RM No. A8E04

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EXPERIMENTAL INVESTIGATION AT SUPERSONIC SPEEDS OF TWIN-SCOOP DUCT INLETS OF EQUAL AREA. III - INLET ENCLOSING 37.2 PERCENT OF THE MAXIMUM CIRCUMFERENCE OF THE FOREBODY

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON
July 22, 1948

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EXPERIMENTAL INVESTIGATION AT SUPERSONIC SPEEDS OF TWIN-SCOOP DUCT INLETS OF EQUAL AREA. III - INLET ENCLOSING 37.2 PERCENT OF THE MAXIMUM CIRCUMFERENCE OF THE FOREBODY

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SUMMARY

A twin-scoop duct inlet that enclosed 37.2 percent of the forebody circumference was tested at Mach numbers between 1.36 and 2.01. The approach to each scoop consisted of a ramp that deflected the flow to create an oblique shock wave in front of the duct entrance. Tests were made with the duct walls having slots contiguous to the forebody and immediately behind the inlet to drain retarded air from the diffusor. The total-pressure recovery and mass flow through the diffusor were measured during tests in which the ramp angle, slot dimensions, and angle between the model axis and the stream direction were altered. Comparison of the results with those of previous tests of a model having scoops that enclosed 61.5 percent of the forebody circumference showed that a greater maximum total-pressure ratio could be attained with the narrow scoops because the effectiveness of ramps placed before the inlet continued to higher ramp angles. Slots in the walls of the ducts contiguous to the forebody and immediately behind the inlet caused a marked increase in both pressure recovery and flow stability. At an angle of incidence of 0°, the model having scoops with a 12° ramp and slots in the duct walls attained maximum total-pressure ratios nearly equal to those of a normal shock wave at Mach numbers less than 1.70; at a Mach number of 2.01, the pressure recovery was 4 percent less than that of a normal wave. At angles of attack or yaw of 6°, the decrease in pressure recovery after diffusion was 6 percent or less.

INTRODUCTION

Previous tests at supersonic speeds of an air-induction system that had the inlet situated in a region of appreciable boundary layer showed that the recovery of total pressure after diffusion and the stability of the flow in regard to separation were improved if the inlet consisted of twin scoops instead of an annular opening. (See reference 1.) The reason for the improvement was that less boundary-layer air could enter the ducts through the scoops because, although the entrance area was equal to that of the annular entrance, the scoops enclosed only a portion of the forebody circumference. Further tests of the twin-scoop inlet showed that slots in the walls of the ducts immediately behind the inlet and contiguous to the forebody produced an additional increase in the pressure recovery. (See reference 2.) The slots permitted the pressure difference between the inside and the outside of the diffusor to force some of the boundary layer that had entered the inlet to flow with a lateral component and out of the ducts. The maximum total-pressure recovery attained during tests of a slotted inlet that enclosed 61.5 percent of the forebody circumference was about 10 percent less than that through a normal shock wave occurring at the test Mach number.

Since an improvement in pressure recovery was attained by reducing the portion of the forebody circumference that the inlet enclosed from 100 to 61.5 percent while maintaining the same entrance area, it was reasoned that a further reduction might produce an additional improvement. It is the purpose of the present report to describe the results of tests of a model having a twin-scoop inlet that enclosed 37.2 percent of the forebody circumference.

SYMBOLS

H total pressure

M Mach number

A area

m rate of mass flow

α angle of attack

ψ angle of yaw

c forebody circumference

Subscripts (The subscripts indicate the station of the measured quantity.)

o free stream

1 duct entrance

3 settling chamber

4 exit throat

APPARATUS AND TESTS

The tests were performed in the Ames 8- by 8-inch supersonic wind tunnel through a Mach number range of 1.36 to 2.01 and at Reynolds numbers, based upon the length of body ahead of the inlet, between 2.21 and 3.10 million. The apparatus and test procedure are described in reference 3.

Photographs of two of the model configurations tested are shown in figure 1. The forebody of the model is the same as that of the models of references 1, 2, and 3; it consists of a 10-caliber ogival nose followed by a cylindrical section. The inlet is comprised of two diametrically opposed scoops located five forebody diameters behind the apex of the ogive. The entrance area is 34.8 percent of the frontal area at the inlet station. The inlet encloses 37.2 percent of the maximum circumference of the forebody, and the height-to-width ratio of each of the scoops is 0.75.

The dimensions of the model are shown in figure 2. Slots of 0.085-inch height, a dimension selected from the results of reference 2, and lengths of 0.10, 0.20, 0.30, and 0.40 inch in the stream direction were tested. To check the effect of slot height, measurements were also made with the model having slots 0.044-inch high and 0.30-inch long. Various ramps were formed by changing the length of the ramp while the height remained the same; the angles obtained in this manner were 2.5°, 5°, 9°, 12°, and 15°.

The effect of angle of incidence upon the pressure recovery through the diffusor was determined by mounting the model in the wind tunnel so that an angle of 6° existed in the vertical plane between the longitudinal axis of the model and the stream direction. The normal position of the inlets was assumed to be in the vertical plane, as illustrated in figure 1. For such a position, the angle of incidence between the model and the stream represents an angle of attack of 6°. With the model rotated 90° about the longitudinal axis, this angle represents an angle of yaw of 6°.

The total pressure in the settling chamber of the model was measured at three circumferential positions that were 120° apart.

At angles of incidence of either 0° or 6° and at pressure ratios near the maximum, the differences between the three measurements were less than 2 percent of the total pressure in the settling chamber. However, when the outlet-inlet area ratio A_4/A_1 of the model was large and the total-pressure recovery small, the differences were as large as 15 percent at an angle of 0° and 30 percent at an angle of 6°. The total-pressure and mass-flow ratios[1] presented in this report were computed using the average value of the three total-pressure measurements.

RESULTS AND DISCUSSION

Data discussed in this report are divided into four parts to show the effects of inlet proportions, ramp angle, slot dimensions, and angle of model incidence upon the pressure recovery after diffusion and the mass flow through twin-scoop duct inlets. The effects of these variables on the drag force contributed by the inlet have not been investigated as yet.

Inlet Proportions

Figure 3 compares the variations of maximum total-pressure ratio $(H_3/H_0)_{max}$ with free-stream Mach number for the twin-scoop inlets that enclose 61.5 and 37.2 percent of the forebody circumference. The scoop height-width ratios of these models are 0.3 and 0.75, respectively. Since the greatest recovery with the former model was attained with a 5° ramp (reference 1), the variations of maximum total-pressure ratio for the two inlet configurations having this ramp are compared. At Mach numbers greater than 1.70, the scoops that enclose the larger portion of the forebody produce the greater total-pressure ratio; the recovery at lower Mach numbers is nearly the same. A possible cause of this fact is that the inlet that encloses the smaller portion of the forebody extends a greater distance into the stream, since the entrance areas are equal. Although this narrow inlet receives a smaller portion of the retarded air from the flow over the forebody, the flow over the outside lip of the inlet is at a larger Mach number and experiences a greater loss in total pressure because of more intense flow disturbances than occur with the scoops of small height-width ratio.

[1]Mass-flow ratio is defined as the mass of fluid entering the ducts divided by that which would flow through a tube of the same area in the free stream.

Ramp Angle

Figure 4 shows the variation of maximum total-pressure ratio with the ramp angle of the scoops that enclose 37.2 percent of the forebody circumference. Whereas the total-pressure ratio increases appreciably to a ramp angle of only 5° with the scoops that enclose 61.5 percent of the forebody (reference 1), the recovery continues to increase to an angle of 12° with the narrow scoops, enabling this inlet to attain a larger pressure recovery. At a Mach number of 1.36, the maximum total-pressure ratio attainable by the scoops enclosing 37.2 percent of the forebody circumference is 4 percent greater than that of the wide scoops; at a Mach number of 2.01, this improvement is 1 percent.

A greater ramp angle can be used with the narrow scoops possibly because less of the boundary layer from the flow over the forebody enters the inlet and the pressure losses inside the diffusor resulting from this retarded air are a smaller portion of the total losses. Although the compression through a more intense oblique shock wave from the ramp leading edge causes an increase in the boundary-layer thickness, it also decreases the inlet Mach number and reduces the pressure losses in the main diffusor flow. In the case of the wide scoops, the boundary-layer losses may represent an appreciable part of the total losses; therefore, an increase in boundary-layer thickness may have a greater effect than a decrease in inlet Mach number. If the boundary-layer losses with narrow scoops are small, a relatively intense oblique wave can originate from the ramp and cause an appreciable increase in pressure recovery because the decrease in inlet Mach number has a greater effect than the increase in boundary-layer thickness.

At ramp angles greater than 12°, there is no further increase in the total-pressure ratio attainable with the model having narrow scoops. Since the boundary layer bridges the break in the surface with these steep ramps, the angle through which the flow is deflected on approaching the inlet and the resulting compression are less than would occur if the flow had followed the surface (reference 2). Measurement of the flow deflection with the steep ramps shows that the stream is turned nearly the same amount as when it followed the surface of a 12° ramp; therefore, the pressure recovery is nearly the same.

Slots

Figure 5 shows that the maximum total-pressure ratio throughout the range of test Mach numbers increases as the slot length is increased to 0.300 inch. With a 0.400-inch slot length, there is no further improvement, and, if the height of the slot is reduced from 0.085 inch to 0.044 inch, there is a decrease in the total-pressure ratios. At Mach numbers between 1.36 and 1.70, the maximum total-pressure ratio attainable with the slotted inlet is practically equal to the recovery through a normal shock wave occurring at the test Mach number. The recovery at greater Mach numbers is slightly less than that of a normal shock wave; the difference is 4 percent at a Mach number of 2.01.

The effect of slots upon the variation of total-pressure recovery with mass-flow ratio is shown in figure 6. The slots decrease the range of flow ratios over which the boundary layer is separated ahead of the inlet and also cause an increase in pressure recovery. As described in reference 2, retarded air from the flow over the forebody escapes from the inlet passage through the slots. Since there is then less low-energy air that can be disturbed by the adverse pressure gradient inside the diffusor, the forereaching effect of the compression upon the boundary layer ahead of the inlet and the pressure losses inside the diffusor are reduced. The effect of decreasing the slot height is to reduce the flow through the slots and thus to increase the range of flow ratios over which separation occurs and also to decrease the pressure recovery at a given mass-flow ratio. (See fig. 6(b).)

In addition to removing boundary-layer air from the diffusor and thereby increasing the stability of the flow in regard to separation, the slots tend to stabilize the position of the shocks inside the diffusor in a manner similar to that of the perforated nose inlets described in reference 4. As shown in figure 7, the shock wave through which the flow is decelerated from supersonic to subsonic velocities occurs in the inlet passage near the forward end of the slots at a mass-flow ratio corresponding to maximum pressure recovery. Such a position is stable in respect to pressure disturbances coming upstream from the settling chamber. If a positive pressure pulse moves toward an inlet without slots, it would push the shock wave forward. However, with a slotted inlet, the pulse will force air out of the slots from behind the shock wave, and it will tend to dissipate itself and reduce the effect upon the shock position. In the case of a negative pressure pulse, the shock wave tends to move downstream. This movement will reduce the amount of air flowing out the slots, thereby increasing the pressure and pushing the shock pattern back to its equilibrium position.

Figure 7 also shows schlieren photographs of the flow about the model when the boundary layer was separated. Consecutive photographs taken at the mass-flow ratio at which separation first appears show that the flow is unsteady and similar to that described in reference 3.

Angle of Incidence

When the model having 0.085- by 0.300-inch slots and a 12° ramp is at either a 6° angle of attack or yaw, the pressure recovery at Mach numbers greater than 1.36 is less than that of the model at zero incidence, as shown in figure 8. With the scoops in the vertical plane (at an angle of attack), this decrease is about 6 percent at Mach numbers of 1.36 and 2.01. When the model is yawed, the maximum total-pressure ratio is about equal to that of a normal shock wave at the test Mach number of 1.36, but at a Mach number of 2.0 the recovery is again 6 percent less than that of a normal shock wave.

An explanation of the reduced pressure recovery when the model is at an angle of attack is suggested by the schlieren photographs of figure 9. These pictures, when compared to those of figure 7, show that the boundary layer on the upper surface is thickened considerably when the model is at an angle of attack of 6°. The thickening is the result of secondary flow in the boundary layer caused by the pressure differences around the circumference of the forebody. Since the pressure on the upper half of the model is less than that on the lower half, the boundary layer tends to flow around the body with the result that a relatively large quantity of retarded air flows into the upper scoop. The result is a reduction in the attainable pressure recovery. When the model is yawed, the boundary layer flowing into the scoops should be no thicker than when the model is parallel to the stream direction. The fact that the loss in recovery increases with Mach number for this condition suggests that the increasing intensity of the expansion zone and the shock wave from the inclined scoop lips may adversely affect the flow through the diffusor.

The effect of model inclination on the variation of total-pressure and the mass-flow ratios is shown in figure 10. With the model at an angle of attack, separation occurs at greater mass-flow and smaller total-pressure ratios than when the model was not inclined (fig. 6). These results are probably caused by the thicker boundary layer flowing into the upper scoop as observed in the schlieren photographs. When the model is yawed, the range of mass-flow ratios over which the flow is separated is less than for either the zero-inclination or the 6°-angle-of-attack conditions. This improvement in performance is possibly due to less retarded air flowing into the diffusor because of the secondary boundary-layer flow around the body. However, for a given mass-flow ratio with an unseparated boundary layer, the total-pressure ratio is the least with the yawed model. This loss is possibly due to the previously mentioned flow pattern in the inlet passage caused by the inclined scoop lips.

CONCLUSIONS

Tests at Mach numbers between 1.36 and 2.01 of twin-scoop duct inlets that enclose 37.2 percent of the forebody circumference have shown the following effects:

1. The pressure recovery attainable after diffusion with the model having a 5° ramp and no slots was no greater than the maximum recovery attainable with a comparable inlet enclosing 61.5 percent of the forebody circumference.

2. The maximum total-pressure ratios throughout the Mach number range were attained with a 12° ramp. Because the boundary layer bridges the break in the surface at the leading edge of the ramp, there was no further improvement in pressure recovery at greater ramp angles.

3. Slots in the walls of the ducts contiguous to the forebody and immediately behind the inlet caused a marked increase in both pressure recovery and flow stability.

4. At an angle of incidence of 0°, the model having scoops with a 12° ramp and slots in the duct walls attained maximum total-pressure ratios nearly equal to those of a normal shock wave at Mach numbers less than 1.70; at a Mach number of 2.01, the recovery was 4 percent less than that of a normal wave. Changing the angle of attack or yaw to 6° decreases the pressure recovery after diffusion 6 percent or less.

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REFERENCES

1. Davis, Wallace F., and Goldstein, David L.: Experimental Investigation at Supersonic Speeds of Twin-Scoop Duct Inlets of Equal Area. I – An Inlet Enclosing 61.5 Percent of the Maximum Circumference of the Forebody. NACA RM No. A7J27, 1948.

2. Davis, Wallace F., and Goldstein, David L.: Experimental Investigation at Supersonic Speeds of Twin-Scoop Duct Inlets of Equal Area. II – Effects of Slots Upon an Inlet Enclosing 61.5 Percent of the Maximum Circumference of the Forebody. NACA RM No. A8C11, 1948.

3. Davis, Wallace F., Brajnikoff, George B., Goldstein, David L., and Spiegel, Joseph M.: An Experimental Investigation at Supersonic Speeds of Annular Duct Inlets Situated in a Region of Appreciable Boundary Layer. NACA RM No. A7G15, 1947.

4. Evvard, John C., and Blakey, John W.: The Use of Perforated Inlets for Efficient Supersonic Diffusion. NACA RM No. E7C26, 1947.

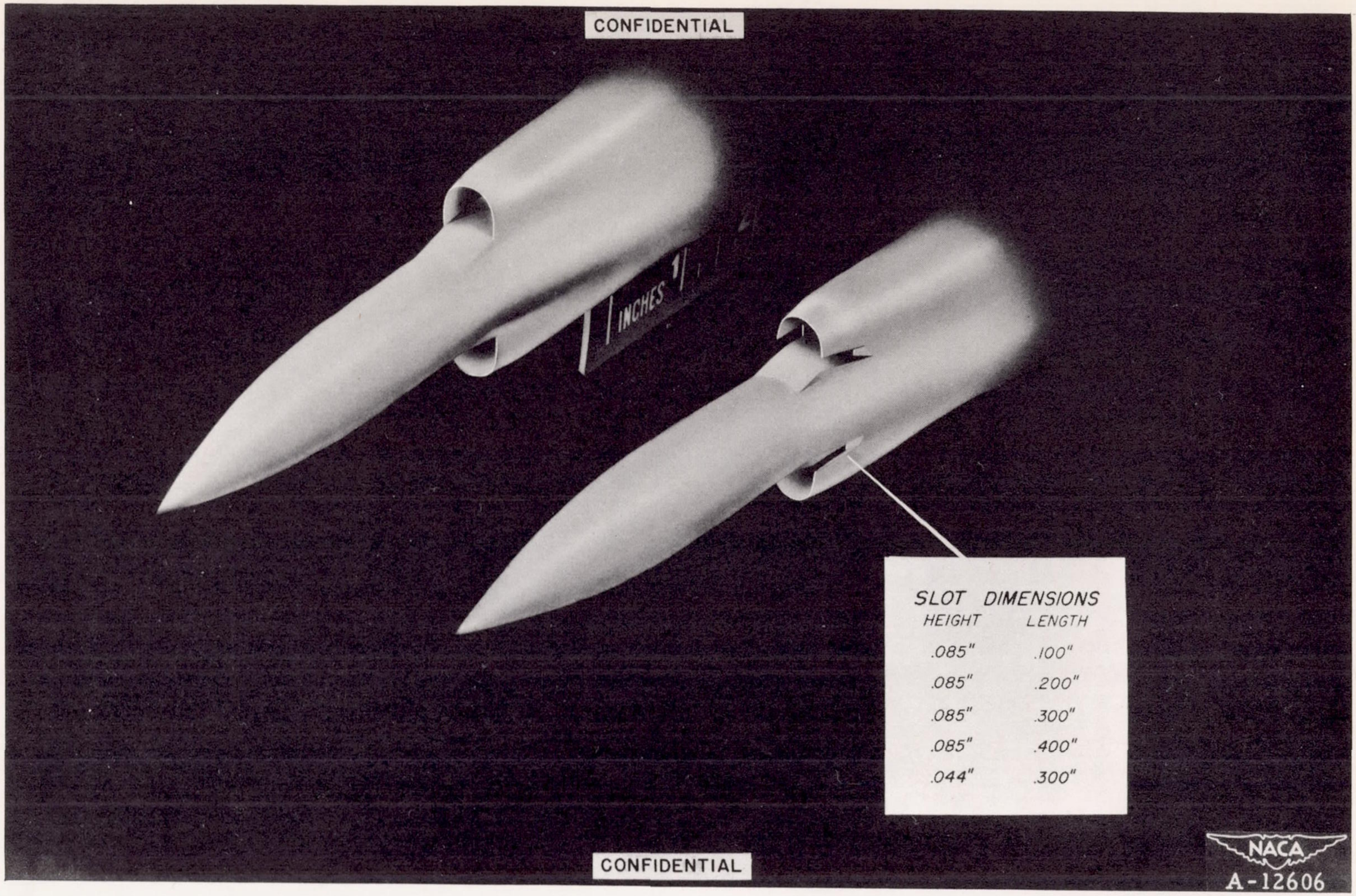

Figure 1.- Model with twin scoops enclosing 37.2 percent of the forebody circumference.

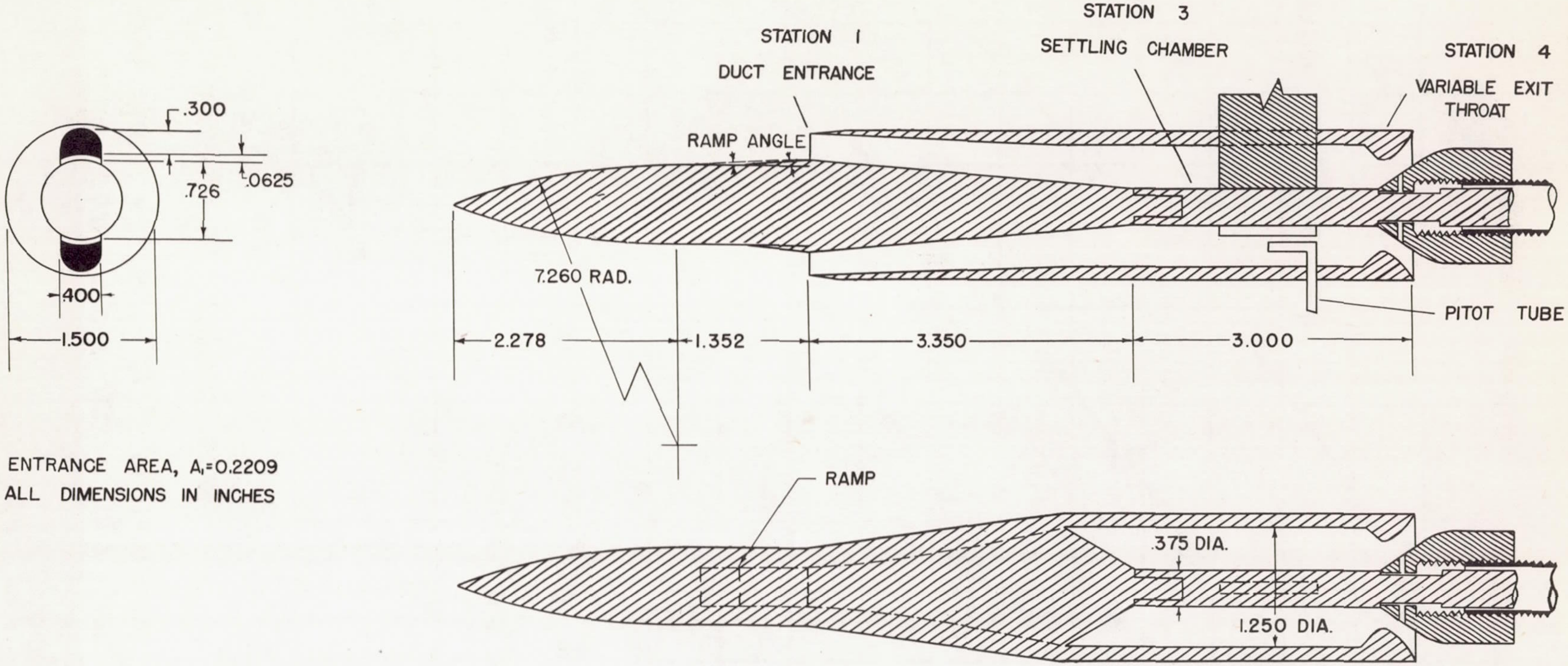

FIGURE 2. —MODEL DIMENSIONS.

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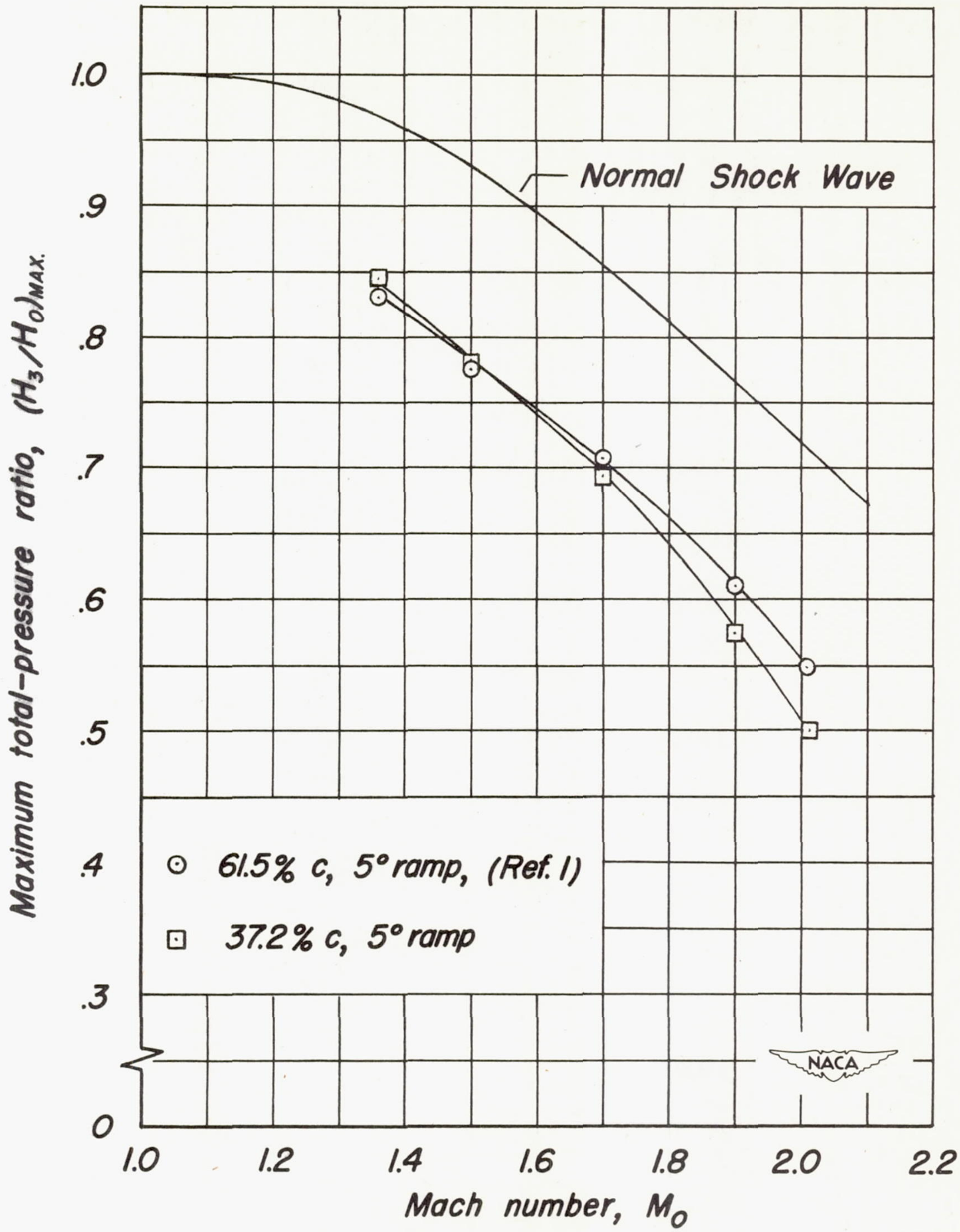


Figure 3. – Variation of total-pressure ratio with Mach number and inlet height-width ratio.

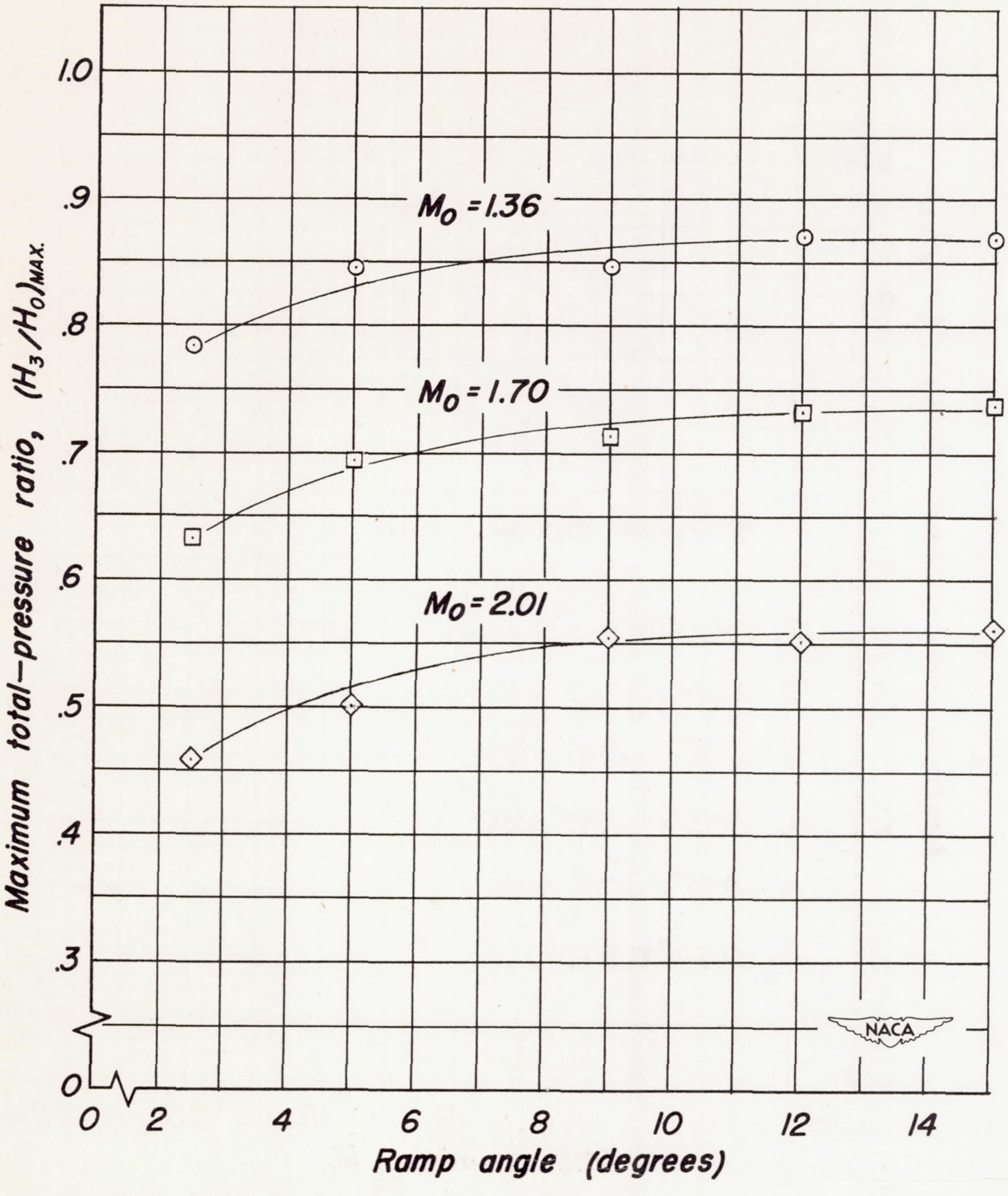


Figure 4.—Variation of total-pressure ratio with ramp angle at several Mach numbers.

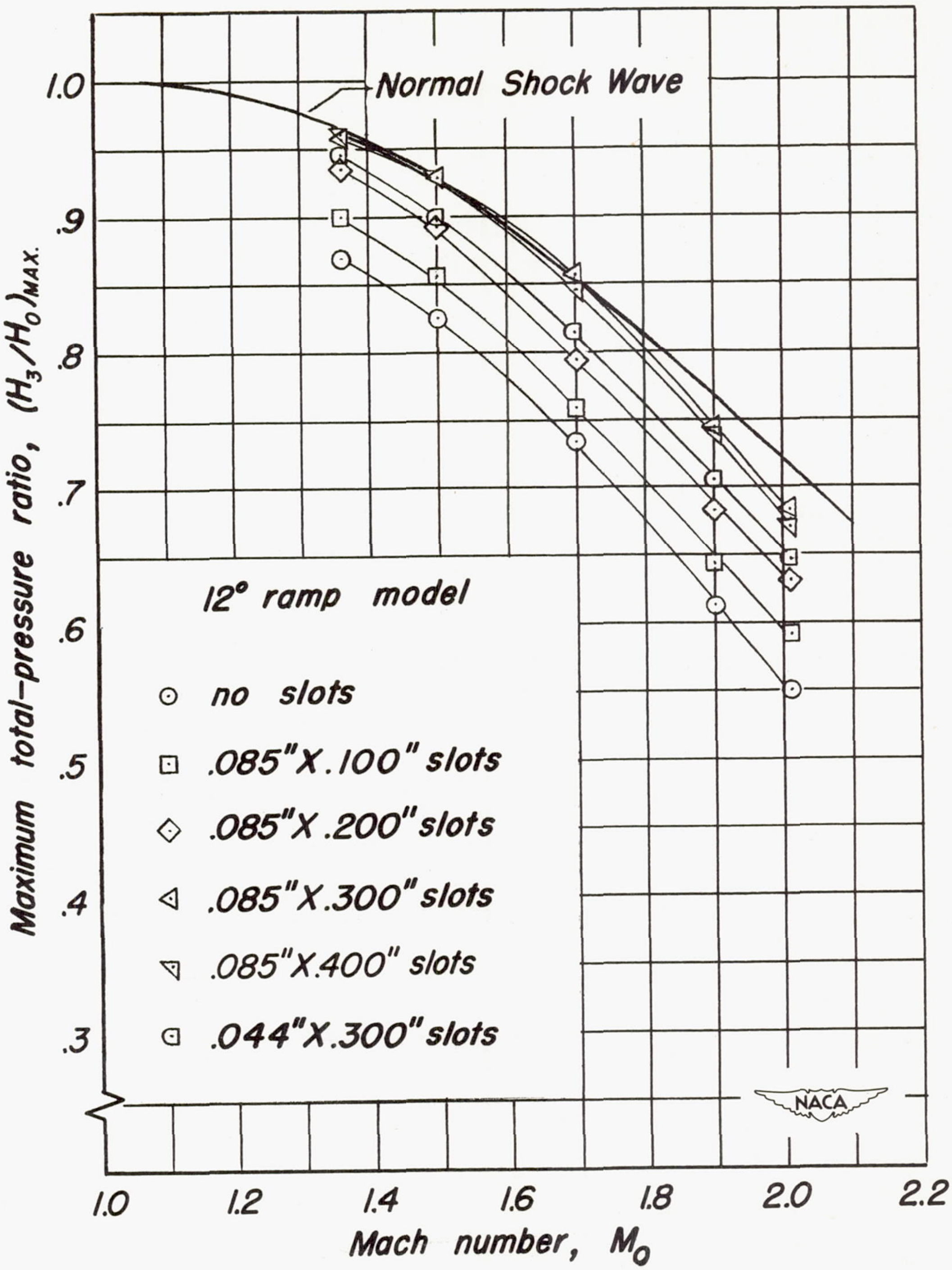
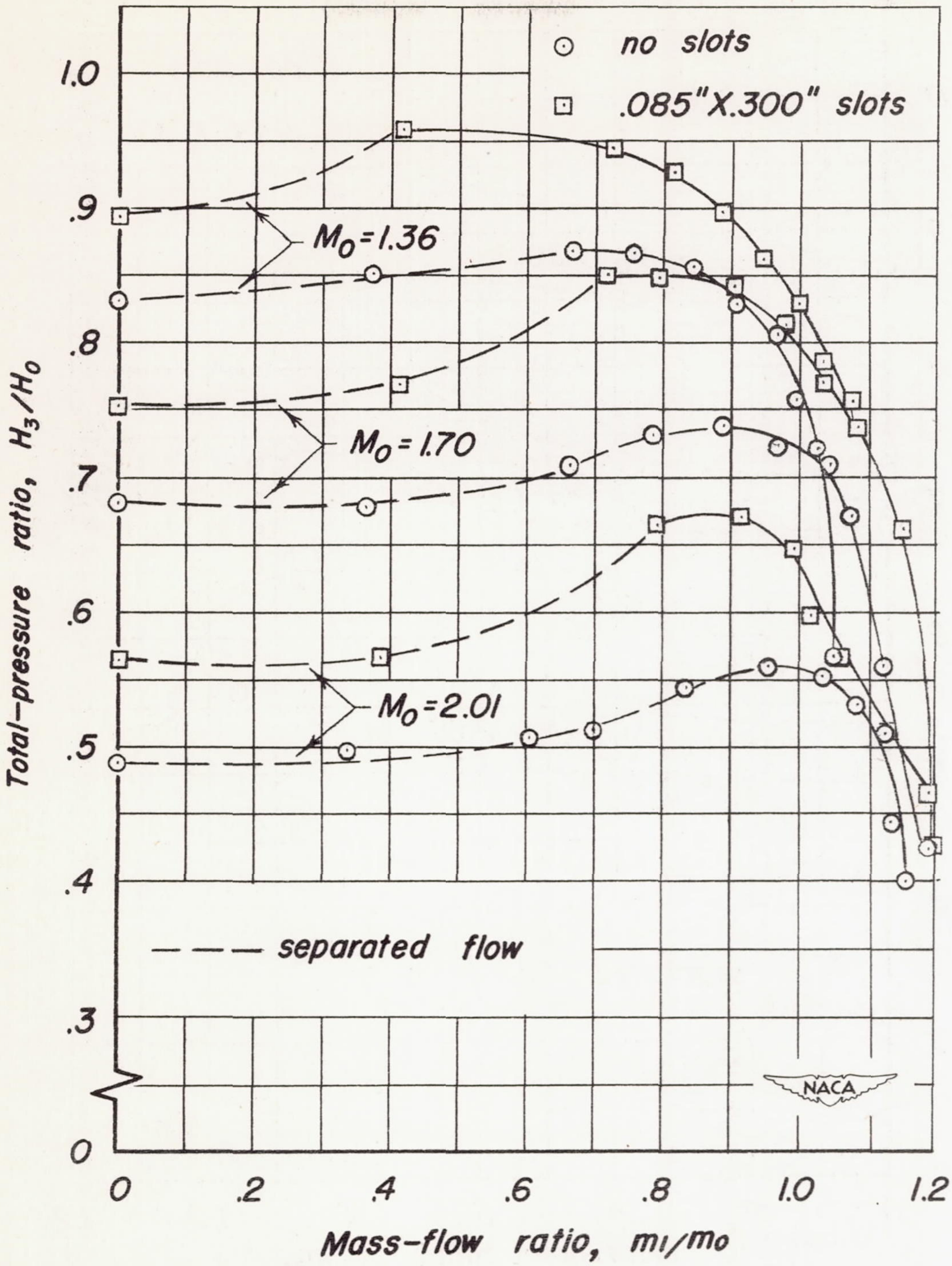
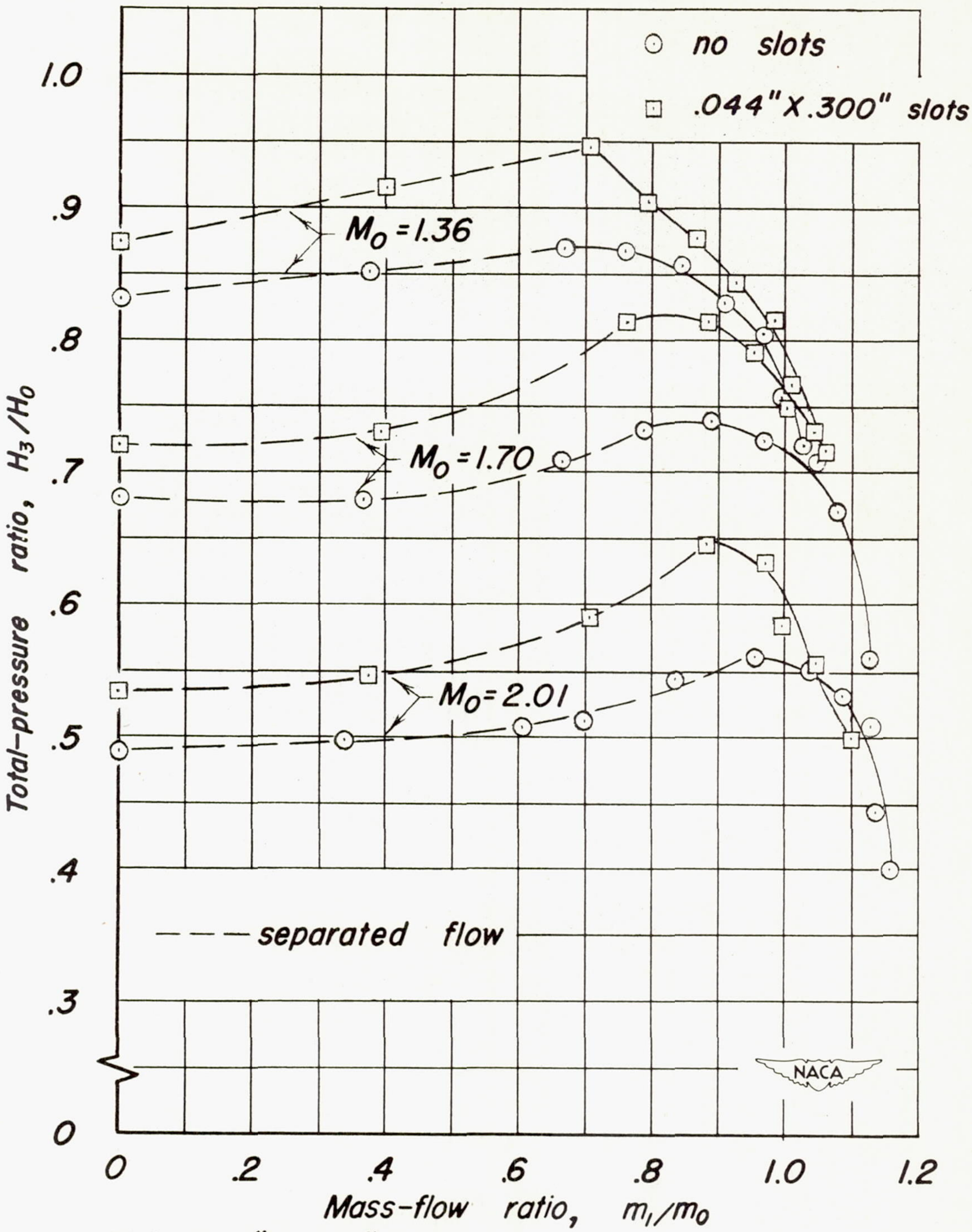


Figure 5.—Variation of total-pressure ratio with Mach number and slot size.



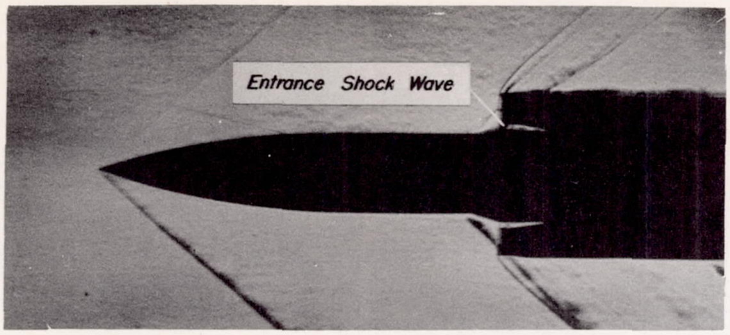
(a.) .085"X.300" slots

Figure 6. —Variation of total-pressure ratio with mass-flow ratio for 12° ramp angle at several Mach numbers.

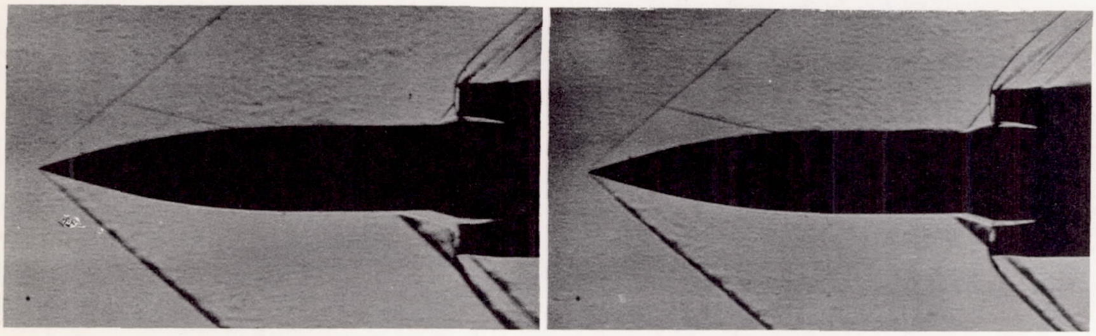


(b.) .044"X.300" slots

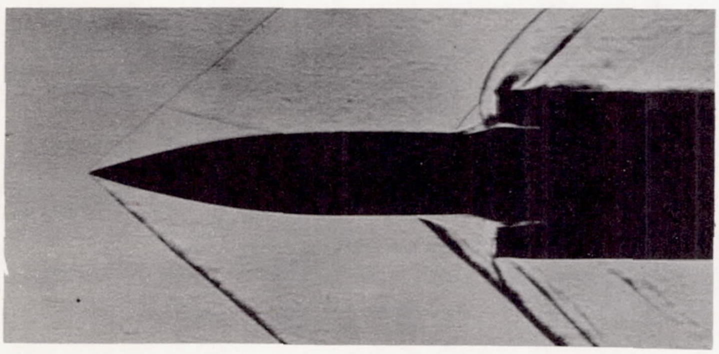
Figure 6. —Concluded



$H_3/H_0 = 0.85$ $m_1/m_0 = 0.79$



$H_3/H_0 = 0.85$ $m_1/m_0 = 0.72$



$H_3/H_0 = 0.75$ $m_1/m_0 = 0$

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Note: Knife-edge parallel to stream direction.

Figure 7.– Schlieren photographs of flow about inlet with 0.085 in. by 0.300 in. slots and 12° ramp at $M_0 = 1.70$ and $\alpha = 0^\circ$.

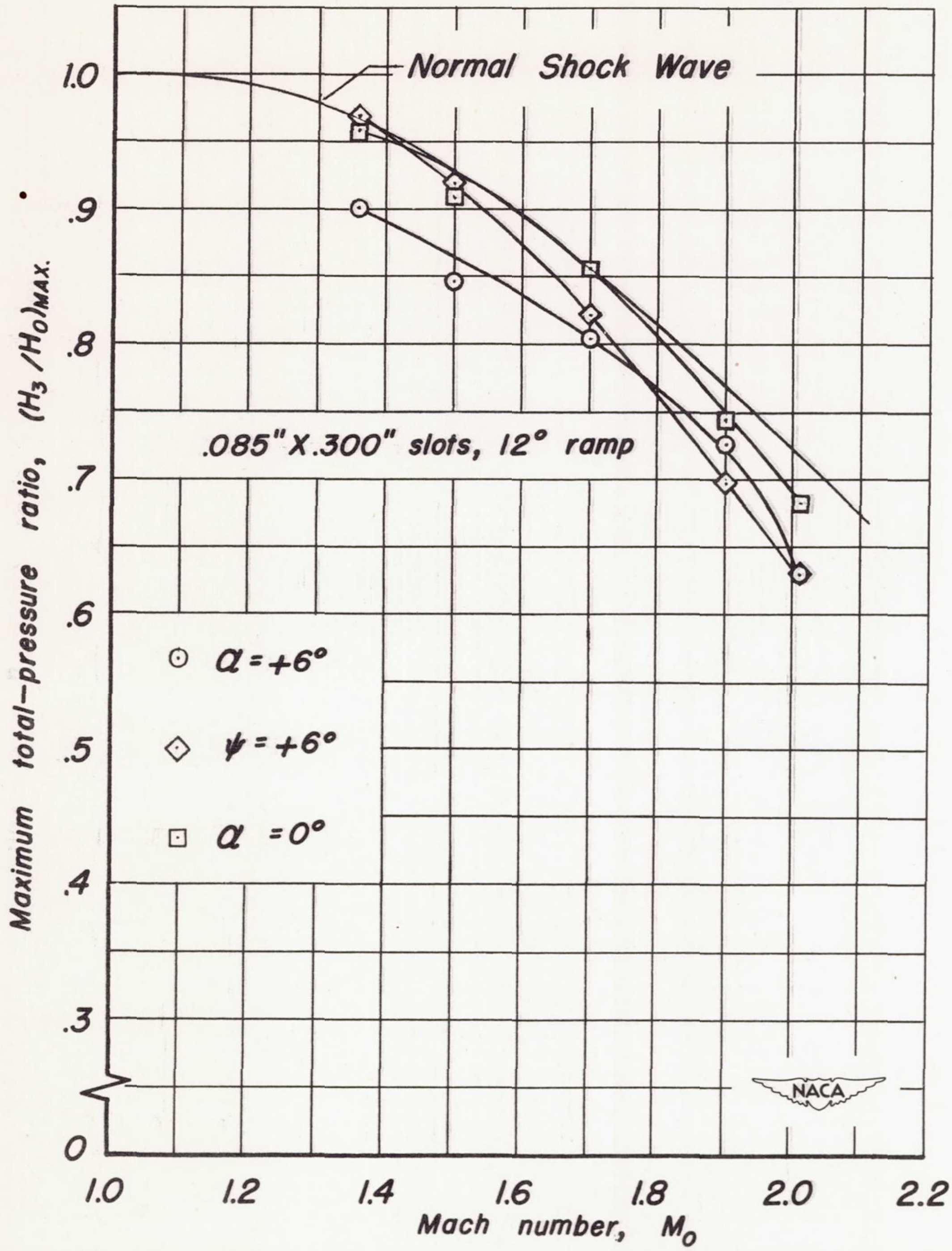
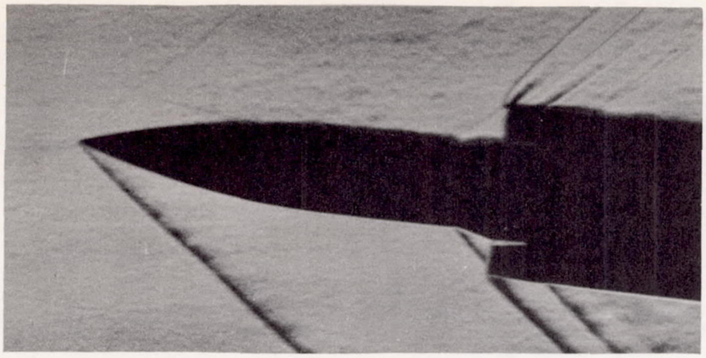
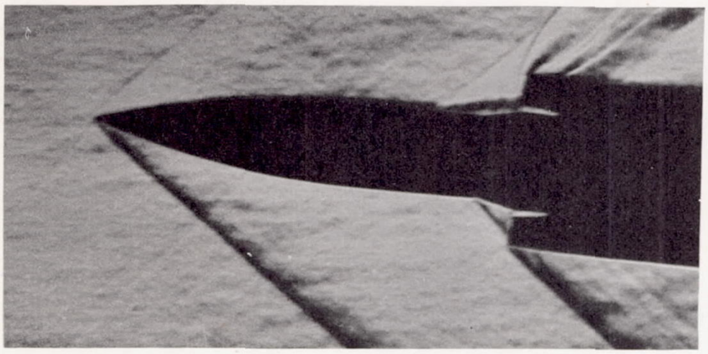


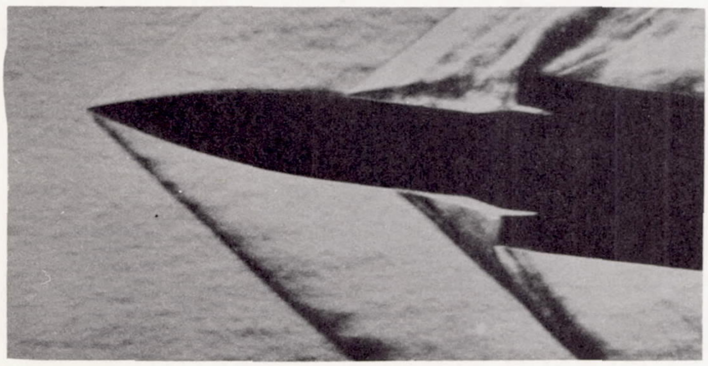
Figure 8.—Variation of total-pressure ratio with Mach number and angle of incidence.



$H_3/H_0 = 0.69$ $m_1/m_0 = 1.02$



$H_3/H_0 = 0.80$ $m_1/m_0 = 0.75$



$H_3/H_0 = 0.69$ $m_1/m_0 = 0.37$

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Note: Knife-edge parallel to stream direction.

Figure 9.- Schlieren photographs of flow about inlet with 0.085 in. by 0.300 in. slots and 12° ramp at $M_0 = 1.70$ and $\alpha = 6^\circ$.

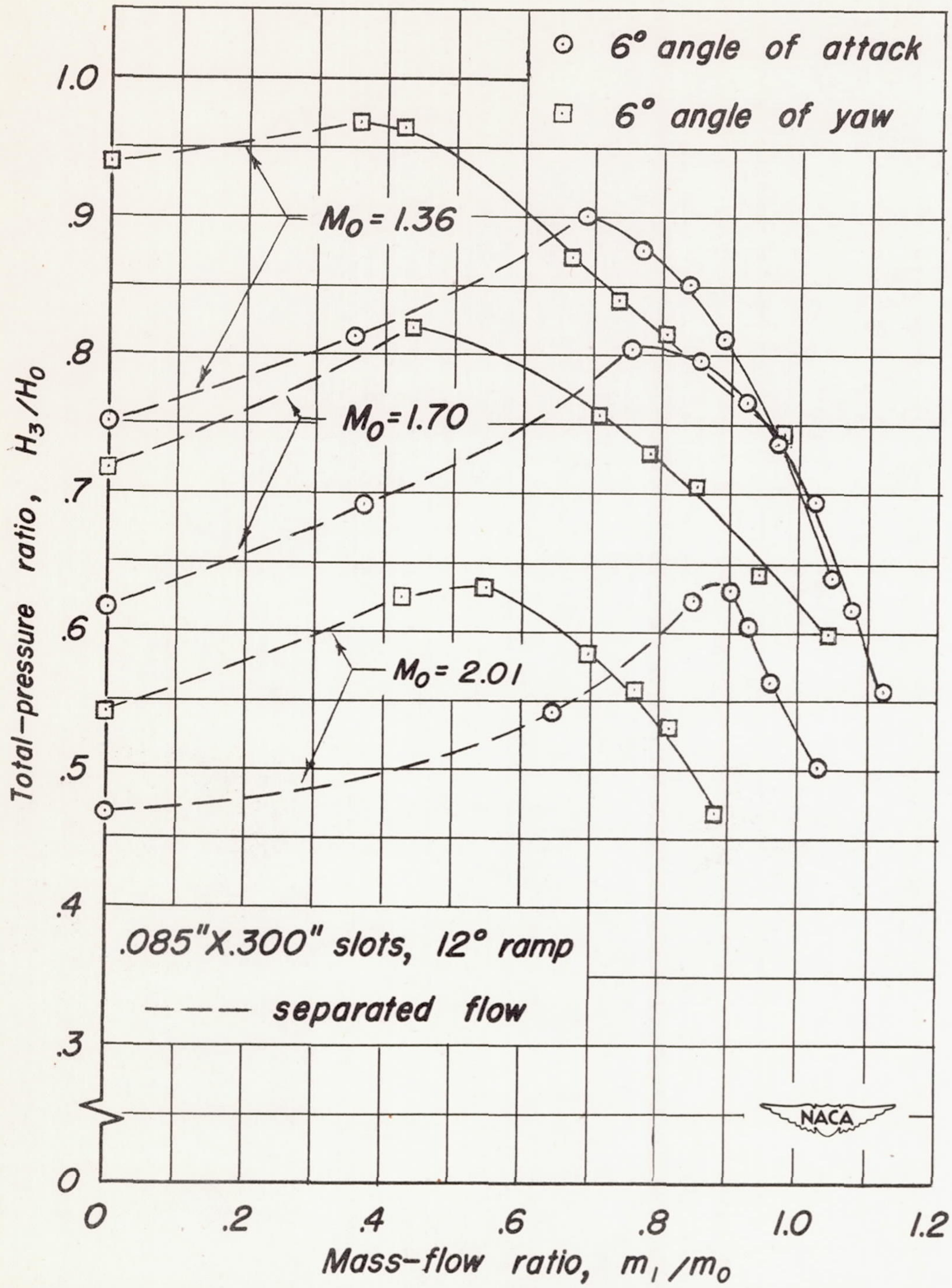

Figure 10. –Variation of total-pressure ratio with mass-flow ratio and angle of incidence at several Mach numbers.