



Quick Write

How do you think NASA scientists should protect against the hazards of space impact? Are collisions in space an acceptable part of the price to pay for space exploration?

Learn About

- the threat caused by high levels of radiation
- the hazard of impact damage to spacecraft
- the threats associated with surface landings
- fire hazards in space

A funny thing happened in 1967 on *Mariner 4*'s trip home from a flyby of Mars: It got caught in a cloud of dust. This wasn't just any dust. It was a cloud of space dust, and it was a pretty intense experience, even for NASA controllers who were monitoring it all from millions of miles away.

As Bill Cooke of the Marshall Space Flight Center Space Environments Team recalled later, "For about 45 minutes the spacecraft experienced a shower of meteoroids more intense than any Leonid meteor storm we've ever seen on Earth."

The impacts ripped away bits of insulation and turned *Mariner 4* around. But this was minor damage, sustained on the return journey after a mission accomplished. It could have been worse. Interplanetary space holds many uncharted dust clouds like the one that clobbered *Mariner 4*. Some of them are probably quite dense.

The Threat Caused by High Levels of Radiation

When you're planning a space mission, you have to understand the space hazards your spacecraft will face and develop defenses against them.

Of the many hazards to spacecraft, radiation exposure is one of the biggest. Outside the protection of Earth's atmosphere and magnetic field, spacecraft and their crews are exposed to **solar radiation**—*solar flares*—to cosmic radiation from elsewhere in the universe (called galactic cosmic rays), and to belt radiation trapped in Earth's magnetic field. Accordingly, one of the biggest challenges of long-distance space travel is to re-create, in some form, Earth's "safety blankets" to protect spacecraft (and astronauts) from long exposure to radiation.

Vocabulary



- solar radiation
- solar storm
- plasma
- microgravity
- oxidant



This shot, taken over northwestern Africa, shows Earth's atmosphere—composed of 78 percent nitrogen, 21 percent oxygen, and 1 percent other elements. One of the most important things the Earth's atmosphere does is to protect the planet from radiation—whether from the Sun or from other sources in outer space.

Courtesy of NASA/JPL/UCSD/JSC

The Threat of Solar Storms to Spacecraft in High Orbit

Electrical storms can cause plenty of trouble on Earth by overloading power lines and leading to widespread blackouts. A similar threat to hardware in space is a **solar storm**, or geomagnetic storm—an episode of violent space weather resulting from particles streaming outward from the Sun.

The solar particles themselves don't cause severe space weather, but they become energized when the solar magnetic field becomes oppositely directed to Earth's and reconnects in a different way.

Star POINTS

This new discovery about holes in the Earth's magnetic field came from NASA's THEMIS mission. THEMIS stands for Time History of Events and Macroscale Interactions during Substorms. Earlier missions had sampled the enormous layer of solar particles within the Earth's magnetic field. But the THEMIS fleet consists of five spacecraft—enough to span the whole layer and make definitive measurements.

Researchers have recently discovered that Earth's magnetic field often develops two large holes, one at high latitude over the Northern Hemisphere, and one at high latitude over the Southern Hemisphere. The holes form over Earth's daylit surface, on the side of the magnetic shield facing the Sun (Figure 3.1).

Scientists think this new discovery will likely allow them to better predict the severity of solar storms. They compare it to predicting storms on Earth. For example, a weather forecaster knows to expect more-intense hurricanes at a time when the oceans are warmer.

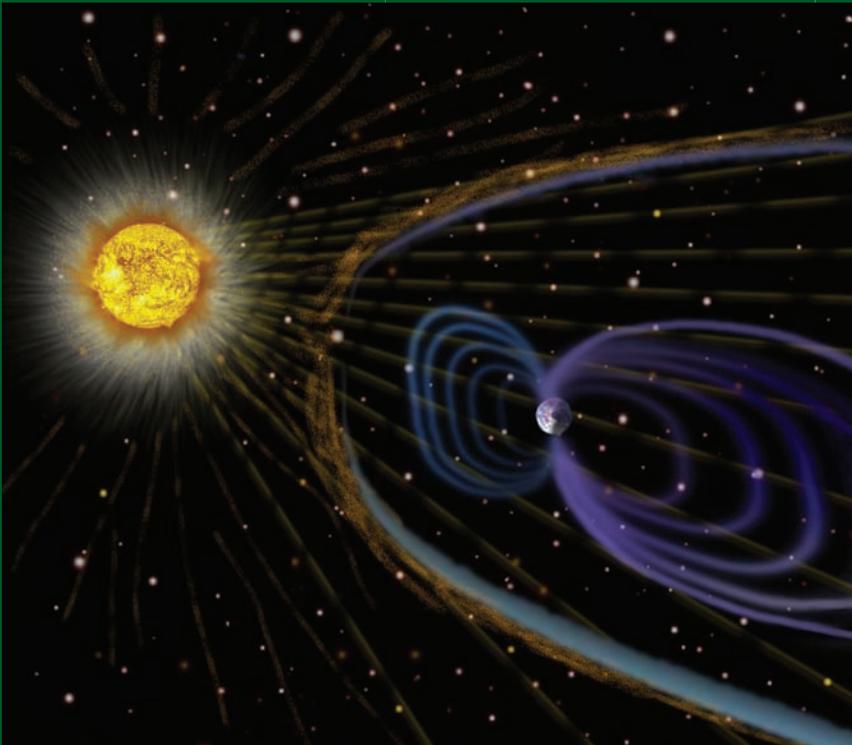


Figure 3.1 In this illustration, Earth's magnetic shield protects the planet from solar winds. The magnetic shield appears as concentric purple ovals, shorter on the side facing the Sun and stretched out on the far side due to pressure from the solar winds. One of the biggest challenges of long-distance space travel is to re-create Earth's "safety blankets" to protect spacecraft (and astronauts) from long exposure to radiation.

Courtesy of SOHO/ESA & NASA



NASA's TRACE spacecraft records solar activity, such as this solar flare from 21 April 2002. Outside the protection of Earth's atmosphere and magnetic field, space crews will be exposed to solar and cosmic radiation.

Courtesy of NASA/Goddard Space Flight Center, Scientific Visualization Studio

How Radiation Can Damage Machines and Cause Computer Failure in Space

This radiation from the Sun and elsewhere in space poses several threats to space hardware. It can cause metals and materials to deteriorate, lose strength, and become less flexible—similar to what happens to plastics on Earth that sit in the Sun for a long time. How a spacecraft and its materials withstand radiation determines the craft's lifetime. So NASA studies different materials to determine which ones hold out best against the radiation in space.

In addition, very high doses of radiation can cause machines to fail by triggering computer malfunctions—and in the space program just about every machine relies on a computer. For example a large solar event bombarded the Martian Radiation Environment Experiment (MARIE) instrument aboard the Mars Odyssey spacecraft with radiation in 2003. NASA engineers and scientists believe a solar particle crashed into MARIE's computer board, damaging a chip. MARIE was unable to collect data after that event.

Electronics can break down when cosmic rays pass through critical parts and short the circuits. But that's not the only kind of trouble that radiation can make. Ions or electromagnetic radiation can affect the output or operation of an electronic device. The term for this is a single event upset, or SEU. An SEU is considered a “soft error” that doesn't permanently damage the device. But it can produce faulty data transmission, or give a false reading on a navigational device, causing a spacecraft to miss its destination, for instance.

To protect against these dangers, critical computer systems need the ability to detect and correct errors. The space shuttle, for instance, has four computers that “vote” on each action before they make a decision. This protects against the possibility of a computer “memory lapse” because of exposure to charged particles.

The Hazard of Impact Damage to Spacecraft

Another serious threat to spacecraft is colliding with another object in space. But one problem many people think of is actually *not* much of a risk: collision with asteroids. Popular movies may make it seem otherwise. But lots of space lies between asteroids. Thousands of them may roam the Solar System, and astronomers may spot several hundred new ones every year. Yet these asteroids are spread over a ring more than half a billion miles around, more than 50 million miles wide, and millions of miles thick.

Nonetheless, plenty of other impact hazards, ranging from space junk to space dust, fill outer space.

The Damage That Meteoroids Can Cause to Spacecraft

Asteroids may not be much of a problem, but meteoroids definitely are, even in Earth’s own backyard. The tiniest meteoroids can pose a risk for Earth-orbiting satellites. They can blast holes in solar panels. They can pit surfaces. And they can short out electronics. Both the space shuttle and the *Mir* space station have suffered broken windows because of strikes by tiny objects in Earth’s orbit.

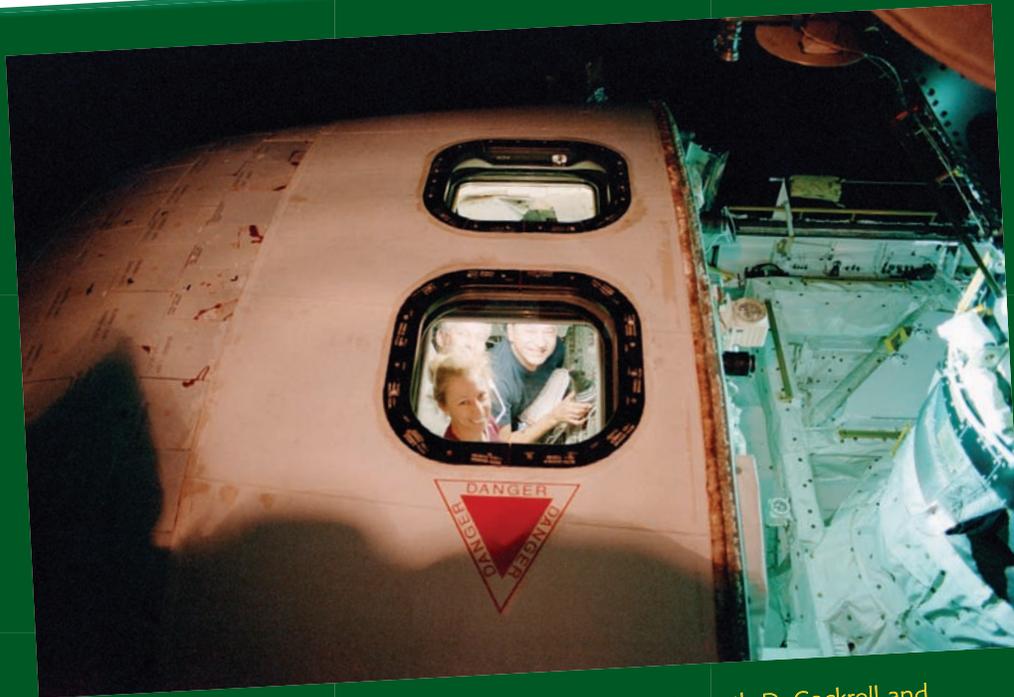
This is apparently what happened to the European Space Agency’s *Olympus* communications satellite in 1993. When a meteoroid hits a spacecraft, the meteoroid can disintegrate, creating a cloud of **plasma**—*an electrically charged gaseous form of matter distinct from solids, liquids, and normal gases*. Under the right (or arguably, the *wrong*) conditions, this plasma cloud can set off a chain reaction, causing a massive short circuit and zapping a satellite’s delicate electronics.

This is what scientists think happened to *Olympus*.

Star POINTS

Windows are a major issue for spacecraft designers. It’s obviously desirable for astronauts to be able to see out. But the fragility of windows makes them a real vulnerability.

When scientists forecast meteoroid showers, NASA and other authorities take precautions, such as pointing vulnerable systems away from the incoming meteoroids. They also may power down sensitive instruments to minimize damage in the event of a collision.



Mission Specialist Marsha S. Ivins, along with astronauts Kenneth D. Cockrell and Mark L. Polansky, looks through a window in the space shuttle *Atlantis* at one of her spacewalking colleagues who snapped this photo in 2001. Windows on both the space shuttle and the *Mir* space station have suffered damage from strikes by tiny objects in Earth's orbit.

Courtesy of NASA

The crew of any mission to Mars would have to be alert to risks from meteoroid strikes. The odds of such a thing happening are not large, but the damage would be devastating if it did. Even a small particle of debris can do a lot of damage if it travels on a collision course with a spacecraft. At this point, an object has to be about the size of a baseball to show up on NASA's radar.

How Junk in Space Can Damage Spacecraft

Besides natural threats to spacecraft, there's a class of manmade threats as well: space junk.

What goes up doesn't always come down. Satellites and humans have been going into space for half a century. Some spacecraft have returned to Earth, touching down at a landing strip or dropping more or less harmlessly into the ocean. Others have mostly burned up in the Earth's atmosphere. Some objects sent into space, like the two *Voyager* craft, are still at work years after their launch.

But many items no longer serving a useful purpose remain in orbit. They keep going round and round the Earth—posing a potential collision hazard to everything else in space that still does have a useful purpose. Eventually items in Earth orbit reenter the atmosphere, where most of them burn up.

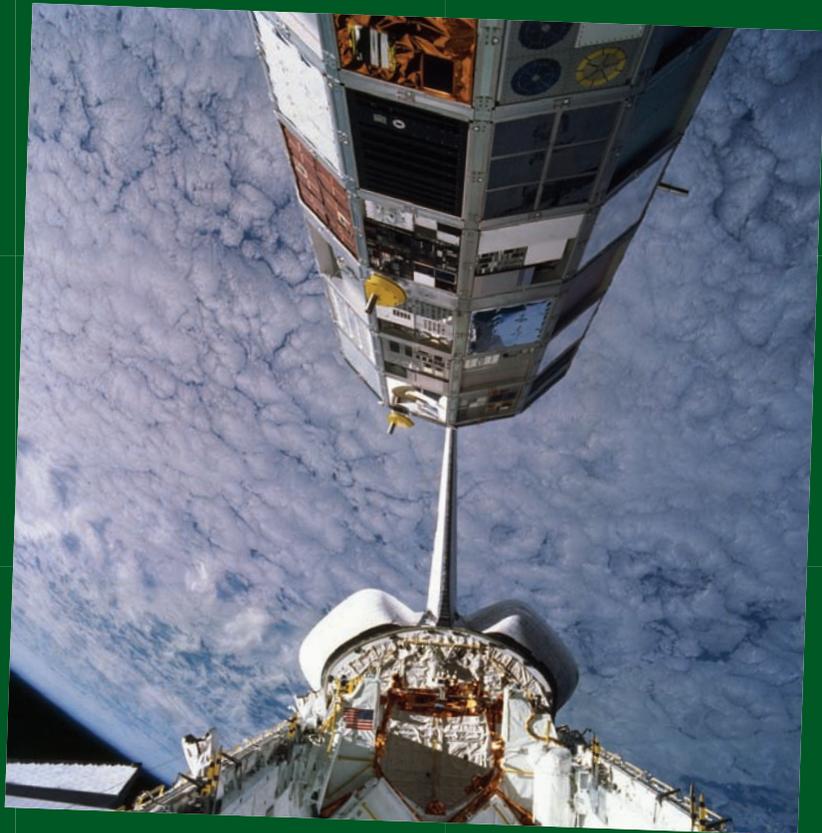
Space junk can be as small as a dot of paint that has flaked off a spacecraft. Or it can be as big as a satellite that has stopped working. The United States tracks as much space junk as it can. Radar finds a lot of it. And scientists have ways of estimating what they can't see with radar.

Space junk moves pretty fast. That makes it all the more dangerous. As with meteoroids, even a small object can do a lot of damage. The International Space Station is relatively strong and can stand up to strikes from space junk. The space shuttle's advantage is maneuverability—it can do more to get out of the way of a threat. But it still returns to Earth with tiny craters and even cracks in its windows.

The space shuttle Challenger (at bottom) deploys the Long Duration Exposure Facility (at top) on 7 April 1984.

The LDEF's five-year mission was to test the effects of space junk, micrometeoroids, radiation particles, atomic oxygen, and solar radiation on spacecraft materials, components, and systems. NASA found that atomic oxygen significantly eroded some test materials, especially on trays facing away from Earth.

Courtesy of NASA



The Threat Caused by Clouds of Space Dust

A similar danger is space dust. *Mariner 4*'s encounter with a dust cloud, which you read about at the beginning of this lesson, was an example of this impact hazard in space. As it happened, that spacecraft was the only one of NASA's Mars spacecraft to be sent off with a micrometeoroid detector. As expected, it registered occasional impacts from interplanetary grains of dust. These are harmless in small numbers. But when *Mariner 4* encountered the cloud, the impact rate increased 10,000 times.

Think of yourself in the desert. If the wind throws a single grain of sand in your face, that's no big deal. But if you're caught in a sandstorm, suddenly thousands of grains of sand are hitting you. That's a very different story—for one thing, it hurts!

As NASA's unmanned missions to Mars continue, this kind of encounter with a dust cloud is likely to be repeated. That's why it's a priority for NASA to map these dust clouds and calculate their orbits.

Much of this work involves computer modeling of streams of cometary debris. These are long rivers of dust shed by comets as they orbit the Sun. NASA scientists study how clumps form within the streams and how the gravity of planets, especially Jupiter, deflect them. Scientists also watch the sky for meteor outbursts on Earth. It's a good way for them to test their models and discover new streams of debris to track.



This much-enlarged photo shows a grain of space dust 10 microns across. A U-2 aircraft in the stratosphere captured it. Dust clouds are another type of impact hazard in space.

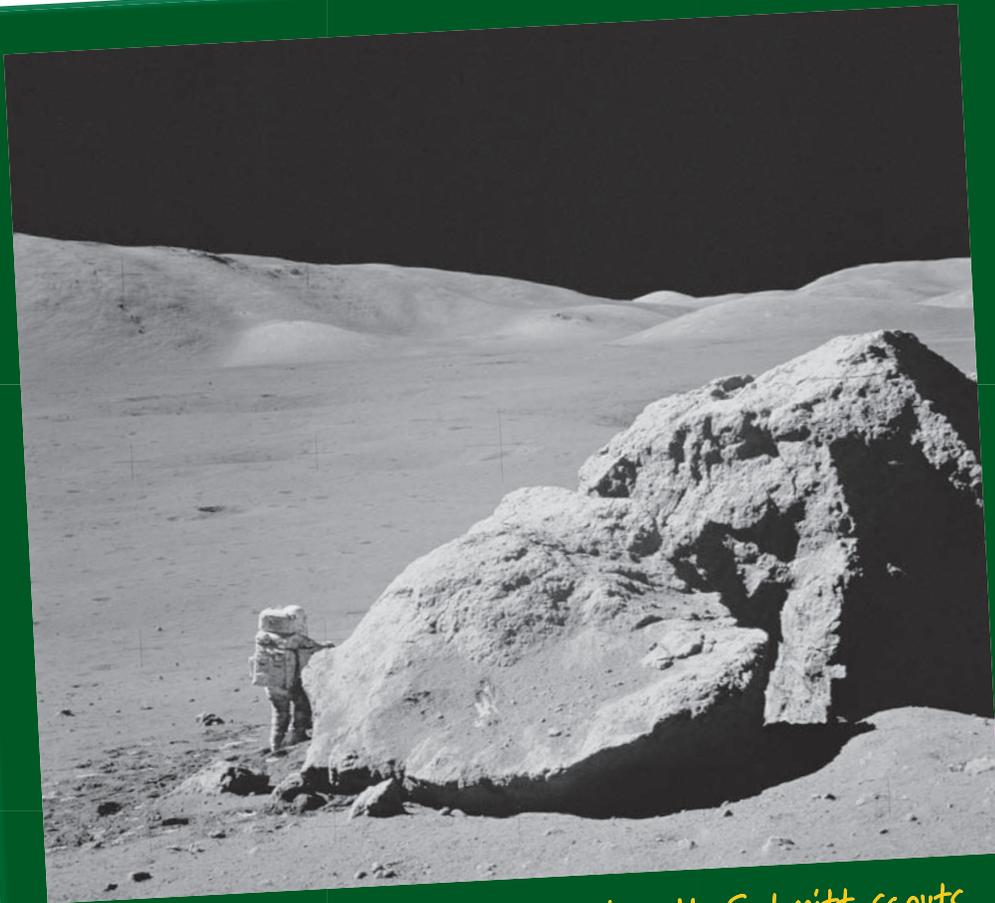
Courtesy of NASA

The Threats Associated With Surface Landings

After all the planning and designing and training that goes into a mission, and all the stresses involved in launching a rocket, the next step is engineering the landing on the Moon or another planet. This raises an entirely different set of new issues.

How Autonomous Landing and Hazard Avoidance Technology Helps Spacecraft Avoid Hazards

“The Apollo landing missions were an unqualified success,” Chiold Epp of NASA's Johnson Space Center in Houston said in 2008. Every single time a lunar module headed toward the surface, it landed successfully and its crew got out and did a great job. “But that doesn't mean there were not close calls,” Epp went on. “On four of the six Apollo landings, conditions were such that it gave us pause.”



Apollo 17 Lunar Module Pilot Harrison H. Schmitt scouts around a large boulder for rock samples on the Moon's surface during the 1972 mission.

NASA's Autonomous Landing and Hazard Avoidance Technology (ALHAT) project is designed to detect hazards, such as boulders and craters, and make lunar module landings safer.

Courtesy of NASA

Epp is the manager of NASA's Autonomous Landing and Hazard Avoidance Technology (ALHAT) project. The project's aim is to provide NASA's next Moon crews with the data that could make the difference between a good day and a very bad day. The ALHAT system is designed to automatically detect hazards—such as craters and boulders—then direct landers to the safest spot available for touchdown.

It's a job that will have to be done on the fly. Like the Apollo crews, Moon crews on future missions will have limited fuel supplies. They will have to act quickly. Things move fast during a Moon landing. But ALHAT will be able to guide spacecraft precisely and repeatedly to certain designated landing sites—anywhere on the Moon's surface.

How Surface Boulders, Craters, and Sloping Hillsides Threaten Spacecraft

The advantages that ALHAT provides will be particularly important for future Moon expeditions because the locations future crews will explore will be more hazardous than those the Apollo astronauts visited. The terrain and lighting will be notably more challenging.

One such site is near the Moon's south pole, near the rim of a cavity called the Shackleton Crater. It's nearly 12 miles (20 kilometers) wide and about 7.5 miles (12 kilometers) deep. Sunlight can throw shadows that minimize or hide surface features that an astronaut pilot will want to see when trying to bring a lunar lander down safely.

Any single boulder, crater, or sloping hillside could be enough to threaten a spacecraft's safe landing. Failing to see such an obstacle, a pilot might land the craft at an awkward angle, or even cause it to topple over.

Another lunar safety hazard that's just as important is the blinding dust that the lunar lander's rocket exhaust kicks up. That dust can block an astronaut's view of boulders, craters, and other features.

But NASA is confident that ALHAT is the answer to all these challenges. The system provides light and helps astronauts figure out the nuances of the surface terrain from far enough away that dust is not an issue.

Fire Hazards in Space

Another space hazard is one familiar to everybody—fire. In outer space there's no neighborhood firehouse or 911 to call. There's no “normal” gravity either. This causes fire to behave differently in space.

But astronauts rely on fire—in the form of rocket engines—to get around. They have no choice but to learn to manage fire hazards in space. As a NASA official put it, “The safety of NASA's space crews and vehicles can depend on our knowledge of combustion in space.”

The Threats Associated With Propulsion Maneuvers in Space

Spacecraft rely on enormous rockets to get up into space in the first place, and then on smaller rockets to maneuver once they leave Earth. Spacecraft even use rockets as braking systems. The reverse thrusters that softened the landings of the Apollo program's lunar modules were a type of rocket.

Any time a spacecraft pilot fires up the rockets to maneuver into or out of orbit, he or she is playing with fire. At any point, something could go wrong, as happened in the shuttle *Challenger* disaster. And so at every moment astronauts must pay attention to safety and to minimizing threats.

The biggest threat from a propulsion system is the possibility that it won't work properly—leaving the spacecraft unable to maneuver in space.

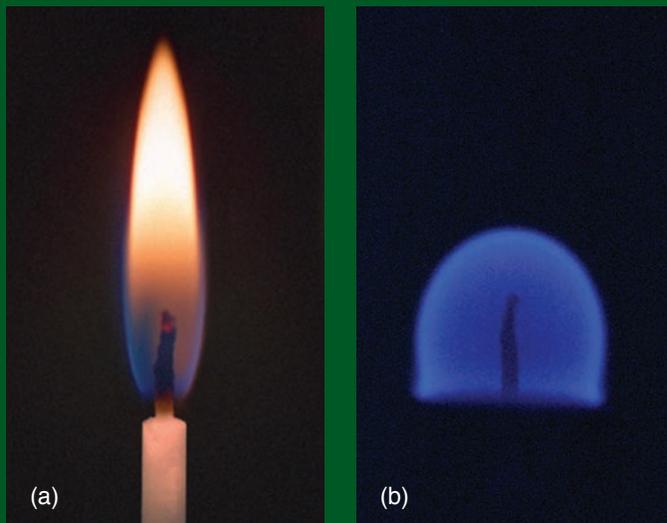
The Special Concerns for Fire Prevention in a Microgravity Environment

The familiar teardrop shape of a candle flame is the result of gravity. A process called gravity-driven buoyant convection carries soot to the flame's tip, making it yellow. But this rule applies only on Earth. In **microgravity**—*a condition of gravity so low that weightlessness results*—no convective flows exist, and flames are spherical, soot-free, and blue.

The presence of gravity and the effects of air or gas movement, plus the type of fuel and **oxidant** (*a chemical substance that mixes with oxygen*), determine many things about a flame:

- its shape
- its temperature
- its burn rate
- its burn pattern
- its soot production and deposition
- the speed with which you can or can't extinguish it.

No wonder NASA is studying fire in microgravity! The scientists have plenty of variables to consider. All this is interesting just as a matter of pure research. But as a practical matter, scientists also need to understand how a fire that broke out aboard a spacecraft would burn. What if fabric caught fire? What if chemicals or electronics did? It is vital to know what makes flames start and stop in low gravity, and how flames in such conditions behave while burning.



On Earth, gravity and the forces of convection give a candle flame its characteristic teardrop shape and yellow color (a). In microgravity, a candle flame is spherical, soot-free, and blue (b).

Courtesy of NASA

Research Into Spiral Flames

Some important research on how flames behave in microgravity has focused on creating spiral flames. By studying these peculiar flames in the comfort of the lab, researchers hope to mitigate fire hazards on spacecraft and gain new insights about complex systems in nature.

Two researchers at the University of California at San Diego experimented by taking plastic disks about the size of an ordinary compact disc and setting them on fire with a blowtorch. With the disk stationary, starting a fire at the center produces a flame front that moves outward in a circle. It fades as the fire consumes the disk (the fuel). If the disk is spinning, however, the circular disk flames become spiral flames under certain circumstances.

The researchers thought that spiral flames could be common in microgravity. It was a big surprise, though, to find they could create spiral flames under the conditions of normal Earth gravity.

All this is interesting because scientists want to understand better the phenomenon of *fire whorl*, or “devil wind,” and they think they can learn from studying spiral flames. A fire whorl is like a tornado of fire, or a spike of flame that towers over the rest of a fire. It is a terrifying phenomenon when it occurs on Earth, typically as part of a wildfire.

Star POINTS

The spiral is an important shape throughout the natural world. Galaxies often have a spiral shape. So do tornadoes and hurricanes and the shells of mollusks. Even within the human body, the heart’s bioelectric impulses move in a spiral pattern. Brain waves seem to flow along the neurons and down the spinal cord in a spiral pattern.





Scientists hope the study of spiral flames will help them understand fire whorls, tornadoes of fire that often appear in wildfires.

© Nancy G. Fire Photography, Nancy Greifenhagen/Alamy Images

But scientists worry what it could do to a spacecraft. And so combustion studies are a key aspect of spacecraft safety research.

As you've read, spacecraft face hazards from radiation, collision with space objects and dust, surface landings, and fire. You can imagine, then, that if space is risky for spacecraft and hardware, it's even riskier for humans. In the next lesson, you'll read about those risks and the ways in which scientists are studying how to overcome them.



CHECK POINTS

Lesson 3 Review

Using complete sentences, answer the following questions on a sheet of paper.

1. What is a geomagnetic storm?
2. What is a single event upset, or SEU?
3. What is thought to have happened to the communications satellite *Olympus*?
4. What advantage does the space shuttle have over the International Space Station with regard to avoiding space junk?
5. What piece of equipment did *Mariner 4* have that none of NASA's other Mars probes had, and what did it do?
6. What is the ALHAT system designed to do?
7. How will the lunar destinations of future Moon missions be different from those of the Apollo program?
8. What is the risk inherent in all propulsion maneuvers in space?
9. If you lit a candle in a microgravity environment, what would its flame look like?
10. Why are NASA researchers studying spiral flames?



APPLYING YOUR LEARNING

11. If Earth's atmosphere were to let more radiation from the Sun penetrate to ground level, what would be some of the effects, based on what you have read in this lesson?