Technology Development and Infusion by NASA's Entry Systems Modeling Project

This paper describes recent development of modeling and simulation technologies for entry systems and their infusion into NASA's exploration missions. Technology development is organized and prioritized using a system-level perspective, resulting in four broad technical areas of investment: (1) Thermal protection material modeling, (2) Shock layer kinetics and radiation, (3) Computational and experimental aerosciences, and (4) Guidance, navigation, and control. The paper will highlight key contributions from each of these areas, their impacts from a spacecraft and mission design perspective, and discuss planned future investment. Aspects of each technical area are only briefly summarized here. Thermal protection material modeling is geared toward high-fidelity, predictive models capable of optimizing design performance, post-flight reconstruction, and quantifying thermal protection system reliability. New computational tools and experimental techniques have been applied to Orion, MSL/Mars 2020, Mars InSight, and Mars Sample Return missions. Research and development in the area of shock layer kinetics has focused on air and CO2-based atmospheres. In both cases, substantial improvements in model uncertainty have directly impacted the development of mission margin policies, flight instrumentation design and analysis (Orion and Mars 2020), and have even revealed the importance of neglected phenomena like mid-wave infrared radiation of CO2. Aerosciences is a very broad area of interest in entry systems, yet a number of important challenges are being addressed: Coupled fluid-structure simulations of parachute inflation and dynamics affecting Orion, Commercial Crew, and Mars programs; Experimental and computational studies of vehicle dynamics; Multi-phase flow with dust particles to simulate augmentation of aerothermal environments at Mars during dust storms; and studies of roughness-induced heating augmentation relevant to tiled (Orion, Mars 2020) and woven (Mars Sample Return) thermal protection systems. Guidance and control in the context of entry systems has focused on development of methods for multi-axis control (i.e. pitch and yaw, rather than bank angle alone) of spacecraft during entry and descent, with precision landing requirements driven by Mars human exploration goals.