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MEMORANDUM

CRASH-FIRE PROTECTION SYSTEM FOR T-56 TURBOPROPELLER

ENGINE USING WATER AS COOLING AND INERTING AGENT

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CRASH-FIRE PROTECTION SYSTEM FOR T-56 TURBOPROPELLER ENGINE USING WATER AS COOLING AND INERTING AGENT

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SUMMARY

A crash-fire protection system to suppress the ignition of crash-spilled fuel that may be ingested by a T-56 turbopropeller engine is described. This system includes means for rapidly extinguishing the combustor flame and means for cooling and inerting with water the hot engine parts likely to ignite engine-ingested fuel.

Combustion-chamber flames were extinguished in 0.07 second at the engine fuel manifold.

Hot engine parts were inerted and cooled by 52 pounds of water discharged at ten engine stations.

Performance trials of the crash-fire prevention system were conducted by bringing the engine up to takeoff temperature, stopping the normal fuel flow to the engine, starting the water discharge, 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

As part of a continuing study of crash-fire safety for turbine-powered aircraft, the Lewis Research Center recently completed an evaluation of the crash-fire protection requirements for the interior of the T-56 turbopropeller engine. This work followed an extensive laboratory and full-scale crash program with turbojet airplanes, which showed that fuel spilled in the crash is often ingested into the engine with intake air (refs. 1 and 2). This ingested fuel may be ignited by combustor flames and by some of the hot metal of the engine interior. The resulting flames issue from the engine tailpipe and ignite other fuel spilled around the crashed airplane to set the main fire.

Fire-setting by turbojet engines was prevented by rapidly extinguishing the normal combustor flames and also cooling and inerting specific hot metal parts of the turbojet immediately upon crash (water was the cooling and inerting agent). The turbojet engine program showed that cooling all the hot metal of the engine is unnecessary. Strategic location of the points of application of the water according to the principles discussed in reference 2 can effect a large economy in the weight of water needed.

A similar type of crash-fire protection system can be applied to a turboprop engine because the combustor flame and hot-metal ignition sources found in the turbojet engine are also present in the turboprop engine. However, the turboprop differs in a few ways from the older turbojets that have been studied. It was necessary, therefore, to determine whether these differences would markedly affect the arrangement of a crash-fire protection system. The present report discusses the crash-fire protection system requirements determined for the T-56 engine in this investigation and the methods used for evaluating the effectiveness of the system.

The differences between the T-56 turboprop engine and the turbojet engines previously studied are shown in figure 1, where a diagram of the T-56 turboprop engine is compared with the J-30 turbojet engine discussed in reference 2. Both engines have the same power section diameter and approximately the same mass airflow. The additional stages of the turboprop compressor produce higher diffuser metal temperatures associated with the higher compression ratio. The maximum diffuser metal temperature of the turboprop is 600° F, compared with 350° F for the turbojet. Because of the high temperatures in the latter stages of the turboprop compressor, the fuel ingested into the engine is more thoroughly preheated and therefore will ignite more rapidly. The combustor sections, however, and fronts of the turbines of both engines have similar temperatures and consequently have about the same tendency to ignite ingested fuel. The four-stage turbine rotor of the T-56 turboprop has greater mass and heat capacity than the single rotor of the J-30 turbojet. The turboprop turbine also has many hidden surfaces that cannot be sprayed directly with a cooling and inerting agent. The turbine of the turboprop thus is more likely than the turbojet to ignite fuel. However, because more work is done by the gases in passing through the four-stage turbine, the exhaust nozzle of the turboprop runs cooler, 900° F, than that of the turbojet, 1100° F. Because of the higher compressor and diffuser temperatures and the greater heat capacity of the turbine, the T-56 turboprop is somewhat more likely to ignite ingested fuel than the J-30 turbojet engine.

The airflow through the engine, following actuation of a crash-fire protection system, is useful in the distribution of the cooling and inerting agents to the dangerously hot metal surfaces. While this airflow may carry crash-spilled combustibles into the engine, it also served to ventilate the engine. The contact time between ingested fuel and hot surfaces is reduced with high ventilation rates, and the likelihood of ignition is correspondingly reduced. Likewise, this airflow helps to cool the hot metal of the engine interior.

A comparison of the airflow through the T-56 and the J-30 after the fuel flow to the combustors has been shut off is shown in figure 2. The marked reduction of the T-56 airflow over the J-30 is related to the energy absorbed by the propeller and to the action of an antiwindmilling brake on the rotor of the T-56. After the turboprop stopped rotating at 45 seconds in a normal coastdown, the turbojet still would be turning and pumping a few pounds of air per second. A feathered propeller stopped rotation and airflow even more quickly - in 13 seconds. If, in a crash, the propeller were to drag the ground to a maximum within the stress limits of the gearing, it is conceivable that air pumping could stop in about 1 second.

DESCRIPTION OF CRASH-FIRE PROTECTION SYSTEM

The crash-fire protection system for the interior of the engine extinguishes the normal combustor flame and also inerts and cools the dangerously hot metal surfaces that could ignite fuel. Coolant quantities and points of application within the engine, shown in figure 3, were obtained by a test-stand engine study following the procedures described in reference 2. An engine fuel-manifold shutoff and drain system quickly extinguished the combustor flame. Two types of water spray systems cooled and inerted the dangerously hot metal surfaces. These systems are described in the following paragraphs.

Fuel Shutoff and Drain System

During a normal engine shutdown, flames persist in the combustion liners about 0.5 second after the Allison Fuel Control Electric Cut-Off Valve, which is standard equipment, is energized. These flames are fed by fuel remaining in the manifold after shutoff that normally drips from the lower nozzles until the fuel manifold is drained by the engine dump valve. The flame supported by the dripping fuel can instantly ignite crash-spilled fuel ingested by the engine. These flames also will ignite combustibles over greater limits of mixture, pressure, and velocity than will the hot engine surfaces. Therefore, they should be eliminated as quickly as possible.

The lingering flame just described was eliminated by the fuel shutoff and drain valve shown in figure 3. This valve simultaneously stopped the flow of fuel to the engine manifold and vented the manifold overboard.

The combustion-chamber air pressure, available at the instant the valve operated, then reversed the flow of fuel in the nozzles and manifold through the overboard vent. The combustor flame was extinguished in 0.07 second.

Water Spray Systems

The water spray systems that inerted and cooled the hot engine parts were built to take into account the heat-dissipation properties of the various engine parts. Thin metal parts such as combustion liners, transition liners, exhaust ducts, and turbine blades have large ratios of surface to mass and may be cooled quickly. Massive parts such as turbine rotors and support structures have smaller surface-to-mass ratios and cannot be cooled rapidly. For this reason, two types of water spray systems were used to cool the hot surfaces within the engine.

A short-duration discharge of water suppressed ignition of the thin structures around the main gas stream. These very hot structures cool rapidly, and a short-duration discharge is adequate. However, because the surface area is large, a large flow rate is needed. The short-duration discharge system is subsequently referred to as the "combustor system."

A slow-flow long-duration discharge of water inerted and cooled the massive turbine rotor and rear-bearing-support structure. Because these parts are massive, it was necessary to inert and cool them until the internal heat was insufficient to reheat the surfaces to ignition temperature after the water spray was stopped. The long-duration water system was located at the turbine and is subsequently referred to as the "turbine system." These water spray systems are shown in figure 3 and are described in detail in the following paragraphs.

<u>Combustor system</u>. - The combustor water system consisted of three subsystems. Two of these subsystems were located in front of the combustion chambers, and the water from these subsystems inerted and cooled the combustion liners and structures enclosing the main airstream. The third combustor subsystem sprayed water on the outer rear surfaces of the combustors.

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. 4(a)). In order to make use of the revolving rotor and the airflow to distribute the water over the diffuser and the combustion-liner surfaces, each nozzle was placed so that the water jet discharged upstream and parallel to the 14^{th}-stage compressor stator vanes. The nozzles were aimed so that the water jets would strike the bases of the rotating 14^{th}-stage blades and be dispersed circumferentially. The airflow through the diffuser-straightening vanes would then tend to carry the water droplets through the diffuser to the combustion liners. Each nozzle orifice was 0.089 inch in diameter.

A cold airflow model of the diffuser and combustor sections of the engine indicated that the water from these nozzles wet the two-thirds of the combustor-liner surfaces farthest from the engine centerline. The cumulative water discharge with time of the compressor-outlet subsystem is shown in figure 4(b). To facilitate the measurement and future duplication of the water discharge, the data shown in figure 4(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 4(b) is somewhat higher than those rates obtained in the engine. The cumulative water discharge with time of all the subsystems and systems described herein was measured in this manner.

Inner-diffuser-fairing subsystem: In order 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 5(a). A 0.060-inch ($\pm$0.020-in.) gap between the end of each tube and the inner cone dispersed the water from the inner ends of the tubes. The cumulative water discharge with time is shown in figure 5(b). The water washed over the cone surface and traveled through the gaps between the fairings and the cone into the radially inward part of the main airstream closest to the engine centerline.

Outer-rear-liner subsystem: The outer rear areas of the liners with their reinforcing hat sections (fig. 6(a)) are made of thin metal; the hat sections are not located in the main gas stream. These 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 6(a) and (b). One pound of water was widely distributed over the surfaces of the liners by very flat, 155° hollow-cone-pattern nozzles. The rated discharge of these nozzles was 7.1 gallons per hour at 80 pounds per square inch gage. 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 6(c).

These hat sections enclose a space where the airflow is negligible and the 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 7. 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 8(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 of the entire combustor system is shown in figure 8(b).

Although a propelling-nitrogen pressure of 700 pounds per square inch gage was used as an experimental expedient in the final trials of this system, a lower pressure might be desirable in a commercial installation. In preliminary experiments, a propelling pressure as low as 400 pounds per square inch gage was satisfactory when used with a larger volume of propelling nitrogen and with larger and slightly different orifices. Pressures below 400 pounds per square inch gage could produce the desired discharge timing when the water is discharged through larger orifices to atmospheric pressure. However, pressures below 400 pounds per square inch gage 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 with water the dry-passage volumes between the water-supply-tank valve and the metering discharge orifices. Large dry-passage volumes thus reduce the pressure available at the nozzles and also increase the time taken to fill the lines. Because the propelling-pressure and water-discharge history depend on 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 8(a). A commercial version of the system should not have any greater dry volumes in the water supply lines and manifolds than those used in this experimental system. Reduced dry volumes would enable a commercial version to spray water more quickly and therefore inert and cool the engine more rapidly.

Turbine system. - The turbine system consisted of five subsystems. Two of the subsystems sprayed water on the front and rear surfaces of the massive rotor assembly. Two other subsystems sprayed water on the heavy, rear turbine bearing-support assembly. The fifth subsystem sprayed water both into and through the turbine casing, onto the rotor.

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 3 shows the arrangement of these subsystems, which are designated front-rotor, rear-rotor, inner-rear-support, outer-rear-support, and turbine-casing subsystems.

Front-rotor subsystem: Six 95° flat-spray nozzles discharged 5.3 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 100 pounds per square inch gage. The installation of these nozzles is shown in figures 9(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 9(c).

Rear-rotor subsystem: Three 95° flat-spray nozzles covered most of the rear face of the fourth-stage turbine wheel with 2.7 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 100 pounds per square inch gage. The installation is shown in figures 10(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 10(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. A cross section of one of these struts is shown in figure 11(a). 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 0.7 pound of water through the open strut ends. Six nozzles, each producing an 80° semihollow-cone-pattern spray, were located outside of the engine as shown in figure 11(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 gage. The cumulative water discharge from this subsystem is shown in figure 11(b).

(2) Outer-rear-support subsystem: Six 95° flat-spray nozzles, mounted in the inner-rear-exhaust cone, sprayed 0.7 pound 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 gage. Details of the installations are shown in figure 12(a). The cumulative water discharge is shown in figure 12(b). Only a small amount of water was needed to cool the exterior of these struts because this section of the engine is partly protected by the upstream combustor system.

The four turbine subsystems just described were supplied from a single tank containing 9.4 pounds of water as shown in figure 13(a). The volume and pressure of propelling nitrogen and the nozzle orifice areas were selected to give the desired long-duration discharge.

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 subsystems (figs. 11(b) and 12(b)).

The total comulative water discharge with time of these four turbine subsystems, along with the propelling-nitrogen pressure decay in the tank, is shown in figure 13(b). Less initial propelling pressure was used for these turbine subsystems than in the combustor system (150 against 700 lb/sq in. gage) because smaller initial discharge rates were needed.

Turbine-casing subsystem: The separation space between the turbine casing and each stage of the turbine stator assemblies has the form of an annular chamber running circumferentially around the engine as shown in figure 14(a). Water was sprayed into the annular chambers formed by the first-, second-, and third-stage stator assemblies and onto the turbine rotor. No water was sprayed into the annular chamber formed by the fourth-stage stator assembly. A slow flow of water over a long interval cooled these metal parts while providing inerting steam around their surfaces; 8.3 pounds of water discharged through three nozzles at a constant rate for 600 seconds.

The single orifice, 0.026 inch in diameter, located inside the first-stage annular chamber sprayed water in this chamber as shown in figure 14(b). Expansion joints between segments of the first-stage stator assembly allowed water and steam to escape towards the turbine rotor.

A single 80° flat-spray nozzle discharged water into each of the second- and third-stage annular chambers and onto the turbine rotor and base of the stator assemblies (fig. 14(b)). Each nozzle was located inside one of the annular chambers at the top of the engine and directly above an expansion joint in the stator assembly (fig. 14(c)). A 5/16-inch-diameter hole was drilled through these stator assemblies at the expansion joint. The nozzles were placed in the turbine casing so that most of the water passed through the holes and onto the rotor and base of the stator assembly (figs. 14(b) and (c)).

These two nozzles were oriented so that the flat spray was approximately parallel to the stator vanes as shown in figure 14(d). This water-cooled and inerted the rotor and the interstage seal assemblies. The edges of the water spray patterns were intercepted by the edges of the holes, and inerted and cooled the annular chambers formed by the second- and third-stage stator assemblies.

These three nozzles of the turbine-casing system were supplied from a single tank under a constant pressure of 15 pounds per square inch gage (fig. 3). Each nozzle discharged an equal quantity of water. A separate driving-gas supply was used to maintain a regulated pressure of 15 pounds per square inch gage on the water-supply tank. Check valves were used to prevent the flow of hot turbine gases through the system during normal engine operation.

TRIAL PROCEDURE AND CONDITIONS

To evaluate the effectiveness of the crash-fire protection system, trial runs were made with the T-56 engine mounted on a test stand. Severe crash fuel spillage was simulated by fuel sprays placed in the engine inlet and tailpipe to produce the most hazardous conditions of crash-generated fuel mist and liquid-fuel spillage described in references 1 and 2. The fuel mist can be carried through the engine inlet airflow, and liquid fuel might enter the engine inlet or tailpipe after the airplane is no longer moving and the engine has stopped. For these trials, the engine was mounted on a portable test stand consisting of a stripped C-82 airframe (fig. 15). 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 conditions corresponding to those that would exist in a crash on takeoff were established. 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. Then, at a moment that corresponded to airplane crash, the fuel flow to the engine combustors was stopped and the water spray system was actuated.

Three-tenths of a second after the engine fuel valves were closed, JP-5 fuel was sprayed into the engine inlet to simulate ingestion of crash-spilled fuel. Initially, fuel was sprayed into the inlet to match the airflow, approximating a twice-stoichiometric fuel-air ratio; a twice-stoichiometric fuel-air ratio was used because this mixture is the most easily ignited. As the engine slowed, the inlet air velocity became too slow to carry the coarse twice-stoichiometric spray and the fuel began to collect in the bottom of the inlet duct. This spray was then replaced by 4-to-5-second-long pulses of atomized fuel spray. The pulsed, atomized fuel spray was directed into both the inlet and 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 up to too rich. During the latter part 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 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 represents the kerosene-type fuel intended for commercial use. The spontaneous ignition temperature of this fuel is one of the lowest of all the combustible liquids carried in a turboprop airplane.

In a normal engine shutdown, the fifth- and tenth-stage compressor bleed valves normally 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 coastdown pitch was selected to give the two possible extremes of a 45-second, normal flat-pitch coastdown and a 13-second feathered coastdown. This was done to simulate the most severe ignition conditions for both the initial and later phases of a coastdown after the combustor fuel was shut off. In the initial part of the coastdown, the 13-second feathered coastdown had been found easier to protect, since it required less water to inert and cool the combustion liners. However, the continued rotation and airflow of the normal 45-second coastdown helped carry cooling water over the turbine and permitted the turbine to be inerted and cooled with less water in the later period of the coastdown. To insure that the final system would be satisfactory for both modes of coastdown, both coastdown propeller-pitch selections were used in these evaluation trials.

Because the ambient air temperature ranged between 25° and 32° F during some of the experiments, a 6-percent inhibited sodium chloride solution was added to the water in those experiments. A more suitable antifreeze solution for operational use, lithium chloride, is described in reference 3.

FIRE DETECTION

Fires that resulted from inadequacies of the preliminary crash-fire protection system were often difficult to detect. Visible or audible propagation of fire out of the exhaust or inlet provided a reliable affirmative indication of fire. However, a fire can occur inside of the engine without a visual flame or audible explosion propagating out of the engine. The final form of the engine crash-fire inerting system described in this report prevented these local internal engine fires as well as those that propagate out of the inlet and exhaust.

The most sensitive and reliable means of detecting these local internal fires was by taking motion pictures through windows in the combustion-chamber housing; these windows are shown in figure 16. 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 1/10-second duration could be photographed.

Thermocouple fire detectors, although useful in preliminary studies of the ignition hazards in the T-56 engine, were not capable of detecting brief flashes of flame when almost enough water to prevent fire had been used.

Pressure pulses within the engine, caused by fire or explosions, were a useful supplement to the other methods of fire detection in both preliminary and final performance trials. Although pressure-pulse fire detectors were more sensitive than the thermocouple fire detectors, they were not as reliable as the motion pictures taken through the windows for detecting brief flames in the engine.

Indications from the methods of detecting fire were reviewed in each experiment to determine whether fire did or did not occur. Although the function of a crash-fire protection system requires only that the engine must not ignite fuel spilled outside the engine, the objective that all detectable nonpropagating flame within the engine also be prevented was realized. Flames within the engine, even though they do not propagate, indicate marginal fire suppression.

RESULTS OF PERFORMANCE TRIALS

The crash-fire protection system just described kept the T-56 engine from igniting ingested fuel in twenty severe performance trials. Ten of the twenty trials were made using a long engine coastdown time of 35 to 45 seconds, while the remaining ten trials were made using a short coastdown time of 13 seconds. 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 spray systems will 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.

GENERAL REMARKS

The quantity of water used by the crash-fire protection system possibly could be reduced further by curtailing the time during which ignition is suppressed. Figure 17 shows the amount of water discharged by the crash-fire protection system as a function of time after fuel shutoff. By protecting the engine only until a certain time, the water that has not been discharged by that time could be eliminated. The potential saving of water accomplished, however, may be more than offset by the attending increase in potential hazard. Although water from both the combustor and turbine systems was expended in 600 seconds as shown in figure 17, fire protection persisted at least through the 15-minute (900-sec) periods of the operational trials.

In a crash, the clouds of fuel mist that may be drawn through and ignited by the engine are likely to persist for less than 17 seconds after a fuel tank is ruptured. This 17-second time period is the most hazardous period for crash-fire ignition; after 17 seconds a lesser hazard exists from fuels spilled in the liquid form. A more complete discussion of this hazard time is given in references 1 and 2. If the system operation were initiated in a crash at the instant of violent fuel-tank rupture, protection against the major hazard of the 17-second fuel-mist cloud might be obtained with a system that provided protection for only 17 seconds. Figure 17 indicates that 14.2 pounds of water may be eliminated with such a system. However, preliminary experiments showed that the turbine remained hot enough to ignite JP-5 fuel after the 17 seconds of cooling. Therefore, if a 17-second system is used, the engine may ignite fuel spilled in liquid form in the latter phases of the crash.

The protection of a 17-second system also may be lost if it is designed to be actuated manually. If the pilot anticipated the crash and operated the system prematurely (to the extent that the 17-second protection expires before the fuel-mist cloud forms or disperses), the hot turbine, cleared of steam, would ignite the ingested fuel mist. It appears, therefore, that the effectiveness of the system would be unduly jeopardized by limiting the period of protection in order to reduce the quantity of coolant slightly.

In designing a production-engine system, some changes in details from the system described herein are to be expected because of manufacturing necessity. The geometry of the nozzle installations probably can be modified in minor ways if the distributions and discharge histories of water in the various subsystems are essentially unchanged. On the basis of experience gained in the experimental program, it is felt that minor variations in nozzle angles and spray patterns will not produce major changes in the effectiveness of the system. Consequently, it is believed that the system will not require precise duplication in its manufacture. When major modifications are involved, it would be desirable to subject the modified protection system to trials similar to those described herein.

The integrity of the system must not be allowed to deteriorate during its flight life or during a crash if it is to fully protect against crash-ignition in the most severe exposures to crash-spilled fuel. On the other hand, experience obtained during preliminary studies on the T-56 engine showed that minor damage or blockage of individual nozzles does not result in a complete loss of crash-fire protection. In some preliminary experiments, water lines to individual nozzles have broken and caused only local flames that did not propagate into the main gas stream. A crash-fire hazard does not exist under these circumstances.

When this T-56 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 that 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. If protection is required for the exhaust ducting and the exterior of the engine, the methods described in reference 2 may be used. In the method described in these references, the hot exterior surfaces are covered with a waffled 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 during cooling.

A complete aircraft fire-protection system will also require the deenergizing of ignition sources not associated with the engine by the methods described in reference 1. These ignition sources include other hot surfaces, such as those associated with auxiliary powerplants and combustion heaters, and the sparks and hot wires 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 preferable. 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 has been proposed in reference 4. Such automatic systems can be considered for airplane use only after highly reliable equipment has been developed and tested.

Lewis Research Center
National Aeronautics and Space Administration
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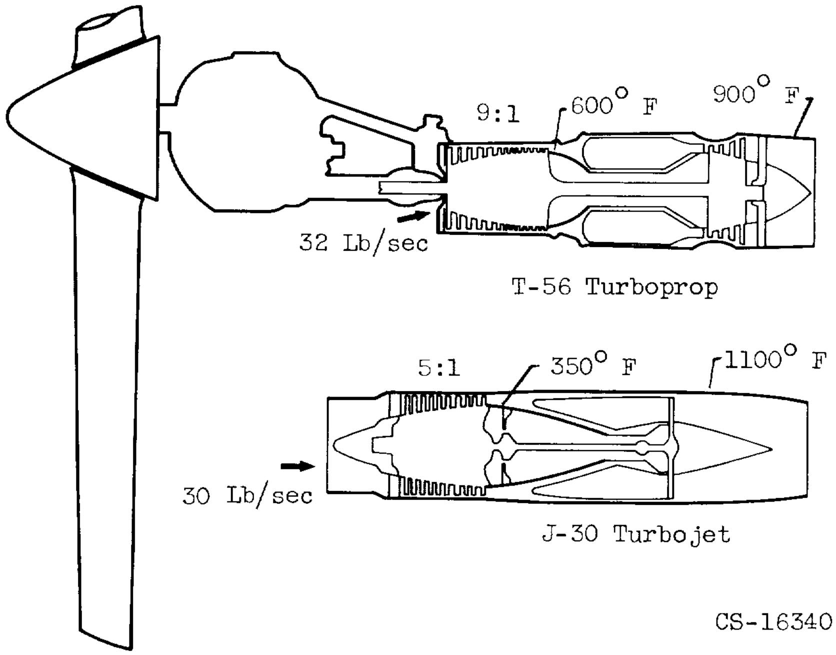


Figure 1. - Comparison of T-56 turboprop and J-30 turbojet engines.

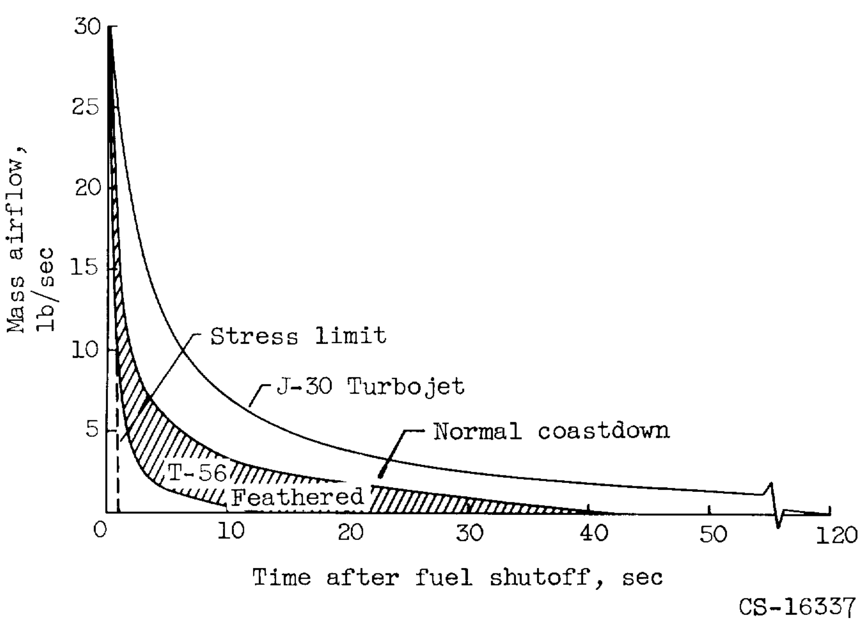


Figure 2. - Comparison of coastdown airflows of T-56 turboprop and J-30 turbojet engines.

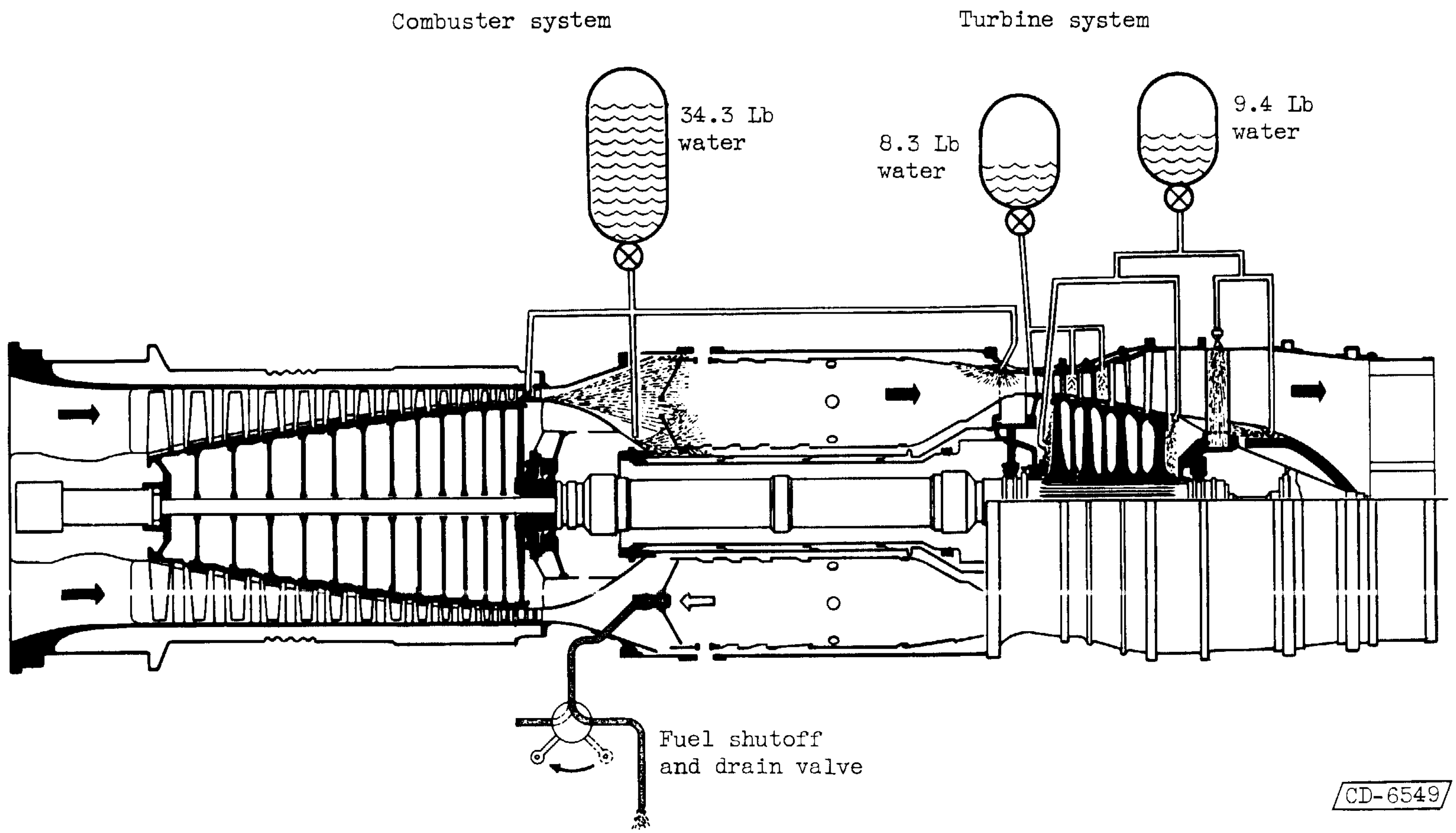
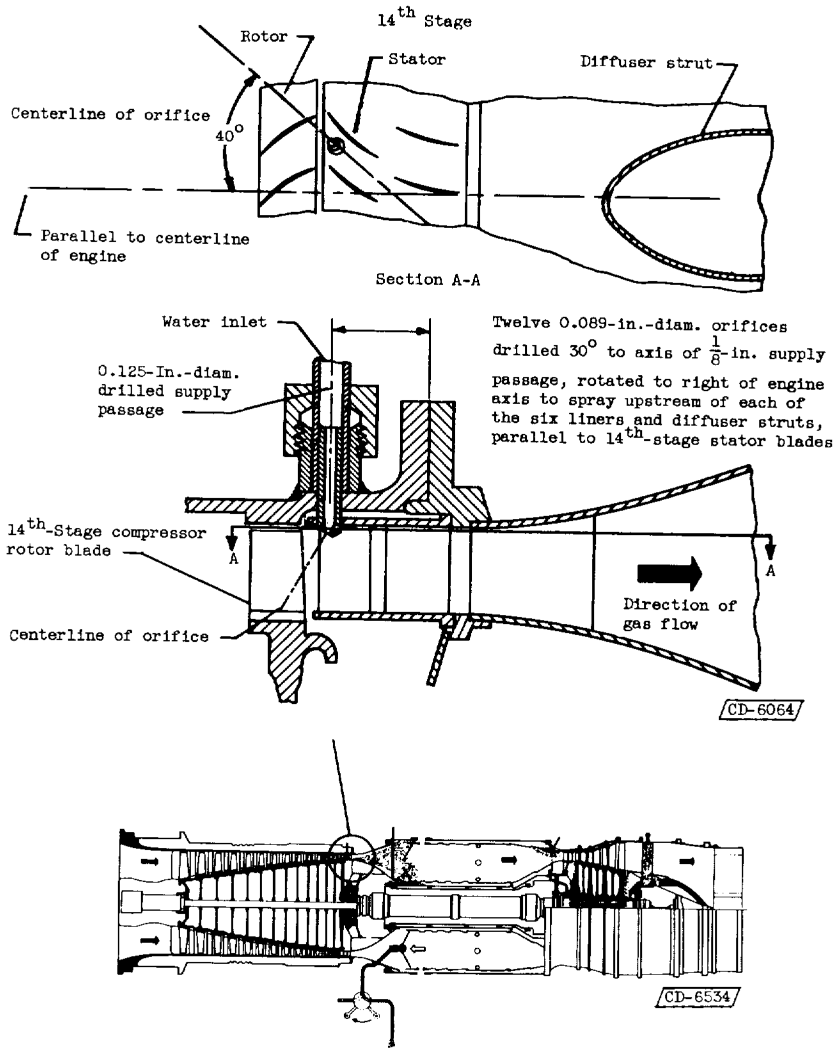
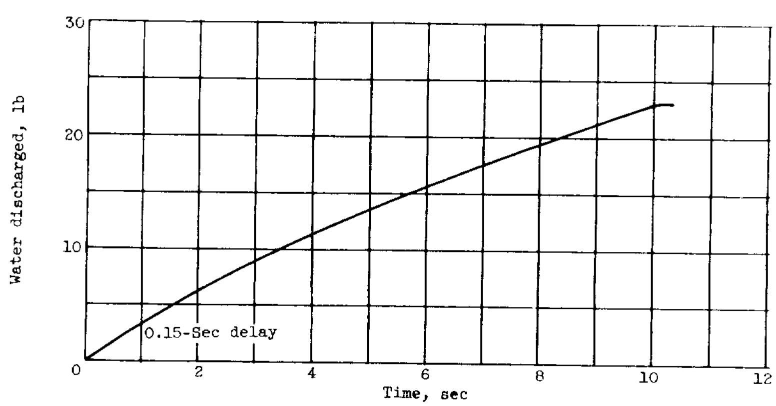


Figure 3. - Crash-fire protection system for T-56 turboprop engine.

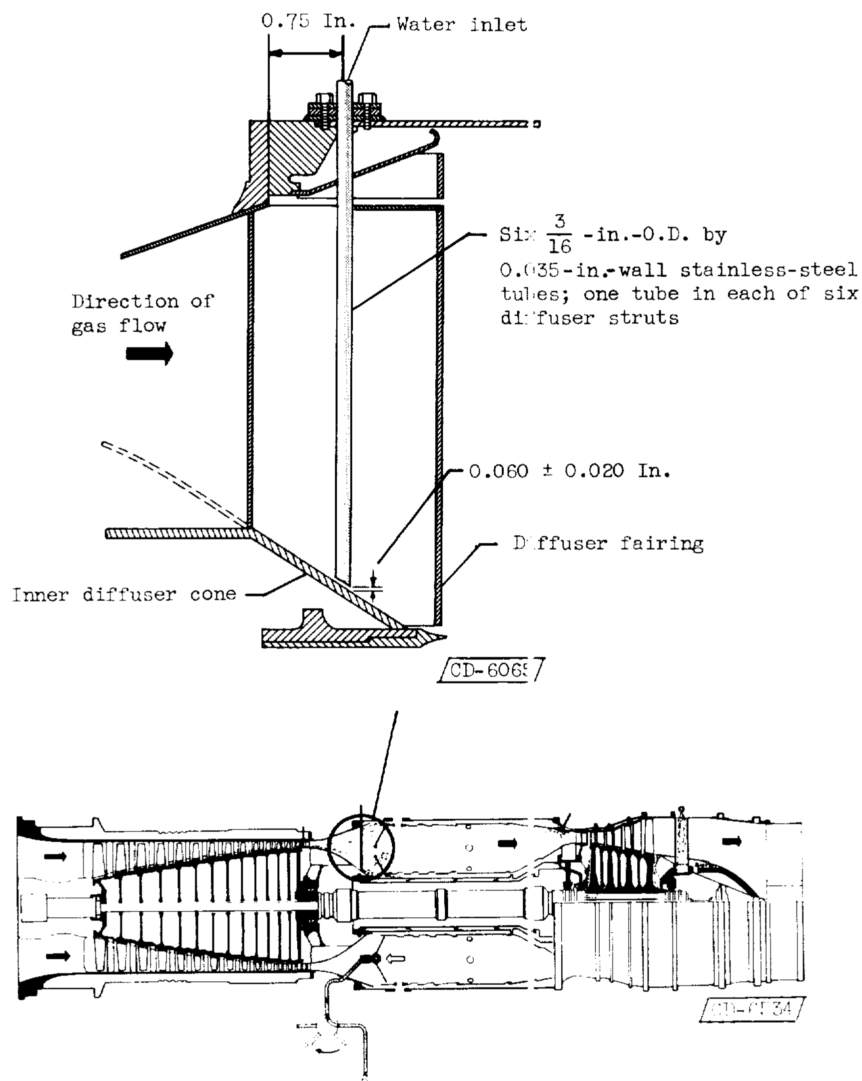


(a) Installation of nozzles.

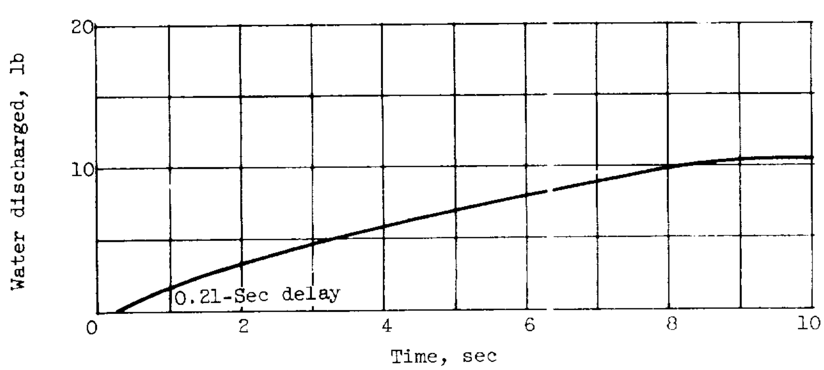


(b) Cumulative water discharge.

Figure 4. - Compressor-outlet subsystem.

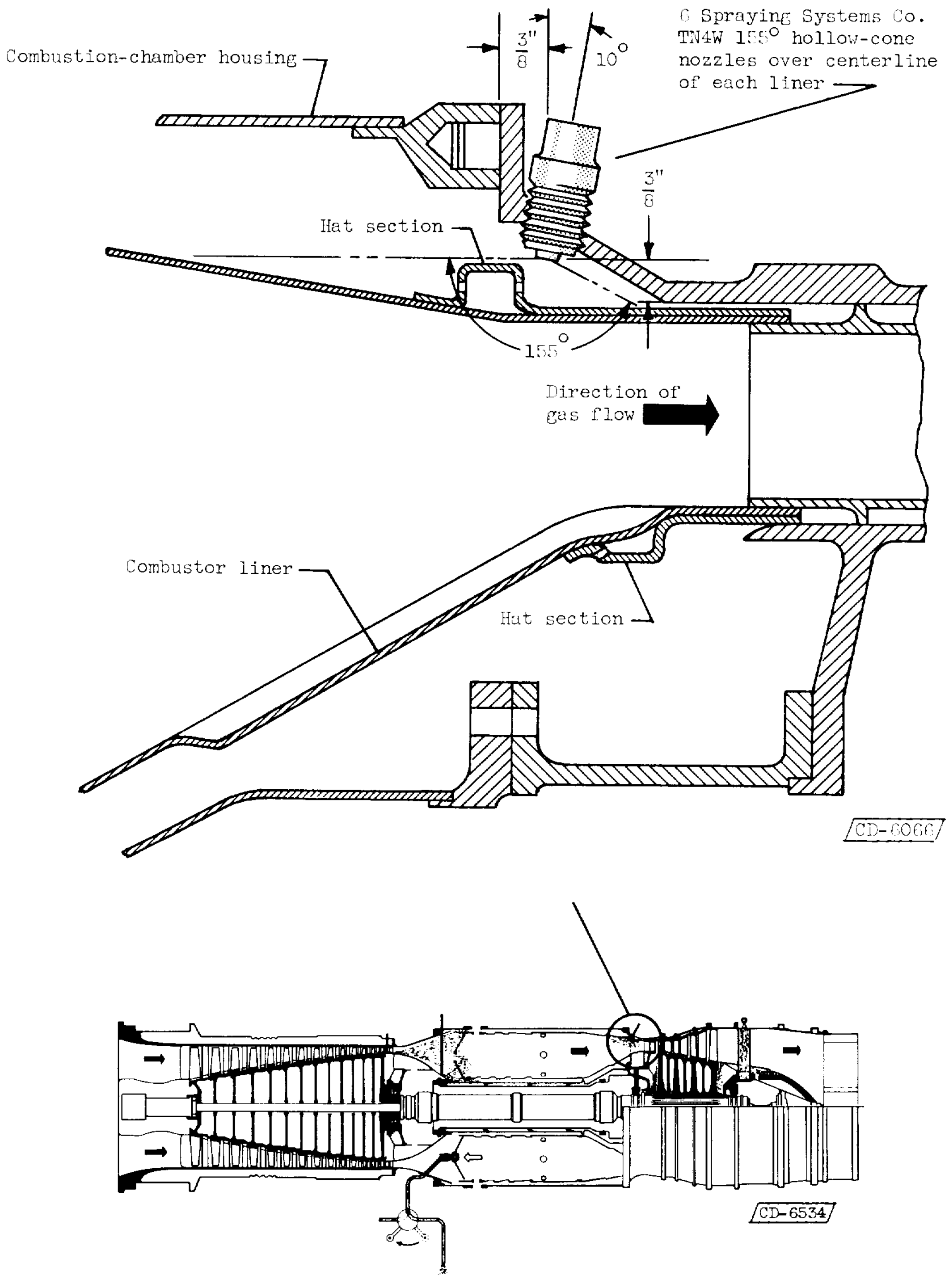


(a) Water spray nozzle installation.



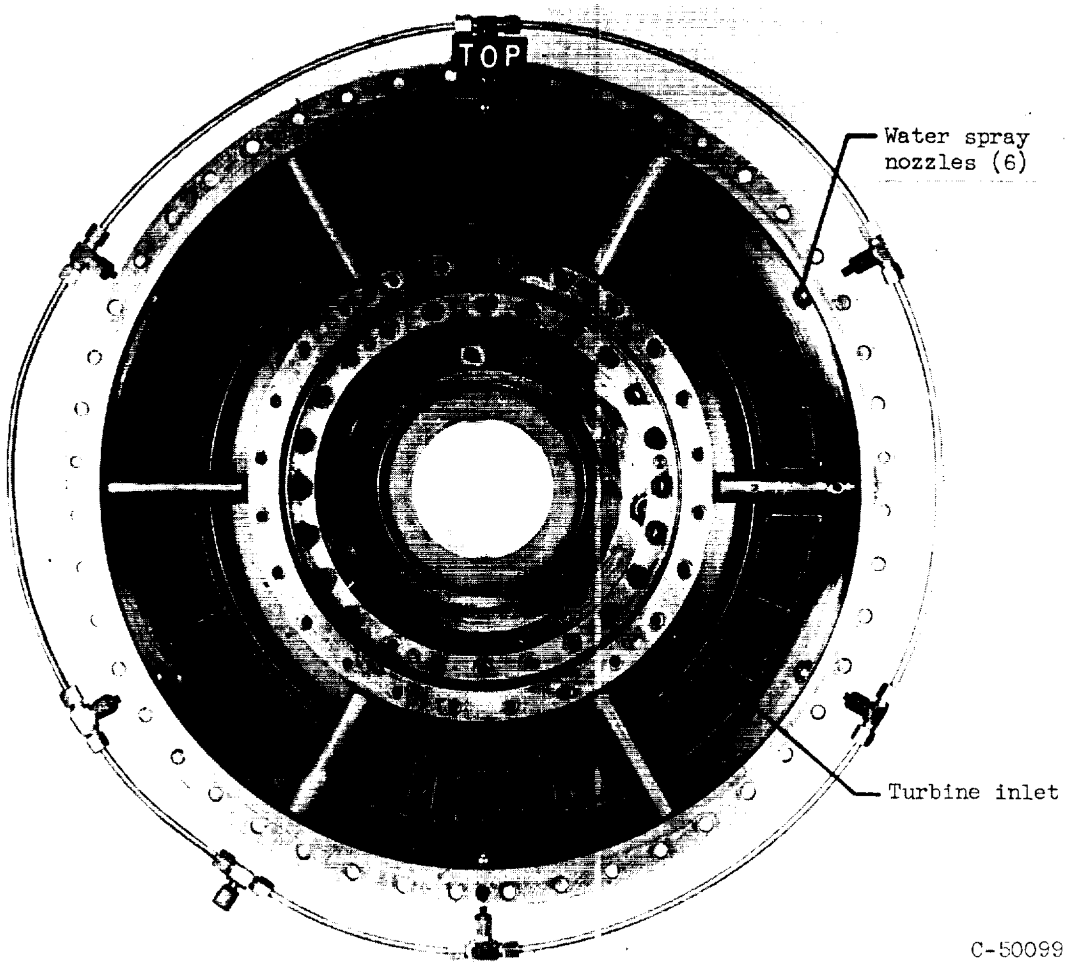
(b) Cumulative water discharge.

Figure 5. - Inner-diffuser-fairing subsystem.

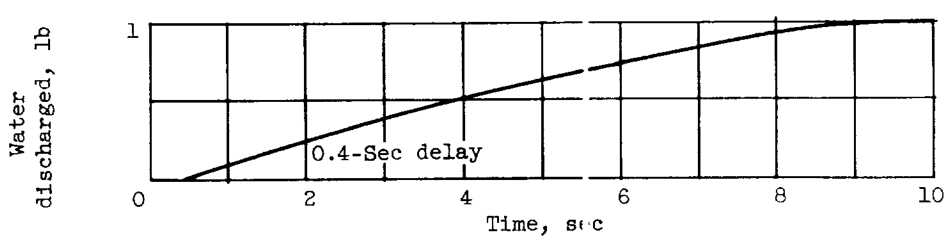


(a) Schematic diagram of water spray nozzle installation.

Figure 6. - Outer-rear-liner subsystem.



(b) Photograph of water spray nozzle installation.



(c) Cumulative water discharge.

Figure 6. - Concluded. Outer-rear-liner subsystem.

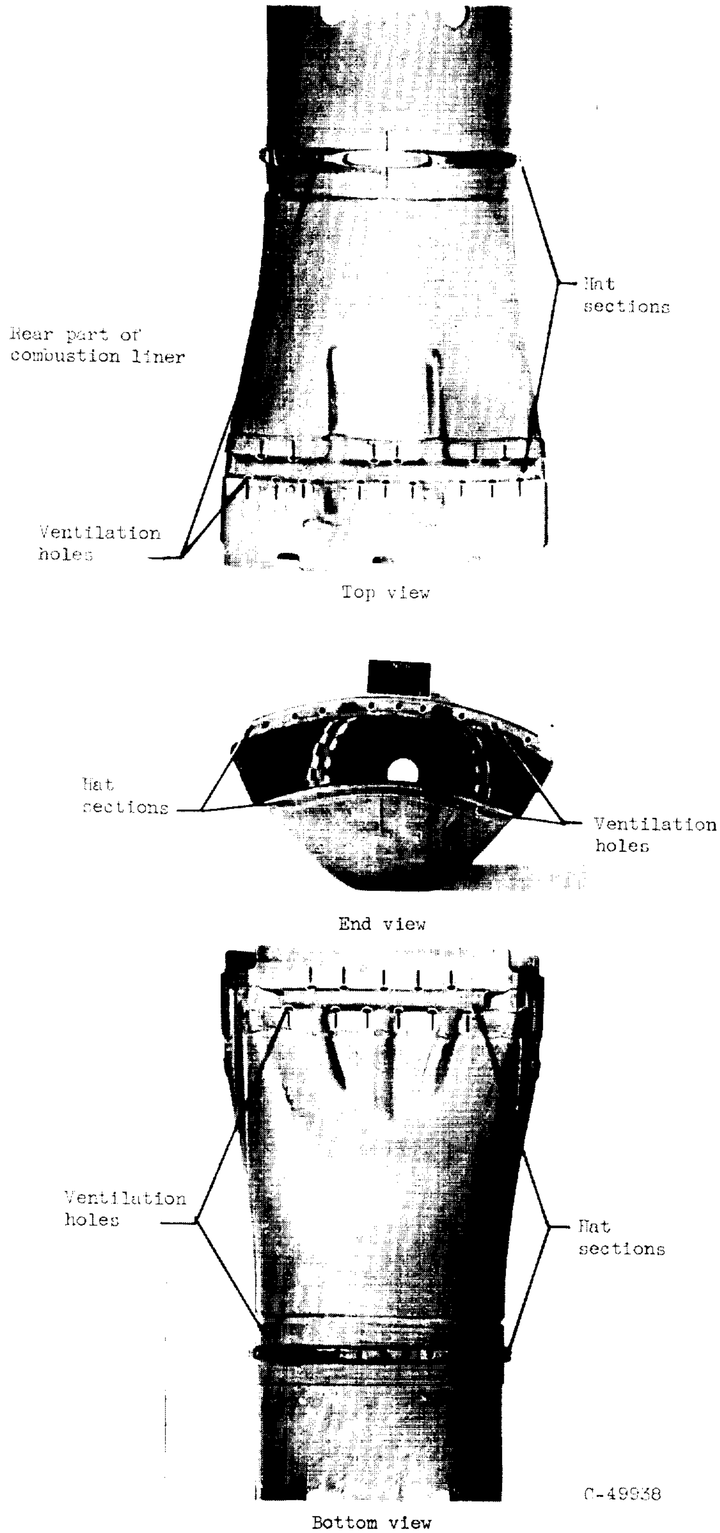
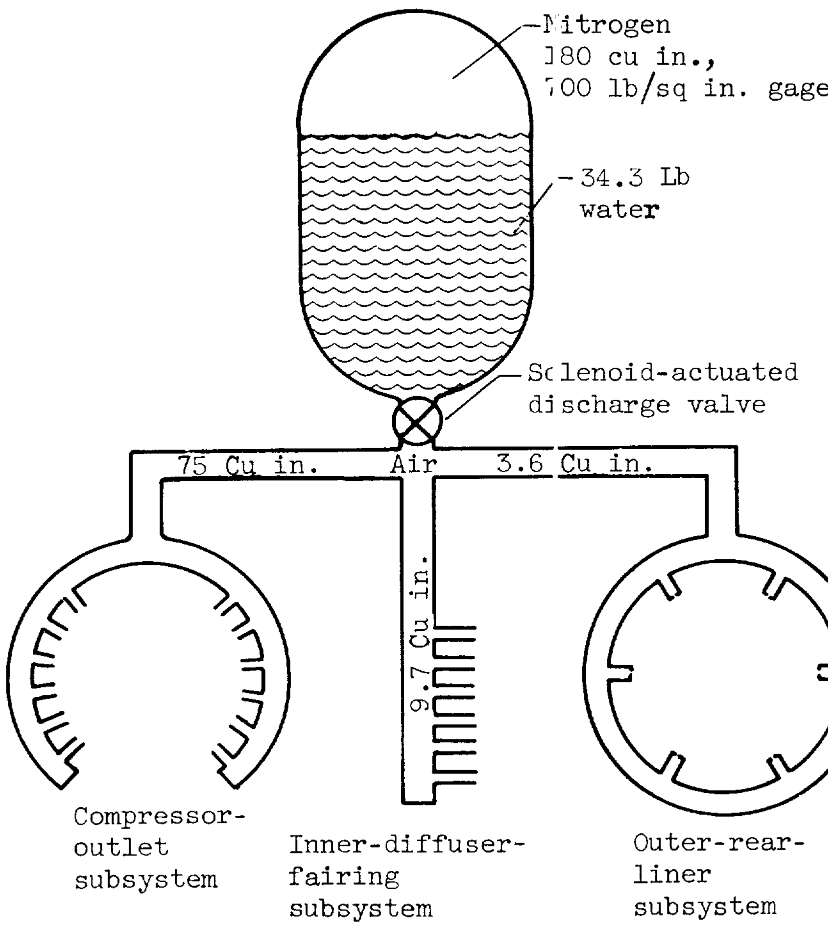
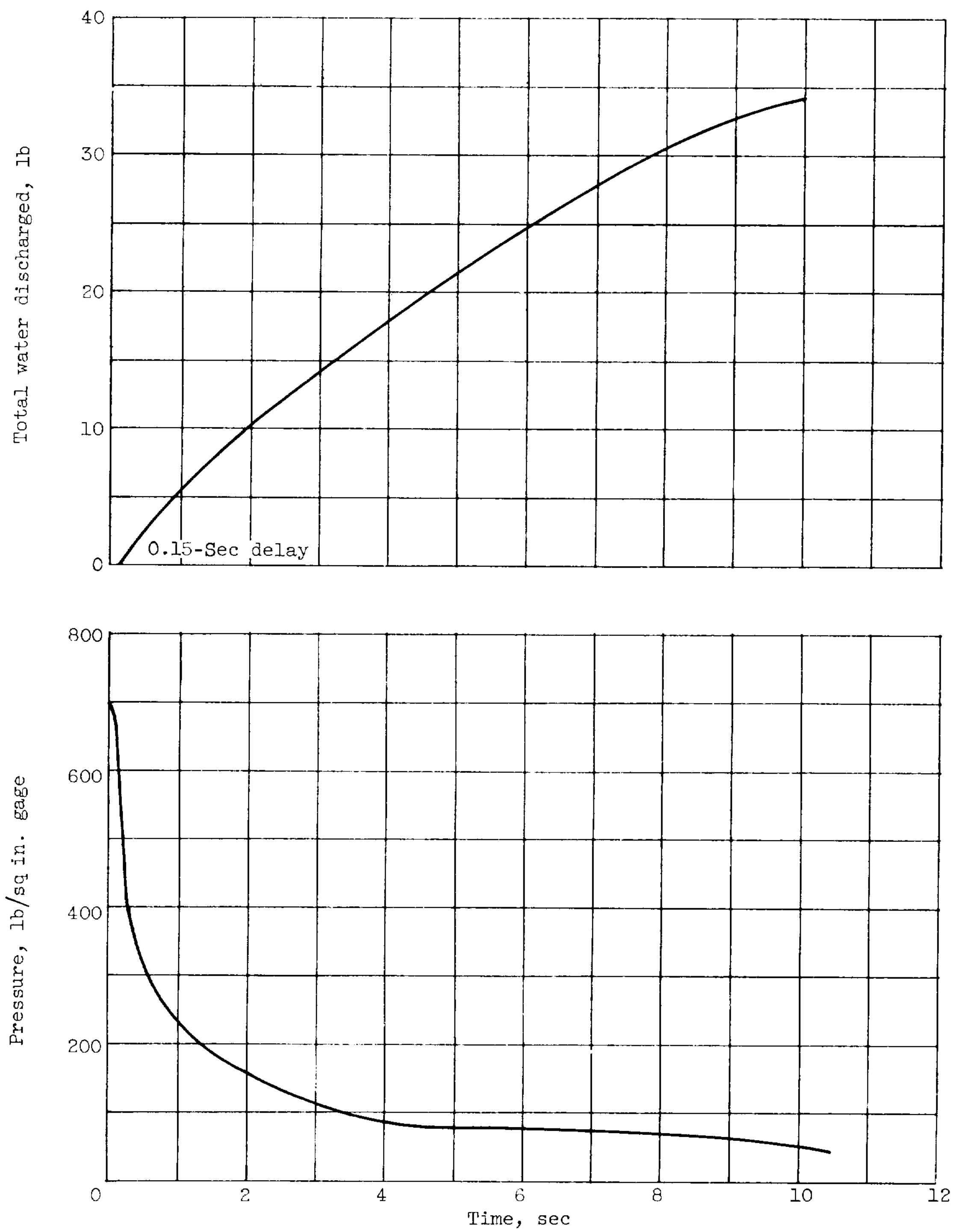


Figure 7. - Ventilation holes drilled in hat sections of combustion liners.



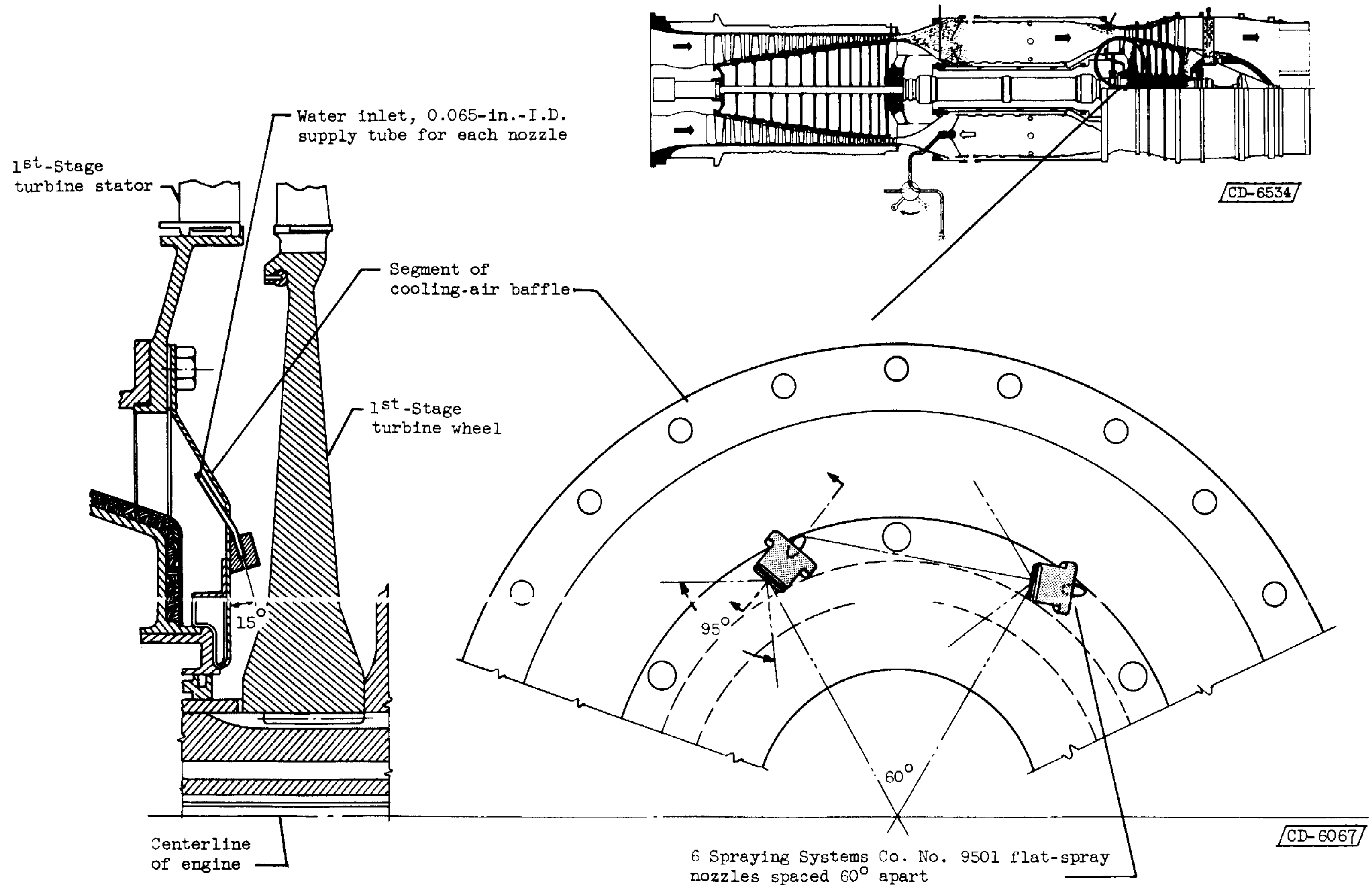
(a) Schematic diagram.

Figure 8. - Combustor system.



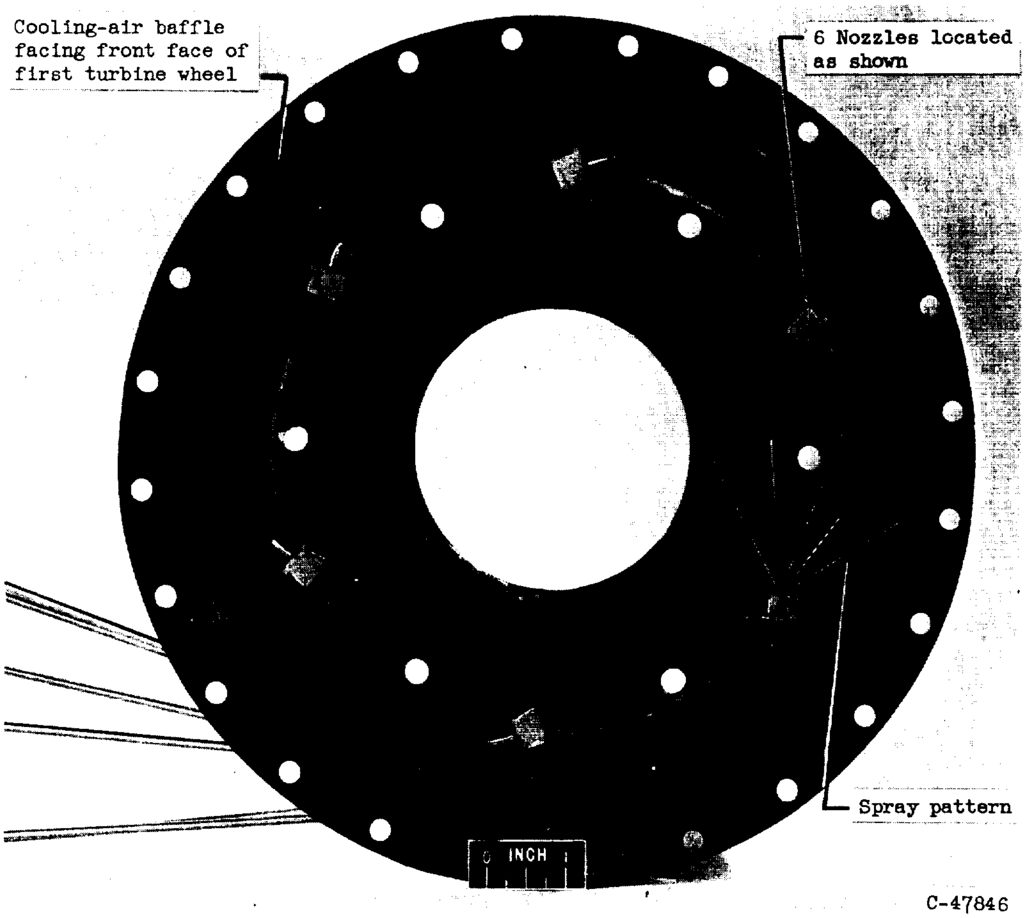
(b) Total cumulative water discharge and propelling pressure decay.

Figure 8. - Concluded. Combustor system.

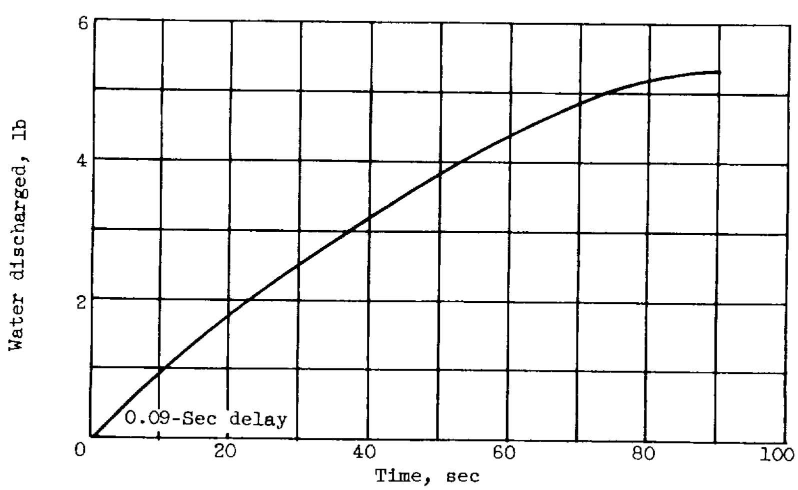


(a) Schematic diagram of water spray nozzle installation.

Figure 9. - Front-rotor subsystem.

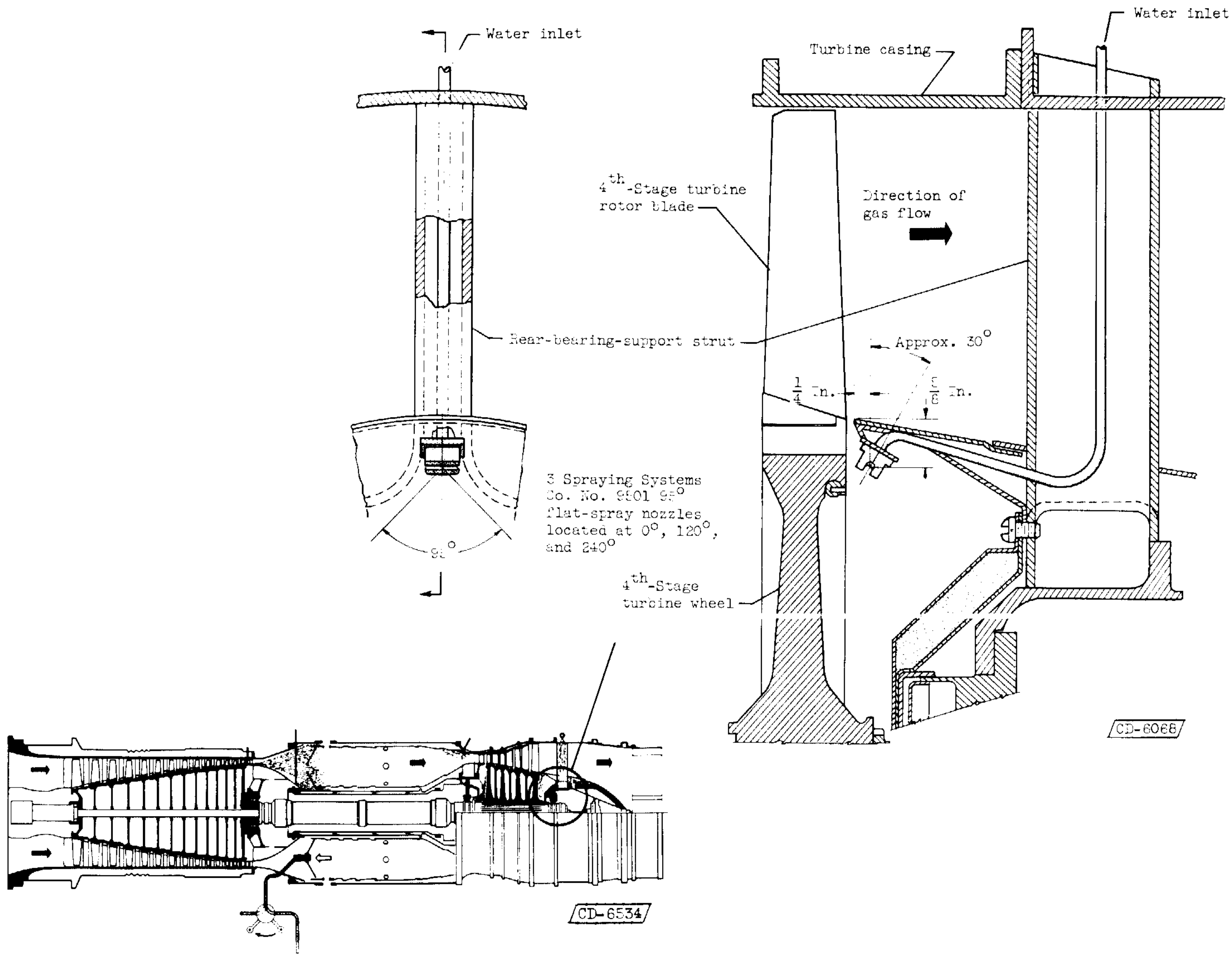


(b) Photograph of nozzle installation.



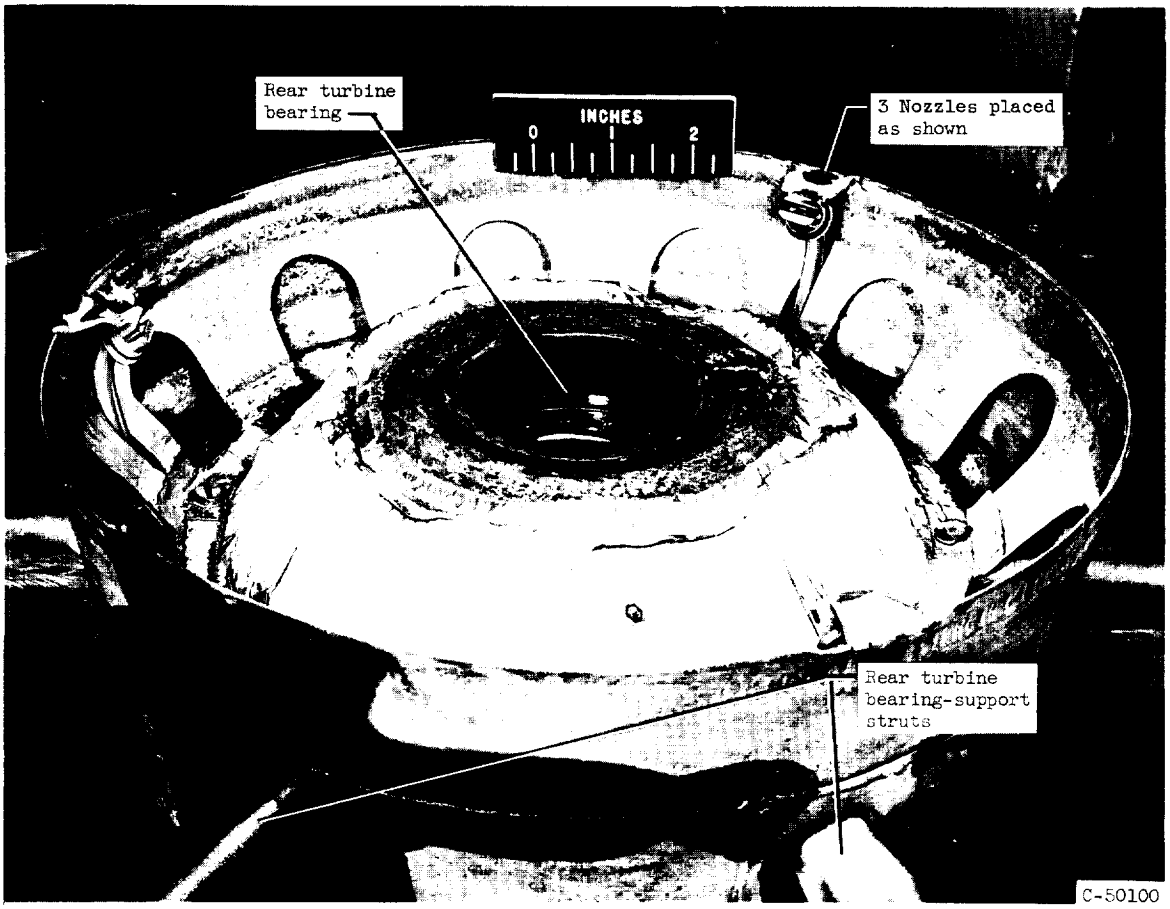
(c) Cumulative water discharge.

Figure 9. - Concluded. Front-rotor subsystem.

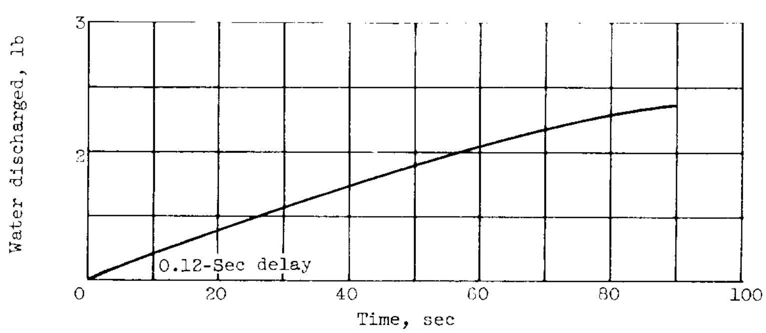


(a) Schematic diagram of water spray nozzle installation.

Figure 10. - Rear-rotor subsystem.

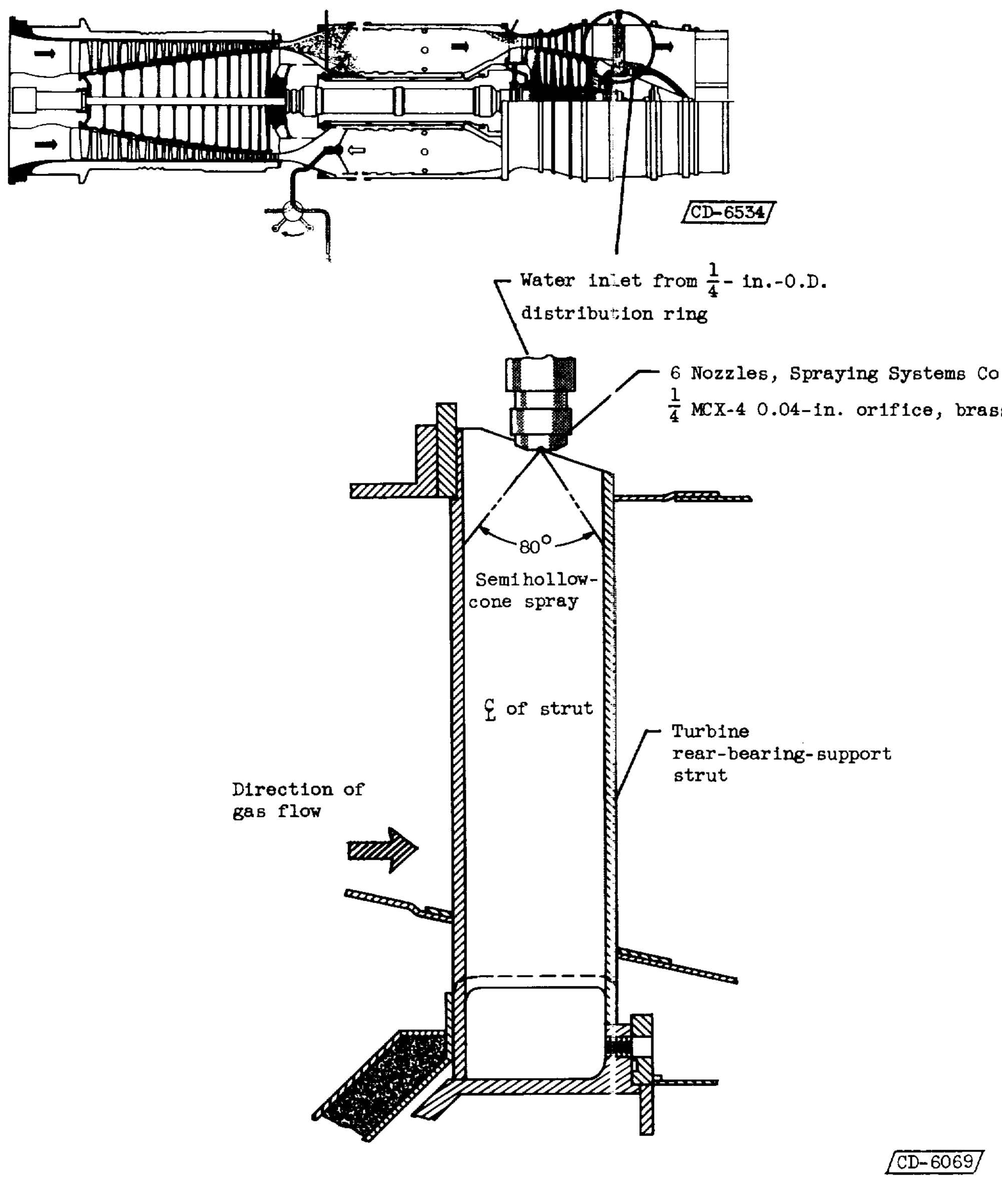


(b) Photograph of nozzle installation.

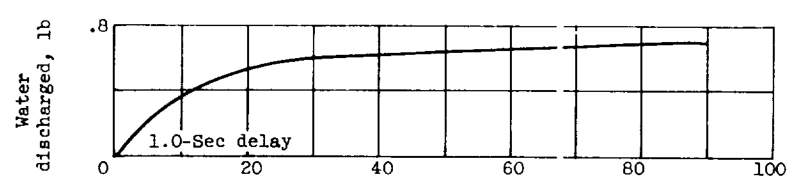


(c) Cumulative water discharge.

Figure 10. - Concluded. Rear-rotor subsystem.

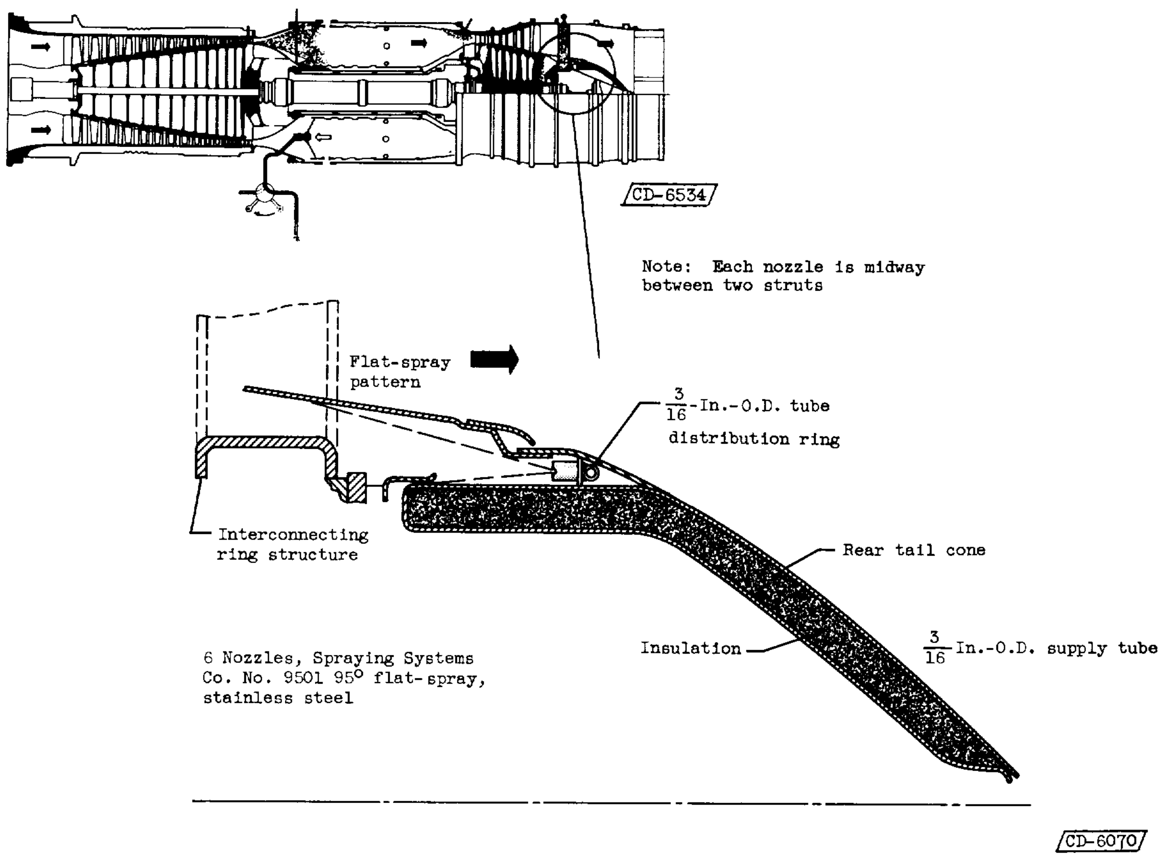


(a) Water spray nozzle installation subsystem.

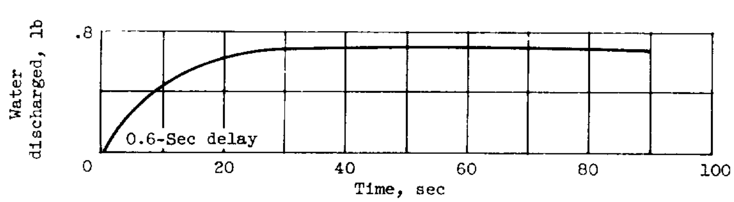


(b) Cumulative water discharge.

Figure 11. - Inner-rear-support subsystem.

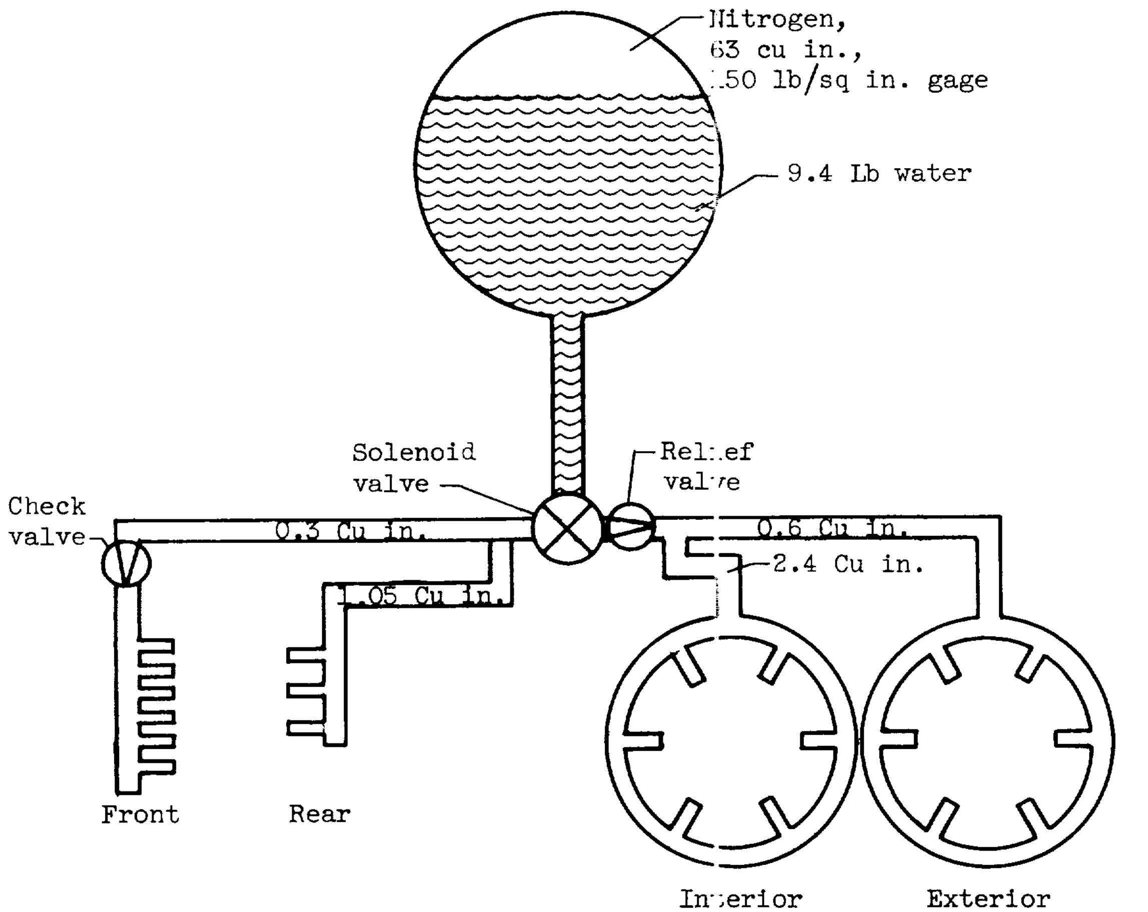


(a) Water spray nozzle installation.



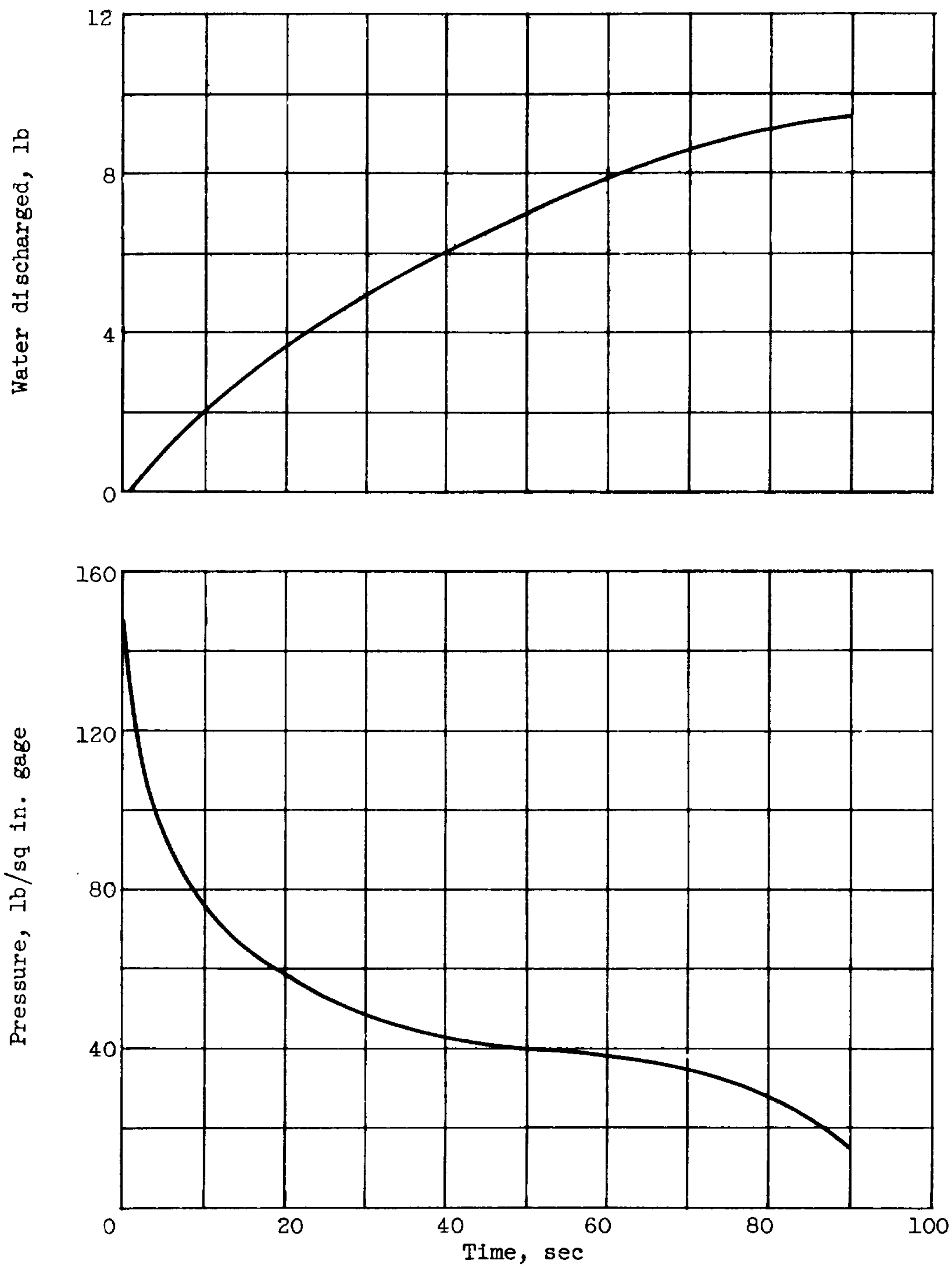
(b) Cumulative water discharge.

Figure 12. - Outer-rear-support subsystem.



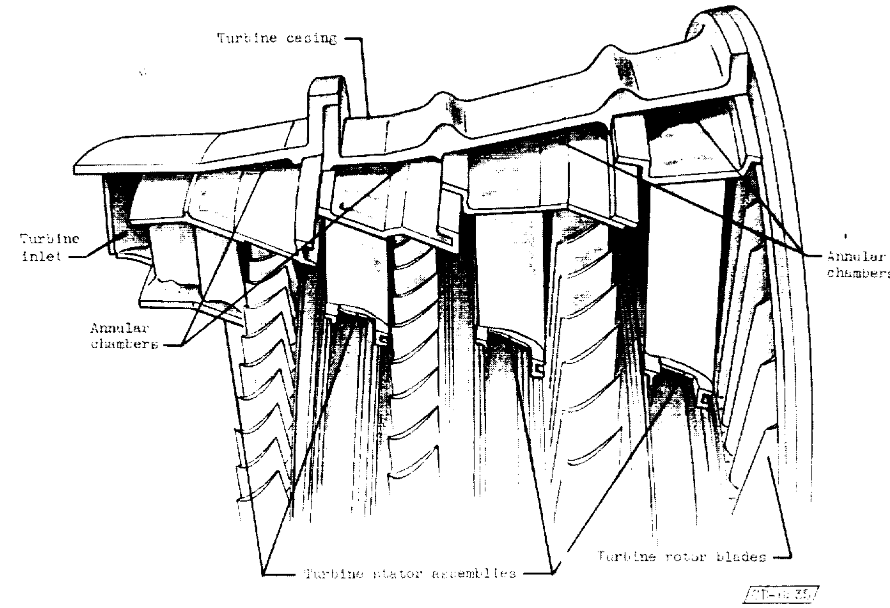
(a) Arrangement.

Figure 13. - Turbine rotor and rear-bearing-support subsystems.

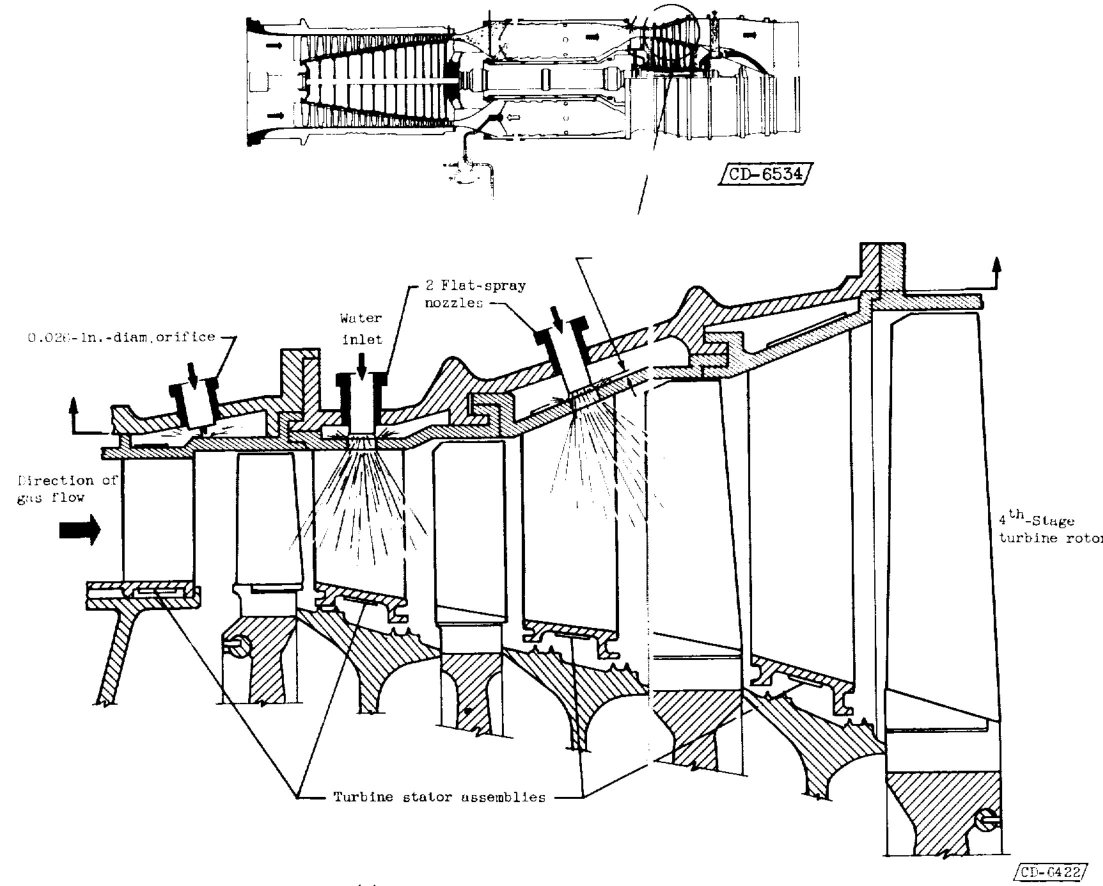


(b) Total cumulative water discharge and propelling pressure decay.

Figure 13. - Concluded. Turbine rotor and rear-bearing-support subsystems.

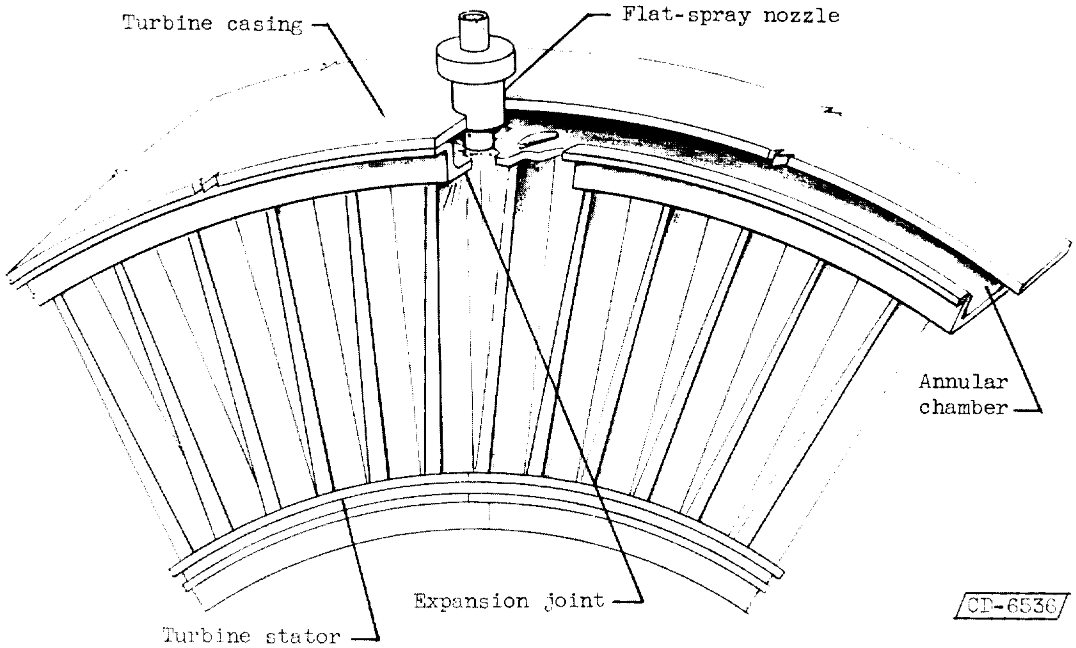


(a) Annular chambers between turbine casing and turbine stator assemblies.

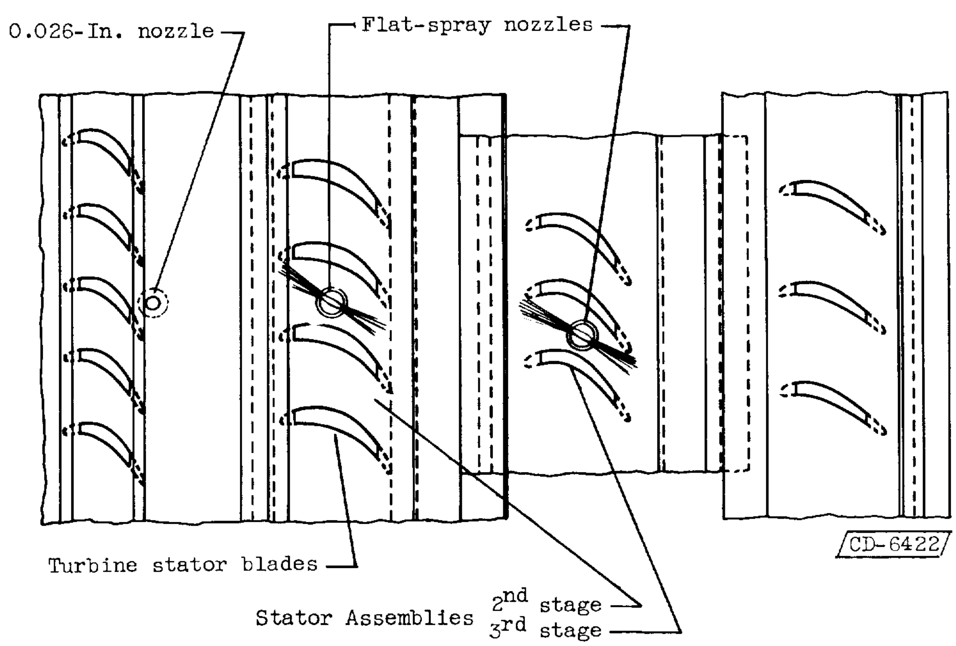


(b) Water spray nozzle installation.

Figure 14. - Turbine-casing subsystem.



(c) Typical installation of flat-spray nozzle in annular chamber between stator assembly and turbine casing.



(d) Top view of turbine stator assemblies showing figure direction of water spray.

Figure 14. - Concluded. Turbine-casing subsystem.

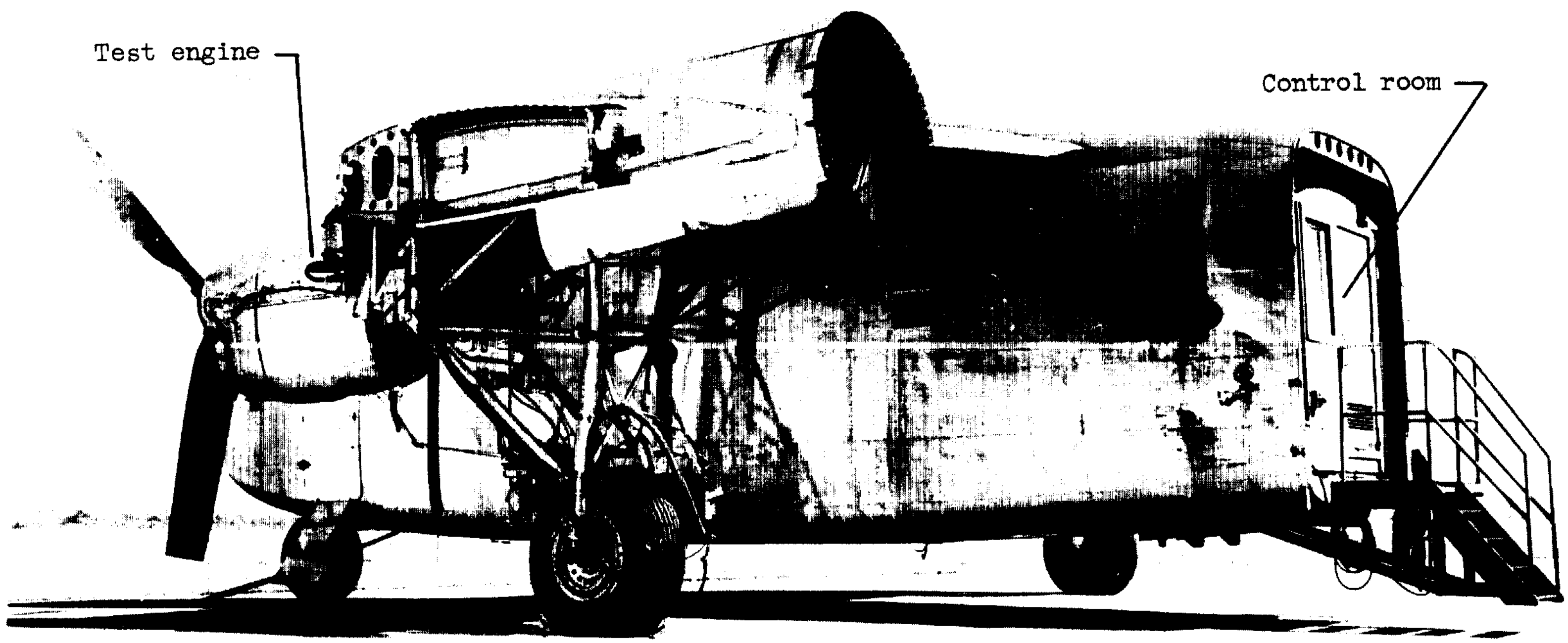


Figure 15. - Stripped C-82 airframe used as movable turboprop test stand.

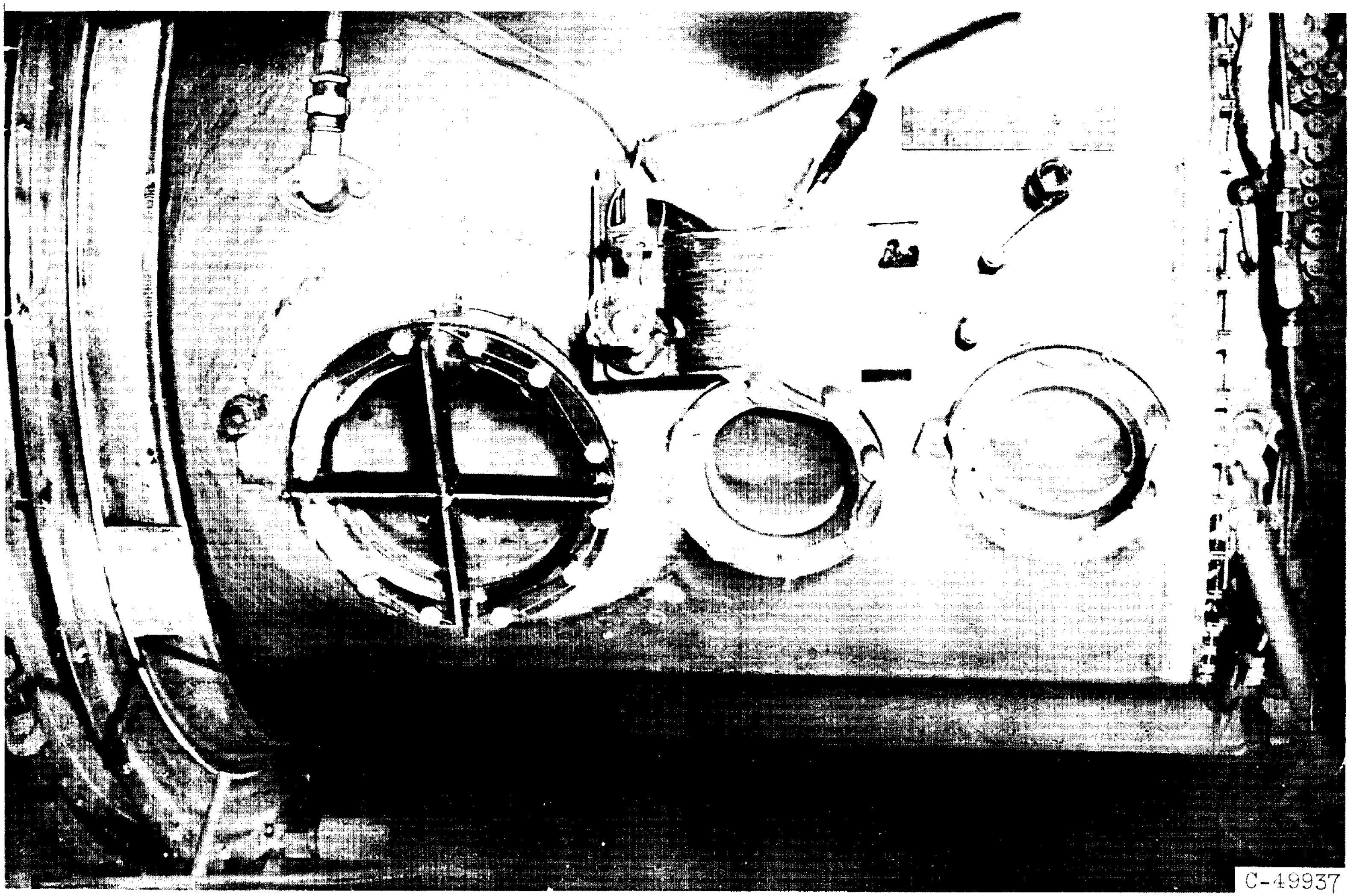


Figure 16. - Quartz windows installed in combustion-chamber housing.

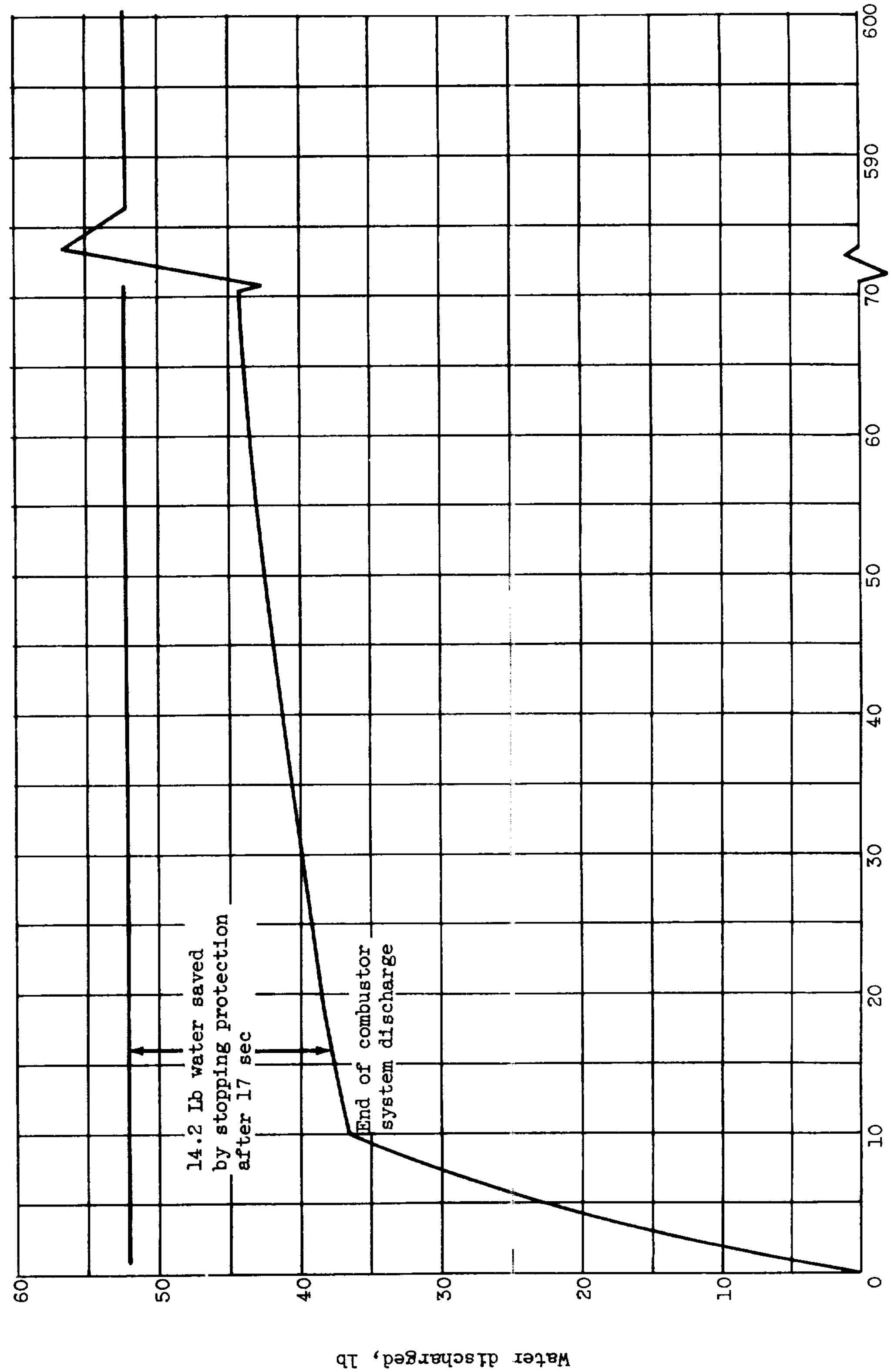


Figure 17. - Total cumulative water discharge for crash-fire protection system.