# Method for Increasing Wind Tunnel Mach Number for Large-Scale Inlet Testing

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## Theme

FOR the development of efficient mixed-compression inlet systems for supersonic aircraft, relatively large-scale models are required to accurately assess the inlet performance. Large-scale models are particularly essential as design inlet Mach numbers increase above about $M^\infty = 2.2$. That is, for mixed-compression inlets the throat contraction ratio increases, resulting in small throat heights and large negative pressure gradients; under these conditions accurate measurements of the inlet performance parameters would be difficult without large models.

For inlet tests above Mach numbers of 3.5, few wind tunnels exist that are suitable for large-scale (50 cm capture diam) models. To overcome this problem, a simple and inexpensive technique to extend the Mach number range in existing wind tunnels for large-scale inlet testing has been investigated. The technique involves an expansion plate, wherein flow is expanded two-dimensionally around the sharp leading-edge to create a local uniform flow field with higher than freestream Mach numbers. Previously, flow expansion plates have been used to vary the Mach number in supersonic tunnels,[1,2] and occasionally they have been used to achieve special test conditions.[3]

The objective of the investigation was to show the feasibility of using locally expanded flow to extend the Mach number range of supersonic wind tunnels for large-scale inlet testing. The primary considerations of this investigation were to determine the Mach number increase possible and to define the uniformity of the expanded flowfield.

## Contents

A small-scale expansion plate model consisting of a flat plate with a sharp leading edge that could be rotated to various expansion angles, mounted between two fixed side plates was tested in the Ames 8- × 8-in. blow-down wind tunnel. Flowfield and boundary-layer data were obtained. Figure 1 shows the average exit Mach number (as determined from an 8-tube pitot flowfield rake) of the expanded flow as a function of the expansion plate angle. The Mach number at each tube position was determined from the ratio of pitot pressure to freestream total-pressure measurement. The tunnel freestream Mach number of 3.47 was expanded to a maximum of 4.34, which corresponds to the expansion angle limit of 12.3°. Prandtl-Meyer inviscid expansion theory compares well with experiment up to approximately 7° with some small deviation at higher expansion angles. Mach number variations in the expanded flowfield were small, being approximately the value of freestream variations in the test facility.

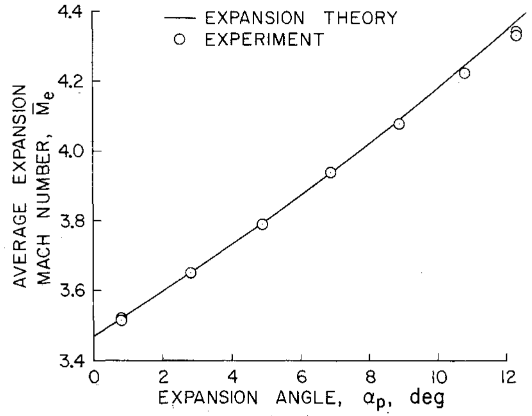


**Fig. 1 Expansion plate exit Mach number.**

Expanded flow pitot-pressure-ratio profiles on the model centerline are shown in Fig. 2 as a function of expansion angle. Some variations in pitot pressure outside the boundary layer can be seen; however, as mentioned previously, they are small and contribute to only small variations in Mach number. The expansion plate boundary layer appears to remain attached at all expansion angles and the boundary-layer thickness remains constant up to an expansion angle of 6.9°. The increase in boundary-layer thickness at angles greater than 6.9° tends to decrease the effective expansion angle; consequently, the theoretical Mach number at expansion angles greater than 6.9° is higher than the measured Mach number as shown in Fig. 1. Velocity-ratio profiles (not shown) of the plate boundary layer throughout the expansion angle range indicate a transitional boundary layer that is not fully turbulent (approximately 1/3-power profile). Boundary-layer thickness determined from simple turbulent boundary-layer theory[4] some agree well at the lower expansion angles, but underestimates the boundary-layer thickness above an expansion angle of 6.9°.

Results of the small-scale investigation indicate that an expansion plate can be used to locally expand wind tunnel

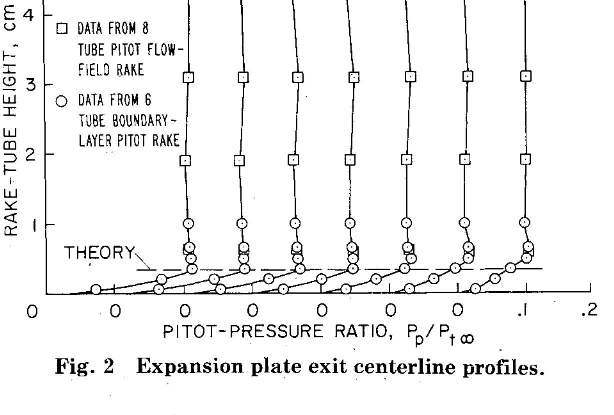


**Fig. 2 Expansion plate exit centerline profiles.**

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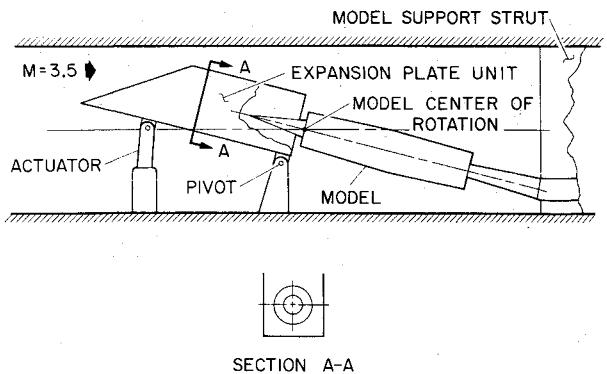


**Fig. 3 Expansion plate in Ames 8- × 7-foot wind tunnel.**

flow to higher than freestream Mach numbers; the local Mach number was increased by approximately 25 percent and the flowfield remained relatively uniform. Because the expansion plate method appears feasible, a system showing a typical inlet model has been designed for installation in the Ames 8- × 7-ft wind tunnel (Fig. 3). The proposed expansion plate system consists of a single moving unit with the sidewalls fixed to the expansion plate forming a channel which is open on the top (see section AA, Fig. 3). This arrangement eliminates the need for seals between the expansion plate and sidewalls and allows sidewall boundary-layer compensation to be built into the unit. The expansion plate pivots near the trailing edge to maintain the test region at nearly a constant location. The plate expansion angle is controlled by a lead screw used to support the forward portion of the plate. The system can expand the maximum freestream Mach number of 3.5 to a local Mach number of 4.5. To obtain a region of expanded flow large enough for large-scale (50 cm capture diam.) inlet testing, the expansion plate is approximately 320 cm long and 86 cm wide, resulting in a test region height of 73 cm at Mach number 4.5. Expansion plate size is limited by the combination of expansion plate and model total-pressure losses, which would cause the tunnel to unstart as the plate is pitched. The expansion plate trailing edge is positioned approximatley 10 cm in front of the inlet cowl lip to allow visual observations of the model shock system with the tunnel schlieren system, as well as to minimize possible adverse effects of an inlet unstart (fluctuating and nonsymmetrical loadings of the model and expansion plate). For practical application of this technique (as in the 8- × 7-ft wind tunnel), the wind tunnel model support system must properly position the model relative to the expansion plate. That is, the inlet should be pivoted near the cowl lip to maintain the model in the limited test region and prevent physical interference of the model and expansion plate as the plate and model are pitched.

When expanding flow ($M_e = 3.5 - 4.5$) for large-scale inlet testing, the Reynolds number of the expanded flow in the 8- × 7-ft wind tunnel is great enough to provide realistic inlet boundary-layers and liquefaction of air is not a problem. Application of this method to other large wind tunnels, however, will require a careful assessment of the problems peculiar to each wind tunnel.

## References

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