N94-34988

Concepts and application of dynamic separation for agility and super-maneuverability of aircraft-an assessment.

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1. Introduction

Aims for improvement of fighter aircraft pursued by the unsteady flow community are high agility[1] (the ability of the aircraft to make close turns in a low-speed regime) and super maneuverability[2] (the ability of the aircraft to operate at high angles of attack in a post stall regime during quick maneuvers in a more extended speed range). High agility requires high lift coefficients at low speeds in a dynamic situation and this requirement can be met by dynamically forced separation or by quasistatic stall control. The competing methods will be assessed based on the known physics. Maneuvering into the post stall regime also involves dynamic separation but because even fast maneuvers involving the entire aircraft are "aerodynamically slow" the resulting dynamic vortex structures should be considered "elicited" rather than "forced". More work seems to be needed in this area of elicited dynamic separation.

2. Dynamic separation as a vortex phenomenon

Everyone who visualizes flow around airfoils in rapid maneuvers quickly realizes that separation foremost means vorticity separation from various points of the lifting surface, i.e., from leading edge, trailing edge and other surface points. As a consequence physical understanding is mainly approached from the vorticity point of view[3] and is greatly aided by vortex visualization methods[4]. A large body of information on forced dynamic separation has been collected by many experimentalists as previous workshops on unsteady flow attest to [5, 6]. Many flow configurations and their parameter spaces have been surveyed and are available for assessment.

3. Transient dynamic stall phenomenon (Kramer[7] effect).

The dynamic stall phenomenon of temporary lift augmentation during transient maneuvers of airfoils beyond static stall is interpreted as a diffusive-inertial delay of leading edge vortex development and subsequent convective shedding into the free stream. Unfortunately, the stall vortex gets useless for lift augmentation when shed and a low lift deep stall regime ensues. The time and strength of transient lift augmentation depend considerably on flow configuration and parameter space. Usually the stronger the lift augmentation is, the shorter is the lift augmentation time, which is an unfortunate correlation when applications to agility are considered. Lift augmentation time does not exceed a few times the convection time $t_c = c/U_0$ of the airfoil, where c is the chord length and U_0 is the free stream speed. Since this time is orders of magnitude smaller than the time needed for high lift maneuvers, no decisive advantage can be obtained from the Kramer effect nor is it likely that this will change in the future.

4. Repetitive dynamic stall phenomenon (Harper-Flanigan[8] effect).

If during maneuver time the dynamic stall phenomenon could be rapidly repeated a useful cumulative dynamic stall enhancement of lift could be achieved. This is indeed possible as was first demonstrated by Harper and Flanigan[8] and has since been demonstrated many times[1, 3]. In essence, the airfoil has to be rapidly cycled between stalled and unstalled conditions. For instance, a lift coefficient of 1.8 was achieved by Maresca, et al.[9] by dynamic periodic forcing. Jumper and Stephen[10] have proposed the study of an unsteady-flow airplane based on a dynamic lift augmentation by a factor 1.5.

An area of maneuverability where utilization of repetitive dynamic stall seems to have found its niche is far removed from aircraft application: the hovering flight of insects. According to Freymuth[11, 12] a single airfoil executing appropriate periodic pitch-plunge maneuvers in still air is capable of generating a hover-jet (Fig. 1) with a lift coefficient as high as 7. In these maneuvers stall vortices generate high lift and are discarded into the jet before deep stall sets in. Every half cycle generates a new stall vortex for generation of high lift. Insects seem to use these maneuvers during their hovering flight.

It thus seems that repetitive dynamic stall is a viable means for lift enhancement in principle. It must be judged, however, against competing methods of lift enhancement, which will be assessed in the next section.

5. Stall control-the equivalence of dynamic and static stall control.

An important strategy to circumvent the fleetingness of dynamic stall is to prevent dynamic stall vortex generation during high angle of attack maneuvers while trailing edge separation of starting vortices allows buildup of airfoil circulation to high values for lift generation. This task is essentially the same as the task of static stall control in conventional aircraft by means of flaps, suction, blowing, moving boundaries and turbulators[13, 14] (slats and 3-d vortex generators). The effectiveness of static stall control methods in a dynamic situation has recently been demonstrated by Freymuth[15]. An airfoil with a nose consisting of a rotating cylinder (stall control by a moving boundary) was rapidly pitched from 0° to 50° angle of attack and held (Fig. 2). During and after pitchup a trailing edge stall vortex separated from the airfoil while leading edge vortex generation was inhibited as long as the cylinder was kept rotating. Similar results were obtained for periodic pitching. Therefore, static stall control measures are applicable in a dynamic

Fig. 1
Hover-jet moving upward into a still air environment (from Ref. 11).

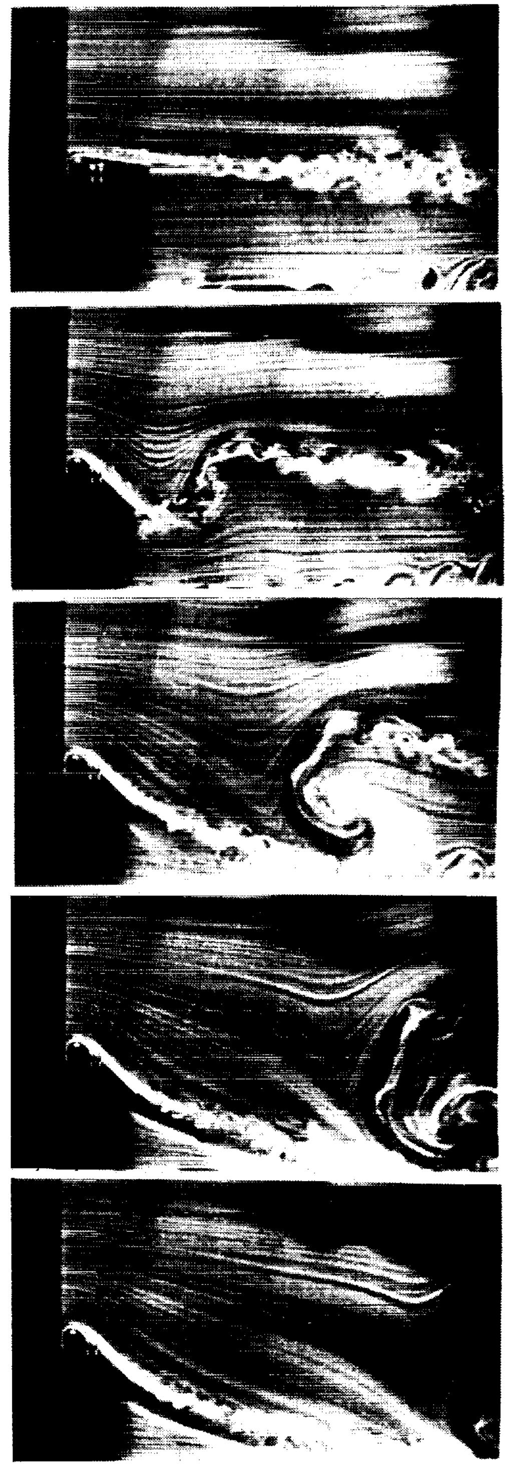

Fig. 2
Stall controlled pitch-down maneuver of an airfoil (from Ref. 15).

situation and represent a viable alternative for lift enhancement in fast maneuvers at low speed (compressibility effects decrease static and dynamic lift enhancement[1]).

Static stall control methods have produced lift coefficients in the range 2 to 6[13, 14]. Oversizing the wings would further increase the lift range capabilities if this need arises in special aircraft and thrust vectoring at near zero speed adds further lift control.

Comparing lift enhancement by dynamic stall methods and by dynamic stall control methods it seems unlikely that the former will outperform the latter in aircraft applications and currently hardly reaches into the same range. The dynamic stall method of lift enhancement therefore hardly represents a crucial development toward the achievement of high agility and even a minor niche for it has yet to be found.

6. Dynamic stall elicitation for super maneuverability

What benefits could post stall maneuvers add to a high agility aircraft? A quick turn of a high agility aircraft can only be realized at a speed low enough to not exceed the g-load limits suitable for pilots. In order to decelerate an aircraft to this low speed and for target pointing post stall maneuvers could still remain attractive. Since force coefficients are not enhanced in such maneuvers they can be initiated at considerably higher speed U_0 than high agility maneuvers without exceeding set g-limits. Since post stall maneuvers are aerodynamically slow, the resulting dynamic vortex structures are not forced but elicited.

From the workshop proceedings[5, 6], it seems that dynamic elicitation has not received detailed attention. This author recommends investigation of elicited vortex structures and their influence on maneuvering control. Such work should entail two-and three-dimensional lifting surfaces and possibly entire aircraft models as has been investigated by Ashworth, et al.[16] in the forced range. This recommendation amounts to investigating the low dimensionless pitch rate range during entire maneuvers for whichever configuration and associated parameter space appeals to an investigator.

7. Conclusion

Methods of lift enhancement by means of dynamic stall and by means of dynamic stall control have been assessed for application to high agility aircraft. It appears that stall control methods outperform stall enhancement. Therefore dynamic stall cannot play a crucial role in design of high agility aircraft. This is in contrast to helicopter blade and vertical windmill blade design[1] and to insect hovering flight[12] where dynamic stall is of the essence.

The role of dynamic separation in supermaneuvers has also been assessed. Dynamic elicitation in contrast to dynamic forcing of separation seems to be the key and should be investigated.

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