Designing a Space Suit to Meet the Challenges of Long-Term Exploration Missions

With assistance from a life-size robot, NASA-supported investigator Dava Newman is accumulating data that will help the space agency design advanced space suits to meet the needs of astronauts on future long-term missions of space exploration.

Since human space exploration began, one of NASA's most important challenges has been to supply astronauts with the basic necessities of life support. In the near vacuum of space, a human being would survive no more than a few seconds unprotected by a spacecraft or space suit.

Astronauts are most vulnerable when they leave the spacecraft to perform extravehicular activities (EVAs), or spacewalks. The space suit worn for EVA has to fulfill many functions. First and foremost, it keeps the astronaut alive by providing warmth, air to breathe, water for body cooling, and pressure to support the body in the absence of an atmosphere.

The suit also provides protection against meteoroids and is insulated to prevent radiant heat transfer. The outer layer reflects sunlight and is highly resistant to punctures, abrasions, and tears. Last but not least, the space suit and gloves must offer enough mobility and dexterity to enable the astronauts to perform their EVA tasks.

Space Suit Needs for Space Exploration Missions

The familiar bulky white space suit worn by space shuttle astronauts weighs about 118 kg (260 lbs) when its life support system (the backpack) is fully charged.

"The current space suit is a wonderful suit design that has performed extremely well on space shuttle missions," says Dava Newman, Ph.D., an associate professor of aerospace engineering and a MacVicar Faculty Fellow at the Massachusetts Institute of Technology (MIT), whose research focuses on optimizing human performance in space.

However, Newman adds, the current suit is inappropriate for use on future space exploration missions in which astronauts will have to perform complex, physically demanding tasks in the extreme environments of microgravity and partial gravity. "The existing suit is far too heavy and, although it has some flexibility, it is not designed for locomotion, which will be the key activity of planetary astronauts."

Christopher Carr, a graduate student at MIT, wears the liquid cooling and ventilation garment, the innermost layer of the current space suit worn by NASA astronauts. The electromyographic sensors attached to his body measure muscle activity and work required to perform space-suited tasks. On the right, the robotic space suit tester is seen "wearing" a pressurized space suit.

Wearing a space suit is rather like wearing a heavy winter coat or a garment with several cumbersome layers of resistance, says Newman. "As the limbs move back and forth, the suit fabric tends to bunch up. Eventually the sheer quantity of compressed material limits joint flexibility."

Analyzing Space Suit Performance

Newman directs a research effort aimed at quantifying all aspects of the performance of the current NASA space suit and applying this information to the design of a new suit to meet the needs of astronauts on future space exploration missions. Co-investigators in this effort include other MIT faculty members as well as researchers at the University of Pennsylvania and at Hamilton Sunstrand, the company that manufactures the current space suit under contract to NASA.

The investigators have completed a four-part study of the performance of the current space suit, using humans and a life-size robotic space suit tester on loan from NASA to Newman's MIT lab. The robot, which has 12 programmable joints in its right arm and leg, simulates an astronaut's movements with and without a space suit.

"We began by measuring the position of an astronaut's body, arms, and legs as he or she performed various tasks that would be done on an exploratory mission, such as walking, bending over, reaching with the arms, and using a shovel to dig," explains Newman.

The next step was to repeat the same activities and measurements with the subject wearing a space suit. Cameras recorded the subject's movements in three dimensions. Film-like sheets embedded with pressure sensors were placed against the subject's body to identify pressure points where the body's motion required working against the suit.

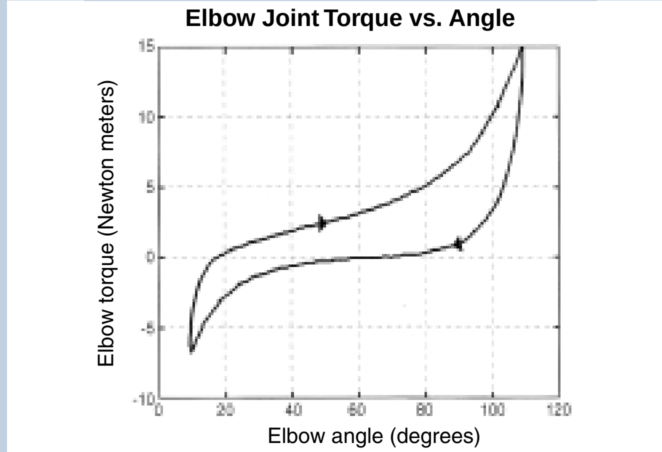
Robotic Space Suit Tester Leads to Extensive Database

These experiments quantified for the first time how the space suit accommodates and limits astronauts' mobility. Certain measurements, however, such as joint torque—the amount of work involved in bending a joint such as the elbow or the knee—cannot be obtained noninvasively from human volunteers.

This is where the robotic space suit tester comes in. Its joints are constructed to provide a mobility equivalent to that of human joints, but embedded in the robot's joints are high-precision torque sensors capable of measuring exactly how much work is required to move the joint.

The investigators fed the data on the human subjects' performance into the robot's computer and programmed the robot to re-create the astronaut's motions. They then measured joint angles and torques in the robot, first without a space suit and then with the robot wearing a suit.

"We now have an extensive database of information about human performance in NASA's current space suit," says Newman. "We know, for example, that wearing the suit forces an astronaut to adopt an unnatural posture. We can show exactly how hard the space suit forces the astronaut to work to perform certain types of movement. This had never been quantified before for simulated planetary EVA activities."



The effect of the space suit on elbow movement. The effort (torque) required to move a suited elbow from a fully extended to a bent position (upper curve) and then back again (lower curve) is different, due to bunchings and expansions of the suit.

Advanced Space Suit

These data—together with other data Newman and her colleagues have obtained from computer simulations that provide physics-based analysis of EVA tasks such as manipulating a satellite—provide an important knowledge base for recommendations on the design of an advanced space suit, says Newman.

The design concept for an advanced space suit should be ready by 2010, she predicts. This suit will look nothing like the current space suit, she says.

"It will need to be very light and comfortable to wear. The ideal suit for a Mars mission will weigh less than 27 kg (60 lbs). It will have to be made of highly durable but flexible materials that provide full mobility in the torso, hips, knees, and ankles so that astronauts can bend over, walk, jump, and climb. Ideally, it will be a 'smart' bio-suit that can monitor the astronaut's vital signs and help him—or her—to lope in partial gravity."

References

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