Astronautical Engineering

# 18

# *Shooting for the Moon*

## Aprille Ericsson

Courtesy of Aprille Joy Ericsson

In the next decade, if all goes as planned, a spacecraft developed by NASA may bring dust from Mars back to Earth for the first time. These tiny pieces of dust, from the Martian surface and throughout its atmosphere, could reveal secrets about the red planet's past and future—including its potential to sustain life.

Sound exciting? I think so too. I'm Dr. Aprille Joy Ericsson, and I'm an astronautical engineer at NASA's Goddard Space Flight Center in Maryland. Astronautical engineering is a branch of engineering concerned with creating new technologies to explore specific areas. Right now, I'm developing a proposal for the SCIM mission. SCIM stands for Sample Collection for the Investigation of Mars. NASA missions are large projects that involve hundreds of engineers and scientists, as well as some of the most cutting-edge technologies of our time.

**Key Concepts from Previous Chapters**

- 2 Engineering Design Process
- 2 Testing and Evaluating
- 11 Thermal Expansion
- 17 Fluids
- 17 Pressure
- 17 Working and Work

The SCIM mission involves not only designing the spacecraft, but also planning the entire journey of the spacecraft. This planning includes the design of all supporting technology. My team must choose a launch vehicle, develop a feedback and control system for maneuvering the spacecraft, determine the route to and from Mars, and decide how the spacecraft will relay information to scientists and engineers back on Earth. These are a few of many, many complex design decisions.

The SCIM mission is a massive design project, but that's exactly why I find it so appealing. As an astronautical engineer, I must challenge myself constantly to aim high—literally. I first caught the aerospace bug in a summer program after my junior year in high school. I visited an air force base in New Hampshire, where I got to sit in the control tower and fly in a flight simulator—and I received a pilot's score! From then on, I wanted to design technologies that fly. I attended the Massachusetts Institute of Technology (MIT), where I received a degree in aeronautical/astronautical engineering.

When I graduated in the early 1980s, most aerospace engineering jobs were for strategic defense, which meant my future job probably would have required me to develop missiles. I carefully considered how that work might impact society and decided not to apply for those jobs. Instead, I went back to school and became the first female to earn a doctorate in mechanical engineering from Howard University, a historically black college in Washington, D.C. My specialty in aerospace helped me get a job as an astronautical engineer at NASA's Goddard Space Flight Center. I have worked my way through a variety of missions.


Courtesy of Aprille Joy Ericsson

## Mars Scout

proposal I'm working on is very exciting, and I truly hope be selected for funding. The process for selection is very NASA starts by issuing an "Announcement of Opportunity" This document invites teams of researchers, scientists, and from universities, industries, government, and nongovernment organizations all over the world to submit proposals for a an engineering design challenge.

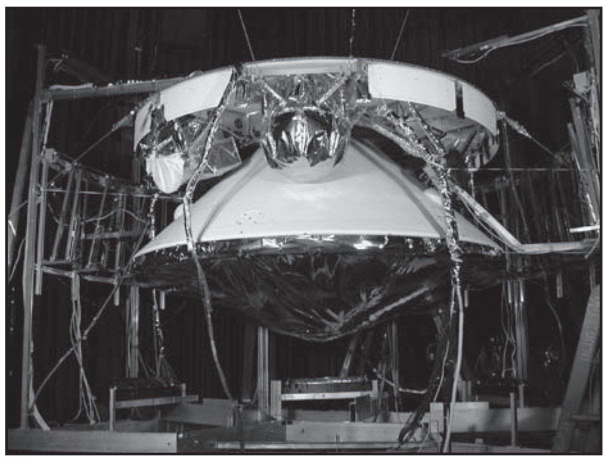
The AO lists the mission requirements, sets constraints on how much the mission can cost, and estimates a completion date. Teams submit very detailed proposals, and a few teams receive funding to flesh out their ideas, which may mean constructing and testing a prototype. Only a few teams are chosen as finalists to receive enough funding to design and complete their proposed missions.

Right now, I'm developing the first proposal for the SCIM. I can't share all of the details, but I can give you an idea how my team of engineers and scientists is working to solve the problem.

The original AO asked for proposals for "Mars Scouts." The Scout could be a Mars-orbiting spacecraft that takes remote observations; a spacecraft that lands on the planet and uses instruments to study the Martian atmosphere, surface, or subsurface; or a spacecraft that lands on Mars, collects samples, and returns them to Earth. The total cost of each Mars Scout mission—from launch to landing—must be under $4.5 million. The spacecraft is set to launch by December 31, 2011.

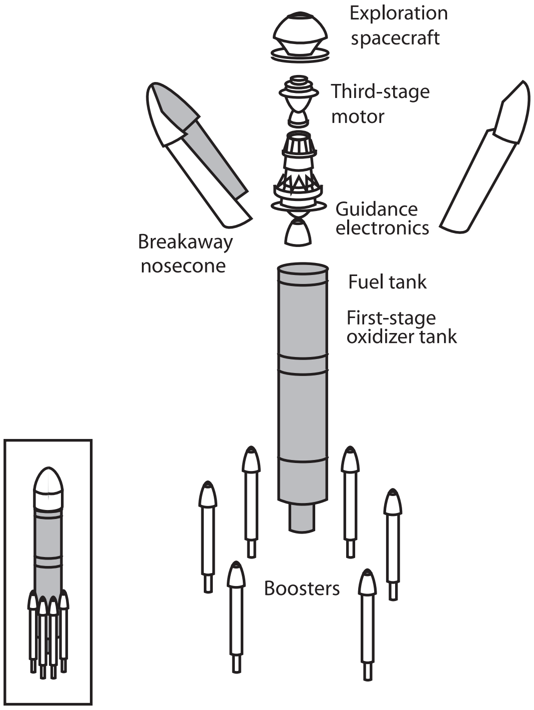
As you can see, the challenge is open-ended. Many possible solutions could meet the criteria and constraints it outlines—and many teams will submit proposals. To be selected, my team must make a strong case that our mission will give scientists an invaluable tool that will perform optimally throughout the entire mission.

We believe the SCIM will practically sell itself. That's because no samples of Martian material have ever been brought back to Earth for study. What could Mars dust tell us? The dust particles found on Mars may hold important clues about the age and composition of rocks on Mars. They may also carry telltale markers of current or past life. Without bringing the samples back to Earth so scientists can analyze them, we probably won't ever know what information Mars has to share.



Courtesy of NASA

Mars Rover



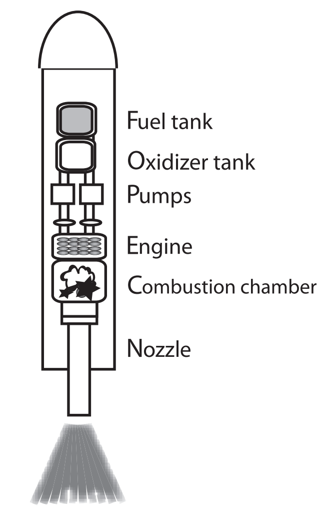

## The Mission: From Earth to Mars and Back Again

Our proposed mission will use a launch vehicle to lift the spacecraft into the Earth's upper atmosphere, which starts over fifty-three miles above the Earth's surface. The launch vehicle is a very large-scale version of the toy rockets you might find at a science shop. At launch, a rocket engine burns fuel and, in an amazing cloud of burning gases, leaves the launch pad and races toward outer space. Within minutes, the rocket travels at speeds exceeding 13,000 miles per hour. The first stage of the launch vehicle will carry the SCIM into the upper atmosphere; once there, the first-stage rocket falls away from the spacecraft, burning up as it reenters the Earth's atmosphere.

A second-stage rocket attached to the SCIM spacecraft will fire after the first-stage rocket has fallen away. This rocket will propel the SCIM spacecraft even farther into space; then it will fall away. After leaving the Earth's atmosphere, the spacecraft will continue moving along its flight path toward the red planet. The spacecraft will move at speeds of approximately two miles per second, firing onboard thrusters to adjust its direction. But even at this speed, the vehicle's journey to Mars and back to Earth will take about four years.

*Editor's Note*

### Rocket Science




1) Engine burns the fuel.
2) Pressure inside engine increases.
3) Pressure difference between inside the engine and outside launches the rocket.

How does a launch vehicle accelerate a spacecraft to speeds greater than 13,000 miles per hour in just minutes? The engine makes this feat possible. An ***engine*** is a system that uses temperature differences to create pressure differences. These pressure differences can be harnessed to do useful work. Just how engines are designed to do this work will be explored later in this unit.

One commonly used launch vehicle, the Delta 2 rocket, burns highly refined kerosene. On launch, fuel and liquid oxygen are pumped into the ***combustion chamber*** of the rocket, where they combine and burn explosively. The expanding gases from the intense, continuous burning of fuel enormously increase the pressure in the combustion chamber. The hot gases from the burning fuel escape through a small opening, called the ***nozzle,*** at a very high speed. The mass of these gases escapes from the nozzle, propelling the rocket and its contents forward toward outer space.

Why this occurs is explained by Isaac Newton's Third Law of Motion, which states that every action has an equal and opposite reaction. The direction of the push on the first object is opposite to the direction of the push on the second object. We can use this law to describe why the rocket moves forward. As the rocket pushes gases in one direction, the rocket is pushed in the opposite direction.

Make your own rocket by blowing up a balloon and pinching the neck closed. When you let go of the balloon's neck, the balloon "rockets" around the room. In this case, the balloon acts like the combustion chamber of a rocket, pushing gases through the tiny neck of the balloon.


According to Newton's third law, the air pushed out of the balloon is the "action" and the forward movement of the balloon is the "reaction."

Engineers must design rocket engines with enough thrust to lift the rocket and its contents against the force of gravity. ***Thrust*** is the force or action that causes the reaction of the rocket's forward movement. Thrust is measured using the rate mass is ejected from the nozzle, the velocity of the escaping gas, and the pressure at the nozzle exit. To adjust how much thrust an engine has, engineers alter how rapidly the fuel in the engine is burned, the size of the combustion chamber, and the diameter of the nozzle. All of these factors determine how fast the hot gasses are ejected from the nozzle, which affects the amount of thrust. Of course, real engines don't always behave exactly as expected, so it's necessary to build a prototype and measure the actual thrust of the new engine before it's used to lift a rocket into space.

In outer space, spacecraft often use onboard thrusters to change their direction. These thrusters work like small rocket engines joined to the spacecraft that can be fired to give the vehicle a push now and then to correct its direction.

***Newton's Third Law of Motion:***
Every action has an equal and opposite reaction. ⇆

The (mass × acceleration) of the gas ejected from the rocket engine backward = the (mass × acceleration) of the rocket forward. "Acceleration" is the scientific term for speeding up.

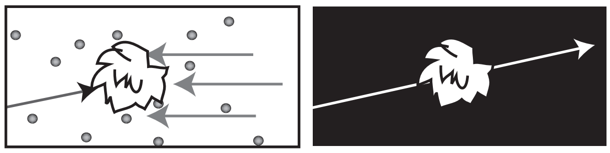
**Resistance** is any force that opposes motion.

**Newton's First Law of Motion:** An object in uniform motion will continue in uniform motion unless acted on by an outside force.

## Resistance-Free Travel

After it leaves Earth's atmosphere, the SCIM spacecraft will travel at a high speed toward its rendezvous with Mars without burning fuel, except when it uses thrusters to adjust its position. So, how does it keep moving? To answer that question, let's consider our own experience with moving objects on Earth.

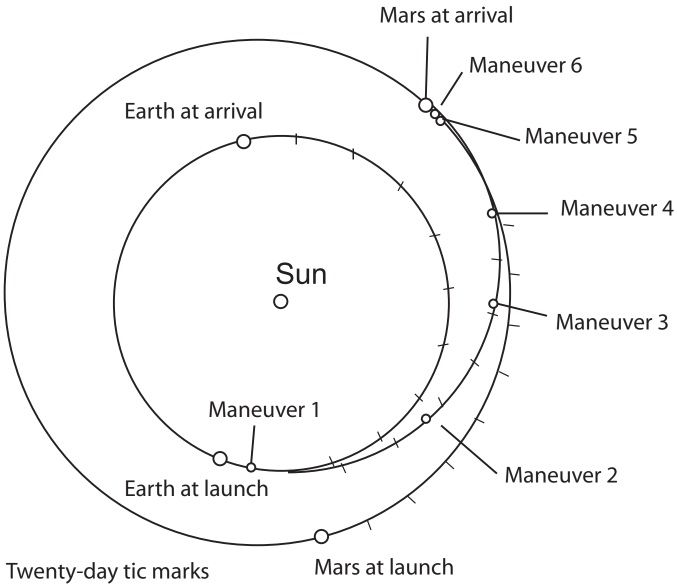
Every moving object on Earth meets resistance of some sort. ***Resistance*** opposes movement. Wad up a sheet of paper and see how far you can throw it. You'll see that it will slow down and drop to the ground. As it moves, it bumps into air particles, which slow it down. But in space, there is no air and, therefore, no air resistance. If you threw the wad of paper in outer space, it would keep going forever unless something got in its way. That's Newton's first law: "An object in uniform motion will continue in uniform motion unless acted on by an outside force."



This law explains why spacecraft don't need to burn fuel continuously in space to move forward the way cars or airplanes do here on Earth. After a spacecraft has left the Earth's atmosphere and has entered the air-resistance-free environment of space, it travels at the same speed.

When planning a route for the Mars SCIM, we must consider how gravity will affect the spacecraft. Even after it leaves Earth's atmosphere, the spacecraft will still be affected by Earth's gravity. Remember that the moon stays in its orbit due to its gravitational attraction to the Earth, so the influence of Earth's gravity extends far into space. However, as the craft gets farther away from Earth, the strength of the Earth's gravitational pull decreases. At this point, the sun's gravity becomes more important. Gravitational attraction is directly proportional to a body's mass. The sun is 333,000 times as massive as Earth, so its gravity is 333,000 times stronger. In fact, we must consider the gravitational attraction of the Earth, sun, moon, and Mars to determine what path the spacecraft will take.

There are two Mars Rovers that have already made the trip to Mars: Spirit and Opportunity. The following diagram shows the flight path of the Mars Rover Opportunity, which was launched in 2003. The Mars Rover left Earth's atmosphere and entered into an orbit around the sun. It was scheduled to fire its thrusters six times to fine-tune its orbit. NASA made calculations accurate enough that the thrusters only needed to be fired three times. When the spacecraft came close enough to Mars, the planet's gravity pulled it in for a landing.




The diagram shows the original flight path of the another Mars-bound spacecraft, the Mars Rover Opportunity, which was launched in 2003. According to the diagram, the Mars Rover left Earth's atmosphere and entered orbit around the sun. It was scheduled to fire its thrusters six times to "tweak" its orbit, in order to swing close to Mars. However, only three were needed. When the spacecraft came close enough to Mars, the red planet's gravity pulled it in for a landing.

## The Low Pass

After the SCIM reaches Mars, it will enter Mars' atmosphere and pass as close as twenty-three miles above the planet's surface for about one minute. To collect samples of Martian material, the SCIM spacecraft will open side panels to expose panels made from "aerogel," a very low-density, sticky gelatinous substance. Think of it as a clear, lightweight Jell-O. As the spacecraft flies through the dusty Martian atmosphere, pieces of dust will be trapped and preserved in the aerogel panels. Besides collecting dust particles, the SCIM spacecraft will also measure the concentration of dust in the atmosphere, collect gas samples, and take photographs.

After completing its mission, the spacecraft will fire its thrusters once again. The SCIM will accelerate to a higher altitude, leaving the Martian atmosphere behind, and begin orbiting the planet. The spacecraft will swing around the planet; then, at the appropriate orientation, the spacecraft will fire its thrusters to break free of Mars' gravity and begin its long trip back to Earth. Upon returning, the SCIM will be captured by Earth's gravity. Slowing its descent by firing its thrusters, the spacecraft will use a parachute to gently land at a predetermined location. I'll be waiting with other scientists and engineers ready to meet it.

## Minimizing the Potential for Failure: Testing and Evaluating

Because we will be bringing back samples from Mars, and there is a chance, however remote, that these samples may contain living organisms, we must make sure that we do not contaminate the Earth. An extraterrestrial life form could escape and pose a danger to life on Earth. To minimize risk, we're designing a system that retracts the aerogel panels into the spacecraft's interior. During the return trip, these panels will be baked at temperatures higher than living organisms can tolerate.

I've been working on engineering the mechanism that will retract the panels into the ship's interior. What happens if the mechanism fails to fully retract the panels? Well, because it would be impossible to bake the samples, we wouldn't be able to let the SCIM land on Earth.

This is just one example of a system failure that could threaten the success of the multi-million-dollar mission. To minimize the possibility of failure, we always include some backup systems that will operate in case the primary system fails. Of course, we can't include too many backup systems, as each one adds weight and cost.

Because our backup options are limited, we'll conduct many tests ahead of time to make sure the spacecraft will perform its tasks during the mission. This testing means simulating some of the extreme conditions of outer space. For instance, we know that the SCIM spacecraft will experience dramatic temperature fluctuations. Outer space can be very cold, because there is no air to absorb and store warmth from sunlight. However, when the spacecraft is in direct sunlight, the sunny side may heat up to very high temperatures. These dramatic temperature differences can cause materials to deform. To make sure our materials will perform they way we expect them to, we must test them under very high and very low temperatures.

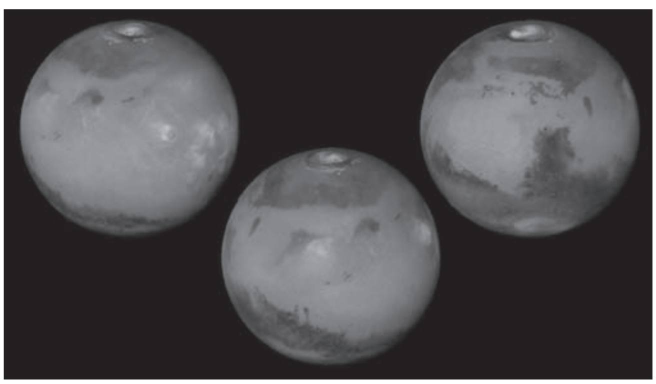
Here on Earth, our atmosphere protects us from high-energy space particles called ***cosmic rays.*** Without protection from the atmosphere, the spacecraft will be bombarded by this radiation. High levels of radiation can cause certain materials—such as electronics or solar cells—to degrade. While it's possible to shield devices on the spacecraft that are particularly prone to radiation damage with special materials, these protections add weight and increase costs. So we subject the spacecraft components to high levels of radiation to determine which components are in danger and how much protection they need.

Changes in pressure pose another problem. While on Earth, the spacecraft is subjected to the pressure of the atmosphere; but in space, air pressure is so low that it's negligible. This tremendous pressure difference can cause problems for some components, such as the fuel tank that will be needed for mid-course corrections. We can design the tank so that it adjusts its internal pressure during launch, but we can't be sure it will work unless we test it in a vacuum chamber where we can simulate the types of pressure changes the spacecraft is likely to experience on its journey.

These are just a few of the many tests we plan to conduct on the prototype. As soon as the spacecraft is launched, there is very little we can do to repair it should a system fail. We have to get it right the first time. This means troubleshooting and optimizing the prototype until we have great confidence the spacecraft will operate as expected.

As you can imagine, a successful mission requires significant planning and hard work. It also means coming up with new and innovative ideas. Engineers play a very important role at NASA. It's a common misconception that NASA employs mostly scientists. In fact, NASA employs ten times as many engineers as scientists.

When working on projects like this one, I like to keep in mind one of my favorite quotes: "Shoot for the moon, and if you miss, you'll still be among the stars." These words help me keep perspective. Every new proposal we work on here at NASA is "shooting for the moon." After all, we're proposing technologies that have never before existed and may make invaluable contributions to science. Even when a proposal I've submitted is not selected, the ideas my team developed are not wasted. Chances are good that the ideas will be incorporated into other future missions. Most importantly, I've had the satisfaction of working with people here and all over the world who are as full of passion and motivation as I am. So I'm already among the stars.


Courtesy of NASA

Three views of Mars

## What's the Story?

1. Why is it important that the Mars SCIM may bring dust from the Martian atmosphere back to Earth?

2. How will the engineers on Dr. Ericsson's team test the spacecraft before it is launched?

## Designing with Math and Science

3. What is Newton's Third Law? Use it to explain how a rocket engine propels a spacecraft into outer space.

4. Why must the engineers like Dr. Ericsson consider pressure differences when designing components such as the fuel tank? Explain your answer in terms of fluid movement and pressure differences.

5. What is meant by the term "resistance"? Explain a scenario in which you have experienced fluid resistance.

## What Do You Think?

6. Describe at least three other technologies that use Newton's Third Law.