Development of a Multi-fidelity Framework for Destructive Atmospheric Entry Simulation*

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Abstract. The re-entry process is distinguished by the presence of several fragments with intricate geometries resulting from the demise process, which may lead to complex features in the re-entry flow. An example of these features is shock impingement, which leads to highly localized loading of pressure and heat flux on the bodies' surface. These loads impact the overall dynamics and cannot be captured using state-of-the-art low-fidelity approaches, requiring the use of high-fidelity methods such as Computational Fluid Dynamics and Direct Simulation Monte Carlo. The present work is focused on showcasing the capabilities and underlying methodologies of a fully automated multi-fidelity based tool for the simulation of destructive atmospheric re-entry. The current developed features will be showcased through the numerical simulation of an ATV-like cargo vehicle destructive re-entry.

Keywords: Destructive re-entry · Multi-fidelity.

1 Extended abstract

Between 2000 and 2020, the number of man-made objects in orbit around the Earth has increased by approximately 82%, reaching a value close to 20000 objects, from which 53% are fragmentation debris[1]. The current tendency is for the number of space objects to grow with the emergence of new satellite and CubeSat constellations.

To avoid the cluttering of space and decrease the risk of in-orbit collisions, they must be safely removed after reaching their end of life. A quite effective solution to this problem is to make the objects undergo destructive atmospheric re-entry, either controlled or uncontrolled, through which it breaks into several fragments, eventually demising due to the high aerothermal loads experienced during the re-entry process.

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The accurate prediction of the destructive process and trajectory dynamics is of utmost importance to correctly assess the ground impact risks of surviving fragments. However, most state-of-the-art prediction tools use engineering and surrogate models that are unable to capture the occurring flow interactions formed by complex geometries and by the presence of multiple fragments in high-enthalpy regimes, which can impact the structural integrity and dynamics of the objects. Such flow features can be captured using high-fidelity tools, but its strict use is not computationally feasible.

To overcome this issue, a multi-fidelity based framework[2–4] is being developed. The tool uses a fully automated criteria to identify the level of fidelity required at each time-step, enabling to switch between low-fidelity and high-fidelity models to compute the aerodynamic and aerothermodynamic quantities at the different flow regimes experienced by the bodies during the reentry process (e.g. rarefied, transitional, slip-flow and continuum regime), minimizing the results uncertainty. The dynamic motion of the objects is computed using the integrated 6 Degrees Of Freedom (DOF) trajectory propagator, enabling to analyse the individual fragment trajectory. Structural dynamics are accounted through the inclusion of an open-source PDE solver, enabling the computation of structural displacement and stress that may trigger the fragmentation process. In addition, the material properties are retrieved from a material library, improving the material characterization for the thermal and structural computation.

This work intends to present the tool capabilities and underlying methodologies for the computation of the trajectory, structural dynamics and aerothermal quantities during a destructive re-entry simulation. In addition, the capabilities will be showcased by performing numerical simulations of an ATV-like cargo vehicle re-entry.

References

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