National Aeronautics and Space Administration

Game Changing Development Program

Game On

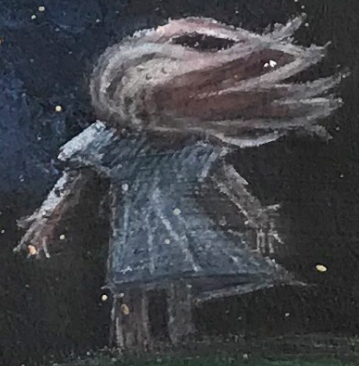
Pop-Up Flat-Folding Explorer Robots
A network of small rovers could change space exploration

Mars Entry, Descent and Landing Instrumentation 2
GCD technology will fly on Mars 2020

Astrobee
Free-flying robots will advance zero-gravity research

Space Synthetic Biology
A technology for creating nutrients in space, on demand

NASA's BIG Idea Interns
Students design innovative, high-fidelity Mars greenhouse



Space Technology
Mission Directorate

2019

It is always a pleasure working with the EPO team to put together the Annual GCD Program Magazine. It allows you to stop and reflect on the multitude of technical activities that researchers and engineers within NASA, industry, and academia are developing to enable missions to the Moon, Mars and beyond. A number of those activities are cross cutting and are applicable to both Science and Human Exploration.

The program was stood up in 2011, and since then, a number of technology projects have progressed further to technology demonstrations or infusion. For example, the Composite Cryotank Technology Demonstrator and Composite Technology for Exploration projects have resulted in infusion into the Space Launch System and into launch vehicles being developed by industry. The increase in the mission directorate's budget—which includes GCD—is a testament to the progress that has been made throughout the program and directorate. It is also a very exciting time for the agency as a whole, as NASA is planning a return to the Moon's surface by 2024. A host of technologies GCD is developing will enable Commercial Lunar Landers, Human Landing Systems, and Lunar Surface Systems capabilities.

The program has had many technology successes this year. We have delivered technology experiments and operational systems to the International Space Station, which includes Space Synthetic Biology, a project developing a technology for producing nutrients for astronaut health on long-duration missions. We also sent Astrobee robots to the station. The autonomous robots will offer inventory and logistics support, and provide an experimental platform for guest scientists and researchers. Other technology demonstrations include RAMPT completing a successful hot fire test of a GRCop Composite overwrap nozzle, long-duration (5000hrs) testing of a 600 watt Hall thruster. Additionally, Splice has demonstrated Navigation Doppler Lidar capability on a rocket sled test in June as well as terrain relative navigation on Masten's Xodiac 03 rocket this September.

In closing, I would like to thank Dr. LaNetra Tate who has been the GCD Program Executive for the past four years. She has had a significant impact on the program and led the organization to many successes. Dr. Tate was recently selected to lead STMD's Technology Demonstration (TDM) Program. I am confident her strong leadership will be of great benefit to TDM. I would also like to welcome our newly selected Program Executive, Niki Werkheiser, who brings a wealth of experience to the program. Additionally, we look forward to GCD's continued partnerships with researchers and developers within NASA, industry and academia, to continue playing a key role in getting back to the Moon in 2024 and on to Mars.

Drew Hope

GameOn
2019

Space Technology Mission Directorate

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On the cover: Seventh grader Peter Wardrip-Luso created this original artwork, "Looking at the Milkway," for NASA Langley Research Center's 2018 annual Explore Art Contest. Find more information about the art contest at artcontest.larc.nasa.gov

Small Robot Carries Big Promise for Planetary Exploration

A small, smart-phone sized rover could be the answer to more thorough planetary surface exploration for NASA.

Currently, planetary exploration is limited to somewhat smooth operating surface areas due to the inability to land and traverse challenging terrain. Additionally, certain locations are considered not worth exploring because of the risk of losing an expensive rover. Unfortunately, the most compelling locations are often in these extreme terrains.

Game Changing Development's (GCD) A-PUFFER project is developing a small, autonomous rover that can explore extreme terrains in areas of scientific interest that may be too rough for astronauts to investigate on foot. Pop-Up Flat-Folding Explorer Robots (PUFFERs) feature the smallest rover design yet, and are cheaper to build than current rovers. They can also provide greater surface mobility than one larger rover because of their compact design. A large number of PUFFERs can be packed into a larger "parent" spacecraft at a low payload cost, and then used by the parent spacecraft to provide increased surface mobility. If one PUFFER becomes damaged or destroyed, additional PUFFERs can still continue on with exploration and continue to send significant data back to the lander.

THE COMBINATION OF SMALL, BUT CAPABLE HARDWARE WITH AUTONOMY ALLOW PUFFERS TO BE A NEW EXPLORATION TOOL ON FUTURE MISSIONS,"

—Jean-Pierre de la Croix, PUFFER Project Manager

Each PUFFER is outfitted with collapsible wheels on each side, motors, a camera, micro imager, batteries, and a radio. The explorer robots will communicate over wireless links and work together to create maps and identify hazards in real-time in the surrounding areas as they explore. Once one PUFFER has explored and mapped an area, all other PUFFERs will have that map and know of those hazards.

An example mission is a planetary lander that requires small rovers for increased exploration, or a larger parent rover could use a collection of PUFFERs to explore extreme terrains that are easier to access with a small, low-cost "child" rover. When the parent spacecraft finds an exciting region for exploration, it simply ejects one or more PUFFERs, which then pop up and go on to explore the target or targets of interest.

The Autonomous PUFFER project demonstrated autonomous capabilities with a PUFFER in June 2019 in an indoor testbed. During the test, a PUFFER successfully navigated to locations predetermined by an operator while avoiding any rocks, accurately estimating its position, and building a 2-D map. During later tests, the PUFFER successfully explored the testbed on its own without requiring a person to specify goals or a prior map. The PUFFER selected new driving goals to reach parts of the testbed it had not yet discovered as it built a map of the testbed.

"For this test, all the autonomy capabilities came together for the first time to demonstrate a PUFFER capable of full, on-board autonomous exploration—a key building block for the multi-agent autonomous capabilities that will follow," de la Croix said.

PUFFERs will provide an avenue for a more affordable, thorough planetary exploration during future NASA missions.

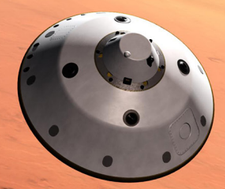
MEDLI2 Poised for Flight on NASA's Mars 2020 Mission

Hardware installed onto the Mars 2020 entry vehicle this summer will help to increase the safety of future Mars landings.

Game Changing Development's (GCD) Mars Entry, Descent and Landing Instrumentation 2 (MEDLI2) project developed a suite of sensors that will measure aerothermal environments and the performance of thermal protection system (TPS) material during the hypersonic entry phase on the Mars 2020 mission. Engineers installed the first batch of items delivered by MEDLI2 onto the heatshield of the entry vehicle this summer. The aeroshell of the entry vehicle consists of a heat shield and backshell and will protect the Mars 2020 rover in transit from Earth to Mars and during the entry through the atmosphere of Mars on its way to the surface.

> "UNDERSTANDING THE ACTUAL PERFORMANCE OF OUR CURRENT GENERATION OF ENTRY VEHICLES IS CRUCIAL TO SAFE, RELIABLE LANDING OF FUTURE ROBOTIC AND CREWED MARS MISSIONS. MEDLI2 PRESSURE AND THERMAL MEASUREMENTS ARE THE KEY TO THAT UNDERSTANDING."
>
> *—Todd White, MEDLI2 Principal Investigator*

MEDLI2 also completed environmental testing on flight hardware at NASA's Langley Research Center in Hampton, Virginia this summer. The testing, including vibration and thermal vacuum testing, demonstrates the ability of the hardware to survive the large vibratory loads experienced during the launch, and the extreme cold during the cruise to Mars. High temperature sterilization of some of the hardware has also been successfully concluded, allowing MEDLI2 to minimize the potential of transporting terrestrial biological material unintentionally to the surface of Mars. All of the MEDLI2 components are set to be completely installed on the Mars 2020 aeroshell by early January 2020.

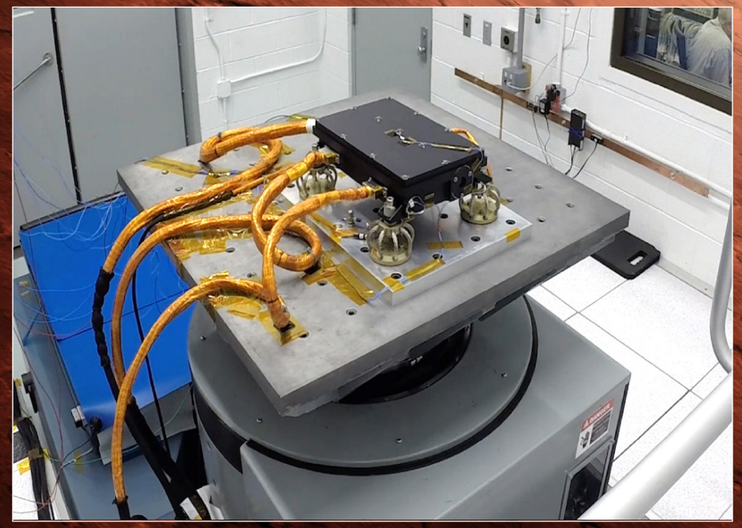


MEDLI2 includes three types of sensors (thermocouples, heat flux sensors, and pressure transducers), a data acquisition and signal conditioning unit (the Sensor Support Electronics Unit) to record the heating and atmospheric pressure experienced during entry and through parachute deployment, and the harnessing between the sensors and the Sensor Support Electronics unit. Building on the first MEDLI suite, which flew on NASA's Mars Science Laboratory mission (MSL), instrumentation is again being applied to the heat shield (but in a different configuration to better measure the flow characteristics) and this time to the backshell to collect measurements of the heating and the surface pressure to aid in reducing the large uncertainty (200 percent to 300 percent) applied to the current predicted results.

The Mars 2020 spacecraft will enter Mars' atmosphere traveling about 12,500 mph. MEDLI2 will start to collect data about five hours prior to the entry and continue to collect data throughout the entry and part of the descent phases. That's about how long it will take to slow the spacecraft from 12,500 mph to just under 2 mph. MEDLI2 will measure crucial entry and descent performance data on the Mars 2020 heat shield and backshell.

MEDLI2 flight data will fill critical space entry, descent and landing knowledge gaps which would advance current entry, descent, and landing technology. This technology also has the potential to reduce TPS mass by up to 35 percent, which would result in significant cost reductions. This technology and data will also help reduce the size of the landed footprint (the uncertainty footprint) by at least 30 percent, allowing access to sites with high scientific interest that might otherwise be difficult to reach.

"Uncertainties in our ability to model and predict the performance of an entry vehicle and the associated thermal protection system mean that large margins (100 to 200 percent) need to be included in our



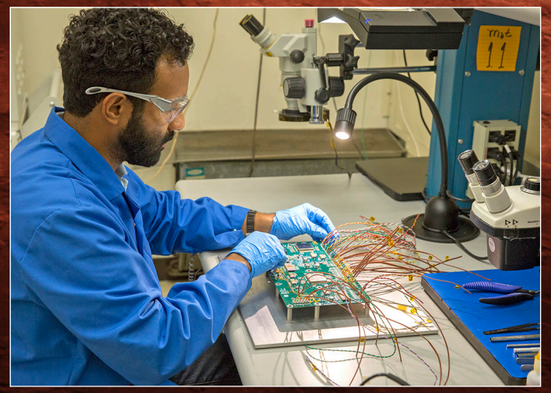
Vibration testing of the MEDLI2 primary electronics box was successfully completed recently at NASA's Langley Research Center in Hampton, Virginia. Flight hardware is being shipped and installed on the Mars 2020 entry vehicle in preparation for next year's launch.

predictions to ensure the entry vehicle can survive the worst case conditions," Wright said. "Flight data will allow the uncertainties in the models to be further reduced, leading to a more accurate prediction of the loads and performance."

The key objectives of MEDLI2 are to reduce design margin and prediction uncertainties for the aerothermal environments and aerodynamic database. Close analysis of MEDLI2 flight data is vital to future NASA exploration of the Red Planet. MEDLI2 will explore areas not addressed during the MSL mission and seek answers to questions generated from examining MEDLI/MSL data.

MEDLI2 is managed at Langley and implemented in partnership with NASA's Ames Research Center in California's Silicon Valley and the Jet Propulsion Laboratory (JPL) in Pasadena, Calif. JPL manages the Mars 2020 spacecraft development for the Science Mission Directorate at NASA Headquarters in Washington D.C.

Researchers at Langley conduct vibration testing of MEDLI2 hardware.



A technician at Langley assembles the custom electronics critical to the collection of MEDLI2 data.

Researchers at Langley conduct thermal-vacuum testing of MEDLI2 hardware.

Space Computing Levels Up

One Game Changing Development (GCD) project is developing a spaceflight computing system that will provide 100 times the computational capacity of current spaceflight processors.

The High-Performance Spaceflight Computing (HPSC) project consists of newly designed computing chiplets with multiple processing units and operating software to run the chips. The chips and software are being developed by Boeing.

"HPSC WILL REVOLUTIONIZE HOW WE THINK ABOUT COMPUTING IN SPACE, PROVIDING UNPRECEDENTED FLEXIBILITY AND SCALABILITY IN FLIGHT COMPUTING."

—Rich Doyle, Project Manager for HPSC

It has been about 20 years since NASA last invested in flight computers. Current space-qualified computing technology must be configured around the part of a mission that requires the most power, or data, or fault tolerance, a practice which is good for mission success but inefficient over the lifetime of a mission.

For example, a Mars surface mission has extreme needs for high-speed data movement and intense calculation, as well as stringent fault tolerance, during planetary landing. The flight computer must be configured to meet these needs, which draws significant power and other resources. However, once safely landed, routine mobility and science operations may never need this level of capability, at least not in a sustained manner. Nighttime operations can draw even fewer resources.

HPSC's improved chiplet design is dynamic enough to only use the power it needs during a particular mission phase, which will save a large amount of energy and improve overall computing efficiency.

An extremely high-performing computing chip will affect many areas of spaceflight operations, including extreme terrain landing, managing a vehicle's health, automated guidance, navigation and control, autonomous and telerobotic construction, and more. A more efficient computing system, like HPSC, will benefit all types of NASA operations, from earth science missions, to human spaceflight.

HPSC, as a technology development project, is currently in a replanning phase to finalize the choice of fabrication line for the chiplets, and to prepare for demonstrations on space platforms such as lunar landers. Chiplets would be available in the 2023-2024 timeframe, with single-board computers incorporating HPSC following shortly after.

The overall HPSC project is managed by the Jet Propulsion Laboratory in Pasadena, California, with the chiplet acquisition managed by the NASA's Goddard Space Flight Center. Additionally, the Air Force Research Lab, and Space and Missile Systems Center have closely collaborated on this project to ensure that the chiplet will be relevant to their mission requirements.

Future NASA space mission scenarios require an improved computing system with significantly stronger computational performance and a much more efficient use of energy. HPSC will assist with these spaceflight computing needs over the next two decades.

"FLIGHT COMPUTING IS A TECHNOLOGY AMPLIFIER, AND ENABLES NEW SPACECRAFT-BASED CAPABILITIES, WHICH, IN TURN, ENABLE NEW MISSION CONCEPTS EQUALLY RELEVANT TO EARTH SCIENCE, SOLAR SYSTEM EXPLORATION, ASTROPHYSICS AND ALSO NATIONAL SECURITY."

—Rich Doyle

New Precision Technology Broadens the Horizon for Moon Landings

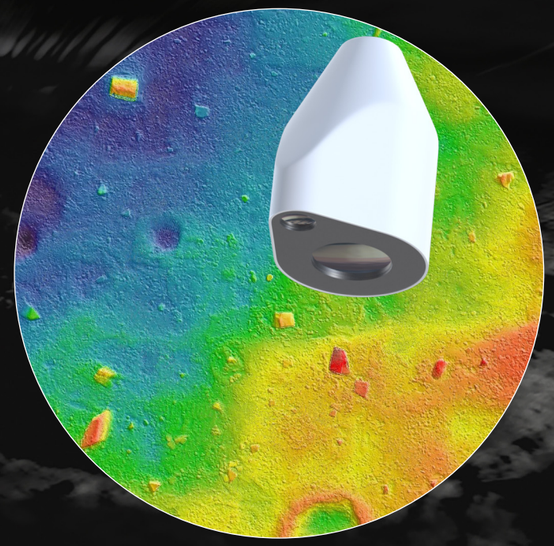
NASA will need precision descent and landing technology to land astronauts safely on the Moon in 2024 and afterwards.

To answer this need, the Game Changing Development (GCD) Safe and Precise Landing—Integrated Capabilities Evolution (SPLICE) project is developing an advanced system of sensors, avionics and algorithms for safely landing on planetary surfaces. The technologies being matured under SPLICE include a navigation Doppler lidar (NDL, right) for velocimetry and ranging, a hazard detection lidar (HDL, top right) for generating real-time 3-D hazard maps, a descent and landing computer (DLC, far right) that incorporates a surrogate for the in-development NASA high-performance spaceflight computing (HPSC) processor, and next-generation guidance, navigation and control algorithms needed to fully leverage these new capabilities.

The NDL is used to provide direct velocity and range measurements during the last 7 km of descent. The NDL is being developed at NASA's Langley Research Center in Hampton, Virginia, and is comprised of a small electronics box connected by fiberoptic cables to three optical telescopes. Each telescope transmits a laser beam which is reflected off the ground and back to the vehicle, which is processed in order to provide range and velocity measurements along the line-of-sight of the beams.

"INCREASED PRECISION WILL ENABLE US TO LAND IN AREAS THAT HAVE MUCH MORE HAZARDOUS TERRAIN THAN COULD BE TARGETED BY THE APOLLO ASTRONAUTS—WE CAN NOW LAND IN NARROWER AREAS, LIKE LIGHTED CRATER RIMS THAT REQUIRE LANDING PRECISION WITHIN 100 METERS OF PERMANENTLY SHADOWED CRATERS."

—John Carson, SPLICE Project Manager



"THIS RECENT TEST VALIDATES THE NDL'S ABILITY TO PROVIDE EXTREMELY ACCURATE VELOCITY MEASUREMENTS DURING DESCENT AND LANDING, WHICH IS A PART OF CRITICAL TESTING REQUIRED TO VALIDATE ALL OF THE SPLICE TECHNOLOGIES FOR FUTURE NASA MISSIONS."

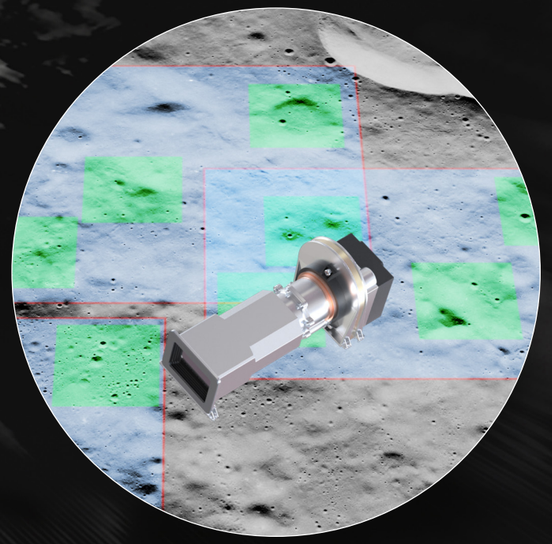
—John Carson

Engineers at NASA tested the performance of NDL's velocity measurement capability during a high-speed rocket sled test at China Lake in Kern County, California this summer. During the testing, the NDL unit accurately tracked the speed of a target at 450 miles per hour (200 meters per second).

SPLICE also tested its terrain-relative navigation (TRN)—a capability to capture and compare real-time images with known maps of surface features—this September. Initial post-flight analysis shows that TRN successfully identified features in real time.

The SPLICE suite of sensors and algorithms uses real-time images and 3D-generated maps to precisely navigate during descent and landing toward safe touch-down locations in close proximity to targeted planetary surface locations. The NASA HPSC chip enables SPLICE computing to rapidly process high volumes of data with complex algorithms that determine precise navigation information, intelligent guidance maneuvers, and the safest landing sites for future missions.

SPLICE technologies will be infused into Commercial Lunar Payload Services (CLPS) missions within the next five years, with the NDL planned to fly on both the Astrobotic and Intuitive Machines lander missions in the summer of 2021. SPLICE's advanced sensing, computing and algorithm technologies will enable safe and precise landing for future NASA missions.



“Helper Robots” Making a Buzz on the ISS

Game Changing Development’s (GCD) Astrobee project launched two free-flying robot cubes—Honey and Bumble—to the International Space Station (ISS) on April 17, 2019 aboard Northrop Grumman’s 11th Commercial Resupply Services mission from NASA’s Wallops Flight Facility in Virginia.

Astrobee is a free-flying robot system that will provide a research platform for the orbiting laboratory. The system includes three robots—named Honey, Bumble and Queen—as well as a docking station for recharging. Astrobee’s highly modular hardware and software design makes it possible for the robots to do a wide range of tasks or experiments—even things that have not yet been imagined.

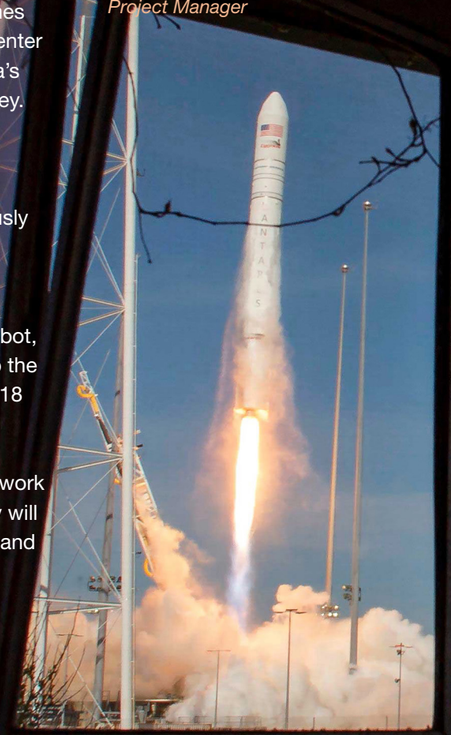
“The main purpose of the Astrobee platform is to provide a zero-gravity testbed for guest scientists to try out new robotic technologies in space,” said Maria Bualat, Astrobee Project Manager at NASA’s Ames Research Center in California’s Silicon Valley.

Bumble robot flew autonomously aboard the ISS this past June and the third Astrobee robot, Queen, launched to the ISS from SpaceX CRS-18 Falcon 9 in July.

Learning how robots can best work with humans in close proximity will be key for exploring the Moon and other destinations.

“ASTROBEE WILL PROVE OUT ROBOTIC CAPABILITIES THAT WILL ENABLE AND ENHANCE HUMAN EXPLORATION. PERFORMING SUCH EXPERIMENTS IN ZERO GRAVITY WILL ULTIMATELY HELP DEVELOP NEW HARDWARE AND SOFTWARE FOR FUTURE SPACE MISSIONS.”

—Maria Bualat, Astrobee Project Manager



NASA Exploring On-Demand Nutrients

The Game Changing Development (GCD) Space Synthetic Biology project kicked off its BioNutrients experiment with an April launch aboard Northrop Grumman’s 11th Commercial Resupply Services mission to the International Space Station. Over the next five years, the project will continue testing a platform that will enable microorganisms to create vital nutrients in space, on the spot.

The strategy NASA scientists developed to accomplish this is modifying baker’s yeast to produce particular nutrients and providing the appropriate equipment that will allow astronauts to grow this same “actively producing yeast” in space.

The plan is for this yeast to create the nutrients beta carotene and zeaxanthin, antioxidants that maintain eye health and are typically found in vegetables. Techniques are also being developed to use carbon dioxide and water obtained during the mission to “feed” the microbes.

These newly-advanced synthetic biology technologies will play a critical role in supporting innovative and sustainable exploration of the Moon, Mars and beyond.

“THERE IS A STRONG NEED TO MAKE CERTAIN PRODUCTS IN SPACE, ESPECIALLY THINGS LIKE VITAMINS AND MEDICINES WITH SHORT SHELF LIVES. BIONUTRIENTS WILL DEMONSTRATE IN-SITU MICROBIAL PRODUCTION OF TARGETED NUTRIENTS.”

—John Hogan, Project Manager of the Space Synthetic Biology project at NASA’s Ames Research Center in California’s Silicon Valley

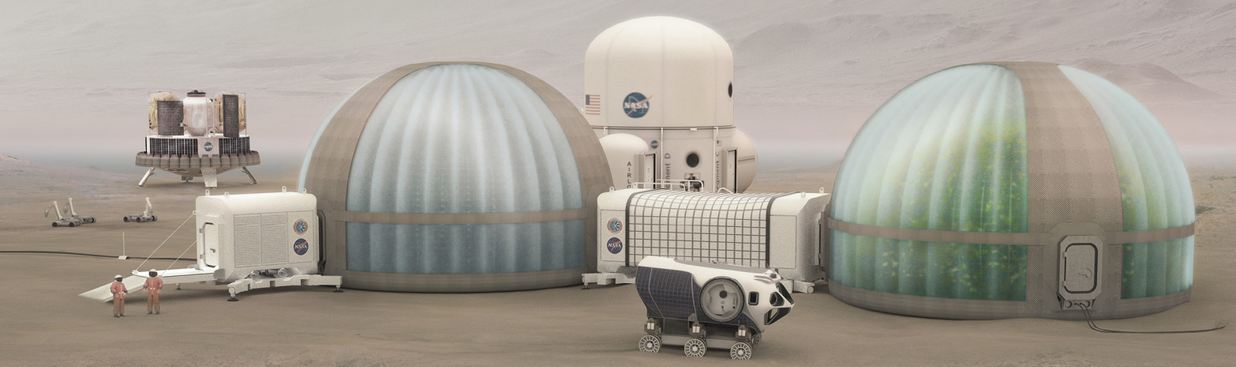
BIG Idea Interns Design Habitable Mars Greenhouse

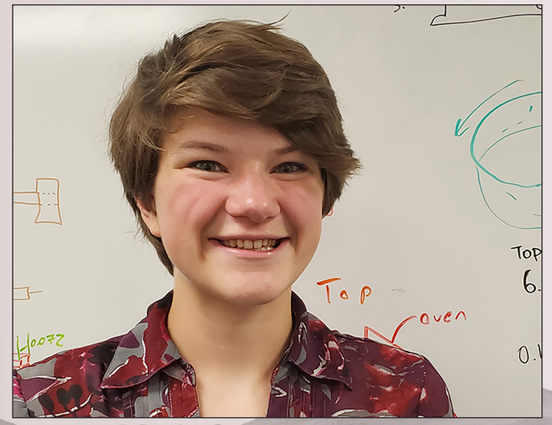
This summer was filled with truly innovative ideas, hard work and personal growth for the 2019 BIG Idea student interns. This year's BIG Idea Challenge called on students to create an operational habitat-sized greenhouse for Mars.

Five of the 2019 BIG Idea challenge participants spent two months interning with Game Changing Development (GCD) this summer, where they solidified designs for an inflatable Mars greenhouse under the direction of mentor and GCD Project Element Manger, Kevin Kempton. During this time, the students did more than research, analysis and design work. They also grew their professional network, learned to work with others from different technical backgrounds, and developed an entirely new concept for dehumidification.

"The 2019 BIG Idea interns combined the best features of the different Mars greenhouse concepts to produce what is currently the highest fidelity design of a Mars greenhouse available today," said Kevin Kempton.

The students were required to prepare two presentations and coauthor a technical paper on their work.





Their work centered on an inflatable greenhouse design called CYBELE, the Crop Yielding, Bioregenerative Environment for Life-support and Exploration (CYBELE). The greenhouse would yield enough support for a four-person crew for a 600-sol mission on Mars.

Their thorough design concept included radiation shielding, crop production, a waste management system that recovers nutrients, and software that alerts crew when plants are diseased or ready to be harvested.

Massachusetts Institute of Technology student, Sheila Baber (top left) designed CYBELE's waste management system. She consulted specialists in the field to inform her work, and enjoyed the chance to broaden her knowledge in areas she wasn't too familiar with.

"I really enjoyed the opportunity to explore topics that are outside my focus," Baber said. "Kevin (my mentor) encouraged us to reach out to as many subject matter experts as possible, and this made me more confident about reaching out to researchers and others for assistance."

University of Wisconsin-Platteville student, Eva Birtell (center left), also contributed to CYBELE's waste management design and led the crop selection efforts. Birtell used the summer as a chance to challenge herself academically and come up with solid solutions to issues through deep research.

"There were so many instances where we had a problem and needed an answer, and I had the opportunity to dig into a wide breadth of research in order to present my team with the best options for moving forward," Birtell said.

Benjamin Greaves (bottom left), from University of Michigan, developed strategies for answering quantity-versus-quality questions for CYBELE, like deciding between a crop that is healthier, but doesn't taste good, and a crop that tastes good but doesn't have many nutrients. He enjoyed this type of research and believes in-space agriculture will enable solutions for a myriad of current space habitat issues.

Kaixin Cui (top left), from University of Boulder, Colorado, worked on risk mitigation, artificial intelligence and more for CYBELE. She enjoyed working with students from all around the country and appreciated the opportunity to network with aerospace experts, she said.

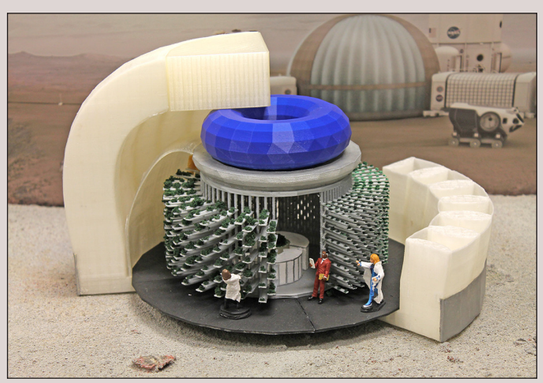
Dartmouth College student, Alexa Escalona (bottom left), provided guidance on the structural mechanics and systems integration of the CYBELE design. She was inspired by the work she and her peers did over the summer, and enjoyed learning about the techniques and technologies they put into the system.

Escalona wasn't the only one impressed by the students' work this summer. GCD Program Manager, Drew Hope, praised the students' innovative design and presentation. "The students will certainly excel in their careers in the future," he said.

Once approved for public release, the student's greenhouse design report will be made available on the Big Idea website along with graphics developed for their exit presentations.

"AFTER MEETING THE STUDENTS THIS PAST SUMMER AND HEARING ABOUT THEIR WELL-RESEARCHED AND DETAILED GREENHOUSE DESIGN, I HAVE NO DOUBT THAT EACH OF THEM WILL CONTINUE ON TO SUCCESSFUL CAREERS IN THEIR FIELDS, WHETHER THAT BE WITH NASA, INDUSTRY OR ELSEWHERE."

—Drew Hope, Game Changing Development Program Manager

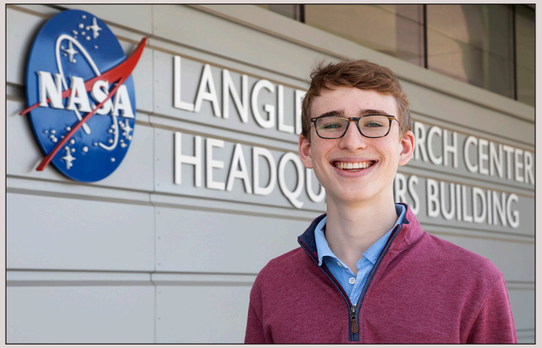


A model of the 2019 GCD interns' CYBELE greenhouse.

Summer Interns Improve Asteroid Belt Mission Concepts

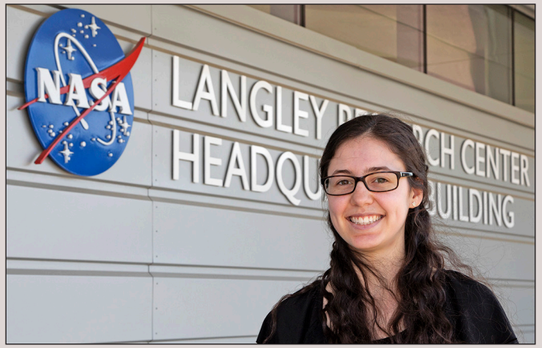
This past summer, NASA Game Changing Development (GCD) interns Carter Swift and Kayla Schang of Macalester College worked on design concepts for a mission architecture that can support humans on the multi-year missions required to visit targets in the asteroid belt. During their internship, Carter and Kayla added fidelity to the HEIMA, the Human Exploration ISRU-based Mission Architecture (HEIMA) design—a flexible, extensible architecture that utilizes ISRU-derived water ice for sustainable human exploration at the frost line and beyond. This work included determining the necessary thickness of shielding to protect the astronauts adequately from radiation, finding the optimal shape of the habitation modules to minimize shielding mass, producing estimates of delta-V and propellant requirements, and ensuring that the structure would have stable rotation about the correct axis. They also researched habitable volume, the effects of living in microgravity, life support baseline values and assumptions, crew size and more.

Their research and analysis will provide a strong design foundation for other engineers who wish to continue on to structural analysis and prototyping of the HEIMA architecture.



"THE MOST ENJOYABLE PART OF THIS PROJECT FOR ME HAS BEEN APPLYING MY KNOWLEDGE OF PHYSICS AND MATH TO TURN THE VERY CONCEPTUAL IDEA OF HEIMA INTO A BIT MORE SUBSTANTIVE OF A DESIGN. MY FAVORITE PART OF THE INTERNSHIP IN GENERAL HAS BEEN SEEING FIRSTHAND SOME OF THE INCREDIBLY INTERESTING WORK BEING DONE AT LANGLEY, AND AT NASA IN GENERAL."

—Carter Swift, Macalester College



"I HAVE ENJOYED LEARNING ABOUT ALL THE DESIGN ASPECTS THAT GO INTO CREATING A NEW VEHICLE OR MISSION DESIGN. IT HAS BEEN FASCINATING TO LEARN ABOUT ALL THE REQUIREMENTS."

—Kayla Schang, Macalester College

NASA Intern Cuts Out Months of Work for Engineers

Technologists and engineers working on the Entry Systems Modeling (ESM) project will soon be able to cut out months of tedious work, thanks to the labor of NASA intern, Joseph Feghhi.

The ESM project aims to develop validated tools and frameworks that enable planning and optimization of entry, descent and landing (EDL) missions.

Over the course of four months, Joseph created a graphic user interface system for ESM while an intern at NASA's Ames Research Center in Silicon Valley, California. The University of Michigan undergraduate started from scratch with only the prompt "We need a better system to integrate planning and optimization software."

The interface he created shows engineers upfront all the available platforms and software tools needed to plan and optimize an EDL mission. The platform enables locating and installing any needed software not on the engineers' system and provides a framework for coupling the software for a specific mission design.

For example, one software that a mission designer will need on their computing platform is a material response code (e.g., PATO) which, in turn, needs the OpenFOAM software module installed on their system.

However, in order to operate OpenFOAM, engineers will first need to have OpenMPI (a message-passing library that enables parallel processing), and GNU (a compiler system) on the computing platform. The GUI Joseph created enables the users to install all these types of dependent software at once with the click of a button.

Having the ability to easily install predetermined needed software and being able to visually couple them through connecting lines that verify that dependencies are satisfied will save ESM engineers months of tedious research into what the dependencies are between software and platforms. This GUI could reduce software preparation, download time and learning time from one month to one day.

Joseph, who is studying Aerospace Engineering, said he thoroughly enjoyed his time creating the interface.

The newly-created platform will help to enable safe and optimized entry, descent and landing missions in the future.

"I ENJOYED THE CHALLENGE. I'VE LIKED CODING SINCE BEFORE HIGH SCHOOL, SO IT'S GREAT I'M ABLE TO USE MY SKILLS FOR SUCH A USEFUL PROJECT."

—Joseph Feghhi, University of Michigan

Technology Trailblazers: A Sampling of GCD's Project Managers

Jean-Pierre de la Croix

PUFFER Project Manager

Background

Jean-Pierre de la Croix is a Robotics Systems Engineer in Maritime and Multi-Agent Autonomy group. He joined Jet Propulsion Laboratory (JPL) in Pasadena, California after completing a Ph.D. in electrical and computer engineering at the Georgia Institute of Technology in 2015. His research focused on new control techniques for large-scale robotic systems, such that humans can easily and effectively interact with these complex systems. At JPL, he continues to work on multi-agent robotics for new and challenging applications to explore our universe.

Project Scope

"The Autonomous PUFFER (Pop-Up, Flat-Folding Explorer Robot) project is focused on developing the autonomous capabilities for multiple miniaturized rovers to explore extreme terrains and gather science data together. Rather than taking this task on independently, PUFFERs collaborate to achieve what may be out of reach or too risky to access for a parent rover or lander. Consequently, PUFFERs must not only be able to sense and navigate within the environment like other autonomous rovers, but share information with other PUFFERs to make decisions on how to collaboratively explore the environment using the available resource across all PUFFERs."

Top Project Successes?

"Most recently, we were able to demonstrate on-board autonomy for a PUFFER to explore an environment relying only on its on-board sensors. PUFFER successfully was able to navigate to operator-specified goal locations at first—without colliding with any rocks, accurately estimating its position, and building a map. During later tests, PUFFER successfully autonomously explored the environment without requiring operators to specify goals or a prior map—PUFFER selected new driving goals to reach parts of the environment it had not yet discovered as it built a map of the environment."

Challenges You've Overcome?

"The most significant challenge so far has been to integrate the autonomy and hardware elements for a rover of the size of PUFFER (<1kg!), and to ensure that it performs robustly during testing. Now that we've overcome this challenge, our next challenge is to ensure that PUFFERs can communicate effectively and efficiently to coordinate their activities—a key challenge for any multi-agent system."

Hobbies and Family

"I live in LA with my wife, Lauren, our daughter, Margaux, and our black cat, Wednesday. I like to spend some of my off time going on long runs for the challenge and the exercise. I also enjoy wood working or building electronics, since it's an opportunity to create hardware rather than software."

Greg Barnett
TALOS Project Manager

Background
Greg Barnett has a bachelor's degree in mechanical engineering from the University of Alabama in Huntsville. Before working for NASA, Greg served in the Unites States Marine Corps and also worked as an engineer with SIEMENS VDO. He began work at NASA in 2008, and since then, has worked with combustion devices, the SLS, the Exploration Systems Development, and the Science and Technology Office. He has extensive experience with the design and testing of swirl-coaxial injectors.

Project Scope
"The principal goal of the Thruster Advancement for Low-Temperature Operation in Space (TALOS) project is to develop a domestic capability for low-temperature propulsion applications. These applications are primarily deep space oriented. The TALOS will provide NASA and the commercial market a propulsion option designed to operate at low temperatures from the lunar surface and beyond. Two thrust classes are being developed, but the TALOS will be extensible to a wide range of thrust options."

Top Project Successes?
"The TALOS project's greatest success to date was completion of the risk reduction test program in 2018. During this test program, TALOS demonstrated stable operation and high performance at scaled conditions. The test program consisted of 65 hot-fire tests run at varying conditions. The data were positive and the project held the schedule and cost goals firm. The risk reduction testing has done a lot to prove out the technology to our stakeholders and show that our industry partner Frontier Aerospace Inc. will be delivering a robust and novel product."

Challenges You've Overcome?
"The TALOS project is connected to many aspects of NASA's mission goals. The TALOS is baselined for the Science Mission Directorate's commercial partner, Astrobotic, for the 2021 mission. This mission means that TALOS will directly support a commercial landing to the lunar surface. However, TALOS capability is not limited to the Lunar surface. TALOS is designed to meet the demands of deep space operation and to be extensible to larger applications. The TALOS capability garners a lot of attention, which brings the accountability of many stakeholders. The project carefully manages expectations and demands that accompany multiple mission directorate stakeholders while keeping its development focused on the immediate mission. We keep communication frequent and transparent. Stakeholder diagrams are communicated often with the whole team and we tightly control the many requirements of our product."

Hobbies and Family
"I have been married for 18 years to my wife, Linda. We have been foster parents for nine years and have had 15 different children. We just adopted a 6-year-old girl named Claira. My hobbies are reading lots of theology and history (my Masters is in theology) and woodworking. I love learning and building things with my hands."

Maria Bualat
Astrobee Project Manager

Background
Maria Bualat has been at NASA's Ames Research Center in California's Silicon Valley since 1987, working in the mobile planetary robotics field since 1995. She has served as a Deputy Group Lead for the Intelligent Robotics Group since 2005. Maria has managed projects for NASA's Science Mission Directorate, Exploration Systems Mission Directorate, Office of the Chief Technologist, and Space Technology Mission Directorate. Maria received her bachelor's degree in electrical engineering from Stanford University, and her master's degree in electrical engineering, emphasis Controls, from Santa Clara University.

Project Scope
"The goal of the Astrobee project is to develop a free-flying robot to operate inside the International Space Station (ISS). Astrobee will address multiple scenarios: (1) microgravity robotics research facility on ISS, (2) remotely operated mobile sensor platform to perform intra-vehicular surveys (e.g., sound levels), and (3) mobile camera to improve situation awareness for ISS flight controllers. The project will deliver and commission three free-flying robots, and a docking station for on-orbit use, as well as provide control station software, ground units, communications and data servers, and various spare parts."

Top Project Successes?
"One of the project's top successes so far has been delivery and launch of the Astrobee robots to the ISS. Delivery of the flight hardware was the culmination of four years of work to design, integrate, and test a very complex system, including resolution of several issues through the course of development."

"Another top success is the first flight of Bumble Bee, the first of the three robots to be commissioned on-orbit. Bumble has demonstrated that the propulsion system is very responsive and precise. Continued testing will allow further characterization of the system."

Challenges You've Overcome?
"One of the biggest challenges the project faced was developing an intra-vehicular propulsion system for Astrobee that provided good thrust performance for guest scientist needs while meeting ISS requirements for health and safety (including meeting noise limits), and project requirements for volume (size), consumable recharging, reliability, and serviceability. An initial design using distributed fans was completely overhauled about a year into the project, leading to the current solution of centralized fans with nozzles."

Hobbies and Family
"My family is based in the San Francisco Bay Area. My father immigrated from the Philippines, having joined the U.S. Army during WW II. My mother was a school teacher in Germany, where they met when he was stationed there. My siblings and I were born and raised in San Francisco and most of us still reside in California."

"I don't have a pet, per se, but I do have a horse named Simon. He's a 17-year-old, 16-hand, chestnut quarter horse. My two main hobbies are horseback riding (English-style, a little jumping) and knitting. I find riding a horse to be fun and thrilling, and building a relationship and trust with such a powerful, but gentle animal is very rewarding. Knitting appeals to both the analytical and creative sides of my mind, and I find it very satisfying that it is both relaxing and productive."

New Faces in GCD

During this past year, Game Changing Development (GCD) welcomed two new project element managers, Matt Melis and Mark Thornblom, a new chief engineer, Amanda Cutright, and a new communications manager, Hillary Smith. Read on to learn more about the newest additions to GCD.

Amanda Cutright
Chief Engineer

Amanda Cutright transitioned into GCD's Chief Engineer position this past summer. She previously served in the NASA's Langley Research Center Engineering Directorate as a Systems and Mechanical Engineer. Most recently, she served as the Orion Flight Test Management Office Systems Engineering and Integration Team Deputy on the team that executed the Ascent Abort 2 flight test of the Orion Launch Abort System (LAS).

During her almost 20-year career at NASA, Amanda gained hands-on experience in a variety of NASA's mission directorates on multiple successful project teams to include: Orion Pad Abort 1 LAS flight test, Radiation Dosimetry Experiment, Hypersonic Inflatable Aerodynamic Decelerators, as well as the DEVELOP National Program, along with various branch, directorate, and center level teams to provide technical or policy feedback.

Amanda graduated with a bachelor's degree in mechanical engineering from Virginia Polytechnic Institute and State University (Virginia Tech) and a master's degree in Engineering Management and Systems Engineering from Old Dominion University (ODU). She is also a Fellow of the Society of Allied Weight Engineers for mass properties. Amanda's hobbies and interests include a variety of water sports, dancing, health and wellness subjects, homesteading activities, crafts, and spending time with family and friends.

Hillary Smith
Communications Manager

Hillary Smith joined the GCD office in October 2018. Before this transition, she worked as a journalist for the Virginia newspaper, the Daily Press, and California-based newspaper, The San Gabriel Valley Tribune. While there, she enjoyed reporting on local government, economic development and cutting-edge advancements in the health and technology fields.

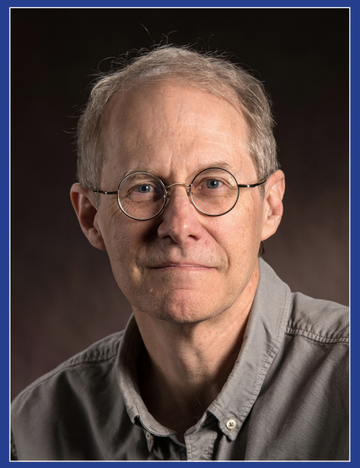
Hillary holds a bachelor's degree in journalism from San Francisco State University. She's written content for the San Francisco Chronicle, the San Francisco Bay Guardian, BBC, and more. At NASA, she takes pride in publicizing critical advancements in GCD space technology through high-quality video, publicly-accessible articles and fact sheets, and by supporting industry and academic conferences for GCD. Hillary enjoys traveling to new countries, hiking, and spending time with her friends and family, as well as her cat, Ringo.

Mark Thornblom
Project Element Manager

Prior to joining GCD this past January, **Mark Thornblom** served as the branch head of the Systems Integration and Test Branch, within the Engineering Directorate at NASA's Langley Research Center in Hampton, Virginia. In this role, he coordinated integration and flight qualification test activities for a wide variety of successful space flight missions for NASA and the Department of Defense.

He served on the American Institute of Aeronautics and Astronautics Ground Test Technical Committee, the NASA Space Environments Capabilities Leadership Team, and as the NASA Langley representative to the Space Environment Testing Management Office.

Mark holds a master's degree in aerospace engineering, with an emphasis in space flight systems analysis, and has more than 15 years of experience developing space flight systems. His areas of expertise include passive thermal control engineering, thermal test engineering, contamination control engineering, and flight systems assembly, integration, and testing. Mark enjoys spending time with his family while camping, hiking, and teaching his three boys to hunt and fish. He is also an avid runner and cyclist.



Matt Melis
Project Element Manager

Matt Melis joined the GCD office in early 2019, and serves as the Project Element Manager for robotic, cryofluid, autonomous, and advanced manufacturing technologies in the program. His primary background is in advanced finite element modeling and analysis methods, including nonlinear and dynamic impact loading. He has been recognized for expertise in actively cooled structures, stress analysis, and ballistic impact research during his tenure at NASA's Glenn Research Center in Cleveland, Ohio. He has worked on numerous aeronautics and space programs for the agency, including the International Space Station, the Space Shuttle, and NASA's Exploration Program.

In the four and a half years that followed the 2003 Columbia accident, Matt was assigned full time to working the Columbia Accident Investigation and the Shuttle Return to Flight Program as technical lead of the NASA Glenn Ballistic Impact team. Since 2003, he has delivered dozens of invited lectures, seminars, and conference keynote presentations on mission safety and NASA's lessons learned from the Columbia tragedy.

Matt received both a bachelor's in civil engineering and a master's in engineering mechanics from Michigan State University and has worked at the NASA Glenn Research Center for 36 years. Matt's hobbies outside of NASA include working with the international aboriculture community (tree scientists), gardening, and fly fishing in Northern Michigan.

Kennedy Space Center's Kevin Grossman discusses ISRU operations with a Tech Day attendee.

GCD Experts Engage Cong ressional Staffers at Tech Day on the Hill

GCD projects Rapid Analysis and Manufacturing Propulsion Technology (RAMPT), Autonomous Pop-Up Flat-Folding Explorer Robot (A-PUFFER), In-Space Resource Utilization (ISRU), In-Space Manufacturing (ISM), Safe and Precise Landing—Integrated Capabilities Evolution (SPLICE), and High-Performance Space Computing (HPSC) participated in Tech Day on the Hill in Washington, D.C. June 6.

Project experts explained the significance of their additive manufacturing, resource utilization, and landing technologies to congressional staffers. NASA Administrator Jim Bridenstine and STMD Associate Administrator Jim Reuter—among many others—attended the event and spoke with GCD technology experts.

Tracie Prater of ISM engages a visitor on the integrated recycler and printer, the Refabricator.

PUFFER Robotics Mechanical Engineer Kalind Carpenter operates a working PUFFER model to explain the miniature rover system to Tech Day attendees.

NASA Administrator Jim Bridenstine asks the RAMPT project team about their additive manufacturing technology.

GCD Activities Attract Crowds at the Apollo 50 Anniversary Festival

A young visitor controls a working model of the GCD Pop-Up Flat-Folding Explorer Robot (PUFFER) at the Apollo 50 Festival celebration.

Thousands attended the National Air and Space Museum and NASA's Apollo 50 Festival on the National Mall July 18 through 20 in Washington, D.C. Each NASA mission directorate was represented throughout the exhibit tents lining the mall outside the National Air and Space Museum. The Space Technology Mission Directorate (STMD) tent drew a steady crowd during the event, with dozens lining up to try out real astronaut gloves, look at the Astrobee robot model, or operate Sphero robots. Many Game Changing Development (GCD) volunteers staffed the STMD tent over the three days—despite the 100-degree weather—and engaged hundreds on GCD technology.

Apollo 50 Festival Support

From the GCD Program Office
GCD Program Manager Drew Hope, Project Element Managers Mark Thornblom and Kevin Kempton, Communications Manager Hillary Smith, and GCD Exhibit Specialist Brandon Guethe.

From the GCD 2019 interns
Alexa Escalona, Kai Cui, Eva Birtell, Sheila Babar, Kayla Schang, Carter Swift, and Connor Dolan.

From GCD projects
Astrobee Project Manager Maria Bualat and Tyler Hudson of the Rapid Analysis and Manufacturing Propulsion Technology (RAMPT).

Chief of Staff Mike Green (from left), Technology Demonstrations Missions Communications Lead Keyke Reed, and GCD Exhibit Specialist Brandon Guethe.

GCD interns Connor Dolan (left) and Kai Cui test out the astronaut glove vacuum chamber.

Tyler Hudson (from left) of RAMPT, GCD intern Kayla Schang, and GCD Program Manager Drew Hope.

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