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Strong ARM for seizing a space rock

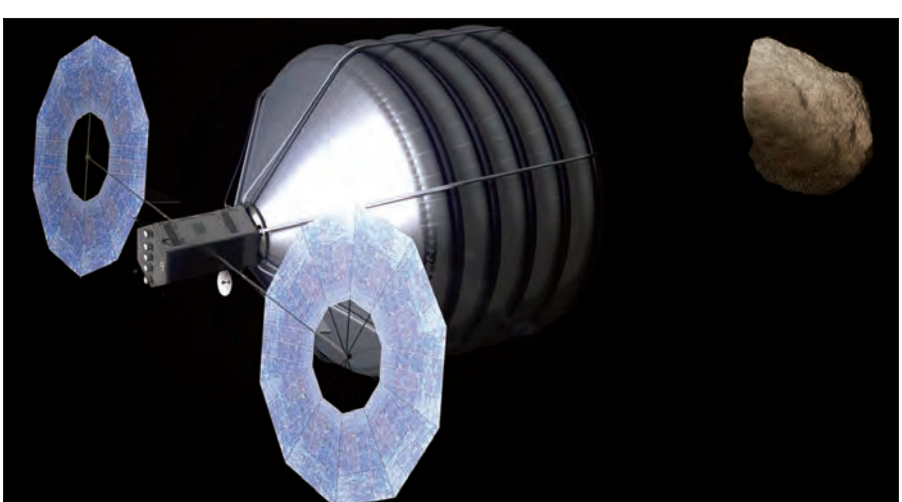
Bill Gerstenmaier, the top manager of NASA's Human Exploration and Operations Mission Directorate, is a master of the concise, technical language of engineering. Yet at AIAA's Space 2013 conference in September, the veteran space operator roused his audience with an uncharacteristic pep talk: "Turn off your logical side and turn on your touchy-feely side, the one you almost never use," he said. "Then jump up and down and do some break-dancing. We're going to grab a space rock and we're going to move it!"

Steve Stich, deputy director of engineering at NASA Johnson, was similarly fired up at breaking new exploration ground with the Asteroid Redirect Mission (ARM): "This is a bold mission," he said. "We are talking about sending two crew farther than we've ever been in space."

Capturing Congress

The ARM, first announced in April, is perhaps too bold for Congress. The House's proposed FY14 budget for NASA bars any spending on an asteroid capture mission. Back in July the chairman of the House Committee on Science, Space and Technology, Rep. Lamar Smith (R-Texas), argued that an asteroid mission would do little to advance science or planetary defense, and that it would not develop a lander, habitat, or other technologies necessary for long-duration missions into deep space. Committee members much preferred that NASA focus again on returning humans to the Moon. The best the Senate could manage was a legislative 'no comment.'

Because the continuing resolution expected to fund NASA through FY14 will likely say nothing about the ARM, NASA will keep studying the concept internally while readying it for next year's budget proposal. The agency will further develop the mission's technical approach and try to prepare a compelling, attractive sales pitch to Congress. At stake are U.S. prospects for getting astronauts into deep space in the coming decade, or for decades to come.



The ARM capture mechanism must cope with target asteroids of up to 1,000 tons, spinning at up to twice a minute, with a long dimension of up to 14 m. Even small asteroids might retain a significant dust layer, or consist of a rubble pile of small fragments held together only by molecular Van der Waals forces. Credit: NASA.

Mars is too far, too expensive. The Moon was ruled out as a destination when the White House canceled Constellation in 2010. Now, with NASA directed toward the asteroids, its deep space plans are being squeezed both by House antipathy to administration proposals and the latter's failure to deliver promised budget support.

The SLS and Orion vehicles are NASA's only option for travel beyond LEO, but if the White House accepts a budget hovering near $16 billion for its remaining three years, both booster and spacecraft may go on the chopping block. The situation is eerily similar to that described by the Augustine Committee in 2009, when Constellation's lunar goal was dismissed as unaffordable. Now the president's own 2025 asteroid goal seems to be outstripping the resources available. Delays to 2030 or beyond seem likely.

What, then, could NASA do for the next 17 years? Circumlunar and Lagrange point missions would exercise Orion and SLS but deliver little in the way of scientific or commercial payoff. Spending 17 years 'getting ready' to go someplace meaningful is a sure way to ensure one will go nowhere at all. A cash-strapped Congress or a president beset by more pressing priorities could cancel SLS and Orion altogether. Even a looming Chinese lunar landing may not be enough to revive NASA's fortunes. When in the late 2020s the ISS is retired, U.S. human spaceflight could well be decommissioned, too.

Something different

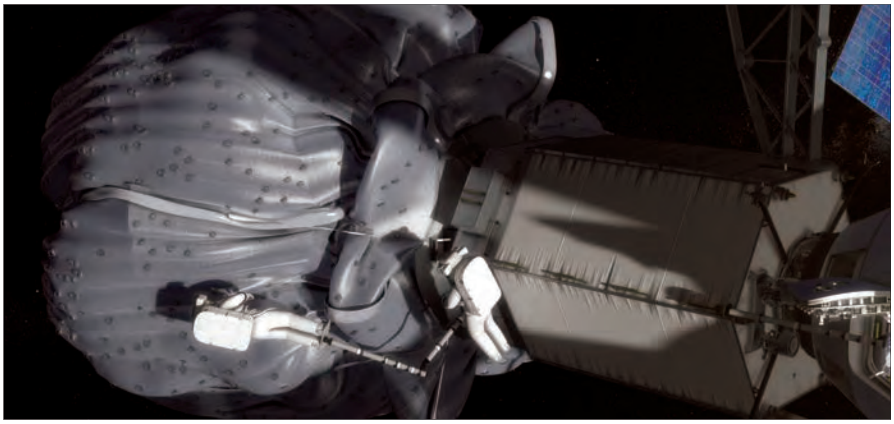
Confronting those barren prospects, NASA proposed in April the asteroid initiative, a broad effort pairing increased planetary defense activity with the ambitious ARM. In the latter mission, a robot spacecraft boosted by a single Atlas V launch would spiral outward under solar electric propulsion (SEP) from LEO, heading for a small near-Earth asteroid (NEA) in an Earth-like orbit around the Sun.

After matching orbits and spin rates, the asteroid redirect vehicle, or ARV, would position the open mouth of a fabric capture bag over an asteroid measuring 7 or 8 m across with a mass of up to 1,000 tons. Securing the asteroid, the ARV would despin its prize and begin thrusting toward the Earth-Moon system.

The 40-kW, xenon-fueled SEP system would nudge the asteroid's orbit just enough so that lunar gravity would capture the object into a distant, retrograde orbit of the Moon. There, Orion astronauts on a 3- to 4-week mission would dock with the robotic craft, gather an array of asteroid samples totaling a few tens of kilograms, and return them to Earth for analysis. The robotic vehicle would then maintain the asteroid's orbit and attitude for future astronaut follow-up or robotic exploitation by international and commercial partners.

The optimum target asteroid for capture is a low-albedo (dark) object with a C-type spectral classification, analogous to carbonaceous chondrite meteorites. These meteorites are black, low-density, organic-rich rocks little altered since their formation nearly 4.6 billion years ago. Some carbonaceous chondrites, like the Tagish Lake meteorite recovered after it fell in Canada in 2000, are as fragile as a charcoal briquette and contain as much as 20% water. Because of their fragility and susceptibility to rapid weathering, most of these asteroids break up on atmospheric entry, and few fragments survive on the surface long enough to be collected.

Water-rich, C-type asteroids are attractive targets, but they are difficult to find and characterize. Their low reflectivity means a 10-m asteroid is visible for only a few days near its Earth approach. After a detection, astronomers must quickly nail down the object's orbit through multiple observations, juggling precious telescope time to get the infrared spectra needed to confirm its composition. If the object is within range, radar from Arecibo or Goldstone can confirm its orbit, shape, and spin. Within two or three days of discovery, the potential target vanishes, unseen until its orbit carries it close to Earth again, as many as 10 years later.



The ARM mission would end with two Orion astronauts exploring the captured asteroid on several EVAs over the course of a week. The crew would conduct extensive sampling and emplace long-lived science and resource prospecting instruments. Credit: NASA.

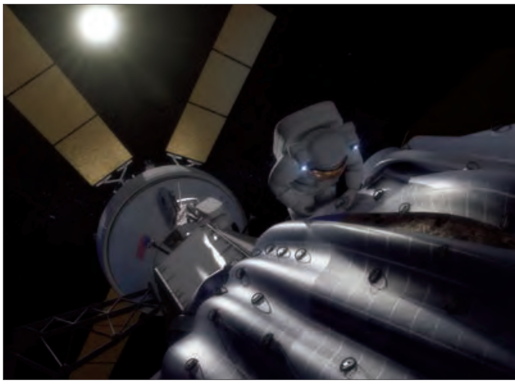
To enable ARM launch opportunities before 2020, NASA's first priority should be detection and characterization. In September, JPL asteroid dynamicist Paul Chodas said that three of 14 catalogued small asteroids had orbits favorable for robotic retrieval (requiring less than 2.5 km/sec of delta-V from the SEP system). With NASA-funded upgrades, ground-based observing programs could sift another five targets annually from the roughly 10,000 potential ARM candidates.

The best candidates will have C-type composition, a spin rate of less than 2 rpm, a mass under 1,000 tons, and a diameter smaller than 14 m in the long dimension. The search will be tedious and hard, but ground-based telescope time is relatively cheap. If NASA gets its $20 million in augmented search funding, it should discover 15-20 asteroid targets by 2018.

Brand new bag

Recent NASA studies show that several candidate capture mechanisms can cope with the challenges of corralling a small NEA. JPL has proposed a fabric bag held open by inflatable struts. With spin rates matched and the bag flown slowly over the asteroid, a cluster of 'Mars rover'-style airbags would inflate, stabilizing and gripping the asteroid inside. By triggering the inflation precisely, the craft can remove any minor axis rotations (tumbling). Retracting cables then close the bag around the asteroid, nestling it against the vehicle. Reaction control jets can then despin the spacecraft/asteroid stack.

An alternative capture design envisions a spidery set of lightweight arms holding open a wide-mouthed membrane; the arms fold inward to grasp the asteroid. Other despinning techniques under investigation include using the spacecraft's ion thruster plume to slow the asteroid's rotation, or lin-



The first Orion crew visit to the asteroid would be followed by robotic prospecting or science craft from commercial or international partners. Subsequent crew visits might follow if resource extraction techniques can benefit from astronaut assistance. Credit: NASA.

This fragment of the Tagish Lake meteorite, recovered after its fall in Canada in 2000, contains a variety of exotic amino acids whose formation was influenced by water percolating in the parent asteroid. Credit: Michael Holly, Creative Services, University of Alberta.

ing the capture bag with flexible bristles that apply passive retarding force across the asteroid's surface.

NASA is confident that ground-based simulations and mechanical testing can yield a capable, robust capture design, able to handle asteroid masses of up to 1,000 tons. More concepts could emerge at NASA's Asteroid Initiative Idea Synthesis Workshop, which was delayed by the partial government shutdown.

With the asteroid nestled safely in the capture enclosure, the redirect vehicle would begin the multiyear process of nudging the orbit toward a close encounter with the Moon. Once the asteroid is captured by lunar gravity, several months of SEP thrusting should suffice to park it in a very stable, distant retrograde orbit around the Moon. There is no chance of Earth impact from there, even without an active shepherding spacecraft: It would take more than a century for the asteroid to slam harmlessly into the lunar surface. Earth's atmosphere provides another layer of safety, as asteroids smaller than about 30 m in diameter break up and incinerate upon entry.

The capture in context

The deep-space experience and hardware needed for visiting a large NEA on a voyage of six months or more, as the president envisioned in 2010, are unlikely to be available before 2030. Without an improved budget picture, the ARM is the only way U.S. astronauts can reach an asteroid surface by the mid-2020s. However, the mission is not just about meeting some technical or political deadline. An asteroid encounter in lunar orbit would have real importance for conducting future expeditions to distant asteroids, the Moon's surface, and the Mars system.

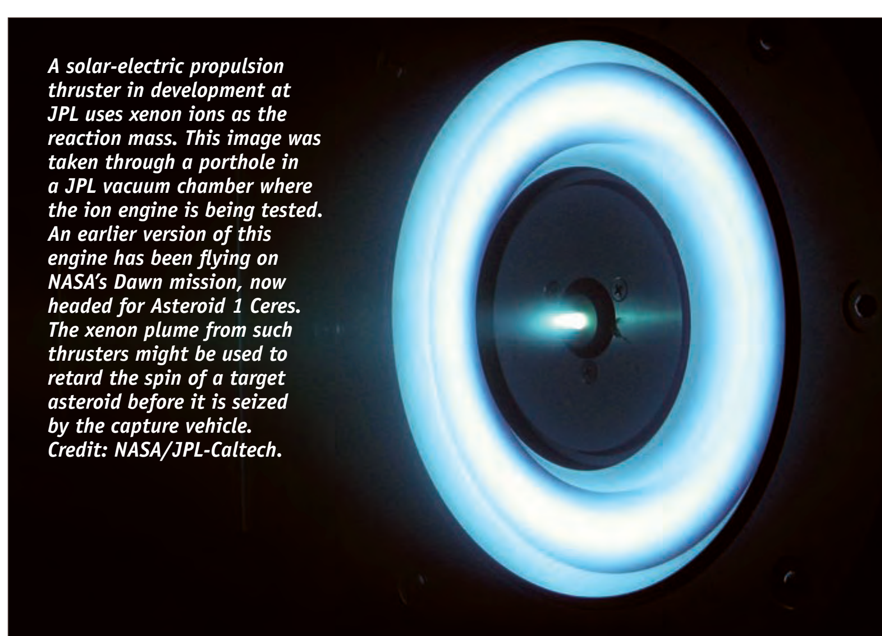
In the near term, the ARM would put U.S. explorers beyond the Moon about 10 years from now, with astronauts traveling well beyond Earth's protective magnetosphere, surpassing all Apollo benchmarks. The mission would be an affordable way to wring the kinks out of SLS and Orion systems, building deep-space operations experience for ground teams and astronaut field explorers.

The mission will not have a revolutionary impact on planetary science—a pair of asteroid sampling missions, Hayabusa 2 and OSIRIS-REx, may have succeeded in returning a few grams each from C-type NEAs by the early 2020s. But it will enable trained scientist-astronauts to return tens of kilograms of samples from an intriguing, previously unexplored class of small asteroids.

They are made of exotic stuff. Carbonaceous chondrites preserve material nearly unchanged since the formation of the solar system, including interstellar dust granules that predate the solar nebula. Using handheld coring instruments, the crew will penetrate a few tens of centimeters into the asteroid and retrieve pristine samples of its interior.

By emplacing long-lived science instruments on the NEA, the crew will gather important planetary defense information, too. Asteroids this small are not a threat to Earth, but do represent the building blocks of larger, hazardous rubble-pile asteroids. We should be able to sound the asteroid's interior structure, measure its thermal profile with depth, examine its optical properties to refine remote sensing methods, and assess the object's cohesion, porosity, and mechanical strength.

The mission's greatest potential is opening a new era of space exploration: using space-generated raw materials to supplant expensive propellants and consumables hauled from Earth. Investigators should feed some of the returned samples into processors at the ISS, working out practical methods to extract water, volatile elements, and valuable metals in a free-fall environment. NASA should also assess using the bulk mass of the asteroid as ready-made shielding against



A solar-electric propulsion thruster in development at JPL uses xenon ions as the reaction mass. This image was taken through a porthole in a JPL vacuum chamber where the ion engine is being tested. An earlier version of this engine has been flying on NASA's Dawn mission, now headed for Asteroid 1 Ceres. The xenon plume from such thrusters might be used to retard the spin of a target asteroid before it is seized by the capture vehicle. Credit: NASA/JPL-Caltech.

solar storms and galactic cosmic rays.

In the decade following an initial astronaut visit, NASA should partner with other space agencies and commercial firms in using the captured NEA as a testbed for mining and extraction technologies. By putting 500 tons of water-rich rock just outside the gravity wells of the Earth and Moon, the ARM may represent the first step on a long road to in-space propellant production, eliminating the need to ship cryogenic propellants from Earth.

Many advances must follow up the initial ARM: gathering asteroidal rocks, gravel, and dust in free fall; preparing them for processing; extracting water and separating it from organic material and other noxious volatiles; and finally, storing hydrogen and oxygen in a conveniently located free-fall facility. NASA, though, can take that most important first step—making raw space 'stuff' available to inventive users. Commercial innovators may then find ways to use in-space propellants, fluids, and industrial materials to address the logistical demands of industry and exploration.

The goal of the Asteroid Redirect Mission is not just putting a couple of astronauts in physical contact with a thousand-ton asteroid. It is instead to be the first in a series of incremental human spaceflight milestones aimed at reaching the Moon, more distant asteroids, and Mars. As budgets and experience permit, the ARM could be followed by visits to the Sun-Earth Lagrange points, then multimonth asteroid expeditions, or sorties down to the lunar surface. These options will depend upon the readiness of heavy-lift launch, reliable life support, and deep-space-qualified habitats.

The ARM provides a near-term astronaut target in deep space, beyond the Moon, within the coming decade. Even its critics recognize that under current policy and budgets, NASA lacks practical, affordable alternatives. This nontraditional yet promising mission may recapture for NASA and the nation some of the excitement missing in our recent space efforts.

ARM will be tough to sell, tougher to execute. NASA must answer crucial questions like those raised in July by veteran JPL engineer Gentry Lee: "Can we make it work? Can we make it useful?" If so, NASA will advance our scientific knowledge of asteroids, improve our planetary defense skills, and unlock a promising combination of human exploration, commercial innovation, and unlimited resources from space.

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