

# Space in Our Lives

## 4.1.1

### In This Section You'll Learn To...

- List and describe the unique advantages of space and some of the missions that capitalize on them
- Identify the elements that make up a space mission

### Outline

#### 4.1.1.1 Why Space?

The Space Imperative  
Using Space

#### 4.1.1.2 Elements of a Space Mission

The Mission  
The Spacecraft  
Trajectories and Orbits  
Launch Vehicles  
Mission Operations Systems  
Mission Management and Operations  
The Space Mission Architecture in Action

**W**hy study space? Why should you invest the considerable time and effort needed to understand the basics of planet and satellite motion, rocket propulsion, and spacecraft design—this vast area of knowledge we call astronautics? The reasons are both poetic and practical.

The poetic reasons are embodied in the quotation at the beginning of this chapter. Trying to understand the mysterious beauty of the universe, “to boldly go where no one has gone before,” has always been a fundamental human urge. Gazing into the sky on a starry night, you can share an experience common to the entire history of humankind. As you ponder the fuzzy expanse of the Milky Way and the brighter shine and odd motion of the planets, you can almost feel a bond with ancient shepherds who looked at the same sky and pondered the same questions thousands of years ago.

The changing yet predictable face of the night sky has always inspired our imagination and caused us to ask questions about something greater than ourselves. This quest for an understanding of space has ultimately given us greater control over our destiny on Earth. Early star gazers contemplated the heavens with their eyes alone and learned to construct calendars enabling them to predict spring flooding and decide when to plant and harvest. Modern-day star gazers study the heavens with sophisticated ground and space instruments, enabling them to push our understanding of the universe far beyond what the unaided eye can see, such as in Figure 4.1.1-1.

To study space, then, is to grapple with questions as old as humanity. Understanding how the complex mechanisms of the universe work gives us a greater appreciation for its graceful and poetic beauty.

While the practical reasons for studying space are much more down to Earth, you can easily see them, as well, when you gaze at the night sky on a clear night. The intent sky watcher can witness a sight that only the current generation of humans has been able to see—tiny points of light streaking across the background of stars. They move too fast to be stars or planets. They don’t brighten and die out like meteors or “falling stars.” This now common sight would have startled and terrified ancient star gazers, for they’re not the work of gods but the work of people. They are spacecraft. We see sunlight glinting off their shiny surfaces as they patiently circle Earth. These reliable fellow travellers with Earth enable us to manage resources and communicate on a global scale.

Since the dawn of the Space Age only a few decades ago, we have come to rely more and more on spacecraft for a variety of needs. Daily weather forecasts, instantaneous worldwide communication, and a constant ability to record high-resolution images of vital regions are all examples of space technology that we’ve come to take for granted. Studying space offers us a chance to understand and appreciate the complex requirements of this technology. See Figure 4.1.1-2.

Throughout this book, we’ll focus primarily on the practical aspects of space—What’s it like? And how do we get there? How do we use space for our benefit? In doing so, we hope to inspire a keen appreciation and sense of poetic wonder about the mystery of space—the final frontier.



**Figure 4.1.1-1. Hubble Image.** This photo of a star forming region is one of thousands sent to Earth by the Hubble Space Telescope. (Courtesy of the Association of Universities for Research in Astronomy, Inc./Space Telescope Science Institute)



**Figure 4.1.1-2. Milstar Communication Satellite.** The state-of-the-art Milstar satellite system provides worldwide communications to thousands of users simultaneously. (Courtesy of the U.S. Air Force)

## 4.1.1.1 Why Space?

### In This Section You'll Learn To...

- List and describe the advantages offered by space and the unique space environment
- Describe current space missions

### The Space Imperative

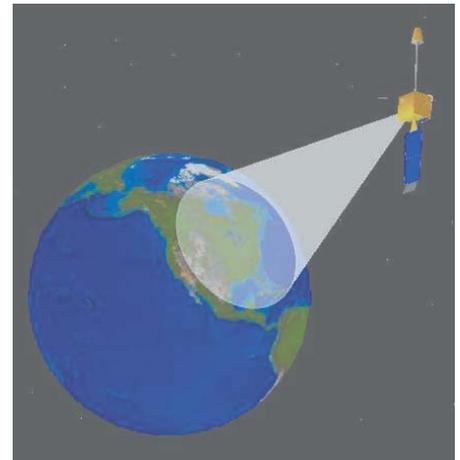
Getting into space is dangerous and expensive. So why bother? Space offers several compelling advantages for modern society

- A global perspective—the ultimate high ground
- A clear view of the heavens—unobscured by the atmosphere
- A free-fall environment—enabling us to develop advanced materials impossible to make on Earth
- Abundant resources—such as solar energy and extraterrestrial materials
- A unique challenge as the final frontier

Let's explore each of these advantages in turn to see their potential benefit to Earth.

Space offers a global perspective. As Figure 4.1.1-3 shows, the higher you are, the more of Earth's surface you can see. For thousands of years, kings and rulers took advantage of this fact by putting lookout posts atop the tallest mountains to survey more of their realm and warn of would-be attackers. Throughout history, many battles have been fought to "take the high ground." Space takes this quest for greater perspective to its ultimate end. From the vantage point of space, we can view large areas of Earth's surface. Orbiting spacecraft can thus serve as "eyes and ears in the sky" to provide a variety of useful services.

Space offers a clear view of the heavens. When we look at stars in the night sky, we see their characteristic twinkle. This twinkle, caused by the blurring of "starlight" as it passes through the atmosphere, we know as *scintillation*. The atmosphere blurs some light, but it blocks other light altogether, which frustrates astronomers who need access to all the regions of the electromagnetic spectrum to fully explore the universe. By placing observatories in space, we can get instruments above the atmosphere and gain an unobscured view of the universe, as depicted in Figure 4.1.1-4. The Hubble Space Telescope, the Gamma Ray Observatory, and the Chandra Observatory are all armed with sensors operating far beyond the range of human senses. Results using these instruments from the unique vantage point of space are revolutionizing our understanding of the cosmos.



**Figure 4.1.1-3. A Global Perspective.** Space is the ultimate high ground; it allows us to view large parts of Earth at once for various applications. (Courtesy of Analytical Graphics, Inc.)



**Figure 4.1.1-4. Space Astronomy.** Earth's atmosphere obscures our view of space, so we put satellites, like the Hubble Space Telescope, above the atmosphere to see better. (Courtesy of NASA/Johnson Space Center)



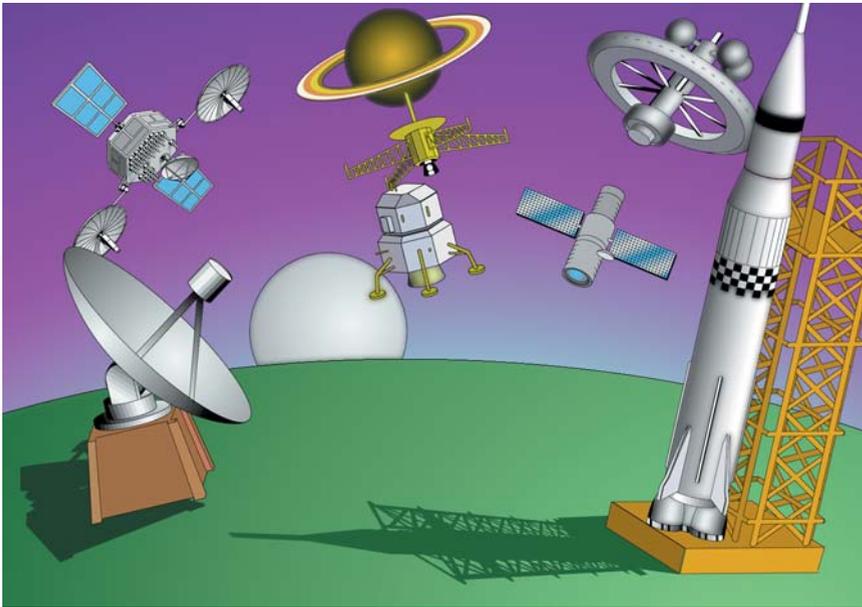
**Figure 4.1.1-5. Free-fall Environment.** Astronauts Duque (right-side up) and Lindsey (up-side down) enjoy the free fall experience on STS-95. (Courtesy of NASA/Johnson Space Center)

Space offers a free-fall environment enabling manufacturing processes not possible on Earth's surface. To form certain new metal alloys, for example, we must blend two or more metals in just the right proportion. Unfortunately, gravity tends to pull heavier metals to the bottom of their container, making a uniform mixture difficult to obtain. But space offers the solution. A manufacturing plant in orbit (and everything in it) is literally falling toward Earth, but never hitting it. This is a condition known as free fall (NOT zero gravity, as we'll see later). In *free fall* there are no contact forces on an object, so, we say it is weightless, making uniform mixtures of dissimilar materials possible. We'll explore this concept in greater detail in Chapter 3. Unencumbered by the weight felt on Earth's surface, factories in orbit have the potential to create exotic new materials for computer components or other applications, as well as promising new pharmaceutical products to battle disease on Earth. Studying the effects of weightlessness on plant, animal, and human physiology also gives us greater insight into how disease and aging affect us (Figure 4.1.1-5).

Space offers abundant resources. While some people argue about how to carve the pie of Earth's finite resources into ever smaller pieces, others contend that we need only bake a bigger pie. The bounty of the solar system offers an untapped reserve of minerals and energy to sustain the spread of mankind beyond the cradle of Earth. Spacecraft now use only one of these abundant resources—limitless solar energy. But scientists have speculated that we could use lunar resources, or even those from the asteroids, to fuel a growing space-based economy. Lunar soil, for example, is known to be rich in oxygen and aluminum. We could use this oxygen in rocket engines and for humans to breathe. Aluminum is an important metal for various industrial uses. It is also possible that water ice may be trapped in eternally-dark craters at the Lunar poles. These resources, coupled with the human drive to explore, mean the sky is truly the limit!

Finally, space offers an advantage simply as a frontier. The human condition has always improved as new frontiers were challenged. As a stimulus for increased technological advances, and a crucible for creating greater economic expansion, space offers a limitless challenge that compels our attention. Many people have compared the challenges of space to those faced by the first explorers to the New World. European settlers explored the apparently limitless resources, struggling at first, then slowly creating a productive society out of the wilderness.

We're still a long way from placing colonies on the Moon or Mars. But already the lure of this final frontier has affected us. Audiences spend millions of dollars each year on inspiring movies such as *Star Wars*, *Star Trek*, *Independence Day*, and *Contact*. The Apollo Moon landings and scores of Space Shuttle flights have captured the wonder and imagination of people across the planet. NASA records thousands of hits per day on their Mars Mission websites. Future missions promise to be even more captivating as a greater number of humans join in the quest for space. For each of us "space" means something different, as illustrated in Figure 4.1.1-6.



**Figure 4.1.1-6. Space.** Space is many things to many people. It's the wonder of the stars, rockets, spacecraft, and all the other aspects of the final frontier.

## Using Space

Although we have not yet realized the full potential of space, over the years we've learned to take advantage of several of its unique attributes in ways that affect all of us. The most common space missions fall into four general areas

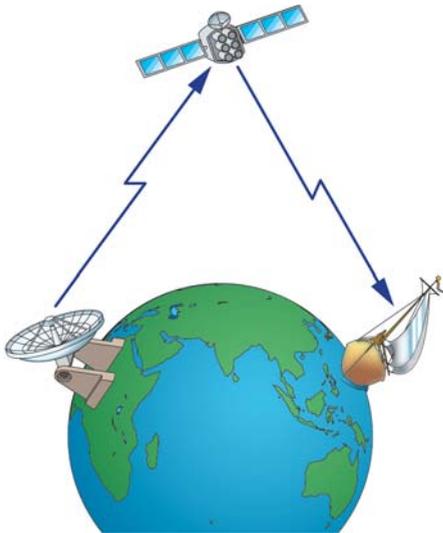
- Communications
- Remote sensing
- Navigation
- Science and exploration

Let's briefly look at each of these missions to see how they are changing the way we live in and understand our world.

### Space-based Communications

In October 1945, scientist and science-fiction writer Arthur C. Clarke (author of classics, such as *2001: A Space Odyssey*) proposed an idea that would change the course of civilization.

*One orbit, with a radius of 42,000 km, has a period (the time it takes to go once around the Earth) of exactly 24 hours. A body in such an orbit, if its plane coincided with that of the Earth's equator, would revolve with the Earth and would thus be stationary above the same spot . . . [a satellite] in this orbit could be provided with receiving and transmitting equipment and could act as a repeater to relay transmissions between any two points*



**Figure 4.1.1-7. Communication Through Satellites.** A satellite's global perspective allows users in remote parts of the world to talk to each other.



**Figure 4.1.1-8. Satellite Communications.** The explosion in satellite communication technology has shrunk the world and linked us more tightly together in a global community. Here we see a soldier sending a message through a portable ground station. (Courtesy of Rockwell Collins)

*on the hemisphere beneath . . . . A transmission received from any point on the hemisphere could be broadcast to the whole visible face of the globe. (From Wireless World [Canuto and Chagas, 1978].)*

The information age was born. Clarke proposed a unique application of the global perspective space offers. Although two people on Earth may be too far apart to see each other directly, they can both “see” the same spacecraft in high orbit, as shown in Figure 4.1.1-7, and that spacecraft can relay messages from one point to another.

Few ideas have had a greater impact in shrinking the apparent size of the world. With the launch of the first experimental communications satellite, Echo I, into Earth orbit in 1960, Clarke’s fanciful idea showed promise of becoming reality. Although Echo I was little more than a reflective balloon in low-Earth orbit, radio signals were bounced off it, demonstrating that space could be used to broaden our horizons of communication. An explosion of technology to exploit this idea quickly followed.

Without spacecraft, global communications as we know it would not be possible. We now use spacecraft for most commercial and governmental communications, as well as domestic cable television. Live television broadcasts by satellite from remote regions of the globe are now common on the nightly news. Relief workers in remote areas can stay in continuous contact with their home offices, enabling them to better distribute aid to desperate refugees. Figure 4.1.1-8 shows a soldier in the field sending a message via satellite. Military commanders now rely almost totally on spacecraft, such as the Defense Satellite Communication System and the Milstar system, to communicate with forces deployed worldwide.

Communication satellites have also been a boon to world development. Canuto and Chagas [1978] described how the launch of the Palapa A and B satellites, for example, allowed the tropical island country of Indonesia to expand telephone service from a mere 625 phones in 1969 (limited by isolated population centers), to more than 233,000 only five years later (Figure 4.1.1-9). This veritable explosion in the ability to communicate has been credited with greatly improving the nation’s economy and expanding its gross national product, thus benefiting all citizens. All this from only two satellites! Other developing nations have also realized similar benefits. Many credit the worldwide marketplace of ideas ushered in by satellites with the former Soviet Union’s collapse and the rejection of closed, authoritarian regimes.

Today, a large collection of spacecraft in low-Earth orbit form a global cellular telephone network. With this network in place, anyone with one of the small portable phones can call any other telephone on the planet. Now, no matter where you go on Earth, you are always able to phone home. We can only imagine how this expanded ability to communicate will further shrink the global village.

## Remote-sensing Satellites

*Remote-sensing* satellites use modern instruments to gather information about the nature and condition of Earth's land, sea, and atmosphere. Located in the "high ground" of space, these satellites use sensors that can "see" a broad area and report very fine details about the weather, the terrain, and the environment. The sensors receive electromagnetic emissions in various spectral bands that show what objects are visible, such as clouds, hills, lakes, and many other phenomena below. These instruments can detect an object's temperature and composition (concrete, metal, dirt, etc.), the wind's direction and speed, and environmental conditions, such as erosion, fires, and pollution. With these sophisticated satellites, we can learn much about the world we live in (Figure 4.1.1-10).

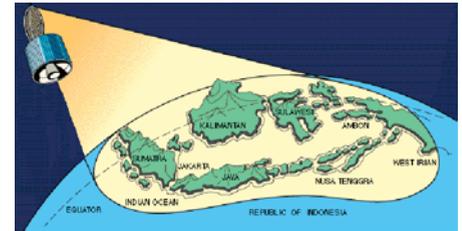
For decades, military "spy satellites" have kept tabs on the activities of potential adversaries using remote-sensing technology. These data have been essential in determining troop movements and violations of international treaties. During the Gulf War, for example, remote-sensing satellites gave the United Nations alliance a decisive edge. The United Nations' forces knew nearly all Iraqi troop deployments, whereas the Iraqis, lacking these sensors, didn't know where allied troops were. Furthermore, early-warning satellites, originally orbited to detect strategic missile launches against the United States, proved equally effective in detecting the launch of the smaller, Scud, missiles against allied targets. This early warning gave the Patriot antimissile batteries time to prepare for the Scuds.

Military remote-sensing technology has also had valuable civilian applications. The United States' Landsat and France's SPOT (Satellite Pour l'Observation de la Terre) systems are good examples. Landsat and SPOT satellites produce detailed images of urban and agricultural regions, as demonstrated in Figure 4.1.1-11 of Washington, D.C., and Figure 4.1.1-12 of Kansas. These satellites "spy" on crops, ocean currents, and natural resources to aid farmers, resource managers, and demographic planners.

In countries where the failure of a harvest may mean the difference between bounty and starvation, spacecraft have helped planners manage scarce resources and head off potential disasters before insects or other blights could wipe out an entire crop. For example, in agricultural regions near the fringes of the Sahara desert in Africa, scientists used Landsat images to predict where locust swarms were breeding. Then, they were able to prevent the locusts from swarming, saving large areas of crop land.

Remote-sensing data can also help us manage other scarce resources by showing us the best places to drill for water or oil. From space, astronauts can easily see fires burning in the rain forests of South America as trees are cleared for farms and roads. Remote-sensing spacecraft have become a formidable weapon against the destruction of the environment because they can systematically monitor large areas to assess the spread of pollution and other damage.

Remote-sensing technology has also helped map makers. With satellite imagery, they can make maps in a fraction of the time it would take using a laborious ground survey. This enables city planners to better keep up



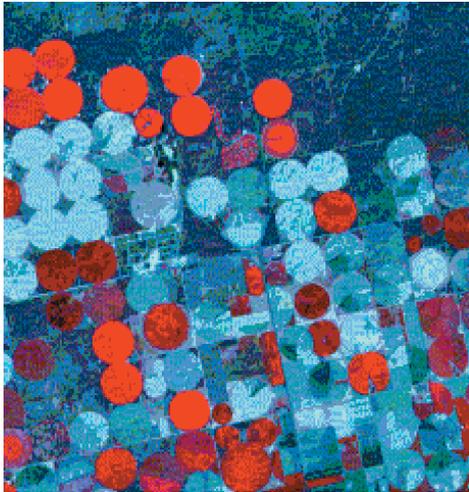
**Figure 4.1.1-9. Palapa A Coverage.** The coverage for the Palapa A satellite means telephone service is available from one end of Indonesia to the other. (Courtesy of Hughes Space and Communications Company)



**Figure 4.1.1-10. Earth Observation Satellite (EOS).** This satellite takes high-resolution images of sites on Earth's surface. Government agencies and commercial firms use the images for many purposes, such as city planning and market growth analysis. (Courtesy of NASA/Goddard Space Flight Center)



**Figure 4.1.1-11. City Planning from Space.** Government officials can use remote-sensing images, such as this one from the Landsat spacecraft, for urban planning. In this image of Washington, D.C., specialists merged a Landsat image and a Mir space station photograph to get 2-m resolution. (Courtesy of NASA/Goddard Space Flight Center)



**Figure 4.1.1-12. Two Views of Kansas.** A remote-sensing image from the French SPOT satellite shows irrigated fields (the circular areas) in Kansas. Red means crops are growing. Light blue means the fields lay fallow. On the right, astronaut Joe Engle, a native of Kansas, gives his opinion of being in space. (Courtesy of NASA/Goddard Space Flight Center and Johnson Space



**Figure 4.1.1-13. Viewing Hurricanes From Space.** It's hard to imagine a world without weather satellites. Images of hurricanes and other severe storms provide timely warning to those in their path and save countless lives every year. (Courtesy of NASA/Johnson Space Center)

with urban sprawl and gives deployed troops the latest maps of unfamiliar terrain.

National weather forecasts usually begin with a current satellite view of Earth. At a glance, any of us can tell which parts of the country are clear or cloudy. When they put the satellite map in motion, we easily see the direction of clouds and storms. An untold number of lives are saved every year by this simple ability to track the paths of hurricanes and other deadly storms, such as the one shown in Figure 4.1.1-13. By providing farmers valuable climatic data and agricultural planners information about potential floods and other weather-related disasters, this technology has markedly improved food production and crop management worldwide.

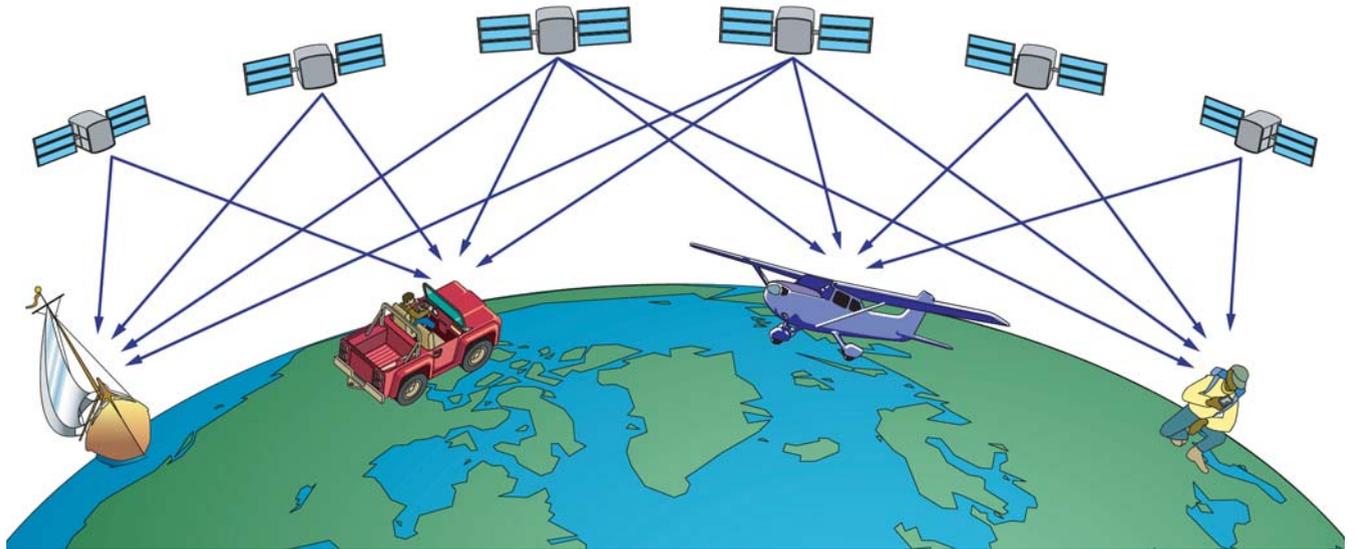
Overall, we've come to rely more and more on the ability to monitor and map our entire planet. As the pressure builds to better manage scarce resources and assess environmental damage, we'll call upon remote-sensing spacecraft to do even more.

### Navigation Satellites

Satellites have revolutionized navigation—determining where you are and where you're going. The Global Positioning System (GPS), developed by the U.S. Department of Defense, and the GLONASS system, developed by the Russian Federation, use a small armada of satellites to help people, airplanes, ships, and ground vehicles navigate around the globe.

Besides supporting military operations, this system also offers incredible civilian applications. Surveyors, pilots, boaters, hikers, and many others who have a simple, low-cost receiver, can have instant information on where they are—with mind-boggling accuracy. With four

satellites in view, as shown in Figure 4.1.1-14, it can “fix” a position to within a hundred meters. In fact, the biggest problem some users face is that the fix from GPS is more accurate than many maps!

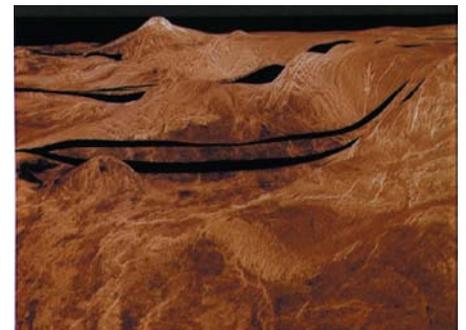


**Figure 4.1.1-14. Global Positioning System (GPS).** The GPS space segment consists of a constellation of satellites deployed and operated by the U.S. Air Force. GPS has literally revolutionized navigation by providing highly accurate position, velocity, and time information to users on Earth.

Car manufacturers now offer GPS receivers as a standard feature on some models. Now you can easily find your way across a strange city without ever consulting a map. You simply put in the location you’re trying to reach, and the system tells you how to get there. No more stops at gas stations to ask directions!

### Science and Exploration Satellites

Since the dawn of the space age, scientists have launched dozens of satellites for purely scientific purposes. These mechanical explorers have helped to answer (and raise) basic questions about the nature of Earth, the solar system, and the universe. In the 1960s and 1970s, the United States launched the Pioneer series of spacecraft, to explore Venus, Mercury, and the Sun. The Mariner spacecraft flew by Mars to give us the first close-up view of the Red Planet. In 1976, two Viking spacecraft landed on Mars to do experiments designed to search for life on the one planet in our solar system whose environment most closely resembles Earth’s. In the 1970s and 1980s, the Voyager spacecraft took us on a grand tour of the outer planets, beginning with Jupiter and followed by Saturn, Uranus, and Neptune. The Magellan spacecraft, launched in 1989, has mapped the surface of Venus beneath its dense layer of clouds, as shown in Figure 4.1.1-15. The first mobile Martian—the Sojourner rover—part of the Mars Pathfinder mission, fascinated Earthlings in 1997, as it made the first, tentative exploration of the Martian surface. The Hubble Space



**Figure 4.1.1-15. Images of Venus.** Magellan, another interplanetary spacecraft, has provided a wealth of scientific data. Using its powerful synthetic aperture radar to pierce the dense clouds of Venus, it has mapped the Venusian surface in detail. (Courtesy of NASA/Jet Propulsion Laboratory)



**Figure 4.1.1-16. Hubble Image.** This photo of Spiral Galaxy M100 is one of thousands sent to Earth by the Hubble Space Telescope. (Courtesy of the Association of Universities for Research in Astronomy, Inc./Space Telescope Science Institute)



**Figure 4.1.1-17. Going to Mars.** Future human missions may explore the canyons of Mars for signs that life may have once flourished there, only to be extinguished as the planet's atmosphere diminished. (Courtesy of NASA/Ames Research Center)



**Figure 4.1.1-19. International Space Station (ISS).** The ISS will provide a free fall laboratory for studying many aspects of spaceflight. (Courtesy of NASA/Ames Research

Telescope orbits Earth every 90 minutes and returns glorious images of our solar-system neighbors, as well as deep-space phenomena that greatly expand our knowledge, as shown in Figures 4.1.1-1 and 4.1.1-16. Although all of these missions have answered many questions about space, they have also raised many other questions which await future generations of robotic and human explorers.

Since the launch of cosmonaut Yuri Gagarin on April 12, 1961, space has been home to humans as well as machines. In the space of a generation, humans have gone from minute-long missions in cramped capsules to a year-long mission in a space station. The motivation for sending humans into space was at first purely political, as we'll see in Chapter 2. But scientific advances in exploration, physiology, material processing, and environmental observation have proved that, for widely varying missions, humans' unique ability to adapt under stress to changing conditions make them essential to mission success.

### Future Space Missions

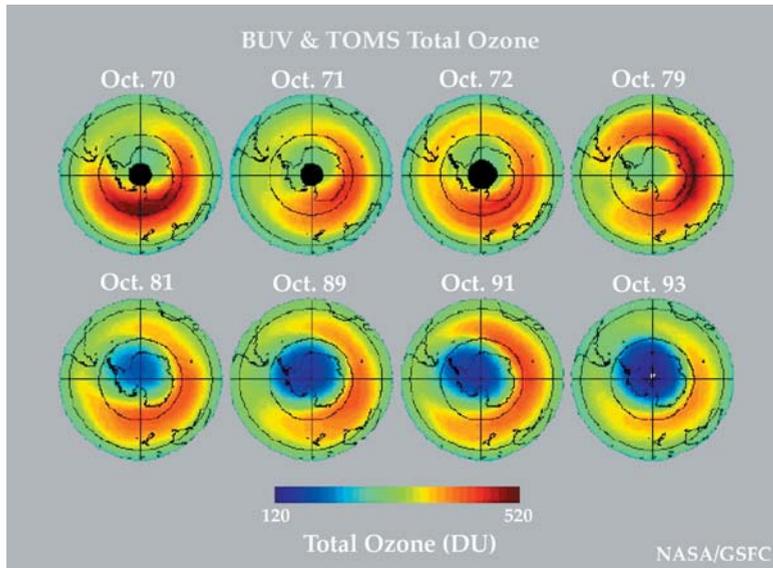
What does the future hold? In these times of changing world order and continuous budget fluctuation, it's impossible to predict. The International Space Station is under construction. The debate continues about sending humans back to the Moon, this time to stay, and then on to Mars, as shown in Figure 4.1.1-17.

As we become more concerned about damage to Earth's environment, we look to space for solutions. We continue to use our remote sensing satellites to monitor the health of the planet. Data from these satellites help us assess the extent of environmental damage and prepare better programs for cleaning up the environment and preventing future damage. Figure 4.1.1-18 shows one example of monitoring the environment from space. We use these images, taken by the Total Ozone Mapping Spectrometer, to track the ozone concentration which protects us from harmful ultraviolet radiation. Concerns about its depletion have mobilized scientists to monitor and study it in greater detail using a variety of space-based sensors.

The International Space Station had its first module launched in November 1998, and will continue adding modules through 2004 (Figure 4.1.1-19). The research onboard this modern vessel will advance our understanding of life and help us improve our quality of life worldwide.

The manned mission to Mars continues to gain momentum, but overcoming the obstacles for this mission will take experts in many fields and several governments to commit resources. The rewards for exploring Mars are many and varied, including medical research, Martian resource evaluation, and scientific innovation.

The eventual course of the space program is very much up to you. Whether we continue to expand and test the boundaries of human experience or retreat from it depends on the level of interest and technical competence of the general public. By reading this book, you've already accepted the challenge to learn about space. In this study of astronautics you too can explore the final frontier.



**Figure 4.1.1-18. Monitoring Ozone.** Images from the Nimbus 4 Backscatter Ultraviolet (BUV) instrument for 1970–1973, and Total Ozone Mapping Spectrometer (TOMS) for 1979–1993, show variations in the ozone amounts over Antarctica. A DU is a Dobson Unit. 300 DUs is equivalent to a 3 mm thick layer of ozone at standard sea level atmospheric pressure. Black dots indicate no data. Note that the amount of dark blue (low total ozone) grows over the years. (Courtesy of NASA/Goddard Space Flight Center)

## Section Review

### Key Concepts

- Space offers several unique advantages which make its exploration essential for modern society
  - Global perspective
  - A clear view of the universe without the adverse effects of the atmosphere
  - A free-fall environment
  - Abundant resources
  - A final frontier
- Since the beginning of the space age, missions have evolved to take advantage of space
  - Communications satellites tie together remote regions of the globe
  - Remote-sensing satellites observe the Earth from space, providing weather forecasts, essential military information, and valuable data to help us better manage Earth's resources
  - Navigation satellites revolutionize how we travel on Earth
  - Scientific spacecraft explore the Earth and the outer reaches of the solar system and peer to the edge of the universe
  - Manned spacecraft provide valuable information about living and working in space and experiment with processing important materials

## 4.1.1.2 Elements of a Space Mission

### In This Section You'll Learn to...

- Identify the elements common to all space missions and how they work together for success

Now that you understand a little more about why we go to space, let's begin exploring how. In this section we introduce the basic building blocks, or elements, of space missions. These elements form the basis for our exploration of *astronautics* (the science and technology of spaceflight) in the rest of the book.

When you see a weather map on the nightly news or use the phone to make an overseas call, you may not think about the complex network of facilities that make these communications possible. If you think about space missions at all, you may picture an ungainly electronic box with solar panels and antennas somewhere out in space—a spacecraft. However, while a spacecraft represents the result of years of planning, designing, building, and testing by a veritable army of engineers, managers, operators, and technicians, it is only one small piece of a vast array of technology needed to do a job in space.

We define the *space mission architecture*, shown in Figure 4.1.1-20, as the collection of spacecraft, orbits, launch vehicles, operations networks, and all other things that make a space mission possible. Let's briefly look at each of these elements to see how they fit together.

### The Mission

At the heart of the space mission architecture is the mission. Simply stated, the *mission* is why we're going to space. All space missions begin with a need, such as the need to communicate between different parts of the world (Figure 4.1.1-21) or to monitor pollution in the upper atmosphere. This need creates the mission. Understanding this need is central to understanding the entire space mission architecture. For any mission, no matter how complex, we must understand the need well enough to write a succinct *mission statement* that tells us three things

- The mission *objective*—*why* do the mission
- The mission *users or customers*—*who* will benefit
- The mission *operations concept*—*how* the mission elements will work together

For example, the mission objective for a hypothetical mission to warn us about forest fires might look like this

*Mission objective—Detect and locate forest fires worldwide and provide timely notification to users.*



**Figure 4.1.1-21. Iridium Phone.** The need for a *global* cellular telephone service triggered the iridium commercial enterprise. With these hand-held phones, you can phone anyone on Earth from anywhere on Earth. (Courtesy of Personal Satellite Network, Inc.)



**Figure 4.1.1-20. Space Mission Architecture.** A space mission requires a variety of interrelated elements, collectively known as the space mission architecture. Central to the architecture is the Space Mission. Surrounding the architecture is the Mission Management and Operations.

This mission objective tells us the “why” of the mission: we’ll explore the “who” and “how” of this space scenario in much greater detail starting in Chapter 11. For now, simply realize that we must answer each of these important questions before we can develop a cohesive mission architecture.

We’ll begin investigating the elements of a space mission architecture by looking at the most obvious element—the spacecraft.

## The Spacecraft

The word “spacecraft” may lead you to conjure up images of the starship *Enterprise* or sleek flying saucers from all those 1950s Sci-Fi movies. In reality, spacecraft tend to be more squat and ungainly than sleek and streamlined. The reasons for this are purely practical—we build spacecraft to perform a specific mission in an efficient, cost-effective manner. In the vacuum of space, there’s no need to be streamlined. When



**Figure 4.1.1-22. Upper Atmospheric Research Satellite (UARS).** The payloads for the UARS are sensitive instruments, which take images of various chemicals in Earth's atmosphere. (Courtesy of NASA/Goddard Space Flight Center)



**Figure 4.1.1-23. Defense Satellite Communication System (DSCS).** The spacecraft bus for this DSCS III spacecraft provides power, attitude control, thermal control, and communication with mission operators. (Courtesy of the U.S. Air Force)



**Figure 4.1.1-24. The Orbit.** We can think of an orbit as a fixed racetrack in space that the spacecraft drives on. Depending on the mission, this racetrack's size, shape, and orientation will vary.

it comes to spacecraft, form must follow function. In Chapter 11, we'll learn more about spacecraft functions, and resulting forms. For now, it's sufficient to understand that we can conceptually divide any spacecraft into two basic parts—the payload and the spacecraft bus.

The *payload* is the part of the spacecraft that actually performs the mission. Naturally, the type of payload a spacecraft has depends directly on the type of mission it's performing. For example, the payload for a mission to monitor Earth's ozone layer could be an array of scientific sensors, each designed to measure some aspect of this life-protecting chemical compound (Figure 4.1.1-22). As this example illustrates, we design payloads to interact with the primary focus for the mission, called the *subject*. In this example, the subject would be the ozone. If our mission objective were to monitor forest fires, the subject would be the fire and we would design spacecraft payloads that could detect the unique characteristics or "signature" of forest fires, such as their light, heat, or smoke. As we'll see in Chapter 11, understanding the subject, and its unique properties, are critical to designing space payloads to detect or interact with them.

The spacecraft bus does not arrive every morning at 7:16 to deliver the payload to school. But the functions performed by a spacecraft bus aren't that different from those a common school bus does. Without the spacecraft bus, the payload couldn't do its job. The *spacecraft bus* provides all the "housekeeping" functions necessary to make the payload work. The bus includes various subsystems that produce and distribute electrical power, maintain the correct temperature, process and store data, communicate with other spacecraft and Earth-bound operators, control the spacecraft's orientation, and hold everything together (Figure 4.1.1-23). It's the spacecraft's job to carry out the mission, but it can't do that unless it's in the right place at the right time. The next important element of the space mission architecture is concerned with making sure the spacecraft gets to where it needs to go.

## Trajectories and Orbits

A *trajectory* is the path an object follows through space. In getting a spacecraft from the launch pad into space, a launch vehicle follows a carefully-chosen ascent trajectory designed to lift it efficiently out of Earth's atmosphere. Once in space, the spacecraft resides in an *orbit*. We'll look at orbits in great detail in later chapters, but for now it's useful to think of an orbit as a fixed "racetrack" on which the spacecraft travels around a planet or other celestial body. Similar to car racetracks, orbits usually have an oval shape, as shown in Figure 4.1.1-24. Just as planets orbit the Sun, we can place spacecraft into orbit around Earth.

When selecting an orbit for a particular satellite mission, we need to know where the spacecraft needs to point its instruments and antennas. We can put a spacecraft into one of a limitless number of orbits, but we must choose the orbit which best fulfills the mission. For instance,

suppose our mission is to provide continuous communication between New York and Los Angeles. Our subject—the primary focus for the mission—is the communication equipment located in these two cities, so we want to position our spacecraft in an orbit that allows it to always see both cities. The orbit’s size, shape, and orientation determine whether the payload can observe these subjects and carry out the mission.

Just as climbing ten flights of stairs takes more energy than climbing only one, putting a spacecraft into a higher (larger) orbit requires more energy, meaning a bigger launch vehicle and greater expense. The orbit’s size (height) also determines how much of Earth’s surface the spacecraft instruments can see. Naturally, the higher the orbit, the more total area they can see at once. But just as our eyes are limited in how much of a scene we can see without moving them or turning our head, a spacecraft payload has similar limitations. We define the payload’s *field-of-view (FOV)*, as shown in Figure 4.1.1-25, to be the cone of visibility for a particular sensor. Our eyes, for example, have a useful field of view of about 204 degrees, meaning without moving our eyes or turning our head, we can see about 204 degrees of the scene around us. Depending on the sensor’s field of view and the height of its orbit, a specific total area on Earth’s surface is visible at any one time. We call the linear width or diameter of this area the *swath width*, as shown in Figure 4.1.1-25.

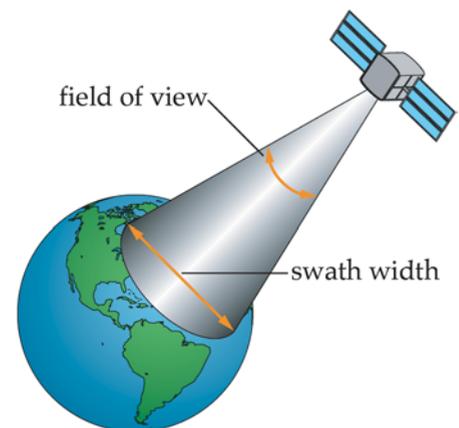
Some missions require continuous coverage of a point on Earth or the ability to communicate simultaneously with every point on Earth. When this happens, a single spacecraft can’t satisfy the mission need. Instead, we build a fleet of identical spacecraft and place them in different orbits to provide the necessary coverage. We call this collection of cooperating spacecraft a *constellation*.

The Global Positioning System (GPS) mission requirement is a good example of one that requires a constellation of satellites to do the job. The mission statement called for every point on Earth be in view of at least four GPS satellites at any one time. This was impossible to do with just four satellites at any altitude. Instead, mission planners designed the GPS constellation to contain 24 satellites working together to continuously cover the world (Figure 4.1.1-26).

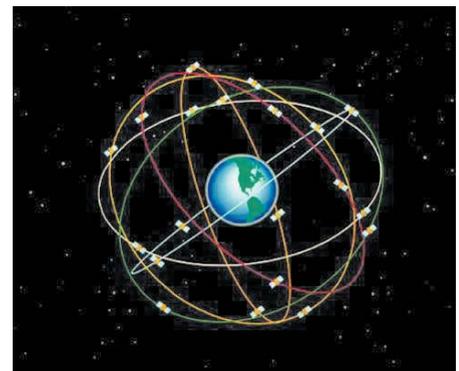
Another constellation of spacecraft called the Iridium System, provides global coverage for personal communications. This constellation of 66 satellites operates in low orbits. This new mobile telephone service is revolutionizing the industry with person-to-person phone links, meaning we can have our own, individual phone number and call any other telephone on Earth from virtually anywhere, at any time.

## Launch Vehicles

Now that we know where the spacecraft’s going, we can determine *how* to get it there. As we said, it takes energy to get into orbit—the higher the orbit, the greater the energy. Because the size of a spacecraft’s orbit determines its energy, we need something to deliver the spacecraft to the right mission orbit—a rocket. The thunderous energy released in a rocket’s



**Figure 4.1.1-25. Field-of-View (FOV).** The FOV of a spacecraft defines the area of coverage on the Earth’s surface, called the



**Figure 4.1.1-26. Global Positioning System (GPS) Constellation.** The GPS constellation guarantees that every point on the globe receives at least four satellite signals simultaneously, for accurate position, velocity, and time computations. (Courtesy of the National Air and Space Museum)



**Figure 4.1.1-27. Lift Off!** The Space Shuttle acts as a booster to lift satellites into low-Earth orbit. From there, an upperstage moves the satellite into a higher orbit. (Courtesy of NASA/Johnson Space Center)



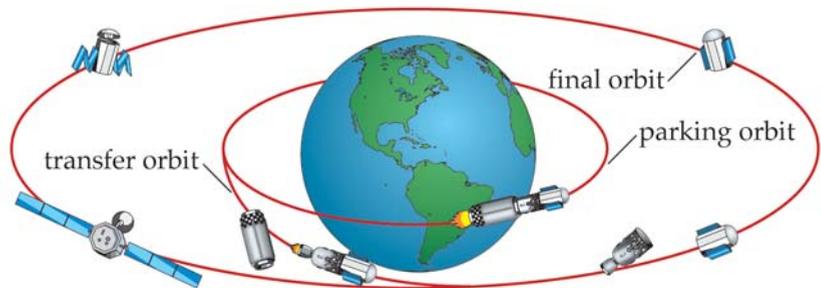
**Figure 4.1.1-28. Ariane.** The European Space Agency's Ariane V booster lifts commercial satellites into orbit. Here we see it lifting off from its pad in Kourou, French Guyana, South America. (Courtesy of Service Optique CSG; Copyright by Arianespace/European Space

fiery blast-off provides the velocity for our spacecraft to “slip the surly bonds of Earth” (as John Gillespie Magee wrote in his poem, “High Flight”) and enter the realm of space, as the Shuttle demonstrates in Figure 4.1.1-27.

A *launch vehicle* is the rocket we see sitting on the launch pad during countdown. It provides the necessary velocity change to get a spacecraft into space. At lift-off, the launch vehicle blasts almost straight up to gain altitude rapidly and get out of the dense atmosphere which slows it down due to drag. When it gets high enough, it slowly pitches over to gain horizontal velocity. As we’ll see later, this horizontal velocity keeps a spacecraft in orbit.

Current technology limits make it very difficult to build a single rocket that can deliver a spacecraft efficiently into orbit. Instead, a launch vehicle consists of a series of smaller rockets that ignite, provide thrust, and then burn out in succession, each one handing off to the next one like runners in a relay race. These smaller rockets are *stages*. In most cases, a launch vehicle uses at least three stages to reach the mission orbit. For example, the Ariane V launch vehicle, shown in Figure 4.1.1-28, is a three-stage booster used by the European Space Agency (ESA).

For certain missions, the launch vehicle can’t deliver a spacecraft to its final orbit by itself. Instead, when the launch vehicle finishes its job, it leaves the spacecraft in a parking orbit. A *parking orbit* is a temporary orbit where the spacecraft stays until transferring to its final mission orbit. After the spacecraft is in its parking orbit, a final “kick” sends it into a transfer orbit. A *transfer orbit* is an intermediate orbit that takes the spacecraft from its parking orbit to its final, mission orbit. With one more kick, the spacecraft accelerates to stay in its mission orbit and can get started with business, as shown in Figure 4.1.1-29.



**Figure 4.1.1-29. Space Mission Orbits.** We use the booster primarily to deliver a spacecraft into a low-altitude parking orbit. From this point an upperstage moves the spacecraft into a transfer orbit, and then to the mission orbit.

The extra kicks of energy needed to transfer the spacecraft from its parking orbit to its mission orbit comes from an *upperstage*. In some cases, the upperstage is actually part of the spacecraft, sharing the plumbing and propellant which the spacecraft will use later to orient itself and maintain its orbit. In other cases, the upperstage is an autonomous spacecraft with the one-shot mission of delivering the spacecraft to its mission orbit. In the latter case, the upperstage releases the spacecraft once it completes its job, then moves out of the way by de-orbiting to

burn up in the atmosphere or by raising its orbit a bit (and becoming another piece of space junk). Regardless of how it is configured, the upperstage consists mainly of a rocket engine (or engines) and the propellant needed to change the spacecraft's energy enough to enter the desired mission orbit. Figure 4.1.1-30 shows the upperstage used to send the Magellan spacecraft to Venus.

After a spacecraft reaches its mission orbit, it may still need rocket engines to keep it in place or maneuver to another orbit. These relatively small rocket engines are *thrusters* and they adjust the spacecraft's orientation and maintain the orbit's size and shape, both of which can change over time due to external forces.

## Mission Operations Systems

As you can imagine, designing, building, and launching space missions requires a number of large, expensive facilities. Communicating with and controlling fleets of spacecraft once they're in orbit requires even more expensive facilities. The *mission operations system* include the ground and space-based infrastructure needed to coordinate all other elements of the space mission architecture. It is the "glue" that holds the mission together.

Operations systems include manufacturing and testing facilities to build the spacecraft, launch facilities to prepare the launch vehicle and get it safely off the ground, and communication networks and operations centers used by the *flight-control team* to coordinate activities once it's in space.

One of the critical aspects of linking all these far-flung elements together is the communication process. Figure 4.1.1-31 shows the components of a typical communication network. Whether we're talking to our friend across a noisy room or to a spacecraft on the edge of the solar system, the basic problems are the same.

## Mission Management and Operations

So far, most of our discussion of space missions has focused on hardware—spacecraft, launch vehicles, and operations facilities. But while the mission statement may be the heart of the mission, and the hardware the tools, the mission still needs a brain. No matter how much we spend on advanced technology and complex systems there is still the need for people. People are the most important element of any space mission. Without people handling various jobs and services, all the expensive hardware is useless.

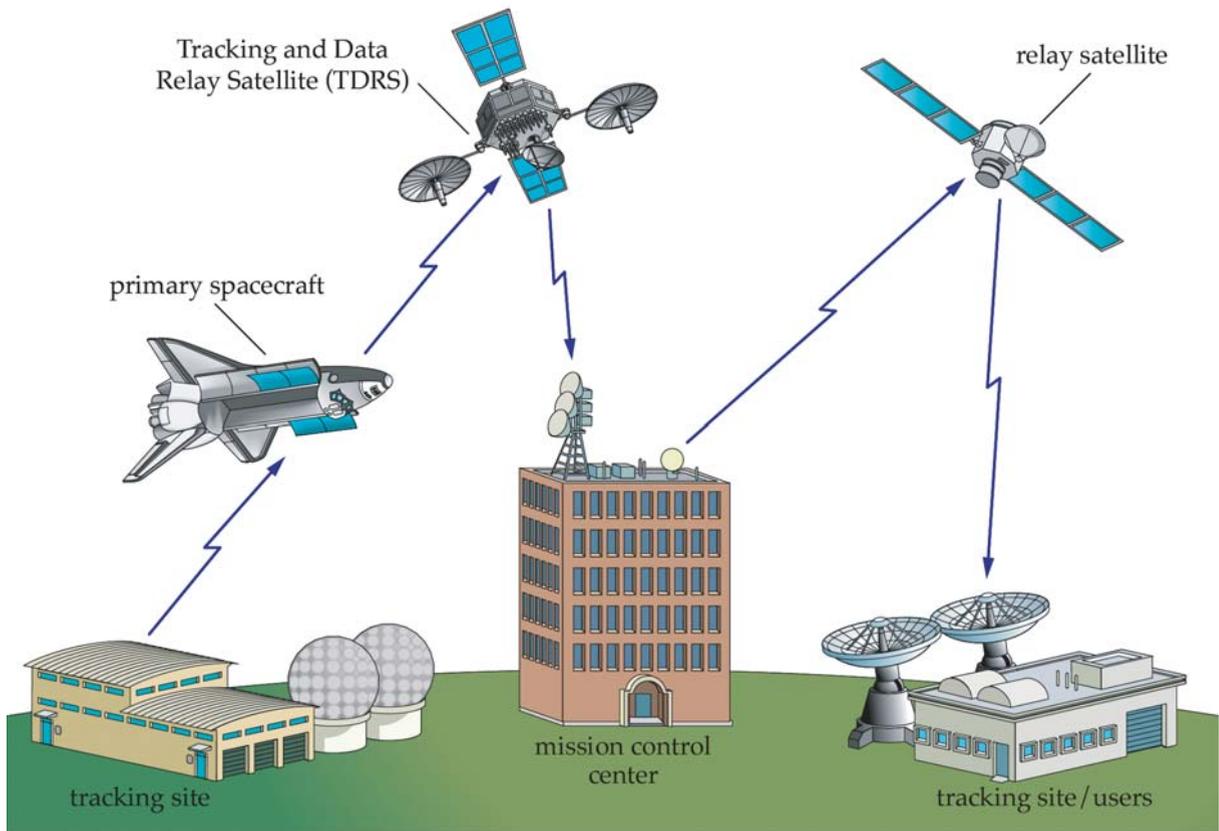
Hollywood tends to show us only the most "glamorous" space jobs—astronauts doing tasks during a space walk or diligent engineers hunched over computers in the Mission Control Center (Figure 4.1.1-32). But you don't have to be an astronaut or even a rocket scientist to work with space. Thousands of jobs in the aerospace industry require only a desire



**Figure 4.1.1-30. The Inertial Upperstage (IUS).** The IUS, attached to the Magellan spacecraft, boosted it to Venus. (Courtesy of NASA/Johnson Space Center)



**Figure 4.1.1-32. Mission Control Center.** After several tense days, the mission control team at the Johnson Space Center watch the Apollo 13 crew arrive on the recovery ship after splashdown. (Courtesy of NASA/Johnson Space Center)



**Figure 4.1.1-31. Mission Operations System.** The flight-control team relies on a complex infrastructure of control centers, tracking sites, satellites, and relay satellites to keep them in contact with spacecraft and users. In this example, data goes to the Space Shuttle from a tracking site, which relays it through another satellite, such as the Tracking and Data Relay Satellite (TDRS), back to the control center. The network then passes the data to users through a third relay satellite.

to work hard and get the job done. Many of these jobs are in space mission management and operations. *Mission management and operations* encompasses all of the “cradle to grave” activities needed to take a mission from a blank sheet of paper to on-orbit reality, to the time when they turn out the lights and everyone moves on to a new mission.

Mission managers lead the program from the beginning. The mission management team must define the mission statement and lay out a workable mission architecture to make it happen. Team members are involved with every element of the mission architecture, including

- Designing, building, and testing the spacecraft
- Performing complex analysis to determine the necessary mission orbit
- Identifying a launch vehicle (or designing, building and testing a new one!) and launching the spacecraft to its mission orbit
- Bringing together the far-flung components of the mission operations systems to allow the flight-control team to run the entire mission

But mission management is far more than just technical support. From food services to legal services, a diverse and dedicated team is needed to get any space mission off the ground. It can take a vast army of people to manage thousands of separate tasks, perform accounting services, receive raw materials, ship products, and do all the other work associated with any space mission. Sure, an astronaut turning a bolt to fix a satellite gets his or her picture on the evening news, but someone had to make the wrench, and someone else had to place it in the toolbox before launch.

As soon as the spacecraft gets to orbit, mission operations begin. The first word spoken by humans from the surface of the Moon was “Houston.” Neil Armstrong was calling back to the Mission Control Center at Johnson Space Center in Houston, Texas, to let them know the Eagle had successfully landed. To the anxious Flight Director and his operations team, that first transmission from the lunar surface was important “mission data.” In the design of an operations concept to support our mission statement, we have to consider how we will collect, store, and deliver the mission data to users or customers on Earth. Furthermore, we have to factor in how the flight-control team will receive and monitor data on the spacecraft’s health and to build in ground control for commanding the spacecraft’s functions from the complex, minute to minute, activities on the Space Shuttle, to the far more relaxed activities for less complex, small satellites, as shown in Figure 4.1.1-33.

It would be nice if, once we deploy a spacecraft to its final orbit, it would work day after day on its own. Then users on Earth could go about their business without concern for the spacecraft’s “care and feeding.” Unfortunately, this automatic mode is not yet possible. Modern spacecraft, despite their sophistication, require a lot of attention from a team of flight controllers on the ground.

The *mission operations team* monitors the spacecraft’s health and status to ensure it operates properly. Should trouble arise, flight controllers have an arsenal of procedures they can use to nurse the spacecraft back to health. The flight-control team usually operates from a Mission (or Operations) Control Center (MCC or OCC) such as the one in Houston, Texas, used for United States’ manned missions and shown in Figure 4.1.1-34. U.S. military operators and their contractor support teams control Department of Defense robotic satellites at similar MCCs (or OCCs) at Schriever Air Force Base, in Colorado Springs, Colorado, and Onizuka Air Station, Sunnyvale, California. A new OCC is under construction at Schriever AFB—the old Falcon AFB.

Within the mission’s operation center, team members hold positions that follow the spacecraft’s functional lines. For example, one person may monitor the spacecraft’s path through space while another keeps an eye on the electrical-power system. The lead mission operator, called the *flight director* (*operations director* or *mission director*), orchestrates the inputs from each of the flight-control disciplines. Flight directors make decisions about the spacecraft’s condition and the important mission data, based on recommendations and their own experience and judgment.



**Figure 4.1.1-33. Small Satellite Ground Station.** The size and complexity of the control center and flight-control team depends on the mission. Here a single operator controls over a dozen small satellites. (Courtesy of Surrey Satellite Technology, Ltd., U.K.)

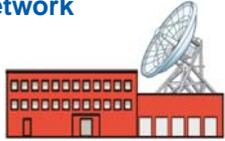


**Figure 4.1.1-34. The Space Shuttle Mission Control Center in Houston, Texas.** Space operations involves monitoring and controlling spacecraft from the ground. Here, flight controllers attend to their Guidance/Navigation, Propulsion, and Flight Dynamics consoles. (Courtesy of NASA/Johnson Space Center)

## The Space Mission Architecture in Action

Now that we've defined all these separate mission elements, let's look at an actual space mission to see how it works in practice. NASA launched Space Shuttle mission STS-95 from the Kennedy Space Center (KSC) in Florida on October 29, 1998. The primary objectives of this mission were to deploy three science and engineering satellites, run experiments on human physiology, and operate microgravity tests. The three satellites were the Spartan 201 Solar Observer, the International Extreme Ultraviolet Hitchhiker Experiment, and the HST Optical Systems Test platform. In Figure 4.1.1-35, we show how all the elements for this mission tie together.

**Communication Network**

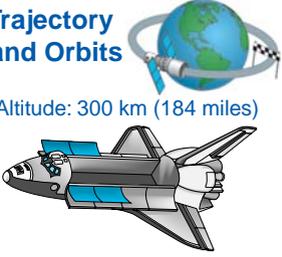


NASA's tracking and data relay satellite system



Clockwise from top: Scott Parazynski, John Glenn, Curtis Brown, Steven Lindsey, Stephen Robinson, Pedro Duque, and Chiaki Mukai.

**Trajectory and Orbits**



Altitude: 300 km (184 miles)

**Launch Vehicle**



The Space Shuttle delivers the crew and cargo to low-Earth orbit.



**Mission Operations Systems**



Operation Concept: Ground controllers in Houston, Texas, monitor and support the Shuttle crew around the clock for this 10-day mission.

**Spacecraft**



Deploying the Spartan satellite.

Figure 4.1.1-35. STS-95 Space Mission Architecture. (All photos courtesy of NASA/Johnson Space Center)

## Section Review

---

### Key Concepts

- Central to understanding any space mission is the mission itself
    - The mission statement clearly identifies the major objectives of the mission (why we do it), the users (who will benefit), and the operations concept (how all the pieces fit together)
  - A space mission architecture includes the following elements
    - The spacecraft—composed of the bus, which does essential housekeeping, and the payload, that performs the mission
    - The trajectories and orbits—the path the spacecraft follows through space. This includes the orbit (or racetrack) the spacecraft follows around the Earth.
    - Launch vehicles—the rockets which propel the spacecraft into space and maneuver it along its mission orbit
    - The mission operations systems—the “glue” that holds the mission together. It consists of all the infrastructure needed to get the mission off the ground, and keep it there, such as manufacturing facilities, launch sites, communications networks, and mission operations centers.
    - Mission management and operations—the brains of a space mission. An army of people make a mission successful. From the initial idea to the end of the mission, individuals doing their jobs well ensure the mission products meet the users’ needs.
-

## References

- Canuto, Vittorio and Carlos Chagas. *The Impact of Space Exploration on Mankind*. Pontificia Academia Scientiarum, proceedings of a study week held October 1–5, 1984, Ex Aedibus Academicis In Civitate Vaticana, 1986.
- Wertz, James R. and Wiley J. Larson. *Space Mission Analysis and Design*. Third edition. Dordrecht, Netherlands: Kluwer Academic Publishers, 1999.
- Wilson, Andrew (ed.), *Space Directory 1990–91*. Jane's information group. Alexandria, VA, 1990.