MATERIALS AND STRUCTURES SYMPOSIUM (C2)
Space Environmental Effects and Spacecraft Protection (6)

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AN ANALYTICAL-NUMERICAL MODEL FOR OPTIMIZING THERMAL PROTECTION SYSTEMS SUBJECTED TO AERODYNAMIC HEATING

Abstract

A procedure based on one dimensional analytical/numeric approximated solutions of transient non-linear analyses has been developed in order to estimate the temperature variation with time and space of a multilayered body subjected to aerodynamic heating inside a radiating space. The analytic method used to evaluate the thermal response of the body is the integral method developed by Polhausen and Von Karman. The integral method is an approximated one since it assumes that the spatial temperature distribution is an "a priori" chosen expression. To be more precise, it is necessary to follow four steps to apply the integral method. First of all, the partial differential equation of the heat conduction is integrated over a phenomenological distance called "thermal layer" which represents the distance beyond which heat flux is zero. The result of the integration is the integral equation which is an ordinary differential equation. Then, a polynomial expression for the temperature distribution is chosen. The coefficients of the polynomial expression become function of the thermal layer since boundary conditions are applied. The resulting temperature distribution is introduced in the integral equation which solution is the thermal layer variation with time. Finally the spatial and temperature variation in the body is known. The described procedure is valid for semi-infinite bodies, but can be applied also for finite bodies where the time variation of the temperature distribution is not given by the thermal layer, which has no significance for finite bodies. In order to take into account thermal properties variation with temperature, which is fundamental for structural components of hypersonic vehicles where relevant temperature variations are encountered, a discretization of the time interval has been considered. Then, the entire time interval is divided in a certain number of time steps which length is such that the aerodynamic heating variation in the time step does not exceed the 5The described method can also be used to evaluate the temperature distribution for multilayered bodies. The present paper illustrates the advantages of adopting the proposed analytic/numeric procedure in the preliminary design phase of structural components subjected to aerodynamic heating. In fact, it allows to solve complex thermal problems in very short times and with a very good accordance with the results obtained with commercial codes allowing to perform complex optimizations to minimize the weight of the component. The procedure has been applied to optimize the thickness of the ceramic wing leading edge of a re-entry vehicle. The results demonstrate that the time needed to preliminary design the component is ten times shorter than the time needed to obtain the same results by adopting Finite Element commercial codes.