National Aeronautics and Space Administration

NASA

Game Changing Development Program

Game On

Ready for Launch

GCD Technologies Take Flight

New Astronaut Glove Designs Under Study

Oxygen Recovery Research to Evaluate Four New Ideas

Rover Operations Suite Makes a Run During Night Drive Testing

High School Students Become "Junior Game Changers"

Space Technology 2016

Team,

This year's Hollywood release of *The Martian* brought the concept of surviving on Mars into the public's eye and piqued interest in overcoming the technical challenges to do so. Do we have the disruptive technologies and innovative solutions to survive such a feat?

This year we made great strides to significantly improve existing solutions and enable new space science and exploration capabilities. Andy Weir's story of survival and ingenuity may be fictional, but the struggles his character Mark Watney face are real. "If the Oxygenator breaks down, I'll suffocate. If the Water Reclaimer breaks down, I'll die of thirst. If the Hab breaches, I'll just kind of explode. If none of those things happen, I'll eventually run out of food and starve to death."

GCD's Next Generation Life Support systems focus on converting available resources to provide oxygen, food, water and fuel for survival. Advanced materials and new manufacturing techniques are being used to reduce the weight on spacecraft structures while improving the performance of key systems. Next-generation power systems are being developed to provide propulsion and surface power needed to travel to and explore Mars. Robotic systems and rover technologies continue to gain momentum as we prepare for robotic precursor missions. And landing safely is the number one priority of the Advanced Entry Descent and Landing team, which is evaluating multiple techniques for a downselect in 2018. Each of these efforts allows us to make travel to Mars a reality.

2016 also brought significant emphasis on teaming with industry, academia and other government organizations. The team has done a phenomenal job bringing solutions to the table that pull from not only NASA's strengths but also the strength of strong partnerships that have direct infusion paths. From the ACOs and Tipping Points to the Industry Day and Technology Day on the Hill, efforts with strategic partnerships allow us to optimize the agency's technology investments.

Finally, but in my opinion most important, thank you for your continued dedication to growing the next generation of NASA's engineers, scientists and explorers. This year, more than a dozen Education and Public Outreach events were conducted and we had more than 200 students engaged with GCD. Inspiring students takes a unique ability to relate to the students. You have to make the technology tangible by sharing personal experiences with your work, both successes and failures. Our GCD team's work with transferring the two R5 humanoid robots to universities, the Early Career Initiatives, the NASA Robotics Initiative and the Big Idea Challenge are just a few examples of involving students/early career employees with NASA's mission. These opportunities engage them directly because we're not just talking about the great work we've done, we're having them actively participate in the technology development for what we still need to do.

Thank you for your continued support and for developing tomorrow's technologies today. Looking forward to a productive year in 2017!

Warmest regards,

Mary Beth Wusk

Game On 2016

Space Technology Mission Directorate

Game Changing Development Program Office

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The theme of this year's annual magazine is "Ready to Launch," but that phrase doesn't apply to only hardware going up into space. In addition to the successful launch, installation and testing of the Phase Change Material project in July of 2016, GCD also "launched" a number of other game changing initiatives, including Sharepoint, a GCD app, a university challenge, an industry day and a summer camp, among many others. Read more about these topics in this issue of Game On.

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Project team members share the latest updates

Phase Change Materials

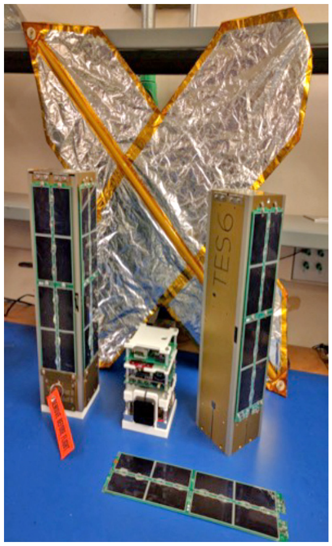
The phase change material heat exchanger (PCM HX) development project's objective is to create viable solutions for future exploration vehicles in the area of long-term supplemental heat rejection.

The risk of using a PCM HX is the fact that the expansion and contraction of the Phase Change Material may cause damage to the heat exchanger when used. The project has mitigated this risk by introducing a novel design feature called thermal shunts. This proprietary design methodology is expected to help mitigate the excessive pressure increases in the PCM HX during freezing/thawing.

Data will be communicated to the payload team's lab for evaluation of the HX's performance. Furthermore, United Technologies Aerospace Systems, the prime PI for the heat exchanger, will assess the data and provide a final report on its performance on orbit. This report will be submitted to Orion for verification of performance, which will lead to the Heat Exchanger design review for implementation into Orion's EM2 mission.

Phase Change Material Heat Exchangers are required for any human mission to the Moon and Mars. Due to this need, by testing viable PCM HX's on ISS, the project is helping drive down Orion's risk for implementation into its EM2 vehicle. *—Rubik Sheth, Johnson Space Center*

Entry Systems Modeling



Scheduled for launch with the 3U cubesat TechEdSat-5 (TES-5), the Exo-Brake technology is a large drag-modulated (like a parachute), passive means of deorbiting from low-earth orbit that can reconfigure itself as necessary to enable controlled reentry. The Exo-Brake demonstration planned is to perform a large-scale drag modulated test flight and hot reentry test.

These experiments are difficult and pose many challenges. The Corona project from the 1960s required 13+ tries before a successful deorbit was achieved. Knowing this, an important part of the design process is maintaining low cost and using incremental design—the technology is advanced piece by piece using various orbital and suborbital flights. Key hardware risks are extensively tested, first on the ground and then suborbitally and/or in balloon flights, prior to the first deployment in low-Earth orbit (LEO).

Data will be used to: a) perform analysis using the evolving numerical tools with the flight test data; b) improve the command/control and related interval; c) permit improved system HW (e.g., the winch control/thermal system) design and application for TES6-7; and d) provide data for scaling studies at 'full' scale applications.

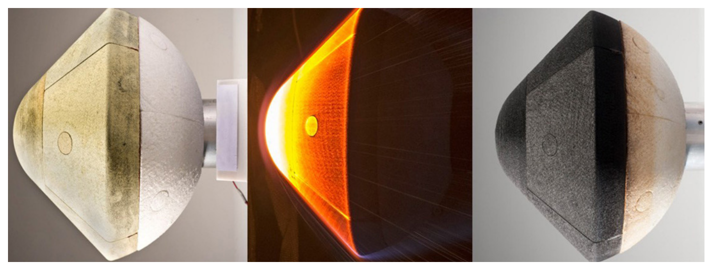
The intended primary use is to provide a nonpropulsive ('safe') means of targeted deorbit. Potential applications included on-demand payload return from ISS, free-flying flight laboratories in LEO, and end of life de-orbit of spacecraft. In addition to returning samples to Earth, the technology could be used to land small payloads on Mars or other planets with atmospheres. *—Marcus Murbach, Ames Research Center*

Conformal Ablative TPS

A Conformal Ablative Thermal Protection System (CA TPS) over a rigid aeroshell has the potential to solve a number of challenges faced by traditional rigid TPS materials. Compared with other tile or honeycomb type materials and conventional monolithic Phenolic Impregnated Carbon Ablator (PICA), CA TPS offers a high strain to failure, or compliant, nature that will make it much easier to integrate with aeroshell structures because larger segments can be used, reducing the overall parts count and the cost of installation.

The project is responsible for providing instrumented TPS bonded on to the aeroshell (heatshield and backshell) provided by Terminal Velocity Aerospace (TVA). In order to have mission success, we requested TVA to provide us the aeroshell and we verified manufacturing and integration process development by building and testing arc jet test articles very similar to flight configuration and size. This gave us the confidence to proceed with building and integrating the flight articles.

Because the test article size is just big enough to test in ground facility and small enough to be cost effective for flight, testing the same size article, post-flight test, at conditions very similar to that of flight will allow us to understand ground test facility to flight performance. This is important because it allows us to minimize the mass margin on actual large scale flights if our predictions based on ground measurement alone match that of flight.



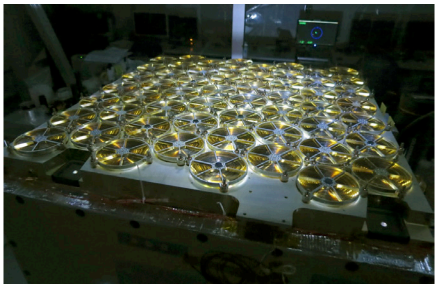
Successful flight test allows mission planners to have higher confidence in the conformal ablator and mission infusion is that much closure than without it. Missions to Venus, Saturn, Sample Return missions, Orion (back-up heat shield) could consider conformal PICA for future missions.

—Ron Chinnapongse, Ames Research Center

SEXTANT

SEXTANT is the Station Explorer for X-ray Timing and Navigation Technology. As part of a multipurpose mission, SEXTANT is planned for flight on SpaceX-11 with the Neutron-star Interior Composition Explorer (NICER) instrument for an in-space demonstration of X-ray pulsar navigation. This one-of-a-kind investigation seeks to demonstrate advanced navigation capabilities from a relatively low-cost instrument that takes advantage of an already existing platform, the International Space Station.

For a project like NICER/SEXTANT, the initial project disposition is to accept significant risks but do your best to mitigate them with thorough testing, and that was precisely our approach. We built numerous, early engineering models of



the most important hardware, and spent as much time testing with it as we could before we moved to the flight build. Then, as the flight build progressed, we performed those same tests on the flight payload and compared them to our engineering model tests to verify that they were in family.

Because we have GPS available with NICER, we will be able to assess our performance in real-time in the NICER telemetry stream. In addition, because all of the raw photon events will be telemetered to the ground, we will use that data to: 1) tune our ground testbed to match on-orbit performance, 2) evaluate navigation performance with realistic spacecraft local oscillator models, and 3) evaluate the performance of modified or new photon processing algorithms.

SEXTANT will attempt, for the first time on-orbit, to demonstrate real-time navigation using only observations from X-ray emitting millisecond pulsars, a process often called XNAV. This is a significant step in the quest to establish a GPS-like navigation capability available throughout our solar system and even beyond. Ultimately it may enable science beyond the outer planets or coordinated measurements over large distances.
—Jason Mitchell, Goddard Space Flight Center

Affordable Vehicle Avionics

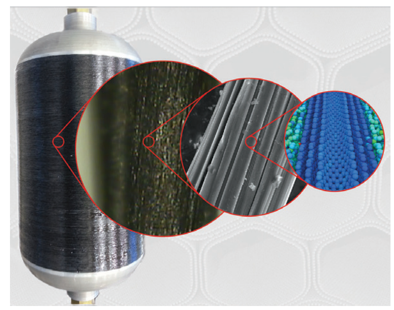
Public and private "nanolaunch" developers are reducing the cost of propulsion, but conventional high-performance, high-reliability avionics remain the disproportionately high cost driver for launch. Affordable Vehicle Avionics (AVA) enables nanolaunch providers to offer affordable rides to low-Earth orbit as primary payloads and its flight opportunity hopes to demonstrate technology advancements that can provide order-of-magnitude reductions in recurring costs of avionics suitable for guiding small launch vehicles to low-Earth orbit.

Critical challenges for AVA are survival and correction operation in the extreme launch environment, and questions regarding accurate GPS signals during ascent.

The test results will enable the AVA team to characterize its performance in the space launch environment, compare actual performance to desired performance, validate the AVA simulations of rocket performance, and obtain metrics about the labor and engineering costs of integrating AVA to any of a number of future rockets.

AVA will demonstrate a self-contained guidance system that can be integrated and operated at a fraction of the recurring costs of existing units, ready to license to launch vehicle vendors. *— Jim Cockrell, Ames Research Center*

Nanotechnology



Carbon nanotube (CNT) reinforced Composite Overwrapped Pressure Vessels (COPV) could enable 30 to 50 percent mass savings for aerospace structures as compared with carbon fiber lined pressure vessels.

Given a small sample set of COPV test vessels, there is a possibility that the amount of CNT required per vessel will increase, the maximum allowed pressure will be insufficient to move the cold gas thrusters and range safety may not accept the tank for flight. Mitigation: If A-basis allowables are not able to be obtained and the tank has a high safety factor then the operational pressure will be reduced to accommodate this. The pressure will yield the metal liner, but not approach the ultimate strength of the liner.

It seems that the team will need to answer the question: Do current best practices for quality assurance of traditional composites suffice for novel fibers such as CNT spun fibers? What metrics are critical during manufacturing and how are these validated? Do we need additional techniques to certify feedstock as of adequate quality? Part of this in my mind includes a total look at the manufacturing and quality maturity, not just one process.

There is a lot of value coming out of the work on establishing quality assurance standards for working with nano for structural applications. Obtaining certification requires a significant level of quality control to reduce uncertainties. The CNT COPV project is more than just flying a COPV as an alternative to a standard structure but the goal is to successfully infuse the use of carbon nanotubes to show their potential infusion on components that require structural support as well as light weighting.
—Azlin Biaggi-Labiosa, Glenn Research Center

Changing the Business Automation Game

—Robert F. Hodson, Deputy Program Manager,
Game Changing Development Program

This year the Game Changing Development (GCD) Program managed a technology development portfolio of about 75 activities to develop new capabilities for NASA missions. Many of these activities are technology firsts, having never been done before. Alongside these technology developments, the GCD Program is developing another first for NASA business automation.

This year marks the launch of three new management tools: GCD's cloud services site, an advanced SharePoint web site for program/project management, and the GCD Mobile App. The novel aspect of GCD business automation efforts is not just the collection of these new tools but an unprecedented level of connectivity between them. This connectivity allows project updates to be communicated directly to mobile users. For example, a change in a project's milestone can be communicated quickly, securely, and conveniently to a stakeholder's mobile device.

To further push the limits of business automation, GCD has built its mobile app on gaming technology for a visually rich and interactive mobile environment. The combination of visualization and interactivity with filterable data sets enables scenario-based analysis from a mobile device. Examples include looking at multiyear funding trends, project partnering, and project life cycle. Visualizing many other scenarios is only a few hand gestures away; accessing and interacting with information is easier than ever.

Robert Hodson.

GCD has blazed the trail from the desktop to mobile devices via the cloud, but many challenges had to be overcome along the way. The team tackled issues of network security, software licensing, 508 (disability) compliance for mobile apps, multisystems capability, and many other challenges. The development efforts spanned across three NASA centers and the rollout was across all centers including the Jet Propulsion Lab.

These business systems are now providing timely and consistent information for the GCD management community and its stakeholders. With the tough problems of initiating the effort and launching the application conquered, these systems continue to evolve to provide even greater program/project management efficiencies. It is our hope that GCD's effort to bring business automation and data mobility to our user community can "change the game" and serve as an example throughout all of NASA.

David Clark Company's unique pressure restraint. Image credit: David Clark Company.

'Hand in Glove' Efforts Put New Gloves in Hands of Researchers

—Denise M. Stefula

Over the summer of 2016, the Next Generation Life Support (NGLS) project received delivery from three industry partners of several new promising spacesuit technologies, namely for advancing glove designs and capabilities. Glove prototypes incorporating these technologies are now undergoing testing and performance evaluation under increased operating pressures and in the more challenging environments expected during future space exploration.

As NASA seeks to expand its horizons in space, current spacesuit and glove technologies must be advanced to meet the new challenges astronauts will face. These missions cannot be performed with existing suit technologies, for example, current EVA gloves have limited life, severely limited hand mobility, and are a significant source of injury during spaceflight.

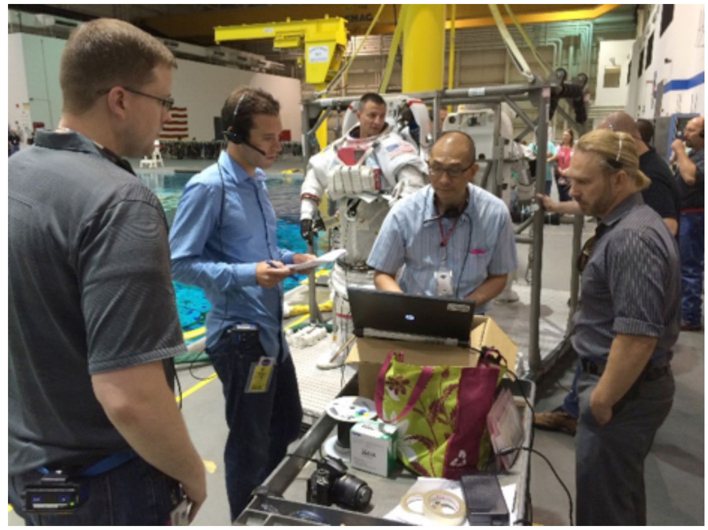
"When we look toward human exploration of new locations, such as an asteroid or Mars, the environments are quite different and we need to look at many factors to ensure our astronauts are kept safe," says Sarah Walsh, project element lead for High Performance EVA Gloves (HPEG).

NGLS research and development of new technologies with Space Technology's Game Changing Development Program focuses on providing capabilities to fulfill the needs of future exploration missions. Collaborating with NASA's Human Research Program, under the Human Exploration and Operations Mission Directorate, NGLS is investigating mechanisms causing hand injury and will be developing new gloves to significantly reduce injury and improve performance, including mobility and glove life.

"It has been incredibly interesting to see how new technologies have been brought in and applied toward advancing EVA gloves," says Walsh. "We have worked with a number of companies that have various areas of expertise and backgrounds. Going through the process of how to best bring new designs and materials into an environment that they may not be familiar with is challenging, but enlightening."

To say the efforts have been 'hand in glove' may seem cliché, but the close relationships NASA nurtures with industry, academia, and other government agencies help bring forward the best in new technologies for testing and advancement. The test series currently underway is evaluating range of motion, tactility, dexterity, grip strength and mobility. The glove technologies are:

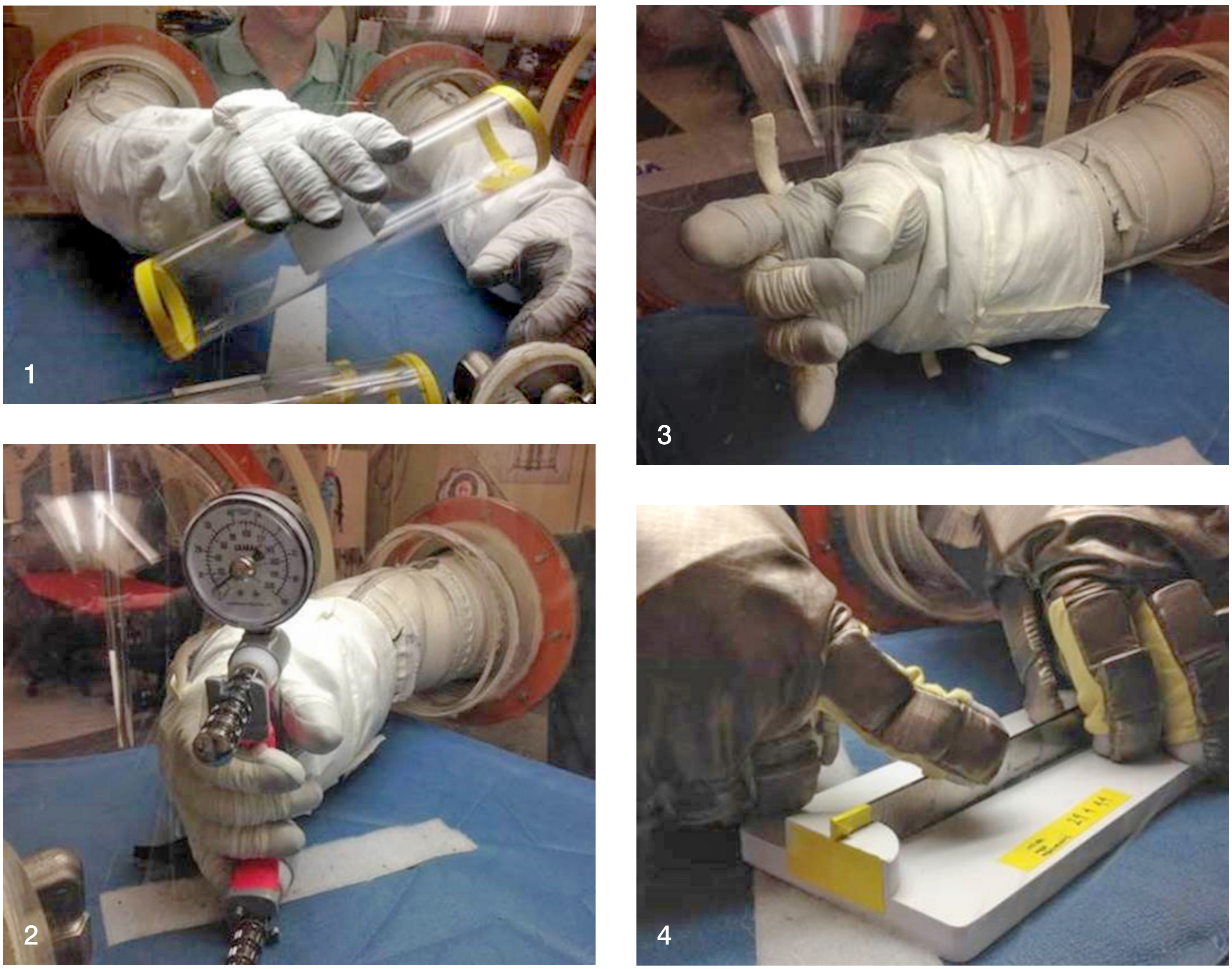
- ILC Dover, who has supplied spacesuits for NASA, delivered its latest iteration of gas pressurized gloves, which contained several new materials and components. Gas pressurized gloves have been the standard, using a bladder layer containing the gas and maintaining the pressure, a restraint layer providing structural support, and an outer layer providing thermal and physical protection from the environment.
- The David Clark Company, Inc., delivered a unique pressure restraint layer for gas pressurized gloves using "link net", an alternative style of pressure restraint the company is developing that has the potential to increase mobility. A link net restraint layer is a fishnet-like, loosely woven fabric that makes up the layer of a spacesuit or glove that helps the gear conform to the wearer's body.
- Final Frontier Design delivered its prototype mechanical counter pressure gloves, a concept that counteracts the effects of space (which expand the body) by applying counter pressure to an astronaut's body with a tight material that has limited elasticity instead of compressing the body using a volume of air.



The test team follows procedures to configure the sensor suite for data collection. In the background, a test subject prepares for testing procedures, which were held in the Sonny Carter Neutral Buoyancy Laboratory at Johnson Space Center.

Test subject performing glove box operations in front of data collections screen wherein real time glove pressures and several views of glove box can be viewed during testing.

- The Robotic Assist Glove, also known as the Spacesuit RoboGlove, is a spinoff of the highly successful RoboGlove system developed as part of a partnership between General Motors and NASA. The assistive device augments human strength by transferring part or the entire grasp load from human tendons to artificial ones in the glove. Current work to integrate the technology into an advanced spacesuit design is being led out of NASA's Johnson Space Center.
- Sensor Suite/Sensor Glove system testing at Johnson was completed with about 30 different sensors, collecting data on fingernail strain, force, temperature and humidity. These data are expected to provide additional insight into glove performance, discomfort and injury, all part of HPEG's overall objectives to mature design to reduce injury and improve overall performance.



Comparative glove performance tests are performed in the delta pressure glove box at Johnson's Advanced Space Suit Laboratory. Testing involved several different protocols for evaluation glove performance on the HPEG-ILC Dover gloves (1), Robotic Assist gloves (2 and 3), and HPEG David Clark gloves (4).

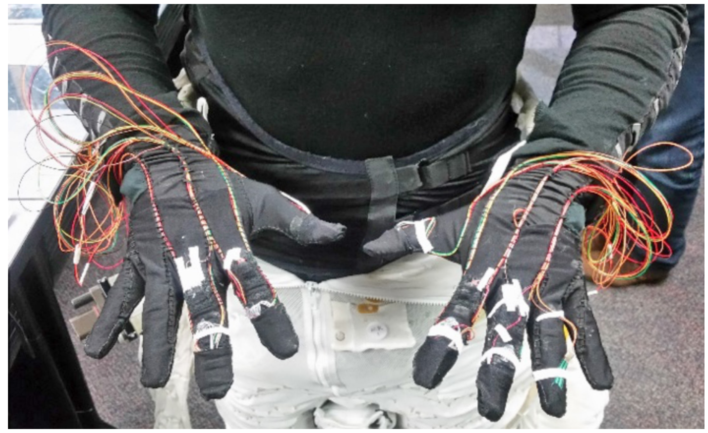
The technologies being tested reflect what Walsh says has been of great interest for a long time: alternative pressurization concepts, the role robotics concepts can play, and improved materials to counteract damage.

"Mechanical counter pressure is an idea that, instead of using gas pressure to generate the required pressure on the body, we can use a physical restriction to provide the pressure, similar to compression socks," says Walsh. "There are numerous potential benefits such as reduced mass and increased mobility."

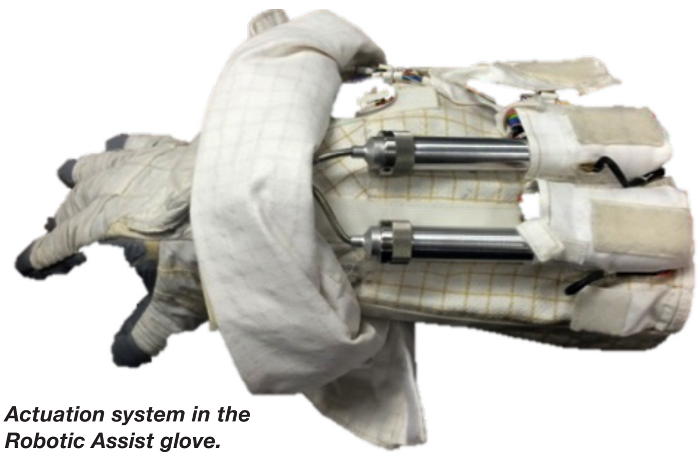
Because gloves have three layers, and so much is required of the gloves, they are bulky and the pressure differential between outside and inside causes them to be very stiff. It's actually quite strenuous to physically move your hands in EVA gloves.

"The goal of robotic assist gloves research is to understand the benefit associated with adding a system that can help offload some of the physical demand on an astronauts' hands and to understand the integration requirements with the rest of the spacesuit," says Walsh. "Our other gas pressurized prototypes are focused on adding new components, materials, and manufacturing techniques to achieve a more flexible, durable and capable glove for the future."

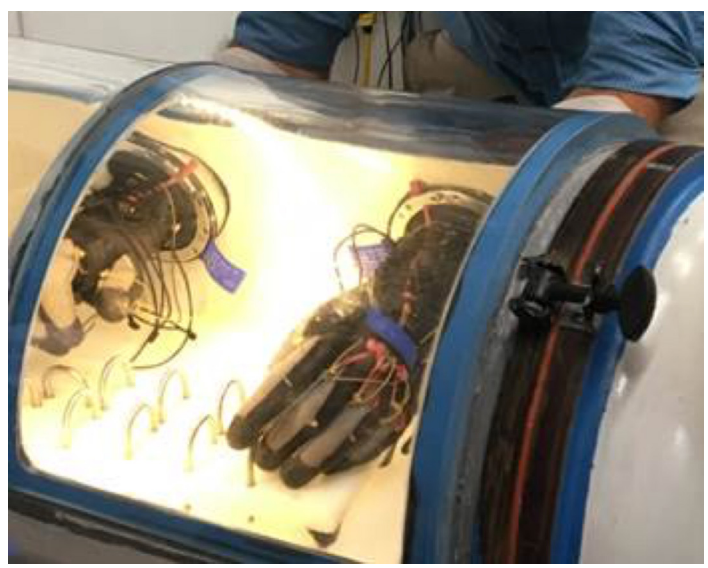
A major focus for us is to think about the larger integration aspect," Walsh continues. "The glove is an important part of an entire spacesuit system and that spacesuit will be used for specific missions. We need to make sure we consider how these technology advancements may have broader impacts. And some of these discoveries will have applications that reach further than the spacesuit glove alone."



Sensor gloves configured for testing in Johnson's Sonny Carter Neutral Buoyancy Lab.



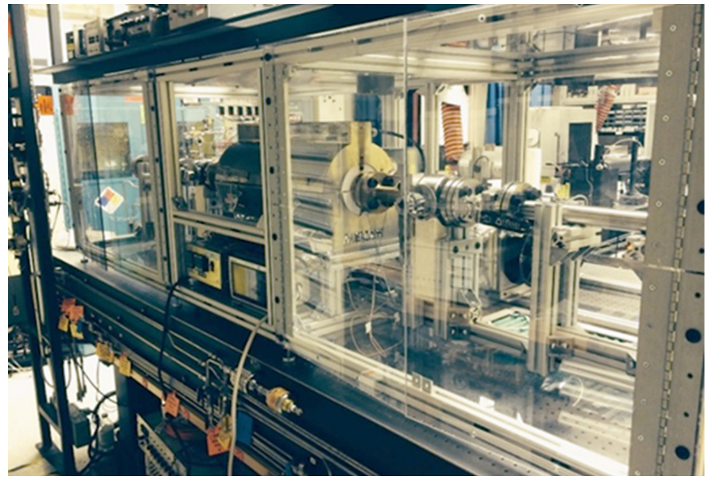
Actuation system in the Robotic Assist glove.



Final Frontier Design's mechanical counter pressure gloves performing a peg board dexterity glove box test at FFD's Brooklyn facility.

got O_2?

NASA Scores Four Ideas



On long duration deep space missions, providing crewmembers with a steady supply of oxygen is a real challenge. Because resupply is not an option and taking huge tanks of oxygen on exploration spacecraft is not practical, oxygen must be recovered from what is produced during normal metabolism.

Astronauts breathe in oxygen and most is turned into carbon dioxide and water vapor. Getting the oxygen from the water is pretty straightforward and can be done with electrolysis alone. The real trick is efficiently getting oxygen from the carbon dioxide.

"There are many methods for doing this but on an enclosed spacecraft with limited power it becomes a real challenge," says Kevin Kempton, Game Changing's program element manager for Affordable Destination Systems and Instruments. "Right now systems on the International Space Station only recover about 50 percent of the oxygen. About half the oxygen is vented as methane, which is a byproduct of the current recovery process."

To explore the technical possibilities, NASA's STMD created the Spacecraft Oxygen Recovery (SCOR) project, and a Space Tech REDDI, Game Changing Development Program call for proposals addressing "Advanced Oxygen Recovery for Spacecraft Life Support Systems" was put out as a NASA Research Announcement. NASA uses competitive, collaborative opportunities to complement NASA research initiatives and address specific technology gaps in NASA programs.

In Phase I, four SCOR teams were competitively selected to develop their concepts into engineering development units (EDUs) that could be evaluated for future trade studies. A minimum of 75-percent oxygen recovery was specified as a hard requirement and teams had to predict the "equivalent system mass" of a flight unit so technology comparisons can be made.

NASA received four very different EDUs over the summer for further testing as potential components in the overall Environmental Control and Life Support System (ECLSS) on future spacecraft. All four development teams overcame significant technical challenges to deliver their systems in time. These teams developed new catalysts, new ceramic fabrication techniques, new chemistries, and novel mechanical systems to make their EDUs work. Many of the techniques have great potential for use in terrestrial applications here on Earth.

The four teams were composed of personnel from industry, academia, and NASA:

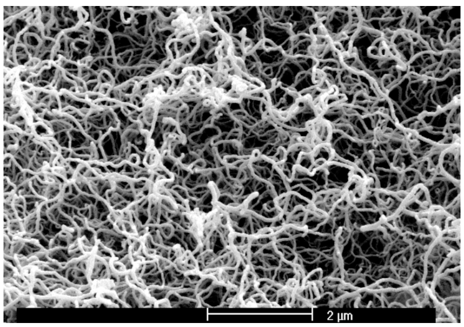
1. UMPQUA Research Company with Continuous Bosch Reactor Technology
2. NASA Glenn Research Center/pH Matter LLC with a Solid Oxide Co-Electrolyzer (SOCE) and a Carbon Formation Reacto r
3. NASA Glenn Research Center/University of Delaware with an Ion Exchange Electrolysis Unit and a Carbon Formation Reactor
4. University of Texas-Arlington with a Microfluidic Electrochemical Reactor

Kempton explains that SCOR technologies can also play a key role on the surface of Mars where carbon dioxide is readily available in the atmosphere. "Using in situ resources to generate oxygen for propellants and consumables will be a big driver in making a trip to Mars feasible," he says.

NASA is continuing SCOR technology development with a Phase II effort in 2017. The SCOR team will take what has been learned and advance this key exploration technology closer to flight readiness.

Engineers at UMPQUA Research Company, Myrtle Creek, Oregon, developed a continuous Bosch reactor technology in which oxygen is recovered from carbon dioxide in the form of water using catalysts developed in-house at its research facility. A water electrolysis unit is operated in tandem to provide oxygen to the crew. The continuous Bosch reactor operates at high temperatures to achieve nearly 100-percent recovery of oxygen.

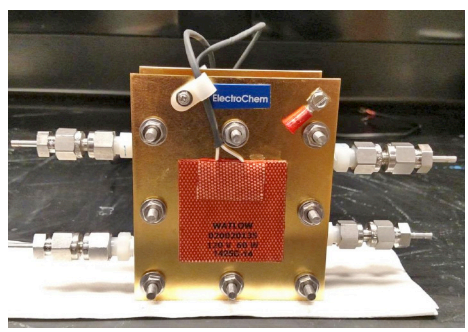
Carbon-coated catalyst developed for UMPQUA's continuous Bosch reactor.



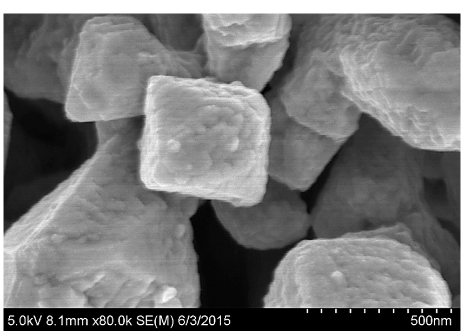
Scanning electron microscopy image of carbon formed on catalyst prepared using pH Matter's proprietary formulation and preparation technique.

Engineers at NASA's Glenn Research Center teamed with small business pH Matter, LLC, Columbus, Ohio, in developing an oxygen recovery system comprising a high-temperature solid oxide co-electrolyzer (SOCE) combined with a carbon formation reactor. The SOCE produces oxygen directly from the co-electrolysis of water and carbon dioxide. The carbon formation reactor employs catalyst formulations and preparation techniques to achieve nearly 100-percent recovery of oxygen.

Another group of engineers at NASA's Glenn Research Center teamed with University of Delaware investigating an approach combining an ion exchange membrane electrolysis unit and a carbon formation reactor. The room-temperature electrolysis unit, developed at University of Delaware, employs an ion exchange membrane in which oxygen is electrolytically produced directly from carbon dioxide, also producing carbon monoxide as a byproduct. The oxygen is provided to the crew and the carbon monoxide is directed to the carbon formation reactor, resulting in nearly 100-percent recovery of oxygen.

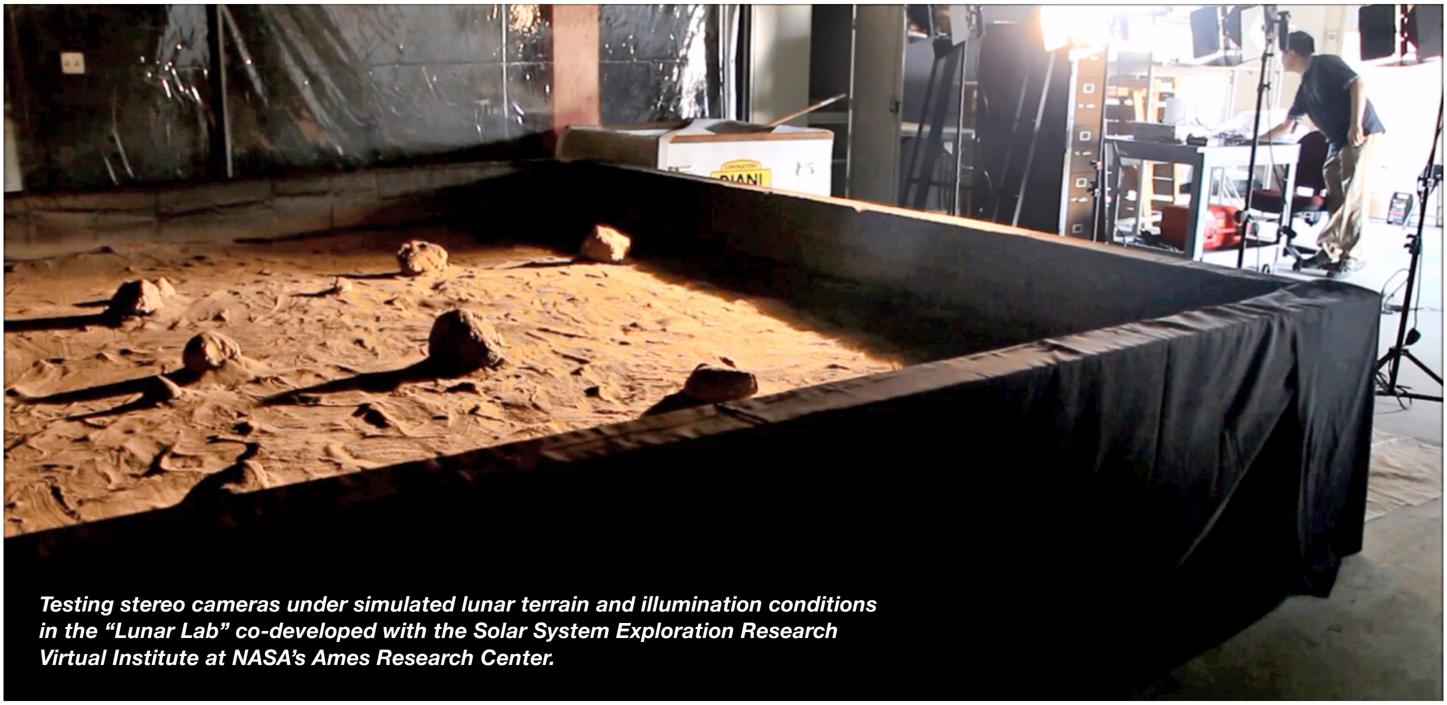


University of Delaware's ion exchange membrane electrolysis unit.



Scanning electron microscopy image of catalyst crystals electrodeposited within UT-Arlington's microfluidic electrochemical reactor.

The University of Texas-Arlington developed a microfluidic electrochemical reactor designed to recover oxygen from carbon dioxide through carbon dioxide electrolysis. In this approach, oxygen is released directly to the cabin while byproduct hydrocarbons may be discarded or stored for other purposes. Using experiences in electrode development and fabrication, the team is optimizing an electrochemical cell designed to operate at room temperature and pressures and achieve approximately 77-percent recovery of oxygen.



Testing stereo cameras under simulated lunar terrain and illumination conditions in the "Lunar Lab" co-developed with the Solar System Exploration Research Virtual Institute at NASA's Ames Research Center.

Night Drive Testing Illuminates Capabilities of Full Rover Operations Suite

—Denise M. Stefula

Nearly all of us believe in our above-average driving capabilities, although many are a little nervous about driving at night. Even NASA rovers, with all the high tech capabilities afforded them, find some challenges with night driving.

The Game Changing Development Program's Human Robotics System (HRS) project completed exploratory engineering tests August 29 to begin studying what it takes for rovers to successfully perform night driving near or at the lunar poles.

Testing was conducted at NASA's Ames Research Center using the K-Rex rover prototype and at Johnson Space Center using the RP rover prototype, and evaluated several capabilities. "The night drives involved teams from Resource Prospector (RP) Mission operations, science and engineering, and culminated from years of work in developing designs for a very different type of rover mission than NASA has done before," says Scott Askew, rover mobility lead at Johnson.

"No one has driven in the polar regions of an airless body," says Uland Wong, HRS project engineer at Ames, who is leading the lunar regolith lab characterization efforts. "NASA rovers use cameras and stereo vision to navigate. We are questioning if this will work because without direct evidence, can we infer what driving at the poles will look like? Can we use this information to train human operators?"

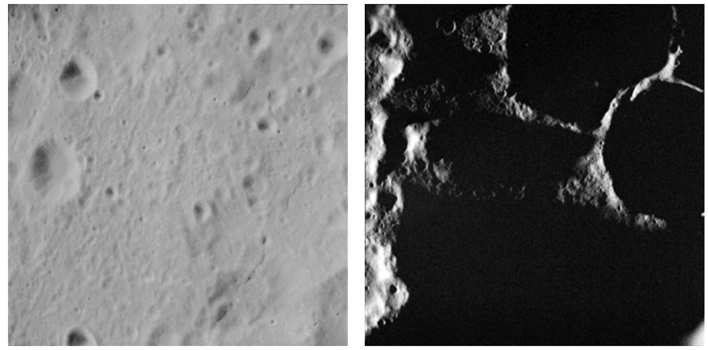
Currently, rovers on Mars operate only in daylight; researchers want to advance the rover's potential to function in dark conditions to prepare for NASA's Advanced Exploration Systems RP Mission, which aims to be the first mining expedition on another world. Building on earlier findings proving that water exists near the lunar poles (e.g., Lunar Crater Observation and Sensing Satellite), RP plans to use a suite of instruments to locate elements from the lunar polar region. The planned rover is being designed to excavate volatiles in support of in situ resource utilization.

"For exploration of near-polar sites, the sun ranges from below the local horizon to a maximum of around 11 degrees elevation over the period of a lunar "day", or about 28 Earth days," says HRS Project Manager Bill Bluethmann. "Low sun elevation and lack of atmosphere to scatter light results in harsh contrasts near the poles, with bright surfaces and long, dark cast shadows as well as permanently shadowed regions in low lying areas and inside craters. Pilots of remotely driven rovers exploring such regions will need to be capable of driving in the dark or in harsh contrast regions."

During testing, a number of options were explored, including driving with stereo versus mono cameras, varying compression for image collection, and skid steer versus crab drive. Test conditions were a rough approximation of lunar polar low-light conditions and sought to determine how well pilots can judge size and distance of obstacles, navigate to specified locations, and gauge decision time based on infrequent images and large obstacle size (i.e., rocks).

Lessons learned from the night drives will inform not only the future planned RP Mission to study the lunar polar regions, but also refinement of operational methods and key rover capabilities to achieve success in this and other mission types.

One informative discovery had to do with using cameras for situational awareness. The cast shadows resulting from polar lighting conditions created dark regions wherein



A drastic difference in the optical environment exists between a planetary body's equatorial high noon (left) and the polar region (right), as seen in these lunar images, which impacts a rover's capability to traverse the surface and collect data.

assessing slopes or obstacles in the terrain can be very difficult. The type of camera being used is highly important to rover operations for judging obstacle size and distance, and for determining orientation.

"A fixed, narrow field-of-view camera makes acquisition of good situation awareness slow," says Bluethmann. "The rover must stop and reposition itself multiple times to get a broader overall picture of its environment. It is also difficult to assess the scale and relative distance to obstacles using only monocular images without additional external reference."

Testing also revealed that with limited field of view through a monocular camera and the inability to build maps on the fly, it is extremely difficult to remember terrain hazards. "The operators were surprised several times by obstacles previously encountered," says Bluethmann.

The K-Rex rover prototype is designed to operate over rough terrain and uses software to find traversable paths across obstacle-filled landscapes. This image was captured during night drive testing at Ames Research Center.

The Resource Prospector rover prototype is designed to reconnoiter a planetary surface, create maps of the nature and distribution of volatiles, and even demonstrate processing while on the surface. This image was captured during night drive testing at Johnson Space Center.

These observations, among many others collected during testing, will help the HRS team refine the tool suite for operators to achieve desired surface mobility, better enabling rovers in reaching places researchers need them to go to collect science. To achieve manned deep-space exploration, harvesting resources in situ to create breathable air and potable water is paramount for humans to live and work in these destinations.

Hydrogen and oxygen—the basic components of air and water, as well as rocket fuel—are known to exist on the moon. A successful lunar mining effort capturing the elements necessary for survival, like that the RP Mission has planned, brings us one step closer to understanding how we can use in situ resources to generate vital consumables during extended missions.

The August 2016 night drive testing culminated from 2 years of work by researchers and engineers throughout the Agency. While under advancement with the Human Robotics Systems team, many rover technology achievements have been realized during 2016. This picture gallery highlights just a few elements of the rigorous testing that has occurred.

November 2015

Active Response Gravity Offload System (ARGOS) testing covered numerous capabilities, such as gathering data to understand traverse capabilities in soil simulant. Specific objectives for understanding included slope, wheel geometry, and sensitivity of traverse capability to ground pressure.

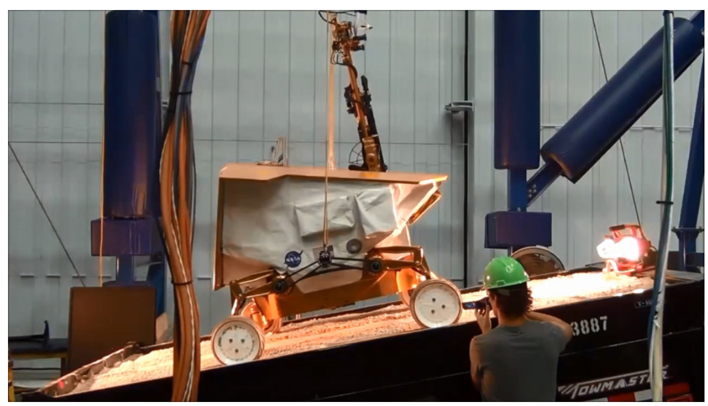
During the ARGOS traverse testing, different wheel geometries (below) were studied.

Testing of rover mobility exiting the pallet lander (top right) demonstrated feasibility of getting off the lander with up to a 30-cm step, simulating having landed on a rock. The rover body was yawed to offset wheels coming off the ramp, and

RP15 Wheels

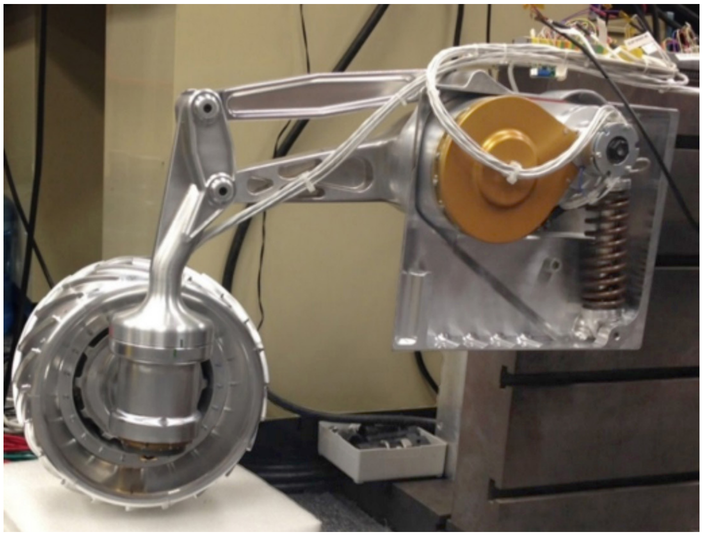
Slicks

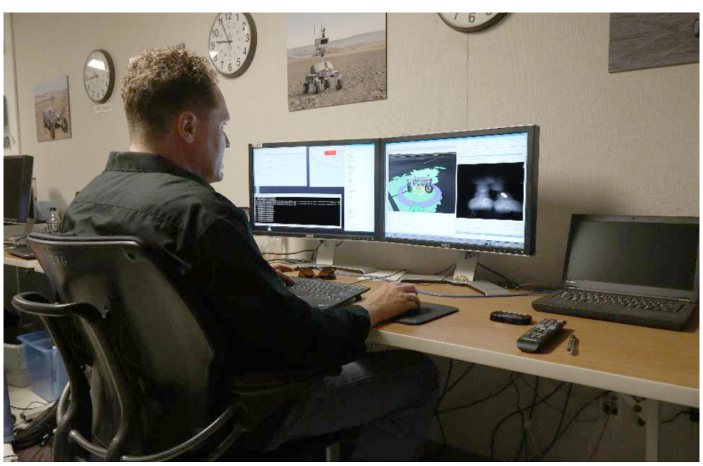
Grousers



the suspension system was evaluated for “stepping” off the pallet one wheel at a time.

The ARGOS testing also performed mission risk reduction testing to determine stability of drilling with the rover on various slopes (above). Even with the rover at a slope of 20 degrees the drill saw no slippage or experienced any excess side loading while drilling into simulant tubes of JSC-1A. Additional testing over the prior year has found similar results, thus the probability of this risk has been greatly reduced in the project’s risk matrix.





March 2016

Thermal vacuum testing of rover components (top left) verified the commercial-off-the-shelf sensors and motors, as integrated in the RP15 system, performed nominally over the defined operational temperature range as well as in a vacuum environment. The model-based torque controllers used in RP15 demonstrated their ability to manage the wide efficiency variation of the Harmonic drive gear trains. Read more about this milestone here: https://www.nasa.gov/image-feature/resource-prospector-progresses-with-thermal-vacuum-testing

April 2016

Shock/Vibe testing of rover components (middle left) covered functional checkouts during and post-test for mobility, mast deploy, gimbals, cameras, and sampling drill. Sine sweep data was used for identifying resonant peaks in rover structures, particularly at payload interface locations. The test article was subjected to acceptance and qualification levels as set forth in the environmental specifications, and only one minor interference was found. Overall the simple sheet metal structure performed quite well with a few areas identified for stiffening to be added.

August 2016

The full rover prototype operations tool suite evaluation occurred during night drive testing. Below left, Mark Allan of the Ames Research Center Intelligent Robotics Group uses the VERVE driving tool, an integrated 3D view, to guide the K-REX rover through a simulated traverse using waypoint commands. Using the hazardous obstacle detection and mapping features, Mark uses the synthetic map of the environment to determine waypoint commands for the rover. In contrast, the black and white image displayed on the right of his monitor was the only visual aide he was provided in the monocular driving test, with no ability to track obstacles as the rover moved. Coordinating these tests with the Resource Prospector Science and Mission Ops team members demonstrated critical benefits of the rover driving tool suite being developed under the STMD Rover Technologies.

GCD Tasks: *A task is meant to be a small, limited timeframe activity that allows a civil servant to explore an idea or concept to see if it merits further investigation and investment in the Game Changing portfolio.*

SUPERball Bot Harnesses Forces at Play

—Denise M. Stefula

Each planet and moon in our solar system is unique, although many have characteristics in common that can be hazardous for exploration—unstable crevices, ravines and steep cliff faces, broken jagged ice, and rocky, boulder-strewn terrains—all of which are inaccessible to the currently used wheeled rovers. These locations are largely excluded from exploration planning because one mishap can end a mission.

A few years ago, a team at NASA's Ames Research Center, supported by the NASA Innovative Advanced Concepts (NIAC) Program, established the value and feasibility of a new class of structurally compliant "tensegrity" robots. These robots are so resilient that theoretically they do not need air bags to land on other planets and can safely accommodate the risks inherent in terrains previously left out of mission planning, opening up new exploration strategies and enabling new mission profiles.

SUPERball Bot, a seedling task through 2017 under the Game Changing Development Program's Human Exploration Telerobotics 2 project, is investigating sensing and control algorithms for these novel tensegrity robots, and building a new prototype to demonstrate the mission concept.

Tensegrity is a structural principle—based on isolated components in compression inside a net of continuous tension—that offers innovative ways of thinking about how parts and wholes interact. The compression components (bars or struts) do not touch one another and the tension members (cables or tendons) delineate the system spatially.

This characteristic property produces exceptionally robust structures for a given mass and for the cross section of components. The structure's integrity is derived through balanced tension, or the forces at play among the cables.

The SUPERball task is establishing fundamental engineering principles for this new class of robot, paving the way for researchers to design and build tensegrity robots with increasing complexity and sophistication.

"Going forward, we will be building, testing, and then building another iteration of a single SUPERball 2.0 rod over the next several months, and then building out the full robot (i.e., six identical rods) in the spring of 2017," says Vytas SunSpiral, task manager for SUPERball at Ames. "Next summer we will start testing locomotion controls and perform increasingly higher drop tests until we demonstrate our intended target for this prototype of landing at 7.5 m/s by rolling off the roof of a building and then proceeding to a mock science target."

Ultimately, the goal is to demonstrate a full suite of mission relevant capabilities in one integrated terrestrial prototype. Features include the ability to deploy from a packed launch configuration, land at high speeds, move to targets of high scientific interest, and place instruments at desired science sampling locations.

SUPERball is only a single example of what is possible with this new class of robot. Others include lightweight, robust-legged robots with the terrain-access capability of a mountain goat—opening up whole new possibilities for accessing high priority science targets on the planets and moons of our solar system.

The SUPERball Bot is conceptualized here landing without assistance.

Oxidizer Turbopump Offers the Ability to Demonstrate Components

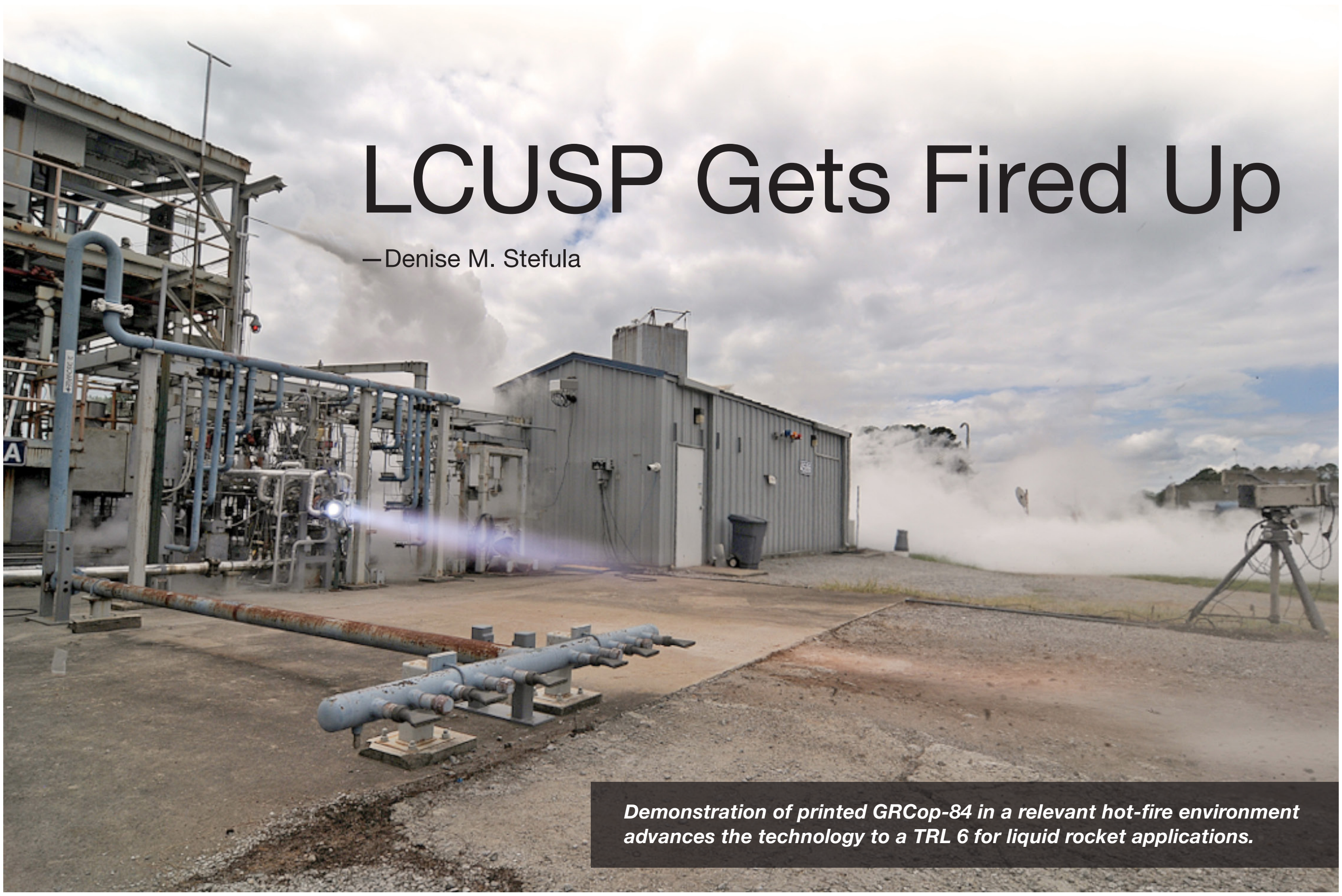
The Oxidizer Turbopump offers the ability to demonstrate additively manufactured rotating, vaned, and critical pressure vessel components in relevant operating environments. These include the main housings, impeller, and turbine components. The images show the additively manufactured impeller (right) and pump housing (below). One goal of the task is to understand the benefits and limitations of additive manufacturing as it applies to the complex geometries needed for rocket engine turbomachinery. Plans include turbopump assembly and component testing in 2017.

Bioregenerative Closed Loop Life Support System Investigates Food Production

Bioregenerative Closed Loop Life Support System, a task under the Game Changing Development Program's Next Generation Life Support project, is investigating food production in situ that will reduce the mass required to produce food and add essential nutrients to crew members' diets. One example is genetically engineered plums, which flower and fruit in as little as 1 year. These plums were developed by the U.S. Department of Agriculture, Agricultural Research Service, and produce fruit on very small (dwarf) plants. Technology Lead Ray Wheeler, NASA's Kennedy Space Center, says "in situ food production systems will require efficient production approaches and recycling of nutrients (e.g., from inedible biomass and wastewater) to increase mission autonomy." In this image, Dr. Matt Mickens, NASA Postdoctoral Program fellow, is pollinating dwarf plums grown at Kennedy.

LCUSP Gets Fired Up

—Denise M. Stefula



Demonstration of printed GRCop-84 in a relevant hot-fire environment advances the technology to a TRL 6 for liquid rocket applications.

The Low Cost Upper Stage Propulsion (LCUSP) project achieved a technology first August 10, 2016, at NASA's Marshall Space Flight Center when the largest GRCop-84 copper alloy, 3D printed combustion chamber underwent hot fire testing. NASA is investigating fabricating rocket engine combustion chambers using additive manufacturing processes, which promises time and cost savings over conventional fabrication methods, making rocket engines more affordable for everyone.

The GRCop-84 (copper, chrome, niobium) alloy was created by NASA's Glenn Research Center. It is under investigation with the Game Changing Development (GCD) Program because this unique alloy requires no special fabrication methods or techniques, it can be manufactured in a variety of shapes, and its process can be easily scaled to produce large components. GRCop-84 also has a good combination of increased thermal and mechanical properties, making it well-suited for rocket thrust chambers, which must use propellants as coolant to cool the chamber walls to around 1000 °F in an environment where combustion gas temperature exceed 5,000 °F.

"The first step to prove out this process was to fabricate the chamber out of GRCop-84 using Selective Laser Melting, or SLM," explains GCD's Acting Program Manager, Mary

Beth Wusk. "SLM uses a laser to heat up the copper material consistent with a 3D CAD model of the chamber. It is an impressive process to watch the chamber materialize as the machine continues to add raw material and the laser melts the material into the structure, one layer at a time."

Manufacturing time for a rocket engine combustion chamber using standard procedures presents a challenge because it can take up to 65 weeks. With new additive manufacturing techniques such as 3D printing to fabricate the rocket engine combustion chambers, the team plans to reduce manufacturing time to approximately 27 weeks.

LCUSP Project Manager John Fikes says there are other benefits beyond the nearly 60 percent time savings in the manufacturing process. While GRCop-84 properties are highly desired for rocket applications, the alloy is more expensive than alternatives. SLM printing of GRCop-84 improves that cost difference by eliminating some steps other alternatives require.

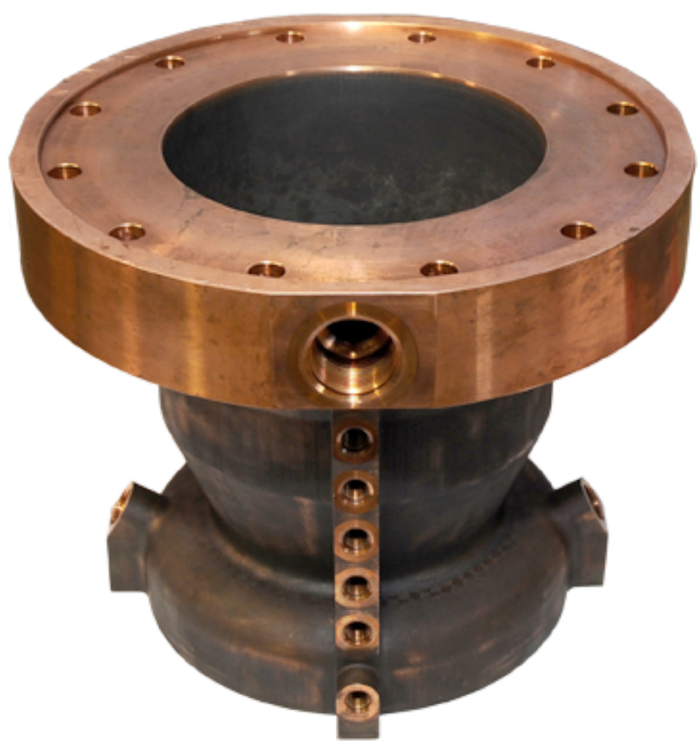
"The ability to SLM-print copper combustion chamber liners will reduce the cost of space transportation by eliminating several fabrication steps used in conventional manufacture of chambers," he says. "Additional savings can be realized for engineering as well by reducing the time required to build and revise these designs. This technology also allows engineers to tailor designs and include custom geometries that were costly or impossible to realize in parts before the technology was developed."

The combustion chamber was built up from over 7,000 individual layers of laser-melted GRCop-84 powder. The printed structure included 107 axial coolant channels with a thin hot wall to aid conduction and with printed inlet and exit manifold volumes. Researchers want to understand how the additive manufactured chamber and nozzle perform under extreme temperatures and pressures simulating conditions inside the engine as it burns propellant during flight.

Wusk says the test will provide important thermal data to verify and validate thermal models. "GRCop-84 was selected for its ability to withstand high temperatures. The team needed to verify that the material and manufacturing techniques would withstand the harsh environments of a hot fire test. The chamber successfully completed the testing with no apparent rough spots on the wall and no burn-throughs."

"This was the first ever hot fire of a printed copper alloy chamber using fuel—methane in this case—flowing through integrally printed passages to cool the high heat-flux throat region," says LCUSP Lead Propulsion Engineer, Chris Protz. "The hardware performed excellent, and looks like new post-test, demonstrating the viability of using components manufactured with SLM in relevant environments."

The chamber tested included several features to collect thermal data that were enabled by additive manufacturing, including thermocouple ports spaced along one of the axial channels and chamber pressure access through the hot wall. Data from these tests will be compared to existing thermal models and used in design improvements of future printed and methane-cooled chambers.



LCUSP additively manufactured copper alloy chamber.

"For some of the testing, methane was completely vaporized from liquid to gas within the chamber passages," Protz says. "The thermal data achieved are unique and will advance the state of knowledge on cooling chambers with subcritical methane. Data collected during testing feeds back into thermal models to improve predictive capabilities for phase-transitioning methane coolant and also into analysis used to design printed coolant passages."

Demonstration of printed GRCop-84 in a relevant hot-fire environment advances the technology to a TRL 6 for liquid rocket applications, meaning it is one step closer to a system prototype demonstration in a space environment. In the more immediate future, Fikes says demonstrating the technology in this highly challenging environment makes it available for use in a variety of propulsion applications, including ongoing projects such as a 4K lb_f- and a 22K lb_f-thrust-class methane engine.

Data will also be used to improve thermal models for the LCUSP LOX hydrogen GRCop-84 additive-manufactured 35K lb_f-thrust chamber that will be hot fire tested in 2017. The 35K lb_f-thrust-class hydrogen engine will incorporate an additively deposited nickel alloy (Inconel 625) jacket applied by NASA Langley Research Center's LCUSP team members. The two materials combined on this prototype will allow the engine chamber to handle relevant-environment temperatures that an engine will experience.

"Now that this hot fire testing effort is complete, the team will deliver the integrated GRCop-84 chamber with the required Inconel cladding over the chamber to provide additional structural support for the engine," says Wusk. "The team has taken lessons learned from the earlier manufactured units and are in the process of fabricating the final prototype for testing in late FY17."

NASA will continue to mature additive manufacturing technologies for rocket chambers and nozzles, building a foundation of and sharing test data on materials properties and design, enabling new upper stage engine development previously impossible with conventional fabrication methods. Future partnerships with commercial space industry could include materials development, additive manufacturing of engine components, machining techniques, and sharing of test data and test infrastructure.

Pictured here is the LCUSP team at the methane chamber hot fire test stand; from left to right: Chris Protz, Robert Johnson, John Fikes, Eric Eberly, Tony Kim, Sandy Elam.

A Camp Where 'Junior Game Changers' Get Their Game On

—Amy McCluskey

Arduinos. Spheros. Microcontrollers. All foreign sounding words to a group of rising ninth graders from Newport News who, before coming to NASA's Langley Research Center, on July 25, hadn't had much interaction with robots or drones.

"What IS an Arduino?" asked student Evan Shephard.

That answer and many others came during the four-day camp, which offered 35 rising high school freshman an opportunity to learn more about science, technology, engineering and math (STEM) from NASA experts.

The Junior Game Changers Camp was the brainchild of Mary Beth Wusk, acting program manager for the Game Changing Development (GCD) Program and avid supporter of education and internships.

Wusk wanted to create a camp that reached the "at-risk" students, the ones who maybe just needed a little nudge in the right direction, a positive role model, and some extra encouragement to get them to pursue a STEM-related field.

"We really wanted this camp to be innovative and different, and we wanted to reach students who might not easily get an opportunity to come to a NASA center," said Wusk.

Mary Beth Wusk gives soldering pointers to Devonté Williiams.

The rising ninth graders are also a part of the Newport News schools system's STEMulating Minds summer program, a free offering for Heritage High School Governor's STEM Academy.

The academy is designed to raise students' aspirations and expand their options, whether it is in STEM-related college studies or technical careers.

For Junior Game Changer Kelvin Kariuki, the NASA camp reaffirmed what he already knew—he loves engineering and computer programming.

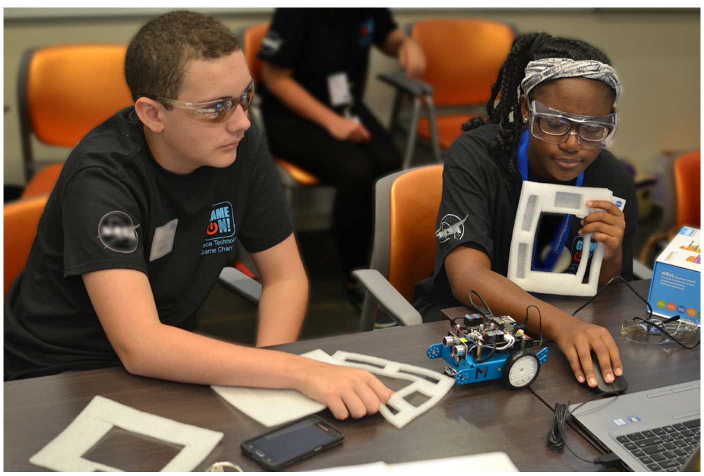
"I really enjoyed building the mBot," said Kelvin. And one word he'd use to describe the overall experience?

"Awesome!"

Kelvin said the camp wasn't what he expected. "I thought we'd be in rooms with people talking all day," he said.

That wasn't the case.

In the four short days the students were in camp, they programmed mBots, Sumos and Ollies, flew drones, learned Autodesk and Tickle, worked with 3D printers, soldered, and toured Langley facilities such as the flight simulators, hangar and ISAAC robot under the guidance of GCD staff and interns, the National Institute of Aerospace, and volunteers.



Alexander Strait and Cheyanne Harris program their mBot.

Lanetra Tate, with Damian Taylor, discusses challenges.

Jahya Hawk-Parker practices soldering skills.

Nancy Hornung, GCD program analyst, served as the camp's project manager. Hornung said that all the planning was worth the outcome.

"It is humbling to me to think that our camp interaction may change a life," Hornung said. "These students were eager to learn and we definitely planted seeds."

Another innovative aspect of the camp is that Wusk used the energy and youth of several NASA Internships, Fellowships and Scholarships (NIFS) interns who were supporting GCD as part of the Space Tech Academy.

The interns did everything from develop the curriculum for the camp, from teaching and supervising the campers to documenting the experience with photos and video.

"Don't allow anyone to label you. Create your own path."

—Lanetra Tate, Program Executive

Mark Marioneaux, a physics and engineering teacher at Heritage High School, said the camp has been good for the students, particularly the hands-on activities.

"They really loved the drones and the soldering," Marioneaux said. "All of the students have been talking about jobs in programming and if they can solder back at school. The fact that college interns served as their mentors was huge. It's nice for them to be around people closer to their age, they can really relate to them."

In addition to all of the hands-on activities the campers experienced, they also received guidance and support from lunchtime speakers. Langley's Mia Siochi, Anna McGowan and Juan Cruz were among those who took time to inspire the campers.

Even Lanetra Tate and Damian Taylor of the Space Technology Mission Directorate traveled down from NASA Headquarters in Washington D.C. to share their personal journeys with the Junior Game Changers.

"Don't allow anyone to label you," Tate offered. "Create your own path."

Tate, who majored in chemistry in college, said it wasn't her favorite subject, but she chose it because it was a challenge.

"It took dogged determination to conquer chemistry," she said. "But I did it, and so can you."

Taylor offered a similar message.

"It's not where you start in life, it's where you want to go," he said.

Damian Taylor shares his personal journey.

> *"It's not where you start in life, it's where you want to go."*
>
> —Damian Taylor, Configuration Manager

Thirty-five rising high school freshmen, shown here with the NIFS interns, Newport News schools educators, and GCD staff in NASA Langley's aircraft hangar, took part in a four-day camp to learn more about STEM.

Images of Space Launch System Qualification Motor 2 test without using HiDyRS-X camera (top) and with HiDyRS-X camera (bottom).

Revolutionary Camera Recording Propulsion Data Completes Groundbreaking Test

—**Scott Conklin, GCD Summer Intern**

While thousands turned out to watch NASA's Space Launch System (SLS) recently complete a full-scale test of its booster, few were aware of the other major test occurring simultaneously. NASA's High Dynamic Range Stereo X (HiDyRS-X) project, a revolutionary high-speed, high dynamic range camera, filmed the test, recording propulsion video data in never before seen detail.

The HiDyRS-X project originated from a problem that exists when trying to film rocket motor tests. Rocket motor plumes, in addition to being extremely loud, are also extremely bright, making them difficult to record without drastically cutting down the exposure settings on the camera. Doing so, however, darkens the rest of the image, obscuring other important components on the motor.

Traditionally, video cameras record using one exposure at a time, but HiDyRS-X records multiple, slow motion video exposures at once, combining them into a high dynamic range video that perfectly exposes all areas of the video image.

The HiDyRS-X project began as part of NASA Space Technology Mission Directorate's Early Career Initiative (ECI), designed to give young engineers the opportunity to lead projects and develop hardware alongside leading innovators in industry. Howard Conyers, a structural dynamist at NASA's Stennis Space Center, was awarded as an ECI grant in 2015. After initial proof of concept and a preliminary design review, the HiDyRS-X project was placed within NASA's Game Changing Development program to complete its first prototype. Created in partnership with Innovative Imaging and Research Corporation, the project was tested on small rocket nozzle plumes at Stennis.

The massive booster test served as a rare opportunity to test the HiDyRS-X hardware in a full-scale environment.

The Qualification Motor 2, or QM-2, test was held at Orbital ATK's test facility in Promontory, Utah, and was the second and final booster test before SLS's first test flight in late 2018. SLS will be the most powerful rocket in the world, and will take our astronauts farther into deep space than ever before.

In moving from the smaller-scale tests to QM-2, Conyers says the most difficult challenges were seen in compensating for brightness of the booster plume, which is several orders of magnitude brighter than what they had tested before. They were also faced with transporting and assembling the equipment at the QM-2 test site located in the desert of Utah—a remote environment requiring the HiDyRS-X team to be self-sufficient, as well as deliberate and methodical in their preparation and set up. Unlike the smaller scale rocket engine tests at Stennis, boosters are extremely powerful and, once ignited, cannot be turned off or restarted. The HiDyRS-X team had one shot at getting good footage.

In the days prior to the test of QM-2, the HiDyRS-X team double- and triple-checked their connections and start procedures to allow the camera to collect as much footage as possible. Leading up to the day of the test, the team performed several more dry runs using the camera to ensure that everything was working perfectly, Conyers says.

With thousands of people assembled over a mile away to watch the fiery plume of the solid rocket booster, Conyers and his team monitored the camera from a safe distance, ready to act in case something went wrong. As the countdown clock ticked down to zero, the SRB ignited and the HiDyRS-X team watched the camera's automatic timer fail to go off. Luckily, they were quick to hit the manual override, allowing the camera to turn on just moments after ignition.

Once engaged, the camera recorded several seconds of the two-minute test before the power source was suddenly disconnected. In an unanticipated series of events, the sheer power of the booster shook the ground enough for the power cable to be removed from the power box.

Having had two unexpected camera outages during the test, Conyers described being disappointed.

"I was bummed," Conyers says. "Especially because we did not experience any failures during the dry runs."

When the team reviewed the camera footage, they saw a level of detail on par with the other successful HiDyRS-X tests. The team saw several elements never before caught on film in an engine test.

"I was amazed to see the ground support mirror bracket tumbling and the vortices shedding in the plume," Conyers says. The team was able to gather interesting data from the slow motion footage, and Conyers also discovered something else by speeding up the playback.

"I was able to clearly see the exhaust plume, nozzle and the nozzle fabric go through its gimbaling patterns, which is an expected condition, but usually unobservable in slow motion or normal playback rates."

Howard Conyers.

Although initially disappointed with the camera anomalies, Conyers and the HiDyRS-X team came out of QM-2 with proof that their technology worked and that it had the ability to provide unprecedented views of high exposure rocket motor tests. The test experience also left Conyers with two major lessons learned for the future. First, to start the camera a full ten seconds before ignition to allow the ground team time to start the camera manually in the event of a timer failure. The second lesson, Conyers adds, is to understand just how powerful the engine tests are to properly protect and secure the electronics hardware from damage or disconnection.

"Failure during testing of the camera is the opportunity to get smarter," Conyers says. "Without failure, technology and innovation is not possible."

HiDyRS-X will continue testing at Stennis, while a second prototype of the camera is built with more advanced high dynamic range capabilities, using data gathered from the past few years of experimentation. The second HiDyRS-X prototype will be made with an improved manufacturing process to enhance the alignment capabilities of mutiple exposure settings—a challenge overcome in the first prototype.

HiDyRS-X not only stands as a game changing technology expected to revolutionize propulsion video analysis, but it also stands as a testament to ECI and the power of determined young engineers within NASA. Seasoned NASA employees and recent hires alike have the capacity to significantly contribute to NASA's research and development goals. ECI's emphasis on pairing young engineers with innovative industry partners enables technological leaps that would otherwise be impossible.

Education and Public Outreach

In 2016, the Game Changing Development (GCD) Program supported more than two dozen outreach events across the United States including congressional visits, media days, college talks, large-scale conferences and agency supported events such as the Chicago Air and Water Show.

Through social media channels, GCD increased its outreach into the millions by working together with project managers and STMD to get amazing content onto highly-followed NASA accounts, such as Instagram and YouTube.

A revolutionary video by the HyDRS-X project captured amazing details of the QM-2 SLS booster engine test and also captured our biggest audience yet—1.4 million views on YouTube. (Watch it here: https://www.youtube.com/watch?v=nPfcwT4Fcy8)

Amy McCluskey demonstrates a model of the Hypersonic Inflatable Aerodynamic Decelerator at the Chicago Air and Water Show.

Project Manager Rubik Sheth participates in a prelaunch social media briefing, which reached thousands through Facebook Live and Twitter.

Installation of the GCD Phase Change Material project's heat exchanger into the International Space Station shown on Instagram drew 1.3 million views, and a "shareable" made its way through Facebook and Twitter.

This year, GCD extended its communication reach into academia and industry by completing its first university challenge and by holding its first "Industry Day." Each of these new initiatives proved incredibly fruitful. More than a dozen teams competed in the Big Idea university challenge with the hopes of getting an internship at NASA Langley. Industry Day was attended in person by more than 100 people and over 4,000 by way of Livestream.

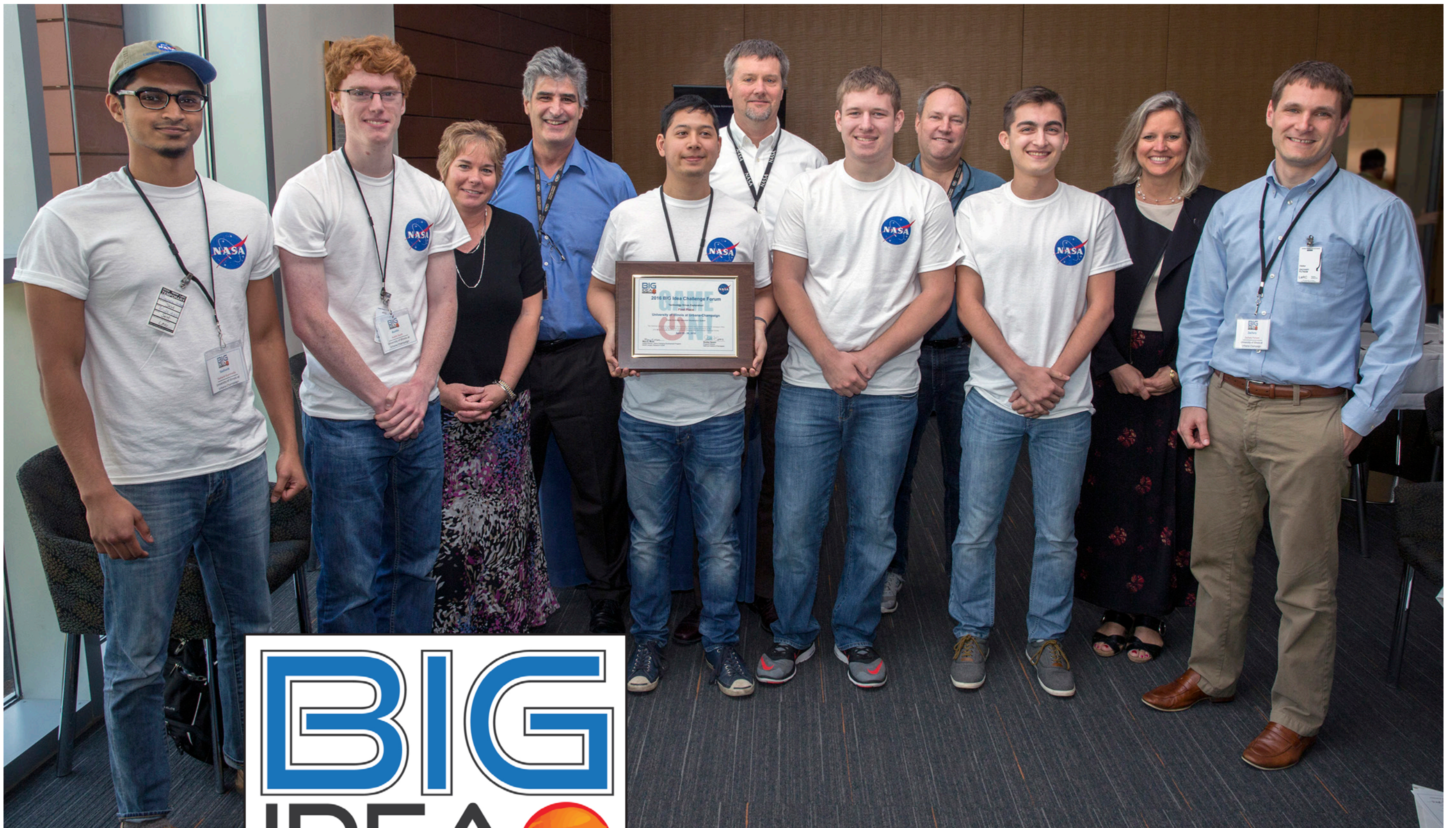
See more highlights from our busy, yet amazing year at these links:

Web: gameon.nasa.gov

Facebook: NASA Technology

Twitter: NASA_Technology

Flickr: NASA Game Changing Development



A group of students from the University of Illinois at Urbana-Champaign took top honors in NASA's first Breakthrough, Innovative and Game-changing (BIG) Idea Challenge. The challenge solicited ideas to increase the lift-to-drag ratio on the Hypersonic Inflatable Aerodynamic Decelerator.

Around 100 people attended the first Game Changing Development Industry Day in person June 29-30, and more than 4,000 attending virtually via Livestream.

For more information about Game Changing Development projects and activities, go to gameon.nasa.gov.

National Aeronautics and Space Administration

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