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Aeronautics: Frontiers of the imaginable

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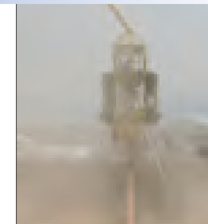


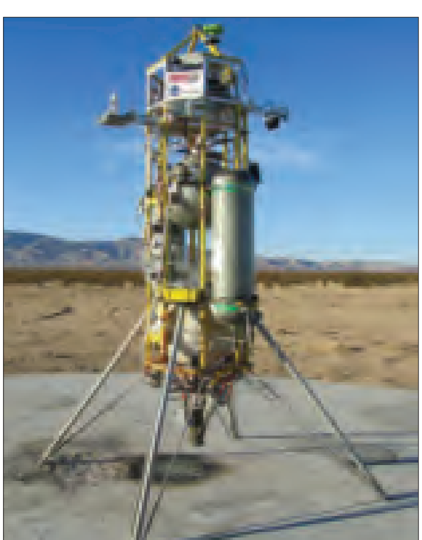
Will GENIE guide Xombie to a landing?

One of the hurdles to delivering humans or robots to the surface of asteroids, the Moon, or Mars is the lack of options for realistically testing entry, descent, and landing technologies.

"If there's a new laser altimeter out there that's being developed by NASA, the only way [developers] can really get the full testing [of the device]—with the actual velocities and altitudes—is to actually go to the Moon or Mars," says Tye Brady, a systems engineer at the Charles Stark Draper Laboratory NPO in Cambridge, Massachusetts.

That is a problem, Brady says, because more sophisticated navigation systems are at the heart of NASA's desire to land in places that are scientifically more interesting. Safely reaching those destinations will require detecting and avoiding unanticipated hazards in real time, and touching down at precise locations.

Perhaps in light of this, NASA is showing fresh interest in a new class of low-altitude 'terrestrial test rockets' that would fly no higher than kilometers and hurtle back to Earth to mimic the last stages of extraterrestrial descents. New navigation sensors and control software would be tested on the rockets, which also would have their own systems in case one of the new technologies did not perform as expected.



Masten Space Systems' Xombie rocket with Draper Laboratory's GENIE flight control system rests on its launch pad at the Mojave Air and Space Port. Photo Credit: Draper Lab.

Brady and his teammates at Masten Space Systems of Mojave, California, are starting to test an early version of such a terrestrial test rocket, using $2 million from NASA's 2012 budget.

Heart of a Xombie…

Draper chose Masten's open-frame vertical takeoff and landing Xombie rocket as the core of the vehicle, which will be steered by a Draper developed guidance, control, and navigation system. The goal is to mimic the last 1-2 min before a lander touches down. The team has begun a series of incrementally more challenging test flights in hopes of proving the concept before building a successor. That next version would be protected by an aeroshell to fly higher and faster.

As a starter vehicle, NASA likes Draper's choice of Xombie, which is propelled by isopropyl alcohol fuel and liquid oxygen oxidizer. "The Xombie platform offers many advantages for landing technology demonstrations—it has few moving parts, a simple control system, and allows for a high rate of descent," says NASA Dryden's John Kelly, manager of the Flight Opportunities Program, which funds experiments on aircraft and reusable rockets.

Kelly's office oversees the Draper work, which is funded through an existing contract between Draper and NASA Johnson.

…and GENIE for a brain

Steering the rocket is GENIE (guidance embedded navigator integration environment), Draper's 23-kg package measuring 46x46x66 cm. It includes a laser altimeter, inertial measurement unit, GPS receiver, and a processing computer. GENIE is programmed with algorithms that rapidly assess the vehicle's position from a perch atop the Xombie rocket.

NASA likes GENIE for its flexibility. It "allows for quick integration of new landing technology algorithms and hardware onto the test bed," says Kelly.

The Draper terrestrial test rocket is smart enough to fly on its own, but with NASA making plans to send humans into deep space someday, Draper is working to keep those humans in the loop. "We actually have a cockpit here at Draper Lab where we've had Apollo astronauts come in and land these future vehicles interactively with the GENIE algorithms," says Brady.

Twice as smart

One of the Draper terrestrial test rocket's big innovations is that it has two brains—one is GENIE and the other is Xombie's own avionics system, which acts as a backup. Engineers can therefore afford to let GENIE get daring with the descent trajectory. They will need to be daring to create realistic conditions for what the terrestrial rocket might eventually carry—up to 45 kg of prototype sensors and computers.

In some scenarios, the test equipment probably would operate in shadow mode; in others, new sensor data or algorithms might actually be incorporated into GENIE to help steer the vehicle. If GENIE were to lead the rocket astray, the Masten avionics system would step in to try to regain control, landing it straight down in an emergency, or on an abort pad.

"The reason to have this fail-over capability is that it's one thing to hand someone the keys to your car; it's another to make sure you're going to get your car back," says Sean Mahoney,

Masten Space Systems XA0.1E rocket, nicknamed "Xoie" (pronounced Zoey) hovers under rocket thrust at the Mojave Air and Space Port in California. Kluft photo.

Masten's chief operating officer.

GENIE relies on algorithmic software called a Kalman filter to rapidly recalculate the rocket's attitude and location. The filter "blends information from multiple noisy sensors to create a navigation measurement that is better than any of the individual sensors could be alone," Brady says by email.

Still to be worked out for the long term is which organization would own the Draper terrestrial test rocket and operate it as a testbed technology developer.

"NASA could choose to have us stick around and do more, or NASA may want us to transition the whole concept to someone like a commercial suborbital RLV provider," says Draper program manager Rick Loffi by email. "We would then walk away, proud to have helped NASA. This part hasn't been decided—all indications are that [the Flight Opportunities Program] wants us to continue advancing the concept, but there are a lot of variables at play."

No matter who ends up providing the service, project engineers are pretty certain they know how customers in the technology development community would use their terrestrial test rocket.

In the first flight of a prototype altimeter, for instance, the device's readings probably would not be used to steer the terrestrial test rocket. After the flight, the developer would compare the altimeter's readings to those from GENIE to assess how well the altimeter performed over the descent and landing profile. In later flights, the altimeter's readings might actually be used as part of GENIE's overall guidance, navigation, and control solution.

Engineers want the rocket to be reusable, which is a key to the anticipated cost savings. "I don't have to fish the parts out of the ocean. This thing comes right down to the pad," Brady explains.

Playing together

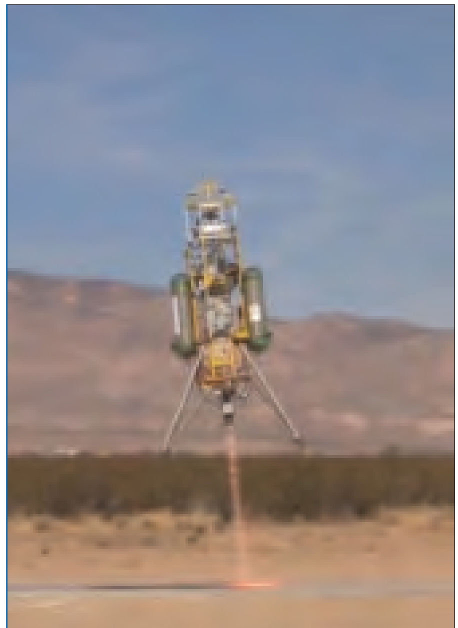
On December 20, 2011, the project team dangled a tether from a wheeled crane and flew the terrestrial test rocket for about 30 sec at the Mojave Air and Space Port. Then, on February 2, the team conducted its first free flight. GENIE steered the rocket to a point 50 m above the pad, moved the rocket laterally 50 m to a spot above another pad, and landed straight down to conclude the 67-sec flight.

Later this year, perhaps this summer, engineers want to begin a series of flights that would more closely resemble a planetary landing. In those flights, the rocket would make arcing descents from higher and higher altitudes. "We're talking about going as high as 240, 250, 260 m, and then shaping that parabolically down, landing 50 m away at the other pad," Brady says.

The first free flight was merely a hop, but project leaders say it was important: "We now know that GENIE and our system can play well together," says Mahoney.

Eventually, Draper wants to install GENIE inside a rocket covered by a composite aeroshell so that GENIE can fly higher and mimic more of the descent trajectory. Xombie's altitude and velocity are limited by its open frame and nonaerodynamic shape.

Masten has an aeroshell rocket in the works. Called Xaero, it is a project whose technical link to a precursor vehicle named Xoie is sometimes overstated. "The connection between Xoie and Xaero is often told as 'just wrap an aeroshell around Xoie,' but in practice it is several steps removed.



Xombie performs a vertical takeoff/vertical landing test flight. Photo courtesy Masten Space Systems.

"The original idea was just that; but as things progressed we realized this would be an entirely new build with the same core design," says Mahoney. The confusion arises because some parts from Xoie are indeed used on Xaero.

Xoie is notable because it won the $1-million top prize in one category of the 2009 Lunar Lander Challenge put on by NASA, Northrop Grumman, and the X-Prize Foundation. The craft took the Level-2 prize, which required it to fly for at least 3 min and avoid obstructions designed to mimic the lunar surface. Xombie—the same vehicle Draper is trying out for NASA—took second place in the less challenging Level-1 category.

For the new Flight Opportunities project, Masten engineers needed to adapt Xombie to carry Draper's navigation system. They built an open-frame extension, which they call the 'GENIE bottle.'

Xaero will be a more aerodynamic successor. The rocket would fly to 30 km at a top speed of Mach 0.9. It would shut off its engine, go through a parabolic coast phase, position itself to fall engine first, then relight its engine to land in that attitude, according to NASA.

Draper is definitely interested in Xaero or 'Xaero-class' vehicles for the future, Brady says. "That is going to be super exciting, when you see a vehicle go maybe to 5 km of altitude. That thing is going to get tiny. It's going to come screaming down at high velocities and land very precisely a kilometer away on this tiny little pad."

Mahoney predicts this will happen quickly: "I imagine in the next year you'll be seeing a lot more capabilities and demonstration of things at much higher speeds," he says.

Heritage

Draper assembled GENIE in the span of seven weeks in 2010. The first users were Johnson's Autonomous Landing Hazard Avoidance Technology program and a related effort called Project M, in which engineers were brainstorming concepts for landing a 'humanoid' walking robot on the surface of the Moon.

To test the necessary control algorithms, Draper flew GENIE on an Armadillo Aerospace Pixel rocket. Moving GENIE to Xombie was a big challenge, because the two rockets have very different designs. Whereas Xombie's fuel and oxidizer are stored in in-line tanks, Pixel's propellants are stored in spherical tanks arrayed on the same plane.

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Brady predicts that if Draper's terrestrial test rocket succeeds, a dam-burst of innovations for entry, descent, and landing technologies will follow.

Today, engineers find it relatively easy to push sensors and algorithms to level 5 on NASA's technical readiness level or TRL scale, which calls for component-level validation. They have a much harder time achieving level 6, which calls for demonstrating prototypes in relevant environments. Too often, the jump to TRL 6 becomes "the valley of death for entry, descent, and landing sensors," laments Brady.

Terrestrial test rockets developed by Draper, Masten, and other organizations could turn out to be the way across.

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