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Wall Interference Evaluation from Pressure Measurements on Control Surfaces

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Nomenclature

A	= constant in Eq. (8)
C_p	= pressure coefficient
f_H	= defined by Eq. (3)
f_B	= defined by Eq. (4)
h	= test section height
M_∞	= freestream Mach number
q	= source strength
x,y	= physical coordinates
α	= geometrical angle of attack
β	$=\sqrt{1-M_\infty^2}$
γ	= vortex strength
ΔM	= Mach number correction
$\Delta\alpha$	= angle-of-attack correction
μ	= doublet strength
ξ	$=x$
ϕ_m	= far-field perturbation potential

Subscripts

B	= bottom wall
H	= top wall

Introduction

CONVENTIONAL methods of calculating wall interference corrections are based on boundary conditions which require a knowledge of the porosity parameter for ventilated walls and are not suitable for deformed walls. The correction methods are uncertain and, on occasion, inadequate. In some methods, the ventilated walls are regarded as imaginary walls with uniform characteristics which are estimated through numerical simulations or wind tunnel experiments. These methods have not been uniformly successful. This is particularly true where nonlinear effects are important, such as when the model is not small enough compared to the height of the tunnel, the incidence is large, or the flow is high subsonic.

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A method proposed by Capelier, Chevallier, and Bouniol[1] dispenses with the need to resort to additional tests to determine the porosity characteristics and replaces them by pressure measurements on a control surface near each wall of a wind tunnel. The method is valid only for subcritical flows or for flows with weak shocks. Like the classical methods, it represents the model by singularities which are deduced from its geometry and measured forces. This method can be applied to all types of walls, permeable or solid, flat or deformed.

Mokry and Ohman[2] have used a method similar in principle to the approach of Ref. 1, but different in the selection of boundaries and implementation of the integration of wall pressures. It utilizes the Fourier solution of the Dirichlet problem for a finite rectangular region. It requires only the value of the flow angle at a selected reference point sufficiently distant from the airfoil.

In view of the scatter in wall pressure measurements, the data were smoothed using cubic splines before calculating the values of the boundary functions, but it was found that the method was relatively insensitive to the smoothing factor. As the evaluation of interference corrections by the method of Ref. 1 requires that the pressure distribution be known along the entire length of the control surface extending from upstream to downstream infinity, an attempt was made to evaluate the contributions from the regions beyond the extent of experimental pressure measurements to $\pm\infty$ by trying out various types of pressure distributions.

The present method uses a simple exponential decay of pressure distribution beyond the most upstream and downstream limits in order to evaluate the expressions for the Mach number and incidence corrections as given by Ref. 1. It is satisfying to note that the incidence correction checks surprisingly well with Mokry's[3] results for a BGK-1 airfoil at $M_\infty = 0.784$ and 2.56 deg, even without the reference value of incidence. The upstream contribution to incidence correction is considerable and cannot be ignored. The upstream and downstream contributions to Mach number correction are negligible. Numerical experiments were made with various types of variations for C_p beyond the experimental range of pressure measurements and the exponential decay of pressure was found to be appropriate.

Method of Solution

The final expressions for Mach number and incidence correction[1] are

$$\Delta M = \left(\frac{1}{\beta h}\right)\int_{-\infty}^{+\infty} \frac{f_B(\xi)+f_H(\xi)}{2\cosh(\pi\xi/\beta h)}\,d\xi \tag{1}$$

$$\Delta\alpha = \left(\frac{1}{h}\right)\int_{-\infty}^{+\infty} \frac{f_H(\xi)-f_B(\xi)}{1+\exp(2\pi\xi/\beta h)}\,d\xi \tag{2}$$

where

$$f_H(\xi) = -\frac{1}{2}C_{pH}(\xi) - \left(\frac{\partial\phi_m}{\partial x}\right)_H \tag{3}$$

$$f_B(\xi) = -\frac{1}{2}C_{pB}(\xi) - \left(\frac{\partial\phi_m}{\partial x}\right)_B \tag{4}$$

For a thin lifting airfoil in subsonic linearized flow, ϕ_m is given by

$$\phi_m = -\left(\frac{\gamma}{2\pi}\right)\arctan\left(\frac{\beta y}{x}\right) + \left(\frac{\mu}{2\pi\beta}\right)\frac{x}{x^2+\beta^2y^2} + \frac{1}{2}\left(\frac{q}{2\pi\beta}\right)\ln(x^2+\beta^2y^2) \tag{5}$$

Differentiating Eq. (5) with respect to x, substituting in Eqs. (3) and (4), and simplifying, the final expressions for ΔM

and $\Delta\alpha$ are obtained as

$$\Delta M = -\left(\frac{1}{\beta h}\right)\int_{-\infty}^{+\infty}\left\{\left[\frac{C_{pB}+C_{pH}}{2}-\left(\frac{\mu}{\pi\beta}\right)\frac{x^2-(\beta^2h^2/4)}{x^2+(\beta^2h^2/4)^2}+\left(\frac{q}{\pi\beta}\right)\frac{x}{x^2+(\beta^2h^2/4)}\right]\Big/2\cosh\left(\frac{\pi\xi}{\beta h}\right)\right\}d\xi \qquad (6)$$

$$\Delta\alpha = -\left(\frac{1}{h}\right)\int_{-\infty}^{+\infty}\left\{\left[\frac{C_{pH}-C_{pB}}{2}+\left(\frac{\gamma}{2\pi}\right)\frac{\beta h}{x^2+(\beta^2h^2/4)}\right]\Big/\left[1+\exp\left(\frac{2\pi\xi}{\beta h}\right)\right]\right\}d\xi \qquad (7)$$

The method consists in first evaluating the corrections for the region from x_1, the most upstream station, to x_2, the most downstream station over which the pressures on the control surface have been measured, by using Eqs. (6) and (7) and the trapezoidal integration rule. Next, the corrections for the region from x_1 to $-\infty$ and x_2 to $+\infty$ are evaluated using an exponential fit for C_p of the form

$$C_p = A\exp(-x) \qquad (8)$$

for both upper and lower walls where the constant A has been determined from experimental data for the corresponding walls. It was noticed that there were practically no contributions to ΔM beyond x_1 and x_2 to $\mp\infty$, whereas the contribution from x_1 to $-\infty$ to $\Delta\alpha$ was considerable. The downstream contribution to $\Delta\alpha$ was negligible.

Results

In order to validate the method, Mokry's data[3] for a BGK-1 airfoil from the NAE 15×60-in. wind tunnel were used. The ΔM and $\Delta\alpha$ corrections obtained by the present method were −0.017 and −0.667, as compared to Mokry's values of −0.015 and −0.669. Like Mokry's method, the reference value of the flow angle at a selected reference point is needed.

Conclusion

A simple exponential fit to pressure coefficient beyond the most upstream and downstream measuring points on the control surfaces in a wind tunnel gives Mach and incidence corrections using the method of Capelier, Chevallier, and Bouniol that agree well with those obtained by other methods such as fast Fourier transforms.

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Existing Time Limit for Overwater Operations—Its Validity

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Nomenclature

p = probability of performance falling below the datum in the event of an engine failure
Q = incident probability per flight
t = intended duration of flight, h
γ_m = performance margin in terms of climb gradient, %
π_1 = probability of failure of one engine per flight
π_2 = probability of failure of two engines per flight
ρ = engine failure rate per engine hour
σ_r = standard deviation of single-engine climb gradients, %

Introduction

THE airworthiness and operational requirements relating to the performance of an airplane during the enroute phase are designed to ensure that the airplane can clear all obstacles by a sufficient margin in the event of one engine becoming inoperative. In addition, the airplane is required to be capable of a positive climb gradient at 1500 ft above the landing place (destination/alternate).

Under FAA requirements, no two-engine airplane may operate over a route that contains a point farther than 60 min flying time, with one engine inoperative, from an adequate airport.[1] Annex 6 of ICAO stipulates a limit of 90 min in respect to turbine engine airplanes only.[2] Air Navigation Orders, while not specifying any time limit, require safe landing capability at a given place (with the exception of performance group X airplanes).[3]

Historically, the 60/90-min rule is based on the reliability of the old piston and turbine engines. During the last decade, the reliability of turbine engines, especially that of jet engines, has improved substantially. However, this improved reliability is yet to be reflected in the performance requirements of existing airworthiness codes. A considerable gain in the operating economy and capability of airlines can be effected if the increased reliability is accounted for while establishing the time limit. This paper examines the validity, in regard to modern jet airplanes, of the 60/90-min rule.

Basis of Existing Time Limit

The desired level of safety should be achievable, during any flight stage, with one engine inoperative, by a two-engine airplane. This is ensured by specifying a minimum performance margin (γ_m) above a specified datum performance. The former is 1.1 and latter, zero, in terms of climb gradient during the enroute phase. Performance margin depends on the following: 1) selected incident probability—defined as the probability of performance falling below the datum performance (the ICAO stipulated, during the early 1950s, a value ranging from 2×10^{-6} to 7×10^{-6} per flight; this probability also determines the desired level of safety); 2) engine failure rate per engine hour; 3) standard deviation of climb gradients; and 4) duration of flight.

Methodology Used

The variance of enroute climb gradients with one engine inoperative has been determined here by using the

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