Separation Studies on Sphere and Cube Clusters in Mach 12 Flow

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The aerodynamic forces and aerothermal loads experienced by spacecraft components during a fragmenting reentry likely influence their trajectories, demisability, and, as a consequence, the resulting ground casualty probability. Due to the complexity of this phenomenon, Design for Demise tools often simplify the dispersion of the fragments and the interactions between the components, considering their trajectories as independent (i.e. neglecting any mutual interaction) as soon as a structural limit triggers the fragmentation event. Studying the interaction of proximal bodies and clusters is required to develop improved separation models that can advance demisability predictions.

The present study (HiSST-2024-0142) investigates the aerodynamic separation of compact fragment clusters. Fragmentation scenarios assuming cluster compositions of equal-size spheres and cubes were analyzed. The aim of the investigation is twofold. First, to extend earlier sets of measurements towards higher Mach numbers in order to determine to which extent this parameter influences the flow separation velocities. Second, to evaluate to which extent the shape of the fragment can influence the dynamics of the separation process (spherical geometries have mostly been used to date, but might be poorly representative of a real fragmentation event). The experimental analysis was conducted in the VKI Longshot hypersonic wind tunnel at Mach 12 flow conditions. A dual-camera free-flight testing methodology was employed to observe separation scenarios and track the motion of the fragments in six degrees of freedom. The test articles are initially confined in a sabot, which separates into two pieces and exposes the models to the freestream upon the arrival of the flow. Two tests were performed on 11 spheres, two tests on 11 cubes, and one on 36 spheres.

Experiments on 11 sphere clusters yielded a reasonable agreement regarding the mean terminal velocities with the experimental observations of Whalen et al. 2021 (https://doi.org/10.1007/s00348-021-03157-z) and the correlation proposed by Park et al. 2020 (https://doi.org/10.1016/j.asr.2019.10.009). Increasing the sphere population to 36 yielded greater object spread. During both the 11 and 36 sphere tests, the formation of sub-clusters was observed, i.e., objects gathered behind a leading body. Similar observations were reported by Whalen et al. 2021. Tests on clusters of 11 cubes demonstrated significantly larger object dispersal, higher lateral terminal velocities, and larger maxima compared to the 11 sphere cases. These results indicate that the object shape contributes to the dispersal and should be accounted for in demisability predictions. The mean value and the distribution of the terminal velocities imply a reasonable consistency for the repeated experiments; however, such fragment separation is expected to be complex. Therefore, in order to draw clear conclusions and to represent adequately the separation dynamics on a macroscopic scale, a high number of repeat tests are required, and the problem must be assessed on a statistical basis.