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RESEARCH MEMORANDUM

FOREIGN-OBJECT RETENTION AND FLOW CHARACTERISTICS OF RETRACTABLE ENGINE-INLET SCREENS

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NATIONAL ADVISORY COMMITTEE
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FOREIGN-OBJECT RETENTION AND FLOW CHARACTERISTICS OF RETRACTABLE ENGINE-INLET SCREENS

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SUMMARY

An investigation was conducted to determine and improve upon the foreign-object-retention capabilities and pressure-loss characteristics of retractable engine-inlet screens. Tests were made with two commercially made retractable screens installed in the engine-inlet sections for which they were designed. Air was drawn through the screens by means of an exhaust system. Retention studies were made by manually placing foreign objects on selected portions of the screens and observing their movement visually and photographically while the screens were retracted and extended. Turbulence during retraction and extension and large physical clearances between the screens and the ducting were factors which caused retractable screens to have very poor retention characteristics. Pressure loss of the screen installation was approximately double that of the screen element loss. The additional loss was caused by the uncovered screen retraction wells in the wall of the duct. Several modifications were made that significantly improved the retention and pressure-loss characteristics of the screens.

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INTRODUCTION

Foreign-object damage is shown statistically in reference 1 to be an important cause of engine damage. One way of eliminating foreign object damage is to use screens. Fixed screens used in early model engines were discarded because ice formed on the screens and blocked the flow of air to the engines. Retractable screens were developed to eliminate the icing problem and to avoid thrust losses after the aircraft was in the air and the screens were no longer needed. It is believed that retractable screens have prevented the ingestion of many large objects which might have caused aircraft accidents. However, small objects that escaped the retractable screens either before, during, or after retraction are still frequently found inside turbine engines. Furthermore, repair records indicate that the frequency of nicks and dents in axial-flow-compressor blades has not been reduced by the use of retractable screens.

As a part of the program at the Lewis laboratory to gain an understanding of some of the basic physical processes associated with the problems of gas-turbine-engine reliability, an investigation was made of the foreign-object retention properties and the related airflow problems of retractable air-inlet screens for turbine engines. The objectives of this investigation were to (1) discover the processes associated with the failure of retractable screens to retain objects, (2) determine the factors that cause pressure loss through the screen installation, and (3) demonstrate and suggest methods of improving the retention and pressure-loss characteristics of retractable screens.

Two full-scale screen designs were investigated. One screen, designed for an early model jet engine, had circumferentially oriented screen elements. The other, designed for an engine currently being introduced into extensive service use, had radially oriented screen elements. The screens were mounted in a duct rig in which sea-level static engine airflows were simulated by means of an exhaust system.

Retention studies were made by placing foreign objects on the extended screens and observing their motion visually and with a motion-picture camera as the screen was retracted and extended. Records were kept of the number and type of objects retained by the screens. Total-pressure-loss studies were made with the screens in opened, closed, and intermediate positions and with the screen retraction wells faired and unfaired.

Foreign objects used in the study, believed to typify debris causing much of the damage to engines in service, included pebbles and metal aircraft nuts. In the conduct of the investigation, improvements indicated by the observations were made and evaluated.

APPARATUS

Screens

Two retractable engine-inlet screens were used in the investigation. For the tests each screen was mounted in the inlet section of the engine for which it was designed. Screen A, with circumferential elements, was mounted in the inlet section of engine A, as shown in figure 1. Screen B, with radial elements, was mounted in the inlet section of engine B, as shown in figure 2. This particular screen was not equipped with the metal hinge seals that were included on the majority of the production screens of this type.

Both screens are divided into segments and are retracted by rotating forward about a hinge line located at the outer edge of the annulus. When the screens are fully retracted, they fit into a recess in the outer surface of the annulus. This recess is referred to herein as the "retraction well." The screen section of engine B has individual retraction wells (fig. 2), while the screen section of engine A has a common retraction well (fig. 1). Screen A was retracted electromechanically and required about 3 seconds to move from a fully extended to a fully retracted position. Screen B was hydraulically operated and moved from its extended to fully retracted position in about 0.43 second. Retraction time of either screen was not significantly affected by airflow.

Sketches showing cross-sectional views of these screens and their installations are shown in figures 3 and 4. It will be noted that screen A had an element thickness-to-chord ratio t/c of 0.22, a gap G of 0.20 inch, and a stagger ratio a/c of 0.80. Screen B had a thickness-to-chord ratio of 0.06, a gap of 0.22 inch, a small but variable stagger ratio, and a sweep angle of 30°.

Hinge detail and the location of retraction-well covers are shown in figures 3 and 4 also. The retraction-well covers shown by the dashed lines were pieces of sheet metal added at a later part of the investigation to smooth the outer wall of the inlet annulus.

The modifications made to screen B are shown in figure 5. Figure 5(a) shows the rubber hinge-seal flaps cemented in front of the hinge line, and figure 5(b) shows the intersegment gap cover made from wire cloth.

Test Facility

The test facility used in this investigation is shown in figure 6. The engine-inlet section containing the screens and actuation mechanism was attached to a plenum chamber, which was in turn attached to an exhaust system. A wire safety screen was located at the downstream end of the plenum chamber to recover objects lost by the retractable screens.

In order to systematically study the motion of the foreign objects, it was decided to observe only one quadrant of the engine inlet at a time. Three of the quadrants were therefore blocked. The flow to the quadrant being studied was guided by the bellmouth, the two radial sheet-metal walls, and the engine centerbody. This arrangement is shown in figure 7(a) for screen A and in figure 7(b) for screen B. Figure 7 shows the ducting as it was arranged during the testing of the screens in the top quadrant. The ducting was rotated to the side and bottom quadrants during the course of the investigation.

Instrumentation

A high-speed motion-picture camera operating at approximately 700 frames per second was used to study the motion of objects on the screens and the paths by which they escaped the screen. The camera was located in front of the bellmouth and focused on the front of the screens.

Nylon-yarn tufts were attached to the screens and the duct walls to aid in determining the direction of local flows and turbulence. These tufts can be seen in figure 7.

Total-pressure rakes were installed upstream and downstream of the retractable screens to measure pressure loss through the screen station.
The location of these rakes is shown in figures 3(b) and 4(b). The rakes 4344
were removed during the tests in which foreign objects were introduced.

Eight total-pressure tubes and two wall static-pressure tubes located in a contracted section of pipe downstream of the plenum chamber (fig. 6) were used to measure airflow through the system.

Foreign Objects

The three types of foreign object used for the object-retention studies are shown in figure 8. They are 3/8 to 1/2-inch pebbles, 1/4-inch castellated steel nuts, and 3/8-inch aluminum stop nuts. All the objects used, with the exception of a few of the pebbles, were too large to pass between the elements of the screen. These objects were considered typical of those which could cause strength-reducing nicks to compressor blading. It was believed that these objects, as opposed to such objects as screws and bolts, would provide a severe test of the retention properties of the screens, because they had no edges or protrusions which could lodge between the screen elements.

PROCEDURE

Retention Tests

For the retention tests, airflows from 80 to 100 percent of rated airflow per unit area were passed through the extended screens. About eight objects of one of the types shown in figure 8 were then manually placed in selected positions on the face of the screens. The positions were selected so that at the end of all the testing a foreign object of each type had been located in every significant area on the face of each screen. The movie camera was started and the screens were retracted and extended repeatedly until the movie film was used. From one to three retractions were usually accomplished in this time. Usually after about three cycles of retraction and extension, an object had either been lost or had moved to a position on the screen from which it could not be lost. A "camera's-eye" view of the objects on the screen before the first retraction is shown in figure 9. In addition to the photographic studies, visual observations were made of all the retention tests by two or more persons. After each retention test, objects retained by the screens were counted and compared with the number placed on the screen to determine the percentage of retained objects.

Pressure-Loss Tests

Total-pressure loss through the screen station was measured over a range of Mach numbers immediately upstream of the screens from 0.26 to 0.49. The Mach number was calculated from the measured weight flow, the flow area, and the total pressure immediately ahead of the screen station. Total pressures fore and aft of the screen station were read visually from a multiple-tube water manometer board.

RESULTS AND DISCUSSION

Retention

Unmodified screens. - The percentage of objects retained by screens A and B is shown in figure 10. The percentages shown are those of a particular type object in a particular quadrant retained over the course of the entire investigation. In most cases these percentages are based on about 20 objects of each type in each quadrant. The generally low values in figure 10 demonstrate that both screens A and B in their unmodified form failed to do a satisfactory job of foreign-object retention.

The screens failed to retain objects in several different ways. It will be recalled from the APPARATUS section that screen A had circumferentially arranged screen elements. Observations of tufts attached to the screens indicated that the circumferential screen elements, which moved to a high angle of attack during retraction, caused the flow through the screen to first stall and then flow turbulently back through the screen, dislodging objects present on the face of the screen. In many instances the dislodged objects were blown over the lip of the screen or between the screen segments. Both paths are shown in figure 11(a). Flow stall loss also occurred as the screen was extended.

Turbulence apparently continued to exist in the area around the circumferential screens even after the screens were fully retracted, because objects were frequently lost over the edges of the fully retracted screens.

The radial screen elements of screen B, on the other hand, minimized turbulence during retraction and extension and few foreign-object losses occurred because of turbulence. In addition, individual retraction wells were provided for each screen segment so that it was more difficult to dislodge objects from the screens after the screens were fully retracted. Observation disclosed that the poor retention capability of screen B was chiefly due to large openings at the hinge line. This observation is verified by the data in figure 10. As shown in this figure, a low percentage of objects was retained in the bottom quadrant of screen B where the objects, under the influence of gravity, fell towards the hinge line. Fewer low-density pebbles fell towards the hinge line than high-density steel nuts because of the tendency of low-density objects to stick to the screen. Thus, more pebbles than steel nuts were retained in the bottom quadrant, even though the two were of approximately the same size. Because it is believed that, under actual operating conditions, most objects would enter the bottom quadrant, the retention characteristics of screens in the bottom quadrant are particularly important.

The B screens were actuated hydraulically and retracted much faster than the electromechanically operated A screens. Fast retraction appeared to have some advantage since less time was allowed for turbulence to dislodge objects from the screens during retraction. However, the screen segments of screen B retracted individually rather than simultaneously. It is believed that, in a few instances, the resulting circumferential flow blew objects laterally across the face of the extended screen segment and that the objects then escaped through the opening left by the fully retracted segment. The path of a foreign object under these conditions is sketched in figure 11(b). However, relatively few objects were lost in this manner.

Modified screens. - Because the radial screen (screen B) caused much less turbulence during retraction than the circumferential screen (screen A) and because its major shortcoming was merely a large hinge gap, this screen was selected for modifications. Flexible rubber flaps (fig. 5(a)) were placed in front of the hinge. In addition, as a protection against losses due to turbulence and nonsynchronous retraction of the screen segments, wire cloth was fastened between the screen segments (fig. 5(b)). No objects were lost through this modified screen during the course of testing, which consisted of about 50 cycles of retraction and extension, at airflows ranging from 80 to 100 percent of rated. Although the modifications shown would not be acceptable for a flight installation because of the material and fabrication methods used, their success in preventing losses demonstrates that the retention capabilities of a segmented retractable screen can be considerably improved.

Pressure Tests

Pressure profiles. - Total-pressure profiles were taken upstream (station 1) and downstream (station 2) of the inlet screen for each screen type. These profiles are shown in figures 12 and 13 where the pressures shown are the mean values of a 3 percent pressure fluctuation, which occurred because of the nature of the ducting. Figure 12(a) shows the profiles for the unmodified screen A. Curves for screens retracted, screens extended, and screens half extended are shown. As would be expected, the pressure at station 2 is less with the screens extended than with the screens retracted, and a flow distortion exists with the screens half extended. Because all the pressure profiles dropped near the outer wall (near the retraction wells), the wells were covered. The resulting profiles, which are shown in figure 12(b), are considerably flatter.

The profiles obtained with screen B are shown in figure 13. Figure 13(a) shows the profiles with the unmodified inlet, and figure 13(b) shows the profiles with the retraction wells covered. Covering the retraction wells again raised the pressures toward the outer wall, thus tending to flatten the profiles.

Pressure loss. - Total-pressure loss through the screen station was computed for screen B only, and is shown in figure 14 as a function of Mach number. A mass-flow weighting technique based on measured total pressures, and a static pressure calculated from the total pressures, the flow area, and the weight flow was used to evaluate the average total pressure upstream and downstream of the screen. Similar data for screen A are not shown because its mounting section contained large bearing support struts (fig. 1), which disturbed the air entering the screens, making it impossible to evaluate the losses caused by the screens in that area. On the other hand, the mounting section for screen B was unencumbered by support struts (fig. 2) so that a pressure loss measured at one radial position was closely representative of the loss around the entire screen station. However, it was not certain whether the measured pressure loss was affected by the sharp-cornered ducting leading to the screens. To substantiate the measured pressure loss, an estimated thrust loss at static sea-level conditions was computed from the pressure loss according to the equations of reference 2. The resulting thrust loss compared favorably with thrust losses measured during flight tests with several similar inlet screens as reported in references 3 to 5. A scale of estimated thrust loss at static sea-level conditions is included on the right side of figure 14.

Figure 14 contains curves for the screens retracted and extended with the retraction wells covered and uncovered. A pressure-drop curve for the screen elements alone is also shown. This curve was obtained by measuring the pressure loss in midstream, and represents the minimum loss that could be obtained from this particular screen in its extended position. The screen elements curve falls just slightly below the curve for the screens extended with wells covered, and both of these curves are considerably below the curve of the screens extended with wells uncovered. Therefore, about half of the pressure loss with the screens extended could be avoided and the pressure loss of the installation reduced to almost the screen element loss by devising some mechanism to cover the retraction wells after the screens have been extended.

The curve for pressure loss with screens retracted and wells uncovered is the loss that would be incurred during cruising flight with the unmodified screen section. This loss could be reduced to less than half by covering the wells after the screens were retracted, as shown by the curve for screens retracted and wells covered.

In general, it is evident from figure 14 that the pressure loss of any configuration could be reduced by locating the screen at a low Mach number station in the duct.

CONCLUSIONS

The two standard retractable engine-inlet screens used in this investigation did not satisfactorily retain foreign objects. Objects escaped through large physical clearances around the screens, particularly at the hinge line, and were blown off the screens by flow stall and turbulence during retraction and extension. Initially retained objects were also observed to escape the screen after the screen was fully retracted. About half of the pressure loss caused by the screen installation with the screens either retracted or extended was caused by the retraction wells. However, the results of the tests made with these screens and the success of several modifications led to the conclusion that the retention properties and pressure-loss characteristics of these and other retractable screens could be improved by the following features:

1. All gaps around the screens should be as small as possible. This is particularly true of the hinge line because most objects are forced into this area either by aerodynamic or gravitational forces. A flexible sealing flap ahead of the hinge apparently would be a good method of making the hinge ingestion proof.

2. Screens and retraction motion should be designed so that flow stalling and turbulence is minimized during retraction and extension. Radially arranged screen elements appear to reduce flow stall and turbulence to an acceptable level with the type of retraction considered in this investigation.

3. Rapid retraction of the screen should be provided for so that less time is allowed for turbulence to dislodge objects. Also, the actuation system should be such that all segments retract simultaneously, thus preventing objects from being blown off the screens by circumferential flow.

4. The intersegment gap of the segmented-type screens should be covered to retain objects blown into this area by turbulence during retraction.

5. An object-tight retraction well should be provided for each screen segment so that objects cannot be lost after the screen has been retracted.

6. Retraction-well covers should be provided when the screens are both extended and retracted to reduce the pressure loss through the screen station.

7. The screen should be located at as low a Mach number station of the inlet duct as possible to reduce pressure loss through the screen.

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National Advisory Committee for Aeronautics
Cleveland, Ohio, January 18, 1957

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3. Munter, Paul L.: Effect of Engine Air Inlet Screens upon F-86E Performance. Tech. Note WCT-53-54, Wright Air Dev. Center, Air Res. and Dev. Command, United States Air Force, Wright-Patterson Air Force Base, Mar. 1954.

4. Munter, Paul L.: Effect of Engine Air Inlet Screens upon F-84G Aircraft Performance. Tech. Note WCT-53-54 (Addendum No. F-84G), Wright Air Dev. Center, Air Res. and Dev. Command, United States Air Force, Wright-Patterson Air Force Base, May 1954.

5. Munter, Paul L.: Effect of Engine Air Inlet Screens upon F-86D Performance. Tech. Note WCT-53-54 (Addendum No. F-86D), Wright Air Dev. Center, Air Res. and Dev. Command, United States Air Force, Wright-Patterson Air Force Base, Aug. 1954.

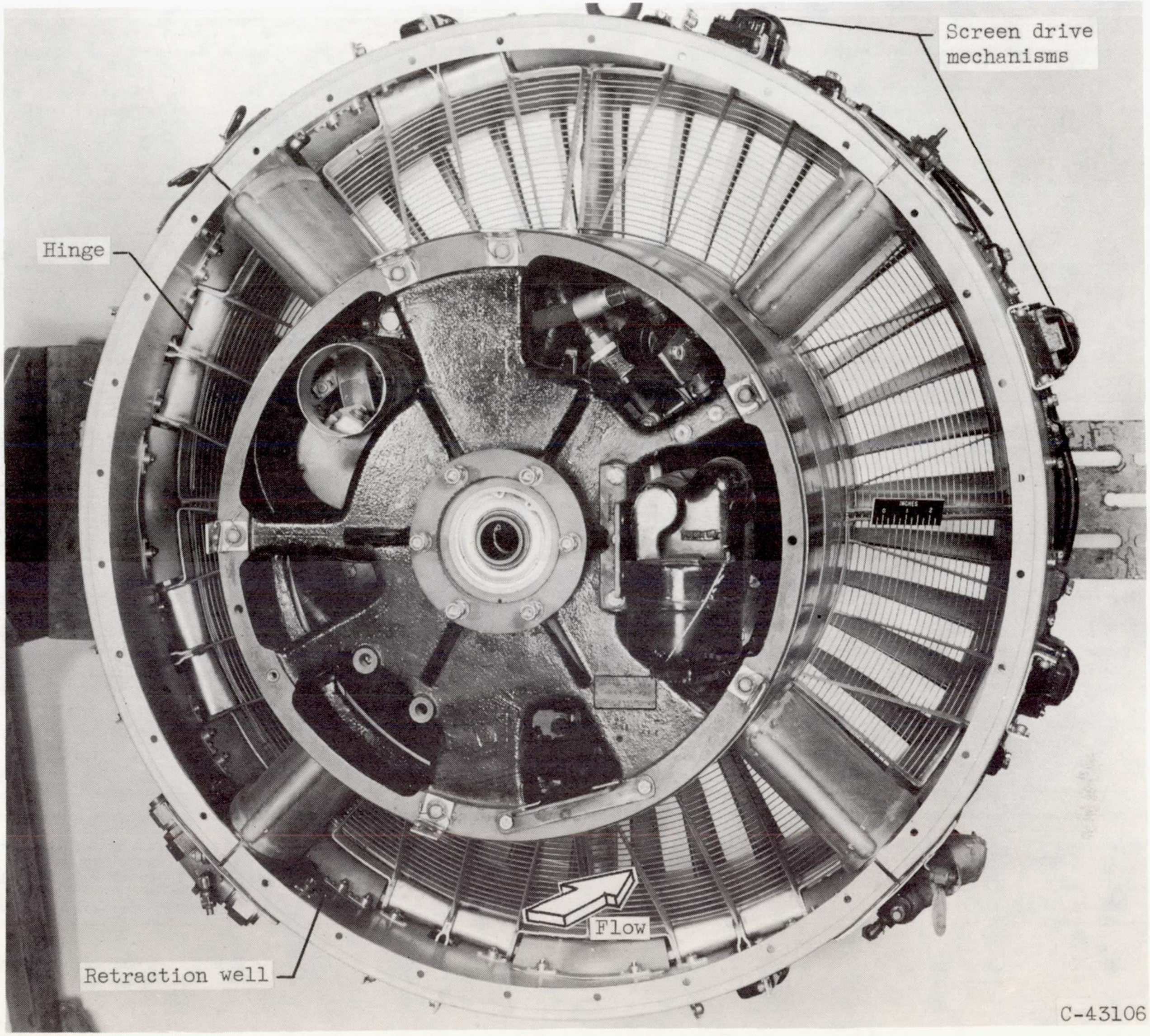

Figure 1. - Screen A installed in inlet section of engine A.

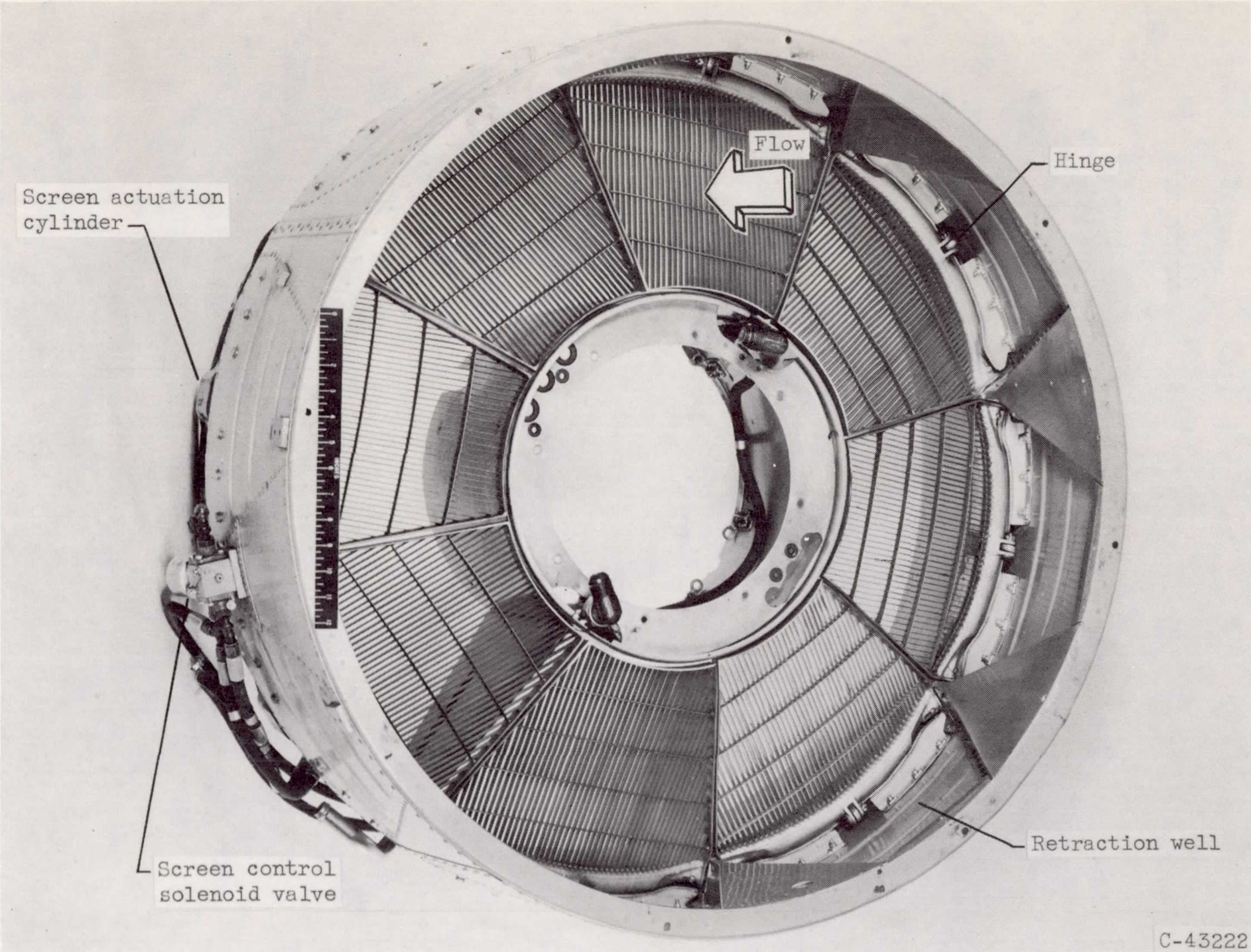

Figure 2. - Screen B installed in inlet section of engine B.

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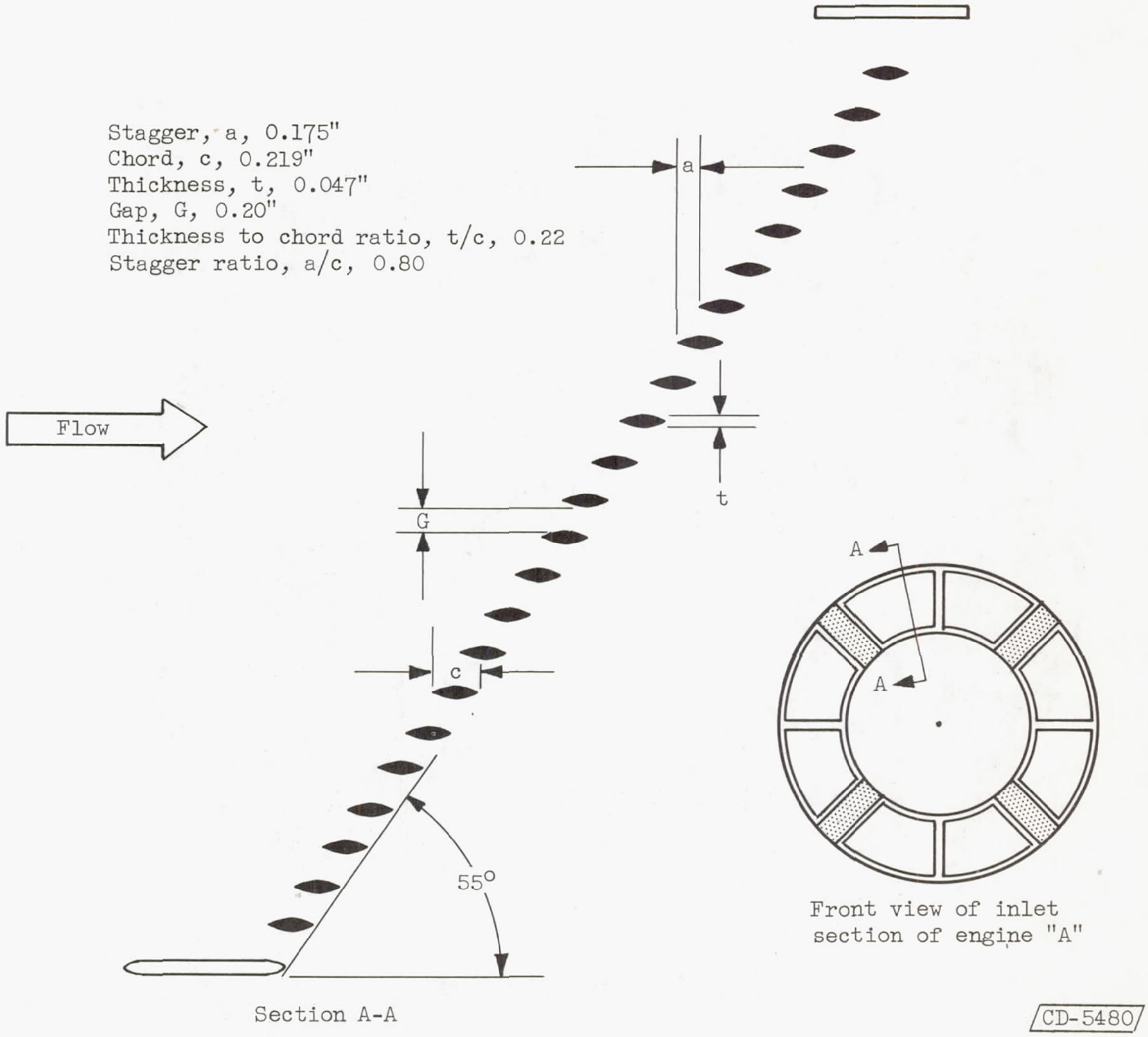
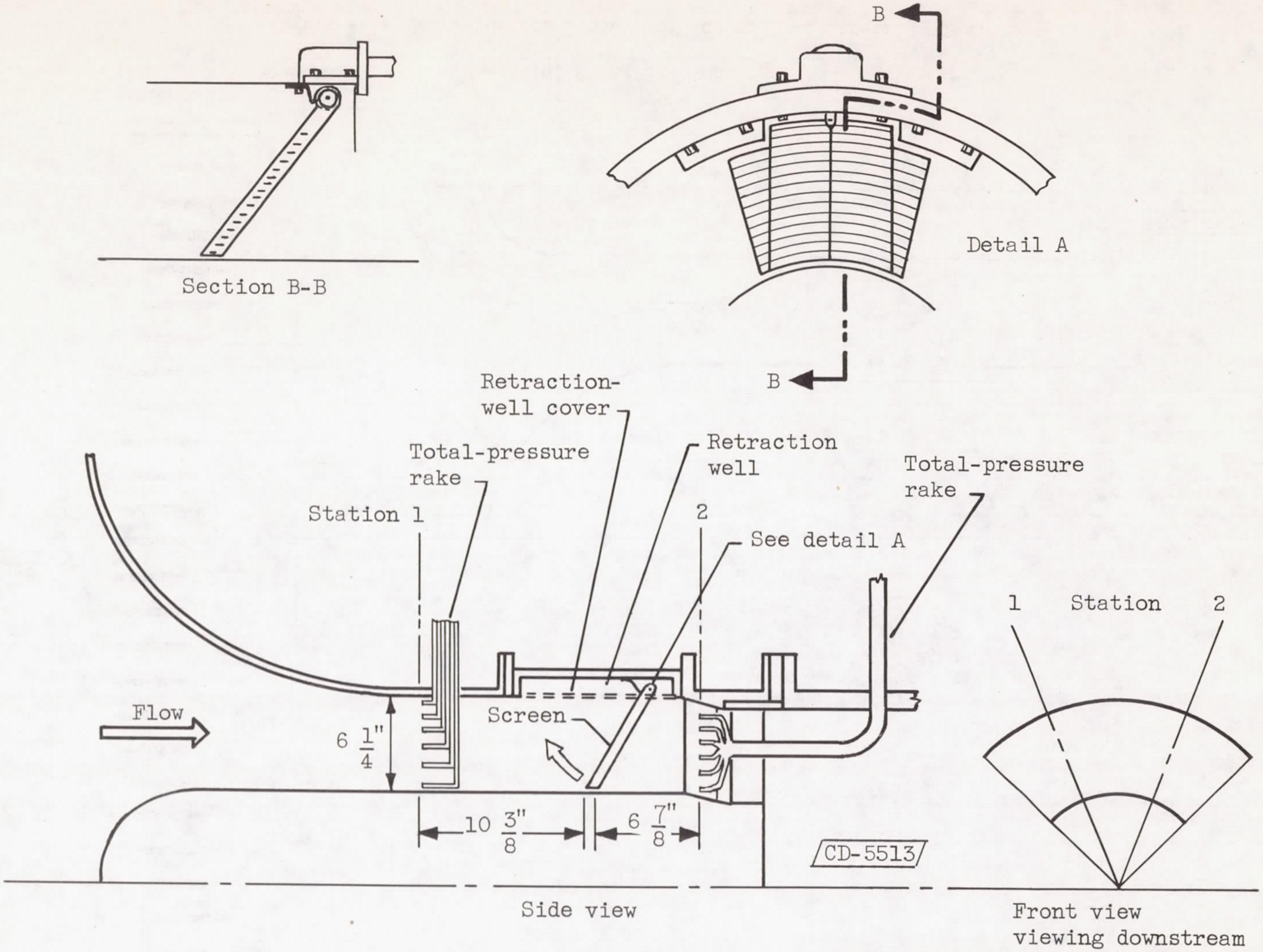


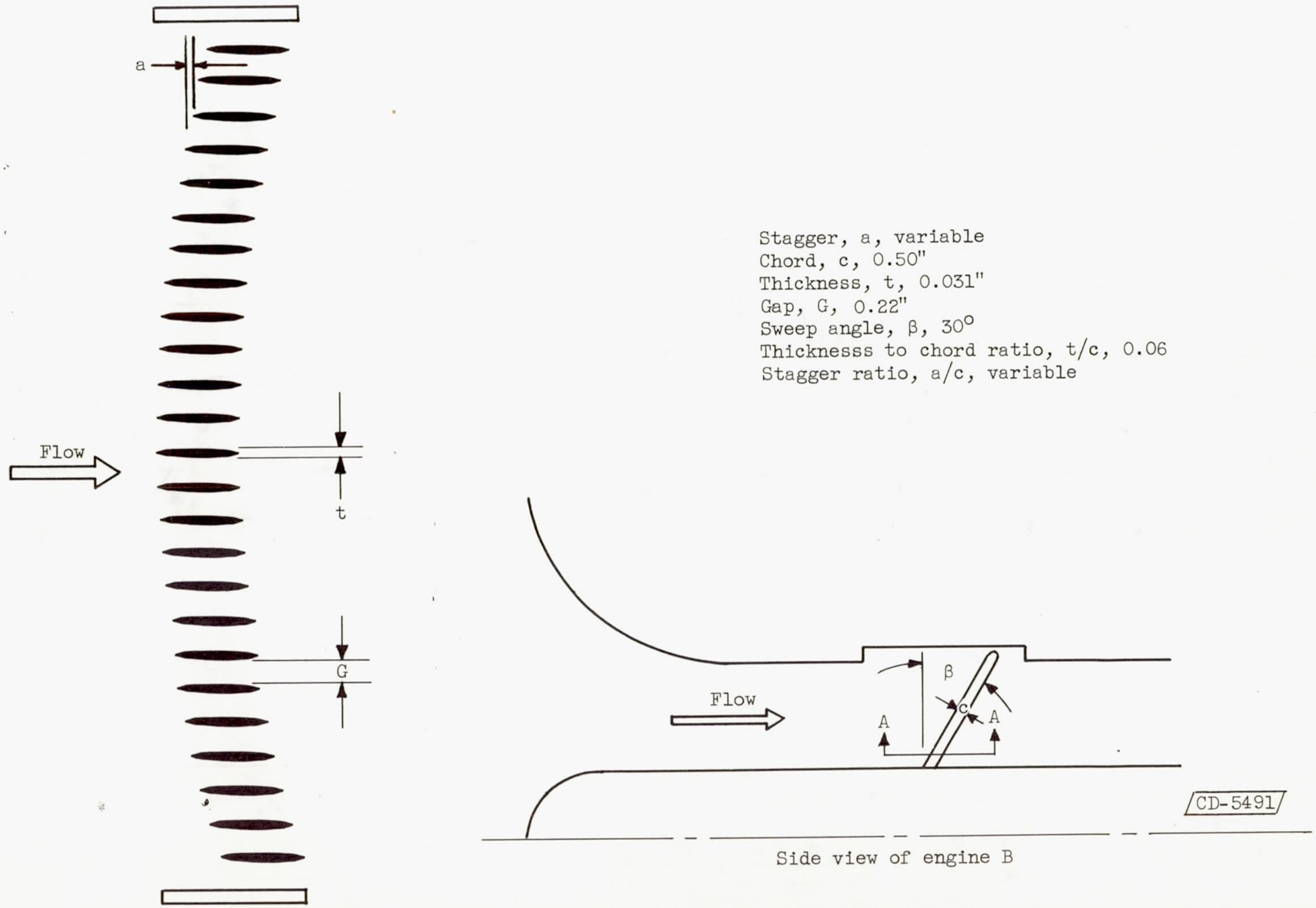
(a) Cross section.

Figure 3. - Cross-sectional views of screen A and installation.



(b) Installation of screen A.

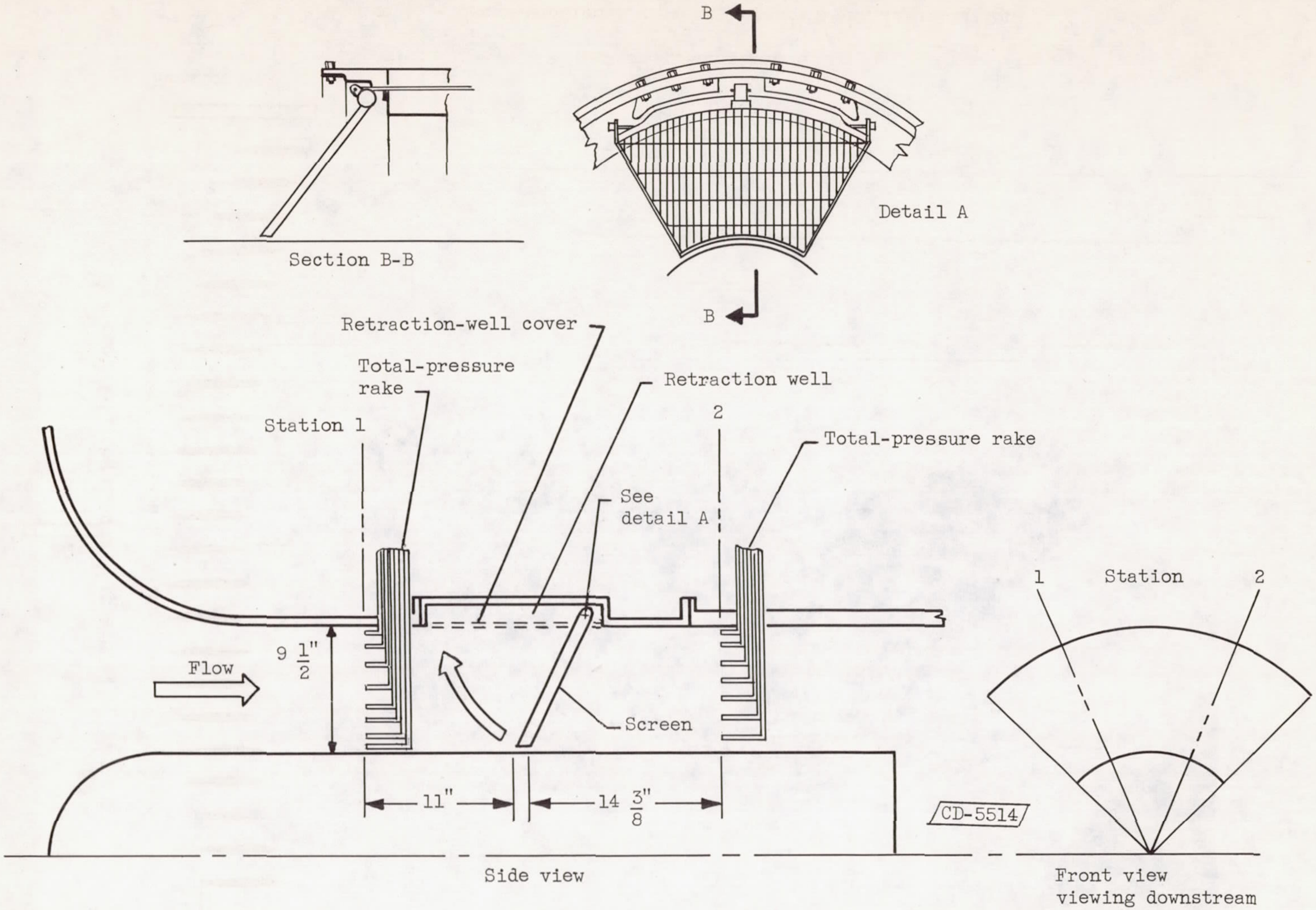
Figure 3. - Concluded. Cross-sectional views of screen A and installation.



Section A-A

(a) Cross section.

Figure 4. - Cross-sectional views of screen B and installation.



(b) Installation of screen B.

Figure 4. - Concluded. Cross-sectional views of screen B and installation.

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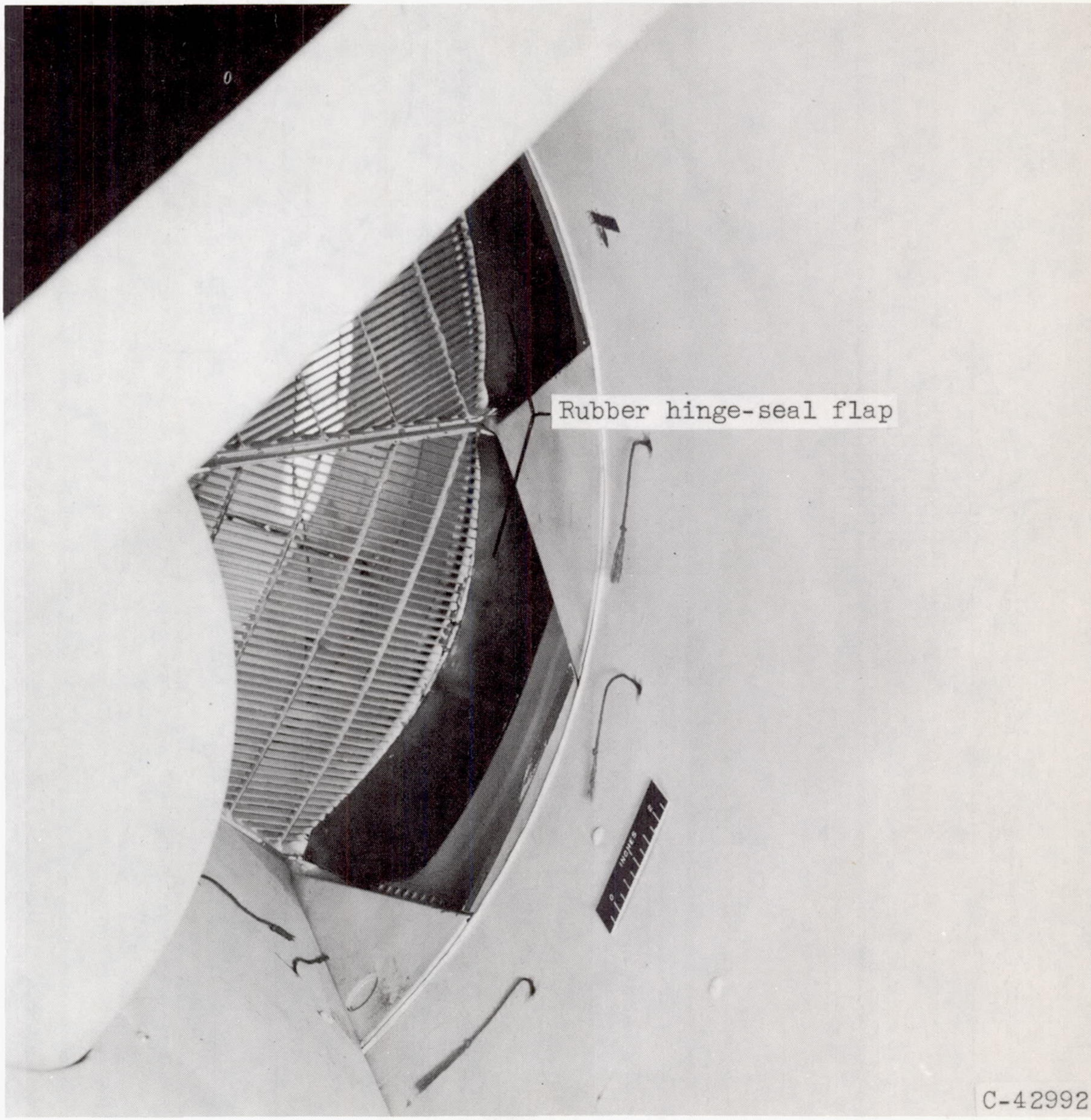

(a) Rubber hinge-seal flaps.

Figure 5. - Screen modifications.

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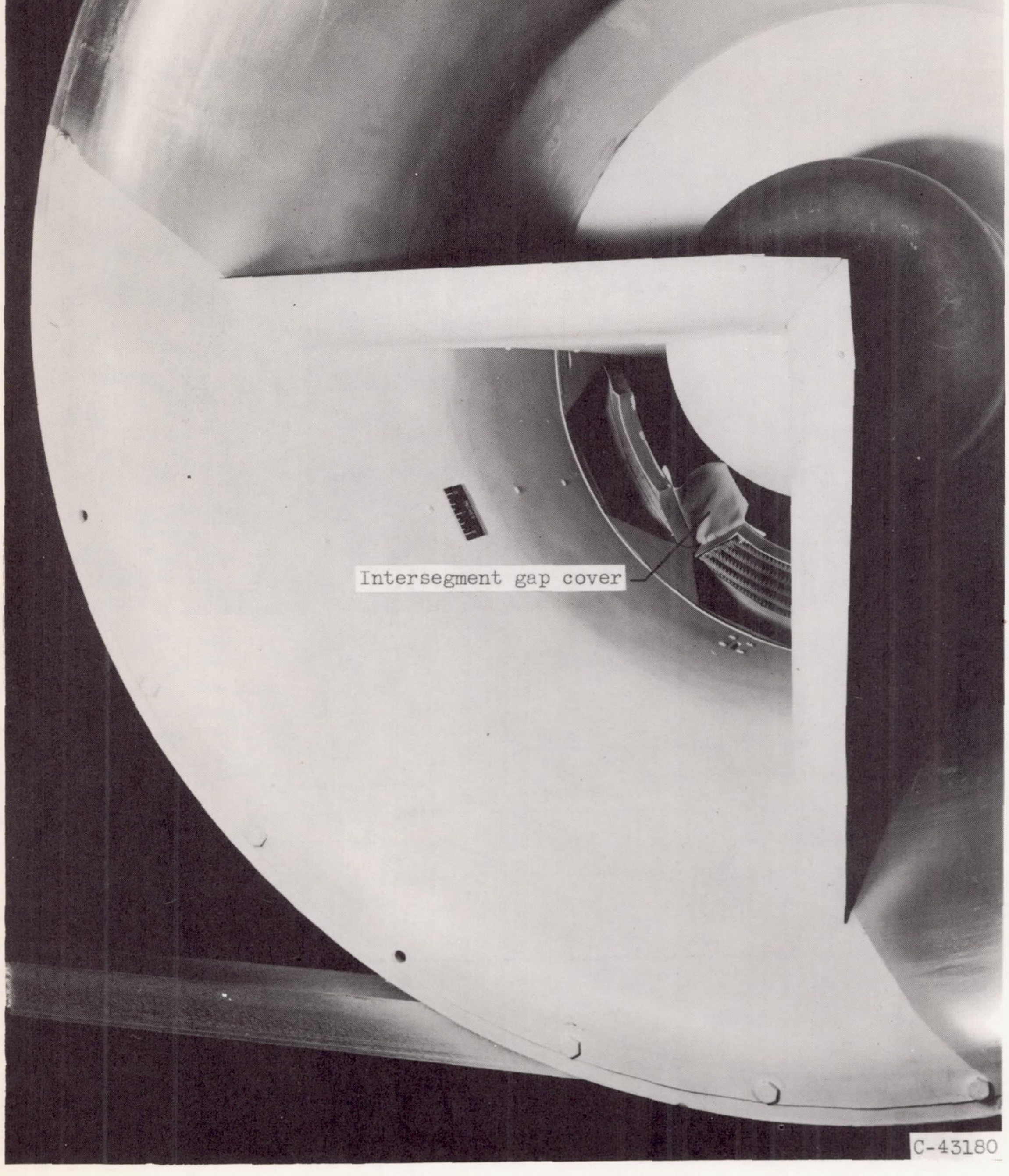


(b) Intersegment gap cover.

Figure 5. - Concluded. Screen modifications.

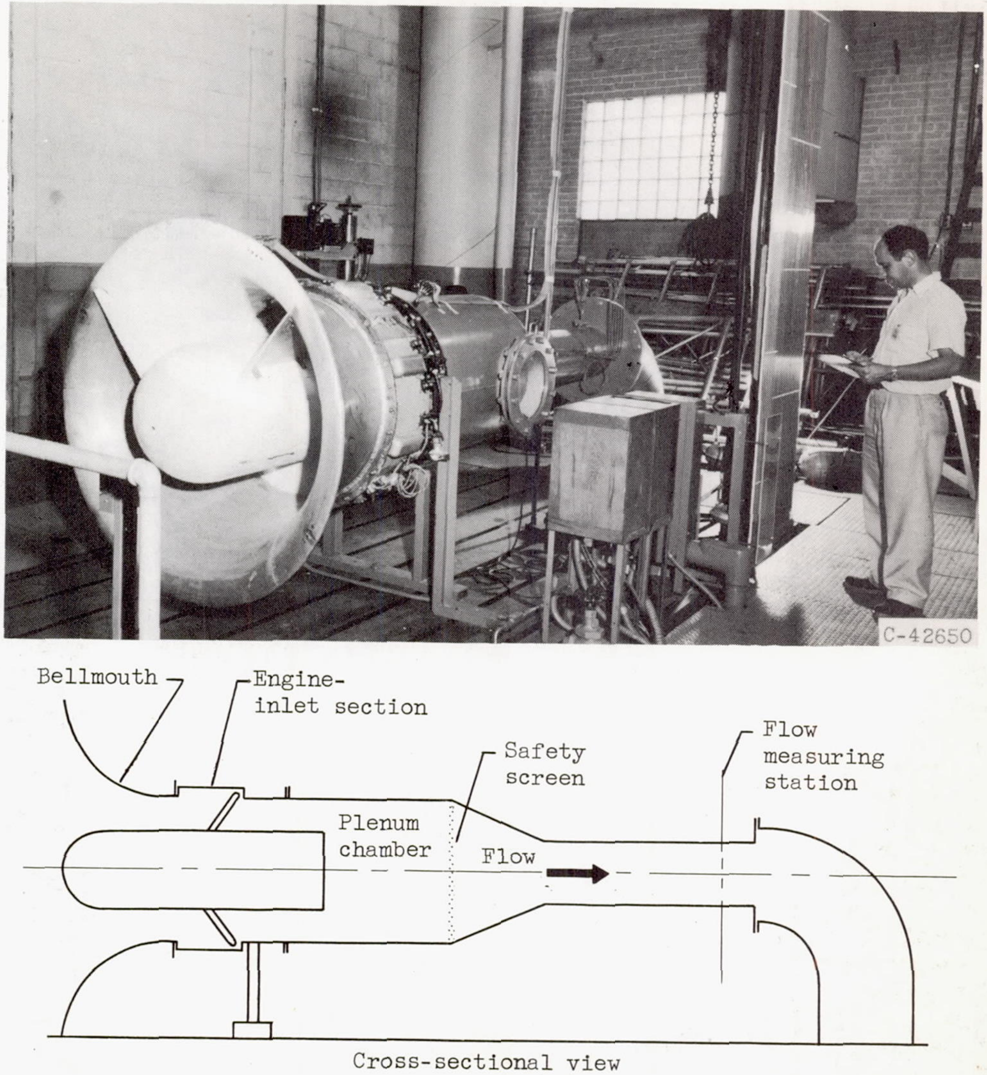
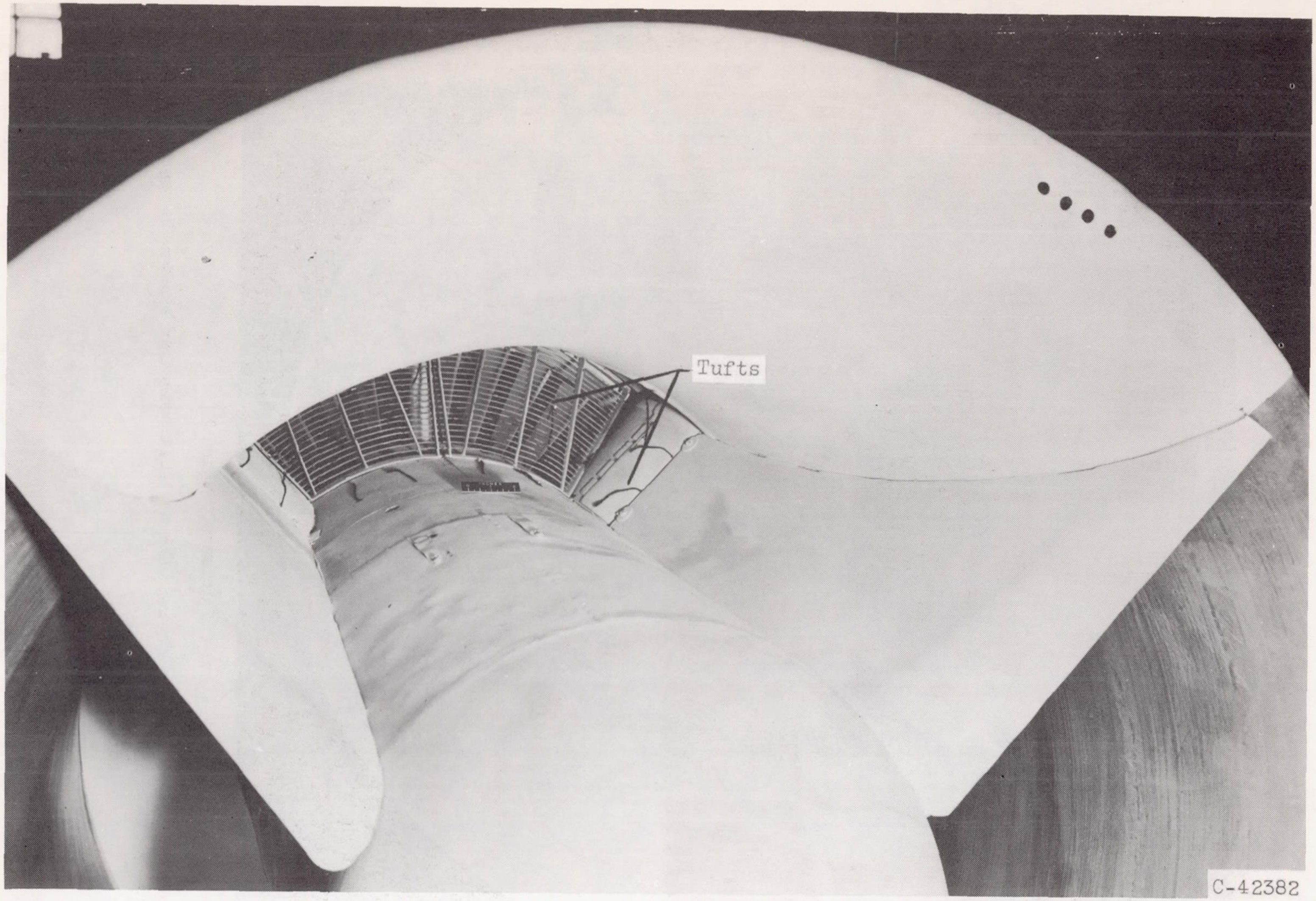


Figure 6. - Engine-inlet-screen test facility.



(a) Inlet of engine A.

Figure 7. - Ducting used to limit retention studies to one quadrant of engine inlet.

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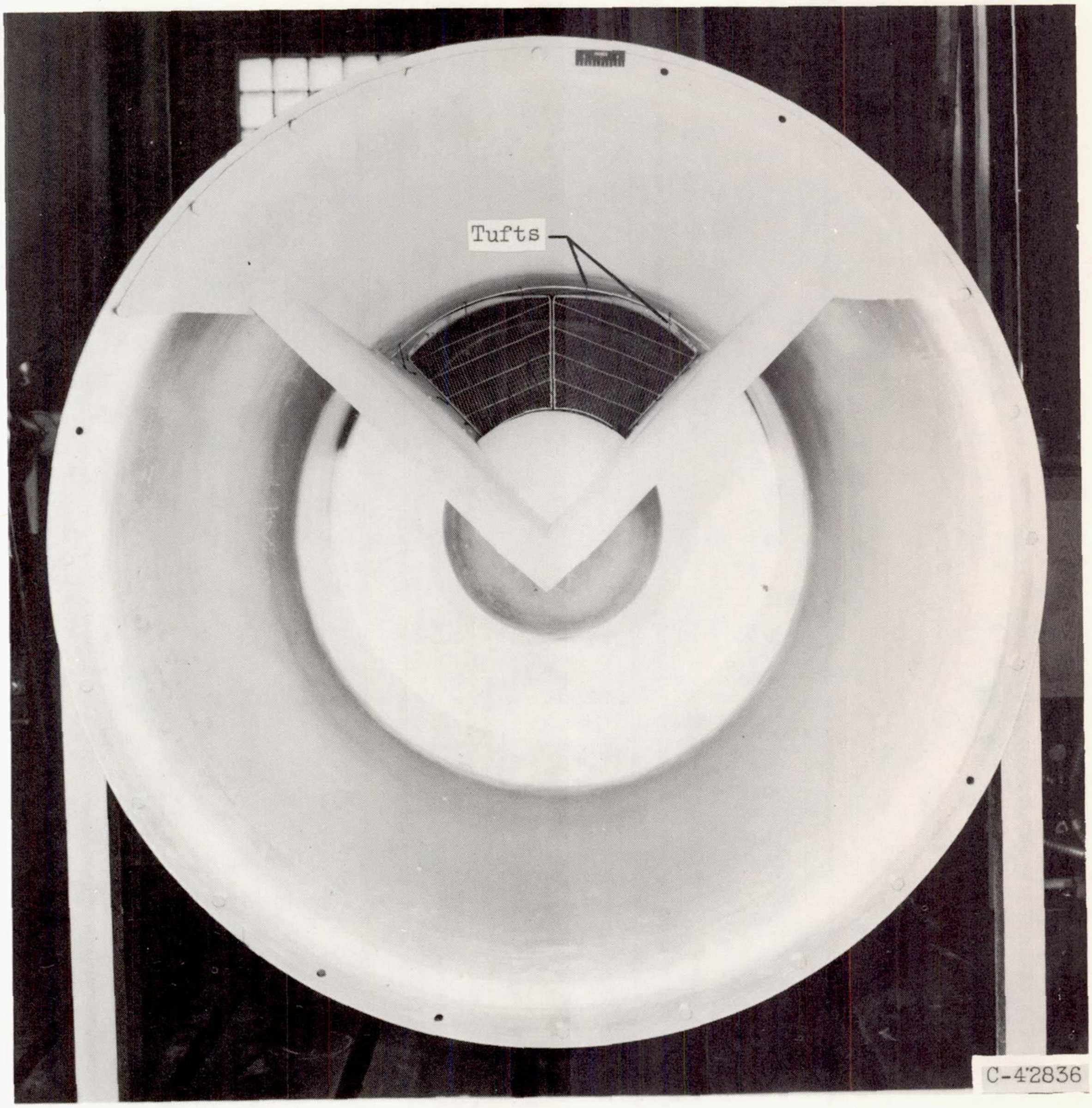

(b) Inlet of engine B.

Figure 7. - Concluded. Ducting used to limit retention studies to one quadrant of engine inlet.

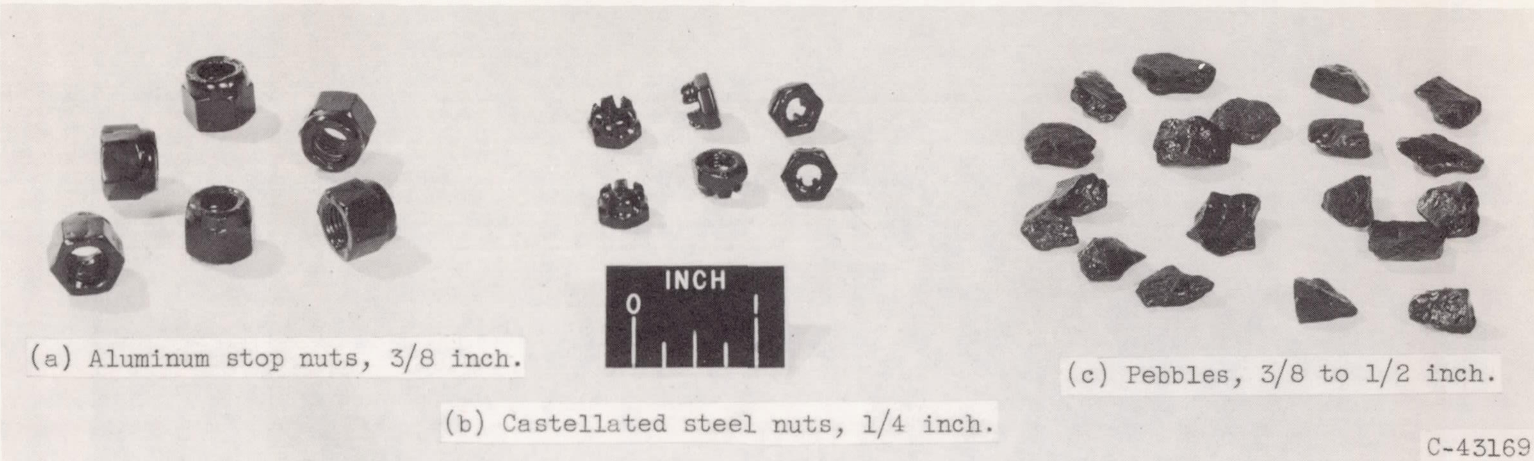

Figure 8. - Foreign objects.

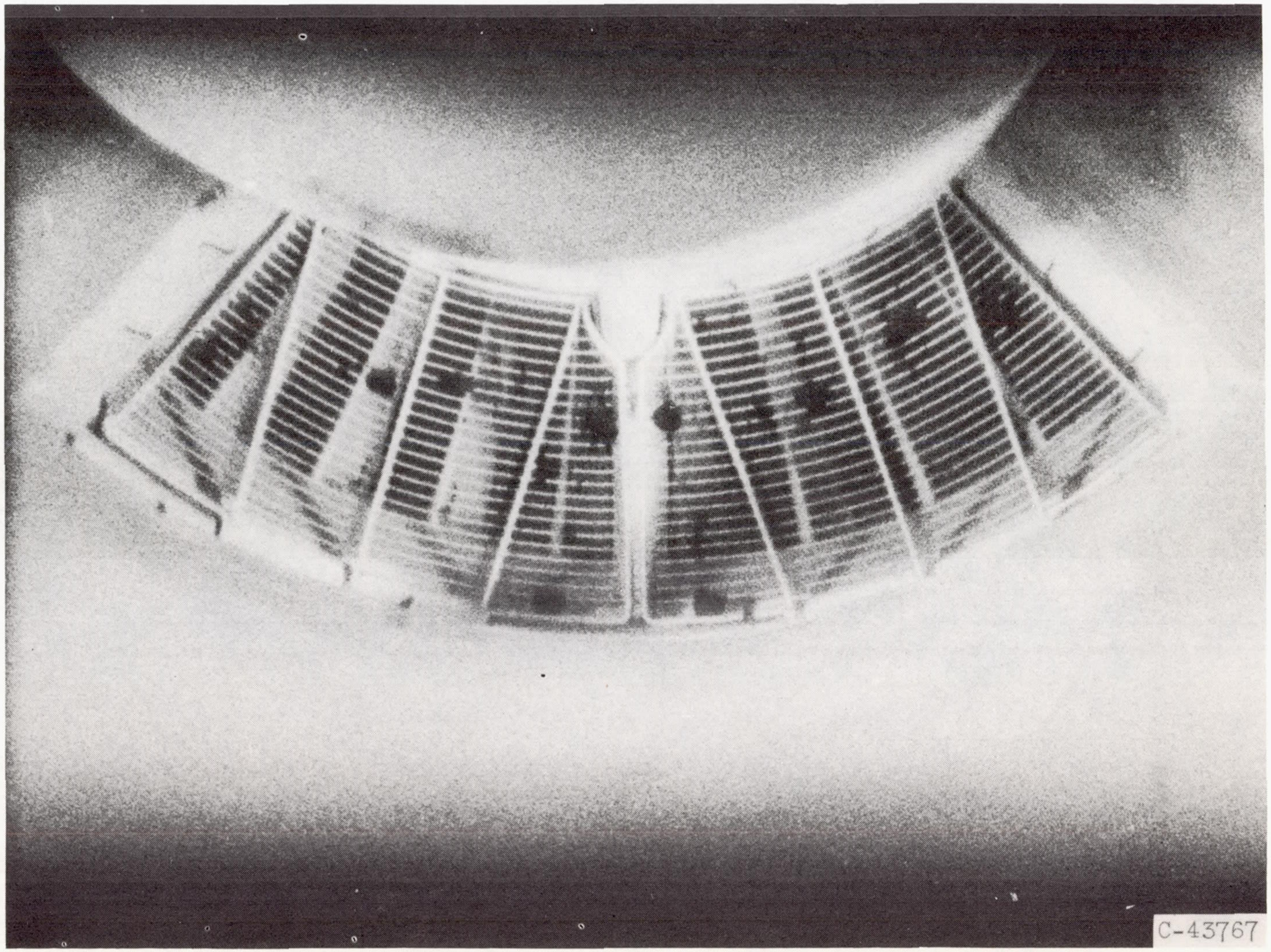

Figure 9. - Typical arrangement of foreign objects on the face of the screens.

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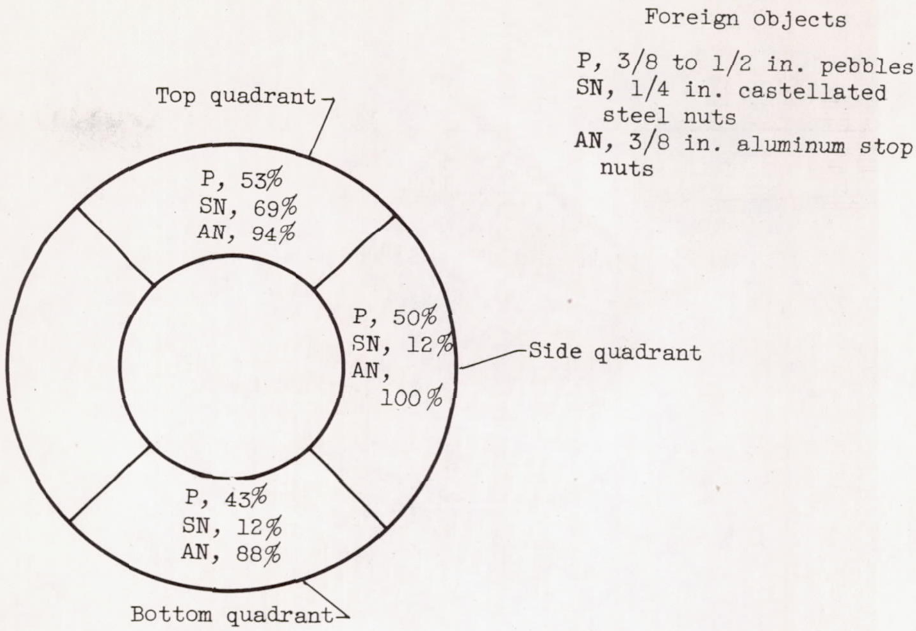
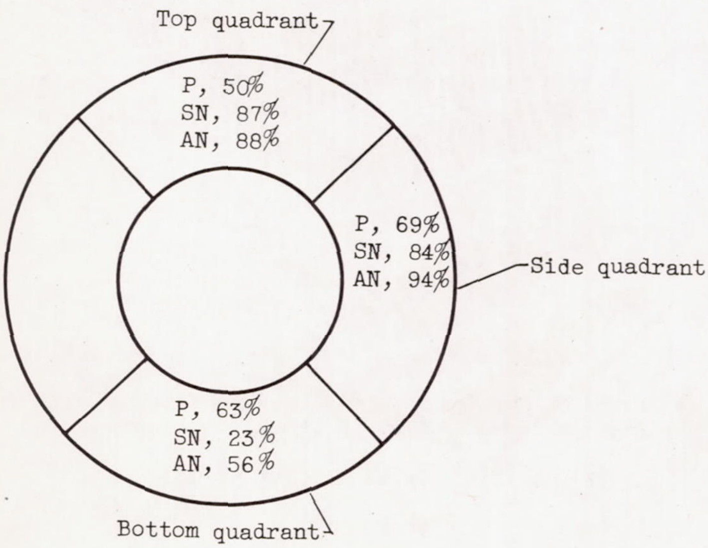


(a) Screen A



(b) Screen B

Figure 10. - Percentage of objects of each type in each quadrant retained by retractable screens A and B.

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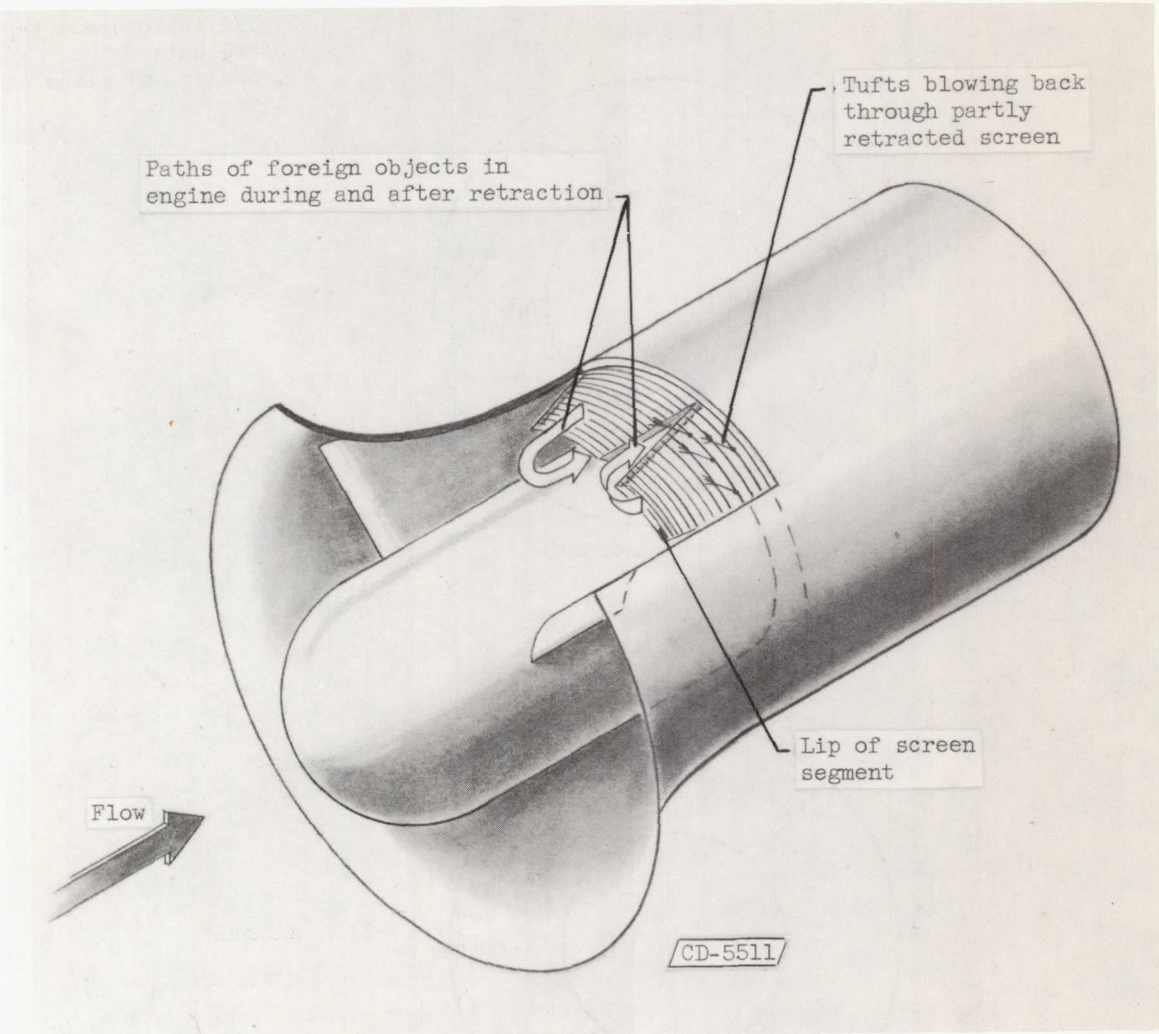
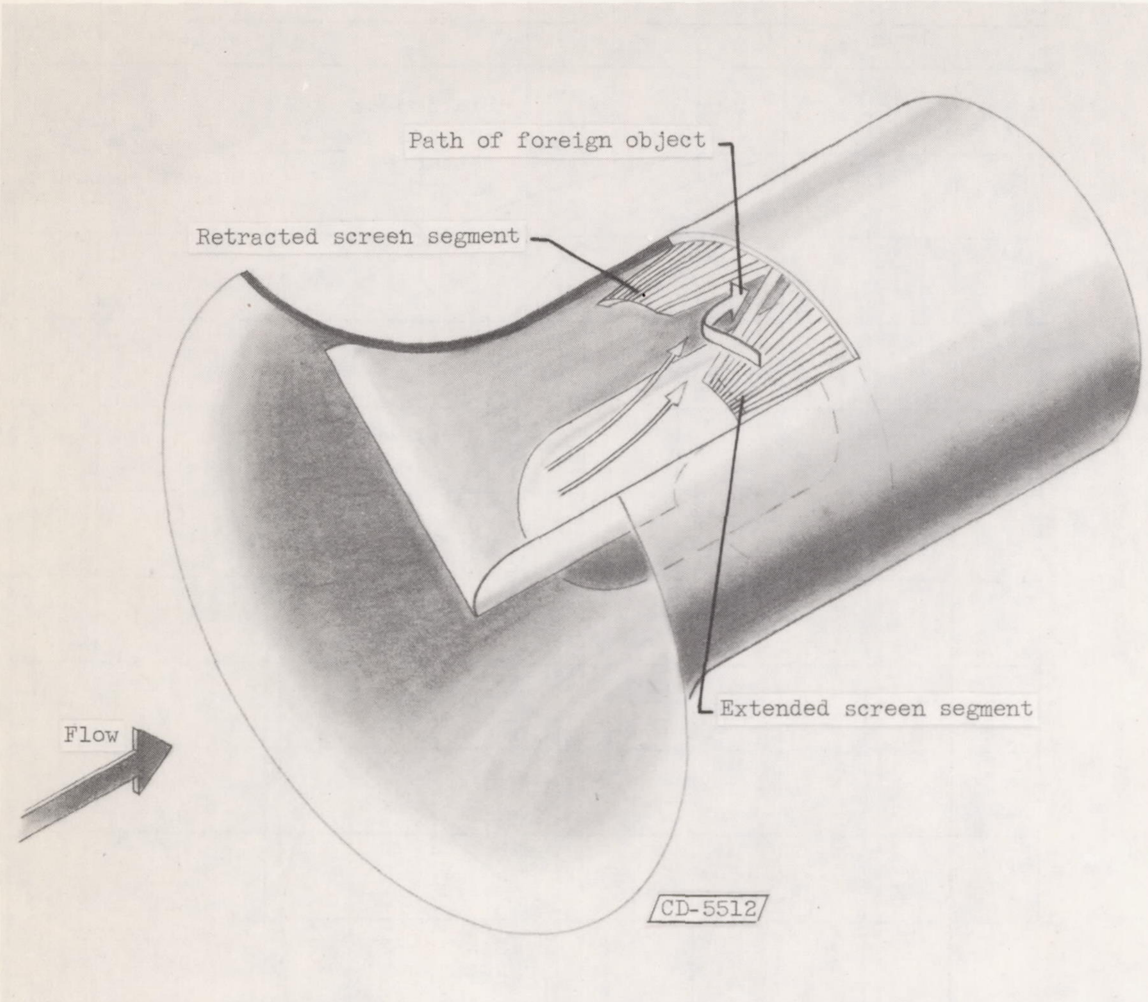


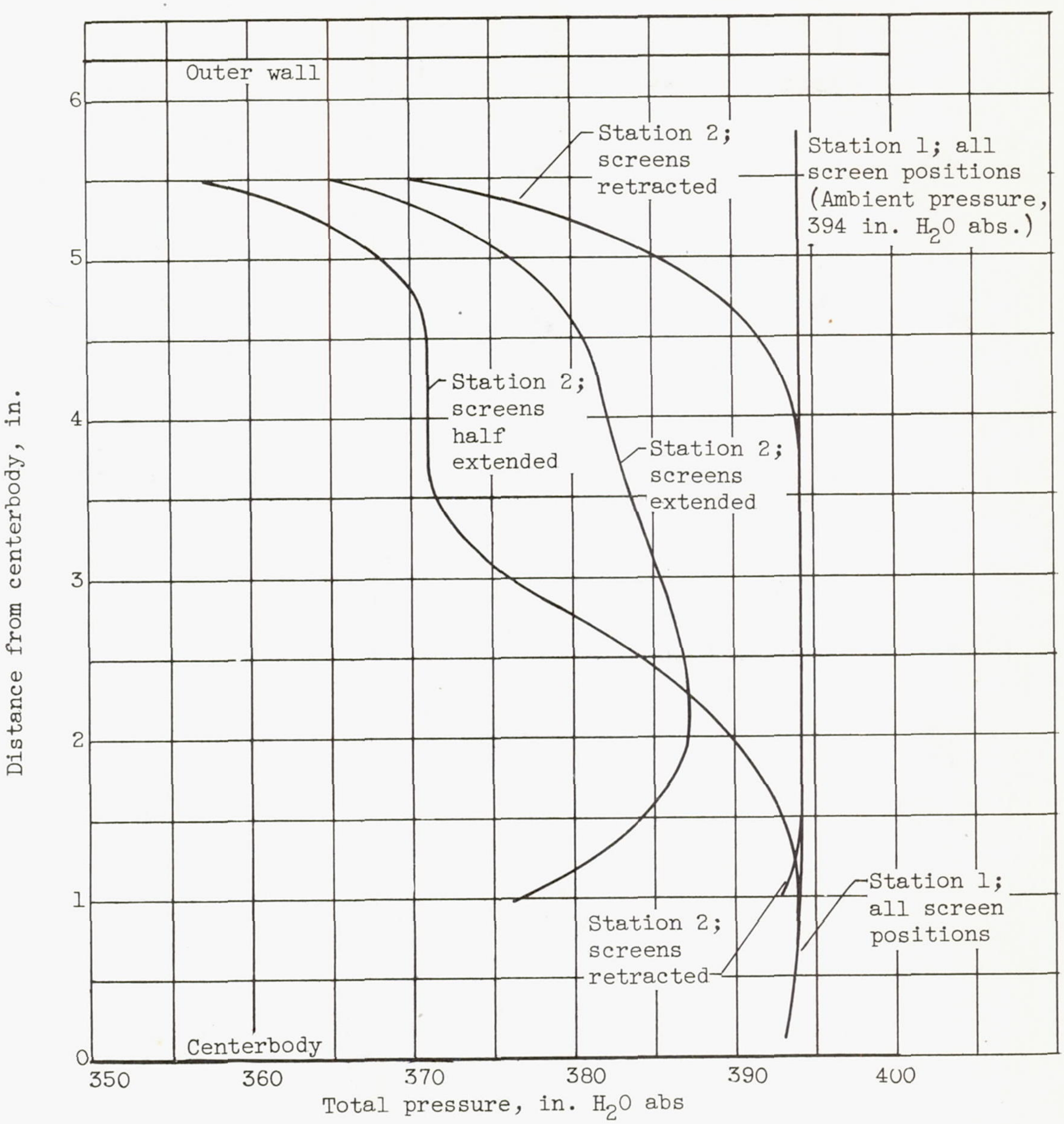
(a) Paths of foreign objects dislodged from circumferential element screens by flow stall and turbulence.

Figure 11. - Types of foreign-object loss.



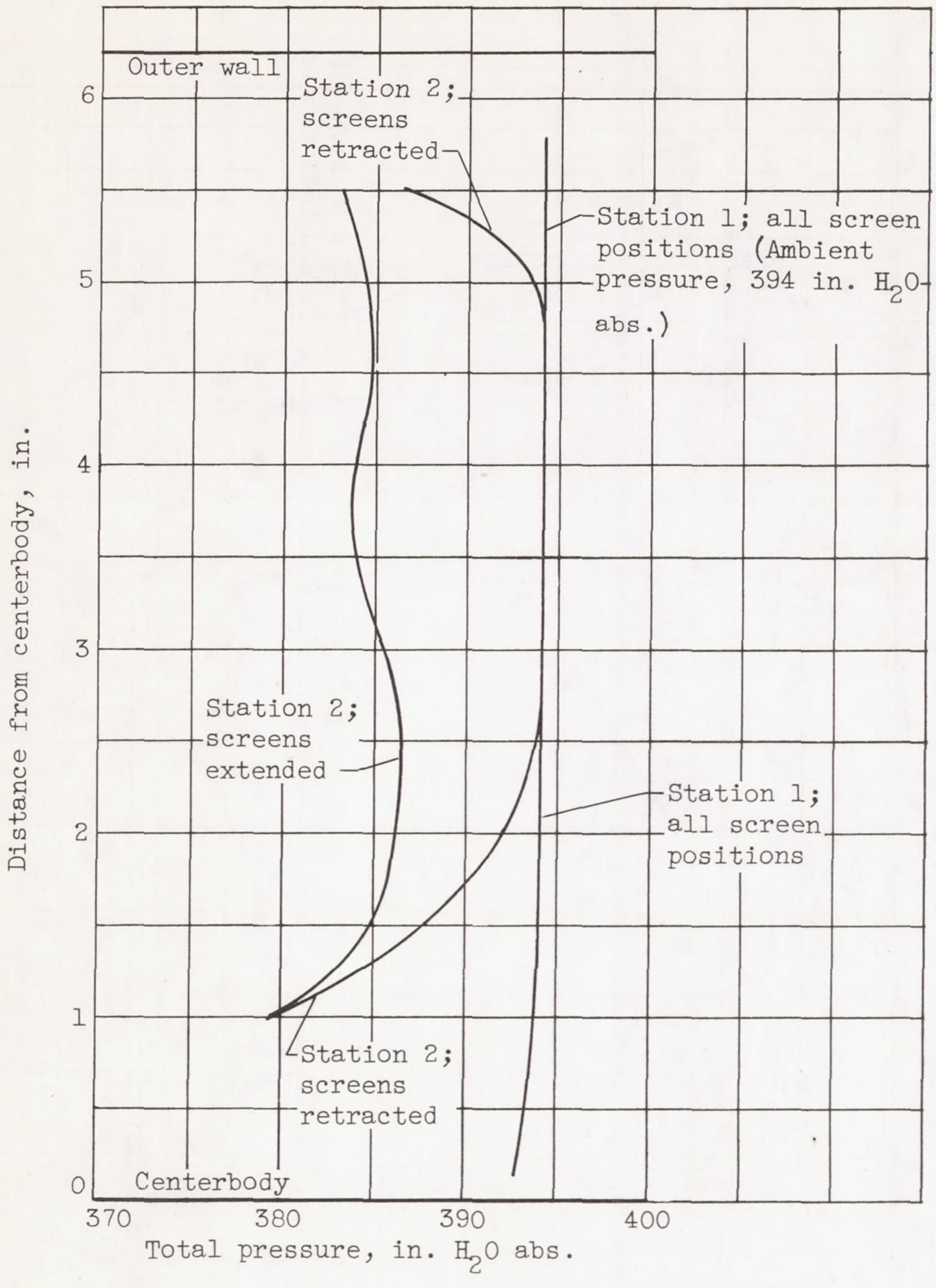
(b) Paths of foreign objects dislodged from screens by circumferential flow resulting from nonsynchronous retraction of screen segments.

Figure 11. - Concluded. Types of foreign-object loss.



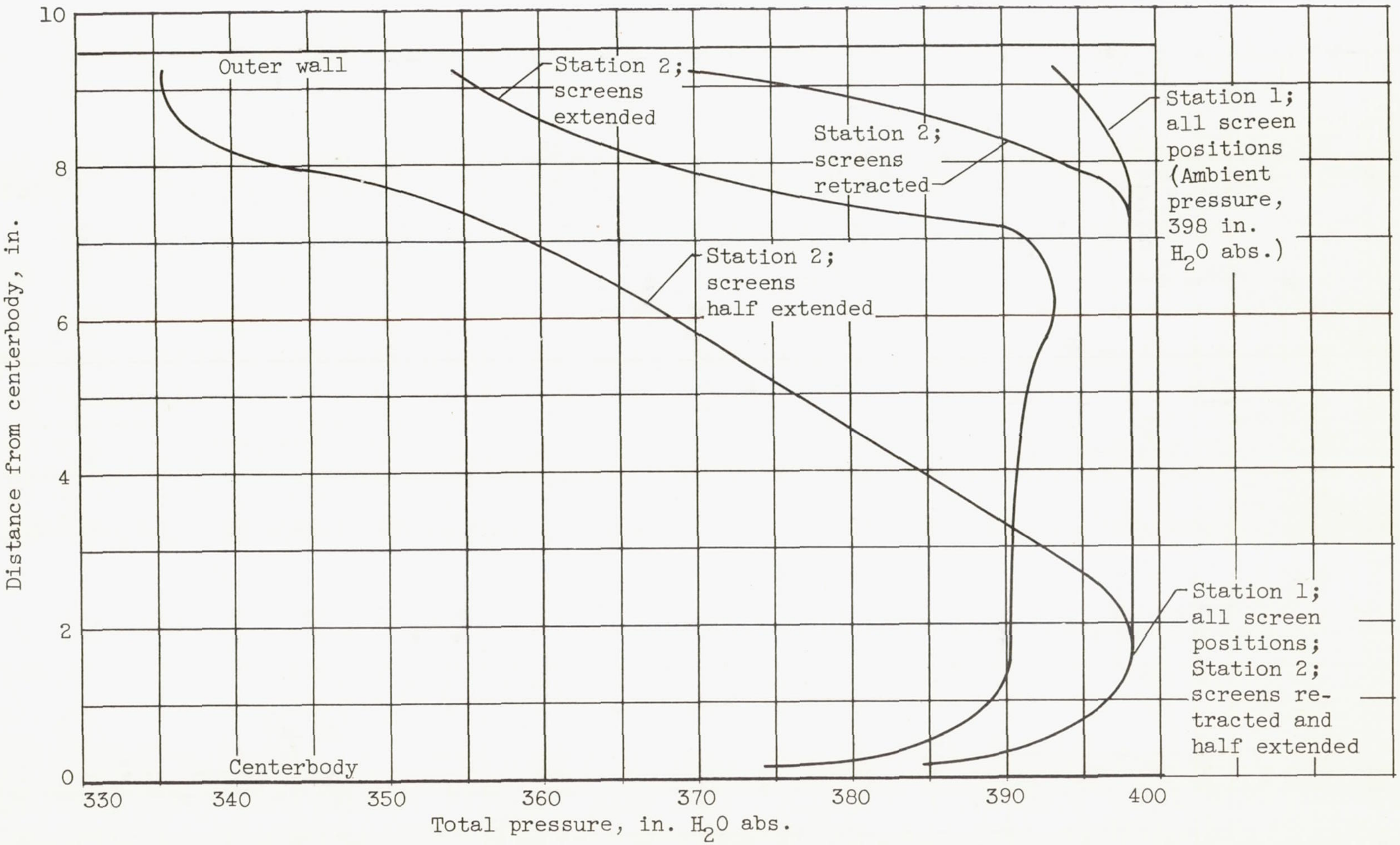
(a) Retraction wells uncovered

Figure 12. - Total-pressure profiles in inlet section using screen A. Mach number, 0.48; airflow about 100 percent of rated sea-level static flow.



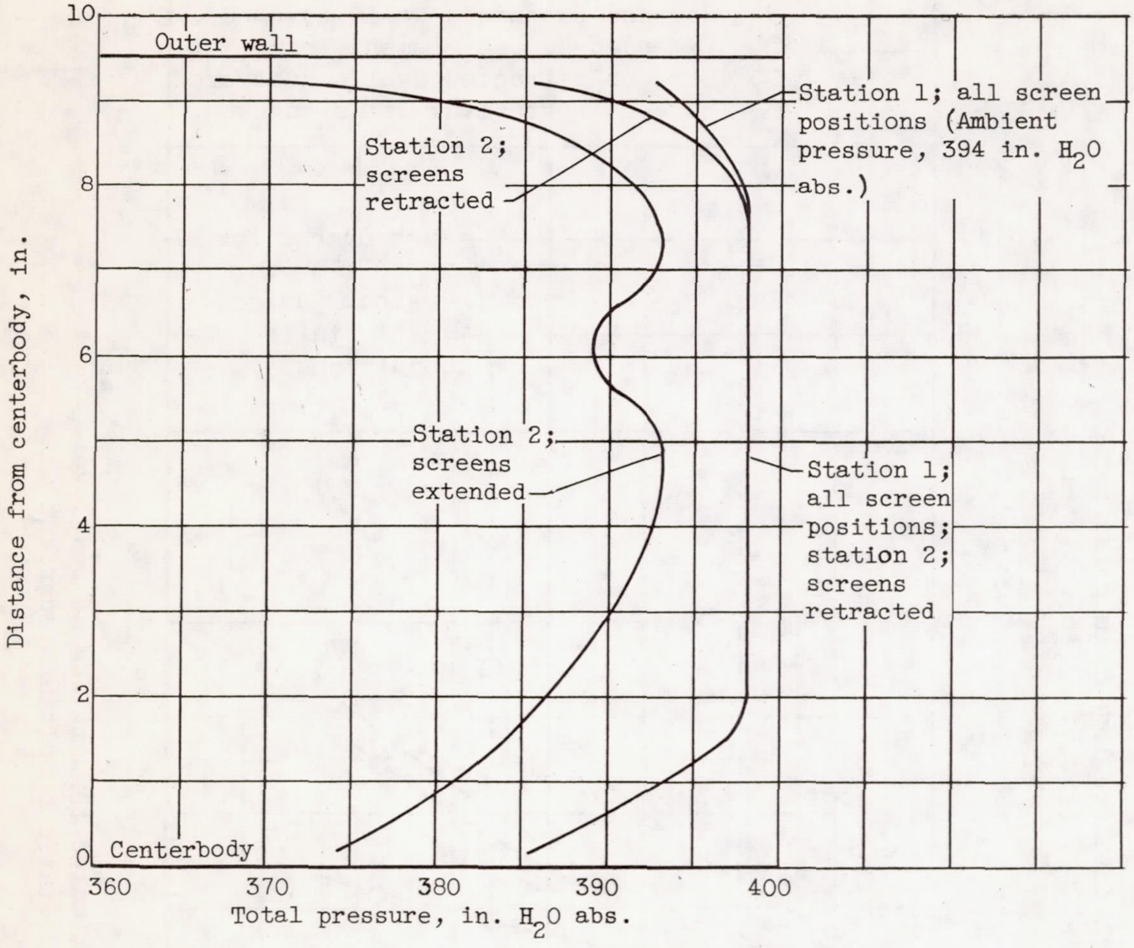
(b) Retraction wells covered

Figure 12. - Concluded. Total-pressure profiles in inlet section using screen A. Mach number, 0.48; airflow about 100 percent of rated sea-level static flow.



(a) Retraction wells uncovered

Figure 13. - Total-pressure profiles in inlet section using screen B. Mach number, 0.43; airflow about 100 percent of rated sea-level static flow.



(b) Retraction wells covered

Figure 13. - Concluded. Total-pressure profiles in inlet section using screen B. Mach number, 0.43; airflow about 100 percent of rated sea-level static flow.

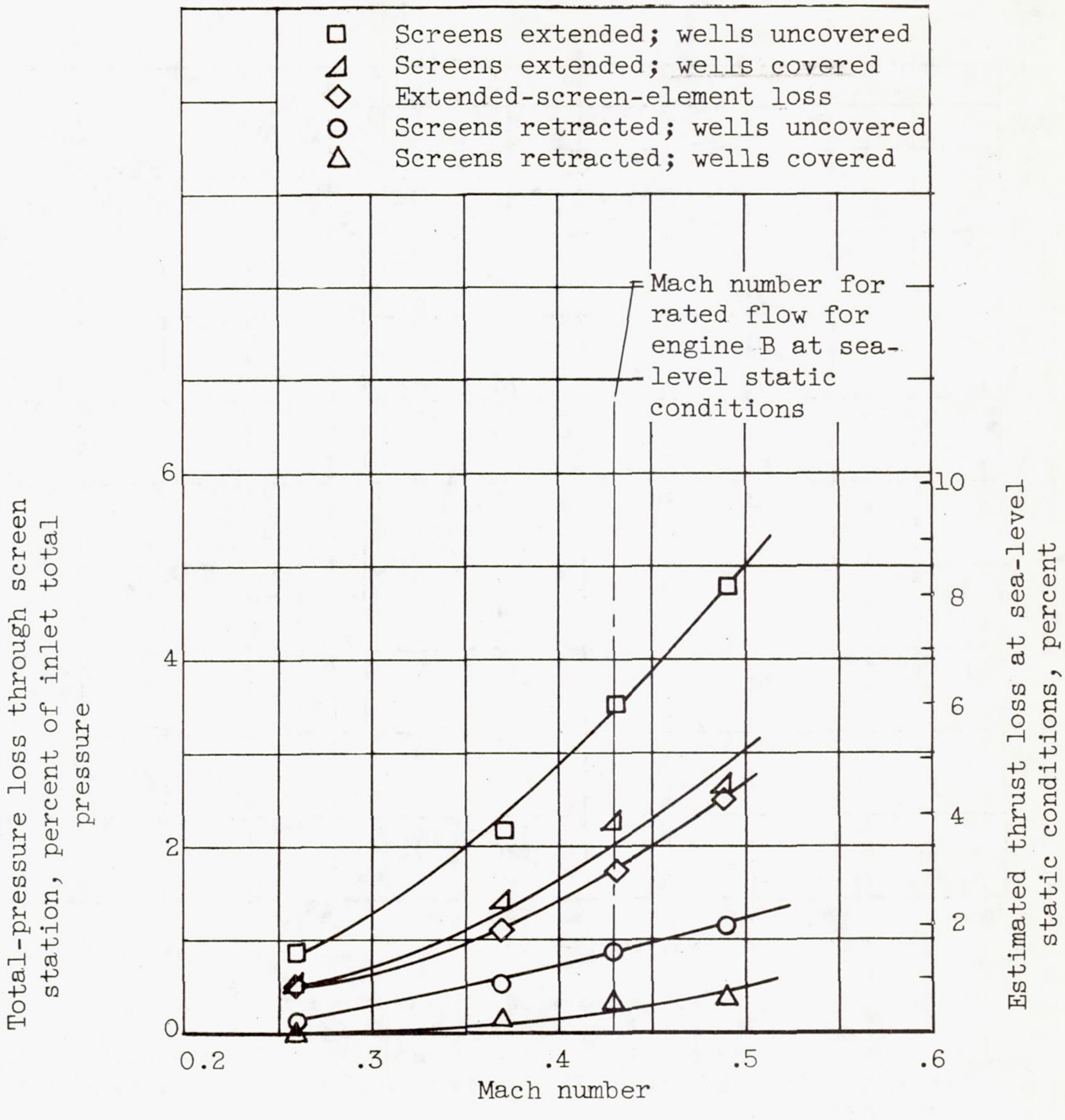


Figure 14. - Variation of total-pressure loss with Mach number in inlet of engine B.