High-energy-density chemical fuel powers bug-sized robots to leap, lift and race

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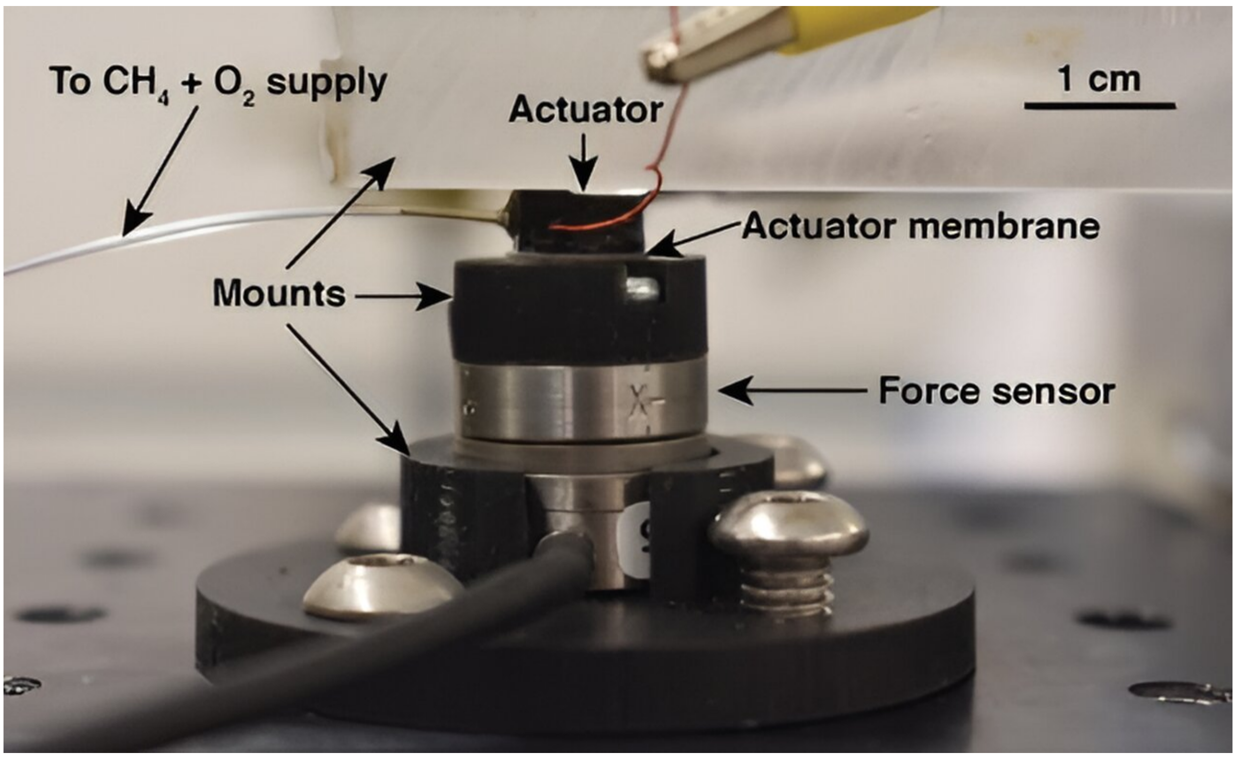

Blocked force testing configuration. A Nano17 Titanium force sensor was used to collect force data at 20 and 40 kHz sampling rates. Credit: *Science* (2023). DOI: 10.1126/science.adg5067

Cornell researchers combined soft microactuators with high-energy-density chemical fuel to create an insect-scale quadrupedal robot that is powered by combustion and can outrace, outlift, outflex and outleap its electric-driven competitors.

The group's paper, "Powerful, Soft Combustion Actuators for Insect-Scale Robots," was published Sept. 14 in *Science*. The lead author is postdoctoral researcher Cameron Aubin, Ph.D. '23.

The project was led by Rob Shepherd, associate professor of mechanical and aerospace engineering in Cornell Engineering, whose Organic Robotics Lab has previously used combustion to create a braille display for electronics.

As anyone who has witnessed an ant carry off food from a picnic knows, insects are far stronger than their puny size suggests. However, robots at that scale have yet to reach their full potential. One of the challenges is "motors and engines and pumps don't really work when you shrink them down to this size," Aubin said, so researchers have tried to compensate by creating bespoke mechanisms to perform such functions. So far, the majority of these robots have been tethered to their power sources—which usually means electricity.

"We thought using a high-energy-density chemical fuel, just like we would put in an automobile, would be one way that we could increase the onboard power and performance of these robots," he said. "We're not necessarily advocating for the return of fossil fuels on a large scale, obviously. But in this case, with these tiny, tiny robots, where a milliliter of fuel could lead to an hour of operation, instead of a battery that is too heavy for the robot to even lift, that's kind of a no brainer."

While the team has yet to create a fully untethered model—Aubin says they are halfway there—the current iteration "absolutely throttles the competition, in terms of their force output."

The four-legged robot, which is just over an inch long and weighs the equivalent of one and a half paperclips, is 3D-printed with a flame-resistant resin. The body contains a pair of separated combustion chambers that lead to the four actuators, which serve as the feet. Each actuator/foot is a hollow cylinder capped with a piece of silicone rubber, like a drum skin, on the bottom. When offboard electronics are used to create a spark in the combustion chambers, premixed methane and oxygen are ignited, the combustion reaction inflates the drum skin, and the robot pops up into the air.

The robot's actuators are capable of reaching 9.5 newtons of force, compared to approximately 0.2 newtons for those of other similarly sized robots. It also operates at frequencies greater than 100 hertz, achieves displacements of 140% and can lift 22 times its body weight.

"Being powered by combustion allows them to do a lot of things that robots at this scale haven't been able to do at this point," Aubin said. "They can navigate really difficult terrains and clear obstacles. It's an incredible jumper for its size. It's also really fast on the ground. All of that is due to the force density and the power density of these fuel-driven actuators."

The actuator design also enables a high degree of control. By essentially turning a knob, the operator can adjust the speed and frequency of sparking, or vary the fuel feed in real time, triggering a dynamic range of responses. A little fuel and some high-frequency sparking makes the robot skitter across the ground. Add a bit more fuel and less sparking and the robot will slow down and hop. Crank the fuel all the way up and give it one good spark and the robot will leap 60 centimeters in the air, roughly 20 times its body length, according to Aubin.

"To do all those multi-gait movements is something that you don't typically see with robots at this scale," Aubin said. "They're either crawlers or jumpers, but not both."

The researchers envision stringing together even more actuators in parallel arrays so they can produce both very fine and very forceful articulations on the macro scale. The team also plans to continue work on creating an untethered version. That goal will require a shift from a gaseous fuel to a liquid fuel that the robot can carry on board, along with smaller electronics.

"Everybody points to these insect-scale robots as being things that could be used for search and rescue, exploration, environmental monitoring, surveillance, navigation in austere environments," Aubin said. "We think that the performance increases that we've given this robot using these fuels bring us closer to reality where that's actually possible."

More information: Cameron A. Aubin et al, Powerful, soft combustion actuators for insect-scale robots, *Science* (2023). DOI: 10.1126/science.adg5067

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