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INTEGRATED THERMAL PROTECTION SYSTEM DESIGN FOR HYPERSONIC VEHICLE BASED ON NEW THERMAL-MECHANICAL METHOD

Abstract

With the development of hypersonic reusable vehicle, the integrated thermal protection system (ITPS) should satisfy the characteristic of light weight, cost effective, bearing aerodynamic and easy maintenance. From the points above, a efficient and accurate ITPS design with new thermo-mechanical method is presented in the paper, which combines the vehicle geometry and trajectory data. The main contents of the new thermo-mechanical method include the following aspects:

For the problem of heat transfer, a novel approximate analytical method based on separation of variables and orthogonal expansion technique is presented for temperature prediction through ITPS subjected to convection and radiation boundary conditions, which considers the effects of temperature-dependent thermal material properties. Some advanced linearized approximations for radiation boundary condition and distribution of thermal diffusivity are developed for the approximate analytical model.

For the problem of static analysis, a C0 higher-order layerwise finite element model combined with homogenization techniques is presented. An advanced analytical equivalent model based on energy approach for the mechanical properties of the ITPS structure is presented. In the layerwise theory, different orders of polynomial distribution for displacement are assumed properly in corresponding structure layers. As a result, the finite element is developed to equivalent the ITPS structure as a two-dimensional plate, and the freedoms of calculation are declined significantly. By employing the layerwise theory and the principle of structural mechanics, the stress distributions in ITPS under thermal-mechanical loads are predicted. The method considers the effects of temperature-dependent material properties and local displacements in every sheet.

For the problem of stability, a simplified three-dimensional finite element model is present according to the periodic structural character of ITPS, which can reduce the time cost of buckling solution. And the corresponding boundary conditions are developed for the simplified model.

Based on the proposed methods of heat transfer, static analysis and static buckling, an optimization design for ITPS is developed. Implementation of the design method is demonstrated by applying it to design the ITPS of two examples: space shuttle and hypersonic reusable vehicle. And weight loss in the two cases are presented by comparing with the tranditional thermal protection system (TPS). The paper aims to provide a better method for promoting the application of ITPS in hypersonic vehicle, which puts the foundation for the development of hypersonic reusable vehicle.