# Investigation of transonic buffet loads on aeroelastic launch vehicle model using couple CSD-CFD approach

Amit K Onkar[a1], Mutturaj H Medar[a], Arun Kumar A[a], Rahul B Choudhary[a], Shivaprasad M V[a], Raja S[a]

[a] Structural Technological Division, CSIR-National Aerospace Laboratories, Bangalore 560017, India

## 1. INTRODUCTION & OBJECTIVE

Transonic buffet response in a flexible launch vehicle is an aeroelastic phenomenon that arises due to the interaction between aerodynamic forces and the vehicle's structural dynamics. This phenomenon, classified as a fluid-structure interaction (FSI), is characterized by several complex flow features, including shock wave oscillations, boundary layer separation, turbulence, and vortex shedding [1]. These unsteady aerodynamic effects make transonic buffeting a critical concern in the design and analysis of launch vehicles, as it can significantly influence the structural integrity and performance of the vehicle during ascent. The present study aims to develop a hi-fidelity FSI simulation framework to study the buffet load and buffet response on flexible launch vehicle. The numerical buffet load measured on the scaled aeroelastic launch vehicle is also compared with the in-house WT test data in the transonic regime.

## 2. METHODS OF ANALYSIS

The FSI framework adopted for the transonic buffet studies is based on coupled computational fluid dynamics (CFD) – computational structural dynamics (CSD) approach. CFD solver is based on unsteady N-S equations with turbulence modelled using Detached Eddy Simulation (DES) technique and CSD solver is based on time integration of the structural dynamic equations using HHT algorithm. A partitioned FSI approach is adopted, where aerodynamic forces and structural displacements are updated at the end of every physical time step. Mesh morphing of the CFD grid is modelled using the B-spline interpolation technique.

## 3. NUMERICAL RESULTS

Figure 1(a) shows the schematic representation of a scaled aeroelastic launch vehicle model with sting considered in this study. All the major dimensions indicated in the figure are in *mm*. A modular construction is used in the form of spar-rings-skin for the design of scaled launch vehicle model. Metallic materials such as aluminium and steel are chosen to build the skeleton and GFRP (glass fiber reinforced plastic) composite is used for skin. The material properties chosen for different components of the model are: Spar and Ring (Aluminium): $E_1 = E_3 = 70$ GPa, $\nu_{12} = \nu_{13} = \nu_{23} = 0.3$, $\rho = 2850$ kg/m$^3$; Ring and Sting (Steel): $E_1 = E_3 = 210$ GPa, $\nu_{12} = \nu_{13} = \nu_{23} = 0.3$, $\rho = 7800$ kg/m$^3$; Skin (GRPF): $E_1 = E_2 = 130$ GPa, $G_{12} = G_{13} = G_{23} = 4.2$ GPa, $\nu_{12} = \nu_{13} = \nu_{23} = 0.22$, $\rho = 1900$ kg/m$^3$.

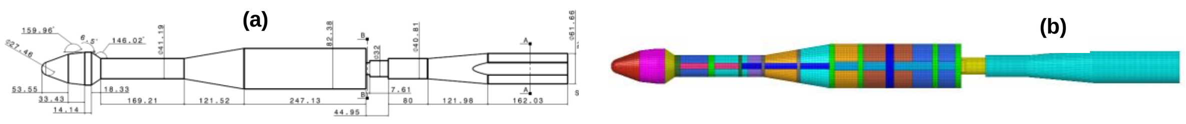


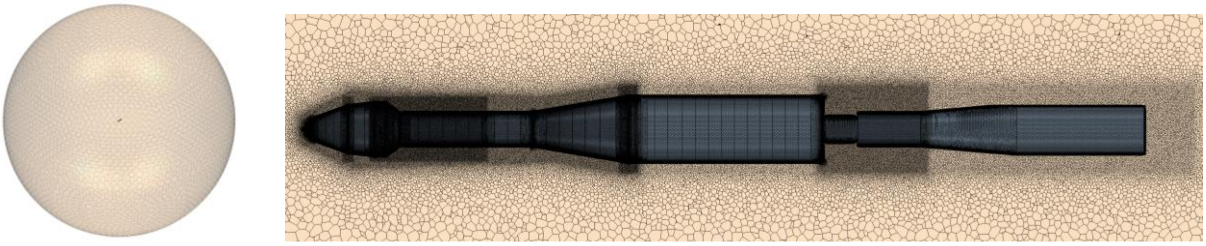

**Figure 1:** Schematic representation of scaled aeroelastic launch vehicle model with sting, and its finite element model

The finite element model of the scaled aeroelastic launch vehicle is shown in Fig. 1(b). It consists of hexahedral solid elements and quadrilateral shell elements. The total number of elements and nodes are 134610 and 157209 respectively. The model is constrained at the sting root in all the degrees of freedom.

[1] Communicating Author: Amit K Onkar and aeroamit@nal.res.in.

The dynamics of the scaled launch vehicle is studied through free vibration analysis in terms of natural frequencies and mode shapes. The 1st mode is observed to be 1st bending with natural frequency of 116.93 Hz and the 2nd mode is observed to be second bending with natural frequency of 551.32 Hz. These natural frequencies are also compared with the in-house ground vibration test results.

Figures 2 shows the CFD model with the following parameters. Farfield = 50 m, 1st cell height = 1e-6 *m*, prism layer total thickness = 2.7 mm, No. of prism layers = 35. The shock regions and shear layer regions are appropriately refined. The number of cells obtained in CFD grid is approx 17 million.



(a) Farfield domain (b) Sectional view of the model

**Figure 2:** CFD model of scaled launch vehicle with sting

FSI analyses are carried out for various combinations of Mach number ($M$) and angles of attack ($\alpha$), and results in terms of the mean and RMS of pressure coefficients on the launch vehicle are studied. These numerical results are also compared with the wind tunnel test data conducted at CSIR-NAL. Figure 3 shows the comparison of mean and RMS of pressure coefficient with test data at $M = 0.9$ and $\alpha = 0°$. The figure also includes the rigid unsteady simulation results to show the effect of flexibility. The simulation results successfully capture the front and rear peaks of the Mean *Cp* distribution, demonstrating a good agreement with the WT measurements. However, a forward shift in the flow reattachment region is observed in the numerical simulations. Further, the amplitude of RMS *Cp* (unsteady pressure fluctuations) in the simulations is overestimated relative to the experimental data. It indicates that further refinements in the computational model may be necessary to achieve better buffet response predictions.

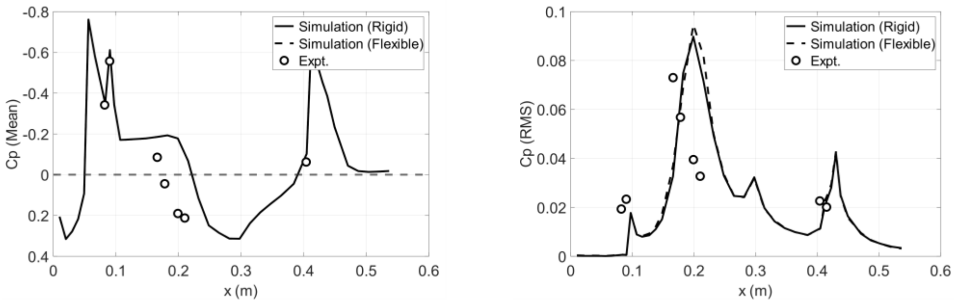



**Figure 3:** Comparison of mean and RMS Cp coefficients at Mach = 0.9 and α = 0°

## 4. CONCLUSIONS

The present study focuses on establishing a hi-fidelity FSI framework for transonic buffet investigations on a scaled aeroelastic launch vehicle. The simulated buffet results are also systematically compared with the in-house wind tunnel test data conducted at CSIR-NAL. The comparative analysis reveals that a good correlation in the buffet load trends is observed. However, some discrepancies between numerical results and experiment data in terms of flow reattachment region and peak RMS *Cp* are observed.

## 5. REFERENCES

[1] J. M. Ramey, M. K. Sekula, D. J. Piatak, P. S. Heaney, and F. Soranna, "Development of Buffet Forcing Functions using Frequency-Dependent Coherence Factors," in *AIAA Scitech 2021 Forum*. doi: 10.2514/6.2021-1653.