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Astrobee

Preface

When I was little, my dad used to take me to his lab at NASA Ames where I would doodle on his whiteboard and meet the other engineers collaborating on exciting projects. I always loved hearing about what he was working on and learning more about NASA programs in space. This year, I got permission from NASA to return to the Ames Research Center for my own mission of writing this book. I confess, I learned more about my dad's robots in researching them this year than from a decade of family dinner conversations. Now I find more meaning in searching the night sky for the International Space Station orbiting Earth.

As humans keep looking upward, we move outward with our aspirations for space travel. Now, with the complexities present in future projects such as the Artemis program going to the Moon and Mars, we have come to realize the value of having robot companions to help us do things we can't do on our own. Robotic caretaking frees us to explore further.

I watched a crucial step in this process blast off from the NASA Wallops Flight Facility in Virginia on April 17, 2019. It launched a project that has been a leader in developing robotic caretaking. That project is called Astrobee.

Introduction

In April 2019, I watched a rocket ignite and rumble into space. This rocket was special—it contained my dad's robot. My family watched the launch together on a sunny afternoon and simultaneously cheered for the rocket and for my dad. After years of designing, building and testing, Astrobee was finally headed to the International Space Station (ISS).

The Astrobee project includes a duo of robots that are currently in the ISS. Their names are Bumble and Queen, and they are free-flying robots, acting as both a platform for science and helping out with astronaut chores. Their current focus is robotic caretaking, when robots like Astrobee assist astronauts with various tasks, independently maintain systems and address problems. Astronaut time is valuable, and there won't always be astronauts present on space stations to make sure everything is working properly. When that happens, robots like Astrobee will serve as the caretakers. Not much is known about the future of humans in space, but we do know that robots will be a big part of it. Astrobee is paving the way for new technology and innovation leading towards changes in what we imagine is possible in space travel.

Chapter 1: The Launch of Astrobee

Astrobee is a series of robots which fly around inside the International Space Station and do various tasks. They use cameras to "see" their surroundings and compare these images with their internal map of the ISS. Using the features inside the ISS to localize themselves and navigate, they fly around with a fan-based propulsion system. With this mechanism, Astrobee can propel itself in any direction and rotate on any axis. Because of the microgravity environment in the ISS, Astrobee floats freely relative to its surroundings. Astrobees are cube-shaped, a foot in each dimension, with two propulsion modules on the sides and the main components in between, including spaces where different components can be attached. These are called payloads.

"Payload" is the nickname for any company that wants to test their technology in microgravity using Astrobee and its free-flying abilities. More specifically, the payload is the hardware component that the company designs and attaches onto the Astrobee to test their technology (Barlow).

In addition to doing science and jobs for astronauts, Astrobee is easy to maintain by being able to take care of itself and recharge its own batteries. Like a space Roomba, Astrobee flies itself home to its dock, where it backs onto the charging module.

The Astrobee team is based at NASA Ames Research Center in Mountain View, California. Ames has been a government research facility since 1939 back when it was known as NACA (National Advisory Committee for Aeronautics) (*NASA's Ames*). In 1958 it helped blast us into the Space Age and was unveiled as a NASA facility. Since then, it has contributed to space biology, small satellites, and aircraft testing, among other NASA projects. It is home to the largest wind tunnel in the world.

Ames is the former home to a robotic system that preceded Astrobee. SPHERES (Synchronized Position Hold, Engage, Reorient, Experimental Satellites) was in the ISS since 2006 and was only recently phased out (Kanis). There were three robots in service, each about the size of a volleyball. They were used for a similar purpose to Astrobee, to act as a free-flying robot that helps conduct science and leads innovation. SPHERES bots propelled themselves around using the systematic release of CO_2 stored in tanks inside their body, which had to be replaced by astronauts when they ran out. One of the goals of Astrobee was to make it a more updated and sustainable system than its predecessor. It was designed to use rechargeable batteries and the ambient air in the ISS instead of tanks of CO_2.

Meet the Engineers

Jonathan Barlow began at NASA Ames in 2009 and currently works as the engineering lead for the Astrobee team. Before Astrobee, Barlow worked on the SPHERES team, and took what he learned there to create a newer, better robot with Astrobee. He currently enjoys working with Astrobee from the ground, coordinating payloads, doing science in space and helping pave the way for new technology. He says, “There are so many things that people are using Astrobee for that is more than we would be capable of doing on our own. We get to help make it happen… and just helping people to do really cool science is a lot of fun” (Barlow).

Maria Bualat started at NASA in 1987 and moved over to robotics in 1995. She was on the Astrobee team as deputy project manager from creation to launch. Currently, Bualat works on the ISAAC project, using Astrobee to do robotic caretaking and connect different systems and robots. Bualat is happy to see Astrobee’s progress. She says, “It's very exciting… I think of the Astrobees kind of like my kids….watching them fly around on the Space Station is just so great. It's like watching your kids be independent” (Bualat).

Barlow says creating the proposal and design for Astrobee had multiple challenges. “It's only a foot by a foot by a foot, but there's thousands of parts in that thing. And we didn't just build one … we also found it very useful to have units down on the ground to be able to test out what we were going to do in space.”

As the launch date neared, Astrobee had to go through a rigorous testing process to make sure that it was safe to go up to space and be around astronauts. Bualat said there are endless "…considerations you have to take into account when you're in the same space as humans in space… What if we run into a human? what if a human runs into us? – which is actually more dangerous. [Safety is] very challenging." When Astrobee was finally approved, the robots were sent to the ISS to begin their work in space.

Chapter 2: Astrobee Operations & Cooperations

Because the ISS is orbiting the Earth, time is a tricky thing. To help astronauts keep a schedule, it was decided that space would be included in the Greenwich Mean Time zone (GMT). They picked this time zone because of its location as the midpoint of ISS partners, so that the main mission control centers in Moscow and Houston would each be able to cover a half-day shift (Ally). Unfortunately for the Astrobee team at Ames in Silicon Valley, this means that when astronauts are starting their day, it can be midnight for Californians! So for test sessions, which happen about once every 2-3 weeks, the team goes to bed very early so that they can wake up before midnight, set up for the test session, and be ready to begin when the astronauts start their workday. Running the experiment takes a few hours, followed by downloading data from space. Then the Astrobee team can finally sleep.

Because of the pandemic, the Astrobee team, like the rest of the world, had to learn to work from home. Even now, the team will sometimes be running a test session and directing Astrobee from their home offices or kitchen tables. Barlow says, "Yeah, I've gotten to drive robots from my house. From a hotel room sometimes if I was on a trip."

NASA Ames labs help the Astrobee team and the companies they work with to test-run their procedures before they're performed in space. Two Astrobees, identical to the ones on the

ISS, live in the Granite Lab–nicknamed so because of the giant slab of granite which sits in the middle of the room. The table forms the base of a physical, life-size simulation of the ISS module. The two Astrobees here are B# and Melissa, nicknamed Wannabe. The granite slab serves as a reverse hockey table, where the air comes out of the puck. Each Astrobee is on a carriage which has two canisters of CO_2 gas. The air can be systematically released, downward onto the granite, to allow the robots to move around. This simulates a frictionless environment. The physical simulation isn't perfect, however. On Earth, we still have to obey the laws of gravity. In space, Astrobee can rotate on any axis, but in the lab, Astrobee can only move along one plane.

On the body of Astrobee, there are three places called expansion bays where a guest user can plug in their hardware. Here, users can design a payload with their technology, adding on their components. There is no need to reinvent the wheel for companies who want to test in space. Barlow says users "don't really need or want to design their own robot. [They say], 'You guys are already designing this robot. Let's just design a reader to put on Astrobee.'"

There are many examples of the cool science that Astrobee is helping to do. Here are a few.

Gecko: Astobee's current perching arm is part of the basic Astrobee system, and fits into one of the expansion bays. It can unfold its arm and grab onto a handrail if it needs to hang out in a certain spot for a while, to serve as a monitoring camera, for example. One of Astrobee's payloads is experimenting with gecko-inspired material, switching Astrobee's perching arm with a gripper to test different materials' adherence to flat surfaces.

SVGS (Smartphone Video Guidance System): Another Astrobee payload is SVGS, which uses smartphone-level cameras and processes to localize Astrobee and help it navigate in a different way. While Astrobee's localization was designed specifically for the ISS, SVGS is looking at localization in the wider area of outer space, where localization using close surrounding features is far less accurate.

SoundSee: Another user, SoundSee, is using Astrobee to create a panoramic map of the ISS, except using sound. By pointing Astrobee in different directions, they can take readings of the sound and put it together to create a map of the inside of the ISS that shows where the sound is coming from, and how loud, similar to a heat map but with sound. The robotic caretaking element of that is when you can detect changes in the sound that is coming out of a certain area, which could be a potential failure or malfunction. It helps monitor activity inside the ISS.

REALM (RFID-Enabled Automated Logistics Management): REALM is a payload that helps find lost things using RFID tags (Radio Frequency Identification). RFID tags are fairly common on Earth as well as on the ISS. They are small, flat chips that serve as trackers. For example, if you forget to check out a book before walking out of the library, an alarm will sound because of the RFID tag passing by the sensor. On the ISS, they use RFID tags with inventory management. Usually, astronauts have to take an RFID reader around to check inventory, but that is time consuming. REALM worked with Astrobee to help it move around with an RFID reader, and the software manages communication to help Astrobee know where to look. In this way, Astrobee becomes an autonomous RFID reader to help find things that were misplaced, or that floated off and got lost on the ISS.

Other than physical components that are added onto Astrobee, some users are more interested in the software and exposing future engineers to coding. There are two coding competitions that happen yearly, and encourage youth to try their hand at coding a program that Astrobee can perform in space. One, called Kibo RPC (Robot Programming Challenge), is put on by the Japanese space agency JAXA and is targeted for students in high school and college. Another is Zero Robotics, which has two competitions, one for middle school and one for high school students. The students are challenged to write code for Astrobee. “The final rounds are done on the actual hardware in space, which is really cool to see,” Barlow says. “It's exciting for students to be able to… have their code run in space.”

These are some of the things Astrobee has been doing, but what else is in store for these robots? Barlow says he believes Astrobee will continue to benefit us in different ways: “I think Astrobee will always be important in the sense that people are always going to want to test their things in space.” The Astrobee team hopes to work with a lot of different people and companies, and continue learning, improving and innovating.

Meanwhile Astobee continues to help out with chores on the Space Station. On the ISS, there is a periodic safety review requiring an astronaut to pan a video camera across the walls, so that a team can review it for concerns. Now, Astrobee is helping streamline this process and save astronaut time by doing this task autonomously. Instead of a video, Astrobee will create a full panorama, similar to Street View on Maps. Also, if there is something that someone on the ground needs to keep an eye on, they can have Astrobee perch nearby and set a camera on it without any astronauts needing to get involved.

All of these payloads are helping us figure out what we can do with something like Astrobee and this technology in the future. Astrobee plays a key role in furthering robotic caretaking.

Chapter 3: Gateway to the Future

One program that is using Astrobee to look at robotic caretaking is ISAAC (Integrated System for Autonomous and Adaptive Caretaking). ISAAC's goal is to limit human involvement in caretaking by connecting robots like Astrobee to the systems around it. ISAAC is using Astrobee to test and demonstrate this type of technology, and they're all about robot teamwork. For example, they are working on having the two Astrobee bots coordinate with each other to complete a task. After a job is given to one robot, they communicate with each other to delegate certain parts, and update each other on their progress as they complete it.

Barlow says, "[ISAAC is] an attempt to join a lot of these systems that are currently very separate systems. The robots on ISS… don't talk to each other very much. I mean, Astrobees talk to other Astrobees, but there are other free fliers on ISS that we don't have a way right now of communicating and coordinating with them to do a common task."

ISAAC is also trying to increase teamwork between robots and the vehicle itself that they are serving. In a space station or other space vehicle, there are life support systems and monitors that maintain certain conditions. If there is ever an issue, humans have always been the ones to notice the difference in the readouts, identify the source of the problem, and fix it. ISAAC eliminates the human element by helping robots detect and address a problem. For example, if a theoretical sock got stuck on a vent, the various monitors would notice a change in air flow. Robots have the capability to remove the sock, but they wouldn't know what the problem is or how to address it without some direction. ISAAC is the middleman here. It reads the data, notices the difference in air flow, and sends a robot such as Astrobee to find the source of the problem. Astrobee's cameras pick up a sock blocking the vent. ISAAC then directs a robot to remove the sock, and the problem has been addressed. ISAAC helps integrate these robots with the vehicle systems that are already there, so that robots can address any issues without much human involvement.

This kind of communication is important because the farther you get from Earth, the longer the delay is in communication between the robot and its team on the ground. As we go to the moon and beyond, robots being able to communicate and address problems themselves is very important to lessen the dependence on humans on Earth. Barlow remarks, “I think the real value in Isaac is for it to be able to detect and respond to problems that need to be responded to and do that without having a large time delay.”

The technology and innovation we are learning from Astrobee and ISAAC is carrying on into the future of space exploration. Astrobee will be especially important in designing and testing new technology for an exciting new space program that will rely heavily on robotic caretaking.

Gateway is the planned lunar space station, part of the Artemis program. NASA describes Gateway as “a vital component of NASA’s Artemis program [that] will serve as a multi-purpose outpost orbiting the Moon that provides essential support for long-term human return to the lunar surface and serves as a staging point for deep space exploration” (Mars). There will only be humans on this space station for a few months out of the year, so for the rest of the time, maintaining Gateway will be up to caretaking robots like Astrobee.

“The relatively small size of Gateway is possible because the station won’t be crewed most of the time—astronauts may pass through for a few weeks, but the expectation is that Gateway will spend about 11 months out of the year without anyone on board.” (Ackerman).

Gateway’s design includes plans for robots like Astrobee, “including things like adding visual markers to important locations, placing convenient charging ports around the station interior, and designing the hatches such that the force required to open them is compatible with the capabilities of robotic limbs” (Ackerman). This makes problem solving easier for robots to do without the presence of humans.

Barlow says that Astrobee and ISAAC are going to be “in the near future a very important way to test potential technologies for future NASA space stations like Gateway.” Astrobee is an important part of preparing to go to the moon and developing the technology we’ll need for Gateway and further space exploration. Astrobee and ISAAC are showing the world that robots can fix problems and do repetitive, unpleasant, dangerous, or time-consuming tasks.

Bualat is excited for the future. She says, “I think we're proving that robotics has advanced enough that we can even start considering this… For me, that's great because that's exactly what we're trying to do. We're trying to get robots into actual human exploration missions.”

The International Space Station was originally meant to last only 15 years (Atkinson). Its lifetime has been extended by many years, but eventually it will be retired to a watery grave. What comes next? What’s the next step for humans in space?

While operations in lower orbit are being commercialized, NASA is setting its sights farther out into space, to the moon and Mars and beyond. “That's always been NASA's job,” Bualat says. “We'll do the things that are much more distant… that you might not find a profit from.”

Whatever direction we go, Barlow hopes that the international cooperation that has been present in the ISS project will continue as we begin a new chapter of space exploration. “It's been a great facility. It's been a great collaboration between a lot of countries. I hope that if they do decide to replace it, whatever replaces it has that same spirit of cooperation, trying to include as many countries as they can" (Barlow).

He believes that both the ISS and Gateway provide unique learning opportunities as we continue progressing in the space industry and as humans (and robots). "By facing the challenges, we push ourselves to learn more and do more… And I think that benefits us as humans because we are stretching our capabilities and having to design new things… I hope that continues. I think it's a benefit for us to work together towards a common goal. If we didn't have space exploration as a common goal, I don't know what would fill that gap" (Barlow).

Conclusion

One could argue that it has been many decades since human exploration in space made any significant progress. When we think of space travel, it often feels like something from the far-distant future. Gateway will be the first major human push beyond low orbit in more than 50 years. With Astrobee and ISAAC, we witness current projects demonstrating technologies that will be essential for Gateway's long-term success. In this way, they change the way we imagine space travel. Humans are creating robots that can support them and their ingenuity in moving forward to the edges of their curiosity. As Bualat says, "there's agreement in the agency that, yeah, robots have their part in human exploration. And I think what we're doing… is trying to demonstrate that yes, robots can do these things." Astrobee is an essential stepping stone in the path to successful space missions in the future, maintaining human presence farther into the reaches of space. Humans have limitations, but as we create robots that overcome these limitations, our possibilities become limitless.

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