Two-Dimensional Wind-Tunnel Wall Interference

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Introduction

TWO-DIMENSIONAL wind-tunnel wall interference is important in the testing of airfoils, particularly at transonic speeds. The complex flow features at the ventilated test section boundaries introduce uncertainties in the boundary conditions. Therefore, modern wall interference calculation methods, in lieu of the classical boundary conditions, use experimentally measured values of the pressure and/or flow inclination at the wall to correct the test data.

Reference 1 gives a comprehensive review of different methods to calculate two-dimensional wall interference. Most of the methods[2,3] are based on subsonic flow theory and still give useful results in the low transonic regime as long as the flow is subcritical at the walls. Methods developed by Murman[4] and Kemp[5] employ transonic analysis. Kemp's method, based on the solution of the transonic small-disturbance equation, represents the state-of-the-art in transonic wall interference calculations. The method is useful as a benchmark for validating other simpler methods.

Reference 1 gives a comparison of the results of the various methods for a test case of the Bauer-Garabedian-Korn (BGK-1) airfoil tested in the National Aeronautical Establishment (Canada) wind-tunnel two-dimensional test section. It is interesting to note that the results for Mach number and angle-of-attack corrections predicted by methods based on simple model representation and wall pressure measurements agree with Kemp's method. Hence, for routine interference calculation in airfoil tests, the simpler methods offer a quick approach to estimate wall interference effects.

One of the main features of Kemp's method is the repetitive application[6] of the procedure until a satisfactory match between measured and calculated pressure distributions is obtained. The repetitive application is often found to change only the angle-of-attack correction without affecting the Mach number correction significantly. For the test case reported in Ref. 1, all of the simple approaches give a Mach number correction of -0.015 and an angle-of-attack correction of -0.67 deg. However, a second application of Kemp's method yields an angle-of-attack correction of -0.89 deg.

The change in the angle-of-attack correction in the second and subsequent applications in Kemp's method arises because of the uncertainty in estimating the upstream flow inclination, which is not accounted for in the simple approaches. The upstream flow inclination is often difficult to measure in wind-tunnel tests. Kemp's method uses a technique of matching the airfoil camber line with the local flow angle to estimate the upstream flow inclination. The purpose of this Note is to examine two approximate methods to estimate the correction due to upstream flow inclination effects considered in Kemp's method.

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Analysis

The first method uses the well-known method of images. It is assumed that the top and bottom wall effects are properly accounted for in the simpler approaches and the ventilated test section permits proper deflection of the streamlines downstream. Hence, the only effect that needs to be considered is the change in the upstream condition due to the airfoil model. At the entry of the test section, it is reasonable to presume that the strong effect of the wind-tunnel contraction persists in keeping the flow along the axis of the tunnel.

The model lift, which can be represented by a point vortex, requires the streamline shapes to vary logarithmically upstream in the free air. This effect is suppressed by the wind-tunnel contraction. Hence, the effect of the contraction in the wind tunnel can be represented by a single image vortex located upstream of the test section entry. The strength and direction of rotation of the image vortex will be the same as the vortex representing the airfoil circulation, as shown in Fig. 1.

The image vortex induces correction to the downwash velocity along the test section centerline. The induced velocity ν due to the image vortex is given by

$$\nu = -(\Gamma/2\pi)\,[\beta x/(x^2 + \beta^2 y^2)] \tag{1}$$

where Γ is the airfoil circulation and β is the compressibility factor. The distances x and y are measured from the image vortex. At the airfoil quarter chord location corresponding to $x = 2L$ and $y = 0$, Eq. (1) can be simplified to give

$$\nu / U_\infty = -(C_l c\beta / 8\pi L) \tag{2}$$

where c is the airfoil chord, C_l is the airfoil lift coefficient, and U_∞ is the freestream velocity. The angle-of-attack correction at the airfoil quarter chord location can be easily estimated from Eq. (2) for the airfoil lift and the test Mach number.

The second approach is much simpler. As shown in Fig. 2, instead of the image vortex, it is assumed that the streamlines passing through the upstream end of the test section are rotated to correspond to the free air streamline slope. The slope of the streamlines in free air at the upstream end, due to airfoil lift, is given by

$$\alpha_f = C_l c\beta / 4\pi L \tag{3}$$

However, if the streamlines are rotated by α_f, the airfoil lift will change, due to change in angle of attack. Assuming the rotation required is α_m, it can be written that

$$\alpha_m = \alpha_f - (\Delta C_l c\beta / 4\pi L) \tag{4}$$

where ΔC_l is the change in the lift coefficient. Assuming a lift

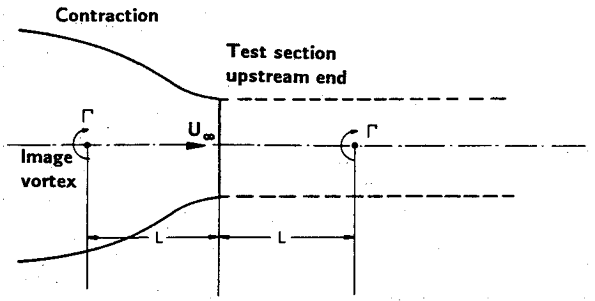

Fig. 1 Image vortex method.

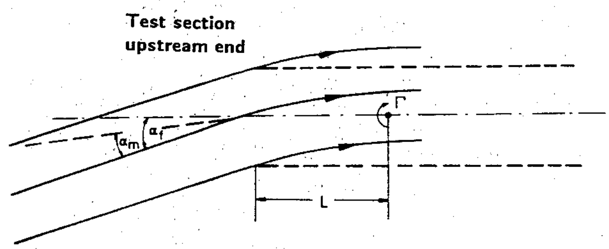

Fig. 2 Rotation of streamlines passing through the test section upstream end.

curve slope of $2\pi/\beta$, the rotation of the streamlines required at the upstream end is given by

$$\alpha_m = \alpha_f / (1 + c/2L) \tag{5}$$

The corresponding correction to airfoil angle of attack will be $-\alpha_m$.

Results and Discussion

For the test case considered in Ref. 1, the test Mach number is 0.784, lift coefficient 0.764, airfoil chord 25 cm, and the distance from the entry of the test section to the airfoil quarter chord location 206 cm. Substituting these values in Eq. (2), the first approach gives an angle-of-attack correction of -0.13 deg. Combining this with the top and bottom wall angle-of-attack correction of -0.67 deg gives a total correction to angle of attack of -0.80 deg, which is close to the result of Kemp's method with a second pass. The agreement suggests that the simple well-known image vortex method accounts to a large extent for the upstream flow inclination effect.

Applying Eq. (5), the second approach gives a correction of -0.25 deg. With this, the total correction for the angle of attack becomes -0.92 deg, which fortuitously gives a much better agreement with Kemp's method. The two approaches account for upstream effects, but the magnitude of the corrections is different due to different flow models considered. Both the approaches give the same flow conditions at the test section entry. However, the flow boundaries upstream of the test section entry are not properly simulated. Good agreement of results by the second method for the test case is encouraging. More detailed comparisons for different test cases will help in determining the extent of corrections required for a particular test section.

The present analysis suggests that the correction increases linearly with lift coefficient, as noted in the extensive study of Kemp's method in Ref. 6. The correction tends to become smaller with an increase in test Mach number due to reduced upstream effect. The present results with the results of the top and bottom wall interference calculation methods will be useful in making a quick estimate of the interference effects.

Conclusion

The correction to angle of attack due to upstream flow inclination is estimated using two different approaches. The methods are an image vortex in the contraction and rotation of streamlines passing through the test section upstream end, respectively. The magnitude of the corrections predicted by the two methods is different; the method based on the rotation of streamlines is found to be in closer agreement with the results of the more refined calculations. Since the physical flow upstream of the test section entrance is not properly represented in both methods, it appears that the results of the two methods give bounds of corrections for the angle of attack. Detailed calculation for a specific test section will be necessary to determine the extent of correction needed.

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References

[1]Mokry, M., Chan, Y. Y., and Jones, D. J., "Two-Dimensional Wind Tunnel Wall Interference," AGARDograph 281, edited by L. H. Ohman, Nov. 1983.

[2]Capellier, C., Chevallier, J. P., and Bouinol, F., "A New Method for Correcting Two-Dimensional Wall Interference," ESA-TT-491, European Space Agency, Paris, France, Aug. 1978, pp. 1–30.

[3]Mokry, M., and Ohman, L. H., "Application of the Fast Fourier Transform to Two-Dimensional Wall Interference," *Journal of Aircraft*, Vol. 17, June 1980, pp. 402–408.

[4]Murman, E. M., "A Correction Method for Transonic Wind Tunnel Wall Interference," AIAA Paper 79-1533, July 1979.

[5]Kemp, W. B., Jr., "Transonic Assessment of Two-Dimensional Wind Tunnel Wall Interference Using Measured Wall Pressures," *Advance Technology Airfoil Research*, Vol. 1, NASA CP-2045, Part 2, 1979, pp. 473–486.

[6]Gumbert, C. R., and Newmann, P. A., "Validation of a Wall Interference Assessment/Correction Procedure for Airfoil Tests in the Langley 0.3-m Transonic Cryogenic Tunnel," AIAA Paper 84-2151," Aug. 1984.