Reentry

by

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ABSTRACT

"Reentry" most often evokes an image of the space shuttle flying through earth's atmosphere, glowing hot from friction, then landing on the runway and rolling to a halt. By then, the astronauts' job is finished. The hard part is over. Adjusting after six months in space – or even two weeks – should be a snap. But there's more to coming home than landing on solid ground.

This thesis presents the little-known story of what happens once the Space Shuttle or Soyuz capsule returns to earth. It covers physical effects on astronauts transitioning from microgravity to earth gravity, as well as psychological effects such as post-flight depression, reintegration with family, frequent travel for publicity, and getting back to normal life. In addition to reference books, articles and memoirs, this thesis draws on interviews with shuttle and space station astronauts, NASA flight surgeons, medical researchers, and psychological support personnel to describe a part of the space program the public rarely sees.

Thesis Advisor: Marcia Bartusiak
Title: Visiting Professor, Graduate Program in Science Writing

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The space shuttle starts in for a landing twenty times higher and seven times steeper than a commercial airliner. After firing through the atmosphere, it closes in fast on the Florida coast. The nose flattens out parallel with the ground with less than a minute to go. The landing gear drops over the edge of the runway – not a moment to spare. Any sooner and the gear would rip off from the shuttle's sheer speed.

Smoke churns as the back wheels screech against pavement. Halfway down the runway the nosegear eases down, makes contact, burns rubber. A drag chute flies out the back end, fighting crosswinds.

The shuttle chugs to a halt, coughing forward, then back. It rests majestically, if slightly worn, on the runway. The parachute ejects and flutters toward the ground.

"Houston, wheel stop," the shuttle commander transmits.

"Copy, *Endeavour*," returns Mission Control. "Wheel stop."

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"Reentry" most often evokes an image of the space shuttle flying through earth's atmosphere, glowing hot from friction, then landing on the runway and rolling to a halt. By then, the astronauts' job is finished. The hard part is over. Adjusting after six months in space, or even two weeks, should be a snap. After all, astronauts spend almost their entire lives on earth. But when the shuttle touches down at Kennedy Space Center or Edwards Air Force Base; when the parachutes fly; when the kids ask mom or dad if dad or mom is really coming home; when the astronauts lift their arms and feel them as heavy as a ship's anchor; when the mission is officially complete; the journey isn't over. The real reentry begins at wheel stop.

Gravity hits them first. Astronauts cope with intense physical changes on earth after getting used to living weightless in space. Then come the more subtle problems. After weeks or months away from home, astronauts have to work to reintegrate back into their families. At the same time, they're traveling to tell their story to the world. And they have to deal with the psychological challenges of no longer being "number one," NASA's main squeeze; by the time they get back, new space crews have taken their place as top priority for NASA and the press. Like reverse culture shock, re-immersion in the native environment of earth can be more disorienting than leaving in the first place.

In the cradle days of extraterrestrial travel, researchers didn't know if humans could even survive for long periods of time in microgravity, the "zero-g" environment of the vacuum of space. Yuri Gagarin, Alan Shepard, and their contemporaries rocketed into space for minutes or hours at a time, a day or two at most. Longer missions sent astronauts home tired and weak, unable to function as well as they had before they left. Indeed, when Russian cosmonauts had to be carried out of their space capsules on stretchers, concerns for human adaptability seemed justified. But the problem wasn't in adapting to space. That part the human body mastered. The problem, it turned out, was in coming back to earth.

On his first day home from the International Space Station, Mike Lopez-Alegria gripped the wall. If he closed his eyes, he thought, he would fall down. He couldn't tell without looking which way was up.

One of the hardest experiences of Greg Chamitoff's life was trying to get from the bed to the bathroom. He crawled. He tumbled. He crawled some more. He struggled with every inch of progress. Gravity was pinning him down.

Jeff Hoffman lay on his back in bed. Just returned from his first of five Space Shuttle flights, he was feeling pretty good. He relaxed his arms and legs. He closed his eyes in the dark, as previous fliers had told him to do. For a moment, he could have sworn he was floating in space.

Rick Linnehan woke up his first morning back feeling weightless. He rolled over to get up, as he had every morning on the shuttle. He fell flat on his face.

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In space the body stretches. Without gravity, the spine lengthens; shorter astronauts enjoy the extra inch or two. Blood and fluids, no longer pulled down through the body, rush to the head. Faces puff up and sinuses congest, while legs shrink to skinny spindles. The body senses this fluid shift and "down-regulates," purging about a liter of water and plasma within the first few days of spaceflight.

The inner ear fluid no longer responds as it would on earth. That throws off balance and sensory perception. There's no set "up" or "down," because in a floating world, directions lose meaning. At first the brain scales back its reliance on signals from

the inner ear, and astronauts learn to trust only their eyes. They can feel vertigo or space motion sickness as their "neurovestibular" sensors adjust. It takes most astronauts a few days to get oriented to new signals from the brain and body.

Muscles atrophy from disuse; there's no reason to stretch them in space. (If you want to pick something up off the floor, you simply flip over, pick it up, and flip back over again.) Bones sense less loading from inactive muscles and zero body weight; they rein in their production cells and consequently lose mass, most notably in the lower body's weight-bearing hips and thighs. Though it varies per person, bone loss in space averages about one percent per month – what some older adults lose in a year on earth.

These effects are the body's way of adapting to a novel environment. It's ruthlessly efficient. Jonathan Clark, Space Medicine Advisor for the National Space Biomedical Research Institute and a former NASA flight surgeon, calls the body's new stable state "space normal," as opposed to "earth normal." Considering that the human body never evolved to live and work in space, he thinks it's an impressive capability. It works well, if people are going to stay up there.

"Space legs" do no good, however, when the astronauts come home.

"Earth normal" starts to pull them back when the shuttle reaches entry interface at 400,000 feet, after its fiery descent through earth's upper atmosphere. Though it's not actually gravity they feel first (it's atmospheric drag) it puts a clinch on the sensation of zero-g, or weightlessness.

"Very gradually gravity comes back," says astronaut Garrett Reisman. Short duration shuttle crews sit up for reentry, as they would in an airplane. But Reisman, who returned in 2008 from a three-month stay on the International Space Station, had to lie on his back for the voyage home. He was expecting the worst. He had his barf bag ready. But since he didn't feel sick, he used it as a "g-meter" instead, holding it in front of his chest to test how long it took for the bag to fall. "It fell fast in 1.4g's," the force astronauts feel during a shuttle landing. Later he demonstrated this test to his wife using Q-tips; when he let go of one, expecting it to float, it dropped to the floor and he realized, "I'm back!"

Gravity really hits home once the shuttle stops and the astronauts begin to move around. Locked inside for about thirty minutes, while huge fans outside blow poisonous propellant away from the shuttle and ground crews "safe" the vehicle for exit, they start to move their heads, unstrap from their seats, and, if they're ambitious, test their earth legs.

After Reisman's shuttle landed, he slowly propped himself up and took off his helmet. "I felt like I was holding the anchor of the USS Nimitz," he says. "I thought, 'I won't be able to brush my teeth, or even pick up a toothbrush!'"

About fifteen minutes later he stood up. He would have fallen over if he hadn't grabbed on to handholds along the wall. After three months of ignoring "garbage signals" from his inner ear, Reisman's brain was struggling to factor those signals back in. "The vestibular system gets all messed up," he explains.

To get his brain back in gear, Reisman started turning his head, looking up the ladder to the flight deck where the pilot and commander sit, then back down to his own mid-deck. Though normally long duration astronauts are told not to move their heads too much when they land, Reisman felt well enough to help pass equipment down from the flight deck, preparing for the crew's exit.

Paolo Nespoli, an Italian astronaut and Reisman's good friend, was the first to open the shuttle hatch from the outside. He found Reisman leaning against the wall at the door, arms crossed, like he was waiting for a bus.

"What kept you?" Reisman laughed.

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It's hot in the shuttle, from reentry friction and close confinement with whirring avionics equipment. The astronauts have been cooped up for two weeks, or in Reisman's case, three months. They're eager to get out.

The Crew Transport Vehicle (CTV) is their ticket to freedom. A sort of mobile medical unit, the CTV raises up on a mechanized platform and attaches to the shuttle hatch, ready to receive its occupants.

After they crawl through the hatch – an action they call "provocative," as it over-stimulates the vestibular system and sends their senses into fits – the astronauts head for

large recliners in the CTV. Medical teams get them settled in and give them clear liquids to drink; occasionally a station crewmember needs an IV to help load up on fluids lost in space. The astronauts test their movements, sometimes getting up to take a stroll around the CTV. When they're ready, they shuck their bulky orange reentry suits and pull on much lighter blue flight suits – a welcome relief.

The crew's immediate goal is to recover for the shuttle walk-around. An aviation ritual that involves the recovery teams, NASA managers, flight surgeons, and as many astronauts from the flight as feel up to it, the walk starts on the left side of the shuttle, goes around or under the wings, and ends up back at the nose. Oddly enough, astronauts don't normally see their orbiters up close and personal, from the outside. The post-flight walk-around is their chance to get a closer look. They examine the shuttle's underbelly, note any punches or damaged tiles, and pose for photographs. Long duration station returnees are normally banned from the walk-around and remain in the CTV to rest.

Afterward the astronauts board a bus bound for crew quarters, where they reunite with their families for the first time. Crew quarters come equipped with handicap bathrooms, since even showering can be a dangerous affair. Still wobbly and off-balance, the astronauts could slip and fall; handrails and chairs in the shower minimize their risk. The first shower itself is a pleasure, since they've been limited to sponge baths in space.

Those who aren't feeling well tend to take it easy that night, and dieticians serve up their first meal on earth in their rooms. For the more adventurous it's a night on the town: dinner in Cocoa Beach with their families and possibly a stop at the local bar. Flight surgeons flock with them to keep an eye on their charges. Reisman wasn't allowed out without one. He remembers eating half a hamburger and drinking half a beer.

"I still wasn't a hundred percent," he says. His pale eyes twinkle and he smiles. "But it didn't take me long to catch up."

The day after landing the crew flies back to Houston, celebrating their return with a small private gathering in an airplane hangar at NASA's Ellington Field. This can overwhelm an astronaut who's spent the past six months seeing just two other faces; former astronaut and 2002 space station flier Dan Bursch says "it was almost intimidating to see the crowd." Astronaut Sunita Williams agrees. "People thought I was going to fall

over," she says of facing the crowd at Ellington Field after her 2007 station tour. "I said, 'no, there's just so many people!' It was sensory overload."

They're released for the afternoon and told to show up to work the next morning. For station astronauts this means being picked up in a van and driven to work. They're not allowed to drive for a month after they land, since situations such as turning a corner in a car can cause disorientation while they're still adjusting. Greg Chamitoff, who landed in November 2008 from his first spaceflight, a six month tour on the space station, says that in the van he had to put the seat back as far as it would go for the short ride to NASA's Johnson Space Center. Gravity was taking its toll, and he "couldn't sit up for more than two minutes" without his back starting to hurt. He wishes he'd had a couple days just to relax at home, but NASA wants its astronauts back as soon as possible to begin the next several weeks of medical tests, rehabilitation in the gym, and debriefings with every training and mission support crew that can get its hands on them.

Reisman's first day back at the office found him snake-walking down the hall, still wobbly. "Wobbly" is the astronauts' favorite word to describe their immediate sensations. They walk with their feet spread apart, arms out to steady themselves. When turning a corner they tend to tip over, or list to one side, as if they were getting off a sailboat. Former astronaut Jeff Hoffman, a five-time shuttle flier, says his wife always laughed when she watched him and his crewmates walk. "We looked like a bunch of drunks staggering around."

It's not just a minor inconvenience. NASA and civilian researchers are looking into the immediate effects of neurovestibular adjustment because of the ultimate goal of returning to the moon or heading to Mars. If astronauts are going to operate effectively when they land on an extraterrestrial moon or planet, they need to be able to control their balance and movement during "transition" times, i.e. the first few days of a new gravity environment (the moon pulls on astronauts with one sixth of the force of earth's gravity, while Mars rakes in about a third). In those first few days, says Dr. William Paloski of the University of Houston, astronauts will have to be setting up equipment and getting the lay of the land. Even climbing down a twenty-foot ladder on the moon, when balance is wobbly, could be disorienting.

Paloski, who collaborates with NASA flight surgeons, studies the challenges of sensory-motor adjustment post spaceflight. His goal is to figure out "quick tests" of whether the vestibular system is fully reintegrated or not. Sometimes, he says, the body can trick itself into thinking it's okay when it hasn't yet recovered. One astronaut, for example, feeling fine, headed out to play basketball with his kids on his second day home. But when he went up for a jump shot, he got disoriented and lost control. He landed in a heap on the driveway. "The body gets good enough at using alternative systems," like eyes and other body balance sensors, Paloski says, that it can bypass the neurovestibular system without thinking. "You don't know there's a deficit" until you get into an unusual situation like a jump shot, or even standing high on a rooftop.

Paloski has devised tests for earthbound patients who've lost vestibular control through injury or disease, tests which help predict balance problems such as how often patients will fall down. What he doesn't have, however, is access to the astronauts to do the same tests on them. "It's hard to get data sets and participation," he says. Astronauts are so busy during their first few days back that it's tough to snag them – and the official approval to study them. To make the problem tougher, vestibular effects wear off quickly, so the research window is small.

Some effects last longer, however, and many station astronauts take a month or two to get back to feeling totally normal. Bursch says he felt aches and pains for about a month in his calves and shins. "My tailbone hurt when I sat down," he adds. "I hadn't sat down in six and a half months." Chamitoff, after four months on earth, finally got over the lower back pain he felt from his muscles cramping up in gravity. He still feels his hips ache – from significant bone loss, he says – when he goes running.

Over the first few weeks back on earth, astronauts build back balance and strength, working with Astronaut Strength and Conditioning Rehabilitation Specialists, or ASCRS (pronounced "acers"), and athletic trainers in NASA's astronaut gym. While shuttle crews readapt quickly and generally work out on their own, station returnees are on tap for at least forty-five days of required rehab in the gym. They do stretching exercises to increase flexibility – their muscles have tightened up in space – and they work on moving side to side to retrain their brain-body connection. In one exercise to "re-

saturate" the vestibular system, the astronauts stand back to back with their trainer and pass a ball to each other as fast as they can, so the head is always spinning.

They also work on walking. Part of the body's balance system includes tactile sensors on the hands and feet, which get used to pushing off walls in space. Back on earth, those sensors need to recalibrate; feet must relearn to walk heel to toe, receiving input from earthbound friction.

Reentering gravity affects astronauts' extremities in another way as well. Bursch says he'd lost all the calluses on his feet by the time he got back after six months in space. His skin was as smooth as a baby's. "I had pretty feet again!" he says.

The astronauts and their trainers slowly add resistance exercises, working from a treadmill for gait and balance, to a bike for cardiovascular conditioning, to weight machines, and finally to free weights for muscles and bones. After forty-five days, a flight surgeon evaluates their progress and releases them, or orders up more rehab.

Garrett Reisman defied the typical long duration response. He recovered quickly enough to pass his neurological test on the third day back and got to drive early, rather than waiting a month. He was back to regular strength within a week, pumping out as many pushups as he had before he left. The problem with his quick recovery, he says, was that the flight doctors stopped noticing his feats. "I had to juggle chainsaws by the second week to impress anyone," he grumbles.

Reisman attributes his relatively quick re-adaptation to three factors: a shorter time in space (three months versus six), sticking to his exercise program on the space station, and... he's short.

"It's the second time in my life being short came in handy," he jokes. And the first? "I won a lot of limbo contests as a kid."

NASA's flight surgeons won't swear by it, but anecdotal evidence suggests that short and stocky astronauts do have an easier time readjusting to earth than long, lean ones. They're not sure why. And despite attempts to predict who might have a hard time and who won't, flight surgeons haven't been able to tell. Tom Marshburn, who spent ten years as a NASA flight surgeon before joining the astronaut corps in 2004, says his people used to try everything they could to predict who'd have a hard time on the return.

They took notes in the Boeing "Vomit Comet" and T-38 jet rides. They flipped trainees around in multi-axis trainers. They even tracked eye movements. Nothing worked, he says. No one could tell.

No one, that is, except Inessa Kozlovskaya.

Considered the "grandmother" of Russian exercise training in space, Inessa Kozlovskaya has been studying cosmonaut physiology, neurovestibular systems, and sensory-motor physiology for over thirty years at the Institute for Biomedical Problems, Russia's research arm for biological issues in spaceflight. She and her colleagues still use tests like flipping cosmonauts around to prepare them for neurovestibular changes in space, and to predict their potential for easy adaptation on the return. Marshburn, who observed Kozlovskaya's work during NASA's Shuttle-Mir missions in the 1990s, says she can point to a cosmonaut lineup heading for launch and say, "I saw him in training, he's going to have problems," or, for another, "That one, he will do fine." And, Marshburn says, "she's always right."

Paloski, who's worked with Kozlovksaya on seven or eight station missions, agrees. He says she tracks everything the astronauts and cosmonauts do in space – from their exercise regimen, to sleep patterns, to R&R – and she talks with them throughout the mission. She can tell from her notes, and her long experience, how they'll react when they come back. So far she's the only one who can.

Despite Kozlovskaya's knack, the majority of astronauts and NASA's flight surgeons claim there's no surefire way to tell who'll come back easy and who'll come back hard. To them it doesn't matter anyway, since it doesn't affect the astronaut's status or reputation. They claim there's no stigma attached.

Shannon Lucid, who holds the record for the longest U.S. mission on the Russian space station Mir, which she completed in 1996, says she felt her system flip back to normal the day after she got back from her six-month voyage. She remembers landing in Florida on Thursday, getting back to Houston on Friday, taking her kids to the bookstore on Saturday (her usual post-spaceflight tradition), cooking dinner Saturday night, and going to church on Sunday. Some people have it, she says, and some people don't. "It has

nothing to do with whether you're a good person or a good astronaut," she adds. "That's just the way it is."

Reisman agrees. What happens on the tail end gets less scrutiny, since it doesn't affect the mission. While quick readaptation could help for a mishap on the runway during landing (in case astronauts need to scramble out quickly), if all goes well, it's a moot point. "Our job is done when we land," he says. Readjusting quickly doesn't mean you're better; "it just helps for life."

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Most of NASA's attention focuses on getting astronauts ready for their mission, rather than their return. But the astronauts aren't left completely to their own devices. To ease the physical reentry, NASA and the Russian Space Agency have employed countermeasures in space since the early days of flight. Russian Salyut and Mir stations, NASA's Skylab station and Space Shuttles, and now the International Space Station (ISS) have required astronauts and cosmonauts to exercise in space to keep their bodies primed as much as possible for returning to earth.

Some grumble about the routine. After all, they're up in space, and exercising there is not fun. You have to strap yourself down to a treadmill with a harness and bungee cords, which feels like wearing a heavy backpack, and sweat tends to collect quickly without rolling off the skin; in a zero-g sprint, you're drenched within minutes. Jeff Hoffman says he exercised a few times on his first shuttle mission, but realized that "it felt like being on earth – and I was there to be in space." He decided it wasn't for him and barely exercised again during his next four missions, though once he did take the bicycle up to the flight deck and ride it all the way around the world – a ninety minute lap with a killer view.

Shuttle astronauts can get away without exercising too much, since they'll soon be back and can deal with the effects fairly easily. Long duration flights are another matter. Astronauts are supposed to exercise at least two hours a day on the ISS, keeping a steady pace all the way through their mission.

Astronaut Peggy Whitson, who flew her first station mission in 2002 and returned for a second round in 2007, made it her goal on the ISS to exercise as much as possible.

She spent several hours every day smacking bone against treadmill to remind her body of its earthly weight; riding the bike to stimulate her cardiovascular system; and pumping space iron – especially with squats – to keep the hip bones active and remind her muscles not to get lazy. Her effort paid off; Whitson lost far less bone mass than most people, demonstrating that it is possible to slow the loss through exercise countermeasures.

Researchers still aren't convinced, however. As much as exercise helps, there's no consistent link between amount of time spent exercising and percent of bone lost. It worked for Whitson, but some astronauts who keep up their regimen still lose bone; it all depends on the person. Paloski believes that exercise countermeasures alone will never solve the problems of long duration spaceflight – certainly not for neurovestibular effects, but not even for muscle and bone. Two to five hours out of twenty-four can't make up for the remainder of the body's sojourn in zero-g, he says.

And if humans are to keep up their stamina on long trips to Mars, they're going to need something more practical than an 800-pound machine – like the Advanced Resistive Exercise Device, or ARED, recently sent up to the station – to keep them going. John McBrine, a NASA manager with background in exercise physiology, thinks NASA went the wrong way in trying so hard to keep the astronauts active in space. He thinks they should have been testing how *little* exercise the astronauts could get away with and still stay healthy on their return. If the goal is really to get to Mars, he says, they'll have to use the smallest space and weight possible for fitness equipment. But testing lower limits is a hard sell when people want to come home to earth healthy and strong, and to get back to normal life as soon as possible. Plus, Paloski adds, the ethical issues in letting astronauts wither away for research purposes might not pass muster.

Exercise isn't the only space-based countermeasure available. "Fluid loading" helps combat orthostatic intolerance, or fainting, when the astronauts return to earth. Since fluids like water and plasma shift up toward the head in space (causing characteristic puffy faces and spindly legs), the body senses that it has an excess amount of fluid. To compensate, it triggers a purge; astronauts urinate frequently during their first few days in orbit, which leaves less overall fluid volume than they'd normally have on

earth. When their bodies reunite with gravity and fluids drain to the legs, the blood- and plasma-starved brain gets woozy.

Astronaut John Grunsfeld laughs recalling the "organic" fix: "it wasn't a huge research project from first principles," he says. Instead, astronauts and flight surgeons put their heads together. Hmm, they said. Maybe we should put that fluid back before we come down. Their solution? Hot 'n' salty chicken soup.

Some first-time fliers go with the soup option, but most choose to drink salt tablets dissolved with lemonade and artificial sweetener (real sugar slows down the body's absorption of salt). Astronauts start fluid loading about two hours before landing to give their bodies enough time to absorb the liquid, without enough time to purge it.

"The astronauts hate it," says Jonathan Clark. If they're going to get queasy, he explains, a full stomach only makes it worse. Plus, they're still up in space when they start fluid loading, so they get puffy and congested again, and generally feel bad. "Or," he says, "they have to pee, and they don't like having to use a diaper."

Tom Marshburn agrees it's uncomfortable. Since the astronauts are also wearing reentry g-suits – pressure suits that keep blood from pooling in their legs – the g-suit pushes hard on the abdomen, which "just took in a load of salt water."

But they have to do it, and they are scolded by example; astronauts who don't drink their fluids have fainted at post-landing press conferences. That's embarrassing for everyone, though sometimes loading up on schedule doesn't work so well, either. Sunita Williams did drink her fluids after six months on the space station, but she still felt dizzy and needed IVs in the crew transport vehicle. Next time she flies, she says (hopefully), she plans to start fluid loading a full day before landing. That's how the Russians do it, and they seem to turn out fine.

Russian cosmonauts do appear to handle the return well, Marshburn says. A rare breed of flight-surgeon-turned-astronaut, Marshburn spent time in Russia during the Shuttle-Mir program in the mid-1990s, when NASA sent astronauts to Moscow for long duration mission training and then to the Russian space station Mir. From his observations as a flight surgeon, Marshburn thinks cosmonauts have an easier time coming back, particularly with neurovestibular issues. "They don't seem to have the head

spinning," for one, he says. Because he doesn't have hard data, he hesitates to claim the experience overall is easier for cosmonauts, and the process varies for each individual.

Still, Marshburn thinks the return environment might have something to do with it. Russians come back to Star City, an isolated compound in the middle of a forest outside Moscow. It's quiet and calm. It's totally contained. "There's no street like NASA Road 1 in Star City," Marshburn comments, pointing out the Starbucks window to the bustling four lane road outside NASA's Space Center Houston (even at 6:30am the street is packed with cars). Star City, he says, is "more like a suburb in northern Maine."

Those who come back to Star City have more rest time – three weeks in "official" quarantine, though newly returned cosmonauts can be spotted walking around the compound, sometimes loitering to have a cigarette. After quarantine, which includes debriefings and physical rehabilitation, cosmonauts often take an extended vacation with their families. The pace in Russia is generally slower, say many NASA astronauts, who spend three weeks in Star City themselves if they return to earth in a Russian Soyuz capsule. Some astronauts enjoy the break (and some who don't get it are envious), while others – Peggy Whitson, for example – can't wait to head home to the States. After two weeks of recovery in Star City, Whitson booked a flight out, ready to get back to normal life.

In some cases, though, "normal" isn't what greets space travelers on their return.

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Sergei Krikalev was orbiting earth when his country fell apart.

A cosmonaut who's logged over two years off the planet, spanning two Mir missions, two shuttle missions, and two ISS missions, Krikalev was serving on the space station Mir during the Soviet Union's August 1991 coup attempt. Because the country was literally collapsing beneath him, with funding falling out from under the space program and upcoming crew launches combined from two to one, he agreed to stay in orbit for a second term. By the time he left in March of 1992, he was leaving the Russian – not the Soviet – space station Mir. While he went to space a native of Leningrad, he returned to earth a citizen of St. Petersburg.

Astronaut Frank Culbertson was circling earth on September 11, 2001. He could see the smoke from the twin towers clearly – a reminder every time he passed over New York City that when he got home, his world would never be the same.

Astronaut Dan Tani's mother was killed in a car crash while he was orbiting on the ISS, just before Christmas of 2007. He couldn't go home until two months later.

NASA flight surgeon J.D. Polk says the hardest thing about spaceflight is that "people assume the world won't change while they're gone." When the Soviet Union fell, the cosmonauts came back with invalid passports, a new flag, new cities, and new street names. When the twin towers fell, the astronauts came back to a country in mourning. That's a big psychological factor, says Polk.

The changes are also hard because astronauts and cosmonauts in space can't take part in events on earth. Though they may sometimes see the effects as they orbit – as with the smoke over New York City – they are disconnected from their families and friends, and from the events themselves.

This hit home for the crew of ISS Expedition 6 in 2003. Circling on the station while the space shuttle *Columbia* conducted final experiments and geared down for reentry, they had no idea they would never see the shuttle's crew again. Still in space after the *Columbia* broke up over Texas, Don Pettit and Ken Bowersox couldn't attend their friends' funerals. They didn't get to say goodbye.

The loss of *Columbia* changed their world in another way. Since it grounded the U.S. space shuttle fleet, Pettit and Bowersox became the first NASA astronauts to return to earth in a Russian Soyuz spacecraft. An Apollo-era capsule shaped like a gumdrop, the Soyuz holds three people across in tight confinement. The astronauts had received training on Soyuz craft so they weren't concerned for their safety, but it was still a risky mission. This was the first Soyuz-TMA craft – a modified version of the older Soyuz model – and if it failed right after the *Columbia* had, Polk says, that "could have ended human spaceflight."

It didn't. Bowersox, Pettit, and their Russian commander, Nikolai Budarin, landed safely. However, the Soyuz TMA-1 – designed for an automatic landing rather than a piloted one – came in on a ballistic reentry path. That means it defaulted to a much

steeper flight path than normal, thrusting 8g's on its occupants who for five and a half months had been floating in microgravity.

The Soyuz is designed to withstand this kind of reentry; unlike the space shuttle, you can toss it any which way and as long as the parachute deploys, it will land relatively safely, if with a few bumps. The landing was harder on the crew than it was on the spacecraft, but they managed to crawl out and lie on the ground to rest while they waited for a lift to Moscow. Because they'd landed short of their drop zone and their radio antenna had snapped off, they waited over two hours for rescue helicopters – which had to refuel before finding them – to pick them up and take them home. They later told the press that the best part about their landing was smelling the dirt and hearing the birds chirp.

Now when astronauts go into space, they prepare beforehand for how they want their information – over easy, or over hard. Some want to hear bad news relating to their immediate family only, while others want to know everything. They plan out their strategy in advance with their families, and the flight director, flight surgeons, and NASA's Behavioral Health and Performance group – the BHP – make sure everyone is tracking. That way, when the time comes, they hope to minimize the shock.

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Disasters on the home planet make for a challenging reentry, but routine mission endings have their own psychological snags – not just for returning astronauts, but also for their families.

Former astronaut Dan Bursch spent six months of 2002 flying around in a tin can, with two other crewmembers and nowhere else to go. On his mission, the station was less than half the size it is now, with livable, workable space about the size of a large airplane's interior. That doesn't give three people much room to maneuver, especially if they have an argument. Some flights have come to fist fights; on one early Russian mission, two crewmembers didn't speak to each other for a full one hundred days. It's like friends becoming roommates, Bursch says, or like being locked in a house with two people you don't choose. "Little things bug you," he says. Being separated from family doesn't make it any easier.

But Bursch wasn't the only lonely one. His wife Roni was back on earth, taking care of their three small children on her own, while working part time as a nurse anesthetist. For her, the mission was a completely different experience. She held down the fort while he whizzed high overhead, zipping by unseen every ninety minutes.

The disparity between their experiences lasts even today. If Bursch turns on NASA TV at home, for example, his wife often asks him to turn it off. Though it's been a few years, Bursch says, it still brings up sad times for her, when she was alone with the kids. "Maybe that will change sometime in the future," he adds, "but it hasn't yet."

For Bursch and other station astronauts, family reintegration can be a tricky part of the return journey. "It's not unlike a military deployment," says Bursch, a retired navy captain. "You have to gradually understand where you fit in."

Studies of Antarctic expeditions and military deployments, particularly submariners at sea and, increasingly, soldiers deployed to Iraq and Afghanistan, have shown that spouses left behind do adjust to their partner's absence. Though their workload increases as they add a spouse's responsibilities to their own, they find a balance. It's when the partner comes home, trying to fit back into the family the way he or she would have before, that tensions build.

That's where the BHP comes in.

Since the beginning of U.S. spaceflight, NASA has been steeped in a short duration, "sprint" mentality. Mercury, Gemini, and even Apollo missions to the moon lasted days at most, while shuttle missions have lasted a week to two weeks, sometimes eighteen days. Three trips to Skylab, NASA's space station experiment in the 1970s, put astronauts in space for one, two, and three months. Not until the mid 1990s, when NASA astronauts hitched rides on the Russian Mir station for four to six months, did long duration spaceflight become an American reality. And only with the first missions to ISS, starting in 1998, did it become a permanent fixture in NASA's plans, and control rooms.

It's a tough transition from sprint to marathon. From learning to operate a 24-7 schedule in mission control (you can do anything for two weeks, one controller said, as long as you get vacation afterwards), to incorporating psychological support for the astronauts and their families, NASA is finally catching on.

The Behavioral Health and Performance group, or BHP, was formed in 1994 as Mir missions were underway and plans for the ISS were taking shape. The group brought together psychologists and psychiatrists who now dedicate their services to improving the experience of long duration astronauts and their families before, during and after their flights.

NASA flight surgeon and psychiatrist Gary Beven, a leader of the BHP, says there's a "higher degree of psychological mindedness" inherent in long duration missions, versus short ones. His goal is to maintain the astronauts at peak performance throughout their time on the station, as well as to enhance their experience.

To that end, psychological perks abound: weekly video conferences with families and an internet protocol phone for calling earth during free time, "discretionary events" where astronauts can talk to celebrities of their choice, a guitar and keyboard on station for recreation, receiving movies before their release dates on earth, or even getting a digital copy of their hometown newspaper every night. Then there are the re-supply ships – the space shuttle or an unmanned Russian Progress capsule, similar to the Soyuz – which bring gifts from families, fresh fruit, new clothes, and, in the space shuttle's case, visitors.

Astronaut perks can be stressful for their partner on the ground. Bursch says his wife had to pull together care packages for deadlines months before a supply ship was launched, and after struggling to collect three small kids every two weeks for a trip to mission control, she resorted to taking just one child at a time to their family conferences (now video conferences are set up for private communication once a week in the family home). The goal, despite the stress, is to keep everyone connected.

Sometimes that can be as easy as an avatar. Astronaut Mike Fincke, who finished his second tour on the ISS early this year, had a cardboard cutout of himself at home that his wife Renita called "Flat Mike." Their youngest daughter, who was three months old when he went into orbit, got to know him not just through his cutout – provided by the BHP – but also through video conferences and phone calls from space. Renita wasn't worried about her daughter. "She's getting to know him, so he won't be a stranger when he comes home. She'll be surprised though, when he's warm, and real!"

Although most of these initiatives are in place to ensure an astronaut's smooth functioning during the mission, the thinking goes that happy astronauts communicating with their families from space make happier astronauts on the ground afterwards.

The BHP pairs each astronaut with a team of three support specialists, assigned two years before the astronaut flies on station. This gives the team time to get to know their charge and his or her family in order to individualize their services. After the flight, they are scheduled to meet with their astronaut three times: first at three days after landing and finally at thirty days post-flight. During that time they're available for family conferences, and they remain open to the astronauts and their families even after the 30-day review.

Walter Sipes, another leader in the BHP group, says that his teams brief astronauts and their families on what to expect from reentry long before they even fly. Roles and responsibilities have shifted, they tell families, and children may be confused or distant. It takes time to readjust. Don't try to take control the minute you walk through the door.

Right before the astronaut is due to return home, BHP teams email a set of briefing notes to both the astronaut and his or her spouse, again reminding each of what to expect during reintegration. Some take the briefing slides lightly – Garrett Reisman and his wife later teased each other about "changing roles and responsibilities" – while others, often those with young children, have a harder time rallying for the endgame.

Greg Chamitoff says he wishes the BHP would actually meet with spouses, as opposed to just sending PowerPoint slides. His wife, a doctor, was busy doing her job as well as taking care of their three-year-old twins; she didn't have time to read every email NASA sent. Important things like those slides can slip between the cracks, Chamitoff says. A meeting and "direct discussion" might have prepared his wife better for the post-mission timeframe. "They did a great job throughout the mission," Chamitoff adds, to clarify. "But the idea of preparing family for the post-flight could be done a little better."

After all, astronauts don't just come home and start mowing the lawn or doing the laundry. Even after rehab and debriefings, which take the first few weeks, the "mission" isn't over yet – at least not for them. Next up come the public relations tours, which take

astronauts away so often that it can seem to their families as if they're still in space. Coming back, in other words, doesn't mean they're home yet.

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Publicity tours often last three months for shuttle crews, while station crews go six months or more post-flight. They travel the world, but it's not all fun and games. Aside from the additional time away from family, the tours themselves can be stressful. While some shuttle crews travel together, astronaut Mike Lopez-Alegria says station astronauts do most events on their own. NASA's budget doesn't include sending people to help, so they deal with the logistics, such as equipment set up, themselves. And no matter how much they enjoyed their mission, it can be a drag to keep talking about it. Often astronauts find themselves in the equivalent of cocktail-party-introduction mode multiplied a hundred times: repeating their stories over and over each step of the way.

Publicity can be bad for their health, too. Garrett Reisman says he got sick on his hometown visit – after shaking hands with so many people, giving so many speeches, answering questions and running from school to school, he was in bed for two days, voice gone, flu symptoms flaring. He was exhausted in Japan and cut short a sightseeing excursion in Kyoto. Though PR tours are an indispensable part of NASA's space communication program, and a delight to schoolchildren and the public worldwide, astronauts have to learn to proceed with caution.

"They load you up," Reisman says, and "you have to push back, be good at saying no." If you're not, they'll clobber you.

Shannon Lucid knows what that's like. After her record-setting Mir mission – she earned the space endurance record for Americans in 1996 and held it until 2002 – Lucid was away from home every week over the next year. "It was the worst year of my working life," she says. Because she wanted to fly again, she did what NASA asked and went where they told her to go. Even at Christmas they were calling her at home to schedule events. She had one reporter tell her she was "the second biggest story in the world, next to mad cow disease." She was mobbed everywhere she went.

"I would tell my husband, 'Okay, I'm going to the grocery store,' and three hours later I'd come home." Everyone recognized her. Everyone stopped her. It got so bad her

daughter refused to go to the mall with her, and when she asked the family to go to church on Christmas Eve, her daughter said, "Only if you put a bag over your head!"

"And it was true," Lucid says ruefully. "It took a *long* time to die down." The pace only quieted after she started saying no – no to the press, no to NASA, no to everyone. Despite her year on tour, Lucid never got another mission.

The publicity tours do have their rewards, including inspiring the younger generations, meeting enthusiastic kids, and visiting friends, teachers and mentors who helped set them on the astronaut path in the first place. Speaking can also help them reflect on the spaceflight experience. After oodles of talks, Lopez-Alegria has finally found a way to answer the first question on everyone's mind: "what's it like in space." He tells people it's like laughing: hard to describe, but you know it feels good.

Greg Chamitoff, who just got back, says he's excited to share his stories with others. He wants to give people a sense of what his trip was like, what he did in space, from educating his Russian comrades on the merits of *Star Trek*, to communicating with MIT engineers in real time for station experiments with his alma-mater. "You spend your whole life hoping you'll do something that makes a difference," he says, and while his flight achieved a personal goal, he believes his contribution now is to spread the wealth.

What he tells people is that space is not a novelty anymore, not like it was in the early days. Sure, the experience will be life-altering for him, but more because it confirms a worldview people already accept. We all see from movies, ads and pictures that the earth is round, beautiful, fragile. It's part of the common consciousness; astronauts just get to confirm it. Telling the world about that, in Chamitoff's view, is more a repayment than a chore.

Post-flight duties and tours also give astronauts time for fun. Dan Tani remembers the excitement of activities with his shuttle crew after landing, when they finally got to spend time together outside training and the mission. You get really close to the crew in training, Tani says, but then you're always working. Post-flight is the best part, when you're still together in debriefings, remembering stories, putting the mission video together, going on tour. It's more relaxing than before. These are some of the best times,

Tani thinks, because "the best part about space is the crew." They're like another family – the space family, that is.

But when the tours finally end, it hits home: the mission is over.

"Once you start to see [the crew] break up, that's the sad part," Tani says. He felt let down when his crew left their joint office and went their separate ways to new assignments. When they were no longer together, he says, "it was like breaking up the family."

Tani isn't the only one to feel a loss. NASA flight surgeons recognize a post-flight depression, what some astronauts call the "post-flight low." They say it's common, and applies to both shuttle and station crews. The astronauts have been training a long time to do their mission, explains flight surgeon Jim Locke. Then, as they get closer to launch, more people are paying attention to them – the media, NASA training teams, mission control, everyone. The mission itself is an adrenaline rush, then suddenly it's over. After a few post-flight PR rounds, Locke says, the astronauts can feel left in the lurch.

Jonathan Clark agrees. The astronauts' schedule is most rigorous right before the mission, he says, and station crews have been training for at least eighteen months before flight – half of which they've spent away from home. Then they do a six month mission, then a month of rehab, then six more months of post-flight travel and debriefings. Then, says Clark, they ask, "what do I do now?" They "come down from this massive high.... There's a sense of loss, of 'I'm not going to do this again.'" One morning they wake up in space, says Tani, and the next night they're changing the kitty litter.

The post-flight low usually hits when flight involvement – all the activities for memory, data collection, and public travel – are over, whether it's three months later for a shuttle crew, or six months after a station mission. Former shuttle astronaut Jim Newman realized he was disappointed a few months after his first flight. "It was this immense high: we didn't screw up, everything went well, we were still alive." But he says he felt a personal low wondering how long it would be "before I get to do *that* again." (His answer: two years.) Garrett Reisman, who was headed to Israel for a publicity tour the

day after we met, was still on the road seven months after landing. As for his post-flight low? "Ask me again in six months. I'm still doing the victory lap."

Research suggests that an emotional low after a "peak experience" like spaceflight – or the Olympics, or climbing Mt. Everest – is normal, even common. NASA psychologists, psychiatrists and flight surgeons are on hand in case the astronauts need help, but don't seem fazed by the phenomenon. "If they ask about it, we tell them it's normal," Locke says. But there's no set plan to deal with it systematically, and as usual, it's different for everyone. "After a little while they get over it," Locke adds with a shrug. "They move on."

Because of the difference in mission length, shuttle and station flights don't always feel the same. Mike Lopez-Alegria felt the furious pace of both training and mission, followed by the post-flight slowdown, for all three of his shuttle flights. With shorter missions, he explains, you train for a year and in the last part you're running fast, then you launch and the whole mission is an adrenaline surge. "You're going full afterburner the whole time," he says. "Then you come back and it's over. It's a big let down every time."

Station astronauts, on the other hand, have been gone for six months and are often ready to come home. Lopez-Alegria commanded a seven-month ISS mission, landing in 2007, and thinks post-flight psychology on the long duration missions is easier – and more satisfying – than on the shuttle.

"You're living there," he explains. There's time to look out the window, time to spin upside down. Time for the moment. "It's a different kind of experience." He says he came away from the station thinking "it was enough." Not "enough, like get me off this thing," but enough to fill the experience and return content. With the station, he says, you're up there so long that "it's just nice to be back." Compared to his shuttle missions, says Lopez-Alegria, coming home from the space station "was the period at the end of the sentence, instead of the dot dot dot."

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Once the astronauts land, their rigid pre-flight and in-flight structure suddenly disappears. It's an "alien tempo," says former astronaut Kathy Sullivan, the first

American woman to walk in space. It's like Wile E. Coyote, "running like hell" till he finds himself off the cliff, suspended for a moment in midair. "You were running at top speed, the center of the universe for at least thirty days before flight," she says. "Then nothing. The cliff falls out from under you." Sure, NASA support teams say "welcome back," and they help the astronauts adjust their sleep schedules and rebuild their workout schedule. But in general, Sullivan says, by the time you get back, "everything is moving forward to other crews."

In fact, she adds, right as the shuttle's tail clears the tower on launch, seven people on the ground stand up and say, "Prime Crew!" They are the new hot tamales, the next crew at center stage, and the just-launched astronauts are already headed for history. "They go on to the next crew," says Lopez-Alegria, "and you're nobody. You are so yesterday's news."

It's not quite what every five-year-old pictures when day-dreaming of becoming an astronaut. It's a tough job to land in the first place, and even harder work to keep it up. As one astronaut points out, it's a job with lots of training, lots of travel, lots of administrative work, and only a little bit of flying in space. The pressures are intense, and the strain on family life is real; divorce isn't foreign to the astronaut corps. The risks are real, too. Peggy Whitson told this year's round of astronaut candidates that the hardest part about being an astronaut can be watching friends die. Yet despite the challenges, thousands of people apply for ten to fifteen slots each time a new class opens up, and the astronauts themselves volunteer again and again to fly in space. They'll take the risk, though as Chamitoff comments, it's reassuring once the shuttle wheels touch pavement, and you know you'll see your family again.

Astronauts are hard chargers, professional, intelligent, and funny. They're normal people who happen to get a paycheck for an unusual day at the office. And like Olympic athletes, they spend years preparing to achieve their dreams. They work hard to get to Houston, even harder to get to space. For many, the trouble lies in what comes afterwards. Rushing back into the bustle of life on earth – and the physical, familial, and psychological readjustment in store after wheel stop – can make the space journey itself seem surreal. Disbelief sets in. After you land, Sullivan says, "you're plopped back into

normalcy, into what 41.9 of your 42 years have been. You know you did this," she adds a little wistfully, "but you can't remember how amazing it felt to be there."

Some astronauts find substitutes on earth. John Grunsfeld, an astronomer and veteran shuttle astronaut, says flying in space is just one adventure. He keeps his earthbound schedule full to compensate, climbing mountains, flying airplanes, and investing time in "high performance challenges" like trying to solve issues in climate change. Mountain climbing in particular, says Grunsfeld, like spaceflight, is something "physically very hard and emotionally spectacular." Looking out over a beautiful vista gives him "the same feeling as 'wheel stop' after a successful mission."

For Lopez-Alegria it's not quite so easy. He says "it's always a challenge to find another challenge." He knew his station mission would be his last, so he was satisfied with his spaceflight career. Still, he says frankly, he hasn't been inspired by anything else since flying in space.

Then was it worth it? "Absolutely," he says. Even with the training time, the tough schedules, and the long separation from family? "That's all true," he says, "but when you put it in perspective, it's a small price to pay."

SIDEBAR: Up Close and Personal with a Soyuz Reentry

While NASA's space shuttle lands like an airplane, the Russian Soyuz lands like a really big rock. Soyuz is an Apollo-era capsule with barely enough room to fit three people squished side by side in their reentry spacesuits. Unlike the shuttle, piloted by its commander, the Soyuz reenters earth's atmosphere on automatic pilot. Astronauts and cosmonauts are passengers along for the ride.

It's a spectacular entry, says astronaut Mike Lopez-Alegria. The capsule glows with the heat of atmospheric drag. The astronauts feel about 4g's, or four times as heavy as they would on earth. After "the heat and danger are over," at about ten thousand feet, the parachute jets out and catches air. It jerks the capsule around, swinging it like a toy on a string.

Right before impact with the Kazakh steppe, the Soyuz fires soft-landing jets to ease its controlled crash. Soyuz hits the deck. Lopez-Alegria says it felt like getting rear-ended. So much for the landing jets.

Sometimes the parachute catches more air, bouncing and dragging the capsule along. The second landing, when it finally stops, is on its side. This part, says Lopez-Alegria, felt like getting "pushed into an intersection and T-boned."

Lopez-Alegria always felt fine on his shuttle landings. He'd get "a little dizzy," he says, "like being drunk, but not unpleasant." No such luck with the Soyuz, after seven months in space. He felt weak, he says, and nauseous. No wonder, considering the ride home.

When the ground crews arrive on the scene – almost immediately if Soyuz lands on target, hours later if it doesn't – they roll the capsule to the right orientation to get the door open. More nausea ensues. The passengers would tumble like socks in a dryer if they weren't strapped in.

Once the Soyuz is positioned, the recovery team pries open the hatch. Astronauts and cosmonauts breathe their first fresh air in half a year. The ground teams, on the other hand, are greeted by a whiff of stale air and un-showered humans. The smell can be overwhelming after seven months of sponge baths for the capsule's three occupants.

While the astronauts adjust fast in space and don't notice (smell, some say, is the first sense to go), ground crews aren't so lucky. They reach in anyway to pull out their fliers.

The center seater is the first one "literally hauled out," says Lopez-Alegria. He himself was the last one out, which was fine with him. "I was just happy it wasn't moving anymore," he says. But he didn't get a break for long.

"You come out on your belly, then they flip you onto your back. It felt awful. I hated it. I wanted my feet on land. Even if I'd needed help to stand, I would have wanted my feet on the ground."

Lopez-Alegria was carried to a camping chair, wrapped in animal skins, and given an apple and water, per Russian tradition.

"It was a surreal experience," he says. He was in the middle of nowhere, staring at a totally flat horizon. The only signs of life were his space capsule, a fleet of helicopters with blades whining, a blow-up medical tent, and about fifty people who clustered around him and his crew – doctors, nurses, people with cameras. It had been eighteen hours since Lopez-Alegria woke up on the station. All he wanted was to sleep. But he was nowhere near his final destination.

He and his crew sat in their chairs for about ten to fifteen minutes, then they were taken to the medical tent to get out of the sun and into normal clothes. The person next to him was throwing up. Lopez-Alegria was feeling alright. A U.S. flight surgeon and Russian nurses hovered around them for about half an hour in the tent, then they drove a hundred yards in ATVs to a pack of Mi-8 helicopters – one for each astronaut, plus several for the gear – and flew another forty-five minutes to the local Kazakhstan airport.

They received a royal welcome. They were taken to chairs in the hall of the airport and given bread and salt, a Russian tradition for returnees from a long journey. They were also given capes and big crown hats to wear for the press conference. "We looked ridiculous!"

They didn't stay long ("thank goodness") and were soon in the air. Each astronaut got a cabin equipped with a personal flight surgeon for the three hour flight to Moscow. When they finally arrived at Star City, late at night, a Russian marching band struck up

and four girls in white shirts, black skirts and red bowties presented them with (more) bread and salt.

There the nations split. Lopez-Alegria headed back to the American village of Star City to rehab with his own flight surgeons and strength and conditioning specialists. His Russian crewmates headed into the profectorium, a mysterious facility where cosmonauts go to recover in isolation. Even the permanent American team in Star City knows little about what goes on inside.

Lopez-Alegria stayed three weeks, taking part in medical tests and debriefings. He rode a stationery bike in the makeshift basement gym of one of the American cottages, gaining back strength and balance. After official Russian quarantine ended, a final ceremony celebrated his crew's return to earth. They laid flowers on Yuri Gagarin's monument in Star City. They gathered for speeches – all given in Russian, even by the Americans. They toasted, they gave gifts, they rubbed shoulders with dignitaries. There were flowers everywhere.

Then Lopez-Alegria came back to Houston to begin reentry again, the American way.

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