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How to Survive in Space

Course Guidebook

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HOW TO SURVIVE LAUNCH

We go to space for a variety of reasons—a challenge that tests our limits, a competition that pushes us to excel, and an opportunity for scientific discovery that expands our understanding of the world and universe. The downside is that certain aspects of space exploration affect every organ system in the human body: forces during launch and landing; microgravity; radiation; and an isolated, confined, and extreme environment. Through the course of this lecture series, you will examine the reality of these effects, how they are portrayed in pop culture via Hollywood, and what Hollywood gets right and wrong. In this first lecture, you will focus on where it all starts—launch—and take a closer look at some of the less glamorous aspects of space travel that Hollywood ignores, such as quarantine, dietary changes, sleep disruption, and waste elimination.

G-Forces

To survive launch, you must survive g-forces that can cause you to pass out. You'll have to endure a headward fluid shift caused by being in a head-down tilt for a long time, even after you're in space. Increased g-forces are sometimes called hypergravity. Before liftoff, you will only feel the force of Earth's ordinary gravity, which is 1 G. During launch, you will feel larger g-forces.

In the early days of the space program, the rockets would sometimes subject astronauts to forces as high as +10 Gs. Lying transversely to the direction of acceleration is key to withstanding up to 9 Gs, but even that position won't allow you to tolerate over 10 Gs. At this acceleration, you will hardly be able to move your chest wall to breathe.

G-forces in one direction cause the body's tissues to resist in the opposite direction. In other words, the inertial forces compress soft tissues against underlying structural tissues (your bones or skeleton). If the g-forces aren't pushing your soft tissues into your bone, they are pulling your soft tissues away from your bone. Likewise, g-forces will shift the blood volume away from the direction of acceleration, affecting blood pressure. If high g-forces shift blood away from your head, this reduces blood and oxygen delivery to your brain, and there is a high probability that you'll pass out.

Nowadays, the acceleration you would experience is much lower than 10 Gs. The early rockets that launched men into space were literally nuclear missiles with their warheads swapped out for astronaut capsules. Later, space shuttle g-forces peaked at about +4 Gs.

To survive the longer-duration high g-forces of space flight, astronauts wear special g-suits, which are designed to counteract the effects of high Gs by squeezing the legs and abdomen. The suit is like a soft tourniquet that prevents blood from draining into the legs. This helps to keep blood flowing to the brain and other vital organs. In addition to keeping your blood in your brain, you'd want to make sure you weren't squished like a pancake against your seat. In this regard, the Tempur-Pedic mattress uses a special material called memory foam, which is a viscoelastic foam that conforms to the shape of the body but returns to its original shape when the forces deforming it are removed. It "remembers" its shape.

Along with g-suits and the Tempur-Pedic mattress, being in a reclined position protects against the high Gs of launch. However, it also marks the start of the headward fluid shift. Normally, when we stand, our blood and the fluids that bathe our tissues hang out by our feet. While astronauts are reclined during prelaunch, all the blood that was hanging out at their feet pools in their head, and this will continue once they are in space. This prelaunch phase is often overlooked in Hollywood depictions, but it is a crucial part of the process.

Quarantine, Dietary Changes, and Sleep Disruption

Before launch, astronauts must go through a rigorous quarantine period to ensure they don't bring any illnesses or diseases into space. This can mean spending weeks or even months isolated from friends and family in a special quarantine facility. During this time, astronauts must also endure a variety of physical and medical tests to ensure they're fit to fly. These can include everything from blood tests and x-rays to psychological evaluations and fitness assessments. They also have to follow a tailored diet to prepare their bodies for the physical demands of space travel, which can include everything from high-protein meals to special supplements.

During the preflight phase, when an astronaut is preparing for a mission, they will need to shift their sleep cycles and be on a schedule that mimics the one they'll be on in space. Astronauts can't just wake up early and return to sleep—they must fully shift their circadian rhythms, the internal processes that regulate our sleep–wake cycle, hunger, and other physiological processes.

NASA uses a variety of techniques, such as light therapy and melatonin supplementation, to help shift astronauts' circadian rhythms to the schedule they'll be on in space. This can be challenging, as the body is used to a 24-hour schedule, but it's important for the astronaut's well-being and performance on the mission.

NASA also tries to keep the astronaut's sleep cycle consistent, as the body's internal clock is very sensitive to changes in sleep schedule. They also monitor the astronaut's melatonin levels to ensure they are staying in sync with the mission schedule.

Overall, the goal is to prepare the astronaut's body for the schedule they will experience in space so that they can perform at their best and avoid "jet lag" during the mission. Since this circadian shift happens during quarantine, that means astronauts must deal with isolation, dietary changes, and sleep disruptions before they've even left the ground.

Eliminating Waste

On May 5, 1961, Alan Shepard became the first American to fly in space. On that day, his launch had been delayed for 4 hours. For such a short mission, NASA's mission control had not anticipated that he would need to pee and therefore had not yet developed a solution. With no other alternative, mission control gave the green light for Shepard to let loose in his space suit.

If you're sitting upright, high g-forces can cause all the blood to drain from your head and into your feet, causing you to pass out. But if you're reclining with a slight head-down shift—as Shepard was—then you're much better able to withstand those high forces. Unfortunately, that same position caused Shepard's urine to flow upward instead of down, pooling on his back.

NASA decided to take the issue seriously and began developing a more advanced solution. They initially looked to devices used by military pilots and hospital patients for inspiration, but they soon discovered that earthbound devices wouldn't work in zero gravity.

Today, astronauts are fitted with urine collection pants, called the Maximum Absorbency Garment (MAG), that resemble baby diapers. They are much more comfortable and can be used by men and women. They

Urine collection and transfer device used during the Apollo 11 mission in July 1969

serve as a last resort during takeoff, landing, and spacewalks. They're made of a material called sodium polyacrylate that can absorb up to 300 times its weight in distilled water. This allows the astronaut to change the diaper as infrequently as every 8 to 10 hours without compromising on comfort.

In the American space program, astronauts typically use laxatives to help them go to the bathroom before launch. This can involve taking a pill or drinking a special solution to help stimulate bowel movement. Russian cosmonauts use water enemas to help them eliminate waste before launch. This is a more invasive process, but it's considered more effective in ensuring that the cosmonauts are completely empty before launch. In Hollywood, the use of laxatives and enemas in the space industry is often overlooked completely or downplayed, but it's standard practice and essential for the safety and well-being of astronauts and cosmonauts.

Countdown to Launch

In Hollywood, the countdown is often depicted as a thrilling and dramatic moment, with the clock ticking down and the tension building. In reality, the experience can be a long and tedious process, with astronauts spending hours or even days sitting around waiting for launch to begin.

And there's no guarantee of surviving the prelaunch phase. On January 27, 1967, a tragic accident occurred during a test rehearsal for the upcoming launch of the Apollo 1 mission. A fire broke out in the cockpit, resulting in the death of all three crew members. As a result of this accident, NASA implemented several changes to improve the safety of the astronauts, the most important of which was replacing the intensely flammable cabin air of 100% oxygen with a mixture of 60% oxygen and 40% nitrogen. The investigation into the accident also revealed that the astronauts were not fully wearing their pressure suits at the time of the fire, which would have provided some protection from the flames and smoke. So, NASA made it mandatory for astronauts to wear full pressure suits during launch and reentry.

Once you survive the prelaunch phase, you'll have to survive launch. Launching a rocket into space is essentially a controlled explosion that propels the spacecraft upward. The process begins with the ignition of the rocket's engines, which produce a tremendous amount of thrust directed downward, causing an equal and opposite reaction that propels the rocket upward. As the rocket rises, it must navigate through Earth's atmosphere, which is thick and turbulent. The craft must also withstand the intense heat and pressure generated during its ascent.

Another danger during launch is the risk of human error, such as a mistake in the rocket's guidance system or a failure in the communication systems that can lead to a loss of control of the rocket. Additionally, the intense vibration and acoustic loads generated by the rocket's engines can cause damage to the spacecraft and put the crew at risk.

The *Challenger* accident tragically illustrated the risks associated with the launch phase. On January 28, 1986, the *Challenger* space shuttle exploded 73 seconds after liftoff, killing all seven crew members—and the cause of the accident turned out to be so simple.

The gases that make up the controlled burn are directed through various rocket stages (or sections) before they exit at the nozzle. These various stages are connected by joint seals, which prevent the hot gases from entering any other rocket stages. These joint seals can handle very high heat, but they don't work if they freeze. In the hours before sunrise and the launch, the temperature fell all the way to 22°F, and the booster rocket's joint seal failed.

The seal failure allowed hot gases to escape from the lowest stage of the rocket, and the escaping hot gases ignited the main fuel tank. And yet, even the resulting explosion is not w hat caused the loss of the crew. The crew compartment had been successfully designed to withstand incredible heat and forces, and therefore, the crew survived the explosion. The blast did not kill them—the impact following the 30-second drop to Earth did.

As with the Apollo accident, the *Challenger* accident resulted in changes in safety and an improved culture of communication. NASA redesigned the rocket joints and seals, added crew pressure suits and a limited crew escape capability, and banned potentially unsafe practices and payloads from shuttle missions. This accident highlights the need for rigorous testing and inspection of all the components of the rocket. The failure of a single component can cause catastrophic results, and NASA maps everything that has been learned from prior failures and close calls into later missions.

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2

HOW TO SURVIVE
SHORT-TERM WEIGHTLESSNESS

When movies like *Gravity* and *Armageddon* show astronauts experiencing weightlessness, it's either treated as routine, if the astronaut is seasoned, or as wondrous, if the astronaut is a rookie. They never show the real problems that come with extended time in space. In fact, real-life astronauts themselves initially hid the downsides of living in space. In this lecture, you'll learn about some of the uglier side effects that microgravity can have on the human body—from massive headaches to serial vomiting.

Weightlessness and the Vascular System

What happens to your vascular system in a weightless environment? Anyone who's ever spent time upside down knows how your head feels like it's trapped all the blood in your body. This is called a headward fluid shift. For astronauts, it starts while waiting for launch, in a reclined position. Once in space, they enter microgravity, and the fluid shift continues.

Our veins and arteries have some elasticity to them. On Earth, gravity pulls our blood toward our feet. But in space, blood is redistributed more evenly, based on the elasticity of our vasculature, and that elasticity pushes a lot of that fluid toward the head, increasing the pressure in the head. This leads to puffiness of the face, a feeling of fullness in the head, and what astronauts have described as the worst headache of their lives—which can last for 3 to 5 days.

Your cells don't have water pumps to get rid of fluid, but they do have sodium-potassium pumps. For a long time, experts thought that your body's way of fixing the fluid imbalance is to ramp up its excretion of sodium, leading to increased urine production. The hypothalamus—the part of your brain that makes you feel hungry, thirsty, or tired—responds to this apparent excess of fluid by reducing thirst. So, according to this theory, over time, your extra peeing combined with less drinking reduces your body fluids, which relieves the pressure in your head and chest.

Astronauts lose about 10% to 17% of their plasma within the first 10 days in space. They also lose roughly that amount in red blood cells. Researchers initially believed that the loss of red blood cells in space might only be a result of the fluid shift. However, they found that red blood cell destruction continues long after the initial fluid shifts. On Earth, there is normal turnover of red blood cells throughout one's life, but in space, 54% more red blood cells are destroyed than on Earth. That's why astronauts returning from space must be carried instead of walking on their own. They suffer orthostatic intolerance: When standing upright, they become dizzy and often pass out because significantly less blood reaches their brains.

Certain research groups are questioning whether the fluid is actually lost. They have found that the data is conflicting and that astronauts do not seem to lose body weight or overall fluid. Their theory is that the water is driven from within the arteries and veins to within the muscles and between cells. This can happen because without gravity, muscles don't have to work as much, and muscle tone is much less.

Motion Sickness

Fluid shift isn't the only thing that could cause unsteadiness. Microgravity severely disrupts the body's spatial orientation and posture control systems, causing disorientation and motion sickness during the first few days in space. To understand why, it helps to understand what causes us to feel motion sick in the first place.

In 1882, William James, the father of American psychology, was on a ship in stormy weather and noticed that everyone except roughly 15 deaf passengers was violently seasick. The workings of the inner ear were well documented by James's time, and scientists understood that deafness could be caused by damage to the vestibular system. In a flash of intuition, James wondered if the vestibular system was somehow also responsible for motion sickness—and he was right.

The next big discovery came from Archie McIntyre, an engineer turned medical doctor, who specifically researched motion sickness in airmen. Researchers noted windowless passengers suffered much more from motion sickness than pilots; blind flying—when pilots use only their instruments—in rough weather was particularly nauseating; and flying boat crews—who were down in the fuselage and could not see out—suffered more than the crews of other aircraft. McIntyre then hypothesized what is now widely accepted: Motion sickness occurs when motion is felt but not seen or seen but not felt. This sensory conflict contradicts the normal agreement of vestibular and ocular systems that is learned from many past experiences.

The theory explained why pilots rarely suffered airsickness: They could look out the window and see the horizon—they could see what they felt. Their unfortunate passengers in the plane's fuselage with no windows felt motion but did not see it. Research conducted after World War II added to McIntyre's theory. Changes in vertical speed were found to be the most nauseogenic. In any environment, tilting or nodding one's head would make the nausea worse.

Returning to space sickness, vomiting in a space helmet carries the very real risk of drowning in one's own vomit. It doesn't pool, and as it floats, it can be inhaled. But even if vomiters don't drown, they may be distracted or disabled and make an error that could catastrophically endanger themselves and their comrades.

Space Adaptation Syndrome and the Vestibular System

During the Cold War space race, neither the Soviet nor the US space program publicized its issues with space sickness. Even among the astronauts themselves, space sickness was a dirty secret. If they admitted they were prone to throwing up in space, they might be grounded. Space Adaptation Syndrome, as it was politely called, could also come on with explosive suddenness, meaning space sickness was likely to appear without the warning period of nausea that often precedes seasickness.

Space Adaptation Syndrome is still not fully understood, but it's likely due to a variety of causes. For example, on Earth, people who get motion sick learn to recognize their warning signals. However, some people who suffer space sickness have never been motion sick on Earth, so they don't recognize those signals. Plus, in space, not only is your vestibular system completely out of whack but also there are lots of disorienting visual inputs: Imagine turning around to see an upside-down colleague—this sudden profound disorientation might take you by surprise and cause vomiting.

Since the astronauts themselves hid its prevalence, it's difficult to pinpoint which missions were affected by space sickness. The problem seems to have started in US astronauts by the time of Apollo 7 in 1968. The spacecraft had a roomier cabin than any of its predecessors, which meant the astronauts had more room to move their bodies and heads, which can increase nauseousness.

NASA hadn't aggressively researched the problem because it hadn't realized its extent, but its researchers knew that in microgravity, the vestibular system is confused since there is no sense of "up." The more an astronaut moved around, the more that seemed to distress the vestibular system, leading to vomiting.

The vestibular apparatus helps you balance, and it sits in the middle of your head at about the level of your ear. The vestibular organs are also connected to the eyes to enable you to maintain your focus on an object while in movement or rotating the head. This happens because the vestibular organs send information to the brain that enables it to automatically rotate the eyes in equal and opposite directions to the rotation and movement of the head.

PRIME CREW OF THE FIRST MANNED APOLLO SPACE MISSION, APOLLO 7

Although we believe that controlling our eyes while running is voluntary, something called the vestibulo-ocular reflex (VOR) kicks in to make small adjustments so that our eyes act like a Steadicam. We only notice that we aren't in control when we get dizzy and it seems like the world is racing in front of us.

What's actually happening is that our eyes are moving back and forth without our control. Spinning around causes our endolymph fluid to move. We are dizzy because it is still moving even after we stop spinning. Our eyes move back and forth because our brain is automatically rotating our eyes to match the continuing movement of the fluid—it believes our head is still moving. In this regard, the vestibular system and eyes need to work together.

Adaptation, Readaptation, and Reducing Motion Sickness

In microgravity, the VOR cannot do its job properly due to a phenomenon known as “retinal slip.” The eyeballs lag in their movements, causing images to race across the retina, producing the blur that you see when you wave your hand in front of your face. In microgravity, the vestibular system is already struggling to adapt, and it is further taxed by the VOR’s efforts to compensate for retinal slip. The more astronauts move their heads around, the more the VOR struggles to do its job, and the more it fails.

Fortunately, this isn’t permanent. According to NASA scientist Millard F. Reschke:

> The brain is very good at adapting and says, “I’ve got to make up the difference somehow.” The period of adaptation, when the brain is trying to do this, is when motion sickness is probably going to be the most prevalent—and that is typically when the person has just gone into space. It may last a day, it may last 2 or 3 days. In some cases, adaptation has never taken place and people are sick for the entire flight.

When astronauts return to Earth, the vestibular system must readapt, and another period of sickness may follow. But readjustment is usually much quicker since the vestibular system is adapting back to its normal environment. In his research, Dr. Reschke looked for a way to shorten readaptation times. He drew on Canadian researcher Geoffrey Melvill Jones’s experiments from the 1970s, in which volunteers wore glasses fitted with prisms to reverse the images they saw.

If volunteers turned their heads to the left, the image would also track to the subject’s left instead of to the right, as it would normally. Not surprisingly, this sensory mismatch was a highly nauseogenic stimulus, though the VOR could eventually adapt. However, Jones discovered that if he flashed a strobe light during the adaptation period, the test subjects did not get motion sick. He hypothesized that strobing froze images on the retina, providing a sort of antidote to the nauseating effects of the sensory mismatch.

Reschke reasoned that if he could construct a device that strobed the environment at the right frequency, he might forestall the onset of motion sickness. In 2003, he collaborated with two junior NASA scientists to design a pair of glasses with LCD lenses that could strobe four times a second. Most of the time, the lenses were opaque, but four times per second, they were clear for less than 0.5 milliseconds—long enough for an image to leave an impression on the retina.

Four-hertz strobing is very noticeable to the user, and wearers are mostly not actually seeing anything: With the Reschke glasses, they could see for a total of only 2 milliseconds each second and could not see for the remaining 998 milliseconds. In activities like operating a spacecraft, where split-second reaction times are important, vision impaired to this degree would be impractical, but in test conditions in cars, boats, parabolic plane flights, and military operations, the glasses do reduce motion sickness. The glasses were successful in long-term testing in Black Hawk attack helicopters for instrumentation crews, who must read their instrument panels as they bounce in the windowless fuselages. Since Reschke's work, the technology has been developed further, and these glasses are now on the market.

While strobing glasses are effective, antiemetic drugs are still more practical because you can see 100% of the time. NASA has also had success with biofeedback programs. Tiny, portable biofeedback machines alert astronauts when their bodies are beginning to show signs of motion sickness that they would otherwise be unaware of. Through exercises, astronauts learn how to normalize metabolic functions that weightlessness might otherwise skew into the nausea zone.

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3

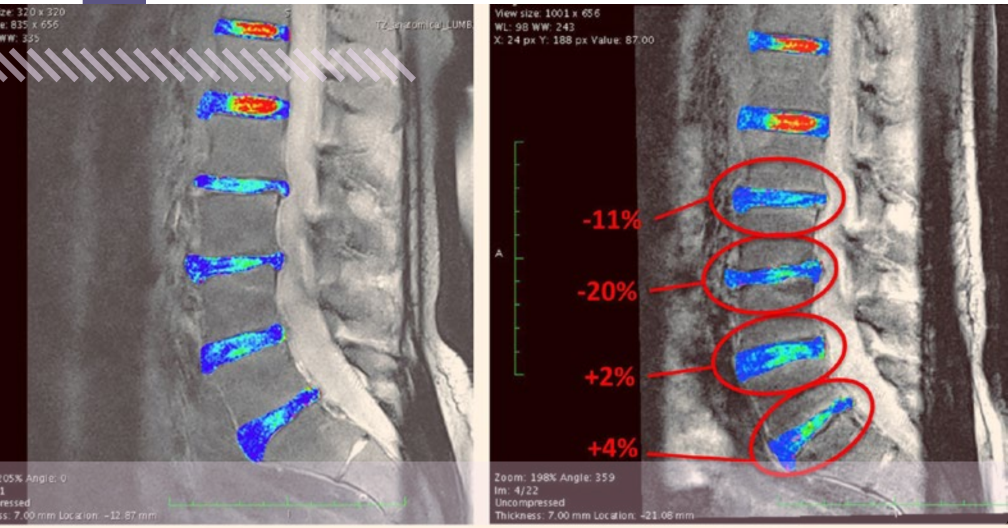
HOW TO SURVIVE LONG-TERM WEIGHTLESSNESS

Extended time in space affects nearly every single body system, including balance, the cardiovascular system, and the musculoskeletal system, making falls a near certainty—which is why astronauts are carried from their spacecraft. Shuttle astronauts who are in space no more than 3 weeks typically regain their balance within 12 hours to 2 or 3 days. But astronauts who spend months on the space station tend to take more than a week to fully readjust to gravity, just in terms of balance. In terms of the musculoskeletal system, it can take years to return to normal. In this lecture, you'll look at a wide range of effects that occur when astronauts experience extended periods of weightlessness.

Spinal Damage and Muscle Atrophy

Spaceflight changes how your body looks and functions in significant ways. For example, without gravity to compress your spine, the vertebrae separate, and you become up to 3 inches taller. In between your vertebrae are the intervertebral disks. On Earth, they are compressed somewhat under gravity, so they have room to stretch when you bend over and move around. But in a microgravity environment, without that compression, they're much more likely to already be stretched to their limit. When you bend over in space, they have no "slack," and they can tear. As a result, astronauts who have been in space for an extended period are at greater risk of a herniated disk, which can lead to persistent pain.

In addition, the fluid shift that happens in the first week continues throughout the rest of an astronaut's time in space. While the extra pressure in the head and chest leads to puffiness in the face, swelling of the neck veins, and hardening of the arteries, the reduced pressure in the legs leads to skinny "chicken" legs. This is due in part to muscle atrophy.



Preflight **Postflight**

Simply moving your own body weight in the presence of gravity involves using your muscles. This "loading" helps to maintain muscle mass. "Unloading" means completely not using a muscle. If you're an astronaut in space, this unloading is like nothing your muscles have ever experienced before, and it leads to muscle atrophy. Astronauts on spaceflights as short as 5 to 11 days have lost 20% of their muscle mass.

And this atrophy is the worst in the weight-bearing muscles, the so-called antigravity muscles. These are the muscles in your legs and lower back that actively work to keep you upright, even when you are not aware of it. When you are standing, they are working against gravity, making tiny adjustments in your posture to keep you upright. In space, though, these muscles have nothing to do, and they shrink over time. To keep them from shrinking, astronauts exercise about 2.5 hours per day to make up for the complete lack of muscle loading, and they eat a diet designed to minimize muscle loss. In addition to exercise, personalized hormone countermeasures are also being investigated to help combat space-related muscle loss.

Bone Resorption

Just like muscle, bone gets lost in space. Bone loss is called bone resorption. Astronauts returning from long stays can develop osteoporosis. Research has reported that an astronaut in space loses bone at a rate of 1%–3% per month.

No matter how old you are, the oldest that any of your bone cells can be is about 10 years. This is because all of the tissues in your body are constantly being turned over, including bone. If you understand material fatigue, it really makes sense. Have you ever bent the tab on a soda can back and forth until it broke? Cycling the metal back and forth causes tiny cracks to develop, accumulate, and form one giant crack that propagates until the material fails—this is fatigue. To prevent this from happening over time in bone, your bone cells go through and eat away these tiny cracks and then replace them with new bone. This entire process is called "remodeling."

Bone is a living dynamic tissue that will change its shape to fit the load. Similarly, when part of the body is "unloaded," the bone will decide that less tissue is necessary and begin to resorb some. So, in addition to exercising to keep their muscles from atrophying, astronauts exercise to keep their bones from resorbing too much.

Bone is mostly made of calcium, and when it resorbs, all that excess calcium goes into the bloodstream. In addition to contributing to osteoporosis, dumping so much calcium into the bloodstream can result in the development of kidney stones, which is a risk and has been reported by at least 30 NASA astronauts.

This turns out to be an area where lessons learned from osteoporosis patients help astronauts and vice versa. Drugs called bisphosphonates have been used in osteoporosis patients for nearly 20 years, and they work by inhibiting osteoclasts—the cells responsible for breaking down bone. And despite the salt excretion driven by the fluid shift, astronauts retain a disproportionate amount of sodium, making their bodies more acidic, which can contribute to bone loss.

In some studies, researchers have been able to halt bone loss with a combination of bisphosphonates, improved resistance exercise devices, and diets also shown to help osteoporosis patients. Bisphosphonates are effective in astronauts and in other people because stopping the osteoclasts helps to maintain bone and prevent the development of osteoporosis.

The Cardiovascular System in Space

The impact of space on the cardiovascular system is a little more complicated. The heart is a muscle, and although cardiac muscle responds to stress differently than skeletal muscle, even cardiac muscle will atrophy in space. After all, it has less blood volume to expand it—less "flexing" to do. So, the reduced blood volume leads to the heart shrinking in size and becoming more spherical in shape. On Earth, gravity seems to be the most important factor in terms of how spherical a normal heart is. From other studies on the heart, we know that spherical heart shapes are less efficient.

While this less-efficient heart has less blood to pump, it also has less assistance than on Earth, where gravity helps the heart get blood to the feet. Also, muscle activity in the "antigravity muscles" normally squeezes the veins, helping return blood from the feet to the heart, but in space, this assistance is gone. Because there is less blood, the heart can't contract as forcefully, and because the heart is rounder, it can't contract as efficiently. This results in the smaller, more spherical heart beating faster just to maintain the same circulation rate.

Although it is not known whether these changes are unhealthy, astronauts have been shown to lose a quarter of their aerobic capacity after just 2 weeks in space. They have also reported irregular heartbeats.

The reduced blood volume that contributes to many of these changes is called hypovolemia. Research has shown that surgical patients with otherwise asymptomatic hypovolemia experience impaired wound healing. This is a concern because skin injuries are the most common injury reported in space. Research has shown that astronauts do indeed have impaired wound healing. It is unknown how much being in a hypovolemic state contributes to this, though, because all cells behave differently in space. These include the various skin cells that help heal wounds and immune cells, which also play a role in wound healing.

The Immune System in Space

The immune system is also suppressed in space as part of a normal stress response. The body is under incredible physical and psychological stress in space. Studies of otherwise healthy people on Earth—for example, caregivers of people with dementia—show that high levels of stress, even emotional stress, release hormones that suppress the immune system. Under stress, the body shuts the immune system down to focus on more essential systems. In microgravity, the fluid shift and the unloaded bones and muscles are stressors for the body.

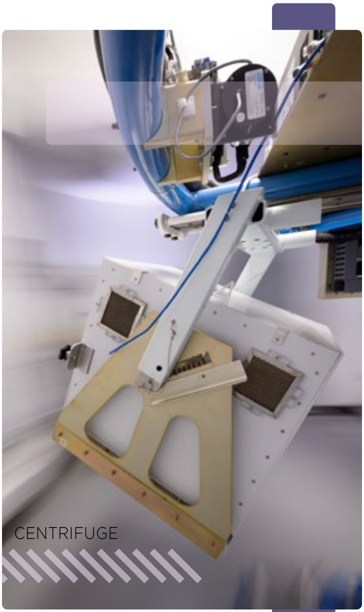
There is also the stress of being in an environment without true day-night cycles. The International Space Station (ISS) orbits Earth every 90 minutes. This means there is a sunrise and a sunset every hour and a half. In space, the high psychological stress and lack of clear day and night signals disrupt the circadian cycles that dictate sleep and wake times. As a result, astronauts are perpetually sleep-deprived and sleep only 6 hours per sleep cycle. This has an effect on cognition and performance. In fact, performance deficits are so common that astronauts have dubbed them "the space stupids."

Astronauts in long-duration spaceflight also have increasingly reported vision problems—more so than their short-duration counterparts—that can persist for years after the original spaceflight. This phenomenon is known as spaceflight associated neuro-ocular syndrome (SANS). This is an area where sex differences may come into play. Currently, 82% of male astronauts versus 62% of female astronauts have some symptoms of SANS. But, as of 2017, every clinically significant case had only occurred in male astronauts. In other words, if you looked in the back of their eyes, both men and women had changes, but only the vision of the men was affected.

Countermeasures

Space researchers are constantly investigating methods to counter the dangers of spaceflight—called countermeasures. If we can figure out how to control it, one promising countermeasure for muscle atrophy is myostatin, which is a protein that suppresses skeletal muscle development. Mutations in myostatin genes lead to much larger muscles. Some athletes and other remarkably strong people have been found to carry one mutant myostatin gene. Research into myostatin mutations is being conducted to help people with muscle-wasting diseases, such as muscular dystrophy, or people with muscle atrophy, like the immobile … or astronauts.

Research suggests that centrifuges, even short-radius centrifuges small enough to be brought onboard the space station, could help. The acceleration they provide mimics gravity enough that short doses of simulated gravity may be sufficient to counteract many of the changes caused by prolonged weightlessness.


CENTRIFUGE

Research with mice in space shows that when they are in centrifuges, the acceleration acts like artificial gravity. These astronaut mice do not lose any bone or muscle, unlike their buddies who aren't in centrifuges.

Research is also exploring lower-body negative-pressure suits, which have been used in space since the 1970s. These suits essentially put the lower body into lower pressure than the rest of the body to counteract headward fluid shifts and generate ground reaction forces. These ground reaction forces are thought to be beneficial for maintaining bones and muscles by producing gravity-like loads experienced on Earth. Although such suits have been used in space for decades, the jury is still out on the ideal dose and best design.

Both lower-body negative-pressure suits and centrifuges have been tested in ground models of weightlessness. While these studies can replicate many of the symptoms of being weightless, such as the headward fluid shift, muscle atrophy, and bone resorption, there are some effects of weightlessness that are only seen in space. For these reasons, researchers won't know how helpful the lower-body negative-pressure suit and short-radius centrifuge are until they study them in space.

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4

HOW TO SURVIVE MICROBES IN SPACE

As on Earth, human beings in space are covered with microbes, inside and out, roughly 100 trillion per person. This entire collection of microorganisms (bacteria, viruses, fungi, etc.) that live on and inside the human body is called our microbiome. Disruptions in the microbiome have been linked with gastrointestinal conditions and wider systemic manifestations of disease, such as obesity, type 2 diabetes, allergies, asthma, and even brain and psychological involvement. With this in mind, the focus of this lecture will be on the effect of—and how to survive—microbes in space.

Personal Hygiene in Space

There are no showers or laundry in space. Crews come from different cultures. People from the US like to shower every day and use deodorant. Not everyone does. Even if it were possible to shower in microgravity, American levels of water use would not be possible. An average person in the United States might use up to 350 liters of water per day. In space, astronauts use far less water, with each astronaut using only about 4.4 liters per day; much of that is recycled. Most of this water is used for drinking or to rehydrate food pouches. Only half a liter is used each day for personal hygiene.

Moreover, microgravity makes showers impossible. The spray from a shower wouldn't fall—it would just float out, everywhere. Worse, water touching you would not fall off but would stay attached to you, trapping you in a giant water sphere, where you would most likely drown. Managing small amounts of water is possible, since the water stays together, due to surface tension. For example, once you have a big drop of water, you can put it on a toothbrush.

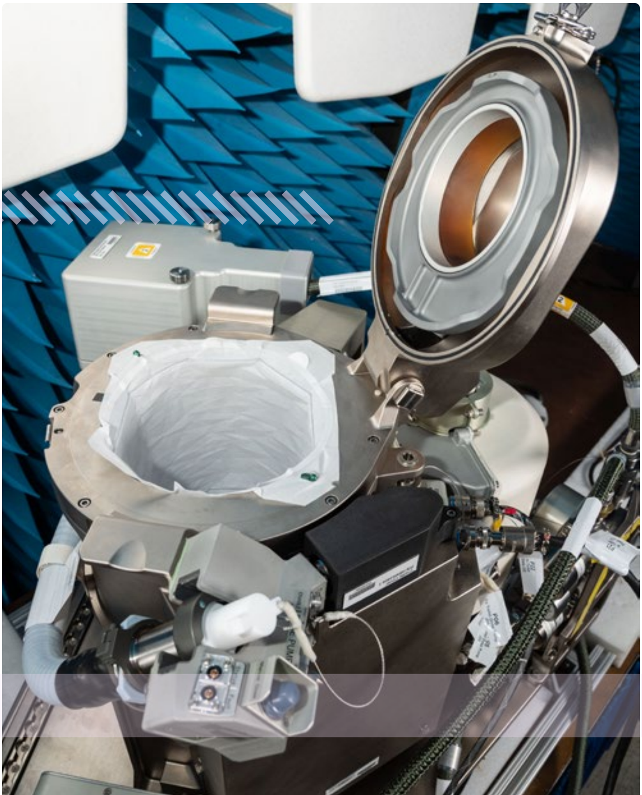
Still, personal hygiene for astronauts is an important aspect of space travel, as it helps maintain their health and comfort. Maintaining good hygiene is also crucial for preventing the spread of diseases and infections, especially in close quarters. So, astronauts use other methods to keep clean. Instead of showers or baths, they use a combination of wet towels and water-based wipes to clean their bodies. Toothpaste tablets use less water.

For their hair, astronauts use waterless shampoos. The shampoo is applied to the hair and then rubbed in. After that, it's "rinsed out" with a damp towel.

Astronauts who want to shave can use an electric razor that collects hair or safety razors with removable blades and shaving cream that can be wiped off with a towel.

For toileting, there's a whole other set of challenges. Again, because there's no gravity, you use not water and a bowl but a specialized toilet, where you attach yourself with leg restraints to hold yourself in place while using a funnel attached to a vacuum hose. These high-cost space station toilets collect and separate solid and liquid waste. The solid waste is exposed to the vacuum of space to be sterilized and is then packaged. From the ISS, an unmanned supply ship full of poop is disposed of by undocking it, and it burns up in Earth's atmosphere. The liquid waste is purified and recycled into drinking water. To be as self-sufficient as possible, all forms of used liquid, including sweat, breath vapor, and urine, are recycled to produce fresh drinking water.

ISS UNIVERSAL WASTE MANAGEMENT SYSTEM



As of June 2023, the recycling rate on the ISS had reached about 98%. Given these water constraints, astronauts do not launder their clothes. Instead, dirty laundry is regularly sent back to Earth via resupply ships or incinerated in the atmosphere. To minimize the need for resupply, astronauts have been known to wear the same clothes for 6 months or more, leading to high levels of body oils, dander, particulate matter, salts, and odor-causing bacteria. The smell from these bacteria persists because the air is in a contained environment: You can't open the window to get fresh air, and although there are filters, no filter is perfect.

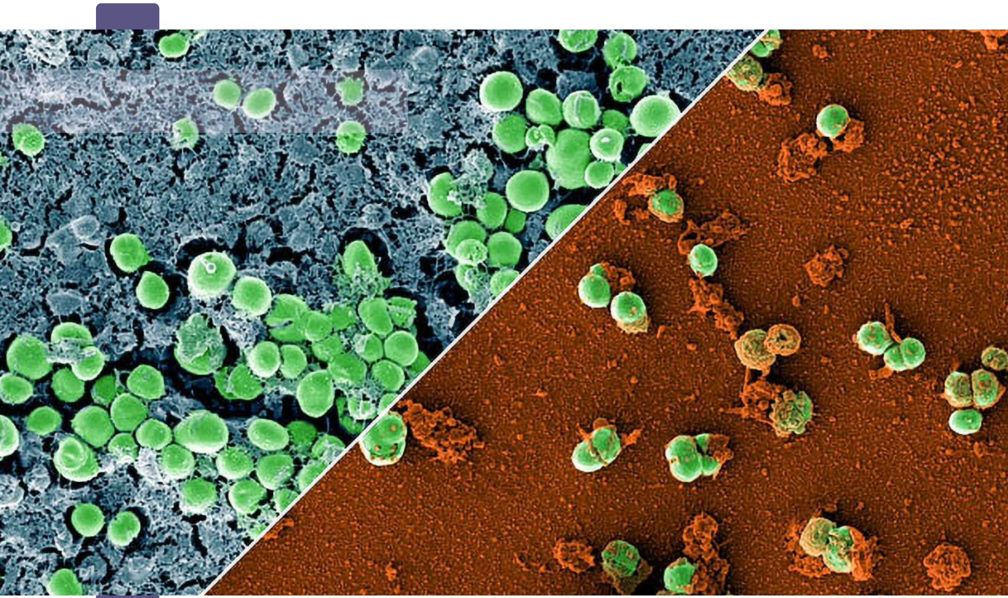
The Microbiome and the Space Environment

Microbes cause problems for every system within the crew habitat. When microbes grow, they form colonies. Then, to protect those colonies, the microbes form a biofilm over themselves. Biofilms are thin, slimy films that are like a shield, and because the films adhere so well to surfaces, once a biofilm is formed, it is harder to get rid of the bacteria. Biofilms have been found on the interfaces of station parts and components. They can cause damage requiring costly repairs and create other technical issues on both crew contact and food contact surfaces. Microbes are also found in drinking water and even in the air, which increases the potential risk of inhaling microbial pathogens.

Of course, most of the bacteria in space aren't on the walls but are on—and in—the people. The microorganisms that make up the microbiome of a human being are estimated to outnumber human cells by a factor of 10 to 1, and they play critical roles in human health and well-being. One of the key ways that the human microbiome affects health is through its influence on the immune system. The microorganisms in the gut play a role in training our immune system to identify and respond to harmful pathogens while also helping to prevent overactive immune responses that could lead to conditions such as allergies and autoimmune diseases. It is also becoming increasingly clear that the human microbiome plays a role in mental health. Ongoing studies have found connections between imbalances in the gut microbiome and conditions such as depression and anxiety.

Just like everything else, the microbiome is affected by the space environment. One of the most notable effects of spaceflight on the human microbiome is a shift in the composition of gut bacteria. Studies have shown that the abundance of certain bacteria decreases during spaceflight, while that of others increases. These changes in gut microbiome composition can lead to digestive issues, such as diarrhea and constipation, as well as altered immune function and nutrient metabolism.

Some of these changes in the microbiome are due to the space environment, like microgravity and radiation exposure; others are due to appetite, digestion, and diet changes; and others are likely due to a combination of these factors. Researchers have discovered that microgravity, in particular, can affect bacteria and fungi by altering the way they grow and interact with their environment. In particular, microgravity causes bacterial cell membranes to become thicker and less permeable, which makes the bacteria harder to kill. When bacteria are harder to kill, there is increased pathogenicity and bacterial resistance, making antibiotics less effective.



STAPHYLOCOCCUS CAPITIS ON STAINLESS STEEL VERSUS ANTIMICROBIAL COPPER

The big picture is this: At the same time your immune system takes a hit, you are surrounded by superbugs that refuse to die. Microgravity is altering the cells that coordinate your immune system. It changes both the number of immune cells you have and how they function. So, your defenses are down at the same time that many microbes are becoming more hostile and harder to defeat.

Reducing Bacterial Growth and Colonization

Historically, the ISS has only monitored microbial growth in water, and although surfaces are cleaned, they are not assessed to determine the effectiveness of cleaning. So, you have no idea what's safe to touch. While the habitat systems do have high-efficiency filters that help to minimize smells, in microgravity, any residual odors do not rise or descend, as they would on Earth.

Additionally, no air filtration is perfect. In fact, the rate at which smells are being made is generally faster than the rate at which they can be removed. Dust, dander, skin cells, and any microbial life can also remain airborne, entering the eyes and noses of astronauts, potentially causing irritation and allergic reactions.

One proposed solution to this problem is to build everything with contact-killing surfaces. For example, one study found that surfaces coated with a copper-silver alloy were effective at killing 99.9% of bacteria within 2 hours of contact. In fact, Russians and other Europeans on the ISS use silver ions to disinfect their water.

There are also nonmetallic nanopillar surfaces that are modeled after the wings of dragonflies—a hierarchical surface structure made up of small ridges, posts, and grooves, which make it difficult for bacteria to adhere and grow and cause them to experience shear stress when coming into contact with the wing, leading to physical disruption and death. Studies have shown that contact-killing surfaces are effective at reducing bacterial growth and colonization by 99% compared to smooth surfaces.

With such contact-killing surfaces, we might have far less microbial infestation than we have previously had aboard the space station—at least until the microbes adapt. Researchers stress the importance of understanding the types of microbes that become dominant in space environments. Space microbes may affect not only the health of crew but also the integrity of the spacecraft.

Microbe Adaptation and Evolution in Space

Everything brought on board a ship has bacteria. When the microbes arrive in space, they continue to multiply and evolve, and added to the mix is the microbial life shedding from the astronauts. They shed hair, skin cells, eyelashes, perspiration, and tears, and along with their own cells are microbes from their skin, breath, flatulence, etc. Those accumulate inside a spacecraft, eventually creating what is called the environmental microbiome of the ship as a whole. According to the lead researcher on a 2019 study, the walls of the spacecraft take on a coating of crew members' skin cells, and the ship's air filters come to resemble the crew's nasal passages.

This works in the opposite direction, too. Each person's individual microbiome adjusts to reflect that of their environmental microbiome. Because the life span of bacteria is so much shorter, there is time for these adjustments to occur over generations. As a result, the bacteria evolve as they adapt to these adjustments. In space, they evolve dramatically.

One bonus of space affecting microbial life so profoundly is that this may allow us to accelerate medical treatments against them. *Salmonella* is a type of bacterium that can cause food poisoning in humans and animals. Research has shown that, just as it does on other microorganisms, spaceflight can have an impact on the growth and behavior of *Salmonella*, and these changes may have implications for human health, both in space and on Earth.

Studies have shown that exposure to microgravity can alter the way *Salmonella* grows and spreads, making it more virulent and resistant to antibiotics. The altered growth and behavior of *Salmonella* in microgravity may also have important implications for the development of vaccines and treatments against *Salmonella* infections.

For example, studies have shown that exposure to microgravity can increase the production of certain antigens. Allergens are particles from substances that cause an allergic response; antigens are particles that cause an immune response. Certain bacteria increase their production of antigens, which could potentially lead to the development of more effective vaccines.

For instance, both *Salmonella* and *Staphylococcus aureus*, a strain of bacteria resistant to certain antibiotics and more commonly known as MRSA, have been studied in zero gravity as part of the Pathfinder program. The increased resistance of *Salmonella* and *Staphylococcus* to antibiotics observed in microgravity could also have implications for the development of new treatments for infection. For example, understanding the mechanisms underlying this increased resistance could lead to the discovery of new targets for antibiotics, which could be used to treat MRSA or *Salmonella* infections, both on Earth and in space.

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5

HOW TO SURVIVE IN A SPACE SUIT

NASA calls them extra vehicular activity (EVA) suits, but you know them as “space suits.” What you may not have considered is that this kind of space suit is essentially a tiny spaceship that conforms to one’s body: It has an atmosphere and, sometimes, food and drink. Often, astronauts have to go to the bathroom in there. If you put on a space suit, it protects you from the vacuum of space, just like a spaceship, but you will still face several potential dangers while wearing it. In this lecture, you’ll explore most of the ways in which the space suit is a mini spacecraft and some essentials for surviving in one.

Space Suit Risks

Despite being made to wear in the vacuum of space, a space suit isn't designed to keep you warm—it's actually designed to keep you cool. That's because a space suit is a sealed environment, so an astronaut's body heat builds up inside the suit over time. To counteract this, you'll probably wear several layers under your space suit, including a liquid cooling and ventilation garment, which keeps you cool by circulating chilled water through plastic tubing.

Space suits are bulky and heavy, which can make it difficult for astronauts to move around and do their work. Unlike the lighter suits astronauts often wear while inside their spaceships, space suits can weigh anywhere from 110 to 330 pounds depending on the model and mission requirements. Additionally, when the suit is pressurized to protect the astronaut from the vacuum of space, it becomes stiff and difficult to move. As a result, just from moving around, a person inside a space suit is exerting a lot of extra effort.

Like any workout, this effort generates a lot of heat, and by design, the space suit is insulating you from the outer environment. As a result, a major challenge of wearing a space suit is heat stress. If you are in a space suit and you are doing strenuous activity, you can quickly become overheated. This can lead to dehydration, heat exhaustion, and even heat stroke.

LIQUID-VENTILATION COOLING SUIT

Beyond overheating, injuries have been caused by the awkward movements and postures required to work in the bulky space suits. Astronauts have reported fatigue, muscle strain, and other musculoskeletal problems after performing spacewalks. The suit's gloves, which are also pressurized, not only make it difficult for astronauts to manipulate objects with their fingers but can also cause astronauts to lose fingernails.

To minimize these risks, NASA puts astronauts through careful training, monitoring, and medical support. To prepare for spacewalks, astronauts train in a giant pool called the Neutral Buoyancy Laboratory at NASA's Johnson Space Center. The pool contains a life-size mockup of the ISS and other space vehicles as well as underwater replicas of tools and equipment.

Although one might think that there is no danger of drowning in space, astronaut Luca Parmitano almost drowned in his space suit in 2013. The water leak in his suit came from a hole in the suit's cooling system, which uses water to regulate the temperature inside the suit. In the pressurized environment of a helmet, there is no other place for water to go, so the water in Parmitano's helmet became trapped and started to accumulate. NASA examined the details of this alarmingly close call and introduced hundreds of changes to processes and procedures, not only for spacewalks but across the board, to prevent a recurrence and to reduce response time should anything similar happen.

NEUTRAL BUOYANCY LABORATORY AT NASA'S JOHNSON SPACE CENTER

Another major problem of a space suit is that while it protects your body from the outside environment, it also prevents you from accessing your own body. You can't scratch your nose or wipe your eyes. Even though you may not drown if something gets in your eye, you might be blinded. And while the chances of that are low, it has actually happened.

Low Pressure and Science Fiction Movie Errors

Unfortunately, getting into and out of a space suit is not simple. The space station is pressurized at about 1 atmosphere—the atmosphere at sea level on Earth. Space suits are pressurized to about a third of that because if the suit is pressurized much higher, it becomes too stiff for the astronaut to move in it. However, that's a lot of decompression and recompression. On Earth, you'd have to climb near the top of Mount Everest to get down to one-third of the air pressure at sea level.

As a result, when astronauts enter or exit a space suit, they must follow additional specific protocols to ensure they do not experience decompression sickness or other medical issues related to changes in pressure. To do this, astronauts conduct a prebreathe protocol, which involves breathing pure oxygen for several hours before a spacewalk and after the suit is sealed. Nitrogen can form gas bubbles that cause astronauts to feel pain in their joints, including their shoulders, elbows, wrists, or knees. This condition is called "the bends" because it affects places where the body bends. Pure oxygen helps to flush nitrogen out of their system and prevent decompression sickness. This oxygen is typically supplied through an umbilical cord from the ship.

During these several hours on pure oxygen, the astronaut may also use a rebreather to help maintain a consistent level of oxygen and carbon dioxide in their breathing mixture. Rebreathers are devices that recycle the air that the astronaut breathes out, removing carbon dioxide and replenishing oxygen.

The prebreathe protocol is conducted in an airlock or other designated area. It usually starts with 10 minutes of vigorous exercise while breathing pure oxygen, followed by 50 minutes more on pure oxygen and then lowering the pressure inside the airlock from the sea-level pressure of 14.7 pounds per square inch (psi) to 10.2 psi. After 30 minutes at that lower pressure, it's time to put on the space suit. Depending on the suit model, the seals are often at the waist, gloves, and helmet. The entire protocol might last as long as several hours before the spacewalk.

Pressure in the airlock is gradually lowered all the way down to around 4.3 psi, with the pressure inside the space suit gradually reduced to match. The astronaut continues to breathe pure oxygen to flush nitrogen out of their system—essentially from sea-level atmospheric pressure to about 30,000 feet of altitude. This process is known as depressurization, and it usually takes around 45 minutes to complete.

Before and after depressurization, astronauts go through a series of pressure checks to ensure that their suit is functioning properly and that they are acclimated to the lower-pressure environment. If all systems check out, after the airlock pressure is stabilized at the lower pressure, the astronaut will continue breathing pure oxygen for another 60 minutes, make final checks and switch from the station rebreather to their suit's air, exit the airlock, and begin the spacewalk.

Now that you know how low the pressure is inside a space suit, you can better assess the scenarios proposed in some science fiction movies. In the movie *The Martian*, Matt Damon's character cuts a hole in his space suit's glove to use the escaping air as a propulsion method. In reality, if you were to cut a hole in your glove, your hand would be likely to plug the hole back up. Conversely, if the hole were larger, the air would rapidly escape from the suit and cause the suit pressure to drop. This extremely sudden loss of pressure would lead to a very dangerous situation because, at best, you would undergo the bends. At worst, you would not be able to survive direct exposure to the ultra-low-pressure conditions of space.

Despite what another popular space movie, *Gravity*, might have you believe, jetpacks are not a common or routine method of movement in a spacecraft or during a spacewalk. The vast majority of spacewalks are conducted using tethers rather than jetpacks. They are the primary safety measure to keep astronauts attached to the spacecraft or the space station during an EVA, something a jetpack doesn't do. In the film, George Clooney's character uses a jetpack to take joy rides around the Hubble. In reality, the primary goal of a spacewalk is not to travel around in space but to perform specific tasks, such as repairing or upgrading equipment, collecting samples, or conducting experiments. As such, most spacewalks involve a combination of tethers, tools, and handholds to keep astronauts safely attached to the spacecraft or space station while they carry out their tasks.

HANDHELD SELF-MANEUVERING UNIT

Sustenance, Space Debris, and Space Suit Fit

Although the average duration of a spacewalk varies widely depending on the specific mission and objectives, in general, it ranges from 5 to 8 hours. As such, astronauts will likely have to eat and use the restroom during a spacewalk. Astronauts can drink and snack in space using a straw that is attached to a pouch filled with water or another beverage. The pouch is usually strapped to their arm or leg so that they can access it easily during a spacewalk. The straw has a one-way valve that prevents liquid from escaping when the astronaut is not drinking and also helps prevent bubbles from forming in the drink. For snacks, astronauts may have bite-sized food that can be easily consumed without creating crumbs or any kind of mess. However, eating and drinking in space require careful planning and execution to ensure that nothing interferes with the spacewalk or gets in the astronaut's eyes or helmet.

To relieve themselves, some astronauts will use a diaper or a catheter to manage urine, while others may use a fecal collection device. In some cases, astronauts may also have to carefully time their fluid intake leading up to a spacewalk in an effort to minimize the need to relieve themselves during the EVA. Sometimes, that works, but sometimes, it doesn't.

Like spacecraft, space suits are also subject to the dangers of space debris. Space experts have warned that space activities—including both human travel and the dependable operation of satellites—will become increasingly dangerous if new rules are not put in place to control debris. There is actually a lot of traffic in space, with more than 60 countries and dozens of companies and educational and nonprofit organizations all operating satellites, with zero universal oversight.

What if your space suit doesn't fit? There aren't multiple space suit sizes on the ISS, in large part due to the cost of manufacturing and transporting them to the station. Space suits are complex and expensive to build, and the cost increases significantly for each additional size that is produced. Also, the space station has limited storage space, and it would be challenging to store multiple space suit sizes on the station. As a result, NASA has decided to use a one-size-fits-all approach for space suits, with some adjustments available for individual astronauts' comfort, like interchangeable components for different sizes. In addition, as you've seen, the absence of gravity results in fluid shifts and muscle atrophy. This causes astronauts to experience changes in their body shape and size, which can affect how well a space suit fits.

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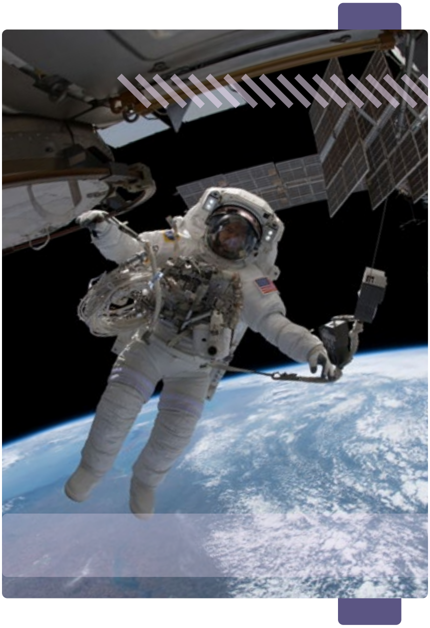
6

HOW TO SURVIVE
IN A VACUUM

If you are headed to space, you will be surrounded by a vacuum—the absence of air. Essentially, you'd have about 10 seconds to save yourself if you were exposed to the vacuum all at once. After that, you'd need a friend to save you within 90 seconds. If an air leak was caused by a small meteorite, then you could probably sleep in and then patch the hole with some cloth and glue in the morning. If it happened because of an explosion, you would go to an emergency capsule and maybe bring along some extra food and water if you didn't want to go on a crash diet. In this lecture, you'll explore what you'd experience if your space suit failed and how to survive low pressures and the vacuum of space.

The Reality of Exposure to the Vacuum of Space

Hollywood is consistently in conflict with the reality of what a vacuum would do to the body, with depictions of exposed astronauts instantly freezing or exploding or experiencing hurricane-level winds when a hatch or door of their spacecraft is opened. However, the reality is significantly different.



While the vacuum of space is indeed extremely cold, it is also a poor conductor of heat. You need matter to conduct heat. In space, there are no molecules of anything to conduct the heat away. This means that if an astronaut were to be exposed to the vacuum of space without protection, they would not actually freeze instantly. Instead, the heat in their body would slowly radiate out into space over a period of minutes or even hours, depending on factors such as their body mass and the thickness of their clothing.

Similarly, the idea that people would explode in a vacuum is also a myth. While the pressure difference between the vacuum of space and the pressure inside the human body could cause some discomfort and potentially even injury, it would not cause the body to explode. In fact, there is at least one documented case of a person surviving exposure to near-vacuum pressures. In 1965, a technician named Jim LeBlanc was accidentally exposed to a vacuum while working on a space simulation chamber. Although he lost consciousness within seconds, he was quickly rescued and received medical attention. Despite suffering from some minor injuries, such as a ruptured eardrum, LeBlanc made a full recovery and went on to live a normal life.

The notion that anyone would be able to hold their breath is also a popular myth. Any gases would be expelled from your nose, mouth, and posterior—all involuntarily. Even if you could hold your breath in a vacuum, you could not keep the oxygen in your body. In space, there is no oxygen or carbon dioxide. So, both oxygen and carbon dioxide are literally ripped out of the red blood cells in the lungs. Even if you were the world champion free diver and could hold your breath for 10 minutes, you would lose consciousness in 10 to 12 seconds because the air would be ripped from your body and dumped into space. Within roughly 1 minute and 40 seconds, you'd die.

Also, any gases saturated in your blood would immediately expand and bubbles would form. The best analogy for this is to imagine shaking a container of carbonated soda and feeling the pressure within get very high. All of the saturated carbon dioxide gas is under higher pressure inside the container than it would be outside. When you rapidly open that soda, the pressure is suddenly released, bubbles form, and the soda bubbles over.

If your body is subjected to a vacuum, a similar process would occur inside your blood, joints, and brain—everywhere there is fluid. As humans breathe oxygen and nitrogen and exhale carbon dioxide, they all have gases saturated in their blood. This is also what happens when divers get "the bends."

Oxygen and Pressure Levels

Fortunately, you have your spacecraft to protect you from the vacuum of space. In the past, the pressure in a spacecraft was typically much lower than that on Earth. This is because creating a higher pressure requires thicker walls and stronger seals, which can add to the overall weight, complexity, and cost of any spacecraft. Aside from reducing the weight, designing a spacecraft to operate under lower pressure atmospheres can help reduce the risk of leaks and other failures in the spacecraft's systems.

It is important to note, though, that this lower pressure means that the atmosphere inside your spacecraft must be adjusted. When the pressure is lower, the amount of oxygen in the air needs to be increased to ensure that there is enough for the astronauts to breathe. Otherwise, people start passing out.

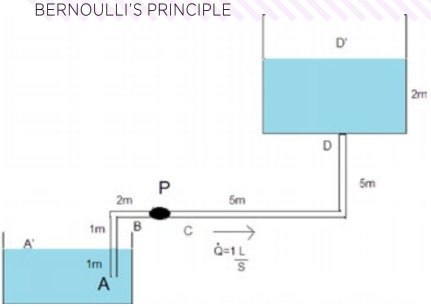
In the tragic case of the Apollo 1 fire, which killed all three astronauts aboard, the spacecraft was pressurized at a very low pressure with 100% oxygen, meaning that any sparks or flames could easily ignite the entire spacecraft, causing a catastrophic fire. Investigators later discovered that the fire started as the result of an electrical short inside the command module—filled with 100% oxygen.

It doesn't take 100% oxygen to increase the risk of fire: Even in a relatively low percentage of oxygen, any increase in oxygen increases fire risk. Studies have demonstrated that materials that are not flammable at atmospheric oxygen, or 21% oxygen, are highly flammable at 30% oxygen. Such studies have underpinned the transition from the 100% oxygen atmosphere of the early spacecraft to the 21% oxygen atmosphere aboard the ISS today.

Although this lower oxygen means a higher pressure, none of the drawbacks of a higher pressure include accidentally causing a hurricane due to some explosive decompression event. Hollywood movies like to show any breach in the spacecraft accompanied by gale force winds that blow equipment, people, and everything aboard into space. Never mind that the atmosphere on the spacecraft would be rapidly exhausted—in the movies, that wind continues.

These gale force winds are a misconception due in part to confusing what happens aboard an airplane to what happens aboard a spacecraft. The whole reason that planes can fly is explained by Bernoulli's principle. When a fluid, which is either a gas or a liquid, moves very rapidly, the pressure in it drops. Airplane wings are designed so that the air moves more rapidly over the top of the wing than the bottom. Less pressure on the top of the wing than the bottom is precisely what causes lift. That higher pressure pushes the plane up.

BERNOULLI'S PRINCIPLE



This pressure drop is proportional to the square of the velocity of the fluids. So, while the pressure at 35,000 feet is about 80% less than it is at sea level, the pressure drop caused by the moving air is more than 1 atmosphere. This causes an effect equivalent to a suction, which is why an explosive decompression might happen, even if only a small hole is made in the shell of an airplane. If that does happen, the high speed of the aircraft would create the winds we see in the movies.

In space, this Bernoulli effect is absent. The only thing that is driving the loss of pressure is a difference of 1 atmosphere. If there were a hole in the spacecraft, there would be no explosive decompression and no swirling of winds. Depending on the size of the hole, as the pressure slowly dropped, someone might notice, and they would go to find the hole.

The Apollo 13 Explosion

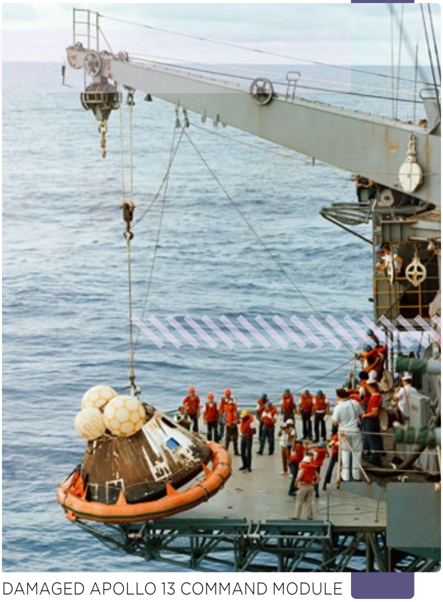
A year before the Apollo 13 explosion, someone made a mistake. In 1969, an oxygen tank originally installed on Apollo 10 was removed to modify it. During the move, it was dropped 2 inches, slightly jarring an internal fill line. Just to be safe, they replaced the Apollo 10 tank with another and inspected the exterior of the original tank. They did not see the internal damage, and the tank was eventually reinstalled—as tank number two in the Apollo 13 command module.

There were warning signs that were overlooked. During preflight testing, tank number two showed some anomalies. For instance, it would not empty correctly. Since they often used heaters in the tank in short bursts to slightly warm up the liquid oxygen to keep the oxygen flowing, they decided to use the heater to fix this problem. Instead of a short burst, they turned the heater on for 8 hours to boil off the excess oxygen that wasn't flowing.

These oxygen tanks were originally designed to run off of the 28-volt DC battery power of the command and service modules. Because they also needed to run on the ground, the tanks were redesigned to also be able to run off of the 65-volt battery power at Kennedy Space Center. All of these components were upgraded to be able to accept 65 volts—except the heater thermostatic switches, which were forgotten.

In a later investigation, it was believed that this excessive voltage welded the switches shut, allowing the temperature within the tank to rise to over 1,000°F. The high temperatures worked, and the tanks emptied. However, there was serious damage to the Teflon insulation on the electrical wires to the power fans within the tank.

Apollo 13 launched on April 11, 1970. On April 13, an explosion happened. The astronauts turned on the power to the fans within tank number two to stir the liquid oxygen. The damaged insulation resulted in exposed wires that powered the fans. These wires short-circuited, and the Teflon insulation caught fire within the pure oxygen environment of the tank. The resulting fire rapidly heated and increased the pressure within the tank until it exploded, damaging oxygen tank number one and parts of the service module. Thirteen minutes after the explosion, the astronauts noticed the oxygen venting into space.



DAMAGED APOLLO 13 COMMAND MODULE

These tanks powered the fuel cells. Without power to the fuel cells, there was no heat and no ability to stabilize the pressure within the command module. After the explosion, the air pressure in the command module dropped from its normal level of around 5 psi to around 4 psi. The loss of pressure was due to the damaged hull of the spacecraft, which caused a slow leak of oxygen into space. The crew had to conserve their remaining oxygen and rely on the lunar module Aquarius as a “lifeboat” until they could return safely to Earth. Although the lunar module had heat and maintained pressure, it was only intended to keep two people alive for 45 hours. Now, it needed to keep three people alive for 90 hours.

PRIME CREW OF THE APOLLO 13 LUNAR LANDING MISSION

Maintaining environmental pressure and other life support systems within the lunar module also required power, not to mention the little task of returning to Earth. They had to turn off all noncritical systems and reduce the energy consumption to one-fifth of what it was, charging the command module with the lunar module's power. Because water was needed to cool critical components in the spacecraft, the crew conserved water and cut down to drinking one-fifth of their normal intake per day. As a result, they became dehydrated, but all three astronauts returned to Earth safely.

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7

HOW TO SURVIVE
EXTREME TEMPERATURES

Hollywood films attempt to depict the low temperature of space by showing its cooling effects, but they almost universally get the rate that it happens horribly wrong. Whenever an astronaut gets exposed to space in a movie, they either instantly freeze or explode. However, that’s not how it really works. In this lecture, you’ll explore the extreme temperature changes that occur in the vacuum of space and what you’d need to do to survive them.

Protection against Temperature Extremes

In space, heat is lost through radiation, which is a very slow process. For example, if you model the human body as a homogenous sphere of water and imagine that it's floating through deep space, that body would take 44 minutes to reach hypothermia, 18 hours to freeze solid, and 6,342 years to reach the temperature of space.

If that water sphere human model were in orbit around a planet or moon, it would probably never fully reach the temperature of interstellar space—meaning outside our solar system. If it were near a sun, it would burn to a crisp or vaporize.

Should you find yourself lucky enough to make it to space one day, one of the biggest challenges you will face is dealing with these temperature extremes. The temperature in space can range from as low as –270°C (–454°F) in the shadows to as high as 120°C (248°F) in direct sunlight. In this regard, the temperature in space varies from very, very, very cold to very, very hot.

The best protection you have against these temperature extremes comes from space suits, spacecraft, and space stations. However, like anything, these options aren't always perfect. In the early days of spaceflight, astronauts experienced some thermal discomfort due to limitations in space suit technology and spacecraft design.

On February 9, 1995, on shuttle *Discovery* mission STS-63, astronauts Bernard Harris and Michael Foale performed an EVA to test their space suits against extreme cold. Reflecting on that, Harris said:

> We got on the end of the robotic arm, which extends about 35 feet. Astronaut Michael Foale and I hung out as the commander maneuvered the vehicle from pointing toward the Earth—where we can get radiant heat to keep temperatures from getting too extreme—to flipping the vehicle around to deep space, where we're radiating our heat.
>
> Within 10 to 15 minutes, the temperature went from 200° to minus 165°. It was crazy cold. So cold that my feet felt like I was standing on ice cubes. My hands were so cold I could barely keep them in my

> glove. We turned our temperature control to full heat, but it wasn't enough. The only way we could stand being out there was to move and raise our body temperature.

Several modifications were subsequently made to the space suit systems to prevent astronauts' hands and feet from becoming cold. On the liquid cooling garment, for example, the cooling tubes running down the arms are now bypassed so that astronauts' arms are not cooled. Additional layers of material were added to the thermal undergarment and the exterior of the suit's gloves for warmth.

In addition, astronauts' visors help with thermal regulation by reducing heat generation within their space suits. The visors are made of a special material that reflects a significant amount of the sun's heat, which helps to keep the astronaut cooler during EVAs. The visors also have a thin layer of gold, which has the ability to allow visible light to shine through so that astronauts can see while helping to reflect the sun's infrared radiation.

The Moon's Temperature Extremes and the Apollo Landings

Because the moon has no atmosphere, it is exposed directly to space, and with no atmosphere to dissipate heat, its surface undergoes extreme temperature variations. Plus, the moon's slower rotation period leads to temperatures that range from around 260°F (127°C) during the day to –280°F (–173°C) during the lunar night.

The Earth does not experience moon-like temperature extremes due to its atmosphere, which—along with its faster rotation period—helps to regulate temperature. This combination leads to shorter exposure times to extreme temperatures.

During the Apollo moon landings, the astronauts landed on the side of the moon that faces the Earth, also known as the "near side" of the moon. This was necessary to maintain communication between the spacecraft and Earth, which required a direct line of sight. Communication between the astronauts and ground control would not have been possible if they had landed on the "far side" or the "dark side" of the moon.

During the Apollo missions, astronauts landed on the moon during the lunar day and performed their activities during this time. They then returned to their lunar module, which was designed to provide a certain level of insulation from the extreme temperature on the moon's surface.

Because there is no atmosphere to distribute the heat, any object in direct sunlight will heat up quickly, and the temperatures inside the lunar module ranged from 6°F to 81°F. To cope with the heat, the astronauts wore special cooling garments and took measures to minimize their physical activity at the direction of ground control.

Each Apollo mission had a different duration and schedule, but in general, the missions lasted a few days, and the astronauts spent a relatively short period of time on the lunar surface. For example, the duration of the Apollo 11 mission was only a few days, and the astronauts spent a total of 21 hours and 36 minutes on the lunar surface.

All Apollo landings occurred shortly after lunar sunrise to minimize extreme temperatures. In later Apollo missions, the astronauts stayed on the lunar surface for longer periods of time and had the opportunity to experience later periods in the lunar day when the sun would be higher in the sky.

Temperature Extremes on the ISS

Just like the surface of the moon, the exterior of the ISS experiences a temperature cycle of hot to cold approximately every 45 minutes due to the station's orbit around the Earth. As the ISS orbits the Earth, it passes through sunlight and shadow, resulting in a rapid change in temperature on the exterior of the station. These temperatures can vary greatly depending on its location relative to the sun and other factors.

PART OF THE INTERNAL THERMAL CONTROL SYSTEM ON THE ISS

When the ISS is in sunlight, the solar panels and other components can become very hot, and the temperature has risen as high as 121°C (almost 250°F). On the other hand, when the ISS is in the Earth's shadow or "night" side, the temperature has dropped as low as −157°C (less than −250°F). Luckily for the ISS crew and all its hardware, thermal balance was a priority when the station was designed and constructed—and it is equipped with a thermal control system that keeps the astronauts and their equipment cool and comfortable.

The first design consideration for thermal control is insulation—to keep heat in for warmth and to keep it out for cooling. In space, radiation is the primary source of heat exchange, so the space station's insulation is designed to block radiation. The insulation on the ISS is a highly reflective blanket called multilayer insulation (MLI) made of aluminized Mylar and Dacron. Aluminizing Mylar makes it so that solar thermal radiation cannot pass through it but is instead reflected off of it. To prevent heat from being conducted through the insulation—aluminum is a great conductor—layers of Dacron fabric keep the Mylar sheets separated, which ensures that most of the heat transfer through the blanket is via radiation.

MLI works against both temperature extremes: It keeps solar radiation out and the extreme cold of space from penetrating the metal skin of the ISS. Because the MLI works so well, it does not dissipate heat that is generated within the station. The internal temperatures are always on the rise inside the ISS because it is fully stocked with many kinds of heat-producing instruments.

The ISS: Control Systems

Electricity from solar arrays flows into the ISS to run the electronics that power all of the station's many systems. They all produce heat, and to get rid of all this excess heat, the ISS uses cold plates and heat exchangers, both of which are cooled by a circulating loop of cold water. The station's internal atmosphere is cooled and dehumidified by air and water heat exchangers, while any equipment that runs really hot is attached to cold plates.

STARBOARD SOLAR ARRAY WING PANEL OF THE ISS

So, the heat goes from the air and equipment into the water; then, the heat in the water is sent to radiators to be ejected into space. Since water circulated in pipes in the shadowed side of the ISS would quickly freeze, waste heat is exchanged a second time to another loop containing ammonia instead of water—ammonia freezes at –107°F (–77°C) at standard atmospheric pressure. The heated ammonia circulates through huge radiators on the outside of the ISS, releasing the heat through radiation and cooling down as it flows.

This system is called the Active Thermal Control System (ATCS). The Environmental Control and Life Support System (ECLSS) controls air quality and flow on the ISS. These two systems work together. Since convection is the fastest way to transfer heat in air, the air must move for that to happen. To ensure one side of the station isn't cold while the other side is balmy, the ECLSS provides the flow.

This is necessary because in microgravity, hot and cold air don't rise and fall like they do on Earth. Air circulation distributes the heat and helps to prevent unwanted cold areas that could cause condensation, electrical shocks from the water, and/or serious corrosion and even contribute to microbial growth.

Regulating Body Temperature

While the ATCS and the ECLSS are working hard to maintain a comfortable temperature on the ISS, even that isn't enough. With extreme temperatures kept at bay, you still have to deal with your own internal body temperature. The human body naturally generates heat, but in the microgravity environment of space, it can be challenging for astronauts to regulate their body temperature.

During sleep, the core body temperature rises and falls in a predictable manner. One study found that astronauts on the ISS experienced a phase delay in this core body temperature cycle during sleep. This delay was over 2 hours, likely due to the absence of appropriate time cues.

While awake, astronauts have been found to have something of a "space fever." Multiple studies have found increased core temperatures in astronauts, and chronic fever could lead to many health problems and decreased cognitive performance on long journeys. Also, when the astronauts exercised, their core temperatures reached up to 40°C (104°F). Hyperpyrexia, or fever of 106°F or higher, is a medical emergency. If the fever is not lowered, brain and organ damage and death can result.

Animal studies have also been conducted to investigate the effects of space radiation on thermal regulation. Researchers found that rats exposed to simulated galactic cosmic radiation showed changes in their body temperature regulation, including a decrease in core body temperature when they were in the light, whether awake or asleep. If they were in the dark, there was no difference in their core body temperatures compared to rats that were not irradiated. In essence, not only will you be exposed to temperature extremes in space but also space will mess up your natural ability to stay warm and keep cool.

What if you ever make it to Mars? The temperature extremes are less extreme than on the moon but still challenging for spacecraft and humans. The average surface temperature on Mars is around −65°C (−85°F). Mars also experiences seasonal temperature variations, with temperatures varying more widely in some regions than in others. However, the fact that people can survive the frigid cold in Antarctica—and have survived the extreme temperatures of the moon—bodes well for humans surviving Martian temperatures.

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8

HOW TO SURVIVE SPACE FOOD

Astronauts have to get used to the fact that there is little to no fresh food in space. Some science fiction movies that feature pasty, unrecognizable food in pouches give a pretty accurate representation of what astronauts must contend with. Although space agencies are continually working to improve space food, both astronauts and individuals simulating space missions in remote locations like the desert complain about mushy food, the monotony of meal choices, and an overwhelming desire for something—anything—crisp. In this lecture, you'll examine why space food is so unappetizing.

Food and Nutrition in Space

Without gravity, our senses of smell and taste are affected. On Earth, mucus is continually draining from our sinuses under the steady pull of gravity. In space, the mucus has nothing to cause it to drain. The sinuses become congested due to mucus accumulation, and astronauts have to deal with a diminished sense of taste that goes along with a congested head. In addition, the decreased atmosphere and the dry cabin environment in space combine to further decrease taste buds' ability to taste by about 30%. This double hit against both the sense of smell and the tastebuds may make food taste bland in space.

Microgravity also affects digestion by reducing the intestines' ability to digest food and accelerating their ability to empty. However, even when the digestive tract is working to the best of its ability, the lack of gravity presents issues. Digestive gases do not float upward when gravity is absent. As a result, much less gas is released by belching. Therefore, a disproportionate amount of gas is expelled by the active movement of your digestive system. Both the blandness of food and the bloating astronauts experience likely contribute to a diminished appetite.

Food and nutrition are critical factors for the well-being and performance of astronauts during space missions. Built into the nutritional makeup of space food are some countermeasures against muscle and bone loss. However, due to the unique environment of space, it's challenging to provide astronauts with a balanced and palatable diet—there is limited space, there are no refrigerators, and the capability to grow food is still in its infancy.

When designing the diet for space missions, several additional factors along with taste, nutritional content, and shelf life must be considered. Since every ounce of cargo has to be lifted into space, the weight and size of the food also have to be taken into account.

To minimize weight, space food is often dehydrated or freeze-dried and rehydrated with water once in space. All space food must have a long shelf life since it can be difficult and expensive to restock supplies during a mission.

The Evolution of Space Food

Currently, methods to extend food's shelf life include using vacuum-sealed packaging, radiation sterilization, and other preservation methods that have evolved over the decades as technology has advanced. The Mercury missions (from 1958 to 1963) probably had the least appetizing foods—semiliquids similar to the consistency of toothpaste that had to be squeezed out of tubes. The food on the Gemini and Apollo missions was slightly better: dehydrated meals sealed in plastic that could be rehydrated by adding room-temperature water.

After the first space missions, NASA also transitioned from food paste to food cubes. However, none of these cubes were particularly appetizing either. A gelatin layer was added to the cubes to prevent crumbs, and they were rehydrated using only the astronauts' own saliva as they chewed—no additional water was added.

By the time Apollo astronauts were flying, they had hot water, which simplified the process of rehydrating foods and improved their taste.

The "spoon-bowl pack" introduced a water valve to further simplify the process. To eat the rehydrated food, astronauts would open a ziplock at the top of the food bag and scoop it out with a spoon instead of squeezing food directly into their mouths. The paste-like consistency of the food caused it to adhere to the spoon rather than float around.

The space shuttle program (from 1981 to 2011) offered foods from trays rather than pouches. Astronauts were also given liquid salt and pepper to make seasoning their food more manageable. Additionally, access to a new "fresh food locker" provided fruits and vegetables.

For the 2006 launch of the space shuttle *Discovery*, astronauts were given menus that were tailored to their preferred foods. To create these menus, NASA sought the help of renowned chef Emeril Lagasse, who contributed several recipes, and NASA ended up selecting five of Lagasse's recipes to be included in the astronauts' meals.

In November 2000, the ISS received the first astronauts who would stay for long-term missions. NASA initially intended to provide personalized meals to the astronauts onboard the ISS, but that didn't work out so well because the cargo shipments and crew arrivals weren't coordinated. NASA now provides a diverse and nutritionally balanced menu of approximately 200 food items and beverages, allowing the astronauts on the ISS to have maximal variety and limited repetition in their meals.

Because a mission to Mars would require a more extended stay in space than a typical mission to the ISS, packing all the food needed would be impractical. As a result, NASA has explored the possibility of astronauts sustaining themselves by consuming their feces. In 2015, NASA awarded researchers at Clemson University a grant to investigate whether human waste could be recycled and converted into space food. Although this sounds unappetizing, wastewater from condensed water vapor from crew sweat and breathing, toothbrushing, bathing, and other personal hygiene—as well as urine—are all reclaimed for drinking water. So, although astronauts are not yet eating recycled poop, they are definitely drinking recycled pee.

Astronauts aboard the ISS are able to enjoy a much more enjoyable menu than ever before because of new rocket technology. SpaceX's Dragon capsule can return to Earth without burning up in the atmosphere during reentry. This is different from previous cargo vehicles used by NASA and permits the return of medical and scientific samples back to Earth. When the freezers intended for research samples returning to Earth are empty, that leaves room for other things to go up into space—like ice cream. Cargo vehicles sent to resupply the ISS also include what are called "fresh-food kits," with items such as citrus fruits and carrots. These are transported at ambient temperature, so they should be shelf-stable for up to a week without refrigeration and still edible once in space.

The Problems and Benefits of Growing Food in Space

When you water a plant on Earth, gravity pulls water down toward the plant's roots and then allows the excess water to drain away through the soil. However, in the microgravity environment of space, the water does not naturally flow downward and can instead accumulate around the roots and adhere to them. Oxygen in the water is quickly used up by the roots, and without the natural flow of water, the oxygen is not replenished, leading to a stagnant environment in which the roots essentially drown.

To avoid drowning, space plant growth systems often use hydroponics and/or aeroponics, where the roots are grown in a nutrient-rich solution rather than in soil or misted with that solution to create a thin film of nutrients on the roots. This enables better oxygenation of the roots since they are not completely submerged in water.

In addition, water levels must be carefully monitored and controlled to prevent roots from drowning. Aeration systems may also be added to provide air circulation to the plant's roots, which helps to prevent drowning and ensure that the roots have access to sufficient oxygen.

There are many benefits of growing food in space. It provides a sustainable source of fresh food for astronauts, and since food is one of the heaviest items that need to be transported to space, growing food on-site can help reduce the weight and size of the payload required for missions. It would also reduce the need to resupply ships, making autonomous long-distance missions to other planets like Mars possible.

There's another advantage, even for shorter-term missions. Plants are natural air purifiers that can help remove carbon dioxide from the air. Considering that too much carbon dioxide is toxic, the ability to remove it is especially important in space, where the air is limited and recycled.

Last but not least, the psychological benefits of growing food in space cannot be understated. Aside from the typical sense of connection to nature and the calming influence of the act of gardening, fresh food is known to break up the monotony of limited space menus, and this additional option goes a long way in the isolated and high-stress environment of space.

Space Analog Food Research

Having long-term space crops that require regular care, maintenance, and harvesting might not be so easy in the future—at least that's what some space analog teams have found. Space analog teams are groups of science and engineering researchers and volunteers who conduct experiments and simulations in settings that mimic the conditions of spaceflight. These teams often study the growth and production of plants in analog environments—like in the middle of the desert or in a remote Hawaiian location—to better understand how to grow food in space.

Several of these teams have experimented with growing food in space-like conditions, and their findings have been mixed. Some teams were successfully able to grow crops in simulated space environments using hydroponic and other controlled growth systems. However, other teams reported problems such as low yields and slow growth rates. One of the main challenges identified by these teams is the need for a balanced nutrient supply to ensure optimal plant growth.

In a closed environment like a spacecraft or a planetary habitat, it can be difficult to ensure that all the necessary nutrients are present in the growing medium or hydroponic solution. Despite these efforts, there is still a lack of a comprehensive plan for quality assurance on how to make space-grown food safe to eat. This is primarily due to three factors.

First, the effects of long-term space-related radiation exposure on plants and their nutritional content are not fully understood. Second, there is a very real potential for colonization by space-adapted microorganisms, which could become pathogenic and develop new microorganisms. Third, there is limited data on the potential health risks of consuming space-grown food.

With decades of research, NASA has ever-evolving methods to both attempt to make space food taste good and to counteract the space environment. Astronauts take calcium and vitamin D supplements to help combat the loss of bone density that can occur in space and reduce the risk of fractures. High-protein foods, such as meat, fish, and legumes, as well as protein supplements, are provided to combat muscle atrophy and help maintain muscle mass. Astronauts are also supplied with omega-3 supplements and foods high in omega-3 fatty acids, such as fish and nuts, because omega-3s have anti-inflammatory properties and may help reduce the risk of cardiovascular disease. Finally, to protect their cells from damage, astronauts consume foods high in antioxidants, such as fruits and vegetables.

Because supplemented food is not often synonymous with delicious food, space analog teams have also researched the palatability and nutritional value of current prepackaged space food. In their taste tests with astronauts, the teams established that issues aren't simply the result of changes to astronauts' sense of taste. They reported that the taste and texture of space food itself can be unappetizing and monotonous, especially during long-duration missions. Moreover, the teams analyzed the nutritional content of space food and found that it can be deficient in nutrients such as vitamin D, which is essential for bone health.

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9

HOW TO SURVIVE EXTREME CONFINEMENT

The stress of being in an environment that can kill you at any time cannot be understated. In space, the stress is partly physical, courtesy of microgravity, but astronauts also endure the stress of being in an ICE (isolated, confined, and extreme) environment. In addition, knowing that any mistake you make might kill you or your crewmates creates a constant state of psychological stress. In this lecture, you'll explore the impact of extreme isolation and confinement in space.

The Psychosocial Effects of ICE Environments

Humans are social beings. Recent research has shown that being completely separated from a community for a prolonged period of time causes permanent brain damage. Even though people in ICE environments are not solitary, they are separated from friends and family, have little privacy, and can't easily escape their crewmates for a metaphorical or literal "breath of fresh air."

Researchers study ICE environments to understand how crews operate in them. The NASA Extreme Environment Mission Operations (NEEMO) is an ICE environment that serves as a simulation for what astronauts aboard the space station might experience. These simulations are called analogs. NEEMO sends groups of astronauts, engineers, and scientists to live in a deep-sea underwater laboratory for up to 3 weeks at a time. Other analogs are in isolated locations in places like remote Hawaiian Islands, where mockups of Martian habitats are constructed, and participants live up to a year in these analogs.

One commonality among these ICE environments is the kind of psychosocial disturbances that they induce in the people who live there. NASA astronaut Dan Bursch has given some insight into the psychosocial effects of long-duration missions, some of which persist after an astronaut's return. In 2002, he spent 6 months aboard the ISS, which was less than half its current size—roughly the size of a large airplane's interior. "It's like friends becoming roommates," Bursch said. "Or like being locked in a house with two people you don't choose. Little things bug you."

Back on Earth, Bursch's wife was caring for their three small children while working part-time as a nurse anesthetist. For her, the mission was a lonely experience in a different way. A decade later, the effects of that experience were still apparent. For instance, if Bursch was home and began to watch NASA TV, his wife would ask him to turn it off. According to Bursch, "it still brings up sad times for her, when she was alone with the kids."

Reintegrating into their family and larger community can also be challenging for many astronauts. When studying the families of people in ICE environments, it becomes clear that the remaining spouse adjusts to their partner's absence and the increased workload at home pretty well. Tensions build when the partner returns. Trying to fit back into the family the way they had before and making decisions again—that's easy for the person who left, but it can be tough for the spouse who held down the fort, particularly if they had gotten used to making all the decisions.

As the duration of missions increased, so did the astronauts' psychosocial issues. Russia has done long-duration missions since 1971, during which they observed many psychological phenomena, such as asthenia, which is nervousness or mental tiredness that occurs mainly in the monotonous later portion of the mission. Its symptoms are hypersensitivity, irritability, and hypoactivity. Ground crews treated it by giving astronauts additional free time and stimulation—like books—and supplying them with extra audiovisual communication with friends and family.

Community Connection and Space Analog Research

American astronauts didn't experience missions over 3 months long until they joined the Russians on the Mir station. In response to Mir missions, and in anticipation of the ISS, NASA developed the Behavioral Health Program to help with the psychosocial health of astronauts. This program is composed of psychologists and psychiatrists whose goal is to improve the psychological, social, and mental health and experience of long-duration astronauts and their families before, during, and after their flights. They are assigned 2 years before the astronaut flies on the space station so that the team can get to know the astronaut, their families, and their family dynamics.

The group's goal is to ensure mission success by maintaining the astronauts at peak performance while they are on the station. They achieve this by being available to astronauts and their families and by enhancing their experience with psychological perks that were not prioritized on shorter missions—for example, video conferences with families and an internet protocol phone so that astronauts can call anywhere on Earth during their free time. Astronauts also have access to a guitar and keyboard on the station and can see movies before their release dates on Earth. In addition to these perks, the resupply ships bring care packages from their families that include things like candy, fresh fruit, or new clothes. The goal in all this is to keep astronauts connected with their support community at home.

Research into the psychosocial effects of ICE missions comes largely from space analogs. One such study enlisted four Antarctic expedition leaders and five doctors wintering over in Antarctica and surrounding islands, on both long- and short-duration missions. Researchers found that group interaction was by far the most important category of behavioral issues they observed. In both long and short missions, results showed that subgroups will form that can negatively affect group harmony if permitted to develop to an extreme. Researchers have also seen this play out in space.

Another source of negativity arises in communications. Communications between headquarters and remote duty personnel frequently are sources of frustration and can arise from an "us versus them" mentality, when headquarters is considered "management" and "against us."

Communications with loved ones were also found to be problematic for Antarctic crew. For example, misunderstandings, negative news, or anything causing bad feelings has the potential to cause nostalgia for home or resentment and tension. These kinds of findings can inform the Behavioral Health Program to help astronauts' families minimize conflict during outside communications.

Everyday meals, special meals, and celebrations were extremely important to expedition members and contributed to both group solidarity and individuals' ability to successfully adjust to their environment. These celebrations were enjoyed, discussed for days on end, and remembered. Surprisingly, work was also found to be a primary source of satisfaction, and recreation and leisure provided a variety of experiences and contributed to group solidarity and individual adjustment.

Gender Differences

As missions have become longer, more studies have examined the success of teams with and without women on them to see how these teams would compare. Women in mixed-gender polar and space simulation groups assumed—or were placed into—more nurturing and less dominant roles. All-female expedition groups or women in mixed-gender groups consistently showed greater cooperative orientation, supportive relationships, and concern about the welfare of their team members. In contrast, all-male expedition teams showed marked competitiveness and little sharing of personal concerns.

Researchers concluded that including women in wintering-over groups on Antarctic stations had positive effects on the general climate of the group by reducing rude behavior. They also found that women provided emotional support and help to team members that all-male groups do not. However, if the number of women in the group was too few, researchers noted stress that seemed to be caused by rivalry, frustration, and sexual harassment.

Considerable cultural and gender differences in attitudes toward women team members have also been noted in various studies and can contribute to destabilizing effects. Essentially, if there is a single woman in a crew with men from cultures that do not see women as equals, there will be problems.

In all, these analog studies suggested that the presence of women exerts a positive influence and discourages certain behaviors, like drinking and fighting, that could lead to injury or group conflict. The researchers noted that women performed equally well or superior to men in Antarctic stations and underwater habitat studies.

They also discovered that the men found small, confined spaces stressful while the women tended to find them social and that men were, in general, physically stronger, which was well suited for an ICE that required strength. However, they also concluded that women were psychologically more resilient, which helped them endure the isolation and confinement.

Finally, the presence of women was found to be better for the men present, while the presence of men was worse for the women present. The study authors concluded that women deal with ICE environments better than men but stopped short of concluding that they would make better astronauts, stating that more research was needed.

Female Leadership

A 2022 study based on Mars simulations in the Utah desert examined the difference in female and male leadership. Although both female and male commanders had task-oriented leadership styles, female commanders discussed their crew members more often. Where male commanders would focus on team spirit, loyalty, and accomplishments, female commanders prioritized mutual support, motivation, and a positive environment.

Finally, the female commanders micromanaged less and used general terms when discussing daily activities. Contrary to the stereotype that male leaders are purely task oriented and women are purely social, they found that both female and male leaders were equally focused on task completion, but the female commanders encouraged their teams more often with positive supportive messages.

Researchers noted that these are sociocultural behaviors that are not inherent to either gender but arise through one's upbringing. For instance, they noted that female leaders are socialized to show more positive feelings toward others and to hide negative emotions like anger.

Because in an ICE environment, interpersonal conflict can jeopardize team and, therefore, mission success, the researchers suggested that this aspect of female leadership might be beneficial to long-duration space missions. Social scientists generally agree that a leader in a long-duration space mission should have both agentic and communal skills. For these reasons, researchers have suggested that women might be better suited for long-term space missions than men.

Female Physiology and Living Together

In recent years, there have been increasing numbers of women astronauts. The initial inclusion of women may have been, in part, to end discriminatory practices. Now, the effort is rooted in the research about how women react in ICE environments and another well-kept secret—in many ways, the female physiology is better suited for space.

In general, men have more muscle mass than women, which make their performance in activities requiring athleticism better, on average, than that of women. In this regard, in general, men do have a strength advantage. However, being an astronaut requires more than physical strength.

Research on the viability of sending women into space began when space flight was in its infancy. Dr. William Randolph Lovelace II began a privately funded research project to determine whether women would make good astronauts, reasoning that women were generally smaller and lighter and ate less—all qualities that might be useful for working in tight spaces and allow for easier transport of both food and human payload.

In recent years, Army pulmonologist Kathy Ryan dug up the historical data recorded on the women that entered the program. She compared the test results recorded for the Lovelace women against that of the Mercury astronaut candidates and showed that the women did better than the men, on average, especially in cardiopulmonary function. Other studies from the 1950s revealed that women did better in isolation tests and in sensory-deprivation tests than men. According to the researchers, the women also complained less and had greater motivation.

In addition to gender, the nationality of the crew must be considered because cultural differences can affect both astronauts' comfort and potentially the mission itself. For example, the average personal distance that people feel comfortable in varies from culture to culture. In an international setting, it is important that crews understand these cultural differences, or they can lead to conflict.

Hygiene also plays an important role in how you will get along with your crewmates. There are no showers aboard the ISS, which reportedly smells like a jail—antiseptic, garbage, and socks. As a general rule, Americans do not like the natural smell of human beings, so they shower daily and apply copious amounts of deodorant. Not all cultures have a habit of bathing daily or of wearing deodorant at all. Working with someone whose smell you find repulsive might certainly lead to conflict if you are trapped within a small, confined space for a year. These are things that must be selected for and that crews must be trained to understand.

In addition, studies have shown that every person needs a minimum volume of living space to avoid having a psychological impairment. Therefore, the habitable volume of the spacecraft and the number of crew sent to work and live there must be considered along with hygiene issues.

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10

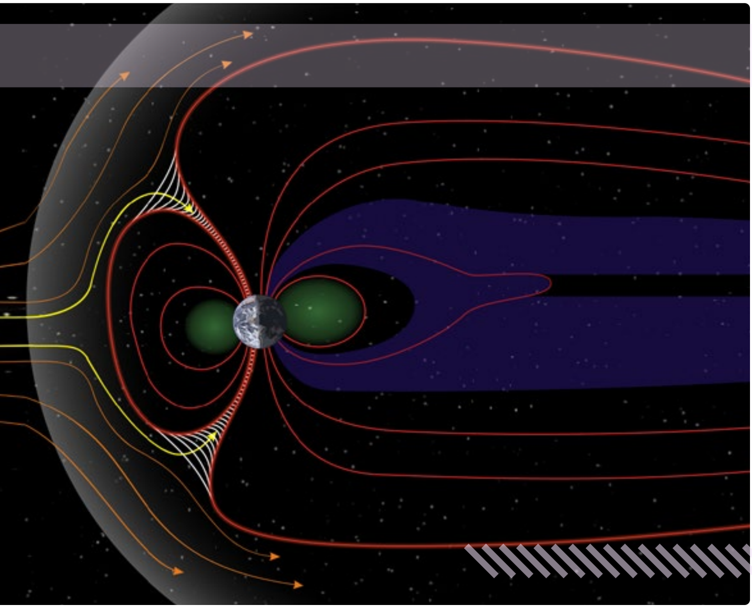
HOW TO SURVIVE SPACE RADIATION

Space is a radioactive environment, and of all the risks in space—weightlessness, bone resorption, muscle atrophy, and social isolation—NASA is most concerned about radiation. When it comes to space radiation, you can't just rely on dumb luck if you want to build moon colonies, travel to Mars, or journey to another star. In this lecture, you'll explore two important questions: How do you survive space radiation? And how do you go to Mars? By doing so, you'll explore solutions such as shortening the total time in space or using nanotubes and artificial magnetic fields.

The Magnetosphere and Solar Particle Events

The way we measure radiation is generally separated into the activity, the exposure, and the dose. Radiation activity, measured in part by a Geiger counter, gives you an idea of how radioactive something is, but it won't tell you the total amount of radiation a radioactive object releases. Radiation exposure is a little more abstract, as it is an attempt to quantify the amount of radiation in the air around you. The exposure rate multiplied by the exposure duration is the absorbed dose, which is what we care about if we're talking about survival.

On Earth, you're protected from most radiation by a magnetic field, which is caused by a self-sustaining process called a geodynamo. As the Earth rotates, molten iron in the outer core sloshes around and generates massive electrical currents that, in turn, create and reinforce the magnetic field. Earth's magnetic field extends tens of thousands of miles into space, and the area where it interacts with charged particles is called the magnetosphere. If it weren't for the magnetosphere, life on Earth wouldn't be possible.



SCHEMATIC OF THE MAGNETOSPHERE

The ISS is completely outside of Earth's atmosphere but is still protected by the magnetosphere. The radiation dose on the station has been calculated to be over 1,000 times the yearly sea level dose on Earth. In deep space, beyond the protection of Earth's magnetosphere, the radiation dose would be over 400 times the dose on the space station and nearly 500,000 times Earth's yearly sea level dose.

Out in space is a complex radiation field, the majority of which comes from the sun—in the form of protons and helium nuclei. The sun is a giant ball of plasma, constantly roiling and turning itself inside out, and when charged particles move like this, they create a magnetic field. All this churning causes ropes of magnetic field lines to tangle, rise, and break at the sun's surface, releasing tremendous amounts of energy.

Because the plasma fields follow these magnetic lines when the energy is released, there are giant eruptions on the sun. Energized particles are ejected and head throughout the solar system at speeds of 1 million to 45 million mph. We call these rapidly moving particles the solar wind.

The outermost part of the sun's atmosphere, called the corona, is usually hidden by the bright light of the sun, which makes it difficult to see unless you have special instruments or there's a total solar eclipse. The sun's corona is composed largely of protons, electrons, and some heavier ions. When an eruption is caused by the breaking magnetic field lines, they can cause a coronal mass ejection, sending large clouds of plasma with their magnetic fields into space.

For NASA, solar particle events are a major cause for concern. Both solar flares and coronal mass ejections can deliver a significant dose of radiation, so you do not want to be outside of the spaceship on a spacewalk if there is going be a solar particle event. The radiation exposure from this single event can be equivalent to about 100 to 1,000 chest x-rays. NASA wants to avoid having a spacecraft or space station exposed to these if at all possible. Thankfully, we have satellites that can warn us of these, and astronauts can take cover from them because they come from the sun.

The solar wind induces a magnetic sphere, called a heliosphere, that directs the electrons and protons the sun ejects toward the Earth. Most of these particles are deflected by the Earth's magnetosphere, but some get trapped within it. When this happens, they interact with gases in Earth's upper atmosphere, ionizing them. In addition, the edge of the heliosphere, called the heliopause, helps block radiation called galactic cosmic rays, which are remnants of ancient supernovas coming from outside the solar system. So, both Earth's magnetosphere and the sun's heliosphere protect us from all of this deep-space radiation.

Neutron Radiation and Van Allen Belts

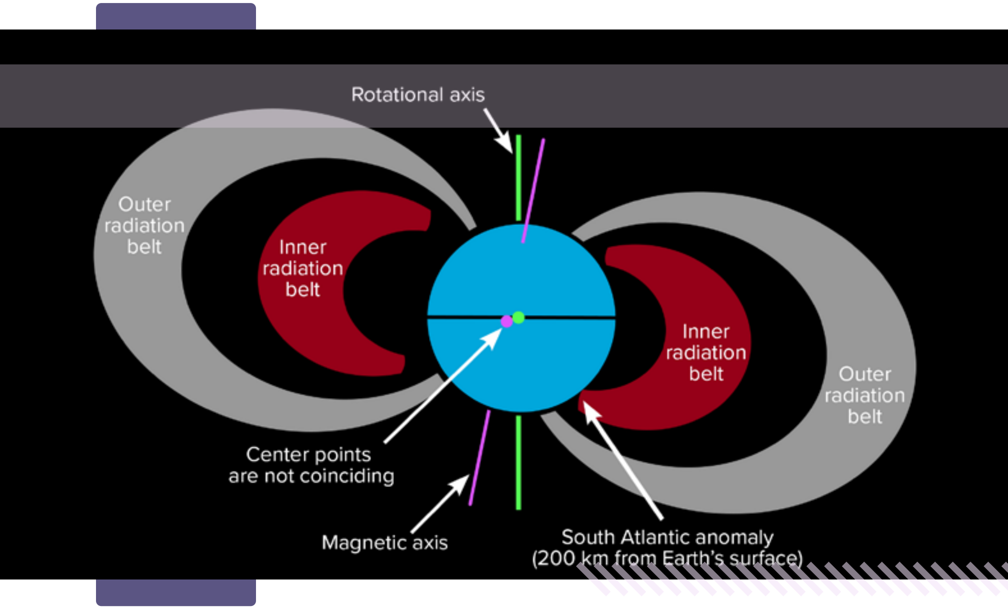
On planetary bodies of the solar system without a magnetosphere, like Mars or the moon, the galactic cosmic rays knock the neutrons in soil and rocks out of their atoms and produce albedo neutrons. Galactic cosmic rays are the primary radiation, and the albedo neutrons are secondary radiation. These neutrons are constantly escaping the planet's surface into space as neutron radiation. So, just as the Apollo astronauts who went to the moon did, when we go to Mars, we'll get a neutron dose.

How can we protect ourselves against neutron radiation? It turns out that hydrogen atoms slow neutrons down, so a thick layer of water would be a good shield since there are plenty of hydrogen atoms in water. NASA is researching structural materials that contain hydrogen to act as both spacecraft building material and shielding. Without such a shield, the safest place would be underground. NASA's current plans are to have astronauts colonize on the side of a cliff to exploit the existing geology of the planet.

The Earth is also surrounded by bands of radiation called Van Allen belts. The outer belt is made up of billions of high-energy particles that originate from the sun and become trapped in Earth's magnetosphere. The inner belt results from interactions between cosmic rays and Earth's atmosphere. The protons and electrons within the Van Allen belts bounce back and forth hundreds of times per second from the Earth's north pole to its south pole.

Where the inner Van Allen belt dips closest to Earth—to just 120 miles above the Earth's surface—there's a strange dent in Earth's magnetic field that causes orbiting craft to get dosed with high levels of radiation. Known as the South Atlantic Anomaly, this dent has been responsible for everything from periodic glitches to total mission failure. It even dictates when astronauts can perform spacewalks.

Spacecraft in low Earth orbit could periodically pass through the South Atlantic Anomaly, exposing their occupants to large amounts of trapped high-energy particles—in other words, potentially damaging doses of radiation. This initially caused massive concern since it is one of the major sources of radiation that impacts anyone orbiting the Earth in a spacecraft or in the ISS. However, the particles in the South Atlantic Anomaly can be avoided if the orbit of the spacecraft can be adjusted.



Galactic Cosmic Rays and Ionizing Power

The biggest radiation threat in space—galactic cosmic rays—cannot be avoided or shielded against. Although these remnants of supernovas from outside our solar system consist predominantly of hydrogen and helium ions, they are composed of every element from hydrogen to iron. And these are the fully ionized nuclei of atoms that are traveling near the speed of light. This speed gives them a lot of energy: In terms of mass, hydrogen is like a cotton ball, while iron is like an iron bullet.

In addition, a field of these rays has no single direction. It's a crossfire coming from every recent supernova in our galaxy, so you can't just put a shield up on one side of the spacecraft. Even if you tried, there is nothing that blocks these particles. They all have different energies—some are similar to what is ejected in a solar particle event, and others are a thousand times more powerful. This is essentially the space radiation problem: These particles will travel through an entire ship and through every inch of a person's body.

NASA is particularly concerned about the relative ionizing power of these particles. Ionizing radiation by definition causes atoms to become ions. An element's atomic number reflects its atomic weight. A heavier atom has more protons and neutrons in its nucleus, and with a larger number of protons and neutrons, the number of ionizations per unit volume increases tremendously. This is what is meant by ionizing power.

In any given volume of space, individual hydrogen particles cause very few ions to be formed, but an iron ion slamming into the body at nearly the speed of light is going to cause much more ionization. So, for any given dose, these bigger nuclei cause much more damage to the human body.

In DNA, ionizing radiation causes damage both directly and indirectly. It can react with the water in your body and cause free radicals to form—chemicals made of oxygen that are very reactive and harm things in the body. Free radicals can damage DNA by breaking chemical bonds and causing them to reform with themselves. Also, the ionizing radiation can cause damage both to DNA and to the cellular repair machinery that fixes the damage. DNA is double-stranded, and this radiation can break one or both strands.

The double-strand breaks can result from iron or carbon particles, and these are much more consequential and difficult to repair than single-strand damage or even double-strand breaks from helium or hydrogen. The larger the ion, the worse the damage. So, the complexity of breaks and damage caused by heavier elements cause NASA a great deal of concern.

This ionizing radiation is a danger to spacecraft as well. All atoms have nuclei and electrons in their orbits, but most of the atom is just empty space. So, when these high-energy nuclei come in from outer space, most of the time they just pass right through matter. But every now and then, they'll collide with nuclei—maybe in the matter that makes up the ship's hull. This collision will produce fragmentation products through a low linear energy transfer.

Thus, the inside of the spacecraft is bombarded with the high-energy galactic cosmic radiation particles that are going through unperturbed as well as the fragmentation products that are created from the hull of the ship, from things inside the ship, and from the astronauts' bodies. The only way to shield against these particles would be to increase the number of nuclei between you and space—like a foot-thick wall of water all the way around the spacecraft—but launching such an enormous payload is prohibitively expensive.

Radiogenic Cancer

In the early days of human spaceflight, most of what was known about radiation and the long-term risks for people had to do with secondary cancer production, or radiogenic cancers. Later, as the space station became a reality and long-duration spaceflight became more common, NASA and other space agencies were worried about cancers caused by radiation.

Most people don't realize that radiation is not a very strong carcinogen. Radiation alone cannot turn a healthy cell into a carcinogenic cell. What it can do is damage DNA so that when that cell produces daughter cells, the errors that accumulate are more likely to result in a carcinogenic cell down the line.

In light of research involving survivors of the Hiroshima and Nagasaki atomic bombs and people living close to nuclear bomb tests and nuclear accidents, NASA's main concern is assuring mission success, and cancer is not really a top threat. Why is this? If an astronaut is on a mission to Mars, from day 1 to the end of the mission would be no more than 3 to 5 years. That astronaut will not get cancer from space during that mission. They might get it, say, 20 or 30 years later. However, most astronauts are over 40, and 30 years later, many 70-year-olds develop age-related cancers anyway.

Radiation and the Brain

While cancer is not a major worry for NASA, the effects of radiation on the brain definitely are. It's been known since the early 1990s that people who undergo radiation treatment develop progressive cognitive impairments due to the radiation, not the tumor.

What exactly space radiation does to the brain has really only been discovered through research conducted since about 2015. A team led by Professor Charles Limoli of the University of California, Irvine found that cosmic radiation may harm astronauts' brains more than previously thought. They exposed mice to charged particles mimicking galactic cosmic radiation and then measured both behavioral performance and physical damage revealed by brain imaging.

Simulated cosmic radiation damaged a region of the mouse brain called the medial prefrontal cortex, which is associated with memory. In this area, neuron protrusions called dendritic spines that enable learning and memory decreased in size and number by 20%–40%.

In their initial studies, Limoli's team only examined male mice. When they compared male mice to female mice, they found that female mice show a marked resistance to similar doses and did not exhibit the same level of behavioral deficits as observed in male mice following exposure to the radiation. They found that male mice exposed to the simulated galactic cosmic radiation showed significantly higher levels of neuroinflammation and more extensive cognitive deficits than females.

Every day, we normally make about 700 new neurons. Some will die, but some will form connections and integrate into that hippocampus circuitry. If these cells get killed, you will start to lose your ability to do pattern separation. In other words, you won't be able to tell the difference between events that occurred from time one to time two.

You can see why the effects of galactic cosmic rays are a primary concern at NASA. The effects of this damage in the brain of an astronaut would be catastrophic for any mission. Unfortunately, there is not yet a solution to the problem.

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11

HOW TO SURVIVE
A MEDICAL EMERGENCY IN SPACE

When you think of emergencies in space, you might think of catastrophic failures that have claimed the lives of astronauts, such as the *Challenger* disaster of 1986. However, surviving a medical emergency is one the toughest challenges in space. NASA researchers—and space researchers in general—spend a lot of time thinking about these potential problems. It's so challenging precisely because the least is known about it. In this lecture, you'll explore the things that can hurt you in space and learn that the most common causes of accidents are not what most people suppose.

Medical Conditions and the Space Stupids

If you're in space for a long time, your bones will begin to resorb. They will become fragile—several astronauts have returned from space with osteoporosis. The gravity of Mars is only 38% that of Earth's, but depending on the location in the body, bones resorb at a rate of 1%–3% per month. A 20% loss in bone mineral density is the most any person can lose before being prone to breaks. Some long-term astronauts have lost as much as 20% of their bone mass in some long bones while in space. If you lose that much bone on your way to Mars, then a fall might hurt you even in the reduced Martian gravity.

Although NASA tries hard to select healthy people to avoid medical emergencies, not all preexisting conditions can be predicted, especially since some of these conditions may be triggered primarily by being in space. For instance, there have been ventricular arrhythmias following EVAs. Space is an ICE environment, just like a submarine or an Antarctic research station, with a lack of access to outside help during medical emergencies. Such ICE environments generally bring their own physicians.

In addition to the disorientation felt by astronauts due to the lack of gravity pulling on their vestibular system, space can cause distorted vision and duller thinking—the space stupids! Astronauts describe the disorientation as an uncanny valley feeling, where everything feels like a doppelgänger of itself. This feeling is so profound that it has caused astronauts to vomit, and this disorientation may contribute to more general cognitive problems and distorted perception.

Although this might initially sound amusing or merely inconvenient, the consequences could be dire. Astronauts sometimes get lost on the ISS, and getting lost is a big deal if you are trying to find an escape pod or a colleague in distress. Some astronauts have also reported pulling switches in the wrong direction during delicate technical missions. Anecdotal accounts suggest that astronauts may also misjudge the speed of an approaching vehicle during docking. In a medical emergency, the space stupids could make things even worse.

Heart Attacks in Space

Have you ever heard about the heart attack on the moon? The most remote heart attack in human history occurred during the Apollo 15 mission. The lunar module commander, James B. Irwin, overexerted himself while tired and then had abnormal heart contractions. Specifically, he had an irregular heart rhythm called bigeminy, which is where each normal heartbeat is followed by an abnormal beat, and also reported a brief loss of consciousness at the time the arrhythmia was noted. This kind of abnormal heart rhythm is a strong indicator that something is interfering with blood flow to the heart.

Twenty-one months after returning to Earth, Irwin had a major heart attack at the age of 43. He had several additional heart attacks before the final heart attack that killed him at age 61. Although NASA doctors doubt that the heart attacks were related to space and were more likely due to a preexisting condition, other researchers posited that space was a contributing factor—possibly due to fluid shift changes, radiation, or the malfunction in his EVA suit that left him dehydrated.

Researchers trying to piece together the causes of cardiac events in space have settled on mineral deficits. Prior to Apollo 15, many astronauts tended to suffer a significant magnesium ion deficit because they trained in the intense summer heat of Houston, Texas. This deficit would persist for months and was then compounded by an additional magnesium deficit caused by skeletal muscle atrophy that occurs in microgravity. This severe magnesium deficit could lead to deficits in other electrolytes, including potassium, leading to cardiac arrhythmias as well as enhanced blood clot formation, which could in turn cause injuries to blood vessels.

Ironically, the body does this to keep the heart beating. When magnesium is low, there is inhibition of renal outer medullary potassium channels, leading to increased urinary excretion and depletion of intracellular potassium levels. This reduces the threshold required for generating an action potential in the cardiac myocyte. In other words, to keep your heart beating, when magnesium is low, your body deliberately lowers potassium to enable the heart's electrical signals to propagate. In addition, being dehydrated causes the body to lose its protection from elevated free radicals, which can lead to blood vessel injuries and spasm of those blood vessels.

Some have suggested that without proper nutrition, the Apollo 15 space syndrome may be more common on longer space missions due to the changes that occur in the body and the likelihood of frequent and persistent magnesium deficiency.

So, what do you do if you are having a heart attack in space? Maybe nothing—if you're in a space suit, that is. If you're not, maybe get into a space suit. Because while the ship may contain only 21% oxygen, the space suit contains 100% oxygen, which was the atmosphere of the Apollo orbiter that Irwin recovered in. At the time, the flight surgeon, Charles Berry, said:

> In truth, he's already in an ICU. He's getting 100% oxygen, he's being continuously monitored, and best of all, he's in zero G. Whatever strain his heart is under, well, we can't do better than zero G.

Accidents and Surgery

What if you had an accident instead of a heart attack? What if you needed surgery? Although modern countermeasures, such as exercise and nutrition, have ameliorated many potential adverse events, many remain. To date, arrhythmias, renal colic, venous thrombosis, and infections are among the over 47 conditions that have been documented during space flights. NASA has a list of over 100 potential medical emergencies that have been identified as continuing risks, which also include heart attack, stroke, embolism, massive hemorrhage, appendicitis, and emergencies related to renal stone formation. Then there are the injuries considered possible, including fractures of the wrist, hip, spine, and lower extremities.

If you needed surgery, it would be complicated. The fluid shift tricks the body to lower blood volume and red blood cell mass when in space. On Earth, when your body needs to regulate blood flow, blood vessels constrict or dilate. In space, they don't constrict very well anymore. Because of this impaired vasoconstriction and the lowered blood volume of astronauts, bleeding at a rate that would not be lethal on Earth would be deadly in space. In addition, the body's machinery that is involved in wound healing is upset, which makes it harder for even a minor cut to stop bleeding.

It’s known that stress can change the balance of a lot of your hormones. Cortisol is a stress response hormone, and when it is present for too long, it can affect other hormones as well as your immune system. This happens in space, as well, and the stress is not just psychological but also physiological.

In addition to cortisol-related changes to your immune system, microgravity itself impairs the production and function of immune cells, so your immune system is depressed. All of this leaves you less able to fight infection, while any wound you do have stays open longer, leaving you more vulnerable to infection. Further, weightlessness allows bacteria to float indefinitely, which means they may enter your wound or surgical incision.

Performing Surgery in Space

All of this doesn’t even take into account the difficulty of performing surgery in space. First, general anesthetics that are used on Earth might kill you in space. They lower blood pressure and dilate blood vessels. They paralyze the patient and require ventilation to keep the person breathing. Nobody even knows what anesthesia would do to the space-adapted body, and that’s not even considering the fact that anesthetic gases are often flammable and may require special ventilation or scrubbing so that they don’t cause the surgical team to pass out.

Second, on Earth, the typical space-adapted astronaut’s blood volume would likely necessitate a blood transfusion before even starting surgery, but a transfusion would be impossible in space, or at least very difficult. There have been experiments in space where IV fluids were successfully delivered to a dummy arm, but the bubbles in the fluid bag do not float up to the top, instead remaining dispersed throughout the fluid. Bubbles in the body are bad. When they block a blood vessel, they are called air or gas embolisms, and they can cause serious and potentially fatal conditions, such as a stroke or heart attack. This is still a problem that researchers are trying to figure out. Unlike on Earth, where gravity delivers the fluid, in space, you’d need a pump to deliver the blood transfusion to make the surgery possible. If that pump stops working, you’d be in trouble.

On Earth, refrigerated blood can last for a month and plasma for a year, but the shelf stability of blood or pills or other kinds of drugs are simply not known in deep space, where there is so much more exposure to galactic cosmic radiation. Keep in mind that a trip to Mars is likely to take 1 to 3 years—so much for that plasma.

Third, following an incision in space, blood would not drip away but would collect like a dome at the site. This would make it impossible for the surgeon to see what they are doing. Any kind of open surgery would lead to floating blood droplets and fluids in the cabin, and it would be impossible to maintain a sterile field—remember, there's all that drifting bacteria.

MIRA and Medical Emergencies

Instead of trying to address these issues outside the body, researchers have designed a miniaturized surgical robot to be inserted entirely inside a patient's abdomen, requiring only a single surgical incision. This robot has been named the miniaturized in vivo robotic assistant (MIRA) and is slated to fly aboard the ISS for the first time in 2024 to perform simulated surgical procedures in microgravity.

MIRA would be inserted into the incision through a hermetically sealed surgical enclosure that is fluid-filled and self-healing. So, the robot would mush against the incision, preventing blood from making a red dome surgeons couldn't see beyond. One advantage of this space robot surgery is that tools aren't being removed and inserted repeatedly, potentially introducing infection. Presumably, the robot would stay in until the surgery is complete.

Another advantage is that a surgeon could remotely—say, from Earth—perform an operation assisted by a minimally skilled crew member who is in space with the patient. Such a remote operation could potentially benefit astronauts on the ISS because there is less than a 1-second communication delay. There is a small chance that remote surgery could also help someone on the moon, where there is a 1.25-second delay. However, the communication time lag would be too large to benefit astronauts directly on Mars, where the communication delay is a minimum of 5 minutes one way and a maximum of as much as 20 minutes each way, depending on planet position.

If you do have a major medical emergency aboard the ISS, it is possible to launch an emergency return to Earth, but since emergency return vehicles have always been in Soyuz vehicles, this may not always be possible. Of course, there's no emergency return option at all if you are on Mars or in deep space.

Traumatic injury rising to the level of a medical emergency is the risk most likely to negatively impact the success of a planetary mission and the risk with the most unknowns. Researchers are trying to answer some of these questions by conducting tests aboard the "vomit comet"—an aircraft that follows a parabolic arc, giving about 25 seconds of complete weightlessness. During these brief periods of weightlessness, teams have performed intubations, opened and closed wounds, repaired blood vessels, and performed various animal surgeries.

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12

HOW TO SURVIVE TOUCHDOWN

By now, you should understand why you can't stay in space forever. Eventually, you have to either land at your destination or return to Earth. So far, every crewed mission has been round-trip, so you can always expect Earth to be a landing site. In this lecture, you'll conclude the course by considering the most important task of all—how to survive landing in a spacecraft, whether on Earth, the moon, Mars, or even some asteroid. To get there safely, a lot of things must go right: You have to survive reentry, landing, and, with your body weakened from all your time in space, navigating on whatever celestial body you find yourself on.

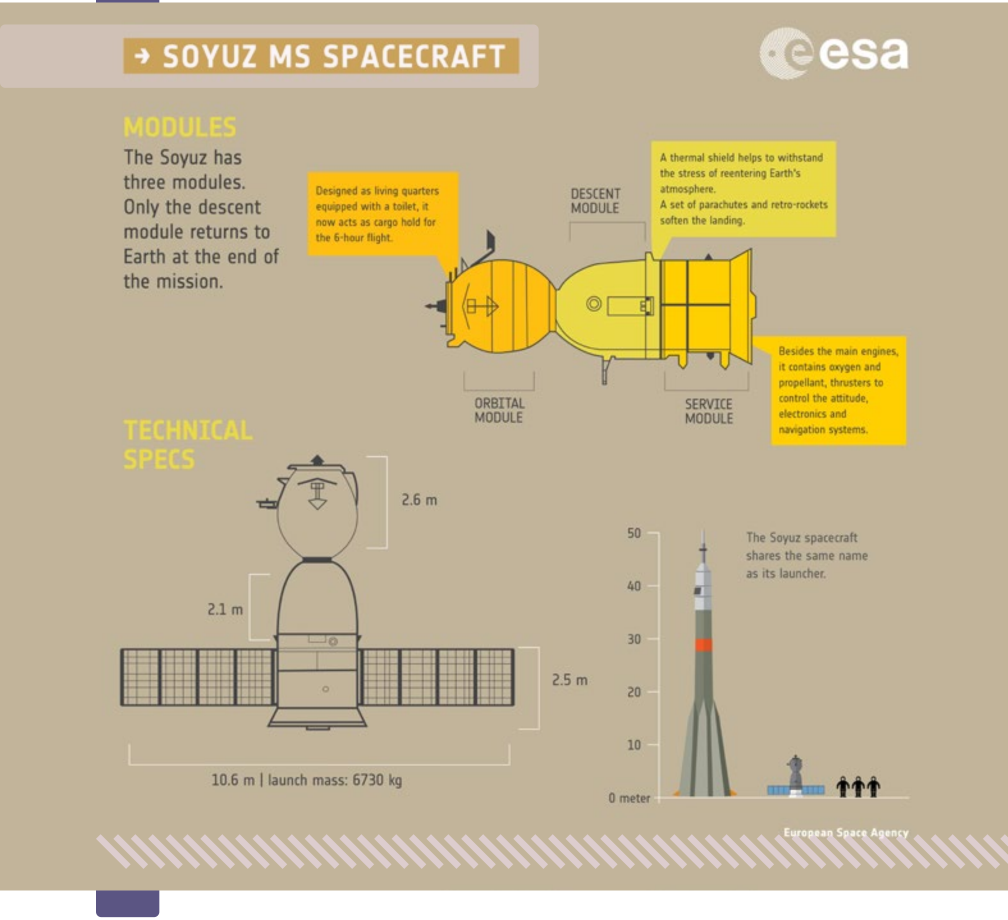
Heat and Friction on Reentry

Landing a spacecraft on Earth can be challenging because the atmosphere is thick, which generates friction and heat. Anyone who has ever seen a movie about space knows that things heat up incredibly during reentry.

When first designing the space shuttle, the story goes that engineers were initially stumped trying to design a tile that would not burn up. Eventually, they landed on the idea that it did not need to be fireproof. It just needed to be fire resistant. In other words, if it burned away really slowly, that was fine as long as the time it took to burn away was much greater than the time it took the astronauts to reenter. These tiles were continually replaced, and they were critical to protect the shuttle from the heat of reentry.

The *Columbia* disaster in 2003 directly led to the retirement of the space shuttle program in 2011. After shuttles were retired and before the SpaceX Dragon was available in 2020, the Russian Soyuz vehicles were the only way for NASA and other space agencies to transport crews to and from the ISS, and even though the Soyuz vehicles are considered the most reliable in the world, there have been reentry problems.

SOYUZ TMA-15M SPACECRAFT



→ SOYUZ MS SPACECRAFT

MODULES

The Soyuz has three modules. Only the descent module returns to Earth at the end of the mission.

Designed as living quarters equipped with a toilet, it now acts as cargo hold for the 6-hour flight.

A thermal shield helps to withstand the stress of reentering Earth's atmosphere.
A set of parachutes and retro-rockets soften the landing.

Besides the main engines, it contains oxygen and propellant, thrusters to control the attitude, electronics and navigation systems.

TECHNICAL SPECS

The Soyuz spacecraft shares the same name as its launcher.

When everything goes according to plan during reentry, Soyuz g-forces typically do not exceed 4.5 Gs. After the Soyuz separates from the ISS, the propulsion or “service” module is supposed to detach, exposing the heat shield and allowing the capsule to enter the atmosphere and descend to Earth smoothly. However, on three missions, the propulsion module did not detach, overwhelming the descent module’s navigation computer, which then entered a safety mode. That safety mode is a ballistic mode—one driven entirely by gravity.

In ballistic mode, the g-forces experienced by the crew are doubled. US astronaut Peggy Whitson was aboard the Soyuz on one mission and later described feeling waves of nausea as the capsule violently plunged through the atmosphere toward Earth. The descent, which lasted around 23 minutes, also subjected her to 8 Gs for around 60 seconds. The capsule eventually slowed down due to friction in the lower atmosphere, and that friction caused the vehicle to glow red-hot as outside temperatures soared. The first of four parachutes deployed, and small rockets fired in an attempt to cushion the impact, but the landing was still rough and about 300 miles from the target area in Kazakhstan.

That's just surviving a trip from low Earth orbit. The speed that a spacecraft returns to Earth from the moon is over 24,500 miles per hour. This is 40% faster than its 17,500 miles per hour speed when it's returning from low Earth orbit. Coming from Mars, the speed would likely be much greater. This means that if you are coming from the moon or Mars, landing will be much more dangerous and intense than if you were returning from the ISS.

Addressing the Risks of High G-Forces during Reentry

During the Apollo missions, NASA determined that a direct "ballistic" entry into the Earth's atmosphere could easily exceed 17 Gs, which would be too much for a human crew to handle. So, researchers developed a plan where the Apollo spacecraft would generate lift, which is an upward force produced when air moves rapidly over a surface in the right way. Lift kept the spacecraft in the outer atmosphere longer, allowing it to slow down more gradually. This reduced the forces the crew had to endure from 17 Gs to around 7.5 Gs—uncomfortable but survivable.

Such high reentry Gs are a result of direct reentry angles, which are very steep. While these forces were acceptable for the shorter Apollo missions, longer 50- to 100-day stays on the moon could lead to physical deconditioning and decreased tolerance for high g-forces. So, as of the end of 2023, NASA has safety standards in place that limit the maximum g-forces experienced by astronauts during reentry based on their condition.

In the Apollo missions, the direct reentry method still required the use of a massive heat shield to protect the crew from the high temperatures and limited the spacecraft's ability to make a precise landing, so it had to splash down in the ocean. This can cause structural damage to the spacecraft and make it difficult to control during descent. Additionally, landing in the wrong location can put the astronaut at risk of being injured or killed.

To address the potential risks associated with high g-forces during reentry, NASA has implemented the "skip entry" approach rather than direct reentry. This uses aerodynamic forces to reduce the spacecraft's speed and cause it to reenter into a low Earth orbit. The spacecraft then completes a second reentry, with the peak g-forces and heat the capsule is subjected to significantly reduced.

Landing on the Moon and NEOs

Landing on the moon is another story. The lack of atmosphere on the moon means that there is no air resistance to slow a spacecraft down during descent, which makes control of the speed of the spacecraft entirely reliant upon retro-rockets. Therefore, astronauts are at a greater risk of crashing if the landing is not executed properly. Additionally, the moon's surface is covered in craters, dust, and debris, which can make it difficult to find a safe landing spot.

Assuming all goes well, after over 100 days on the moon, astronauts returning to Earth will be deconditioned at a rate comparable to astronauts on the ISS. However, without the Earth's magnetosphere to protect them, they'll be subjected to radiation that ISS astronauts are not. In addition, the moon itself is highly radioactive and astronauts will also have to contend with moon dust, which can result in adverse health in humans and damage the lungs. Astronauts exposed to radiation on the moon, in addition to lunar dust, who then land on Earth may have unique health issues that have not been observed in those returning from the ISS.

NASA has also investigated the feasibility of sending astronauts to a near-Earth object (NEO) like an asteroid, which is considered a stepping stone on the way to Mars, providing a setting to test necessary technologies.

Astronauts traveling to a NEO would only have the spacecraft as their habitat. Depending on the size of the asteroid visited, it would have little to no gravity and could be highly radioactive. So, you would have to survive ISS-like conditions plus cosmic radiation.

However, sending astronauts to an asteroid may present a bigger challenge than sending them to Mars. Although all the near-Earth asteroids that NASA would consider are closer than Mars, the proximity advantage is outweighed by the greater knowledge scientists have gained of Mars due to the many Mars missions launched over the years.

Landing on Mars

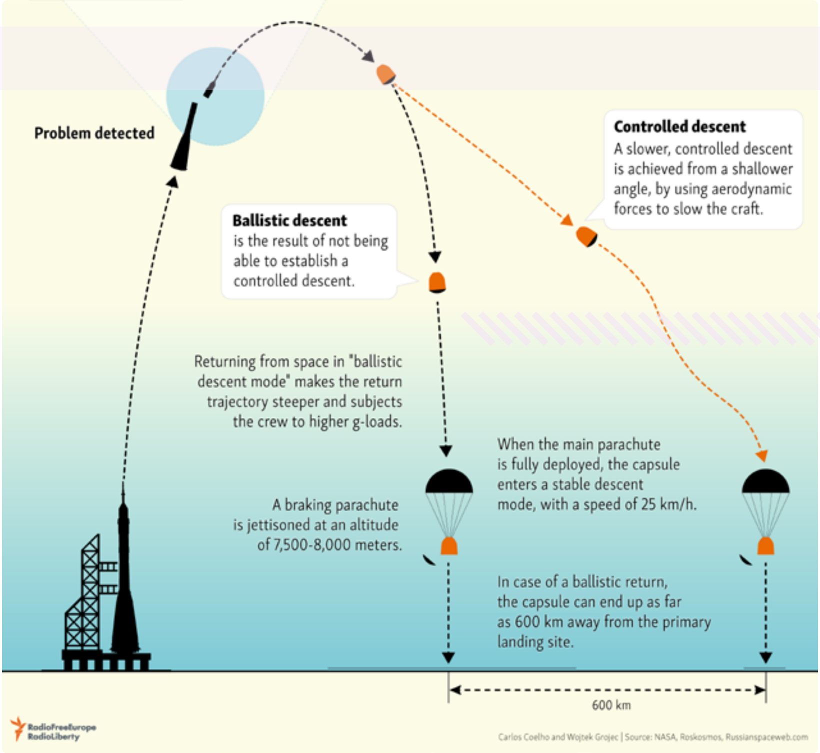
Landing on Mars poses challenges similar to those involved in landing on the moon, few if any of which have ever made it into a Hollywood movie. The thin atmosphere of Mars makes it difficult to generate enough lift to slow down the spacecraft during descent. This means that it needs to rely on other methods, such as retro-rockets, to slow down. Additionally, the planet's surface is rough and rocky, which can also make it difficult to find a safe landing spot.

Further complicating matters is the issue of the communication lag. Radio signals take an average of 10 minutes to reach Earth from Mars, meaning every message sent would take around 20 minutes to receive a response.

Skip landings are not an option for a planet with such a thin atmosphere, and as on the moon, failure of the retro-rockets could spell disaster. Unlike on the moon, there is an atmosphere on Mars, albeit a very thin one. Therefore, using parachutes to decelerate is possible as well.

Martian dust will also be a problem, potentially a greater one than lunar dust. In addition to being a mechanical irritant, Martian dust may also be a chemical poison. Unlike on the moon, the atmosphere of Mars permits storms. There are considerably strong windstorms that can involve the majority of the planet from its poles to the equator. During these storms, the dust permeates everything. To survive, you must find a way to avoid the poison dust, and since it is electrostatic, it will cling to you like a sock fresh out of the dryer. Once you've safely landed on Mars, you'll have to contend with the reality that Hollywood never mentions—orthostatic intolerance, where the astronauts can't stand up.

It has been estimated that a trip from the Earth to Mars will take about 7 to 9 months. So, all the deconditioning that happens on the ISS will occur in transit. Will the astronauts pass out? Will they have enough blood to stand up? Will they have enough muscle? Will their bones be strong enough or too brittle to support their own weight? Will they breathe in toxins that they bring in from the planet? Can they survive the radiation they'll be exposed to?



Carlos Coelho and Wojtek Grojec | Source: NASA, Roskosmos, Russianspaceweb.com

Should you decide to go, it is estimated that your trip to Mars would take about 21 months: 9 months to get there, 3 months there, and 9 months to get back. The gravity on Mars is only about 38% of Earth's, so the time you spend on the planet won't fully recondition you. Will you be strong enough to perform the duties necessary to return? What is the psychosocial impact of spending 21 months in a spacecraft with a living space no larger than a school bus? As of 2023, the longest anyone has stayed in space is 14 months. We know that radiation has an impact on cognition, as does being in an ICE environment. Even if you are physically capable, will you be intellectually capable of performing your duties?

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