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RESEARCH MEMORANDUM

PRELIMINARY INVESTIGATION OF EFFECT ON PERFORMANCE OF DIVIDING CONICAL-SPIKE NOSE INLETS INTO HALVES AT MACH NUMBERS 1.5 TO 2.0

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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PRELIMINARY INVESTIGATION OF EFFECT ON PERFORMANCE OF DIVIDING CONICAL-SPIKE NOSE INLETS INTO HALVES AT MACH NUMBERS 1.5 TO 2.0

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SUMMARY

Two different axisymmetric spike-type inlets were investigated with and without a thin splitter plate inserted the length of the subsonic diffuser. Pressure-recovery and mass-flow data were obtained at Mach numbers from 1.5 to 2.0 at zero angle of attack.

One inlet, which had a nearly constant-area throat section 4.28 hydraulic diameters long, experienced a pressure-recovery loss of about 1 percent because of the addition of the splitter plate. This loss was attributed to friction on the increased surface area. The other inlet had a diffuser flow-area increase of 30 percent in the first 2.3 hydraulic diameters of length. The pressure-recovery losses incurred by the splitter plate for this second inlet were 5 and 6 percent, respectively, at Mach numbers of 1.8 and 2.0, and less than 1 percent at Mach number 1.5.

INTRODUCTION

Pressure recoveries obtained with side inlets where fuselage boundary layer was removed have been as much as 5 percent lower than comparable symmetric nose inlets. Generally, a side-type inlet is different from its nose-inlet counterpart in several respects. These differences include subsonic diffuser duct bends and offsets and, sometimes, a diffuser-shape transition from that at the throat. In addition, the inlet is located in a flow field usually different from that of the undisturbed free stream with respect to local Mach number, total pressure, and flow angularity. Each of these factors can contribute to lowered performance.

A preliminary investigation was conducted in the NACA Lewis 8- by 6-foot supersonic tunnel to determine the origin of the seemingly inherent pressure-recovery loss in side inlets. A symmetrical conical-spike inlet was tested with and without a thin splitter plate inserted the length of the subsonic diffuser. Thus, back-to-back side-type inlets without duct turning or duct-shape transition were simulated. The flow field of the inlets was the same as that of the nose-type inlet obtained when the splitter plate was removed. Presence of the splitter plate can introduce flow disturbances not occurring in nose inlets such as corner effects, which were found to be detrimental in reference 1; the possible generation of secondary flows; and differences in boundary-layer growth and shock - boundary-layer interaction on the compression surface and splitter plate; and so forth.

Two inlet-diffuser combinations were tested. One inlet was designed for a mass-flow ratio of 1 at Mach number 2.0 and had a long constant-area throat section. The other inlet was designed for about 10-percent conical-shock spillage at Mach number 2.0. The subsonic diffuser for this second inlet had a rapid increase in flow area downstream of the throat. Data were obtained over a range of mass-flow ratios at Mach numbers of 1.5, 1.6, 1.8, and 2.0 at zero angle of attack. Splitter plates having sweptback and straight leading edges were investigated. Various attempts were made to visualize the internal flow.

SYMBOLS

The following symbols are used in this report:

A flow area, sq ft

D_h hydraulic diameter, $\frac{4A}{\text{wetted perimeter}}$ (computed at cowl leading edge)

H total pressure

L length of subsonic diffuser, in.

M Mach number

m mass flow

$\frac{m_3}{m_0}$ mass-flow ratio, $\frac{\text{mass flow through inlet}}{\rho_0 V_0 A_1}$

V velocity

x longitudinal station

θ_l cowl-position parameter, angle formed between model centerline and line from cone tip tangent to cowl lip

ρ mass density of air

φ mean turning angle

Subscripts:

l cowl lip

x longitudinal station

0 free stream

1 leading edge of cowl lip

3 diffuser exit, 36.67 in. from cowl lip for inlet A

4 static-pressure measurement for mass-flow calculation

5 maximum diffuser area, 46.9 in. from cowl lip for inlet A

Pertinent areas:

A_1 inlet capture area defined by cowl lip (measured), 0.155 sq ft

A_5 maximum diffuser area, 0.289 sq ft

APPARATUS AND PROCEDURE

A schematic drawing of the model is shown in figure 1. The configuration consisted of an external-compression single conical-shock inlet and an annular subsonic diffuser. A 1/32-inch-thick splitter plate extended from the cone tip (sweptback plate) or the cowl lip (straight splitter plate) to slightly downstream of the diffuser exit. The splitter plate was alined with one pair of the centerbody support struts and added about 10 percent to the wetted surface area of the diffuser.

A geometric comparison of the two inlet diffusers (designated as inlets A or B hereinafter) is shown in figure 1(c), and the diffuser-area variations are compared in figure 2. Addition of the splitter plate had a negligible effect on flow area. Inlet A was designed for a mass-flow ratio of 1 at Mach number 2.0. Internal and external cowl-lip angles were 8° and 12°, respectively (fig. 1(b)). The subsonic diffuser had about a 4-percent increase in geometric flow area in the first 3.5 hydraulic diameters of length without the splitter plate, and in 4.28 hydraulic diameters with the splitter plate installed (fig. 2). Inlet A was basically the same as inlet B of reference 2 with the exception of the splitter plate. Inlet B had a cone tip projection for about 10-percent conical-shock spillage at Mach number 2.0. Internal and external cowl-lip angles were 17.5° and 22°, respectively (fig. 1(b)). The subsonic diffuser for inlet B had a flow-area increase of about 30 percent in the first 2 hydraulic diameters of length without the splitter plate and in 2.3 hydraulic diameters with the splitter plate installed (fig. 2). The remainder of the area distribution is similar to but displaced relative to that for inlet A. The area distribution of inlet B was not intentional, but was a result of the series of cone positions simulated in reference 3. Addition of the splitter plate decreased the equivalent conical diffuser angle from 5.5° to 4.7°, 1 hydraulic diameter downstream of the cowl lip for inlet B; for inlet A this change was insignificant. Inlet B was 1.34 inches longer than inlet A (fig. 1(c)) and was the same as the 39.1° cowl-position parameter inlet of reference 3, except for the splitter plate. Both inlets had 25° half-angle cones and equal cowl-lip and diffuser-exit diameters. The external and internal contours of the outer shell are identical for the two inlets downstream of the cowl-junction station (station 8.67 for inlet A). (Station numbers refer to number of inches from cowl lip.) The mean turning angle experienced by the flow at each station varies with the axial-distance ratio as is shown in figure 2. Inlet B has a more rapid rate of turning as a result of the steeper initial cowl-lip angle.

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Mass-flow ratio is the mass flow passing through the model divided by that of a free-stream tube based on cowl capture area. Mass flow through the model was computed using the measured static pressure at station 41, a mass-flow control plug flow coefficient of 0.99, and a Mach number determined from a one-dimensional isentropic area ratio between station 41 and the minimum-flow area at the mass-flow control plug. Total-pressure recovery and average flow Mach number at station 36.7 were computed by means of the flow area, measured static pressure, and mass-flow ratio. This procedure accounted for losses due to the rake bodies that supported the static-pressure instrumentation. Since the static pressures from each side of the inlet can interact between the end of the splitter plate and the control-plug sonic point, the possibility for unequal duct flow exists. Regions of unequal duct flow or pulsing (only in-phase pulsing of both sides of the inlet was encountered) are indicated. However, mass-flow ratio and pressure-recovery values are not precisely correct, since the method of calculation does not permit large amounts of asymmetric or unsteady flow.

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Various flow-visualization techniques were used on inlet A. These methods consisted of injecting quick-drying dye near the centerbody splitter-plate junction at station 1.0, a comparative total-pressure survey at station 2.0 near the splitter plate and 90° away from the plate (fig. 6), and the installation of a Pyrex cowl between stations 5.0 and 14.0 in order to observe a pattern of thread tufts on the centerbody and splitter plate. For data obtained with the Pyrex cowl and the inlet total-pressure survey rake installed, the cowl-lip-position parameter θ_l was 42.3° compared with 43.4° for the pressure-recovery and mass-flow data presented for the remainder of the inlet A tests.

Patternmaker's leather fillets having a radius of 1/4 inch were installed in all the splitter-plate inner- and outerbody corner junctions for part of the inlet A tests. These fillets, which extended the length of the diffuser, had a short tapered metallic lead from the splitter-plate leading edge to the beginning of the fillets. Inlet A was tested as a nose inlet without the splitter plate, whereas data from reference 3 were used for the performance of inlet B without the splitter plate.

RESULTS AND DISCUSSION

The variation of total-pressure recovery and diffuser-exit Mach number with mass-flow ratio is shown in figure 3 for inlet A with various splitter-plate combinations for Mach numbers of 1.5, 1.6, 1.8, and 2.0 and zero angle of attack. Similar data for inlet B with a sweptback splitter plate are shown in figure 4 for Mach numbers of 1.5, 1.8, and 2.0. In each case, the performance of the inlet without the splitter plate is included.

The pressure recoveries obtained with inlet A, which were not particularly high, were reduced about 1 percent by addition of the splitter plate. This loss is largely attributed to increased friction because of the 10-percent increase in wetted surface area. Neither changing the splitter-plate plan form from sweptback to straight (flush with cowl leading edge), nor the addition of corner fillets had any significant effect on performance. The stable subcritical mass-flow range was not appreciably changed by addition of the splitter plate.

For inlet B the pressure-recovery loss was about 6 percent at Mach number 2.0, 5 percent at Mach number 1.8, and less than 1 percent at Mach number 1.5. For this inlet at Mach number 2.0, the splitter plate did not effect any increase in stable subcritical range and, in fact, resulted in reduced stability at a Mach number of 1.8.

The reason for the splitter plate causing a significant total-pressure loss for inlet B but not for inlet A can be explained, in part, by examining the flow visualization and internal total-pressure survey results obtained on inlet A. Photographs of flow patterns resulting from dye injection are shown in figure 5 for inlet A. The type of dye pattern obtained depended to some extent on both the amount of dye and the particular splitter-plate configuration used. Since the dye was injected on the port side of the model, the dye pattern on the starboard side is a result of leakage between the splitter plate and conical surface. The similarity of the two patterns demonstrated that the injection spray had little, if any, disturbing effect on the flow. The data are of a qualitative nature and simply demonstrate flow disturbances in the form of secondary flows not ordinarily present in annular symmetric inlets. Secondary flows of low-energy boundary-layer air are a result of radial-pressure gradients due to turning or shock - boundary-layer interaction, or both. Flow patterns similar to the dye patterns presented here have also been observed in two-dimensional cascades (ref. 4). 3825

The total-pressure survey taken at station 2.0 (fig. 6) indicates no appreciable total-pressure defect in the stream or near the corners, in spite of the graphic demonstrations of secondary flow at the throat. At mass-flow ratios less than 0.86, low-energy air is found at the corners, particularly near the centerbody. These corner losses originate internally, since the data are for the straight splitter plate, which does not protrude externally. However, the effect on over-all pressure recovery with this inlet is very small as shown in figure 3. The region of pressure recoveries of about 0.95 on profiles (figs. 6(a) and (b)) is attributed to the higher pressure recovery of a lambda shock caused by a shock boundary-layer interaction.

A typical schlieren - tuft photograph of inlet A is shown in figure 7. Observation of these tufts did not reveal any pronounced flow disturbances, such as separation areas or secondary flow in the stable subcritical mass-flow range.

Thus, for inlet A, flow disturbances due to the splitter plate were indicated by means of dye patterns at the inlet throat and were not detrimental to over-all pressure recovery. These disturbances seemed to dissipate downstream of the throat, as evaluated by a total-pressure survey and observation of tufts.

Comparison of the subsonic diffusers for inlets A and B suggests an explanation for the difference in losses caused by addition of the splitter plate. For inlet A, entrance-flow disturbances associated with the splitter plate may have been effectively mixed by the 4.28-hydraulic-diameter nearly constant-area section before the flow was diffused. Thus, only the expected friction losses occurred. The subsonic diffuser for inlet B, however, had a 30-percent increase in flow area in the first 2.3 hydraulic diameters of length. This diffuser was more efficient than that of inlet A, as indicated by the relatively higher performance obtained without the splitter plate. However, with splitter-plate flow disturbances present at the inlet throat, the subsonic diffusion process was not as efficient as that obtained without the plate. This effect is largely attributed to the inability of this diffuser to remove or reduce such disturbances prior to diffusion. An allied effect was demonstrated in reference 5, where flush slots, ram scoops, or area suction were used to remove about half of the compression ramp boundary layer near the diffuser throat. This resulted in substantial pressure-recovery increases. Removal of such low-energy air would, in part, improve the entrance-flow profile and permit more efficient subsonic diffusion.

The results of this investigation suggest that side inlets without additional flow-control methods may inherently have lower performance than comparable nose inlets. At least two positive methods of flow control for higher performance are available. One method, which has been demonstrated elsewhere, is the removal of portions of the boundary layer in the throat region where shock - boundary-layer interactions and secondary flows originate.

The other method is using a long constant-area throat section to promote mixing of flow disturbances. In either case, improvement of the flow profiles in the throat region prior to diffusion permits the subsonic diffuser to maintain high efficiency. However, the removal of low-energy flow usually increases pressure recovery in addition to maintaining diffuser efficiency, whereas a constant-area section decreases pressure recovery slightly because of increased friction.

SUMMARY OF RESULTS

A thin splitter plate was used to divide an axisymmetric spike-type inlet into halves. The resulting inlets are considered as simulated ideal side inlet-diffusers without duct bends or shape transition. Two different diffuser geometries were investigated at Mach numbers from 1.5 to 2.0. The following results were obtained:

1. No significant decrease in pressure recovery was obtained other than a friction loss of about 1 percent attributed to increased surface area for inlet A, which had about a 4-percent increase in flow area in the first 4.28 hydraulic diameters of length. This inlet did not have high critical pressure recoveries even without the splitter plate but did have substantial subcritical stability in either case.

2. Total-pressure losses of 5 and 6 percent were obtained at Mach numbers 1.8 and 2.0, respectively, with the splitter plate installed in inlet B, which had about a 30-percent increase in flow area in the first 2.3 hydraulic diameters of length. At Mach number 1.5, a friction pressure loss of less than 1 percent was obtained. This inlet had comparatively high critical pressure recoveries without the splitter plate.

The subcritical stability range for this inlet, which was appreciably smaller than that of the other inlet, was reduced at Mach number 1.8 when the splitter plate was installed.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
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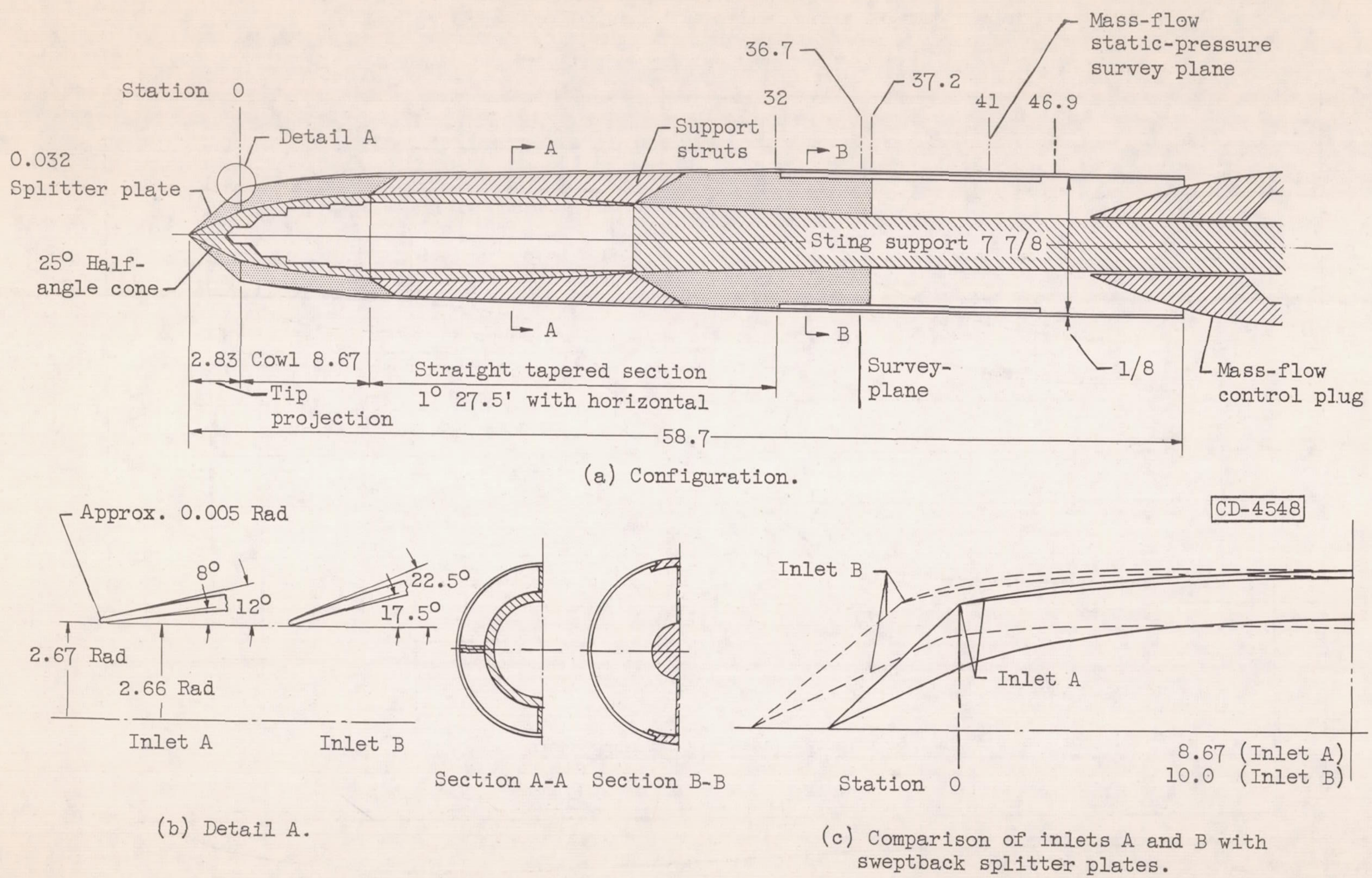

Figure 1. - Schematic diagram of model. (All dimensions in inches; stations measured from cowl lip.)

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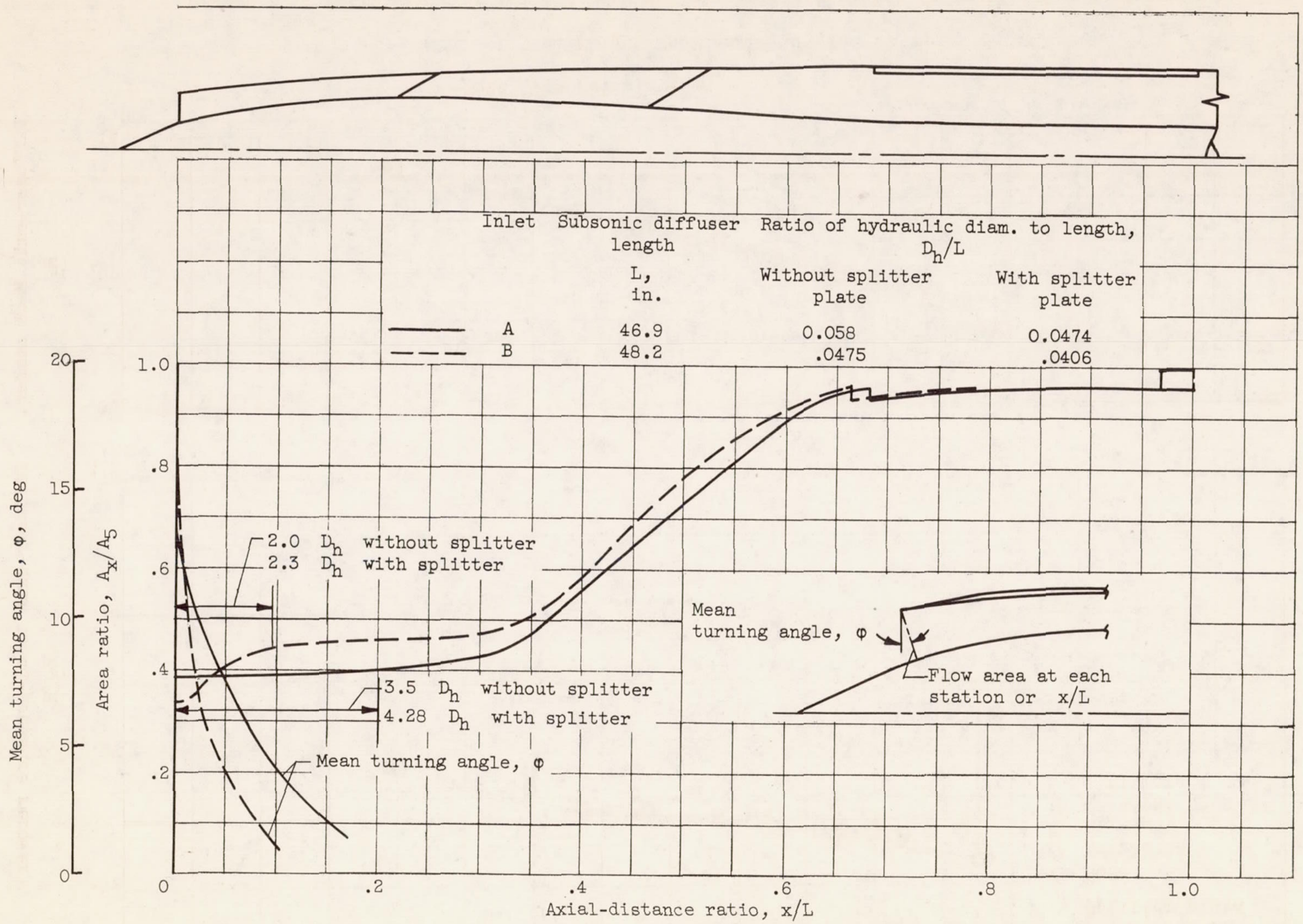

Figure 2. - Subsonic diffuser-area and mean turning angle variation.

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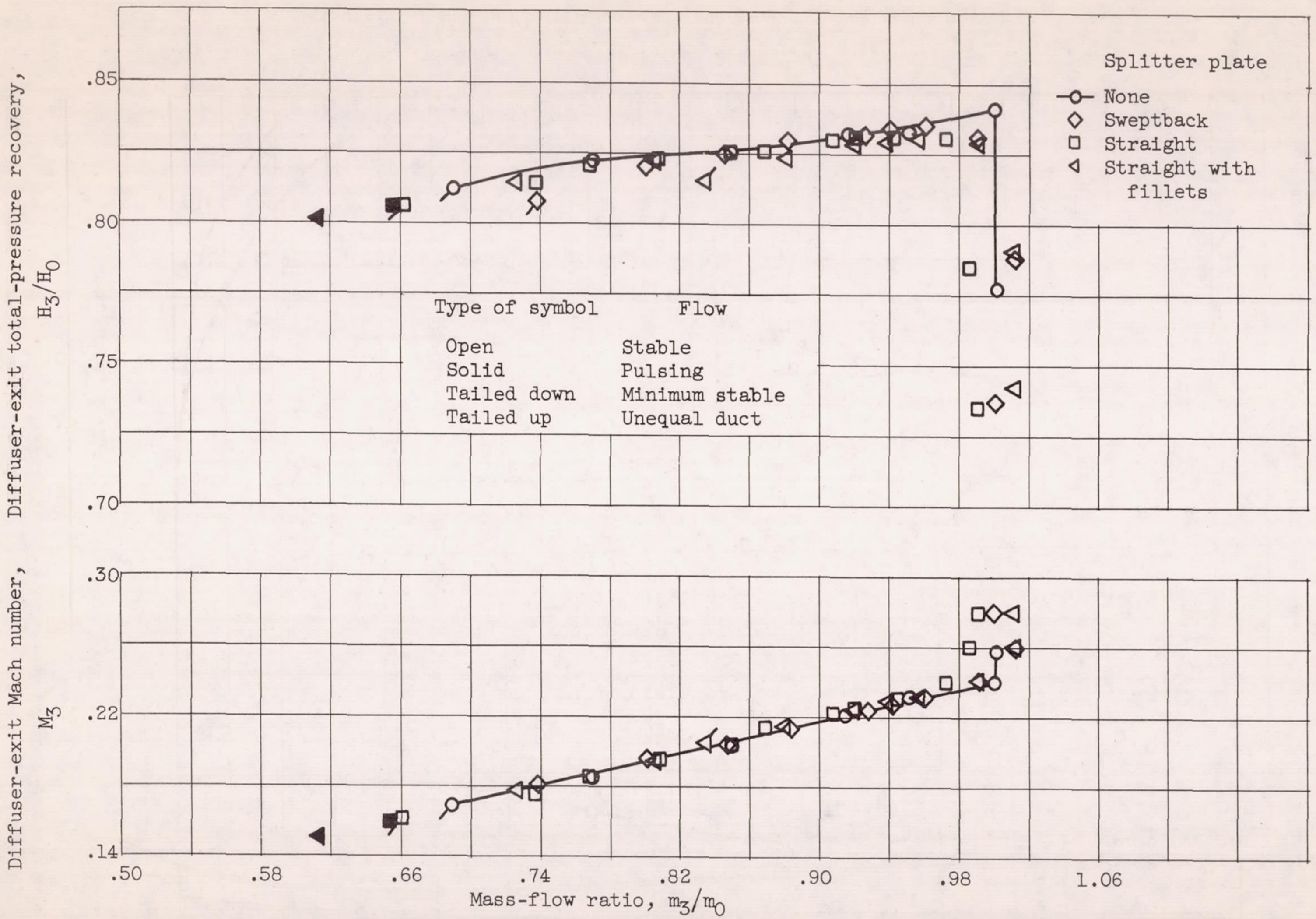

(a) Flight Mach number, 2.0.

Figure 3. - Performance of inlet A with various splitter plates at zero angle of attack.

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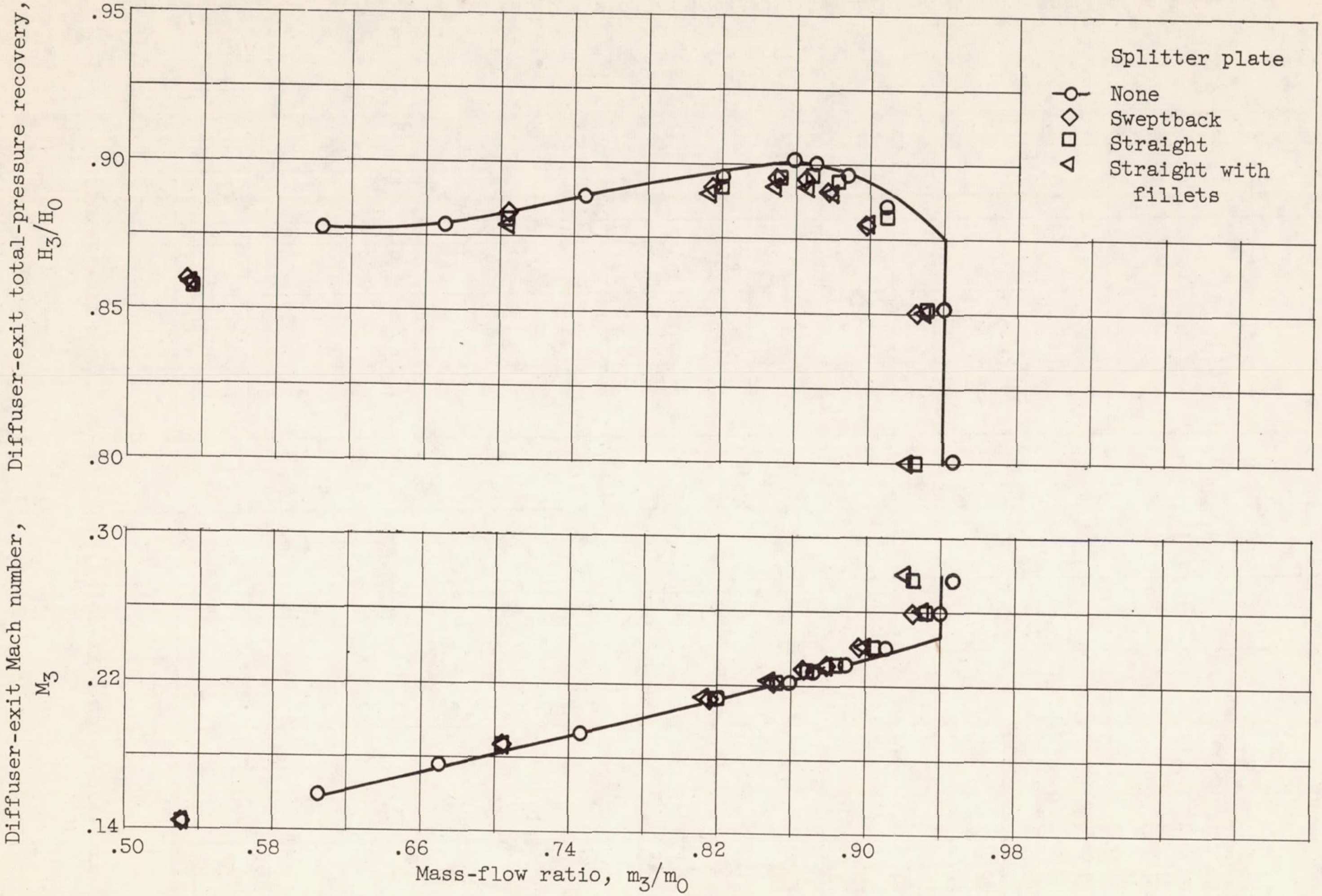

(b) Flight Mach number, 1.8.

Figure 3. - Continued. Performance of inlet A with various splitter plates at zero angle of attack.

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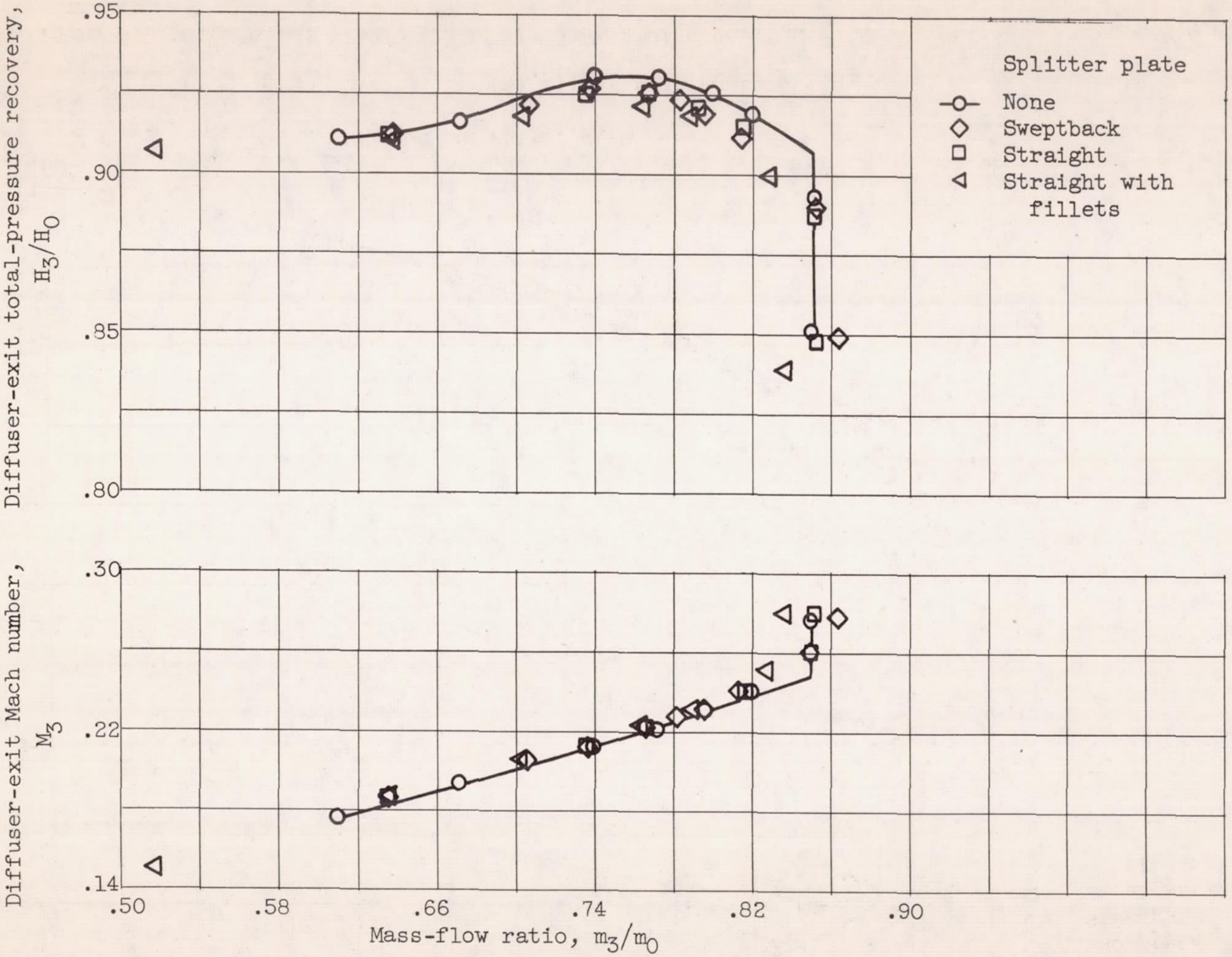

(c) Flight Mach number, 1.6.

Figure 3. - Continued. Performance of inlet A with various splitter plates at zero angle of attack.

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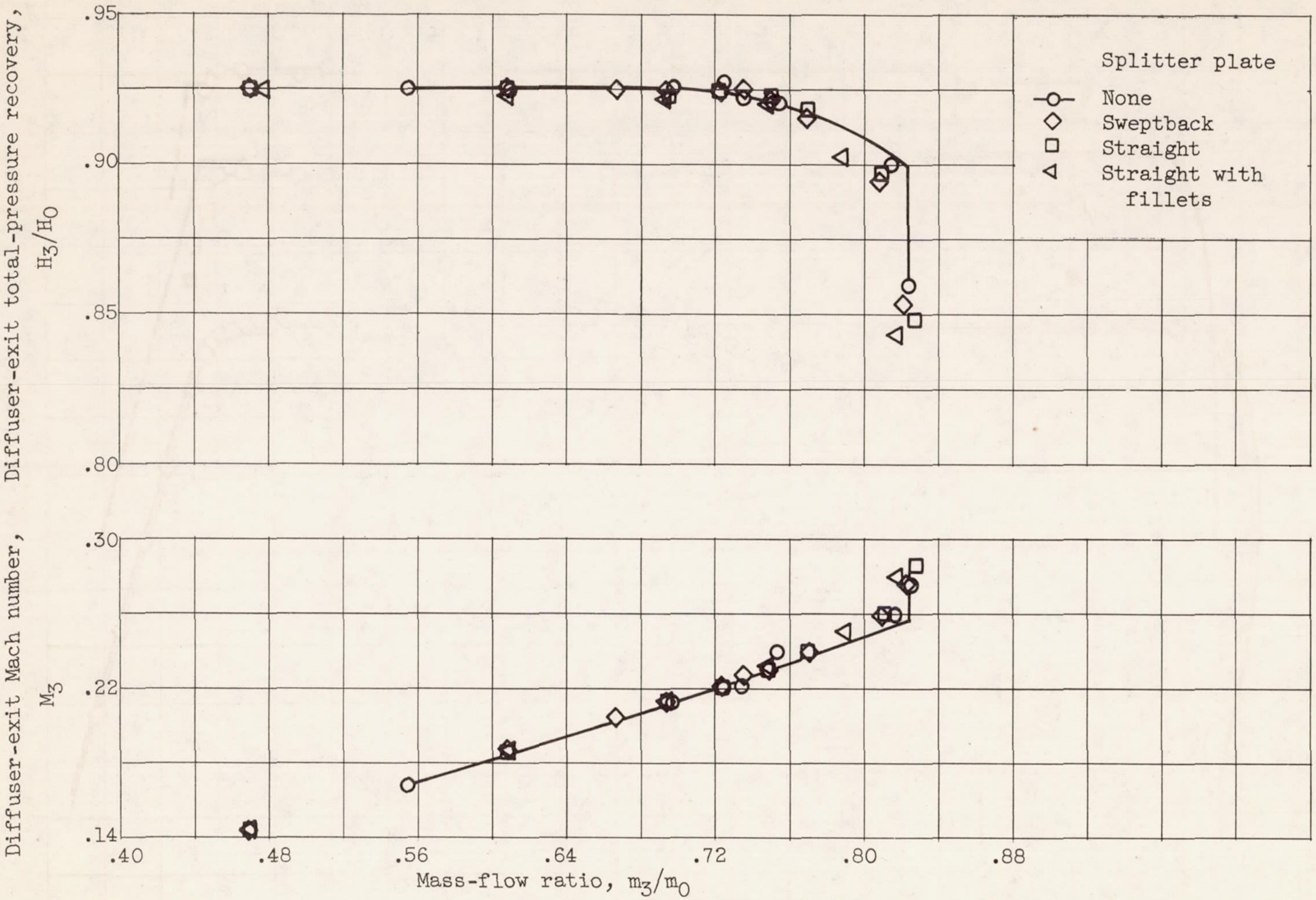

(d) Flight Mach number, 1.5.

Figure 3. - Concluded. Performance of inlet A with various splitter plates at zero angle of attack.

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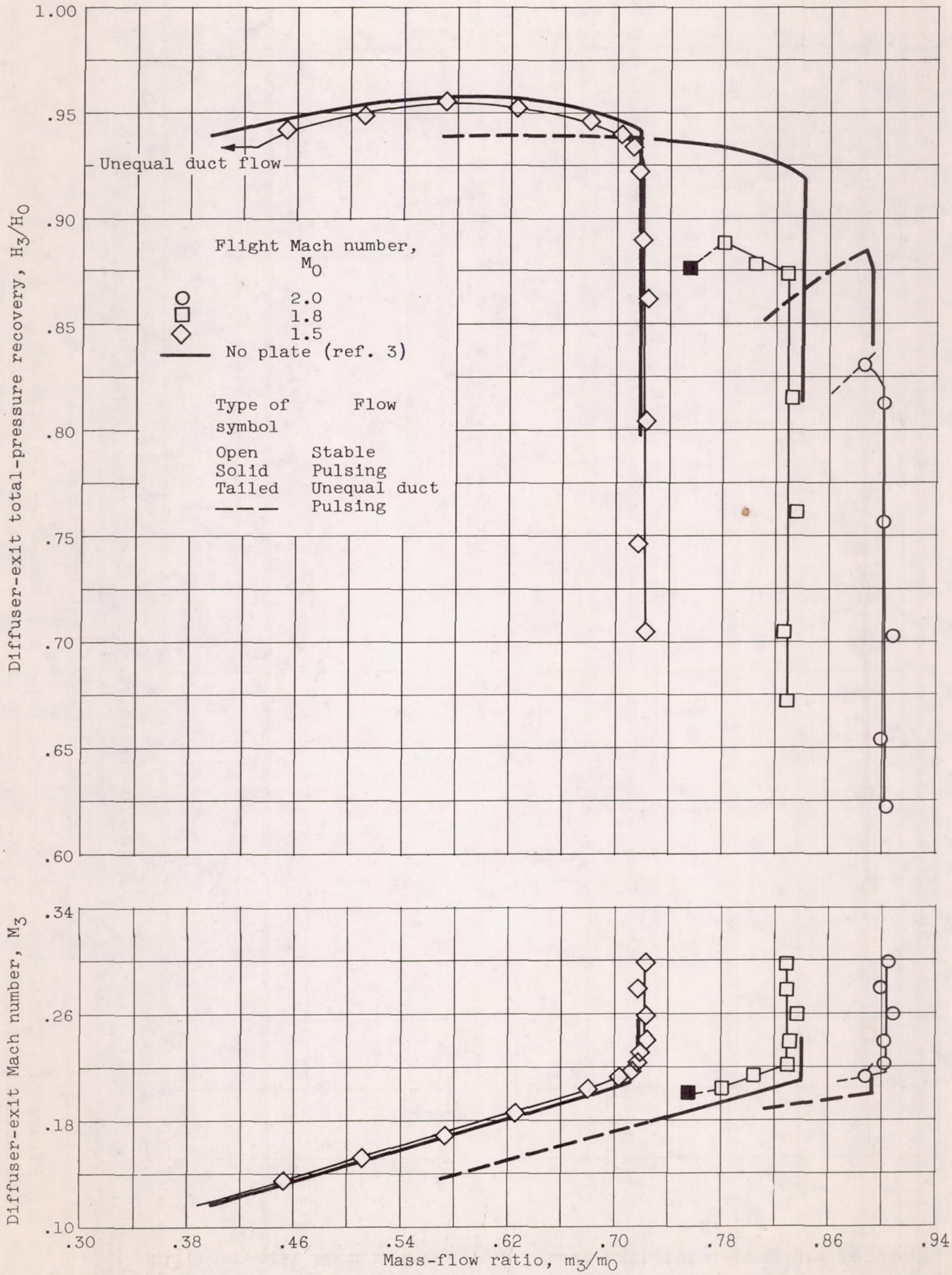
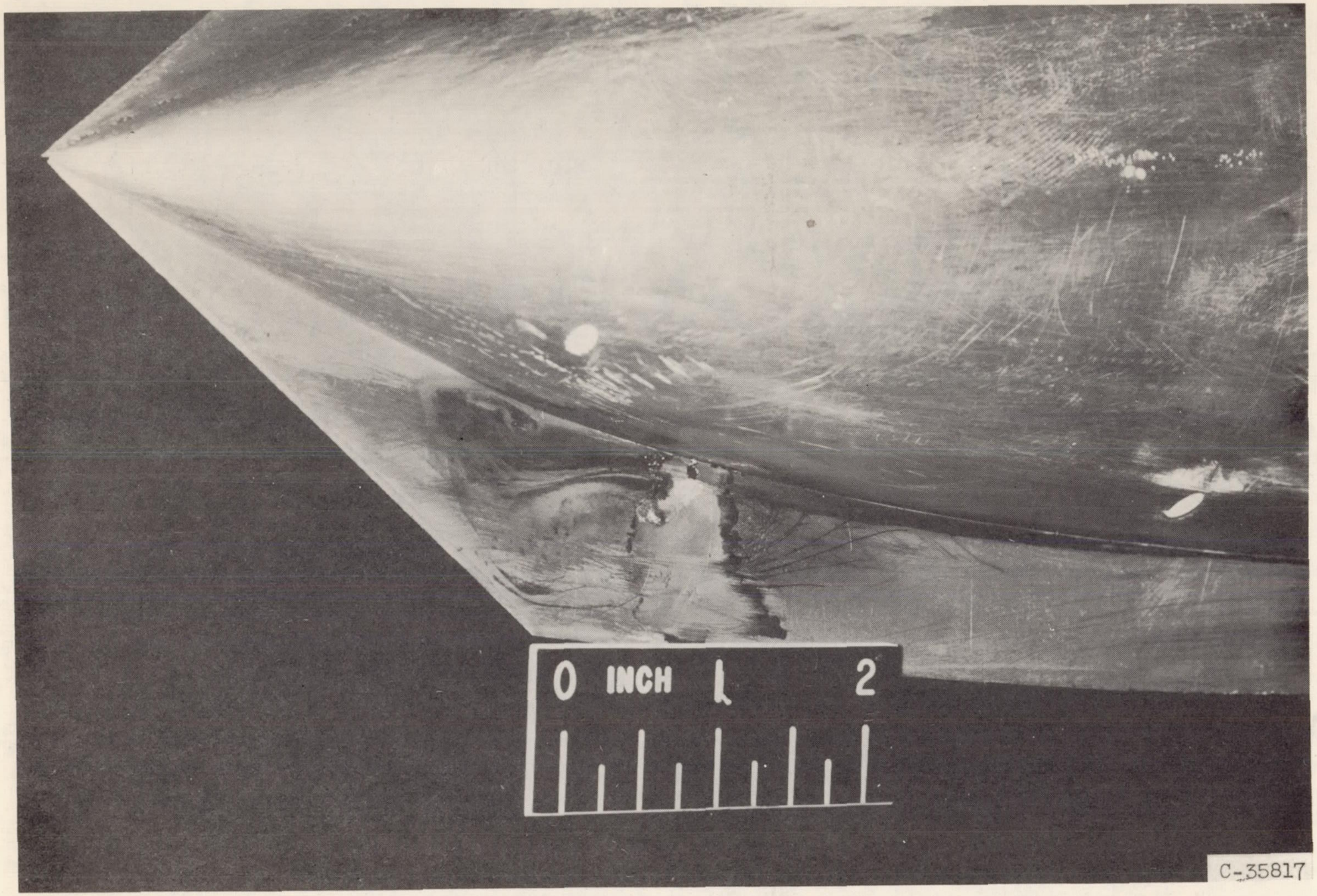
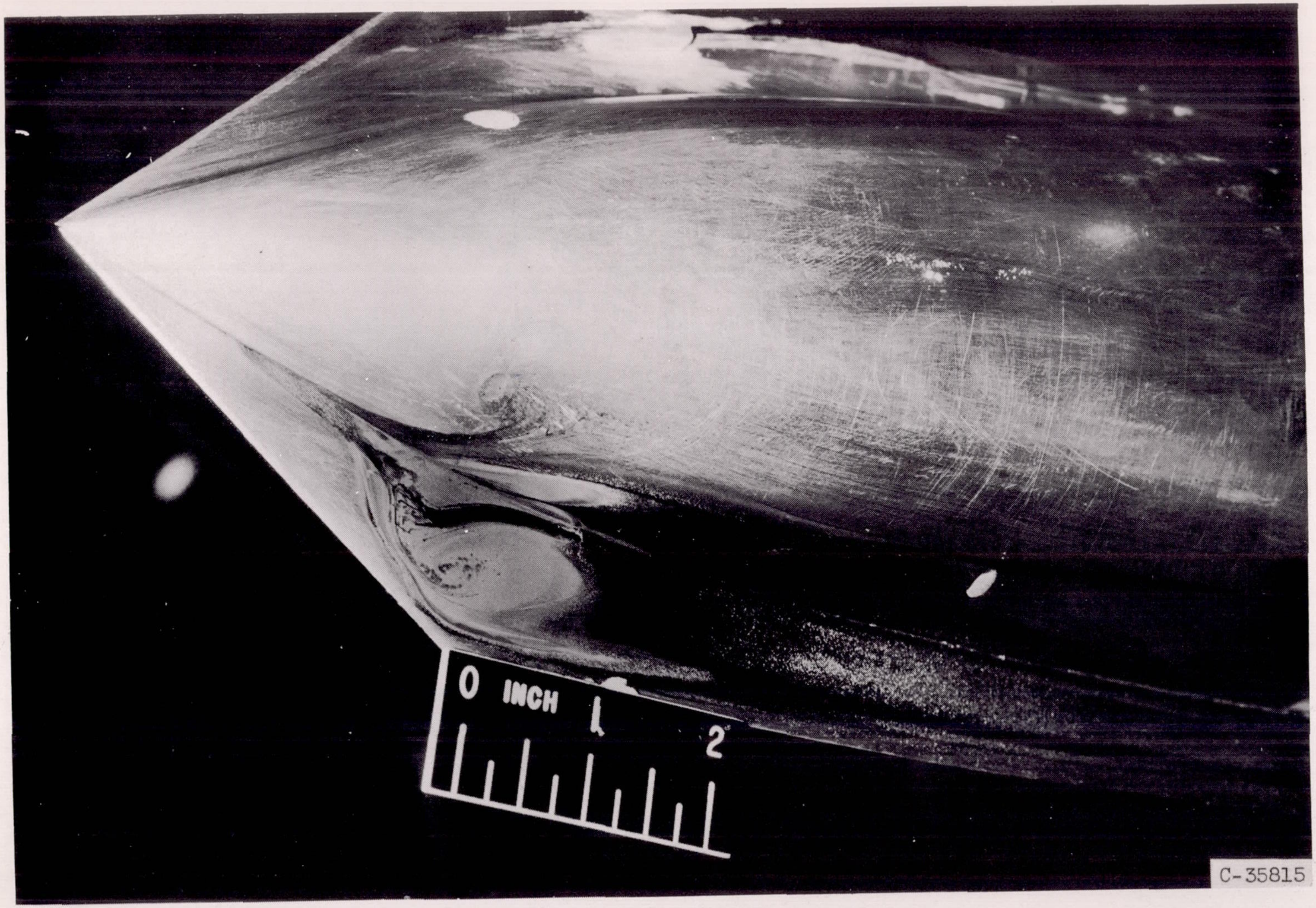


Figure 4. - Effect of sweptback splitter plate on performance of inlet B at zero angle of attack. Cowl position parameter, 39.1°.



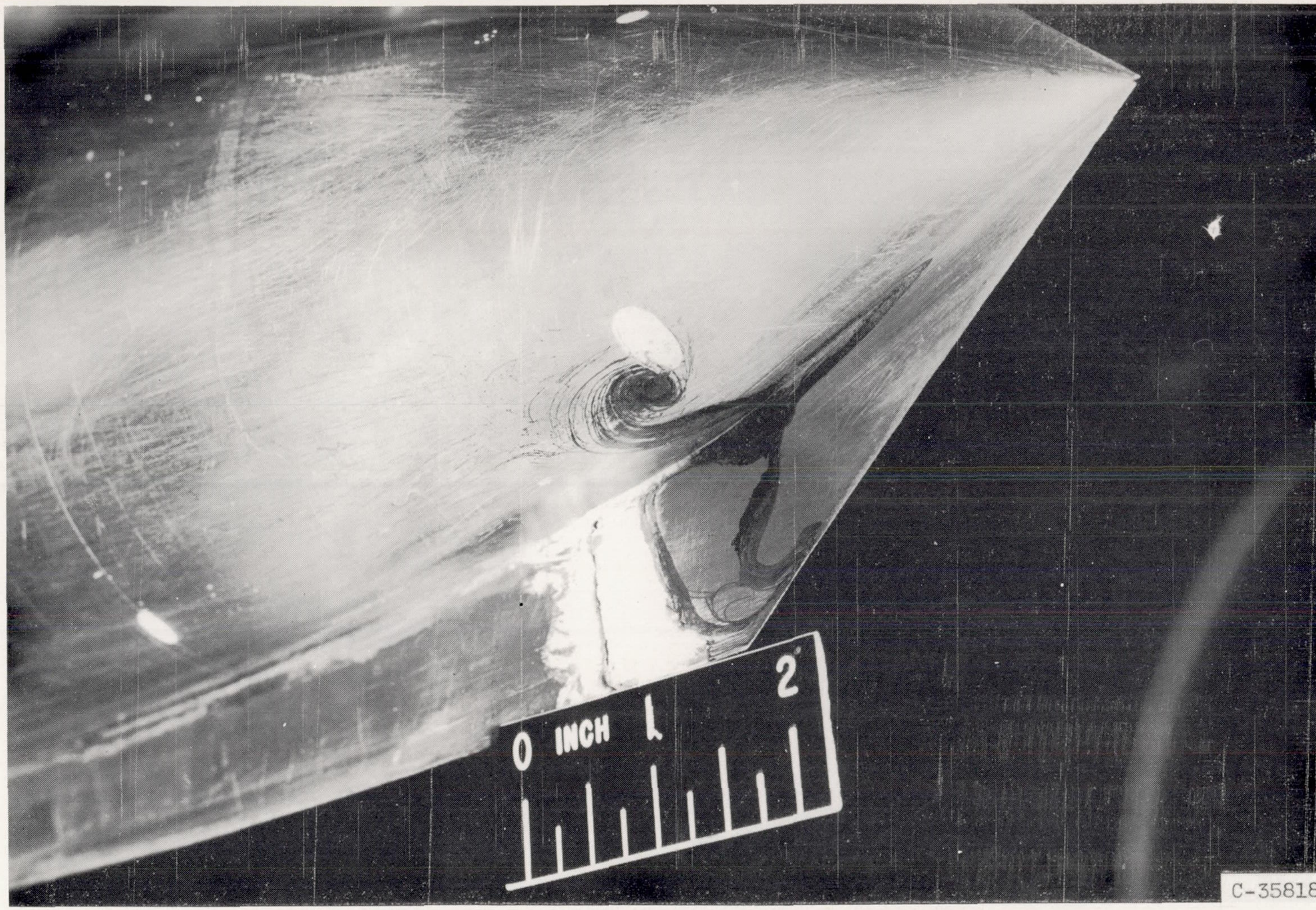
(a) Port side; 10-second injection.

Figure 5. - Dye traces for inlet A, sweptback splitter plate without fillets. Flight Mach number, 2.0; mass-flow ratio, 0.92; zero angle of attack.



(b) Port side; 20-second injection.

Figure 5. - Continued. Dye traces for inlet A, sweptback splitter plate without fillets. Flight Mach number, 2.0; mass-flow ratio, 0.92; zero angle of attack.



(c) Starboard side; 20-seconds injection.

Figure 5. - Concluded. Dye traces for inlet A, sweptback splitter plate without fillets. Flight Mach number, 2.0; mass-flow ratio, 0.92; zero angle of attack.

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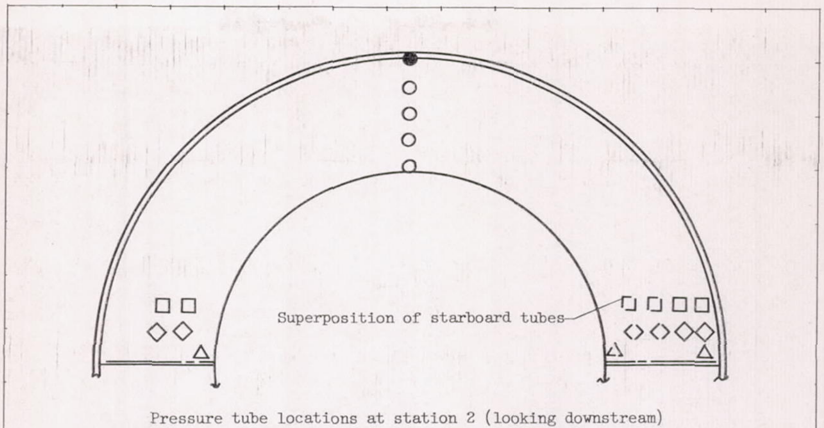
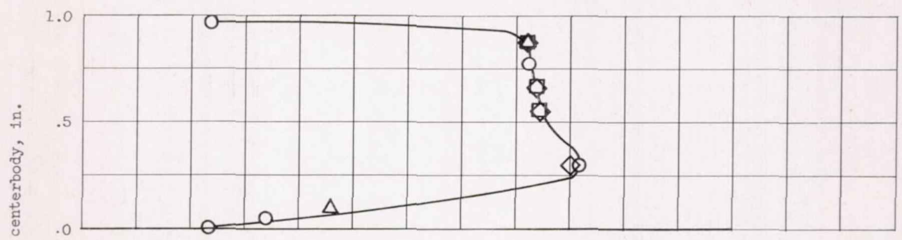
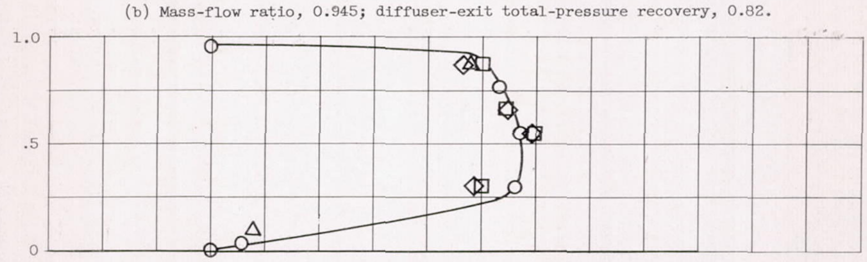


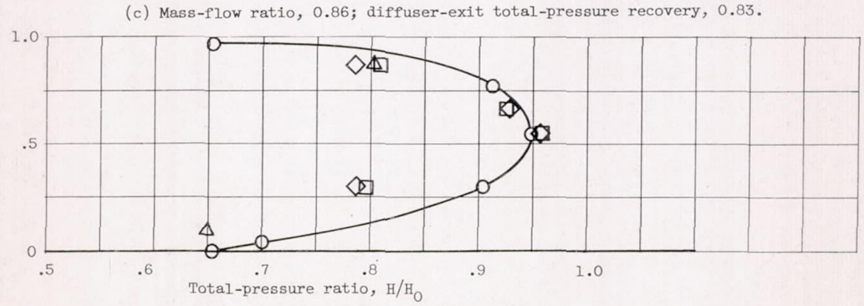
(a) Mass-flow ratio, 0.975; diffuser-exit total-pressure recovery, 0.80.



(b) Mass-flow ratio, 0.945; diffuser-exit total-pressure recovery, 0.82.



(c) Mass-flow ratio, 0.86; diffuser-exit total-pressure recovery, 0.83.



(d) Mass-flow ratio, 0.80; diffuser-exit total-pressure recovery, 0.82

Figure 6. - Total-pressure profiles of inlet A with straight splitter plate taken at station 2.0. Flight Mach number, 2.0; zero angle of attack; cowl-position parameter, 42.3.

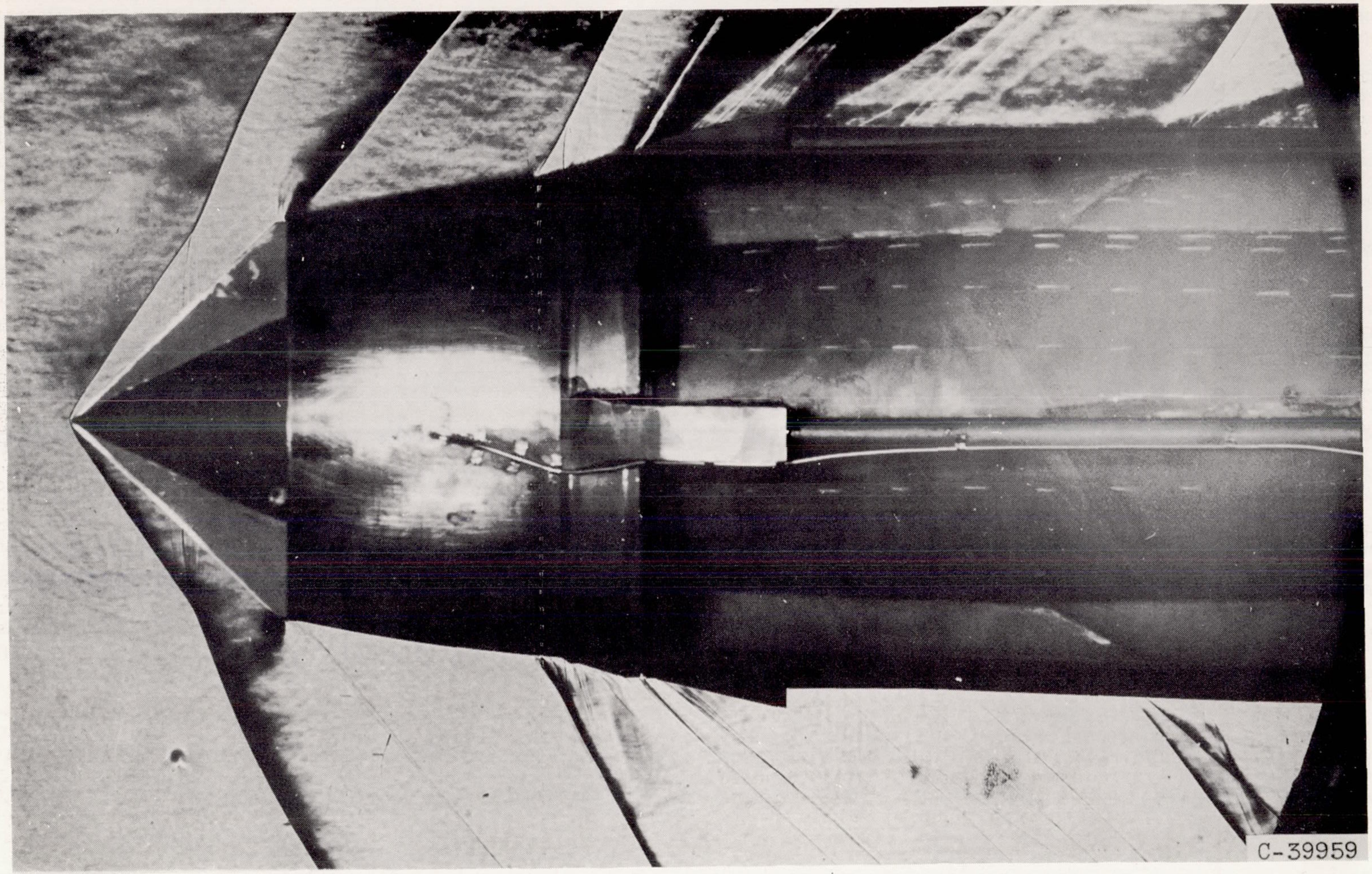


Figure 7. - Schlieren and tuft photograph of inlet A. Flight Mach number, 1.5; cowl-position parameter, 42.3; mass-flow ratio, 0.72.