Engineering Notes

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Tunnel Interference Reduction on a Finite Airfoil

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THE ventilated wind tunnel has been introduced and refined over the last two decades from the fixed geometry to the variable porosity perforated walls. Both theoretical results[1] and experimental data[2] have demonstrated that it was difficult to eliminate pitching-moment interference of an aircraft model simultaneously with lift interference when using walls with uniformly distributed porosity. The evidence[3] in the experimental development of walls for V/STOL testing indicates that it becomes possible to simultaneously eliminate pitching moment and lift interference in a slotted tunnel with nonuniformly distributed porosity.

The interference reduction concept has been demonstrated by the author's previous paper[4] in which a mathematical technique is presented to predict the interference on an airfoil represented by a single singularity in a Gaussian-type distribution of porosity. The present paper extends the mathematical technique to the case of a finite chord airfoil to predict the proper porosity distribution to eliminate the interference. The present calculation becomes urgent and necessary for an experimental program developing a new "nonadaptive" wall. On the other hand, the self-correcting wind tunnel concept[5,6] which refers to the "adaptive" wall, has been demonstrated by a numerical method[7] to achieve interference-free flow conditions. This wind tunnel requires the provisions either to adjust the deflections of the wall surfaces, or to adjust the wall porosity and plenum pressure behind the wall to establish unconfined flow conditions. The present result of interference calculation is primarily for the improvement of the current existing nonadaptive wall wind tunnel.

Analysis

The airfoil is placed at the centerline of a perforated tunnel having walls with nonuniform distribution of porosities. The tunnel interference on a model is divided into two parts in the investigation, i.e. the blockage and lift interferences.

Based on the thin airfoil theory, the airfoil thickness and camber may be treated separately. The blockage and lift interferences are induced by the presence of the airfoil thickness and camber in the tunnel, respectively. The formulation for both types of interferences is essentially similar, except for the different mathematical representations of the airfoil thickness and camber. The small perturbation theory for subsonic flow is used in the analysis with a homogeneous boundary condition at the perforated tunnel walls. The boundary value problem is summarized in Fig. 1.

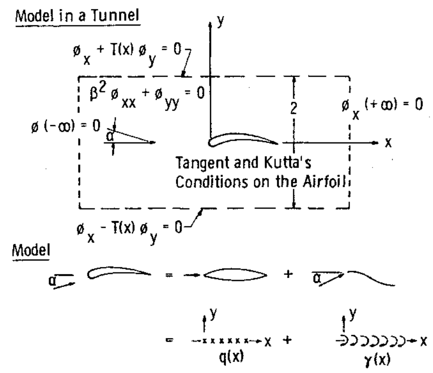

Fig. 1 **Boundary value problem for tunnel interferences.**

For the two-dimensional inviscid subsonic flow, the linearized field equation of the perturbation velocity potential is utilized. For the boundary condition of the tunnel perforated wall, the mass flow is assumed proportional to the pressure drop across the wall expressed in the x-y coordinates as $\phi_x \pm T(x)\phi_y = 0$ at $y = \pm 1$ where $T(x)$ is the empirical constant or porosity parameter of the perforated wall which is a function of streamwise location. Within the assumptions of linearized theory, the perturbation velocity potential may be decomposed into two parts, $\phi = \phi_i + \phi_m$, where ϕ_i is the interference potential caused by the presence of tunnel walls and ϕ_m is the disturbance potential induced by a model. The interference potential may be calculated in a selected distribution of porosity tunnel for lift and blockage interferences separately.

Lift Interference

The lift interference is induced by the camber line and incidence of an airfoil, and the distribution of vortices is used to represent the camber and incidence as

$$\phi_m = \frac{-1}{2\pi} \int_o^{C_h} \gamma(\zeta) \tan^{-1}\left[\frac{y}{x-\zeta}\right] d\zeta$$

where $C_h = c/\beta h$ is the normalized airfoil chord. For the simplification of computation, a discrete distribution of vortices can be adopted as

$$\phi_m = \sum_j \Delta\phi_{m,j} = \frac{-1}{2\pi} \sum_j \gamma(\zeta_j)\Delta\zeta \tan^{-1}\left[\frac{y}{x-\zeta_j}\right]$$

The formulation is set up for each single discrete vortex. The method to obtain the lift interference for a single discrete vortex is described in Ref. 4.

The lift interference factor $\delta(x)$ along the centerline may be expressed as

$$\delta(x) = \left[\sum_j \gamma_j E_j(x) \;/\; \sum_j \gamma_j\right]$$

It should be noted that the coefficients $E_j(x)$ depend on the tunnel configuration only. The lift interference factor can be obtained for any type of loading airfoil in a given tunnel whose influence coefficients $E_j(x)$ are available.

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Index categories: Aircraft Testing (including Component Wind Tunnel Testing); Subsonic and Transonic Flow.

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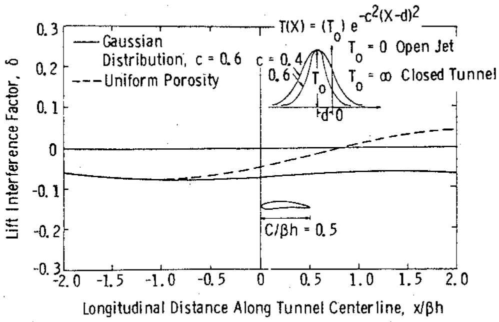

Fig. 2 **Lift interference for NASA 64-series airfoil in tunnels with Gaussian and uniform distributions of porosities at $\beta T(x=0)=4.0$, $d/\beta h=-1.0$.**

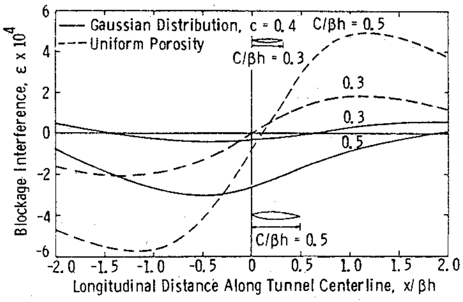

Fig. 3 Blockage interference for a biconvex airfoil with 6% thickness ratio in tunnels with Gaussian and uniform distributions of porosities at $\beta T(x=o)=1.5$, $d/\beta h=-1.0$.

The results of lift interference for the NACA-64 airfoil series in tunnel walls with Gaussian and uniform distribution of porosities are shown in Fig. 2. The comparison between these two curves indicates that improvement of lift interference is found by utilizing the Gaussian distribution. Specifically, the lift interference at the tail has the same sign and magnitude as that at the wing for a wing-tail model.

The pitching moment obtained from a uniform distributed porosity tunnel which has opposite signs of interference between the wing and the tail is difficult to correct. In a Gaussian distribution of porosity, the interference has the same sign and magnitude on the wing and the tail. The only correction required to the model data is for tunnel flow angularity.

Blockage Interference

For the blockage interference calculation, the model potential for the airfoil thickness is represented by

$$\phi_m = \frac{U_\infty}{\pi}\int_o^{C_h}\frac{dy_t(\zeta)}{dx}\log\,[(x-\zeta)^2+y^2]^{1/2}d\zeta$$

Similarly to the lift interference case, a discrete distribution of source singularities is adopted as

$$\phi_m = \sum_j \Delta\phi_{m,j}$$

$$= \frac{U_\infty}{\pi}\sum_j \frac{dy_t(\zeta_j)}{dx}\Delta\zeta_j\cdot\log[(x-\zeta_j)^2+y^2]^{1/2}$$

The formulation is set up for each single discrete model potential in terms of the axial perturbation velocity.

The blockage interference, $\epsilon = u_i/\beta h U$, is calculated[8] for a biconvex airfoil shown in Fig. 3 for $C_h=0.3$ and 0.5. The comparison demonstrates clearly that the blockage interference gradient for uniform porosity is greatly reduced by using the Gaussian distribution. In the uniform porosity tunnel, the blockage interference not only has a rather large gradient but also changes signs from the leading edge to the trailing edge of airfoil.

Conclusions

The solution is computationally simplified by assuming a discrete distribution of singularities for a finite chord airfoil. The form of influence coefficients is obtained for a given wind tunnel. The tabulated influence coefficients can be used to calculate interference factors for any finite airfoil with a given loading and thickness distribution at a given angle of attack.

The potential to reduce tunnel interferences on a given finite airfoil is demonstrated by a selected Gaussian distribution of porosity. For a specific airfoil, one of a family of Gaussian distribution may be used for interference minimization although superior porosity distributions may be found for the general case.

The interference calculation for the previous examples indicates that a large gradient of porosity, especially in the neighborhood of the test model, is required to significantly change the value of interference factors of a tunnel. In other words, any small amount of variation of porosity does not greatly affect tunnel interferences. For the subsonic case, the blockage interference is usually negligible[9] as compared to the lift interference. Hence, the consideration of lift interference should be emphasized in the selection of tunnel wall porosity distribution.

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Effect of Combined Roll Rate and Sideslip Angle on Aircraft Flight Stability

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Introduction

IT has long been known that rapid roll rates can destabilize the motions of aircraft. The introduction of high-

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