Wind Tunnel Noise Reduction at Mach 5 with a Rod-Wall Sound Shield

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Nomenclature

p_t = pitot pressure
R = freestream unit Reynolds number per meter
x = distance from model leading edge (axial), cm
y = vertical distance normal to model centerline, cm

Superscripts

$(\tilde{\ })$ = root mean square (rms) value
$(\bar{\ })$ = mean value

Abstract

A METHOD of shielding a wind-tunnel model from noise radiated by the tunnel-wall boundary layer has been developed and tested at the Langley Research Center. The shield consists of a rectangular array of longitudinal rods with boundary-layer suction though gaps between the rods. Tests were conducted at Mach 5 over a unit Reynolds number range of $1.0\text{-}3.5 \times 10^7$/m. Hot-wire measurements indicated the freestream noise, expressed in terms of the rms pressure fluctuations normalized by the mean pressure, was reduced from about 1.4% just upstream of the shielded region to a minimum level of about 0.4% in the forward portion of the shielded flow.

Contents

Noise radiated from turbulent boundary layers on the walls of supersonic and hypersonic wind tunnels causes premature transition on simple test models.[1-3] One method of reducing the directly radiated noise is to use a shield. If a test region is shielded form this noise, the local stream noise levels can be reduced, provided the noise reflected or generated at the shield walls is minimized. Several shield configurations have been tested.[4-9] The configuration used for this investigation incorporates a minor modification of two previous shields.[8,9] The purpose of this modification was to eliminate any flow compression in the fairing region between the sharp flat leading edges and the open suction gaps between the rods.

The tests were conducted in the Mach 5 pilot tunnel[10,11] at the Langley Research Center. This tunnel (Fig. 1a) consists of a settling chamber, a Mach 5 axisymmetric nozzle, an open-jet test section within a vacuum chamber, and a diffuser section. The Mach 5 axisymmetric nozzle incorporates a boundary-layer suction slot just upstream of the throat. The purpose of the slot is to bleed off the settling chamber turbulent boundary layer before it enters the nozzle. During the present tests, the bleed valves were closed which resulted in fully turbulent nozzle wall boundary layers over the present range of test conditions, thus providing freestream noise at about the same levels as in conventional wind tunnels.

A schematic representation of the rod-wall sound shield mounted in the tunnel is included in Fig. 1a. Additional details of the model are given in Figs. 1b and 1c. As shown in Fig. 1c each of the leading edges are inclined into the flow by 1 deg which is approximately the same angle used for the rods. The rods are inclined into the freestream flow to compensate for the suction mass flow and thereby minimize any deviations in the mean flow angles within the shielded region.[4]

Mean freestream pitot pressures were measured inside the rod-wall sound shield in the vertical centerplane of the model. These data showed that at all test Reynolds numbers ($1.0 \times 10^7 \leq R \leq 2.9 \times 10^7$) a reasonably uniform flow was obtained within the rod-wall shield along the centerline from

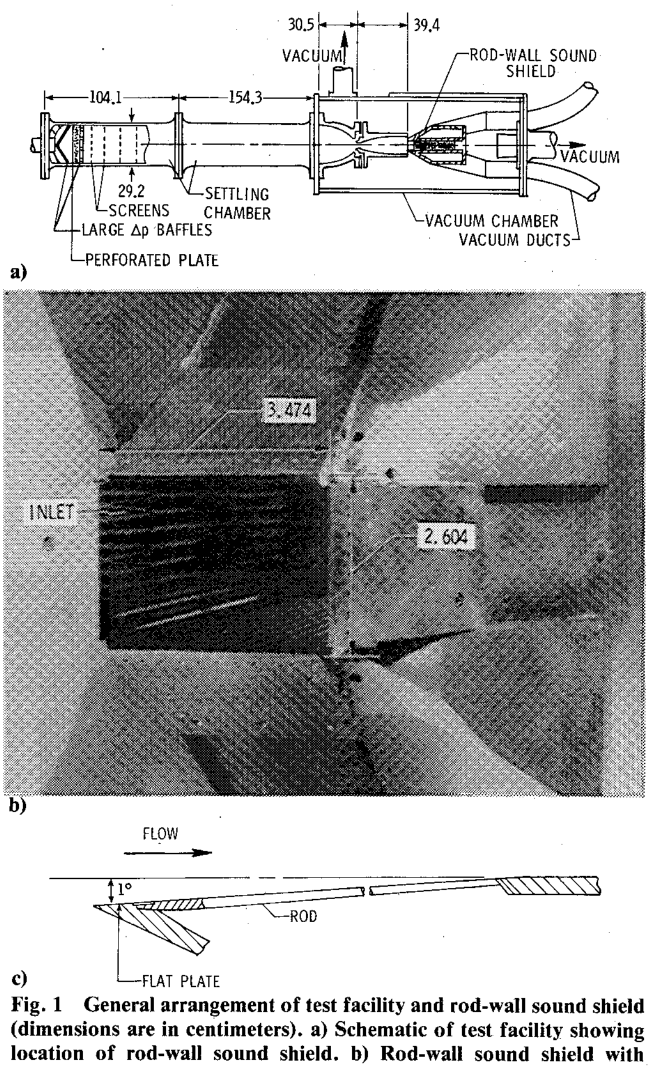

Fig. 1 General arrangement of test facility and rod-wall sound shield (dimensions are in centimeters). a) Schematic of test facility showing location of rod-wall sound shield. b) Rod-wall sound shield with plenum ducts removed. c) Modified leading edge of rod-wall model showing 1 deg compression angle.

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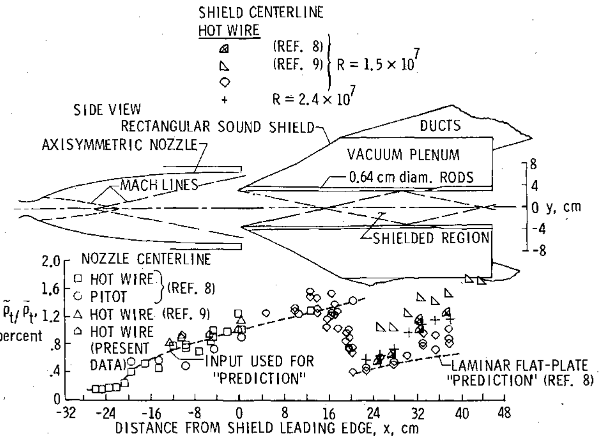

Fig. 2 Normalized pitot-pressure fluctuations along centerline of nozzle and rectangular rod-wall sound shield.

an x station of 22 cm to approximately 40 cm giving a total length of 18 cm of uniform core flow. The off-centerline core flow length was decreased by the effects of the angled leading-edge shocks.

The location of transition in the rod boundary layers was determined from distributions of surface pitot pressures on the rods. These transition data on the flow side of the rods from the present investigation were compared to corresponding results from previous investigations[8,9] for a Reynolds number range of $1.6\text{-}2.9 \times 10^7/\text{m}$. In general, the locations of transition move forward with increasing unit Reynolds number. The present data indicate a longer run of laminar boundary layer on the center rod at $R = 1.6 \times 10^7$ than the two previous configurations.

Hot-wire data, using a constant-current anemometer, were obtained within the sound shield and the nozzle. The data reduction techniques and probe design are the same as used previously by Anders et al.[12] The present data, expressed as the rms fluctuating pitot pressure normalized by the local mean pitot pressure (an equation given by Stainback and Wagner[13] was used to convert static pressure ratios to pitot pressure ratios), are compared with previous data[8,9] in Fig. 2. A schematic drawing, showing a side view of the shield (with the leading edge 1.64 cm inside the Mach 5 nozzle) is also presented in Fig. 2.

As a check of the hot-wire probes and data reduction methods, several data points were taken within the nozzle. These data are in good agreement with previous results. An extensive hot-wire survey along the shield centerline at $R \approx 1.5 \times 10^7$ was performed at 10-38 cm, with more data points concentrated in the area where the leading-edge shocks crossed ($10 \leq x \leq 20$). The level of $\tilde{p}_t/\bar{p}_t$ is seen to decrease from approximately 1.4 to 0.4% within an x distance of about 6 cm. A comparison of the present data with previous results[8,9] indicates a significant reduction in $\tilde{p}_t/\bar{p}_t$ at the downstream stations where the present results approach the laminar flat-plate prediction.[7,8] These lower noise levels are attributed to the longer run of laminar boundary-layer flow on the center rod of the present model as compared to that of the previous models.

In spite of the lower measured noise levels in the present model, the full noise reduction "potential" of the rod-wall shield to provide noise levels as low as 0.1% (based on analysis and data[7] from a flat rod-wall panel tested in a conventional Mach 6 wind tunnel) was not achieved in the present tests because of the small scale of the facility. Two related effects involved in this scale problem are[8]:

1) The small size of the nozzle and comparatively high unit Reynolds numbers cause the fully turbulent nozzle wall boundary layers in the far upstream acoustic origin regions of the nozzle to radiate noise at very high frequencies.

2) This high-frequency noise energy is incident upon the rod boundary layers and more energy is reflected into the shielded region than would be the case with lower frequencies. That is, if the shield is to develop its full noise-reduction potential, more of the incident noise energy must be absorbed by the laminar boundary layers on the rods as apparently occurred in the rod-wall panel tests at Mach 6. Furthermore, the high-frequency acoustic energy in this small nozzle probably causes transition to move farther upstream on the rods than was observed for lower frequency energy as in the tests of the original rod-wall panel in the 20-in. Mach 6 tunnel.[5-7]

Thus, it may be tentatively concluded that a rod-wall sound shield of the same basic design as the present model, but scaled up for use in a larger, conventional wind tunnel would experience much longer runs of laminar flow on the rod walls. The noise levels in the shielded region would then be reduced to the minimum projected levels of about 0.1% over sufficient test region lengths to give length Reynolds numbers of $10\text{-}20 \times 10^6$ on test models.

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