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INVESTIGATION OF SIDE INLETS AT SUPERSONIC SPEEDS

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Although a very high diffusion efficiency can be attained at supersonic speeds by nose inlets such as those discussed in reference 1, practical design considerations often make side inlets more desirable. For this reason, tests are being performed at supersonic speeds upon inlets that are situated in a region of appreciable boundary layer. Preliminary tests have shown that the presence of the boundary layer can cause a relatively poor recovery of total pressure because the severe adverse pressure gradient produced by a rapid deceleration of the flow at high speeds causes the boundary layer to thicken and separate. The results of the separation are a fluctuating flow through the intake and a maximum total-pressure ratio after diffusion that is limited to about two-thirds of that occuring across a normal shock wave at the same Mach number. (See reference 2.)

To improve the pressure recovery attainable through a side inlet, the severity of the compression inside the duct must be reduced, the amount of low-energy air of the boundary layer that enters the inlet must be diminished, or both factors must be reduced simultaneously. These considerations have been used in the design of side inlets for tests in the Ames 8- by 8-inch supersonic tunnel. Both annular and twin-scoop inlets are being investigated because applications for the two types may be found in the design of high-speed aircraft.

The tests are being performed at Mach numbers between 1.36 and 2.01 and at Reynolds numbers, based upon the length of the body ahead of the intake, of between 2.23 and 3.09 million. Only measurements of the pressure recovery attainable after diffusion with the various inlet designs at an angle of attack of 0° have been made at the present time. Angle-of-attack and comparative-drag studies together with tests at subsonic speeds are to be performed in the future.

ANNULAR INLETS

Three methods for improving the total-pressure recovery attainable after diffusion through an annular inlet are being investigated. The first method is to reduce the inlet Mach number and thus the adverse pressure gradient that is imposed upon the boundary layer inside the duct by deflecting the stream ahead of the inlet to create an oblique shock wave. A photograph of a model is shown in figure 1. The outside diameter of the inlet is about one inch, and the inlet area

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is about one-third of the frontal area at the station of the duct entrance. The length of the forebody is five times the diameter of the cylindrical section ahead of the ramp. The ramp angle that deflects the flow is increased to increase the intensity of the oblique shock wave by reducing the length of the ramp while the height remains the same.

The second and third methods for improving the recovery both reduce the amount of low-energy air that flows through the inlet. Drawings of the models that have been tested are shown in figure 2; these models are of the same general size and shape as the ramp model. With the model of figure 2(a), the boundary layer is drawn from the surface of the forebody through an auxiliary scoop at the station of the duct entrance by vacuum pumps located outside the wind tunnel. With the model of figure 2(b), energy is added to compensate for the energy decrement in the boundary layer by ejecting high-velocity air along the surface of the forebody upstream of the duct entrance. This jet is supplied by an air bottle from outside the wind tunnel, and the air is expelled through an annular nozzle that is designed to eject the air at a Mach number of 2.2. The width of the nozzle throat is 0.0045 inch and that of the outlet is 0.009 inch.

The results of tests upon these three models are shown in figure 3, in which the maximum total-pressure recovery after diffusion through the annular inlets is plotted against the Mach number of the free stream. The results are compared with the total-pressure ratio of a normal shock wave, with that of a model having no ramp or boundary-layer control, and also with that attainable with the nose inlets described in reference 1.

The model that utilizes an oblique shock wave to reduce the inlet Mach number was tested with ramp angles of 5°, 10°, 15°, and 17.5°. Throughout the Mach number range of the tests, the recovery of total pressure increases with ramp angle up to an angle of 15°, at which value the maximum total-pressure ratio is still relatively low, about three-quarters of the recovery through a normal shock wave.

With a suction slot through which 12 percent of the mass of air flowing through the inlet is drawn, the maximum total-pressure ratio attained at a Mach number of 1.36 is 81 percent and at a Mach number of 2.01, the recovery is 44 percent. Calculations based upon the available theory indicate that the amount of air in the boundary layer should be no more than 4 percent of that flowing through the inlet. The reason that the pressure recovery is not greater if more than this mass of air is removed is not understood and is being investigated at the present time.

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When high-pressure air is ejected at a Mach number of 2.2 to compensate for the energy decrement in the boundary layer, the apparent recovery is relatively high at the low supersonic Mach numbers; but, as the Mach number of the free stream approaches that of the ejected air, the improvement in the total-pressure ratio decreases. The "apparent" recovery indicates the total pressure that would exist at the face of the compressor of a turbo-jet engine. However, since the engine would have to supply the high-pressure air to the nozzle, the effective recovery, as far as the overall propulsive system is concerned, is considerably less. If the total-pressure and mass-flow ratios attained during the tests are assumed to occur in a hypothetical engine operating in the isothermal atmosphere, the greatest effective pressure recovery occurs when 14 percent of the air flowing through the inlet is recirculated. The effective recovery would then be 74 percent at a Mach number of 1.36 and 44 percent at 2.01; in other words, it is about 15 percent less than the apparent recovery. It is to be expected that scale has an appreciable effect upon these results because the process is largely dependent upon viscous forces. Tests at a larger scale will probably show greater effective total-pressure ratios.

TWIN-SCOOP INLETS

An entry, such as a twin-scoop inlet, that does not completely encircle the fuselage does not recieve all of the boundary layer resulting from the flow over the forebody and, therefore, has an initial advantantage over an annular entrance. It is to be expected that greater effective total-pressure ratios can be attained than with an annular inlet and that, for the same entrance area, the greatest pressure recovery will be attained by the inlet that encloses the smallest portion of the circumference of the forebody.

Photographs of the two twin-scoop models that have been tested are shown in figure 4. The shape of the forebody, the entrance area, and the expansion ratio of the subsonic diffusor are the same as those of the models having annular entrances. The scoops of the model shown in figure 4(a) enclose 37.2 percent of the maximum circumference of the forebody, and the height of one scoop is 75 percent of the width. The inlet of figure 4(b) encloses 61.5 percent of the circumferential length, and the height is 28 percent of the width. In order to reduce the inlet Mach number, ramps were tested as with the models having annular entrances. A ramp may have an additional advantageous effect with a twin-scoop model because of the three-dimensional nature of the flow about the scoops. A compression over the surface of the ramp may cause a cross-flow that will tend to make the boundary layer flow around the inlet.

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The only method for controlling the boundary layer flowing into the scoops that has as yet been tested is to pass the boundary layer out of the subsonic diffusor through slots cut along the sides of the duct next to the central body. A photograph of the arrangement is shown in figure 5. Slots of various widths and lengths have been tested with the models having the two different scoop shapes.

The results of the tests upon these twin-scoop models are summarized in figure 6 in which the maximum total-pressure ratio attained after diffusion is plotted against the free-stream Mach number. The reduction in the amount of boundary-layer air flowing through the inlet that results from the use of twin-scoops causes an improvement in the total-pressure ratio that is about the same as the improvement produced by the addition of a 5° ramp to the annular intake. The difference in the recovery attained by the inlet that encloses 61.5 percent of the circumferential length of the forebody and that attained by the model enclosing 37.2 percent of the circumference is less than 3 percent. The addition of a ramp improves the pressure recovery of both inlets. The maximum recovery with the 61.5-percent entry occurs with a ramp angle of about 5°; with the 37.2-percent entry the optimum ramp angle is about 10°. If slots are cut along the sides of the duct, the optimum ramp angle increases. The effectiveness of the slot increases with ramp angle; at angles less than 5° the slots cause no improvement. With the 61.5 percent entry having a slot whose depth is 50 percent of the height of a scoop and whose length is 6 percent of the length of the subsonic diffusor, the optimum ramp angle is 12° and the total-pressure ratio is about 88 percent of that occurring across a normal shock wave. The 37.2-percent entry having the same ramp and slots of the same dimensions produces a total-pressure ratio that is about 8-percent greater at a Mach number of 1.36 and the same at a Mach number of 2.01. If the length of the slots of this model is increased to 9 percent of the length of the subsonic diffusor, the total-pressure ratio attained is practically equal to that of a normal shock wave at Mach numbers between 1.36 and 1.70. The recovery after diffusion is 96 percent at a Mach number of 1.36, or it is equal to that of the Ferri-type nose inlet. Although this high recovery is obtained at the expense of external drag, the increase in the drag force may be small in comparison to the improvement in the total-pressure recovery. If so, the inlet will be satisfactory for aircraft flying at low supersonic Mach numbers. The pressure recovery decreases a small amount in relation to that through a normal shock wave for Mach numbers above 1.70. At a Mach number of 2.01 the recovery attained by this model is 94 percent of normal-shock recovery.

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REFERENCES

1. Ferri, Antonio, and Nucci, Louis M.: Preliminary Investigation of a New Type of Supersonic Inlet. NACA RM No. L6J31, 1946.

2. 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.

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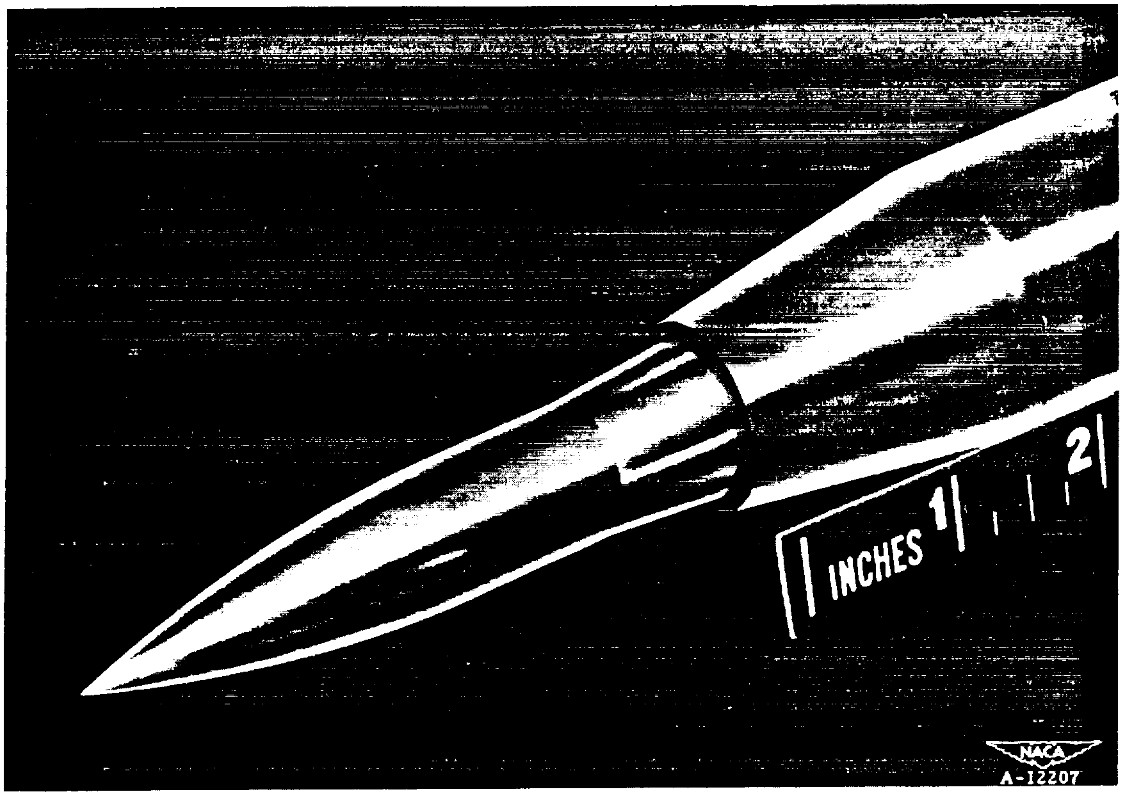
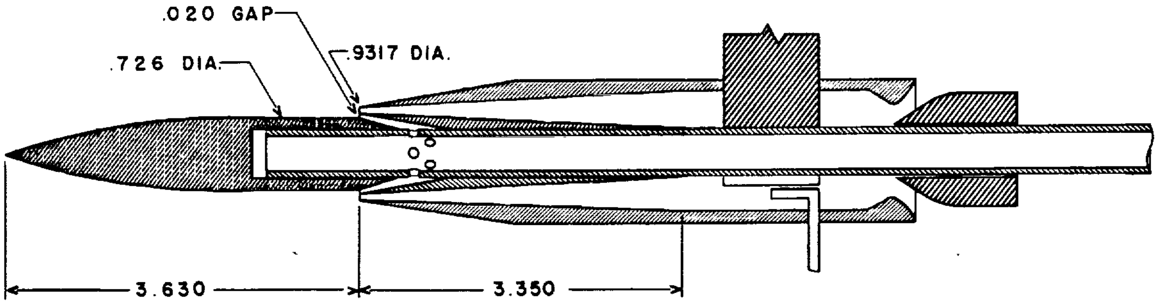
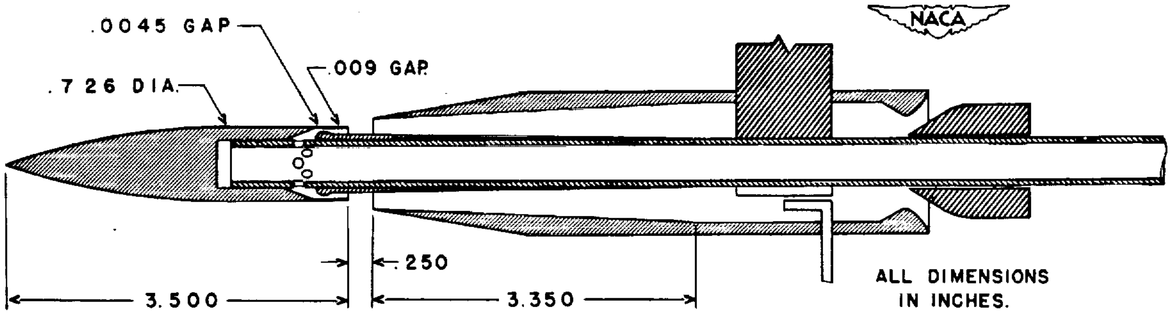


Figure 1.- Annular-entrance model with 5° ramp.



(a) Model with boundary-layer suction slot.



(b) Model with nozzle to accelerate the boundary layer.

Figure 2.- Annular-entrance models with boundary-layer control.

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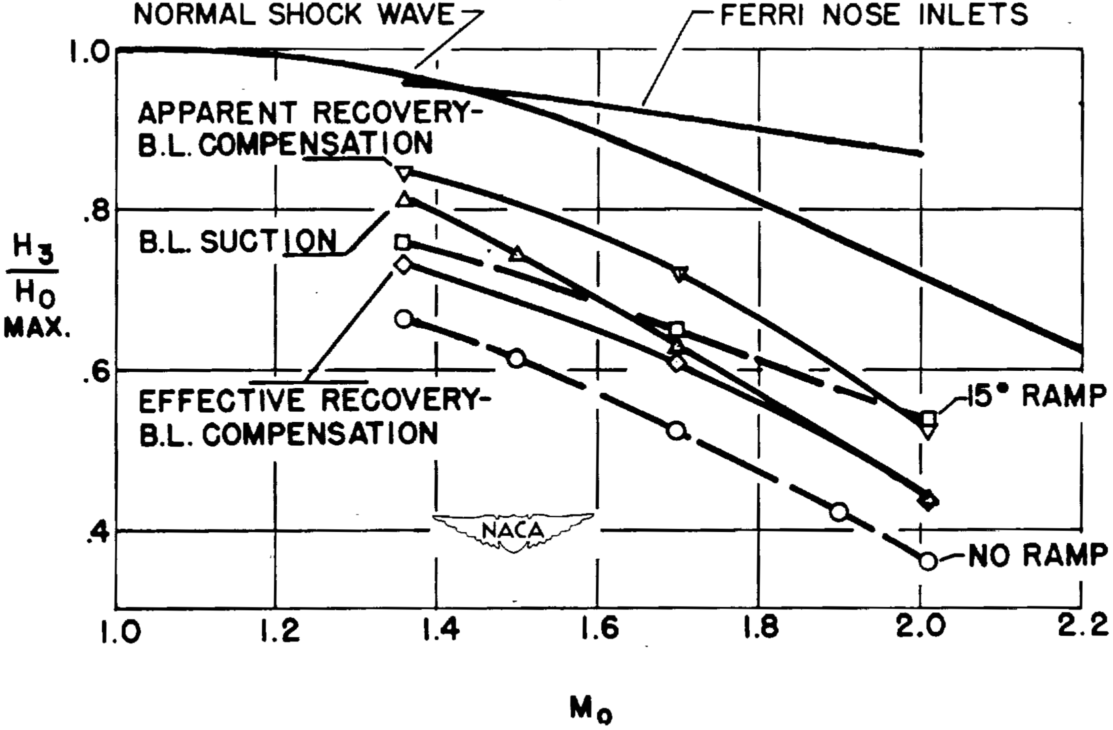
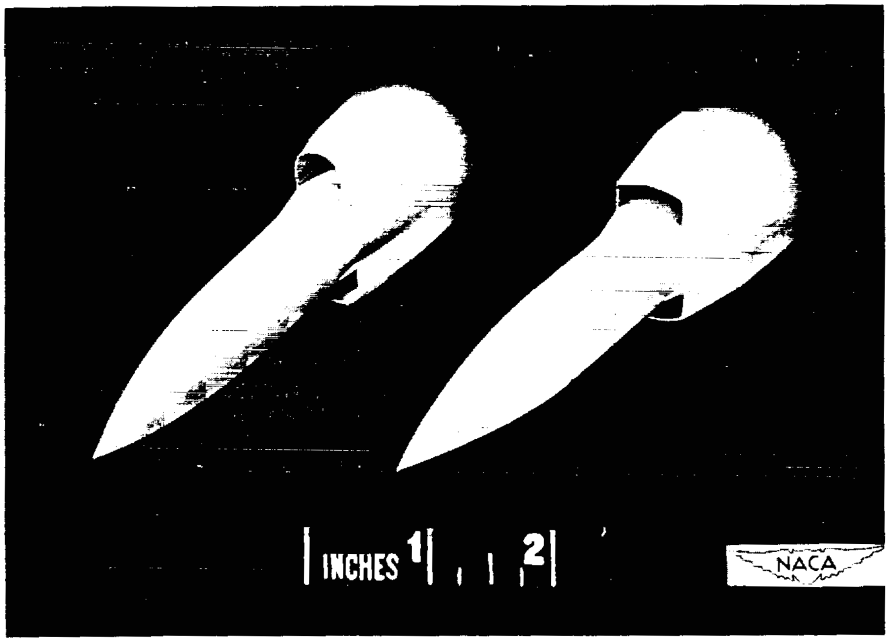


Figure 3.- Variation of maximum total-pressure ratio with Mach number for annular-entrance models.



(a) Inlet enclosing 37.2 percent of the circumference of the forebody.

(b) Inlet enclosing 61.5 percent of the circumference of the forebody.

Figure 4.- Twin-scoop models with 9° ramps.

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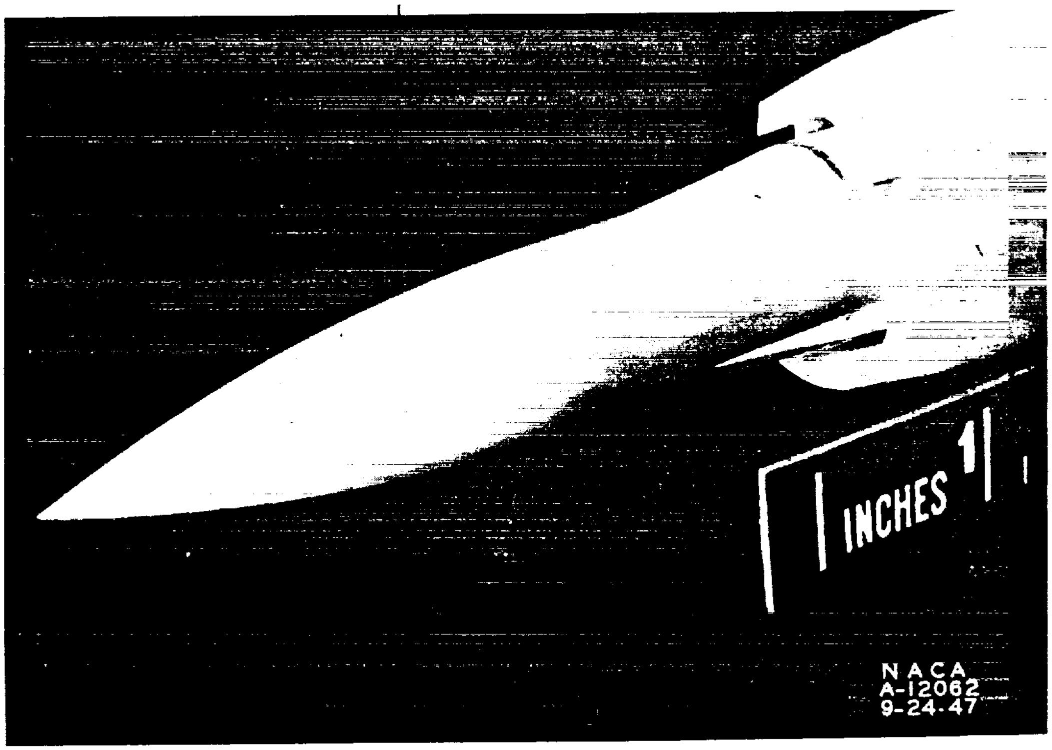

Figure 5.- Twin-scoop model with slots.

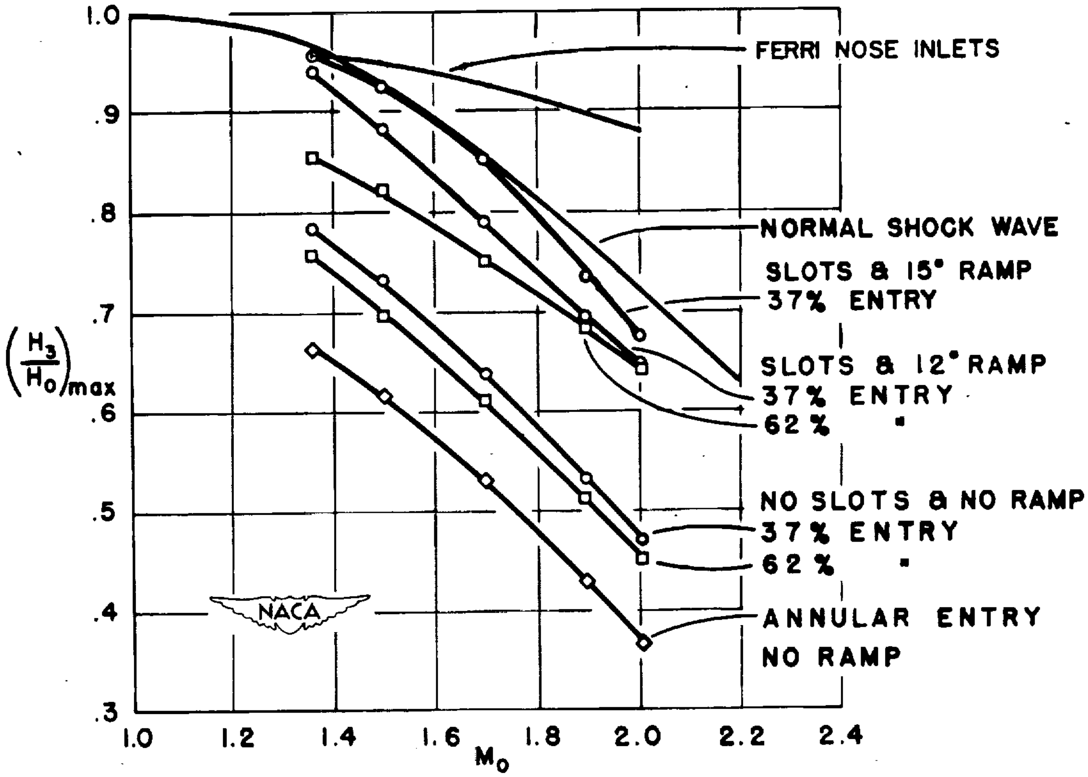

Figure 6.- Variation of maximum total-pressure ratio with Mach number for the twin-scoop models.

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