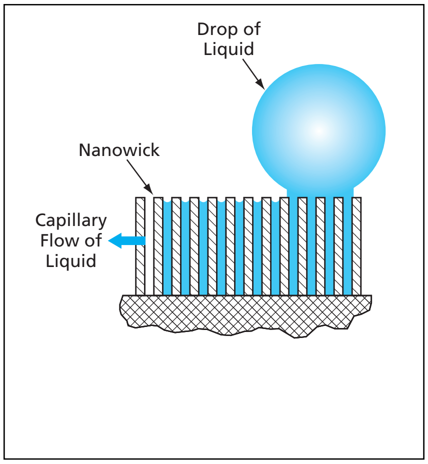

Figure 2. A **Drop of Liquid** would be placed on a nanowick. The liquid would be absorbed into the wick and transported by capillary action.

A nanowick (see Figure 1) typically consists of carbon nanotubes grown normal to a substrate in a tailorable pattern. The liquid of interest is constrained to flow in the interstices between the fibers. (In practice, the liquid must include a surfactant because carbon nanotubes are hydrophobic.) By suitable control of the growth process, the interfiber distance and/or the fiber length can be made to range from nanometers to millimeters and to vary with position (in one or two dimensions) on the substrate. Similarly, the fiber diameter can be made to vary with position. The spatial variation in spacing and/or diameter can be chosen to obtain such effects as prescribed spatial variations in wicking speed or prescribed degrees of separation among different biomolecules.

The following are examples of potential applications and potential variations in designs of nanowicks:

- Somewhat analogously to strips of litmus paper, wicking chips could be made as disposable devices for rapid testing of liquids. To start a test, a drop of liquid would be placed on top of the array of nanofibers on a wicking chip (see Figure 2). After absorption of the drop and transport of the liquid by wicking, the liquid could be filtered and analyzed (for viscosity, for example) in a very simple manner, without need for any complicated pumping mechanism.
- A liquid could be made to flow continuously, as in a capillary-pumped loop. The liquid would enter a nanowick at one end, would flow through the mat of fibers by capillary action, and would be made to evaporate at the other end. The evaporation would sustain the pumping action in the same manner in which evaporation of water from leaves sustains capillary pumping in living plants.
- A nanowick could serve as both a filter and a pump: While a liquid was flowing through a nanowick, the fibers could trap particles and large molecules (for example, protein and deoxyribonucleic acid molecules).
- The pattern of nanofibers could be tailored to exploit a combination of diffusion and extensional flow to promote nanoscale mixing of two liquids.
- Nanowicks could be patterned to act as various fluidic logic devices, including ones that exert fluidic effects analogous to the electrical effects of transistors and diodes. Unlike macroscale and microscale fluidic devices, the nanowick-based fluidic devices could, conceivably, be designed and built without channels and could operate without mechanical pumps.
- It might be possible to construct nanowicks in which selective wicking could be controlled electrically.
- Although capillary forces would suffice to contain a liquid within a nanowick, without need to place the wick in a channel, the nanowick could be capped, if desired, to prevent evaporation.
- Nanowicks could be used to transport liquids through interstitial spaces into which tubes could not inserted.

This work was done by Flavio Noca, Michael Bronikowski, Elijah Sansom, Jijie Zhou, and Morteza Gharib of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).

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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Refer to NPO-40440, volume and number of this NASA Tech Briefs *issue, and the page number.*

Lightweight Thermal Protection System for Atmospheric Entry

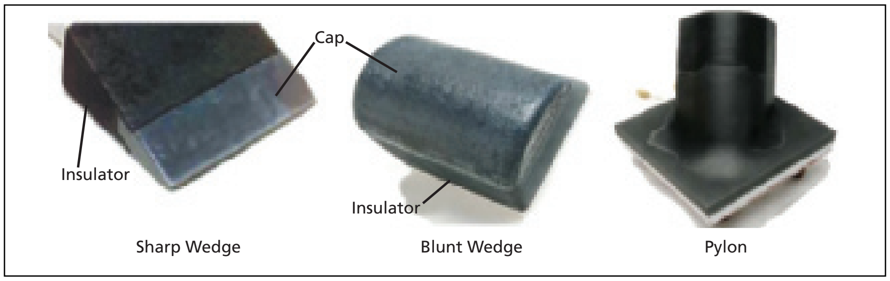
The material withstands up to 1,970 K to protect wing leading edges and nose caps on hypersonic vehicles.

Ames Research Center, Moffett Field, California

TUFROC (Toughened Uni-piece Fibrous Reinforced Oxidation-resistant Composite) has been developed as a new thermal protection system (TPS) material for wing leading edge and nose cap applications. The composite withstands temperatures up to 1,970 K, and consists of a toughened, high-temperature surface cap and a low-thermal-conductivity base, and is applicable to both sharp and blunt leading edge vehicles. This extends the possible application of fibrous insulation to the wing leading edge and/or nose cap on a hypersonic vehicle.

The lightweight system comprises a treated carbonaceous cap composed of ROCCI (Refractory Oxidation-resistant Ceramic Carbon Insulation), which provides dimensional stability to the outer mold line, while the fibrous base material provides maximum thermal insulation for the vehicle structure. The composite has graded surface treatments applied by impregnation to both the cap and base. These treatments enable it to survive in an aero-convectively heated environment of high-speed planetary entry. The exact cap and base materials are chosen in combination with the surface treatments, taking into account the duration of exposure and expected surface temperatures for the particular application.

Current leading edge TPS systems weigh approximately 1.6 g/cm^3, while the TUFROC version weighs 0.4 g/cm^3. The RCC system used on the orbiter operates at heat fluxes below 70 W/cm^2 during Earth re-entry. Not only are systems like this heavier than TUFROC, they are far more expensive with RCC costing approximately 100 times more than TUFROC components of equivalent size. Furthermore, RCC requires significantly longer fabrication lead times — 12 rather than the



Various Configurations of TUFROC have been prepared and tested in high-energy arc-jet environments.

roughly a month needed for TUFROC.

TUFROC systems have been fabricated and tested in the various configurations as shown in the figure. The 5° blunt cone is 6.35 cm thick, and has a 1.27 cm corner radius. The sharp leading edge wedge has a 10° half-angle, is 10.2 cm wide, and has leading edge radii of 0.158 cm and 0.318 cm. The blunt leading edge wedge has a leading edge radius of 5.08 cm and is 20.2 cm wide. These configurations have thermocouples installed at the junction between the cap and insulator, and in the aluminum base-plate behind the insulation. Finally, to evaluate the flight performance of a TUFROC TPS on the wing leading edge of the X-37, a pylon test article was created consisting of two tiles: a base tile (20.3×20.3 cm square) with a pylon protruding from it, and an upper portion 10.2 cm long. All test articles, except the pylon, contain a threaded aluminum-mounting ring bonded into their bases so that they can be attached to a water-cooled strut.

This work was done by David Stewart and Daniel Leiser of NASA's Ames Research Center. Further information is contained in a TSP (see page 1).

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning rights for the commercial use of this invention should be addressed to the Ames Technology Partnerships Division at (650) 604-2954. Refer to ARC-15201-1.