Comparison Between the Kinetic Fokker-Planck and TAU Navier-Stokes Simulations of Hypersonic Air Flow Around the the RFZ-ST2 Upper Stage

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Predictions of the flow around a vehicle play an important role in the development of space applications. Simulations can support the design process in many ways, from performance analysis, over load predictions to control system design. Computational fluid dynamics (CFD) are well established and well suited for applications in denser atmospheres, such as airplanes or first stages or reusable vertical takeoff landing (VTVL) stages [1]. However, the underlying continuum assumptions lose their validity for higher Knudsen numbers, which are the typical regime for upper stages at higher altitudes and lower atmospheric densities. In these higher Knudsen (Kn) number regimes the flow can be described by the Boltzmann equation. A common approach to numerically solve it is the Direct Simulation Monte-Carlo (DSMC) method pioneered by Bird [2]. The method is very efficient for high Knudsen numbers but becomes increasingly computationally intensive when approaching the continuum limit. A good alternative in this regime is to numerically solve the Boltzmann equation using the kinetic Fokker-Planck (FP) method [3]. In order to validate the new FP implementations, to better understand the limits of CFD and FP and to investigate the differences, our team is currently looking into several test cases. One of the more applied and large cases we selected is the simulation of an upper stage. The aim is to validate the methodologies, to gain insights into their limitations and to establish best practices on where and how to apply each method. For the CFD simulations the DLR TAU code is used. It is well established for the simulation of space applications [4]. For the FP simulations a DLR in-house development of the method has been implemented using the DSMC code SPARTA [5] developed at the Sandia National laboratories. The FP method has been extended to model internal degrees of freedom using the Master Equation Ansatz for diatomic [6] and polyatomic molecules [7] as well as mixtures [8, 9]. For the upper stage simulation, the second stage of the RFZ model was selected. The RFZ model is an initiative of the spacecraft department (Institute of Aerodynamics and Flow Technology) at the German Aerospace Center in Göttingen, and aims to to provide an open source, common research model for reusable launch vehicles [10]. The specifics of the upper stage are presented in ref [11]. In this work we continue our previous investigation with CFD and FP of the upper stage [12], by expanding the modelling from considering only single species diatomic N_2 as fluid to representing air as a gas mixture. First we shortly introduce the underlying simulation methods and explain the relevant differences. We then compare the resulting flow fields and pressure distribution and discuss relevant differences.

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