This airfoil, defined by Eq. (8), is named NAL-00XX. Table 1 also shows the coordinates and the velocity of NAL-0015 airfoil defined by Eq. (8). One can see that the NAL-0015 airfoil is similar to the Sunya airfoil of the same thickness and can provide a benchmark for analysis and testing like the NACA 0015 airfoil.

Conclusions

Since NAL-00XX airfoils are essentially equivalent to the Sunya airfoil of the same thickness there is no point in using the approximation given by Eq. (8), and as such the Sunya airfoil can be taken as a standard model for analysis and testing. NAL-00XX airfoils have only an academic interest.

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Partial-Span Leading-Edge Vortex Characteristics in High-Rate Oscillations in Pitch

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Introduction

IN recent pitch–oscillation tests[1] with a sharp-edged 45-deg delta wing the overall objective was to alter the development of the leading-edge vortex and decrease the extent of stall on the wing. The experimental results are of considerable interest. The modest leading-edge sweep is typical of many agile aircraft operating at high angles of attack. It produces a partial-span leading-edge vortex (Fig. 1a), such as has been observed on a wing with a 49.4-deg swept leading edge[2] (Fig. 1b).

Analysis

The time-lagged dynamically equivalent steady (DES) flow concept described in Ref. 3 is used in an attempt to define the unsteady flow physics causing the measured dramatic effects of pitching frequency on the vortex characteristics of a 45-deg delta wing[1] (Fig. 2). The flow visualization results are for the chordwise section at 45% span. Comparing the stationary results in Fig. 1a with the static data in Fig. 1b, one finds that in both cases the partial-span leading-edge vortex is located aft of or near midchord at 45% span. Judging by the measured static camber effect on the spanwise location of the leading-edge vortex[4] and, in particular, on the chordwise location of vortex breakdown,[5] one can expect the dynamic camber effect (Fig. 3) to be large for the partial-span vortex on the 45-deg delta wing.[1] The experimental results[1] for $\bar{\omega} = 2k = \omega c/U_\infty = \pi$ in Fig. 2 show that the partial leading-edge vortex stayed

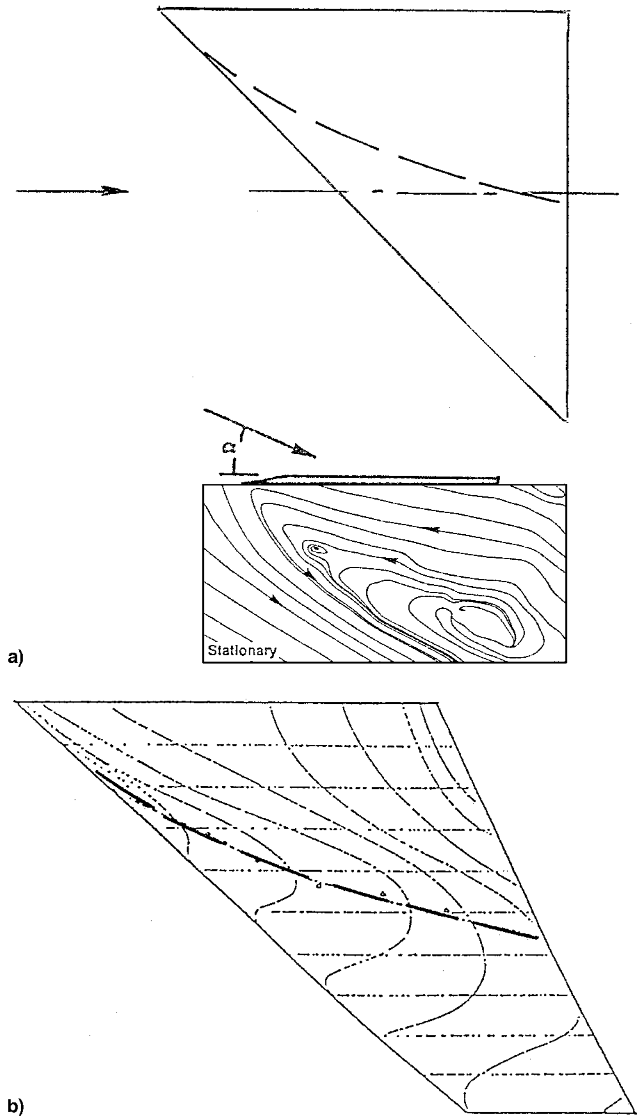

Fig. 1 Partial-span leading-edge vortices: a) 45-deg delta wing at α = 30 deg[1] and b) 49.4-deg cropped arrowhead wing at α = 20 deg.[2]

forward of the static location throughout the pitch–oscillation cycle. One expects the favorable effect of the pitch-rate-induced camber on the partial-span vortex to be analogous to that on vortex breakdown observed in pitch–oscillation tests with a 70-deg delta wing, where the vortex breakdown stayed aft of the static location throughout most of the oscillation cycle[6,7] (Fig. 4) and the extent of flow separation through vortex burst was decreased from its static value. This result is similar to the camber effect on the 45-deg delta wing, in that the extent of the lost vortex-induced lift at the leading edge was decreased. The vortex in Fig. 2 and the vortex breakdown in Fig. 4 have difficulty getting back to the stationary location because of the long transients, causing the initial static flow conditions to have a dominant effect on the dynamic characteristics.[8] If the oscillations in Fig. 2 had been initiated at C rather than A, one would expect the vortex to stay behind its stationary location throughout the oscillation cycle.

The separation-delaying action of the dynamic camber effect dominates over the α effect, causing the partial-span vortex to be located farther forward than in the static case throughout the pitch–oscillation cycle (Fig. 2). For this high frequency ($\bar{\omega} = \pi$) the favorable dynamic camber effect has already had a significant effect on the flow topology when point A is reached, resulting in a strong vortex near the leading edge.

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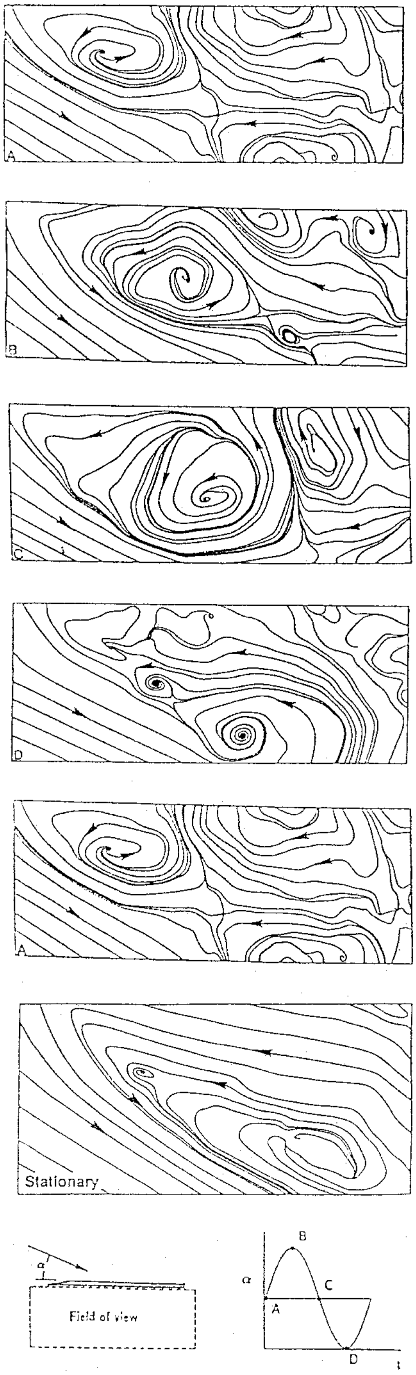

Fig. 2 Instantaneous streamline patterns for phase-locked response of flow structure on a 45-deg delta wing at α = 30 deg, $\Delta\alpha$ = 5 deg, $\bar{\omega} = \pi$ (Ref. 1).

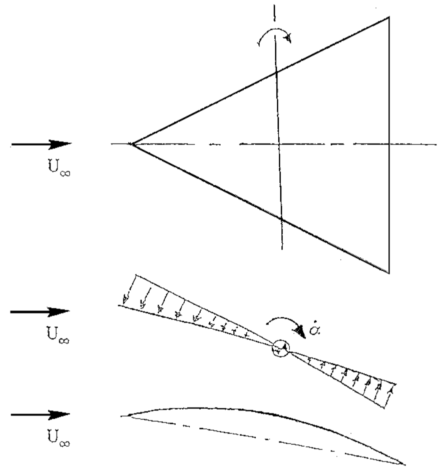

Fig. 3 Pitch-rate-induced camber effect.

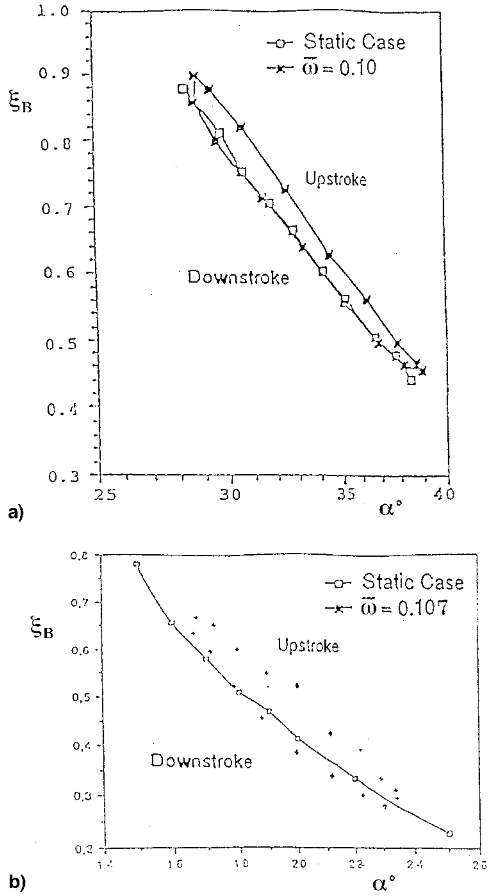

Fig. 4 Vortex breakdown location on a 70-deg delta wing describing oscillations in pitch: a) α_0 = 34 deg, $\Delta\alpha$ = 5 deg, $\bar{\omega}$ = 0.10 (Ref. 6) and b) α_0 = 20 deg, $\Delta\alpha$ = 3.5 deg, $\bar{\omega}$ = 0.107 (Ref. 7).

Because of the time-history-effect, much of the strong dynamic camber effect generated at A is still acting at B, resulting in only a modest downstream movement of the leading-edge vortex. At C, the adverse dynamic camber effect generated during the downstroke, starting at B, has moved the vortex aft, a continuing movement that at D has placed the vortex only slightly ahead of its static location. That is, the dynamic camber effect on the location of the partial-span leading-edge vortex in Fig. 2 is analogous to that measured on the location of vortex breakdown on the 70-deg delta wing in Fig. 4. Going from D to the repetition of A, one finds that the original leading-edge vortex generated one cycle earlier has moved to an aft position close to, but still ahead of, the location of the vortex in the stationary case, whereas a new, strong vortex is generated near the leading edge by the favorable pitch-rate-induced camber effect.

The analysis in Ref. 3 shows that the α-generated changes of the vortex are convected with the velocity $\bar{U}_\alpha \geq U_\infty$; whereas the camber-induced changes, which largely controlled the vortex breakdown, were convected at $\bar{U}_c \approx 0.7\bar{U}_\alpha$ for the tested 52-deg delta wing[9] that had a full-span leading-edge vortex. Thus, it was concluded that $0.5U_\infty < \bar{U}_c < U_\infty$. With $\Delta t = c/\bar{U}$ being the time required for a change of angle of attack or camber to be fully experienced by the vortical flow over the 45-deg delta wing, the corresponding phase lag is $\omega\Delta t = \bar{\omega}U_\infty/\bar{U}$. For a change of angle of attack, one obtains $\omega\Delta t_\alpha \leq$

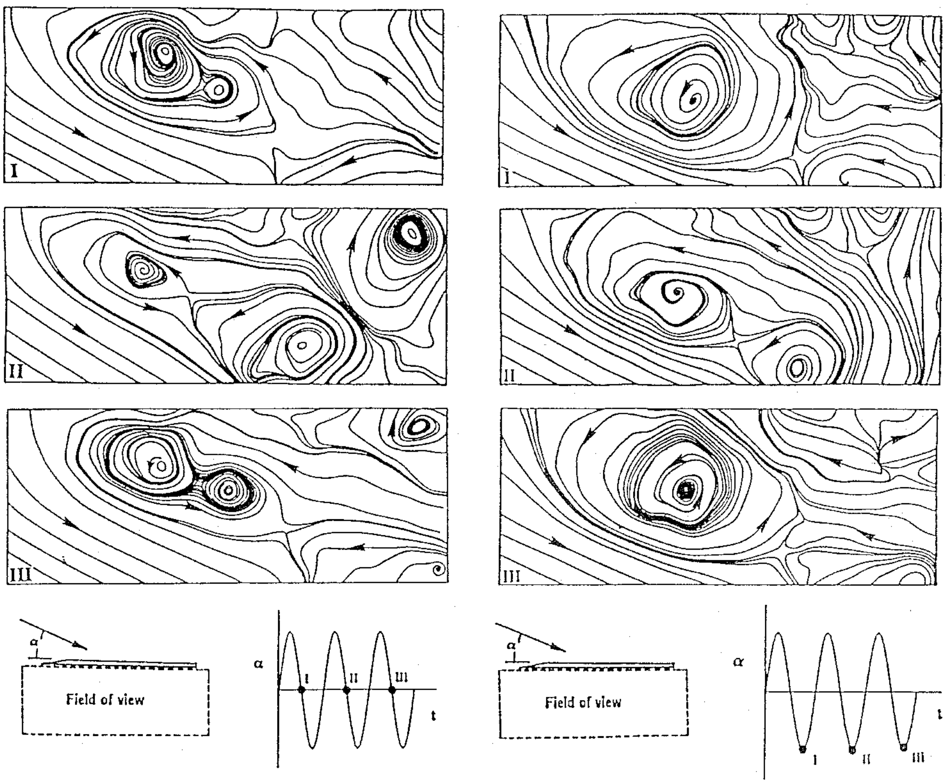

Fig. 5 Instantaneous streamline patterns for phase-locked response of flow structure on a 45-deg delta wing at α = 30 deg, $\Delta\alpha$ = 5 deg, $\bar{\omega} = 2\pi$ (Ref. 1).

$\bar{\omega}$, and for full realization of the dynamic camber effect $\bar{\omega} < \omega\Delta t_c < 2\bar{\omega}$. That is, for $\bar{\omega} = \pi$, $\omega\Delta t_c < 2\pi$, so that every cycle of the oscillation in Fig. 2 starts out fresh, whereas $\omega\Delta t_c > 2\pi$ for $\bar{\omega} = 2\pi$, causing remnants of the dynamic camber effect to be present from the previous cycle (Fig. 5). As a consequence, the vortex pattern repeats every other cycle, not every cycle as in Fig. 2 for $\bar{\omega} = \pi$.

Conclusions

An analysis of recent high-rate pitch-oscillation tests with a 45-deg delta wing has shown that the use of an earlier developed time-lagged DES flow methodology is very helpful when trying to reach an understanding of the flow physics, even in cases where the pitch-oscillation frequency is extremely high, $\bar{\omega} > \pi/2$, where time-history effects cannot be approximated by the effect of a single, constant time lag.

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Smart Stiffness for Improved Roll Control

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I. Introduction

THE application of smart structures technology offers some intriguing possibilities for high-performance aircraft. For

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