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Engineering Notes

ENGINEERING NOTES are short manuscripts describing new developments or important results of a preliminary nature. These Notes cannot exceed 6 manuscript pages and 3 figures; a page of text may be substituted for a figure and vice versa. After informal review by the editors, they may be published within a few months of the date of receipt. Style requirements are the same as for regular contributions (see inside back cover).

Effects of a Closely Coupled Static and Oscillating Canard

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Introduction

THE maintenance of air superiority in the future will depend upon the ability to perform rapid transient maneuvers at high angles of attack, often into the poststall flight regime. With the advent of new highly maneuverable aircraft, a resurgence of interest has taken place in the favorable interaction between a close-coupled canard and a highly swept or delta wing for enhanced lift. Many new fighter aircraft designs, including the Israeli Lavi, the Swedish Gripen, the French Rafale, the French Mirage 3, and the European Fighter Aircraft (EFA), employ such a configuration. An exception is the X-31, which uses a long-coupled canard for the purpose of pitch recovery at high angles of attack rather than for enhanced lift.

Early work[1] considered an array of arrangements of the close-coupled canard with regard to relative canard size and canard longitudinal and vertical placement for optimum lift enhancement. More recent studies[2–4] have further documented the important mechanisms of wing-leading-edge vortex-breakdown delay and reduced inboard-wing-section angle of attack.

Lacking in many of the studies was a consideration of the role of canard deflection in the lift-enhancement process. In many cases, the canard was coplanar with the wing for all angles of attack. It was of interest to ascertain whether canard deflection actually could play a significant role in optimal lift enhancement in the poststall regime.

Following up on recent successes with applications of dynamic stall for airfoil lift enhancement,[5] investigators in the late 1980s began to consider the dynamic vortex as a potential secondary driver of enhanced lift. An applied topic of related interest was whether an oscillating close-coupled canard could further enhance the increased lift on a trailing wing. Ashworth et al.[6] made local flowfield measurements on an X-29 model with an oscillating canard, but no force measurements were taken for the oscillating or static case. Huyer and Luttges[7] treated two-dimensional airfoils of equal chord, separated longitudinally by a half-chord length, with the forward airfoil in oscillation. Integrated surface-pressure data on the trailing airfoil resulted in a periodic normal-force response, but no comparison to static testing was discussed. A comparison to three-dimensional wings would be difficult, as highly swept canards provide the energizing mechanism in the form of the strong leading-edge vortex not present in the two-dimensional case. A recent flow-visualization study[8] using an X-31-like model with an oscillating canard concluded that small-amplitude, hf oscillations appeared to delay vortex bursting, but the reduced frequencies ranged from 1.7 to 10.4, one to two orders of magnitude higher than values typically found to maximize lift in dynamic-stall experiments.[5]

First, a study was performed to ascertain if an optimal lift enhancement could methodically be achieved through static canard deflection. Second, based on optimal canard settings from the first study, an investigation was carried out to determine if a mean lift enhancement due to the oscillation of a close-coupled highly swept canard could be produced.

Experiment

The wind tunnel uses an external three-component strain-gauge balance attached to a turntable flush with a reflection plane. The close-coupled canard half-model is shown in the wind tunnel in Fig. 1 at 60-deg angle of attack. The wing has a 50-deg leading-edge sweep and an AR of 3; the canard has a 60-deg leading-edge sweep and an AR of 2. For the oscillation tests, the canard pivoted at 0.25 of its mac. The NACA 64A008 airfoil was used for both canard and wing sections. For more information on the wind tunnel and model, see Refs. 9–11.

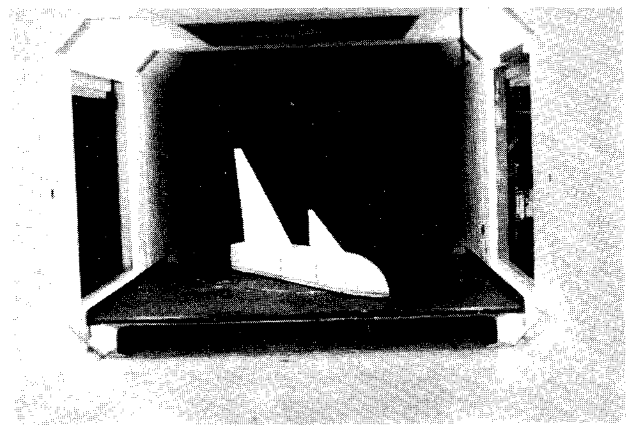

Fig. 1 Wind-tunnel model, 60-deg angle of attack.

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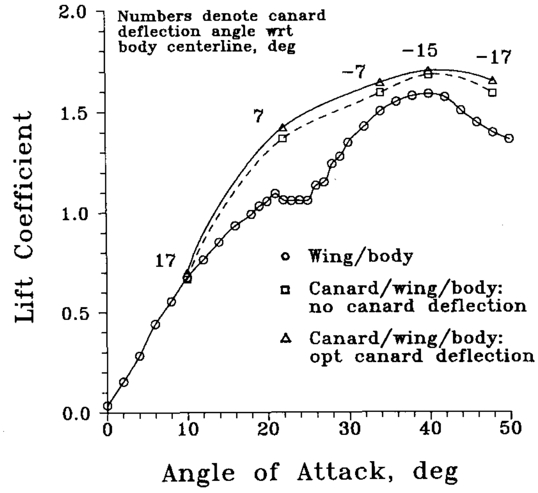

Fig. 2 Lift coefficient vs angle of attack.

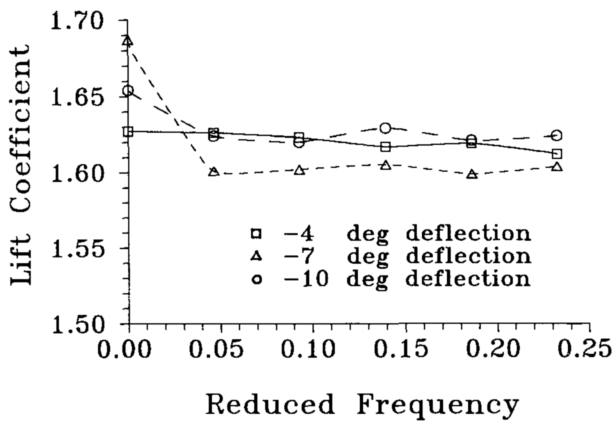

Fig. 3 Oscillation-canard case, model angle of attack of 34 deg, canard oscillation amplitude of ±10 deg.

Results

Static Tests

Figure 2 shows a comparison of the cases of no canard deflection (coplanar canard) and optimal canard deflection against the wing-body results. The additional lifting area of the canard has been included in the reference area when used. A significant enhancement due to the addition of the canard is seen to take place in the first poststall region, where the flow previously separated, but where no strong wing-leading-edge vortex had yet formed. The enhancement increases again in the second poststall region, but in this case the wing-leading-edge vortex is already providing a reattachment mechanism; the canard vortex contributes, but does not dominate, as it did in the first poststall region.

Small additional benefits were found to be gained for an optimized deflection. Enhancements were about 3% of the total lift, or about 15–30% of the total lift enhancement. As it turns out, the canard angle of attack (relative to the freestream) remained relatively constant at about 27 deg, and was fairly independent of the wing-body angle of attack.

Oscillating Canard Tests

Based on the static-canard results, two tests were conducted with an oscillating canard: the first was with the model at 22-deg angle of attack, and the second was at 34 deg. The canard was positioned at mean deflection angles of 4, 7, and 10 deg for the first case and at −4, −7, and −10 deg for the second case. At each of the canard mean deflection angles, the canard was oscillated at amplitudes of ±5 and ±10 deg at reduced frequencies ($k = \varpi mac/[2V]$, where ϖ is the oscillation frequency in rad/s and V is the freestream velocity) ranging from 0.05 to 0.23.

Figure 3 shows the results at a typical test condition of model angle of attack of 34 deg and oscillation amplitude of ±10 deg. A small loss of lift is experienced at −7 and −10 deg across the range of reduced frequencies, while the −4-deg case is insensitive to oscillation. Other cases vary, and some small enhancements resulted for some combinations of frequency, amplitude, and mean deflection, but no significant gains were observed during the tests.

An error analysis was conducted, and it was estimated that the lift coefficient is accurate to within a value of ±0.03; this order of uncertainty is of the same magnitude as any noted changes due to oscillation enhancement. Therefore, it can only be concluded that for the configuration tested, over the range of frequencies typically used to provide dynamic-stall lift enhancements for airfoil testing, no measured benefits could be found.

Concluding Remarks

While no investigator enjoys presenting negative results, at least an important question has been addressed that has occupied various researchers for the past decade. Most studies of dynamic stall of two-dimensional sections have taken the pitch axis to be the quarter-chord; further answers need to be sought of the proper pitch-axis location for highly swept surfaces. There has been very little investigation concerning the whole issue of dynamic stall of three-dimensional wings. While time-dependent lift enhancements may be achievable for two-dimensional surfaces, aircraft require steady benefits, or at least ones with a significantly longer time constant than is provided at typical dynamic-stall reduced frequencies. The search for nonsteady aerodynamic solutions to high-lift problems will no doubt continue.

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