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FREE-FLYING ROBOTS IN SPACE

HOW REAL-LIFE DROIDS ARE TESTING NEW TECH

ON PAGE 2

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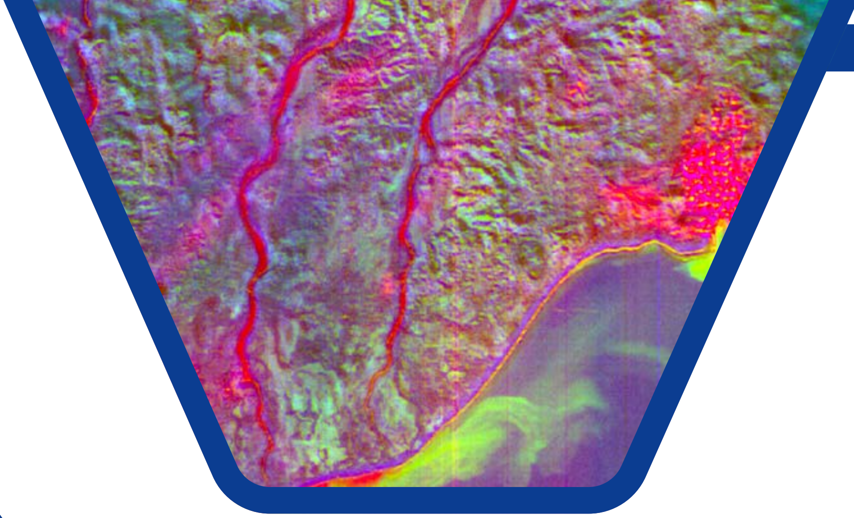

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VIEW FROM THE CUPOLA

By Donna Roberts, Deputy Chief Scientist for the ISS National Lab

Donna Roberts is the deputy chief scientist for the ISS National Lab, where she supports the development of interagency research programs in space for the benefit of humans on Earth.

I am excited to introduce this edition of Upward magazine, which highlights how flying robots, helpful sidekicks, and tissue chips containing living human cells all found their way to the International Space Station (ISS). No, this isn't from a science fiction novel—it's all part of the exciting research sponsored by the ISS National Laboratory®.

In this issue's cover story, we learn about the Astrobees—a trio of free-flying robots that assist astronauts and conduct research and technology demonstrations on station. The Astrobees are also helping shape the next generation of space industry leaders through MIT's Zero Robotics program, in which middle and high school students develop computer coding for the Astrobees to carry out specific tasks. Participation in the program will remain a highlight for these students for years to come. It brings to mind my first visit to a college campus to participate in a high school coding competition. Although I knew little about computer hardware or software at the time, to my surprise, I won first place. The experience sparked my interest in computers and left such an impression that I chose computer engineering as my undergraduate degree. Programs that engage students in science, technology, engineering, and mathematics (STEM) are now more important than ever. A 2023 report[1] by the National Space Council found the number of students entering STEM fields has steadily declined. Meanwhile, a study[2] by the Space Foundation indicates a strong need for a STEM-educated workforce to support the continued growth in commercial space industry employment.

Another article highlights a special relationship between an MIT biological engineering professor and his students that inspired valuable research on post-traumatic osteoarthritis (PTOA). This story is particularly meaningful for me because one of the most fulfilling aspects of my career has been mentoring students conducting space-based medical research. PTOA is a degenerative disease affects young adults who sustained a joint injury as a high school or college athlete. The condition is tricky to study, and space-based research could lead to a better understanding of disease initiation and progression. In an investigation funded by the National Institutes of Health, the team sent tissue chips containing knee tissues to the space station. Spaceflight has been shown to result in a greater than 10-fold acceleration of certain processes in the body by mimicking accelerated aging[3]. In microgravity, disease progression and bone loss occur over much shorter periods—on the order of weeks compared to years on Earth—making it more practical to study cellular pathways involved in disease development and test therapeutics.

This issue also features the story of a small startup called Orbital Sidekick that had a big idea to provide Earth monitoring services to global customers using an advanced imaging technique known as hyperspectral imaging. However, the company needed to validate its sensor technology in space before deploying imaging satellites. Orbital Sidekick used the Nanoracks External Platform located on the space station's exterior to test its sensor technology. This allowed the company to gain valuable operational data to move toward commercialization. This is a great example of how space-based research can provide significant value, helping innovative startups get off the ground. The story also demonstrates how the quick thinking and ingenuity of ISS National Lab Commercial Service Providers like Nanoracks can save a mission through real-time problem solving.

1. Roeder, T. Study Shows Steady Decline in U.S. Students Studying Engineering, Science. The Space Report. 2023.

2. Borowitz, M. U.S. Space Employment Continues to Slow, Steady Climb Since 2016. The Space Report. 2023.

3. Vernikos, J and Schneider VS. Space, gravity and the physiology of aging: parallel or convergent disciplines? A mini-review. Gentrol. 2010;56(2):157-166.

Free-Flying Robots in Space

How Real-Life Droids are Testing New Tech

By Amy Thompson,
Contributing Author

Five years ago, on a space station not so far away, a trio of cube-shaped robots embarked on a multi-year mission to help pave the way for future robots and autonomous systems in space. Much like the droids of the "Star Wars" universe, NASA's free-flying robotic system, Astrobee, aims to assist astronauts on the International Space Station (ISS) with tasks and test out new technologies in ways not possible on Earth.

From communicating with various computer systems to grappling spacecraft or identifying potential hazards such as leaks on spacecraft, robotic helpers will be an integral part of future space exploration. They can also assist with everyday tasks and maintenance, enabling crews to focus more on research. That's the idea behind Astrobee, a small swarm of free-flying robots buzzing around the space station.

NASA astronaut Megan McArthur with the Astrobee robotic free-flyers.
NASA

Seemingly straight out of the pages of science fiction, Bumble, Honey, and Queen have helped with more than 150 investigations, many of which are sponsored by the ISS National Laboratory®, to test various technologies in space that have direct applications for both future exploration efforts as well as industries here on Earth.

Since beginning operations on the space station in 2019, the Astrobee facility, operated out of NASA's Ames Research Center in Silicon Valley, has logged more than 1,200 operational hours. "One of the Astrobees' main jobs right now is to conduct research that supports scientists who want to do space-based research," said Jonathan Barlow, lead engineer for the Astrobee facility at NASA Ames. "Researchers may not be able to design a whole robot or spacecraft from the ground up, so they can leverage this platform to conduct their research."

In addition to more technical ISS National Lab-sponsored experiments like acoustic mapping or testing spacecraft rendezvous and docking capabilities, the 'bees also do science, technology, engineering, and mathematics (STEM) education outreach as part of the Massachusetts Institute of Technology's (MIT) Zero Robotics program.

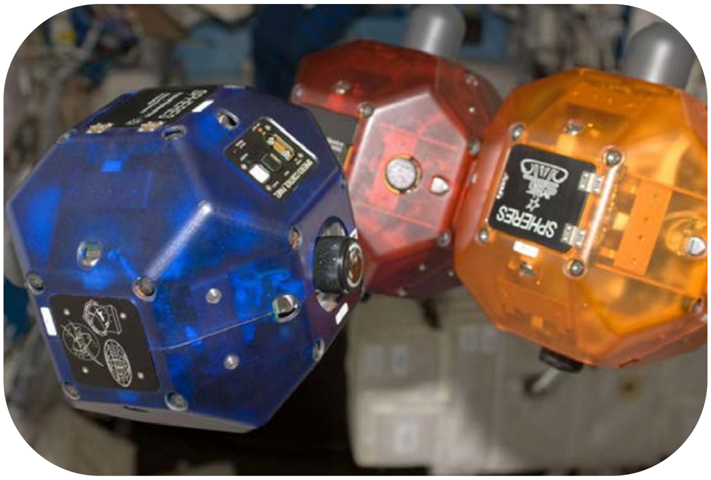
According to Barlow, the space station is an ideal place to test how projects run using the Astrobees to inform robotics systems for future space stations and even NASA's planned Gateway lunar space station, which may not be crewed year-round and will need autonomous systems to remain operational. "The Astrobees are testing technologies that could be implemented in future long-duration or deep space missions, where crew might not be available," Barlow said.

These Are the Droids You're Looking For

One of the iconic scenes in "Star Wars" shows Luke Skywalker onboard the Millennium Falcon, learning the intricacies of "the Force" from Jedi master Obi-Wan Kenobi. Luke battles a training droid that resembles a floating ball, zapping him with lasers as part of his training.

That orb inspired the design of Astrobee's volleyball-sized predecessors, a trio of 18-sided polyhedral satellites called Synchronized Position Hold, Engage, Reorient, Experimental Satellites (SPHERES).

"The inspiration for the SPHERES project was actually a remote from 'Star Wars,'" said Barlow. "David Miller, an MIT professor, showed that clip to his senior design class and said, 'I want you to build me this.' And sure enough, that's exactly what they did."



NASA's SPHERES robots were created to test new technologies on the space station.

NASA

According to Barlow, Miller's graduate students received funding from the Defense Advanced Research Projects Agency (DARPA) to build three SPHERES robots that launched to the space station in 2006. SPHERES operated for more than 10 years, participating in nearly 600 experiments that tested concepts from autonomous formation flying to navigation, mapping, and more. In 2010, the SPHERES project transferred from MIT to NASA Ames, where its success led to the rise of the Astrobees.

Queen Bees and Wanna Bees

Queen, Honey, and Bumble, along with a set of other test Astrobee robots, were named by the team at NASA Ames. "We wanted something on theme that wasn't too irreverent or crazy," said Barlow.

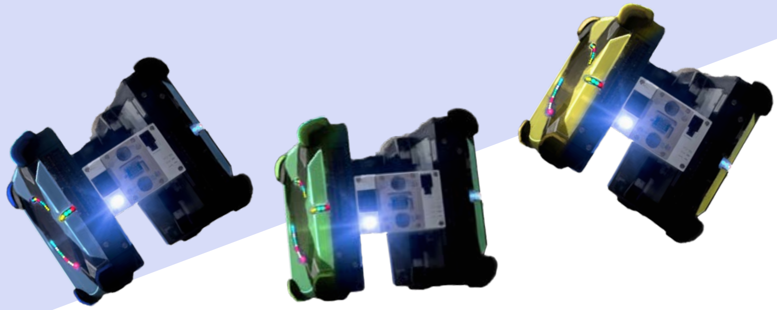
He explained that the name "Astrobee" was decided through a top coder competition, but the Ames team named the individual robots. Following a brainstorming session, the team selected the names for the space-based robots and their ground-based counterparts, including Wanna Bee, Bee Sharp, and Killer Bee.

Powered by electric fans, the Astrobees utilize cameras and sensors to "see" how to navigate and conduct experiments. They also have arm attachments to hold objects or keep steady for tasks requiring stability. Barlow says when designing the Astrobees, the teams envisioned a robotic system that's smart and versatile enough to handle simpler maintenance and monitoring chores, leaving astronauts free to tackle more complex work.

"SPHERES were more limited in what they could do because we always had to have a crew member present as part of the safety controls," Barlow said. "When we were developing the Astrobees, we wanted to take advantage of advances in technology and make them more robot-like as opposed to SPHERES, which were more satellite-like and were not designed to really interact with crew or their environment."

(Below) Jonathan Barlow working with a SPHERES robot at NASA Ames Research Center.

NASA/Eric James



Running off carbon dioxide tanks and disposable alkaline battery packs, the SPHERES robots were not designed to assist astronauts in practical ways, and their unique shape proved difficult to sustain. When designing the Astrobees, Barlow said the team opted for a cube shape to facilitate its design and accommodate potential attachments to increase its capabilities.

"Just the design challenges alone, like having to create curved circuit boards and other necessary parts, was enough to warrant the new shape," he said. "It takes a lot of extra work to manufacture the parts needed to operate SPHERES, and the new design allowed for more payload capacity both inside the robot and on its exterior."

Flight of the Bumble Bee

On June 14, 2019, Bumble became the first Astrobee to fly under its own power in space. Canadian Space Agency astronaut David Saint-Jacques was on hand to manually move the blue cube around the space station's Kibo module, which enabled Bumble to calibrate its navigation system and verify that it could not only locate its position within the space station but also navigate as expected.

Canadian Space Agency astronaut David Saint-Jacques working with the free-flying Astrobee named Bumble onboard the ISS.

NASA

"This was such a fun project to work on, and I still remember it to this day," Saint-Jacques said. "As an astronaut living on station, we spend a lot of our time repairing things that are broken or doing experiments that can be incredibly technical, but this project was completely different and a lot of fun."

Saint-Jacques and his crewmates commissioned Bumble and set up the robots' "hive," or docking port, on station. Located in the Kibo module, the specialized platform would enable the 'bees to recharge themselves and provided a storage place when they were not in use.

"One of the cool things about this project was that we were able to interact directly with researchers on the ground," said Saint-Jacques. "It was really memorable because you could tell this project meant a lot to them. We could hear cheering in the background when the robot flew for the first time."

Following Bumble's initial success, Honey and Queen arrived on station. Researchers can use one Astrobee or two—or, on rare occasions, all three. Barlow says that typically, only one or two 'bees are used because there are only two charging ports for them, with the third robot acting as a backup. The Astrobees can be operated via ground controllers or work autonomously.

NASA astronaut Megan McArthur also worked with the robotic assistants during her tenure on station. "As a science fiction nerd, I love all of the ideas about how humans and robots will work together in space to do all of the things that we do," she said. "I love the idea of one day in the future having little free-flying robots that can move around and do things like take pictures of something instead of me having to stop, secure all of my tools, and find the camera."

NASA astronaut Megan McArthur with one of the Astrobees on the ISS.

NASA

See-ing Through Sound

In science fiction movies, characters often carry portable electronic scanning devices to detect anything from machine malfunctions to potential hazards. Astronauts on the space station are also tasked with periodically scanning onboard equipment to identify issues before they become major problems.

But what if there was a better way? Samarjit Das, chief scientist at global engineering firm Bosch, thinks his company has developed technology that can help free up one of the most valuable resources on station: crew time.

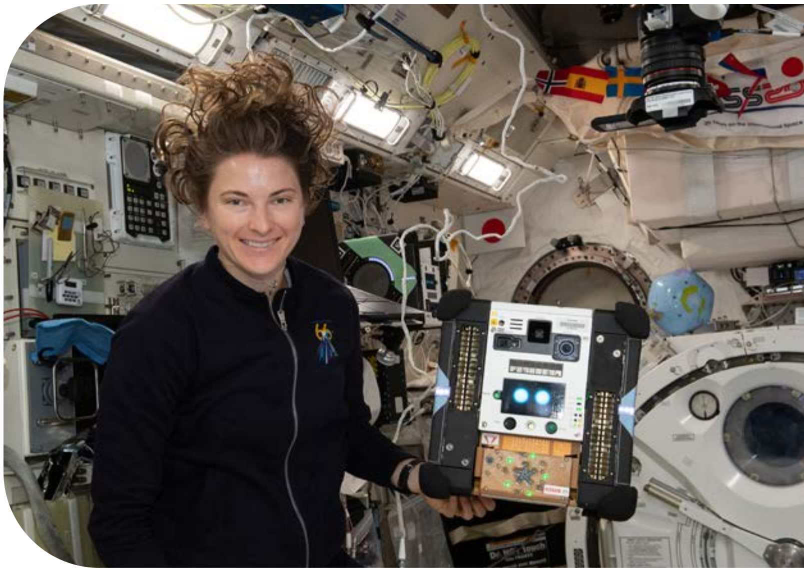
C-3PO, the iconic protocol droid from "Star Wars," is known for being well-versed in more than six million forms of communication and his ability to communicate with equipment. Similarly, Das and his team hope that a specialized microphone array combined with machine learning software can decipher the language of various pieces of equipment used on the space station and by industries here on Earth.

"People from around the world speak different languages, so it makes sense that everything around us is also talking, just in its own language," Das said. "Everyday items, such as your computer, your car, and HVAC systems, are constantly communicating through sound vibrations, frequencies, and even currents."

Das and his team partnered with Astrobotic—a private aerospace company developing robotic spacecraft and technologies for use on the Moon and other planetary bodies—to build a cutting-edge smart microphone array called SoundSee. Attached to a free-flying system like Astrobee, SoundSee could diagnose anomalies in spacecraft. Soundsee could also be used for applications on Earth, like in the automotive industry or manufacturing.

The SoundSee system installed on an Astrobee on the space station.

NASA



NASA astronaut Kayla Barron sets up an Astrobee for the SoundSee experiment.

NASA

As a bustling scientific laboratory in low Earth orbit, the space station can be a noisy place. In an ISS National Lab-sponsored investigation, Das said the team was able to demonstrate its SoundSee technology works.

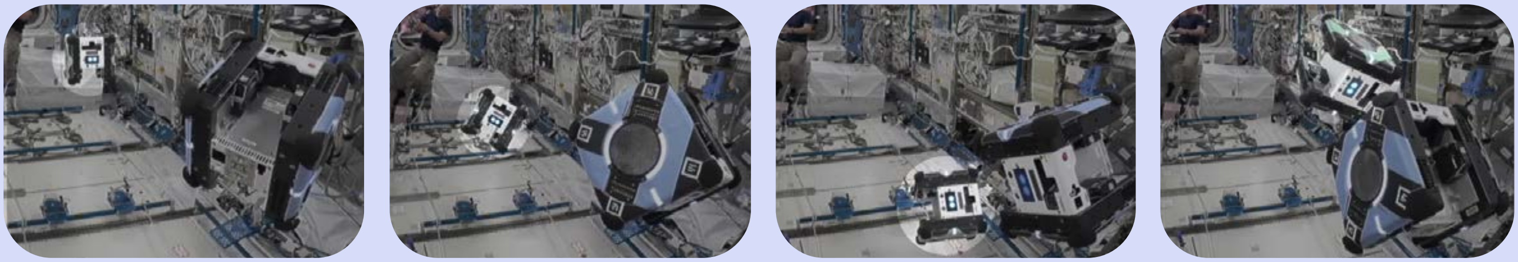
"We wanted to demonstrate that a floating robot could essentially act as an automated inspector, conducting autonomous acoustic surveys, freeing up the astronauts to do more meaningful work," he said. "And we did."

Das says that Bosch is working on refining its microphone array and artificial intelligence capabilities for commercial use. The company hopes to use the technology in many industries and work with NASA and the ISS National Lab to deploy it on future missions and platforms like commercial space stations, the planned Gateway lunar space station, and more.

Stay on Target

The iconic command to stay on target may have been uttered by a squadron of X-wing pilots trying to blow up the Death Star in "Star Wars," but a team of researchers from MIT and the German Space Agency (DLR) are hoping the mantra could help them recover tumbling satellites in space. Operations to rendezvous with an object are hard to plan when you don't know exactly how the object is moving. However, the research team found a potential solution, which they tested in an ISS National Lab-sponsored investigation.

"We've assembled a set of algorithms that figures out how the target is tumbling, and then along with our other tools that allow us to account for uncertainty, we can produce a plan to get us to the target, despite the tumble," said Keenan Albee



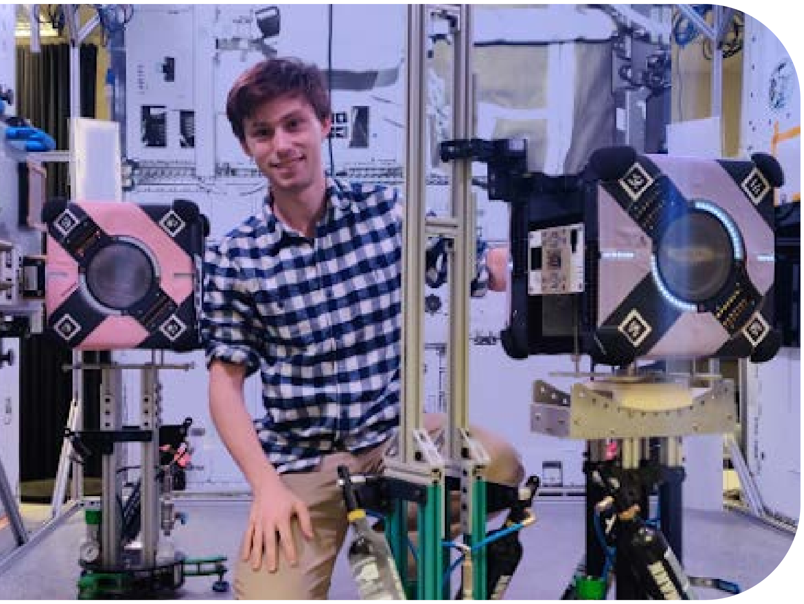
The Astrobees carrying out a rendevous as part of the ROAM investigation.

NASA

who led the Relative Operations for Autonomous Maneuvers (ROAM) project at MIT before earning his Ph.D. and accepting a role in robotics at NASA's Jet Propulsion Laboratory in California.

The team identified a set of algorithms they wanted to test in microgravity, focusing on simultaneous localization and mapping (SLAM), system identification, and predictive control. The project required two Astrobees—one acting as the tumbling target and the other acting as a chaser trying to rendezvous with the target.

Data collected from the Astrobees' onboard cameras and sensors helped the chaser 'bee model the target 'bee's motion and inertial properties. Using this data with the team's algorithms, the chaser 'bee identified a fixed point on the target 'bee's frame, resulting in a successful rendezvous in orbit. The ability to see the code operate in real time and refine the algorithms between runs was invaluable and resulted in multiple successful rendezvous maneuvers with different tumbling patterns.



Keenan Albee working with the Astrobee granite table facility at NASA Ames during payload maneuvering testing in preparation for the MIT ReSWARM investigation.

Brian Coltin/NASA

Following ROAM's success, Albee and the MIT team launched another Astrobee project, called RElative Satellites sWArming and Robotic Maneuvering (ReSWARM), to evaluate how well specific algorithms are able to control multiple satellites and perform in-orbit assembly maneuvers.

These projects not only allowed the researchers to advance their software but also provided enhancements to the Astrobee system. Portions of the data collected from the two investigations helped improve Astrobee's localization system, which is used to identify where the robot is, and the flight code software. These updates will help future Astrobee users.

Inspiring the Next Generation

One of the legacies of the SPHERES project is its educational outreach. In 2009, the MIT Space Systems Lab created the Zero Robotics program. Modeled after the successful First Robotics program in schools across the country, Zero Robotics focuses more on software rather than building hardware, encouraging students to create code for competitions using the SPHERES robots on station.

For the first space-based competition, the challenge was to complete a task with the SPHERES robot before your opponent. The competition was a success, with more than 200 students from 19 states participating.

Danielle Wood, a professor at MIT, currently runs the program. "We call it 'Zero Robotics' for a reason: It's in 'zero gravity,' there's zero cost, and there's zero configuration," she said. "This means the teams don't have to set up and configure the robots."

When the SPHERES gave way to the Astrobees, the MIT team knew they had to keep Zero Robotics going. The program now holds competitions annually, with one in the summer targeting middle schoolers and another in the fall focused on high schoolers. Through these competitions, students use code to complete a different challenge every year.

"Students have the opportunity to design code and have it tested using Astrobee robots on the space station," said Barlow. "They earn points, compete with other teams, and learn valuable skills to help them in the future."

Wood says the number of students participating has increased over the years. “We had 600 students participating in 2023, and we keep trying to grow up to the next level year to year,” she said. “We’re really proud of what we’re achieving with this program and the students we’re reaching.”

As an ISS National Lab Space Station Explorers partner program, Zero Robotics significantly impacts students. By providing real-world experience both with the robots and the crew members on station, the program hopes to inspire students to pursue careers in STEM fields.

“I think when you find something that’s interesting for children, you can show them how it’s relevant to real research and the way we live and work in space,” said McArthur. “I think that’s really important for kids of all ages and from all walks of life. If they can see themselves doing something or find something that’s meaningful to them personally, it makes a connection that can inspire them.”

Benefits a Buzz

Droids are ubiquitous in the “Star Wars” universe, with nearly every household and spacecraft having at least one, but robotic helpers on the space station are just getting started. Thanks in part to their autonomous nature, the Astrobees are demonstrating they have the potential to be the robotic assistants NASA is looking for.

The Astrobee facility is a lower-cost technology test bed that allows researchers and students to test software and sensors through ISS National Lab-sponsored investigations. The facility’s increased capabilities have allowed it to far surpass its predecessor.

“We can run similar experiments to what we ran on the SPHERES, but the Astrobees’ enhanced capabilities have enabled so many additional investigations,” said Barlow. “The Astrobee facility has allowed us to essentially double the number of experiments we can do using robotic assistants.”

Robots will play a significant role in the future of space exploration, whether on the space station, future commercial space stations in low Earth orbit, NASA’s planned lunar space station, or missions to deep space. The Astrobees and other robotic helpers could serve as caretakers for destinations in low Earth orbit and beyond, as not every outpost will always be crewed. Through investigations such as those sponsored by the ISS National Lab, the team behind the Astrobee facility hopes to show everyone just how valuable these little space robots can be.

Students participating the 2023 Middle School Zero Robotics Finals at MIT with NASA astronaut Woody Hoburg.

Zero Robotics

Students at a school in the Hopi Native American nation watching the 2023 Middle School Zero Robotics Finals.

Zero Robotics

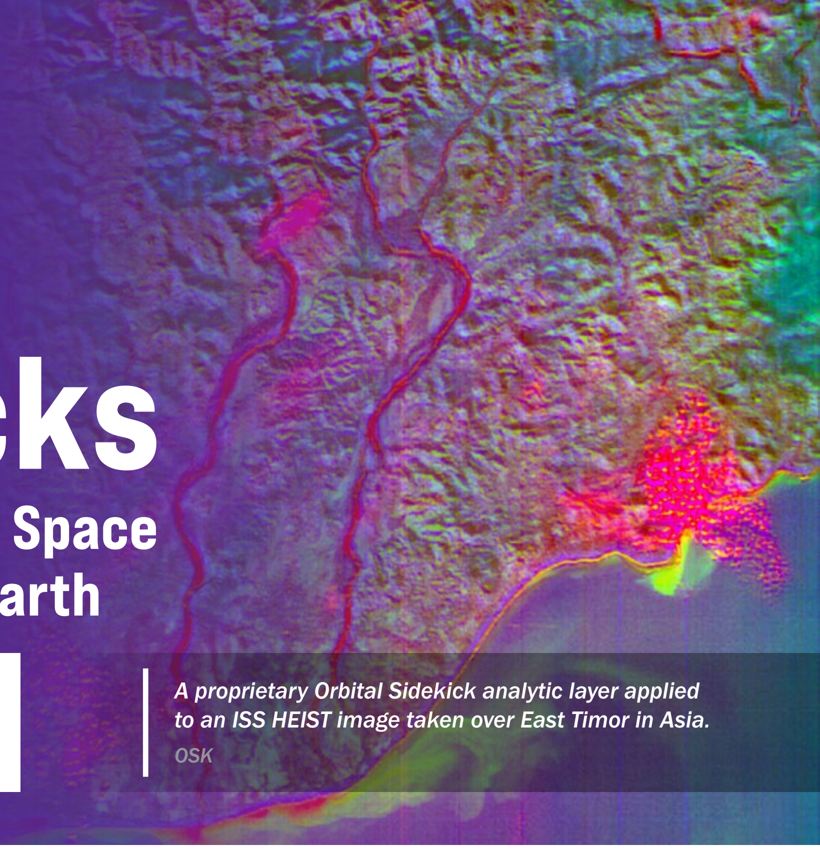
Students at the San Antonio Museum of Science watching the 2023 Middle School Zero Robotics Finals with NASA astronaut Woody Hoburg.

Zero Robotics

Sensors, Satellites, and Sidekicks

Chemical Fingerprinting From Space for Valuable Applications on Earth

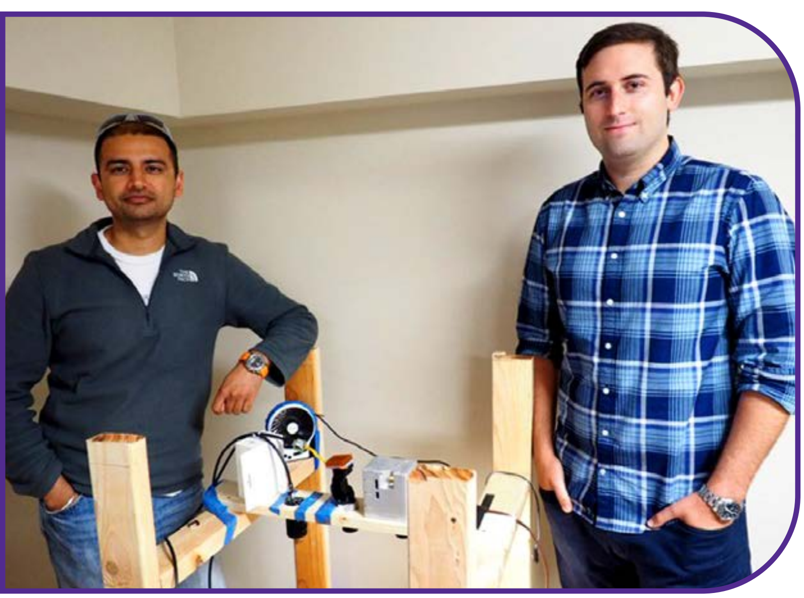
By Amelia Williamson Smith,
Managing Editor



A proprietary Orbital Sidekick analytic layer applied to an ISS HEIST image taken over East Timor in Asia.
OSK

Beside some of the greatest heroes, you'll find a loyal sidekick ready to jump in and help whenever a challenge arises. Batman has Robin. Han Solo has Chewbacca. And Mario has Luigi. When Dan Katz and Tushar Prabhakar founded their global monitoring company in Katz's San Francisco garage in 2016, they envisioned being a trusted partner for their customers.

From high above our planet, satellites equipped with hyperspectral sensors can capture images of the Earth that reveal more than what we can see with our eyes. These sensors detect electromagnetic radiation beyond the visible light that typical cameras capture. Hyperspectral data allows scientists to identify specific chemicals and materials that may be present in the image, which can serve as an indicator for a wide variety of applications.



Orbital Sidekick founders Dan Katz (right) and Tushar Prabhakar (left).
OSK

Using hyperspectral satellites, Katz and Prabhakar sought to establish a company that would provide monitoring services to help solve its customers' most pressing challenges. Whether it's finding leaks in pipelines, identifying areas susceptible to wildfire, detecting valuable materials for mining, or assessing the health of crops, the company would serve as a sidekick to its customers—an Orbital Sidekick.

"Hyperspectral imaging is a powerful tool for global monitoring," said Katz, CEO of Orbital Sidekick. "One of our core tenets is partnering with our customers to provide actionable insights so they can have better operational integrity and make smart decisions about their assets."

But before they could get their company—and hyperspectral satellites—off the ground, they needed to test their sensor technology in space. They realized early on that launching their own satellite for testing would be a significant task because they would also need to figure out how to get the satellite to work and get the data from the sensor back to Earth.

"Having to worry about not just the new hyperspectral sensor technology but also everything else that goes along with the mission is a lot to handle, especially for a small team," Katz said. "So, we started thinking, what other ways could we demonstrate the sensor in space and not have to worry about the infrastructure?"

It was while Katz and Prabhakar were at SpaceCom, a global commercial space conference, that they stumbled upon the answer: the International Space Station (ISS) National Laboratory. At the conference, they met with representatives from the ISS National Lab and Nanoracks, part of Voyager Space's Exploration Segment. They realized the space station was the perfect platform to test their sensor technology. In an investigation sponsored by the ISS National Lab, Orbital Sidekick launched its sensor— Hyperspectral Earth Imaging System Trial (HEIST)—to station, where it was installed on the Nanoracks External Platform (NREP), which is mounted to the exterior of the orbiting laboratory.

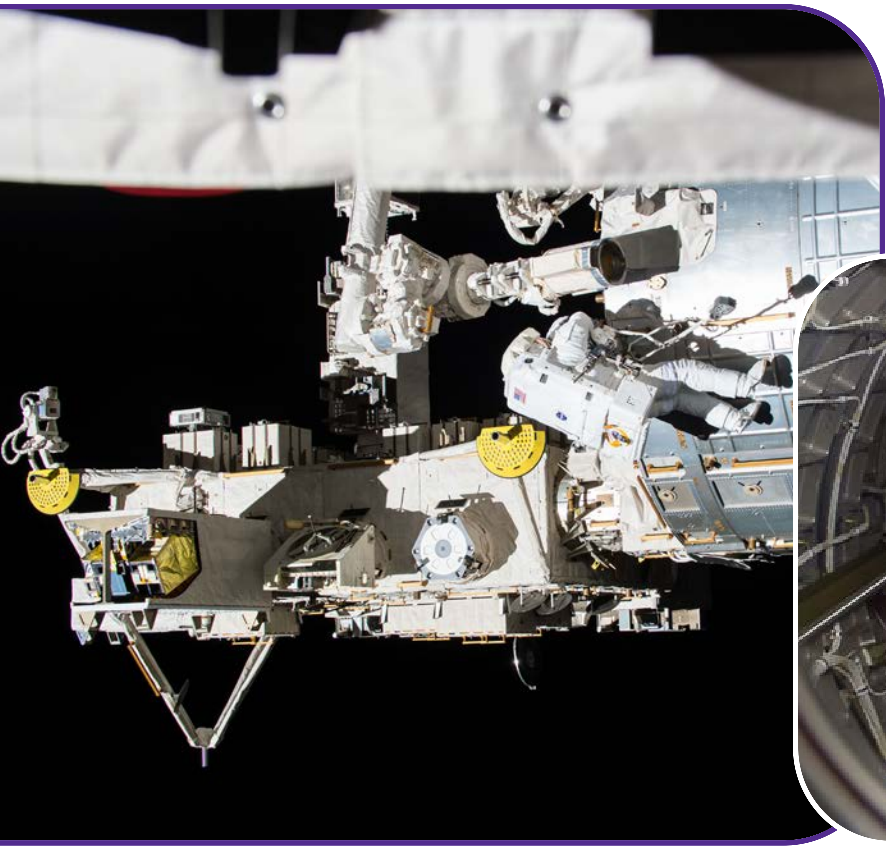
"It was very appealing to us because the space station is a stable platform and has all the infrastructure and downlink capability in place, so all we had to really worry about was making sure the hyperspectral sensor worked, which was a huge relief," Katz said. "Our goal was to see if we could demonstrate that there's a viable path forward to commercialization by leveraging space-based hyperspectral sensing. The mission was wildly successful and really set the table for everything we're doing today with our commercial satellites."

Seizing an Opportunity

Traveling in the form of waves, electromagnetic radiation is all around—from radio waves that transmit our favorite songs to microwaves that heat our food, ultraviolet (UV) rays that can cause sunburn, infrared waves that are in some heaters, x-rays used in hospitals, and gamma rays that deliver high-energy radiation to kill cancer cells. However, the type of electromagnetic waves you are most familiar with come in the form of visible light (red, orange, yellow, green, blue, indigo, and violet). This is the only type of electromagnetic waves we can see with our eyes.

Electromagnetic radiation is organized in a spectrum of wavelengths, with high-energy gamma rays at one end, low-energy radio waves at the other, and visible light in the middle. High-energy waves have shorter wavelengths, meaning the waves are closer together, and low-energy waves have longer wavelengths, meaning the waves are spaced farther apart.

Orbital Sidekick's HEIST can detect a range of wavelengths from around 400 nanometers (which is violet visible light) to about 1,000 nanometers (which is near-infrared, just beyond the visible light part of the spectrum, which ends around 700 nanometers at deep-red visible light). The sensor captures light through the lens, and a diffraction gradient (a tool that acts like a prism) has a pattern of grooves that split the light into discrete spectral bands that can be used to characterize the area imaged.

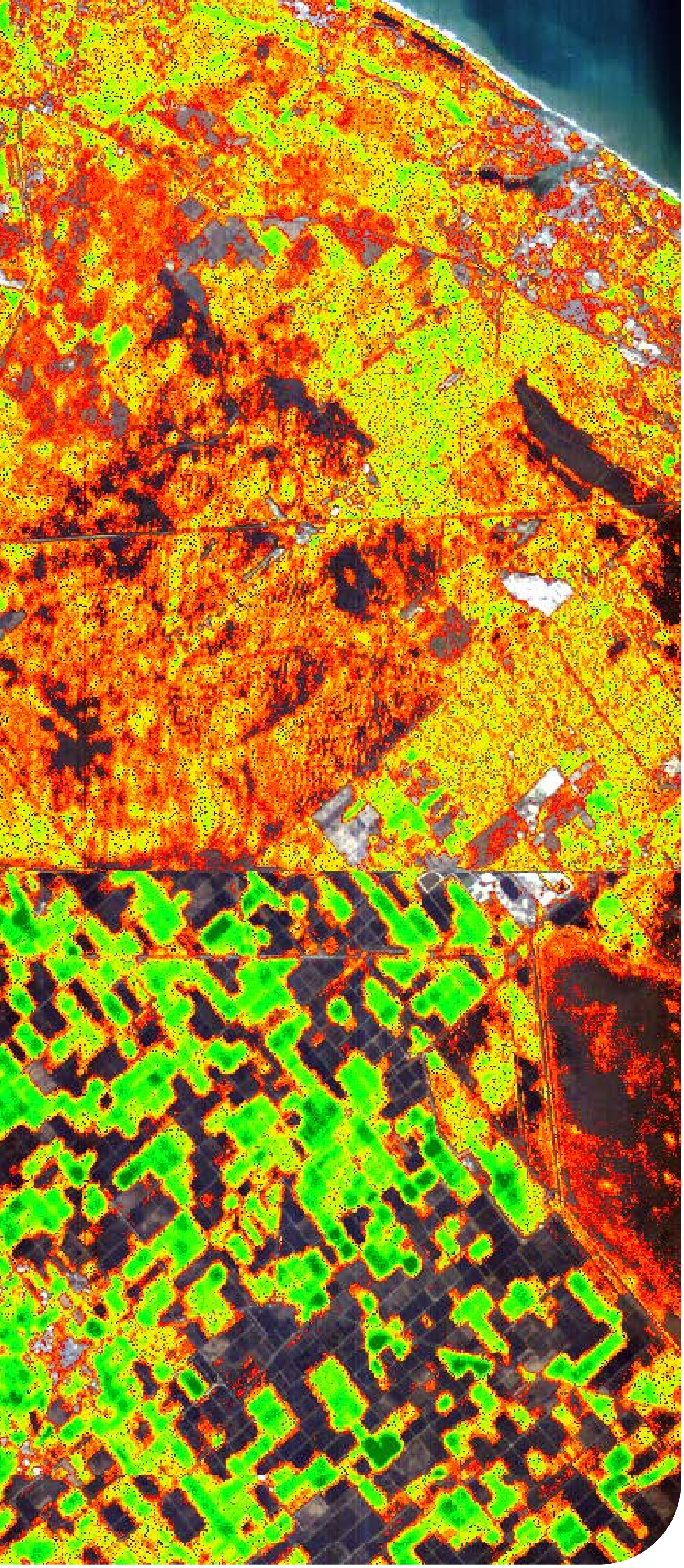


(Above) View of the Japanese Experiment Module and its Exposed Facility, which houses the NREP. Also featured in this image is the Japanese Robotic Arm used for moving the NREP from its location to the slide table to transfer inside the ISS via the Japanese Experiment Module airlock.

NASA

The NREP inside the Japanese Experiment Module airlock. Payloads are installed inside the pressurized volume of the ISS, and then the NREP and payloads are transferred outside and installed on the Japanese Experiment Module Exposed Facility.

NASA



A normalized difference vegetation index (NDVI) analytic layer applied to an ISS HEIST image taken over Florida. NDVI is often used to assess the health of vegetation.

OSK

Images of Earth taken by HEIST have a spatial resolution of 28 meters. This means that each pixel in an image represents 28 meters on the ground. That may seem like a low resolution compared with images from satellites like those used by Google Earth, which can capture areas on the ground as small as 15 centimeters. However, typical satellites cannot provide the detailed spectral data that HEIST can. Most imaging satellites can only capture three spectral bands (red, green, and blue visible light, similar to the camera in your cell phone), compared with HEIST's 150 discrete spectral bands that go beyond the visible spectrum. By analyzing the spectral bands in an image, Orbital Sidekick can do what Katz calls "chemical fingerprinting."

Assembly of HEIST in Orbital Sidekick's downtown San Francisco office.

OSK

Everything absorbs light in a unique manner, and different materials reflect different intensities of light. HEIST can capture the absorption and reflectance features in each pixel of an image, and the team can use a database of chemicals, compounds, molecules, and materials to see what the features correspond to. For example, the features may correspond to chemicals that are health indicators for crops or may reveal the presence of lithium, nickel, cobalt, or other battery storage materials for mining.

"I call it chemical fingerprinting because everything has unique spectral fingerprints, and we can identify those fingerprints using our sensors and provide the chemical identification to our customers," Katz said. "It's a more detailed and in-depth way to classify what you're looking at, especially for things you cannot see with the naked eye, such as energy-sector contamination events or emissions."

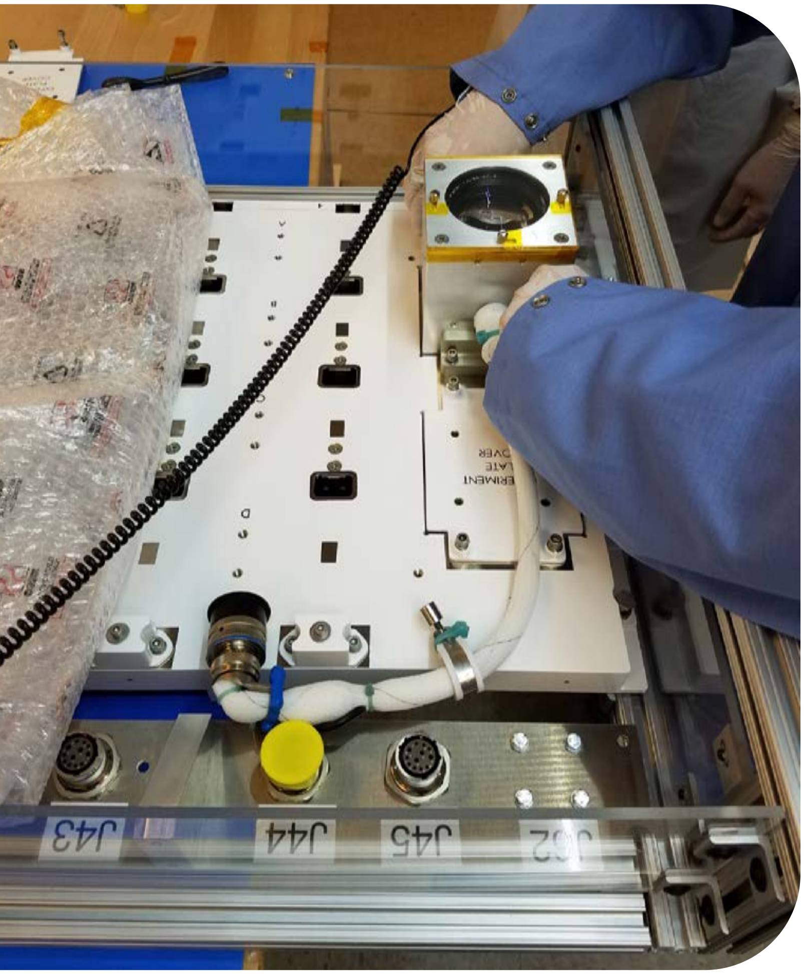
With the expanding commercial space market and the push for sustainable energy transition, Katz and Prabhakar saw an opportunity to leverage hyperspectral satellites to monitor oil and gas pipelines. Using hyperspectral data, they could help pipeline operators identify threats like oil spills and methane leaks and address the problems quickly.

"There aren't many experts who know how to extract insights from hyperspectral data, so it was clear to us early on that we had to build a pretty vertical company," Katz said. "We knew we would need to launch hyperspectral satellites and process the collected data with an analytics engine so we could extract meaningful insights and deliver them to our customers in the form of a monitoring service."

Translating From Ground to Space

Orbital Sidekick's first steps toward providing a hyperspectral monitoring service were testing HEIST in orbit and building an analytics engine. As Katz and Prabhakar prepared their sensor for launch, they worked closely with Nanoracks to ensure it met all safety and compliance requirements. Nanoracks also did integration work to ensure the sensor would interface with the NREP and NASA systems and operate smoothly and effectively in orbit.

"There were a lot of things they really helped us think through," Katz said. "It was things we wouldn't have known to do or didn't have the expertise in, everything from high-level information to low-level details. They really held our hand through the whole process."



Test integration of HEIST onto the NREP in Houston.

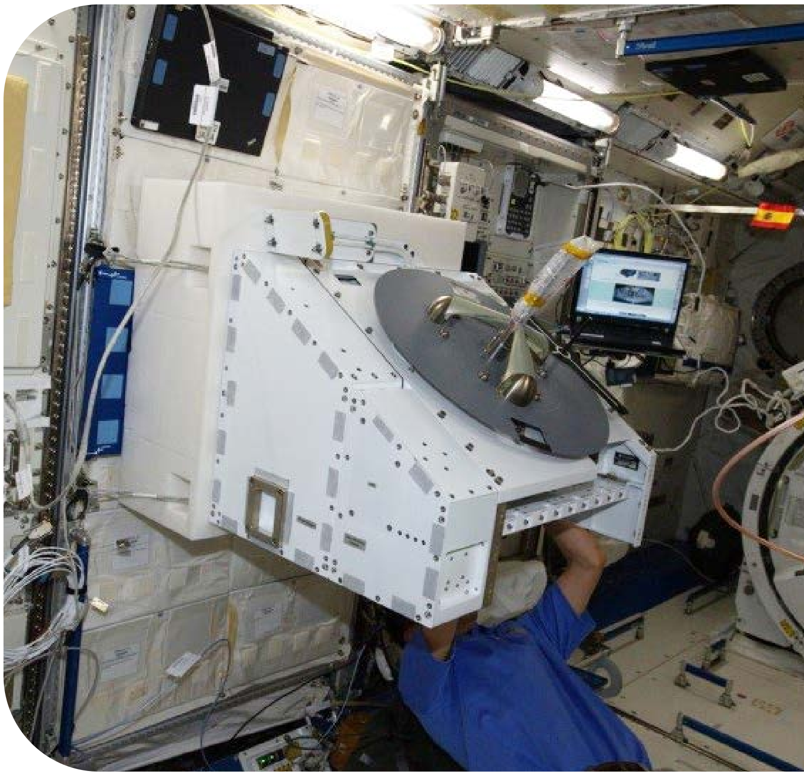
OSK

In June of 2018, HEIST was finally ready to launch. As the Orbital Sidekick team watched from NASA's Kennedy Space Center, they were filled with excitement and a little anxiety. But the nervousness stripped away as they watched the SpaceX Falcon 9 rocket launch their project into orbit.

"It was sometime in the middle of the night, and we had a great view of the launch," Katz recalls. "It lit up the whole night sky, almost like the sun was rising. It was a pretty incredible experience to see that spacecraft go up and know that our system was on it."

Once HEIST was on station, it needed to be installed on the NREP. Payloads for the NREP are installed on the station's exterior via an airlock in the Japanese Experiment Module (JEM). Placed on a special plate, the payloads are transported with the help of the Japanese robotic arm and installed on the NREP. Once plugged in, the NREP provides the payload with power and data communications.

"We pride ourselves on enabling space-based research and development," said Michael Lewis, Nanoracks chief innovation officer. "The philosophy of the company since the start has been to make the space environment more accessible. The NREP is designed to interface directly with the space station, and payloads can just attach to the platform, so there's almost no barrier for our customers."



Astronaut installing a payload on the NREP inside the ISS. The NREP hosts payloads and has mechanical, electrical, and data interfaces.

NASA

Clearing Hurdles and Pushing Boundaries

However, when designing payloads for spaceflight, things don't always go as planned, and you have to be ready to come up with creative solutions—and HEIST was no exception. While working with Orbital Sidekick on the HEIST payload, Nanoracks ran into a problem. Payloads can only extend from the NREP 10 centimeters in the Earth-facing direction, but HEIST needed a lens with a focal length that exceeded that limit. To address this, Nanoracks built a custom plate with holes that allowed the sensor's lens barrel to extend upward into the NREP to achieve the proper focal length while meeting the size requirements.

To help the ISS crew members install HEIST on the custom plate, Nanoracks developed special brackets designed to fit together easily. But once the payload was on station, the team ran into another problem. The astronauts couldn't get the brackets to fit correctly. In talking with the crew, the Nanoracks team realized that the brackets had been assembled in reverse order on the ground.

"At first, I couldn't believe it because I had assembled it myself," said Keith Tran, Nanoracks director of mission operations. "But in real time, we were able to quickly make a change in the plan and told the crew. They swapped the payload around and rotated the cable, and we were able to install it successfully and complete the mission."

HEIST also drove the development of new and enhanced capabilities on the NREP, Lewis said. The NREP obtains data about position from the space station, but because HEIST was imaging very precise locations on Earth, the platform needed a GPS receiver, which was installed. Another challenge led to an increase in bandwidth for data transfer from the NREP.

Hyperspectral imaging produces a lot of data, and it took quite a bit of coordination to get all of Orbital Sidekick's data down to Earth, Lewis said. The NREP was equipped with Wi-Fi, but the connection was too slow, causing a bottleneck. Normally, the NREP would send down data between 2 gigabytes and 10 gigabytes per week, but Orbital Sidekick needed more on the order of 100 gigabytes daily.

"We tackled the data issue on both ends," Tran said. "On the NASA side, we worked to get more bandwidth so we could bring the data down, and Orbital Sidekick worked on their end to reduce the amount of data by only taking images where needed and compressing the data into smaller files."

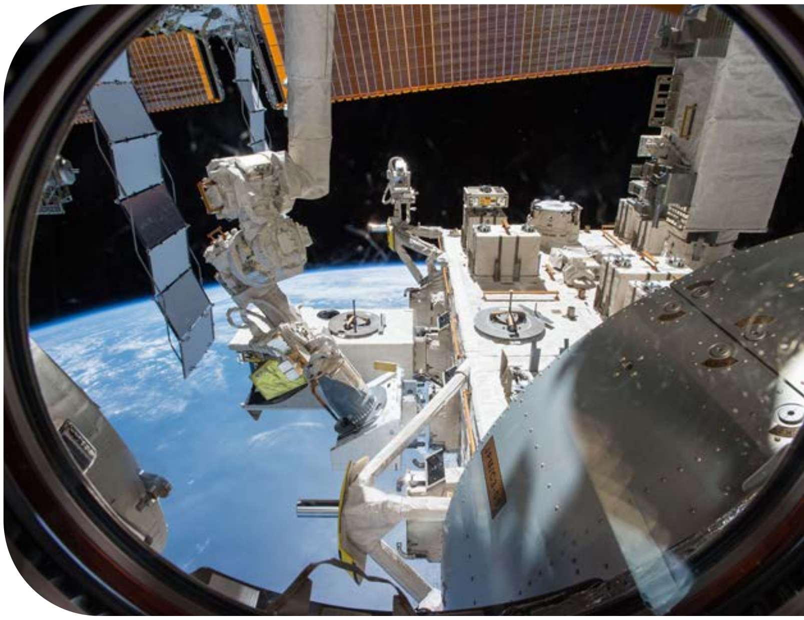
Originally, HEIST testing was slated to take place over 15 weeks, but the project was so successful, it stayed on station for more than a year. In the end, Orbital Sidekick captured more than 30 million square kilometers of hyperspectral imaging, which was a little more than 20 terabytes of data.

The team successfully demonstrated the company could build a hyperspectral sensor, send it to space, retrieve and analyze data, and extract valuable insights for several use cases.

"The data can be used for a whole host of different things—from the energy sector to the mining sector, agriculture, food quality and safety, fire risk assessment, and everything in between," Katz said.

HEIST integrated into the NREP onboard the ISS prior to deployment out of the airlock.

OSK



View of the NREP through a window in the Japanese Experiment Module, nicknamed Kibō.

NASA

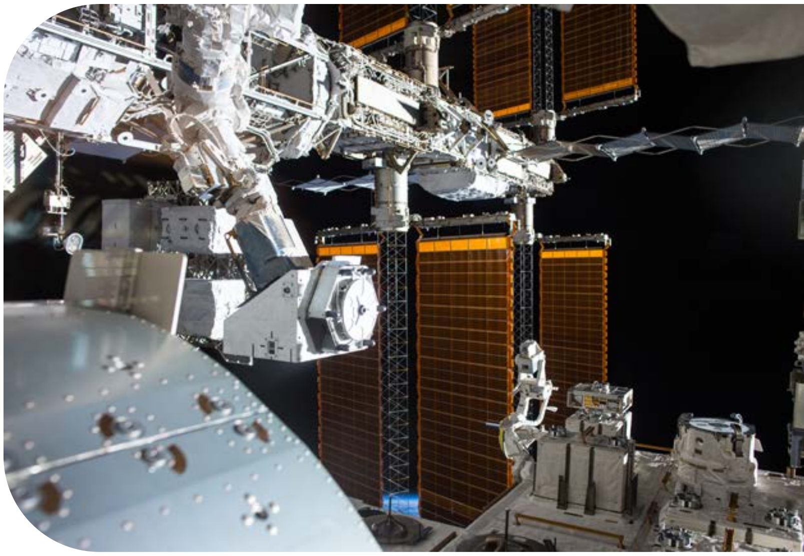
Springing From Station to Commercial Satellites

Since Orbital Sidekick's ISS National Lab-sponsored project, the company has launched five commercial satellites that make up its GHOST™ (Global Hyperspectral Observation Satellite) constellation, with two of these satellites launching last month. Each GHOST satellite is equipped with an upgraded hyperspectral sensor that can detect wavelengths up to 2,500 nanometers, which is farther into the infrared. The upgraded sensor's spatial resolution is eight meters, which is a big improvement from HEIST's 28 meters. The company plans to expand GHOST to include a total of 14 satellites.

"This will allow us to map the entire globe every week with high-resolution hyperspectral data," Katz said. "Our goal is to monitor millions of kilometers of pipeline every week with our satellites, which is a big commercial opportunity for us."

Following the completion of its ISS investigation, Orbital Sidekick has raised nearly $50 million in investment dollars, obtained several government grants and contracts, and signed more than a dozen large energy companies for pipeline monitoring services. According to Lewis, this project is a great example of what can be accomplished by harnessing the space station as a research platform.

"This was an opportunity to take a sensor in the early stages of development and enable the company to go on to produce a strong commercial product," he said. "I'd say their ability to use our NREP platform put them ahead in the industry—they had identified a market and found a way to get into that market by increasing the technology readiness level of their sensor in space."



The NREP being translated to the Japanese Experiment Module Exposed Facility by the Japanese Robotic Arm.

NASA

Orbital Sidekick has come a long way since its early days as a fledgling startup in a San Francisco garage. Katz said he can't imagine where the company would be had they not leveraged the ISS National Lab. "It allowed us to focus our resources on what's really driving value for our company, which is the intelligence platform, analytics engine, and product development for our end user—that's what's important for our commercialization effort," he said. "Our ISS National Lab mission was an amazing launch point for our company—it was the enabling instrument that unlocked so much for us. It was incredible."

Group photo of the Orbital Sidekick team.

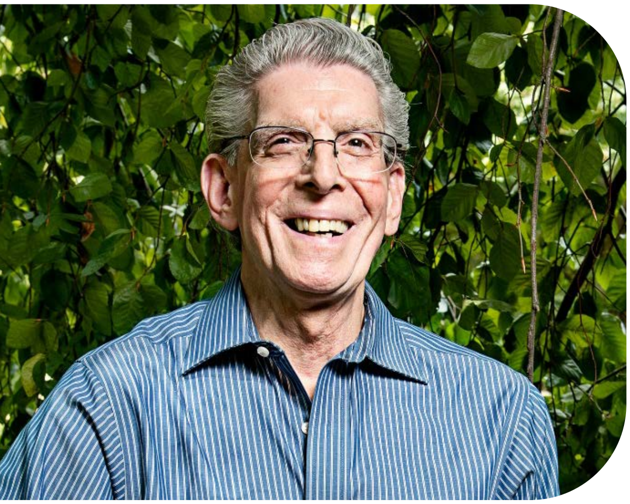
OSK

From Root Cause to Remedy

Can Microgravity Help Prevent Post-Traumatic Osteoarthritis?

By Stephenie Livingston, *Staff Writer*

Alan Grodzinsky sees things differently. When he uses fluorescent dyes to test cell viability in the cartilage tissue he studies, dead cells are supposed to light up red in a field of green live cells. But when he looks at them through a microscope, the colorblind biologist only sees green. These hindrances mean he relies on and gets to know his students more than some professors. It was among them that he saw an unexpected and growing "epidemic" firsthand: early-onset osteoarthritis.



Portrait of Al Grodzinsky.

Al Grodzinsky

"It's an epidemic among young women playing sports like soccer in high school and college," he said. "Totally normal knee, and all of a sudden, you have a joint injury, and within 5 or 10 or 15 years, you develop full-blown osteoarthritis."

Grodzinsky, a biological engineering professor at the Massachusetts Institute of Technology (MIT), studies the lasting effects of traumatic injuries on human joints, the cartilage and tissue structures that connect our bones and enable our movement. He's most interested in post-traumatic osteoarthritis (PTOA), a common condition that affects around 20 percent of the 650 million people worldwide with osteoarthritis. However, no U.S. Food and Drug Administration-approved drugs exist to treat osteoarthritis. While osteoarthritis research and treatment usually focus on older people, Grodzinsky's research is inspired by young people who begin to develop PTOA after injuries, such as ACL and meniscus tears in the knee.

The initiation of PTOA is difficult to study, and delivering medications to cartilage is notoriously tricky. So, doctors only treat the symptoms rather than the underlying causes that drive the disease to prevent long-term joint damage. But Grodzinsky sees a different path toward prevention: addressing its trigger.

When a joint is injured, inflammatory proteins called cytokines are immediately released from a connective soft-tissue membrane called the synovium. When the inflammation dies down, the cytokines stick around and continue to wreak havoc in the cartilage, tendons, and other tissues. Even if the initial injury heals, too often, the tissue is never the same.

To better understand this process, Grodzinsky and his team turned to space. They thought it might simulate osteoarthritis characteristics quicker, with past research demonstrating accelerated bone loss in microgravity. Grodzinsky said it was also an opportunity to understand how spaceflight might affect the initiation of osteoarthritis in astronauts.

Garima Dwivedi (left) and Lisa Flaman (right) prepare samples in Al Grodzinsky's lab.

Al Grodzinsky

The team's International Space Station (ISS) National Laboratory®-sponsored experiment, funded by the National Institutes of Health, developed a microphysiological system—also called a tissue chip—capable of mimicking the earliest events of PTOA's initiation and providing an in vitro platform for testing drugs that may hinder or even block its progression.

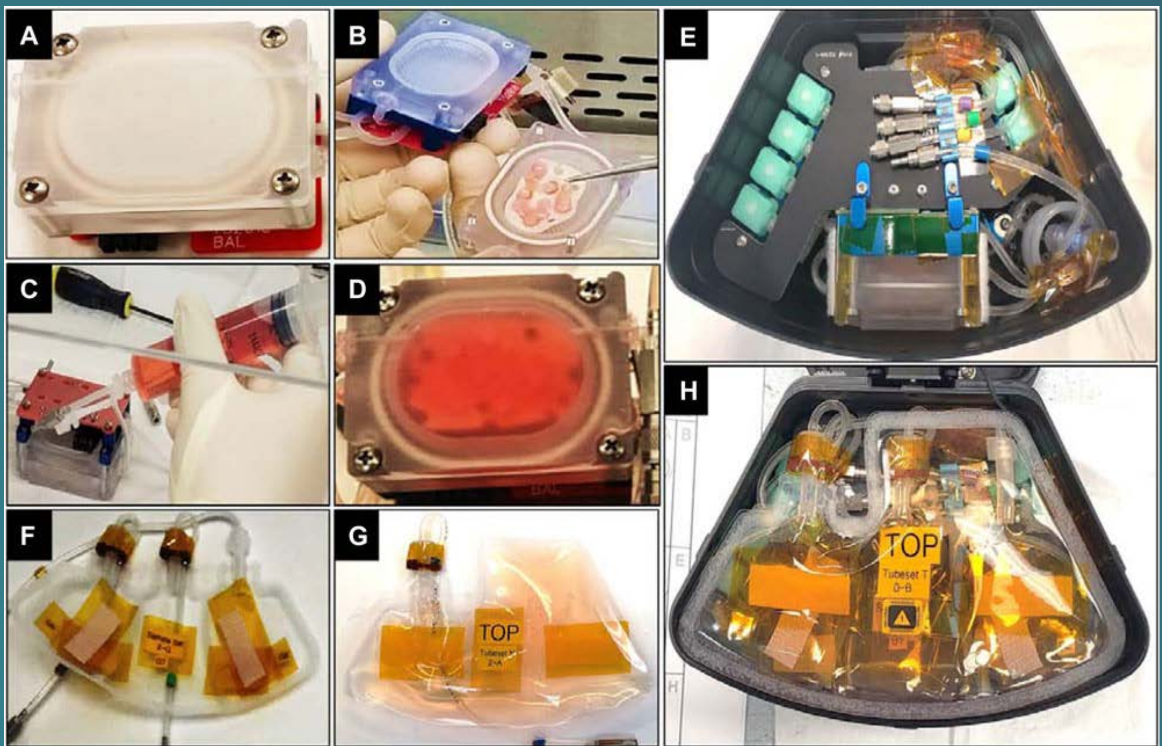
The tissue chips, created using human tissues in a small plastic dish, mime the cartilage, bone, and synovium (CBS) in certain joints. CBS joints, like knees and hips, are the most common sites of osteoarthritis.

The results, published in Frontiers in Space in March 2024, were striking. The researchers found that their tissue chip model successfully reproduced a physiologically relevant joint model with viable and reproducible human CBS cocultures that generated a baseline for PTOA disease and treatment conditions. Specifically, the device could accurately simulate the progression of PTOA and treatment effects with drugs commonly used to treat inflammation and pain in osteoarthritis patients, as well as a drug for tissue growth shown to stimulate cartilage repair. These findings provide valuable insights into the disease process and potential therapeutic strategies.

"This opens up new possibilities for testing drugs and interventions for osteoarthritis and other joint disorders," says Grodzinsky. "It could also aid in developing preventative treatments."

The Long Road From Boston to the Space Station

Grodzinsky anxiously watched the night sky in the early morning hours. After a string of scrubbed launch attempts during the spring of 2019, this time—he hoped—his experiment would travel to the ISS on SpaceX's 17th Commercial Resupply Services (CRS) mission, contracted by NASA.



This figure shows various parts of the experiment, including (B) a tissue card placed inside a culture chamber and (H) nutrients connected to the culture chamber and placed inside the module.

Al Grodzinsky

(Above) Shown here is the cargo Dragon spacecraft packed with scientific experiments, including Grodzinsky's, before the launch of SpaceX's CRS-21 from Kennedy Space Center in late 2020.

NASA

NASA's SpaceX CRS-17 mission launches from Space Launch Complex 40 on Cape Canaveral Air Force Station in Florida in the early morning of May 4, 2019.

NASA

Months earlier, the team decided to use donated human tissue for the study to jumpstart the type of data collection that can lead to human trials and avoid animal trials. Before turning to human donors for his spaceflight investigations, Grodzinsky's lab experimented using cow cartilage, typically used to tackle everything from joint disease to bone cancer. As you walk into his office at MIT, a painting of a cow greets you, and dozens of cow figurines line the shelves.

But when it came time to launch the investigation, transporting live human tissue from a lab in Boston to the space station was a "logistical nightmare," said Lisa Flaman, a former staff research specialist in Grodzinsky's lab. Scrubbed launches worsened the situation, resulting in a need for last-minute tissues.

Grodzinsky added, "Along the way, there were daily and nightly heart attacks as we tried to make sure we could get new donor tissues from donor banks about a week before the rocket went up. When the rocket goes up, you've got to be on it, and you just never know when you'll get a donor."

Finally, at 2:48 a.m., launching against a pitch-black sky, Grodzinsky could clearly see the rocket exhaust plume and the Falcon 9's flame light up the night as it carried his experiment to space. If he missed any colors, he couldn't tell. Flaman remembers the instant relief she felt watching the rocket carrying her project leave Earth.

"We were drinking espresso just to stay awake, and, thankfully, it went off," she said. "It was beautiful—the greatest thing ever. Life-changing. I still watch my little videos from the launch."

Once on station, for several weeks, the automated tissue chips were cocultured inside specialized incubators designed by ISS National Lab Commercial Service Provider Techshot, which is now part of Redwire Corporation. The effects of microgravity on cartilage, bone, and inflammatory cells were monitored using quantitative experimental and computational analyses. Back at MIT, pressure was applied to the cartilage just before launch, providing a realistic PTOA model.

In other words, the experiment took "a hammer" to the cartilage affixed to the bone to simulate an injury. Then, the tissue was put into a culture medium to see if the injured synovium released inflammatory cytokines into the synovial fluid-like media that bathes the cartilage. Next, the platform's microfluidic system delivered nutrients, and in some cases drugs, to the cells, allowing the researchers to test the tissues with and without disease-modifying medications.

A device used during the experiments to apply stress to cartilage tissue, simulating a PTOA-like injury.

Al Grodzinsky

When Grodzinsky's experiment applied a mechanical injury to the cartilage layer, the injured cartilage showed signs of exposure to inflammatory cytokines secreted from the synovium, mimicking the early stages of PTOA. The team was optimistic—the objective, after all, was to develop a system where researchers could detect the earliest events that occur at the initiation of the disease. "So, we thought we were on the right track," said Grodzinsky.

However, problems with the microfluidics system hindered drug delivery in that first experiment. So Grodzinsky's team geared up to relaunch the experiment on NASA's SpaceX CRS-21 in December 2020 with an improved microfluidic system.

With the onset of the COVID-19 pandemic that year, Grodzinsky feared his work would stall. He received special permission from MIT to continue preparing for the launch. With Boston and his institution in shutdown, his team went to Logan Airport in Boston to pick up cadaver knee joints, then drove them back to MIT to do the tissue harvest at his lab before shipping the tissue down to Florida for launch.

"We were racing to get the experiment 250 miles from ground to the space station, but the first 1,500 miles is getting the tissues from Boston to Florida intact," added Grodzinsky.

Despite "lots of ulcers," the second experiment was successfully executed. Over a four- to five-year stretch, the team used tissue from 88 knees from 55 donors between ages 23 and 88 for two launches, two experiments in space, and dozens of control experiments on Earth.

Flaman said that, in the end, it's all about helping patients. "My aunt is a scientist, and looking up to her inspired a lot of my interest in science, and now she has osteoarthritis," she said. "There really aren't enough treatment options for people like her, and that's upsetting because the number of people with this condition is growing every year. It's an unmet need."

Canadian Space Agency astronaut David Saint-Jacques processes samples for an ISS National Lab-sponsored experiment that studies the effects of spaceflight on musculoskeletal disease as part of efforts to develop drugs to prevent post-traumatic osteoarthritis.

NASA

A Joint Effort to Treat Post-Traumatic Osteoarthritis

Translating the results from these space-based experiments to real-world applications on Earth requires a collaborative approach to tackle the most difficult challenges. For example, according to Chris Evans, a cell and molecular biologist with the Mayo Clinic whose team develops genetic therapies to treat joint diseases, injecting medication into cartilage is "a bit like trying to get a drug into a piece of rubber."

Evans, who advised Grodzinsky's experiments and his students' post-ISS research, says cartilage is dense and hard to penetrate, but his and Grodzinsky's labs have figured out some ways to do it. Evans' experiments use viruses to deliver drugs to cartilage, while Grodzinsky has pioneered the use of drugs with a very specialized positively charged chemistry that can penetrate the negatively charged cartilage.

For Grodzinsky's second space station experiment, the team tested the drug dexamethasone (Dex), among others, for its potential to inhibit the cytokines that damage cartilage and joints. However, Evans said the drug has "a bad rap" due to evidence that shows it might inhibit tissue repair.

(From left to right) Al Grodzinsky, Lisa Flaman, and Garima Dwivedi with members of the Techshot team, which is now part of Redwire Corporation.

Al Grodzinsky

"But we've shown that with the right dose, you can have the good effect of stopping these bad molecules from being made without damaging the good ones, so the results are encouraging along those lines," Evans said.

Grodzinsky's team found that the space-tested drugs could "mollify or ameliorate cell death caused by the cytokines," meaning the drugs hindered their blow. The postflight analysis also showed that the space environment enhanced certain inflammatory responses in the tissues under all test conditions. Not just the injury model but even the control.

Was it microgravity? The small amount of radiation? Or is it something that depends on donor variability, a factor that "came out in spades" when the experiment was repeated on Earth with dozens of knee samples, Grodzinsky said.

Grodzinsky wonders if the findings were a "luck of the draw." Did the tissue from two donor knees used in the tissue chips sent to space happen to have this response, or would this happen to anyone's tissue?

But unlike experiments on Earth, "you can't just go back up to the space station a week or two later," he said. So, while the findings are an exciting and promising start, he said further testing in space is needed.

Evans added, "These sorts of experiments had never been done before in this way. Just the opportunity to see what these cells do under reduced gravity is tremendously appealing. It feels like you're working at a new frontier, which is rare."

Evans says this research also opens doors for engineering cartilage in space and better understanding the impact of long-term space travel on human joints. "I mean, there are many interesting possibilities," he said. More directly, the research could result in an off-the-shelf injectable drug to treat damaged cartilage in patients on Earth.

"We've just finished a clinical trial for an osteoarthritis gene therapy, so we're in the groove," said Evans. "And anything that comes out of Al's work, I would certainly elbow my way to the front of the queue to give it a shot in a carefully planned clinical trial."

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