

Comm Check...: The Final Flight of Shuttle Columbia

By Michael Cabbage, William Harwood

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Michael Cabbage and William Harwood, two of America's most respected space journalists, are veterans of all but a handful of NASA's 113 shuttle missions. Tapping a network of sources and bringing a combined three decades of experience to bear, the authors provide a rare glimpse into NASA's inner circles, chronicling the agency's most devastating failure and the challenges that face NASA as it struggles to return America to space.

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Editorial Review

About the Author
Michael Cabbage is the space editor for the *Orlando Sentinel*. Before that, he wrote for *Florida Today* and the *South Florida Sun Sentinel*. He has covered more than 40 shuttle missions and written about spaceflight on three continents. He was nominated for a Pulitzer Prize in 2001/2002.

Bill Harwood has been the Senior Space Consultant for CBS News since 1992. For the previous decade he was Cape Canaveral Bureau Chief for UPI. He also covers space exploration for *The Washington Post* and *Astronomy Now* magazine. He lives in Merritt Island, Florida.

From The Washington Post

What is it about the space program, anyway? When the Mars Rover began sending pictures to Earth a while ago, the NASA Web site received more than a billion hits within a couple of days. When President Bush wanted to find a national goal that would transcend everyday concerns, he chose returning to the moon. Why, in a time of war and terrorism, are our spirits lifted because a small machine millions of miles away sends back some photographs, or when our political leaders remind us of larger goals?

You won't find much attention to this intriguing question in Comm Check. What you will find instead is a gripping, detailed account of what happens when you try to translate the glowing vision of space exploration into the nuts and bolts of real-world accomplishment. The authors, both veteran reporters on the NASA beat, have taken as their subject the tragic events of Feb. 1, 2003, when the space shuttle Columbia disintegrated as it re-entered the Earth's atmosphere over the southwestern United States. Starting with a short description of the horrified silence that fell on the control room in Houston when instruments lost track of the craft, the authors walk us through pre-launch preparations 16 days earlier, the disaster itself and the investigation that followed.

The story is a complicated one, involving a chain of technical and bureaucratic errors. During the launch, some insulating foam came off the external fuel tank and crashed into the leading edge of the craft's wing, opening a hole about a foot wide. The damage couldn't be seen from the spacecraft and wasn't picked up by ground cameras during launch. Higher-level executives ignored warnings from engineers and vetoed requests that damage be assessed by photographs from highly classified military surveillance satellites, although later analysis showed that even if the damage had been documented, nothing could have been done to save the astronauts once they were in orbit.

The authors' account is highly readable and largely free of technical jargon. When they introduce a new player, they always give a thumbnail sketch of the person's background to give you a sense of who he or she is. They also include a very useful appendix of acronyms to help the reader deal with NASA-speak, though sometimes the details get a bit overpowering. Closet techno-geeks like me, for example, will be absolutely mesmerized by the second-by-second account of what happened to Columbia's left wing as it re-entered the atmosphere, but the eyes of the general reader may well glaze over. Interspersed with the details are some fascinating bits of information. When President Bush was told about the disaster, for example, his first words were "Where are the families?" -- a reply I took to be a significant insight into the man's value system. Ultimately, the authors give us as complete and readable an account of the Columbia disaster and the inside workings of NASA as we are likely to get.

But in the end, the significance of this book, particularly at this moment, derives from what it has to say about the debate going on in the space program -- the questions of whether we should be sending humans into space at all. As the Columbia disaster shows, this is both risky and expensive. Wouldn't it be better, some argue, to send out (relatively) cheap robots rather than fragile humans to explore the solar system?

I suppose this argument would make sense if the only goal of the space program were to gather data on the planets. But sometimes, when I'm in a contemplative mood, I think about humanity's move away from our home planet in a different way. I wonder what history books will say about our generation 500 years from now. In that perspective, the great conflagrations of the 20th century -- even World War II -- will mean no more than the War of the Spanish Succession does to us today. The War on Terror, whether it turns out to be the start of a clash of civilizations or just the dying gasp of a fundamentalist ideology unable to move into the 21st century, will mean no more than the Crusades. In the end, I think, we will be remembered primarily for our many scientific achievements -- splitting the atom, decoding the genome. But most of all, they will say about us, "Yes, they were the first people to walk on the moon."

And I want to tell you, my friends, that there are a lot worse things to be remembered for.

Reviewed by James Trefil

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Chapter One: Re-Entry

Looks like a blast furnace.

-- *Shuttle commander Rick Husband, midway through re-entry*

Plunging back to Earth after a 16-day science mission, the shuttle Columbia streaked through orbital darkness at 5 miles per second, fast enough to fly from Chicago to New York in two and a half minutes and to circle the entire planet in an hour and a half. For Columbia's seven-member crew, the only hint of the shuttle's enormous velocity was the smooth clockwork passage of entire continents far below.

Commander Rick Husband knew the slow-motion view was misleading, a trick of perspective and the lack of anything nearby to measure against the craft's swift passage. He knew the 117-ton shuttle actually was moving through space eight times faster than the bullet from an assault rifle, fast enough to fly the length of 84 football fields in a single heartbeat.

And Husband knew that in the next 15 minutes, the shuttle would shed the bulk of that unimaginable speed over the southwestern United States, enduring 3,000-degree temperatures as atmospheric friction converted forward motion into a hellish blaze of thermal energy. It had taken nearly 4 million pounds of rocket fuel to boost Columbia and its crew into orbital velocity. Now the astronauts were about to slam on the brakes.

For Husband, a devout Christian who put God and family ahead of his work as an astronaut, flying this amazing machine home from space was a near religious experience in its own right, one he couldn't wait to share with family and friends gathered at the Kennedy Space Center in Florida. He had served as pilot on a previous shuttle flight, but this was his first as commander, and in the world of shuttle operations, it's the

commander who actually lands the spacecraft.

He relished the opportunity. But his life as an astronaut took a backseat to his deep faith in God. Before blasting off on his second space flight as commander of Columbia, he videotaped 34 Bible lessons for his two kids, one each for the 17 days he would be away from home.

"The space shuttle is by far the most complex machine in the world," he had told his hometown church congregation three years earlier. "When you think about all the thousands of people it took to sit down and design this machine -- the main engines, auxiliary power units, the hydraulics, the flight control systems, the reaction control jets, the solid rocket boosters, the external tank that fuels the main engines, the crew compartment with all the controls and all the time that was spent to put this thing together and make it work -- it's to me inconceivable that you could take a look at the universe and think that it all just happened by accident.

"And inside that vehicle are seven astronauts, each one of which is more complex than this vehicle we went up in," he continued. "And God is an awesome God."

Looking over his cockpit instruments as he prepared Columbia for entry, the 45-year-old Air Force colonel chatted easily with his crewmates, coming across more as an older brother than as the skipper of a $3 billion spacecraft. But underneath the friendly camaraderie was the steady hand of a commander at ease with leadership and life-or-death responsibility.

"People have characterized him as a laid-back guy, easy-going," said entry flight director LeRoy Cain, who shared Husband's deep religious convictions. "But a lot of that was based in his faith, realizing our time here is limited and ultimately the real goal is to have that relationship with your maker. And he had that and he wanted to share that in a way that wasn't intrusive or offensive. And that's the biggest reason this crew gelled so well together."

Husband was also the first pilot since the astronaut class of 1984 to be given a shuttle command on his second mission. Kent Rominger, chief of the National Aeronautics and Space Administration's astronaut corps and commander of Husband's first mission, said Husband "came out of that flight with a really strong reputation. Rick worked hard, did a really good job, was a great leader. He was a really gifted pilot."

So good, in fact, that data tapes charting his every move at the controls of NASA's shuttle training aircraft were frequently used to show other pilots how a textbook approach and landing should be flown.

"This is Mission Control, Houston. Columbia's altitude is now 90 miles above the Pacific Ocean to the north of the Hawaiian Islands, about two minutes away from entering the Earth's atmosphere," said NASA commentator James Hartsfield, his words carried around the world by satellite over NASA's television network. "All activities continuing to go smoothly en route toward a touchdown at the Kennedy Space Center at 8:16 A.M. Central time."

Getting to Columbia's flight deck hadn't been easy for Husband, who grew up dreaming about one day flying in space.

"I've wanted to be an astronaut all my life, ever since I was about four years old," he once said. "It was the only thing I could think about wanting to do."

So he planned his education and a military career with that single goal in mind.

After graduating from high school in 1975, the boy from Amarillo enrolled at Texas Tech University in Lubbock, a two-hour drive, where he earned a bachelor's degree in mechanical engineering in 1980. There, he fell in love with Evelyn Neely, who, like Husband, had grown up in Amarillo. The two were married in their hometown at First Presbyterian Church. Now, 20 years later, the couple had two children, a 12-year-old daughter, Laura, and a 7-year-old son, Matthew.

The first seven years after his college graduation included an endless procession of Air Force bases, where he learned to fly the F-4 fighter and eventually became so good at it he was promoted to instructor. In 1987, he was assigned to the legendary test pilot school at Edwards Air Force Base in Southern California's Mojave Desert. As an Amarillo schoolboy, he had built models of the flame-belching missiles that catapulted his heroes into orbit. Now, here at the same place where Chuck Yeager had broken the sound barrier, Husband proved he also had the right stuff.

But that wasn't enough.

By the time he arrived at Edwards, Husband already had applied to be an astronaut once and had been turned down. That was just prior to the explosion of the shuttle Challenger in 1986, and NASA ultimately canceled all new astronaut hires. Husband applied again afterward and was turned down a second time. Realizing NASA wanted astronaut candidates with advanced degrees, he went back to school at Fresno State University and earned a master's degree in mechanical engineering. The third time around, he got as far as the Johnson Space Center in Houston for a week of interviews and tests. Worried he might not pass the physical this time because of his eyesight, he wore contact lenses and lied about that on the application. He passed the physical, but again, the answer was no.

In the meantime, Husband drew an assignment as an exchange pilot with Britain's Royal Air Force in 1992 and shipped off to Boscombe Down, England, where he helped test a variety of new aircraft. He prayed for guidance on what he should do.

"God showed me that lying certainly was not the kind of thing that a Christian is supposed to do," he reflected in 2000. "When it came time for me to fill out the application a fourth time, I felt the strongest prompting from God to tell the truth. In studying the Bible more, I had come across Proverbs 3:5-6 that says, 'Trust in the Lord with all your heart and lean not on your own understanding; in all your ways acknowledge him and he will make your paths straight.'

"It was as if God was saying 'Just trust me! You lied last time and didn't make it. Try telling the truth this time and see what happens.' Finally, I had come to the point where I understood what it meant to give my life to God and to trust Him. I said, 'OK, Lord. I want to do what You want me to do, and it doesn't matter if I'm an astronaut or something else.' "

This time he told the truth and was invited to begin training at Johnson in December 1994. But despite his obvious skills in the cockpit, it would be another five years before he was assigned to his first mission. Only two other members of the 20-member astronaut class known as Group 15 waited longer.

"A lot of people didn't know that Rick was one of the last people to fly in his class," said Dave Pitre, an astronaut trainer assigned to Columbia's mission. "And I don't know the reason why, because I think Rick's a great guy. But this is what I speculate.

"You look at his résumé and he's the best. But he's so unassuming. And on the sixth floor [of the astronaut office], there's a lot of competition to be the best, to do the best. There's a lot of jockeying. Rick wouldn't do

that, he never did that. He let his actions speak for himself. So he just sat there patiently in line and waited, and waited, and waited. I think he just wanted to make a statement and so they all tried just so hard, I mean, every training session you just got the feeling these guys were putting out 110 percent all the time. Everybody had something to prove on that flight and I think it just bonded them all together."

"Columbia is currently targeted toward runway 33 at the Kennedy Space Center; the runway selection continues to be discussed here in Mission Control, however. But for its approach to runway 33, Columbia will perform a right overhead turn to align with the runway of about 214 degrees."

Preparations for the shuttle's arrival at Kennedy were in full swing. The landing support team, made up of engineers and technicians required to deactivate critical systems after touchdown, had gathered at dawn to go over their plans and to prepare their equipment. They were stationed at the northwest end of the broad, 3-mile-long Shuttle Landing Facility runway, expecting Columbia to come in from the southeast.

Shortly after sunrise, buses, limousines, and a fleet of sport-utility vehicles and government vans brought a crowd of VIPs, NASA managers, reporters, and invited guests to bleachers strung out on the eastern side of the Shuttle Landing Facility, about midway down the runway. Hartsfield's voice blared from loudspeakers mounted on telephone poles behind the bleachers, sounding clear in some areas but muffled in others. TV monitors, carrying NASA's television coverage of the landing, were spaced out in front of the bleachers, and a large countdown clock was ticking down toward touchdown.

The astronaut families were gathered at a lone set of bleachers at the northernmost end of the midfield viewing site, cordoned off from the other VIPs and guests to ensure a bit of privacy. An astronaut was assigned to each family to answer questions and to provide assistance in case of an emergency.

No problems were expected, and a triumphant homecoming was just minutes away. It was 8:44 A.M. on Feb. 1, 2003, and Columbia was descending through 400,000 feet northwest of Hawaii.

"OK, we're just past EI," Husband told his crewmates, marking when Columbia, flying wings level, its nose tilted up 40 degrees, finally fell into the discernible atmosphere.

He was referring to "entry interface," the moment the shuttle descended through an altitude of 76 miles. At that altitude -- 11 times higher than a typical passenger jet flies -- the atmosphere is still a vacuum in the everyday sense of the word. But enough atoms and molecules are present to begin having a noticeable effect on a vehicle plowing through them at 25 times the speed of sound.

Wearing bulky, bright orange pressure suits, Husband, rookie pilot William "Willie" McCool, flight engineer Kalpana Chawla (pronounced KULP´-nah CHAV´-lah), and Navy physician-astronaut Laurel Clark were strapped into their seats on Columbia's cramped flight deck, working through the final entries on a long checklist.

The shuttle's flight computers, each one taking in navigation data and plugging the numbers into long strings of equations, were doing the actual flying. Husband wouldn't take over manual control until the orbiter was on final approach, 50,000 feet above Kennedy. During this phase of entry, the astronauts were monitoring the ship's progress, discussing the view outside and making last-minute adjustments to their pressure suits. Husband and McCool had just finished drinking a final few bags of salty water in a somewhat unpleasant procedure known as "fluid loading." The concoction would make them less susceptible to feeling woozy during the onset of gravity after 16 days in weightlessness.

Husband was in the front left seat, the command position aboard any aircraft, with McCool to his right on the other side of a switch-studded instrument console. Chawla, a native of India, was a veteran of one previous shuttle flight and an accomplished pilot. Something of a legend in her hometown of Karnal in the Indian State of Punjab, Chawla was a role model in a country where less than half the women were literate. She sat directly behind the central console, calling out and double-checking re-entry tasks. Clark was seated to Chawla's right, almost touching shoulders with the diminutive flight engineer.

Strapped into seats on the split-level crew cabin's lower deck were payload commander Michael Anderson, another shuttle veteran and one of only a handful of African-American astronauts at NASA, physician-astronaut David Brown, a former circus acrobat, jet pilot and amateur videographer, and fighter pilot Ilan Ramon, the first Israeli to fly in space.

The crew was well aware of the high-risk nature of a shuttle flight. Like all astronauts, they had put their affairs in order before flying to Florida for the launch. Anderson, who attended the same Houston church as Husband, typified the tightly knit crew's feelings about personal safety. He told a former pastor not to be concerned if he didn't make it back from a mission. "Don't worry about me. I'm just going on higher."

High-risk missions were nothing new for Ramon. An impressive figure in the Israeli air force, he helped lead a daring 1981 Israeli bombing raid that reduced an unfinished Iraqi nuclear reactor to rubble. But he did not join Columbia's crew as a warrior.

"I represent, first of all, of course the state of Israel and the Jews," he said during an orbital interview a few days earlier. "But I represent also all our neighbors. And I hope it will contribute to the whole world and especially to our Middle East neighbors."

Unlike the upper flight deck with its wraparound airliner-type cockpit windows and large overhead view ports, the lower deck featured a single, small porthole in the shuttle's main hatch, almost out of view on the left side of the cabin. For Anderson, Brown and Ramon, there was nothing to see but rows of equipment lockers. At least they were plugged into the ship's intercom system, following along as the flight deck crew worked through the re-entry checklist.

They were listening in a half-hour earlier as Husband counted down to deorbit ignition, when Columbia's flight computers fired up the shuttle's twin braking rockets as the spacecraft flew upside down and backwards 170 miles above the central Indian Ocean. The two-minute 38-second rocket firing slowed the shuttle by just 176 mph. But that small decrease was just enough to lower the far side of Columbia's orbit deep into the atmosphere above Florida's east coast.

For the first half hour of re-entry, Columbia and its crew simply fell through the black void of space on a precisely plotted course toward a runway on the other side of the planet. But now, finally back in the discernible atmosphere, things were about to get interesting.

For McCool, an accomplished Navy carrier pilot and father of three who brought a boyish enthusiasm to Columbia's flight deck, entry interface was a long-anticipated milestone. Veteran astronauts had told him to expect a spectacular light show. Right on cue, the inky blackness outside his cockpit windows began giving way to a faint salmon glow.

At first, the effect was so subtle he wasn't sure it was really there.

"That might be some plasma now," he observed, as if seeking confirmation from Husband.

"Think so already?" asked Clark, seated directly behind McCool and aiming a handheld video camera out the cockpit's overhead windows.

"That's some plasma," Husband finally confirmed.

"Copy, and there's some good stuff outside," Clark replied. "I'm filming overhead right now."

"It's kind of dull," McCool said a moment later, as if disappointed.

"Oh, it'll be obvious when the time comes," Husband reassured him.

McCool didn't have to wait long. During the next minute, the initial faint glow steadily brightened until there was no mistaking that the shuttle was embedded in a fireball.

"It's going pretty good now, Ilan," McCool reported to the three fliers on the lower deck. "It's really neat, just a bright orange-yellow out over the nose, all around the nose."

"Wait until you start seeing the swirl patterns out your left and right windows," Husband said.

"Wow."

"Looks like a blast furnace," Husband said dryly.

Even so, he and his crewmates were not worried. Focused, yes. Aware of the danger, yes -- as any well-trained astronauts would be when contemplating the energies involved in a shuttle launch or re-entry. But not worried. After all, there was no reason for concern. In the 111 previous space shuttle re-entries, there never had been a catastrophic "in-flight anomaly," as NASA refers to out-of-the-ordinary events. The only disaster in the history of the program, the Challenger explosion, had occurred during launch when one of its boosters had ruptured.

The Columbia astronauts already had survived the eight-and-a-half-minute climb to orbit that most experts, with some reason, considered a far more dangerous phase of flight. A fully fueled space shuttle weighs 4.5 million pounds at liftoff, yet accelerates to 100 mph -- straight up -- in about 10 seconds. In the first minute, more than two million pounds of fuel are consumed by the ship's twin solid-fuel boosters and three hydrogen-fueled main engines as the spacecraft plows its way through the dense lower atmosphere. Seven and a half minutes later, the astronauts are in orbit, moving through space at more than 17,000 mph.

Compared with launch, getting home was a walk in the park. Or so it seemed to most, including many at NASA. The astronauts knew better, of course. All of the energy it took to boost Columbia to orbital speed was still there in the form of the craft's enormous velocity. To make it back to Earth, the shuttle would have to give up that energy in the form of heat from atmospheric friction.

But no one was particularly worried. Of NASA's four space shuttle orbiters -- Columbia, Discovery, Atlantis and Endeavour -- Columbia had a well-earned reputation for experiencing most of its problems on the ground. If the launch team could just get the countdown to zero, engineers joked, NASA's oldest space shuttle would chalk up a smooth flight and a trouble-free return to Earth.

There were exceptions, of course. In 1999, a short circuit five seconds after liftoff knocked out one of Columbia's three main electrical circuits, shutting down two computers that controlled the main engines and

leaving the ship one glitch away from a potentially catastrophic failure. Frayed insulation on old wiring turned out to be the culprit, raising questions about the general health and well-being of NASA's aging fleet of space shuttles.

But the wiring problems were corrected, and Columbia, making its second flight since a major overhaul, was completing another near-perfect mission, returning to Earth after a 6.6-million-mile voyage spanning 255 orbits since blastoff.

In Mission Control, Cain and flight dynamics officer Richard Jones were discussing the weather in central Florida and trying to decide which end of the shuttle's runway Husband should use. From 50,000 feet on down, Husband would be flying Columbia manually, and Cain wanted to guarantee the commander the best possible conditions.

Like Husband, the 38-year-old Cain lived a life that revolved around family, church, and space exploration. He earned a bachelor's degree from Iowa State University in 1988 and promptly went to work for Rockwell Shuttle Operations in Houston as a guidance systems officer in Mission Control.

NASA hired him in 1991, the year the first of his three daughters was born, and he quickly proved his mettle. In 1998, he was selected as a flight director, becoming one of the chosen few entrusted with overseeing operations during the shuttle's high-risk climb to orbit and return to Earth. In the mission operations world of ascent and entry, the shuttle commander and the flight director work hand in hand, one in charge on orbit, the other in charge on the ground. The success of a mission rests squarely on their shoulders. And at no time are the stakes higher than during launch and landing.

"Between you and me, I am nervous every time I walk in the door," Cain said. "People have asked me, is it scary? Hell yeah! Every time I walk in the door, it's almost like -- and this sounds corny, but this is what happens to me -- something comes over me. It's just like this feeling, and suddenly it's almost like this instantaneous rush of focus."

ardFor Columbia's entry, Cain began his day with a standard routine. After a handover briefing from the off-going flight control team, Cain gave the entry team a brief weather update, assessing the odds that Mother Nature would cooperate with their plans to bring Columbia home that morning. He closed with a familiar message: "Let's go get 'em, guys."

The communications loops in Mission Control were quiet as Columbia continued its automated descent under the control of its four primary flight computers, approaching the coast of California just north of San Francisco. Mechanical systems officer Jeff Kling, monitoring telemetry from the shuttle's myriad systems, saw nothing unusual in the numbers flickering on his computer displays. Columbia was living up to its reputation.

To Cain's right, looking on through a large window on the second floor of the Mission Control center were Johnson's senior shuttle managers, including program manager Ron Dittemore, Mission Management Team chairwoman Linda Ham and shuttle engineering director Ralph Roe. NASA's senior astronaut, John Young, was there along with Frank Benz, director of engineering at Johnson. They were all listening to the chatter on the flight control loops, monitoring Columbia's descent.

Seated directly behind Cain were veteran flight directors John Shannon and Phil Engelauf, along with astronaut Ellen Ochoa. All three were on hand to provide advice or assistance if necessary. Hartsfield was seated to Cain's left in the back corner of the room, listening to the loops and relaying details of Columbia's

descent to the public.

But there were no issues of any significance to discuss. On a huge projection television screen at the front of the room, Columbia's actual location was plotted against the ship's predicted path on a map showing the shuttle's planned route to Florida. With a glance, anyone in the room could see the shuttle was right on course.

The only problem of any significance reported by NASA during Columbia's 28th mission -- and it was more an annoyance than anything else -- was the failure of a humidity control system in the crew's Spacehab experiment module. The glitch forced the astronauts to shut down one of their air conditioners early on, and temperatures in the research module went up slightly as a result. But the crew had no complaints. After a wait of two and a half years for mission STS-107 to get off the ground, a bit of unexpected heat was inconsequential.

The growing heat outside Columbia, of course, was another matter.

"This is amazing. It's really getting, uh, fairly bright out there," McCool observed as the glow around the orbiter continued to intensify.

"Yeah, you definitely don't want to be outside now," quipped Husband.

"What, like we did before?" Clark said pointedly as her crewmates laughed.

"Good point," Husband replied.

It was 8:47 A.M. and just three minutes had passed since entry interface. Approaching the coast of northern California, Columbia was dropping like a rock, its nose-up orientation designed to focus re-entry temperatures of up to 3,000 degrees on the heat-resistant reinforced carbon-carbon [RCC] panels making up the wings' leading edges and the orbiter's nose cap. Thousands of black heat-shield tiles making up the belly of the spacecraft would protect the underlying, vulnerable, aluminum skin from slightly lower, but still extreme, temperatures.

The spacecraft had not yet slowed much -- its velocity was still a blistering 24.7 times the speed of sound -- but aerodynamic pressure was steadily building across the underside of the shuttle. It was now up to a half pound per square foot as the craft continued its descent through the thin upper atmosphere. In another minute, it would quadruple, and one minute after that, it would be 20 times greater. Temperatures on the nose and the wing leading edges already were above the 1,200-degree melting point of aluminum.

"Columbia's course toward Florida will take it across the continental United States, crossing the California coast above the San Francisco Bay area and continuing across Sacramento, California, providing a spectacular view for persons in that area of Columbia's descent through the atmosphere."

A continent away at Kennedy, excitement was building for Columbia's homecoming.

When the first members of the landing support team had begun arriving at 6 A.M., the Shuttle Landing Facility, along with the rest of Cape Canaveral, was buried beneath a thick fog. Now, as Columbia zipped toward the California coast, the fog had burned off and given way to a glorious midwinter morning at the Cape, with 52-degree temperatures, light westerly winds, and a few scattered clouds -- near-perfect conditions.

Only an hour earlier, questions about how quickly the fog would lift had presented Cain and the flight control team with a minor dilemma: Do we bring Columbia home on its 255th orbit around Earth? Or do we wait another hour and a half for a try on the 256th revolution, Columbia's final landing opportunity of the day? Waiting an orbit ran the risk of clouds forming near the Cape that could obscure the shuttle's runway.

Ham's Mission Management Team had decided the day before not to activate the shuttle's backup landing site at Edwards. Landings in California added a week or more to a shuttle's ground processing schedule, and it cost NASA about $1 million to fly a shuttle back to Florida atop a 747 transport jet.

As a result, Cain had two shots at getting Columbia back to Florida on Feb. 1 or the mission would have to be extended 24 hours. That's how long it would take before the shuttle's orbital position and the Kennedy landing site synched back up again.

Carved out of a mosquito-infested bog on the edge of the Indian River, the shuttle's 15,000-foot runway was about a third longer and twice as wide as those at major international airports. Columbia and its sister shuttles, however, returned to Earth as huge, unpowered gliders. The joke was they flew like bricks and dropped like rocks. Unlike airplane pilots, shuttle commanders couldn't pull back on the stick and open up the throttle to fly around for another approach if something went wrong. From the moment the braking rockets completed the deorbit burn, Columbia and its crew were locked into a landing at Kennedy. That made the weather a big deal.

Overhead, Rominger was flying a NASA business jet modified to handle like a space shuttle on final approach to the runway. He was making practice approaches to both ends of the runway to check visibility and turbulence.

Joining Rominger aboard the Shuttle Training Aircraft that day was Barbara Morgan, an Idaho school teacher who had served as Christa McAuliffe's backup in NASA's original Teacher in Space Program. Morgan was at Kennedy 17 years earlier, on Jan. 28, 1986, when McAuliffe and her six crewmates died in the explosion of the space shuttle Challenger.

Morgan never gave up her dream of fulfilling McAuliffe's legacy. Now, she was back as a full-fledged astronaut, a member of the crew assigned to Columbia's next flight. She was "shadowing" Rominger, accompanying him through a complete launch-and-landing cycle as part of the normal on-the-job training for a new astronaut. Morgan had come full circle in her quest to fly in space.

Rominger reported both ends of the runway were acceptable for use, and Cain earlier had tentatively settled on runway 33, which meant Columbia would be touching down on the landing strip's southeast end and rolling to the northwest. But he was still considering a switch to the other end to keep the sun out of Husband's eyes on final approach. The photographers and local television crews hoped he stuck with his original decision. Runway 33 meant a better view of the landing.

Workers in the landing support team, gathered at the northwest end of the Shuttle Landing Facility, also were hoping Mission Control would stick with 33. Otherwise, they would have to hurriedly reposition the slow-moving caravan of 20 or so vehicles, known as the Orbiter Recovery Convoy, to the other end of the runway. The technicians' jobs ranged from helping the crew off the shuttle to hooking up cooling systems and making hazardous systems safe.

Waiting with eager anticipation was Ann Micklos, a senior engineer and an expert on the shuttle's heat-shield tiles. She had been dating Brown. While the relationship had cooled, they were still close friends, and she

could hardly wait to welcome him home. He had first asked her out in July 1999, when both were on this same runway after another landing by Columbia. Today, he was returning to Earth aboard the same orbiter, carrying a Swiss watch he had bought her as a birthday present the previous June. She never had seen it. It was going to be a surprise.

"It'll be visible as well through much of the United States' southwest above southern Nevada and northern Arizona and central New Mexico as it continues its descent through the atmosphere, trailing a plasma trail left as it heats the atmosphere around it during its descent."

Aboard Columbia, the astronauts were putting on their gloves, pressurizing their spacesuits and conducting routine communications checks to make sure they could hear each other with their helmet visors down and locked. Clark, who planned to videotape the entire descent, was fiddling with her camera, taking occasional shots through the overhead windows as the plasma continued to build around the vehicle.

"Willie, I can see you in your mirror," Clark said playfully, looking over the pilot's shoulder at a small mirror attached with Velcro to the forward dashboard.

"Now I can see your camera!" McCool said to Clark, looking back in the mirror.

"OK," Husband said, his tone of voice gently telling his crewmates to cut out the horseplay.

"Stop playing," Chawla acknowledged with good humor.

Just before 8:50 A.M., still off the coast of California, Columbia's computers ordered small, right-side steering rockets to fire, moving the shuttle's nose to the right. These roll maneuvers were planned to bleed off velocity before reaching the landing site.

McCool was looking forward to getting a little flying time in the next few minutes. After receiving the go-ahead to fire Columbia's braking rockets to begin the trip home, Husband had notified Mission Control that McCool would be taking the stick briefly, just before touchdown, as the shuttle banked to line up on the runway. Not every commander gave his or her co-pilot a chance to actually fly the shuttle, but that was Husband's nature. McCool couldn't wait.

"Columbia in almost an 80-degree-bank to the right to dissipate speed, the first of four banks it performs as it approaches Florida to slow down as it descends. Altitude now 47 miles or about 248,000 feet. The shuttle's speed is 16,400 miles per hour."

At 8:53 A.M., 23 minutes from touchdown, Columbia finally crossed the coast of California, a long plume of super-heated air trail-ing in its wake. On the big map in Mission Control, the red triangle marking the shuttle's position crept on to land north of San Francisco. Scores of shuttle watchers and amateur photographers across the Southwest had gotten up early to witness Columbia's fiery descent. Bill Hartenstein, a veteran shuttle photographer, and Gene Blevins, a freelance photographer who worked with the *Los Angeles Daily News,* had set up six cameras at the Owens Valley Radio Observatory near Bishop, California, figuring a shot of Columbia streaking through the pre-dawn sky above the big radio telescope dishes in the foreground would be spectacular. Blevins was not disappointed.

"Once we got our cameras set up, sure enough, around 5:52, 5:53 [A.M. Pacific time], here comes this big white dot out over the mountains coming right at us," Blevins said. "This thing was coming in at incredible speed."

He and Hartenstein knew the pictures would, in fact, be spectacular. The conditions were perfect, and in a time-exposure photograph, Columbia would show up as a brilliant streak across the dark sky. But as he watched the shuttle race by, Blevins realized the plasma trail didn't look quite right. It was a subtle effect, and he didn't immediately think anything of it as he tended his cameras. But as the shuttle moved away and the camera shutters closed, "I saw this big red flare come from underneath the shuttle and being forced downward. I was like, 'whoa!' " He turned to Hartenstein. "Bill, did you see that? Something came off the shuttle!"

Hartenstein looked up from his cameras. He didn't see anything unusual, just the dimming space shuttle disappearing from view toward the horizon.

"Shuttle's altitude now 45 miles, speed 15,800 miles per hour, continuing in a right bank with wings angled 70 degrees, the first of four banks it performs to dissipate speed as it approaches landing."

Activity was picking up at Kennedy. At the midfield viewing site, Ramon's wife, Rona, and the couple's four children waited with nervous anticipation. Matthew Husband ran around playing under the watchful eyes of mother Evelyn and older sister Laura. McCool's wife, Lani, and two of their three sons -- Christopher and Cameron -- were there, along with Anderson's wife Sandra, their two young daughters and Chawla's husband, Jean-Pierre Harrison. Brown's parents, at home in Virginia, were watching the entry on NASA television as was McCool's oldest son, Sean, at college back in Canada.

"We're just standing around, it's a beautiful, kind of pleasant day," said Clark's husband, Jon, a Navy captain and NASA flight surgeon. "There wasn't a cloud deck forming, winds weren't at crosswind limits, you know, all that kind of stuff. So I'm thinking hey, we're good to go."

The broad runway was familiar territory for Clark. Years earlier, he had arranged for her to play the role of an injured shuttle flier in a landing disaster simulation at Kennedy. Now she was returning from her first flight, to the very spot where she had once pretended to be a casualty.

The couple's 8-year-old son, Iain, eagerly awaited the sonic booms that would herald Columbia's approach. He, his parents and the family dog had survived a harrowing crash the previous December, when Jon's single-engine Bonanza airplane hit a violent downdraft while trying to land during a storm. No one was injured, but the plane was destroyed. The experience haunted young Iain, and he begged his mother not to fly on the shuttle.

"He was very worried, very worried about her," Jon recalled. "He had some very, very moving premonitions that something bad was going to happen and he didn't want her to go."

In a family video conference during Columbia's flight, Iain asked his mother "Why did you go?" But today, all was forgiven as he romped on the grass in front of the bleachers.

And it wasn't just the children who were happy. A joyful mood had settled in across the midfield viewing site. Just on the other side of the yellow rope separating the astronaut family bleachers were top NASA officials and Kennedy staff.

"I can hear the loudspeakers going but I'm not paying any attention to them because I'm just talking to people and it's kind of a festive atmosphere there," said Wayne Hale, a veteran flight director on assignment to Kennedy for a year to oversee shuttle processing. "I have no real responsibility [for landing]. We're out there, we're talking about, you know, how we're going to walk around the vehicle and greet the crew and how soon

can we do that after they land, that sort of stuff."

At the south end of the viewing site, separated by a small construction zone where NASA was building a new control tower, reporters from a dozen or so news organizations milled about, taking notes, checking the weather and shooting the breeze. Media interest in landings had waned in recent years. But this morning, the reporters' ranks were slightly swelled by a small influx of Israeli journalists there to document Ramon's historic return. As usual, a handful of satellite trucks from Orlando's network television affiliates were standing by, ready to briefly interrupt cartoons and other Saturday morning fare to broadcast Columbia's arrival.

Several reporters were killing time by joking with Bill Johnson, the white-haired, pony-tailed, veteran news chief of Kennedy's public affairs office. One journalist lamented having to get up early on a weekend morning to see an event that had become so routine it no longer was newsworthy.

The cautious Johnson replied that the winds had slightly shifted since Columbia fired its maneuvering engines to come home. In addition, he noted, the onboard laboratory in the orbiter's cargo bay made Columbia's landing weight ever-so-slightly heavier than normal. A reporter next to Johnson piped up with a reminder that Husband was a rookie commander who would be landing the shuttle for the first time and his co-pilot, McCool, never had flown before.

"Oh well," another reporter joked, "I guess that all means they're doomed for sure."

Everyone laughed.

At about that same moment, as Columbia streaked toward the California-Nevada border more than 2,000 miles away, mechanical systems officer Kling in Mission Control noticed something unusual in the stream of telemetry from the space shuttle. Downward-pointing arrows appeared beside readings from two sensors measuring hydraulic fluid temperatures in the shuttle's left wing.

"What in the world?" another mechanical systems engineer, seeing the same data in a different room, said to Kling.

"This is not funny," Kling replied. "On the left side."

"On the left side," the engineer agreed.

They both tried to find some common thread that might explain the readings. Then, a few seconds later, two more down arrows appeared. It was as if the wiring to the four sensors in question, in hydraulic lines leading to the wing's flaps, or elevons, had been cut. Kling notified Cain.

"FYI, I've just lost four separate temperature transducers on the left side of the vehicle, hydraulic return temperatures," Kling reported, speaking quickly. "Two of them on system 1 and one in each of systems 2 and 3."

"Four hyd return temps?" Cain calmly asked.

"To the left outboard and left inboard elevon."

"OK, is there anything common to them?...I mean, you're telling me you lost them all at exactly the same

time?"

"No, not exactly," Kling said. "They were within probably four or five seconds of each other."

"OK," Cain said, mulling over possible explanations. "Where are those, where is that instrumentation located?"

"All four of them are located in the aft part of the left wing, right in front of the elevons, elevon actuators," Kling replied. "And there is no commonality."

Cain pondered that for a moment.

"No commonality," he said after a long pause, his tone of voice indicating bafflement. Multiple sensor failures were rare, usually the result of problems with some common electrical system or component shared by the sensors in question. But these data "dropouts" could not immediately be traced to some single failure point.

Cain's thoughts flashed back to Columbia's launch. He recalled a briefcase-sized piece of foam insulation that broke away from Columbia's external fuel tank 81 seconds after liftoff and slammed into the underside of the left wing. A team of experts had studied the impact and dismissed it as not being a safety-of-flight issue. The Mission Management Team had unanimously accepted the results of the analysis.

"Columbia continuing in a right bank, the wings angled 43 degrees, speed 15,000 miles per hour, altitude 43 miles, 2,090 miles to touchdown at the Kennedy Space Center targeted for runway three-three at Kennedy at present. Crossing the continental United States, now crossing above southern Nevada to the north of Las Vegas."

An unsettling thought crossed Cain's mind. Was the loss of four left-wing temperature sensors related to the foam strike? It couldn't be, he thought. That had to be a coincidence.

"Tell me again which systems they're for?"

"That's all three hydraulic systems," Kling said. "It's...two of them are to the left outboard elevon and two of them to the left inboard."

"OK, I got you," Cain said. It was 8:56 A.M. and Columbia was crossing the Utah-Arizona-New Mexico state lines. Aerodynamic pressure was up to 40 pounds per square foot as the shuttle continued its steep descent.

In the management viewing room above Mission Control, Ham was also worried. About the left wing. About the foam strike earlier in the mission. In her pivotal role as chairwoman of the Mission Management Team, Ham had approved the analysis that concluded the foam strike was not a safety of flight issue. She turned to Roe, a tall ex-football player, who also had taken part in the deliberations.

"Ralph, it's the left wing."

"It's not that," he said.

"Columbia's course continuing across Arizona and the Arizona and New Mexico border near the Four

Corners area of the United States. Its course will take it almost directly above Albuquerque, New Mexico, its altitude now 225,000 feet or 42 miles, speed 14,300 miles per hour, 1,785 miles to touchdown at the Kennedy Space Center. It's banking now back to the left, the second in a series of four banks that dissipate speed of the spacecraft as it becomes an aircraft and descends into the atmosphere toward Florida. Wings angled about 75 degrees to the left."

Other than the four temperature sensors on the hydraulic fluid return lines, everything appeared normal in Mission Control. Flight directors, however, are trained to worry, and Cain was no exception. He told reporters the day before he wasn't concerned about the foam strike, that it had been analyzed and that engineers did not think it was a safety-of-flight issue. But Cain didn't like coincidences.

"My very first thought, when he said it was on the left wing, was we had hot gas in the wing," Cain said later. "I almost pictured the whole sequence in my mind in the first few microseconds. It was pretty chilling. But I didn't believe it."

Cain called guidance, navigation, and control officer Mike Sarafin for a second opinion.

"Everything look good to you? Control and rates and everything is nominal, right?"

"Control's been stable through the rolls that we've done so far," Sarafin replied. "We have good trims. I don't see anything out of the ordinary."

Cain turned back to Kling, saying "All other indications for your hydraulic system indications are good."

"They're all good," Kling confirmed. "We've had good quantities all the way across."

"And the other temps are normal?"

"The other temps are normal, yes sir."

"And when you say you lost these, are you saying that they went to zero or off-scale low?"

"All four of them are off-scale low," Kling said. "And they were all staggered. They were, like I said, within several seconds of each other."

Off-scale low meant the sensors had simply stopped working. The shuttle was equipped with thousands of sensors, and random failures were not unusual. Nothing else in the continuous stream of data from Columbia indicated any signs of trouble. In just three minutes, the shuttle would be out of the region of maximum aerodynamic heating. There was reason to hope that all was well.

Suddenly, Husband called down, his first query since Columbia had entered Earth's atmosphere 15 minutes earlier.

"And, uh, Hou[ston]..." he began. His transmission was cut off. Such dropouts were not unusual during re-entry as the shuttle banked left and right, its big vertical tail fin occasionally blocking signals from reaching a NASA communications satellite stationed over the western Pacific.

A few seconds later, Kling saw more down arrows appear on his computer screen, this time signaling a loss of data from the shuttle's left main landing gear tires.

"We just lost tire pressure on the left outboard and left inboard, both tires," he told Cain, a half minute after Husband's interrupted call. The mechanical systems officer had a sinking feeling in the pit of his stomach.

Astronaut Charles Hobaugh, the flight controller responsible for talking directly to the shuttle crew, heard Kling's report to Cain and promptly radioed Husband: "And Columbia, Houston, we see your tire pressure messages and we did not copy your last."

At the runway viewing site, Jon Clark heard Hobaugh's call over the loudspeakers. A chill settled over him.

"The tire pressure call is a major off-nominal call. So I'm thinking, OK, if that's gone, they can't land with a blown tire, especially with that landing weight. And so I'm thinking, that's not good. I wonder if they're going to have to do a bailout now? And Laurel had 25 parachute jumps, she was probably more experienced than anybody as far as that goes...."

No one else at the viewing site appeared to pick up Hobaugh's call to the crew. Or if they did, they didn't immediately make anything of it. Such things usually turned out to be instrumentation glitches.

But back in Mission Control, Cain was getting seriously worried. There was growing concern Columbia had suffered some sort of major malfunction that could affect its landing, now just 17 minutes away.

"Is it instrumentation?" he asked Kling, hoping the tire pressure reading was the result of a faulty sensor. "Gotta be..."

"Those are also off-scale low," Kling replied.

Seconds later, Husband made another attempt to contact Mission Control, replying to Hobaugh with "Roger, uh, buh..." He might have been saying "before" or "both," but again, the transmission was suddenly cut off and, along with it, the flow of data from the shuttle.

It was 8:59:32 A.M. Cain waited for radio contact to be restored, trying to sort out what might be wrong. Whatever it was, flight controllers would have only a few minutes or so to resolve it before Columbia reached the Kennedy Space Center.

"And there's no commonality between all these tire pressure instrumentations and the hydraulic return instrumentations?" he asked Kling.

"No sir, there's not. We've also lost the nose gear down talkback and the right main gear down talkback," the mechanical systems officer replied, referring to landing gear position sensors.

"Nose gear and right main gear down talkbacks?" Cain repeated.

"Yes, sir."

Cain's discussion was not carried on NASA's television broadcast, and as far as the public knew, everything was proceeding smoothly. Communications dropouts typically lasted several seconds, occasionally longer, but sooner or later communications always resumed. Even so, at the Kennedy midfield viewing site, Bill Readdy, NASA's associate administrator for space flight and the man ultimately responsible for shuttle operations, started paying attention.

Much of the crowd in Florida was oblivious to the drama unfolding in Mission Control. But a couple of reporters huddled around a television set inside the runway's public affairs building had noticed something peculiar.

The big map displayed in Mission Control and broadcast on NASA Television showed Columbia's progress as the ship sped across the continent toward Florida, the red triangle marking the shuttle's position. Inexplicably, that triangle had stopped moving over Central Texas.

"Columbia out of communications at present with Mission Control as it continues its course toward Florida. Fourteen minutes to touchdown for Columbia at the Kennedy Space Center. Flight controllers are continuing to stand by to regain communications with the spacecraft."

Cain queried Laura Hoppe, instrumentation and communications officer, asking how long she expected intermittent contact.

"We were rolled left last data we had and you were expecting a little bit of ratty comm, but not this long?"

"That's correct," she replied. "I expected it to be a little intermittent. And this is pretty solid right here."

Hobaugh radioed Husband to check whether the crew could hear communications from Houston.

"Columbia, Houston, comm check," Hobaugh called at 9:03 A.M. "Columbia, Houston, UHF comm check."

There was no reply.

"CAPCOM Charlie Hobaugh calling Columbia on a UHF frequency as it approaches the Merritt Island tracking station range in Florida," Hartsfield explained, his voice betraying uncertainty for the first time. "Twelve and a half minutes to touchdown according to clocks in Mission Control."

"Columbia, Houston, UHF comm check," Hobaugh tried again. It was 9:04 A.M.

The shuttle now had been out of communication for nearly five minutes. At Kennedy's shuttle landing strip, a small flurry of activity had begun in the VIP area. Clusters of people had grouped together. The laughter and smiles of just 10 minutes earlier had all but disappeared, erased by anxious looks of concern.

At the midfield park site, a landing support staging area about 100 yards in front of the VIP bleachers, NASA engineer Bob Page was standing by with a camera operator, part of a team spread out around the runway to document Columbia's landing. Page had been one of the first to review film and video of the foam impact during launch 16 days earlier.

Listening to an internal audio loop used by members of the landing photo team, Page heard that communications with Columbia had been lost. He immediately thought about the foam strike. He dropped his head, turned around, and walked off the camera mound.

At the north end of the runway, astronaut Jerry Ross, a senior manager with seven shuttle flights to his credit, was chatting with Bob Cabana, a veteran shuttle commander currently serving as director of Flight Crew Operations at Johnson. They were standing beside Kennedy's new convoy commander's van, a mobile command post loaded with communications gear and support equipment.

Suddenly, someone inside started rapping on the window and motioning for the astronauts to come back inside.

"So Bob and I went back in and the first thing they said was, 'We've lost communications with the orbiter,' " Ross remembered. "And we thought, well you know, that's not that big of a deal. And then they said, 'We've lost data.' And then we said, 'Well, if you're going to lose comm, you're going to lose data. So no big deal.' And then shortly, that was followed by 'We've lost tracking.' "

Controllers were expecting tracking radars near Kennedy to lock onto Columbia at any moment as the shuttle approached Florida. By now, they knew something was very wrong. Columbia had been out of contact longer than anyone had expected.

"Flight controllers are standing by for Columbia to move within communications range of the Merritt Island tracking station in Florida to regain communications."

"When were you expecting [radar] tracking?" Cain asked the flight dynamics officer at 9:05 A.M.

"One minute ago."

At the shuttle runway, cell phones starting ringing. Soon, it appeared half the people in the crowd had phones pressed against their ears. Sean O'Keefe, NASA's administrator, heard Readdy say "This is not right, something is not right on this." O'Keefe was stunned. Readdy, the veteran shuttle commander and former fighter pilot, was visibly trembling, his face ashen.

"It was just one of those hit-you-with-a-mackeral kind of moments," O'Keefe said. "You know, 'Good God almighty.' You see someone like him sitting there doing that, and he knows the gravity of it better than anybody. It was enough to make you just start shaking right down to the edge."

Slowly, word began to ripple through the gathering of reporters to the south that something might be amiss. Groups began to form around loudspeakers and television sets. Some reporters began to wonder aloud in hushed tones what could account for the lengthy communications dropout.

Others, unable to hear Hartsfield's commentary, kept watch on the big countdown clock, waiting with mounting concern for the twin sonic booms that would herald Columbia's arrival.

Readdy was carrying a detailed disaster plan in a thin notebook, a set of instructions worked out in the wake of the Challenger disaster outlining what needed to be done in the event of a launch or entry mishap. He began telling other senior managers to get moving, to rendezvous back at the Launch Control Center.

Kennedy shuttle manager Mike Wetmore was overwhelmed. He turned to look at the astronauts' families, the kids still running around in front of the bleachers, unaware of the sense of dread settling over the managers. He was paralyzed by the sight.

"The families were celebrating and happy and I just...I couldn't move. They had no idea," Wetmore said. "I am a dad, I am a dad with two small kids and I am looking over there at these little kids running around, playing and laughing. I just remember a couple of small kids chasing each other back and forth. I was just standing there frozen."

"Columbia, Houston, UHF comm check," Hobaugh radioed again.

There was no reply.

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