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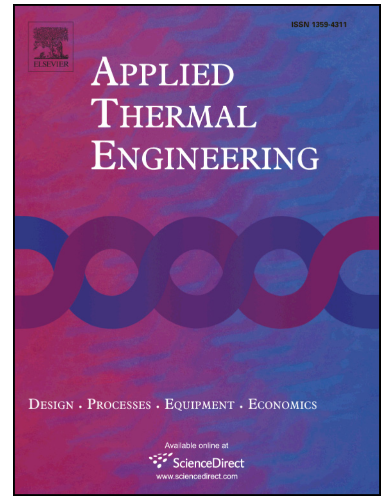

Research Paper

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Optimum Design of Ablative Thermal Protection Systems for Atmospheric Entry Vehicles

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Abstract

The Thermal Protection System (TPS) provides spacecrafts entering the atmosphere with the thermal insulation from the aerothermodynamic heating. The design of such a subsystem is very critical, considering that its damage can lead to a catastrophic failure of the whole entry system, in particular if ablative materials are considered. In order to design an ablative TPS, in fact, a reliable numerical procedure, able to compute surface recession rate, pyrolysis and internal temperature histories under severe heating conditions, is necessary. Indeed, the TPS needs to be sized to effectively shield the spacecraft from the high heat fluxes acting during the atmospheric entry phase. At the same time, its weight has to be the minimum value able to guarantee a suitable protection.

This article aims to describe an optimization procedure for the design of ablative heat shields. In particular, in the present work, the numerical method is applied to the ablative TPS of the hypersonic reentry capsule Stardust.

Keywords: TPS; Ablative materials; Thermal analysis; FEM; Optimization

1. Introduction

During the atmosphere entry, hypersonic vehicles are subjected to strong shocks, equilibrium or non-equilibrium gas chemistry, large heat fluxes, and, as consequence, very high temperatures are reached on the structure. Those conditions require a proper designed Thermal Protection System (TPS). For very high entry speeds, in particular, the use of ablative material is mandatory. To design an ablative TPS, a reliable numerical procedure is needed to compute surface recession rate, pyrolysis effects, and internal temperature histories under severe heating conditions. As can be seen from a historical literature overview, considering the complex phenomenology of the ablative process, numerical models that can describe this phenomenon are still in development [1, 2]. The complexity of the phenomena under considerations is remarked by the unsatisfying analytical methods proposed [3, 4]. Moreover, in the experimental field, tests are not easy to implement considering the complex environmental conditions encountered. Thus far, the most complete methodology for dealing with the problems related to ablation is the numerical resolution of differential equations governing the phenomena of interest. For this purpose, one possible approach assumes that the solid decomposes if a critical temperature is reached. This critical temperature is a material property and it is independent from the incoming heat flow. A further approach considers the chemical reactions in the char layer according to the "frozen chemistry" model or the "chemical equilibrium" model [5]. Despite the wide amount of research carried out so far, the design methodologies of ablative heat shields need not-negligible improvements. A fundamental aspect that these methods have to consider is related to the fact that the TPS usually represents a large fraction of the total spacecraft volume [6]. The objective of this work is to estimate the heat shield minimum volume able to keep the mission requirements for a

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