Aerospace Europe Conference 2023
Joint 10th EUCASS – 9th CEAS Conference

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Title

Wing Rock Prediction in Free-to-Roll Motion Using CFD Simulations

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Abstract

High angle of attack aerodynamics of modern aircraft is often associated with complicated non-linear phenomena leading to aircraft aerodynamic autorotation, deep stall and spin critical regimes [1]. Vortex breakdown on fighter aircraft generate significant unsteady and nonlinear destabilizing effects[2], fin-buffeting [3], limit cycle oscillations for the longitudinal and lateral motions, named pitch bucking and wing rock, respectively [4–6].

The wing rock phenomenon has been extensively studied experimentally, using wind tunnel testing with a free-to-roll experimental rigs and using simplified aerodynamic models [5, 7]. In this paper, dynamic coupling between unsteady separated flow and rigid body dynamics leading to sustainable limit cycle oscillations in the lateral motion is investigated using CFD simulations of unsteady vortical flow closed with a free-to-roll 80 degree delta wing motion. Computational simulations are based on the Unsteady Reynolds Averaged Navier Stokes Equations (URANS) at a range of Reynolds numbers from 400, 000 to 1, 000, 000. The URANS equations are simulated in conjunction with the Spalart-Allmaras [8] model which is well known and widely used for adverse pressure gradient flows in the aerospace industry.

The computational mesh is generated using the multi-block structured grid generation software ICEM CFD. An overset grid approach is used to create two separate mesh domains, one enclosing the delta wing and one for the background wind tunnel mesh. This method allows an extensively free motion of the delta wing without deforming the grid in zones of important flow structures, particularly in the boundary layer and the immediate adjacent fluid zone. Particular focus will be given on high angle of attack wing rock prediction, with consideration of effects from the moment of inertia, shape of the leading edges, and delta wing sweep angle.

A preliminary simulation for the 80 degree delta wing, at Re = 635, 000 and $U_{\{ref\}}$ = $20m/s$ was conducted using a free-to-roll setup at a moderately high angle of attack of α = 32.5◦. The rolling moment coefficient Cl variation with self-excited roll angle ϕ obtained using the CFD simulation is presented in Fig. 1 and the variation of the roll angle against physical time, t, is shown in Fig. 2. The flow visualization of three-dimensional streamlines shown in Fig. 3

indicates formation of vortices above the wing interacting with free-to-roll wing motion.

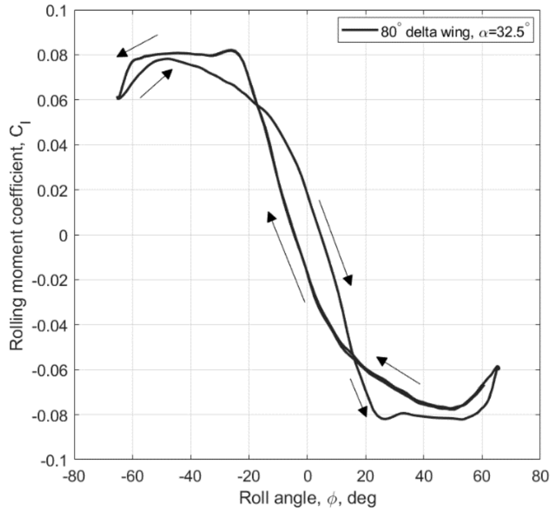

Figure 1- CFD prediction of rolling moment coefficient C_l vs. roll angle ϕ for 80 degree delta wing at Re = 635, 000 and $U_{\{ref\}}$ = 20 m/s.

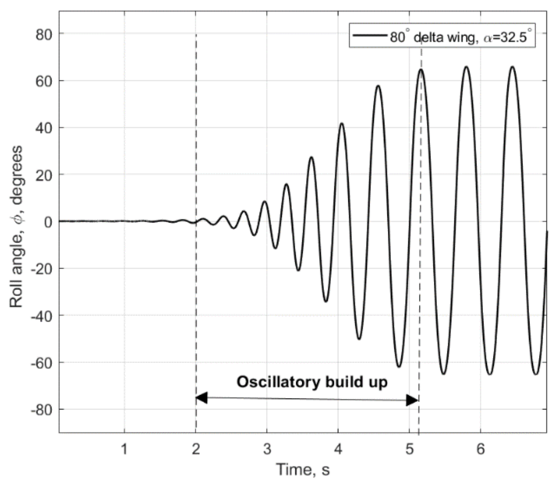

Figure 2- Fig. 2 CFD prediction of Roll angle ϕ variation with time for 80 degree delta wing at Re = 635, 000 and $U_{\{ref\}}$ = 20 m/s.

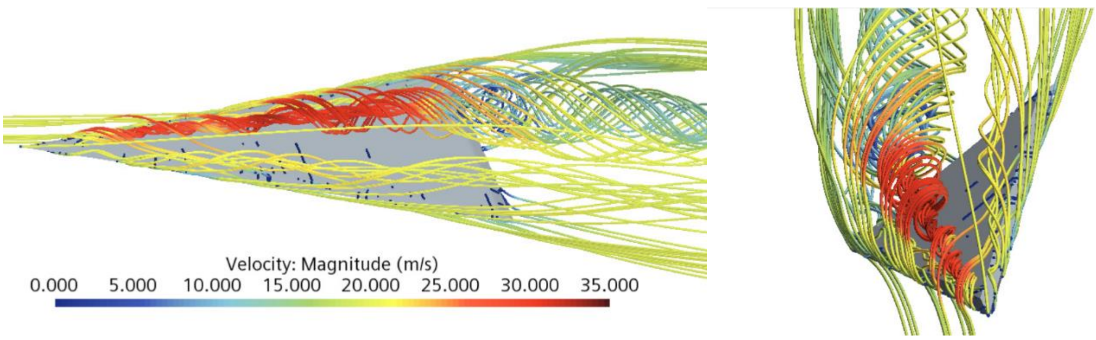

Figure 3 - Visualization of 3D streamlines during wing rock phenomenon from CFD simulations at $\alpha = 32.5^{\circ}$ at

time instance when self-excited roll angle, ϕ = 36.5 degrees

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