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Lift Enhancement of a Wing/Strake Configuration Using Pneumatic Blowing

Richard M. Howard,* James G. Willson,†
and Craig J. Zgraggen‡
U.S. Naval Postgraduate School,
Monterey, California 93943

Introduction

THE maintenance of air superiority in the future will depend upon the ability to perform rapid transient maneuvers at high angles of attack (AOAs), often into the poststall flight regime. Techniques for enhanced lift and control at high AOA are being explored to meet this need. Current-generation fighters often employ strakes for vortex lift; however, at some angle of attack, the strake vortex bursts, reducing the effective lift as well as possibly leading to yaw control loss and tail structural problems.

One technique under study for both yaw control and increased lift is the use of pneumatic blowing, either on the aircraft forebody,[1,2] at the wing leading edge,[3] or over the lifting surface.[4,5] Cornelius et al.[1] studied the effects of various nozzle geometries for blowing at the forebody of an X-29 model, and found that a nozzle orientation of 60 deg in from the longitudinal axis produced the largest yawing moments in manipulating the forebody vortices. Celik and Roberts[3] considered forebody-slot and wing-slot blowing for a delta-wing ogive-nose configuration and noted that forebody blowing produced rolling moments four times greater than with tangential wing blowing. LeMay and Rogers[4] conducted a water-tunnel study of the effects of blowing on strake/wing-vortex coupling. Vortex breakdown was delayed past an AOA of 36 deg from a blowing port at the midstrake position. All blowing did not produce favorable results; blowing from ports aft of the strake–wing junction sometimes led to earlier vortex breakdown. Roach and Kuhlman[5] mapped strake vortices using laser-light-sheet and laser-Doppler-anemometry methods. Reductions in vortex coupling and delays in vortex breakdown were noted in particular for blowing from the forward port locations slightly behind the strake apex. Johari and Moreira[6] studied the enhanced effects of pulsed blowing during ramped pitching.

Past efforts in analyzing the effect of blowing over a strake–wing configuration have involved flow visualization and flowfield measurements. Though progress has been made toward identifying flow mechanisms responsible for vortex-breakdown delay and vortex relocation, few measurements of the global effects on the actual lift and drag have been noted. This study treats those effects. Comparisons involve variations in blowing port position, blowing coefficient, blowing sweep angle, and blowing inclination angle.

Experiment

A test was performed with a half-model used in conjunction with a reflection-plane external balance in a low-speed wind tunnel. The three-component balance is an external column strain-gauge balance attached to a turntable mounted flush with the reflection plane. The reflection plane and balance are designed to accommodate half models oriented in the vertical plane. Figure 1 shows a side view of the model mounted in the wind tunnel. The model was comprised of a half-fuselage with ogive forebody, a 36-deg-sweep wing using an NACA 64A008 airfoil, and a sharp 18-deg-wedge 76-deg-sweep strake. The general planform shape followed that of Kern,[7] though Kern's study used a flat plate with beveled edges. The wing had zero deg of incidence, dihedral, and twist.

Blowing ports 1 and 2 were located 0.235·mac and 0.329·mac aft of the strake apex, respectively [mac being the wing mean aerodynamic (geometric) chord]. The blowing tubes were 0.125-in. stainless-steel tubes. Tube 1 was bent (or swept, defined in the same manner as wing sweep) 30 deg, tube 2 was swept 45 deg, and tube 3 was swept 60 deg. Twisting each tube from −10 to 40 deg away from the strake surface allowed for the variation of tube inclination angle.

A mass flow meter was used to determine the blowing coefficient. Air was fed to the tubes from three storage tanks through a regulator at 65 psi. The air moved through urethane tubing to a plenum chamber inside the model before being fed

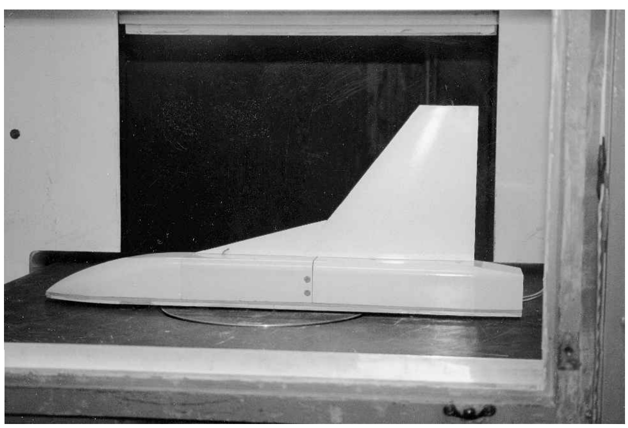

Fig. 1 Wing/strake model with blowing port (shown at port 1 location).

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*Associate Professor, Department of Aeronautics and Astronautics. Senior Member AIAA.

†Graduate Student, Aeronautical Engineering, Lieutenant, U.S. Navy. Member AIAA.

‡Graduate Student, Aeronautical Engineering, Lieutenant, U.S. Navy.

to the blowing tube. Plenum pressures were sufficient to maintain the jet flow at sonic velocity for all blowing coefficients.

Runs were conducted for the various geometries with and without blowing for comparison. Reynolds numbers based on mac were from 5×10^5 to 8.2×10^5; for some tests, tunnel speeds were varied to fix different blowing coefficients. The wind tunnel had an ambient turbulence intensity of 0.2%. Because the study was of a comparative nature, no wind-tunnel corrections were made for wall effects, though standard blockage corrections were applied.

Results

The blowing coefficient C_μ is defined

$$C_\mu = \left(\frac{\mathrm{d}m_j}{\mathrm{d}t}\right) \cdot \frac{V_j}{(q_\infty \cdot S_{\mathrm{ref}})}$$

where $\mathrm{d}m_j/\mathrm{d}t$ is the mass flow rate of the blowing jet, V_j is the sonic velocity of the jet, q_∞ is the freestream dynamic pressure, and S_{ref} is the model wing reference area. Blowing coefficients up to 0.022 could be achieved in the testing environment and maintained for a sufficient time for the measurements to be made. Coefficients of this magnitude fall in the region of those considered by other investigators.

Varying Sweep and Inclination Angles

The first runs were made for each of the three tubes at values of C_μ from 0.0094 to 0.0171 over a range of AOA. Tube 3 at a sweep angle of 60 deg, for both port positions, at the highest C_μ tested, produced the greatest effect on lift enhancement. Therefore, only the results for tube 3 will be presented here. Optimum inclination angles were determined to be 0 deg for port 1 and 10 deg for port 2. Previous studies had found, for the delay of vortex breakdown, the optimum tube inclination angle to be from −10 to 10 deg.[5]

Varying AOA

Runs were conducted at a C_μ value of 0.0171 over an AOA range up to 45 deg. Figure 2 shows the effect of blowing at port 1 with a tube sweep of 60 deg and an inclination of 0 deg. A comparison is made to the baseline wing-and-strake values of lift with no blowing. The enhancement appears to be the greatest in the prestall region around 20 deg; enhancement is also high in the first stall trough at 33 deg, and after the second stall condition. Figure 3 shows the same effect for blowing port 2 with the identical sweep and inclination angles. The enhanced lift is fairly constant across the first poststall region. The blowing appears to provide a reattaching mechanism at 30–35 deg AOA, where a loss in lift is expected. The effect on drag was negligible, and results of drag are omitted here.

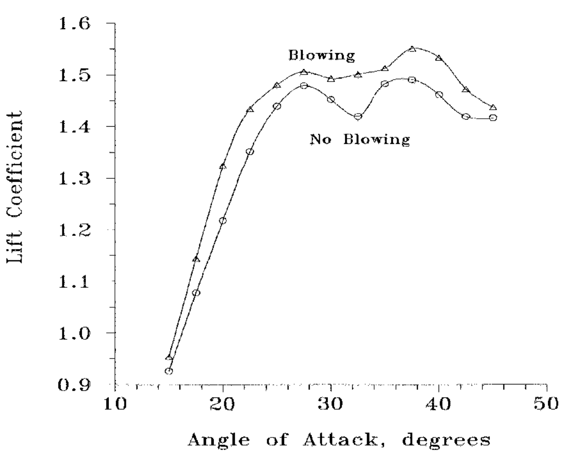

Fig. 2 C_μ **= 0.0171, port 1, 60-deg sweep, 0-deg inclination.**

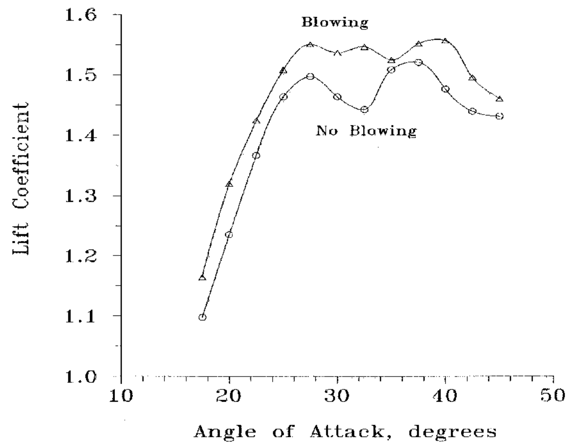

Fig. 3 C_μ **= 0.0171, port 2, 60-deg sweep, 0-deg inclination.**

Varying C_μ

The change of lift with blowing coefficient was studied at fixed AOA for the two conditions where a maximum effect was noted: at an AOA of 20 deg for port 1 and at an AOA of 32.5 deg for port 2. Over the values tested, the enhancement is approximately linear with change in blowing coefficient, with lift enhancement varying from 4% at a C_μ of 0.012 to 9% at a C_μ of 0.022. Should the linear relationship hold for higher blowing coefficients, such as those tested by other researchers[4,8] during flow-visualization studies, enhancements of 12–25% may be achievable.

Conclusions

Pneumatic blowing over the strake led to linear increases in lift of up to 9% with blowing coefficient in the prestall and poststall flight regimes for the values tested. For the sweep angles tested at 30, 45, and 60 deg, higher sweep provided higher increases in lift. The results appeared to be fairly insensitive to inclination angle, with 0 and 10 deg being optimum for the two blowing-port locations considered.

Acknowledgment

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