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RESEARCH MEMORANDUM

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

By Wallace F. Davis and David L. Goldstein

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Moffett Field, Calif.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS
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SUMMARY

Tests were made at Mach numbers between 1.36 and 2.01 of a twin-scoop duct inlet that had slots in the walls of the duct contiguous to the forebody and immediately behind the inlet. The mass flow and total-pressure recovery through the diffusor were measured during tests in which the slot length was constant and the slot width and ramp angle were varied. It was found that boundary-layer air flowed outwards through the slots and that both the stability of the flow and the total pressure that could be attained after diffusion were greater than those of the inlet without slots. The ramp angle that produced the maximum total-pressure recovery was greater with the slotted inlet; therefore, some of the improvements in the total-pressure ratios that were attained were the result of the beneficial effects of a relatively intense oblique shock wave occurring at the ramp leading edge. The maximum total-pressure ratio of the twin-scoop duct entrance having a 9° ramp and slots of which the width was 48.6 percent of the depth of a scoop was about seven-eighths of the pressure recovered through a normal shock wave occurring at the test Mach number.

INTRODUCTION

Preliminary tests at supersonic speeds of annular duct entrances situated in a region of appreciable boundary layer showed that the total pressure recovered after diffusion and the stability of the boundary layer in regard to separation were relatively low. The recovery was approximately two-thirds of that through a normal shock wave occurring at the test Mach number. (See reference 1.) In order to improve the total-pressure ratio of the diffusor, a model was designed to minimize the causes of separation. The adverse pressure gradient imposed upon the boundary layer by the compression inside the diffusor was reduced and the inlet Mach number was decreased by creating an oblique shock wave ahead of the duct entrance. The amount of boundary-layer air flowing into the diffusor was reduced by using a twin scoop instead of an annular inlet while maintaining the same entrance area. (See reference 2.) The maximum total-pressure ratio attained during tests of this model was about four-fifths of the pressure recovered through a normal shock wave, or it was about 10 percent greater than that of a comparable model having an annular entrance. The results of these tests indicated that further improvement in the recovery of total pressure could be produced if more of the boundary layer were prevented from flowing through the inlet.

Since the static pressure inside a diffusor is, in general, greater than that on the outside, a pressure difference exists that might be utilized to divert a boundary layer. Therefore, it was reasoned that, if the walls immediately behind the inlet of a twin-scoop supersonic diffusor had slots contiguous to the body over which a boundary layer had developed, this pressure difference would tend to force the boundary layer outward through the slots and prevent it from flowing through the duct. The result would be an increase in the flow stability and the pressure recovery. It is the purpose of the present report to describe tests of an inlet designed according to these considerations.

SYMBOLS

H total pressure

M Mach number

A area

m rate of mass flow

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 on the length of the body ahead of the inlet, between 2.21 and 3.10 million. All of the tests were made with the model at an angle of attack of 0°. A description of the apparatus and test procedure are presented in reference 1.

The model of reference 2 was used to test the effects of slots. Model dimensions and a photograph of a slotted duct entrance are shown in figure 1. The inlet consists of two diametrically opposed scoops that enclose 61.5 percent of the maximum circumference of the forebody. The intake area is the same as that of the annular entrances of reference 1, about one-third of the total cross-sectional area at the entrance station. A subsonic diffusor connects the inlets to a settling chamber. The pressure in this settling chamber was controlled by varying the area of the throat that forms the exit to the passage through the model.

Slots were cut into the duct walls next to the central body of the model by filing the plastic material from the inlet section. The slots that were tested were 0.200 inch in length and 0.044, 0.085, and 0.120 inch in width. These widths are 25.1, 48.6, and 68.5 percent of the depth of a scoop. Ramp angles of 0°, 5°, 9°, 12°, and 17° were tested with each slot. These angles were obtained by changing the length of the ramp while the height remained the same.

RESULTS AND DISCUSSION

The results that are presented in this report are preliminary in the respect that only a few of the important variables that are involved in the design of a slotted inlet have been investigated. Only the effects of slot width and ramp angle upon the variation of pressure recovery with mass flow through the ducts of one inlet configuration have been considered. Subsequent reports will describe tests of various slot lengths and inlet designs to determine not only the mass flow and pressure recovery but also the drag force contributed by the inlets.

Mass Flow

Slots apparently improve the stability of the flow through an inlet. As the mass-flow ratio[1] m_1/m_0 is reduced from the maximum

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

value by reducing the outlet-inlet area ratio A_4/A_1, the flow through the scoops is supersonic and the total-pressure recovery increases until the shock losses inside the diffusor occur immediately downstream of the inlet section. Further reduction of the mass flow forces the boundary layer to thicken upstream of the entrances and then to separate. Consecutive schlieren photographs of the flow about a slotted inlet do not show the rapid intermittent separation of the boundary layer that occurs with the scoops having no slots. (See reference 2.) The approximate mass-flow and total-pressure ratios at which separation exists for the inlet with and without slots are shown in figure 2, which consists of typical test data. As the slot width is increased and the mass-flow ratio is reduced, separation begins at a greater total-pressure ratio. These facts indicate an increase in the flow stability.

Figure 2 shows the effect of slot width upon the total-pressure and mass-flow ratios. When the flow through the inlet is supersonic, the recovery of total pressure and the mass flow at a given outlet-inlet area ratio are nearly the same for the scoops having no slots and 0.044-inch slots. As the slot width is increased further, the recovery at the same area ratio decreases, indicating either that the slots cause an additional pressure loss or that air escapes from the diffusor through the slots. Since the larger slots produce the greater maximum total-pressure ratios, these facts indicate that little or no air flows out of the 0.044-inch slots, and that an appreciable amount must escape with the larger slot widths. Since the slots are contiguous to the central body, it is supposed that the air that escapes is the boundary layer of the flow over the forebody.

Further evidence that the boundary layer drained through the slots was observed in the flow pattern of a thin film of light grease that was applied to the forebody of the model. The grease moved with a lateral component immediately ahead of the inlet, and most of it came out of the diffusor through the slots.

Total-Pressure Recovery

Figure 3 shows the variation of maximum total-pressure ratio $(H_3/H_0)_{max}$ with ramp angle for several slot widths and Mach numbers. As the ramp angle is increased from zero, the pressure recovery rises rapidly to a maximum value. For the inlet having no slots, the maximum pressure recovery occurs at a ramp angle of about 5°; with larger angles, the recovery decreases slightly at Mach numbers of 1.36 and 1.70, but at a Mach number of 2.01 it remains nearly constant. For the slotted inlets, the maximum total-pressure ratio increases up to a ramp angle of from 9° to 12° and remains nearly constant thereafter. The increase in pressure recovery is from 10 to 20 percent, the greatest increase being produced by the widest slots.

The maximum total-pressure ratio is improved by the presence of a ramp because the oblique shock wave created by the deflection of the stream reduces the Mach number at which the flow is decelerated from supersonic to subsonic velocities inside the diffusor. For the inlet having no slots, the greatest improvement is attained with a relatively small ramp angle because the boundary layer behind the oblique shock wave is thickened by the pressure rise through the wave and also by the forereaching effect upon the boundary layer of the adverse pressure gradient inside the diffusor. Since the slots remove some of the boundary layer that would otherwise flow through the ducts, they reduce the unfavorable effect of the diffusor on the boundary-layer flow and thereby permit use of larger ramp angles. Therefore, because the intensity of the oblique shock wave can be increased and also because less retarded air flows through the diffusor, a slotted inlet produces an improvement in total-pressure recovery.

An explanation for the small change in pressure recovery for ramp angles greater than 12° is provided by the schlieren photographs of figure 4. With a ramp angle less than 12°, the oblique shock wave originates at the leading edge of the ramp, and the apparent outside limit of the boundary layer is nearly parallel to the ramp contour. With greater ramp angles, however, the pressure rise resulting from the deflection of the stream is sufficiently large to thicken the boundary layer ahead of the ramp. As a result, the boundary layer bridges the break in the surface, thereby deflecting the stream through a smaller angle and creating a less intense oblique shock wave than would occur if the flow followed the surface. Measurement of the position at which the oblique shock wave occurs and of the angle between the apparent boundary-layer limit and the stream direction for the model having a 17° ramp indicates that the boundary layer forms an effective ramp angle of about 12°. Consequently, the recovery is nearly the same as when the solid surface diverged at an angle of 12°. A similar phenomenon was observed in the two-dimensional tests of reference 3. It was found that, if an oblique shock wave originates ahead of the boundary deflection point because of the presence of a thick boundary layer, the foremost shock angle is approximately constant and independent of the wedge angle.

The variations of maximum total-pressure ratio with free-stream Mach number for the inlet having no slots and a 5° ramp and for the inlet having 0.085-inch slots and a 9° ramp are compared in figure 5.

The latter configuration was arbitrarily chosen as the best of the slotted inlets tested. A final selection would, of course, require an analysis of the effects of pressure recovery and mass flow upon the thrust force of a specified engine and knowledge of the drag force contributed by the slots and the various ramps. The comparison shows that the slotted inlet produces a 3-percent improvement in the pressure recovery at a Mach number of 1.36 and a 9-percent improvement at 2.01. In other words, the recovery is about seven-eighths of that through a normal shock wave occurring at the test Mach number.

CONCLUSIONS

Tests at Mach numbers between 1.36 and 2.01 of a twin-scoop duct inlet that had slots in the walls of the duct contiguous to the forebody and immediately behind the inlet have shown the following effects:

1. A portion of the boundary-layer air that enters the inlet flows out of the diffusor through the slots; consequently, both the stability of the flow and the total pressure that can be attained after diffusion are greater than those of the inlet without slots.

2. The ramp angle that produces the maximum total-pressure recovery is greater for the slotted duct entrance than for the inlet without slots.

3. The maximum total-pressure ratio of the inlet having a 9° ramp and slots of which the width is 48.6 percent of the depth of a scoop is about seven-eighths of the pressure recovery through a normal shock wave occurring at the test Mach number.

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REFERENCES

1. 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.

2. 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.

3. Pearce, R. B.: Shock Waves on Surfaces with Thick Boundary Layers. North American Aviation, Inc. Rep. No. AL-399, Dec. 30, 1947.

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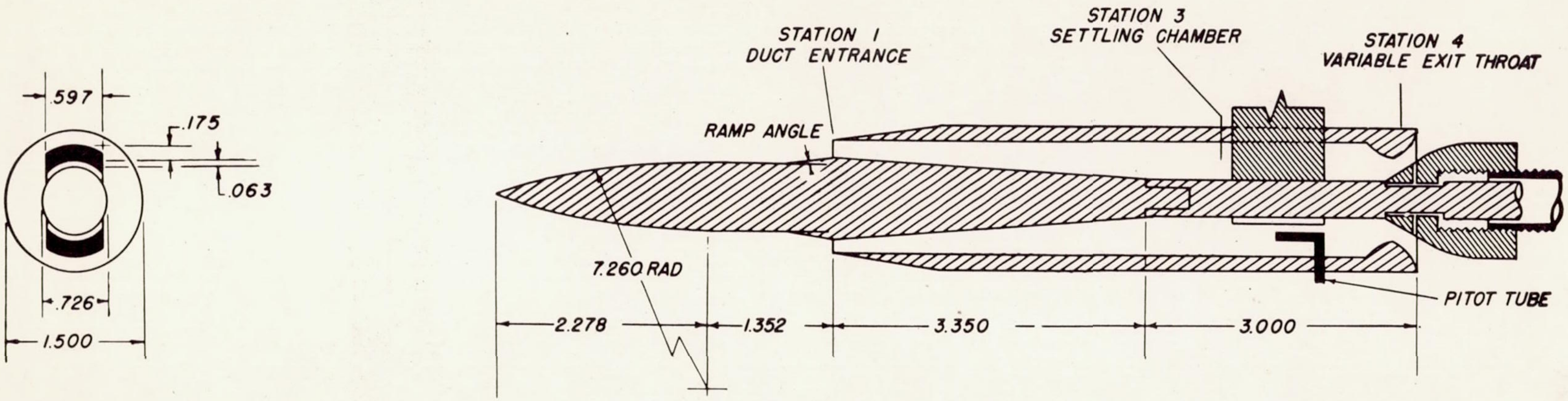
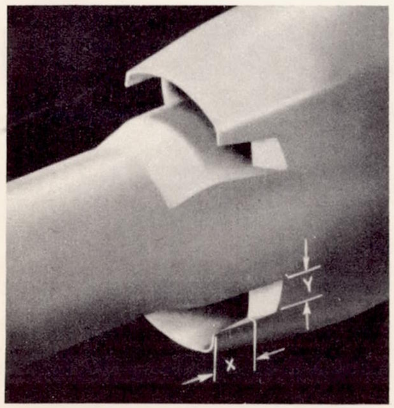
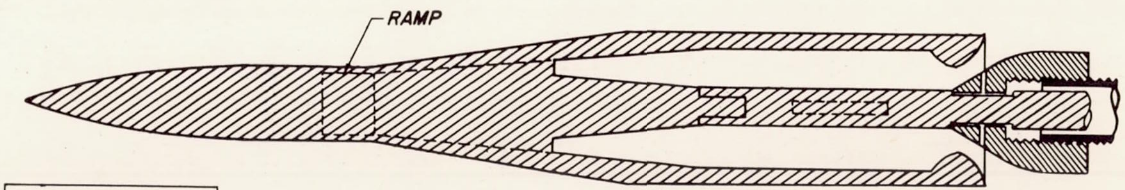




PHOTOGRAPH OF DUCT ENTRANCE



SLOT DIMENSIONS	
X	Y
0.200	0.044
0.200	0.085
0.200	0.120

ENTRANCE AREA, A_1= 0.2209
ALL DIMENSIONS IN INCHES

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Figure 1.– Model Dimensions.

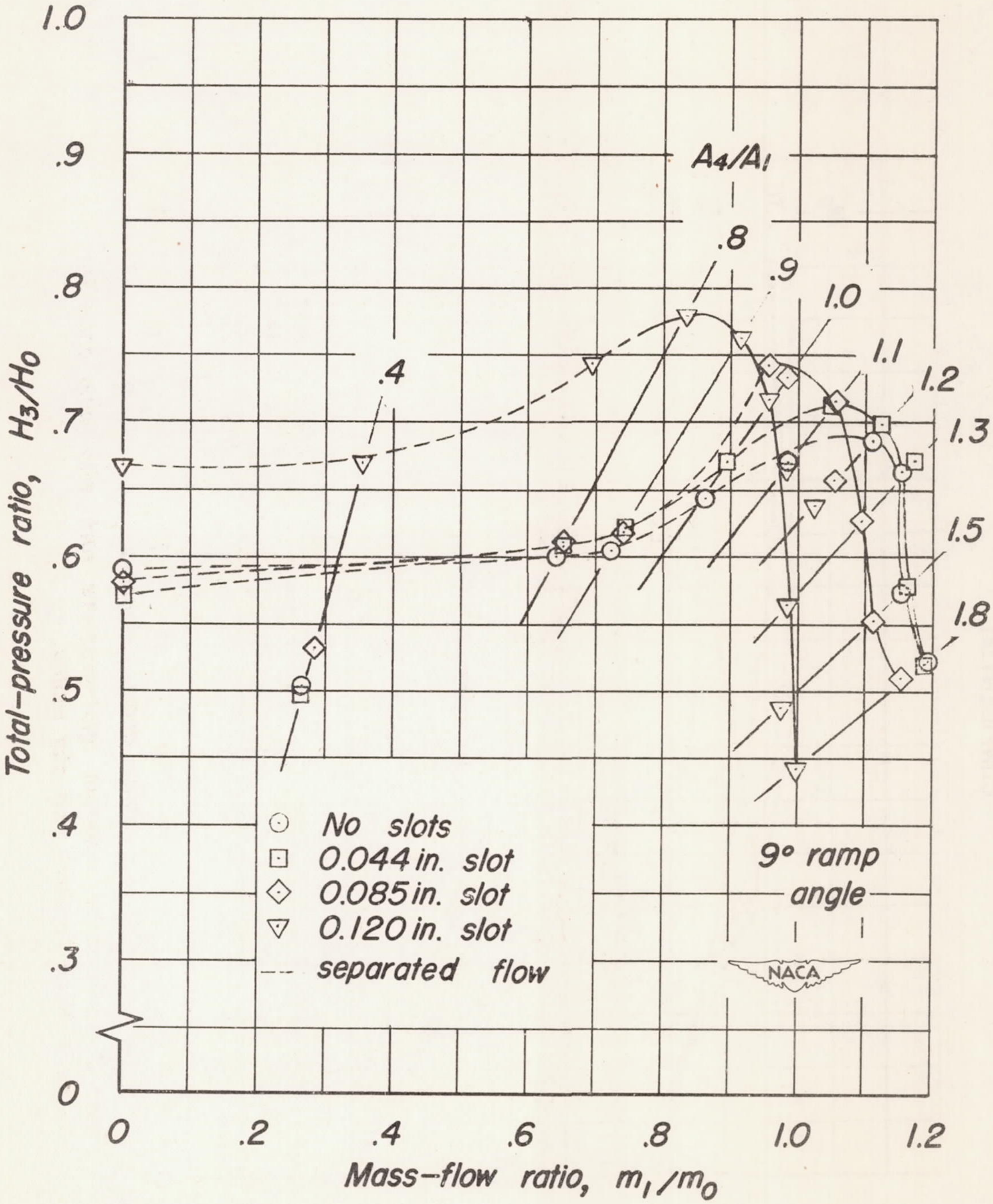


Figure 2. Variation of total-pressure ratio with mass-flow ratio for several slot widths at a Mach number of 1.70.

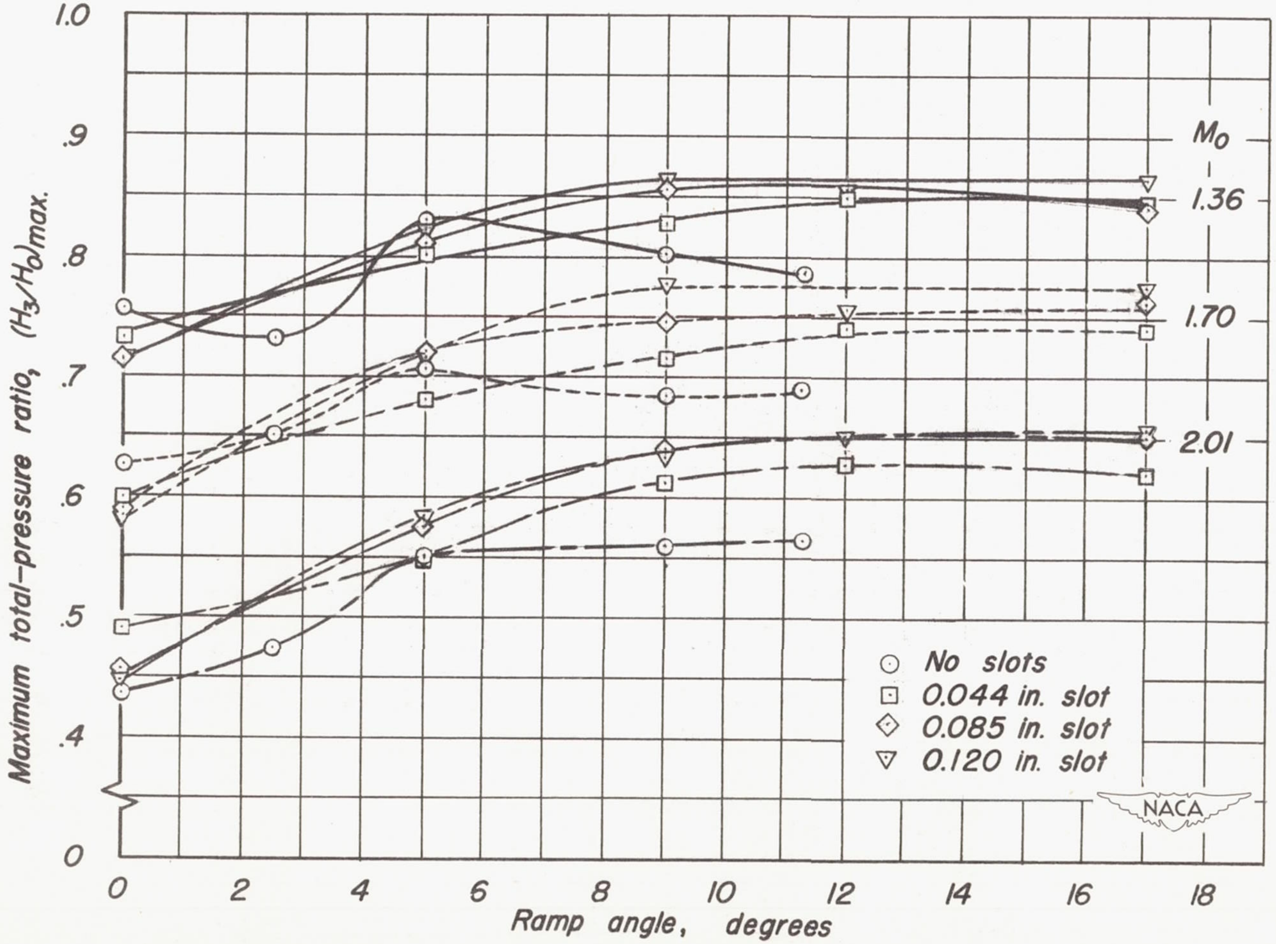
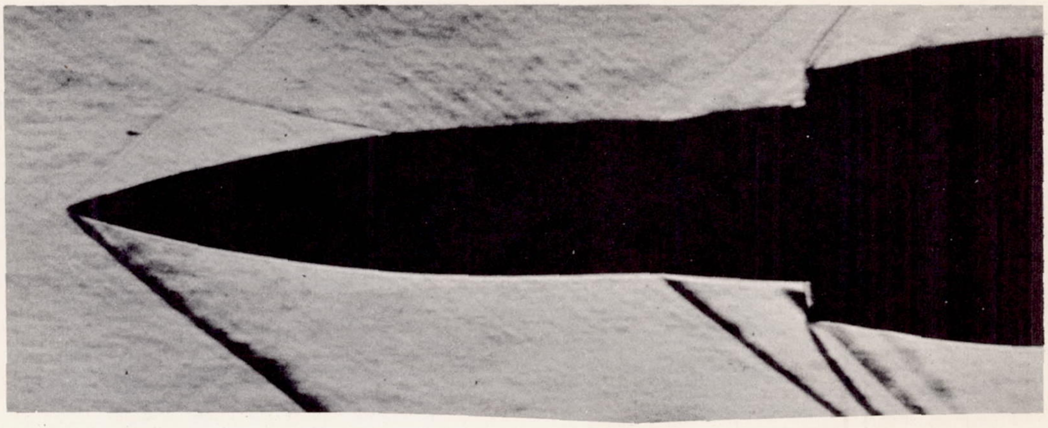
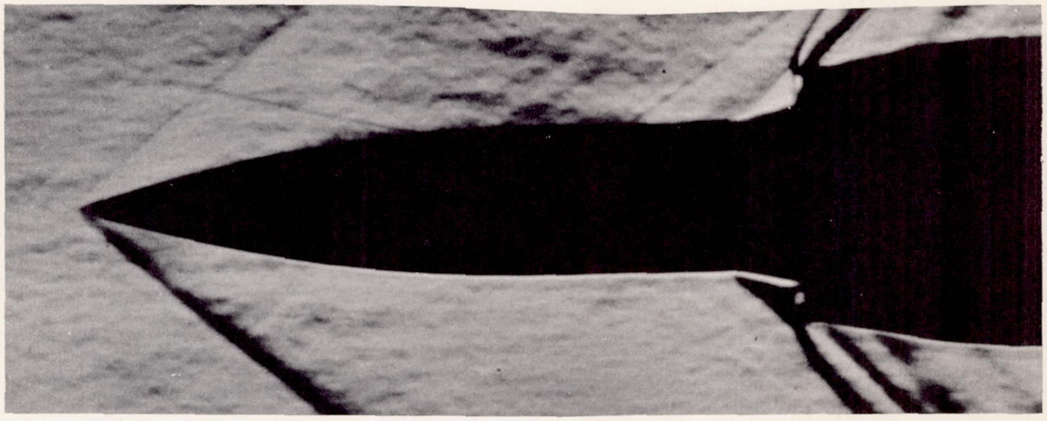


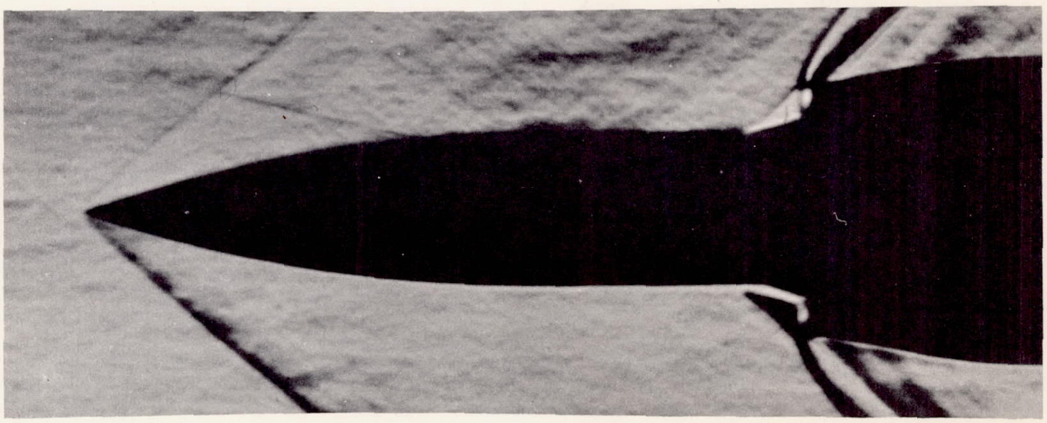
Figure 3. Variation of maximum total-pressure ratio with ramp angle for several Mach numbers and slot widths.



5° Ramp angle



12° Ramp angle



17° Ramp angle

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Note: Schlieren knife-edge parallel to stream direction.
0.085 in. by 0.200 in. slots.

Figure 4.- Schlieren photographs of the flow at a Mach number of 1.70 about a model having ramps of various angles.

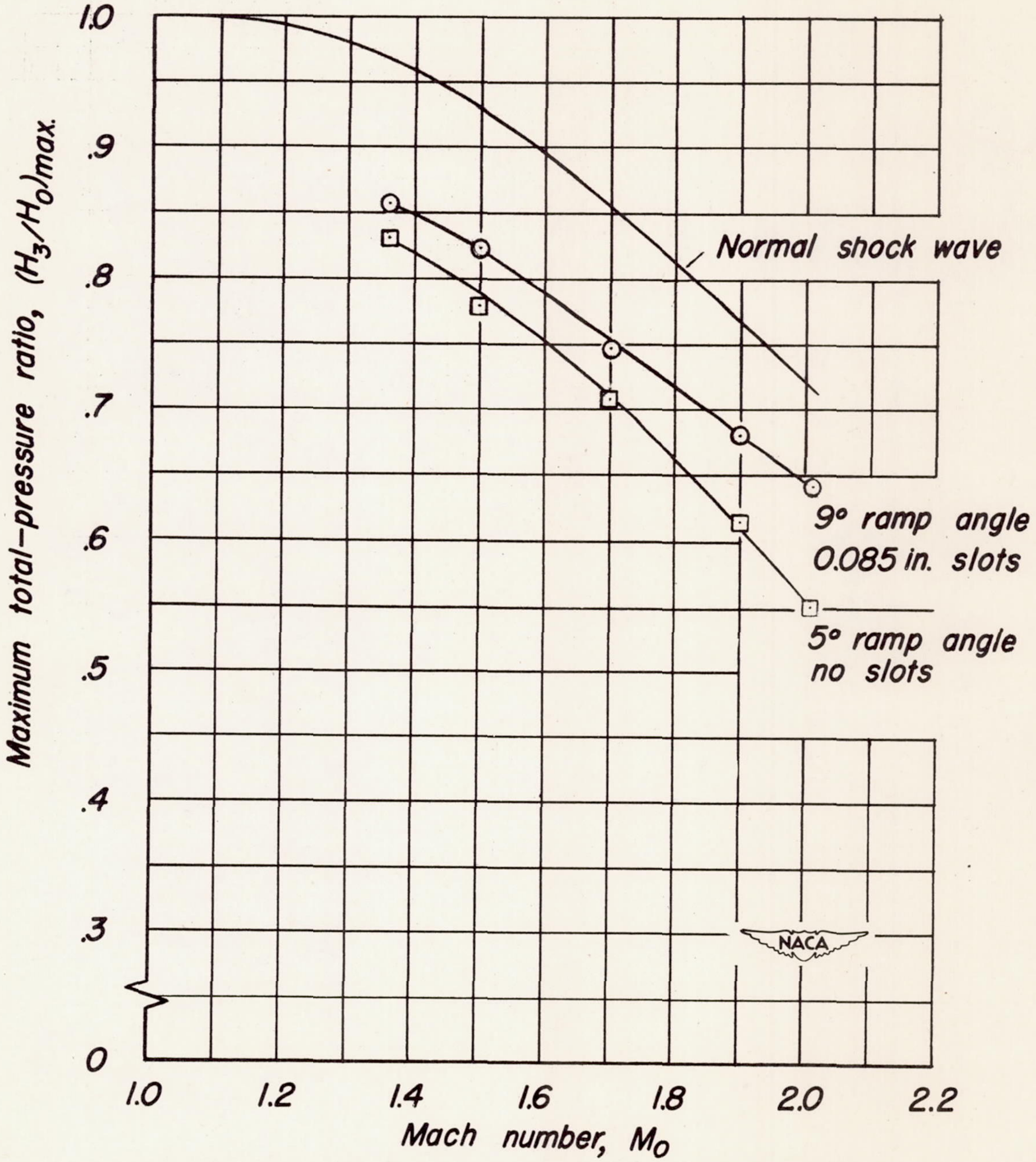

Figure 5. Variation of maximum total-pressure ratio with Mach number.