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A MULTI-FIDELITY AND MULTI-DISCIPLINARY APPROACH FOR THE ACCURATE SIMULATION OF ATMOSPHERIC RE-ENTRY

Abstract

Evaluating the on-ground casualty risk assessments due to controlled/uncontrolled re-entry is highly sensitive to accurately predicting fragmentation and thermal demise events. The current state-of-the-art re-entry analysis tools approximate the prediction of fragmentation process by assuming a fixed altitude break-up model. However, this model is based on limited experimental data, introducing uncertainty into the re-entry analysis. Moreover, the presence of multiple bodies and complex geometries results in complex flow features such as shock-shock interactions and shock-surface interactions, influencing the localised aerothermodynamic loads during hypersonic re-entry. Low-fidelity re-entry analysis tools that use analytical expressions for various flow regimes do not consider the effects of such complex flow features and introduce uncertainties in the process. A possible way to reduce some uncertainties is to use high-fidelity modelling tools for the aerothermal and structural aspects of re-entry analysis. These high-fidelity analysis methods are computationally expensive to utilise at every point along the re-entry trajectory. Thus, a multi-fidelity analysis approach is needed to balance the required complexity and computational time.

This paper proposes a multi-fidelity and multi-disciplinary framework that combines low- and high-fidelity aerothermodynamics, thermal analysis, flight dynamics, and structural analysis in a modular approach to achieve a favourable trade-off between cost and accuracy. The novelty in the current study is two-fold: one is to simulate a more natural destructive re-entry process without using a prescribed altitude trigger for fragmentation, and the other is to implement automatic fidelity switches between high- and low-fidelity models based on an uncertainty threshold that compares the aerodynamic and aerothermodynamic loads between the two models. For the high-fidelity flow modelling, the open-source SU2-NEMO code is used to solve for slip to continuum regime; SPARTA-DSMC solver is used for transi-

tional and free-molecular regimes. To estimate the fragmentation altitude, first a linear structural analysis on objects modelled as joints is continually carried out using the FEniCS finite elements solver. Then, a switching criterion based on the temperature-dependent critical stress in the joints is used to enable dynamic fracture mechanical simulations at elevated temperatures using Peridigm peridynamics solver. The damage contours from the peridynamic simulation result are analysed for crack characteristics to determine the failure of joints and the resulting fragmentation altitude. Finally, the proposed framework will be implemented as TITAN: Transatmospheric Flight Simulation code and few realistic re-entry test case scenarios are utilised to test the effect of the current multi-fidelity framework in reducing the uncertainties associated with the destructive re-entry process.