a fixed orifice. In a crash-fire protection system the mass discharge of $CBrF_3$ must be fairly constant throughout the range of temperatures that might be encountered in aircraft operation. In the performance trials of the crash-fire protection system, the temperature of the $CBrF_3$ was approximately the same in all trials; therefore, the discharge rate was fairly constant in all the trials. In an aircraft installation pressurization of the $CBrF_3$ with nitrogen might be used to lower the sensitivity of the mass discharge rate to the temperature of the $CBrF_3$.

Other flight fire extinguishing agents might also be used to inert the interior of the engine. However, if they were not as effective inerting agents as $CBrF_3$, it would be necessary to use more of the agent and to discharge it at a higher rate than would be the case with $CBrF_3$. Another agent might be more practical to use in an airplane if its density and vapor pressure would not vary widely with its temperature.

Exploratory studies showed that, when $CBrF_3$ was expanded through the water spray nozzles, it cooled sufficiently to freeze residual water in the nozzles. The ice would then block the discharge of any more $CBrF_3$. The use of a lithium chloride antifreeze solution in the water lowered its freezing point to -2° F and prevented the formation of ice in the lines or nozzles.

The combined water-$CBrF_3$ crash-fire protection system would still be very effective even if the $CBrF_3$ had been previously discharged to extinguish a fire in flight. The water system alone supplied protection during the most hazardous time in a crash, the time when fuel mist is likely to be present and when the engine is still rotating. Also, if the engine were not restarted after a flight fire, the hot metal parts would cool more quickly in flight than on the ground. The water system alone might then further cool all the hot interior parts of the engine so that they would be too cool to ignite spilled fuel.

Another possible use of $CBrF_3$ in a crash-fire protection system is in inerting the entire airflow through the engine following a crash. The $CBrF_3$ would have to be discharged at a rate proportional to the mass airflow through the engine, which varies considerably during coastdown. For example, in a 45-second flat-pitch coastdown, the airflow rate at shutdown is 40 times the rate at 30 seconds after shutdown. A preliminary study was made of an all-$CBrF_3$ system, but because of the difficulty in matching the $CBrF_3$ discharge to the declining airflow, the combined water-$CBrF_3$ system appeared more practical. In addition, since $CBrF_3$ does not cool the engine, the hot surface ignition sources in the engine would persist for a long time.

Like the all-water crash-fire protection system described in reference 2, this combined water-$CBrF_3$ system only provides protection for the interior of the engine. References 1 and 4 discuss the other portions of the engine and aircraft which also require crash-fire protection.

Hot exterior surfaces are also potential crash-fire ignition sources. When this engine is installed in an airplane, additional studies will be needed to determine whether the exhaust ducting and exterior of the engine can ignite crash-spilled fuel. The need for an exterior fire prevention system will depend largely on the ventilation provided the exterior of the engine and any exhaust duct which may be used. These hot surfaces should be subjected to test fuel spray trials in the airflow and temperature environment provided by the airframe in which they are installed. Since the interior water systems can help cool the exterior surfaces by conduction, they should be used when making these studies. The interior water systems will also tend to inert and cool the exhaust ducting because of the entrainment of some water in the exhaust leaving the engine. If protection is required for the exhaust ducting and the exterior of the engine, the methods described in references 2 and 5 may be used. In the method described in these references, the hot exterior surfaces are covered with a "waffle grid" of fine mesh screen. Manifolds located between the screen and the exterior surfaces spray water onto the hot surfaces. The screen holds the water in contact with the hot surfaces while they are cooled.

A complete aircraft fire protection system will also require the deenergizing of ignition sources not associated with the engine (ref. 4). These ignition sources include other hot surfaces such as those associated with auxiliary powerplants and combustion heaters and sparks produced when electrical power networks and equipment are destroyed.

A suitable method of initiating the action of these crash-fire protection systems is also needed. At present manual actuation appears to be preferred. The actuation switch must be readily accessible for crash operation but safe from inadvertent actuation in normal flight. An entirely automatic system actuated by events leading to fuel spillage in the crash also is proposed in reference 5. Such automatic systems can be considered for airplane use only after highly reliable equipment has been developed and tested.

Lewis Research Center
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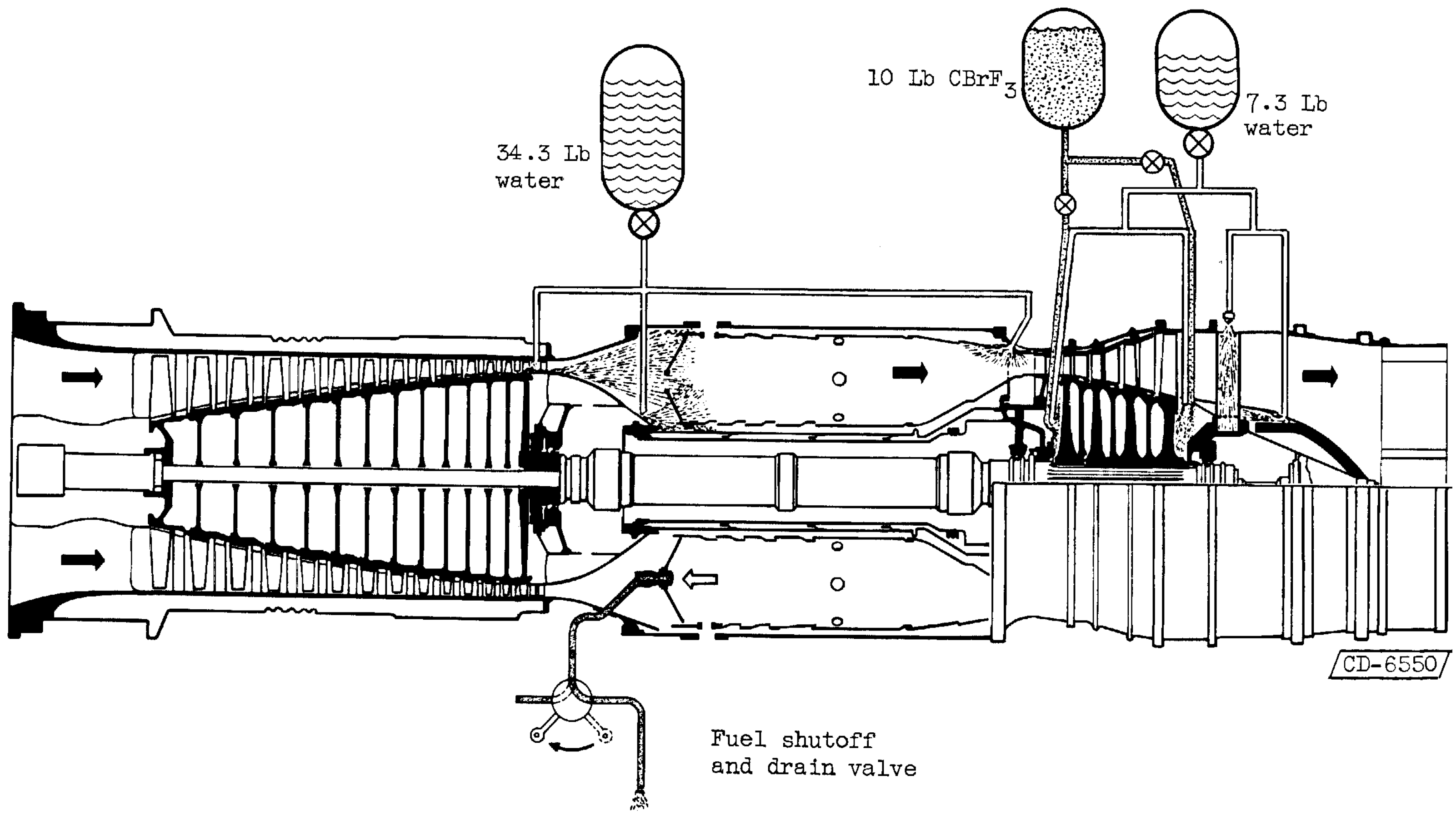



Figure 1. - Combined water-$CBrF_3$ crash-fire protection system for T-56 turboprop engine.

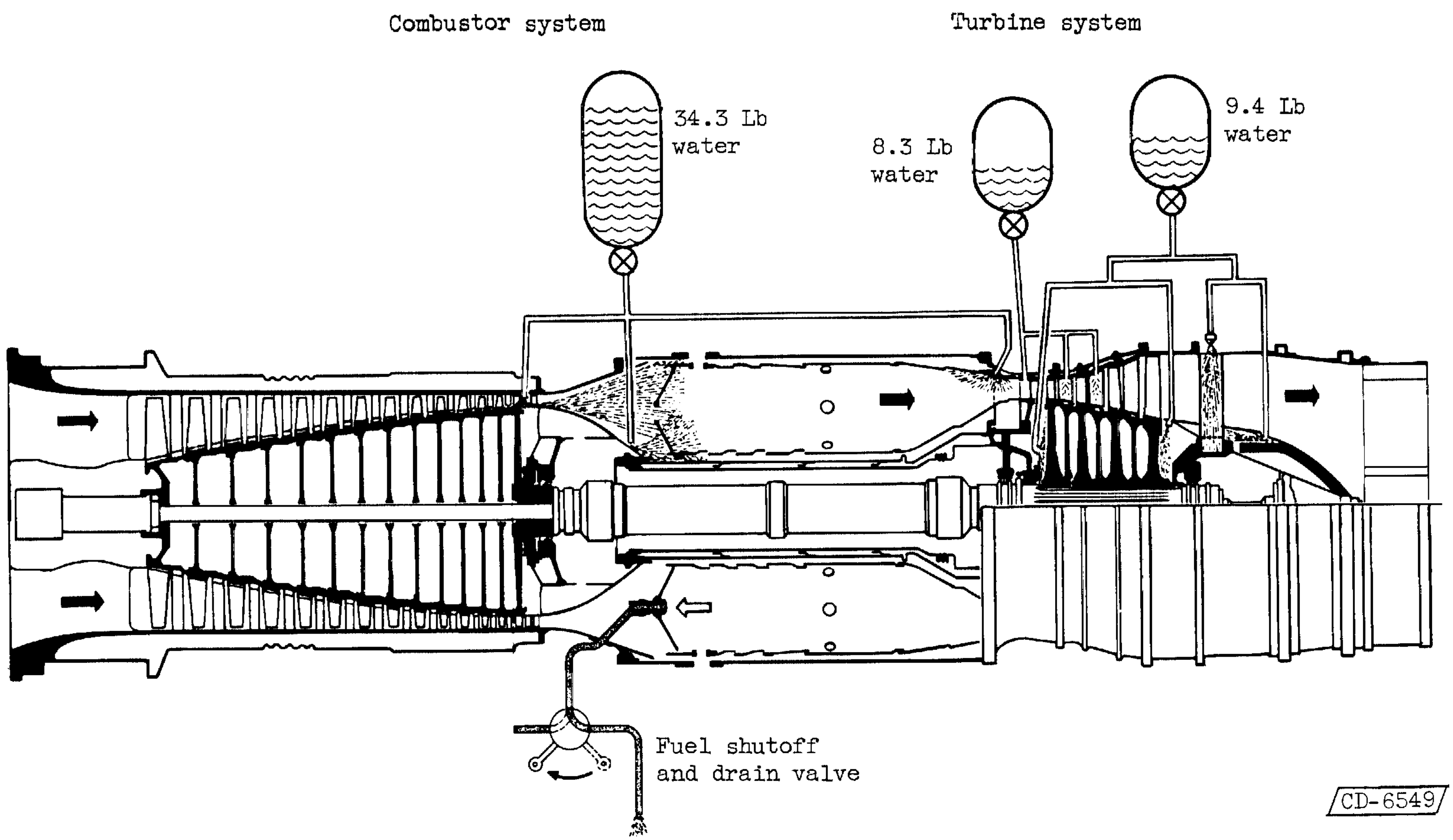
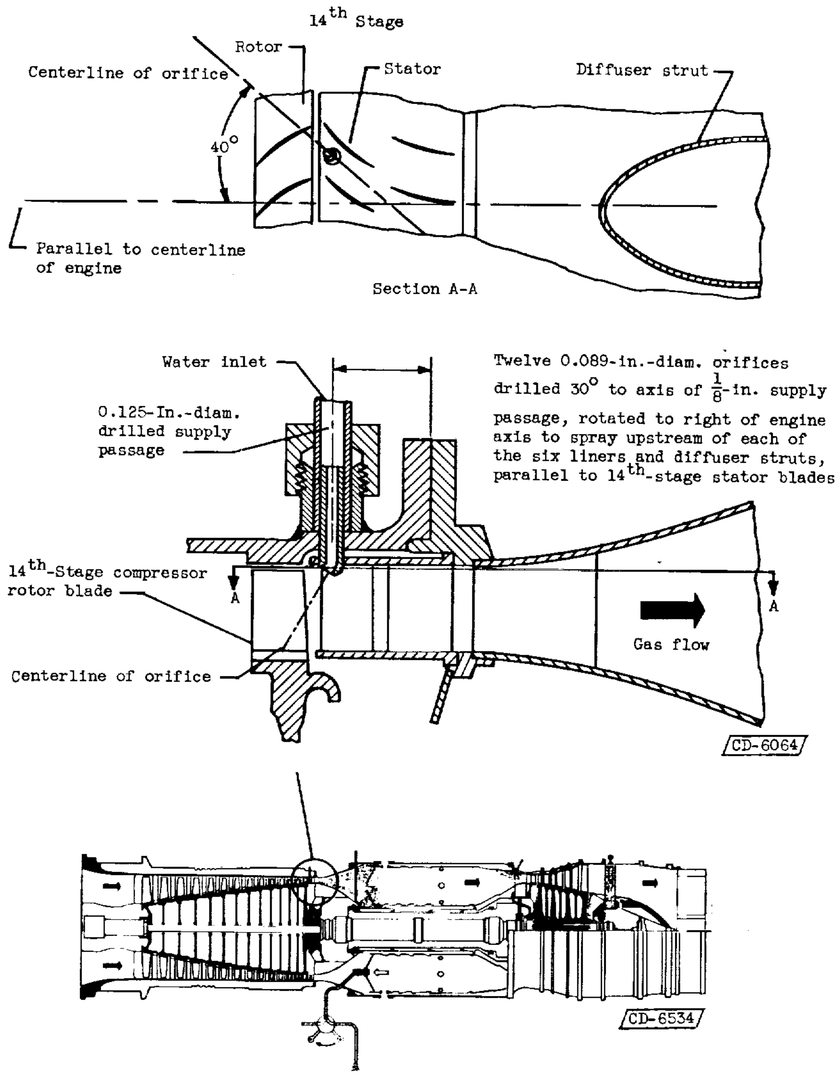
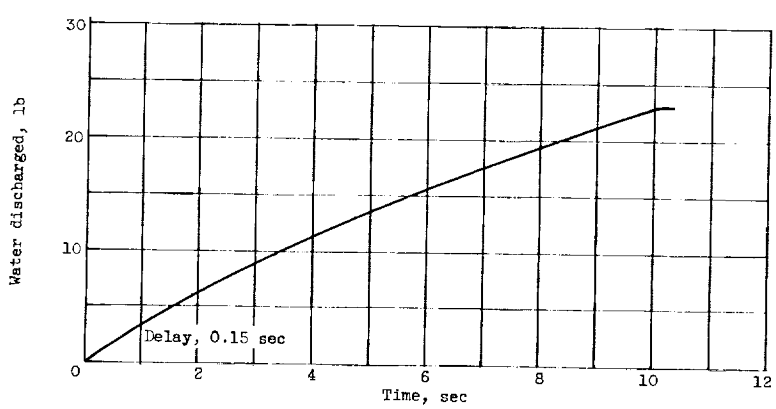



Figure 2. - All-water crash-fire protection system for T-56 turboprop engine (ref. 2).

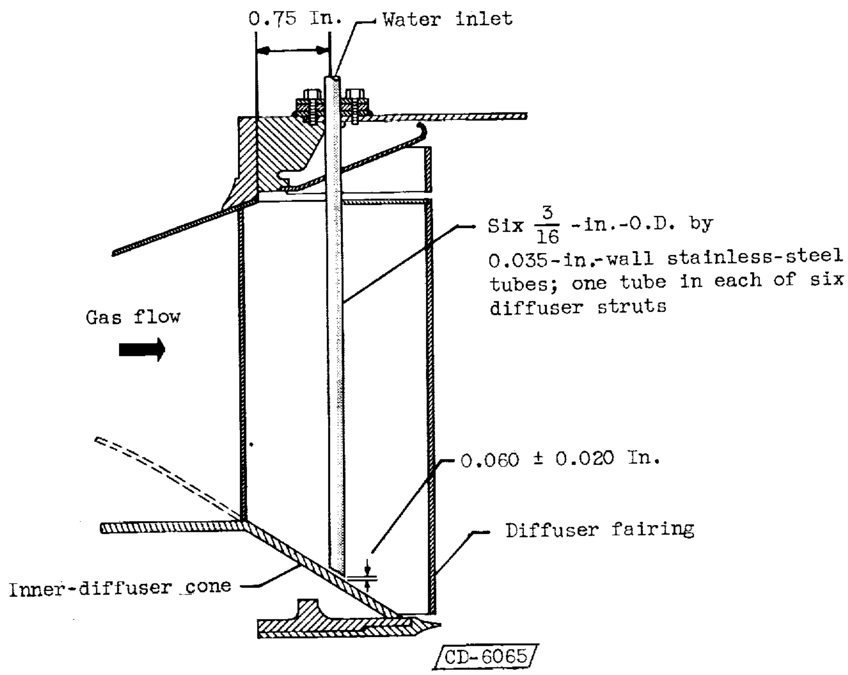


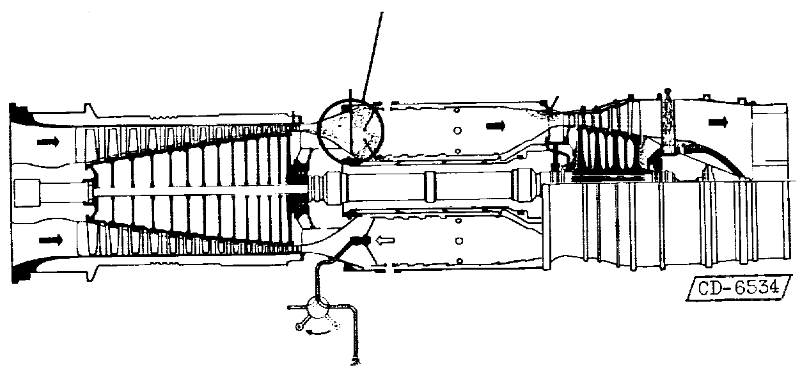

(a) Installation of nozzles.



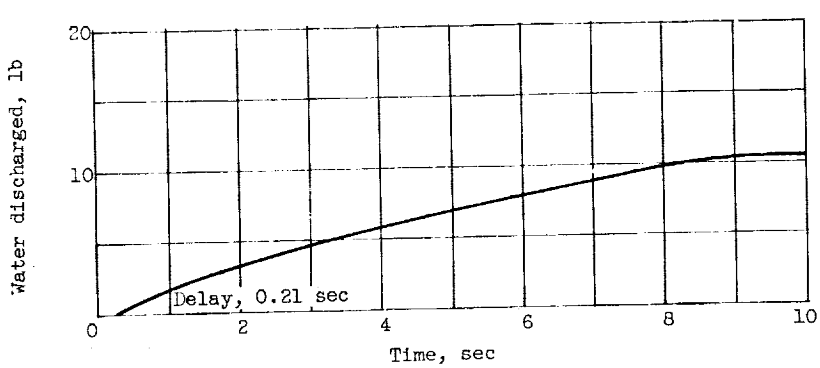

(b) Cumulative water discharge.

Figure 3. - Compressor-outlet subsystem.



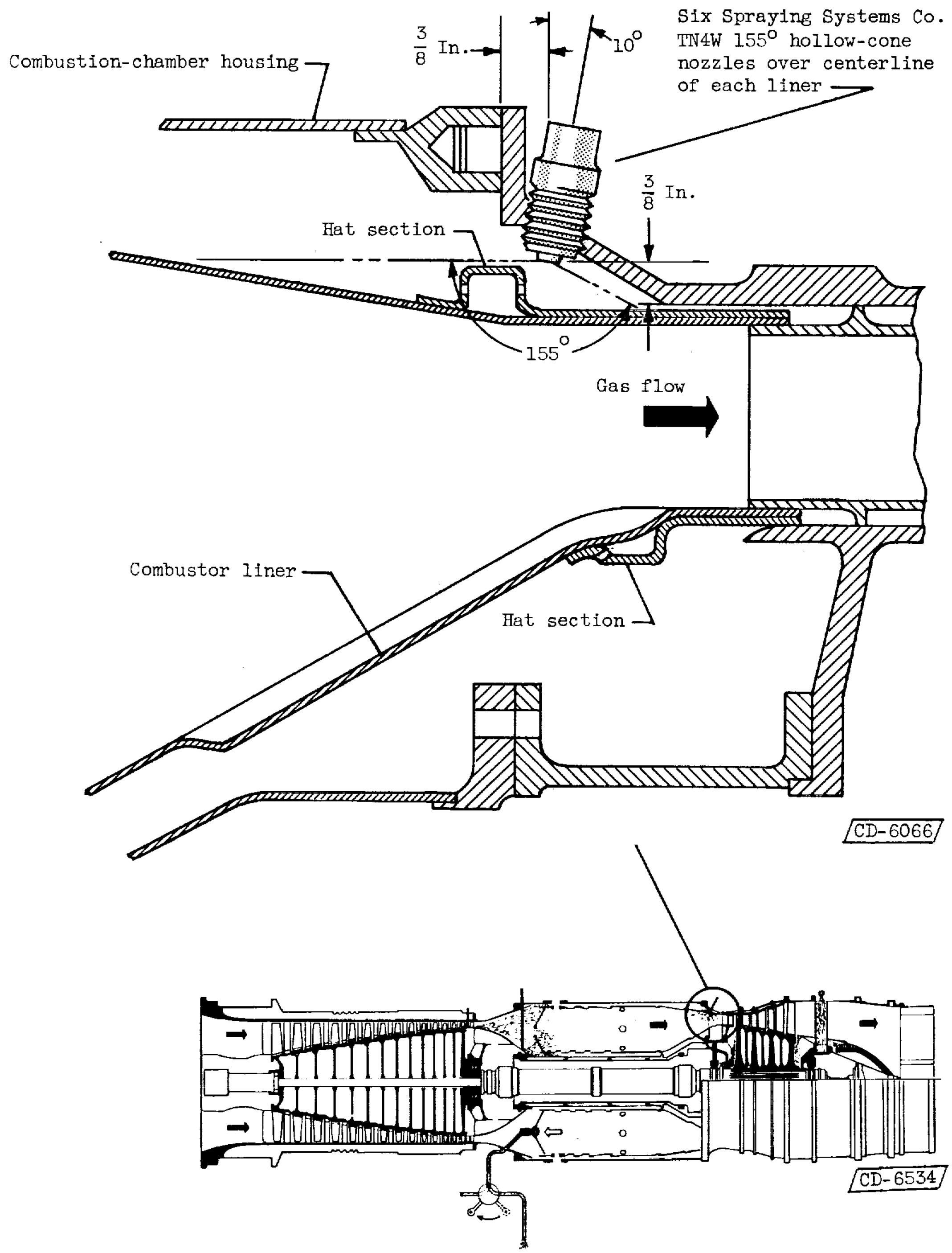




(a) Water spray nozzle installation.



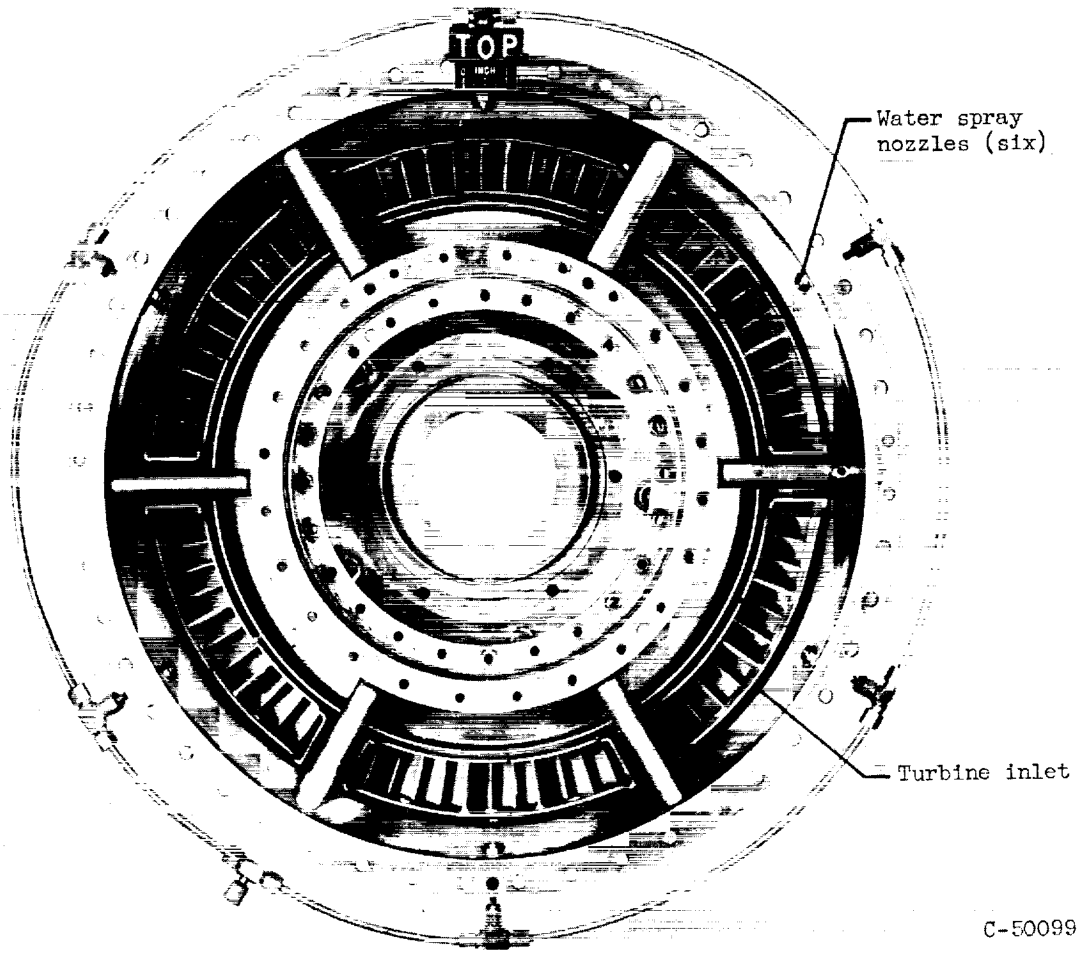

(b) Cumulative water discharge.

Figure 4. - Inner-diffuser-fairing subsystem.




(a) Schematic diagram of water spray nozzle installation.

Figure 5. - Outer-rear-liner subsystem.

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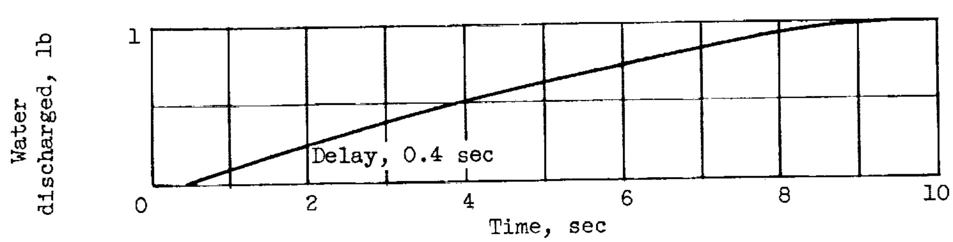
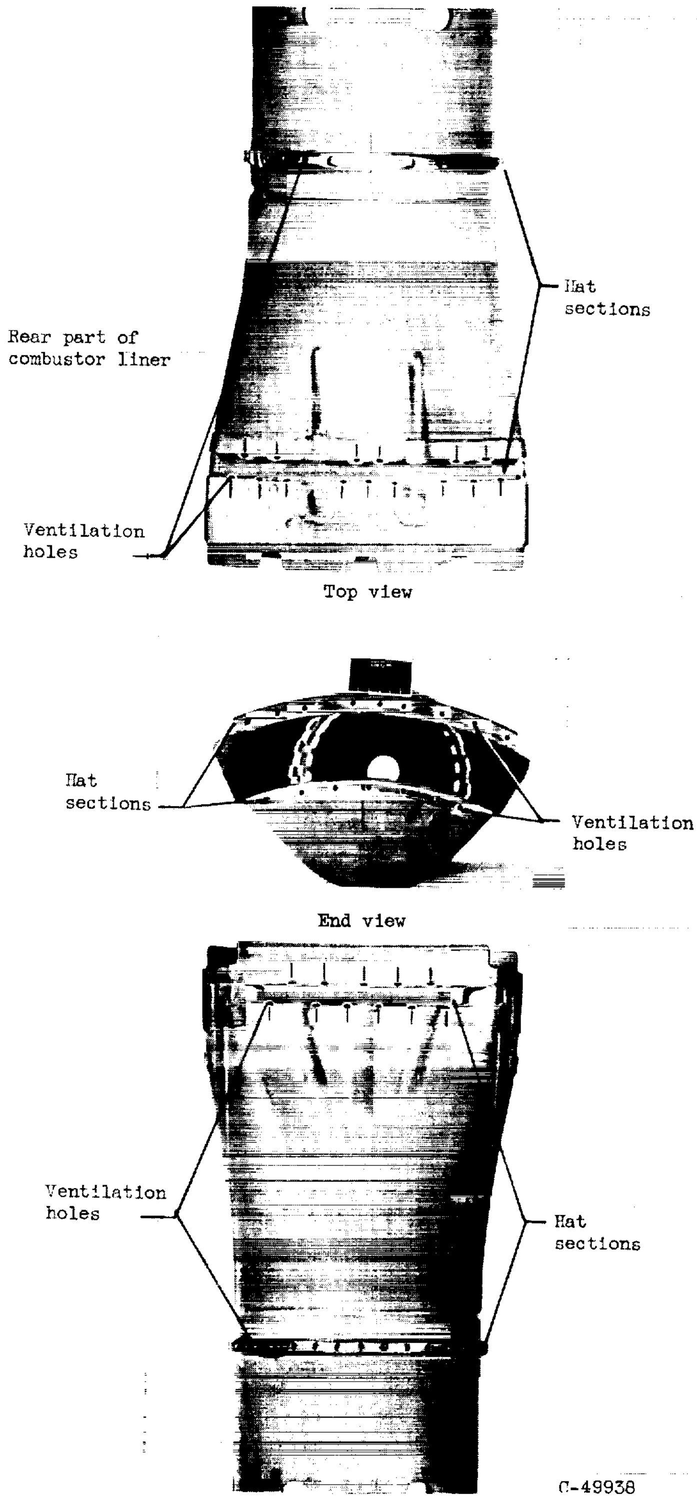
(b) Water spray nozzle installation.



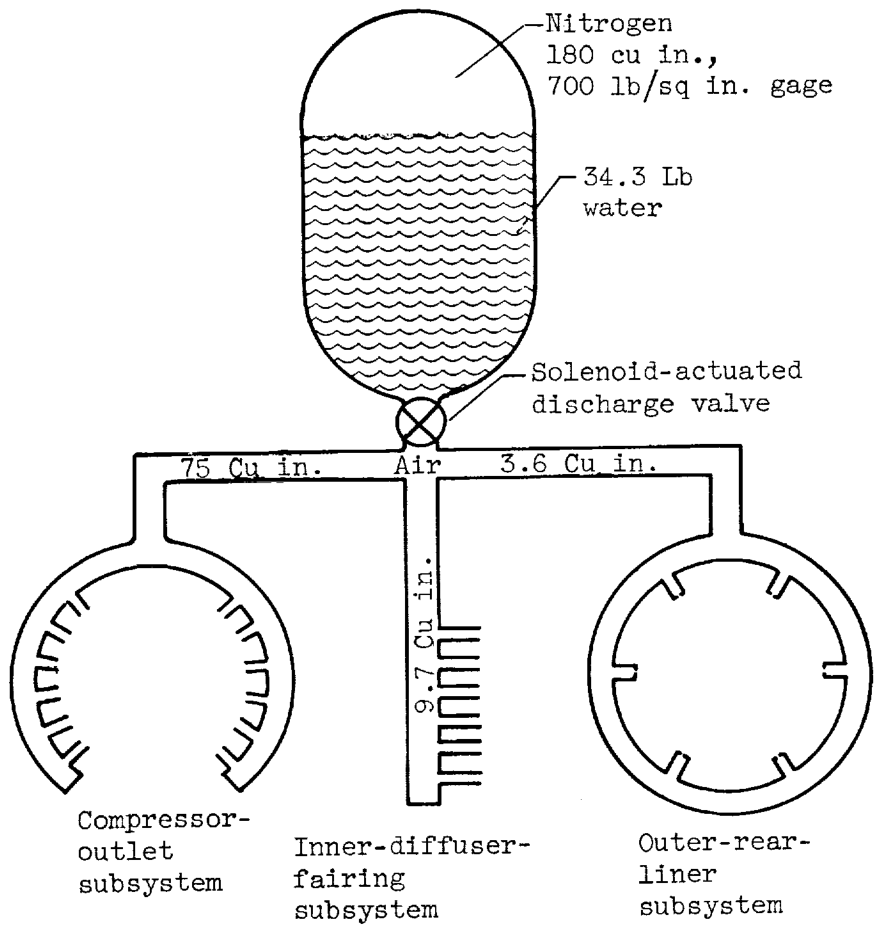

(c) Cumulative water discharge.

Figure 5. - Concluded. Outer-rear-liner subsystem.



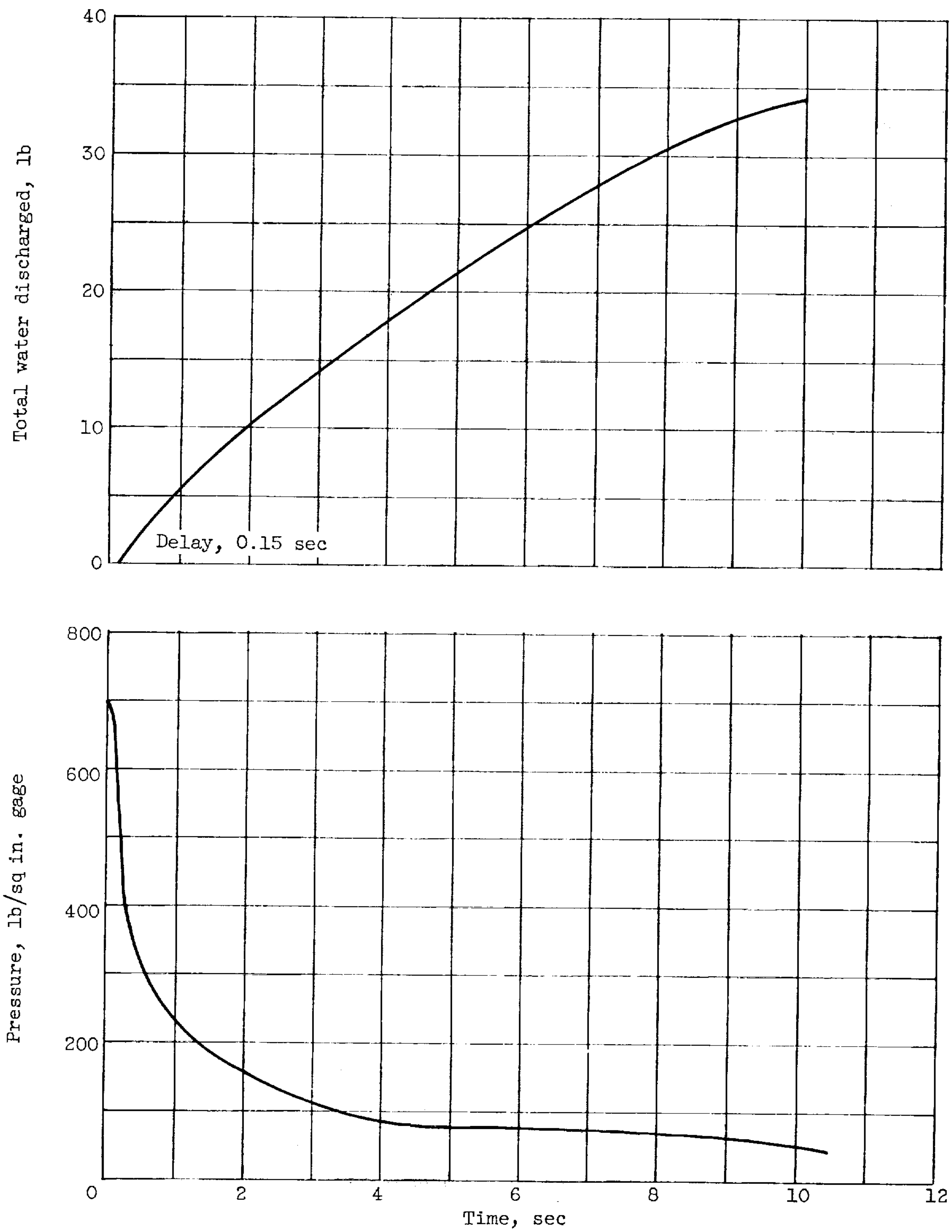

Bottom view

**Figure 6. - Ventilation holes drilled in hat sections of combustor liners.**



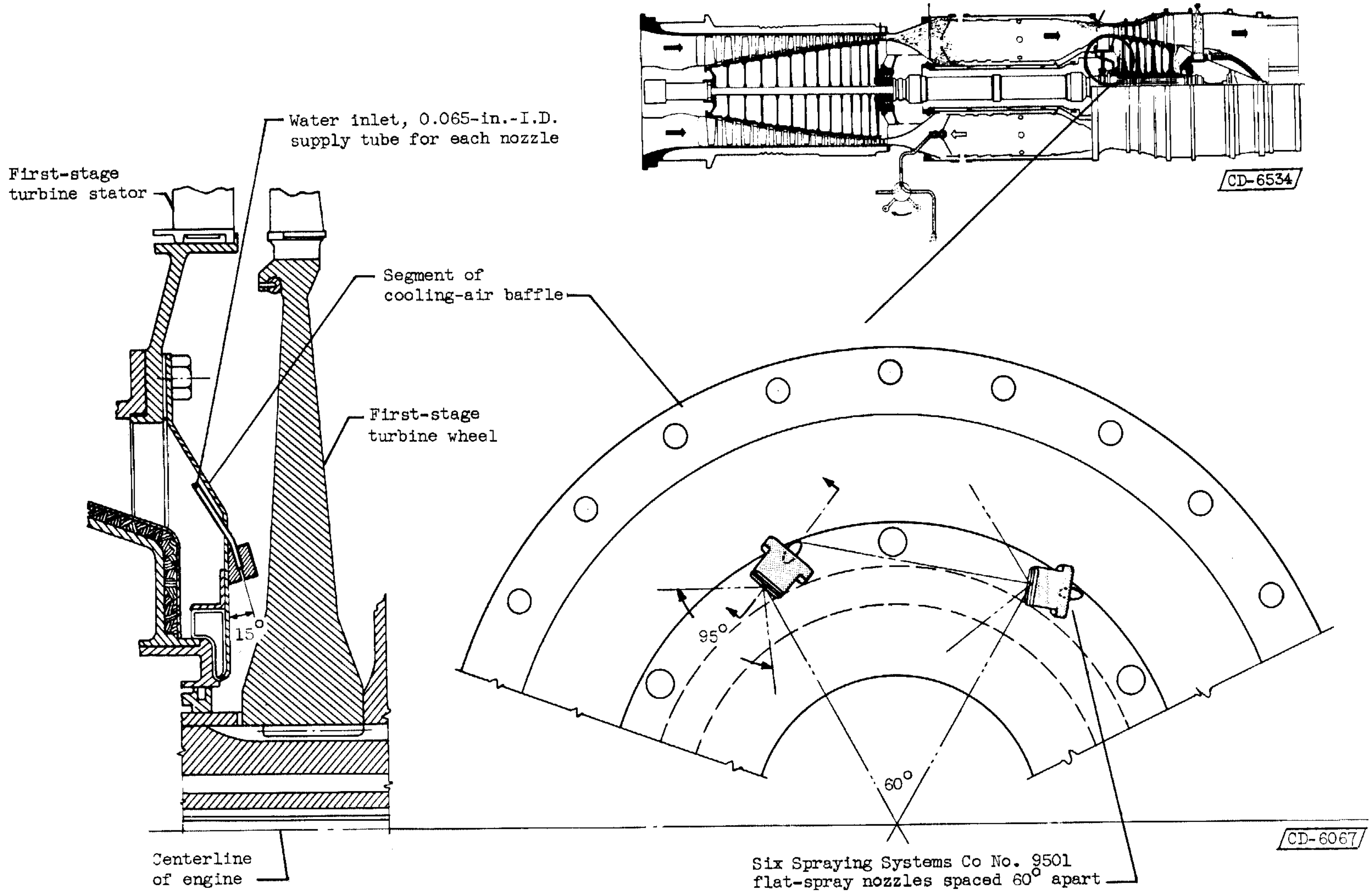

(a) Schematic diagram.

Figure 7. - Combustor system.



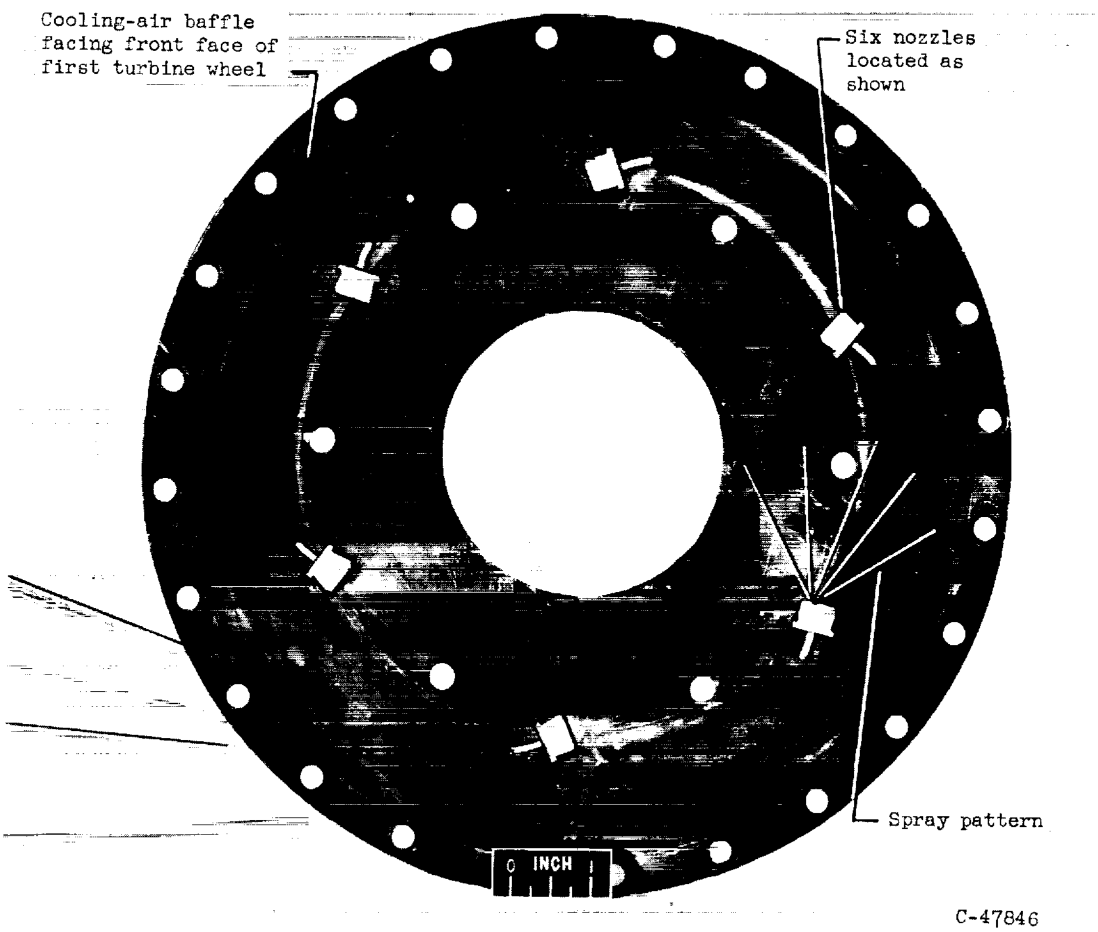

(b) Total cumulative water discharge and propelling pressure decay.

Figure 7. - Concluded. Combustor system.

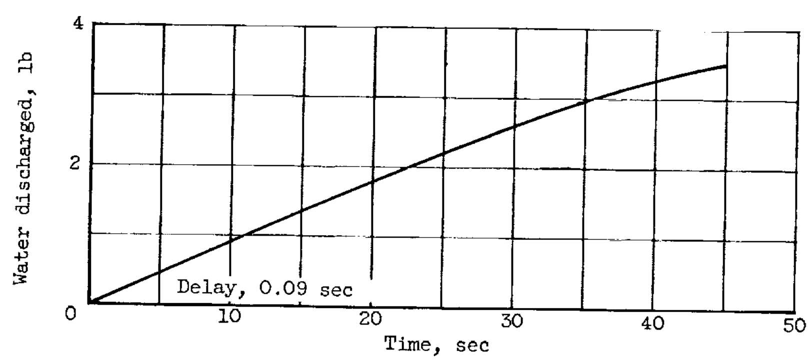



(a) Schematic diagram of water spray nozzle installation.

Figure 8. - Front-rotor subsystem.

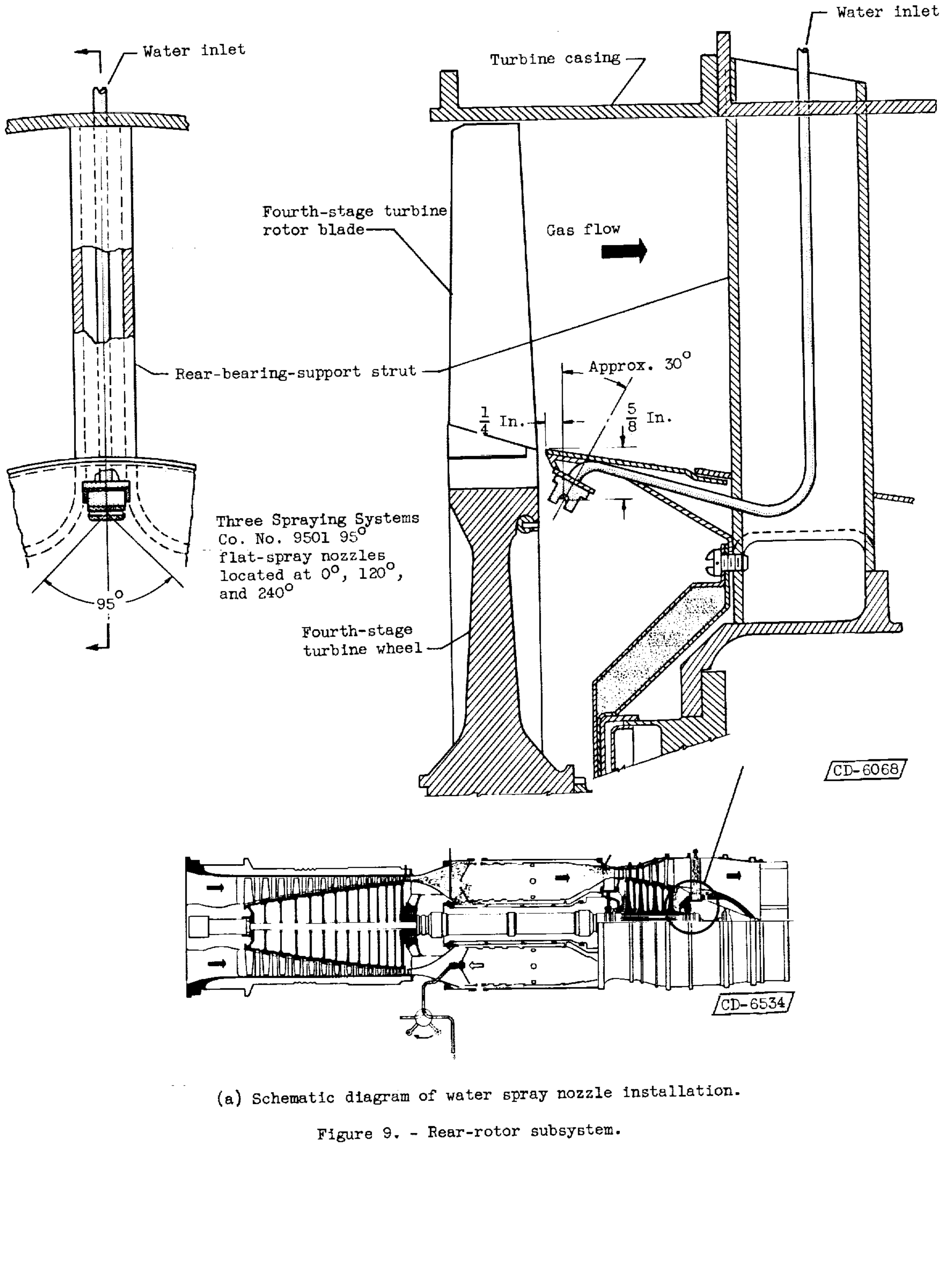



(b) Nozzle installation.




(c) Cumulative water discharge.

Figure 8. - Concluded. Front-rotor subsystem.




(a) Schematic diagram of water spray nozzle installation.

Figure 9. - Rear-rotor subsystem.

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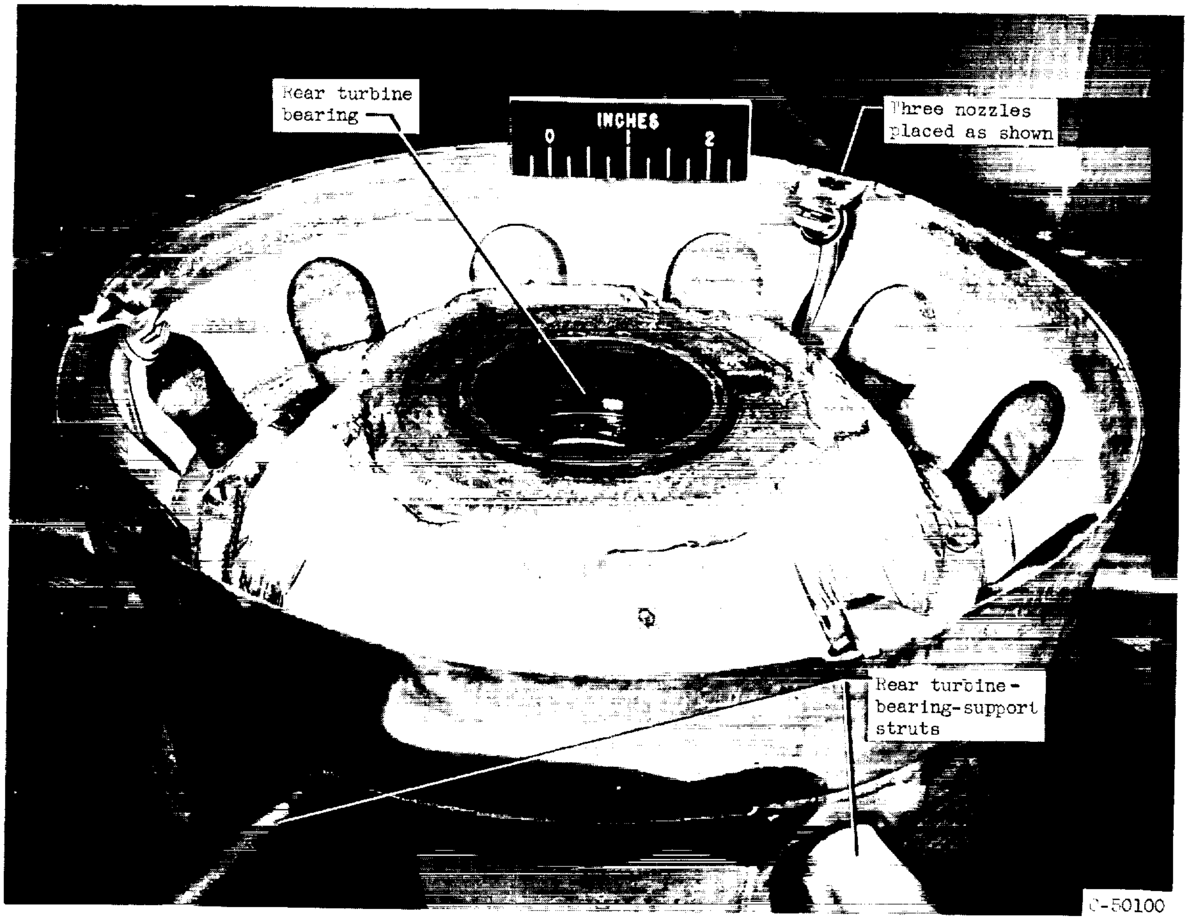
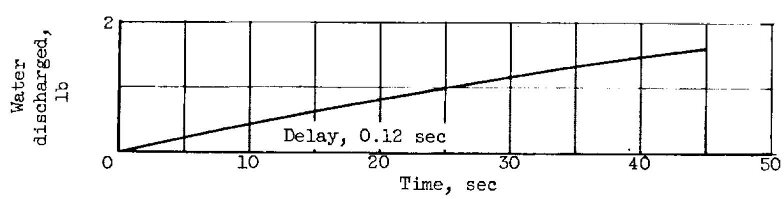
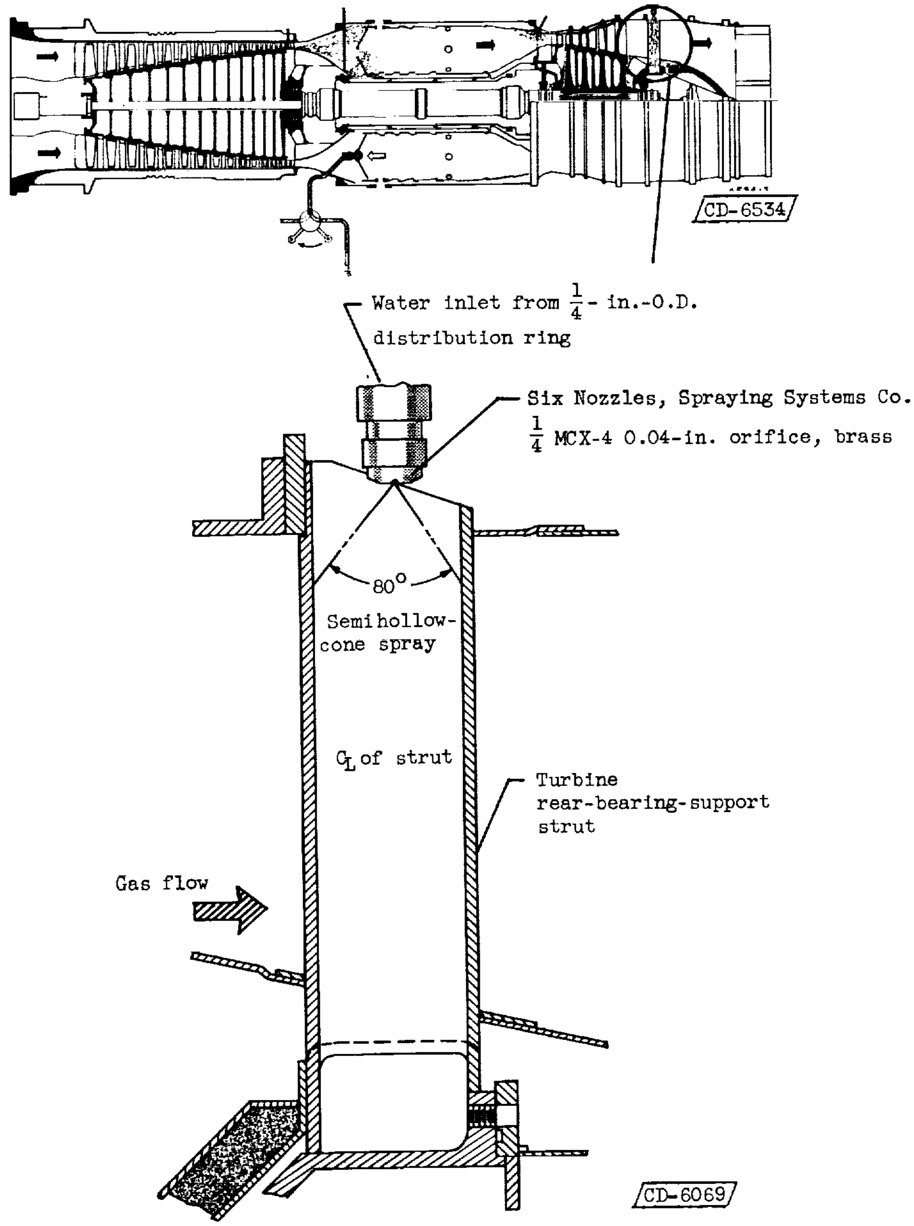



(b) Nozzle installation.

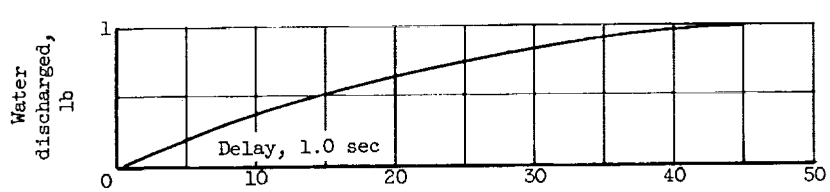



(c) Cumulative water discharge.

Figure 9. - Concluded. Rear-rotor subsystem.

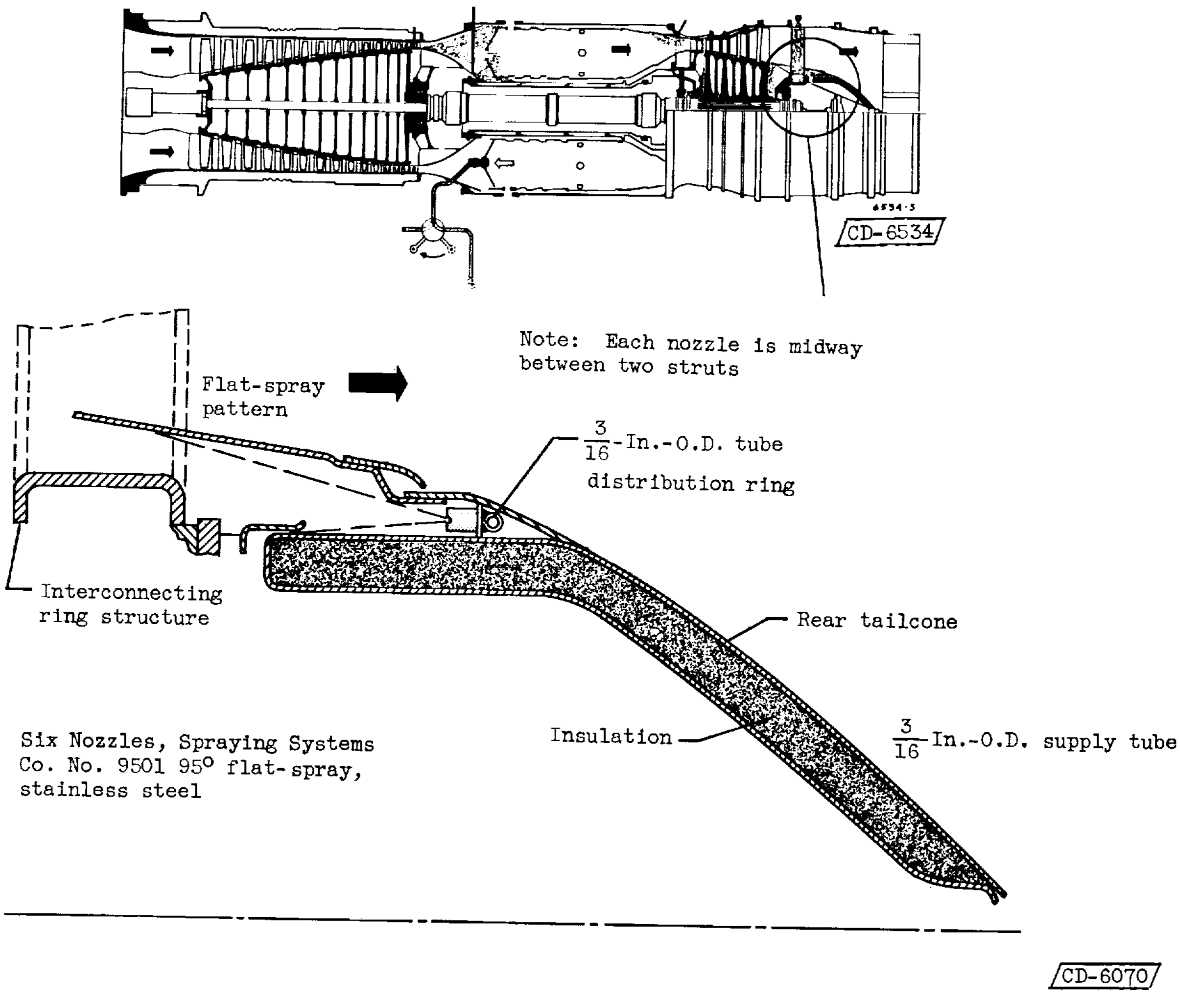



(a) Water spray nozzle installation subsystem.

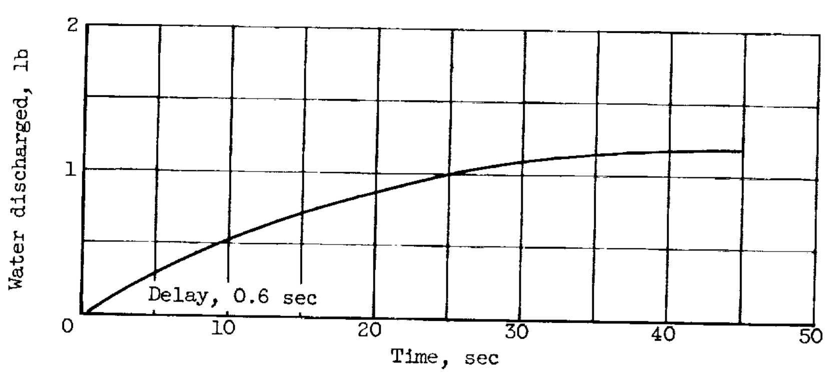



(b) Cumulative water discharge.

Figure 10. - Inner-rear-support subsystem.

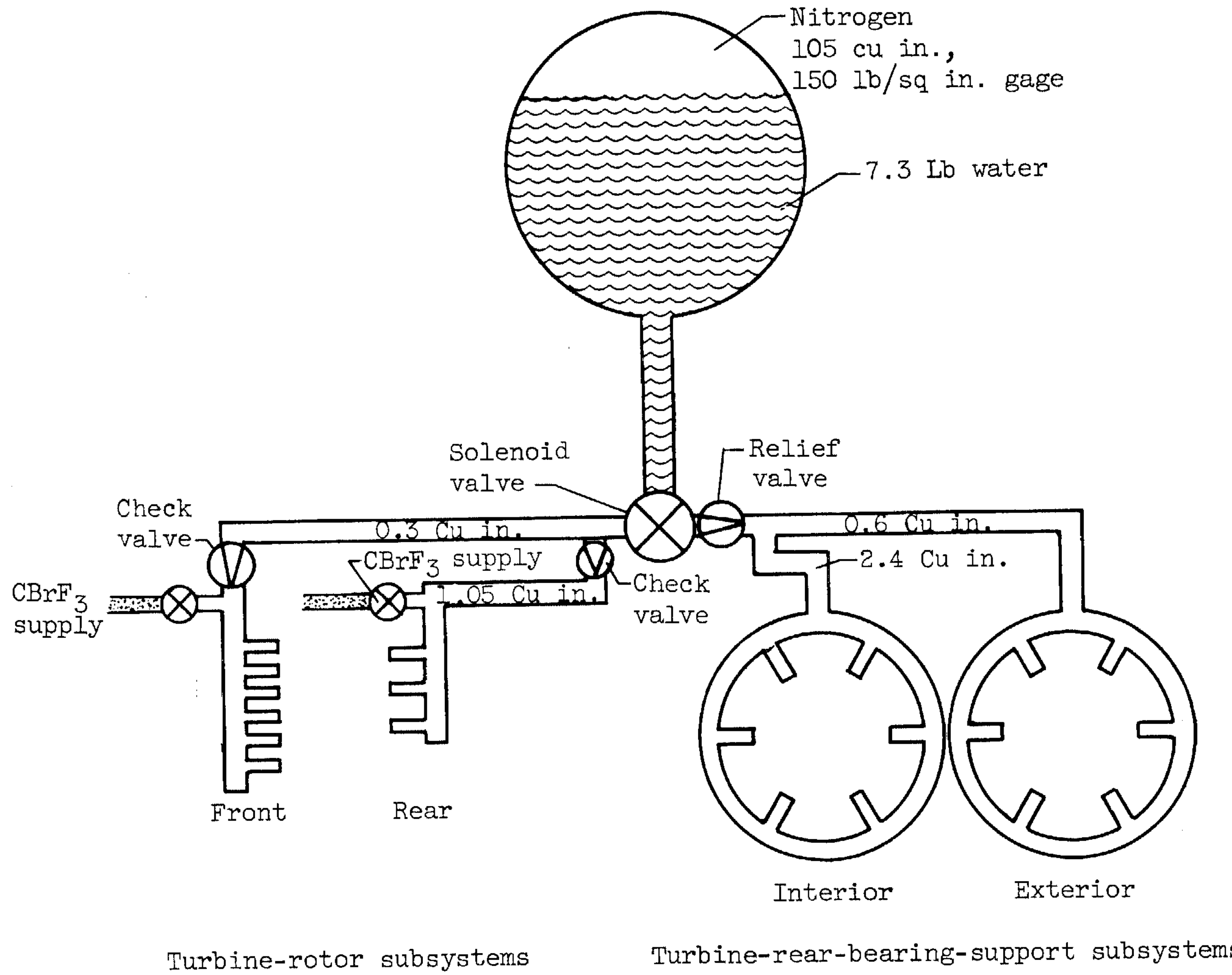



(a) Water spray nozzle installation.



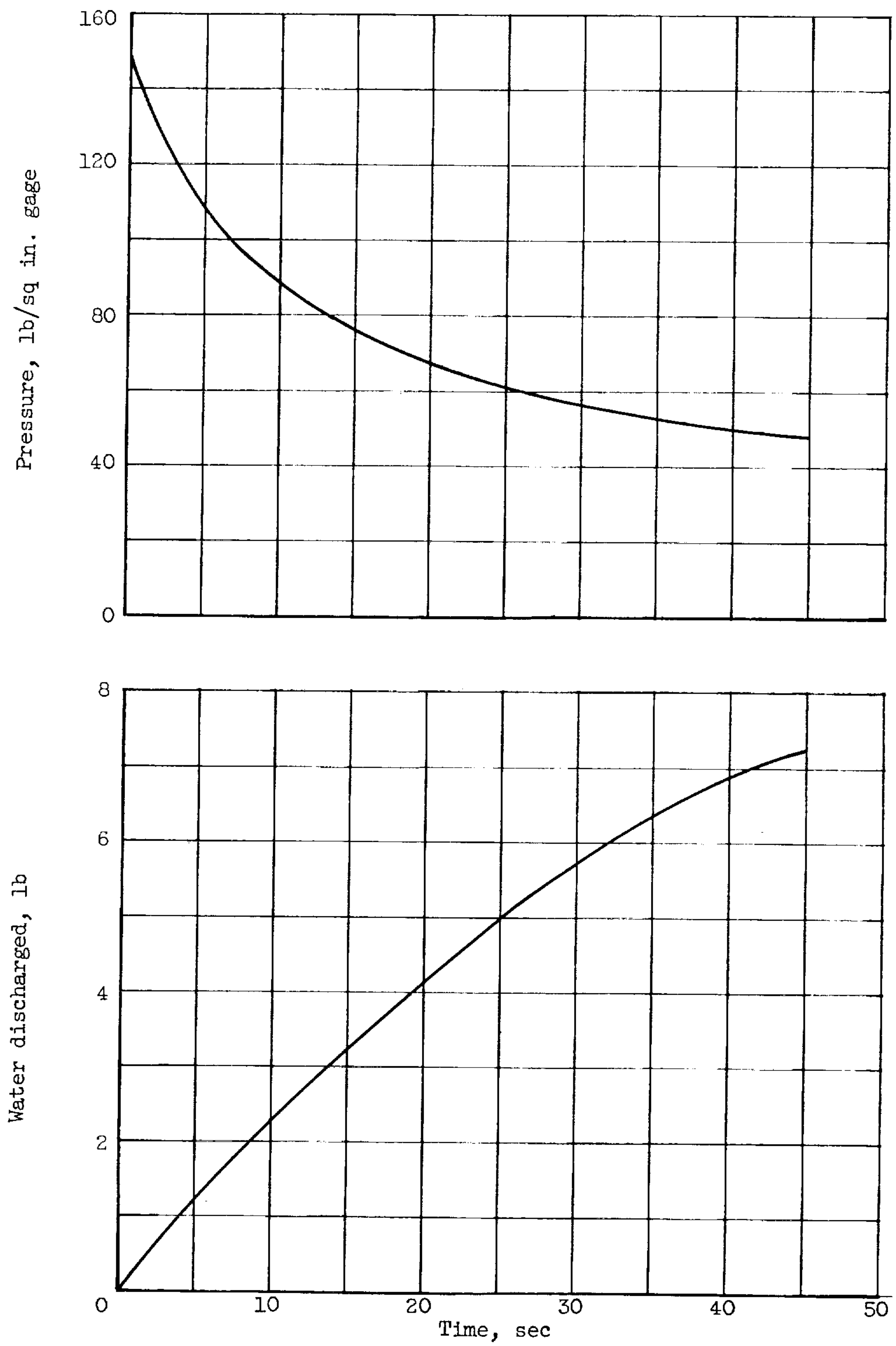

(b) Cumulative water discharge.

Figure 11. - Outer-rear-support subsystem.




(a) Arrangement.

Figure 12. - Turbine system.




(b) Total cumulative water discharge and propelling pressure decay.

Figure 12. - Concluded. Turbine system.

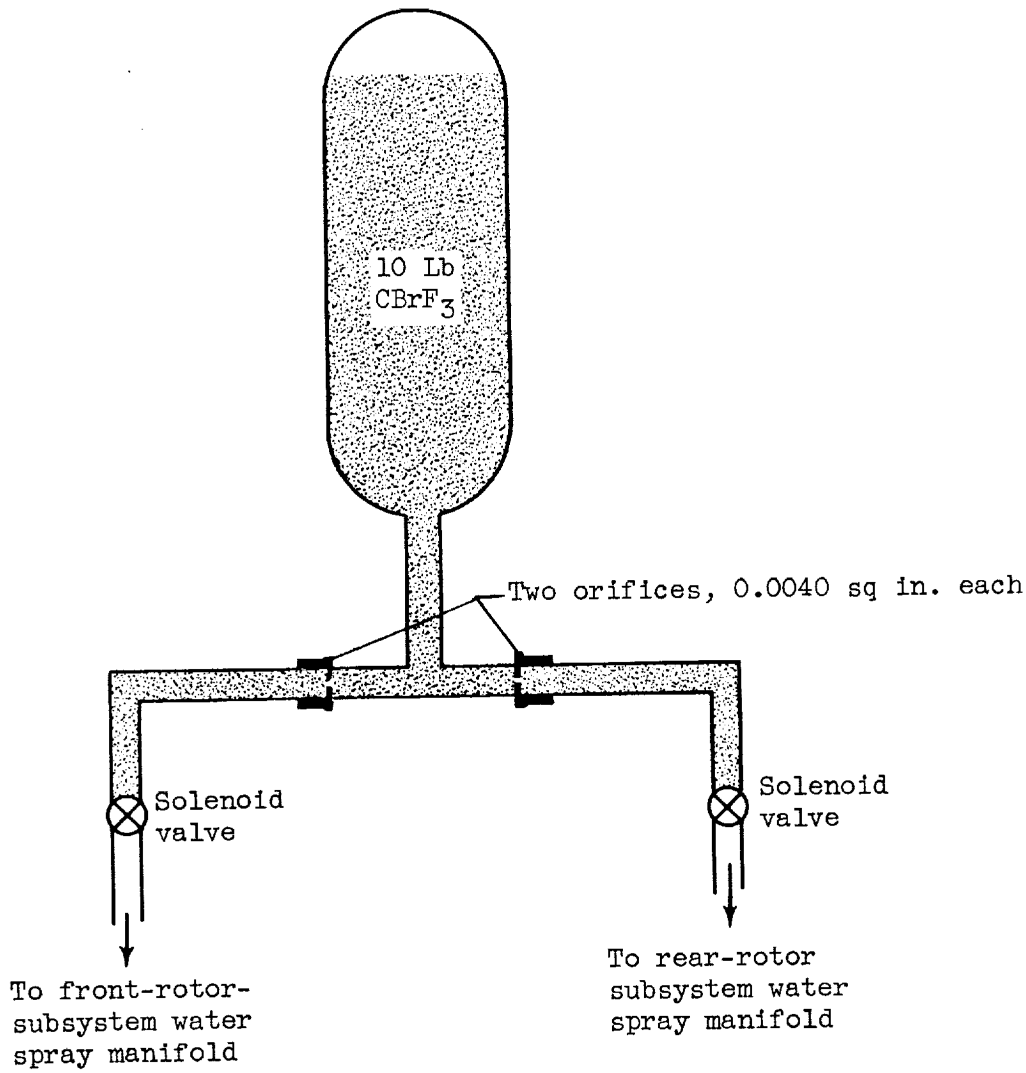



Figure 13. - $CBrF_3$ discharge system.

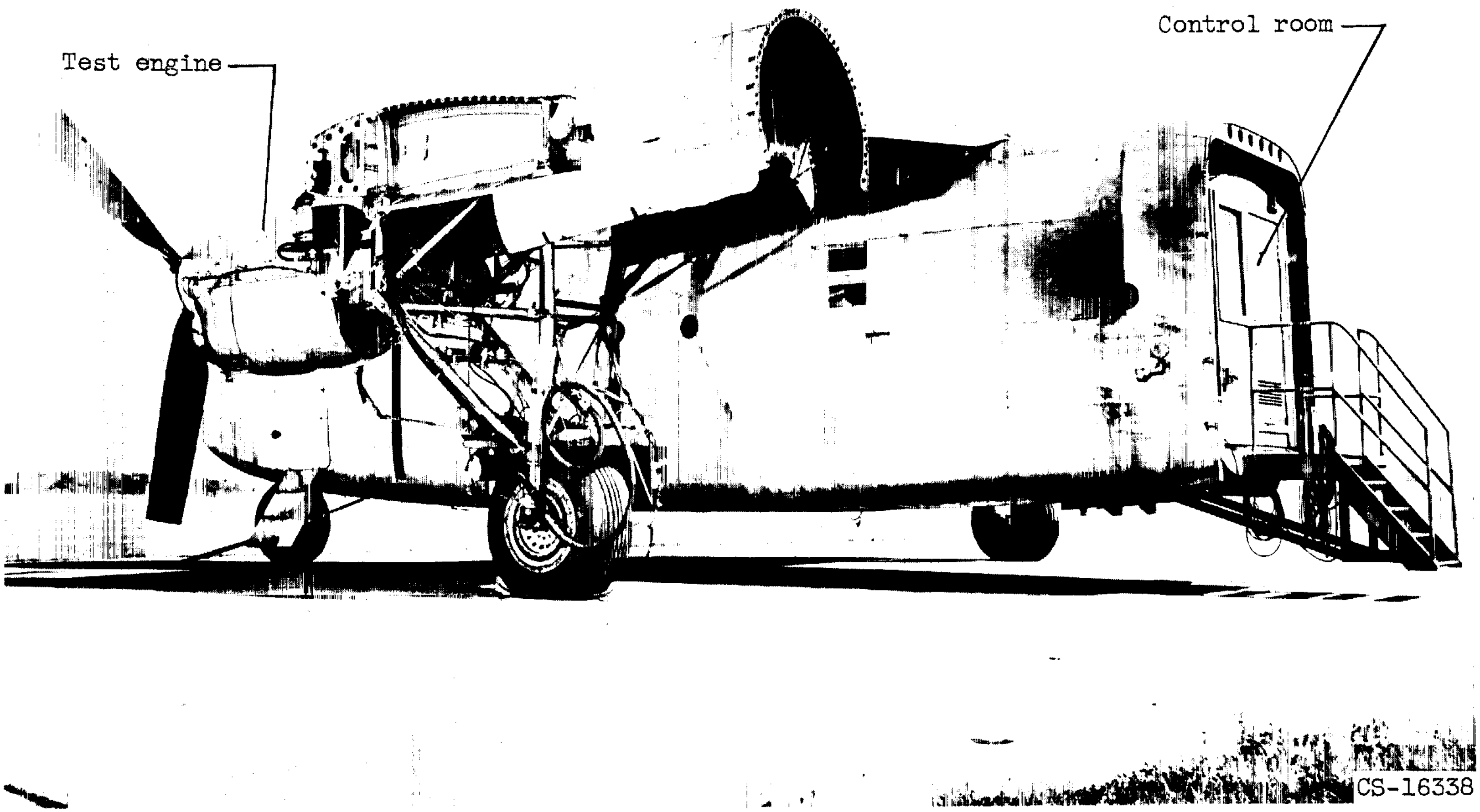



Figure 14. - Stripped C-82 airframe used as movable turboporp test stand.

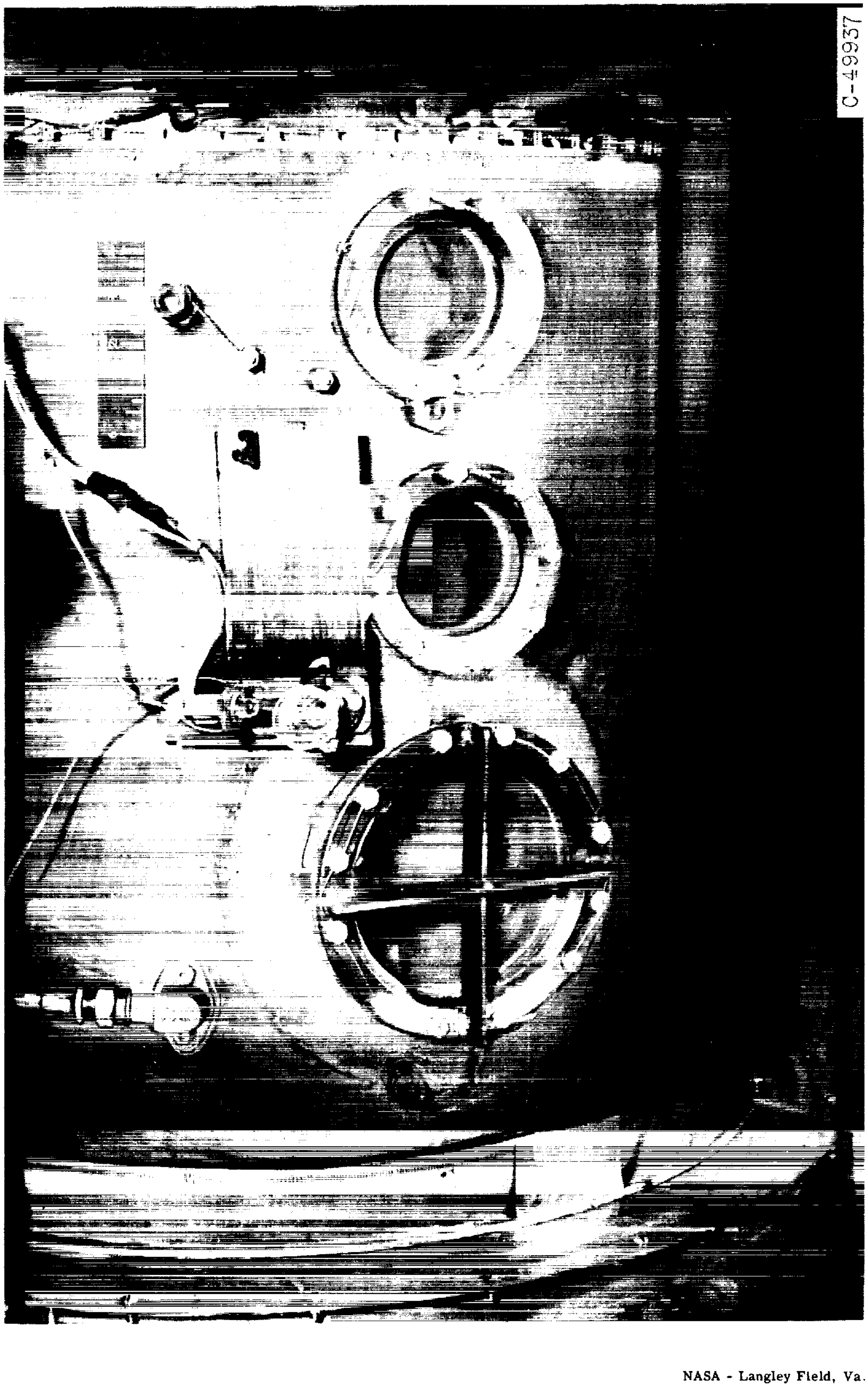



Figure 15. - Quartz windows installed in combustion-chamber housing.