Optimal Design Of Functionally Graded Metallic Foam Insulations
Final report for NASA grant NAG-1-01046

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The focus of our work has been on developing an insight into the physics that govern the optimum design of thermal insulation for use in thermal protection systems of launch vehicle. Of particular interest was to obtain optimality criteria for designing foam insulations that have density (or porosity) distributions through the thickness for optimum thermal performance.

We investigated the optimum design of functionally graded thermal insulation for steady state heat transfer through the foam. We showed that the heat transfer in the foam has competing modes, of radiation and conduction. The problem assumed a fixed inside temperature of 400 K and varied the aerodynamic surface heating on the outside surface from 0.2 to 1.0 MW/m^2. The thermal insulation develops a high temperature gradient through the thickness. Investigation of the model developed for heat conduction in foams showed that at high temperatures (as on outside wall) intracellular radiation dominates the heat transfer in the foam. Minimizing radiation requires reducing the pore size, which increases the density of the foam. At low temperatures (as on the inside wall), intracellular conduction (of the metal and air) dominates the heat transfer. Minimizing conduction requires increasing the pore size. This indicated that for every temperature there was an optimum value of density that minimized the heat transfer coefficient.

Two optimization studies were performed. One was to minimize the heat transmitted though a fixed thickness insulation by varying density profiles. The second was to obtain the minimum mass insulation for specified thickness. Analytical optimality criteria were derived for the cases considered.

The optimality condition for minimum heat transfer required that at each temperature we find the density that minimizes the heat transfer coefficient. Once a relationship between the optimum heat transfer coefficient and the temperature was found, the design problem reduced to the solution of a simple nonlinear differential equation. Preliminary results of this work were presented at the American Society of Composites meeting [1], and the final version was submitted for publication in the AIAA Journal [2].

In addition to minimizing the transmitted heat, we investigated the optimum design for minimum weight given an acceptable level of heat transmission through the insulation. The optimality criterion developed was different from that obtained for minimizing heat transfer coefficient. For minimum mass design, we had to find for a given temperature the optimum density, which minimized the logarithmic derivative of the insulation thermal conductivity with respect to its density. The logarithmic derivative is defined as the ratio of relative change in the dependant response (thermal conductivity) to the relative change in the independent variable (density). The results have been documented as a conference paper that will be presented at the upcoming AIAA 43rd Structures, Structural Dynamics and Materials Conference in Denver Colarado. (Ref. 3)

References

1. Venkataraman, S., Zhu, H., Sankar, B. V., and Haftka, R. T., and Blosser, M. L. "Optimum Design of a Functionally Graded Metallic Foam Thermal Insulation," *Proceedings, American Society of Composites-16th Annual Technical Conference*, September 9-12, 2001, Blacksburg, VA
2. Venkataraman, S., Zhu, H., Sankar, B. V., and Haftka, R. T., and Blosser, M. L., "Optimal Design of a Functionally Graded Metallic Foam Thermal Insulation," submitted to *AIAA Journal*.
3. Zhu H., Sankar, B. V., and Haftka, R. T., Venkataraman, S., and Blosser, M. L., Minimum Mass Design of Insulation Made of Functionally Graded Material," Proceedings, 43rd AIAA/ASME/ ASC/ AHS Struct., Struct. Dyn. and Materials Conference, April 22-25, 2002, Denver, CO.