November 2014

AEROSPACE AMERICA

ORION

The 4-hour flight and fiery re-entry that could give NASA its mojo back

page 24

Proactive on cybersecurity/page 30

Earth-observing Sentinels/page 34

Aireon's Thoma on airliner surveillance

page 22

A PUBLICATION OF THE AMERICAN INSTITUTE OF AERONAUTICS AND ASTRONAUTICS

Preparing to install Orion's heat shield at Kennedy Space Center in anticipation of its Dec. 4 liftoff.

TIME TO FLY

If NASA is going to deliver astronauts to Mars or an asteroid, Lockheed Martin is designing the crew capsules that will take them there. The Orion project has been unfolding for years in board rooms and cleanrooms, but things will get real on Dec. 4 when an unmanned test version blasts off from Florida. Natalia Mironova describes the road to Exploration Flight Test-1 and the technical challenges to come.

If all goes as planned, an unmanned Orion multipurpose crew vehicle will splash down in the Pacific Ocean southwest of San Diego on Dec. 4, having ventured 3,600 miles into space, farther than any crew vehicle has gone since the Apollo 17 mission in 1972. This early version of an Orion capsule will be coming back hot because of a trajectory designed to partially mimic a deep-space mission. The craft will plow into the atmosphere at 6.8 miles per second — that's 80 to 85 percent of the velocity of a trip back from the neighborhood of the moon, where NASA plans to park an asteroid someday. The velocity will beat the 4.7 miles per second re-entry speed of the shuttle orbiters. The result will be melting-pot temperatures of 4,000 degrees Fahrenheit around some parts of Orion.

To survive this, Orion will enter base first like an Apollo capsule and it will be protected in part by an updated version of the same protective foamlike Avcoat material that shielded the Apollo capsules.

If following the Apollo template — but with a capsule 30 percent larger — was supposed to make it easy for NASA and Lockheed to get to Exploration Flight Test-1, that has not been the case. Textron, the Avcoat provider, had to repair cracks discovered in Orion's heat shield in 2013 after a curing process. Lockheed Martin and NASA engineers also had to change the shape of the capsule's launch abort aeroshell to reduce the aerodynamic noise astronauts would hear during an abort. Then there is the issue of spacecraft mass: The EFT-1 version of Orion is within its mass limit, but the Government Accountability Office cautioned earlier this year that mass could become a problem as NASA closes in on the first crewed launch in 2021.

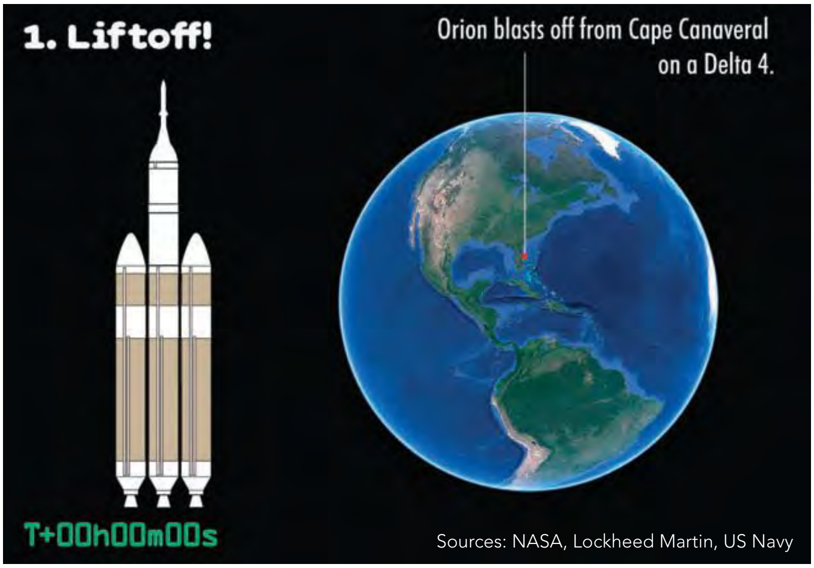
For Lockheed and NASA, the stakes on Dec. 4 could not be higher. A smooth mission would be a confidence builder that could shore up faith in the U.S.' decision to shelve its desire for a single-stage-to-orbit space plane in favor of a simpler capsule and rocket approach.

A maxim among engineers is that tests like EFT-1 are designed to find problems. No matter how things go, Orion advocates are confident they'll learn whatever technical lessons will be required to ultimately succeed. "If we do EFT-1 and the heat shield cracks on us and we end up having a problem because the heat shield failed, that's actually a good test because then we know the limits. We'll have enough instrumentation on there to be able to understand what happened," says Dan Dumbacher, a former NASA deputy associate administrator for exploration systems development and now a professor at Purdue University.

This artist concept shows Orion and its upper stage as they will appear in the Exploration Flight Test-1 mission.

NASA

By Natalia Mironova



Launch illustrations by Anatoly Zak

Survival plan

The attraction of Apollo was the shape's proven ability to handle high-speed re-entries. "We did look hard at other ideas, but it turns out the physics are the same and the shape still makes sense for this kind of mission," says NASA's Mark Geyer, the Orion program manager. Once the engineers determined that they would be using the basic capsule shape of Apollo, they could draw on actual flight data from the Apollo landings. Engineers "have the benefit of all of that previous history — 12 or so full-scale re-entries," says Larry Price, Lockheed's deputy program manager for Orion.

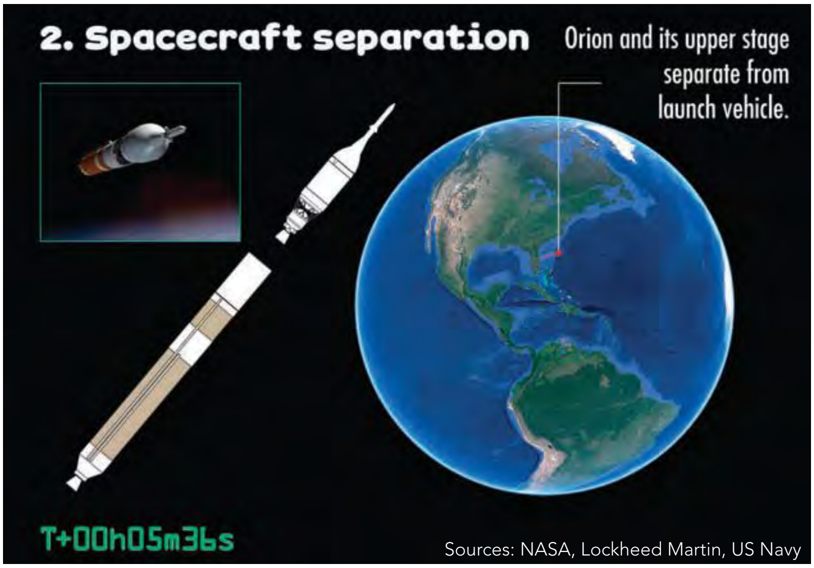
At the top of EFT-1's list of test objectives will be to evaluate its thermal protection system, which borrows from Apollo and also the space shuttle program. When Orion plows into the atmosphere, it will be protected by a dish-shaped, multilayered heat shield covered by Avcoat, an updated recipe of the ablative, or meltable, material that protected the Apollo capsules. Unlike Apollo, Orion will have shuttle-derived protective tiles instead of Avcoat on its conical back shell, which is possible because the back shell won't be subject to as much heat.

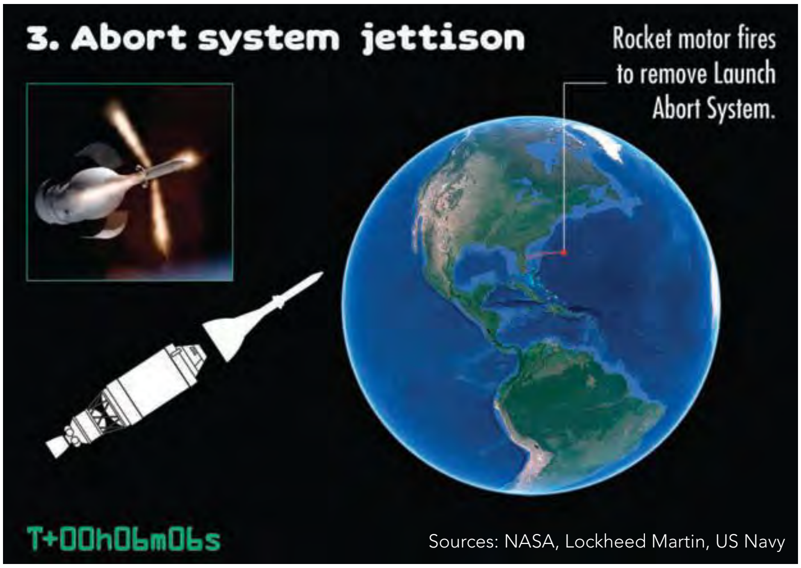
As with everything on Orion, mass was a big driver in the decision to use a combination of these technologies. The heat shield's foamlike Avcoat filler is fairly light, but the honeycomb framework and the titanium structure required to support it will bring the heat shield's weight to 4,000 pounds — that's on average 39 pounds per cubic foot compared with the tiles on the exterior of the shuttle orbiter that weigh 13 pounds per cubic foot.

Using both technologies — Avcoat and the tiles — made for a lighter overall thermal protection system. "If you are lighter you can go further for the same amount of propellant," explains Price.

Relying on a familiar heat-shield material had its advantages, but it also has brought its share of challenges. Avcoat is a mixture of epoxy and phenolic resins with several types of glass fibers and phenolic microballoons inside a glass-reinforced honeycomb structure. On Orion, this is bonded to a titanium framework covered in carbon fiber sheets up to 2 inches thick. GAO in its 2014 "Assessments of Large-Scale Projects," cautioned that thermal expansion during a flight could cause cracks to develop between the "ablative material and the underlying shield structure."

Textron says it used "Apollo proven techniques" to fix thermal expansion cracks that developed during curing, and that no cracking was found after stress tests on the Avcoat and its carrier structure.





withstand extreme pressure loads.

Even with all the efforts to shave mass, the GAO cautions that Orion is 2,800 pounds over the current maximum takeoff limit of 73,500 pounds for the next Orion launch, an unmanned flight called Exploration Mission-1 planned for 2017. "The mass of the spacecraft remains a top program risk," GAO says in its annual assessment. EM-1 will be the first flight of Orion on the new Space Launch System rockets, and GAO says NASA plans to solve the mass problem by relying on the performance of SLS and adjusting the load, mission duration and size of the crew on future crewed flights.

Lockheed says it is fully aware of the mass issue. "For Exploration Mission-1, we have a design that closes on mass, however we have identified some threats to that plan. Those threats are typical for a spacecraft development program and we do not anticipate any issue meeting the mass requirement," says Carol Martin, Lockheed Martin's Orion Exploration Mission director, by email.

A separate concern is that micro-cracks could develop within the Avcoat because of the long-term exposure to deep space. These micro-cracks ultimately were not a problem for Apollo or later missions, but Orion will be in the cold of space longer and will re-enter hotter.

Lockheed doesn't expect micro-cracking to be a problem during EFT-1 because, at just over four hours, the flight won't be long enough to subject Orion to extreme cold, and the company says it is looking at "potential modifications" to prevent micro-cracking on longer missions. But it's impossible to perfectly recreate deep space in a lab, so engineers will still be interested in inspecting the shield for signs of cracks after the December test flight. "We want to gather data in flight and see how Avcoat performs at 4,000-nautical-mile entry as well as future flights and determine if the cracking is a problem or not," says Price, who describes Avcoat as a brittle material.

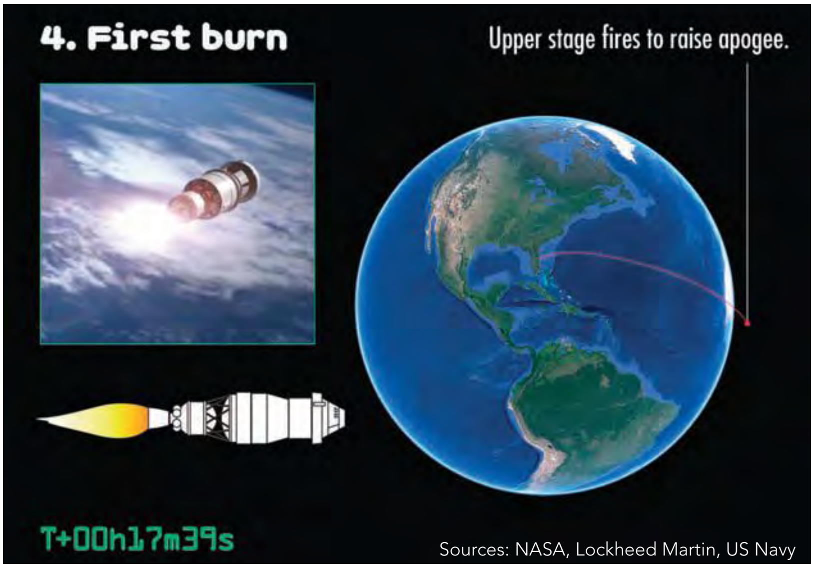
"There is a strong belief that as the material melts and ablates away, it would fill any of those micro cracks," he says. In the end, the team had to compromise to pick the best thermal protection material that was structurally solid and worked within the weight limitations. "Nothing is perfect."

Weight watching

Mass limits are hot on the team's mind too. Orion's pressure hull, for example, is made from aluminum lithium alloy — the same material used to build the shuttle's external tanks — because it is lightweight yet able to

Whisking astronauts to safety

Re-entry is risky, but so is launch. A detach-

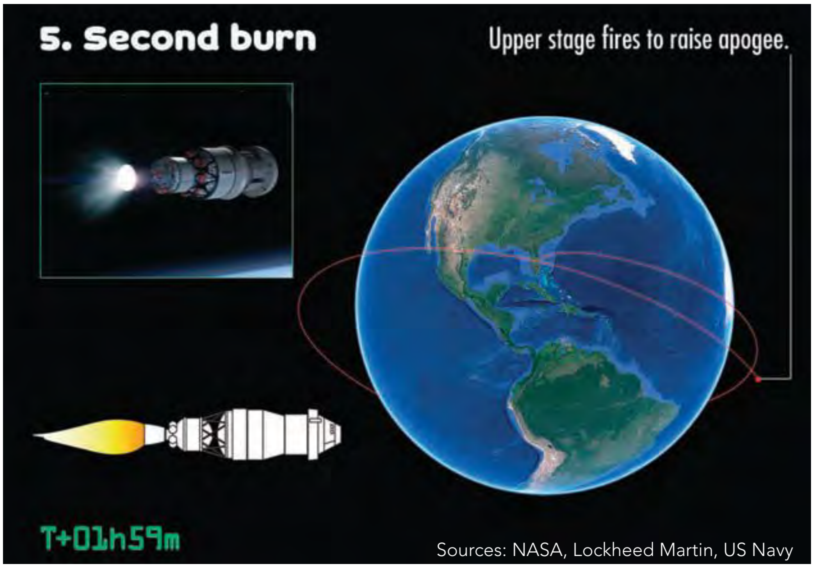


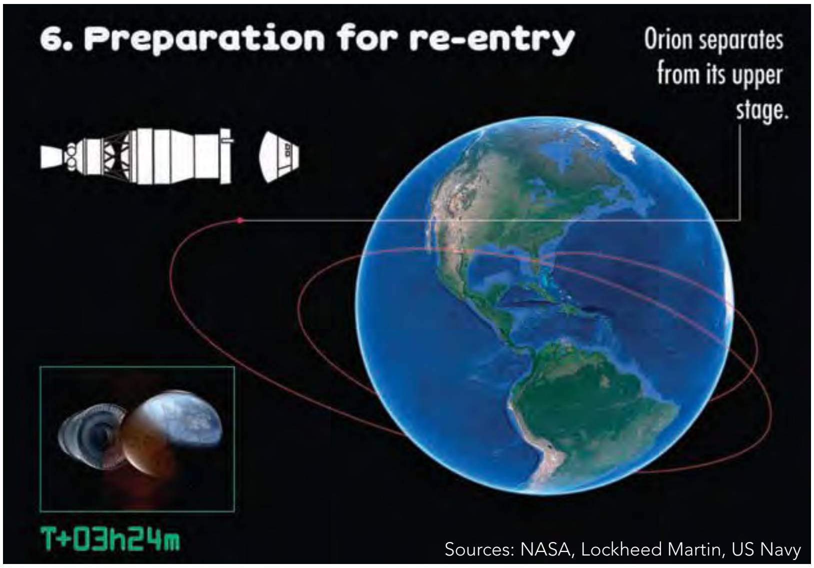
The launch abort system is lowered by crane for installation on the Orion spacecraft for Exploration Flight Test-1 inside the Launch Abort System Facility, at NASA's Kennedy Space Center.

able system of solid rocket motors and an aeroshell will ride atop Orion during ascent and will pull the capsule away from an exploding or out of control Space Launch System vehicle. The GAO warns that a funding shortfall has pushed the next test of the abort system to 2018, which might not leave enough time to fix any problems before the first crewed flight planned for 2021. The launch abort system won't be fully operational in the December test.

The first abort test in May 2010 became something of an Internet video sensation. The Orion mockup is seen soaring a mile into the air. If humans had been aboard, they would have experienced a jolt of 15 Gs that would push them deep into their seats and make it difficult to move and even breathe for the 4.5 seconds of the abort motor burn. A variable-thrust attitude control motor keeps the stack correctly oriented until a jettison motor pulls the launch abort system off the crew module so the capsule can deploy its three parachutes. The 2010 test "was almost perfect. It's a very big deal," says NASA's Geyer. "All three of those motors had to work perfectly, the parachutes had to work, and it worked like a charm."

Engineers learned a valuable lesson from a static test with the abort motor. The noise inside the capsule would have been excessive for the astro-





nauts, so NASA and Lockheed decided to bend the walls of the aeroshell into a curved ogive shape. The 2018 flight would be the first abort test of the new shape. If something goes wrong during the launch in December, there will be no saving Orion, since it will fly with an inert abort and attitude control motor. Only the jettison motor will be operational because it must remove the aeroshell and stack from Orion once it is through the atmosphere.

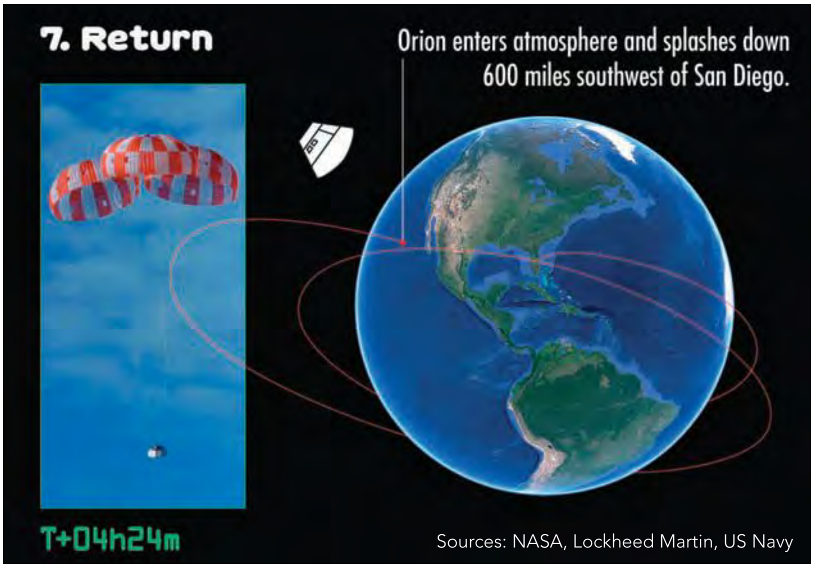
On the inside

The similarities to Apollo are obvious but mostly skin deep for Orion. "On the outside it may look like an Apollo spacecraft, but on the inside it's nothing at all like Apollo," NASA Administrator Charles Bolden told Aerospace America earlier this year.

Orion's interior will draw from the best of the computing revolution sparked in part by the technology investments of the Apollo program. "If you look at a picture of the Apollo control panel — it's fascinating — you see a lot of buttons and switches. So that's how they controlled things, through switches. Ours is now automated; it looks like a touch screen that you see with the fancier computers today and the crew can go through their critical procedures, do all their commands with those screens," says Geyer. Though they look like touch-screen panels, the crew members on future flights will use a mouse-like device in their seats or buttons along the side of the three panels to access the computer. This will avoid accidental pressing of touch-screen buttons by random objects floating around.

The crew interface system won't be used much on a mission that goes smoothly. Even the launch abort system was initially intended to be autonomous or triggered by mission control. Astronauts asked for and have received the ability to trigger it, one contractor says.

These crew interface panels won't be flying during EFT-1. Mass simulators will be used instead. The vehicle management computer — the avionics system supplied by Honeywell Aerospace — will be fully operational though. The VMC is a single electronics unit composed of four computer modules that execute flight control and connect to the communication and tracking equipment. The system is similar to the one currently flying on the Boeing 787 Dreamliner aircraft, beefed up to withstand the radiation, vibration and high temperature requirements of deep-space travel, according to Lockheed Martin's Orion avionics director, Paul Anderson. Some of the test flight objectives include learning how this new computer system will perform under the stresses of Van Allen belt radiation and high-speed re-entry.



Sources: NASA, Lockheed Martin, US Navy

One aspect that will always be challenging for the crew on a long mission is the volume of Orion. On a lunar-class mission, an Orion crew of four might have to spend up to 21 days in a space measuring 305 cubic feet — about twice the passenger volume of a Ford Explorer and eight times smaller than the 2,625-cubic-foot crew compartment of a seven-crew-member space shuttle orbiter. That's not as small as it sounds, suggests Geyer: "The great thing about zero G [is that] once you get into space you can use the ceiling. Normally on the ground there is all this unused space, but you're floating around and so it's actually much bigger volume when you are in zero G because people can be on the ceiling, on the floor, on the sides. You get to use the space much more efficiently."

The truth is that squeezing astronauts into an Orion is a problem that many at NASA are anxious to have. As much as anything EFT-1 will be a tangible step in that direction.

"If we're actually going to do this, if we're actually going to push out beyond the moon and try to go to Mars, it will take daring. It will not be something for the timid," says NASA's Todd May, program manager for the Space Launch System.

Ben Iannotta contributed to this report.