Uncertainty Quantification of SLS Vehicle Loads Subject to Uncertain Aerodynamic Sectional Loads

Derek J. Dalle*, Stuart E. Rogers*,
Aaron C. Burkhead*, Jamie G. Meeroff*
Corresponding author: `derek.j.dalle@nasa.gov`

* NASA Ames Research Center, Computational Aerosciences Branch

Abstract: Launch vehicle loads are generally subject to uncertainties that may be significantly larger than, for example, a CFD grid convergence study would produce. These uncertainties are caused by a number of factors, including differences between design and as-built hardware, changes in the shape of the vehicle during flight, and unmodeled physics in the flight vehicle. This paper presents a technique to estimate how uncertainties in overall integrated forces & moments on the vehicle can be combined with CFD analysis to estimate uncertainty in any other scalar load on the vehicle. To accomplish this analysis, the CFD loads databases are adjusted to match the flight force & moment database used for guidance and control, which is based on wind tunnel testing. Then a further adjustment is applied for consistency with force & moment uncertainty. These adjustments are informed by Proper Orthogonal Decomposition (POD) of the entire CFD load database. Once applied, the adjusted loads can be used to evaluate any scalar quantity that requires knowing the local load on the entire surface of the vehicle.

Keywords: Computational Fluid Dynamics, Launch Vehicles, Uncertainty Quantification, Proper Orthogonal Decomposition

1 Introduction

Aerodynamic sectional load profiles, also called line loads, are used for vehicle-scale structural analysis. The primary way in which this works is that the outer mold line of the vehicle is divided into many slices, which all have boundaries at fixed x-coordinates, and then to integrate the aerodynamic forces on each of these slices individually. Figure 1 shows the slices for NASA's Space Launch System Block 1B vehicle.

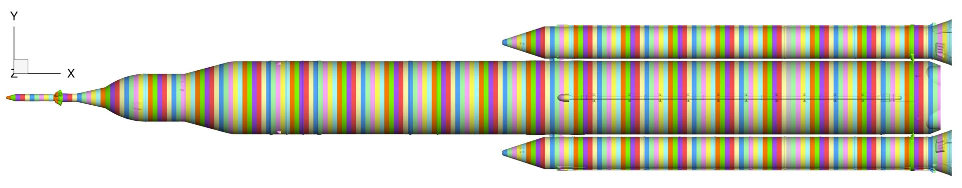
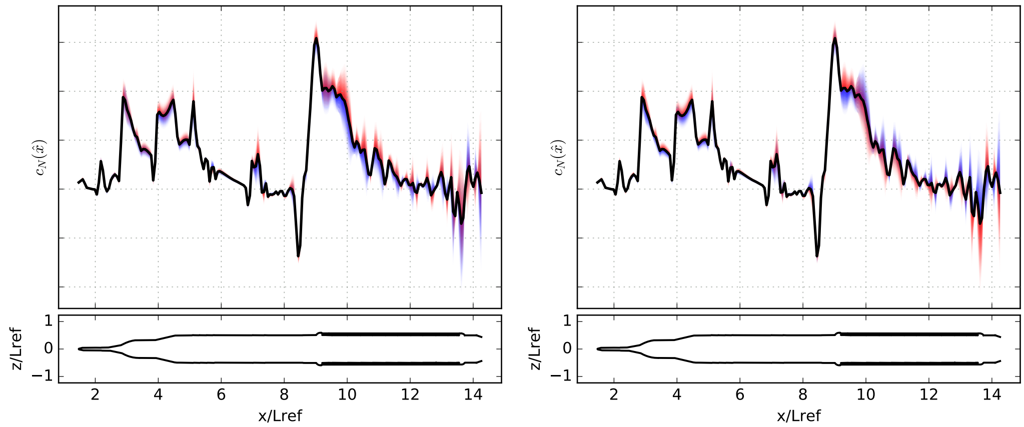


Figure 1: Sectional load slices for SLS Block 1B configuration



(a) Dispersed C_N colored by ε_{CN} (b) Dispersed C_N colored by ε_{CLM}

Figure 2: Dispersed sectional normal loads on SLS Block 1B core at Mach 1.75, $\alpha = 4°$, $\beta = 0°$

2 Sectional Load Adjustments and UQ

This paper uses a technique to adjust CFD-based sectional loads to match an externally-defined force & moment database and its uncertainty [1]. For the SLS program, both these integrated databases are primarily derived from wind tunnel testing [2, 3], and there is no guarantee or expectation that CFD loads will match these exactly.

Figure 2 shows an example of the dispersed sectional loads on the SLS Block 1B vehicle at a flight condition near the expected maximum load on the vehicle. Both the left and right figures show the same data but colored differently. Near x/L_{ref}=9, an increase in the normal force (a high value of ε_{CN}) causes a change in the local load opposite to that of increased pitching moment (a high value of ε_{CLM}). To evaluate the UQ in a vehicle load, one must use each of the curves in Figure 2 individually in the full vehicle load analysis.

3 Conclusion and Future Work

Sectional load uncertainty is not used in the main SLS program certification but has been applied to assess the simpler engineering methods. This effort aims to establish a consistent UQ method configurations that reduces engineering judgment without excessive analysis complexity.

References

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