References

[1]Beam, R., and Warming, R., "An Implicit Factored Scheme for the Compressible Navier–Stokes Equations," *AIAA Journal*, Vol. 16, No. 4, 1978, pp. 393–402.

[2]Jones, W. P., and Launder, B. E., "The Calculation of Low-Reynolds-Number Phenomena with a Two-Equation Model of Turbulence," *International Journal of Heat and Mass Transfer*, Vol. 16, No. 6, 1973, pp. 1119–1130.

[3]Cali, P. M., "Numerical Analysis of Advanced Fighter Auxiliary Power Unit (APU) Exhaust Impingement," AIAA Paper 98-0770, Jan. 1998.

[4]Bryant, M. D., Arendt, L. L., and Hobbs, R. W., "Wind Tunnel Test of a 0.10-Scale Pressure Model With and Without Stores," AEDC-TSR-93-P3, Feb. 1993.

Improvement of a Wing's Aerodynamic Efficiency Using Coanda Tip Jets

R. G. Simpson,* N. A. Ahmed,† and R. D. Archer‡

University of New South Wales, Kensington, New South Wales 2052, Australia

Introduction

THE flowfield in the tip region of a lifting wing is of great interest to the aircraft designer. This region of flow can have a strong influence on the performance of a wing and the production of induced drag. Efforts have been made over the years to reduce the induced drag associated with a lifting wing and to improve the overall lift-to-drag ratio by modifying the wing and the wingtip configuration.

One technique that has been the subject of several investigations is the use of pneumatic blowing outward from the wing tip. The active nature of such a technique offers the advantage that it can be utilized during the phases of flight at which it is best suited. Past efforts in analyzing the effect of blowing in the wing tip region have concentrated on flow visualization and flowfield measurements.[1–4] Some progress has been made toward identifying several aspects of the complex flow mechanisms, but more measurements of the global effects on the lift and drag of the wing are required.

This study looks at the overall lift and drag characteristics associated with blowing from the wing tip with a discrete planar jet exploiting the Coanda effect. The jet geometry has been designed to enhance the effect of blowing by vectoring the jet mass flow against the natural tip vortex. Comparisons involve variations in blowing coefficients and angles of attack at a constant Reynolds number.

Experiments

The test model shown in Fig. 1 is a rectangular wing of 300-mm chord with a half-span aspect ratio of 1.9 and with an NACA 0015 aerofoil section. The wing tip was designed as a body of revolution, and the jet outlet was faired into the shape to minimize the disturbances of the duct outlet geometry. The center of the Coanda jet was located at quarter chord and was 30 mm wide. Interchangeable tips were specifically designed to allow the change between the solid tip for the reference case and that of the Coanda jet.

The tests were performed in a closed circuit wind tunnel with a 1270×914 mm test section at a freestream speed of 25 m/s. The Reynolds number based on chord was 5.1×10^5. Freestream turbulence intensity was measured at 0.3%. A six-component balance was used to obtain the forces acting on the wing and a calibrated mass flow meter was used to determine the blowing coefficient of the Coanda jet. Standard wind-tunnel wall and blockage corrections were applied to the results.

Results and Discussion

Experiments were run for the reference case and the Coanda tip with blowing coefficients up to 0.01. The angle of attack ranged between 0 and 14 deg. For this study the blowing coefficient is defined as

$$C_\mu = \dot{m} V_j / q_\infty S$$

where $\dot{m}$ is the mass flow rate of the blowing jet (kilograms per second). V_j (meters per second) is the velocity of the jet, and q_∞ is the freestream dynamic pressure (pascal). S is the reference area (meters squared) taken as the planform area of the half-wing. Blowing coefficients tested fall in the range of those considered by other investigators.[1–4]

Lift Enhancement due to Blowing

It has been reported in other investigations[1–4] that a lifting wing experiences a lift enhancement due to spanwise blowing. In the study by Tavella and Roberts[2] simple scaling laws were derived to predict the effect of blowing on lift enhancement. This approach was based on perturbing the span of the wing by treating the jet as a thin momentum sheet subject to a pressure differential. The following equation was derived as a result[1]:

$$\Delta C_L / C_{Lo} = k_1 F(A)(C_\mu/\alpha)^{\frac{2}{3}}$$

where k_1 is a constant dependent on jet geometry and $F(A)$ is a function of aspect ratio. A comparison was made to assess the lift enhancement results obtained in this study to the most favorable jet geometry reported by Lee et al.[1] Figure 2 shows a comparison of these results. As can be seen from Fig. 2, the proposed scheme appears to be more effective than the jet configurations reported by Lee et al.[1]

Effects of Blowing on Aerodynamic Efficiency (Lift-to-Drag Ratio)

Figure 3 shows the lift-to-drag ratio for the wing without blowing and with a blowing coefficient of 0.01. Over the higher lift coefficients there is a distinct increase in the lift-to-drag ratio. For a C_L value of 0.8, the wing experiences an increase of about 6% in the lift-to-drag ratio for a C_μ of 0.01. In the lower C_L range (below 0.3) where induced drag is small compared to profile drag, the effects

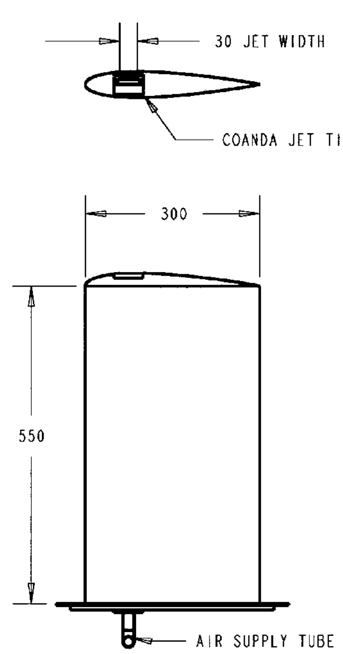

Fig. 1 Wing model, showing Coanda jet location.

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*Graduate Student, Department of Aerospace Engineering.

†Senior Lecturer, Department of Aerospace Engineering.

‡Professor, Department of Aerospace Engineering.

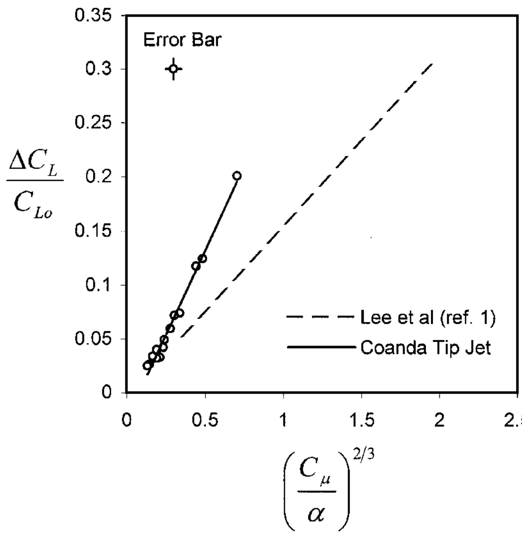

Fig. 2 Lift enhancement due to blowing.

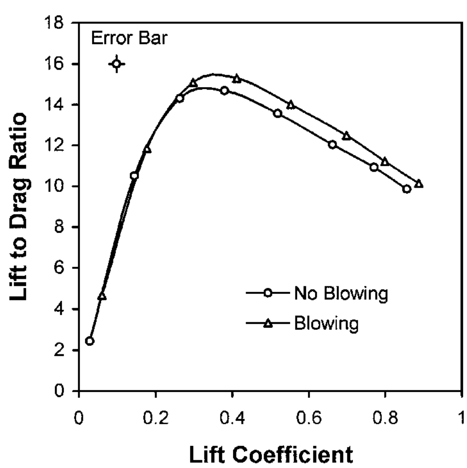

Fig. 3 Aerodynamic efficiency due to blowing at $C_\mu = 0.01$.

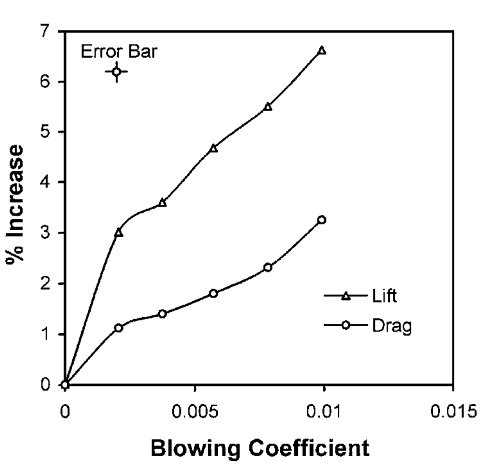

Fig. 4 Percentage increase in lift and drag due to blowing at $\alpha = 8$ deg.

of blowing have minimal effect on the overall lift-to-drag ratio. The enhanced performance appears to be fairly constant above a C_L of 0.4.

Effects of Varying Blowing Coefficient

The effect of blowing on the lift and drag of the wing was studied for five blowing coefficients at a constant angle of attack. Over the values tested, the enhancement was observed to be approximately linear except for the sharper increase in both lift and drag coefficients with the initial introduction of blowing. Figure 4 shows the percentage increase in the lift and drag over the range tested.

Conclusions

Pneumatic blowing through a Coanda tip jet was investigated as a form of increasing the lift-to-drag ratio of a rectangular wing. The scheme was compared to another investigation and shown to have better lift enhancement characteristics. A significant increase in the lift-to-drag ratio in the higher C_L range was produced but little gain was experienced over the lower lift coefficients. Such a technique has the potential of improving a wing's lifting efficiency, particularly during the takeoff and landing phases of flight.

References

[1]Lee, C. S., Tavella, D., Wood, N. J., and Roberts, L., "Flow Structure and Scaling Laws in Lateral Wing-Tip Blowing," *AIAA Journal*, Vol. 27, No. 8, 1988, pp. 1002–1007.

[2]Tavella, D., and Roberts, L., "A Theory for Lateral Wing-Tip Blowing," NASA CR-176931, June 1985.

[3]Wu, J. M., Vakili, A. D., and Chen, Z. L., "Investigation on the Effects of Discrete Wingtip Jets," AIAA Paper 83-0546, Jan. 1983.

[4]Wu, J. M., Vakili, A. D., and Gilliam, F. T., "Aerodynamic Interactions of Wingtip Flow with Discrete Wingtip Jets," AIAA Paper 84-2206, Aug. 1984.

Divergence of an Inflated Wing

Peter Crimi*
Andover Applied Sciences, Inc.,
North Andover, Massachusetts 01845-0578

Introduction

A WING design with inflated tubular spars has unusual structural characteristics that will not accept the classical aeroelastic divergence formulation. This wing construction is particularly well suited for gun-launched observation vehicles and similar systems, where both weight and packaged volume must be minimized while maintaining aerodynamic efficiency of the deployed wing. As shown in Fig. 1, the wing is made up of several inflated woven fabric spars with circular cross section and impervious plastic lining. The wing is covered by a fabric skin. Flexible foam fills the volume between the spars and skin to provide the airfoil shape. The spars are connected at the root to the fuselage and at the tip to a rigid cap. Although the fabric skin does prevent chordwise distortion, the spars are not structurally connected either to the skin or to each other. At a wing section, then, resistance to twist must come from shear reactions rather than torsional stress. At root and tip, however, both torsional moment and shear are applied to each spar. Bending moments are, of course, exerted on the spars at the root, but not at the tip, where all external moments are zero.

The classical second-order differential equation for wing divergence[1,2] is not applicable here because, as will be seen later, reaction to torque at a wing section is proportional to the third derivative of the torsional deflection, rather than the first derivative. In what follows, the effective section torsional stiffness is first quantified. The differential equation for divergence of a constant-chord unswept wing is then derived, and divergence boundaries are calculated. Results indicate that the structure is very resistant to divergence, even though the spars only react torsionally through the end cap.

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*President. Senior Member AIAA.