Sensitivity Study of Dust-Laden Flows in the DLR GBK Facility using the DUST-US3D Framework

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A steady increase in mission complexity over the years culminating in future crewed landings has necessitated an improved characterization of hypersonic entry through the Martian atmosphere. A potential threat to spacecraft during the hypersonic descent is atmospheric dust. The level of dust – both number density and the maximum altitude at which it can be found – significantly increases during major dust storms. The degradation suffered by spacecraft thermal protection systems (TPS) due to dust particle impacts can be comparable to that from thermochemical ablation [1]. The unpredictability of Martian dust storms coupled with long travel times for typical planetary missions makes it imperative that the TPS designs account for the possible damage caused by dust particle impacting the entry vehicle. Motivated by these requirements, the Entry Systems Modeling (ESM) project under the NASA Game Changing Development program and the German Aerospace Center (DLR) have entered into a collaboration to deliver state-of-the-art numerical and experimental assessment of particle-induced heatshield recession.

A Lagrangian particle solver titled DUst Simulation & Tracking (DUST) [2] which works in conjunction with the US3D CFD flow solver [3] has been developed through ESM. The current work is aimed at performing a detailed numerical sensitivity study of dust-laden flow through the DLR GBK facility using the DUST-US3D framework. This is necessary not only for supporting future DLR experimental campaigns but also to establish viable methodologies for accurately modeling dusty flow environments.

The coupled US3D-DUST flow-particle simulation framework adopts a variable-fidelity paradigm. This allows modeling complexity to be adjusted based on the level of realism being sought for describing particle-fluid and particle-particle interactions. Furthermore, quantities of interest such as surface heat augmentation and erosion due to particle impacts can be comprehensively characterized for a wide range of physical conditions. A concerted effort has been made to incorporate numerical strategies that offer a balance between computational tractability and accuracy. The key elements underpinning the current work are an efficient mesh-localization algorithm, time-driven hard-sphere model, point-to-point MPI framework, coarse-graining using computational parcels, and high-order Adams-Bashforth time stepping.

A three-dimensional volumetric grid of the GBK facility with emphasis on a precise reproduction of the dust particle injection process and the transit of particles through the facility has been developed for this work. The sensitivity study on this grid involves varying particle injection parameters such as the diameter distribution probability function, input velocity magnitude, and input velocity direction and accounting for particle-particle collisions. The resulting impact on particle-related statistics such as the dust mass flow rate is studied, and comparisons made to experimental data.

References:

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