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SYSTEMATIC COMPARATIVE ANALYSIS OF EXISTING ABLATIVE MATERIALS FOR THERMAL PROTECTION SYSTEMS' DESIGN OPTIMISATION

Abstract

During a deceleration via hypersonic aerobraking or planetary re-entry, a bow shock is generated in front of the spacecraft due to high kinetic energies, resulting in extreme thermal loads which the Thermal Protection System (TPS) should withstand without been compromised. Currently, ablative TPS are the only viable option for superorbital Earth re-entries and planetary entries into planets with highly dense atmospheres. Virtually, ablators have no maximum service temperature and they can dissipate large heat loads, thanks to their insulating properties and to the self-regulating and gradual removal of exposed surface material during the interaction with the high-temperature environment. Ablative TPS design is a crucial aspect in the overall design of a re-entry vehicle and poses challenging tasks in terms of heat shielding effectiveness. Therefore, ablative materials demand for continuous characterisation and investigation to enhance materials' performance and reduce the overall TPS mass. Within the Institute of Space Systems (IRS) of the University of Stuttgart, a systematic comparative analysis tool for the future characterisation of TPS materials is developed. Contemporary European and American ablative materials characterised at IRS and implemented in already flown missions are analysed and compared in terms of relevant performance. Selected ablators comprise PICA, SIRCA and ZURAM®, a lightweight ablator developed and manufactured by the German Aerospace Centre (DLR) and characterised at IRS, which proved excellent performance compare to those of similar contemporary TPS materials. Surface and volume ablation rates are investigated in terms of material properties and testing conditions (e.g. heat flux, exposure time) to evaluate common trends for selected ablators. Within this analysis, a common engineering-level model for ablation, known as Q^* model, is integrated. Several considerations on ablative TPS performance are therefore formulated and discussed, resulting in the definition of useful trades-off between TPS design and material performance optimisations. Furthermore, the systematic comparative analysis highlights the effect of pyrolysis gases on ablators' response. It results that the pyrolysis mass fraction increases faster than the surface ablation mass with respect to the exposure time and it represents more than 50% of the overall TPS mass loss. Moreover, pyrolysis gases result to affect the recession rate as well. Since the blowing effect connected to the pyrolysis gases seems to deeply impact on material performance, the pyrolysis layer progression over exposure time is investigated using a numerical model based on data from previous experimental campaigns conducted on ZURAM® and its variants.