National Aeronautics and Space Administration

# Game Changing Development Program

# Game On

## Nuclear Thermal Propulsion and Kilopower
NASA invests in space exploration's thrust forward

## High Performance Spaceflight Computing
A technology that can benefit all future NASA missions

## Hypersonic Inflatable Aerodynamic Decelerator
Successful testing, development efforts transition to Technology Demonstration Missions for future flight demo

## NASA Internships
The best of the best: GCD mentors and interns come together

## Robotic Systems
Wearable robotics and cognitive computing push the limits to advance capabilities

**Space Technology Mission Directorate**

**2017**

This past year has been a remarkable one for the Game Changing Development Program. The hard work of our engineers and researchers, as well as academia and industry partners, has produced a number of innovations and technological advancements that will impact a wide range of future missions—from human exploration to the discovery of life.

Here are just a few highlights from the past year:

**High Performance Spaceflight Computing:** NASA selected The Boeing Company in St. Louis, Mo., for the development of prototype chiplet devices, including packaged parts and bare die, a chiplet behavioral model, chiplet evaluation boards and system software. The chiplet will provide game-changing improvements in computing performance, power efficiency, and flexibility, which will significantly improve the onboard processing capabilities of future NASA and U.S. Air Force space missions. Read more about this exciting technology development on page 7.

**Station Explorer for X-Ray Timing and Navigation Technology (SEXTANT):** The SEXTANT project launched into space earlier this year as part of the NICER mission aboard SpaceX CRS-11. While NICER monitors neutron starts, SEXTANT will use NICER's telescopes to detect X-ray light emitted within the pulsars' sweeping beams of radiation to estimate the arrival times of the pulses. In a technology first, the SEXTANT team has already successfully demonstrated fully autonomous, real-time X-ray pulsar navigation (XNAV) onboard NICER. Read more about SEXTANT on page 13.

**Kilopower:** In September 2017, the U.S. Department of Energy's Y-12 National Security Complex completed all quality assurance checks and received approval for packing and shipping of the Kilopower experiment's highly enriched uranium core to the Nevada National Security Site. Following that, the Kilopower project team successfully completed a nonnuclear dry run of the experiment assembly and equipment hardware in NASA Glenn's hangar before shipping to Nevada National Security Site Device Assembly Facility. Official testing began in November and will last three to five months. Read more about Kilopower on page 5.

Another important element of GCD's success is its engagement with industry, academia and student programs. One example is the Big Idea Challenge. The latest challenge sought innovative ideas in 2017 from the academic community for Mars surface solar arrays. Supplying reliable electric power for human missions on the Martian surface is a critical technology need. Learn more about the Big Idea Challenge on page 26.

In closing, I look forward to groundbreaking progress on the multitude of technologies being developed in 2018.

*Drew Hope*

Game On
2017

**Space Technology Mission Directorate**

**Game Changing Development Program Office**

**gameon.nasa.gov**

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*On the cover: Artist's concept of a Kilowatt reactor using Stirling technology circling Saturn.*

# NASA Funds Multimillion Dollar Effort to Create and Test Fuel for Nuclear Thermal Propulsion

As NASA pursues innovative, cost-effective alternatives to conventional propulsion technologies to forge new paths into the solar system, researchers at NASA's Marshall Space Flight Center in Huntsville, Ala., say nuclear thermal propulsion technologies are more promising than ever, and have contracted with BWXT Nuclear Energy, Inc. of Lynchburg, Va., to further advance and refine those concepts.

Part of NASA's Game Changing Development Program, the Nuclear Thermal Propulsion (NTP) project could indeed significantly change space travel, largely due to its ability to accelerate a large amount of propellant out of the back of a rocket at very high speeds, resulting in a highly efficient, high-thrust engine. In comparison, a nuclear thermal rocket has double the propulsion efficiency of the space shuttle main engine, one of the hardest-working standard chemical engines of the past 40 years. That capability makes nuclear thermal propulsion ideal for delivering large, automated payloads to distant worlds.

"As we push out into the solar system, nuclear propulsion may offer the only truly viable technology option to extend human reach to the surface of Mars and to worlds beyond," said Sonny Mitchell, Nuclear Thermal Propulsion project manager at Marshall. "We're excited to be working on technologies that could open up deep space for human exploration."

An NTP system can cut the voyage time to Mars from six months to four and safely deliver human explorers by reducing their exposure to radiation. That also could reduce the vehicle mass, enabling deep space missions to haul more payload.

Given its experience in developing and delivering nuclear fuels for the U.S. Navy, BWXT will aid in the design and testing of a promising, low-enriched uranium (LEU)-based nuclear thermal engine concept and "cermet"—ceramic metallic—fuel element technology. During this three-year contract, the company will manufacture and test prototype fuel elements and also help NASA properly address and resolve nuclear licensing and regulatory requirements. BWXT will aid NASA in refining the feasibility and affordability of developing a nuclear thermal propulsion engine, delivering the technical and programmatic data needed to determine how to implement this promising technology in years to come.

"BWXT is extremely pleased to be working with NASA on this exciting nuclear space program in support of the Mars mission," said Rex D. Geveden, BWXT's president and chief executive officer. "We are uniquely qualified to design, develop and manufacture the reactor and fuel for a nuclear-powered spacecraft. This is an opportune time to pivot our capabilities into the space market where we see long-term growth opportunities in nuclear propulsion and nuclear surface power."

Nuclear-powered rocket concepts are not new. The United States conducted studies and significant ground tests from 1955 to 1972 to determine the viability of such systems, but ceased testing when plans for a crewed Mars mission were deferred. Since then, nuclear thermal propulsion has been revisited several times in conceptual mission studies and technology feasibility projects. Thanks to renewed interest in exploring the red planet in recent decades, NASA has begun new studies of nuclear thermal propulsion, recognizing its potential value for exploration of the moon, Mars and beyond.

This fall, the Nuclear Thermal Propulsion project will determine the feasibility of using low-enriched uranium fuel. The project then will spend a year testing and refining its ability to manufacture the necessary cermet fuel elements. Testing of full-length fuel rods will be conducted using a unique Marshall test facility.

The NTP project's industry partnerships also include Aerojet Rocketdyne.

*Article adapted from a NASA News Release.*

# Kilopower Fission System Technology Demonstration

Nuclear fission power technology is capable of providing safe, abundant, efficient, reliable power anywhere in the solar system. Fission power is enabling missions to places like the surfaces of the moon or Mars, or even locations beyond Mars orbit like Europa where more than a few hundred watts of electricity are required and sunlight is absent or dim.

Space Technology's Game Changing Development Program, partnered with the Department of Energy's National Nuclear Security Administration, has nearly completed the Nuclear Systems-Kilopower project. The Kilopower project's goal is to demonstrate fission power technology for 1- to 10-kilowatt space applications using the novel integration of a reactor core, sodium heat pipes, and Stirling convertors at prototypic operating conditions. Bringing together these existing components to execute an integrated nuclear fission system demonstration will build on the earlier Device Using Flattop Fission bench-top test in 2012, which established that a small team of experts could plan, develop, and test a small fission power system in existing Department of Energy facilities more affordably and more quickly than ever before.

The Kilopower technology demonstration is the practical first step to providing a space fission power system for NASA's key missions to challenging locations. The Kilopower project establishes readiness of fission power for space missions by addressing the major technology challenges for 1- to 10-kilowatt systems, including performance and operability of the uranium/molybdenum monolithic nuclear reactor core fuel form, efficient transfer of heat from the core to heat pipes, and performance and operability of dynamic power conversion using heat from the heat pipe to produce electricity. Unique technology challenges may remain for some specific applications, but the Kilopower project's system-level live nuclear demonstration at the Nevada National Security Site starting in late 2017 will pave the way for abundant, reliable fission power wherever and whenever needed by future human or robotic explorers.

*The Kilopower experiment assembly hangs from a hoist in preparation for being installed into a mockup of the Department of Energy Nevada National Security Site Nuclear Critical Experiment Research Center test stand. The mockup was constructed in the NASA Glenn Research Center airplane hangar so that experiment set-up could be practiced prior to being sent to Nevada, where it will be integrated with its nuclear reactor core, and tested to demonstrate technology for 1- to 10-kilowatt space fission power systems for human and robotic exploration. The vacuum container that will hold the nuclear reactor core is at bottom, the service collar that holds the assembly together is at center, and the power convertors that will turn nuclear heat into electricity are at top.*

As of November 2017, all major elements of development efforts under the working title "Kilopower Reactor Using Stirling Technology," or KRUSTY, have shown they can do what is needed for a successful demonstration. The reactor has gone critical, the heat pipes have transferred heat, the Stirling engines have converted heat to electricity, and the Stirling simulators have mimicked the Stirling engines' thermal load. Final integration of the reactor and power subsystems into the complete KRUSTY system is the last major assembly step in completing the demonstration, followed by the careful iterative increase of reactivity through cold criticals and warm criticals toward the full power test, planned for early March.

"The Kilopower test program will give us confidence that this technology is ready for spaceflight development. We'll be checking analytical models along the way for verification of how well the hardware is working," explains Lee Mason, Space Technology Mission Directorate's principal technologist for Power and Energy Storage.

The Kilopower project's industry partners include Advanced Cooling Technologies, Inc. and Sunpower, Inc.

# New Space Policy Directive Calls for Human Expansion Across Solar System

President Donald Trump is sending astronauts back to the moon.

The president signed at the White House on December 12, 2017, Space Policy Directive 1, a change in national space policy that provides for a U.S.-led, integrated program with private sector partners for a human return to the moon, followed by missions to Mars and beyond.

The policy calls for the NASA administrator to "lead an innovative and sustainable program of exploration with commercial and international partners to enable human expansion across the solar system and to bring back to Earth new knowledge and opportunities." The effort will more effectively organize government, private industry, and international efforts toward returning humans on the moon, and will lay the foundation that will eventually enable human exploration of Mars.

*Representatives of Congress and the National Space Council joined President Donald J. Trump, Apollo astronaut Jack Schmitt and current NASA astronaut Peggy Whitson Monday, Dec. 11, 2017, for the president's signing of Space Policy Directive 1, a change in national space policy that provides for a U.S.-led, integrated program with private sector partners for a human return to the moon, followed by missions to Mars and beyond.*

"The directive I am signing today will refocus America's space program on human exploration and discovery," said President Trump. "It marks a first step in returning American astronauts to the moon for the first time since 1972, for long-term exploration and use. This time, we will not only plant our flag and leave our footprints—we will establish a foundation for an eventual mission to Mars, and perhaps someday, to many worlds beyond."

Work toward the new directive will be reflected in NASA's Fiscal Year 2019 budget request next year.

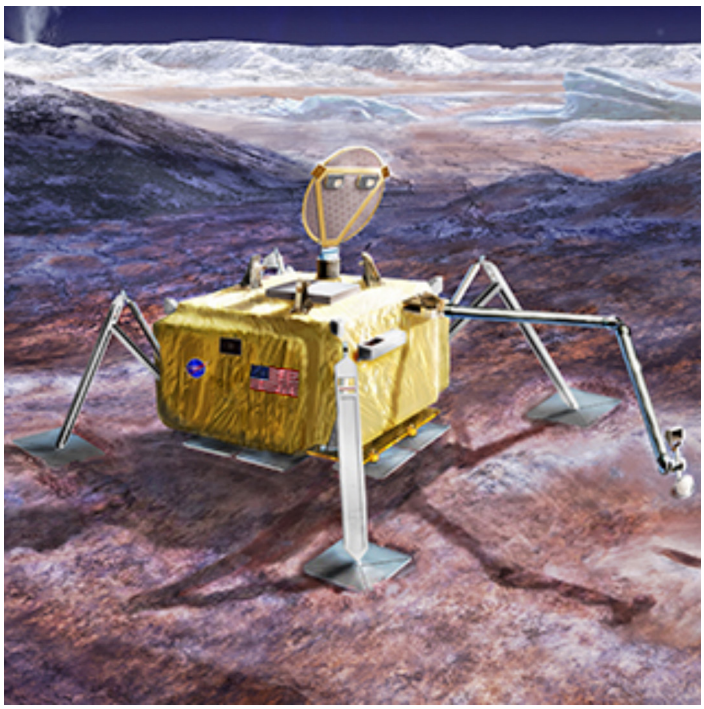
"NASA looks forward to supporting the president's directive strategically aligning our work to return humans to the moon, travel to Mars and opening the deeper solar system beyond," said acting NASA Administrator Robert Lightfoot.

"This work represents a national effort on many fronts, with America leading the way. We will engage the best and brightest across government and private industry and our partners across the world to reach new milestones in human achievement. Our workforce is committed to this effort, and even now we are developing a flexible deep space infrastructure to support a steady cadence of increasingly complex missions that strengthens American leadership in the boundless frontier of space. The next generation will dream even bigger and reach higher as we launch challenging new missions, and make new discoveries and technological breakthroughs on this dynamic path."

***Read the full article at: www.nasa.gov/press-release/new-space-policy-directive-calls-for-human-expansion-across-solar-system***

*HPSC is developing a multicore computing system architecture that not only delivers the increased capacity and reliability future missions require, but also offers a kind of operational flexibility never before available in a flight computing system: the operating point can be dynamically changed to meet the needs of a mission phase or the situation of the moment. Before this critical, high-impact capability transitions to NASA's Technology Demonstration Missions for maturation toward flight-ready status, it will continue to undergo advances under NASA's Game Changing Development Program.*

# Space-Based Computing Steps Up to the Plate



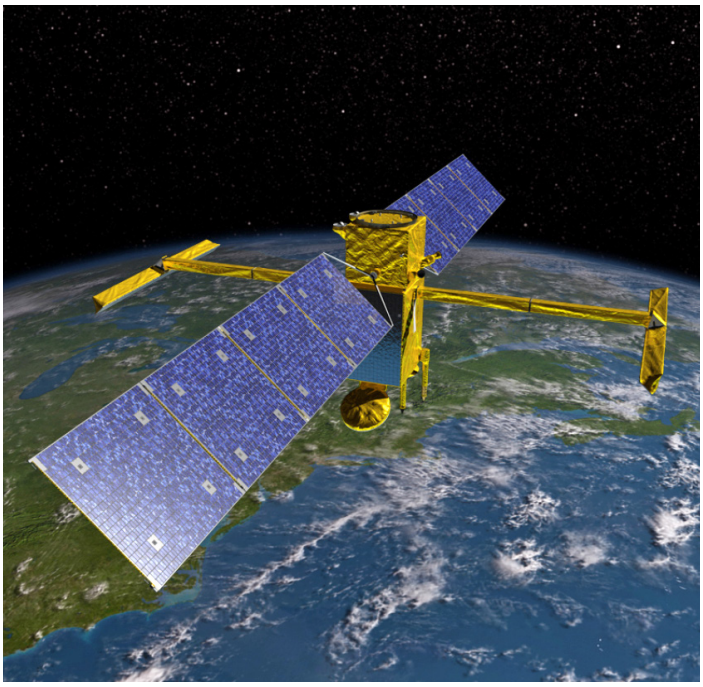
***HPSC capability is relevant to high data rate instruments, mission-critical sequence calculations, and platform autonomy, all critical to outer planetary and other programs within both the Human Exploration and Operations and the Science Mission directorates. This image depicts an artist's concept of a Europa Lander collecting a sample.***

As technology becomes ever more advanced in our everyday world, so too does the need for incorporating advanced technology in our spacecraft. The computers used in today's spacecraft are woefully inadequate compared with the needs of future missions.

Scoring a home run for advancing next-generation space-based computing is the High Performance Spaceflight Computing (HPSC) project. Sponsored by the Space Technology Mission Directorate's Game Changing Development (GCD) Program, HPSC has developed a radically new concept that uses "chiplets" as the basis for a flexible computing architecture that will meet the needs of NASA missions through 2030 and beyond. By initially providing one hundred times the computational capability of current processors for the same amount of power, and then allowing the

**Q: What is fault tolerance?**

**A:** *Fault tolerance enables a system to continue operating properly in the event of a failure of some of its components or subsystems. HSPC's chiplet architecture provides redundancy allowing the system to continue to process information in the presence of faults. This capability enables a NASA mission's successful completion despite localized failure.*



*The chiplet will benefit high data rate instruments by enabling dynamic trading among performance, power and fault tolerance.*

computing system to autonomously set its fault tolerance operating point, the HPSC chiplet provides an unprecedented ability to continually optimize its performance to meet evolving mission needs.

The HPSC team sees the project as a technology multiplier, amplifying existing spacecraft capabilities and enabling new ones. Think of the Mars Rover for example, slowly traversing the Martian sands and even autonomously avoiding rocks, but progress can be quite slow and human oversight and sometimes intervention is required by "rover drivers" back on Earth. An HPSC-equipped rover, on the other hand, could perform science on the fly, even while driving at a high speed over challenging terrain. Similarly, a future Europa lander, Titan balloon or Enceladus vent explorer would be able to autonomously explore and map the terrain, perform high quality science, or work around a damaged subsystem without human intervention and then beam new knowledge back to Earth.

The HPSC team believes the chiplet will be used by virtually every future space mission, all of which will benefit from more capable flight computing. We touched in with three members of the HPSC leadership team: Project Manager Rich Doyle at NASA's Jet Propulsion Laboratory, Deputy Project Manager Wes Powell at NASA's Goddard Space Flight Center, and Chief Engineer Rafi Some, also at JPL.

**GCD Q: Please talk about these mission needs in general: computational performance, energy management and fault tolerance. How do they work together?**

**HPSC:** Computational performance is clearly the central consideration for any flight computing system. HPSC's multicore architecture, in its baseline configuration, will deliver about a two order-of-magnitude increase in computational throughput over current capability, as exemplified by the RAD750. But equally important is a flight computer's ability to operate at low power (especially for deep space missions), to support power scaling, and to manage energy over time. Finally, a flight computer must be highly reliable (again, especially for deep space missions), and be able to handle radiation-induced upsets and other types of faults.

The big win of a multicore architecture is that power scaling essentially comes for free (literally, one can turn individual cores/processors on and off), and a range of software-based approaches to fault tolerance can be supported straightforwardly, such as voting schemes, and management of parallelism. These software-based approaches complement and extend traditional parts-based and hardware-based approaches—also incorporated in the HPSC design—making for a multilayered approach to fault tolerance and system reliability.

Furthermore, HPSC can be operated dynamically: computational throughput, power utilization and fault tolerance can be traded as needed to meet the needs of the mission phase or of the moment. This kind of operational flexibility has never been available before in a flight computing system.

**Q: What is a RAD750?**

**A:** *A RAD750 is a radiation-hardened single board computer manufactured by BAE Systems Inc. The RAD750 multicore processor products include the most technologically advanced microprocessor and space computers for the space community available among today's state of the art.*

**Q: What are voting schemes and management of parallelism?**

**A:** *Voting schemes and parallel computing are special design techniques used for computers in aerospace missions to protect critical mission functions and ensure success. Incorporating "redundancy" of select computer components within these designs plays an important role in reducing risk associated with relying on a single component to operate flawlessly.*

**GCD Q: Why is this chiplet so important to meeting the many-faceted computational needs? What makes it game changing?**

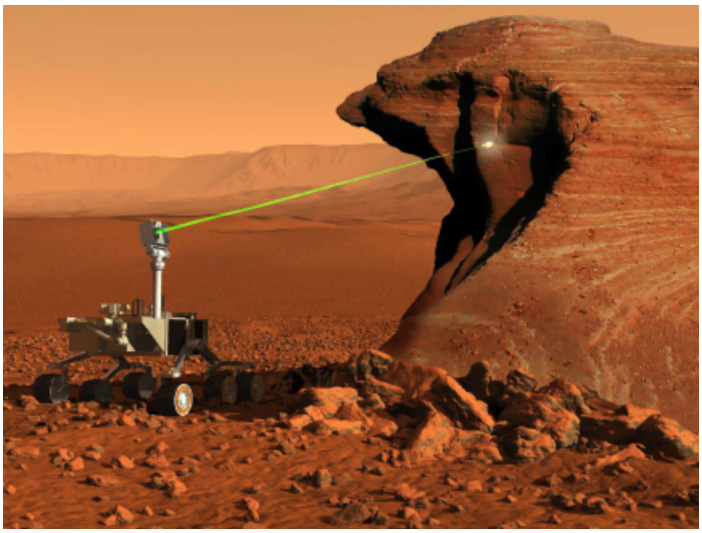
**HPSC:** Certainly, the ability to choose the operating point dynamically is game changing. Thus far, flight computing systems were designed to handle the most stressful scenario and were more or less stuck with that design point—even if it applied to only a small portion of the mission, such as a certain mission-critical sequence.

But HSPC is game changing in at least two more aspects. The architectural concept is open: additional dual quad-core chiplets (the baseline configuration) can be cascaded together to scale up the capability well beyond the default two order-of-magnitude increase. If a mission is not particularly power-constrained (as many Earth orbiters are), this is a great way to go. In addition, the same architectural openness enables HPSC to be configured with specialized co-processors such as FPGAs, GPUs, other DSPs, and future possibilities such as neuromorphic processors. This way, HPSC can be applied in a way that is highly optimized for particular missions and payloads.

Finally, individual processing cores will continue to advance under normal market pressures, without NASA needing to invest in or drive development.

**GCD Q: Please describe the chiplet so we might get a sense of what it looks like and how it is put together.**

**HPSC:** Physically, the chiplet, like other processor chips, is a thin piece of silicon about the size of your fingernail, and about that thickness as well, with hundreds of small square metal "pads" printed on one side. The metal pads are the connections for power, ground, external memory and various interfaces. But this is not what you would see if you opened a future space computer and looked inside. The chiplet will be housed in a protective package that is much larger, about an inch square and perhaps a quarter of an inch thick. On the bottom of the package will be rows and rows of small solder bumps—about a thousand of them—and on the top, an array of extremely small (smaller than a grain of rice) rectangular "capacitors" that help to smooth out any ripples in the power being fed to the chiplet. In future versions, we anticipate placing multiple chiplets into a single "multichip module" (or in our case, a multichiplet module).



*HPSC's chiplet addresses a full set of use cases for NASA missions—Mars, Discovery and New Frontiers are just a few—and for imaging and autonomy applications being explored by the Air Force Research Laboratory.*

**Q: What are FPGAs, GPUs and DSPs?**

**A:** *A field-programmable gate array is an integrated circuit designed to be configured by a customer or a designer after manufacturing. FPGAs contain an array of programmable logic blocks, and a hierarchy of reconfigurable interconnects that allow the blocks to be "wired together", like many logic gates that can be inter-wired in different configurations.*

*Graphics processing units typically handle computation only for computer graphics.*

*Digital signal processing (DSP) is the use of digital processing, such as by computers, to perform a wide variety of signal processing operations. The signals processed in this manner are a sequence of numbers that represent samples of a continuous variable in a domain such as time, space, or frequency.*

**GCD Q: How is the chiplet providing significant improvement in performance/power?**

**HPSC:** The chiplet utilizes state-of-the-art ARM processor circuitry—essentially the same type of circuitry as in your smartphone. Just as in your smart phone, power is optimized on an instruction by instruction basis, and just as in your phone, unused elements of the chiplet can be put to sleep or powered off completely. Unlike your phone, however, the standard commercial circuits are replaced with custom radiation hardened, high reliability versions that can withstand not only extreme radiation, but also extreme temperatures. Having the ability to tolerate severe environments saves power in another way; we don't need to provide as much heating or cooling, and because of the built in fault tolerance discussed earlier, in many applications, we don't need to supply additional, redundant processors.

**GCD Q: Tell us about how Boeing's work is contributing to the technology's advancement?**

**HPSC:** Boeing is contributing to the advancement of HPSC technology by defining the conceptual design of an HPSC chiplet architecture that can meet a wide array of mission needs. Key vendor expertise in robust circuit design is then leveraged to implement the chiplet using circuit design methodologies that allow it to operate reliably in harsh radiation and thermal environments for extended mission durations. To support chiplet application developers, the vendor will provide system software, including compilers, debuggers, and operating systems. The vendor will also provide, early in the development cycle, an emulator that can be used for software development prior to delivery of the hardware, and an evaluation board, a turnkey system that integrates the complete hardware and software stack with memory and support circuitry, suitable for qualification testing of the chiplet and for software.

**GCD Q: Please tell us about some of the project's successes.**

**HPSC:** On the programmatic side, our partnership with two institutions of the U.S. Air Force has been an enormous boon to the project. These institutions are the Air Force Research Laboratory's (AFRL) Space Vehicles Directorate at Kirtland Air Force Base, Albuquerque, and Space Missile Command (SMC) at Los Angeles Air Force Base. The agency-level joint interest in advancing flight computing created the context for our initial partnership with AFRL on the vendor architecture studies—this led directly to the HPSC chiplet concept.

We are conscious of the fact that multicore architectures may not be familiar to our flight software development teams. The middleware—which will assist missions in allocating and managing the suite of processing cores—is intended to ameliorate the learning curve, while still allowing mission teams to optimize down to the hardware level if they wish and have the wherewithal to do so.

On the technical side, as mentioned previously, the chiplet is a modular architecture that can be easily upgraded or expanded in future versions by the addition or replacement of processor, memory controller, or interface modules (aka IP cores). This modular architecture allows easy, low cost upgrade of the chiplet and is a new concept that, after years of study, is coming to fruition.

This concept of modularity is also embodied in the notion of a chiplet. Rather than building a large, expensive, "system on a chip," the chiplet concept is to build larger computing systems by ganging together multiple chiplets to form a "system in a package." Over time, we expect to build a library of chiplets that can be mixed and matched as needed for any given application. Once again, this concept, which has been studied for several years, is now coming to fruition in HPSC.

By working with the ARM family of modular cores, we also ensure that code written for this processor will run on all future versions of the chiplet. This is an extremely significant development. One of the reasons that it has been so difficult to field new space processors is the high cost of porting the large base of existing software to a new architecture. Any future version of the chiplet will be able run the same software developed for this first one.

**Q: What is a solder bump?**

**A:** *Solder bumps are the small spheres of solder (solder balls) that are bonded to contact areas or pads of semiconductor devices. They are used for face-down bonding.*

**Q: What is ARM processor circuitry?**

**A:** *ARM stands for Advanced RISC Machine, and RISC stands for reduced instruction set computing. ARM is a processor architecture based on a 64-bit RISC. ARM architecture is the most commonly implemented instruction set architecture.*

*The chiplet's extensible, interoperable, flexible and future-proofed architecture enables custom mission configurations. This artist's concept illustrates a potential sample return being initiated.*

**GCD Q: There is a transition planned for validation and/or first mission use with NASA's Technology Demonstration Missions. Please tell us a little about that where is this advanced technology going to take us in the future of computing?**

**HPSC:** HPSC will impact all future NASA missions, in that flight computing is a core capability of any space exploration mission, human or robotic. We are in conversation with NASA programs representing Human Spaceflight, Earth Science, Mars Exploration and Outer Planets. Our U.S. Air Force colleagues are in similar conversation with their mission programs. We have found that a useful way to convey the future of computing in space is to talk about three broad categories of computing drivers, which emerged from our survey of 20 or so use cases. These are 1) high data rate instruments, 2) intense mission-critical calculations, and 3) platform autonomy, in various forms.

Hyperspectral and synthetic-aperture radar are two excellent examples of instruments capable of collecting enormous amounts of data. HPSC creates possibilities for performing processing and product generation onboard to mitigate downlink challenges. Note that as related technologies mature—such as optical communications—NASA need not look at the situation as either-or. Rather, HPSC plus high rate communications can represent a rising tide of capability, opening up the possibilities for conceiving future measurements and missions. From a risk management perspective, it may be natural for HPSC to be applied first to a payload (as opposed to a spacecraft) application, and one of these high data rate instruments is a likely candidate.

**Q: What are hyperspectral and synthetic-aperture radar?**

**A:** *Hyperspectral sensors look at objects using a vast portion of the electromagnetic spectrum. Certain objects leave unique 'fingerprints' in the electromagnetic spectrum. Known as spectral signatures, these 'fingerprints' enable identification of the materials that make up a scanned object.*

*Synthetic-aperture radar is a form of radar that is used to create two- or three-dimensional images of objects, such as landscapes. SAR uses the motion of the radar antenna over a target region to provide finer spatial resolution than conventional beam-scanning radars.*

*These remote sensing techniques are commonly used to gather and process data in astronomy, agriculture, biomedical imaging, geosciences, physics, and surveillance.*

HPSC will be up to the task, whether future robotic Mars landings, landing on other planetary surfaces such as Europa, and someday, cargo and human landings on the Moon and beyond to Mars. We are engaged in reconceiving the role of computing in space.

*HPSC will impact **all** future NASA missions, in that flight computing is a core capability of any space exploration mission, human or robotic.*

*HPSC is a challenging topic to understand, much less cover, so it seemed most appropriate to retain the discussion in its interview form, allowing the researchers to speak for themselves. One important note they wanted to share is that the team is conscious of the fact that NASA hasn't invested in a flight computer in 15 to 20 years and the HPSC investment will have enormous cross-cutting impact (basically, as they mentioned, all future space missions). "For that reason," the project reports, "HPSC is driving down now into finer-resolution system engineering and design considerations as it approaches preliminary design review, building out further from the earlier vendor architecture studies that led to the chiplet concept. This is exactly the right time to do so."*

*Solid play, right inning…especially given one of Game Changing's new starts for FY2018 called "SPLICE," which stands for Safe and Precise Landing Integrated Capabilities Evolution.*

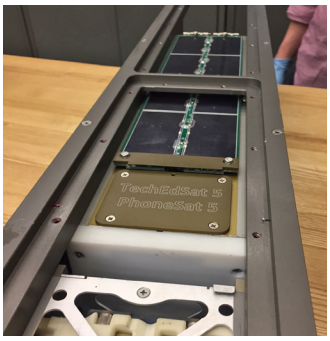
*SPLICE is a "bolt on" subsystem that provides autonomous landing capability to a host vehicle. Originally intended for crewed vehicles landing on the moon, it has since been adapted for robotic landers and other destinations. Given a desired landing point, SPLICE scans the area, detects hazards, and determines the optimum flight path and vehicle orientation for a safe landing as close as possible to the desired landing point.*

*SPLICE will take advantage of all of HPSC's capabilities: high speed sensor data processing for machine vision, the highest level of fault tolerance for crew and mission safety, real time control of the spacecraft during high speed descent and landing, and model based autonomy for situation analysis and decision making.*

***Definitions largely adapted or sourced from Wikipedia and Webster's.***

# Technologies Take Flight in FY17

## ESM Exobrake

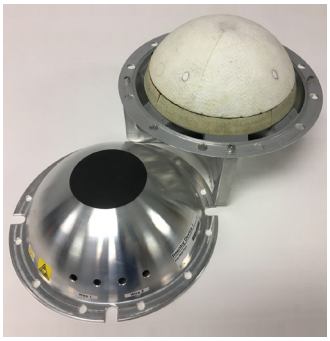



Entry Systems Modeling is involved in two launches in FY2017, TechEdSat-5 and TechEdSat-6.

TechEdSat-5 is the first ever demonstration of ground-commanded drag modulation of Exobrake, a propellantless deorbit device. Exobrake was released from the International Space Station (ISS) on March 6, 2017, with reentry occurring on July 27, 2017. An anomaly prevented data-uplink and minimum success criteria was not achieved, although Exobrake was confirmed to have deployed nominally.

TechEdSat-6 is the first ever demonstration of a targeted reentry using the Exobrake. The importance lies in on-demand sample returns from ISS becoming a growing market, and safety issues preclude traditional propulsive deorbit. Exobrake technology may also be extensible to low cost return from low-Earth orbit, debris deorbit, and planetary netlander missions. TechEdSat-6 had design modifications incorporated to mitigate potential failure modes identified during TES-5's post-flight. Integration into NanoRacks occurred October 3, 2017, and release from ISS into low-Earth orbit occurred November 20 to begin a series of wireless sensor experiments that are the first self-powered tests of sensor networks.

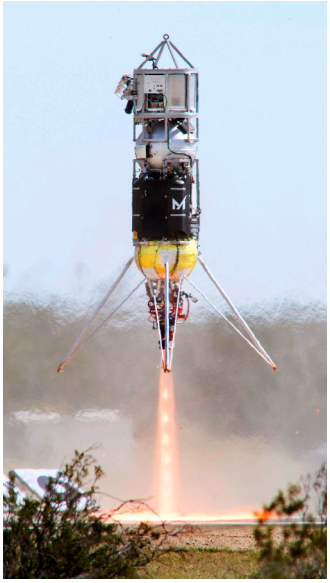
## CA-TPS



The Conformal Ablative Thermal Protection System, or CA-TPS, was installed on a small probe flight article provided by Terminal Velocity Aerospace (TVA) and launched on Orbital ATK's seventh contracted commercial resupply services mission for NASA to the ISS on April 6, 2017. The purpose of the flight test was to demonstrate cost-effective lightweight thermal protection systems for future missions to Mars, Venus and outer planets. The probe is essentially a hard aeroshell covered with the TPS and outfitted with sensors called thermocouples. To measure temperature during atmospheric entry, the thermocouples are embedded within the heat shield's C-PICA and the back shell's C-SIRCA to capture data for understanding how the materials behave in an actual entry environment.

Deployment of three probes occurred in June, and despite the fact that no data was received the progress realized still benefits the technology's development. Failure analyses point strongly to faulty onset of a software trigger such that data was taken and the systems tried to send the data while they were still in the signal-blocking metal shells. Upgrades to the software are planned, and NASA is looking for another opportunity to test.

## COBALT

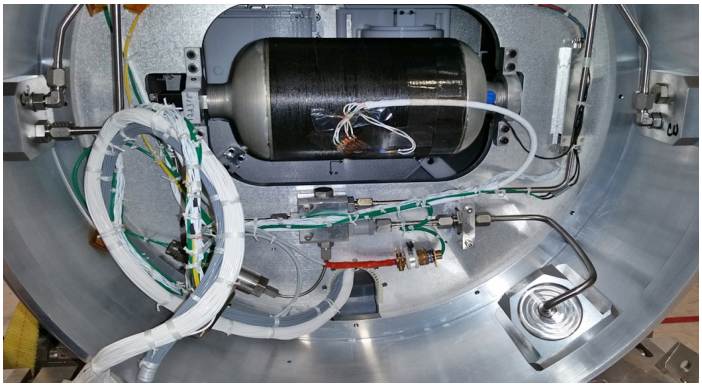


The technologies within COBALT provide a vehicle with sensing capabilities that enable precise descent navigation that can be used for planning and executing propulsive maneuvers to land a vehicle in close proximity of desired surface sites.

The FY2016 flight onboard a suborbital (vertical-take-off/vertical-landing) rocket provided a relevant test environment for evaluating the performance of the COBALT landing sensors and algorithms. For the FY2017 flight, the COBALT payload was flown in an open-loop role onboard the suborbital rocket, which means that the data was used onboard COBALT for precise navigation, but the vehicle did not utilize the COBALT information for planning or executing its propulsive maneuvers during descent.

The project completed the FY2017 flight test and has valuable data sets for analysis and revisions of the COBALT hardware and software in preparation for future closed-loop flight tests. During these tests, the suborbital rocket would use the COBALT precision navigation for planning and executing vehicle propulsive maneuvers during descent.

## COPV



A carbon nanotube composite overwrapped pressure vessel (COPV) flew in May 2017 as part of the SubTec-7 mission using a 56-foot tall Black Brant IX rocket launched from NASA's Wallops Flight Facility in Virginia, and as part of a cold-gas thruster system was tested in July. This test follows on from trade studies looking at incorporating nanotube materials with lower structural densities into a cryotank for a notional launch vehicle.

The COPV is an aluminum tank that is wrapped with a composite material to strengthen the tank's ability to hold a fluid or gas under pressure. In the recent test, the overwrap material was a newly developed carbon nanotube yarn that has 200 times the strength and five times the elasticity of steel. NASA computer modeling analysis has shown that composites using carbon nanotube reinforcements could lead to a 30-percent reduction in the total mass of a launch vehicle and improve the performance of aerospace systems.

The COPV on the sounding rocket test performed exactly as was expected. The payload was recovered and post-test analysis is underway to see if the structural integrity has changed as a result of the flight test.

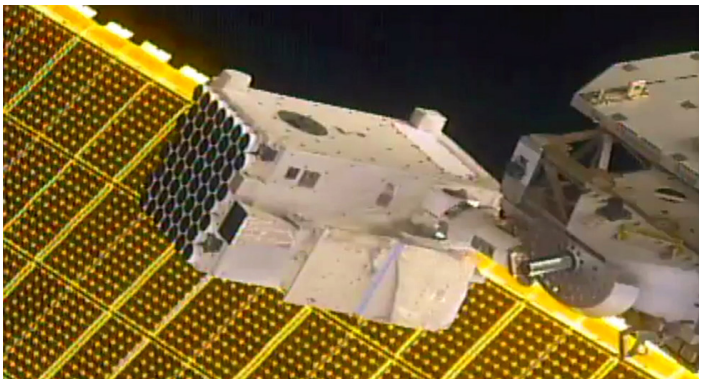
## SEXTANT-NICER

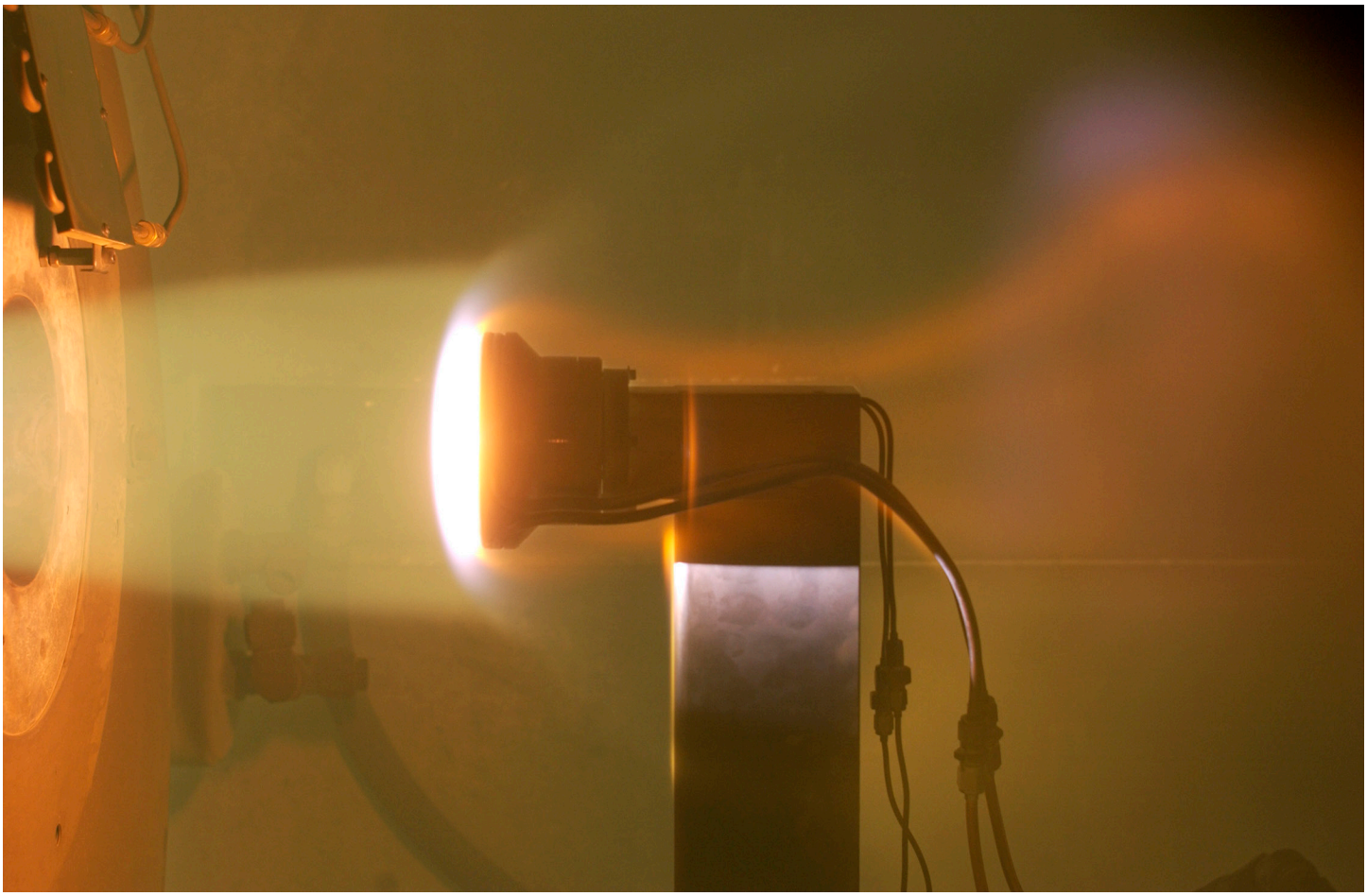
The CRS-11 launch delivered the Neutron-star Composition Explorer (NICER) science payload along with the accompanying Station Explorer for X-ray Timing and Navigation Technology (SEXTANT) demonstration to the ISS. The ISS is a unique platform that enables NICER/SEXTANT to perform both fundamental science and exploration technology development to provide autonomous navigation capability for future crewed and robotic deep space missions. Shortly after launch on June 3, 2017, NICER was successfully installed, deployed, completed commissioning, and then transitioned to science operations in late July.

After calibration, data streams were analyzed to characterize the on-orbit instrument behavior and determine baseline X-ray-to-radio timing offsets compared with preflight models. Using this coarse calibration data in the ground version of the flight software, the SEXTANT team was able to successfully detect pulsations for specific millisecond pulsars (MSPs). This data was used to create an initial flight software configuration that was uploaded on July 27, 2017, which resulted in the first successful navigation measurement generated in real-time by the onboard flight software.

Starting August 1, 2017, the SEXTANT flight software was commanded to nominal navigation mode, and the team continued to improve the coarse calibration, as navigation targets were available, and participated in the NICER observation scheduling procedure. By mid-November 2017, the SEXTANT team reported a technology first: successful demonstration of a fully autonomous, real-time X-ray pulsar navigation onboard the NICER mission. A total of 78 measurements were generated from select X-ray "beacon" pulsars.

This successful demonstration firmly establishes the viability of X-ray pulsar navigation as a new autonomous navigation capability to enable and enhance deep-space exploration anywhere within the Solar System, and potentially beyond. The current flight results will be used to update and tune the flight software, as well as the ground segment software, for a second navigation experiment later in the NICER nominal mission, where SEXTANT's pulsar timing models will be developed using only NICER data.





# HIAD Heat Shield Material Feels the Burn During Arc Jet Testing

NASA heat shield material that could one day be used on an inflatable aeroshell during atmospheric entry on Mars recently underwent testing at Boeing's Large Core Arc Tunnel in St. Louis, Mo.

The inflatable aeroshell, using high temperature advanced flexible material systems, will enable atmospheric entry to planetary bodies and the landing of heavy payloads. The Hypersonic Inflatable Aerodynamic Decelerator (HIAD) project is focused on development of the inflatable aeroshell technology and manufacturing capability at large scale, to support an orbital atmospheric entry flight experiment at Earth and Mars. HIAD overcomes size and weight limitations of current rigid systems by utilizing inflatable soft-goods materials that can be packed into a small volume and deployed to form a large aeroshell before atmospheric entry.

Critical to advancing the technology is development of flexible material systems whose performance must be verified through arc jet testing. During early August testing, small cutouts of the Flexible Thermal Protection System, about 2.5 inches in diameter and anywhere from a half-inch to 1-inch thick, were placed in a supersonic wind tunnel and blasted with jets of superheated plasma gas. The plasma gas hit the cutouts at speeds of Mach 4 or more, and heated the surfaces to temperatures up to approximately 2,700 °F. Thermocouples embedded in the samples measured the material's response to the superheated conditions.

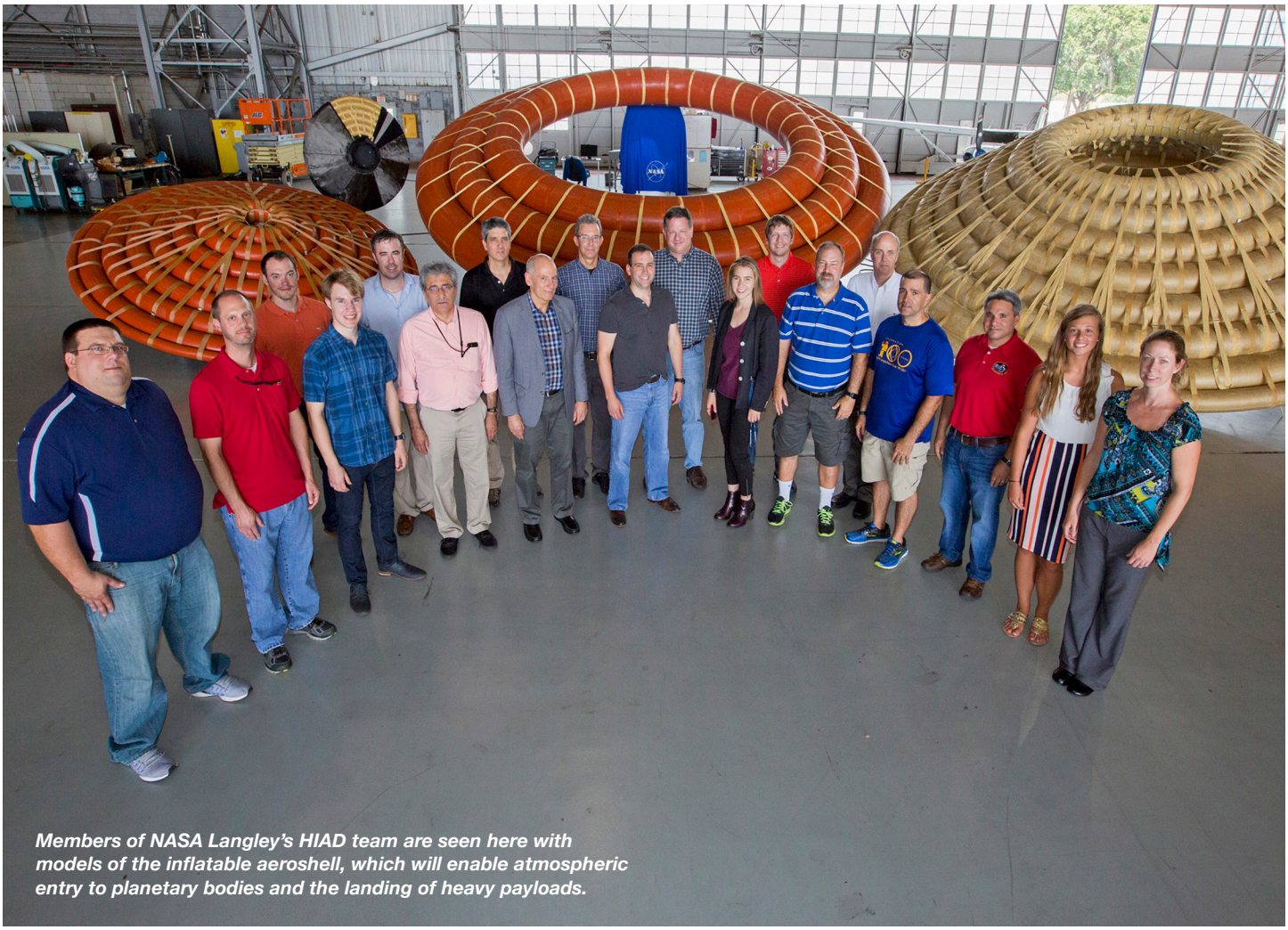
Researchers calibrated tunnel pressure and temperature to be similar to the range of conditions HIADs would face during atmospheric entry on Earth and Mars. The data from these tests will be used to validate mathematical models used for design.

The test team included researchers Steven Tobin, Matt Wells and Andrew Brune of NASA's Langley Research Center in Hampton, Va.; and Grant Rossman, a doctoral candidate at the Georgia Institute of Technology in Atlanta, Ga.

HIAD technology is being developed by researchers at Langley through NASA's Game Changing Development Program, which is part of the agency's Space Technology Mission Directorate. The program advances space technologies that may lead to entirely new approaches to space missions.

**Reprinted from www.nasa.gov/feature/langley/hiad-heat-shield-material-feels-the-burn-during-arc-jet-testing, September 19, 2017.**

*Small cutouts of the Flexible Thermal Protection System (left, top and bottom) for NASA's Hypersonic Inflatable Aerodynamic Decelerator were exposed to temperatures up to approximately 2,700 °F during testing (previous page) at Boeing's Large Core Arc Tunnel in St. Louis, Mo.*
Photo Credit: Boeing



*Members of NASA Langley's HIAD team are seen here with models of the inflatable aeroshell, which will enable atmospheric entry to planetary bodies and the landing of heavy payloads.*

# HIAD Transitions to Technology Demonstration

The largest diameter inflatable atmospheric reentry structure built to date—the first three-tori of a 12-m aeroshell stack—was delivered to NASA's Langley Research Center in Hampton, Va., in April 2017 from industry contractor Airborne Systems.

The Hypersonic Inflatable Aerodynamic Decelerator, or HIAD, is a deployable aeroshell that is stowed for launch and cruise, then deployed exoatmospherically, and uses the atmosphere for deceleration. In FY 2017, multiple HIAD structural elements underwent a series of tests at Langley, and the project is set to transition to Space Technology's Technology Demonstration Missions (TDM) division in preparation for an orbital entry flight demonstration.

Since FY 2012, researchers with the project demonstrated construction and performance of HIAD structures up to 6-m in diameter. FY 2015 to 2016 efforts focused on the extension of inflatable structure and flexible thermal protection system designs, structural modeling, materials, manufacturing, and testing methods extensible to 12-m aeroshells. In FY 2017, 12-m development continued with fabrication of a 12-m HIAD short stack (3 tori) article using flight-relevant materials to demonstrate assembly procedures,

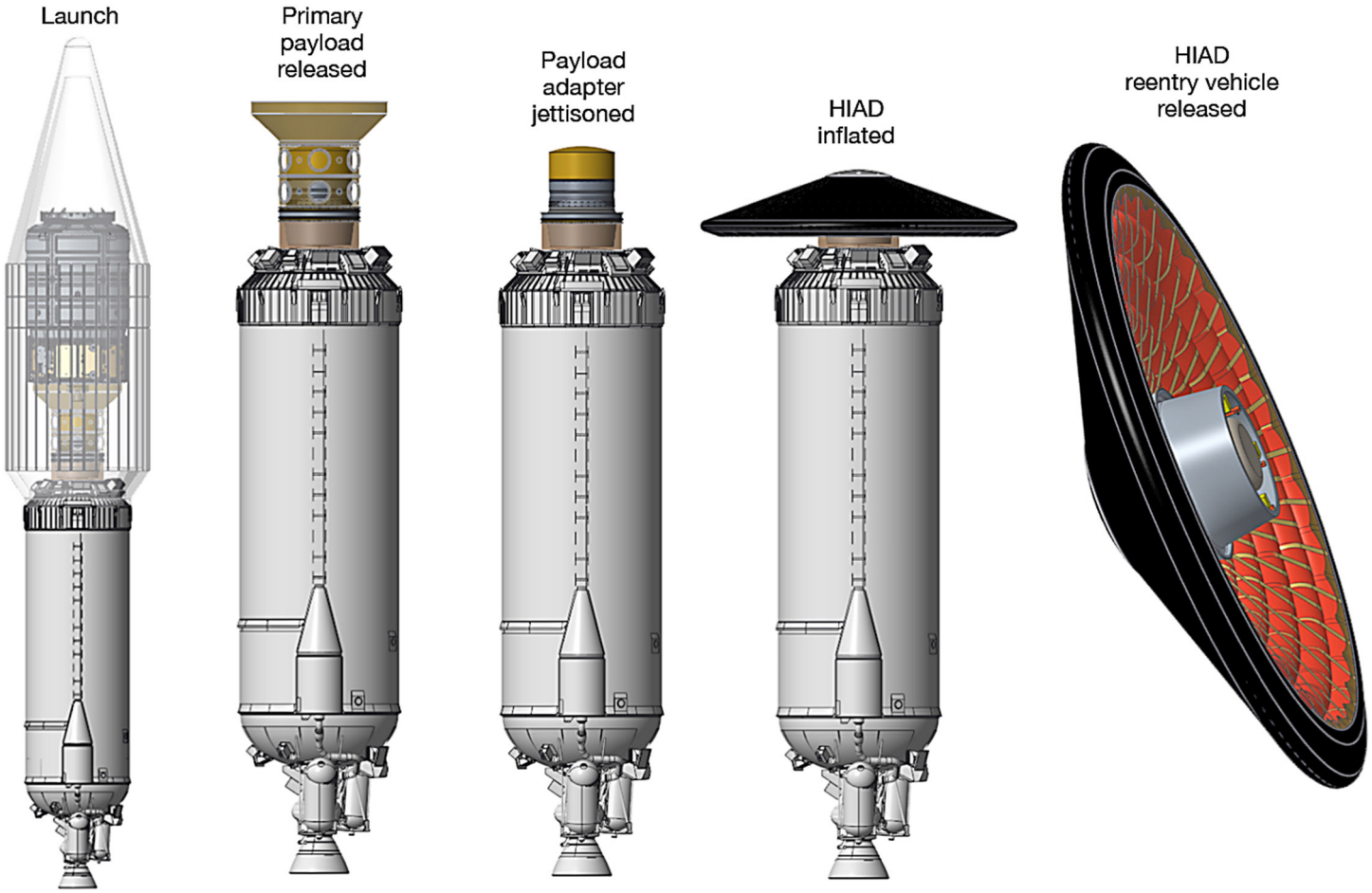
*Above: HIAD's three-tori stack being positioned for testing and demonstration activities at Airborne Systems, Inc., in Santa Anna, Calif.*

manufacturing tools, test equipment, and structural load distribution.

Referred to as "HIAD-2" while undergoing FY 2017 efforts, the Langley-led project's focus has been on developing materials, control mechanisms, and structural design concepts guided by potential mission architectures, as well as demonstrating performance of these advancements. The project executed a series of tests with the goals of 1) establishing manufacturing capabilities for large scale human Mars exploration systems, and 2) extending thermal protection system modeling to provide flight margined design requirements.

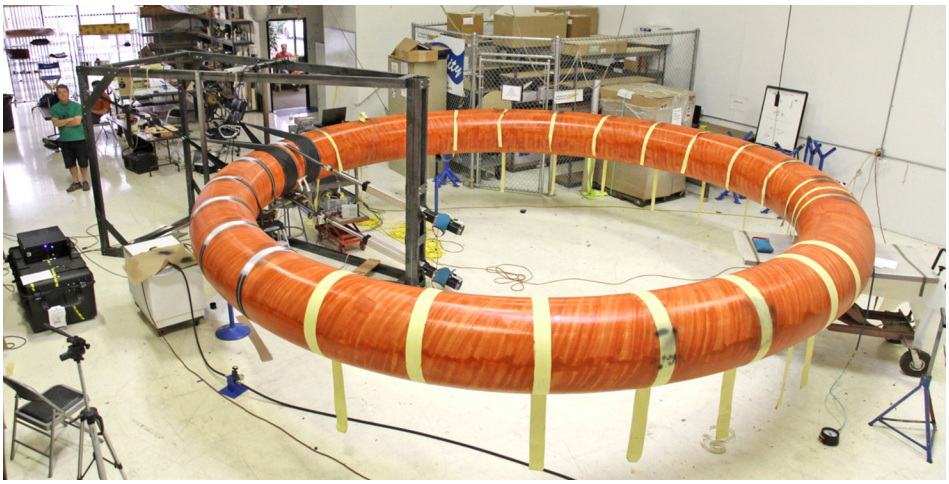
Under Space Technology's Game Changing Development Program, the desired testing outcome has been to mature HIAD entry, descent, and landing technology to a point where it is ready for mission infusion. Development of more efficient structures, pushing the envelope of thermal protection system performance, and establishing manufacturability of large-scale HIAD articles all serve as the underpinnings of future HIAD development work.

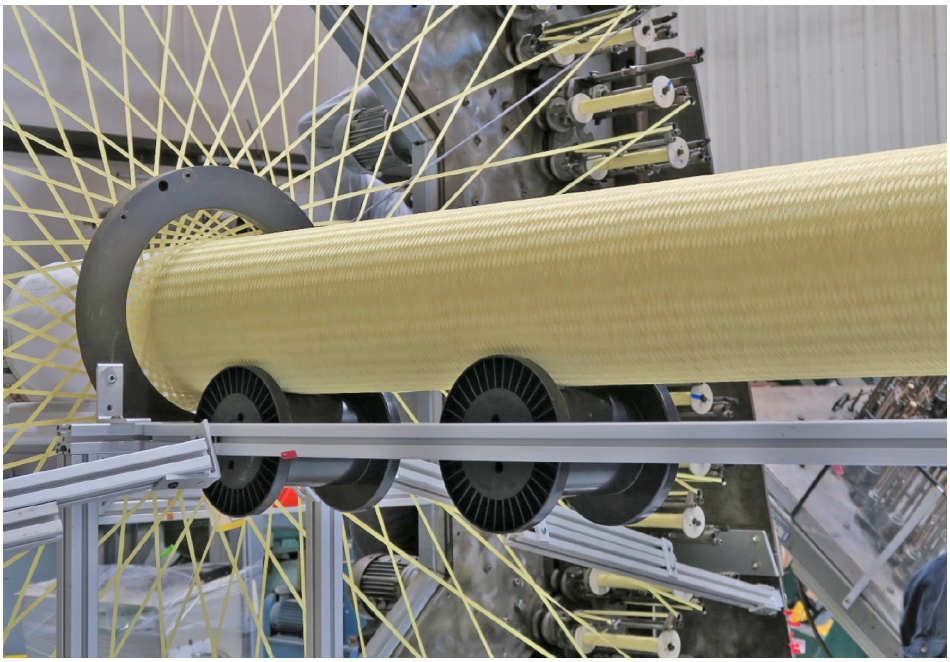
For FY 2018 endeavors, HIAD-2 transitions to TDM where advancement continues as part of the low-Earth orbit flight test of an inflatable aeroshell demonstration, referred to as LOFTID, in partnership with United Launch Alliance. Specifically, a NASA-built HIAD reentry vehicle is planned to be flown as a secondary payload on an Atlas V launch vehicle delivering its primary payload to Earth orbit. After the primary payload is released, the Centaur upper stage will orient, spin-up, and deorbit the vehicle for an Earth reentry. The flight will test HIAD technologies at a scale and entry conditions relevant to identified Earth and Mars mission infusion opportunities.



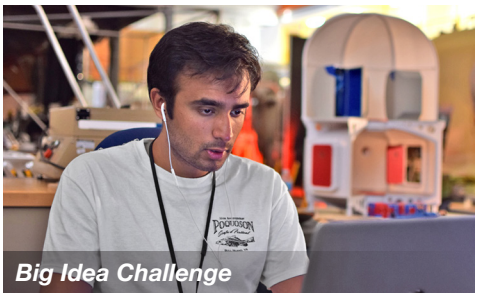

*LOFTID launch, payload and reentry vehicle configuration diagrams.*

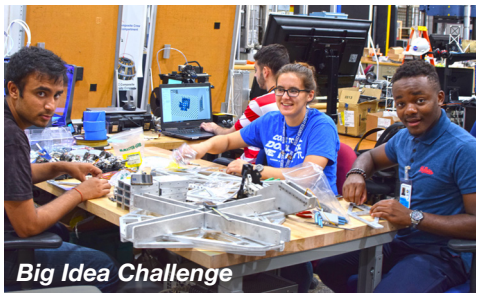
*The three-tori partial stack of a 12-m design was completed by Airborne Systems. The largest inflatable structure built to date, lessons learned from previous work informed build procedures, demonstrating improvements to uniformity of strap preloads. Strap indentation testing (top) was performed to determine maximum strap load before strap delamination. Hydrostatic pressure testing demonstrated pressure integrity and margin above maximum operating pressure. Leak rate testing (middle) proved very good for a large article, lower than totals seen in an IRVE 3-m article. Zylon cord and webbing were manufactured (bottom) and tested for properties such as tensile strength.*





Alexa AVA


Big Idea Challenge


Big Idea Challenge

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Big Idea Challenge

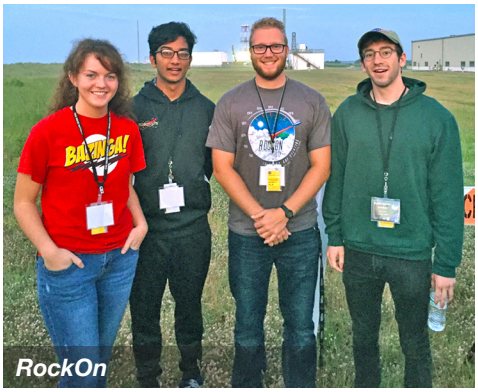
Junior Game Changers

# NASA Interns: The Best of the Best

Big Idea Challenge

RockOn

Big Idea Challenge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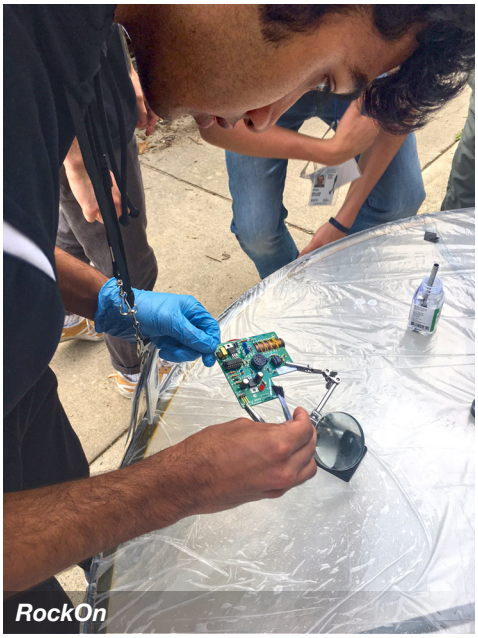
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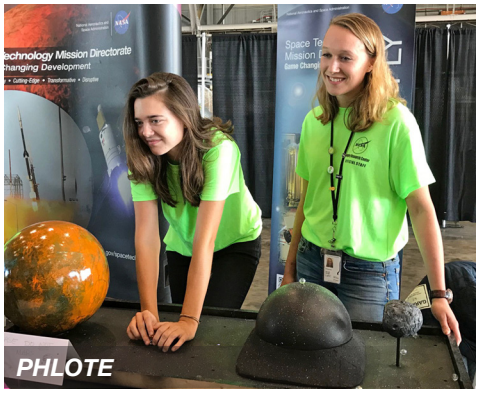
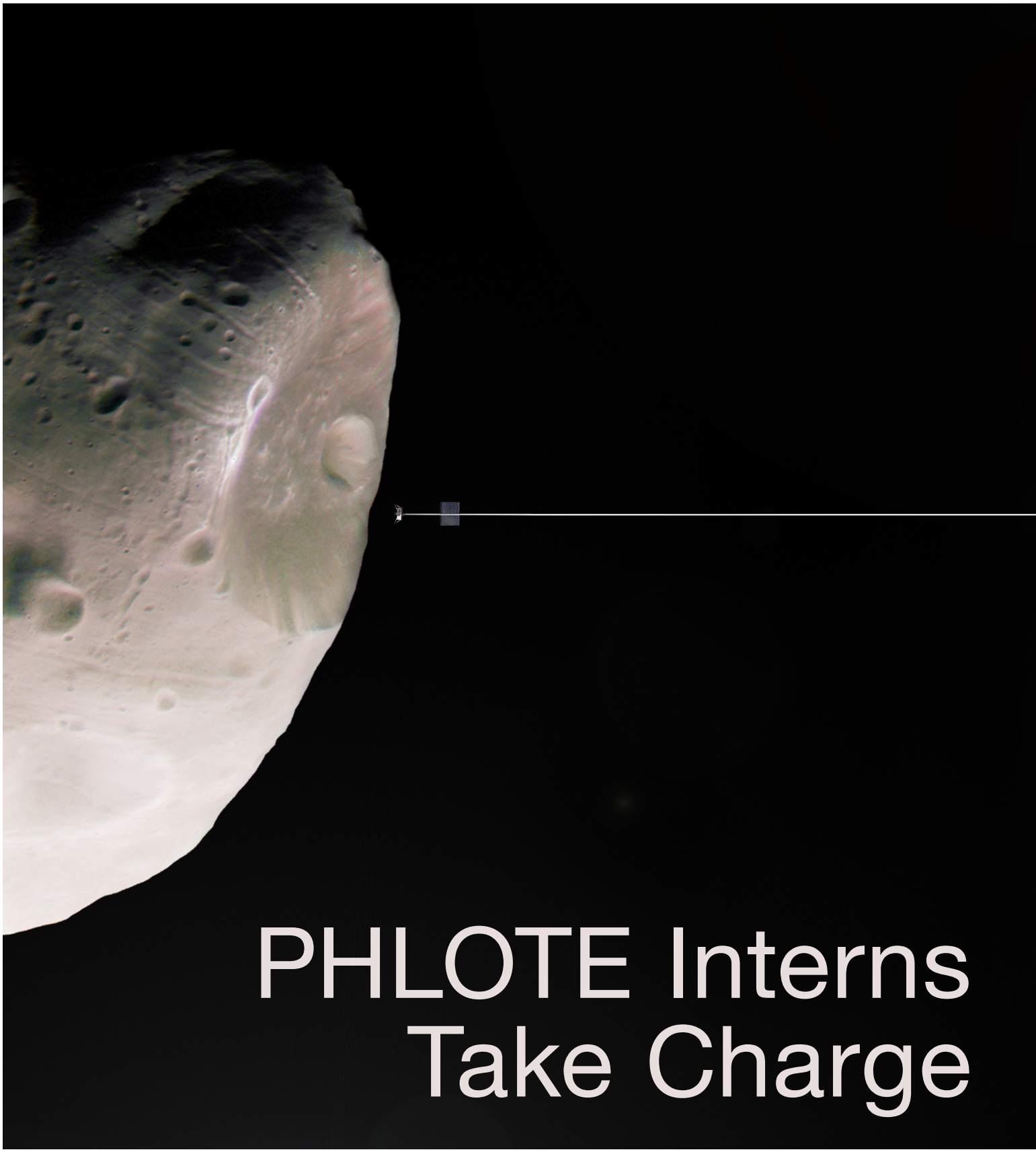
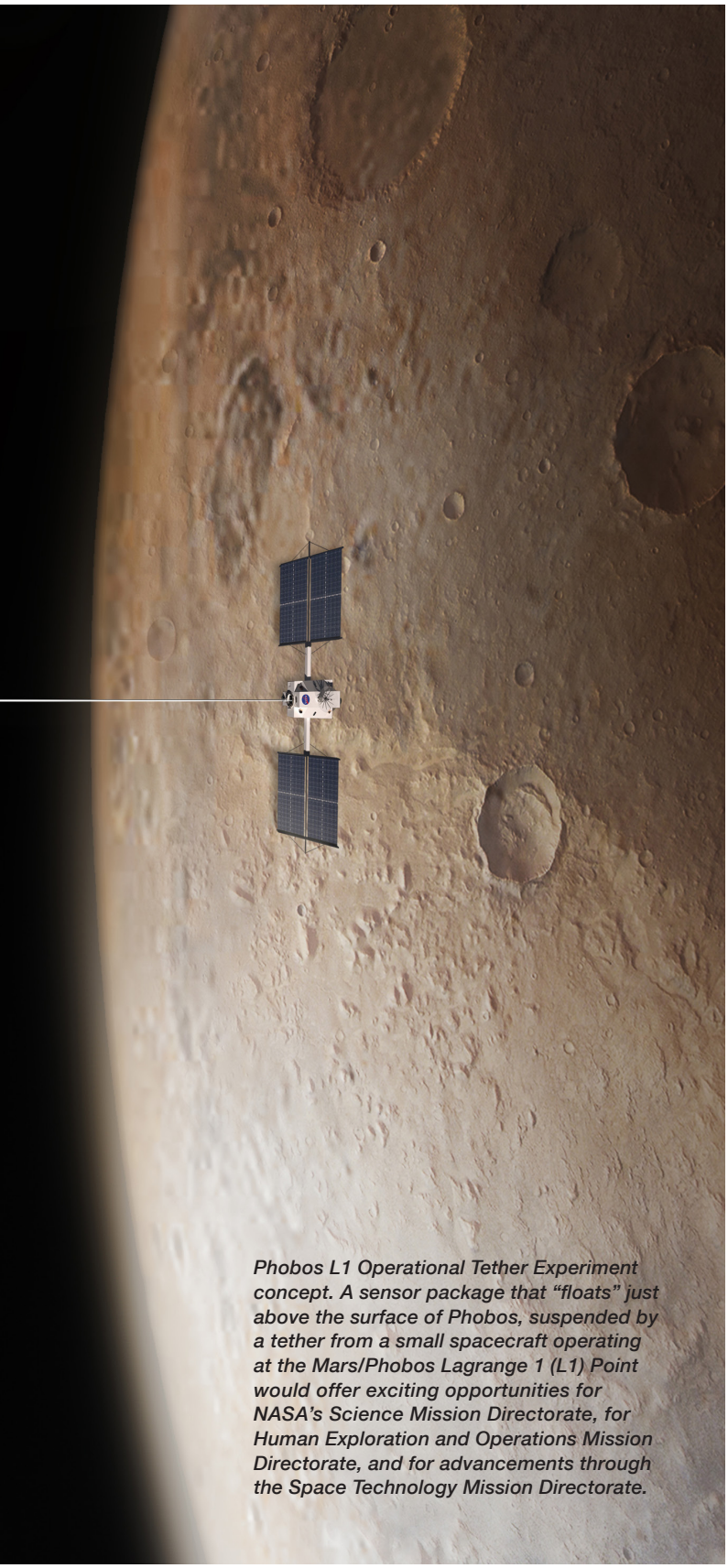

PHLOTE



# PHLOTE Interns Take Charge



*Phobos L1 Operational Tether Experiment concept. A sensor package that "floats" just above the surface of Phobos, suspended by a tether from a small spacecraft operating at the Mars/Phobos Lagrange 1 (L1) Point would offer exciting opportunities for NASA's Science Mission Directorate, for Human Exploration and Operations Mission Directorate, and for advancements through the Space Technology Mission Directorate.*

After talking with the Game Changing Development Program's PHLOTE interns, the lasting impression is that they sound more like seasoned aerospace professionals than college students.

PHLOTE stands for Phobos L1 Operational Tether Experiment and provided internship opportunities for summer and fall interns, giving them a chance to work on a NASA Innovative Advanced Concepts (NIAC) study. The NIAC program looks at far out—and sometimes called 'NIAC crazy'—ideas that can have big impacts to human exploration in space.

The PHLOTE study is developing a technology first: a credible low-cost mission to the Martian moon Phobos where it will perform hover mode station keeping at the Mars Phobos Lagrange point (L1) using new sensors developed at NASA's Langley Research Center in Hampton, Va.

While hovering at the Mars-Phobos L1, PHLOTE would lower a tethered sensor platform that can "float" above the moon's surface or "park" on the moon for direct measurements of the soil. If attached to the surface it could possibly become the first operational space elevator. By extending the tether the spacecraft could pick up rocks and could also become the first operational space crane.

The NIAC study must show that the PHLOTE mission concept is credible. To do so, PHLOTE interns are focused on designing a spacecraft that can meet all of the PHLOTE mission requirements and constraints. They have been working with discipline engineers at Langley to understand navigation sensors, lightweight materials, thermal design, deployable mechanisms, and the myriad of other things needed to design a real spacecraft.

Kevin Kempton, principal investigator for the NIAC PHLOTE study and also a program element manager with GCD's program office, was able to show the interns how Space Technology's development pipeline moves an early stage concept like NIAC-PHLOTE into the next stage of development where GCD would continue to advance the technology.

"The PHLOTE interns have an opportunity to get involved at the beginning of a deep space mission formulation and move rapidly into iterating on a mission design," Kempton says. "They get exposed to a wide spectrum of disciplines needed for a spacecraft and learn a lot about how the space environment impacts a design…systems engineering skills that they are rarely exposed to in the class room. Things like identifying needs, goals and objectives, performing systems trades, and managing technical resources like mass and power."

The PHLOTE summer interns were tasked with performing the initial mission design and analysis, and more pointedly to identify mission constraints based on the specific low-cost launch vehicle selected. They performed mission power assessments and developed a model of the basic configuration. The components for the spacecraft were selected after extensive research on the state of the art (products available for small satellites. A 3D model of the spacecraft was developed and mass and power estimates were generated. All of this was added to the PHLOTE concept of operations document that will be a key deliverable of the study.

The PHLOTE study's summer interns led the charge: Madeline Pomicter from Vermont and Zachary Wells from nearby Yorktown, Virginia. Pomicter studies mechanical engineering at the University of Vermont and brought her 3D modeling skills to the table with a high level of confidence.

"The general mission concept is to send a SmallSat to the Mars-Phobos L1 point where it would lower a sensor package over the surface of Phobos via a tether," Pomicter explains.

*Virginia Polytechnic Institute and State University student Zachary Wells.*

*University of Vermont student Madeline Pomicter.*

"Zach, the other intern on this project, and I have been helping develop a concept of operations for the mission and developing a first iteration of the spacecraft design.

Zachary Wells is a physics major at Virginia Polytechnic Institute and State University who is engaged in his second internship at Langley.

"Project PHLOTE seeks to send a satellite to Mars' moon Phobos and keep it at the balance point between the gravity of the two bodies (at the L1 point) so that it may observe both Mars and Phobos," Wells says. "Maddie and I were responsible for doing a lot of the leg work for the Phase I feasibility study. This means that because the project was still in early stages of development, we had to determine what equipment and parts the satellite would need to complete its mission, design the spacecraft, and perform many of the analytics of the mission to help determine which parts to incorporate into it."

Once into the research, Pomicter and Wells quickly determined how to divide up the work responsibilities to put their individual strengths forward and best benefit the project's needs.

"The spacecraft design work has been my focus," Pomicter says. "I spent a lot of time researching commercially available components and developing technologies and contacting companies to ask for more details. Once I had most of the parts picked out or at least knew generally what they would look like, I came up with a draft of the design itself and made a model using 3D CAD software. I did a couple more iterations until, revision by revision, it started to look something like a credible spacecraft. The design and details

about the chosen components then got incorporated into the concept of operations document, which will be the basis of the final report produced for the study"

"I took to performing the analytics," Wells says. "I did so both by hand calculations and through the use of a physics modelling software called STK. This allowed us to place limits on what the satellite would do and determine how to do it. Doing this is critical at this stage of design because it is those limits you impose that allow an abstract idea to really take shape."

In the fall, two new interns, both mechanical engineering majors, picked up where Pomicter and Wells left off. Amber Dubill attends Rochester Institute of Technology in New York state, where she is from, and Haley Uline, an Air Force brat who claims to be from "all over the place," goes to Miami University of Ohio.

Uline says the fall work all goes toward making the concept of operations as realistic, feasible, and compelling as possible so that this mission is selected for a Phase II study to continue the development toward a detailed design.

"What I really like about the project is that I can choose any aspect of the mission in the con-ops to further develop," Uline says. "I have so far been able to focus on the scientific instruments and creating a new design for the structure of the spacecraft, and can just as easily move on to researching the types of propellant or communications."

Dubill describes her focus as helping refine the design of the spacecraft to show that this is a feasible mission

*Rochester Institute of Technology student Amber Dubill.*

*Miami University of Ohio student Haley Uline.*

architecture. "The research I do will help show credibility and give future engineers on this project a baseline to start with. This mission becoming a reality would add new capabilities that will impact our human exploration of Mars. It's a little of the way out right now, but a mission like this to Phobos may be the first step towards landing humans on our neighboring planet because it would provide really important data to mission planners at a pretty low cost."

Uline agrees with the importance of this study's impact. "A mission utilizing a Lagrange point for hovering and a long tether for closer observation has never been done before. Such a mission, if successful, would make scientific observational missions at other planet systems much more feasible. PHLOTE would also answer questions about Phobos' unknown past and confirm its potential for future manned missions seeking resources and as an important stop on the way to Mars."

For all the students who engaged in the PHLOTE internship opportunities, Dubill's description of what she hoped to gain from the experience summed things up nicely.

"Unlike other internships, I really get experience in all areas of spacecraft design" she says. "Instead of focusing on one subsystem, I am able to perform more of a systems engineering role. I really am learning something new every day. I want to learn as much as I can about mission architectures, spacecraft subsystems, and research as I can. You don't get this kind of learning in school."

# A Girl Who Codes: Helen Zhang

Growing up in the Elmhurst section of Queens, New York City, 20-year-old Helen Zhang says she never expected she'd have an opportunity to intern at NASA.

A computer science major at Boston University, Zhang sort of stumbled on NIFS, or NASA Internships, Fellowships and Scholarships program and its One Stop Shopping Initiative website. The NIFS "OSSI" portal is a NASA-wide system for the recruitment, application, selection and career development of both high school and college students in science, technology, engineering and mathematics disciplines, or STEM.

At Boston University, Zhang took astronomy courses to fulfill a science requirement, saying that they are still some of her favorite classes. One of Zhang's professors took her and a few other classmates to do research using the Perkins Telescope at Lowell Observatory in Flagstaff, Ariz.

"After this experience, I realized how much I loved space and I wanted to see if there was a way I could contribute to the field," says Zhang. "Once I found out about NIFS, I applied and was fortunate enough to end up at Langley for a summer!"

Zhang's summer internship challenge was to create "AVA," or Alexa Voice Access, a voice-activated interface that Game Changing Development (GCD) program managers and other personnel and stakeholders could use to interact with project data in the cloud.

"Made using Amazon's Alexa Voice Service, Lambda, and DynamoDB, AVA can answer questions related to a task or technology's overview, life-cycle cost, point of contact, technology readiness level, and much more," Zhang says. "She is able to maintain a dialog and mimic a conversation."

GCD Deputy Program Manager Bob Hodson, who co-mentored Zhang, says the agency will benefit in several ways from the Alexa development effort. "It has served as a use case for the Internet of Things and challenged security protocols forcing new thought on securely allowing new methods of accessing information. Through demonstration of voice activated queries on projects and technologies it will also serve to effect culture change for a new information access paradigm."

*Above: Helen Zhang consults with mentor Bob Hodson about her work on AVA.*

There is no better example of effecting culture change than the current explosion in artificial intelligence, commonly referred to as "AI." As a result, like many others in her age group, Zhang's hobbies include making computer applications. "There's always a new project to pursue," she says, "and that's what I love about tech."

At Boston University, Zhang currently works with the campus "Girls Who Code" chapter to plan the university's first all-female hack-a-thon.

"It's called Hack the Gap," Zhang says, "and our theme of focus is hacking the gender gap in technology. We've arranged workshops in game design, augmented reality, virtual reality, iOS development, and web development. In addition, we will provide an experienced mentor from the field to each of the participating teams. We believe that this event will be an opportunity for many students to explore their tech interests in a welcoming environment."

Zhang's belief in supporting this opportunity is strong, one with roots in why she never thought she'd be a NASA intern. Zhang's parents were initially a little skeptical about computer science as her chosen field of study, which can sometimes be the case for young women interested in pursuing careers in STEM.

"This internship validated my effort in school, and I'm happy to say that my parents now have a different perspective on women pursuing careers in STEM," Zhang says.

And Zhang certainly seems to be on her way.

Christopher Newport University Lecturer Keith Perkins, with the Physics, Computer Science and Engineering department, teamed up as technical guide for Zhang and the Alexa Ava project. Perkins' role was to help her define the project scope, the tasks involved, and how to manage each of those tasks.

"I was also there to assure her that she wasn't alone on this project, that I thought the project was both doable by and within the reach of a college junior," says Perkins. "Plus, I was willing to jump in and work with her on the more challenging tasks. "

Perkins explained that the Alexa programming interface is new and quickly evolving, as is the case with many new technologies, and because of the rapid growth, there is little documentation to resource and a lack of functional examples. He talked about some of the specific challenges Zhang ran into during the project, and that it was a learning experience for him as well.

"The interface was new, the idea was new, and working in the Game Changing environment was new," Perkins says. "I think it's fair to say that Helen solved problems despite the documentation, not because of it."

But Zhang's success goes beyond the project's obvious attainment to a deeper learning experience and level of personal fulfillment.

"I enjoyed how much control I had in designing and developing AVA," she continues. "This project has been the most challenging by far, and I'm grateful to have had such supportive mentors to guide me during the process. It was the first time I dealt with this kind of technology, and I'm glad that the final result was an overall success."

*Boston University student Helen Zhang (right) demonstrates AVA to Alan Sutton (left), Bob Hodson, and Mary Beth Wusk during a presentation session showcasing summer intern work at NASA's Langley Research Center in Hampton, Va. Zhang came to Langley via the NASA Internships, Fellowships and Scholarships program (NIFS), which is a paid educational, hands-on experience that creates opportunities for students to conduct robust research while working projects side-by-side with Langley's scientists, researchers, engineers and mission support teams.*
*Read more about Langley's 2017 summer interns at: https://www.nasa.gov/feature/langley/nasa-langley-summer-interns-show-off-their-projects-at-poster-presentation*

# BIG Idea's Big Nine

Nine.

That's the number of college students who participated in summer 2017 internship opportunities offered to those making up the first and second place winning teams of NASA's second annual Breakthrough, Innovative and Game-changing (BIG) Idea Challenge.

In May, then acting Program Manager Mary Beth Wusk shared her excitement as the Game Changing Development (GCD) Program's challenge hosted at NASA's Langley Research Center in Hampton, Va., for a third year its top designing teams to participate in the forum that would decide the winners.

"If you haven't heard already, GCD's Breakthrough, Innovative, and Game-changing (BIG) Idea University Challenge is a BIG hit," Wusk said. "NASA initiated this university challenge to engage students in solving some of the agency's toughest problems. Previous technology challenges included shape morphing inflatable entry vehicles and autonomous in-space assembly."

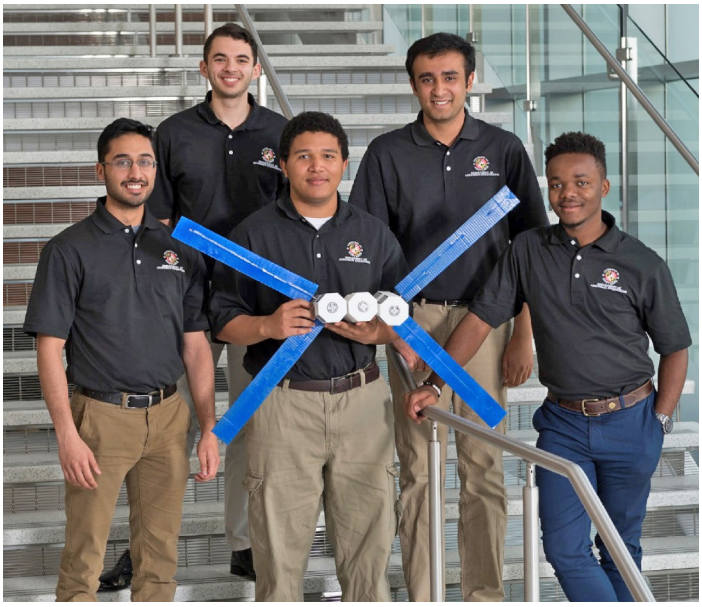
The BIG Idea Challenge is an engineering design competition engaging the university community in driving innovation and developing unique solutions to NASA technology focus areas. The 2017 challenge was to develop concepts for constructing a solar electric propulsion (SEP)-powered space tug using autonomous robotic assembly. Similar to a tug boat, which moves other boats from one point to another on the water, a space tug would transfer modules or payloads from one point in space to another, such as from low-Earth orbit to a lunar orbit.

Tulane University of Louisiana's "The Sunflower—A Modular and Hexagonally Symmetric SEP Cargo Transport Spacecraft" took first place in the competition. Under Professor Timothy Schuler's leadership, students developed a concept using hexagonal modules with distributed power and propulsion and a hybrid deployment/assembly approach to create SEP vehicles scalable from 200 to 500 kW.

A team from the University of Maryland was named first runner-up. Professor Dave Akin led his team to develop a concept called the "200 to 500 kW Solar-electric Modular Flexible Kinetic Escort," or SMo-FLaKE.

During the internships, students worked closely with NASA engineers to learn more about SEP or to advance portions

*Members of the winning team from Tulane University are shown holding a model of their winning design. Top row from left to right are Professor Timothy Schuler, Otto Lyon and Matthew Gorban. On the bottom row are Afsheen Sajjadi, Ethan Gasta, John Robertson and Maxwell Woody.*



*Members of the first runner-up team from University of Maryland are shown holding a model of their winning design. Top row from left to right are Ryan Ernandis and Rounak Mukhopadhyay. On the bottom row are Shaheer Khan, Leandre Jones, Hermann Sipowa and Kaptui Sipowa.*

of their SEP concepts showing potential for high-impact capabilities in crewed space missions.

Mentor Monica Guzik is a gas and fluid systems engineer in the Fluid and Cryogenic Systems Branch at NASA's Glenn Research Center in Cleveland, Ohio. She said intern Matt Gorban (Tulane University) was an integral member of the engineering team supporting the Flow Boiling and Condensation Experiment, which will fly aboard the International Space Station in 2019.

"Matt worked with the project science team to gain valuable test data from our breadboard test hardware that the engineering team needed in order to validate their design," Guzik said. "He did all of the test data analysis and reporting for the engineering team, and helped author test procedures for troubleshooting. Matt was able to learn how to apply skills he had learned in the classroom, such as thermodynamics and laboratory test methods, to a real-world application. In addition, he learned how to communicate and report technical information to support an engineering development team."

Guzik believes NASA's benefit from having interns support summer projects is twofold. "First, it brings new ideas and viewpoints to technical teams. Adding diversity of thought and experience often opens the door for creative solutions to problems that might not emerge otherwise," she said. "Secondly, student interns often bring with them an enthusiasm and eagerness to the projects that they are working on. I believe that this can often refresh and re-inspire their mentors and fellow engineers, which can bring a newfound passion to our work that helps to remind us why we love what we do."

At Langley, Erik Komendera is a research aerospace engineer with the Autonomous In-Space Assembly group in the Structural Mechanics and Concepts Branch. The three interns he mentored were Ryan Emandis, Hermann Sipowa and Rounak Mukhopadhyay (each with University of Maryland), all of whom were placed in one of the branch's in-space assembly research projects. Komendera takes his mentoring responsibility seriously and will assure you up front that he does not give his interns busy work.

"In-space assembly involves several disciplines—mechanical, electrical, and software engineering—and while the interns may have specialties, they occasionally cross into other disciplines as needed," Komendera explains. "They make heavy use of the knowledge they bring with them, but often they have to learn on the spot. They all have played central roles in building and operating the robots and test articles we use in our in-space assembly research. They participate in planning meetings and often make crucial decisions on their own. And they are treated by our team as equal members."

Komendera hopes his interns leave having experienced what it is like to be a robotics researcher working at NASA doing things no one has ever done before. "As accomplished as some of them are coming in, I think their time spent here is the best chance they will have as students to see what doing research is really like. My biggest hope is that they leave the internship convinced that they want to be roboticists, working to solve the problem of how to build things in space and on other worlds."

Kenny Cheung is a member of the chief technologist's staff at NASA's Ames Research Center in Silicon Valley, Calif., who conducts research at the intersection of design, mechanical engineering and material science. Cheung hosted five of the BIG Idea Challenge interns, engaging them in a mix of responsibilities. Leandre Jones attends University of Maryland and the remaining students are from Tulane University: Maxwell Woody, Otto Lyon, Afsheen Sajjadi, and Ethan Gasta. Under Cheung, these interns engaged in both an ongoing project in the lab (that lasts longer than the summer) and a smaller, independent project that they define and implement (with the intent to complete over the summer).

"The objective is to develop the interns' technical skills as are relevant to the projects," says Cheung, "as well as exercising their professional and interpersonal skills. We expect that younger interns come in with limited experience in a professional environment."

Cheung's interns worked on key characteristics of the BIG Idea Challenge concepts. "The students developed various aspects of modular systems," says Cheung. "The projects included development of automated assembly robotics, design and experimentation with ultralight materials mechanics, robust and precision mechanisms, and deployable/foldable structures."

All of the mentors shared a strong desire to provide a positive contribution through these engagement efforts. They see the interns as hard-working, enthusiastic and productive, even teaching the mentors a thing or two about educating and managing talented people who are ready and willing to learn. The mentors also hold great hope in NASA's internships, characterizing the internship programs as crucial and stating that interns are NASA's future.

"Many of them will find permanent work here someday," Komendera said.

We certainly hope so.

# Mentoring Interns: An Awesome Responsibility with Great Rewards

**Adelle Helble—*RockOn, Junior Game Changers*, Langley Research Center**

Adelle Helble has supported the GCD Program Office for six years, and this is her second year mentoring with both the RockOn workshop for college students and Junior Game Changers camp for high-school students. RockOn is a Colorado Space Grant Consortium workshop giving students hands-on opportunities to experience what it's like working in space hardware programs with each team building and launching a sounding rocket. The Junior Game Changer camp is modeled after RockOn in its foundation of how to introduce concepts and help students learn to work through procedures, but the content is different each summer, and the RockOn students are tasked with executing the camp program. Helble took a few moments out of her busy schedule to share with us some things about RockOn and Junior Game Changers collectively, and what it's like to be a mentor.

**GCD Q: Tell us about what the students built.**

**AH:** The interns constructed a small robotic vehicle with instrumentation and a GoPro camera that would survive a landing when dropped from a lift in the gantry area.

**GCD Q: What were their learning goals?**

**AH:** The learning goal for the interns was to construct a camp for rising ninth graders that would continue interest in the areas of science, technology, engineering, and math, commonly referred to as STEM in the education environment. It was also an opportunity to expose both the interns and the students to other facets of the center outside of the GCD Program. There were tours of the hangar, gantry, and other facilities at Langley.

**GCD Q: Which one seemed to pique the most interest and why?**

**AH:** This was really dependent on the intern. Each intern was selected for skills or interest that were expressed. Two of the interns majored in physics while the other two were engineering majors. It provided a well-rounded group with the ability to gain capabilities in other areas that they may not have been comfortable with before.

**GCD Q: What were some of the student comments about projects?**

**AH:** Overall, I believe the students enjoyed the time at Langley Research Center. They were provided with the opportunity to attend RockOn at Wallops Flight Facility in order to gain a better understanding of how to construct the Junior Game Changer Camp and more importantly build a small payload that was launched on a sounding rocket. The event for them was positive and hopefully is a stepping stone to future internships and opportunities at NASA or in the aerospace industry.

**GCD Q: What are your observations about student successes?**

**AH:** The interns were very excited when the drop was successful and the vehicle did not receive any damage. I think that it gave them confidence moving forward with new projects that they may be unsure of.

**GCD Q: What has it meant to you personally to be mentor?**

**AH:** I personally really enjoyed working with and mentoring the interns. The difference of thought and how to accomplish a goal is always refreshing. The interns offer a unique view of problem solving and freshness that often gets lost when being in the environment every day. The interns also breathe new life into the organization and the enthusiasm for being at NASA is contagious.

*Pictured above from left are GCD Communications Manager Amy McCluskey, Senior Aerospace Engineer Adelle Helble, and Program Analyst Nancy Hornung (second from right), along with Junior Game Changers camp participants Abhishek Routray (University of Texas at Austin), Zac Pyle (University of California–San Diego), Sarah Hames Miles (Centre College in Danville, Kentucky) and Rubin Soodak (University of Chicago).*

# …and GCD Team Members Step Up

**Bob Hodson—*Alexa AVA*, Langley Research Center**

"When you commit to mentoring a student you don't know initially how the relationship will develop. With Helen there was a natural connection. She is very bright, self-motivated, eager to learn, inquisitive, and clearly loved working on a new technology project. Helen continued to mature technically throughout the mentorship, but I think the larger benefit to her was the opportunity to work with NASA and university stakeholders as well as engineers. She was given an opportunity to see a project from inception through proof of concept to demonstration, and to work with older, more-experience people as colleagues."

**Keith Perkins—*Alexa AVA*, Christopher Newport University**

Partnering with Hodson as Zhang's mentor for the computer science internship was Keith Perkins, instructor/lecturer with the computer science department at Christopher Newport University in Newport News, Va. "The summer was a learning experience for me as well as for Helen," says Perkins. "The interface was new, the idea was new, and working in the Game Changing environment was new. It was exciting to make a concrete contribution to an open ended project, and be involved with the new ideas in this Alexa project in particular."

**Kevin Kempton—*PHLOTE*, Langley Research Center**

"Having been a scout leader for many years, I believe being a mentor is a very serious responsibility. Helping students build confidence is a top priority. And the students' enthusiasm and excitement about a project and working at NASA is really contagious. You can see their confidence ramp up very quickly as they get into a project and start making contributions. So far our PHLOTE interns have really helped the project and I think they have learned a lot about how NASA works. When the students do a good job on a design, presentation, or poster session you share with them that experience of a sense of pride."

**Kenneth C. Cheung—*Big Idea Challenge*, Ames Research Center**

"I think education is a critical part of NASA's ability to make a positive impact. NASA's education work is also part of the reason I became a scientist, and the opportunity to give back to this effort is a key part of my reasoning for joining the agency. As researchers, we're not tackling hard enough questions unless there is reasonable risk of negative results—even then, there is so much opportunity to learn about the subject and train new scientists and engineers at the same time. It's also the best way I can think of to thank the mentors that I've had."

**Erik Komendera—*Big Idea Challenge*, Langley Research Center**

"The reward I get out of being a mentor goes beyond the simple satisfaction of having extra people around helping on our projects. I love teaching them what it is like to work in a research environment. It is wonderful to see when they coalesce into functional teams working hard and helping each other, and I'm happy knowing that their work here will lead to opportunities elsewhere, whether in academia, industry, or elsewhere. And I feel very proud of them when they are recognized for their achievements. I like to think that I am mentoring my interns as a professor would advise graduate students, and that ultimately what they do here lays the foundation for better things to come. And I think the things they do here, and the visibility that comes with it, will go a long way."

**Monica Guzik—*Big Idea Challenge*, Glenn Research Center**

"I have always felt that mentoring a student is one of the most rewarding aspects of my job. As a past NASA intern, I was fortunate enough to have excellent mentors that helped get me to where I am today. I am so happy to have the chance to do that for another student. It is my hope that, as a mentor, I can give a student the opportunity to explore an engineering career first-hand, and hopefully provide some inspiration and experience to help them succeed in their own careers. I always end up learning as much from the students that I mentor as I hope they learn from me."

# On the Shoulders of Giants, Redux

*NASA's Game Changing Development Program, a program with the Space Technology Mission Directorate, has supported numerous robotic and wearable technology development efforts, including Robonaut, the X1 Exoskeleton and the Spacesuit RoboGlove.*

NASA's investment in wearable robotic technology continues to push the limits of what is humanly possible, largely due to what this technology's development has already proven.

Since 2011, the Wearable Robotics Laboratory (WRL), part of the Automation, Robotics and Simulation Division at NASA's Johnson Space Center in Houston, Texas, has helped pioneer this rapidly advancing technology. With heritage to Robonaut, a humanoid robot designed to assist astronauts in space, the lab leverages decades of experience developing robotic systems that mimic human form and function.

The WRL, whose mission is to develop wearable robotic technologies that expand, protect, and restore human capabilities both in space and on Earth, has developed several wearable robotic solutions, most notably the X1 Exoskeleton and the Spacesuit RoboGlove. Through the development of these and other systems, WRL engineers have adapted their wearable robots to nearly every major joint in the human body.

Recently, in conjunction with Rice University, NASA's WRL has applied previously developed wearable robotic solutions to address rehabilitation and augmentation of one of the most complex human joints, the shoulder.

The soft wearable upper extremity garment, dubbed "Armstrong," is worn on the upper body and actuates the shoulder and elbow joints using a Bowden cable transmission system. The shoulder joint, with its many degrees of freedom, has long vexed the wearable device field, and has seen comparatively little research in academia compared to joints of the lower extremities, in large part due to its complexity. This new wearable system uses actuators on the torso to pull on synthetic tendons that cross the shoulder and elbow joints to create the desired movements.

"This garment is yet another example of technology from the Wearable Robotics Laboratory that can be used across multiple areas such as space, medical, industrial, and military," says Roger Rovekamp, lead developer of Armstrong at Johnson. "Wearable Robotic Device technology is a relatively new field and the applications to these many sectors of society make the development of WRDs even more important."

Armstrong was developed for Warrior Web, a DARPA program looking, in part, to advance technologies to prevent, reduce, and rehabilitate soldiers with neuromusculoskeletal injuries. DARPA's aim is to help soldiers who have had a Traumatic Brain Injury (TBI), which often causes motor impairment and limb weakness similar to a stroke.

The garment has already been used in a formal case study with TBI subjects to show proof of concept actuating limbs in a desired manner. The project team demonstrated the ability to successfully isolate the shoulder and elbow joints during rehabilitation, documented in earlier research as showing more beneficial rehabilitation as opposed to merely performing less-than-natural movements with a device in a clinic a few times per week.

"While developed initially to rehabilitate soldiers with TBI, there is potential for application of Armstrong's technology in future spacesuits," says Raul Blanco, Johnson's Space Suit and Crew Survival Systems Branch Chief. "By enhancing human strength and reducing muscle fatigue, this technology could enhance spacewalk activities and change the paradigm of how extravehicular activity operations are planned and executed. As enabling technologies

## "On the Shoulders of Giants"

Meaning that we use the understanding gained by major thinkers who have gone before in order to make intellectual progress now, it is a phrase that became commonly known after Isaac Newton responded in the 1670s to a contemporary's question as to how Newton had accomplished so much in a particular area of study: "If I have seen further, it is by standing on the shoulders of giants."

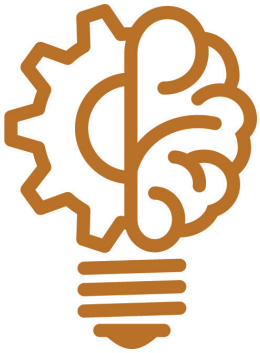
for batteries and actuation continue to improve, this type of system could possess intriguing advantages over current systems for some mission scenarios."

DARPA's perspective on developing the device is to allow for control of the limb, improving the brain's ability to relearn motions and assisting a patient with daily living activities. From a NASA perspective, engineers hope to use this technology to build on the preliminary work and research to benefit astronauts.

"The potential of incorporating a similar 'hybrid' technology in the spacesuit is very intriguing," says Johnson's Christopher Beck, codeveloper of the technology. "It could provide crew members with additional strength to accomplish safer and more efficient spacewalks. It could also help reduce injury and fatigue in the shoulder because of overuse in the spacesuit."

One can easily envision a multifunction spacesuit of sorts, a suit that could provide exercise, rehabilitation, and augmentation for our astronauts even as the technology advances Earth-based wearable robotic applications.

# R2 + AI =



*The term "artificial intelligence", or AI, could soon be obsolete as humanity transforms daily life by implementing smart technologies into our everyday routines. Even as AI continues being advanced, intelligent machines have already cornered a niche in our present day lives, making AI very real.*

*From the seemingly simple concept of refrigerators that forward a grocery list to your hand-held device to highly complex, life-altering medical assists for those with physical limitations—returning their mobility with capabilities such as brain-controlled wheel chairs and powered exoskeletons—AI is everywhere, and NASA's development of Robonaut's cognitive computing capabilities holds promise to augment its abilities to successfully interact with the physical world.*

*Robonaut is a dexterous humanoid robot built and designed at NASA's Johnson Space Center in Houston, Texas. The challenge is to build machines that can help humans work and explore in space, and here on Earth. Working side by side with humans, or going where the risks are too great for people, Robonauts will expand our ability for construction and discovery.*

*This year, Robonaut's technologies were expanded using cognitive computing to provide more ways to interact with humans and its environment, including vision processing, haptic feedback, and natural language processing. Working with cognitive computing capabilities shared by IBM back in 2015 (i.e., Watson), the ground work was laid for creating generic models of tools and interfaces that can be adapted in real-time to a situation in a work environment either in space or on Earth to guide Robonaut's execution of caretaking tasks.*

# Robonaut Gets Schooled

NASA's Robonaut has been getting an education from the most likely of sources, if you are a robot, that is.

In 2015, the R2 Cognitive Computing element of Game Changing's Human Robotic Systems project was provided an in kind contribution by IBM: access to Watson. With HRS's project goal to develop and demonstrate basic cognitive instruction capability with a robotic system, what Robonaut, or R2, can "learn" from Watson would open new possibilities for robots to serve as autonomous caretakers of uncrewed spacecraft and other planetary facilities.

IBM's Watson is a massive technology development capable of drawing conclusions from data using the machine learning technique known as cognitive computing. This means the system, which collects and stores large volumes of information, can take questions and quickly provide detailed answers.

Watson's emphasis on natural language processing and potential applications to computer vision and procedure completion makes Watson a technology platform with several interesting integration points into the R2 research.

Natural language processing is key to human-robotic exchanges resulting in R2 accomplishing a task, so an intersection of capabilities was created. The R2 team at NASA's Johnson Space Center in Houston, Texas, used Google's speech-to-text application programming interface (API) to help R2 understand what was said. Hotword triggers informed R2 when to listen, and keyword maps were used to label known skills. Watson's conversation service was used to fill in the blanks of interactions, such as "tell me a joke," and its text-to-speech feature gave R2 a voice. Finally, the team used Watson's learning feature to instruct R2 how to complete tasks that it didn't already know using keywords that it did know.

"These interactions are a way to label the library of skills that show the versatility and adaptation that is available through this method," R2 Program Manager Julia Badger said.

Also key is object identification, classification, and localization. Humans figure out naturally if something is in the picture, where it is and what it is, but for R2, these capabilities must be programmed in. To assist, Google's TensorFlow™ was put to work to identify and classify various tools, then R2 was trained via models and a routine developed by IBM for this project that uses a modified "iterative closest point" algorithm for the localization.

"This is the hardest part of vision processing for robots," Badger says, "and it is still unclear how to effectively use cognitive computing to solve this problem. Being able to do this for various objects opens up tremendous possibilities for expanding tool interactions out into the real world."

Right now, in a first-ever partnership between NASA and a petroleum company, an R2 is on loan with Woodside Energy in Perth, Western Australia, where the robot's more recently acquired skills are undergoing testing in a real-world application.

**Application Programming Interface (API)**—A software intermediary that allows two applications to talk to each other.

**Speech-to-Text**—When users need to "talk" to their applications, this API can be used to convert audio/voice into written text the application can understand.

**TensorFlow™**—Originally developed by Google, this open-source software library makes it easier for developers to design, build, and train deep learning models.

# From Zero to Hero: Cognitive Science Researchers Prepare Themselves, Robonaut for New Challenge

NASA's humanoid robot "Robonaut" is well known for its work with astronauts onboard the International Space Station. Over the summer of 2017, the space agency delivered one of its Robonauts to Perth, Australia, for a unique opportunity to demonstrate the technology's capabilities and viability in an earthly application.

Woodside's cognitive science research team is investigating remote support and the application of artificial intelligence (AI) and advanced analytics in its operations. Springing off NASA's expertise in Robonauts, the company's ultimate vision is to have robots that use sensors to detect a problem or need and then apply automated mobility and cognitive systems to fix problems or address identified needs.

Before Robonaut could actually begin its new assignment, it needed to "learn" the tools of the trade. Members of Woodside's cognitive computing team spent time at NASA's Johnson Space Center in Houston, Texas, to do some early preparation for Robonaut's visit to Australia.

*Above: Woodside's head of Cognitive Science and Robotics, Russell Potapinski, with the Robonaut and NASA's Robonaut Project Manager Julia Badger.*

"The Woodside team spent three weeks at Johnson going from 'zero to hero' in all things Robonaut," says Julia Badger, Robonaut project manager at Johnson. "They learned how to run, repair, and program the robot. They were taught about basics like robot kinematics, path planning, and vision processing. They were given specifics, like training in our affordance templates [task execution frameworks], and at the end of the stay, they were asked to create a task that was relevant to them."

At Johnson, Badger and her team worked hard incorporating numerous skills before delivery: natural language commanding; conversation abilities; object identification, classification, and localization; autonomous grasp selection; haptic reactions; and more, all in an effort to increase the ways that Robonaut could interact with the world.

Once delivered to Woodside, the stage was set for Robonaut to test in the petroleum industry, but Woodside's benefit from Robonaut's stay was upped significantly much earlier on after NASA began harnessing IBM's cognitive supercomputer capability, Watson.

Watson's high-profile capabilities enabling collecting and storing decades of company information can allow employees to ask questions and quickly receive detailed answers. Live data streams between corporate or supervisory offices and production plants can be used by engineering and operations alike. Using a system like this across industry operations such as Woodside's can reshape the way things are done, improving efficiency and safety.

*Woodside's Chief Technology Officer Shaun Gregory says the company's latest recruit will complement activities carried out by its people.* Photo credit: Attila Csaszar, Business News WA

*The Woodside robotics team spent time training with NASA's Robonaut team at Johnson Space Center in Houston, Texas. Pictured here, left to right, on the back row are Travis Llado, Jason Lee, Craig Kourtu, Mary Hewitt (Woodside), Dustin Gooding, Ken Ruta, and Mike Goza. On the middle row are Hide Muta (IBM), R2C3, and Julia Badger. On the front row are Jonathan Rogers, Russ Potapinski (Woodside), Alison Barnes (Woodside), Anthony Biviano (Woodside).*

# Game Changing's Business Automation Tool Receives ICB Recognition

NASA's Inventions and Contributions Board (ICB) has awarded the Game Changing Development (GCD) Program's mobile data visualization tool honorable mention for the 2017 Software of the Year competition.

Since last year's launch of Game Changing's first for NASA management efforts in connectivity, a boon of activity occurred bringing the collection of GCD's core operational components together into an application that has become known as "GCD Mobile." Key tenets of the architecture include enhanced data management and business process automation, as well as an emphasis on data/analytics and user experience.

With acting Deputy Director Bob Hodson driving the effort, nearly every GCD Program Office team member was engaged at some level, from planning and development to testing and use training. Other key players included two development teams, one at NASA's Johnson Space Center and another with Booz Allen Hamilton. Gov-cloud services are provided through Ames and the Langley Cloud Management Environment. After a near three-year effort of incremental releases of new features, the resulting end-to-end system has been rolled out for stakeholders, management and projects to use across the agency.

Last year when the end-to-end tool was announced, Hodson reported: "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…quickly, securely, and conveniently.…"

What Hodson means by "tools" is that GCD Mobile puts to work the latest information technology platforms using traditional systems (Microsoft Office products) along with

*GCD team members engage in a demo of one iteration in the SharePoint features development. Systems Engineer Adelle Helble, top right, held regular demos after each 'sprint', or time-boxed effort of the agile software development process. Others shown left to right are Daniel Yoo, Mary Koca and Bob Hodson.*

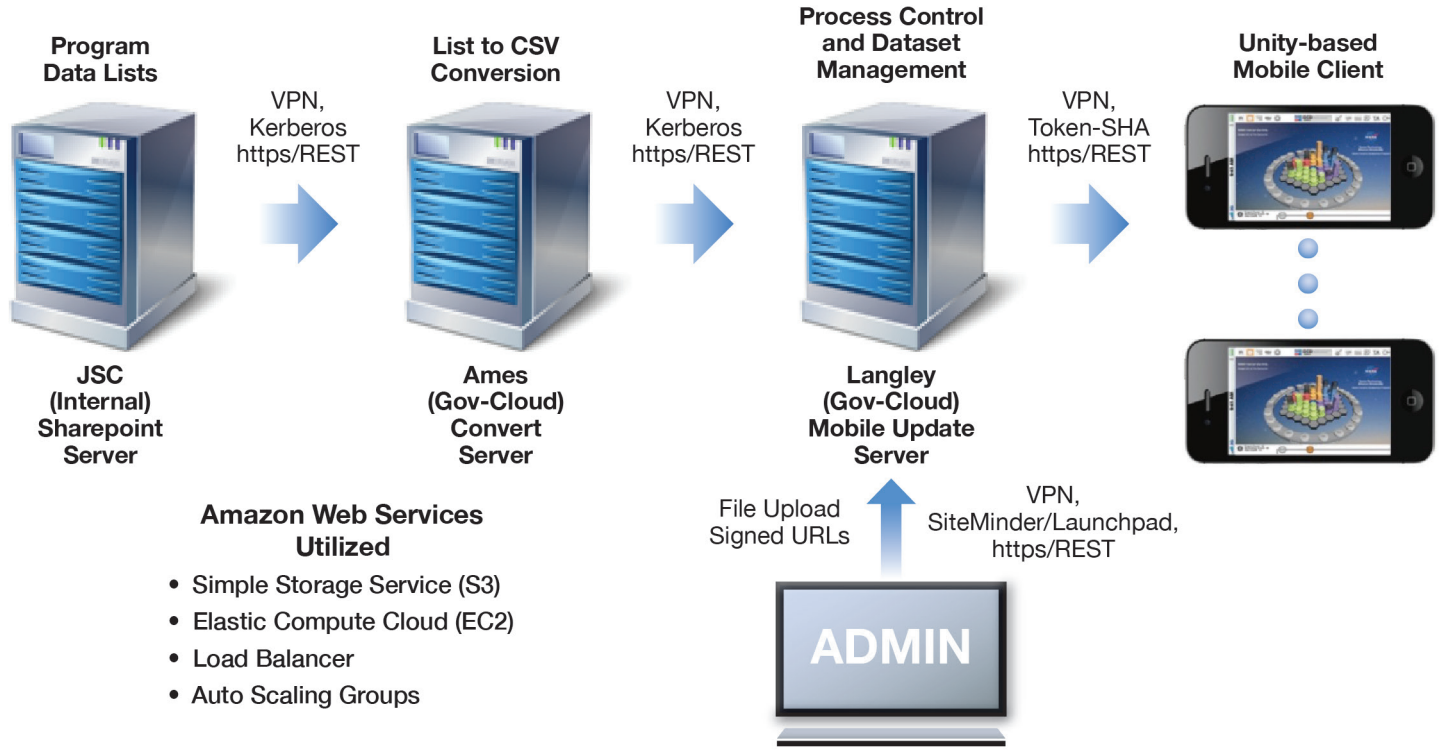
new cloud-based web services and gaming technology for a novel and interactive user environment.

Task Lead and Systems Engineer Chris Munk explains the novelty.

"The team leveraged some of the latest innovative information technologies and advanced platforms being used in both NASA and industry into an end-to-end system that enables the program office, projects, Headquarters, stakeholders, and others interested in GCD technologies to quickly answer over a billion possible business questions about GCD technologies from many different perspectives. The desktop/laptop-based versions of GCD Mobile have the added benefit of generating one to over 300 predefined, interactive HTML5 reports on the GCD portfolio, allowing the program to transition away from publishing a quarterly 200-plus page hardcopy "SmartBook". The app is designed to be flexible and data-driven, so users can remain current through quick and efficient data updates whenever they are alerted that new data are available."

The SharePoint system implements core document repository and configuration management features, but also does much more—it serves as the GCD program's common data source. The organization of information within SharePoint is hierarchical. Information is grouped by themes; themes contain projects; and projects contain technologies and tasks. GCD elected to manage data access at the project level, although finer granularity is possible. The system also varies information views based on user permission levels. For example, a program office manager will see different data and functionality than a project manager or task lead. Thus, the data presented to each system user is filtered by role, providing relevant information to the user experience.

The current system is designed to provide project managers with capability to share schedules, risks, and highlights with the program office. The system leverages the capability to synchronize with Microsoft Project for schedules and implements NASA's traditional 5x5 risk matrix approach that defines likelihood and consequence for each risk. Highlights are a mechanism to report progress (or issues) to the program office. Both the risk and highlight management capabilities can generate consolidated reports across the tasks and technologies within the program. The system also implements workflows for office processes, such as change requests or new project initiations. Workflows allow for notifications and control gates to be programmed into an




*The approach leverages and integrates existing gaming technology, cloud technology, and web-based collaboration technology with secure mobile access and an interactive scenario-based information access paradigm to create an innovative, effective business automation solution with unique, compelling portfolio visualization tailored for NASA's GCD Program.*

automated process to ensure the right steps are performed in the right order by the right people.

The GCD data management architecture utilizes a cloud-based, data update service that enables quicker and more efficient data refreshes to GCD mobile apps when there are GCD Program data changes or updates. In a sense the cloud service is a means to an end—getting information securely, anywhere, anytime. Although this was the original GCD vision, it has become apparent that access to information via mobile app has also provided a new paradigm for knowledge access. Users have the ability to perform scenario-based visualization—the capability to interactively view details of the GCD technology portfolio through filtering on different combinations of multiple criteria.

GCD Mobile is used to support management decision-making as well as outreach communication about the portfolio. GCD Mobile is built on the ubiquitous Unity gaming engine, which runs on numerous platforms and devices, and contains powerful, compelling graphical features and intuitive, natural touch-screen gestures and interactive control. Graphical representation is not new in itself, but by using interactive graphics to make data queries quick and easy, real-time scenario-based queries are now possible.

Daniel Yoo, who provides system development and data management support, says in just this fiscal year alone, the team has given over 20 demos to groups of interest outside GCD. "I think it shows the interest of not only stakeholders, but external partners and organizations as well, about the impact this app can have for their programs. We've been contacted by DoD for follow-on demos for senior leadership."

What's next for GCD Mobile?

"While the GCD Mobile app now incorporates a robust set of functionality and integration with GCD's common data source," Munk says, "the team continues to maintain the app, data sets, and cloud-based web-service to keep the system secure and operational, as well as incorporating occasional enhancements resulting from feedback or new, high-value, priority features."

The ICB, run by the NASA Office of General Counsel, encourages innovation by offering incentives to NASA researchers and inventors. First place honors for the 2017 competition were given to Ames Research Center for its "Terminal Sequencing and Spacing" software, which functions as an air traffic decision support tool.

**Two Mobile Apps**

**GCD Mobile**
For broad distribution with subset of data and basic functionality

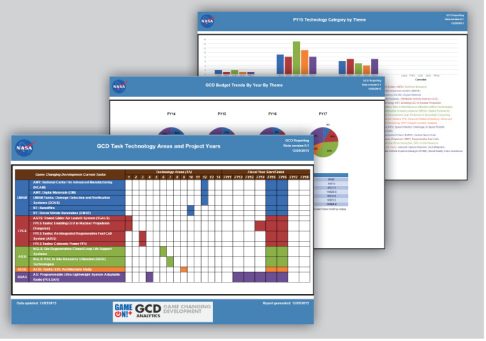
**GCD Analytics**
For Program Office power users—full data set (milestones, resource details) and advanced functionality

**iPad**

**iPhone**

**Desktop/laptop – Windows and MacOS X**

**The desktop app auto-generates interactive HTML5 reports for project/technology metrics, trends and summaries.**



*Program offices can answer key business questions quickly to support stakeholder requests and projects can track and manage actions, risks, scheduling and milestones.*

National Aeronautics and Space Administration

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