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NASA Technology Dawns a New Era for Spacecraft Utility

On a hot summer day at NASA's Goddard Space Flight Center, NASA Robotics Technologist Brian Roberts guides visitors on a tour of the Robotic Operations Center, accompanied by an orchestra of buzzes and whirs as the robots in the lab show off their capabilities.

"Just like sports teams practice before they play a game, we practice with robots, as well," Roberts shares.

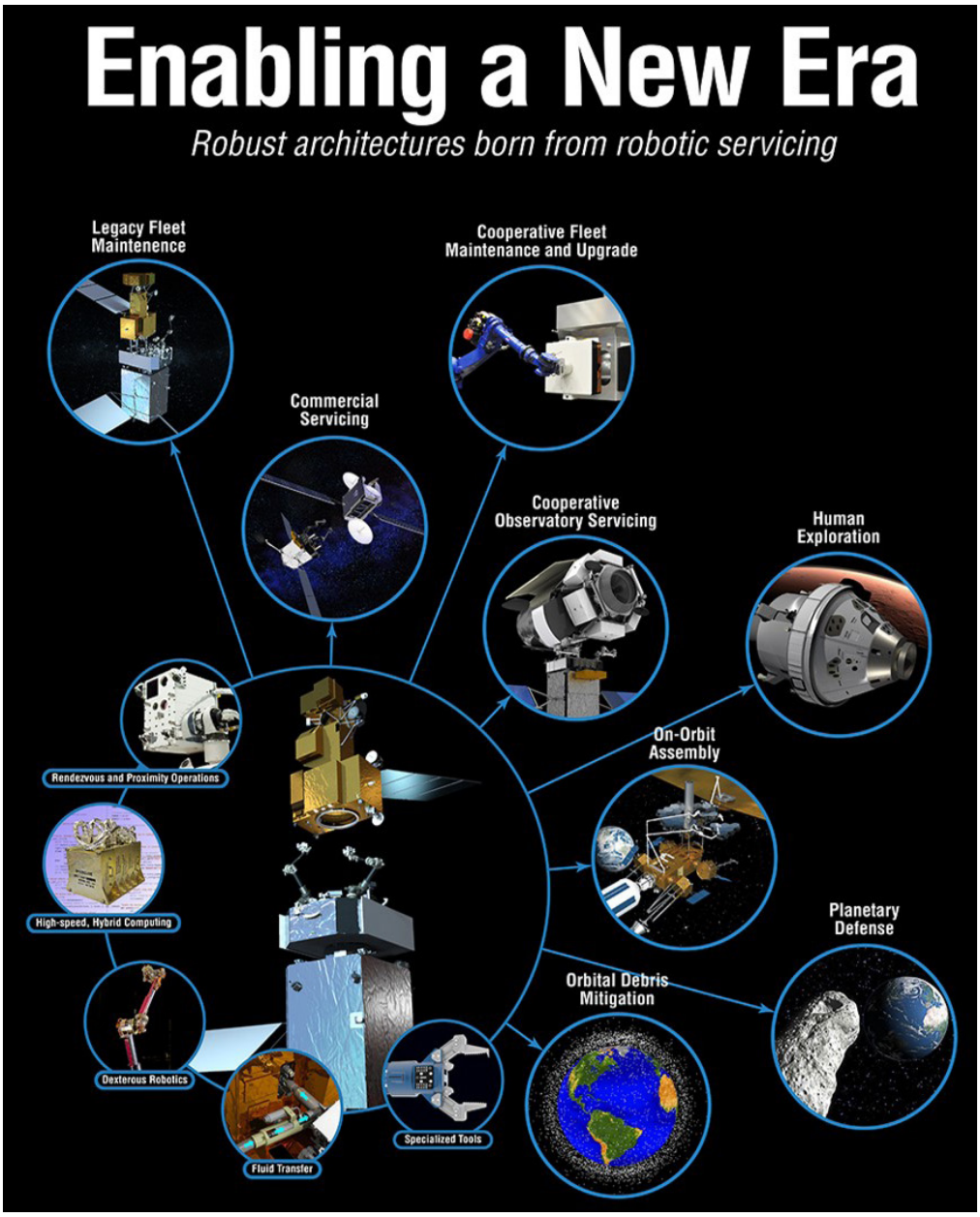
Roberts is part of the Satellite Servicing Projects Division (SSPD), a NASA Goddard team dedicated to ending the era of "one-and-done" spacecraft through robotic servicing missions. In-orbit satellites can gain a second life by receiving new fuel and repairs from robotic spacecraft, which are currently in development at Goddard.

The Restore-L mission, scheduled to launch in 2022, will send a robotic spacecraft to refuel a satellite not designed to be serviced — Earth science satellite Landsat-7 — for the first time ever. The mission will utilize a number of new technologies to autonomously navigate to, rendezvous with, grasp, refuel and release the satellite.

As SSPD manages a growing portfolio of technologies, NASA transfers those technologies to interested U.S. companies, ultimately helping to jumpstart a competitive satellite servicing market. The Restore-L mission will involve six new technology categories: autonomous, relative navigation system; servicing avionics; robotic systems; tool drive systems and tools; fluid transfer system; and cooperative servicing aids.

Within the pages of this pamphlet, we've highlighted how to work with Goddard's Technology Transfer Program and effectively take advantage of NASA's technology resources. Additionally, we've included a list of patented and patent-pending technologies related to satellite servicing and available for licensing.

In the coming decades, robotic servicing is expected to bring about the dawn of a new era of extended spacecraft utility, saving billions of dollars in satellite manufacturing costs. To get there, NASA and industry will need to work together and facilitate the transfer of technology to make this vision of the future a reality.



Technologies developed for and demonstrated by Restore-L have numerous applications beyond satellite servicing and can help enable future missions.

To learn more about technology transfer at Goddard, visit https://partnerships.gsfc.nasa.gov *or* https://technology.nasa.gov.

To learn more about the Satellite Servicing Projects Division, visit https://sspd.gsfc.nasa.gov.

On the cover: Restore-L will rendezvous with, grasp, refuel and relocate a government-owned satellite to extend the satellite's life.

Innovator Interview: Brian Roberts

Satellite servicing at NASA Goddard Space Flight Center began with a 1984 Solar Max repair mission, followed by five missions to service the Hubble Space Telescope. After launch in 1990, Hubble's primary mirror was found to be flawed, producing only blurred images. The first Hubble Servicing Mission in 1993 demonstrated the immense value of servicing when the team installed corrective mirrors, fixing the problem and allowing Hubble to produce decades-worth of spectacular space images. Subsequent servicing missions allowed for other repairs and technology upgrades.

Robotics technologist Brian Roberts first met the Hubble servicing team when he was a graduate student at the University of Maryland, College Park. Impressed with their work, he stayed in touch with the group, ultimately joining the team after graduation and staying on through the team's expansion to satellite servicing.

Now, Roberts leads a dynamic team of software developers, roboticists and technicians in building a robotic arm with seven degrees of freedom, just like a human arm. The Restore-L mission will use the robotic arm to service Earth science satellite Landsat-7 and demonstrate the enormous potential of robotic refueling in space.

"It's exciting to see people realize that satellite servicing is real and can actually happen," Roberts says. "It's not just science fiction." Roberts' interest in space and engineering began early – his father worked as a draftsman, and growing up, Roberts made his own technical drawings on a large drawing board in the basement of his house. In 4-H, he built model rockets and launched them in his parents' backyard on the Fourth of July.

"Occasionally they'd wind up in trees or down the road and show up in the mail the next day," he laughs.

During his senior year of high school, Roberts wrote a paper on NASA's Space Shuttle Program for an English class, which further piqued his interest in space. He ended up studying aerospace engineering at Case Western University, doing summer internships at various NASA centers and landing a final internship at NASA Goddard.

"I was convinced Goddard was the place I wanted to be, because they did do so many cool things there," he says.

Roberts says he appreciates engineering and robotics in particular because he likes solving problems and figuring out how things work. Although he no longer works on the lab floor tinkering with robots, he manages the robotics team to ensure each part of the project succeeds.

Roberts says he enjoys seeing a group of experts come together to tackle various elements of the project, each person specializing in a different discipline. After the Robotic Refueling Mission launched in 2011, the team watched as one of the International Space Station robots successfully demonstrated satellite servicing technologies while mounted to the station. He says the success of that mission sticks out in his mind as one of his most exciting moments while working at NASA Goddard.

"It was really neat to see the robot perform operations in space that we had practiced here on the ground," he adds.

As Roberts and his team have their sights set on the Restore-L mission, they look forward to seeing the promise of the satellite servicing industry realized. As technology demonstrations progress, Roberts says that NASA will continue to transfer technology to commercial partners, and he's excited to see what the future holds.

"We have some really strong partners working with us using NASA's expertise to augment the work they're doing," Roberts says. "NASA can only do so much, but by having companies working with us to build satellites and incorporate satellite servicing as part of their routine, it will become the new norm. I'm really excited to see that happening in the coming years."

Trending Technology: The Cooperative Service Valve

If you've ever tried to charge a cell phone with the wrong connector cable, you know that compatibility is key. This holds true for on-orbit robotic servicing – in order to transfer liquid fuel into a satellite, a robotic spacecraft needs to access the fuel tank of the satellite by connecting to its fuel valve. If the spacecraft and satellite aren't compatible, the task becomes much more challenging.

With servicing technologies showing promising advancements, experts at NASA's Goddard Space Flight Center envision a future when satellites are built ready for on-orbit servicing and fully compatible with robotic tool interfaces. To help facilitate this, Goddard technologists developed the Cooperative Service Valve (CSV).

"Standard fuel valves that are used on satellites today are not designed to be serviced on-orbit," explains Charles Bacon, mission system engineer in cooperative servicing. "The CSV allows the servicer's refueling tool to more easily interface with the valve of the spacecraft in need of servicing."

Currently, in order to service satellites already in space, robotic spacecraft must overcome a number of tricky barriers. Since present-day satellites were not built with servicing in mind, their valves require the removal of numerous caps, wires and layers of insulation blankets, none of which are robot-friendly.

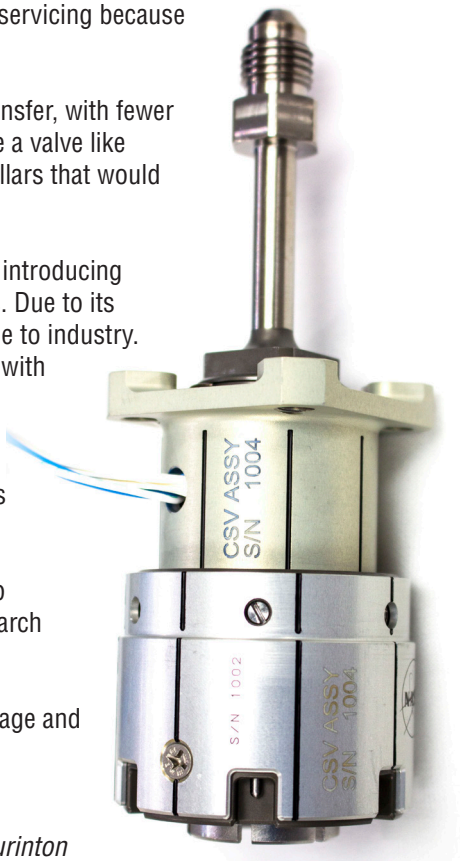
"It's definitely not a simple task," says Hans Raven, lead mechanical engineer for the CSV. "You have to cut through blanket in order to get to the valve, and there's no easy way for the robot to carefully remove the tape holding it down."

For the first time in history, Goddard has developed a suite of technologies to overcome these challenges for the Restore-L mission, which will refuel a satellite not designed to be serviced. Restore-L's client for this demonstration mission is the Earth science satellite Landsat-7. Some of the challenges these technologies will seek to overcome are unique to the satellite's interfaces, but others are applicable to multiple satellites.

"Every operation adds more risk to the overall mission," Bacon says. "The expense is greater for the servicing because you need extra tools to perform these sub-operations, and it takes a lot longer, too."

To eliminate unnecessary sub-operations, the CSV is designed to deliver faster, more efficient fuel transfer, with fewer tools. If refueling satellites via robots becomes an established practice, every satellite can incorporate a valve like the CSV so they can be refueled as needed, extending the life of the mission and saving billions of dollars that would otherwise be spent building and launching replacement satellites.

Goddard is transferring the CSV to industry, fostering innovation in the arena of satellite servicing by introducing new technologies and prompting companies to develop new capabilities based on these technologies. Due to its cooperative design, the CSV makes an excellent "ambassador" technology by being easily transferable to industry. Ideally, these collaborations will result in the creation of an industry standard for satellite fuel valves, with manufacturers adopting a single, compatible interface.



Successful technology transfer plays a key role in the future success of on-orbit servicing. "Having all servicers compatible with each other would make it easier to add servicing to the space operations infrastructure," Bacon says.

To help build this culture of collaboration, NASA Goddard has hosted a series of industry days to help connect companies with Goddard's servicing technologies. Additionally, companies have signed research licenses with NASA Goddard to further explore how to utilize the CSV.

Bacon and Raven say the growing satellite servicing industry will benefit from starting on the same page and consolidating their efforts by working together.

Companies interested in licensing servicing technologies can contact Technology Manager Brooke Purinton (brooke.purinton@nasa.gov) or Technology Manager Kerry Leonard (kerry.w.leonard@nasa.gov).

Five Ways to Work with NASA Goddard's Technology Transfer Program

The Technology Transfer Program at NASA's Goddard Space Flight Center is part of the Strategic Partnerships Office, which connects Goddard's world-class technologies, capabilities and expertise with industry, academia and other government agencies. Goddard technologies can provide the foundation for a new business, add products to a company's portfolio, or complement and enhance existing products.

There are many ways you can work with Goddard's Technology Transfer Program and take advantage of the technology resources available to you, but the following list of options is a great place to start.

1. **License NASA Goddard technology.** If patented or patent-pending technologies listed in this pamphlet meet your technology needs, work with the Technology Transfer Program to begin the licensing process.
   a. First, get in touch with a Goddard technology manager to troubleshoot your requirements and agree on a suitable technology to fit your requirements.
   b. Then, fill out an application through NASA's Automated Technology Licensing Application System (ATLAS).
   c. After submitting your application in ATLAS, a staff member from Goddard's Technology Transfer Program will get in touch for next steps.

2. **Apply for Startup NASA.** Startup companies can take advantage of additional benefits by participating in our Startup NASA initiative. NASA waives licensing fees for participants, removing some of the barriers encountered by tech entrepreneurs looking to secure intellectual property rights. Learn more about this opportunity at https://technology.nasa.gov/startup.

3. **Look at our online software catalog.** Goddard has 181 programs available online to fulfill your software needs, free of charge. Categories include business systems and project management, environmental science, and data and image processing. To request NASA software, go to software.nasa.gov and select the "Request Software" button to begin the process. Some codes and mobile apps offer direct download, while others require a completed request form for processing through Goddard's Software Release Authority. For assistance completing software requests, email gsfc-softwarerelease@mail.nasa.gov.

4. **Sign a Space Act Agreement.** Established in 1958, the National Aeronautics and Space Act allows NASA to form Space Act Agreements (SAAs) with various partners to make progress on shared goals. SAAs facilitate advancements in numerous industries – for example, in 2016, Virginia Electric and Power Company signed an SAA with NASA Goddard to allow researchers to study the effect of Geomagnetically Induced Currents (GICs) on the U.S. power grid. SAAs can play a role in license agreements by allowing Goddard scientists to support technology transfer, as long as it doesn't interfere with their job responsibilities. This arrangement also permits partners to reimburse Goddard for its time.

5. **Leverage your Small Business Innovation Research (SBIR) grant.** Companies with SBIR grants or government contracts can utilize Goddard technology to enhance their research objectives. Your contracting officer or contracting officer representative can assist you in adding new technology to your list of Government Supplied Equipment.

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To learn more about the Strategic Partnerships Office, please visit https://partnerships.gsfc.nasa.gov. *To connect with a technology manager, please email* techtransfer@gsfc.nasa.gov.

Featured Servicing Technologies and Patents

3-D Plus Programmable Read Only Memory (PROM) Emulator Board
Patent Pending

A Method of Capturing a First Free-flying Spacecraft with a Second Free-Flying Spacecraft
Patent number: 7,513,459
Patent name: Method and associated apparatus for capturing, servicing and de-orbiting Earth satellites using robotics

A Method of De-orbiting a Free-flying Spacecraft
Patent number: 7,293,743
Patent name: Method and associated apparatus for capturing, servicing and de-orbiting Earth satellites using robotics

Space Robotic System for In-Space Servicing of Unmanned Spacecraft
Patent number: 7,240,879
Patent name: Method and associated apparatus for capturing, servicing and de-orbiting Earth satellites using robotics

A Servicing Vehicle for Servicing Other Free-Flying Spacecraft
Patent number: 7,438,264
Patent name: Method and associated apparatus for capturing, servicing and de-orbiting Earth satellites using robotics

Advanced Tool Drive System
Patent Pending

Client Berthing System/Mechanism
Patent Pending

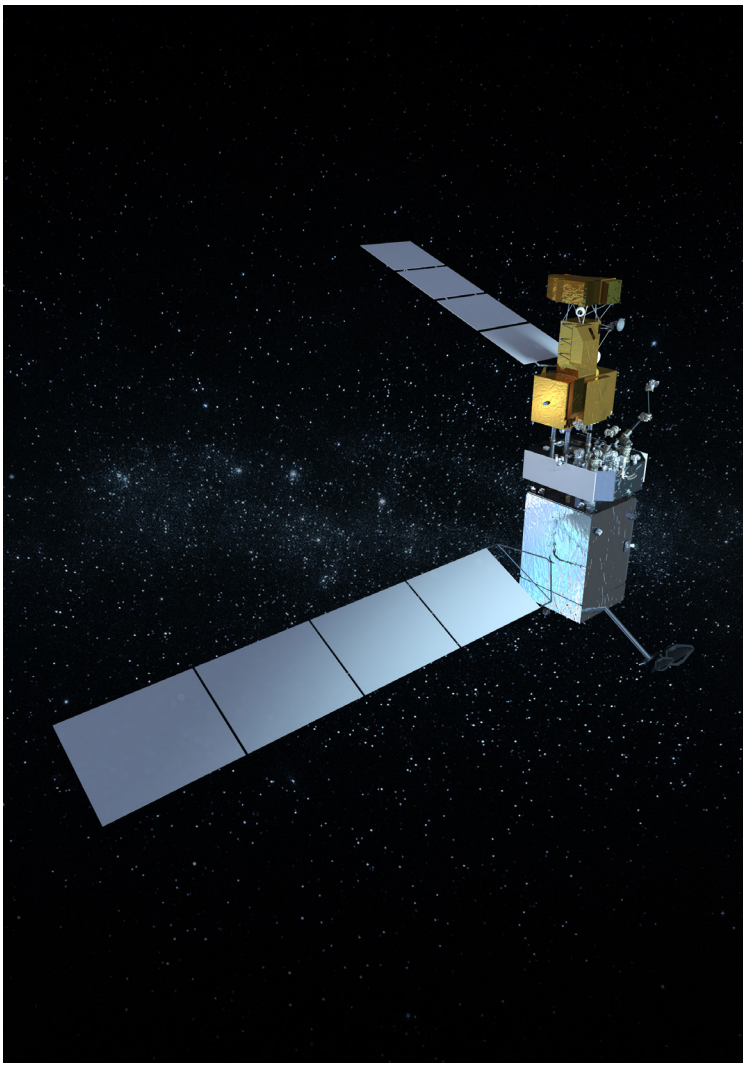
Cooperative Service Valve for On-orbit Cooperative Satellite Fueling
Patent Pending

GPS Navigation System/Navigator GPS Receiver
Patent number: 7,548,199
Patent name: Radiation-hardened fast acquisition/weak signal tracking system and method

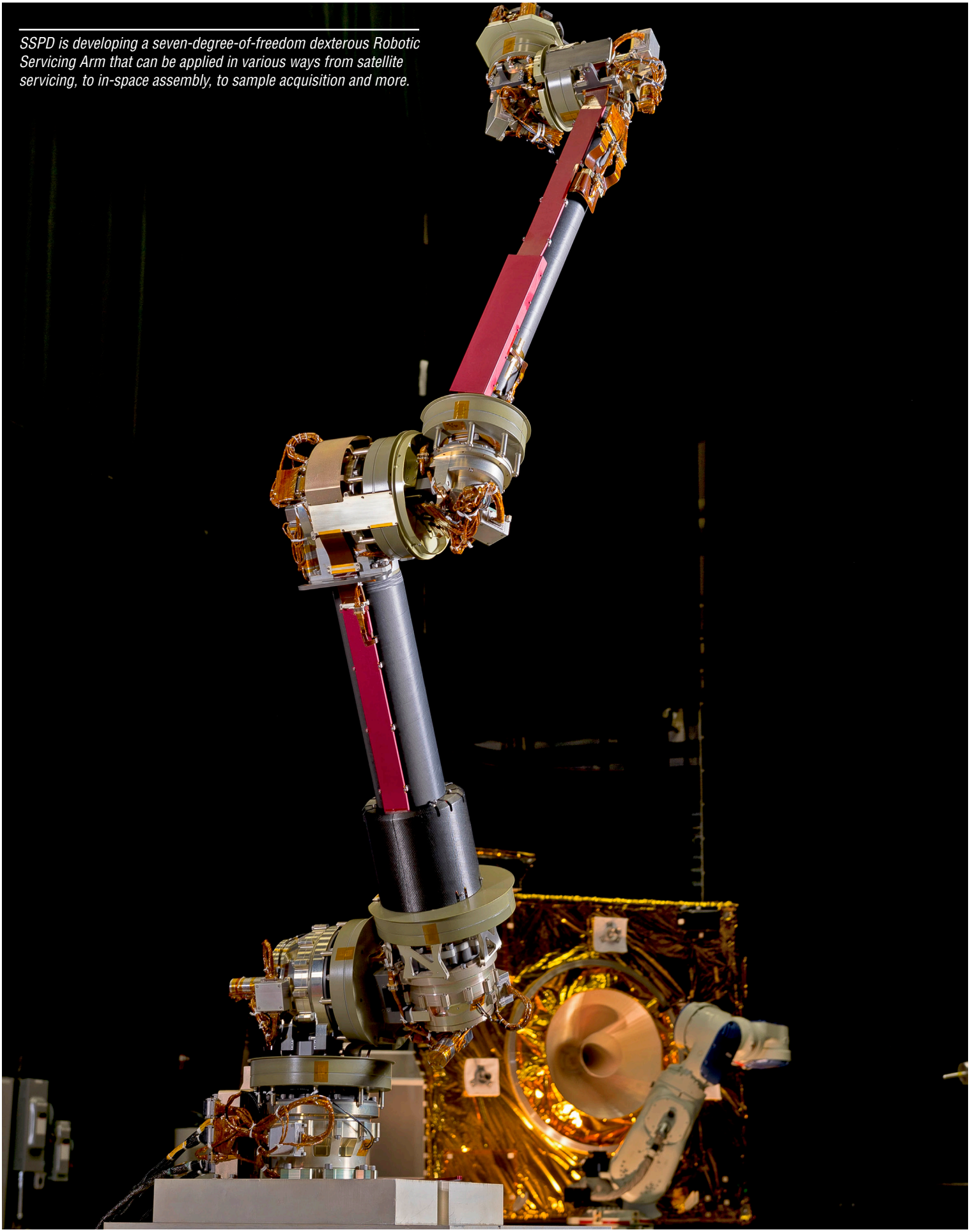
SpaceCube Demonstration Platform
Patent number: 8,484,509
Patent name: Radiation-hardened processing system

SpaceCube v. 2.0 Micro
Patent number: 9,851,763
Patent name: SpaceCube v.2.0 micro single board computer

SpaceCube v. 2.0 Processor Card, Engineering Model
Patent number: 9,705,320
Patent name: Apparatus for controlling low power voltages in space based processing systems

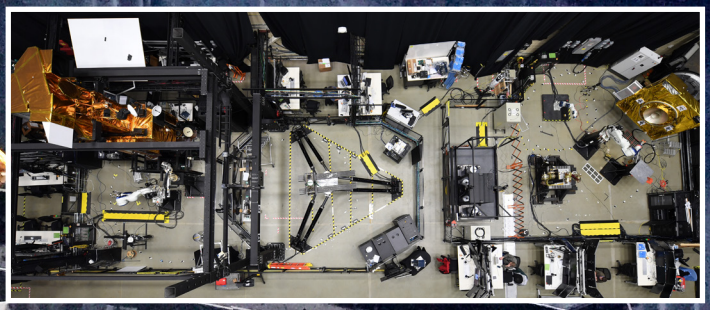


Restore-L will demonstrate various "firsts" including the first ever autonomous rendezvous and grapple of a satellite not designed to be serviced.



SSPD is developing a seven-degree-of-freedom dexterous Robotic Servicing Arm that can be applied in various ways from satellite servicing, to in-space assembly, to sample acquisition and more.

The Robotic Operations Center acts as an incubator for satellite servicing technologies that will allow NASA to repair, refuel and upgrade spacecraft. In this lab, engineers test robotic capabilities in space-like conditions before they are put to action in orbit.



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