Radiative Heat Transfer Modeling in Fibrous Porous Media

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Phenolic-Impregnated Carbon Ablator (PICA) was developed at NASA Ames Research Center as a lightweight thermal protection system material for successful atmospheric entries. The objective of the current work is to compute the effective radiative conductivity of fibrous porous media, such as preforms used to make PICA, to enable the efficient design of materials that can meet the thermal performance goals of forthcoming space exploration missions.

The view factor, $F_{ij}$, between surfaces $i$ and $j$, where $A_i$ and $A_j$ are the areas of the surfaces, are defined in the equation below. A view factor equal to zero implies that two surfaces cannot "see" each other, or in other words, a light ray emitted by one of the surfaces cannot reach the other surface.

$$F_{ij} = \frac{1}{A_i} \int A_i \int A_j \frac{|\hat{r}_{ij}|^2}{|\hat{r}_{ij}|^2} dA_j dA_i$$

The view factors data generated is used calculate the radiative heat transfer in a certain domain. The radiosity $J_i$ or total heat flux leaving a surface, is computed with the equation below. As this constitutes a large sparse coupled linear system, an iterative process is used to solve for the radiosity of each surface between walls 1 and 2:

$$J_i = \varepsilon_i \sigma T_i^4 + (1 - \varepsilon_i) \sum_j F_{ij} J_j$$

where $\varepsilon_i$ is emissivity and $T_i$ is the local temperature. This computation assumes that each surface is isothermal, diffuse, and opaque. The output is the net axial heat flux, averaged over the other two directions.

Using PuMA to render a digital representation of the sample, the radiative heat transfer in the carbon fiber preform is investigated. For the results shown, a temperature gradient of 1K is imposed in the axial direction, resulting in a finite net heat flux.

Ablator Modeling

An efficient and MPI parallel procedure is developed to first obtain relevant view-factors using a collision based Monte-Carlo method and second to compute the final steady-state radiative heat flux [1]. The radiative conductivity computed can be combined with the value calculated for thermal conductivity using PuMA [2], a NASA software for extracting porous material properties, to determine the total effective conductivity from the intrinsic conductivity of constituting phases.

$$q'' = -[k_c + k_r] \nabla T$$

Methods

Background

Results

Conclusions

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References