ure, in the temperature range of 975 to 1,275 K, the *ZT* value of $Yb_{14}MnSb_{11}$ is approximately double that of SiGe. Moreover, as shown in the lower part of the figure, the *s* value of $Yb_{14}MnSb_{11}$ is much closer to that of $CeFe_4Sb_{12}$ than is the *s* value of SiGe. The net effect of the greater *ZT* and closer match of *s* of $Yb_{14}MnSb_{11}$, compared to those of SiGe, is that the thermal-to-electric power-conversion efficiency of a segmented $Yb_{14}MnSb_{11}/CeFe_4Sb_{12}$ leg operating between the given hot-side and cold-side temperatures is significantly greater than that of a $SiGe/CeFe_4Sb_{12}$ leg operating between the same hot- and cold-side temperatures. For example, for a hot-side temperature of 1,275 K and a cold-side temperature of 775 K, the thermal-to-electric power-conversion efficiency of a segmented $Yb_{14}MnSb_{11}/CeFe_4Sb_{12}$ leg is about 7.3 percent, while that of a segmented $SiGe/CeFe_4Sb_{12}$ leg is about 4.5 percent.

*This work was done by G. Jeffrey Snyder and Franck Gascoin of Caltech and Shawna Brown and Susan Kauzlarich of U.C. Davis for NASA's Jet Propulsion Laboratory. In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to:*

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# Polyimide-Foam/Aerogel Composites for Thermal Insulation

## These composites may also afford enhanced acoustic attenuation.

*John F. Kennedy Space Center, Florida*

Composites of specific types of polymer foams and aerogel particles or blankets have been proposed to obtain thermal insulation performance superior to those of the neat polyimide foams. These composites have potential to also provide enhanced properties for vibration dampening or acoustic attenuation. The specific type of polymer foam is denoted "TEEK-H," signifying a series, denoted "H," within a family of polyimide foams that were developed at NASA's Langley Research Center and are collectively denoted "TEEK" (an acronym of the inventors' names).

The specific types of aerogels include Nanogel® aerogel particles from Cabot Corporation in Billerica, MA. and of Spaceloft® aerogel blanket from Aspen Aerogels in Northborough, MA. The composites are inherently flame-retardant and exceptionally thermally stable.

There are numerous potential uses for these composites, at temperatures from cryogenic to high temperatures, in diverse applications that include aerospace vehicles, aircraft, ocean vessels, buildings, and industrial process equipment. Some low-temperature applications, for example, include cryogenic storage and transfer or the transport of foods, medicines, and chemicals. Because of thermal cycling, aging, and weathering most polymer foams do not perform well at cryogenic temperatures and will undergo further cracking over time.

The TEEK polyimides are among the few exceptions to this pattern, and the proposed composites are intended to have all the desirable properties of TEEK-H foams, plus improved thermal performance along with enhanced vibration or acoustic-attenuation performance.

A composite panel as proposed would be fabricated by adding an appropriate amount of TEEK friable balloons into a mold to form a bottom layer. A piece of flexible aerogel blanket material, cut to the desired size and shape, would then be placed on the bottom TEEK layer and sandwiched between another top layer of polyimide friable balloons so that the aerogel blanket would become completely encased in an outer layer of TEEK friable balloons. Optionally, the process could be further repeated to produce multiple aerogel-blanket layers interspersed with and encased by TEEK friable balloons.

The sandwiching of aerogel bulk-fill particles would follow the same methodology or could be mixed directly with friable balloons up to 40% weight loading of the aerogel particles to friable balloons. After sandwiching or mixing of the polymide and aerogel components, the mold, without a top cover, would be placed in a convection furnace and heated at a temperature of 250 °C for one hour. Then the top cover would be placed on the mold and the temperature increased to about 320 °C for between 1 and 3 hours for full imidization of the polyimide component. The resulting composite should have all the desirable properties of TEEK, and its effective thermal conductivity should be less than that of an approximately equally dense panel made of TEEK foam only. The heat transfer reduction is directly proportional to % loading of the aerogel component. The excellent structural integrity of the foam material is maintained in the composite formulations.

*This work was done by Martha Williams, James Fesmire, Jared Sass and Trent Smith of Kennedy Space Center and Erik Weiser of Langley Research Center. For further information, contact the Kennedy Innovative Partnerships Office at (321) 861-7158. KSC-12894*