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Acquisition reform: Real solutions

Shifting fortunes for commercial X-band

A conversation with Eddy Pieniazek

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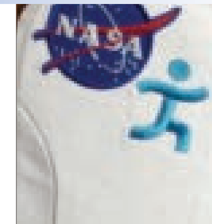


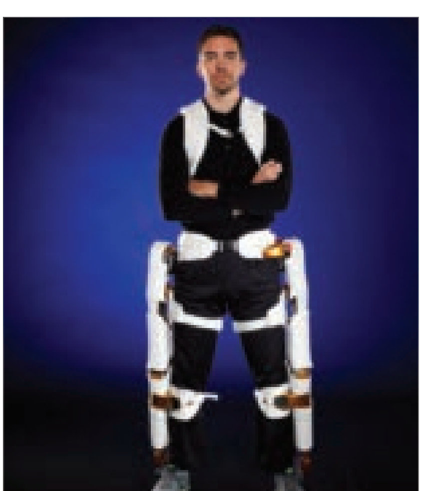
Comfortable in your own exoskeleton

On the outside, NASA's X1 exoskeleton looks like a set of high-tech leg braces with a harness running up the back and over the shoulders. A computer inside a pouch tells the device's motorized joints how much resistance to apply as the wearer moves his or her legs. Sophisticated algorithms match the complexity of human locomotion.

Engineers at NASA Johnson and the Florida Institute of Human and Machine Cognition designed and built the $1.3-million X1 to catch the eye of their colleagues in NASA's Space Life Sciences Directorate, which last August was renamed the Human Health and Performance Directorate.

A flight version of the device could become a new workout tool for astronauts aboard the space station or on the long trip to Mars and back. At least, this is what the development team hopes.

At 57 lb, the X1 is small and lightweight compared to the 1,500-lb squat machine used by astronauts on the space station for working out and to mitigate loss of strength and muscle mass during long stays in space.



Project engineer Roger Rovekamp demonstrates the X1 robotic exoskeleton for resistive exercise, rehabilitation, and mobility augmentation in the Advanced Robotics Development Lab. Image credit: Robert Markowitz

Not doing squat?

Could something like the X1 complement or even replace the squat machine? There is no consensus yet, even among the designers. Finding out exactly what the X1 can and cannot do is one of the team's top priorities for the coming months.

"Our goal right now is to understand what we are getting [in terms of exercise] and what we are not getting," says NASA's Roger Rovekamp, mechanical engineer for the project.

Rovekamp's software engineering partner, Chris Beck, chimes in: "The first priority is to compare our device to what's currently out there and basically try to prove that we can [make] what they have. After we prove that, then we can hopefully try to show them what we also have that they don't currently have."

The bottom line is that after six or so more months of ground tests and design revisions, the team hopes to earn a thumbs-up from NASA to build a flight version for testing aboard the space station.

Spinoff applications

Beyond NASA's walls, the field of wearable robotics is taking off. Assisted walking devices offer new hope of mobility for those recovering from strokes or suffering from spinal cord injuries, with commercial prices expected to range from $80,000 to $150,000. Exactly what a space-qualified exercise version would cost is not certain, but the team predicts that unit costs will be lower than the $1.3 million provided so far for X1 under NASA's Game Changing Technology initiative.

The team has work to do to convince NASA management to send a version of the X1 into orbit. Job one in the Human Health and Performance Directorate is to make sure astronauts get equipment that will benefit them. It must not put them at unacceptable risk of injury in orbit, where there are limited medical supplies and a long to-do list for each astronaut.

NASA needs to be sure the device will not overextend the crew's joints, tendons, or muscles. The agency is conservative on matters of safety; even in the Johnson lab, not just anyone is permitted to don the X1.

"There is a core group of people who are checked out to wear the device and evaluate it," Rovekamp says. "Some people are checked out to operate powered; some are checked out to operate it passively."

For the most part, the testers are project engineers, although "we have had one crewmember in it," he adds.

Safety first

X1 engineers can hardly complete a sentence without uttering the word safety. They considered it from the very start of the design and development work last April.

The device has, for example, built-in mechanical hard stops to make it impossible for the computer to overextend the wearer's joints.

Engineers had two starting points for their design work. One was an assisted walking device called Mina, built by the Pensacola Institute. The Mina software has been adapted to perform the high-level control and integration of data from the different joints. The other starting point was Robonaut 2, a humanoid robot whose torso and arms were delivered to the space station in February 2011 by the crew of Discovery. R2 firmware governs the lower level control algorithms that monitor and run each individual joint.

Robonaut looks nothing like a wearable computer, but it's what's inside that matters.

"The spaceflight-proven software and firmware [for Robonaut] are the same stuff that's on our device," says NASA's Beck, a software expert and biomedical engineer.

Capitalizing on Robonaut let the team save valuable development time. It also created opportunities for brainstorming. The Robonaut team is working on legs for the torso in the same room where the X1 team works.

"We're always talking and understanding what they're doing," expalins Rovekamp.

The X1 team finished the device in December and continues refining it. The big challenge was to make a device whose primary purpose would be just the opposite of Mina's—to provide resistance instead of assistance. Engineers also had to consider how astronauts move in space.

"We're trying to think about things like, what's going to happen in zero *g*? What's the body orientation going to be like? How are you going to react to loads?" says Rovekamp. "If we can remain free floating while using the device, then we can avoid imparting vibration disturbances into the ISS structure," he adds.

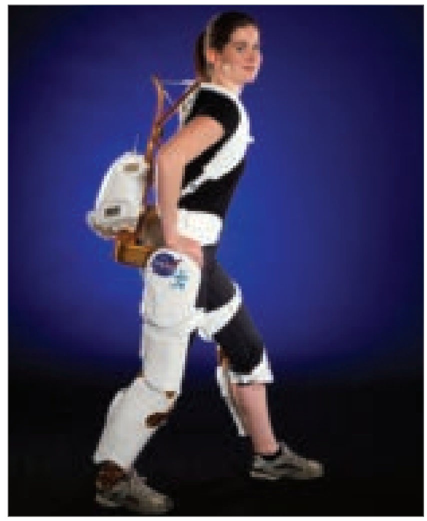
Working with the Pensacola group and the Robonaut team was helpful, but only to a point: "There's really not a precedent to what they've done in the past," says Rovekamp. "It's a very radical concept."

Even in space, the X1 will need stronger motors than those of walking devices to provide the extra torque required for an exercise machine.

Maintaining strength

Flip a switch and the X1 also can become an assisted walking device to give to spacesuit-clad astronauts after they land on Mars. "Now it's helping them walk around if they're a little bit weak after the long space flight," Beck explains.

Exercise remains the top near-term goal, however. The device is programmable, so NASA can adjust an astronaut's exercise routine, and it will be able to stream back dynamometer readings telling doctors how fast the wearer's legs are moving.



Project engineer Shelley Rea demonstrates the X1. Image courtesy Robert Markowitz.

"The doctors can say, 'Okay, your hamstrings are not being exercised properly. We need to change your exercise protocol a little bit," Beck says.

That would be a big improvement over the way things are done now. Before missions, astronauts learn how they will need to exercise to minimize loss of muscle. Dynamometer readings are taken to make sure the exercises are rigorous enough. The astronauts go to space with a prescribed exercise protocol telling them how much they need to work out on various devices, including the squat machine (officially known as the advanced resistive exercise device).

Once the astronauts are in orbit, doctors cannot gauge their performance, but can only wonder, "What was your effort in that squat? Was it a really good squat or are you cheating somehow?" Rovekamp says.

The X1 would improve that process by streaming back dynamometer readings.

None of that can happen without a safe, comfortable, wearable robot. The X1 team started its work by making a quick structural mockup. "One of the challenging things with a device is, where do you pivot?" says Rovekamp. "We put all of the bearings in the position we thought they would be in. A lot of times our initial assumptions were not correct, and it was more comfortable another way."

The result was a design with 10 joints: motorized joints on the hips and knees, plus six passive joints for stepping sideways, turning, and flexing the foot. Adjustment points make the X1 adaptable for different wearers. Mechanical hard stops prevent the wearer from exceeding his or her range of motion.

Sensing and control

The control software is key. The process starts with readings from position sensors at each joint. "We can determine from that what the person's joint angle is," Beck says. "The software is intelligently written so that it can basically manage all the joints at once. It knows where all of them are, and what the person's left knee is doing and what the person's left hip is doing—everything."

The Pensacola group's algorithms were critical. The engineers combined them with the flight-proven Robonaut software: "It has gone through several iterations of safety reviews to make sure it's safe for use on orbit," Rovekamp points out.

That strategy, the team hopes, will lead to quicker approval for a flight version of the X1. Even as they work on it, engineers have the future in mind. The rig might be a game changer, but it still is more bulky than the engineers would like.

"The ideal exoskeleton is like a pair of pants. You're comfortable in them. It's natural," says Rovekamp. "We would like to get even smaller and lower profile."

If the engineers can do that, astronauts could someday wear an exoskeleton for an hour or two and get a workout while doing chores aboard the station or on the way to Mars.

"It has to be extremely comfortable. It has to be low profile so they can zip throughout the space station. We have a lot of different ideas for how this could continue to evolve into a device that has extreme payoff to the crew long term," Rovekamp says.

But first things first: Earning approval to make a spaceflight version of the X1.

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