Noise Generation in Transonic Tunnels

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Theme

RECENTLY, emphasis has been placed on the noise environment in transonic facilities. This increased attention surrounding the tunnel noise problem was brought about by the advent of high lift configurations operating in the transonic regime. Experimental investigations[1,2] have shown that the tunnel noise environment may have a significant influence on high lift model boundary-layer transition and on the character and onset of buffet. Thus, an extensive analytical investigation of the noise generation mechanisms affecting the test section noise environment of porous wall transonic wind tunnels has been undertaken.[3] The noise environment is broken up into three parts: 1) the noise attributable to the jet flow through the porous walls, 2) the noise produced by a wall hole-tunnel resonance phenomenon, and 3) the noise associated with the turbulent boundary layer on the test section walls and with the diffuser. With the formulation of the separate mechanisms, the contributions of each are added, forming a representation of the overall noise generation mechanism.

Contents

To date, essentially all literature concerned with the detection and identification of test section noise has indicated that fluctuating pressure caused by hole resonance was the major source. Numerous authors have derived empirical relationships based on Brown's[4] original concept of edge-tones to describe resonant frequency conditions for both porous and slotted wall configurations. Conceptually, edge-tones are a result of the strengthening of vortices shed at the forward portion of a typical hole by the presence of the sharp trailing portion of the holes as illustrated in Fig. 1.

Two basic facts limit the applicability of the empirical formula to model the noise generation, however. Whereas this description of the generation mechanism does give, in some cases, a reasonable estimate of the position in the frequency plane of discrete frequencies, it does not account for the power contained in these discrete tones or the power upon which these tones build. Secondly, none of the empirical equations, or the basic conept of hold resonance, indicates that resonance will occur at only one Mach number or over a finite Mach number range. Indeed, as Mach number is increased, resonant frequencies decrease with no effects indicated on the fluctuating pressure coefficient. Available experimental results, however, show some form of resonance occurring in the 0.7-0.8 Mach number range. If hole resonance were the primary noise-generating mechanism, it should reflect this resonance in the fluctuating pressure level. Thus, by itself, the hole resonance phenomenon does not model the noise environment in the porous wall test section of a transonic tunnel.

The noise attributable to the jet flow through the walls is considered first. The physical process describing the jet noise contribution is that as flow issues out of the test section through the porous walls at subsonic velocities, subsonic jet noise is generated and is transmitted back through the hole into the test section. The model postulated for this physical process is that a portion of the power created by the jet produced by each hole is transmitted back through the hole into the test section in the form of a distribution of dipole sources oscillating transverse to the flow as shown in Fig. 2. The strength of the set of dipoles describing the noise from each hole is assumed to be directly proportional to the frequency content of the power generated by the jet. By considering the flow of a compressible fluid past an acoustic dipole fluctuating transverse to the mean flow, the acoustic field for harmonic oscillation is derived.

To link the mathematical model with the physical process, the total auxiliary flow, and the flow distribution through the walls were established. The dipole strength q_0 was set equal to a portion of the power radiated by the jet. This established the power spectral density for the equivalent dipole with a frequency of oscillation $\omega_0 = \pi U_j / 2D_e$. Here U_j and D_e are the jet velocity and diameter, respectively. With the power spectral density for the equivalent dipole, representing the power from one hole, evaluated, superposition of a series of these dipoles is used to represent the power caused by a series of holes at a point.

Integration of the power spectral density over the jet Mach number distribution produces the root-mean-square (rms) pressure coefficient attributable to auxiliary mass flow removal.

$$\Delta c_p = c_2 (m/\beta^2 M_\infty^2 \mathcal{T}^4)\ [M_\infty - c_1 (1 + M_\infty^2/5]^3]^4 \qquad (1)$$

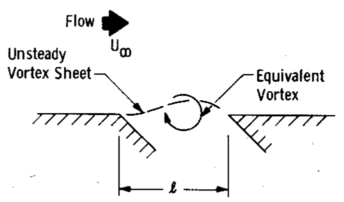

Fig. 1 Illustration of physical model of hole resonance.

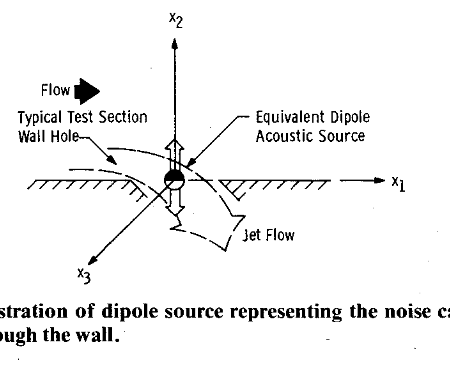

Fig. 2 Illustration of dipole source representing the noise caused by jet flow through the wall.

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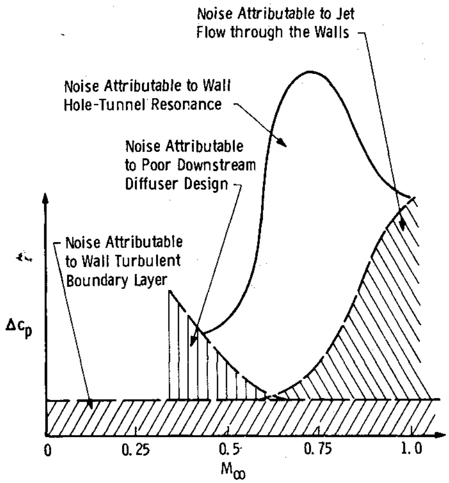

Fig. 3 Graph of ΔC_p vs Mach number showing regions of existence of possible noise-generating mechanisms.

Here, the wall porosity is given by τ, m is a fixed geometrical constant, and c_2 is an undetermined constant. The freestream Mach number is M_∞ and $\beta^2 = 1 - M_\infty^2$. The constant c_1 is determined by requiring that $\Delta c_p = 0$ for a maximum M_∞ with no plenum pumping.

The resonance condition occurring in the 0.7-0.8 Mach number range is postulated to be caused by a natural frequency mode of the holes in sympathy with a natural frequency mode of the porous test section. Employing the governing small disturbance equation and the acoustic boundary condition at the wall, an approximate expression for tunnel resonance is shown to be

$$M_\infty / \beta(1 + M_\infty) \approx 0.67(n/j^{1.68}) \quad (\ell/H) \tag{2}$$

where j determines the edge-tone stage and n determines the tunnel resonance mode. Here, ℓ is the streamwise hole length and H is the tunnel height.

With the establishment of the resonance mode, the energy, reflected in the Δc_p level, associated with the resonance phenomenon is then postulated. The model assumes in essence that the fluctuating energy generated in the main stream (proportional to the dynamic pressure), at resonance, must be balanced by the energy dissipated at the walls and the energy dissipated by the tunnel acting as an organ pipe for the wall hole-tunnel resonance phenomenon. Based on this postulate, it is shown that the fluctuating pressure level Δc_p at resonance is represented by the following expression

$$\Delta c_p = c_3 \beta^4 \frac{(1+M_\infty)}{M_\infty^3} \left[\frac{L}{H}\right]\left[\frac{\ell}{H}\right] \left[\frac{\dfrac{M_\infty}{2} \dfrac{dc_p}{d\theta}}{\left[1 + \dfrac{M_\infty}{2}\dfrac{dc_p}{d\theta}\right]^2 + \left[\dfrac{\ell}{\delta^*}\right]^2 \left[\dfrac{1+M_\infty}{M_\infty}\right]^2} \right]^{1/2} \tag{3}$$

The previous expression defines the fluctuating pressure level relative to some reference for variations in the wall crossflow characteristics ($dc_p/d\theta$), the tunnel length-to-height ratio (L/H), the streamwise hole length-to-tunnel-height ratio (ℓ/H), the streamwise hole length to boundary-layer displacement thickness (ℓ/δ^*), and the resonance Mach number. Figure 3 depicts the regions of importance of the generating mechanisms. By using the relations derived for the noise levels attributable to wall hole-tunnel resonance and those caused by jet flow through the wall, the noise environment in comparable transonic test facilities may be evaluated. This is the first attempt at a complete analysis of the noise environment including fluctuating pressure levels in transonic facilities. Further, by the identification of the important parameters governing the noise environment, a more complete understanding can be obtained of the means by which noise levels may be reduced.

References

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