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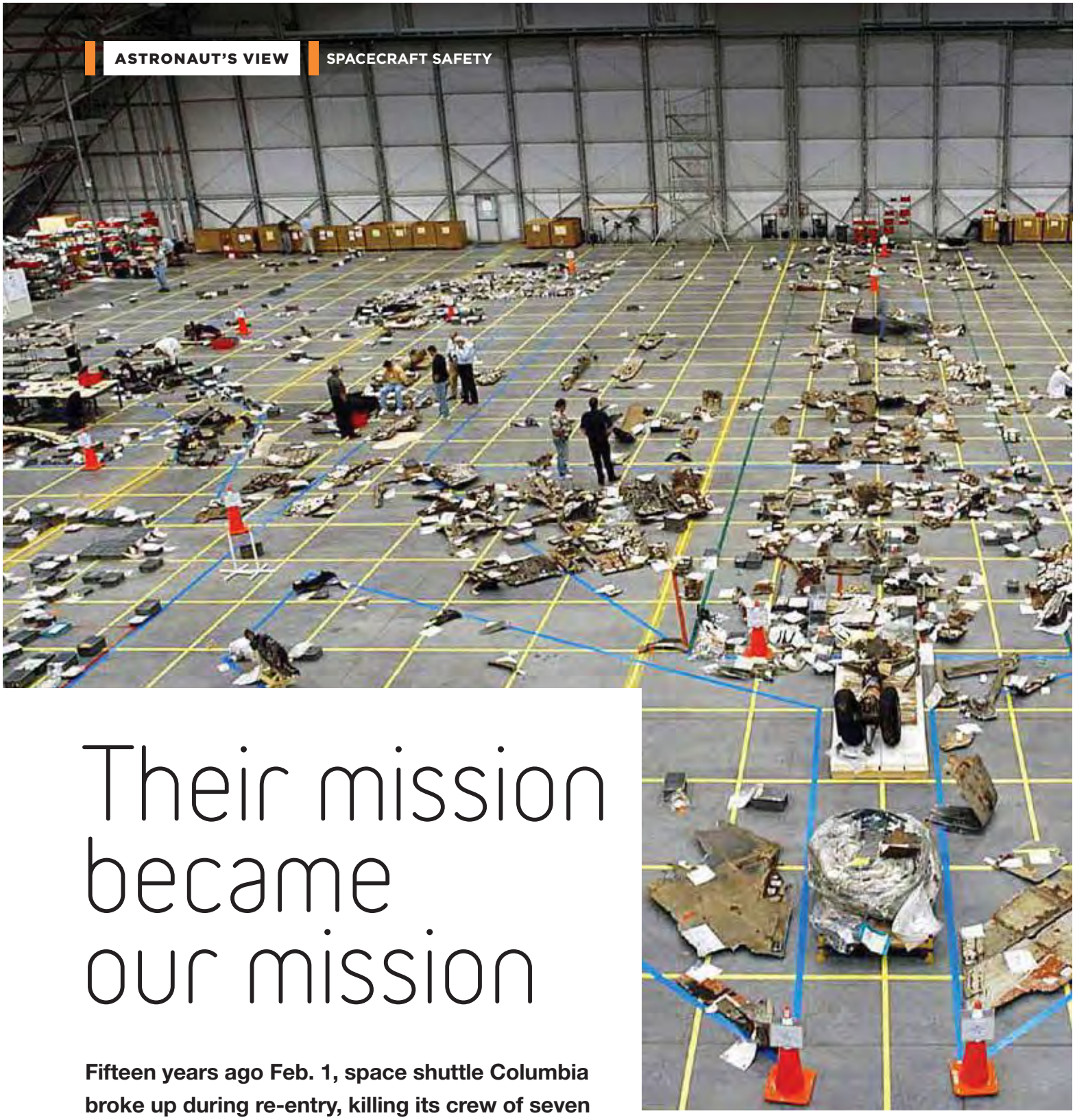

Their mission became our mission

Fifteen years ago Feb. 1, space shuttle Columbia broke up during re-entry, killing its crew of seven and scattering wreckage across east Texas and Louisiana. Veteran astronaut Tom Jones, who flew on Columbia in 1996, describes how NASA is using the recovered wreckage and lessons drawn from the accident to reinforce a culture of flight safety.

By Tom Jones | Skywalking1@gmail.com

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▲ **Reconstruction of Columbia** debris in a hangar at Kennedy Space Center. The process paid special attention to recovered fragments of the heat shield tiles and left wing reinforced carbon-carbon panels at the site of the foam impact.

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▶ **The STS-107 mission astronauts** leave crew quarters at Kennedy Space Center on launch day. Rear, from left to right: Ilan Ramon, Michael Anderson, David Brown. Front, from left: Kalpana Chawla, William McCool, Laurel Clark and Rick Husband.

On Saturday morning, Feb. 1, 2003, I watched on television as shuttle orbiter Columbia, once my spacecraft, headed home from its 28th space mission. Minutes later, with contact lost with the STS-107 mission crew, I knelt in a prayer for those astronauts — my friends. None of us can forget those brilliant streaks etched across the skies of Texas, proof that ship and crew were gone.

Columbia's story didn't end with its searing breakup 60 kilometers (200,000 feet) over Texas. The orbiter's physical remains and lessons from this terrible, preventable accident are teaching a new generation of spacecraft operators and managers how to prevent a future spaceflight tragedy.

Bringing Columbia home

A new book, "Bringing Columbia Home: The Final Mission of a Lost Space Shuttle and Her Crew," tells how thousands of Americans strove to recover Columbia and its crew, while NASA studied physical and electronic evidence to determine the cause of the accident. The authors are Michael Leinbach, who was STS-107 launch director at Kennedy Space Center in Florida and led the Columbia Reconstruction Team, and space historian Jonathan Ward. Together, they capture the unceasing, three-month effort that mirrored the dedication of STS-107's astronauts, and serves today as an example of the perseverance and focus needed to ensure safety in a new generation of spacecraft.

What happened that February morning still commands sobering attention. Columbia was struck during its Jan. 16 launch by a chunk of insulating

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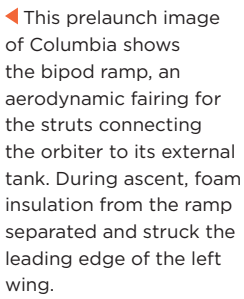

This prelaunch image of Columbia shows the bipod ramp, an aerodynamic fairing for the struts connecting the orbiter to its external tank. During ascent, foam insulation from the ramp separated and struck the leading edge of the left wing.

foam ripped from its external fuel tank 81 seconds after liftoff. The foam was seen on video slamming into the leading edge of the orbiter's left wing. Ascent imagery analysis during the 16-day mission did not reveal any explicit impact damage, and the astronauts themselves could not see the possible impact site from the crew cabin. Nor was the robot arm and its inspection camera installed on this flight. Some flight controllers expressed worry over the re-entry consequences if the thermal protection system had been compromised. These concerns did not reach the mission management team, and a spacewalk inspection (which would have revealed the damage) was never ordered. Mission Control relayed word to the crew that the potential impact damage had been assessed to be insignificant.

Cleared for re-entry, Columbia's crew was unconcerned as their ship streaked into the upper atmosphere at 25 times the speed of sound. But the leading edge of the left wing had indeed been breached, and hot re-entry plasma blazed into the wing and melted its internal aluminum structure. At Mach 18 or 19,000 kph the left wing failed, causing loss of control and disintegration of the orbiter. Debris rained down over a 400-by-30-kilometer swath from Dallas to the Louisiana border.

As heartbreaking video of the breakup splashed across TV screens at the launch control center, NASA Administrator Sean O'Keefe leaned over a desk and asked softly, "I wonder how many people on the ground we just hurt."

Finding Columbia

Within hours of the disaster, NASA had a rapid response team headed for the impact zone. At the newly established command center in Lufkin, Texas, David King, Marshall Space Flight Center's deputy director, took charge of the effort with superb support from the Federal Emergency Management Agency, the Environmental Protection Agency, the FBI and local agencies. His interagency team set immediate priorities:

1. Protect the public.
2. Find and recover Columbia's crew members.
3. Recover the orbiter debris crucial to identifying the cause of the accident.

The air, land and water search eventually grew to involve 25,000 Americans, the largest ground search in U.S. history. The local populace pitched in, determined to help "their" space program in any way possible. Volunteers set up a round-the-clock cafeteria for searchers in the Hemphill, Texas, VFW hall. Astronauts deployed to the area to aid the search for the crew, thank workers and maintain morale.

Search for the crew

Locating the crew was extremely important to the STS-107 families, their astronaut colleagues and NASA's close-knit personnel. The Flight Crew Operations Directorate at Johnson Space Center worked closely with the FBI, Texas law enforcement and the National Guard to mount the search. By calculating the post-breakup trajectory of the orbiter's crew cabin, confirmed by the impact sites of cabin wreckage, search teams pinpointed a second-day search box stretching from Nacogdoches southeast to Hemphill.

As searchers located crew cabin components, astronaut equipment and eventually human remains, the search narrowed to a strip of land south of Hemphill and west of the Toledo Bend reservoir. The painstaking effort found the astronauts, one by one, most within a 2-by-8-kilometer corridor. FBI field agents with forensic experience guarded and documented each recovery site until a NASA team, including an astronaut, could escort their colleagues with honor into the care of their families. Six crew members were located within a week; the last STS-107 astronaut was found 10 days after the accident.

Debris search

As the crew search intensified, so did the wider hunt for every piece of debris that could help unravel the accident's cause. Over a hundred federal, state, local and volunteer organizations participated. Aircrews searched 1.6 million acres along the breakup path, but aerial surveys proved ineffective at locating the thousands of small fragments of Columbia spread across the countryside, much under heavy tree cover.

After two weeks of searching for wreckage with a force of NASA, National Guard, local police and volunteer personnel, King employed U.S. Forest Service wildland firefighters, self-sufficient teams trained to scour rugged terrain in line-abreast fashion. Some 2,000 to 3,000 searchers were in the field at any one time, canvassing every acre of the search grid at arm's length. Augmented by the Texas Forest Service, the teams put in 1.5 million manhours and walked 680,750 acres of rural Texas and Louisiana.

They found Columbia everywhere, in thousands of pieces. Main engine forgings had buried themselves several meters deep in the muddy terrain, while spherical fuel and nitrogen tanks, paper checklists, and even cloth mission patches had decelerated and drifted to earth remarkably intact. Fragments reported by the public (via 12,000 phone calls) or found by searchers were geo-located with GPS, logged, bagged and shipped to Barksdale Air Force Base in Louisiana, and eventually Kennedy Space Center.

When the search concluded by April 30, teams had recovered about 84,000 fragments totaling 38,500 kilograms and comprising 38 percent of the orbiter. One tile fragment was found in far west Texas, near the New Mexico border.

Miraculously, all this debris, including pyrotechnics and toxic rocket propellants, resulted in no inju-

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▲ This boot sole from one of two extravehicular activity spacesuits aboard Columbia was found in Sabine County shortly after the accident.

ries to those on the ground. However, on March 27, 2003, a low-flying search helicopter lost power and plummeted into the forest, killing U.S. Forest Service contractor pilot Jules "Buzz" Mier Jr. and Charles Krenek of the Texas Forest Service.

Data team

Meanwhile, the National Transportation Safety Board had recommended that a NASA-led data team work in parallel with the debris searchers to independently determine the cause of Columbia's loss. This group analyzed orbiter telemetry and ascent and breakup imagery to unravel the accident event sequence.

The data team's work received a huge boost when searchers in Texas recovered Columbia's Orbiter Experiments recorder, a magnetic tape "black box" that logged temperature and load measurements from sensors throughout the orbiter. The suitcase-sized box was found nearly intact on spongy ground just a few hundred meters uprange of a lake. Its tapes preserved crucial data from the orbiter's final moments after the telemetry downlink was lost.

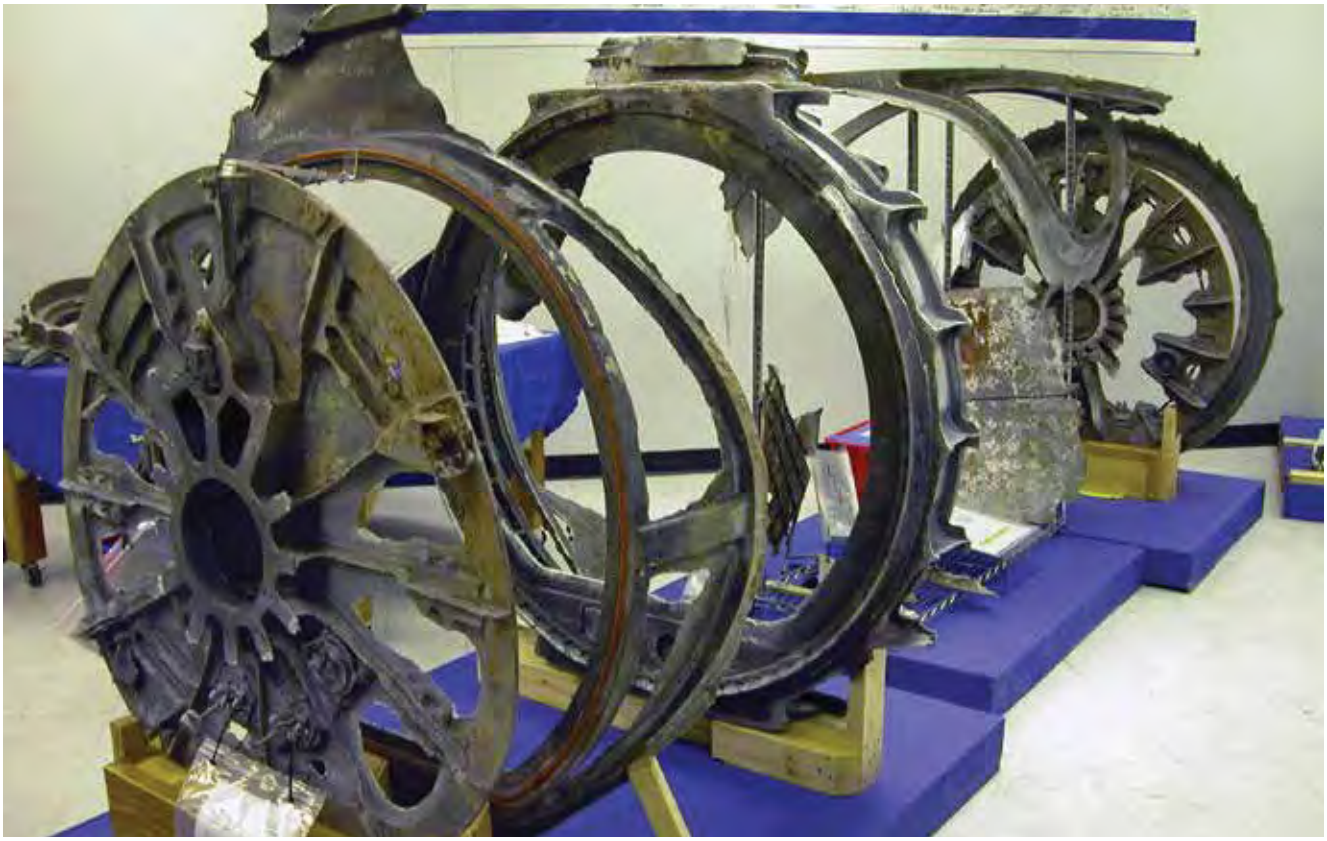
Reconstruction

Debris was collected at Barksdale, where Leinbach was deployed for 12 days to lead the initial debris identification and sorting. The debris was then shipped to Kennedy Space Center and laid out on a hangar floor for Leinbach's Columbia Reconstruction Team. Investigators paid special attention to the belly heat shield, the lower wing surfaces, and especially the foam impact site on the left wing's leading edge. Only tiny shards of those reinforced carbon-carbon panels were recovered, pointing to a breach in that critical surface. By analyzing cooled droplets of molten metal coating other pieces of recovered wing structure, NASA learned how the hot plasma had penetrated and destroyed Columbia's left wing. Thanks to this forensic reconstruction, the Columbia Accident Investigation Board by April had most of the physical evidence it needed to understand the accident sequence.

The board's August 2003 report found that after repeated instances of tank foam loss, NASA had not understood the risk of catastrophic heat shield damage, and continued to fly. Damage from foam loss was normalized as an "accepted risk." Further, during the mission itself there were lapses in leadership and communication that made it difficult for engineers to raise concerns or understand decisions. Managers failed to understand that critical damage might be present, and failed to investigate the actual presence or extent of damage to Columbia.

Their mission became our mission

Unlike Challenger's remains (buried in an isolated missile silo on Cape Canaveral — another story), Columbia's wreckage is today stored on the 16th floor of NASA's Vehicle Assembly Building at Kennedy. Mike Ciannilli, an engineer who worked 58 shuttle launches, 21 as the NASA test director, is today the "Apol-



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▲ These sections of the pressurized tunnel from the crew cabin to the Spacehab module are preserved with other Columbia debris in NASA's Vehicle Assembly Building at Kennedy Space Center.

lo-Challenger-Columbia lessons learned program manager," in charge of acquainting NASA and industry with the experiences of three space tragedies. If we just lock Columbia's remains away, he says, "we're not effectively sharing the lessons from the past that will make our future more successful."

At Kennedy, new employees learn about spaceflight's seriousness with a visit to the Columbia Research and Preservation Area. Ciannilli infuses these visits with hard engineering, but emphasizes the physical presence of the astronauts amid Columbia's debris. Here is an airlock hatch they operated; there, avionics boxes from the crew cabin. "Their mission became our mission," he says.

Since 2016, thousands of NASA personnel have seen the spacecraft's artifacts and heard the importance of effective communication, of getting critical information to sometimes-unreceptive bosses, and of avoiding the "normalization of deviance" that makes an organization comfortable with accepting potentially fatal risks.

Sharing the Columbia story

Ciannilli wants to get those lessons not only to NASA's workforce, but to the new generation of commercial spacecraft engineers and operators. "It's critical to pass on that torch — what we all lived through with Columbia — so that no one repeats those mistakes." The lessons learned program has created a 90-minute HD video presentation aimed at aerospace industry audiences, and a 30-minute version suitable for smaller staff meetings, focused on how to prevent a Columbia-like tragedy. The artifacts reinforce the message that anything less than excellence in spaceflight opens the possibility of another Challenger or Columbia catastrophe.

Outreach also continues through NASA's Debris Loan Program to exploit the research potential of Columbia artifacts. About 450 kilograms of components are out on loan to industry and academia. For example, the University of Texas at El Paso is using recovered debris to refine re-entry dynamics models and so improve future spacecraft designs. The loan program has so far generated three doctoral dissertations.

As Leinbach speaks to NASA and new space groups, he relates the emptiness he felt at the shuttle landing runway, waiting for Columbia to appear, asking himself what he might have done to save the returning crew. Operators and managers, he says, "will make thousands of decisions that affect safety and human life. Listen to your people; listen to what the hardware is telling you. More than in any other technical endeavor, in spaceflight you have to be perfect."

In the coming year, we may see piloted commercial spacecraft launch to the International Space Station, and NASA move closer to its goal of returning astronauts to deep space. Co-authors Leinbach and Ward, writing of the recovery of a lost shuttle and crew, urge us to find the lessons born from tragedy, and act to prevent another on our watch. ★