COMPREHENSIVE CHARACTERIZATION OF THE MATERIAL RESPONSE OF INNOVATIVE ABLATORS FOR SPACE EXPLORATION

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After the successful manned missions to the Moon and many probe entries into the atmosphere of outer planets, the next challenges include bringing back samples to Earth and continuing manned space exploration, which aims to send human beings to Mars and bring them home safely. For such spacecraft entering a planet's atmosphere, prediction of the heat flux to the surface of the thermal protection system (TPS) remains an imperfect science and inaccuracies in these predictions can be fatal for the crew or the success of robotic missions. Difficulty is enhanced for Earth re-entries at velocities higher than 10km/s, where ablative materials are used instead of reusable materials for the heat shield. A new class of low density carbon/resin composites, made of a carbon fiber preform impregnated in phenolic resin (PICA), is currently being developed and has already been applied to flight during the Stardust mission. These ablators allow heat rejection through various complex mechanisms like phase change, chemical reactions on the surface and inside, leading to material removal through pyrolysis and ablation (Fig. 1). Furthermore, the material response during ablation is strongly coupled to other phenomena, such as radiation and gas-surface chemistry, for which coupled multiphysics effects remain challenging, leading to large uncertainties in the engineering models for the heating and aerodynamic performance of the spacecraft. To avoid space mission failure and ensure safety of the astronauts and payload, experimental research is necessary for advancement of the multiphysical prediction tools used for the TPS design of tomorrow's space vehicles and planetary probes.

This thesis aims at understanding of the material behavior by means of experimental research at multiscale level and measurement of crucial data for the development and the validation of physico-chemical models and computational methods, all together being the three basic ingredients for prediction in aerospace science (Fig. 2). A high quality data-set will be provided (pre-test, in-situ, post-test), being the missing link between those numerical tools following state-of-the-art uncertainty quantification methods.

A complementary approach is followed for prediction of the material response and plasma-surface interaction. The 1.2MW VKI Plasmatron facility is used to simulate the aerothermal environment for in-situ ablation measurements, utilizing intrusive and non-intrusive techniques for characterization of:

- **material response** to plasma exposure (temperature, heat transfer, ablation rate)
- **flow field** (surrounding gas phase, effect of "blowing" due to outgassing products)
- **radiation field** (chemically reacting boundary layer, identification and quantification of molecules and atoms such as C, C2, CN).

Pre- and post-test examinations of the ablative samples are carried out by Scanning Electron Microscopy (SEM) as well as spectroscopic tools, such as Energy-Dispersive X-ray spectroscopy (EDX), to analyze the ablation phenomena down to the carbon fiber length scale (□10 µm) and to evaluate the degradation inside the material, such as the depth of pyrolysis and char layer. A preliminary multiscale analysis shows that the depth of the ablation zone, where thinning and erosion of the carbonic fibers occurs, is influenced by the state of oxidation, driven by the ambient pressure.

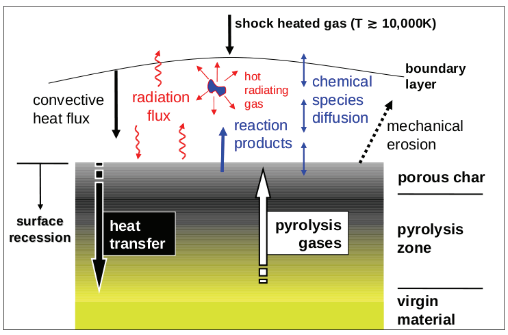

Figure 1 : Ablative material response during reentry with conjugate effects of pyrolysis, ablation and radiation

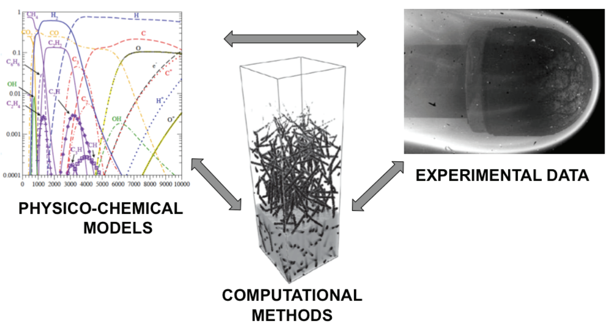

Figure 2 : Complementary prediction tools: model for gas composition, code for material response, thermal protection material testing in VKI Plasmatron