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UNCERTAINTY QUANTIFICATION FOR HYPERSONIC FLOW SIMULATIONS

Abstract

Uncertainty quantification is a method to produce "error bars" on the prediction of the heat flux to the wall of the spacecraft. This is necessary to ensure safety for payloads and astronauts, and avoid failures. The method could potentially replace the current approach of using large safety factors, to reduce the mass of the heat shield, and hence increase the mission payload.

The study intends to quantify the influence of limited knowledge on the wall of a spacecraft on the reconstruction of the freestream conditions, based on the data acquired by pressure and heat flux sensors. Because of the hypersonic flow, certain physical effects arise, which have to be taken into account. Because of the viscous interaction and thin shock layer, the flow becomes chemically reactive and can be in thermochemical non-equilibrium. The calculation thus becomes a computationally complex CFD problem. A suitable model is developed and applied on the chosen geometry: ESA's EXPERT capsule. Suitable means it has to be accurate, stable, take into account all important physics, and most importantly, computationally fast. The latter aspect is important because of the vast number of calculations that are needed to perform a useful statistical analysis of the response functions. The obtained model will of course be a compromise between all these things.

The influence of the freestream parameters on the wall heat flux and stagnation point pressure is then examined. The input parameters taken into account initially are the freestream mach number M_∞ and pressure p_∞. The temperature T_∞ is kept constant. These are the two main parameters that are expected to influence the stagnation point pressure. For the wall heat flux, the recombination efficiency γ at the wall and the forward chemical reaction coefficients k_{f_i} are also expected to have a large influence. Two cases are examined: chemical equilibrium flow at an altitude of $z = 30\ km$ and chemical non-equilibrium flow at $z = 60\ km$. In both cases thermal equilibrium is assumed.

Multiple conclusions can be drawn from the analysis. Firstly, the individual importance of the input variables is quantified. For both p_{st} and q_{st}, M_∞ and p_∞ are always more important than the chemical properties. For the heat flux q_{st} however, the chemistry plays a relatively larger part. Furthermore, the chemical properties influence the non-equilibrium flow more significantly than the equilibrium flow. Finally, the individual chemical reactions can be sorted by importance.