Millions of pounds of machinery will start our journey back to the moon, but only 20,500 pounds will make the full trip back home. None of it would get anywhere without this unassuming bolt.
FROM THE NEXT ROOM, THROUGH A thick granite wall, comes a chug-a-chug-
chug-a, like an old steam train closing in. Rounding the corner, I see the source of the racket: a table, shaking. The long, metal slab jerks quickly back and forth. One in ten panels, a half-dozen rectangular grisms packed with sensors measuring pressure and motion. Each one holds a titanium-alloy bolt the size of a grown man’s forearm and weighing about 10 pounds. As the elaborate assemblage might hint, these bolts are special. Eventually, this remarkable hardware will go to space. The bolts, or ones like them, will hold together sections of the Orion spacecraft, a new vehicle that, sometime in the next decade, will carry humans out of low-Earth orbit for the first time since 1972—in initially to the moon and later on trips to Mars. But before that, the fasteners must survive a mock version of their journey. Only worse.

The shaking they’re enduring is merely the beginning, intended to simulate the violence of a launch. The parts also brave hammering, baking, and freezing—24 tests in total. This before any metal even reaches the launchpad. This process ensures not only that the bolts will hold together massive space-faring machines, but that, at the exact right moment, they’ll break nearly apart. More specifically, they’ll explode, strategically jettisoning segments of Orion’s rocketship away as they do. The design, manufacture, and most of the testing of this combustible hardware happens in an old stone factory in Eastern Connecticut, where engineers have crammed various items full of pyrotechnic material for well over a century. The 200-acre campus of 19th-century brownstone, granite, and brick—a look that’s part factory town, part college—is the home of the Ensign-Bickford Aerospace & Defense Company (or EBAD, because what’s a defense contractor without a vaguely sinister acronym?)? EBAD is one of more than 2,000 companies making Orion’s components, a bit player in this space epic, but the firm’s mission-critical role gives it an outsize gravitational pull. Of the 8.5 million pounds of rocketry (collectively known as NASA’s Space Launch System) and other equipment that will battle in Orion out of the atmosphere, only 20,000—less than 0.38 percent—will come back to Earth. “The last thing we want to do is take all the stuff of launch to the moon and back,” explains Carolyn Overmyer, Lockheed’s deputy program manager for the Orion crew capsule (where the astronauts ride). “We don’t need the blast system at the moon. So where does it go? It separates. It’s a ‘sep event.’” In plain English: Stuff falls off.

The exploding bolts are the catalyst in that process, “central to our mission,” Overmyer says.

There are eight separations in a complete Orion journey to the moon and back. One of the first occurs three minutes after launch: The bolts split alongside explosive-powder-laced rippling fuses called frangible joints to discard the loads that get Orion off the ground. Three nearly-two-story panels, called fairings, that protected the craft from the heat of lift off simply drop. “A 15-foot-tall coffee can goes boom—and just flies away,” Overmyer says, recalling the first time she watched the panels split from the craft during a test flight. “I know it sounds silly to say it, but I found it very, very beautiful.”

As the mission progresses, more systems become irrelevant and break off. The final thing to go is the service module, a trash-can-shaped pod that houses all the liquids and gases for the mission; it holds on to the Orion capsule throughout the 1.3-million-mile journey on the strength of four fasteners made for this exact task. When the crew-carrying vessel begins its dive back to Earth, the fasteners split and release the pod, which then burns up.

Preparing these bolts for their pivotal moment—their perfect failure—presents as a kind of Zen koan. How to fully test a thing that works exactly once? How do you design something that, in order to do its job, must fail? Part of the answer is revealed in the threaded fasteners, called release and retention bolts, shaking and rattling on the table. Of all the variations of hardware EBAD builds for Orion, these must suffer the most intense torture, both here on Earth and in space. “We beat the hell out of ‘em,” says Steve Thurston, EBAD’s manager of test services, as he watches the heroic fixtures rumble angrily against the table’s motion. Thurston turns and walks toward a quieter spot and says softly, almost solemnly: “It’s really not fair to the parts. But that’s the point—to find their limits, to push the envelope.”

Outside, a morning rain gives way to the bright-green beginning of a fall day. A river, which once powered EBAD’s works, winds through the campus; a family of otters has taken up residence. It’s hard to square the setting with what goes on behind the aged stone walls: space-age bolts getting stretched (and mashed and bashed and rattled) to their limits.

Simsbury, Connecticut, has been home to EBAD since well before the Civil War. Back then, there were iron and copper mines and paper quarries throughout the region, which meant a lot of digging and an awful lot of boom. The methods were crude: Dig a hole, fill it with gunpowder, plug it except for a small space to run a fuse (usually string or cloth), light, run. Men died by the hundreds, often because things blew when...
they weren’t supposed to—mostly too soon. In 1831, these techniques began to change—become more refined, predictable, safe. In the city of Cornwall in Old England, where there was even more mining than in New England, an inventor named William Bickford patented the first safety fuse. In the trial and packed gunpowder into a hollow jute rope, which when frizzled at a predictable clip of roughly 30 seconds per foot. In 1899, he partnered with a Connecticut mining company to manufacture and sell his breakers state-side. Ralph Hart Ensign joined on in 1870. His heirs would later expand the firm’s explosives business beyond fuses, developing products such as a banker’s bag that smoked at its entrance. Bickford’s designs were very good at it. We’ve been doing it for a long, long time.” But the key, even in Bickford’s day, is timing. “Timing was—and still is—everything.”

For no one is this truer than the astronauts inside a small hunk of metal hurtling through space at 20,000 miles an hour. Which is why, almost paradoxically, in missions with humans, there’s explosive powder planted in dozens of spots throughout the craft. It does what you want it to do when you need it. NASA doesn’t call these propellants “explosives.” Instead, they’re pyrotechnical systems, or pyro, in which so-called separation bolts are a central part. An electronic switch called an actuator delivers a charge to a threaded incendiary cord that leads to the fastener. The thread breaks at that line,” she explains. If the hard-ware’s weakest point: the fracture plane, the epicenter of the eventual break. Lockheed’s Overmyer likens it to folded paper: “When you deliver the crew back to Earth. “It’s not like you can suddenly change your mind and send Bruce Willis out on a rescue mission,” Novotney says.

Now he and a team of engineers are somewhat obsessed with the trial and error of bolt-making. The end result of their work occasionally winds up in Novotney’s office, in a yellow bucket deep with shards of spent fasteners he likes to show off to visitors. Peering down at this refuse, it looks more like discarded lengths of filled-in pipe than hyperengineered and endlessly tested exploding space stuff. Their task is dead simple yet takes years to perfect: Stay together, break apart, help deliver the crew back to Earth. “It’s not like you can suddenly change your mind and send Bruce Willis out on a rescue mission,” Novotney says.

EBAD has been alternately making amends by breaking Orion hardware since 2009. When it began, Lockheed delivered reams of documents with specs, first a few hundred pages, then several thousand more. Still, EBAD was starting from scratch. The company established a Space Ordnance Division to make specialized fuses in 1965, and a handful of other companies—even NASA—had been crafting separation bolts since then. The problem was broad strokes were, by the early aughts, already out there.

To perfect a bolt that also must, when called upon, be entirely reliable to separate the two ships, EBAD engineers spend an outsized amount of time worrying the hardware’s weakest point: the fracture plane, the epicenter of the eventual break. Lockheed’s Overmyer likens it to folded paper: “When you bend it, you make the crease really strong so it breaks at that line,” she explains. If the hard-ware was going to split too soon, like during launch, it’d happen here. On a bolt, the plane is a razor-thin notch circumnavigating the titanium surface, about two-thinths from one end. In EBAD’s early testing days for Orion, the designers fiddled with the placement, the depth. Most important, they carefully paired it with the internal structures and explosives that would ensure a clean break at the right time, every time. As they work on their refinements, the rules
**PYRO MANIAC**

During 2000’s Exploration Mission 1, Orion’s first journey to the moon and back, 11 pieces of explosive hardware will systematically disassemble the vessel along the way. This is where, why, and how each bit breaks loose. —Penelope Stark

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**Launch shields**

Once Orion clears the atmosphere, it drops the shields, called fairings, that protected the service module from the heat of blastoff. Six gunpowder-boosted zippos, called frangible joints, on the bottom and sides of each panel as well as six exploding bolts fire in rapid succession.

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**Abort system**

The conical top of the craft has motors that could turn the ship around if ascent goes awry. In case of an emergency landing, a motor on the spire of the cone then creates enough thrust to push the assembly clear of the craft.

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**Propulsion**

The vessel circles Earth before speeding toward space. A dedicated rocket (not shown) helps it complete its lap. Before Orion reaches orbit, **four pyro nuts** holding it to the top of the capsule fracture. A motor on the spire of the cone then creates enough power, fluid, and data between the service module and the crew-carrying capsule to push the assembly clear of the craft.

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**Lifeline**

About three weeks and 13 million miles later, Orion rendezvous for its final descent back into the atmosphere. **Two separation bolts** sever the umbilical that funnelled power, fluids, and data between the service module and the crew-carrying capsule throughout the mission.

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**Extra baggage**

The service module is the last thing to go before Orion’s brutal re-entry. The **four fasteners** that have held the parts together fissure. The halves of the hardware that remain on the capsule melt into the craft’s heat shield, helping protect the crew in the final push.

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**ANOTHER WAY TO MONITOR THE SUCCESS**

As they melt, they take the heat with them—like a 4,000-degree push back into Earth’s atmosphere. As they melt, they take the heat with them—like chunks of ice sitting on blacktop on a hot day. As Keon and a group of ERAD engineers describe these final threes, I catch them staring at the conference-room wall behind me. Tucked near the ceiling is a rolled-up projection screen. Test flights are the only real chance for the bolts to prove their mettle, so when they happen, ERAD staff huddle in this room to watch. Right now, NASA is inching toward two big events: a four-minute ride will practice an emergency landing this spring; and, in 2020, Exploration Mission 1 will whip an unmanned spacecraft around the moon and back home.

The last time they piled into this room was in 2014, when Exploration Flight Test 1 circled Orion around Earth twice before splashing down. The unnamed mission was a trial for critical systems such as the heat shield, parachutes, computers, and, of most concern for ERAD, all those separations. That mid-December afternoon, the team ordered pizza, and waited into the night to see how their bolts fared. They paced and sweated, then broke the news the bolts held up. Celebration, though, was tempered by the work—the testing, the refining—they’d return to the next morning. “The mission’s not over,” Keon says.