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DESIGN AND RESEARCH OF THERMAL PROTECTION CONSIDERING THE CARBON FOAM MORPHOLOGY

Abstract

During the operation, structures and systems of hypersonic vehicles, re-entry spacecrafts, solar and planetary probes are subjected to extreme heat loads. The design of reliable and efficient thermal protection of such space vehicles is very critical, because its failure leads to catastrophic consequences for the whole mission. Often the successful fulfillment of the mission's scientific goals greatly depends on the practical solution of problems related to the choice of the thermal protection concept and high-temperature heat-resistant construction materials. High-porous open cell foams have great potential for manufacturing of high-temperature thermal insulation. The benefits of such materials include extremely low density, high temperature capability, sufficient strength at the operating temperatures and low thermal conductivity. Physical properties of cellular materials are not only determined by their base material but also significantly by their microstructure (cell dimensions, length and cross-sectional dimensions of the struts), technology of fabrication and operating conditions. This implies possibility to create open-cell materials with desirable properties, optimal for specific applications. The paper presents a methodology for optimal design of multilayer thermal insulation based on high porosity open cell carbon foam, taking into account the dependence of thermal properties on the foam's morphology. The innovative part of the work lies in determination of cell diameter and porosity of foam together with thickness of layers for multi-layer thermal insulation, ensuring required operational temperature on the boundaries of layers and minimum of total mass of system. The radiation-conductive heat transfer in a layer of carbon foam is described using the available analytical law to predict the radiative properties of open-cell foams. To verify the capabilities of the mathematical model of heat transfer in open cell foam insulation, predicted thermal conductivity and volumetric heat capacity are compared with data obtained through thermal tests of real carbon foam samples. Experimental data was acquired for three samples of open cell carbon foam with different cell diameters by means of the experimental-computational system, developed at the Thermal Laboratory of Department of Space Systems Engineering, Moscow Aviation Institute. Developed algorithm and the corresponding software is applicable without modification for solving a wide range of thermal design problems including the design of advanced thermal protection systems for spacecrafts operating under conditions of extreme thermal loads.