Paper ID: 47837
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IAF MATERIALS AND STRUCTURES SYMPOSIUM (C2)
Advanced Materials and Structures for High Temperature Applications (4)

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MULTI-DIMENSIONAL COUPLED APPROACH FOR THE SIMULATION OF ABLATIVE THERMAL PROTECTION SYSTEMS DURING ATMOSPHERIC ENTRIES.

Abstract

Thermal Protection systems (TPSs) are single point failure systems that enable a great variety of space missions. Their main task is the protection of the spacecrafts internal components from the extreme heating encountered during an atmospheric entry. The missions which require TPS vary from the transport of astronauts from the International Space Station (ISS) to space exploration missions on Titan, one of Saturn's moons. The most commonly used TPSs are ablative materials. These non-reusable materials undergo a degradation, called pyrolysis, to perform the thermal protection task. The pyrolysis is a complex physical phenomenon which is not easy to evaluate. However, codes able to simulate the ablative material exist and are extremely useful in mission design and material development activities.

ARC, Ablative Response Code, is one of these programs. It is based on a one-dimensional code, but it has been used to generate estimates of the three-dimensional behaviour of ablative materials during an atmospheric entry for different planets. In these simulations, ARC was coupled with reduced order aero-thermodynamic tools to consider the interaction between the external environment and the material changes. The results produced with this methodology were compared with in-fight measurements and commercial codes simulations. The precision of the new coupled approach was considered sufficient to perform reliable analyses for the preliminary phases of the mission design.

In this paper, the three-dimensional ARC method is coupled with a CFD tool which is a higher order aero-thermodynamic model and it is used to simulate the Stardust capsule re-entry. The results of this activity are compared with the in-fight measurements and commercial programs simulations. Moreover, they are compared with the results produced with the coupling of two different reduced order aero-thermodynamic models. This study shows that the errors introduced in the first method (reduced order tools and ARC 3D) were mainly due to the reduced order models and not caused by the use of one-dimensional ablative program to produce three-dimensional simulations. Moreover, this study quantifies the errors introduced by neglecting three-dimensional effects inside the TPS while simulating an entire spacecraft geometry. It also proves that the three-dimensional method based on ARC 1D can produce precise analyses that can be used in more advanced phases of the mission design.