National Aeronautics and Space Administration

Game Changing Development Program

Game On

Partnerships

are key to success

Engaging the Technical Community

Working With NASA: An Industry Perspective

Bringing NASA "Down to Earth"

Game Changing Employee: Howard Conyers

Space Technology

2015

Team,

What an incredible year we have had in FY15. The accomplishments are numerous including breakthroughs and Technology Firsts.

Here are a few I'd like to mention:

- 3D-MAT was adopted by Orion in its baseline design.
- The MASH project has a viable soft hatch design and is working with AES to make this compatible with any airlock needs.
- Testing on the Nuclear Systems Technology Demonstration Unit system will conclude this year. This has been a multi-center, multi-mission directorate effort for many years.
- We have two instruments on Mars 2020, MOXIE and MEDA!

We must keep in mind that some of our successes are about failing forward and learning what not to do. These are equally as successful as finding a technology breakthrough or developing a successful solution. We have done those, too!

For example, we stopped work on E-scionic, the water Phase Change Material Heat Exchanger, and two of our MEP thruster designs. Learn more about challenges related to the Phase Change Material project in this magazine.

New projects started in 2015 continue to progress, inside is a peak at new starts for 2016.

We kicked off new work in robotics and Europa technology developments. Our partnership with the Science Mission Directorate continues to grow, and how could I not mention our newest humanoid robot, R5, which made an appearance at the DARPA Robotics Challenge this summer and is the focus of our recent Space Robotics Challenge announcement.

In the Program Office, we started the Space Technology Academy initiative where students get the opportunity to work closely with technologists on exciting projects. This year they worked on fire tents for the USDA Forest Service and a sounding rocket launch of new technologies.

Our goals and focus for the upcoming year have not changed. We will focus on working the STMD "pipeline," both receiving and delivering technologies. We want to see how we can effectively implement more public-private partnerships, Space Act Agreements, and new technology reports for industry spinoffs. We will continue to focus on agile management principles and our "light touch" philosophy to promote less paperwork, more innovation, and more focus on the technologies. Finally, we want to strengthen communications with our projects, center leads and key stakeholders.

Again, thank you for all you do. You are the real heroes. Congratulations to you all.

Warmest regards,

Steve Gaddis

GameOn 2015

Space Technology Mission Directorate

Game Changing Development Program Office

gameon.nasa.gov

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Partnership has always been a vital component of NASA's mission, whether it is through the infusion of new technologies into NASA, or the Agency transferring its technologies out for public benefit. In this issue of the Game On magazine, learn what the Game Changing Development Program is doing to engage with others in industry, academia and other government agencies.

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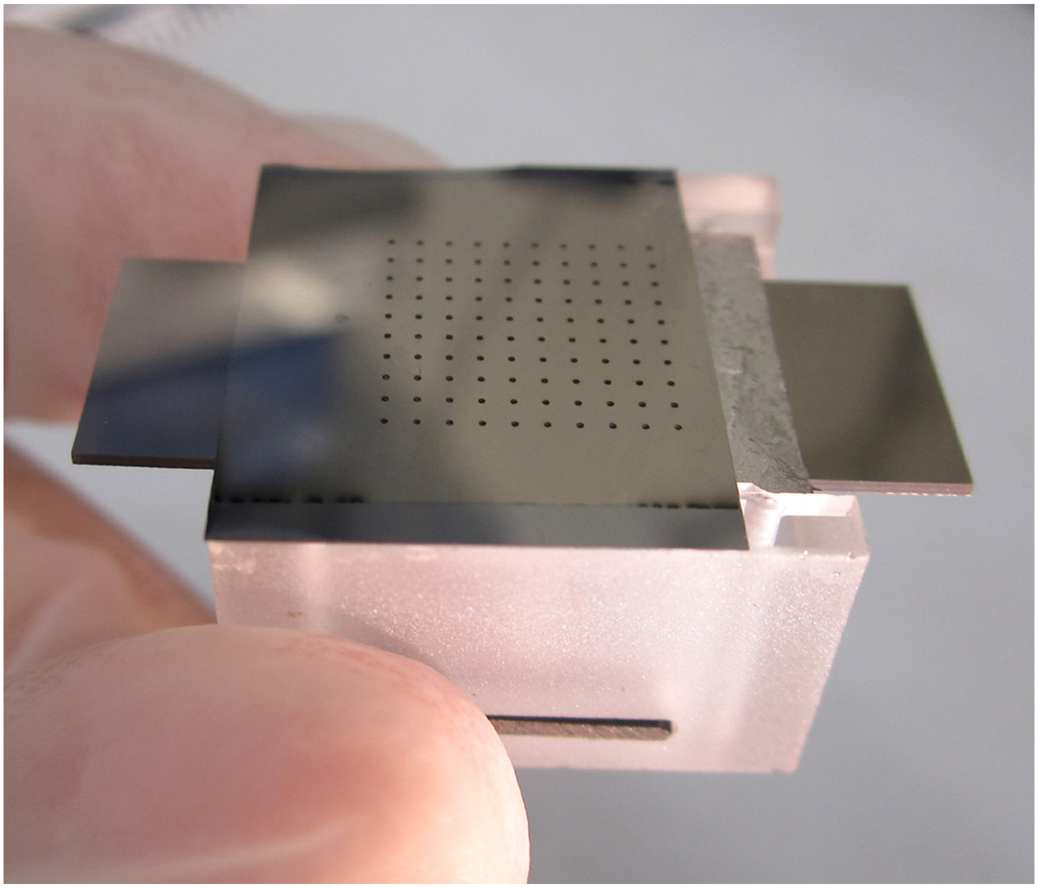


NASA Calls Upon Private Industry for Microfluidic Electrospray Thrusters

—Scott Conklin, GCD Summer Intern

June was a big month for NASA's Space Technology Mission Directorate, as Busek Company, Inc. and Massachusetts Institute of Technology (MIT) both delivered microfluidic electrospray (MEP) thruster submissions to NASA's Glenn Research Center for independent testing and characterization. In 2013, Busek, MIT and the Jet Propulsion Lab (JPL) were selected to compete for an MEP government contract after submitting proposals to a solicitation funded by NASA's Game Changing Development Program. NASA hopes to incorporate MEP thrusters into the designs of future spacecraft.

Above: A laboratory model of JPL's indium MEP thruster.

Satellites come in all shapes and sizes, but NASA has increasingly been making use of small satellites as a more cost efficient way to launch scientific instruments into space. MEP thrusters provide high efficiency, low thrust propulsion to allow small satellites to maneuver in low-Earth orbit and beyond. The need for MEP thrusters comes from the efficiency limitations of current low propulsion technologies such as cold gas and pulsed plasma thrusters.

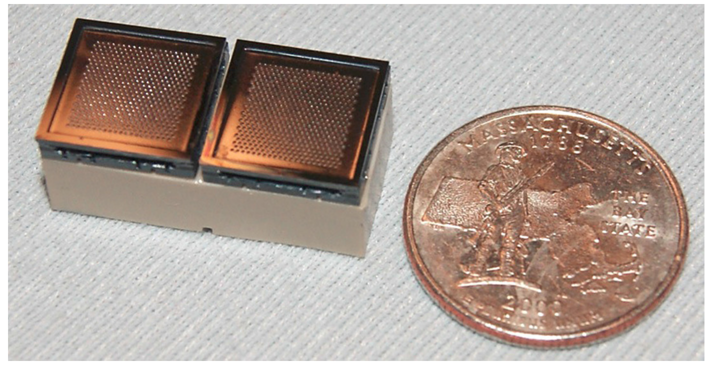
"While effective for attitude control and small changes in spacecraft velocity, the mission options are relatively narrow for systems based on the current technology," explained NASA's MEP Project Manager Tim Smith. "As the utility of small spacecraft—and specifically CubeSats—grows, it is clear a propulsion system that can provide high performance over a wide range of conditions is required for mission flexibility."

MEP thrusters work by accelera ting ions pulled from small droplets of liquid propellant using a static electric field. Though Busek, MIT and JPL have developed MEP thrusters, they have each taken slightly different engineering approaches, which set them apart.

Busek is utilizing a HARPS system, which stands for High Aspect Ratio Porous Surface technology. Busek's MEP thruster relies on the surface emission of charged ionic liquid droplets and ions from a porous metal with a passive capillary wicking system for propellant management.

MIT's system is called S-iEPS, which stands for Scalable Ion Electrospray Propulsion System. Paulo Lozano, MIT's principal investigator for the project, says, "S-iEPs…makes use of a room-temperature molten salt propellant and is based on the emission of ions from two-dimensional surfaces covered with hundreds of micro-tips." The S-iEPS system uses an electrostatic field to extract and accelerate both positive and negative ions from a conductive salt, which eliminates the need for electron charge neutralization.

JPL's indium MEP technology is very different from the other two technologies because it uses liquid metal (indium) propellant instead of an ionic liquid salt propellant. JPL's indium MEP thruster also uses a capillary-force-driven propellant management system, which does away with the need for pressurization, valves and moving parts.



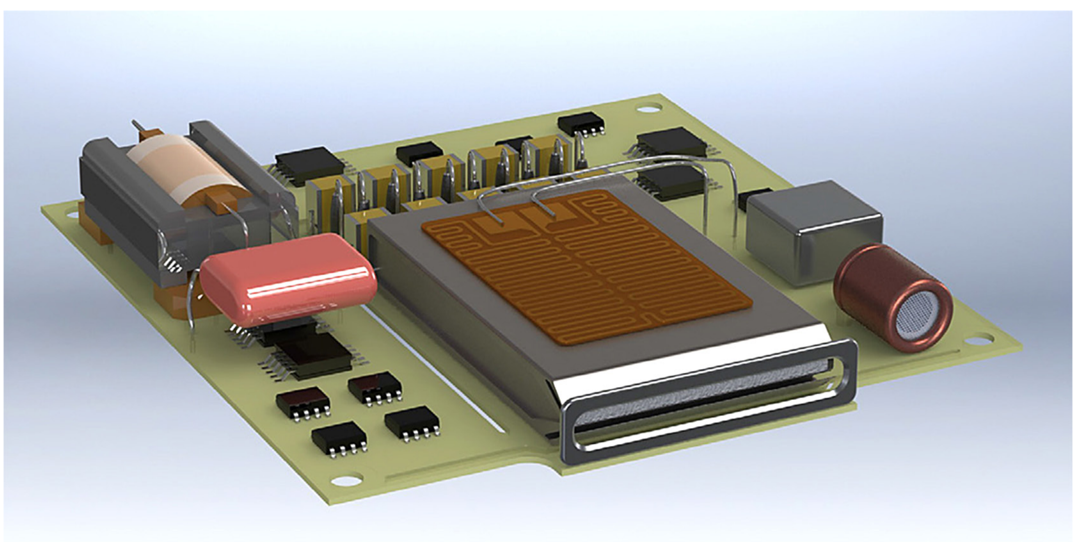
Thruster pair for MIT's S-iEPS. *Image credit: MIT*

The actual thruster is manufactured using a process called microfabrication, which uses technology from computer chip manufacturing. Microfabrication allows for the thruster to be extremely compact and scalable.

NASA routinely reaches out to private industry to help develop and sustain new technologies, and MEP thruster technology is no exception.

Smith says, "Our industry partners are essential to the infusion of this technology for both NASA missions and the commercial sector. While NASA works collaboratively with industry on the development of technologies, ultimately it is private industry that turns the concept into a sustainable product."

With MEP thrusters having the capacity to drastically improve upon current small spacecraft propulsion technology, NASA is eager to begin independent tests and assessments of the three submissions. MEP thrusters from Busek and MIT are beginning testing soon, and JPL's thrusters are expected before the end of the year.



Concept for Busek's HARPS thruster. *Image credit: Busek Co.*

NASA Partnership a Big Score for Small Business

—Mark Harries, Bally Ribbon Mills

As a small business, Bally Ribbon Mills (BRM) takes pride in its capability to engineer custom textiles. So when NASA came to Bally Ribbon Mills in 2010 to learn about woven composites, we were put to the test. Little did we know that in five years we'd be making products that we never dreamed were possible and transforming our business in ways never before imagined.

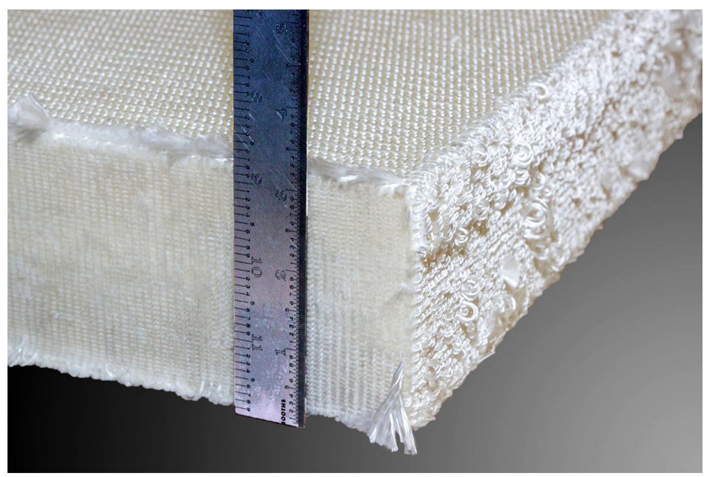
The partnership between BRM and NASA began in 2010 with a sharing of ideas on using woven composites as a thermal protection system (TPS). From the beginning, our relationship was a collaborative effort with both sides contributing inputs and expertise. NASA challenged us with new requirements and applications, and in return we educated NASA engineers on textiles and how they are made. By bringing both sides together we developed a game changing technology in woven TPS. Three Small Business Innovation Research (SBIR) grants allowed NASA and BRM to move ahead and develop the next generation TPS.

Woven TPS can be used as a heat shield for extreme entry environments of robotic science missions in NASA's Game Changing Development Program Heat-shield for Extreme Entry Environment Technology project. The SBIR gave us the opportunity to build a new loom for this project. As a direct result of that work, we were able to weave wider material that was denser and thicker than ever before. This material will reduce the mass of the heat shield by up to 30 or even 40 percent, becoming an enabler for bolder science missions to Venus, Saturn, or Uranus.

In the 3D Woven Multifunctional Ablative TPS (3DMAT) project, we helped develop the thickest material ever woven at BRM. The 3D orthogonally woven quartz panels provide structural strength in addition to providing thermal protection for the Orion crew capsule. 3DMAT is a compression pad located between the Orion crew capsule and the service module. During launch it provides the mechanical strength needed to connect the two modules and during reentry it can withstand the higher temperatures from returns beyond Earth's orbit. It is currently planned to fly on Exploration Mission 1 in 2018.

The Adaptable Deployable Entry Placement Technology system for planetary missions concept is a mechanically deployable semi-rigid aeroshell entry system capable of achieving low-ballistic coefficient during entry. This capability is suitable for a variety of planetary or earth return missions, leveraging the Agency's expertise in TPS material and entry system design, development and testing.

The benefits of working with NASA started from the first brainstorming session and have continued to this day. Weekly teleconferences and continuous feedback and support from engineers have increased our knowledge base considerably. By learning more about the end-product design, we've improved our relationship with not only NASA but all of our customers. This enables us to provide better service and design better parts to our entire customer base.



Developed under the 3DMAT project, the 3-inch thick quartz compression pads for use on all future Orion spacecraft.

Opposite page: Bally Ribbon Mills (BRM) President Ray Harries, left, shows a carbon fiber weaving loom to NASA Administrator Charles Bolden, center, and Vice President and Orion Program Manager for Lockheed Martin Space Systems Company Mike Hawes during a January 2015 tour of the BRM manufacturing facility in Bally, Pennsylvania. BRM is weaving the multifunctional 3D thermal protection system padding used to insulate and protect NASA's Orion spacecraft. NASA's recently tested Orion spacecraft will carry astronauts to Mars and return them safely back to Earth with the help of BRM technology. New woven composite materials are an advanced space technology that mark a major milestone toward development of the space systems that will enable extending human and robotic presence throughout the solar system. *Image credit: NASA/B. Ingalls*

NASA's requirements have pushed BRM to advance the state of the art for 3D woven products. The NASA-BRM partnership has led to many innovative developments, including the patent applications for 3DMAT and Woven TPS.

When working on those projects, we had to design new looms and equipment. The partnership pushed us to rethink how weaving is done and come up with practical ways to increase our capabilities. As a direct result of NASA's requirements, the maximum thickness of a part BRM is capable of weaving has increased 50 percent from 2 inches to 3. Interest in this technology is not limited to space missions, however; commercial and other government entities are interested in the thicker composites we are now capable of producing.

NASA has introduced BRM to new trade shows and marketing opportunities. Together we have exhibited woven thermal protection material that generated high quality leads and new customers. We've also had access to NASA's media contacts. This allowed us to show the world the projects we've helped develop resulting in a visit by Administrator Bolden to showcase the benefits of industry and NASA partnerships.

NASA has also made contribution in our community, when NASA's own Ethiraj Venkatapathy and James Arnold, both from Ames Research Center, spent the day at both the elementary and middle schools in the Oley Valley School District. They showed videos, demonstrated heat shields, and talked to potential future scientists about space and NASA's work.

The processes developed for the NASA projects, with help from the SBIR program, are creating new business opportunities. Equipment modifications are increasing our capabilities. Marketing opportunities are getting the word out about our company to other government entities and private sector companies. And the pride felt by our employees to be partnered with the world's leading space program is boosting morale. Five years ago we thought NASA was going to be just another customer. Instead, we've formed a lasting partnership generating both tangible and intangible rewards.

BRM Marketing Executive Mark Harries is a College of Business and Economics graduate from Lehigh University and has been with BRM since 2003. BRM has been producing quality narrow tapes and webbing since 1923 and has used innovation in design and manufacturing to become a highly respected leader in the woven narrow fabrics industry. BRM products are applicable in a wide range of industries, including military, safety, industrial, recreational, medical, and aerospace. *Image credit: M. Harries*

CHIEFS Task Brings Things "Down to Earth"

Another round of live fire-shelter tests occurred in September in support of a joint effort between the U.S. Forest Service and the Game Changing Development Program's Convective Heating Improvement for Emergency Fire Shelters (CHIEFS) task within the Entry Systems Modeling project. NASA researchers took heart after the 2013 Yarnell Hill tragedy took the lives of 19 firefighters, joining forces with the Forest Service's Missoula Technology and Development Center in an interagency Space Act agreement via the CHIEFS task to develop and test improved fire shelter materials.

Above: A view downward into the full scale test enclosure; testing conducted on one of the NASA thermal pod designs.
Image credits: Ian Grob from the US Forest Service, Missoula Technology and Development Center

The Forest Service has an excellent shelter that works fine in the majority of wildfire cases where shelters are heated predominantly by radiant means. Given the properties of existing flexible heat shield materials used in space applications, structural and thermal systems researchers at NASA wanted to look at options that could crossover to improve the convective performance of fire shelters.

"After the Yarnell Hill disaster, we recognized several commonalities between emergency fire shelters and NASA's flexible heat shield material developed for inflatable decelerators," says Josh Fody, CHIEFS task lead. "At first we wanted to investigate the possibility that these flexible heat shield materials could be directly used to enhance the fire shelter; however, we soon realized that the materials for the fire shelter needed to be much thinner and lighter weight than what we had already developed."

Firefighters have to carry up to 55 pounds of gear all day when fighting fires, so every pound counts.

"It's easy to add bulky or heavy insulations and get great thermal results. Our challenge—the primary challenge—is to develop highly efficient materials that can provide good protection with minimal added size," says Fody.

Fody describes the CHIEFS shelter construction as using lightweight, medium weight, and heavyweight material combinations. Shelters consist of various insulations sandwiched between a high temperature-tolerant structural fabric with a reflective coating and a reinforced gas barrier laminate. One of the more interesting insulations the team looked at is an intumescent graphite paper that can expand many times its original thickness upon exposure to heating.

The first series of tests was a full-scale wildfire scenario held in June in a remote area of Canada's Northwest Territories. The shelters tested are what the CHIEFS team refers to as "gen 1" with all remaining physically intact and functioning as expected after the fire passed the test site.

Preparing one of the NASA M2002 geometry shelters for testing. From left: Tony Petrilli, Mary Beth Wusk, Kamran Daryabeigi, Josh Fody.

Staging the NASA heavyweight M2002 for testing on the full-scale test bed. From left to right: Josh Fody (LaRC), Kamran Daryabeigi (LaRC), and Shawn Steber (MTDC USDA Forest Service). Tony Petrilli (MTDC USDA Forest Service) is inside the shelter performing preparations.

"The data we gathered was informative mostly because we were able to learn a lot of real-world lessons we have learned in the lab, such as the need for methods to mitigate the migration of flame through the ground cover into the shelter interior," says Fody. "These lessons learned are now being integrated into our next series of shelters—"gen 2"—that we plan to test in the spring."

The September tests were conducted in a laboratory at the University of Alberta in Edmonton, Canada, and were designed to imitate the conditions present in the full-scale wildfire tests conducted in June. The advantage of the lab tests over the wildfire tests is that there is very good control and repeatability of environmental conditions.

"For this reason, this is one of the most important tests that the U.S. Forest Service conducts on shelter candidates that they are screening," says Fody. "The results are just now being analyzed, but preliminarily the CHIEFS shelters did very well, especially the heavyweight shelter option, which kept internal air temperatures well below the target maximum breathing limit for at least 2 minutes—significantly better than any other shelter design that we tested."

Fody describes the gen 1 technology push as focused purely on materials development from a thermal performance standpoint, but stresses that the biggest outcome from the test in June and September for CHIEFS was understanding there are real world problems that need to be addressed.

"We can have the best, lightest, insulation in the world, but if we can't address issues like mitigating flame ingress under the shelter floors or mitigating thermal decomposition byproducts of our materials it won't make any difference," says Fody. "So, right now, we are saying 'great, we got fantastic thermal results' but we aren't celebrating until we show that we can make a shelter that addresses these practical issues as well."

Next up for the CHIEFS effort is to advance the technology readiness level to the point of having addressed the full system needs of the fire shelter material and demonstrate that all performance requirements on full scale shelters can be met, ultimately producing and delivering an improved shelter by 2018.

The result has been an exciting project yielding more benefits than the potential of spinning a technology off to the private sector, or the expertise of NASA researchers involved in the flexible heat shield research being shared, or even improving on qualities of the physical materials themselves.

"Our goal has been to develop more mass and volume-efficient insulation concepts and we have been able to feed some of our successful technologies back into space applications; so, there have been synergistic benefits to working with the Forest Service," says Fody.

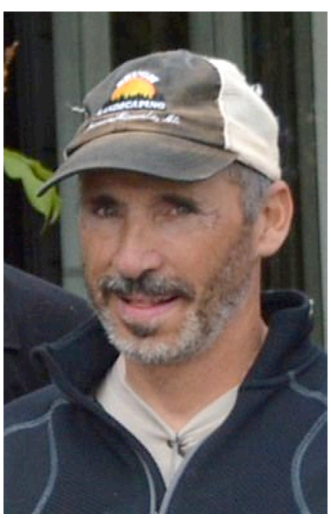
"It has been a privilege to work with the U.S. Forest Service," he continues. "They are a great group of professionals who have both a wealth of test experience from previous shelter revision efforts they conducted in 2000 to 2002, as well as a tremendous amount of real world firefighting experience that brings a lot of practical guidance to our efforts."

This synergy that springs from NASA's collaborative partnerships—whether it be industry, other government agencies, or academia—is the cornerstone of what brings NASA and its researchers "down to Earth."

"NASA's mission includes using aerospace advancements to improve life on Earth," says Fody.

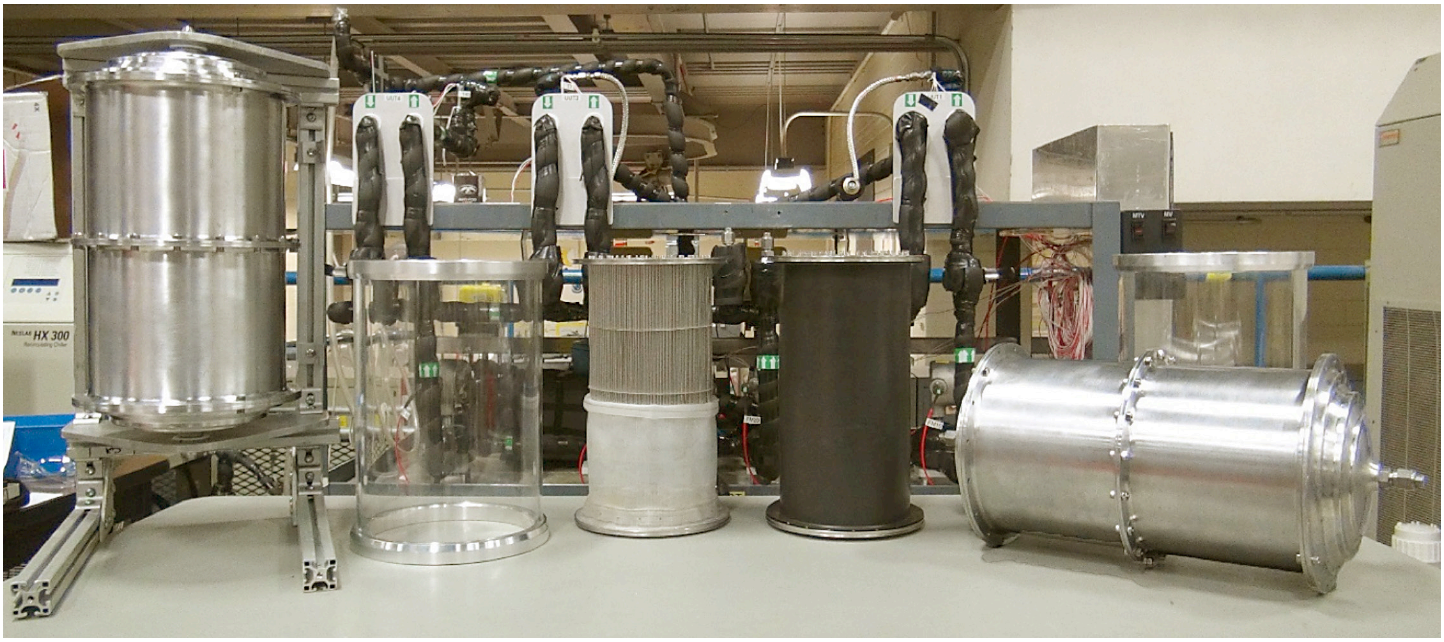
Indeed, since its inception in 1958 by the National Aeronautics and Space Act, section 203, NASA is tasked with finding ways to transfer its technologies to the private sector, and ultimately, for use here on Earth.

"It is our interpretation that one of the important points of the NASA vision is to make sure the advances that we make to technology are used not only to meet project goals but also to benefit humankind," Fody concludes. "We are hopeful that by combining forces with the Forest Service, we will be able to offer our technological expertise as a service to help them save future lives."



"Experience shows that insulative materials are generally heavy, bulky, fragile and/or toxic; these types of materials cannot be used in fire shelter. This is where the challenge is, designing a shelter that can improve survival chances but still is practical within the firefighting mission. The fire shelter project was originally ready to start looking at potentially new and improved materials in 2015. When the Yarnell tragedy happened, we accelerated the review schedule. We were thrilled when NASA reached out to us and wanted to join forces. I think both of our organizations have learned a lot from each other. We've brought the CHIEFS crew into our fire world and we've been more than impressed with their knowledge in thermal, flexible materials needed for re-entry vehicles. We've not only created a present and future working relationship, but also long term personal friendships."—Anthony Petrilli, fire equipment specialist and fire shelters project lead with USDA Forest Service, Missoula Technology and Development Center.

Tony Petrilli is an equipment specialist for the fire and aviation programs at MTDC. Petrilli began working for the Forest Service in 1982 and joined the center full time in 2000. He has worked as a firefighter on the Lewis and Clark and Beaverhead National Forests and as a smokejumper for the Northern Region.



Failure Is Not An Option…or Is It?

—Rubik Sheth/Denise M. Stefula

Spaceflight is a risky endeavor that has many rewards.

Most NASA missions and projects carry some form of risk because the Agency seeks to develop disruptive technologies that push the boundaries of research and discovery. Within the Space Technology Mission Directorate, such risk is inherently a part of all its projects.

"If risk did not exist while developing a technology, is it truly considered a technology development effort?" asks Rubik Sheth, project manager of the Phase Change Material Heat Exchanger Project (PCM HX), Thermal Systems Branch, at Johnson Space Center.

During the course of FY15, the Game Changing Development Program's PCM HX project set out to design and develop water-based PCM HXs for future exploration vehicles. As missions move beyond low-Earth orbit, human spacecraft planned for orbiting the moon or Mars will need some form of supplemental heat rejection to accommodate cyclical heat loads.

Above: The final set of HXs components delivered to NASA Johnson included two HX cores, two flexible bladders, and a set of pressure shells and manifolds.

"In this scenario, a spacecraft's radiators may not be sized to rejection of the largest continuous heat load at the highest sink temperature," explains Sheth. "Due to this sizing, for cyclical heat loads above the radiator capability, the need for using PCM HXs becomes apparent."

Wax-based PCM HXs have been used in the past on the lunar rover and Skylab with inconsistent results. Game Changing's PCM project was looking to develop a novel approach over the traditional waxed-based plate fin PCM HX design.

What the research showed was that wax's heat of fusion, a thermodynamic property that determines the total energy storage of a material that changes phase from liquid to solid and vice versa, is about 155 kJ/kg. Water, on the other hand, has a heat of fusion of 333 kJ/kg—nearly double—

resulting in a considerable mass and volume savings for the required supplemental heat rejection of a vehicle.

"So this brings one to ask," says Sheth, "what is so hard about using water as a phase change material? Have you ever experienced freezing a bottle full of water? This is what the project set out to do within a heat exchanger."

In getting to the project objective, the PCM team partnered with small business Mezzo Technologies in Baton Rouge, Louisiana. Mezzo Technologies specializes in the design and development of microtube heat exchangers.

"Traditional PCM HXs are analogous to standard heat exchanger designs that incorporate alternating layers of coolant flow channels. These heat exchangers are typically a brazed assembly mainly to promote good heat transfer," explains Sheth. "The PCM project leveraged Mezzo's microtube heat exchangers to facilitate a unique PCM HX design with a flexible bladder."

A number of adjustments were necessary before the project could develop the units for testing, but Mezzo's existing design was the perfect complement in a commercial off-the-shelf (COTS) product that Mezzo and NASA could modify to meet PCM HX project needs. To get to critical design review, the development tasks managed many unique challenges building off the Mezzo-designed heat exchangers.

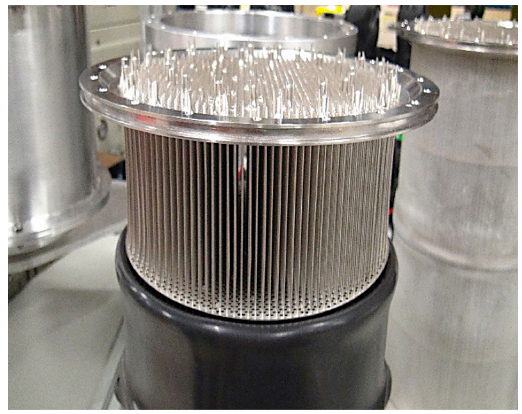
The entire unit required brazing, which offers a more uniform and traceable manner for joining metals than epoxy. An epoxied bond between two metals is not as strong as a brazed or a welded bond, so brazing was a reliable method of attaching microtubes to the shell.

Structural attachments had to be added to facilitate the use of a bladder and a relatively high maximum design pressure. Mezzo's traditional heat exchangers utilized a solid shell to enclose the working fluid. For the PCM HX the team wanted to use a flexible bladder, which required unique structural attachments that were a deviation from traditional COTS microtube HX designs.

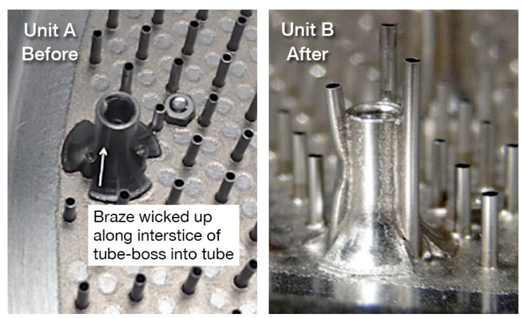
Microtubes of different sizes were used to allow for quick freezing and thawing of the PCM. The project was fighting two opposing requirements: the need for the microtubes to be relatively small in wall thickness due to the need to transfer heat into and out of the working fluid, and the need for the tubes to be thicker to allow for a good braze join between the microtubes and the HX's structural member. The latter requirement Sheth says the project was unaware of earlier on, but learned through testing and failure of the braze joints.

Typically for most hardware in development, the timeframe of high risk is the transition from conceptual design to manufacturing and testing. Upon completion of the water PCM HX's critical design review, the intent of the PCM project was to build two full scale Orion-like water PCM HXs for evaluation, units A and B; however, getting those units functioning for evaluation meant overcoming a critical design challenge.

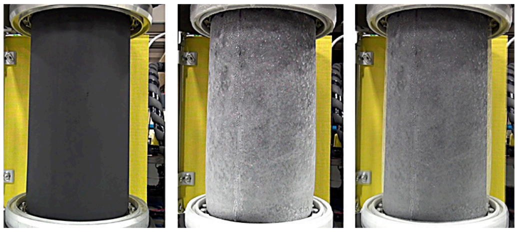
Mezzo Technologies' microtube heat exchangers.



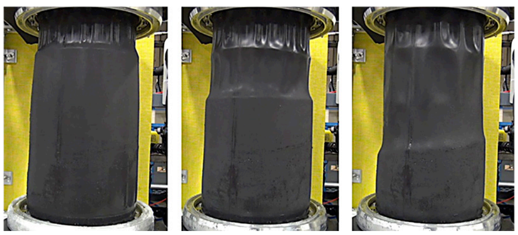
The core of the HX with microtubes surrounded by the flexible bladder. The water PCM would surround the tubes while coolant would flow into the tubes to exchange energy to/from the coolant and PCM.



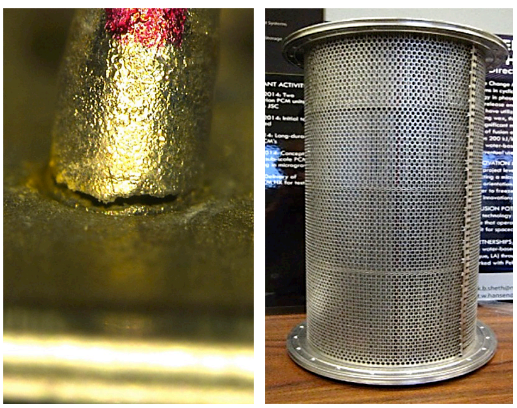
Left: tubes blocked from coolant flow after brazing process. Right: design modification made to prevent wicking that causes tube blockages.



Comparison of PCM at ambient temperature (left) and fully frozen (center). On the right is a comparison of initial to fully frozen.



Progression of bladder contraction observed during thaw phase of testing.



Left: detail of tube cracking experienced during thaw phase. Right: perforated sheet of stainless steel installed to protect microtubes.

"Unfortunately, during the brazing processing of unit A, braze filler wicked between the pressure standoffs and microtubes causing about 25 of over 1000 tubes to be blocked from coolant flow," says Sheth. "For unit B, a design modification was made to prevent any wicking from causing blockage of tubes."

A rigorous test schedule was planned to stress the heat exchangers in various positions and with freeze thaw rates to ensure the water freezing would not cause catastrophic damage to the heat exchanger. Time lapse photos captured how the bladder, encapsulating the water around the microtubes, performed during the freeze and thaw phases respectively.

As most testing goes, microtube water PCM HX testing provided lessons learned that helped evolve the heat exchanger's design. An example from the thaw phase was that the bladder contracted onto the tubes so much the tubes actually cracked and eventually broke on the outside of the HX. The project quickly devised a work around by installing a perforated sheet of stainless steel to protect the tubes, a concept that worked well and was implemented for future designs.

"The redesign allowed for a structural member to act as a method of protecting the tubes from the bladder while still allowing water to flow through the perforated sheet as the water PCM froze and thawed," says Sheth.

The project continued testing the HXs for numerous freeze and thaw cycles. The goal was to achieve 100-plus freeze and thaw cycles without any form of damage to the HX during testing. Unfortunately, after 90-plus cycles, the heat exchanger slowly formed a crack at the microtube and structure interface. This interface is where Mezzo Technologies bonds the tubes to the HX structure via the braze method. Space Technology formed a brazing tiger team to work with Mezzo to review and improve the brazing process.

"Mezzo was still on contract with NASA to build a third heat exchanger," explains Sheth. "The third HX was to be a small, subscale unit, of either unit A or B, to understand scalability of the HX as well as pave the way for design of a potential flight demonstration unit on ISS."

The delivered subscale unit was tested to more than 125 freeze-thaw cycles without a problem, and the unit's design leveraged its success from lessons learned during units A and B testing.

"The project's process of technology development was a great example of leaning forward and failing smart," says Sheth. "Utilizing COTs designs, the project did a fantastic job of pushing the envelope of use for the HX while taking lessons learned through the development cycle to optimize for a better solution."

The water PCM HX can save mass for any vehicle needing supplemental heat rejection. The project is currently evaluating the technology for use on Orion or a potential future manned vehicle to Mars.

Two words: *The Martian*.

—Amy McCluskey

If you haven't read the book or seen the movie yet, you are in the minority. At this juncture, author Andy Weir's fictional tale of surviving Mars should be required reading if you work at NASA.

Reading *The Martian* offers more than just an opportunity to engage in water cooler banter with your colleagues about the various perils the main character Mark Watney encounters on the red planet and whether they are plausible, it also brings to life the many "real" technologies NASA is working on so that we can actually get humans to Mars, and not just on the big screen.

The Martian ***actors Mackenzie Davis (flight controller Mindy Park) and Sebastian Stan (Ares 3 flight surgeon Dr. Chris Beck) were on-hand for a closed NASA screening of the movie in Houston, and they had some behind-the-scenes access at NASA's Johnson Space Center.*** *Image credit: Ars Technica/Lee Hutchinson*

Though not allowed to officially endorse the movie, NASA can still ride the coattails of excitement that a Hollywood movie about Mars inherently creates. Even though the agency has been moving full throttle with a "Journey to Mars" campaign for the past two years, sometimes it takes an A-list actor like Matt Damon trying to grow potatoes in space to really get people talking.

So, what are the NASA technologies featured in the book/movie? A NASA article (https://www.nasa.gov/feature/nine-real-nasa-technologies-in-the-martian) draws attention to the following NASA technologies highlighted in *The Martian*. They include: oxygen generation, water recovery, space batteries, the space suit, habitats, plant farms, solar panels, ion propulsion, and rovers. Though not mentioned in the article, other NASA technologies featured prominently in the book include high performance spaceflight computing and deep space optical communication.

What do all these things have in common? They are all technologies within NASA's Space Technology Mission Directorate (STMD).

This shouldn't be surprising because STMD is charged with rapidly developing the crosscutting technologies and capabilities needed to get to deep space.

Dozens of projects within STMD are addressing the technological challenges that an eventual trip to Mars—some twenty years from now—would entail. As a brief example: the Deep Space Optical Communications project is improving data transmissions rates (so astronauts won't have to communicate with rocks and Morse code like Watney); the Next Generation Life Support project is working on new EVA gloves that will provide enough flexibility to work on rovers and build habitats if needed (Watney does a lot of that in the book); and the Human Robotic Systems project is advancing the development of deep space rovers (Watney spends a lot of time on one trying to get rescued).

As *The Martian* fanfare continues, and we talk about how the movie compares to the book or how implausible a gigantic dust storm on Mars might be, let's also remember how cool it is to be a part of STMD where these futuristic capabilities are becoming realities.

For more information on NASA and *The Martian*, visit: https://www.nasa.gov/realmartians

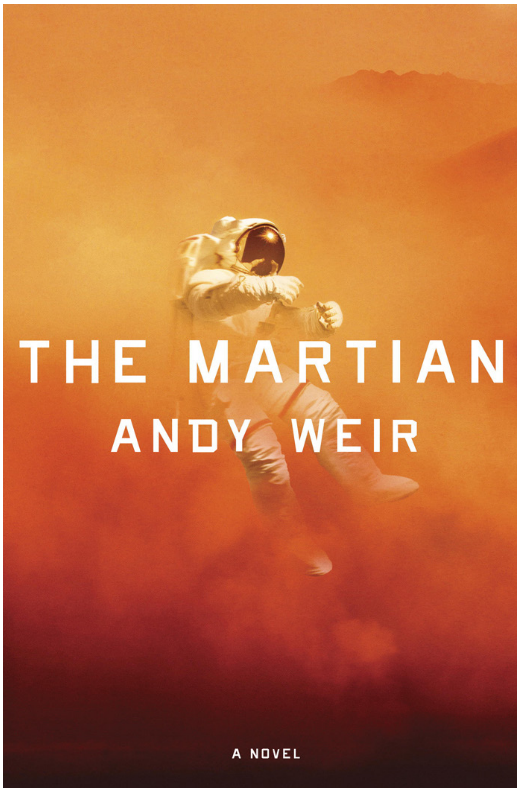
For more information on STMD technology development, visit: www.nasa.gov/tech

***Actor Matt Damon, who plays Mark Watney, visited NASA's Jet Propulsion Laboratory in August prior to the release of the film* The Martian.**

"Public Affairs brought Jessica Chastain by NASA JSC in December. She was on a promotional tour for Interstellar, *but was in filming for* The Martian *at the time. She was freaking out about how similar the rovers were to the movie."*

—Rob Ambrose, Robotics principal technologist

Davis and Stan pose with the multi-mission Space Exploration Vehicle.

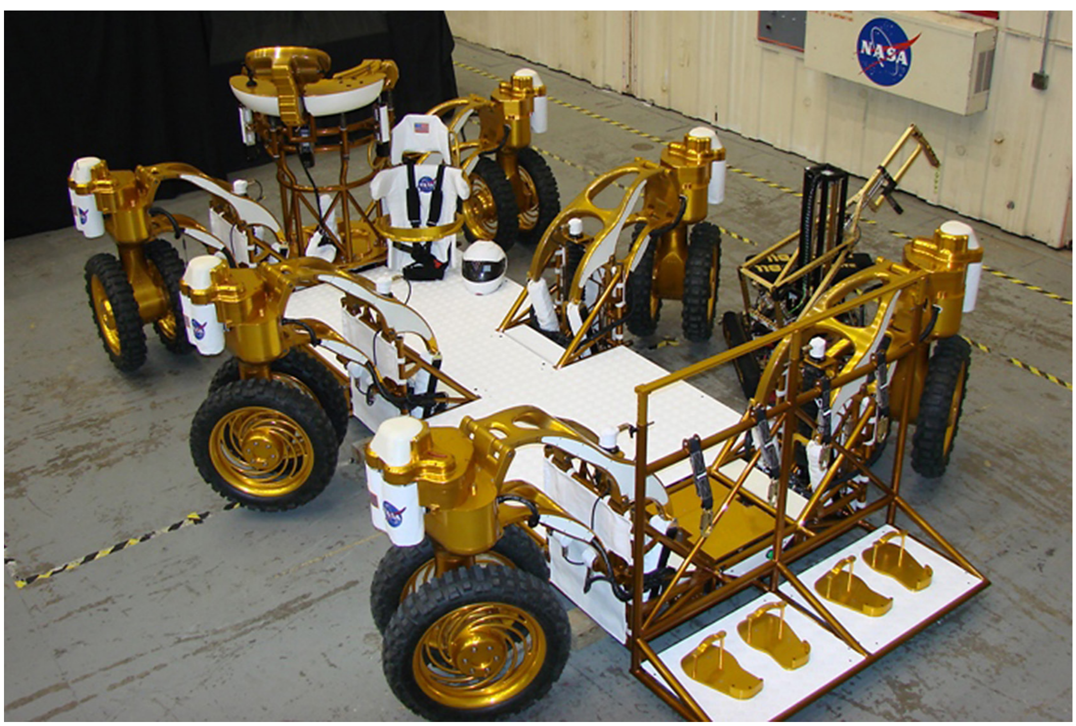


Andy Weir, author of* The Martian*, has participated in several NASA forums and talks, including a panel presentation at Comic-Con.

“My team supported the Houston premiere of The Martian*. The multi-mission Space Exploration Vehicle was a show piece of part of the red carpet event attended by JSC employees and actors Sebastian Stan (Chris Beck) and Mackenzie Davis (Mindy Park).*

“I read most of the book and saw the movie. A couple things in the story popped out at me. First was that being a problem solver can save your life and that we should all focus on problem solving, whether we’re in the space business or not. Second, in addition to paying attention to the crew, the story paid considerable attention to the real stars of space exploration: the scientists, engineers and flight controllers.

“I’ve been working on crew rovers for surface missions for a number of years. I thought they did a good job representing how we might use the rovers on Mars. It was quite clear that the moviemakers paid attention to the work we’ve being doing with NASA. The front end of Mark Watney’s rover looks very similar to the Space Exploration Vehicle 2B. The trailer during Mark’s journey to the MAV 4 lander site was a near replica of the Chariot rover, we built in 2007 that is the chassis for the MMSEV.”
—Bill Bluethmann, Project Manager for Human Robotic Systems



The Chariot rover.

Open Source Challenges Open Doors for NASA

NASA has expanded its capability to solve hard problems and get work done by using crowd-based challenges that are open to the public, giving NASA the opportunity to access valuable contributions by a diverse population from all around the world.

Crowdsourcing, according to Merriam-Webster, is the process of obtaining needed services, ideas, or content by soliciting contributions from a large group of people, and especially from an online community, rather than from traditional employees or suppliers. Using this approach allows for distributed problem solving within a large group of people, then mining viable solutions from that collective intelligence.

Harvesting the spirit and power of crowdsourcing, Mike Ching, challenge coordinator with NASA's Center of Excellence for Collaborative Innovation (CoECI) at Headquarters, turned to other team members to collaborate on a response to our questions about NASA's use of open source challenges. To follow is the collective response he, Lynn Buquo, Steven Rader, and Monserrate Roman shared.

At a high level, the use of crowdsourcing simply increases NASA's ability to make progress on the many challenges that must be overcome in order to explore space. At a more tangible level, challenges are resulting in improvements and advancements in a number of areas, including improved algorithms (and public involvement) in asteroid detection and tracking, advancements in methods for testing, security, and sensing, and new innovative concepts for planetary habitation and construction. While crowdsourced challenges can help with big problems, NASA has also found significant value in applying these tools to the many component problems and challenges such that the cumulative effects are even more significant. Finally, NASA has found that opening challenges to a diverse crowd enables innovative solutions to be found from outside the community within a specific field of expertise.

"Additionally, we've found some areas—like software development, video production, CAD modeling—where the use of certain communities provides NASA with specific expert services that furnish a cost-effective way to augment our workload," says Ching. "This is helping us to do more with less, which is a key to advancing space exploration."

NASA's contract with InnoCentive over the last few years resulted in 21 challenges that not only provided some needed solutions to problems, but also helped the agency validate using this approach. The CoECI just recently launched its new multi-vendor NASA Open Innovation Services (NOIS) contract, which includes InnoCentive and nine other crowdsourced challenge platforms: Appirio (TopCoder), NineSigma, HeroX, The Common Pool, Luminary Labs, Kaggle, Patexia, Tongal, and OpenIDEO. This expands NASA's access to some of the most innovative communities in the world.

The challenges launched through CoECI have provided NASA's project teams with a new tool to find innovative ideas, solutions, designs and more that advance specific projects forward with award incentives that are relatively small. In terms of the Centennial Challenges Program, its scope is much larger and its history longer. Centennial has provided NASA with a unique platform that generates innovative solutions to really big problems of interest to NASA and the nation. It uses incentivized (multi-million dollars) prize competitions to accelerate technology developments, pushes the boundaries of human potential, captures the public imagination and invites them to be part of NASA's mission to Mars. And, like any NASA crowdsourced initiative, awards are only made when challenges are met.

"With the right incentives, which include both prize money and the opportunity to contribute to NASA's mission, we now have a high probability of finding that unique individual or team who has the right experience, knowledge, expertise, and perspective that results in an innovative solution to our problems," says Ching.

In 2015, crowdsourcing benefitted a number of technologies under development or advancement through NASA's Space Technology Mission Directorate's Game Changing Development Program: In Situ Resource Utilization, Additive Construction with Mobile Emplacement, Minimalistic Advanced Soft Goods Hatch, and Human Robotic Systems.

Challenge	Objective
InnoCentive: Flexible Sealing Devise	Develop a new flexible seal device that will enhance the capabilities of future space missions by reducing mass and volume parameters
InnoCentive: Mars Tech Video	Produce a video highlighting one of the many technologies that will enable NASA's mission to Mars for the purpose of efficiently communicating with the public our plans in accomplishing our Journey to Mars
Centennial: 3D Printed Habitat	Advance the additive construction technology needed to create sustainable housing solutions for Earth and beyond
Centennial: Sample Return Robot	Demonstrate a fully autonomous robot that can locate and retrieve several identified samples with no use of GPS or other terrestrial navigation aids
Centennial: Mars Ascent Vehicle	Demonstrate the ability of an autonomous system to insert a sample cache into the ascent rocket while in a horizontal position, erect the r ocket, launch, achieve 3000-ft altitude, and then eject and recover the sample container
Cube Quest: Ground Tournament, first round	Demonstrate ability of CubeSats to communicate beyond lunar distances and to achieve and sustain lunar orbit

NASA's Center of Excellence for Collaborative Innovation (CoECI) was established with support from the White House Office of Science and Technology Policy to assist NASA and other federal agencies in using new tools – such as challenges – to solve tough, mission-critical problems. The Center launches challenges under the umbrella of the NASA Tournament Lab (NTL) and offers a variety of open innovation platforms that engage the crowdsourcing community in challenges to create the most innovative, efficient and optimal solutions for specific, real world challenges.

Be an NTL contestant and help solve NASA's real-world challenges today!

- Create videos to engage citizens in NASA's Asteroid Grand Challenge
- Develop an algorithm to improve Robonaut's vision
- Share novel ideas on how to use crushed basalt rock for utilization on Earth and in space
- Provide bio-inspired approaches for an ultra-compact exercise system for use on the Orion spacecraft
- Develop a test method to assess the protection level of EVA suits used for planetary exploration
- Design the air traffic control system of the future
- Help build NASA's search portal interface

NASA Tournament Lab

Platforms

APPIRIO
Common Pool
INNOCENTIVE
herox
kaggle
LUMINARY LABS
NINESIGMA
openIDEO
tongal
Patexia.

Center of Excellence for Collaborative Innovation

For information on NTL challenges: www.nasa.gov/coeci
For information on all NASA Prizes and Challenges: www.nasa.gov/solve

SOLVE

GCD's 2015 Solicitations Round Up

October — Ultra-lightweight Core Materials for Efficient Load-bearing Composite Sandwich Structures

February — Advanced Energy Storage Systems Phase II

May — Utilizing Public-Private Partnerships to Advance Tipping Point Technologies

May — Announcement of Collaborative Opportunity (ACO) – Utilizing Public-Private Partnerships to Advance Emerging Space Technology System Capabilities

June — Hosting of Humanoid Robots and Validation of Task Performance for the NASA Space Robotics Challenge

August — Extreme Environment Solar Power

Fiscal year 2015

Supporting research in science and technology is a key facet in NASA's overall mission. NASA enhances this support element by issuing research announcements from a wide scope of science and technological disciplines and associated needs to draw on the talents and specialties of those responding to the solicitations.

To accomplish our nation's human and robotic space exploration goals, NASA and the Space Technology Mission Directorate (STMD) must engage the brightest and most innovative minds in the country. Agency solicitations are invitations for that broader community to help NASA achieve national research objectives.

"We cannot realize these lofty exploration objectives on our own," says Ryan Stephan, program executive for the Game Changing Development (GCD) Program. Given the diversity in our country, this talent can be found in several different 'pockets' including academia, industry, and other government agencies. Therefore, the most effective and efficient way to identify both this talent and the most promising technologies, is through competed solicitations."

Stephan explains a significant advantage to this technology development approach: "It affords us the opportunity to economically investigate multiple technical solutions to a single exploration design challenge. For example, this competed technology development approach can be used to investigate a number of technologies and make a well-informed downselect to the most promising of the approaches."

STMD's GCD Program has several technologies represented in the FY 2015 solicitations for proposals.

Ultra-lightweight Core Materials for Efficient Load-bearing Composite Sandwich Structures

Objective: develop and manufacture ultra-lightweight materials for aerospace vehicles and structures of the future.

Proposals will demonstrate lower-mass alternatives to honeycomb or foam cores currently used in composite sandwich structures. Composite sandwich structures are a special type of material made by attaching two thin skins to a lightweight core. This type of composite is used extensively within the aerospace industry and in other applications where reducing weight while maintaining structural strength is important. A common use for these sorts of composites is the shrouds for launch vehicles and other key technology components that will enable our journey to Mars.

Advanced Energy Storage Systems Phase II

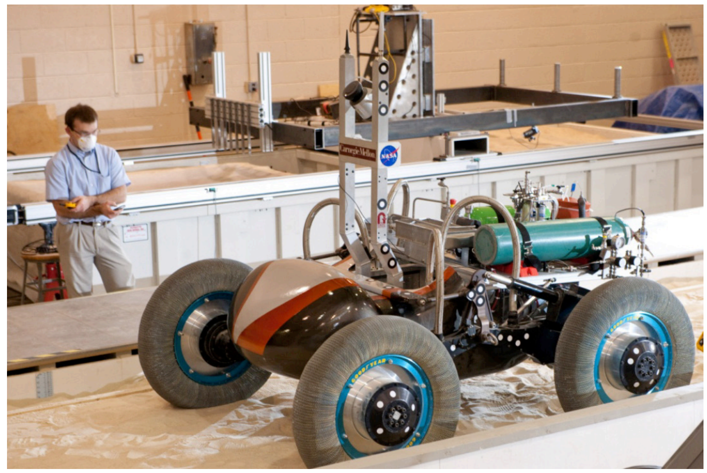
Objective: develop advanced energy storage technologies that may be used to power the agency's future space missions.

Development of these new energy storage devices will help enable NASA's future robotic and human-exploration missions and aligns with conclusions presented in the National Research Council's NASA Space Technology Roadmaps and Priorities, which calls for improved energy generation and storage "with reliable power systems that can survive the wide range of environments unique to NASA missions."

Hosting of Humanoid Robots and Validation of Task Performance for the NASA Space Robotics Challenge

Objective: develop advanced innovation in basic and applied research and technology development for humanoid robots with a focus on the performance of tasks related to space exploration missions.

In 2012, NASA began the design and development of a new bipedal humanoid robot, R5, through the DARPA Robotics Challenge. NASA seeks to advance space technology by providing additional units of R5 to the robotics community for active research of high-level humanoid behaviors. These robots are intended to be the instruments for the Space Robotics Challenge, which NASA will administer separately through the Centennial Challenges Program beginning in 2016.



The Scarab lunar rover is one of the next generation of autonomous robotic rovers that will be used to explore dark polar craters at the lunar south pole. The rover is powered by a 100-watt fuel cell developed under GCD's Space Power Systems project. Supported by NASA, the rover is being developed by the Robotics Institute of Carnegie Mellon University. *Image credit: Carnegie Mellon University*

NASA envisions the R5 as a robotic helper to human astronauts.

Extreme Environment Solar Power

Objective: develop solar cell/solar array design concept technologies for space power applications in high radiation and low solar flux environments.

NASA requires solar arrays for multiple mission applications associated with both robotic and human space exploration. Traditionally, solar cells and array systems have been developed on the basis of beginning-of-life conversion efficiency for intensity and temperature specifications associated with near Earth operation. As NASA considers missions that require exposure to more intense radiation environments and missions ever farther from the sun, the development of solar cells/solar array design concepts better suited for such missions is warranted.

Utilizing Public-Private Partnerships to Advance Tipping Point Technologies

Topic 2: Low Size, Weight, and Power (SWaP) Instruments for Remote Sensing Applications

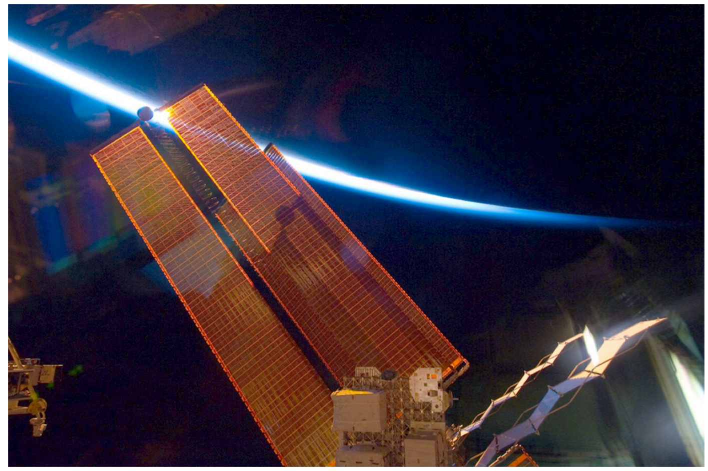
Objective: develop and/or demonstrate new lower SWaP remote sensing instruments and components that are now at a tipping point and which have both commercial and NASA crosscutting potential.

Space-based remote sensing is a major commercial space growth area with numerous constellations of primarily small spacecraft planned and beginning to come online. As the foundations of commercial Earth observation are laid, more advanced and lower SWaP sensors/instruments will offer additional marketable opportunities. If these sensors are delivered at sufficiently low power, low mass, and low size they can utilize small spacecraft platforms, enabling entirely new business plans due to the affordability of small spacecraft platforms.

Announcement of Collaborative Opportunity (ACO) – Utilizing Public-Private Partnerships to Advance Emerging Space Technology System Capabilities

Topic 2: Wireless Power Transfer Development

Objective: develop and validate the capability to wirelessly transfer power between assets.



Intersecting the thin line of Earth's atmosphere, International Space Station solar array wings are featured in this image photographed by an STS-134 crew member in May 2011 while space shuttle Endeavour was docked with the station.

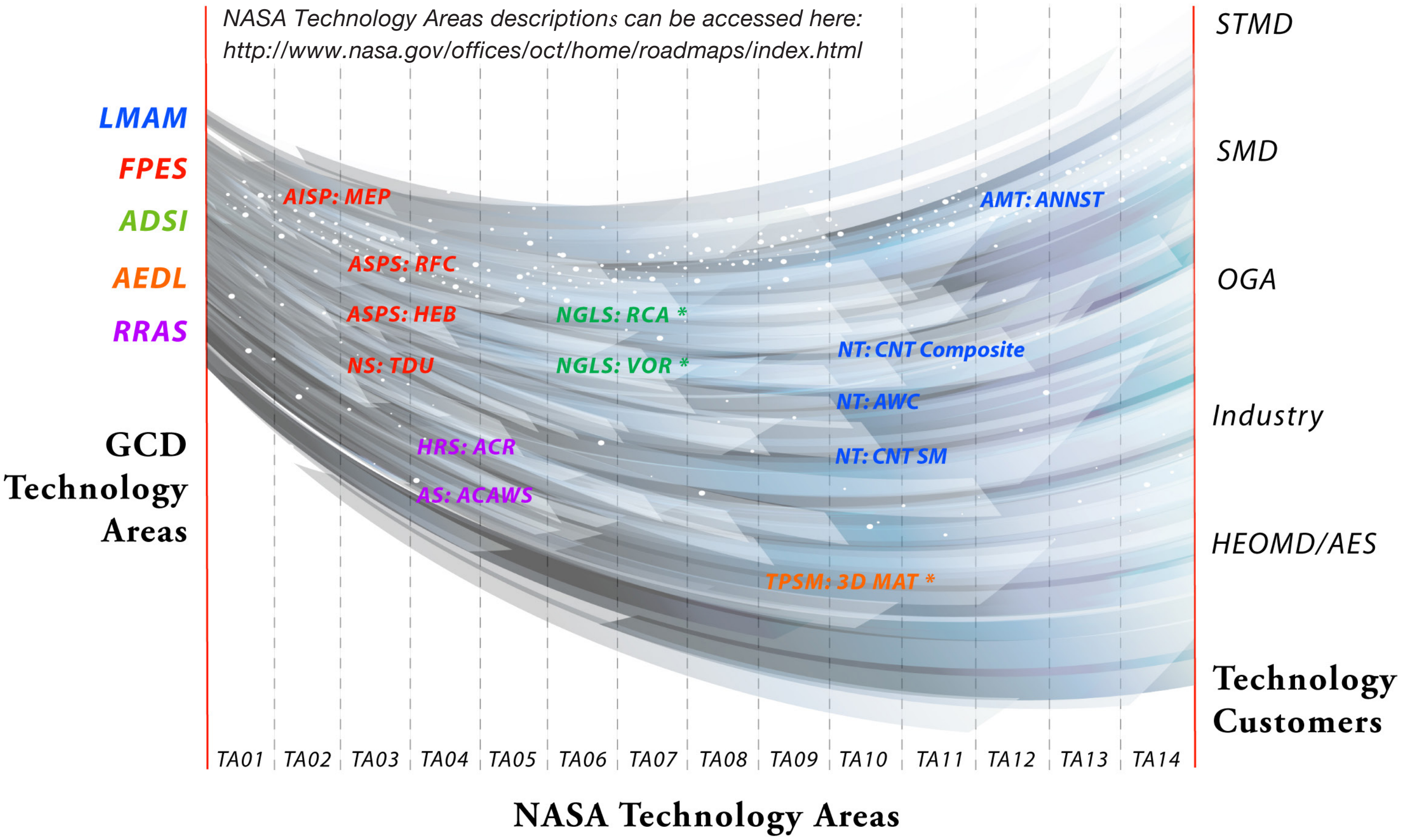
For decades, NASA engineers have sought a means to separate the power generation capability from the end user, and in the process enable missions not otherwise possible. Onboard power generation by space assets such as spacecraft or planetary rovers continues to present difficult challenges, often entailing significant mass penalties, dramatically increasing mission costs and in some cases obviating mission feasibility. Researchers have investigated many techniques to wirelessly transmit and receive power over distances great and small, unfortunately such technology investigations have not yet translated into routine use in aerospace applications. Numerous terrestrial applications are now in operation or in further development, and commercial space applications are beginning to emerge.

Topic 3: TPS Materials and Systems Development

Objective: design, develop, analyze and test new material systems and system components to advance capabilities of the most critical element of every entry system: the thermal protection system (TPS).

Ablative and reusable TPS materials with reduced areal densities, reduced production and/or integration costs, more robust or multifunctional performance, and higher reliability and reusability are of interest to NASA and emerging commercial entities. These systems are not only of interest in performing atmospheric entry from space but are also of interest in returning reusable launch vehicle stage elements to Earth.

GCD's 2015 Infusion-Ready Technologies



HRS: ACR – Human Robotic Systems, Asteroid Capture Robotics

TALISMAN greatly improves the state of the art in space robotics by significantly increasing manipulator reach and dexterity while reducing mass and complexity. It provides new capabilities that can be used for asteroid retrieval missions and other activities, such as astronaut positioning, payload retrieval, in-space assembly and satellite servicing.

Potential customers are TALISMAN Long-Reach Lightweight Manipulator; STMD TDM (orbital assembly), HEOMD (ARM, spacecraft berthing), SMD (telescope assembly), DARPA (orbital debris removal, satellite servicing), industry (satellite servicing).

TALISMAN servicing.

AS: ACAWS – Autonomous Systems, Advanced Caution and Warning System

Spacecraft in low-Earth orbit, such as ISS, are commanded entirely from ground, which is not feasible for deep-space missions with large speed-of-light delays, and cryogenic loading is labor intensive and expensive. The solution is to develop software to automate mission operations and ground operations. This technology development is to design a new failure advisor (FRAd) module to be associated with the Advanced Caution and Warning System. The module will enable the crew with specific information on system faults.

Mission infusion plans are underway in that Autonomous Systems has signed a memorandum of agreement with HEOMD and AES in the areas of Autonomous Mission Operations, Ground Systems Development and, Integrated Ground Operations Demonstration Units for the ACAWS. ACAWS technology was utilized for the Orion EFT-1 EPS subsystem, and the software was demonstrated in shadow mode at Johnson Space Center during EFT-1 December 5, 2014.

NGLS: VOR – Next Generation Life Support, Variable Oxygen Recovery*

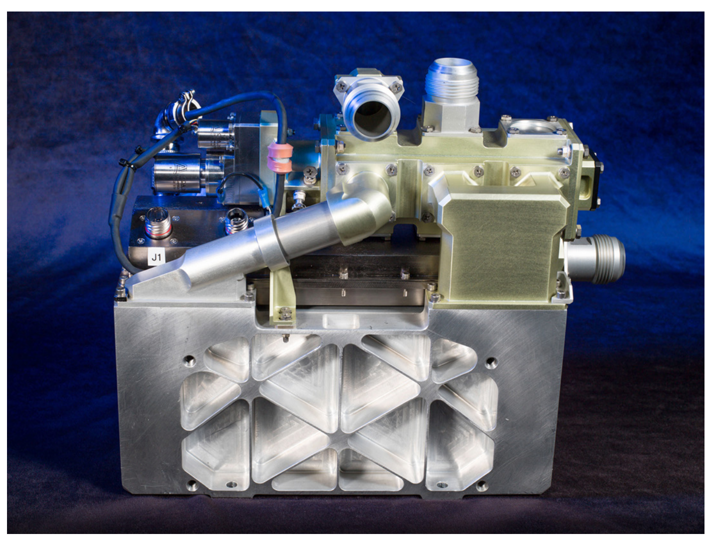
The pressure regulator allows, for the first time, continuous control of suit pressure, resulting in higher levels of flexibility and safety for EVA. Pre-breath protocols could be performed within the suit, decreasing preparation time and allowing for more rapid deployment. The suit will have flexibility to integrate across various spacecraft and missions of the future, regardless of cabin pressure. The regulator has been designed with safety first. It is robust and tolerant of contamination. It will withstand combustion events and retain enough capability after failure to return an astronaut back to the spacecraft safely.

The chief customer is the AES Advanced Space Suit project through its goal to develop the next generation space suit for human exploration missions beyond low-Earth orbit. Second generation hardware (VOR 2.0) was infused in the PLSS 2.0 test article for integrated and human testing. Third generation hardware (VOR 3.0) will be delivered to the AES Advanced Space Suit project for incorporation into PLSS 2.5 and 3.0 for testing, raising the TRL to 6.

NGLS: RCA – Next Generation Life Support, Rapid Cycle Amine Swingbed*

This dual function component for space suit PLSS will remove both carbon dioxide and humidity. It is under development for the next generation pressurized space suit for human exploration beyond low-Earth orbit. The system is regenerative, thus there is nothing to fill or be spent that would limit the duration of EVA; and there is a lot of mass savings because the beds won't have to be changed out. The functions are provided by separate subsystems in the current suit on the ISS. This hardware will reduce the mass and complexity of the suit, eliminating high maintenance hardware associated with moisture removal.

Variable oxygen recovery pressure regulators.



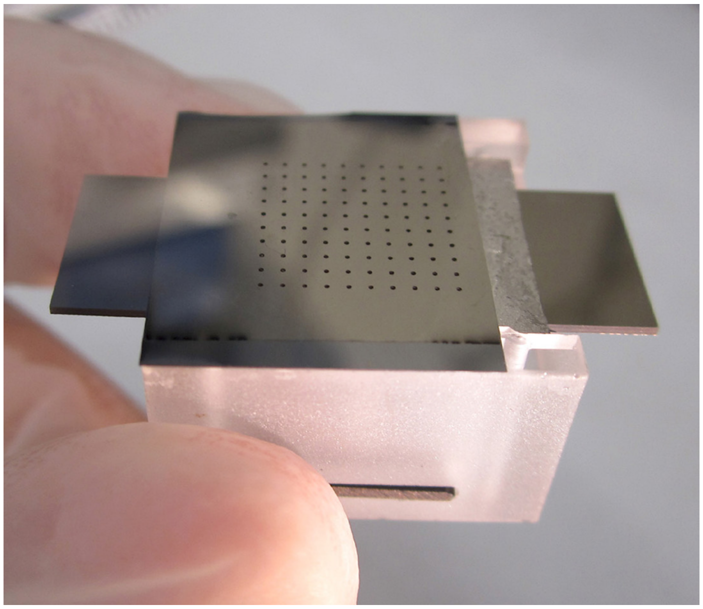
Rapid Cycle Amine Swingbed 3.0 test article.

The chief customer is the AES Advanced Space Suit project through its goal to develop the next generation space suit for human exploration missions beyond low-Earth orbit. Second generation hardware (RCA 2.0) was infused in the PLSS 2.0 test article for integrated and human testing. Third generation hardware (RCA 3.0) will be delivered to the AES Advanced Space Suit Project for incorporation into PLSS 2.5 and 3.0 for testing, raising the TRL to 6.

AISP: MEP – Advanced In-Space Propulsion, Microfluidic Electrospray Propulsion

MEP is developing small-volume microfluidic electrospray propulsion technologies to revolutionize small spacecraft primary propulsion as well as offering an alternative fine pointing capability for larger satellites. MEP modules have the potential to be 4 times more efficient in terms of thrust-to-power and enable more than 10-times improvement in thrust range, mass, volume and cost over state of the art.

The team is in discussions with Ames Research Center's BioSentinel mission for joint testing of the MIT system. BioSentinel would provide flight-like avionics for use during independent verification and validation testing. For Phase II, one or more electrospray technology may be selected for further development to TRL 6 and for a possible space flight demonstration via the SSTP.

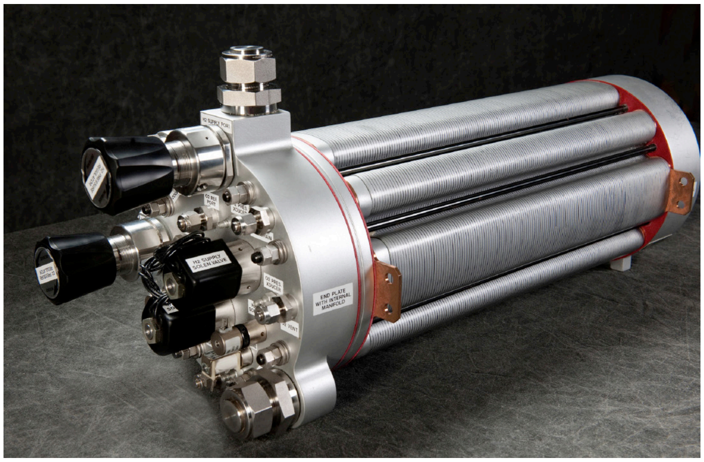


Model of an MEP thruster.

ASPS: RFC – Advanced Space Power Systems, Regenerative Fuel Cell

Develop and demonstrate advanced RFC technologies that meet NASA's space exploration needs for safe, abundant, reliable, and lightweight power generation and energy storage through the use of innovative passive components such as non-flow-through fuel cells and passive, liquid-feed electrolyzers.

Potential customers for the technology are HEOMD and DoD. The non-flow-through fuel cell has near-term applications for power generation in surface systems and in SLS upper stage. The DoD application is for power generation on unmanned undersea vehicles.



3-k non-flow-through proton-exchange-membrane fuel cell.

ASPS: HEB – Advanced Space P ower Systems, High Energy Li-ion Battery

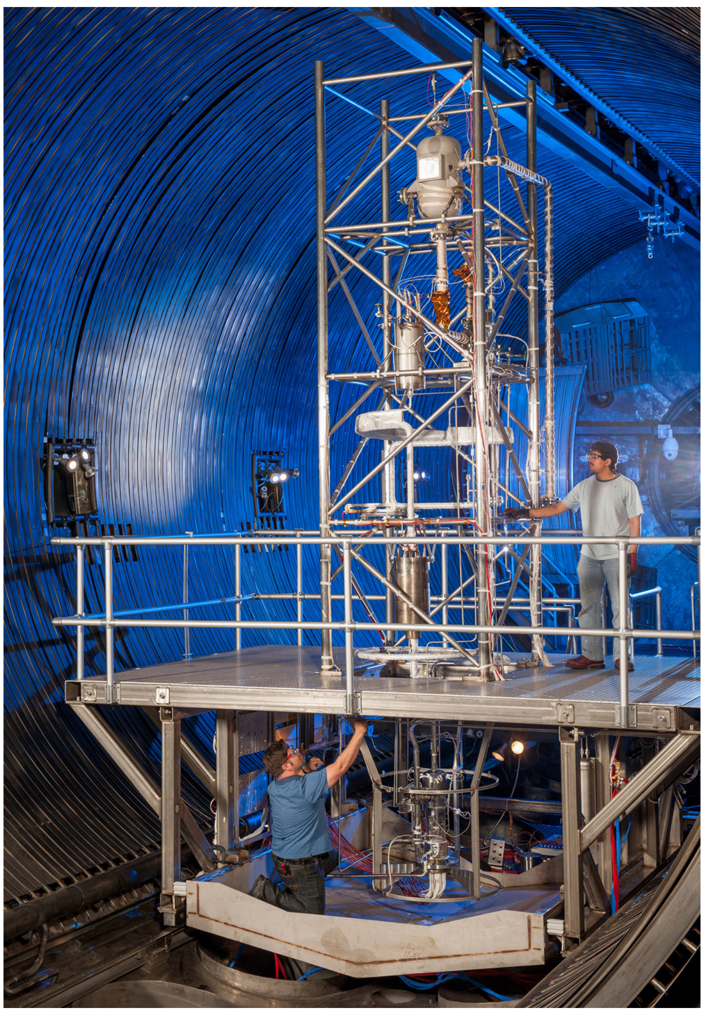
Develop and demonstrate advanced HEB cell technologies that meet NASA's space exploration needs for safe, abundant, reliable, and lightweight energy storage through the integration of high energy nickel-manganese-cobalt cathodes and silicon anodes with flame retardant electrolytes.

Potential customers are HEOMD, DoE, and battery vendor partners. Anticipated use is with portable life support systems on advanced space suits to extend astronaut EVAs from 3 to 8 hours.

NS: TDU – Nuclear Systems, Technology Demonstration Unit

Previous space reactor development programs, such as SP-100 and Prometheus, have failed to complete the all-important system-level demonstration. NS will demonstrate fission power subsystem technology readiness in a relevant environment for two classes of NASA's mission requirements: 10 to 100s kWe for exploration outposts and nuclear electric propulsion via the TDU, and 1 to 10 kWe for robotic science and small exploration systems (kilopower).

Technology-ready in 2015 is the TDU effort. Mission infusion potential customers are TDM, HEOMD, and potential use on a Mars long-term, first human exploration mission.



TDU without the power conversion unit in Marshall Space Flight Center's Environmental Test Chamber.

TPSM: 3D MAT – Thermal Protection System Materials, Three Dimensional Multifunctional Ablative TPS*

3DMAT is developing a robust multifunctional material for use in spacecraft heat shields. The 3D-woven composite has pushed state-of-the-art manufacturing to new levels yielding tailored materials that can be both structure and thermal protection system. The unique structural heat shield material is enabling future Orion missions to take humans far into the solar system.

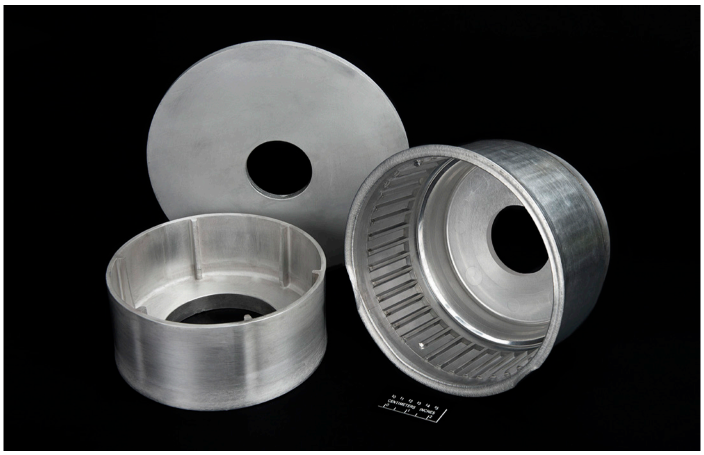
3DMAT is infused and integrated with both NASA and Lockheed Martin Orion TPS teams. Technology transfer occurred in 2015 to Orion MPCV for further development and use as compression pads on EM-1 flight planned for 2018. Potential customers are STMD, SMD, and HEOMD.

3DMAT ablative TPS.

AMT: ANNST – Advanced Manufacturing Technologies, Advanced Near Net Shape Technology

Advanced manufacturing is critical to all NASA mission areas. The AMT project elements and tasks develop and mature innovative, advanced manufacturing technologies that will enable more capable and lower-cost spacecraft and launch vehicles. AMT is making use of cutting edge materials and emerging capabilities including: metallic processes, additive manufacturing, composites, and digital manufacturing. AMT supports the National Manufacturing Initiative involving collaboration with other government agencies.

Potential customer infusion is with TDM, HEOMD, SMD, OGA, and industry. ANNST produces game changing and next generation manufacturing technology and works with various NASA mission directorates and programs, such as SLS, to infuse the technology to dramatically improve affordability and capability. Additionally, ANNST contributes to the NASA Roadmap and collaborates with other agencies, industry and academia.

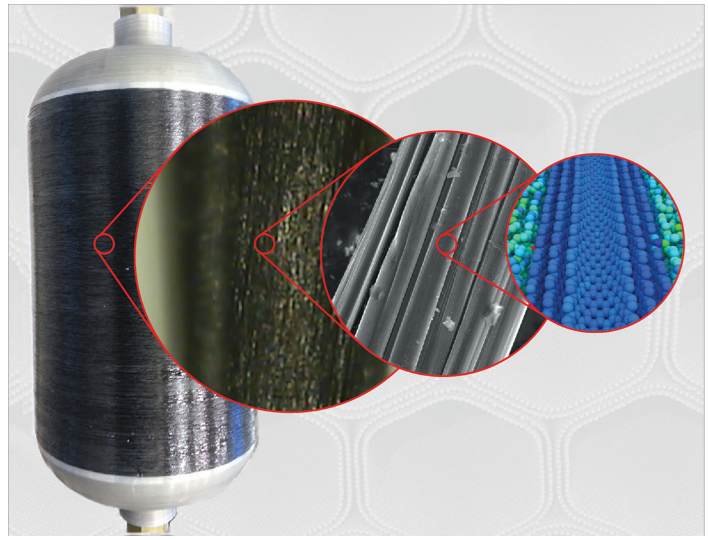


Single-piece integrally-stiffened launch vehicle structures.

NT: CNT SM – Nanotechnology, Carbon Nanotube Structural Material; and CNT Composite – Carbon Nanotube Composite

NASA needs new high strength, low density fibers and fabrics to reduce the weight of future aerospace vehicles. CNT SM and CNT Composite are developing carbon nanotube reinforced composites with 1.5 to 2 times the specific strength of conventional carbon fiber reinforced polymer composites. NT research and development seeks to reduce the structural mass of future aerospace vehicles through the development of ultra lightweight materials and structures through the use of carbon nanotube reinforcements and composites, ultralightweight core materials for efficient load-bearing composite sandwich structures, and mature technologies and demonstrate benefits through a combination of ground and flight tests.

Potential customers are CNT reinforced COPV, CNL structures, HEOMD, and Planetary Exploration 2033 and Beyond. Mission infusion is planned for CNT reinforced structural materials and the National Reconnaissance Organization. Products (data, materials, and processing techniques) from this project will be disseminated to other



Carbon nanotube composite.

federal agencies under the National Nanotechnology Initiative's Nanomanufacturing Signature Initiative.

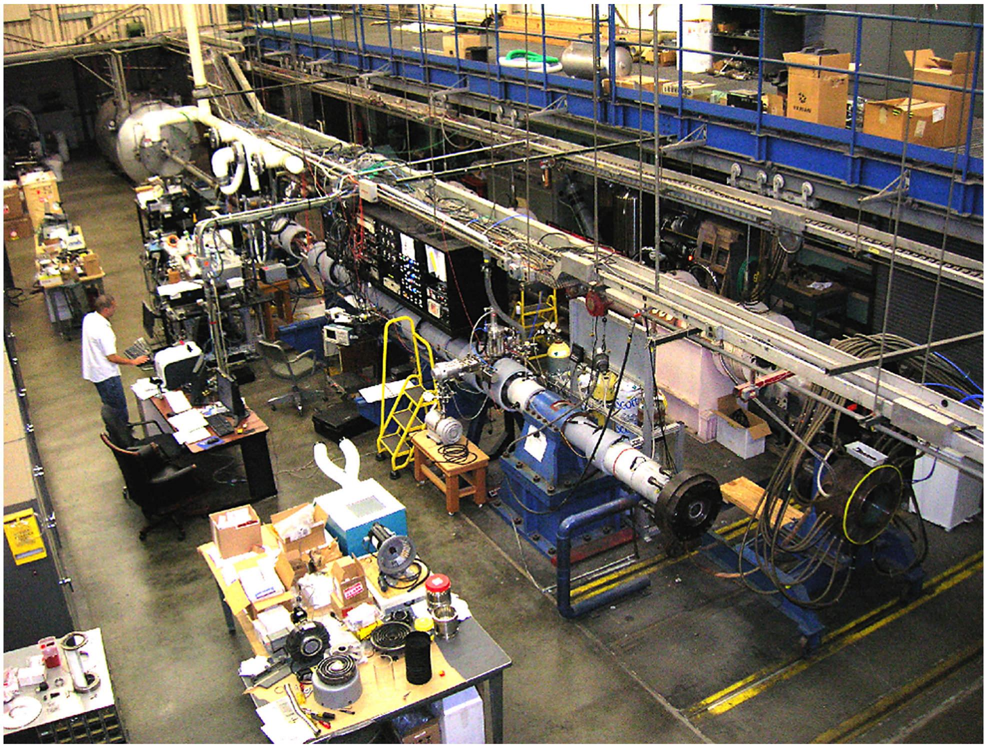
NT: AWC – Nanotechnology, Aerogel Wires and Cables

The AWC team is assessing the developing low conductivity CNT wires and yarns and polymer aerogel electrical insulation for low mass electrical power and data cables. Researchers seek to understand the effects of intercalation methods on CNT wires and yarns and develop fabrication methods for polymer aerogel wire and cable insulation. The study is also assessing electrical and thermal behavior of existing CNT data cables.

Potential customers and mission infusion are identical to that given for CNT SM and CNT Composite.

Acronyms/symbols not defined in content:

AES	Advanced Exploration Systems
DARPA	Defense Advanced Research Projects Agency
DoD	Department of Defense
DoE	Department of Energy
EVA	Extravehicular activity
HEOMD	Human Exploration Operations Mission Directorate
OGA	Other government agency
PLSS	Portable life support system
SLS	Space Launch System
SMD	Science Mission Directorate
SSTP	Small Spacecraft Technology Program
STMD	Space Technology Mission Directorate
*	Denotes a 2015 infusion



Inside the Ames Electric Arc Shock Tube (EAST) Facility. EAST is the only shock tube in the U.S. capable of simulating shock-heated gas environments at very high enthalpies encountered by atmospheric entry vehicles. The facility generates conditions for measurements of spectrally resolved radiance and kinetics of shock-heated gases from the vacuum ultraviolet through mid-infrared. The operating envelope of EAST covers velocities from 1.3 to 46 km/s at pressures between 13.3 and 5.3E+05 Pa in a variety of planetary atmospheres. The radiation data aid validation of computational tools used for the design and analysis of hypervelocity vehicles.

ESM Test Data Improve Confidence in Radiative Heating Models

—Brett Cruden/Denise M. Stefula

The Entry Systems Modeling project performed a series of 45 tests between January and March this year to gather results that will be used to help scientists reduce uncertainty in existing radiative heating models. With planned future crewed missions like Orion, that will be returning to Earth from more distant planetary and space exploration than ever before, data are being collected that will enable crucial studies for development of advanced heat shield solutions to protect a vehicle upon atmospheric reentry.

Radiative heating is seen in the "glow" a reentry vehicle emits once it absorbs extreme levels of heat when passing through the atmosphere. A vehicle's heat shield material must be able to withstand those temperatures to minimize risk to crew and the vehicle, and scientists use data from tests like these to compare with models and determine model accuracy.

"Radiation in the entry regime of 10 to 12 km/s is currently fairly well understood. This allows us to make very accurate predictions for vehicles returning to Earth from lunar orbit," says Brett Cruden of Analytical Mechanics Association and principal investigator for the tests at NASA's Ames Research Center. "The future of space exploration will likely involve returns from Mars or farther distant planets and moons, so the vehicles may be entering our atmosphere at velocities from 12 to 16 km/s."

Radiative heating predictions depend upon flow fields obtained from computational codes, which provide the local conditions experienced during reentry and enable scientists to solve challenges in radiative heat transfer. ESM's tests sought to produce a database of radiation measurements between 9 to 12 km/s at densities equivalent to altitudes from 60 to 70 km for the purpose of fundamental radiation model development and validation.

"This range of interest is strongly influenced by NASA technology needs and overlaps into many missions, including Orion," says Cruden. "We were able to use these tests to reduce the uncertainty in radiative heating from 56 to 38 percent."

The tests were conducted at Ames Research Center's Electric Arc Shock Tube Facility and performed over a range of velocity and pressure regimes and at different spectral regions, including the vacuum ultraviolet (VUV). Gathering data on VUV radiation is important because it is absorbed by the atmosphere at sea level, but not in the upper atmosphere where vehicles enter and is responsible for more than half of the radiative heating. These tests, and following analysis, were incorporated into Orion's radiative heating margin.

"For vehicle sizing, the heating components are computed, adjusted by a margin (i.e., safety factor), and then passed forward into a material response analysis that is used to determine a safe heat-shield thickness," explains Cruden. "Currently, Orion is seeking mass reductions, and the aerotheromdynamics team has used this data to re-evaluate the nominal radiative heating models and margin factors in an attempt to reduce heat-shield material thickness while still meeting all design requirements. Reducing the margin from 56 to 38 percent will save heat shield mass for Orion."

The exact savings will not be known until sizing exercises are completed at the end of October. Further analysis of the results is still pending and will influence modeling parameters in future calculations.

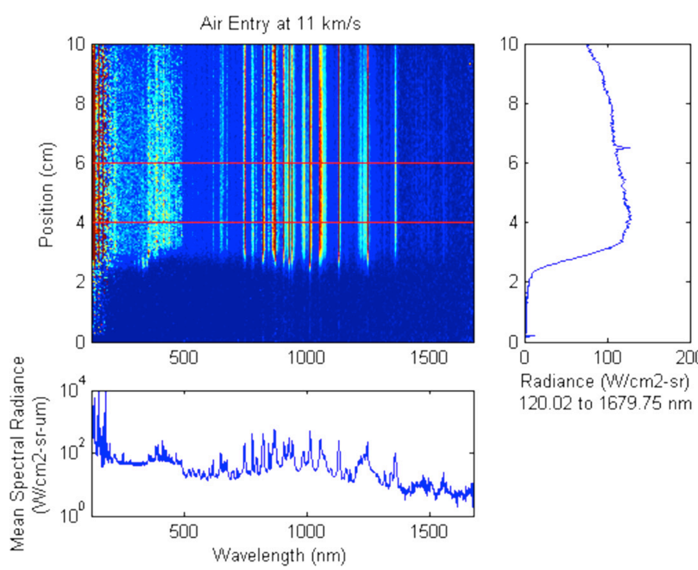
High Speed Radiation Database—Test Overview

In the test, the shock tube is filled with an air mixture at a low pressure corresponding to the density in the upper atmosphere. An electric arc is struck in a small (1 liter) volume at voltages up to 40 kilovolts and 1 mega amp of current. This produces a high pressure, high temperature region that travels down the tube at hypersonic velocities. The high pressure gas compresses and heats the gas in front of it, much as a vehicle entering the atmosphere does. That hot gas glows and emits radiation that is measured with spectroscopic equipment. The radiation emitted is equivalent to that present on an entry vehicle and hence heating predictions can be validated by comparison to the shock tube data.

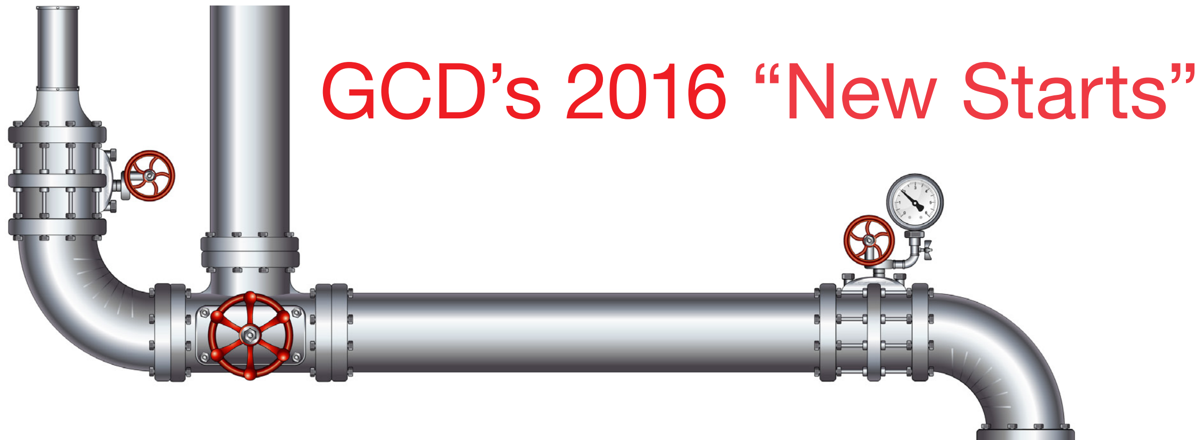
High Speed Radiation Database—Test Discoveries

An interesting outcome of this comparison was finding trace species in the atmosphere (Argon, CO_2) that are usually ignored in heating calculations could actually alter the radiative heating by as much as 13 percent, which had to be incorporated into the margin factor. One significant issue found in the radiation margin development was the disagreement of model predictions to Exploration Flight Test (EFT)-1 data. To that end, a test series is currently under way that will reconstruct the EFT-1 entry environment. This test will be used to evaluate the relative quality of the models and EFT-1 flight data. The data obtained in the shock tube have substantially more detail than the flight data, such that the exact reason for discrepancies can likely be pinpointed and allow the models to be updated to give the most physically meaningful results.

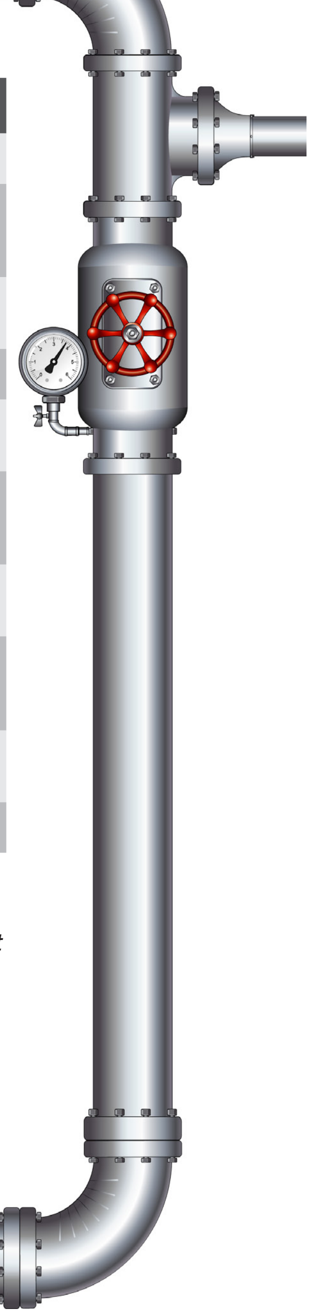
"The desire to extend our validation studies to these more extreme entry conditions remain and will be the subject of future tests," says Cruden. "Similar problems are posed for probe missions entering different planetary atmospheres. We expect testing to continue over a range of atmospheres and entry scenarios in order to bring down uncertainty in radiation predictions over the entire range of planetary exploration."



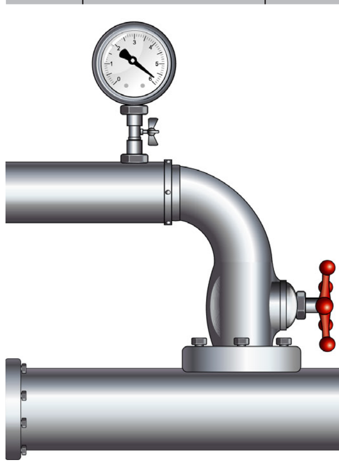
The radiance emitted from the shock is measured as a function of wavelength and distance behind the shock.



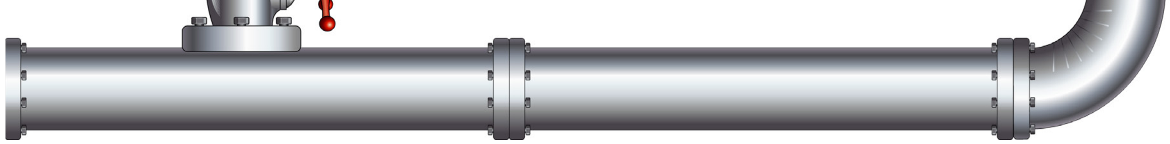
GCD's 2016 "New Starts"



Theme area	Technology area	Project	Duration, years	Objective
LMAM	Nanotechnology	Nano Wire Insulation	3	Develop polymer aerogel coatings for electrical insulation
LMAM	Materials, Structures, Mechanical Systems and Manufacturing	Bulk Metallic Glass Gears	3	Develop gearboxes and strain wave gears capable of reliable operations at temperatures below –50 degrees Celsius, potentially eliminating the need for gearbox heaters
AEDL	Entry Systems Modeling	Parachute Fluid Structure Interaction	2	Develop a fluid structure interaction model to improve modeling and understanding of current and future parachute systems
AEDL	Entry Systems Modeling	Dynamic Computational Fluid Dynamics	3	Improve unsteady, separated flow analysis in NASA CFD tools, with an emphasis on US3D and FUN3D
AEDL	Entry, Descent and Landing Systems	Propulsive Descent Technology	1	Develop engineering CFD models validated using Space-X flight data; develop flight test concepts with commercial partner
AEDL	Thermal Protection Systems	Hypersonic Inflatable Aerodynamic Decelerators 2	2	Overcome size and weight limitations of current rigid systems by utilizing inflata ble soft-goods materials that can be packed into a small v olume and deployed to form a large aeroshell before atmospheric entry
ADSI	Science Instruments and Sensors	High Performance Spaceflight Computing (option 2)	4	Develop a modern, multicore, radiation tolerant spaceflight computing device
ADSI	Science Instruments, Observatories, and Sensor Systems	Ocean Waters Europa Technologies	2	Develop four enabling technologies for Europa missions: ultra low-temperature batteries; ultra low-temp batteries and radiation hard electronics; landing guidance, navigation and control; icy body mobility
RRAS	Robotics	Pop-Up Flat Folding Explorer Robots	2	Develop three fully integrated and instrumented demonstration units providing future missions with low-cost access to hazardous or difficult to reach terrains
FPES	Space Power and Energy Storage	Extreme Environment Solar Power	3	Develop cell/array systems that maximize delivered power under Jovian conditions



A new start is the beginning of technology development for the Game Changing Development Program. Typically, new starts are at a technology readiness level of 3, meaning that the technology has already achieved proof of concept and can be demonstrated via a breadboard or prototype.



The discussion of new starts is always an exciting one for the Game Changing Development team. Our goal is to develop new technologies—both high payoff and high risk, disruptive, and transformative—that will enable innovations, new missions, and change the way NASA makes or does something for an order of magnitude improvement. We do not care where the ideas come from, whether from within NASA such as researchers, scientists, or technologists; responses to challenges; competitions with industry; partnerships with industry; other government agencies; academia; or simply the brightest minds out there. However, all new ideas must go through our front door. The front has been and will remain the STMD principal technologist, as they are now called. Here we have an overview of the new starts that have stepped through that front door for 2016.

—Steve Gaddis, GCD program manager

LMAM – Nanowire Insulation

Plans are to evaluate at least five formulations of aerogel for coating cables for data and power. The aerogel formulations will be assessed for coating adhesion, characterization and optimization of tensile properties, dielectric properties, moisture resistance, and other key material properties such as wear and fatigue resistance.

LMAM – Bulk Metallic Glass Gears

Currently no suitable material systems for gearboxes that can withstand the extreme environments of the outer planets without requiring heaters. The current state-of-the-art for unheated, cold capable gearboxes does not meet mission needs. Gearboxes for Mars rovers require heaters to maintain adequate operating temperatures. These heaters consume a large fraction of the rover's power budget which reduces operational capability. The BMG Gear project will focus on the development of gearboxes and strain wave gears capable of reliable operations at temperatures below –50 °C, which could eliminate the need for gearbox heaters for future missions.

AEDL – Parachute Fluid Structure Interaction

Fluid Structure Interaction has been identified as one of three grand-challenge problems in the NASA Engineering Safety Center Aerosciences Technical Discipline team, and in particular large deflection FSI, as encountered during parachute inflation and unsteady dynamic motion, is a key area of NASA interest for many current and future flight missions. NASA and the broader aerospace community have essentially no capability for performing detailed simulations of parachutes in an unsteady flow field, either singly or operated in clusters. As a result, flight projects rely on drop testing for all stages of recovery system design, development, and qualification. Such drop tests are very expensive, frequently costing in excess of $1M each, and in some cases do not deliver conclusive, repeatable results. The ability to conduct more focused tests (be that the same number of tests but more rigorously planned, or better yet fewer tests because of a companion simulation capability) would be a major advancement, supporting program development schedules and helping to control costs.

AEDL – Dynamic Computational Fluid Dynamics

In recent years, there has been a strong desire among NASA flight projects for analysis of dynamic aerodynamic phenomena that occur during entry and descent of spacecraft. Examples include dynamic stability during uncontrolled portions of the trajectory, fluid-structure interactions of flexible entry and descent structures (HIADs, SIADs, and parachutes), RCS interactions in the wake of controlled entry vehicles, and supersonic retro-propulsion, to name just a few applications of current interest. The NASA Engineering Safety Center lists analysis of dynamic environments among its top three technical challenges for the Aerosciences discipline. Initial experience from the Multi-Purpose Crew Vehicle Aerosciences project, in particular, is clear: Our current generation workhorse aerodynamic analysis tools as they currently exist are not sufficient to meet the challenge. Success will require development of innovative techniques and tools using the latest advances in numerical modeling. Initially, two of these problems will be targeted within this effort: supersonic retro-propulsion and dynamic stability.

AEDL – Propulsive Descent Technology

Because supersonic deceleration strategies are inadequate for future Mars Large-mass landed missions, this project aims to advance the state of the art for high-mass Mars entry, descent and landing capabilities. The goal is to improve confidence in supersonic propulsive descent using flight data from a commercial partner in order to establish updated TRL characterization and identify gaps in reaching TRL 6 for supersonic retro-propulsion. The plan is to obtain two flight data sets and to calibrate engineering models in order to characterize the current technology readiness level across steady state supersonic retro-propulsion.

AEDL – Hypersonic Inflatable Aerodynamic Decelerators 2

This task includes efforts with respect to advanced concepts for the inflatable structure, flexible thermal protection system and inflation system, culminates with a Gen-3, large-scale (>10m) aeroshell manufacturing development unit, static load testing of that article, and subsequent pack and deploy demonstration. Out-year planning refinements activities target improvements to inflatable aeroshell capabilities and manufacturing that relate to scaling diameters greater than 10m, which directly relates to NASA's planetary exploration needs.

ADSI – High Performance Spaceflight Computing

HPSC seeks to develop a next-generation flight computing system addressing the computational performance, energy management and fault tolerance needs of NASA missions through 2030. Space-based computing has not kept up with the needs of current and future NASA missions, and the Strategic Technology Roadmaps call out the need for more capable flight computing. NASA missions have extreme requirements for low power, energy management, and fault tolerance. The HPSC Formulation Study determined that a rad-hard general-purpose multicore architecture is the best fit for NASA application needs. Multicore provides direct architectural support for power scaling and a range of fault tolerance methods. Furthermore, a multicore flight computing system can be operated flexibly, with ongoing dynamic trades among computational performance, energy management and fault tolerance. This game changing investment in a next-generation flight computing system will address both performance and system-level advances, and serve to reinvent the role of computing in space.

ADSI – Ocean Waters Europa Technologies

OWET is investigating advancing several technologies for extreme environments to support the Europa Lander mission.

Ultra Low Temp Batteries: Energy storage advancements are required to enable a landed mission to Europa. Because Europa Lander energy storage devices must be capable of surviving an extremely cold environment while minimizing heater power.

Ultra Low Temp and Rad Hard Electronics: Europa Lander mission requires the development of electronics capable of reliably operating at –180°C in an extreme radiation environment (cruise, landing, and surface operations). State of the art electronics are not capable of meeting this harsh environmental requirement.

Landing GN&C: Europa Lander mission requires development of technologies to enable safe & precise landing. Sensor suite capable of providing terrain relative navigation and hazard detection.

Icy Body Mobility: Promising autonomous mobility and sensing systems. High level analytical study to refine list of promising technologies. Detailed investigation to potentially include development/assessment of prototype hardware.

RRAS – Pop-Up Flat Folding Explorer Robots

PUFFER is a low-volume, low-mass, low-cost mission enhancement for high-reward extreme terrain science. New mobility technology is required for future exploration of high-reward extreme environments such as Europa. The National Research Council said, "Extremely mobile platforms will be a critical component to both the success and diversity of extraterrestrial body exploration." In the NRC Prioritization of the Technology Area 04 (TA04) Level 3 Technologies, Extreme Terrain Mobility and Small Body/Microgravity Mobility were both ranked as high priority.

FPES – Extreme Environment Solar Power

The EESP project seeks to develop solar cell/solar array design concept technologies for space power applications in high radiation and low solar flux environments. NASA missions focused on outer planets (e.g., Jupiter) are subjected to intense radiation while experiencing less than 10 percent of the solar flux relative to a mission in the general vicinity of Earth. Under these conditions, present solar array technology is not as efficient in converting the sun's energy and the solar array performance degrades quickly due to the additional radiation exposure. In addition to these deep space missions, there are also multiple classes of NASA missions, other government agencies, and commercial space interests that perform space missions in Earth orbits exposed to high levels of radiation. The development of new solar cell and array-level component technologies focused on these issues will enable future NASA robotic and human-exploration missions by increasing solar cell performance, and thus increasing mission life and/or decreasing mission mass/cost.

Dr. Howard Conyers

—Scott Conklin, GCD Summer Intern

Dr. Howard Conyers works as a structural dynamicist at NASA's Stennis Space Center in the modeling rocket engine test facilities; in this case, you could say he's a rocket scientist and be exactly right. A quick Google search on his name yields some articles about his profession; however, the list goes on for articles characterizing Conyers' illustrious reputation as a seasoned pitmaster and barbecue chef extraordinaire.

In addition to being an award-winning cook and recognized community leader, the 33-year-old engineer stands as one of the youngest project managers in the Game Changing Development Program, and his career is just getting started. But how does a small town kid from the rural farming community of Manning, South Carolina, end up at NASA?

"My father was a welder and my mom was a social worker, so as far as having engineers in my family I never had that, but I remember wanting to be an engineer before I knew what an engineer was," says Conyers. "I always loved math and science."

The idea of working at NASA, or becoming an engineer was never fully realized for Conyers until hearing about Dr. Ronald McNair while attending North Carolina Agricultural & Technical State University on a full USDA 1890 scholarship to study bioenvironmental engineering. McNair, a NASA astronaut, grew up in Lake City, South Carolina, a mere 45-minute drive from Conyers' hometown of Manning.

"Dr. Ronald McNair was the only close link to NASA that I knew of as a child…and I had a professor at NC A&T who went to school with him. That's when I realized it was possible [to work for NASA]."

Conyers says he chose bioenvironmental engineering because it combined two of his main interests at the time: farming and engineering. Upon graduating from NC A&T at the top of his class, however, Conyers took an interest in fluid dynamics and decided to attend graduate school at Duke University to obtain a masters and then a PhD in aeroelasticity. There he met two world-renowned professors, engineer Dr. Earl H. Dowell and historian Dr. John Hope Franklin, whom Conyers lived with while at Duke. Conyers says that both were extremely valuable mentors, but in different ways.

"Having one academic and one humanitarian mentor helped shape me to become very versatile and disciplined."

Upon completing his PhD at 27 years old, Conyers started interviewing at a number of NASA centers until he was hired on as a structural dynamicist at Stennis Space Center in southern Mississippi. At first, Conyers worked on modeling an oxygen flange for one of the rocket engine main propellant feed-lines, but then applied and was accepted for a detail with NASA Stennis Chief Technologist Dr. Ramona Travis.

One of the tasks assigned to him while on detail with Dr. Travis was to see if there was any interest at Stennis to develop an Early Career Initiative (ECI) proposal in response to an open agency solicitation put out by NASA's Space Technology Mission Directorate. After examining the solicitation, Conyers elected to draft and submit a proposal himself; three months later, Conyers's proposal was selected, and he found himself as the lead program manager on what came to be called the HiDyRS-X project. By strengthening the ECI team through a partnership with Innovative Imaging and Research (I2R), a company that had experience with HDR imagery, Conyers felt confident he could provide the leadership necessary to complete the project.

"I believed in the concept; I knew I wasn't an expert on optics, photography and high speed video systems, but I felt I could learn on the fly, and through other entrepreneurship activities I felt like I had the skillset to make the project successful."

The idea behind the HiDyRS-X project was motivated by rocket engine failures. When engineers are testing rocket engines, or launching rockets, telemetry and high-speed video data is continuously fed to the controllers so they can measure performance and detect abnormalities. In the event of a failure, telemetry data can only tell part of the story. Current high-speed cameras used for analyzing rocket engines struggle to capture detail in the event of an engine explosion due to the intense light produced. Conyers's project mitigates the loss of high-speed video data by utilizing highly modified high dynamic range (HDR) cameras, which enable the camera to capture detail before and after an extreme change in brightness.

Although the HiDyRS-X project, which officially began in January of 2015, is to be completed by the end of next year, Conyers says he'd like to keep developing the technology beyond its originally intended application.

"I think the technology we make for NASA should be transferable to the real world."

Conyers envisions several infusion pathways for the technology beyond NASA including incorporating the technology into consumer products such as cell phones and digital cameras. Conyers says that he hopes the HiDyRS-X technology can be fully utilized, leaving a positive impact on the world.

"Working for NASA is the way I contribute my intellectual ability to help move the country forward."

While his contributions to NASA are just beginning to be felt, Conyers' contributions to his community in New Orleans, Louisiana are well known. Whether it's supporting the local social entrepreneurship incubator "Propeller", or participating in the pediatric brain cancer charity barbecue event "Hogs for the Cause", Conyers says community service is a big part of his life.

"No matter how far you go in life you need to be able to reach back at certain times and give back to others who are maybe less fortunate who don't necessarily know the direction they're going. Community service is a big part of becoming a better person, and I will always say that you should take time to give back to others. You may not have money to give, but you always have little bit of time."

Conyers enjoys using his culinary ability to bring people together, and he says he applies many of the lessons and values learned through engineering to perfect his barbecue.

"People would always ask how I tie engineering to barbecuing. As an engineer I'm very methodical, so I always try to take notes to see how I can improve [my consistency.] I learned that people want a high-quality consistent product, and I've adopted some philosophies [from engineering] into barbecue to make a high quality product every time.

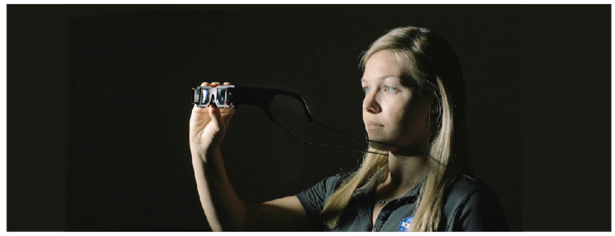
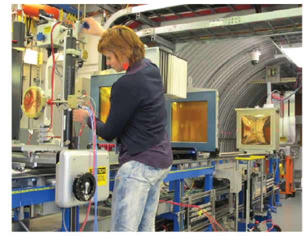
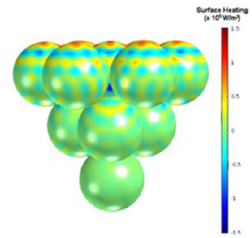
Consistency is very important in the world of barbecue especially when you become known for producing a signature barbecue, as Conyers has. Conyers never envisioned that barbecue would be something he'd gain notoriety for; however, his old school, whole-hog South Carolina-style barbecue has elevated him to a modest level of fame in the New Orleans barbecuing community.

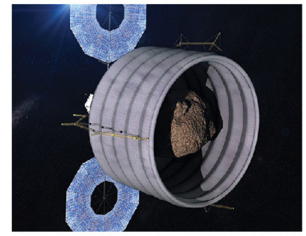
"I really thought engineering would be the thing I'd be known for, and it's still my goal, however this barbecue thing is surpassing it by leaps and bounds."

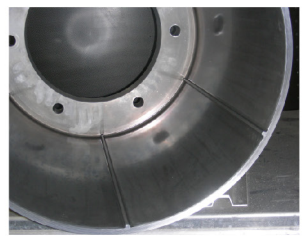
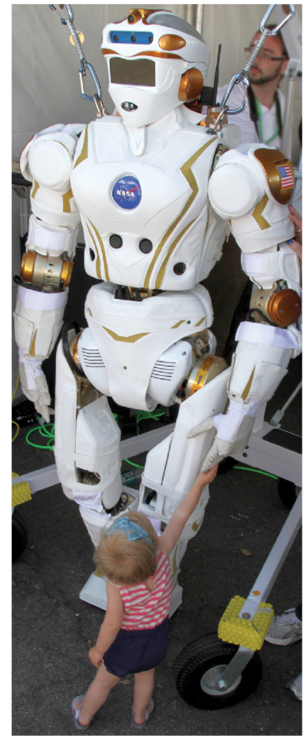
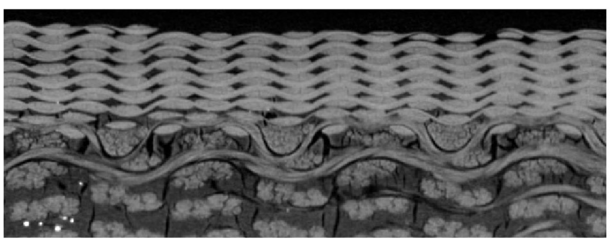
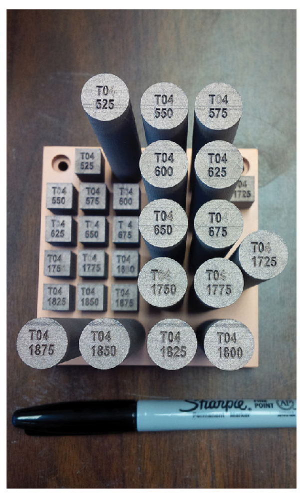
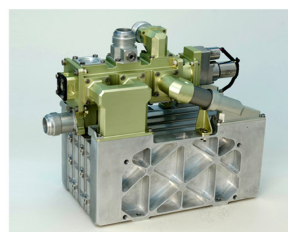
Whether it be barbecuing for the community, or engineering innovative ways to analyze rocket engines, Conyers continues to have a positive effect on the people and technology he touches.

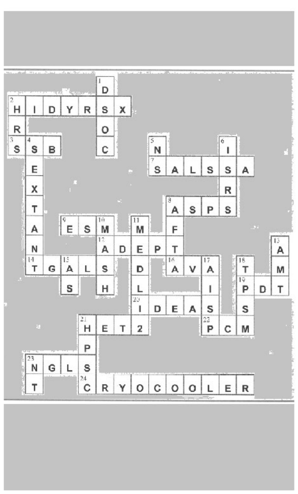
"If engineering and barbecue are my contributions to society, I'm glad to share them."

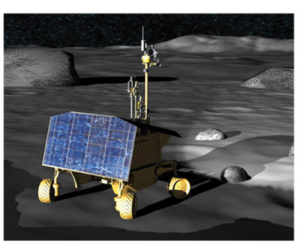
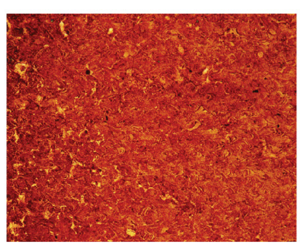
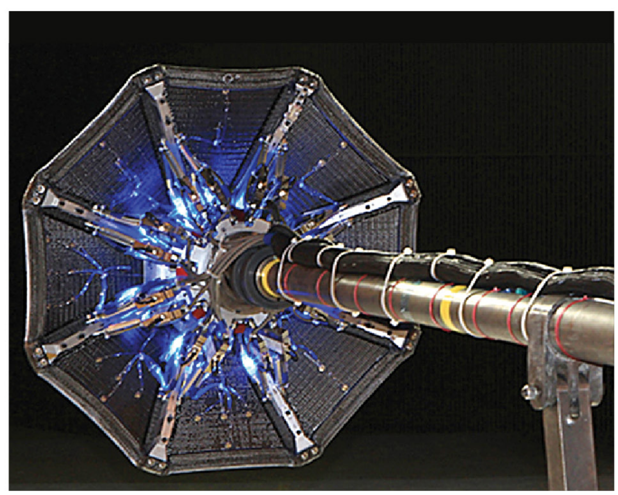
Howard Conyers was profiled in February 2015 in The Daily South, the online, self-described "hub of southern culture" section of SouthernLiving.com. This image Southern Living cites as taken during the 2014 Hogs for the Cause, Charleston, the inaugural event for this location. Hogs for the Cause raises money to provide aid and relief from economic burdens families face when a child is being treated for pediatric brain cancer. The next event will be held April 1 to 2, 2016, in the New Orleans City Park, which is the home location for this annual fundraiser. Come on down, y'all!



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NP-2015-10-655-LaRC