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CONTROL OF WING LOADS BY MEANS OF BLOWING AND MINI-TABS

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INTRODUCTION

Aircraft and wind turbines suffer from extremes of aerodynamic load due to gusts, turbulence and manoeuvres. Performance could be significantly improved if these extremes could be controlled at the first point of contact, *i.e.* the fluid-structure interface. Current load-control technologies use large actuators like flaps or ailerons which inevitably have a low frequency response. This is despite evidence [1-2] showing that a fast frequency response is of the utmost importance. The fluidic and small mechanical actuators devised for lift augmentation provide a viable high-frequency alternative. However, these aerodynamic actuators have not previously been considered as a means of lift-decrease and would need to operate in the unsteady control regime. In this abstract we present measurements for two potential actuators: blowing and the mini-tab, see Figure 1, in steady scenarios, but not necessarily near the trailing-edge. Future measurements will extend these measurements to unsteady and closed-loop control scenarios.

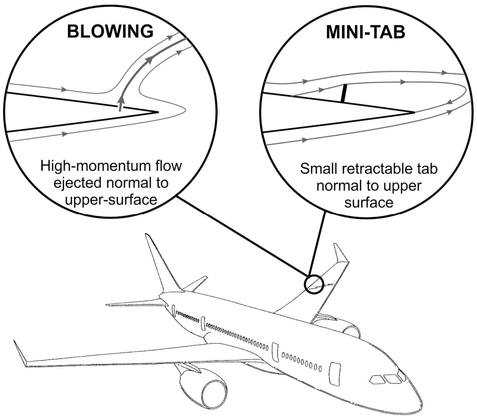

Figure 1: Load control concepts.

METHODOLOGY

Experiments were performed in a closed-loop wind tunnel at a Reynolds number of $Re = 6.6 \times 10^5$. The NACA 0012 wing had a chord length of 0.5 m and span of 1.5 m. It spanned the test section from wall to wall and can therefore be considered an infinite wing. The flow was tripped through a 0.3mm diameter wire at 0.1*c*. Force measurements used a bespoke strain gauge binocular force balance. The accuracy was validated through extensive comparison with measurements from the literature. Particle Image Velocimetry (PIV) measurements used a TSI instruments 2D-PIV system with a 200mJ Nd:YAG Laser and two cameras in tandem so as to cover the entire region of interest.

BLOWING

As shown in Figure 1, the blowing actuation uses a high-momentum flow ejected normal to the surface. This is equivalent to the jet-flap that has previously been investigated for its lift enhancing capabilities. The jet-flap is typically positioned on the airfoil's lower surface near to the trailing edge so as to increase circulation beyond the 'natural state'. However, it has yet to be experimentally investigated for alleviating lift force, which requires actuation on the upper surface, even though CFD calculations have shown favorable results [3-4].

Shown in Figure 2 are selected force and PIV measurements for blowing at x/c = 0.95. The baseline case (C_μ = 0%) demonstrates increasing lift until stall around α = 14° in good agreement with the literature. Increasing momentum coefficient shifts this curve downwards decreasing lift. Typical values for a momentum coefficient of $C_\mu = 2.0\%$ are on the order of $\Delta C_l = 0.15$ which for an aircraft in cruise would be significant. Furthermore this change in lift is relatively constant across the range of angles studied. As shown in the PIV measurements this reduction in lift is associated with the wake being deflected upwards commensurate with lift reduction.

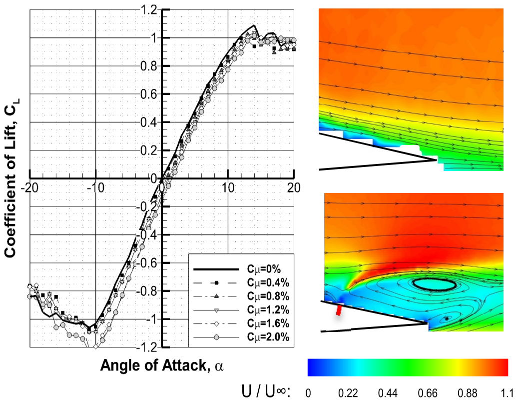

Figure 2: Lift coefficient for blowing at x/c = 0.95 and associated PIV for α = 0° and C_μ = 2.0%.

Spence [5] postulates that the change in lift due to a jet-flap is directly proportional to the root of momentum coefficient ($\Delta C_L \propto \sqrt{C_\mu}$). Figure 3 shows this theoretical curve alongside experimental results from this study and measurements for lower surface (lift increase) actuation from the literature. This comparison between lift increase and decrease is possible due to the symmetry for α = 0°. The experimental measurements show a very wide spread around the theoretical curve. Nevertheless the Bath measurements for x/c=0.95 are in the middle of this spread and closely match the theoretical curve.

The measurements for actuation at x/c = 0.85 and 0.75 show decreasing change in lift as the actuation is moved upstream. This reduced effectiveness is constant across all angles studied. This is in stark contrast to the mini-tab results shown below and an area for further investigation.

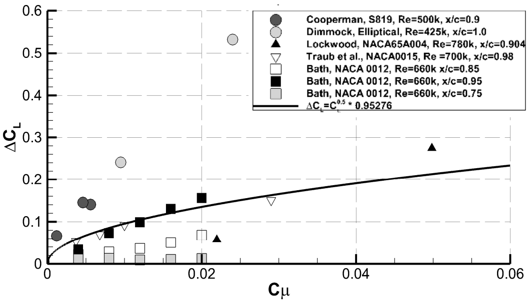

Figure 3: Change in lift coefficient for α = 0°.

MINI-TAB

The mini-tab is a small plate placed perpendicular to the airfoil surface. Its small size implies high frequency of actuation. It is normally placed near the trailing-edge on the lower surface where it creates a pair of counter-rotating vortices that shift the Kutta condition and deflect the wake downwards thereby increasing lift. We are however interested in lift decrease and therefore consider a range of actuation locations on the upper surface.

Shown in Figure 4 are force and PIV measurements for a small mini-tab of height *h*/*c* = 2% mounted in 3 locations: *x*/*c* = 0.08, 0.60 and 0.95. The *x*/*c* = 0.95 location shows a significant reduction but its effectiveness is diminished at higher angles. The flow field for α = 10° (right column) therefore shows a slight intensification of the separation region compared to the baseline but the difference is small reflecting the small difference in lift coefficient at this angle. The *x*/*c* = 0.60 location shows relatively constant reduction until stall with a typical value of $\Delta C_l \approx 0.3$. The flow field shows that the mini-tab has advanced the separation significantly in agreement with the reduced lift. The *x*/*c* = 0.08 location exhibits very different behavior, at low angles it is completely ineffective. PIV measurements not presented here show this is due to the mini-tab promoting separation at the leading-edge but the flow reattaches before the trailing-edge forming a separation bubble. For angles beyond α = 3° the mini-tab is extremely effective reducing the lift coefficient by up to $\Delta C_l \approx 0.6$. The flow field in Figure 4 shows that the mini-tab has advanced the separation point right to the leading-edge resulting in completely separated flow over the upper-surface.

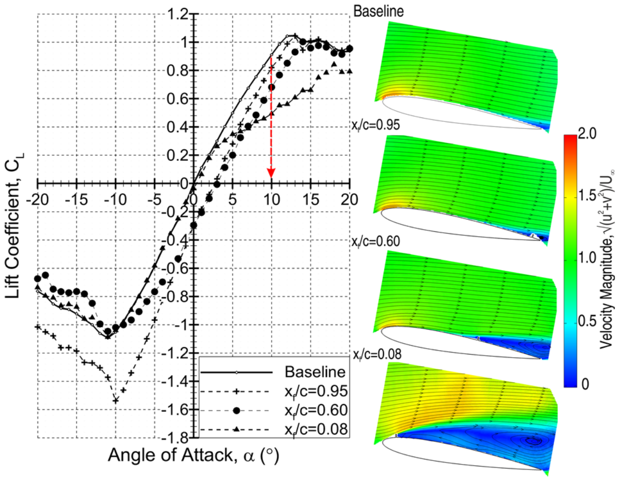

Figure 4: Lift coefficient and associated PIV at α = 10° for a mini-tab of height *h*/*c* = 0.02.

For a particular angle of attack maximum lift reduction is therefore achieved by placing the mini-tab upstream of the natural separation point so as to advance separation. However, if placed too far upstream the flow reattaches negating the effect. There is therefore an optimum region of sensitivity. This is represented as the blue region in Figure 5. For near-zero angles of attack a trailing-edge location is preferable. At small angles of attack a mid-chord location is preferable and for near-stall angles, a leading-edge location is preferable.

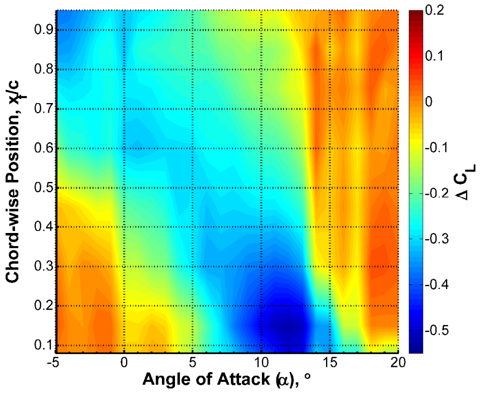

Figure 5: Contour of change in lift coefficient for *h*/*c* = 0.02.

CONCLUSIONS

Experimental measurements have shown that both blowing and mini-tabs are viable methods of load control in steady scenarios, but with qualitatively very different behavior. The blowing deflected the wake upwards thereby reducing lift. It demonstrated relatively constant performance across all angles of attack with locations near the trailing-edge clearly preferable. Conversely the mini-tab promoted separation over the upper surface thereby reducing lift. The optimal location varied according to the angle of attack, with locations near the trailing-edge preferable at low angles of attack and locations near the leading-edge preferable at high angles of attack. Future measurements will consider these devices in unsteady and closed-loop control scenarios.

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