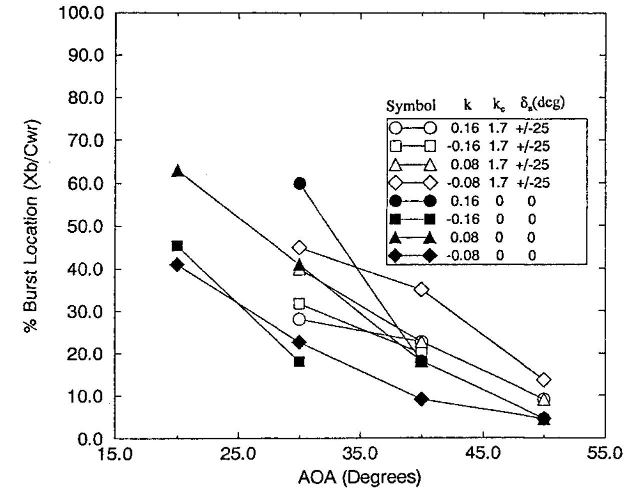

Fig. 7 Wing root vortex burst location for pitching model with oscillating canard.

at low frequencies behaves more like a slowly varying field with negligible unsteady effects. However, with increase in the frequency ($\delta_a = \pm 5$ deg, $k_c = 10.3$), the integrated dynamic effect leads to stabilization of wing vortex core (delayed vortex bursting), which is in contrast to the effect of the static canard deflection angle. This points to possible potential benefits of using canard oscillations for controlling the wing flowfield. The interaction can be quite different during the dynamic motion of the model, with pitch rate influencing the interaction. Indeed, the present data indicate that the large-amplitude, lf oscillations of the canard have negligible influence on the vortical flowfield of the static model, but lead to favorable interactions on the pitching model, particularly at high AOAs.

Conclusions

Static Model

At small amplitude, the lf canard oscillations tend to destabilize the wing vortex core (early bursting), whereas the hf oscillations delay vortex bursting. The large-amplitude, lf oscillations seem to have a marginally favorable effect on the wing vortical flowfield.

Dynamic Model

The dynamic tests indicate that the large-amplitude, lf oscillations of the canard interact favorably with the wing vortical flowfield to delay vortex bursting during pitch-up or pitch-down motion.

Acknowledgments

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Effects of Delta Planform Tip Sail Incidence and Arrangement on Wing Performance

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Nomenclature

C_D = drag coefficient
C_L = lift coefficient
C_m = pitching moment coefficient
ds = sail incidence, defined positive following a nose-down deflection
α = angle of attack

Introduction

NUMEROUS wingtip devices have been investigated to attenuate vortex drag. These encompass apparatus to reduce drag by releasing trailing vorticity over a substantial vertical distance (e.g., endplates[1] and winglets[2,3]), as well as essentially planar devices (e.g., tip sails[4,5] and various forms of spanwise blowing,[6,7] etc.). Generally, any induced drag benefits accruing from vorticity attenuation on an end plate are usually mitigated by interference drag.[8] Winglets have proved to be successful, but require careful design and implementation.[2,3] Blowing[6,7] may improve performance essentially through increasing the wings' aspect ratio (AR),[7] but does introduce the complexity of ducting and air required to operate the system.

In an earlier preliminary investigation,[5] the delta planform tip sail was cited as a simple device to improve wing performance, and avoid complications associated with winglet implementation. This was essentially due to the delta planform tip sail not requiring attached flow, and having reduced sensitivity to Reynolds number. The study included variation of the sails leading-edge sweep angle and its taper ratio. How-

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ever, the effects of using multiple sails on each wingtip, or varying the sail incidence was not investigated.

In this Note, the effects of using two tip sails per wingtip is presented, as are the effects of varying the sail incidence. Comparisons are also made between using one and two sails per wingtip. The results are compared to a basic rectangular wing of equal AR.

Equipment

Figure 1 shows the geometry of the wing and sails and details of sail positioning. The wind-tunnel model employed a NACA 64_2-015 section. The AR of the basic wing was 3.89, as was that of the wing with two sails per tip (the variation of AR with sail deflection was small). With only one sail per tip the wing AR was 4.02. The sails were manufactured from 0.9-mm-thick aluminum plate, had a root chord of 7.5 cm and a span of 3.6 cm. Their leading-edge sweep angle was 65 deg and they were cropped slightly. The sails were rotated about their attachment point, which coincided with the wing's chord. The attachment point for the front sail was at 28% of the wing chord, and the rear at 75% of the chord. The wind-tunnel investigation was conducted using a low-speed elliptic continuous wind tunnel, with test section dimensions of 91.0 cm and 61.0 cm. A six-component pyramidal force balance was used to measure the loads. All forces and moments were corrected for blockage as well as tare and interference and tunnel-flow angularity.[9] All coefficients were calculated using the total area of the respective planform, and moments were taken about the quarter chord. Tests were run at a velocity of 46 m/s. Based on the wing root chord the corresponding Reynolds number was 0.43×10^6. The set angle-of-attack range was from -2 to 18 deg.

Discussion of Results

In the tests the sails were set at angles ranging from 0 to 12 deg in 3-deg increments. However, to improve clarity, graphs for only ds = 0, 6, and 9 deg are plotted as these display the salient trends. Also presented are data for one sail per tip (essentially the rear of the two sails as shown in Fig. 1b), at a deflection angle of 9 deg. Previous unpublished studies have shown this to be the most effective setting for one sail/tip for this configuration. In the data presented in this Note, both the front and rear sails were deflected equally.

Figure 2 shows lift coefficient as a function of angle of attack. It is seen that the effect of sail deflection is analogous

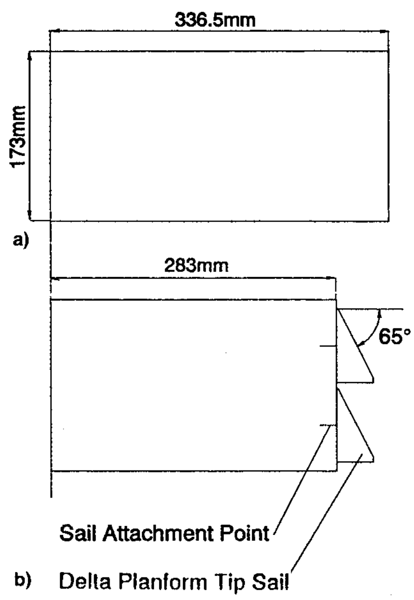

Fig. 1 a) Basic wing and b) wing showing delta planform tip sail attachment.

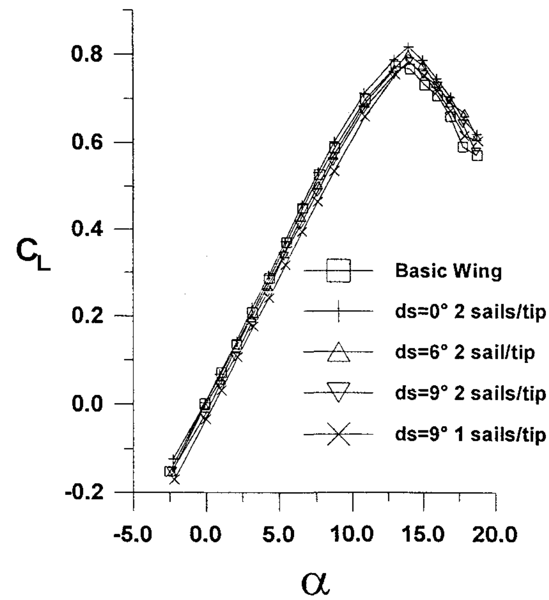

Fig. 2 Effect of delta planform tip sail incidence angle on lift curve.

to camber, with positive sail angles corresponding to negative camber addition (with the zero-lift angle shifting positive). However, with only one sail per tip, the zero-lift angle shifts noticeably more positive resulting in reduced lift for a given α. It is interesting that varying the sail settings has a small effect on the wing lift curve slope (even for one sail). A small increase in the maximum lift coefficient for the wing with sails over the basic wing is also evident.

Figure 3 presents drag as a function of lift. From approximately C_L = 0–0.37, ds = 6 and 9 deg show clear performance improvements over the basic wing. However, for the sails at zero incidence, improvements are less obvious, and for one sail/tip performance is generally impaired. As lifting performance is roughly equal or slightly inferior to the basic wing (Fig. 2), drag performance improvements are presumably due to thrust generated from the sails, as well as a small decrease in minimum drag. At a lift coefficient of approximately 0.5, drag performance of the 6- and 9-deg incidence sails approach that of the basic wing. This C_L corresponds to the sails becoming roughly parallel to the freestream, thus proposing that drag reduction is partly due to thrust from the sails. The data suggests the best overall performance occurs with ds = 6 deg, with effectiveness decreasing with either larger or smaller sail incidence angles. Although the AR of the one sail/tip configuration is 3.3% higher than the other configurations, its inferior performance does suggest that with sail-type devices, using AR as a criterion for data comparison should be treated with caution. However, Fig. 3 shows that for the present wing configuration, a reduction in drag at typical cruise lift coefficients compared to the basic wing may be achievable with suitable sail orientation. This is also achieved by a wing with a span 5.2% less than the basic rectangular wing.

Sail effect on C_m is seen to be slight for $C_L < 0.4$ (Fig. 4). For higher lift coefficients, the effects of the delta planform tip sail is to increase the nose-down pitching moment. As would be expected, the effect on pitching moment for one sail/tip (noting its rearward location) is to shift the aerodynamic center rearwards.

Comparing the results of the current study with those of Ref. 5, suggests that tip configuration (e.g., blunt-edged or with end cap[5]) does affect the impact of the delta planform tip sail on wing performance. In Ref. 5, where the basis of comparison was also AR, sails generally increased the wing lift curve slope over the basic wing. For the blunt-edged wing of the present investigation, this was not the case, and is

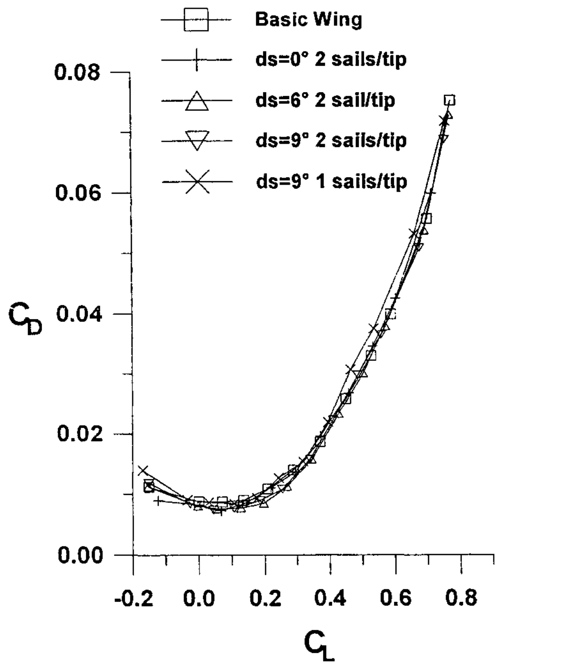

Fig. 3 Effect of delta planform tip sail incidence angle on drag polar.

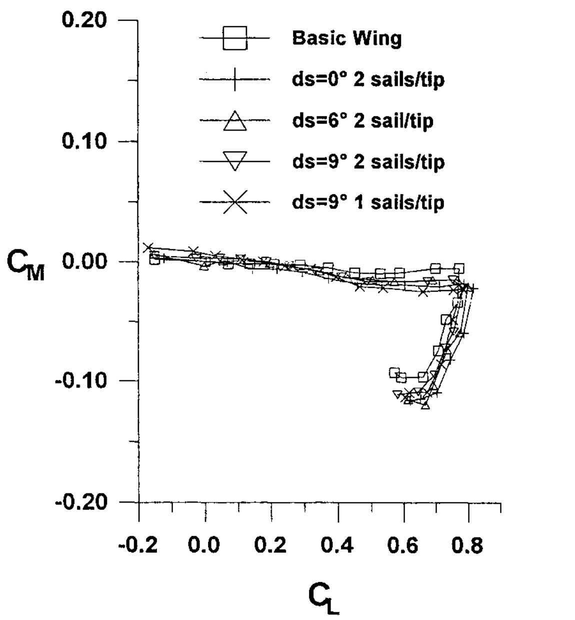

Fig. 4 Effect of delta planform tip sail incidence angle on pitching moment coefficient.

probably due to this tip configuration experiencing a lift increment resulting from suction induced by the wingtip vortices.[10]

Concluding Remarks

This study details an investigation of the effect of delta planform tip sail incidence on wing performance. The results suggest that based on an equal AR comparison, sails have a negligible effect on lifting performance, except for a moderate increase in the maximum lift coefficient. The wing's zero lift angle of attack becomes increasingly positive as the sails' incidence angle is increased. Reductions in drag compared to the basic wing were observed for sail angles of 6 and 9 deg for C_L ranging from 0 to 0.37. Using only one sail/tip resulted in a reduction in performance compared to the basic wing.

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Wall Temperature Effects on the Stability of Laminar Boundary Layers

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Nomenclature

h	=	nozzle throat height
L	=	distance from nozzle entrance
M	=	freestream Mach number
N	=	N factor in e^N for Tollmien–Schlichting wave
p	=	pressure
T_{aw}	=	adiabatic wall temperature, °R
T_w	=	wall temperature, °R
u	=	boundary-layer velocity in the x direction
u''	=	second velocity derivative in y
x, y	=	coordinates in streamwise and normal directions
μ_w	=	viscosity coefficient

Introduction

A UNIQUE, low-disturbance supersonic wind tunnel is being developed at NASA to advance supersonic laminar flow studies at cruise Mach numbers for the High Speed Civil

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