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A cloud-based multi-fidelity solution for debris re-entry prediction

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Atmospheric re-entry of space debris is a daily event and large re-entering objects are known to pose a non-negligible threat. In this work, a cloud-based multi-fidelity suite for debris re-entry simulation is introduced. It offers the possibility to run, from a web browser on any computer, quick low-fidelity estimations of the aerothermal behaviour of a debris along its trajectory and to request higher fidelity coupled aero-thermal CFD simulations of any instant along the trajectory. The two components of the suite are discussed in more details below.

1. The **D**ebris **R**e-entry **F**ast **A**tmostpheric **S**upersonic **T**rajectories **C**alculator allows an all inclusive, low-fidelity, simulation to predict the re-entry trajectory of space debris. The program takes in any discretized multimaterial debris upon the outer skin of which it is possible to compute aerodynamics coefficients and heat flux to evaluate the aerodynamic forces, the possible ablative regression and the evolution of the temperature inside the debris. The 6 degrees of freedom flight mechanics [3] equations allow to march the trajectory of the debris in time. The two previously described steps are repeated until the exit criterion is reached. Where possible, actions are ran asynchronously by multiple concurrent processes to decrease the time-to-solution.
2. On the other hand, **D**ebris **R**e-entry **RANS** **F**ast **A**tmostpheric **S**upersonic **T**rajectories **C**alculator is a coupled aero-thermal high-fidelity code that allows to estimate the external aerodynamics and internal thermal behaviour of any discretized multi-material debris, either for a standalone computation or starting from a state obtained with F.A.S.T.. The external aerodynamics is estimated by solving the three-dimensional Navier-Stokes equations with the finite-volume method, either in RANS or LES formalism [2], and with an immersed boundary condition [1] formulation to account for the presence of the debris in the flow. The numerical method can reach third order accuracy in both space and time for explicit LES computations, whereas the RANS computations rely on an implicit time discretization. Nonetheless, the internal thermal behaviour of the debris is computed by advancing in time the unsteady heat equation with the finite-element method. Speed-up is achieved using a hybrid OpenMP/MPI parallel paradigm [4].

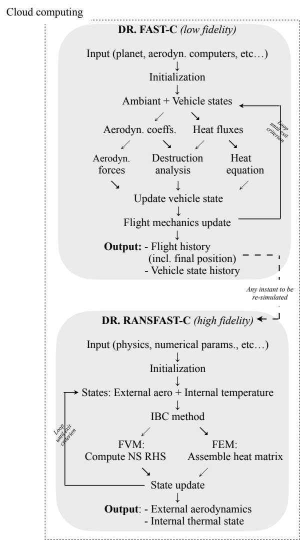

Figure1: Intra- and inter-workflow of the multi-fidelity suite

Validation computations have been carried out on a wide variety of objects and results show good consistency with data found in the literature. This suite is designed to leverage CPU instances found on the cloud via Kubernetes to offer more flexibility and accessibility. Beyond the classical application of such a suite to the prediction of debris re-entry, the design choices selected here also open the door to browser-based uncertainty quantification campaigns for re-entering vehicles such as the Orion space module.

References

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