

TAIL BUFFETING OF A FLEXIBLE WING IN TRANSONIC FLOW

Adithya Udupat, M I Vellaisamy Dinu, Sudha U P V* ands Kartik Venkatramant*

*Airframe Directorate, Aeronautical Development Agency,
Vimanapura Post, Bangalore, India 560017

†Aerospace Engineering, Indian Institute of Science
CV Raman Rd, Bangalore, India 560012

ABSTRACT

Vertical and horizontal tail buffeting is critical during moderate and high angle-of-attack (AOA) maneuvers of a flexible combat aircraft. Vertical tail buffeting refers to the vertical tail or fin vibrating due to the excitation caused by highly vortical flows emanating from the fore-body of the aircraft including the nose/intake/canard/wing at high AOA. Horizontal tail buffeting can occur at moderate AOA. The implications of understanding the flow physics and quantifying the unsteady air-loads have serious consequences for combat maneuverability and structural integrity of the twin vertical/horizontal tail aircraft. Vibrations of the airframe caused by horizontal and vertical tail buffet have implications for the flight dynamics of the aircraft, unsteady loads on avionics, and fatigue failure of the aircraft vertical and horizontal tail.

Lee [1] provides an extensive review of vertical-tail buffeting research in combat aircraft, focusing primarily on the F/A-18 aircraft. The review notes that the SA-RC and IDDES turbulence models could predict unsteady flow behavior near vortex breakdown, although SA-RC failed to capture downstream unsteadiness and the surface-pressure distribution on the tail. The studies also showed that vertical-tail buffeting produced a significant structural dynamic response, despite having only a limited influence on the unsteady aerodynamics. In this paper, we investigate the unsteady aerodynamic behavior of a trapezoidal-wing aircraft configuration with vertical (VT) and horizontal tails (HT), and examine the resulting elastodynamic response to pressure fluctuations. Katzenmeier et al. [2] report URANS simulations with different turbulence models to predict turbulent fluctuations in a flow. . As there is a lack of scale separation between coherent unsteadiness and stochastic turbulence, there is a concern whether URANS can predict the unsteady flow characteristics accurately. So, Detached Eddy Simulations (DES) was used to take advantage of large eddy simulation (LES) in massively separated flow and RANS in boundary layers. A one-way coupling is employed to transfer the CFD results to the structural model. It is reported that SA-RC (Spalart-Allmaras model with Rotational Correction) and IDDES (Improved Delayed Detached Eddy Simulation) were able to predict unsteady flow field effect near the vortex breakdown. SA-RC was not able to capture the unsteady flow field downstream and the surface pressure on the tail. The RMS load computed by SA-RC is four times smaller at the wing as obtained by the IDDES. In conclusion, though both SA-RC and IDDES can be used for tail buffeting load prediction, IDDES is able to capture the energy levels that is transferred from the flow field to the structure surface more accurately. Stegmüller et al. [3] showed that the structural dynamic response due to vertical tail buffeting was significant although tail buffet did not significantly change the unsteady aerodynamics. Also coupling between the fuselage mode and the horizontal tail mode was responsible for the structural dynamic response.

Unsteady transonic flow over the trapezoidal wing planform with horizontal and vertical tail is analyzed at Mach 0.8 using RANS and URANS solvers. The fluid solver is coupled with the structural dynamics of the airframe obtained from a finite element solver. The geometry as

shown in Figure 1 incorporates rounded leading edges and sharp trailing edges, following the methodology in [4] [5]. Simulations were performed using the SU2 [6] open-source CFD solver with the Spalart–Allmaras turbulence model with the Edwards–Chandra correction [6]. The corresponding CFD grids are shown in Figure 2.

Steady-state simulations were conducted at angles of attack of 0° and 15°, with the 15° case forming the primary focus. An unsteady simulation was likewise performed at 15°. Modal analysis using NASTRAN was carried out on the finite element model, with all root nodes on the symmetry plane fully constrained. The first ten modes were extracted for use in the coupled unsteady FSI analysis. The FSI simulation employed the extracted modal structural model and the CFD model at 15°, using SU2 to couple the SU2 CFD code with the NASTRAN structural solver via a Python interface.

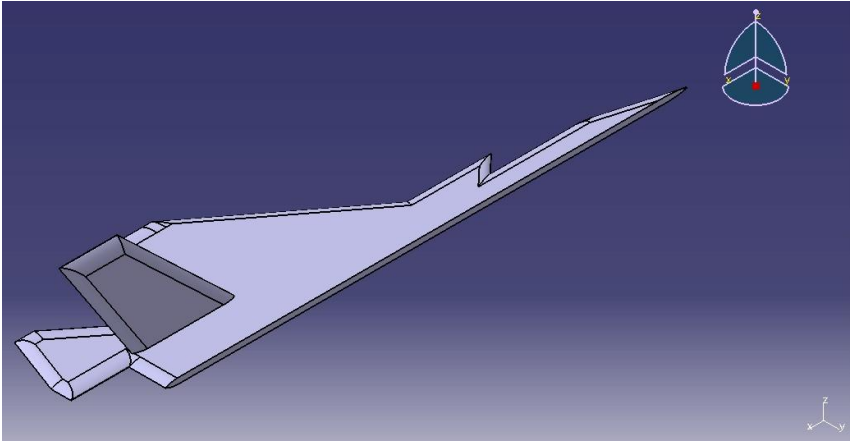
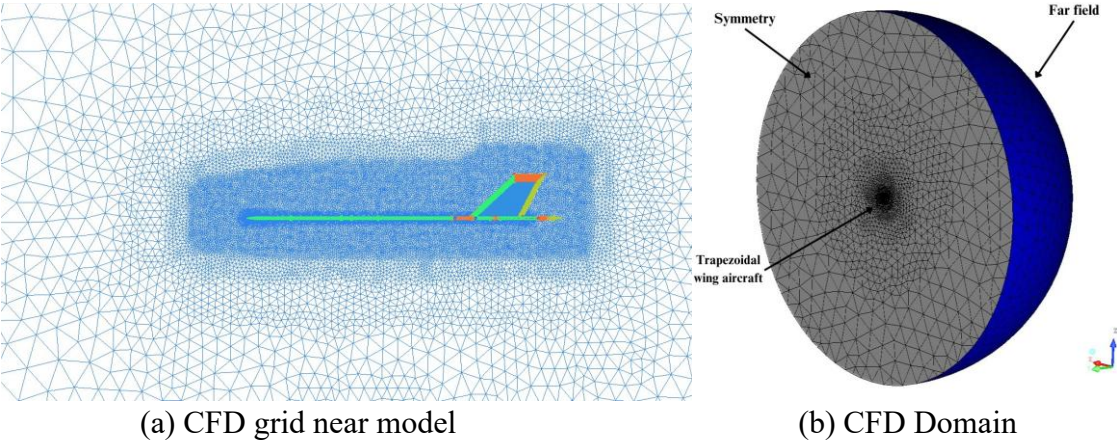


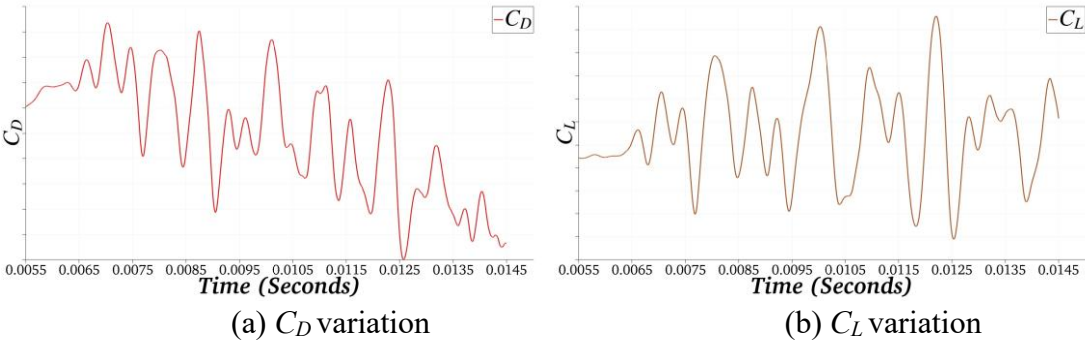
Figure 1: CAD model



(a) CFD grid near model

(b) CFD Domain

Figure 2: CFD grid



(a) C_D variation

(b) C_L variation

Figure 3: C_D and C_L for coupled simulation

Figure 3 presents the temporal variation of C_L and C_D , from the unsteady simulations accounting for the effects of structural flexibility. Figure 4 shows the mean C_P and RMS C_P over the aircraft planform. Comparison of lift and drag coefficients between the rigid and flexible configurations indicates a reduction in both C_L and C_D for the flexible case. This decrease results from structural deformation, which modifies the local flow field. From an aeroelastic standpoint, such flexibility can lower aerodynamic loads, reduce drag, and potentially lessen fatigue. However, the associated reduction in C_L may limit lift generation during aggressive maneuvers, affecting handling and agility. Thus, structural flexibility provides aerodynamic and fatigue benefits but introduces trade-offs in maneuvering performance.

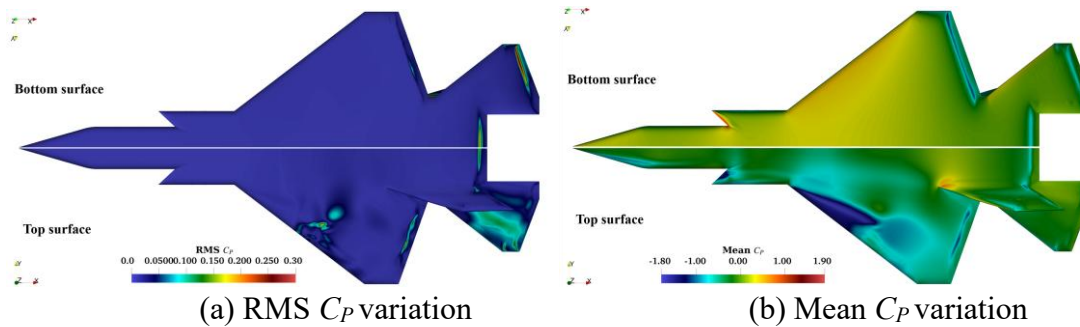


Figure 4: Mean C_P and RMS C_P variation on the planform

The full paper will analyze vortex breakdown and its effect on tail buffeting at different angles of attack. The influence of horizontal and vertical tail dynamic stiffness on alleviating tail buffeting will also be studied.

References

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