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Airbrake controls of pitching moment and pressure fluctuation for an oblique tail fighter model

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ABSTRACT

The pitching moments of a fighter model at an incidence of 32° without and with nine airbrakes are simulated by solving the unsteady Reynolds-averaged Navier–Stokes equations. The maximum reduction (60.22%) of the total pitching moment is obtained by the airbrake with deflection angle of 60° and length of 0.115 times the wing span. Furthermore, the unsteady flowfields are predicted by the improved delayed detached-eddy-simulation model. The breakdowns of the forebody and strake vortices are advanced, and the flow is blocked by the airbrake, jointly leading to a reduction of the pitching moment. Surprisingly, the pressure fluctuations on the oblique vertical tail are also attenuated due to the existence of the airbrake. A maximum reduction of overall sound pressure level by 11.8 dB is found near the leading-edge on the outer surface of the vertical tail due to the use of the 60T1 airbrake. The bursting vortices from the forebody and strake move towards the symmetry plane owing to the low-pressure region after the airbrake, weakening the unsteady interactions between the bursting vortices and oblique vertical tail.

1. Introduction

Super-maneuverability is one of the important flight performance characteristics for the new generation of fighters at high angles of attack (AoAs), despite the massive separation and vortex breakdown on the leeward side become more complicated and extremely unsteady [1]. Unfortunately, the flight stability and safety of the fighter are threatened by the increase of pitching moment in nose up direction and the decrease of rudder efficiency. To ensure stability and controllability, the pitching moment at high AoA must be effectively reduced to avoid the continuous head up motion [2].

When the AoA becomes large enough, the vortices from the wing, strake and even forebody encounter breakdown one by one. The low-pressure region on the main wing diminishes [3] associated with the decreasing slope of lift, increasing slope of drag and approaching the maximum of the pitching moment [4,5]. As the pitching moment reaches the maximum value, flight control becomes difficult and flight safety is threatened. At the same time, tail buffeting often occurs when the oblique vertical tail is immersed in the wake of bursting vortices with broadband frequency [6]. Actually, the dominant frequency of helical mode instability has been found on the delta wing [7]. And other dominant frequencies of breakdown oscillation and pressure sweeps on vertical tail have also been found on F/A-18 [8].

1.1. Pitching moment reduction at high AoA

How to reduce the pitching moment in nose up direction at high AoAs? The direct method is the thrust vector control, such as in F-22 [9] which can generate the pitching moment coefficient of 0.4 with the nozzle deflection angle of 15°. Unfortunately, many fighters do not have nozzles with thrust vector control. Therefore, effective control methods are required to either increase the pressure before the center of gravity (CG) or decrease the pressure after the CG. Correspondingly, destruction of the vortices from the strake and forebody or delay of the separation over the main wing can satisfy the requirements of effective control.

Two control methodologies are usually applied. The first is passive, and the second is active. The pitching moment can be reduced by blowing at the forebody, as was tested for F-16 [10]. This is an active control method, which is limited due to the requirement for the inclusion of an additional system. Passive methods include modification of fuselage configuration [11], forebody strake [12], leading-edge extension (LEX) [13], and so on. Using the former two methods, the low-pressure region before the CG is reduced. The use of a LEX can generate a more stable vortex and delay the

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Nomenclature

AoA	Angle of attack	H	Height of the vertical tail
B	Wing span	L_{AB}	Length of airbrake
C_D	Drag coefficient	MAC	Mean aerodynamic chord
C_L	Lift coefficient	W_{AB}	Width of airbrake
C_M	Pitching moment coefficient	μ_t	Turbulent eddy viscosity
C_p	Pressure coefficient	φ	Adaptive function of the numerical dissipation

separation over the wing. As a result, the pitching moment is directly reduced, and the longitudinal stability is enhanced.

The centerline airbrake is another passive method to reduce the pitching moment, although it is mainly applied to decelerate. Qi et al. [14] and Dong et al. [15] experimentally investigated the effects of the airbrake on pitching moment of the aircraft. Most of their results were the integral forces or moments. The detailed flowfields were not available and mechanisms of pitching-moment reduction were not fully clear.

1.2. Vertical tail buffeting at high AoA

For a fighter with two oblique vertical tails, experiments have proved that tail buffeting originates from the wing or strake vortex breakdown [16]. Furthermore, the bursting vortex can induce structural vibrations and fatigue of the vertical tails [17]. As a result, the pressure fluctuations on the vertical tail surface are enhanced significantly as the tail is completely immersed in the extremely unsteady wake of the bursting strake vortex [6]. Thus, the oblique vertical tail buffeting problem remains to be solved for its limiting to high performance and threatening to security. The frequency characteristics of oblique vertical tail buffeting were studied by Anderson [18] through a low speed wind-tunnel buffet testing on the F/A-22 V-9 model. From the data at Ma 0.2 and an AoA of 32°, it was found that the Strouhal frequency coincides with the structural resonance frequency, possibly producing a maximum response. Furthermore, the use of two fences can significantly reduce the buffet response. Sheta [19] predicted the buffet alleviation of the oblique vertical tail of F/A-18 aircraft at an AoA of 30° by streamwise fences located on the LEX.

For the single vertical tail fighter, the vertical tail may suffer from the direct interaction by airbrake wake. Breitsamter and Schmid [20] investigated the buffeting on a single vertical tail induced by the shedding wake from the upstream airbrake. For an AoA larger than 22°, special peaks can be identified in the range of reduced frequencies of ($k = fc/U_\infty$) 0.6–0.8. The airbrake-induced dynamic loads on the vertical tail surface become stronger with a higher deflection angle. When the deflection angle of the airbrake is 60°, the pressure fluctuations are approximately 4–5 times higher than the baseline.

1.3. Fighter model and the objectives

To validate the numerical methods, an advanced fighter model was experimentally tested by Liu et al. [21] to obtain the aerodynamic characteristics from the FL-14 wind-tunnel in the Low Speed Aerodynamics Institute of the China Aerodynamics Research and Development Center (CARDC). The photo of the aircraft model installed in the wind tunnel test section is shown in Fig. 1 [22]. The detailed information of the wind tunnel tests can be found through the website of CARDC (http://www.cardc.cn). The geometry and flow parameters of FL-14 wind tunnel are listed in Table 1. Wind tunnel corrections have been used, including the aerodynamic deflection, lift effect, horizontal buoyancy and blockage [23,24]. The maximum blockage is 15%, and the blockage is 8% at AoA of 32°. An analysis of the experimental pitching moment coefficients (Fig. 2) showed that the maximum of pitching moment in nose up direction coefficient is obtained at an AoA of 32°. Then, this AoA was used as the baseline case. From the flow patterns, the vortex from the strake encounters breakdown before the oblique vertical tail. Low-pressure regions on the upper surface of the fuselage and wing can be clearly observed before the CG.

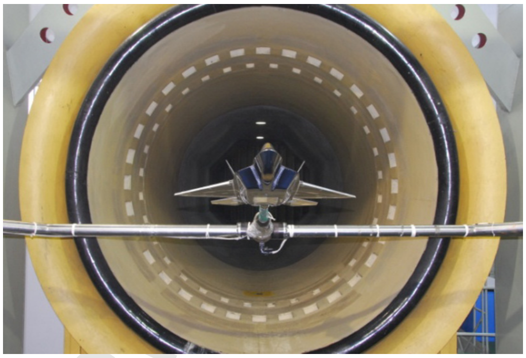

Fig. 1. The wind tunnel and aircraft model configuration [22].

Table 1
The geometry and flow parameters of FL-14 wind tunnel.

	Opening test section	Closing test section
Test section size	Φ 3.2 m × 5 m (length)	Φ 3.2 m × 4.9 m (length)
Maximum wind speed	115 m/s	145 m/s
Minimum wind speed	11.5 m/s	14.5 m/s
Direction field	$\Delta\alpha, \Delta\beta \le 0.5°$	$\Delta\alpha, \Delta\beta \le 0.3°–0.5°$
Turbulence level	$\varepsilon = 0.2\%–0.3\%$	$\varepsilon = 0.168\%$
Axial static pressure gradient	−0.00276/m	0.0025/m

For the aerodynamic forces or moments of the full fighter model, the efficiency, capability and applicability of the URANS methods (unsteady Reynolds-averaged Navier–Stokes) with advanced turbulence models have been proved. Xiao et al. [25] predicted the massive separation at a high AoA past an F-22 like fighter using URANS with two-equation k-g model. Liu and Xiao et al. [21] simulated the oscillating flows past this fighter model using the URANS method based on the shear stress transport (SST) model coupled with the rigid moving grid technique. However, URANS is inadequate for predictions of the pressure fluctuations on the surface.

Really unsteady turbulence predictions are required to predict the massive separation flows past the aircraft at high AoAs and Reynolds numbers. The DES-type (detached eddy simulation) method, which is one of the most popular RANS-LES (large eddy simulation) hybrid methods, has been widely applied for the prediction of massive separation flows. Mortan [8,26] used RANS, URANS and DES methods to simulate the flowfields past F18-C at an AoA of 30°. The results show that DES can predict the vortex breakdown more accurately than RANS and URANS. Forsythe [27] numerically predicted the flows past F/A-18E at high AoAs using DES. They also found that DES performed better than URANS for

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