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AEROSPACE AMERICA

Two views on Russian space

Bright future or...program in decay?

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Reuseable

Attempts to build spacecraft that can be flown more than once are littered with failures. But led by SpaceX, the commercial launch industry is trying again to find ways to reuse engines, stages and perhaps someday the entire vehicle by reassembling it after launch. Debra Werner explains the technical and economic hurdles.

A SpaceX Falcon 9 lifts off from Florida in 2013 with a payload of satellites. The rocket's first stage relit three of its engines, just as a reusable stage would have to do to land on its base.

SpaceX

ROCKET RENAISSANCE

Food, water and equipment for astronauts weren't the only casualties when a Falcon 9 v1.1 rocket disintegrated on its way to orbit in June. The accident also put on hold SpaceX's third attempt to land the first stage of a Falcon 9 on a barge off the Florida coast. No company or government has ever managed to land a spent rocket stage and reuse it, but that would be just a start. SpaceX eventually wants to reuse an entire rocket by recovering the upper stage too and reusing the Dragon cargo capsules. The result would be a reusable rocket, though not the futuristic spaceplane once envisioned by the U.S. Air Force and NASA. Company founder Elon Musk wants to start proving the feasibility of the concept, and apparently not just for the bottom line of his company.

"I think it's important that humanity become a multiplanet species," Musk said last year on the news program 60 Minutes. "I think most people would agree that a future where we are a spacefaring civilization is inspiring and exciting compared with one where we are forever confined to Earth until some eventual extinction event."

Regardless of the setbacks at the barge, SpaceX's efforts at reusability have sparked renewed interest in an arena historically littered with defeats, offset by only modest successes. The space shuttle orbiters required a small army of contractors to get them ready for their next missions. The shuttle's solid rocket motor casings were fished out of the ocean and refilled. The U.S. Air Force has flown four mysterious missions since 2010 with a spaceplane called the X-37B, but it is launched atop expendable Atlas 5 rockets. In the commercial world, every liftoff today ends just like those decades ago, with engines, cases and electronics burned up in the atmosphere, sent to a disposal orbits or dumped into oceans. That includes the 45.7-meter tall first stage of the Falcon 9, and the nine Merlin 1D engines that SpaceX has designed to be reusable.

The U.S. Air Force's X-37B Orbital Test Vehicle taxis on the flightline in 2009 at Vanderberg Air Force Base, California. The secretive spaceplane is part of on-going efforts to develop reusable orbiters

SpaceX has now been joined in the reusability renaissance by two competitors: Airbus, which makes the French Ariane rockets, and United Launch Alliance, the joint venture of Boeing and Lockheed Martin that supplies Delta 4 and Atlas 5 rockets. Success on reusability could mean dramatically reduced launch costs, with Musk regularly predicting that prices could someday shrink to 100th of today's levels.

But achieving reusability will be no easy feat. The Falcon stages have crashed or toppled on two attempts. Airbus has a small prototype of the winged module it wants to build to whisk rocket parts from the fringes of space back to a runway. ULA plans to use a helicopter to grab parts in mid-air, but the concept has not yet been tested in a rocketry context. Perhaps most challenging, the economic underpinnings of reusability — buy it once, use it many times — have not been proven in practice.

"The reason there are no reusable rockets in the world right now is because the business case is awfully tough to close," says George Sowers, ULA vice president for advanced concepts and technologies. "It's never been about the technology to recover and reuse stuff, it's whether you can do that and save money," he says.

How is the industry meeting the reusability challenge? For starters, by accepting some government research dollars but steering clear of the government's visions of spaceplanes roaring down runways and blasting to orbit powered by exotic engines. "We tried to make great jumps," says Daniel Dumbacher, who retired from NASA in

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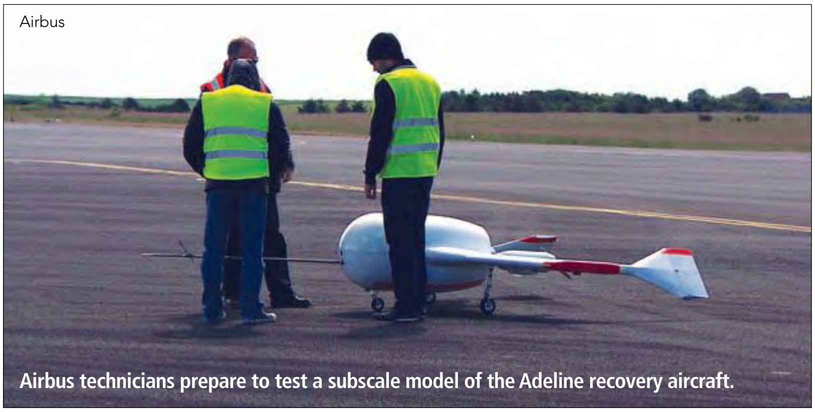
Airbus



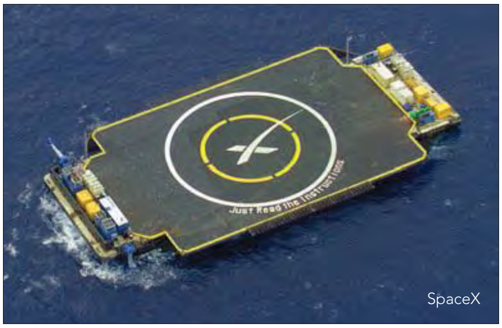
Airbus technicians prepare to test a subscale model of the Adeline recovery aircraft.

2014 and once oversaw the shuttle's propulsion systems, the X-37B when it was still a NASA project and initial work on the expendable Space Launch System. Today, "commercial industry is instead chipping away at the problem."

SpaceX's plans aren't as bold, but they retain the goal of reusing an entire launch vehicle. Airbus and ULA view the economics differently. They want to recover just the most valuable equipment: the rocket engines from the first stages of their future rockets, plus avionics in the case of Airbus.

A key cost driver will be the strategy for bringing the reusable stage or components home. Visionaries of the past wanted to circle Earth and use small rockets or engines to position the craft for reentry and landing back at the launch site or a runway of choice. Reserving fuel for recovery took up mass and volume that could have been dedicated for launch customers, and so reusability enthusiasts have had an epiphany: Why not let the rocket stages or modules fall toward Earth more or less where gravity takes them, and then use rockets, small wings or mid-air grappling techniques to recover them? The components could then be carried back to the launch site or factory by a far less expensive cargo plane, or a barge in the case of SpaceX

Unfulfilled goal: SpaceX's floating platform in the Atlantic Ocean is the intended landing site for the spent first stages of Falcon 9 rockets. Two attempts failed, a third was foiled by a launch failure.



SpaceX

"If you could land downrange, you'll have a lot more payload capacity," says aerospace design engineer John Livingston, who spent more than 40 years with the U.S. Air Force working on space and hypersonic flight projects.

Coming close

Musk's approach to reusability is an incremental one, starting with setting the first stage of a Falcon 9 onto a 52-meter-wide platform floating in the Atlantic Ocean about 200 miles from the Cape Canaveral launch site. The rocket stage has had no trouble finding the platform, but the end game has been trickier. On the first attempt, the booster crashed into the deck. The second time, it managed to touch down, but then tipped over and exploded.

By contrast, Airbus Defence and Space of France is designing Adeline, which stands for Advanced Expendable Launcher with Innovative Engine Economy. It will be a winged module that will carry the first-stage engine and avionics of a future rocket back to a runway landing. Two rotary motor-driven propellers will be unfolded to propel the module. Adeline won't be ready for the first Ariane 6 rockets, but it could be added to later versions.

United Launch Alliance plans to reuse just the two methane-fueled BE-4 engines built by the Jeff Bezos-owned Blue Origin. The engines will be expensive and powerful, providing a combined 1.1 million pounds of thrust for the first stage of the forthcoming Vulcan launcher that will succeed the Delta 4 and Atlas 5.

"The future for reusable rockets looks pretty darn bright after 25, 30 years of false starts," says Livingston. He predicts SpaceX will succeed in landing and reusing a first stage and, eventually, an entire rocket.

Economic questions

Landing on the barge would not answer questions about the economic logic of reusability, something that is far from a no-brainer. Companies would avoid throwing away expensive parts, but those parts would need to be more rugged and, therefore, more expensive to build than those on expendable versions. Plus, after each flight, engineers and technicians would need to test components and refurbish anything that might not last another trip. Reusing rockets or parts of rockets will mean building fewer of them, which tends to drive up unit costs.

Because reusable rockets cost more to build and fly, the idea only pays off if the rockets fly many times and keep up a swift tempo, says Mark Lewis, former U.S. Air Force chief scientist and director of the nonprofit Science and Technology Policy Institute, which is part of the Instiute for Defense Analyses in Washington, D.C. The specific number of flights required and tempo needed to make reusable rockets less expensive than expendables will vary with each launch vehicle. Lewis doesn't know if there is enough demand for all those flights, but he says some people in the space industry are convinced that if launch costs are low enough, new customers will appear.

There can also be surprises, not all of them good ones. NASA's Space Shuttle orbiters cost far more and flew far less frequently than engineers imagined at the outset. NASA wanted to fly shuttles 50 to 60 times a year, with each main engine lasting for 55 flights. Instead, the shuttle launch tempo peaked with nine flights in 1985, and it took a team of 10,000 people nine months to refurbish each orbiter before the next flight.

To operate economically, a reusable rocket will have to be far more rugged than the Space Shuttle, whose main engine components, including the high-pressure turbopumps, had to be removed and inspected after each flight. The ball and roller bearings that supported the turbopump shaft wore out quickly, which added wear and tear on the pump impeller and turbine, according to a 2001 article in the journal Lubrication Engineer. Future reusable rockets should be designed to handle loads "over and above" the ones they are expected to encounter in flight and should include "a propulsion system that can operate when you need it to and how you need it to without a whole lot of tender loving care between missions," says Dumbacher, now a professor of aeronautics and astronautics engineering at Purdue University. "It's not as easy as it looks."

Competing concepts

Airbus, which builds Europe's Ariance rockets, says it will harness unmanned aircraft flight control systems developed by the company's military aircraft arm to bring Adeline's engine module home for a horizontal runway landing. Airbus also will tap re-entry materials and heat shields from its Ariane rocket series. Before Adeline demonstrators begin flying around 2017 or 2018, Airbus engineers will need to develop an aeroshape capable of transitioning from su-

NASA, ULA collaborate on descent tech

NASA engineers looking for a better way to protect Mars landers from the heat of plunging toward the surface have settled on the same solution as engineers at United Launch Alliance, who need to protect the engines of the company's forthcoming Vulcan rockets as they fall back to Earth to be reused. Both camps plan to use inflatable heat shields.

Given their similar needs, ULA and NASA are now discussing a possible joint test in 2018 of the Hypersonic Inflatable Aerodynamic Decelerator technology developed at NASA's Langley Research Center in Virginia. Funding has not yet been identified, but if all goes as hoped, a five- to six-meter inflatable heat shield would be brought back from orbit at a speed of 7.5 kilometers per second.

"This would serve as a half-scale demonstration of what ULA would need for Vulcan and NASA need for the [Mars Entry, Descent, Landing Pathfinder] mission," says Neil Cheatwood, NASA Langley senior engineer for advanced planetary entry, descent and landing systems.

Both groups will need a heat shield of about 10 meters to 12 meters in diameter. ULA plans to use its shield to return the Vulcan's two first-stage BE-4 engines. NASA wants to use its version for the proposed unmanned pathfinder mission ahead of delivering crew and cargo to Mars in the 2030s. Those missions would require a slightly larger shield of 15 meters to 20 meters.

ULA began looking into the technology about six years ago when staff contacted NASA Langley to check out the hypersonic decelerators, long before ULA began work on the forthcoming Vulcan rocket it announced in April.

Debra Werner

NASA has been testing a prototype inflatable heat shield as part of the research to one day land humans and cargo on Mars.

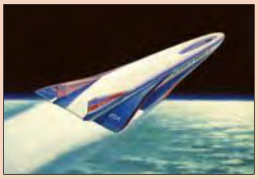
UNFULFILLED QUESTS

Plans for rockets and spacecraft rugged and economical enough for reuse have historically been derailed by high price tags, technical failures or lack of interest. Now, sparked in part by SpaceX, the industry is intensifying efforts to reuse rocket engines or entire first stages.

Here are some of the attempts from the 1960s to the present:

Boeing X-20 Dyna-Soar: *A delta-wing reusable spaceplane proposed by the U.S. Air Force but never flown. The hypersonic glider's nose cap was to be made of graphite and zirconia composite and would of had three retractable struts for landing. Boeing landed the contract in 1959, but the Pentagon killed the X-20 in 1963 for lack of viable military use.*

McDonnell Douglas DC-X: *A low-altitude experimental prototype that took off straight up and landed on its base. Dubbed the Delta Clipper, the DC-X was originally developed for the Pentagon. The conical-shaped, 39-foot unmanned rocket was built by McDonnell Douglas and made its first vertical takeoff and landing in August 1993. It flew 11 more times through 1996 before the technology was transferred to NASA. The agency eventually created the DC-XA (Delta Clipper Experimental Advanced) program but abandoned it in 2003.*



X-30 National Aero-Space Plane: *Secretive program announced in 1986 by President Ronald Reagan, who envisioned NASP as "a new Orient Express" that in two hours would fly from Washington, D.C., to Tokyo. The single-stage-to-orbit vehicle also was billed as a hypersonic space launch vehicle that would take off and land from a conventional runway for aircraft-like operations. Supporters argued that the X-30 would lead to civilian and military derivatives that would ferry cargo and humans to low-Earth orbit. Work on the X-30 ended in 1993 amid budget cuts before any flight demonstrations.*

X-33: *A proposed spaceplane demonstrator intended to clear the way for construction of a cheaper successor to the space shuttle fleet. NASA chose Lockheed Martin in 1996 to design and build the reusable launch vehicle. The agency scrapped the X-33 in 2001, after one of its two liquid hydrogen tanks ruptured during testing.*

Orbital Sciences X-34: *NASA began working on the X-34 in 1996 to build a reliable and reusable spacecraft that would be dramatically cheaper to operate. The unmanned X-34 was designed to travel 50 miles above Earth and reach up to eight times the speed of sound. It made three captive flights in 1999 attached to an L-1011 carrier plane, but never left the ground again. NASA ended the program in March 2001. A review by NASA and Orbital Sciences in 2000 had concluded that changes were needed to ensure the safety and success of the X-34 program.*

Boeing X-40 Space Maneuver Vehicle and X-37 Orbital Test Vehicle: *Boeing received a contract from the U.S. Air Force in 1996 to develop the X-40, a precursor to the X-37 unmanned Orbital Test Vehicle. The X-40, whose shape was reminiscent of the space shuttle, first flew in August 1998 after being dropped from a cradle below a UH-60 helicopter. The Air Force then turned the X-40 over to NASA to use as testbed for the larger X-37 space plane. Then in 2004, NASA transferred the program to DARPA. Two years later, the Air Force announced plans to develop its own variant, dubbed X-37B. The Air Force has shared few details about the X-37B, which in May made its fourth trip to orbit.*

SpaceX Grasshopper: *A 10-story, first-stage Falcon 9 rocket prototype built to test vertical-landing technologies. The Grasshopper was revealed in 2011 when SpaceX applied for an FAA permit to test an experimental reusable launch vehicle. Grasshopper had a single Merlin 1D engine, four steel landing legs with hydraulic dampers, and a steel support structure. Starting in September 2012, SpaceX conducted eight successively higher hops, with Grasshopper reaching 2,440 feet on its eighth and final flight in October 2013. SpaceX retired the Grasshopper that month, and moved on to developing the larger Falcon 9 Reusable Development Vehicle.*

personic to subsonic speeds and a propeller system that can be stowed during the rocket's ascent and unfolded for Adeline's descent, says Benoît Isaac, the Adeline program manager.

As for ULA, the first flights of the Vulcan are planned for 2019, but ULA doesn't plan to start reusing BE-4 Vulcan engines until about 2024, even though they are designed from the start for reusability. ULA will begin recovering BE-4 engines in 2023 to gain experience with the technique and inspect the engines in preparation for reusing them. ULA won't try to recover the Centaur RL-10 engine or the Advanced Cryogenic Evolved Stage engine that will replace it, because they are not designed to be reusable and recovering them would use too much fuel.

On a reusable mission, ULA's Vulcan booster will finish firing, separate from the second stage, and at about 750,000 feet the first stage will jettison a module containing its two BE-4 engines. The module will inflate a heat shield to slow its descent and minimize damage during atmospheric reentry. A parafoil and tether will be released closer to the ground and a heavy-lift helicopter will grab the tether. ULA hasn't determined which heavy lift helicopter it will use.

"Midair recovery is not very difficult," Sowers says. "We have follow-on recovery plans that we are not yet ready to reveal. This is the incremental approach to reusability."

ULA initially studied the pros and cons of recovering Vulcan's entire first stage — rather than just the two engines — and it found that approach would lead to higher costs than an expendable rocket.

"It doesn't payoff to recover the fuel tanks," Sowers says. Bringing back the BE-4 main engines does make sense because those engines comprise 25 percent of the booster's weight and 65 percent of its cost.

Midair recovery has been around since the 1960s when the Central Intelligence Agency's Corona spy satellite ejected 70-millimeter film in a reentry capsule. ULA and Airbus are drawing on state-of-the-art materials and technology to refine their competing techniques.

NASA's Langley Research Center in Hampton, Virginia, is working with ULA to develop inflatable heat shields to protect Vulcan's booster engines during multiple atmospheric reentries. The heat shields, which Langley has been developing for about a decade, look like a stack of donuts that peaks above the tip of the rocket. Each donut is comprised of a synthetic polymer covered with a layer of flexible, high-temperature insulation.

Funding

Airbus, ULA and SpaceX each receive some government funding for their launch programs, but they have largely conducted reusable rocket studies with internal research and develop funds. Airbus, for instance, has invested about 15 million euros on Adeline since the project began in 2010, Isaac says.

That private backing gives these ventures an important boost, rocket experts say, because while government is good at pushing the technology envelope, private enterprise is good at honing in on the problem and finding creative, cost-efficient solutions. Startups like SpaceX and Blue Origin tend to be more inventive, flexible, efficient and fast, Livingston says.

"That's the drive that's going to lead to reusable rockets in a reasonably short amount of time," he adds.

Anxious for reusable rockets

A SpaceX animation online shows two Falcon Heavy first stage boosters, the rocket's upper stage and the Dragon cargo and crew capsule launching and then landing separately on a cluster of pads at a seaside launch site. The parts then would be reassembled for the next launch. That scenario might be years away, but SpaceX already has leased landing pads for Falcon 9 and Falcon Heavy boosters at Cape Canaveral in Florida and at Vandenberg Air Force Base in California. SpaceX began flying a low-altitude experimental vehicle called Grasshopper in 2012 at its test range in McGregor, Texas, to practice landings. These flights that paved the way for the barge attempts.

Rocketeers are anxious to see the competitors make progress toward that type of fully reusable rocket, they concede that the incremental approach makes a lot of sense.

"One thing we've learned in aerospace writ large is crawl, walk, run," Lewis says. "If you try to run or even walk before you're ready, you fall."