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SUMMARY OF NACA SUBMERGED-INLET INVESTIGATIONS

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On many existing and proposed airplanes the fuselage shape is assuming a greater importance. A dominant factor determining the shape of the fuselage for a pursuit-type turbojet airplane may be the ducting system. The general fundamental requirements to be satisfied by jet airplane ducting systems are high efficiency of the impact or ram pressure conversion and small external drag coefficient. The importance of ram recovery can be visualized by considering its effect on a typical pursuit-type airplane, powered by a jet engine and traveling 650 miles per hour at sea level. Analysis shows that for every 10 percent decrease in ram recovery at this speed the net thrust decreases 7 percent and the specific fuel consumption increases about 5 percent. The resultant adverse effects on range, climb, and maximum speed are quite large.

Recognizing the need for a new type inlet which would combine the good qualities of the nose inlet with the short internal ducting of the external scoop, the National Advisory Committee for Aeronautics has developed what is known as a "submerged air inlet". This intake is shown in figure 1 and the component parts are noted in this figure. The entrance is completely submerged below the contour of the fuselage or wall into which it is placed. The air travels down an inclined surface, which we have termed the ramp. Ramp angle is the angle of the intersection of the ramp floor with the fuselage skin, ramp wall divergence is the divergence of the ramp side wall from the parallel, and width-to-depth ratio is simply the ratio of the corresponding dimensions of the inlet. This paper summarizes the results of research on NACA submerged inlets in the 7- by 10-foot, the 40- by 80-foot, and the 16-foot high-speed tunnel sections at the Ames Aeronautical Laboratory.

An entry with parallel ramp walls was the first to be investigated, these tests having been conducted in a small wind channel. As expected, the pressure recovery with this parallel-walled entry was not very good, especially at the low mass flow ratios. It was then reasoned that shaping the walls to conform to the streamlines at some desired mass flow ratio might result in better duct characteristics. Such an entry with divergent ramp walls was designed and tested.

A comparison of the pressure recovery for this inlet with that for a parallel-walled intake is shown in figure 2. These data were obtained from a full-scale duct installation in the Ames 40- by 80-foot tunnel. The ordinate for these curves is ram-recovery ratio, which is the ratio of the ram pressure recovered to the ram pressure

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available. This ratio was selected because it is relatively constant for subsonic Mach numbers and is readily measurable. The abscissa is mass flow ratio, which in the incompressible case is equivalent to inlet velocity ratio. Comparison of the ram recoveries for the parallel- and divergent-walled intakes indicates that a considerable increase results from the use of divergent walls at the low mass flow ratios both at the entrance and at the compressor.

The principal cause of the lower ram recovery for an inlet with parallel walls, especially in the mass flow range less than 1.0, is the rapid growth of the boundary layer due to the adverse pressure gradient along the ramp. Such is not the case for the inlet with divergent walls. Even though the pressure gradient is no less adverse, surveys at the entrance show that the boundary layer on the floor of the divergent-walled inlet starts anew and remains relatively thin, despite the adverse gradient. This probably accounts for the difference in ram recovery at the low mass flow ratios between divergent and parallel-walled submerged inlets. The pressure losses with divergence have a different origin. The boundary layer on the fuselage skin, outside the ramp, is partially kept from flowing over the divergent ramp edges by two factors. The first of these is the pressure gradient over the rear 40 percent of the ramp, the pressures in this region being greater than those of the surface into which the inlet is placed. The second factor is that the outside boundary layer does not flow over the sharp edge of the ramp wall as easily as it does with the edge rounded. The cause for this is not fully understood.

The pressure losses at the entrance for an NACA submerged inlet are concentrated in two symmetrical regions, as shown in figure 3. A major part of these pressure losses appears to originate from a turbulent mixing process set up by a change in the flow direction as indicated in this same figure. It is probable that some of the outside boundary layer is enmeshed and becomes a part of this disturbance.

An extensive investigation has been made to determine the effect of modifications on submerged inlets. Variations in ramp angle, ramp-wall divergence, width-to-depth ratio, ramp-floor shape, and boundary-layer thickness have been tested. Results are given in reference 1. An evaluation of these data indicates that satisfactory duct characteristics may be obtained for a range of the test variables. It appears that an optimum design of these inlets should employ curved diverging ramp walls, a ramp angle between 5° and 7°, and a width-to-depth ratio of from 3 to 5. From measured lip and ramp pressures, high critical speeds were estimated.

The drag attributable to this type of inlet is shown in figure 4 as a function of mass flow ratio. These data were obtained on a $\frac{1}{5}$-scale typical duct installation on a fighter airplane. The drag coefficients

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are based on wing area. For an airplane using a 24c jet engine and operating at a high-speed design mass flow ratio of 0.60, there is no incremental change in airplane C_d, due to the duct installation.

In order to check the validity of the small scale measurements, models identical except for scale were designed and tested in both the Ames 7- by 10-foot and the Ames 40- by 80-foot tunnels. The agreement between the $\frac{1}{5}$-scale and full-scale tests is shown in figure 5. The duct location used in this investigation is noted in the figure. These data show excellent agreement between the two tests and indicate that with proper design high ram recoveries are attainable on full-scale installations. (Reynolds number based on duct depth.) It might be added further that the variation of ram recovery ratio with angle of attack was slight for these and other installations.

One especially important aspect of this study concerned the effects of high-speed flight on the operation of this type duct. Tests of a duct installation on a $\frac{1}{4}$-scale model of a fighter airplane have been made in the Ames 16-foot high-speed tunnel. The results of these tests illustrate the effect of Mach number and of the location of the inlet on the fuselage. The effect of Mach number is shown in figure 6, for constant mass flow ratios. The recovery remains essentially the same for the entire Mach number range of the tests (from 0.3 to a maximum of 0.875). It has not yet been determined how high a Mach number can be attained while still maintaining the high pressure recovery. In figure 7 it may be seen that at a Mach number of 0.875 the critical pressure coefficient was just reached along the front of the ramp floor. A shock disturbance would probably first occur in this high velocity region when the free-stream Mach number became somewhat greater than 0.875. It may be seen that this region extends only over a small portion of the duct width, the flow outside of the ramp on the fuselage skin being still subsonic. Because the disturbance takes place over a smaller duct width, it might then be indicated that the pressure recovery would decrease less severly for a divergent-walled entry than for a parallel-walled one, once the airplane speed was increased enough so that a shock wave formed along the ramp.

Given in figure 8 are the four inlet locations on the fuselage of the $\frac{1}{4}$-scale model, in percent of the root chord forward or rearward of the wing leading edge. It may be seen that the recovery decreases slightly as the inlet is moved rearward. This was expected since the boundary-layer thickness increases in this direction. Even though the decrease in ram recovery ratio may not be considered prohibitive, caution

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should be exercised in moving the inlet rearward. Primary consideration should be given the flow field into which the inlet is placed. At the farthest rear position (58.4 percent root chord) the flow along the basic fuselage became sonic at about the same time as the flow on the wing. When the duct was located at this position, the pressure recovery began to decrease when the Mach number exceeded 0.80. This drop became much more marked at moderate angles of attack, the flow on the side of the fuselage abruptly separating due apparently to the position and intensity of the shock wave on the wing.

In conclusion, NACA submerged inlets may be designed to obtain high ram recovery at a low resultant drag. High-speed tests on a $\frac{1}{4}$-scale model showed that for this installation the ram recovery remained essentially constant up to a Mach number of 0.875.

REFERENCE

1. Mossman, Emmet A., and Randall, Lauros M.: An Experimental Investigation on the Design Variables for NACA Submerged Entrances. NACA RM No. A7I30, 1947.

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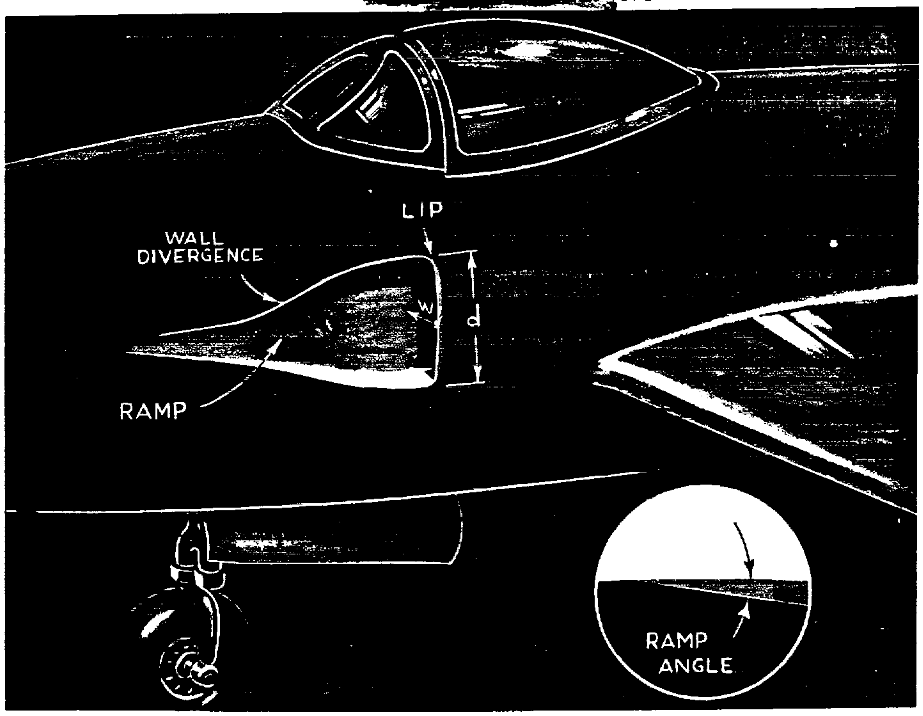

Figure 1.- Schematic view of an NACA submerged inlet installation.

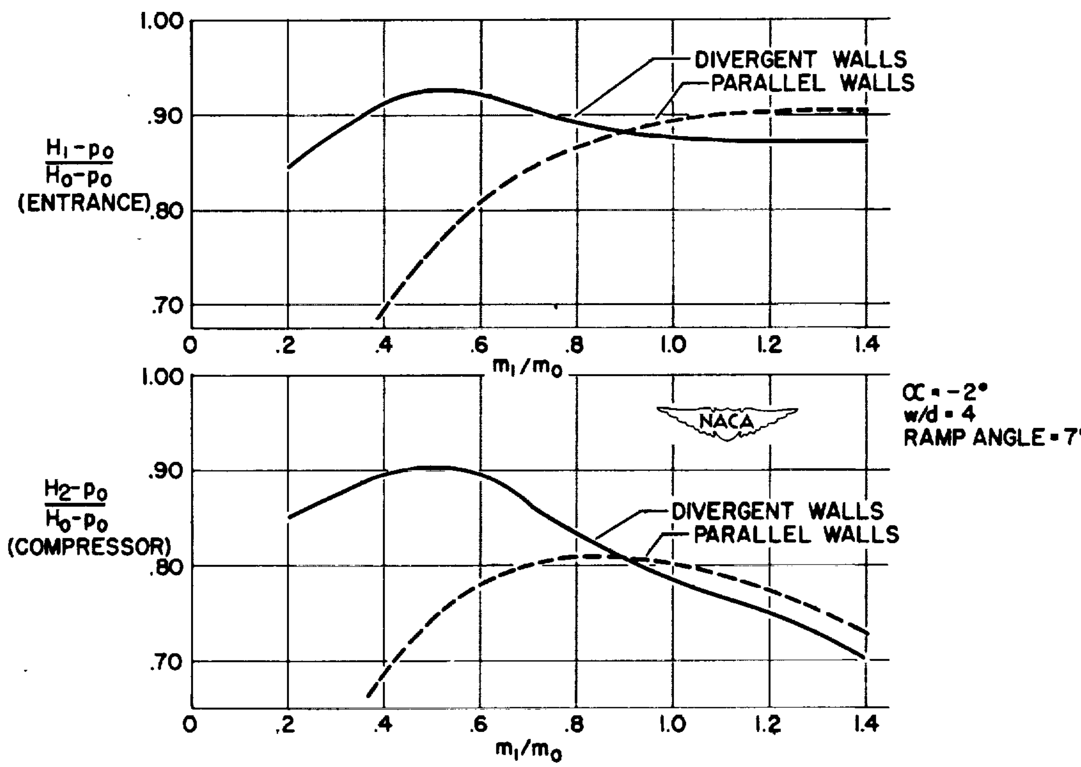

Figure 2.- Comparison of the ram recovery ratio for divergent- and parallel-walled submerged inlets. Full-scale duct installation.

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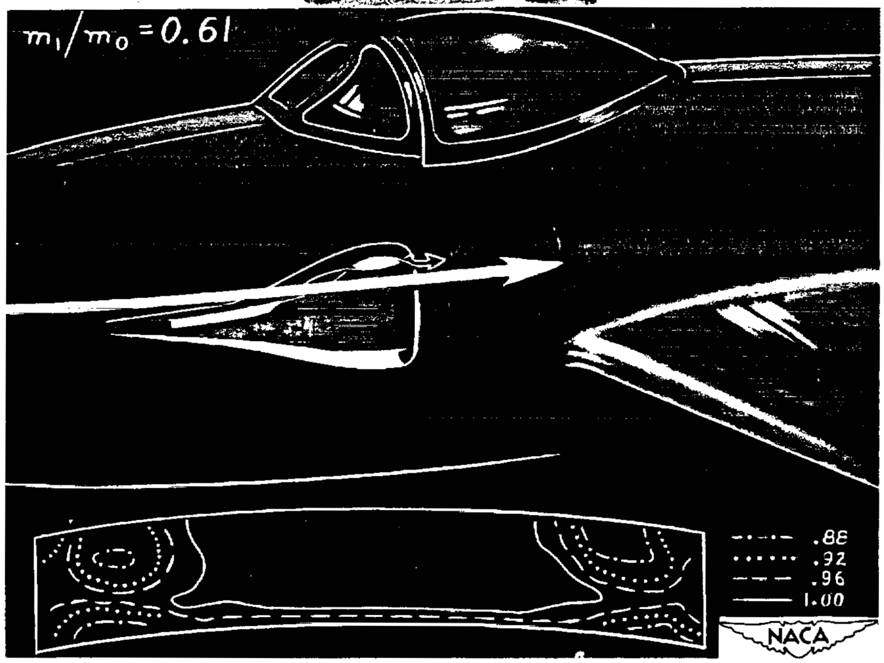

Figure 3.- Ram-recovery-ratio contours at the entrance of an NACA submerged duct installation.

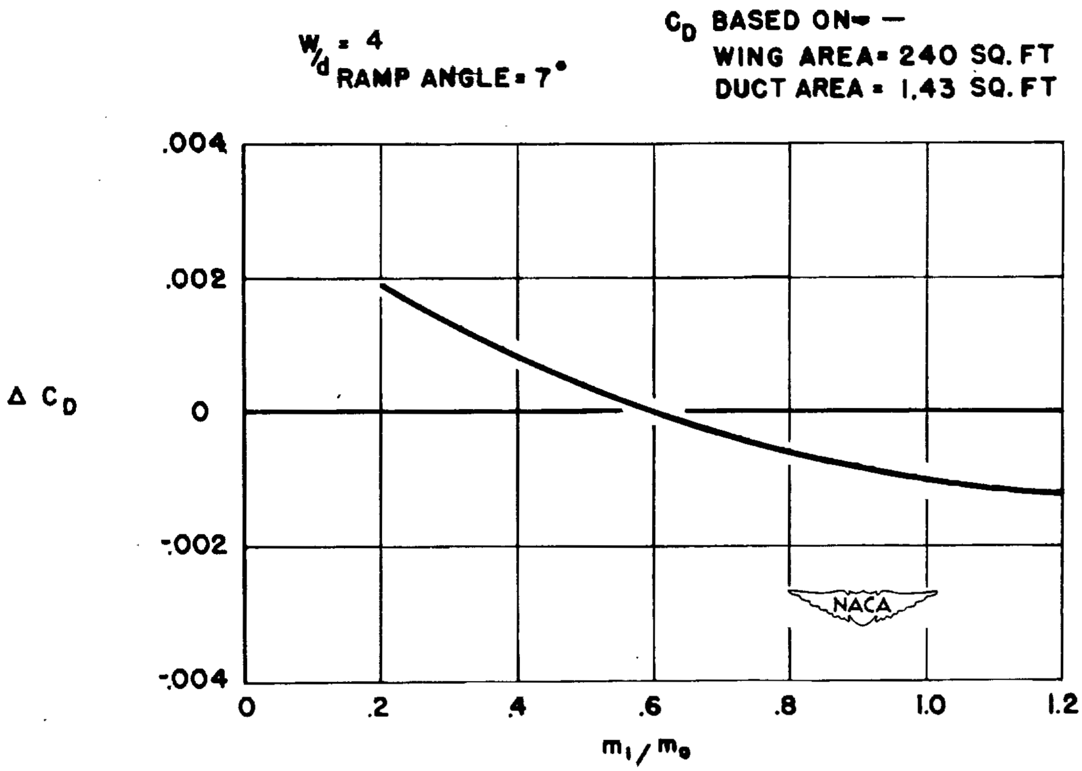

Figure 4.- Incremental change in airplane drag coefficient due to an NACA submerged duct installation. $\frac{1}{5}$-scale model of a fighter airplane.

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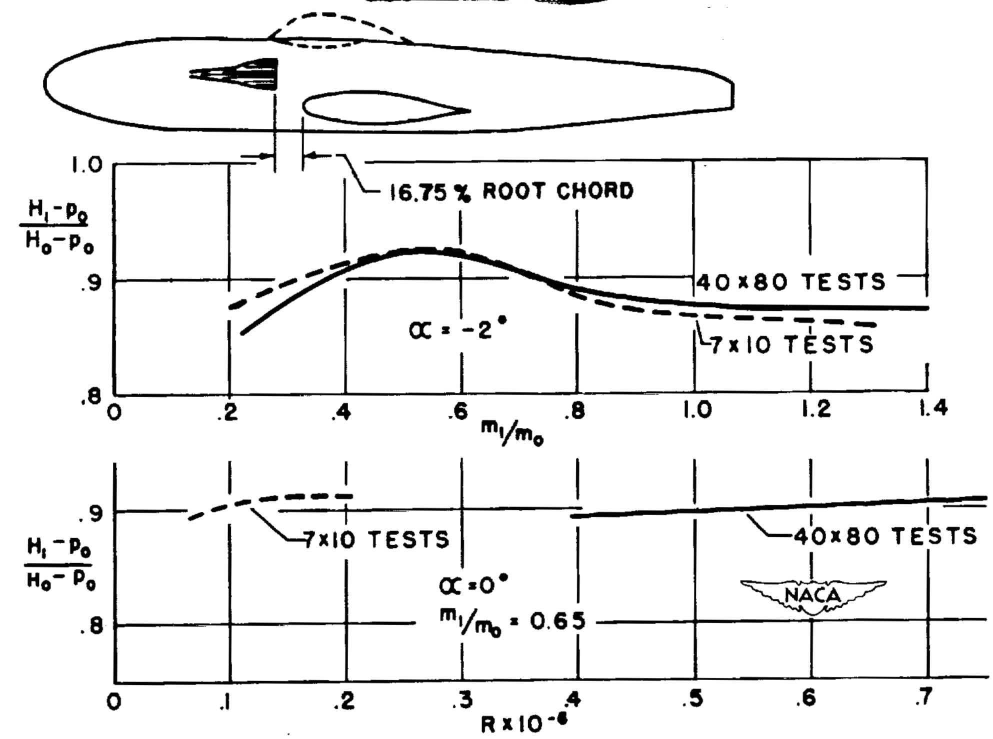

Figure 5.- Entrance ram recovery ratio for comparison of $\frac{1}{5}$-scale and full-scale NACA submerged duct installations.

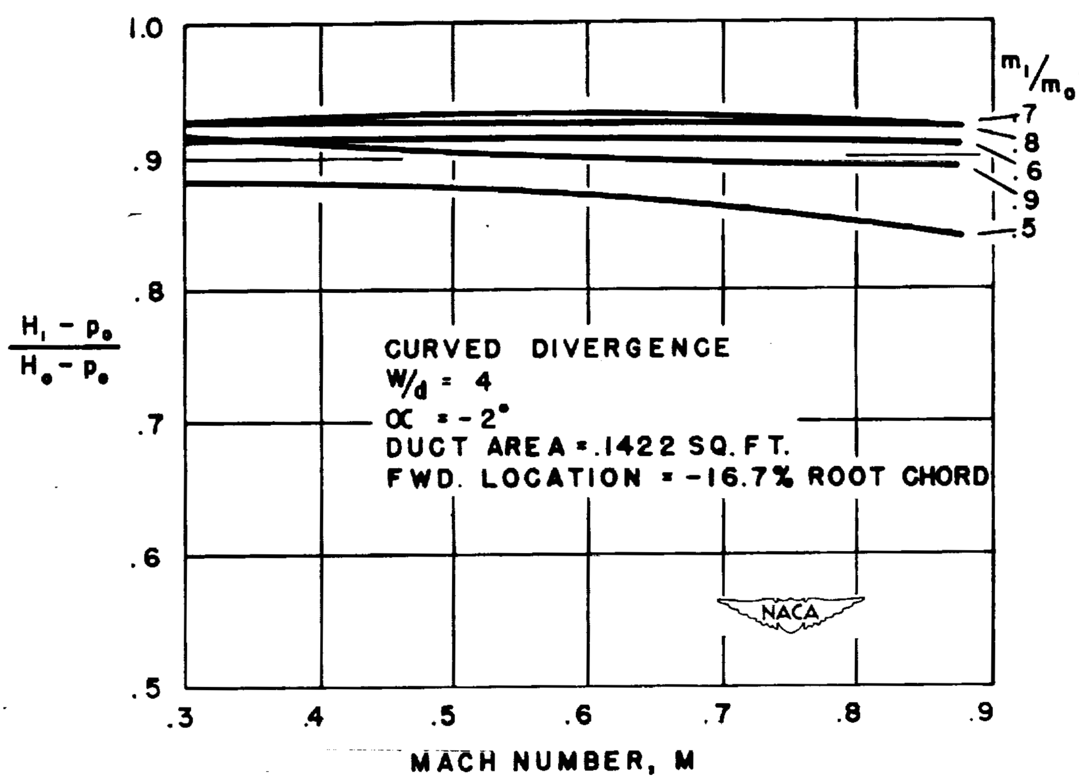

Figure 6.- Effect of Mach number on the ram recovery ratio at the entrance for a $\frac{1}{4}$-scale NACA submerged inlet installation.

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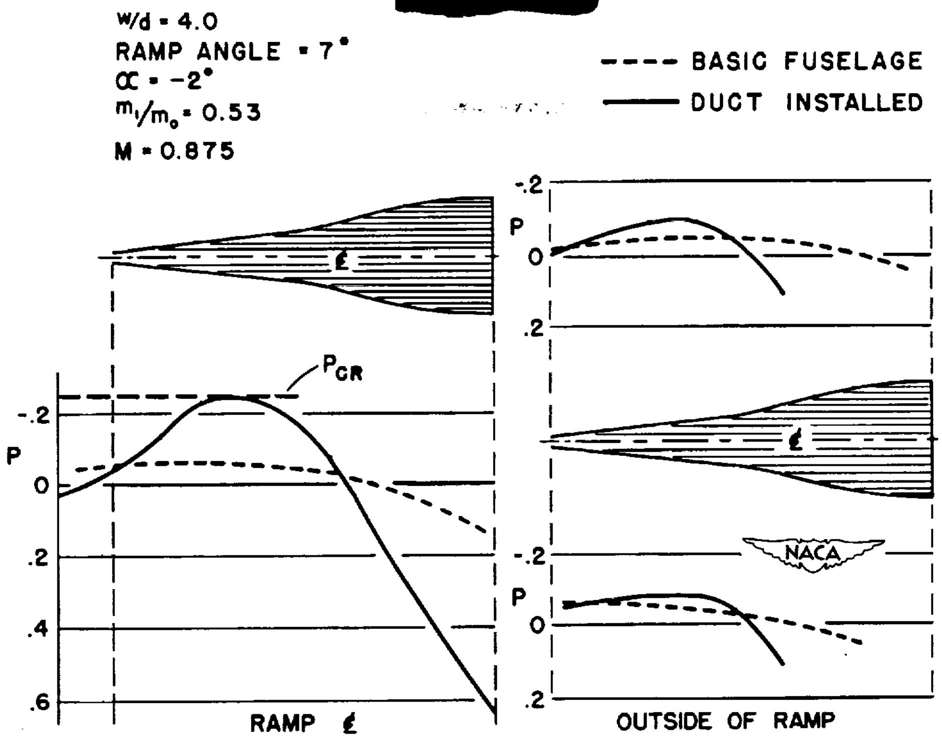

Figure 7.- Pressure distribution along the ramp of an NACA submerged inlet installation. $\frac{1}{4}$-scale typical fighter airplane.

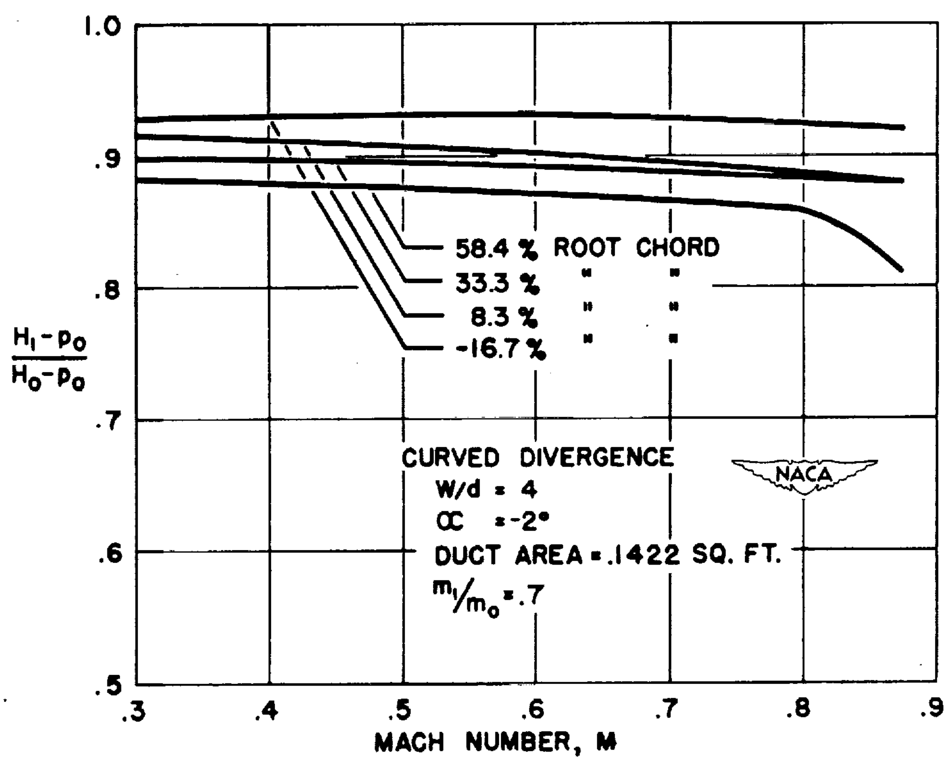

Figure 8.- Effect of an NACA submerged duct location on the fuselage of a $\frac{1}{4}$-scale typical fighter airplane.

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