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DESIGN OF THERMAL PROTECTION BASED ON CARBON AEROGEL COMPOSITE STRUCTURE OPTIMIZATION

Abstract

The study of the Sun, planets and small bodies of the Solar System using the automatic interplanetary stations and descent vehicles is one of the priority areas of fundamental space research, which purpose is to develop the theoretical basis of key scientific disciplines about space. The thermal protection of space vehicles operates under significant thermal loads, which requires its optimal design both in terms of technological and mass characteristics. The reliable and efficient thermal protection guarantees the successful fulfillment of the mission's scientific goals. A promising direction in the composites development for high-temperature thermal insulation is the infiltration of the high-porous open-cell foams with ultralight aerogels. This combination of materials makes a composite with overall improved properties than that of either component by itself. The low strength and fragility inherent to aerogels impede production of large monolithic structures. High-porous open cell foams mechanically strengthens aerogel matrix, providing high mechanical characteristics of the composite material. At high temperatures, the thermal conductivity of open-cell foams increases rapidly as radiation through the porous structure becomes the dominant heat transfer mechanism. The infiltration with carbon aerogel allows reducing the radiative conductivity of open-cell foams. Physical properties of foam/aerogel composite are significantly determined by the foam microstructure (cell dimensions, length and cross-sectional dimensions of the struts). This implies possibility to create material with desirable properties, optimal for specific applications. The paper presents a methodology for optimal design of multilayer thermal insulation based on aerogel-filled 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 the foam cell size 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 optimization problem is solved using the algorithm based on the projected Lagrangian method with the quadratic subproblem. The application of the developed algorithm is illustrated by the design problem of the solar probe multilayer heat shield.