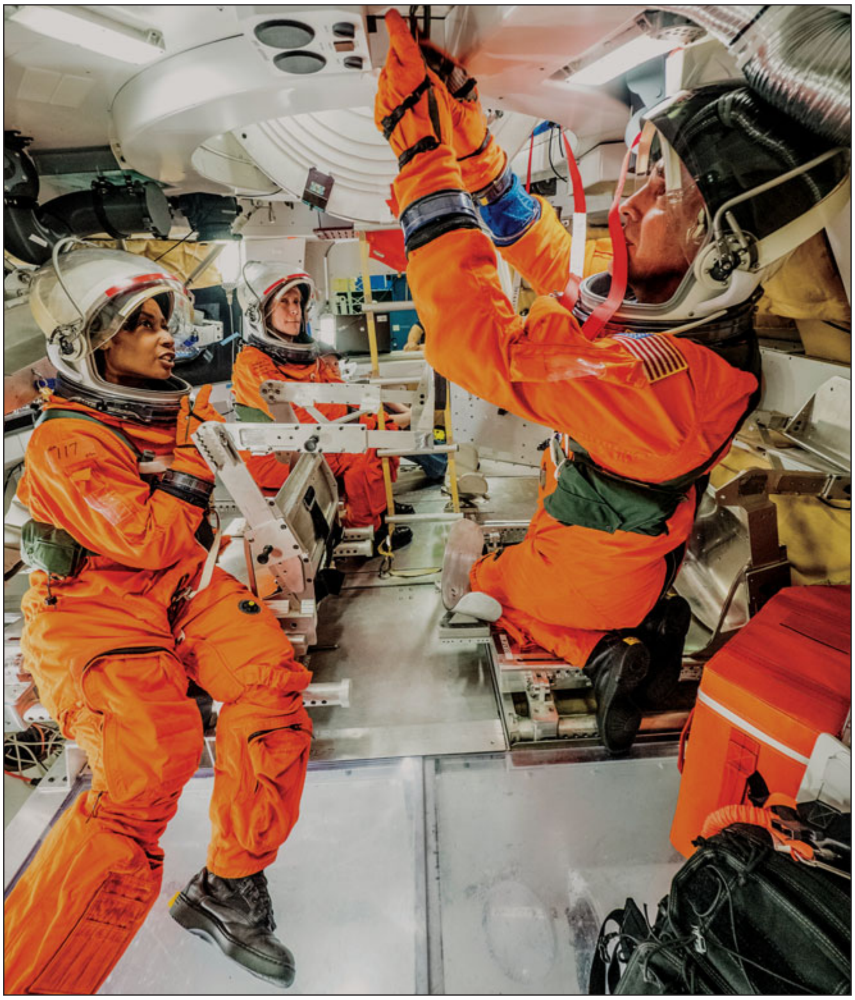
Materials research crucial to achieve NASA's humans-to-Mars mission

Sometime in the 2030s, US astronauts will step off a landing craft to leave the first human footprints on Mars. Their historic, 35-million-mile journey will require a multitude of advances in science and engineering, including the latest and most advanced materials and materials processes for spacecraft, spacesuits, and habitats.

Mars has a reasonable carbon source, said University of Chicago polymers researcher Stuart Rowan at a recent Journey to Mars symposium held August 22 in Washington, DC, hosted by the American Chemical Society (ACS). "We can take advantage of what's there," Rowan said, to make polyethylene, polyester, and "smart" materials such as stimulus-response shape-memory adhesive materials or liquid-crystal elastomers. Three-dimensional (3D) printing, or additive manufacturing technologies, can be used to make structures from the starting materials, he said, for example his design for a "polymeric claw" that could be used to lift objects.



Engineers and astronauts conducted testing in a representative model of the Orion spacecraft at NASA Johnson Space Center in Houston to gather the crew's feedback on the design of the docking hatch and on postlanding equipment operations. NASA's goal is for Orion to carry the first human explorers to Mars. Credit: NASA.

But many scientists and others might ask of a humans-to-Mars mission: "Can it really be done?" NASA officials, and many experts in the space policy community, give a resounding "yes"—on both technological and mission support/funding grounds.

"When we do reach Mars, it will be a civilization-level achievement—a global moment that will endure for centuries," said NASA Acting Administrator Robert M. Lightfoot Jr. at the 2017 "Humans to Mars Summit" (H2M), held in Washington, DC, in May, at George Washington University.

For anyone who might be questioning NASA or the US government's resolve to meet the goal of placing humans on Mars, Lightfoot said, "This is beyond any budget cycle. It's humanity's next giant leap, and it's not just talk."

As one example, Lightfoot cited broad bipartisan support and passage of the NASA Transition Authorization Act of 2017 (S. 442), introduced by US Senators Ted Cruz (R-Texas) and Bill Nelson (R-Fla.), and signed into law by President Donald J. Trump on March 21. The Act is the first such authorization legislation for NASA enacted since 2010, and it directs that "The [NASA] Administrator shall manage human space flight programs, including the Space Launch System [SLS] and Orion, to enable humans to explore Mars and other destinations…."

The Trump administration's FY 2018 budget request for NASA—at some $19 billion—will sustain NASA programs critical to a Mars mission, particularly ongoing development of the SLS

https://doi.org/10.1557/mrs.2017.248 Published online by Cambridge University Press

launch system and Orion space capsule, Lightfoot said. There is no line item for the Journey to Mars project, he said, noting that the research and capabilities the agency needs to develop are spread out across NASA directorates.

He also noted the president's re-establishment, in June of 2017, of the National Space Council, to be chaired by Vice President Mike Pence and to serve as an executive-level guide for US space policy. And in early September, the White House announced intentions to nominate Representative Jim Bridenstine (R-Okla.), a former Navy pilot, to be the new NASA Administrator—a move applauded by many in the space policy community, not least because of Bridenstine's support for deep-space exploration, including landing humans on Mars.

The journey to Mars will be a voyage of seven to eight months—one-way—and it will take some 22 minutes for images of those first footsteps on the red planet to be beamed back to Earth by laser, said former astronaut Janet L. Kavandi, who is Director of the NASA Glenn Research Center in Cleveland, Ohio, and one of the agency's key officials involved in the Journey to Mars program.

A total mission time of at least three years will be needed to make the first manned mission successful and beneficial to all humankind, Kavandi said, speaking at the Journey to Mars symposium in Washington, DC.

On Mars, "*in situ* resource utilization will be absolutely necessary," Kavandi said. With more than 30 million metric tons of materials needed to reach Mars and sustain human life, she said, it will not be possible to haul all of it aboard spaceships.

"We will need to know how to process materials and manufacture and construct habitats on site," she said. Among the needs, she said, will be shielding astronauts from radiation, providing them with lightweight exercise equipment to maintain tissue and bone health in a weightless environment, shape-memory alloys for Mars-rover tires, and lightweight and smart materials for spacesuits, to name just a few of the challenges.

To that end, NASA has selected two new Space Technology Research Institutes (STRIs)—funded to the tune of $15 million each over the course of the next five years—"that will bring together researchers from various disciplines and organizations to collaborate on the advancement of cutting-edge technologies in biomanufacturing and space infrastructure, with the goal of creating and maximizing Earth-independent, self-sustaining exploration mission capabilities," the agency said in a press release.

The Center for the Utilization of Biological Engineering in Space (CUBES), NASA said, will advance research into an integrated, multifunction, multi-organism biomanufacturing system to produce fuel, materials, pharmaceuticals, and food.

The CUBES team is led by Adam Arkin, principal investigator at the University of California, Berkeley, in partnership with Utah State University, the University of California, Davis, Stanford University, and industrial partners Autodesk and Physical Sciences, Inc.

The Institute for Ultra-Strong Composites by Computational Design (US-COMP) aims to develop and deploy a carbon nanotube-based, ultrahigh strength, lightweight aerospace structural material within five years, NASA said in announcing the award. Success, the agency said, could mean a critical change to the design paradigm for space structures.

US-COMP is led by Gregory Odegard, professor of computational mechanics at Michigan Technological University, in partnership with Florida State University, The University of Utah, Massachusetts Institute of Technology, Florida A&M University, Johns Hopkins University, Georgia Institute of Technology, University of Minnesota, The Pennsylvania State University, University of Colorado, and Virginia Commonwealth University. Industrial partners include Nanocomp Technologies, Inc. and Solvay, with the US Air Force Research Laboratory as a collaborator.

NASA also funds many in-house materials research ventures. NASA Senior Materials Scientist Emilie Siochi, for example, conducts research on carbon nanotubes and carbon nanotube fibers at the agency's Advanced Materials and Processing Branch at Langley Research Center in Virginia.

While carbon fiber-reinforced polymer composites have proved excellent for lightweight aerospace structures today, she said, future vehicle designs—such as those needed for the long journey to Mars—can benefit from the even better mechanical properties that may be offered by emerging materials systems such as carbon nanotubes (CNTs).

"CNTs possess attractive nanoscale mechanical properties that can be useful in the fabrication of large structures if these properties are retained as they are scaled up to bulk formats," Siochi said.

Other materials science presentations at the ACS Journey to Mars symposium included work on polymers, 3D printing, aerogels, ionic liquids, and more, that will all have direct bearing on the eventual humans-to-Mars missions.

Virginia Polytechnic Institute and State University researcher Timothy E. Long spoke about designing functional polymers for 3D printing. "The question is, how do we print 3D structures that can survive on Mars?" he said. The Martian atmosphere is extremely cold and so low-temperature extrusion or additive manufacturing processes and materials will be essential.

The polyimide class of materials presents one option because they are already in use for extreme and high-value applications. In fact, he said, polyimides like the commercially available Kapton "are the materials of choice for very demanding applications."

But their highly aromatic molecular structure renders processing challenges, Long said. His group has demonstrated how 3D polyimide structures with micron-scale resolution can be produced with the use of a soluble photocross-linkable precursor polymer that forms a thermoplastic polyimide upon thermal imidization. They have demonstrated their work using two commercially available thermoplastics, Kapton and Ultem.

"Everyone believes that this is our horizon goal," Lightfoot said of humans reaching Mars. "The real goals of humanity have been to reach Mars for a while," he said, adding that, "today's aspirations become tomorrow's realities."

William G. Schulz

https://doi.org/10.1557/mrs.2017.248 Published online by Cambridge University Press

https://doi.org/10.1557/mrs.2017.248 Published online by Cambridge University Press