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Lift-Enhancing Tabs on Swept, Three-Dimensional High-Lift Systems

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Introduction

HIGH-LIFT aerodynamicists continue to look for simple ways to achieve greater lift from multielement airfoil sections. One such possibility is the lift-enhancing tab (LET) introduced by Ross et al.[1] A lift-enhancing tab is a small mechanical tab placed at or near the trailing edge of an airfoil element, similar to a Gurney flap. Two-dimensional studies[2,3] have shown that LETs can dramatically improve high-lift system performance. The present study computationally investigates LETs on a simple, three-dimensional high-lift system, including the effects of wing sweep. Only a brief description of the computational and experimental approaches is given here. A more thorough discussion can be found in Refs. 4–7.

Geometry and Flow Conditions

The geometry consists of a NACA 63_2-215 Mod. B airfoil section[8] that spans the wind-tunnel test section. Over one-half of the span, a 30% chord Fowler flap has been installed with a gap of 3.6% chord, an overlap of 1.5% chord, and a deflection of 40 deg. All of the results were obtained at an angle of attack of 10 deg, an angle representative of the landing attitude for a commercial aircraft. In the cases where LETs are used, a 0.5% chord tab is placed just upstream of the trailing edge of the flapped portion of the main wing. Three leading-edge sweep angles are presented, 0, 15, and 30 deg, but experimental data only exist for the 0-deg case. The wing was swept such that the flapped portion of the wing was forward of the unflapped section.

The experimental investigation was conducted in the NASA Ames Research Center's 7- by 10-Foot Wind Tunnel.[9] The data were obtained at a freestream Mach number of 0.22, low enough to justify the use of an incompressible flow solver. The resulting Reynolds number, based on the unflapped airfoil chord, was 3.7×10^5. A thorough discussion of the experiment can be found in Ref. 7.

Numerical simulation of the flow was performed using the INS3D-UP code.[9] A six-zone, structured mesh containing 1.8 million points was used,[4] requiring 450 iterations to converge. Approximately 20 CPU hours were used on a supercomputer for each case. The one-equation Baldwin–Barth turbulence model was used to model the eddy viscosity in this study.[10]

Results and Discussion

The lift-enhancing tab is most effective when applied to high-lift systems experiencing flow separation on the flap, as shown in Fig. 1. In this figure, a large recirculation region is seen above the surface of the flap. The system is still generating a fair amount of lift (C_L = 2.28) because the main wing is largely unseparated. This does not restrict the use of LETs to poorly designed sections, as flap separation can limit the maximum efficient deflection angle of any section. Lift-enhancing tabs may increase the lift of a well-designed section by allowing the flap to be deflected farther before the onset of separation.

With the addition of the tab the flow remains attached as shown in Fig. 2. Fluid shed from the main element is turned downward by the tab, reducing the effective angle of attack seen by the flap. Attached flow on the flap not only increases the lift carried by the flap, but also increases the lift carried by the main element. The net effect is to increase the lift of the entire system by much more than just the additional flap lift.

Figure 3 shows the total lift coefficient plotted vs sweep angle for all of the presented cases. As expected, the baseline lift, i.e., without LET, decreases as the wing sweep increases. The magnitude of the lift decrease is quite dramatic between 0 and 15 deg, reducing the total amount by nearly one-half. This change is so large because of the low aspect ratio of the flap. With such a low aspect ratio, the change in the flow at the flap tip because of sweep can be felt over the entire span. The change in C_L between 15 and 30 deg is much less. The corresponding values with tabs are also shown. The lift–sweep trends are the same, but the tab reduces the amount of lift loss caused by sweep.

Perhaps a better comparison can be made if the percentage increases in total lift are compared. Figure 3 showed that the baseline lift decreases with sweep angle, and the change in lift because of the tabs gets larger with increasing sweep. This suggests that the relative effectiveness of the tabs strongly increases with sweep, as shown in Fig. 4. A 5% increase in C_L is seen for the unswept wing (both experimental and computed), whereas the increase jumps to 27% for the moderately swept wing (15 deg). The tab is even more effective for the highly swept case, increasing the lift by 36%.

Fig. 1 Particle traces over the flap element at the wind-tunnel wall, unswept case, no tab.

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Fig. 2 Particle traces over the flap element at the wind-tunnel wall, unswept case with tab.

Fig. 3 Total lift coefficient vs sweep angle.

Fig. 4 Relative tab effectiveness for three sweep angles.

Conclusions

A numerical study of lift-enhancing tabs on three-dimensional high-lift systems was performed. Lift-enhancing tabs have been computationally shown to improve the lifting capability of high-lift systems at three leading-edge sweep angles, 0, 15, and 30 deg. The lift coefficient at 10-deg angle of attack is increased by 5, 27, and 36%, respectively. The results for the unswept case were compared with experimental data and the lift increments caused by the tabs agreed closely.

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Spanwise Camber and Quasisteady Effects During Wing Rock

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Introduction

AN inviscid computer model has been used to aid in further understanding and evaluation of the slender wing rock phenomenon. The inviscid model has been coupled with the rigid body equation of motion in oscillations to simulate the fluid–structure interaction. The investigation focuses on an isolation of quasisteady effects on a delta wing through an application of the roll-rate boundary condition. In addition, spanwise camber changes through differential flap deflection was investigated.

Methodology

The computational analysis for this study was performed using a modified inviscid model developed by Arena and Nelson.[1] The modifications made by Ize and Arena[2] allowed the model to be used to study the quasisteady effects and the spanwise camber during wing rock. It was shown that the essential characteristics of the unsteady delta wing can be captured by modeling only the primary flow characteristics, which is based on experimental results. Validation of the model can be found in Ref. 2. The solution to the present model is obtained by using a panel technique where the body geometry is represented by a distribution of constant strength sources and vortices, allowing for arbitrary specification of spanwise boundary

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