September 2014

AEROSPACE AMERICA

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A PUBLICATION OF THE AMERICAN INSTITUTE OF AERONAUTICS AND ASTRONAUTICS

Surviving a bad day

Veteran astronaut Tom Jones understands spaceflight safety issues firsthand, having experienced a space shuttle master alarm before one of his four missions. Jones takes a look at the abort and escape systems in the coming generation of crew spacecraft, from Orion to the planned commercial spacecraft.

On a hazy, humid Florida morning 20 years ago — August 18, 1994 — I was strapped into shuttle Endeavour for the dawn launch of STS-68, the second Space Radar Lab mission. My crewmates and I braced against the jarring rattle of main engine ignition, which shook the entire shuttle stack with more than a million pounds of thrust. Just 1.5 seconds before solid rocket booster ignition and liftoff, we instead heard through our headphones the shocking clamor of the master alarm. Pilot Terry Wilcutt called "Right engine down!" as the engine roar died, and we realized we had a pad abort.

Jeff Wisoff and I, stationed on the middeck, threw off our seat straps and parachute harnesses and prepared to swing the hatch open for an emergency egress. If a fire or explosion had threatened the shuttle stack, which turned out not to be case, we had just one option: Get out as fast as we could and scramble across the swing arm for a 55-mph, quarter-mile ride down the slidewires to what we hoped was safety.

NASA

In an emergency, a rocket assembly would drag an Orion crew capsule away from the launch vehicle and reorient it for a safe landing under a parachute.

Slidewires and parachutes have inherent limitations, and they couldn't save the Challenger or Columbia crews. The new generation of spacecraft will have to do better. Assuring crew escape and survival on a "bad day" will be key elements of the winning proposals when NASA awards commercial crew service contracts, probably by late September, for transportation to the International Space Station.

Tugging Orion

NASA's current commercial crew requirement calls for the probability of loss of crew during ascent to remain less than 1 in 500. What this means in terms of escape design is that during launch, the crew vehicle must get away fast enough to escape the failed launcher's expanding blast wave.

Getting NASA's 23-metric-ton Orion spacecraft free from a failing Space Launch System booster early in the ascent would be no small challenge. Lockheed Martin chose to attach a rocket assembly at the top of the capsule to drag the capsule away from the launch vehicle and reorient it for a safe landing under a parachute. This tractor-motor-based Launch Abort System is similar to the solid-rocket-powered escape systems on Mercury, Apollo and Soyuz. (In 1983, the Soyuz T-10-A launch abort system pulled its crew module free of a leaking, burning booster on the pad, saving the two cosmonauts.)

In the case of the Orion's Launch Abort System, the crew module would be pulled away by a solid-fueled abort motor that fires upward into a reverse-flow manifold, whose four nozzles protrude from the body of the abort rocket assembly to direct thrust downward. The reverse-flow design yields a lighter, more compact propulsion stack — called an escape tower — than the lattice-mounted Apollo motor. ATK supplies the 400,000-lb thrust, composite-case abort motor and also an attitude control motor whose variable thrust vents would guide the tower, shroud and capsule away from the launch pad or booster. Once the crew module is safely away, an Aerojet Rocketdynesupplied jettison motor would separate the tower assembly from the crew module.

The Orion reverse-flow configuration was flight tested at White Sands Missile Range in 2010 during Pad Abort 1. The test showed how the motor would pull Orion clear of a pad emergency and then position the capsule for shroud separation and main parachute opening. Steve Sarah, ATK's Launch Abort System program director, says the test validated the system design and verified performance predictions.

After that test, the LAS development program slowed, Sarah says, but it is gearing up again for a series of Orion tests. ATK has switched from a steel flow manifold to a lighter, stronger version made of titanium and has changed the propellant grain to reduce acceleration loads on Orion and the crew. "We have an igniter qualification test in September, and a qual test on the new titanium manifold coming up," says Sarah. On its first orbital flight scheduled for Dec. 4, Orion will fly unmanned and with an inert abort motor. Only the jettison motor will be live during Exploration Flight Test-1. A high-altitude Ascent Abort 2 test is planned for sometime in 2018.

Rex Walheim, chief of the Astronaut Office's Exploration Branch, says the Orion LAS offers comprehensive abort protection. "Even after the LAS tower is jettisoned, Orion can still separate propulsively from the second stage all the way to orbit," he says. Orion can't steer to a "specific splashdown point" near rescuers, he adds, but that's not a problem because a deep space liftoff would take the crew over relatively warm Atlantic waters with no risk of a splashdown in the frigid, remote North Atlantic.

A shove to safety

Unlike Orion and early crew capsules, SpaceX's Dragon capsule would be pushed to safety from below rather than pulled. This pusher approach "is an improvement over Mercury or Apollo," says shuttle and space station astronaut Garrett Reisman, now the senior engineer for astronaut safety and mission assurance at SpaceX. Those tractor systems jettisoned their towers a couple of minutes into the flight, but "Dragon retains its LAS all the way to orbit, all the way to the end of powered flight," says Reisman. This allows the crew "to abort even in the second stage," and to thrust so as to splash down close to rescuers near north Atlantic coasts.

SpaceX

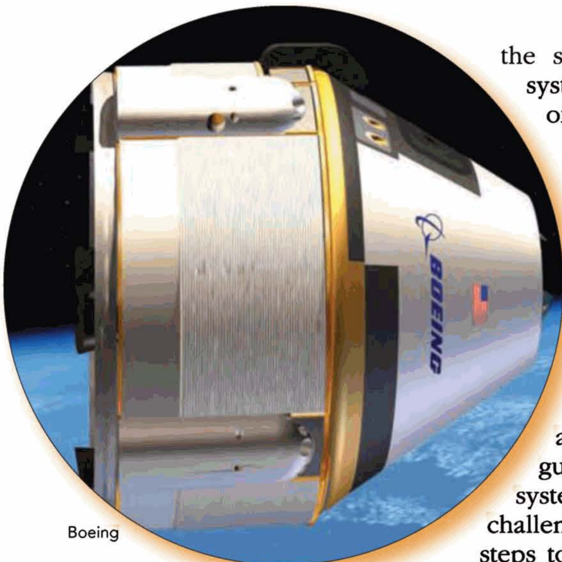
The Dragon V2 from SpaceX. Unlike Orion and early crew capsules, it would be pushed to safety from below rather than pulled.

"By using a pusher syst we reduce our failure mode cause there's no tower to routinely on every ascent," Reisman adds. "We don't have to worry about jettison failure."

The Dragon Version 2 houses its abort fuel in streamlined blisters along the capsule's sides; they feed eight SuperDraco abort motors, each with 16,000 pounds of thrust for clearing a failing Falcon 9 booster. "The engines have a very quick response time, measured in fractions of a second. They also give us active attitude control during the abort," says Reisman.

On a nominal flight, where the abort system is not activated, the engines and excess fuel can be used for orbital maneuvering and rendezvous. "Essentially," Reisman says, "we're using our ejection seat on every mission,

A stack of solid rocket motors, called an escape tower, would blast an Orion crew away from a failing launch vehicle.
NASA



Boeing

Boeing's CST-100 capsule. Unused fuel from its abort engines could be used for rendezvous and docking or space station reboost.

rather than very rarely, and we gain greater confidence in our system, so we'll know it works." Eventually, SpaceX plans to use unspent abort propellant to brake Dragon to a guided, soft touchdown on land.

The company plans a series of qualification and flight tests to demonstrate system performance at the extremes of the abort envelope, says Reisman. In addition to a pad abort test, SpaceX will fly a test out of Vandenberg Air Force Base "to show we can escape a Falcon 9 very close to the maximum drag case, near Max Q," maximum dynamic pressure.

The Boeing push

Boeing's CST-100 capsule, like Dragon's, is designed with a pusher abort system. Its launch abort engines will be below the heat shield in a service module. All the abort propellant will be below the heat shield, "which is where you want it," says Chris Ferguson, who commanded NASA's last shuttle mission and is now Boeing's director of crew and mission operations. "If you store your abort prop above the heat shield, you will run into size problems or reduce your payload."

The engines each have a thrust of about 40,000 pounds. The service module also includes maneuvering thrusters in "dog houses," similar to the shuttle's orbital maneuvering system pods, carrying two types of engines: the orbital maneu- ing and control motors, and wer-thrust reaction control system jets. These jets are more powerful than the shuttle's vernier jets, at 25 pounds of thrust each, but have a rapid cycle time for very precise control.

Ferguson acknowledges that a pusher design requires a more complex control and guidance system than a tractor system, but "we recognize that challenge, and we're taking active steps to minimize the impact of the aerodynamic factors you encounter around Max Q."

On a northeasterly ascent trajectory from Kennedy Space Center toward the international space station, the CST-100 LAS will have no "black zones" — abort regions that are unsurvivable because the cabin or crew cannot survive extreme deceleration loads. Ferguson says, "Late in the ascent we might use the abort system to reach a safe orbit, like a shuttle AOA [abort-once-around], where we know we've lost the mission but we can use the propellant to get to orbit and then perform a normal reentry."

On nominal launches, CST-100 can use saved abort propellant for rendezvous and docking margin as well as space station reboost.

DreamChaser

Sierra Nevada's DreamChaser resembles a mini-shuttle, but unlike NASA's orbiters, the stubby lifting body would provide full launch abort capability. Steve Lindsey, former shuttle commander and Astronaut Office chief, is Sierra Nevada's senior director of Space Explorations Systems. He says DreamChaser will use a pair of hybrid abort motors to push the vehicle rapidly clear of a failing Atlas 5 rocket. "One disadvantage of a tractor abort system," he says, "is that during separation it has to overcome a suction effect created between the spacecraft and booster. The pusher motors eliminate that problem; you get to safe separation with less thrust."

Boeing

The CST-100 in an artist's rendering. Its two launch abort engines each have a thrust of about 40,000 pounds.

Sierra Nevada

Sierra Nevada's DreamChaser. Its two hybrid abort motors would push the capsule clear of a failing Atlas 5 rocket.

The DreamChaser engines, which burn synthetic rubber — hydroxyl-terminated polybutadiene — and nitrous oxide, are positioned on opposite sides of the craft's aft fuselage. "The engines' time to 90 percent thrust shows we'll have no significant risk of asymmetric thrust, and we'll eliminate any worry through testing," says Lindsey.

"DreamChaser will be able to execute an on-pad abort and land back at the Shuttle Landing Facility, a maneuver similar to the shuttle's RTLS [return to launch site] abort mode. Unlike the orbiter, though, we'll have no risk of re-contacting an external tank," he says. "Our plan is that for ISS missions, we can abort to runways anywhere along the ascent profile." These include East Coast or transatlantic airfields. If DreamChaser cannot make it to a runway, the crew can jettison the aft docking hatch and bail out to a water landing. "Late in the ascent we'll have the ability to abort to orbit," Lindsey adds.

He says that on a nominal ascent, DreamChaser will arrive in orbit with about 40 percent excess delta-V, the ability to change velocity over that needed for its nominal mission. "We'll be able to use that prop in orbit for very creative purposes." The abort engines "have completed full-duration abort burn testing, as well as nominal mission firings," says Lindsey.

In designing its safety system, Sierra Nevada applied experience from its role as supplier of the motors for the SpaceShipOne and SpaceShipTwo suborbital space planes.

Escaping the pad

The Apollo 1 fire in 1967 showed the need to provide for the crew's rapid escape during a launch pad emergency. In the shuttle era, crews would have reached the safety of a blast-resistant bunker via the slide-wire baskets at the pad's 195-foot level. The challenge with that kind of system, says NASA's Walheim, is that "the SLS pad is much higher than with shuttle, and you can get going pretty fast on a long slide wire like that. But that can be engineered. We not only need the slide wires for the crew; the pad personnel need a way out, too."

To provide rapid ground egress at Atlas 5's launch Complex 41, CST-100 and DreamChaser will use a swing arm, slide wires, and perhaps a high-speed elevator to exit the pad area. "Essentially, we'll give the crew a fire escape," says Boeing's Ferguson, referring to the CST-100. "My preference would be to leave the pad safely via ground egress, rather than fire an ejection seat-type system [the LAS] and put myself in a different, dynamic emergency situation."

CST-100 crews, like those on Apollo, will use their capsule's side hatch for egress. On the pad, DreamChaser astronauts will use the cabin's overhead hatch for rapid access to the swing-arm.

Over at Kennedy Space Center's Complex 40, SpaceX plans to add slide wires and a high-speed elevator to give Dragon crews a path to safety.

Orion and the commercial spacecraft all have the option of using "the equivalent of a zero-zero ejection seat," which enables them to leave the pad vertically, via rocket-powered pad abort. "We don't want crews descending the launch pad into a fire or explosion situation," says Sierra Nevada's Lindsey.

The abort decision can be made not just by the booster's automatic fault sensing systems, but also by the launch control center or the astronauts. The call is made only if the booster and pad are headed for a structural failure or imminent explosion.

My STS-68 crew was the last to experience a pad abort. When our right engine shut down at T-1.5 seconds, we didn't yet know the cause. Had there been a serious fire or explosion, our only way out was through the side hatch, across the swing arm and pad structure, and down the wire — an awfully long path to safety with a hydrogen fire brewing. Launch controllers quickly determined we'd had a safe shutdown, with no fire danger, so we exited normally about 45 minutes later.

NASA and its commercial suppliers plan to do a lot of flying beginning in 2017; planning for the worst case now can give crews a fighting chance at survival, on the pad and during ascent. The stars may be your destination, but you'd better have options if your booster balks.

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