Robert Behnken *Furthering the Exploration Frontier*

Robert L. Behnken (MS '93, PhD '97) has been serving as the 14th chief of the NASA Astronaut Office for the past two years. He is overseeing the day-to-day operations of the Astronaut Office as an exciting new chapter in space exploration in the post-Shuttle era begins: one that is expected to feature the inaugural flights of U.S. Commercial Crew vehicles and the first piloted voyages beyond Earth orbit in almost five decades.

ENGenious had the opportunity to interview him at the Johnson Space Center, where he also suited up with fellow Caltecher and astronaut Stanley G. Love to carry out a practice contingency spacewalk in the NASA Neutral Buoyancy Laboratory.

ENGenious: What inspired you to become an engineer?

Behnken: My father is a construction worker, and when I was young I saw firsthand a lot of the projects that he worked on. Whether it was pumping stations, pipelines, or something else, I was interested in all the machinery being constructed or that made the construction possible. But since I also spent some time working as a construction worker in the summertime in St. Louis, I also learned that it might be nice to have a job where air conditioning was at least sometimes available! At that age, I could do it and it paid relatively well so it was worth the effort, but as a lifelong career, it can be quite a bit harder on your body than being an astronaut.

ENGenious: How has your Caltech education influenced you?

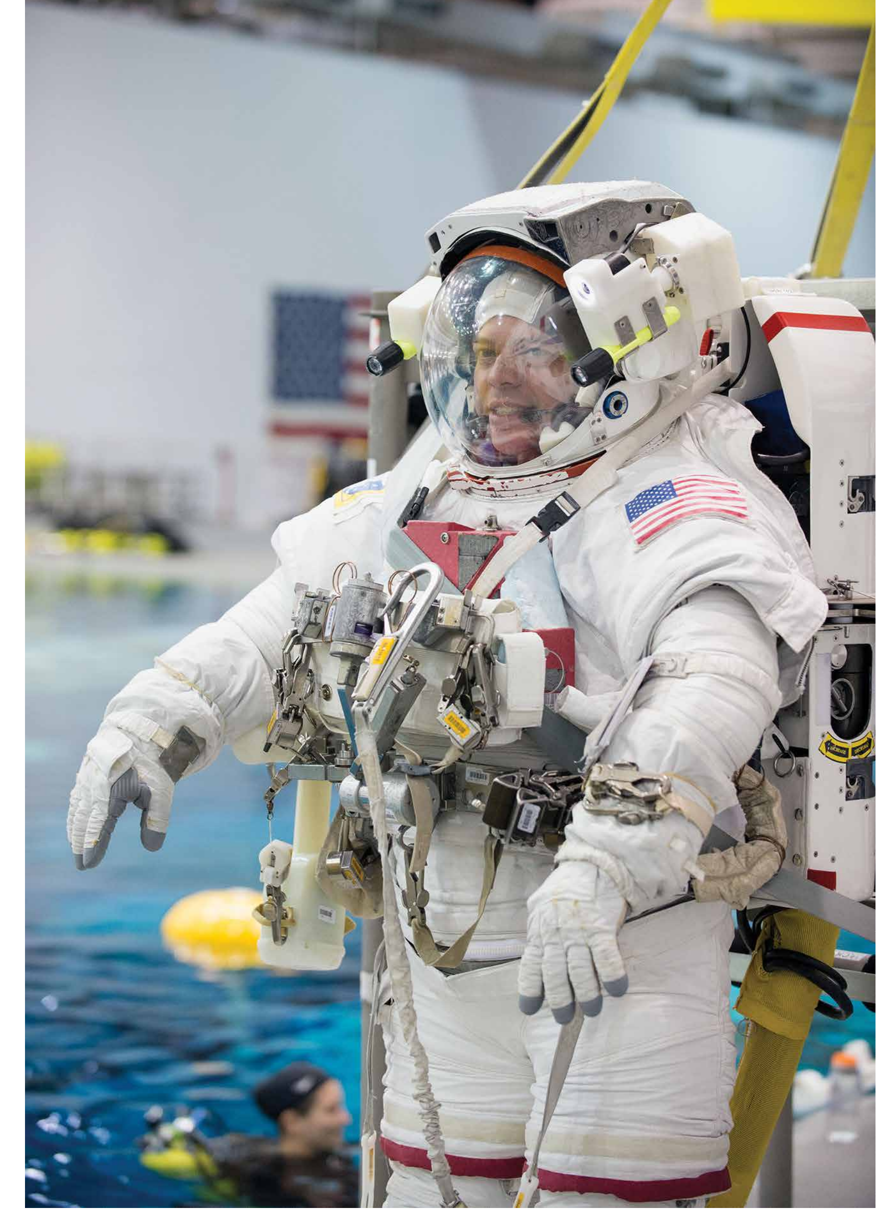
Behnken: My graduate advisor was Professor Richard Murray, and he espoused a hands-on approach combined with a strong theoretical background. That's probably the thing that's been the most valuable, being able to translate the mathematics or theory into real things. For example, when we go out for a spacewalk, someone has to understand and then manage the risk associated with the theoretical charging levels on a large structure that's moving in low Earth orbit. We need to understand the physics behind this and what the repercussions are going to be. Practically, that translates into something very real: What is the risk of electric shock to the astronaut inside the space suit and how do we best manage that?

ENGenious: How does the space suit protect you? How long does it take to be fitted for one?

Behnken: The suit itself is very much an exoskeleton for your body. It protects you from outside temperature extremes and from being in a vacuum in space, clearly a place that we human beings are not designed to operate in. It's very important for that exoskeleton to be the same size as you. It's a rigid structure and as you move your body inside of it, if the suit and your body aren't identically sized, you could stretch or compress an elbow, a shoulder, or some other joint in a way that it shouldn't be. We put significant effort into ensuring an exact fitting so that the person who puts on the suit does it in a safe way. As for how long it takes to get fitted for a suit, it depends on how close your body is to the suits and pieces of suits that have already been built. To produce a set of gloves for a specific individual takes well over a year. I've been an astronaut for quite some time and I don't yet have my own set of gloves because there are some that are close enough to my hands that I can successfully operate in them. They still injure my hands somewhat; I did lose fingernails during the training for and execution of the spacewalks on each of my missions.

ENGenious: Spacewalks are so glamorized, few of us think about this level of detail and this much potential danger with just the suit. What else could happen?

Behnken: The spacewalking suit has an elegant mechanical engineering design; it doesn't need power to provide basic life support. If the suit were to lose electrical power, it would still provide breathing air. You could still get some cooling out of it. You could still make it back inside the space station. With power, the suit of course works significantly better. During a recent spacewalk, however, a failure in the suit pumping system caused the water used for cooling to accumulate in the helmet of a crewmember who was outside the space station in the vacuum of space. Clearly you can't take the suit off outside, and so he and his partner rushed back inside to remove his helmet. In the future, our crewmembers are all prepared with more options in response to this failure. One is to turn the pump off that moves the water around. There's also a snorkel that will allow you to breathe from another pocket of oxygen inside of the suit. There is also now a system for absorbing water should it pool in the helmet, so that it can't accumulate on the spacewalker's head. Losing electrical power or accumulating water in the helmet are just two of the many things that astronauts are prepared for going "off nominal" during a spacewalk.



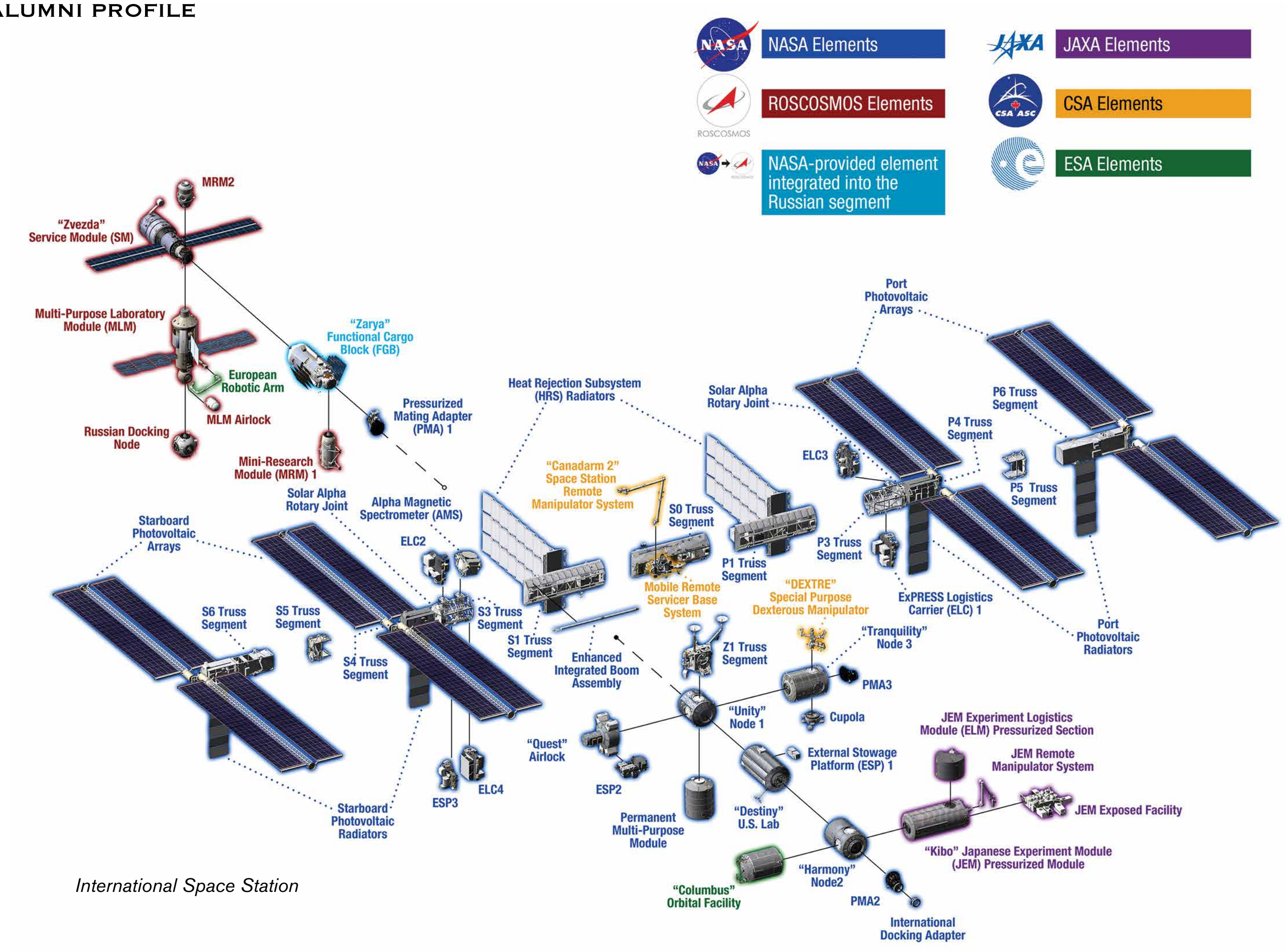
Robert Behnken preparing for a practice spacewalk in the NASA Neutral Buoyancy Laboratory.

ENGenious: How has your Caltech experience helped in your career?

Behnken: One of the things that was really brought home to me at Caltech was the importance of taking a jack-of-all-trades approach to problem solving. When it came time to do research, we didn't have the mindset of being a specialist who only looks at one little area. If you needed to learn to write computer code, you learned how to write computer code. If you needed to build an experiment, you built an experiment. You addressed the problem from all directions and picked up whatever skills you needed to go forward on it. Those I learned from at Caltech had the perspective that you're going to earn one advanced degree, and while maybe it's in mechanical engineering, that shouldn't limit you. If you need to learn electrical engineering to do your research, if you need to learn physics—learn those things. The degree you had earned shouldn't constrain your ability to learn in any area required to address your research.

ENGenious: How would you describe your professional contributions?

Behnken: We astronauts are often just a small piece of a much larger puzzle. The astronaut on board the International Space Station (ISS) or



International Space Station

who repairs the Hubble Space Telescope isn't the principal investigator for the research that will be accomplished. During my space missions, I was primarily a construction worker. I assisted in the installation of four different modules on the ISS: a Canadian robotic manipulator; a part of the Japanese laboratory; a living-quarters module; and the Cupola, a windowed portal for observing robotics operations that also provides spectacular views of Earth. Clearly my contribution during spaceflight was very much in the realm of facilitating others' ability to do research. Currently, as chief of the Astronaut Office, I facilitate other people being successful at carrying out the role I just described. We're primarily operators of the ISS and the hands for the investigator. In that role, it's very useful to have an educational background like I have from Caltech. If I need to know about combustion on a given day, I learn the details of the combustion experiment as quickly as possible and to the level that I need to in order to do what the investigator needs me to do. Tomorrow when I'm scheduled to execute a control systems experiment, I learn the details to the level needed to effectively accomplish the goals of the scientist who designed the experiment. As the chief astronaut, my goal is to make sure that I've created opportunities with training and education so that the astronauts are ready when they have the opportunity to be the hands for those scientists. More important than the glory and excitement, astronauts need to make sure that they are always focused on this responsibility. It's about furthering the envelope of understanding with ISS research. It's about furthering the exploration frontier. Those are not personal accomplishments. They're humankind's accomplishments. If you don't have that perspective, you may be very frustrated as an astronaut; there simply isn't time for you to be a true investigator at the center of every experiment.

***ENGenious*: How can Caltech medical engineers assist astronauts and the astronaut program?**

Behnken: Historically, the space program has been a driver for many of the medical devices that eventually became commonplace. Every time we do a spacewalk, we are instrumented to have our electrocardiogram (EKG) monitored on the ground throughout the entire event. That type of physical monitoring capability is an area that we would definitely like to expand.

It is extremely cumbersome to bring samples back from the ISS. As we continue to move toward doing more biological science on board, if for example monitoring devices become implantable, we'd certainly be interested in taking advantage of them. Devices that allow us to not need to return samples would be hugely beneficial, as well as medical examination equipment that crewmembers can use on their own with limited coaching from a ground team. For example, we regularly do a significant number of eye exams in orbit now because it's been discovered that the geometry of astronauts' eyes are changing during prolonged exposure to the ISS environment. It's unclear if it's due to a zero-gravity-induced fluid shift that increases intracranial pressure, carbon dioxide in the environment changing the chemistry of the blood, or some other phenomenon resulting in pressure on the back side of the eye and changing the shape of the eye and impacting the optical nerve. So we have new equipment on board to measure this phenomenon and provide the data to the investigators multiple times throughout the mission (in the past we only had the pre-flight and post-flight measurements). This is one of many biological phenomena that we need to address, many of which are resulting in new, exciting areas of research. There are of course engineering hardware challenges as well, at least as numerous as the medical challenges.

***ENGenious*: How are astronauts monitored to understand the impact of space flight?**

Behnken: We all receive extremely thorough physicals annually. We have a significant number of astronauts who flew Shuttle missions, and they came back in pretty good shape after days or weeks in space, but for longer-duration missions it's becoming more apparent that there are long-term health consequences. Causes for these health impacts include radiation exposure, the fact that your skeleton is not being loaded in the same way as when you're on the ground, or one of the other phenomena associated with zero gravity. The skeletal changes are particularly interesting; astronauts after long-duration missions have structural differences to the interior of their bones, even though their overall bone density may remain relatively constant. Our astronauts haven't yet aged enough for us to see what the full repercussions of these changes will be. How much monitoring of these astronauts as they age is appropriate is an active area of discussion. One of the intents of such monitoring would be to truly understand what the impact of the space flights on the human body actually is. It's very much a statistics problem because the physiology of humans is so diverse, and it will take more data points—i.e., more astronauts who have flown these missions—in order to develop these statistics. It will also take an astronaut's lifetime for us to understand if their eyes completely recover or regress, if their bone health is impacted as they go through the normal aging process, or if some other phenomenon is significant.

***ENGenious*: What's next for human space flight?**

Behnken: We're hopeful that the next phase of acquisition for U.S. crew vehicles that will fly astronauts back and forth to the ISS will be under way very soon. Currently we expect to see a U.S. crew vehicle arrive at the space station in the 2017–2018 time frame. We also have programs under way to provide the capability to return humans to lunar orbit or to travel deeper into space. Those are a bit further out, closer to 2020 time frame.

***ENGenious*: What will it take for humans to travel deeper into space?**

NASA astronaut Karen Nyberg, Expedition 36 flight engineer, conducts an ocular health exam on herself in the Destiny laboratory of the Earth-orbiting International Space Station.

Behnken: I mentioned the eye phenomenon that astronauts are facing right now. There are other areas from a physical-phenomenon perspective that need to be managed in preparation for a longer stay in space than we have on board the space station. The biggest challenge is the radiation environment, and as you can imagine, there are many ways to address this challenge. Adding shielding that physically protects you from that radiation environment is one solution, but spaceships can only be so big and so heavy before they are unaffordable or impractical for other reasons. There's also a solution that takes a longer view and focuses on healing the cancer after it begins to develop. That solution could help lots of people, not just astronauts in space. A similar but a nearer-term solution is to focus on early detection of the cancer or other impacts of radiation so you have a better chance of effectively dealing with them. It's interesting because, whether it's medical professionals or physicists or engineers, there's room for everyone to contribute to the ability of humans to travel deeper into space. ENG

Robert Behnken is chief of the NASA Astronaut Office.

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