National Aeronautics and Space Administration

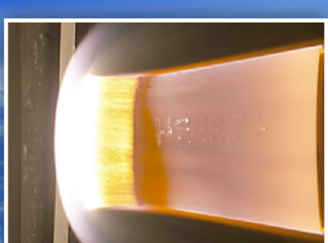
Space Technology

Game On

Game Changing Development Program

Getting There...

...Together!



Advanced Materials

Robotic Systems

Lightweight Cryotanks

Lightweight Materials & Structures

Winter 2013

Team,

I would like to share my personal thanks with each of you for another outstanding year. We've had many challenges, but your professionalism and dedication has pushed us through them all.

The theme of our annual magazine this year is partnerships. Whether it's with industry, academia, Department of Defense or within NASA, it is our goal to work together to better space technology for the future.

In this magazine, you will read articles about student programs that are essential to the Agency's future workforce, an article about a close-knit pairing of small business and innovative engineers who turned an idea on paper into a deliverable in less than 2 years and an editorial that challenges us to think "outside the NASA cubicle" and engage with the public.

In 2013, we exceeded our annual performance goal for the Agency. We achieved nearly 30 technology firsts (showcased in the magazine) with one being the delivery of Robonaut 2 legs to the Technology Demonstration Missions (TDM) Program. We successfully completed all project continuation reviews to date and met all of our deliveries to Advanced Exploration Systems (AES) but one. We worked a groundbreaking new Small Business Innovation Research (SBIR) Phase 3 extension for cryocoolers and created new collaborations with DARPA, Air Force Research Laboratory, and ARPA-E, among others.

Other activities to note in 2013 include:

- Successful transition of the Solar Electric Propulsion project to TDM and transition of In Situ Resource Utilization to AES
- The support of more than a dozen education and outreach events
- The creation of 5 national initiatives, 10 grants, and 3 solicitations with 22 awards
- Projects produced more than 150 publications and presented at 71 conferences or symposiums
- Four projects held successful reviews and transitioned from formulation into implementation

For the upcoming year, we've been challenged to do the following: Invest in the right technologies, achieve the right level of risk posture, get industry involved sooner, and improve our communications.

Again, thank you for an incredible year.

Congratulations to you all. I feel blessed to be working with such an awesome group of people.

Warmest regards,

Steve Gaddis

To read more about Game Changing Development, go to http://gameon.nasa.gov.

Game On

Space Technology Mission Directorate

Game Changing Development Program Office

http://gameon.nasa.gov

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Winter 2013

Front Cover: Image Credits: NASA
Back Cover: Robonaut 2, Image Credit: NASA/Stan Husch

Infusion Success Story: Woven TPS

Partnerships are at the heart of innovation

By Aaron Morris

Many meetings within the Game Changing Development (GCD) Program involve discussions of infusion pathways for technology investments. A natural question for decision makers to ask when considering whether to allocate limited funds to a technology idea is: Who will use this product if GCD develops it? This question is often difficult to answer and can involve multiple infusion pathways, multiple NASA organizations, vendors, and other government agencies. The Woven Thermal Protection System (TPS) project has enjoyed rapid development and has strong possibilities for infusion in the near future. The success Woven TPS projects have enjoyed thus far exemplifies a potential model for infusion.

GCD deals with 2- to 3-year projects, but technology development often occurs with stops and starts of multiple projects over a dozen years or more. While Woven TPS technologies progressed more quickly than average, it is an interesting case study in the life cycle of a technology.

The idea for this technology was conceived during a visit to weaving vendor Bally Ribbon Mills, Inc., on a project related to weaving carbon fabric. During the visit, engineers Mairead Stackpoole, Jay Feldman, and Raj Venkatapathy envisioned the weaving of TPS samples and tailoring the properties for different applications. This idea was proposed for a Center Innovation Fund project led by Don Ellerby at NASA's Ames Research Center.

The project began in April 2011 as a true partnership, with Bally Ribbon Mills contributing free preforms and NASA's Johnson Space Center contributing free arc-jet testing. The project was ultimately very successful and led Venkatapathy to respond to a GCD Broad Area Announcement (BAA) in October 2011 to further expand the idea.

The GCD project started in January 2012 and quickly led to partnerships with Orion because the vehicle—NASA's next human spacecraft—needed a material solution for the compression pad, which is a TPS structure. In addition to the original BAA award, this partnership led to a project called Three Dimensional Multifunctional Ablative TPS, or 3D-MAT. The project is on track to deliver a test readiness level 4 solution to Orion in March 2014. Problem to solution, ready for infusion in 20 months is extremely fast for technology development.

Not satisfied with simply one infusion customer, the team also sought the support of the Science Mission Directorate (SMD) to expand Woven TPS capabilities to extreme environments suitable for planetary exploration at destinations other than Earth. SMD responded in an overwhelmingly positive fashion, which led to another spinoff project called Heat Shield for Extreme Entry Environment Technology (HEEET). HEEET has a strong possibility for mission infusion on upcoming Discovery and New Frontiers Program Announcements of Opportunity.

Woven TPS has enjoyed success that is not typical of technology development, but it is a very real instance of an idea conceived by engineers during travel to a vendor that resulted in multiple technology development projects and infusion customers.

NASA Space Technology Infusion: Woven Thermal Protection System.

National Robotics Initiative: Combined Efforts and Funding Furthers Robotics

By Rob Ambrose, GCD Principal Investigator for Human Robotic Systems

America is poised to win back the robotics industry with students, industry and the government pooling resources and talent to create new markets as part of the National Robotics Initiative.

Organized by the Office of Science and Technology Policy (OSTP), several U.S. federal agencies have joined forces to help make this happen, including NASA, the National Science Foundation, the National Institutes of Health, and the United States Department of Agriculture. These and future agencies will combine research and development (R&D) funding in joint research solicitations, sponsorship of student events, and collaboration with industry to make the most significant advance in robotics in recent years.

The push comes at a time when new technologies are emerging to make robots safe to work around humans, creating new markets for machines that work, explore and protect right next to people. Examples include medical robots, gardening robots, rehabilitation robots and surrogates that can go into dangerous places on our behalf. Key technological advances are making these new robots now just possible and hold the promise for robotic applications beyond the manufacturing roles we see today.

NASA is at the forefront of this initiative, with its Space Technology Mission Directorate funding a mix of external grants, in-house R&D, and industrial partnerships that will change both how we explore and our lives here on Earth.

IMAGE CREDIT: NASA

NRI grants are helping fund the development of a humanoid robot that can respond in emergencies.

NRI Grants

- Long Thin Continuum Robots for Space Applications
- Novel Powered Leg Prosthesis
- Long-Range Prediction of Nongeometric Terrain Hazards
- Active Skins for Simplified Tactile Feedback in Robotics
- Actuators for Safe Strong and Efficient Humanoid Robots
- Manipulating Flexible Materials Using Sparse Coding
- Whole-Body Telemanipulation of the Dreamer Humanoid Robot on Rough Terrains
- Toward Humanoid Avatar Robots for Coexploration of Hazardous Environments
- Building the Robotics Commons

IMAGE CREDIT: NASA

Scarab rover developed by university researchers at Carnegie Mellon under NASA grant.

Technology first achieved	Description	Impact
New tactile sensor	Uses gel, light and camera	Improved robot dexterity
New tendon	Uses soft routing of cable	Enable soft wearable robotics
New surface hazard detection	Uses laser and thermal image ahead of rover	Protect Mars 2020 rover from getting stuck in soft soil

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—Steve Gaddis, Progra

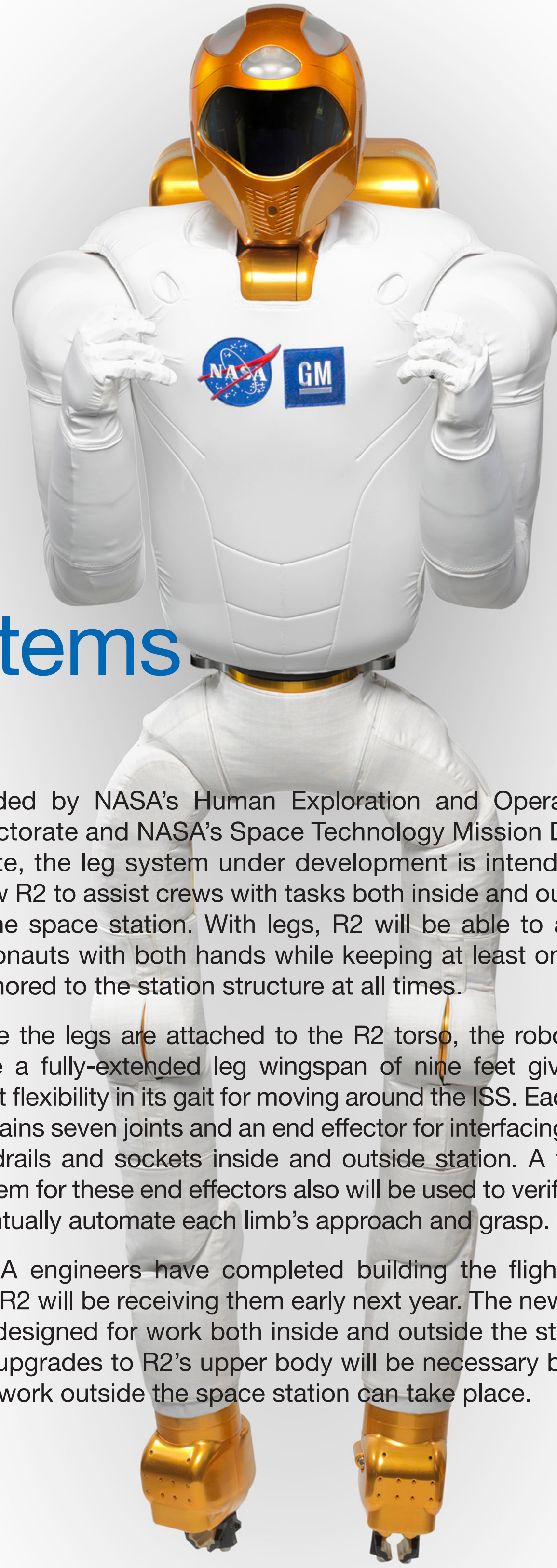


IMAGE CREDIT: NASA

Human Robotic Systems Delivers Milestone

Legs are next for NASA's favorite humanoid

NASA engineers are developing climbing legs for the International Space Station's robotic crew member Robonaut 2, or "R2," marking another milestone in space humanoid robotics.

The legless R2 is currently undergoing experimental trials with astronauts aboard America's orbiting national laboratory. Since its arrival at the station in February 2011, R2 has performed a series of tasks to demonstrate functionality in microgravity. Today R2 is fixed on a stanchion with no lower body. With legs, R2 will have mobility and will be able to help with mundane or repetitive tasks so as to free up crew time for more critical items and scientific research.

"NASA has explored with robots for more than a decade, from the stalwart rovers on Mars to R2 on the station," said Michael Gazarik, associate administrator for space technology at NASA Headquarters in Washington. "Our investment in robotic technology development is helping us to bolster productivity by applying robotics technology and devices to fortify and enhance individual human capabilities, performance and safety in space."

Funded by NASA's Human Exploration and Operations Directorate and NASA's Space Technology Mission Directorate, the leg system under development is intended to allow R2 to assist crews with tasks both inside and outside of the space station. With legs, R2 will be able to assist astronauts with both hands while keeping at least one leg anchored to the station structure at all times.

Once the legs are attached to the R2 torso, the robot will have a fully-extended leg wingspan of nine feet giving it great flexibility in its gait for moving around the ISS. Each leg contains seven joints and an end effector for interfacing with handrails and sockets inside and outside station. A vision system for these end effectors also will be used to verify and eventually automate each limb's approach and grasp.

NASA engineers have completed building the flight unit and R2 will be receiving them early next year. The new legs are designed for work both inside and outside the station, but upgrades to R2's upper body will be necessary before any work outside the space station can take place.

Thinking Outside the Box

By Joey Donatelli, LARSS Intern, Summer 2013

Oftentimes, solutions to challenging engineering problems can't be found solely within the walls of NASA. Here is a good example of how the Agency works with others in innovative ways.

For the past three years Tom Jones, a research engineer in the Lightweight Materials and Structures (LMS) project at NASA Langley, has studied the long-term material strength of Kevlar® and Vectran® straps.

Successful testing of these materials is important because they could be used in long-term space applications, such as inflatable space habitats.

The testing is complex.

"There's essentially four types of straps that we are considering," said Jones. "Two different materials, Kevlar and Vectran, in two strengths: a 6,000-lb breaking load and 12,500-lb breaking load."

"Some of the testing that we're doing is to fill a gap in the material behavior database that we have. We had a lot of short term properties, but we didn't really know how these materials would hold up in the long term, so now we're doing creep tests," Jones explained.

PHOTO CREDIT: NASA

12K test stand (above) and a speckled strap (at top of page).

Long-term, or "creep", testing of the material is accomplished by hanging weights from the straps to see how long it takes for the material to fail. But the real-time creep testing can take months or even years to complete. So, to accelerate the process but still get solid results, Jones and his team began looking for other solutions.

To accelerate the testing, Jones and his team heat the straps because increasing the temperature has a similar effect to increasing the load, reducing the time to failure. They also began using photogrammetry, the science of making reliable measurements using imaging techniques, to measure the strains in the material. The method requires the straps be painted with a speckled pattern. A computer then tracks the location variations of the speckles as they move due to applied load and temperature.

But with new processes came new challenges.

Sometimes the speckled pattern would break up on the 6,000-lb strap due to the heat or couldn't be seen because the individual threads of the straps twisted and turned out of sight of the computer, making it difficult to track the movement.

Melvin Ferebee, manager of the Space Technology projects office, is always considering new ways to solve technical issues and was looking for problems that he could "crowdsource."

"We've got this issue with straps: some can be measured using the photogrammetry system and others can't," said Ferebee. "So this might be something that we could send out to the world."

This is where InnoCentive comes into play.

InnoCentive publishes online technical and theoretical challenges pertaining to science and technology. The challenges are open to solvers from anywhere in the world. NASA teamed up with InnoCentive to look for assistance with the strap strain measurement problem. They received a total of 71 submissions from places as far away as Egypt and Sweden. Because the goal of the challenge was to find theoretical solutions to the strap problem, no testing was required before submitting applications. Jones and other members of the LMS project teamed up with InnoCentive

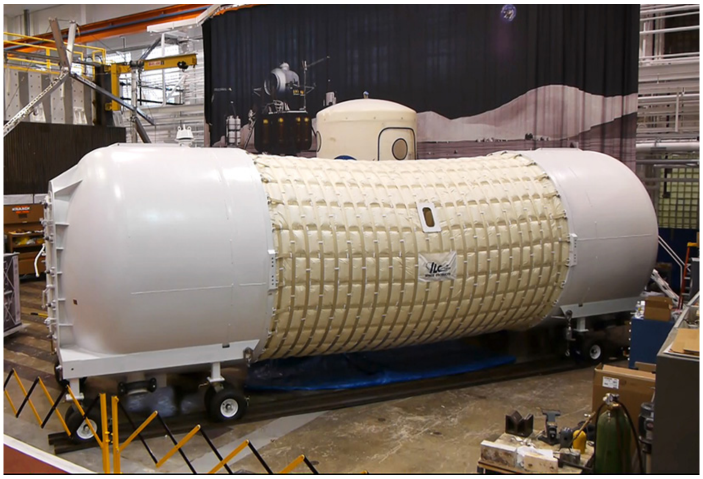


IMAGE CREDIT: NASA

Inflatable habitat structure.

to sift through submissions that weren't economically feasible or simply just wouldn't work, and narrowed the list down to 40 submissions from 19 different countries.

The advantage of using InnoCentive is it allows the team to review many different ideas and approaches from people with various disciplines.

Lynn Bowman, project manager of the Lightweight Materials and Structures Program, explained the importance of using InnoCentive.

"The project benefits by receiving multiple creative and innovative solutions without having invested a lot of resources up front," she said. "It's a win-win scenario—the innovators receive some recognition and a small monetary award and the project gets multiple elegant solutions to a tough problem."

The idea of asking different researchers from all across the world to submit their written proposals increased the LMS team's chances of finding a feasible theoretical solution. Of the 40 submissions considered, three similar approaches were given awards in March of 2013.

The inflatable habitat structure, which can be used for planetary surface operations or space applications, would be the biggest beneficiary of this testing in the near term. It is essential to test and be confident that the straps will last for the duration of the mission because the inflatable habitat could be deployed for months or even years at a time.

The creep test data results are being used to provide recommendations to Advanced Engineering Systems, Inc., for certification of inflatable structures in space. In addition, the creep test data are being used for developing guidelines for the webbing material on the Bigelow Expandable Activity Module (BEAM), an International Space Station flight experiment currently scheduled for 2015.

None of the theories have been tested yet, but Jones and the rest of the team in the Lightweight Materials and Structures project hope to begin testing sometime this summer. Jones is hopeful that this solution will be applicable to other projects that require Vectran and Kevlar straps, and he would use InnoCentive to assist in future challenges.

What is Photogrammetry?

Photogrammetry is the science of making measurements from photographs.

The output of photogrammetry is typically a map, drawing, measurement, or a 3D model of some real-world object or scene. Many of the maps we use today are created with photogrammetry and photographs taken from aircraft.

Types of Photogrammetry

Photogrammetry can be classified in a number of ways, but one standard method is to split the field based on camera location during photography. On this basis we have Aerial Photogrammetry and Close-Range Photogrammetry.

In **Aerial Photogrammetry**, the camera is mounted in an aircraft and is usually pointed vertically towards the ground. Multiple overlapping photos of the ground are taken as the aircraft flies along a flight path. These photos are processed in a stereo-plotter (an instrument that lets an operator see two photos at once in a stereo view). These photos are also used in automated processing for Digital Elevation Model (DEM) creation.

In **Close-range Photogrammetry**, the camera is close to the subject and is typically hand-held or on a tripod (but can be on a vehicle too). Usually this type of photogrammetry is nontopographic—that is, the output is not topographic products like terrain models or topographic maps, but instead drawings, 3D models, measurements and point clouds. Everyday cameras are used to model and measure buildings, engineering structures, forensic and accident scenes, mines, earth-works, stock-piles, archaeological artifacts, film sets, etc. This type of photogrammetry (CRP for short) is also sometimes called Image-Based Modeling.

Sourced from http://www.photogrammetry.com

IMAGE CREDIT: NASA

From the Industry Side: Partnership Drives Innovation

By Dan Rivera, Boeing Program Manager

The Boeing Company's collaboration with NASA to design and build two cryogenic tanks (2.4-m and 5.5-m) out of advanced materials moved out of the design phase and into the build phase in 2013, signaling a key milestone for NASA Space Technology's Game Changing Development Program.

In June, Boeing and NASA completed testing of a 2.4-m (7.8 ft) composite cryotank at NASA's Marshall Space Flight Center in Huntsville, AL. The tests, led by a team from Boeing Research & Technology and NASA, are part of Boeing's multiyear, $26 million contract through NASA's Composite Cryotank Technologies and Demonstration (CCTD) project.

"Completing our precursor test on the cryotank represents a major project milestone for Boeing and NASA," said Dan Rivera, the Boeing program manager. "The test program helps us validate the structural integrity of our tanks, quantify the permeation performance, and improve our analytical prediction capabilities."

NASA's 5.5-m composite liquid hydrogen tank completes the large-scale cure between the spherical pressure vessel shell and the cylindrical outer structure at Boeing's manufacturing facility in Tukwila, WA, under the leadership of Juan Carlos Guzman, Boeing's manufacturing lead for the Composite Cryotank Technologies and Demonstration project.

IMAGE CREDIT: NASA

Dan Rivera, Boeing Program Manager.

These tests allowed engineers to measure the tank's ability to contain liquid hydrogen at extremely cold, or cryogenic, temperatures under pressurized conditions. Composite tanks have the potential to significantly reduce the cost and weight for heavy-lift launch vehicles and other future air and space missions. In addition to producing the tanks at a lower cost, a goal of the CCTD project is to achieve at least a 30-percent weight savings over traditional metallic tanks, which would allow NASA to increase its payload capacity to space.

A larger 5.5-m (18-ft) tank is being fabricated at the Boeing Developmental Center in Tukwila, WA. Boeing will use the data from the 2.4-m (7.8-ft) tank tests to enhance the design of the 5.5-m tank, which is scheduled for testing in 2014. The project's 5.5-m tank critical design review took place at the Boeing Developmental Center earlier this year.

By working together, the process has created a number of industry breakthroughs, including automated fiber placement of out-of-autoclave (oven-cured) materials, fiber placement of an all-composite hybrid laminate that is leak-tight, and a tooling approach that eliminates heavy joints.

As the program matures, Boeing will continue to look at current and future programs where the tank may prove valuable.

One potential future application could be an upper-stage liquid hydrogen or liquid oxygen composite tank for NASA's Space Launch Systems (SLS), an advanced, heavy-lift launch vehicle, which will provide an entirely new capability for science and human exploration beyond Earth's orbit. Boeing is the prime contractor for the design, development, test and production of the launch vehicle cryogenic stages, as well as development of the avionics suite. The SLS upper stage, as currently envisioned by NASA and Boeing, would utilize traditional aluminum cryogenic tanks. Composites would offer a future technology on-ramp to improve stage performance and lower costs.

Composite cryogenic tanks have the potential for application on high-altitude, long-endurance unmanned vehicles such as Boeing's Phantom Eye, a liquid hydrogen propelled aircraft system for persistent intelligence, surveillance and reconnaissance and communications.

"It has been exciting to witness researchers from Boeing and NASA work in partnership applying their collective knowledge to find solutions to our toughest challenges and achieve our shared goals. From the NASA perspective our industry partners are critical to achieve the game changing technologies that we need and to make them affordable."

—John Vickers, NASA National Center for Advanced Manufacturing

Other Department of Defense programs that use reusable launch vehicles would also benefit from the cost and weight benefits developed for CCTD.

Advanced programs in development by Boeing and government agencies such as DARPA, aimed at providing very low cost access to space, can leverage many of the technologies and breakthroughs being pioneered and demonstrated by CCTD.

The overall progression of technology readiness level and manufacturing readiness level demonstrated by CCTD could change the way many, if not all, future programs use cryogenic tanks.

CCTD Team Hits Major Milestone

Earlier this year NASA completed a major space technology development milestone by successfully testing a pressurized, large cryogenic propellant tank made of composite materials. The composite tank will enable the next generation of rockets and spacecraft needed for space exploration.

In the past, propellant tanks have been fabricated out of metals. The almost 8-ft-diameter (2.4-m) composite tank tested at NASA's Marshall Space Flight Center in Huntsville, AL, is considered game changing because composite tanks may significantly reduce the cost and weight for launch vehicles and other space missions.

Switching from metallic to composite construction holds the potential to dramatically increase the performance capabilities of future space systems through a dramatic reduction in weight. A potential initial target application for the composite technology is an upgrade to the upper stage of NASA's Space Launch System heavy-lift rocket.

"These successful tests mark an important milestone on the path to demonstrating the composite cryogenic tanks needed to accomplish our next generation of deep space missions," said Michael Gazarik, NASA's associate administrator for space technology at NASA Headquarters in Washington.

The NASA and Boeing team are in the process of manufacturing the 18-ft-diameter (5.5-m) composite tank that also will be tested at Marshall next year.

"Boeing has experience building large composite structures, and Marshall has the facilities and experience to test large tanks," explained John Fikes, the cryogenic tank deputy project manager at Marshall. "It has been a team effort, with Boeing working with NASA to monitor the tests and gather data to move forward and build even larger, higher performing tanks."

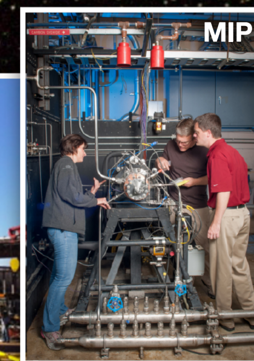
2013 Technology Firsts

Lightweight Materials and Advanced Manufacturing

Nanotechnology
- First to demonstrate the use of reactive polymer cross-linking to improve the tensile properties of carbon nanotube sheets.

Manufacturing Innovation Project (MIP)
- In partnership with Aerojet Rocketdyne, conducted-the first hot fire test of an additively manufactured rocket engine injector.

Composite Cryotank & Technologies Demonstration (CCTD)
- First time a large composite propellant tank was successfully pressure tested.
- First and largest composite cryotank at 5.5 m to be manufactured.



Future Propulsion and Energy Systems

Advanced Space Power Systems
- First lanyardless deployment mechanism and out-of-autoclave manufacturing technology for novel rollout solar array.
- First successful demonstration of improved Li-ion battery safety using the JPL flame retardant electrolyte.

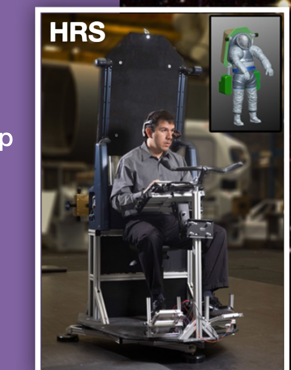
Solar Electric Propulsion
- First time an inductive pulsed plasma thruster was operated at a repetition rate for an input power above 1 kW.

Revolutionary Robotics and Autonomous Systems

Satellite Servicing
- First-time demonstration of spacecraft refueling in orbit.

Human Robotic Systems (HRS)
- First time scientists and astronauts floated over an asteroid mock-up in a reduced gravity simulator while performing simulated tasks.
- First successful test of a hands-free jet pack.
- First development of a hard rock anchor drill designed to anchor mission assets to the surface of an asteroid.

Autonomous Systems
- First fully automated replanning of crew activities.



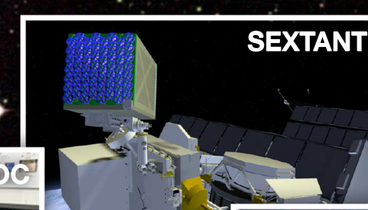
Affordable Destination Systems and Instruments

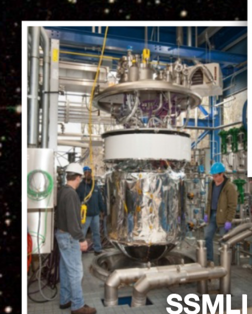
Station Explorer X-Ray Timing and Navigation Technology (SEXTANT)
- Captured first light from new, single foil, grazing incidence, X-ray concentrator optic.
- First-ever demonstration of real-time navigation solutions produced via accurate emulation of millisecond X-ray pulsar observations in a flight-like embedded hardware and software configuration.

Next Generation Life Support (NGLS)
- First integration of forward osmosis secondary treatment with a biological water processor.

Deep Space Optical Communications (DSOC)
- Demonstrated new photon counting detector technology with potential for >7 year lifetime in space.
- NASA demonstrated optical communications from the Moon with the Lunar Laser Communications Demonstration on the LADEE mission.
- Demonstrated record-setting highest efficiency in a large-area photon counting detector for 1550 nm: 61% with 64-micron-diameter 12-pixel WSi detector.

Self-Supporting High Performance Mutli-Layer Insulation (SSMLI)
- First time Load Bearing MLI (LBMLI) was thermally tested on a calorimeter and on a propellant tank with LH2 temperature cold boundary conditions.
- First time that LBMLI was structurally tested on a propellant tank at ambient temperature conditions.





Advanced Entry, Descent and Landing

Woven Thermal Protection System (WTPS)
- First time demonstrating the use of carbon/phenolic blended yarn in weaving TPS material. This allows for approaches for designing ablative TPS without resin infusion.

Heat Shield for Extreme Entry Environment Technology (HEEET)
- Performed the first testing by NASA at AEDC's H1/H3 facilities.
- Demonstrated the first use of a 3D layer-to-layer woven architecture for TPS applications for extreme entry environments.
- 3-in nozzle allowed Ames IHF arc jet facility to achieve highest test conditions relevant to planetary science missions to destinations such as Venus, Saturn, Uranus, Neptune and also higher speed sample return.

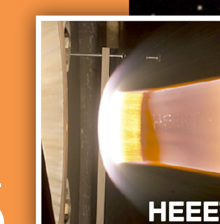
3D Multifunctional Ablative Thermal Protection System (3D MAT)
- Achieved a full-sized 3D orthogonal quartz weave, believed to be the first of its kind using loom weaving methodology.

Conformal A250
- Developed first higher strain-to-failure TPS that can be made into much larger segments, directly bonded and installed without gaps.
- Manufactured first 4-in thick rayon felt, that when carbonized, resulted in 3-in thick carbon felt.

Deployable Aeroshell Concepts
- Development of 4-in thick rayon felt (thickest available felt is 1 in).

Hypersonic Entry Descent & Landing (HEDL)
- First microscopic look at ablator materials using an advanced light source.

Hypersonic Inflatable Aerodynamic Decelerators (HIAD)
- First generation HIAD (10-m class) ready for mission infusion.



Carbon Nanotube Development Could Lead to Weight Savings

By Molly Hornbuckle,
Oak Ridge Associated Universities

For as long as he can remember, James Baker has been interested in aircraft. So, after he received his doctoral degree in polymer science from the University of Akron, Baker found a way to apply his knowledge of organic chemistry, materials science, and polymers to aerospace applications: he pursued an appointment as a NASA Postdoctoral Program (NPP) Fellow.

That appointment led Baker to NASA's Glenn Research Center, where he collaborates with his mentor, Michael Meador, to improve the tensile properties of carbon nanotube-based materials.

"NASA's Game Changing Development Program identified the need for stronger, lighter weight structural materials than those currently available," Baker said. "Individual carbon nanotubes (CNTs) have exceptionally high specific strength and stiffness, but these properties have not translated well to the macroscopic scale. Fiber or sheet materials composed of CNTs exhibit significantly weaker tensile behavior than that of the individual nanotubes."

James Baker (above), a NASA Postdoctoral Program Fellow at Glenn Research Center, examines a piece of carbon nanotube sheet. He hopes to create covalent bonds that link individual carbon nanotubes (CNT) thereby improving the tensile properties of CNT-based materials. Baker's research is supported by NASA's Game Changing Development Program.

The low level of frictional forces between CNTs is one of the major factors that contribute to this discrepancy. When a tensile load is applied to a CNT material, the CNTs can slip past one another rather than transferring the load to adjacent CNTs. Baker, Meador, and a group of researchers at Glenn are examining several methods to overcome this weak interaction between the materials.

Focusing on the creation of covalent chemical bonds, Baker hopes the CNTs will resist the tendency to slide relative to each other because they cannot break the new, stronger covalent bonds.

"Creating new covalent bonds sounds simple, but the high chemical stability of the CNTs means we need to use very reactive intermediates to functionalize them," he said. "We need to strike a compromise between creating enough chemical bonds to link the CNTs together, while trying to minimize the amount of damage we cause to the material in the process. Our research may be a route to the next generation of high-strength, lightweight composite materials that NASA needs."

Baker notes that, according to NASA projections, the team could achieve a weight savings of up to 30 percent over current composite materials if they are able to prepare materials with a tensile strength of 7 to 10 GPa, 7 to 10 billion units of force approximately 1.5 to 2 times the strength of carbon fibers that are currently used in composites on the Boeing 787. If the team is successful, the resulting materials could replace current carbon fiber composites in a variety of applications.

Although weight savings would improve, the cost of production would increase due to the expensive nature of CNTs. Baker acknowledges that cost increase, but he believes using the newer, lighter nanomaterials is attractive for applications where weight savings justify the higher cost—such as with space vehicles and aircraft. Moreover, advances in the research could eventually reduce costs.

"As the technology matures and becomes cheaper, CNT composites could slowly migrate from the aerospace industry into automobiles and other consumer applications, just as carbon fiber composites have," he said.

Through the process of incremental discovery during his NPP appointment, Baker brings that vision closer to reality, making CNT composites one of the most promising technologies in the Game Changing Development Program.

What Does Game Changing Mean to NASA?

"The Game Changing program represents a critical investment in NASA's future. Just one success in providing entirely new mission capability should (could) pay for program many times over!"

—Rob Anderson, Office of the Chief Engineer, NASA Headquarters

"The Game Changing Program is critically important to the success of the Space Technology pipeline
The technologies matured in the Game Changing program will enable future space exploration missions."

—Ryan Stephan, new GCD Program Executive

NASA
POSTDOCTORAL PROGRAM
Administered by Oak Ridge Associated Universities

The NASA Postdoctoral Program (NPP) supports NASA's goal to expand scientific understanding of the Earth and the universe in which we live.

Selected by a competitive peer-review process, NPP Fellows complete 1- to 3-year Fellowship appointments that advance NASA's missions in earth science, heliophysics, planetary science, astrophysics, space bioscience, aeronautics and engineering, human exploration and space operations, and astrobiology.

As a result, NPP Fellows contribute to national priorities for scientific exploration; confirm NASA's leadership in fundamental research; and complement the efforts of NASA's partners in the national science community.

NASA's partner administering the NPP is Oak Ridge Associated Universities (ORAU).

To learn more about the program and available research opportunities, visit the NASA/ORAU NPP site at http://nasa.orau.org/postdoc/index.htm.

Space Tech Fellowships Add to Game Changing Research

By Amy McCluskey

Ask Erik Komendera what he's interested in when it comes to technology, and he doesn't hesitate.

"I like to think of ways to automate processes that aren't already automated," he said.

Specifically his goal is to automate robots and deploy them into space to build structures— such as trusses, telescopes, and even habitats one day.

"We need adaptive robots that can move efficiently (in space)," he explained. The robots would also need to do other important tasks such as sense and maneuver around their environment, keep an internal map and detect problems.

Komendera—who has a bachelor's of science in aerospace engineering and master's of science in computer science—is currently pursuing his doctorate in computer science at the University of Colorado Boulder. He got the idea for the automation of structure assembly in space while in graduate school.

In-orbit assembly of structures is currently a job for astronauts. Komendera argues that it would be cheaper, quicker and safer if well-suited robots could do the work instead of, or in conjunction with, the astronauts.

To prove his technology concept, Komendera looked to NASA for a little help.

In 2011, Komendera applied for NASA's Space Technology Research Fellowship (NSTRF). Sponsored by NASA's Office of Chief Technologist, the NSTRF is dedicated to supporting researchers or graduate students "who show significant potential to contribute to NASA's goal of creating innovative new space technologies for our nation's science, exploration and economic future."

His technology idea fit the bill as being "innovative" as well as a "creative solution" to a current NASA challenge, and he was accepted.

Komendera calls the technology "Intelligent Precision Jigging." In welding and other applications, a jig is the name for a scaffolding device that ensures precision and repeatability. An "intelligent jig" is a jig with some sort of autonomy, capable of sensing, actuation, computation and communication. These capabilities are intended to make the assembly task easier, faster and more reliable.

There are two parts to his research. First, he had to design an algorithm that could compute an Intelligent Precision Jigging assembly sequence for a structure composed of interchangeable parts—this is where his computer science degree came in handy. Next, he needed to validate that algorithm on a robotic test bed to make sure it executed an assembly process with the least amount of error.

The latter part of his research brought him to NASA's Langley Research Center this past summer where he worked with robotics engineer John Dorsey. Among his many assignments, Dorsey supports NASA Space Technology's Game Changing Development Program under the Human Robotic Systems project. He's currently working on a robotic manipulator arm that could be used for the proposed asteroid retrieval mission.

While at NASA Langley, Komendera built a scaffolding robot—called an Intelligent Precision Jigging Robot (IPJR). It is a high-precision robot that demonstrated the capability to work with another robot called the Lightweight Surface Manipulator System (along with human help) to build a 2-m-diameter flat telescope truss using welding techniques.

Komendera's first realization when building a new technology is something NASA engineers experience frequently. Sometimes projects take longer than you think.

"I had planned on it taking two months, but it actually took three and a half months," he said.

The extra time wasn't a bad thing, however, since Komendera got to spend more time in the lab with Dorsey, and other long-time engineers Bill Doggett, Bruce King, Dave Mercer and Robert Hafley.

"Working with him and others in the lab was incredible," he said. "I had years of wisdom and intelligence at my disposal. Having them there to help me has been vital to my growth as a robotocist."

Even though he's waiting on the official results from the tests performed by the robot, Komendera, who returned to school in Colorado in September, considers the experiment at Langley a success.

As for what's next, he plans to continue this project through 2014 where he hopes to build a 3D telescope optical bench with the IPJR robot and a robotic arm—making the experiment completely autonomous. Other plans for 2014 include finishing his thesis and graduating with a PH.D.

The NSTRF provided Komendera with the funding, facilities and mentoring he needed to begin proving out his technology.

"I'm not sure what I would've done without the fellowship," he said. "It's been a huge help for me, in pretty much every way."

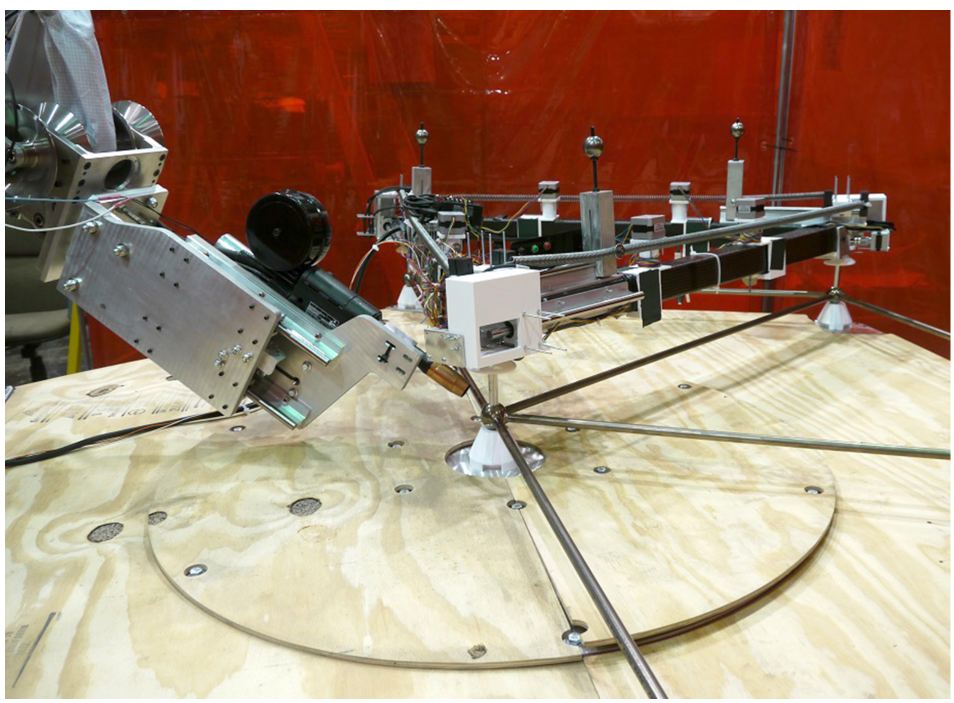


IMAGE CREDIT: NASA

The IPJR works with the Lightweight Surface Manipulator System to build a 2-m-diameter flat telescope truss using welding techniques.

IMAGE CREDIT: NASA/DAVID C. BOWMAN

Game Changing People: Arna Majcher

By Denise Lineberry, NASA Langley Research Center
Reprinted from www.nasa.gov/langley

If Arna Majcher's life were a play, it could be composed of three main acts. Act one: singing. Act two: scheduling. Act three: running. Likely scenes would include the Virginia Opera, NASA's Langley Research Center and the Boston Marathon.

Act one.

The opening scene is set in the 1960s. The curtain raises and there, in costume, stands her mother—a red-haired, hazel-eyed musical theatre singer, who performs in her spare time.

Mom meets dad on New Year's Eve in Germany, and they start dating. After marriage, comes baby Majcher, the star of the show. They name her Arna, and she becomes the fourth female in her family to be named after her great-grandmother.

At the age of five, Majcher follows in her mother's musical footsteps. As their only child, mom and dad nurture her interest, taking her to musicals and theatre, starting with Cats.

As an adult, Majcher begins to sing in local community theatre. She takes vocal lessons to improve her skills and tries out for the Virginia Opera. After two years of lessons and auditions, she earns a hard to come by spot as a mezzo-soprano. She rehearses three or four days each week and performs every few months.

Even now, as a veteran to the stage, there are "always" nerves involved.

"And I think that's good, because I think if you get complacent, you don't perform your best. It's good to have a little edge to it when you are going to sing," Majcher said. "You don't want to be so nervous that you can't breathe when you perform, but at the same time, it's good to stay on your toes. It just makes everything sharper."

Majcher hopes that one of the final scenes might include her singing at the Metropolitan in New York City.

"It might be hard to pull off, since I'm not a full-time singer," Majcher said. "But it's not without possibility, the possibility always exists."

Act two.

Majcher walks the stage of Elon University in North Carolina as an English major. Shortly after graduation, in 1998, she heard that NASA's Langley Research Center was hiring schedulers and thought it could be a good fit for her "type-A" personality. She nabbed the job and started training.

"I have always been attracted to the humanities—English, the arts, history, that kind of thing," Majcher said. "I would have never initially thought of being a scheduler, but it actually comes quite naturally to me."

A few years later, she receives her master's from Old Dominion University in Public Administration. And in 2011, she becomes the lead scheduler for the Game Changing Program Office, based at NASA Langley.

She hasn't settled on a potential curtain call for her career at the center, but for now, she feels right at home with her tasks and her coworkers.

She considers her accidental opportunity with NASA, game changing.

Act three.

In an opening scene, Majcher's father runs with the hopes of qualifying for the Boston Marathon. Running is a regular part of his life, until he is hit with the harsh reality of Parkinson's disease, a degenerative disorder of the central nervous system.

In a later scene, Majcher and her mother are participating in the Walk to End Altzheimer's in Newport News, VA. The walk is dedicated to her grandmother who has Alzheimer's and her father, since both of their diseases affect the same area of the brain (the mid-brain). The walk has become an annual tradition for the mother-daughter team who walks alongside others, sharing their relatable and touching stories.

In a later scene, Majcher and her mother join the Peninsula Track Club and complete their first half-marathon together.

Her father, who is eventually expecting Parkinson's to lead to his passing, asks Majcher to make him a promise. Since he was unable to qualify for the Boston Marathon before he was diagnosed with Parkinson's, he wants her to run it for him, with his remains.

"I promised that to him so that is definitely something that one day, I will do," she said.

Curtain call. Majcher takes a bow.

When threaded together, these acts become a life story filled with powerful scenes, like that of Majcher visiting her grandmother who has become "a shell of her old self." Or one where she witnesses the launch of IRVE-3 at NASA's Wallops Flight Facility. Or another where her parents sit in the audience proudly watching their only child as she sings her heart out.

It would probably include scenes that highlight her sense of humor: calling herself, "a nerd by day, singer by night" and a "back-of-the-pack runner."

Or possibly a scene that reveals Majcher's true running spirit after the recent bombings at the Boston Marathon: "It's unfortunate, but it definitely didn't knock us down and if anything, since that, I've seen locally, with Tidewater Striders and Peninsula Track Club, they've been having events in support of Boston and raising money for the victims," she says. "So, the running communities across the country have really just come together."

No matter the particular act, Majcher chooses to take life scene-by-scene, knowing there are plenty of performances, and curtain calls, yet to play out.

What Do You Love About Your Job?

"I love the people. I love that I am working to help impact technology development that not only benefits NASA but society. NASA is the greatest place to work."

— LaNetra Tate, Principal Investigator

"I like working with all of the different project managers and all of the other employees in our group."

—Larren Asby, Administrative Officer,
Game Changing Development

Education & Public Outreach

Maintaining Inspiration in the Age of PowerPoint

By Aaron Morris

Many of us come to the aerospace industry inspired by romantic notions of flight and space travel. When asked, NASA engineers will cite memories of watching Apollo Moon landings, lying at the end of a runway to watch planes take off overhead, or the influence of fictional works such as Star Wars as a foundational experience that inspired them to study math and physics. The romantic notion of space led them to study something concrete—hardware.

To become inspired by space at a young age is common. I often volunteer for public outreach events, and it's relatively easy to draw a few gasps of wonder and surprise when exhibiting space hardware to the public. I recently volunteered to work at a NASA Space Technology exhibit during a NASCAR race, part of a program called Rockets to Racecars. With the thunderous roar of time trial laps serving as background, numerous children and adults visited the booth, both intrigued by space and interested in learning about NASA hardware. One young, autistic boy, who learned that the NASA booth would be at the race, came with ideas of a robotic exoskeleton that he designed. He was overjoyed at the Robonaut model and video display of the exoskeleton that was looping on the screen. I was amazed at his interest. His mother explained to me that his autism gave him a unique focus that manifested itself through mature drawings and mechanical designs, and that he was particularly inspired by NASA.

Aaron Morris.

Sometimes it's difficult to maintain that level of wonder and excitement in our grown-up workaday lives. I'll admit that, like many of you, in my darkest hours I become discouraged by the programmatic hurdles and documentation necessary to keep projects and programs in synch while developing technology.

To maintain inspiration within our chosen field can be difficult, but it's something we all must strive to do for ourselves and are duty bound to help explain to others. One thing that has helped me is to work projects with tangible hardware. In past jobs, I was fortunate to work on well-funded projects with dozens of flight tests. There's nothing like the rush that comes from watching a flight test to see if it matches your flight mechanics predictions or participating in a wind-tunnel test to anchor data to the real world. Experiencing a small part of a larger enterprise with tangible results can keep me sane through another week of the PowerPoint doldrums. We're fortunate in Space Technology that many of our projects result in just such an outcome—hardware, radical software improvements, ground tests, and even flights.

Although handling hardware is a good way to stay motivated, our responsibility as representatives of this field extends beyond simply keeping ourselves interested. Volunteering for public outreach events with children is a worthwhile and just cause, but we are obligated to make things better in the adult world too. It is our responsibility to engage with the voting public to increase awareness of NASA's mission and strive to increase funding for the space industry.

It is equally our responsibility to engage management and policy makers to help shape the Agency. Ultimately, people are placed in decision-making roles. It's important for us to respect those authority figures, and the decisions they make, to maintain a functioning Agency; however, a constructive level of criticism and suggestions for improvement are necessary and healthy. I'm quite certain that management is open and eager to hear any and all ideas.

I hope this editorial simply serves as a rally cry to work together, to build an even better Agency and program. It starts today with current personnel developing game changing technology and hopefully continues tomorrow as that young, autistic boy brings his designs to fruition and follows his dream to work at NASA.

Education & Public Outreach

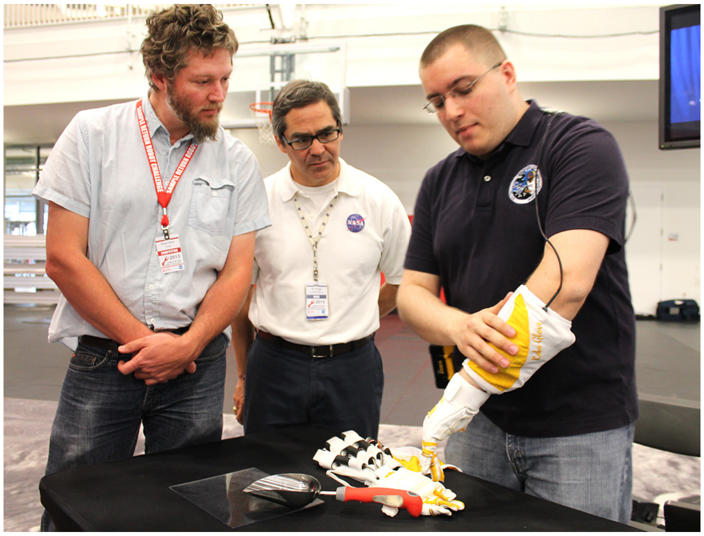


IMAGE CREDIT: AMY McCLUSKEY

Engineers from NASA Johnson brought the Robo-Glove to the Centennial Challenges event at Worcester Polytechnic in June.

IMAGE CREDIT: NASA

Nikki Werkheiser from NASA Marshall shows Dr. Michael Gazarik, associate administor for NASA's Space Technology Mission Directorate, a 3D printer during NASA's Tech Day on the Hill in July.

2013 marked the first year of a full calendar of events that GCD participated in. Whether at the project or program level, education and public outreach is an important part of how we tell our story. Here are few highlights from 2013.

For more exhibit and event photos, visit our Flickr page at www.flickr.com/photos/gamechanging

IMAGE CREDIT: AMY McCLUSKEY

GCD Deputy Program Director Dana Gould talks with students about space technology during the 2013 Homeschool Day held at NASA Langley's Visitor Center in September.

IMAGE CREDIT: AMY McCLUSKEY

Members of the SLOSH team from Florida Institute of Technology staff an exhibit during the Maven Launch at NASA's Kennedy Space Center in November.

National Aeronautics and Space Administration

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