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NOSE INLETS

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For some years the NACA has had in operation a continuous research program on air inlets. The most recent developments and applications of the nose inlet work will be presented in this paper. First, however, some of the past work will be briefly reviewed because of its importance as background.

The basis of much of the high-critical speed inlet work originated with the development of NACA cowl "C" and nose "B" (references 1 and 2). These two inlets were derived on a basis similar to that for optimum critical speed airfoils: namely, a flat pressure distribution with no pressure peaks. It was found that although these two inlets were of greatly different proportions and critical speeds, the basic ordinates were essentially identical. The ordinates were consequently applied to a large family of nose inlets which were tested at medium and high speeds to determine the effects of proportions. The results were published (reference 3) in the form of design selection charts, a simplified version of which is shown in figure 1.

The selection procedure is shown by the arrows; starting at the bottom with the desired value of mass flow coefficient and proceeding vertically to the value of critical Mach number desired, the d/D or entrance diameter ratio is obtained. Continuing to the top of the chart, the X/D or length ratio is obtained. Application of the 1-series ordinates to those proportions yields a nose inlet of the required characteristics. Sample selections are shown for three values of critical Mach number and show that the higher critical Mach numbers involve cowlings of greater length.

These NACA 1-series charts are directly applicable to the design of open-nose inlets and were used in the design of the external lines of the D-558 airplane installation. The charts are also applicable to the design of rotating cowlings, such as the NACA "E" cowling (reference 4).

In addition, the applicability to the design of a protruding fuselage scoop has been demonstrated and reported in an NACA paper (reference 5). Recent tests of NACA 1-series cowlings with protruding propeller spinners (reference 6) have corroborated an analysis included in reference 3 by showing that the effects of spinners of reasonable size are small and predictable, and that cowlings for propeller-driven airplanes can be designed from NACA 1-series data.

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The spinner shape has been found to have important effects upon the flow into a cowling (reference 6). It is usually desirable to admit air at a low value of inlet velocity ratio, since external compression is accomplished at an efficiency of one-hundred percent, while internal compression is accomplished at a somewhat lower value. At values of inlet velocity less than unity, an adverse pressure gradient exists into which the spinner boundary layer must advance. This pressure gradient, coupled with the pressure field of the spinner, may be sufficient to separate the flow at a relatively high value of inlet velocity ratio, thus making it impossible to obtain stable inlet flow with low losses at low values of inlet-velocity ratio. Pressure distributions measured without propeller on two shapes of spinners ahead of a 1-series cowling operating at a medium value of inlet-velocity ratio are shown in figure 2. The curved spinner was designed using the 1-series inlet profile and is approximately elliptical in section. The conical spinner is a straight-sided cone ahead of the inlet. The spinner with the curved surface evinces a higher peak pressure and a consequently greater adverse pressure gradient ahead of the inlet than does the conical spinner.

The effect of this gradient on spinner boundary layer is shown in the right half of figure 2. As the inlet velocity ratio is decreased, an abrupt increase in boundary layer thickness, indicating separation, occurs for both spinner shapes. The inlet velocity ratios for separation are of the order of 0.53 for the curved spinner and approximately 0.12 lower, or 0.41, for the conical. It is believed that the permissible value of inlet-velocity ratio can be still further lowered by modifying this conical spinner. If the cone angle is increased, for example, the pressure gradient can be expected to further diminish, thus permitting a lower value of inlet-velocity ratio to be obtained before separation occurs.

With regard to the general effect of spinners on the critical speed of cowlings, an extension of work by Ruden and Kucheman in Germany has provided an interesting analysis. The theory considers the average forces (obtained by integration of surface pressures) on the cowling and spinner and states that the average force on the cowling plus the average force on the spinner, if present, is equal to the change of momentum of the air entering the cowling. Simultaneous solution of equations for the conditions with and without a spinner gives the spinner force required for zero effect upon the critical Mach number of the cowling. A plot of this spinner force or pressure against inlet-velocity ratio is shown in figure 3. Values above this line indicate a decreased critical Mach number due to the spinner. Variations of average spinner pressure with inlet-velocity ratio obtained by integrating measured pressure

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distributions are shown for the conical and curved spinners of reference 6. The intersection of the curves shows the values of inlet-velocity ratio below which the particular spinner can be used without affecting the cowling critical Mach number. This figure shows that the plain conical spinner can be used in the low inlet-velocity ratio range where its use is desirable from the standpoint of boundary-layer separation. The curved spinner should be used for medium values of inlet-velocity ratio, but its use, at least in the "short" condition, appears to be limited to values of the order of 0.6.

The effect of using a conical spinner at too high a value of inlet-velocity ratio is shown in the pressure distribution on the right of figure 3. A peak is produced at the lip by the conical spinner, whereas the curved spinner has virtually no effect upon the flat cowling pressure distribution at this value of V_1/V_0.

The conical spinner shown in figures 2 and 3 remains conical to the inlet, making the transition to axial aft of the inlet. It has been found from experimental data that the principal influence of the inlet extends to a distance $1\frac{1}{2}$ to 2 times the inlet height ahead of the inlet for spinners of reasonable size. It therefore appears probable that a curved surface might be used in this region to bring the spinner surface axial at the entrance with little or no adverse effect upon the pressure gradient. The advantage of this is that a spinner of smaller maximum-diameter is obtained for given propeller hub clearances. Also, the more axial flow at the entrance may have less tendency to produce pressure peaks at the cowling lip.

The problem of designing air inlets for transonic military airplanes is complicated by simple military requirements such as good visibility downward and space in the nose of the airplane for armament. These two requirements in some cases tend to rule out the nose inlet, which usually represents the optimum from the standpoint of pressure recovery at the inlet, and make necessary some sort of fuselage side inlet, with sufficient fuselage volume ahead of the inlet to house the pilot and armament. The problem which exists in the design of any such configuration is that the fuselage ahead of the inlet must be shock-free in order to avoid shock-separated flow into the air intake. This means that, for a transonic airplane, the flow velocities on the fuselage ahead of the inlet must be substream. A theoretical analysis showed that in order to obtain the required substream velocities, the fuselage forward of the inlet must be very nearly conical in shape. In figure 4 is shown such a configuration which has been tested at low speeds (reference 7). It consists of an NACA 1-series cowling,

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an approximately conical nose, and two canopies whose sections are approximately wedge-shaped forward of the inlet. The low-speed tests showed that substream velocities are obtained ahead of the inlet on all surfaces, thus indicating that shock-free flow can be obtained up to a Mach number of 1.0. Above a Mach number of 1.0, a small shock, first unattached then conical, can be expected to compress the flow on the cone to subsonic up to flight Mach numbers of the order of 1.2. This configuration therefore appears to have characteristics which merit consideration for transonic military aircraft.

In all of the foregoing material, the critical Mach number is defined in the usual fashion: the Mach number at which sonic velocity is first attained at some point on the surface of the body. Numerous tests of airfoils have indicated this criterion to be conservative by showing that clearance exists between critical Mach number and the Mach number at which significant changes occur in the aerodynamic forces. A similar clearance might reasonably be expected in the case of three-dimensional bodies. The amount of clearance available and the nature of the supercritical drag rise are of considerable interest with regard to transonic aircraft.

A preliminary investigation now underway at the Langley 8-foot high-speed tunnel has provided some information on this subject. The results of the tests of one fuselage shape are shown in figure 5. The body consists of an NACA 1-50-100 nose inlet one diameter in length, a cylindrical center section four diameters in length, and a tail section three diameters in length, making an overall fineness ratio of eight. The model was supported by a sting at the tail, with provisions for ducting the internal flow through the sting. The drag of the model was measured by a wake survey rake located on the sting as shown in the figure.

The drag curve for the body at $\alpha = 0^\circ$ is shown in the lower left portion of figure 5. The measured critical Mach number is about 0.8, very close to that predicted by low speed data and from the design chart shown previously. At a Mach number 0.05 to 0.07 above the critical a slight drag rise appears, which continues to increase very slowly up to the highest test Mach number, 0.93 where the drag coefficient reaches a value 27 percent above the lowest value obtained.

Some explanation of the cause of this drag rise and the reason for its small magnitude is found by examination of the pressure distributions and the wake profiles.

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Pressure distributions are shown for three Mach numbers: 0.6, 0.8 (approximately the critical Mach number), and 0.93, the highest Mach number obtained. For the last case, a large area of supersonic velocities is shown to exist, followed by a shock of considerable pressure rise. The pressure recovery at each Mach number is, however, essentially identical over the cylindrical section and at the tail of the body, indicating that no significant separation has occurred.

The wake profile (right half of fig. 5), plotted as point drag coefficient against distance from the surface of the body, also shows no significant separation. Instead a moderate thickening of the boundary layer is shown to occur. A direct shock loss is also measured just outside the boundary layer but is too small to be seen on the plot shown. The contribution of this area to the total drag is therefore negligible.

In conclusion: Data are available for the design of various types of nose inlets, including cowlings with propeller spinners. Also, a type of fuselage side inlet which appears useful through the transonic range has been developed. Tests of a nose inlet at supercritical speeds have shown that, as in the case of airfoils, significant clearance exists between the critical Mach number and the Mach number at which a drag rise occurs. The moderate drag rise which occurs up to a Mach number of 0.93 is due to thickening of the boundary layer by the increased adverse pressure gradient rather than to direct shock losses and shock-induced separation.

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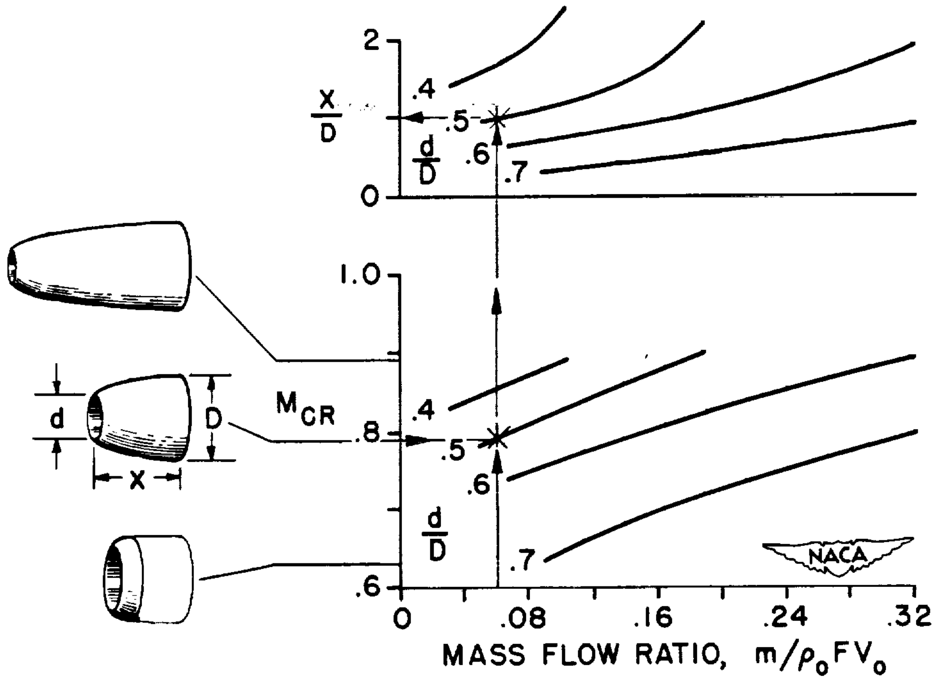
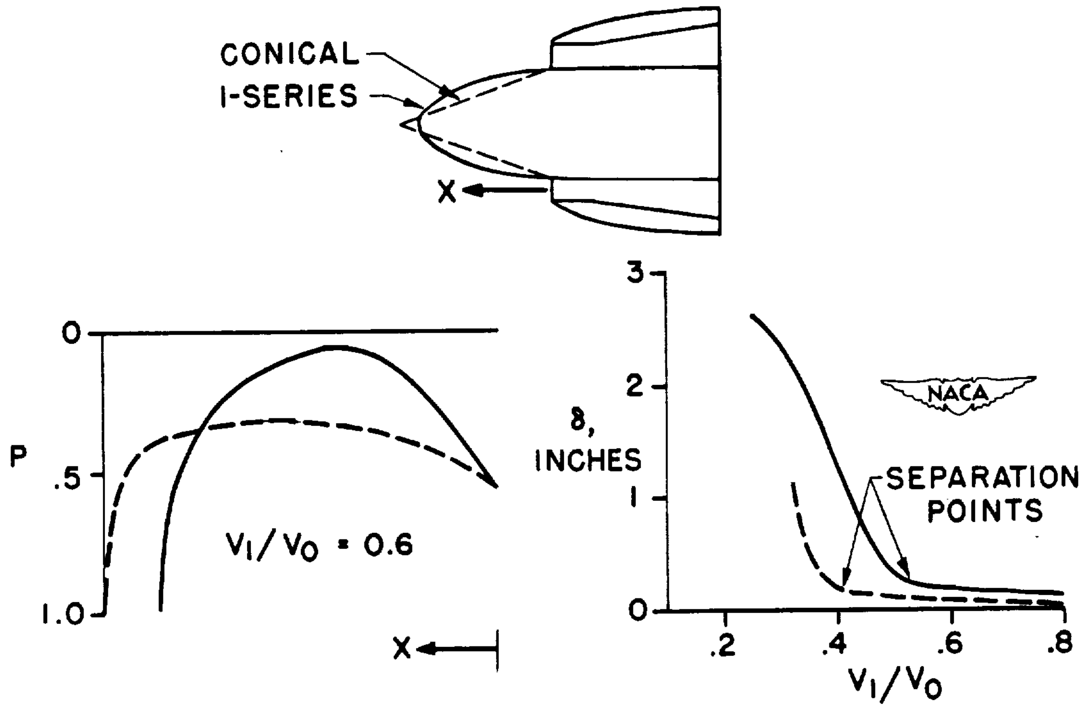


NACA I-SERIES DESIGN CHART

Figure 1.



EFFECTS OF SPINNER SHAPE ON INTERNAL FLOW

Figure 2.

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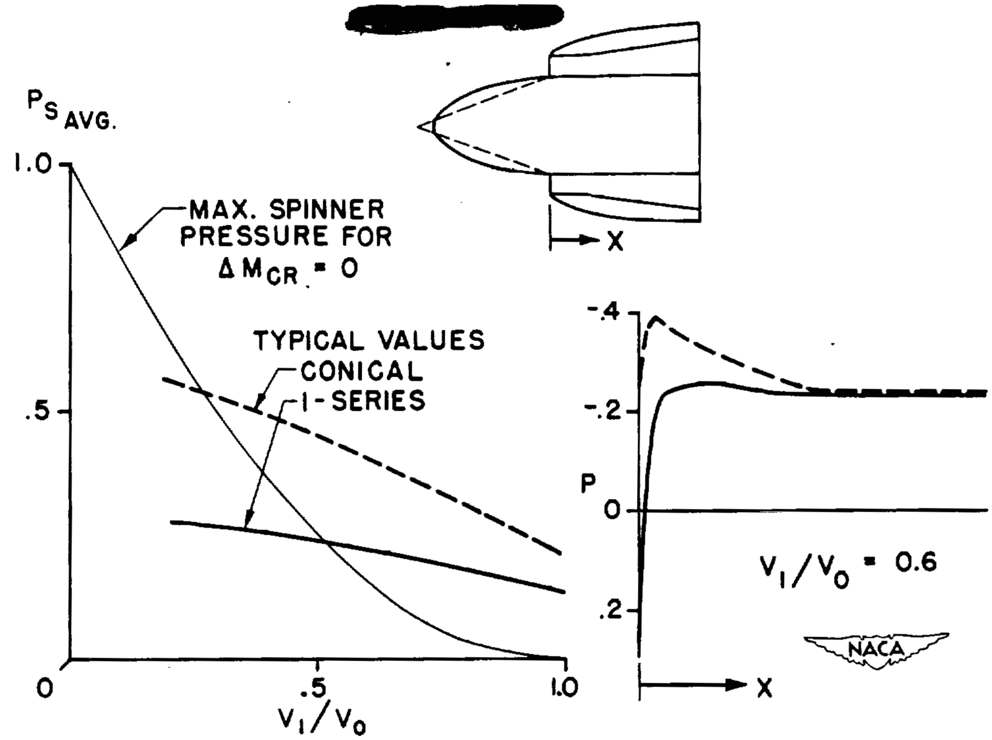
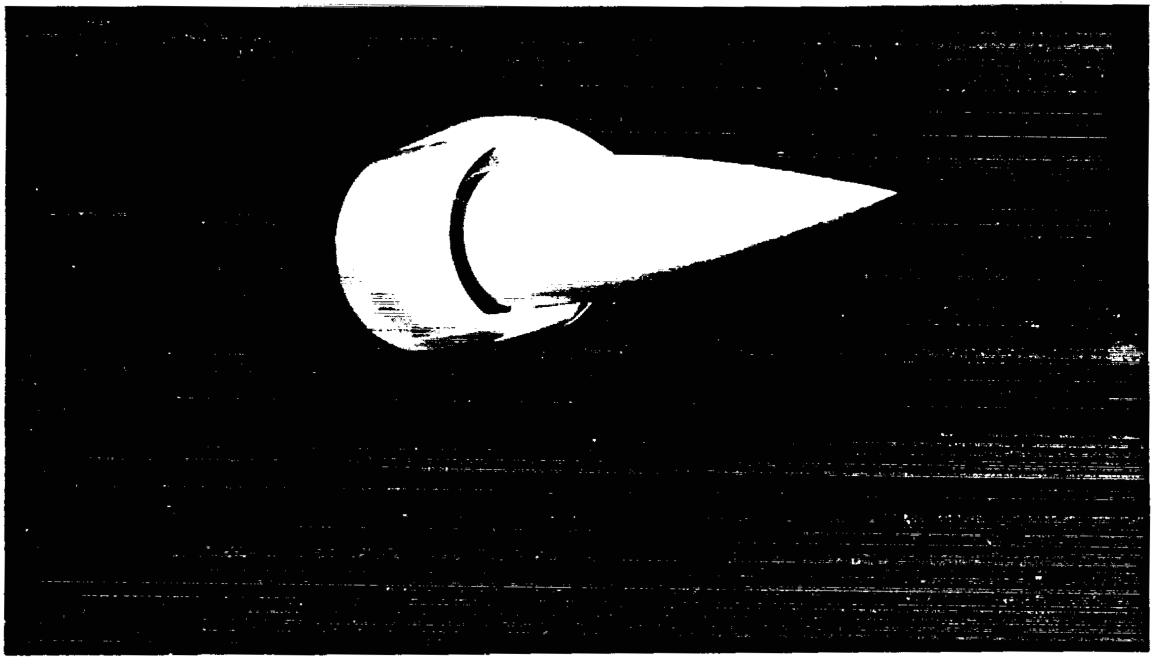


EFFECTS OF SPINNER SHAPE ON EXTERNAL FLOW

Figure 3.



NACA TRANSONIC INLET

Figure 4.

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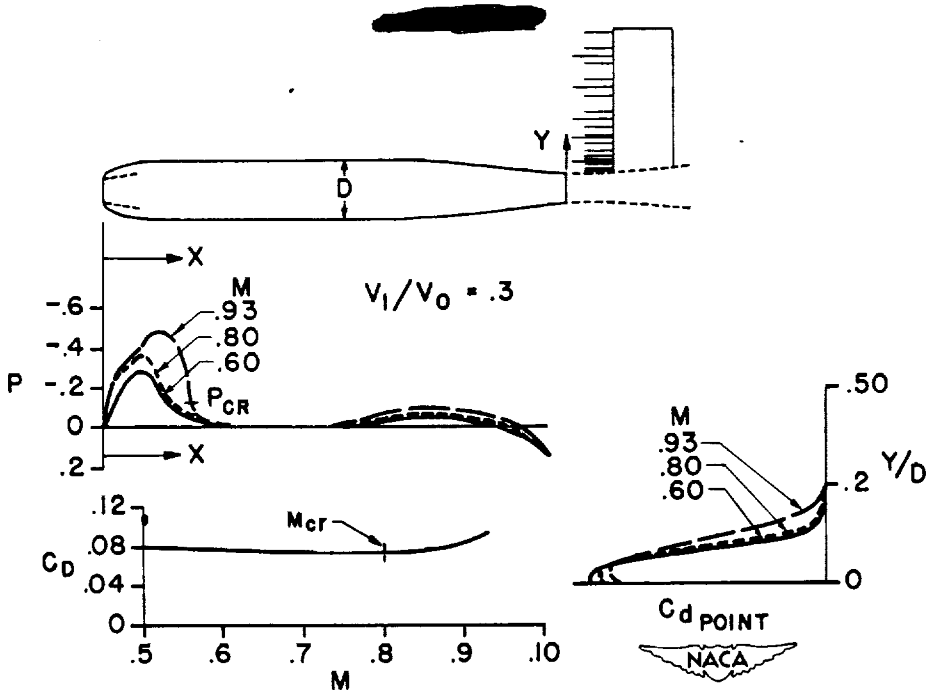

SUPERCRITICAL CHARACTERISTICS OF NACA 1-50-100 NOSE INLET

Figure 5.

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