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Studies on Alleviation of Buffet in Periodic Transonic Flow

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Introduction

AIRCRAFT in flight can be subject to buffet excitation, due to large flow unsteadiness associated with boundary-layer separation or, as in the case of transonic flows, with periodic self-excited shock-induced oscillations. Buffet can also occur in cavities such as aircraft bomb bays, exhaust diffuser of steam turbines, turbomachinery blades, and supersonic intakes of aeroengines. Buffeting is defined as the structural response to pressure excitations. In the case of an aircraft, buffeting can lead to structural deformations and failure of primary, for example, wings and tail plane, and secondary, for example, flaps and rudder, structures. Buffeting can also cause both discomfort to passengers and difficulty for the pilot in attempting to control the aircraft. Thus, buffet limits the cruising speed of commercial aircraft and severely degrades the maneuverability limits for a combat aircraft. An understanding of buffet on oscillatory wings with control surfaces is of specific concern in aeroelastic investigations in determining the power requirements in active control systems for load alleviation and flutter control.

There have been several studies, computational and experimental, on transonic periodic flow over an 18% thick biconvex airfoil.[1–8] The general understanding of this type of flow is as follows: 1) the periodic motion on an airfoil is sustained by the communication across the trailing edge, and the frequency of the periodic motion is directly related to the time required for the signals to travel over the chord length; 2) the periodic motion takes place over a narrow range of Mach numbers; and 3) shock waves move in antiphase on the upper and lower surfaces during shock oscillations.

The known means of eliminating or suppressing shock motion (see, for example, Refs. 3 and 4) include 1) buffet breathers, 2) spanwise wires, 3) altered trailing edge, 4) passive control, 5) vortex generators, and 6) reduced stiffness and span. A spanwise strip located aft of the shock wave eliminated high-frequency transonic oscillations but increased subsonic low-frequency buffet. A suitably positioned vortex generator can also produce a similar effect. Passive control with porous surfaces and buffet breather also have been found to suppress shock oscillations in the transonic range.

This Note presents some of the results of a transonic computational fluid dynamics (CFD) study performed on a biconvex airfoil with a splitter plate extension or with surface cooling with a view to suppress the periodic motion.

CFD Code Development and Validation

A two-dimensional, thin-layer Navier–Stokes code with a moving grid was developed for these investigations. The relative merits of various methods for prediction of transonic periodic flows has been discussed by Edwards.[6] The code developed for the present investigations also has a moving grid option to investigate the effect on periodic flow of a trailing splitter plate motion, a flap motion, and a pitching airfoil.

The implicit code solves the mass-weighted, thin-layer Navier–Stokes equations using an upwind implicit predictor/corrector cell-centered finite volume scheme. A modified version of the simple algebraic Baldwin–Lomax turbulence model is employed. Sutherland's law was used for viscosity, and the Prandtl analogy was employed for thermal conductivity.

A C grid was generated with a 1% radius at the leading edge of the airfoil to remove computational difficulties. The minimum normal grid spacing was reduced to 5×10^{-6} chords, ensuring a value of $y^+ < 5$ everywhere on the airfoil surface. Transition to turbulence was fixed on both the upper and lower surface at 3% chord. The solution was again started from rest on a coarse grid, where 50 iterations were performed before transferring to the fine grid.

The test cases used for validation of periodic flows were 1) 18%-thick circular arc airfoil at zero incidence, Mach number of 0.771, and Reynolds number of 11×10^6; and 2) NACA0012 airfoil at 6-deg incidence, Mach number of 0.7, and Reynolds number of 10×10^6. These test conditions lie within the unsteady range found experimentally and computationally.

The validation for periodic transonic flow over an 18%-thick biconvex airfoil is shown in Fig. 1. The predicted reduced frequency is 0.44. The change in lift coefficient is 0.247. This compares with the corresponding predicted values of 0.465 and 0.265 of Ref. 6 and 0.41 and 0.23 of Ref. 9.

The code correctly predicted Tijdeman type B shock motion on a rigid NACA0012 airfoil at $M_\infty = 0.7$, $Re_\infty = 10 \times 10^6$, and incidence of 6 deg. This type of periodic motion has been computed by Edwards.[6] The nondimensional frequency predicted is 0.21, compared with 0.235 by Edwards.

Some investigations were conducted on the effect of flap deployment. The effect of a flap deployment by a small angle of 3 deg during a time period 1/16 of a period of the original periodic motion (which is considerably less than the time required for the signals to go around the airfoil in one cycle) resulted in the change in shock motion from type B to type A, indicating the significant effect of the trailing edge on periodic transonic flow.

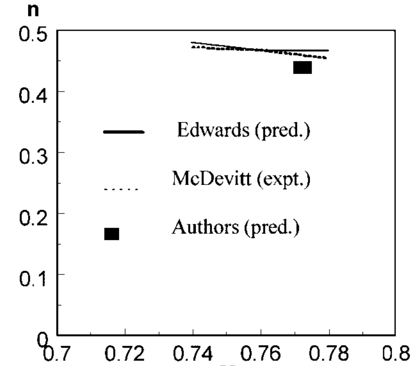

Fig. 1 Correlation of reduced frequencies for periodic transonic flow over an 18% thick airfoil; $M_\infty = 0.77$, $Re_\infty = 11 \times 10^6$, $\alpha = 0$.

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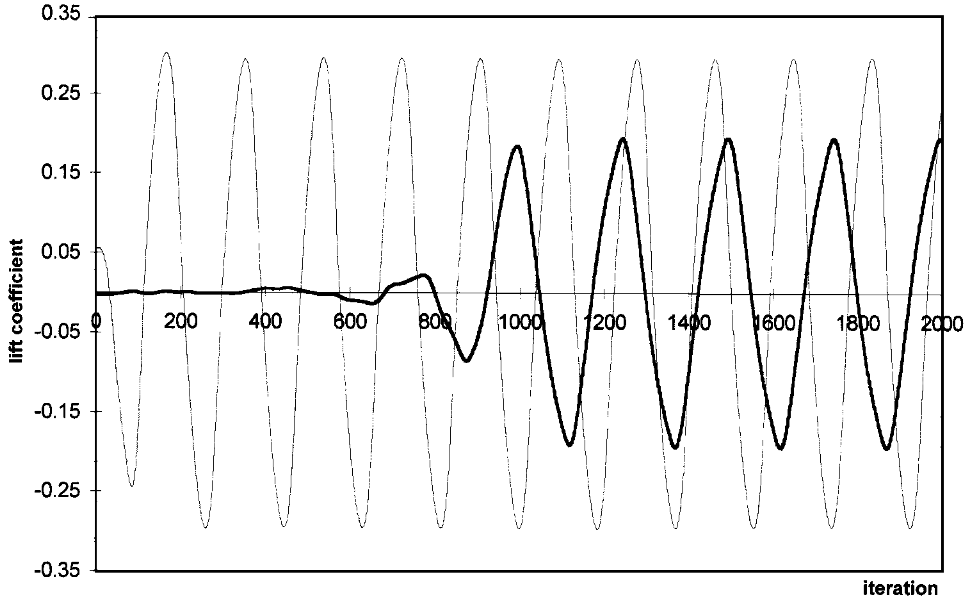

Fig. 2 Effect of a 9% chord splitter plate on periodic transonic flow over an 18%-thick airfoil; M_∞ = 0.77, Re_∞ = 11 × 10^6, α = 0: ——, CL with 9% sp and ——, CL without sp.

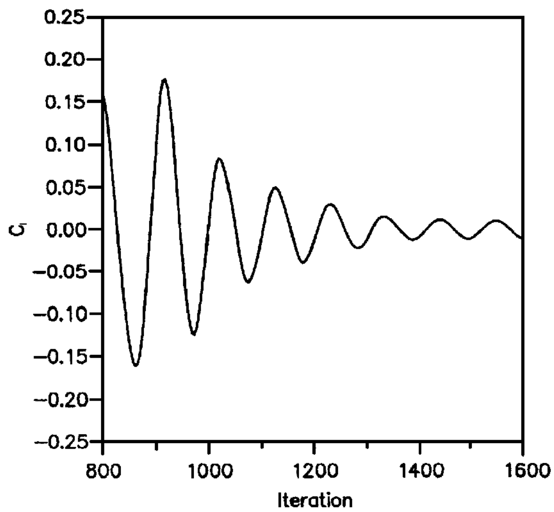

Fig. 3 Effect of heat transfer on periodic transonic flow over a 14%-thick biconvex airfoil; M_∞ = 0.83, Re_∞ = 7 × 10^6, α = 0.

Results

The effect of a splitter plate extension is somewhat similar to that of the flap. Depending on its length, the splitter plate can modify the amplitude of both lift and shock motion or completely eliminate the shock oscillations.

A 9% chord trailing-edge splitter plate extension can change the shock motion from type B to type A (Fig. 2). Both the amplitude and frequency of shock motion are reduced, and this could be due to the reduced effective thickness ratio and increased effective length of the airfoil, respectively. A splitter plate also has a positive effect on wake oscillations. A 25% chord trailing-edge splitter plate completely eliminated periodic shock oscillations. In this case, apart from the effect that the splitter plate extension produces on the wake, it could be argued that at these freestream conditions the effective geometry of the airfoil (thickness ratio of 14.2%) is such that the flow region is outside the periodic regime. Thus, a trailing-edge splitter plate can also be used to alleviate shock oscillations.

An understanding of the effect of heat transfer on periodic motion on airfoils is important in wind-tunnel testing, where the model surface temperature may not be same as the adiabatic temperature. Predictions for the effect of heat transfer on a rigid 18%-thick biconvex airfoil at $M = 0.83$ and $Re_\infty = 7 \times 10^6$ are shown in Fig. 3. The change from adiabatic to cool wall does not occur instantaneously but may be described by an exponential decay to a new periodic limit cycle. It is evident that surface cooling significantly reduces the lift coefficient amplitude in agreement with the experimental results. The movement of the shock has been virtually eliminated and is typical of Tidjeman type A motions rather than the type B ones apparent in the corresponding adiabatic analysis. The effect of heat transfer could be attributed to the boundary-layer development and communication through the trailing edge of signals around the airfoil.

Conclusions

Computational studies of the effects of a trailing-edge splitter plate and surface heat transfer on periodic shock motion in transonic flows are investigated. The results indicate that the periodic motion on rigid biconvex airfoils can be predicted with the code. The effect of a splitter plate extension or surface cooling changed the type or completely attenuated the shock motion.

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