AEROFAST: DEVELOPMENT OF CORK TPS MATERIAL AND A 3D COMPARATIVE THERMAL/ABLATION ANALYSIS OF AN APOLLO & A BICONIC SLED SHAPE FOR AN AEROCAPTURE MISSION

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Abstract

An Aerocapture vehicle travelling from Earth to Mars approaches that planet on a hyperbolic interplanetary trajectory. Upon arrival, the vehicle will perform a single atmospheric pass to significantly reduce its speed, and enters into an orbit around the planet. This manoeuvre uses aerodynamic drag instead of propulsion for orbit insertion, and potentially leads to large mass (fuel) savings as well as reduced flight times (higher arrival speed). However, Aerocapture results in significant aerodynamic heating, necessitating a Thermal Protection System (TPS), as well as the use of a guidance system to assure that the spacecraft leaves the planetary atmosphere on the correct trajectory. In the frame of the seventh European Community Framework Program (FP7), the AEROFAST (AEROcapture for Future space tranSporTation) research and development project aims at preparing a demonstration of a Martian Aerocapture mission and increasing the Technology Readiness Level (TRL).

One of the aims of this paper, is to present the development of an innovative cork based material and the selection process of the different formulations. The material must be able to withstand the severe front shield aerothermal environment. Numerous formulations have been investigated using a parametric combination of cork granule size, resin type/ratio, reinforcement fraction, fillers and the mixing and agglomeration processes. A basic (thermo-mechanical) characterization and qualitative analysis allowed for a first selection of the 4 most promising candidates. These candidates are being tested in the inductive plasma wind-tunnel facilities (COMETE) of ASTRIUM. These tests are performed in a stagnation point configuration, for an aerothermal environment similar to the AEROFAST aerocapture mission.

In parallel, a 3D ablation and charring material model has been implemented in the finite element program SAMCEF, and successfully validated during the AEROFAST project. The numerical model consists of three sets of equations, namely the transient heat balance equation, the steady state mass balance equation and the charring equations. For the charring of the material we use a multi-species Arrhenius model with the species densities as degrees of freedom. The ablation is modelled by a surface imposed and temperature dependent ablation speed, followed by an in volume mesh deformation.

Two main probe aerodynamic shapes and concepts have been evaluated, namely an Apollo like shape and a biconic sled with a characteristic diameter of 4 m. A thermo-mechanical comparative analysis of the front-shield has been carried out. The space probes are made of Norcoat-Liège (a low density phenolic resin impregnated cork material) which will serve as a baseline solution. The 3D heat load history (convective and radiative), over the front-shield, is based on the maximum energy trajectory extracted from a statistical Monte Carlo GNC study for a CO_2 Martian atmosphere. Due to a non uniform heat load distribution on the heat shield (non axisymmetric shape plus a 30° flight trim angle), an optimization of the TPS thickness has been performed in order to save mass.

Finally, the biconic sled vehicle has been selected for its several advantages (internal volume, ease of TPS manufacturing) and its innovative features (possible adaptation to other missions).

On the basis of these preliminary experiments, additional efforts will be devoted to the modelling of the thermal, swelling and ablative behaviour of the selected cork based material (developed within this project).

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