

Social, Cultural, and Educational Legacies

NASA Reflects America's
Changing Opportunities;
NASA Impacts US Culture



Education: Inspiring
Students as Only NASA Can





NASA Reflects America's Changing Opportunities; NASA Impacts US Culture

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The Space Shuttle, which began flying in 1981 and ushered in an entirely new human spaceflight program, was a watershed for cultural diversity within NASA and had substantial cultural impact outside the realm of spaceflight. In the 1950s and 1960s, opportunities for American women and minorities were limited as they were often segregated into pink collar and menial jobs. NASA's female and minority employees faced similar obstacles. The Space Shuttle Program opened up opportunities for these groups—opportunities that did not exist during Projects Mercury and Gemini or the Apollo and Skylab Programs. NASA's transformation was a direct consequence of a convergence of events that happened in the 1960s and 1970s and continued through the following 3 decades. These included: public policy changes instituted on the national level; the development of a spacecraft whose physical capabilities departed radically from the capsule concept; and an increase in the number of women and minorities holding degrees in the fields of science and engineering, making them attractive candidates for the space agency's workforce. Over the course of the program, the agency's demographics reflected this transformation: women and minorities were incorporated into the Astronaut Corps and other prominent technical and administrative positions.

The impact of NASA's longest-running program extends beyond these dramatic changes. Today, the shuttle—the crown jewel of NASA's spaceflight programs—symbolizes human spaceflight and is featured in advertisements, television programs, and movies. Its image exemplifies America's scientific and economic power and encourages dreamers.



Social Impact—NASA Reflects America's Changing Opportunities

Before the Space Shuttle was conceived, the aerospace industry, NASA employees, and university researchers worked furiously on early human spaceflight programs to achieve President John Kennedy's goal of landing a man on the moon by the end of the 1960s. Although these programs employed thousands of personnel across the United States, White men overwhelmingly composed the aerospace field at that time, and very few women and minorities worked as engineers or scientists on this project. When they did work at one of NASA's centers, women overwhelmingly served in clerical positions and minorities accepted low-paying, menial jobs. Few held management or professional

positions, and none were in the Astronaut Corps, even though four women had applied for the 1965 astronaut class. By the end of the decade, NASA offered few positions to qualified minorities and women. Only eight Blacks at Marshall Space Flight Center in Alabama held professional-rated positions while the Manned Spacecraft Center (currently known as Johnson Space Center) in Texas had 21, and Kennedy Space Center in Florida had only five.

Signs of change appeared on the horizon as federal legislation addressed many of the inequalities faced by women and minorities in the workplace. During the Kennedy years, the president ordered the chairman of the US Civil Service Commission to ensure the federal government offered positions not on the basis of sex but, rather, on merit. Later, he signed into law the Equal Pay Act of 1963, making it

illegal for employers to pay women lower wages than those paid to men for doing the same work. President Lyndon Johnson signed the Civil Rights Act of 1964, which prohibited employment discrimination (hiring, promoting, or firing) on the basis of race, sex, color, religion, or national origin. Title VII of the Act established the Equal Employment Opportunity Commission, which executed the law. The Equal Employment Opportunity Act of 1972 strengthened the commission and expanded its jurisdiction to local, state, and federal governments during President Richard Nixon's administration. The law also required federal agencies to implement affirmative action programs to address issues of inequality in hiring and promotion practices.

One year earlier, NASA appointed Ruth Bates Harris as director of Equal Employment Opportunity. In the fall

Changing Faces of the Astronauts From 1985 Through 2010



In 1985, STS-51F—Center: Story Musgrave, MD, mission specialist, medical doctor. To Musgrave's right, and going clockwise: Anthony England, PhD, mission specialist, geophysicist; Karl Henize, PhD, mission specialist, astronomer; Roy Bridges, pilot, US Air Force (USAF); Loren Acton, PhD, industry payload specialist; John-David Bartoe, PhD, Navy payload specialist; Gordon Fullerton, commander, USAF.



In 2010, STS-131 and International Space Station (ISS) Expedition 23—Clockwise from lower right: Stephanie Wilson, mission specialist, aerospace engineer; Tracy Caldwell Dyson, PhD, ISS Expedition 23 flight engineer, chemist; Dorothy Metcalf-Lindenburger, mission specialist, high school science teacher and coach; Naoko Yamazaki, Japanese astronaut, aerospace engineer.



Guion Bluford, PhD

*Colonel, US Air Force (retired).
Astronaut on STS-8 (1983),
STS-61A (1985),
STS-39 (1991), and
STS-53 (1992).*



Astronaut Guion Bluford conducting research on STS-53.

In 1983, Colonel Guion Bluford became the first African American to fly in space. He earned a Bachelor of Science in aerospace engineering from Pennsylvania State University, followed by flight school and military service as a jet pilot in Vietnam, which included missions over North Vietnam. He went on to earn a Master of Science and Doctor of Philosophy in aerospace engineering with a minor in laser physics from the Air Force Institute of Technology. He also earned a Master of Business Administration after joining NASA. Prior to joining NASA as a US Air Force astronaut, he completed research with several publications. Since leaving NASA, he has held many leadership positions.

As a NASA astronaut, he flew on four missions: two on Challenger (1983, 1985) and two on Discovery (1991, 1992).

Dr. Bluford has said, "I was very proud to have served in the astronaut program and to have participated on four very successful Space Shuttle flights. I also felt very privileged to have been a role model for many youngsters, including African American kids, who aspired to be scientists, engineers, and astronauts in this country. For me, being a NASA astronaut was a great experience that I will always cherish."

of 1973, Harris proclaimed NASA's equal employment opportunity program "a near-total failure." Among other things, the agency's record on recruiting and hiring women and minorities was inadequate. In October, NASA Administrator James Fletcher fired Harris and Congress held hearings to investigate the agency's affirmative action programs. Legislators concluded that NASA had a pattern of discriminating

against women and minorities. Eventually, a resolution was reached, with Fletcher reinstating Harris as NASA's deputy assistant administrator for community and human relations. From 1974 through 1992, Dr. Harriett Jenkins, the new chief of affirmative action at NASA, began the process of slowly diversifying NASA's workforce and increasing the number of female and minority candidates.

Though few in number, women and minorities made important contributions to the Space Shuttle Program as NASA struggled with issues of race and sex. Dottie Lee, one of the few women engineers at Johnson Space Center and the subsystem manager for aerothermodynamics, encouraged engineers to use a French curve design for the spacecraft's nose, which is now affectionately called "Dottie's nose." NASA named Isaac Gillam as head of Shuttle Operations at the Dryden Flight Research Center, where he coordinated the Approach and Landing Tests. In 1978, he became the first African American to lead a NASA center. JoAnn Morgan of Kennedy Space Center served as the deputy project manager over the Space Shuttle Launch Processing Systems Central Data Subsystems used for Columbia's first launch in 1981.

Astronaut Corps

Forced to diversify its workforce in the 1970s, NASA encouraged women and minorities to apply for the first class of Space Shuttle astronauts in 1976. When NASA announced the names in January 1978, the list included six women, three African Americans, and one Japanese American, all of whom held advanced degrees. Two of the women were medical doctors, another held a PhD in engineering, and the others held PhDs in the sciences. Two of the three African Americans had earned doctorates, while the third, Frederick Gregory, held a master's degree. The only Asian member of their class, Ellison Onizuka, had completed a master's degree in aerospace engineering. This was the most diverse group of astronauts NASA had ever selected and it illustrated the sea change brought about within the Astronaut Corps by 1978. From then on, all



astronaut classes that NASA selected included either women or minorities. In fact, the next class included both as well as the first naturalized citizen astronaut candidate, Dr. Franklin Chang-Diaz, a Costa Rican by birth.

Admitting women into the Astronaut Corps did require some change in the NASA culture, recalled Carolyn Huntoon, a member of the 1978 astronaut selection board and mentor to the first six female astronauts. “Attitude was the biggest thing we had to [work on],” she said.

Astronaut Richard Mullane, who was selected as an astronaut candidate in 1978, had never worked with professional women before coming to NASA. Looking back on those first few years, he remembered that “the women had to endure a lot because” so many of the astronauts came from military backgrounds and “had never worked with women and were kind of struggling to come to grips on working professionally with women.”

When “everyone saw they could hold their own, they were technically good, they were physically fit, they would do the job, people sort of relaxed a little bit and started accepting them,” explained Huntoon.

Sally Ride, one of the first six female astronauts selected, remembered the first few years a bit differently.

The Gemini and Apollo-era astronauts in the office in 1978 were not used to working with women as peers. “But, they knew that this was coming,” she said, “and they’d known it was coming for a couple of years.” By 1978, the remaining astronauts “had adapted to the idea.” As a sign of the changing culture within NASA, she could not recall any issues the women of her class encountered. This visible change signaled a dramatic shift within the agency’s macho culture.

The 1978 group was unique in other ways. Several of the men and women came from the civilian world and their experiences differed greatly from those of their classmates who had come from the military. Previously, test pilots had comprised the majority of the office. Many of the PhDs were young, with less life experience, according to Mullane, than many of the military test pilots and flight test engineers who had completed tours in Vietnam.

The shuttle concept brought about other measurable changes. The versatility of the Space Shuttle, when compared with the first generation of spacecraft, provided greater opportunities for more participants. The shuttle was a much more flexible vehicle than the capsules of the past, when astronauts had to be 6 feet tall or under to fit into the spacecraft. (The Mercury astronauts could be no more than 5 feet 11 inches

in height.) The capabilities of the shuttle were so unusual that astronauts of all sizes could participate; even James van Hoften—one of the tallest astronauts ever selected at 6 feet 4 inches—could fit inside the vehicle. Eventually, flight crews, which had previously consisted of one, two, or three American test pilots, expanded in size and the shuttle flew astronauts from across the globe, just as Nixon had hoped when he approved the shuttle in 1972. Indeed, the shuttle became the vehicle by which everyone, regardless of protected classes—sex, race, ethnicity, or national origin—could participate.

After the first four flights, the shuttle crews expanded to include mission specialists (a new category of astronauts that would perform research in space, deploy satellites in orbit, and conduct spacewalks). In addition to these scientists and engineers, the shuttle allowed room for a different category—the payload specialist. These individuals were not members of the Astronaut Corps. They were selected by companies or countries flying a payload on board the shuttle. Over the years, payload specialists from Saudi Arabia, Mexico, Canada, West Germany, France, Belgium, the Ukraine, Italy, Japan, the Netherlands, and Sweden flew on the shuttle as did two members of Congress: US Senator

International Participation in the Space Shuttle Program

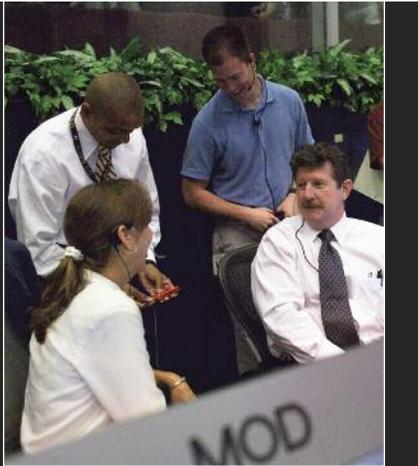
American astronauts flew with representatives from 15 other countries.





Diversity Succeeds

In 2005, NASA selected a new class of flight directors, one of the most diverse ever selected, which included the first African American (Kwatsi Alibaruho) and the first two Hispanics (Ginger Kerrick and Richard Jones). At the time of their selection, only 58 people had served in the position. All three began their careers with NASA as students and then rose through the ranks. Since their selection, Kerrick and Alibaruho have guided shifts in Russia and in the International Space Station flight control room, while Jones has supervised shuttle flights. In all, the class of 2005 dramatically changed the look of shuttle and station flight directors.



A diverse workforce.

Jake Garn of Utah and Congressman Bill Nelson of Florida. Industry also flew its own researchers, who managed their commercial payloads, with the first being McDonnell Douglas' Charles Walker. In 1972, NASA Deputy Administrator George Low remembered that this was one of the things Nixon liked about the program: "the fact that ordinary people," not just test pilots "would be able to fly in the shuttle, and that the only requirement for a flight would be that there is a mission to be performed."

Over the years, women and minorities also made their way into the pilot seat on board the shuttle and eventually went on to direct their own missions, with Eileen Collins serving as the first female pilot and commander. Space Transportation System (STS)-33 (1989) featured the first African American commander, Frederick Gregory, who later became NASA's deputy administrator. An example of NASA's diverse workforce, African American

former Space Shuttle Commander Charles Bolden became NASA administrator in the summer of 2009. In all, 48 women flew on the shuttle over the course of the program between 1981 and 2010.

The female and minority shuttle astronauts quickly became heroes in the United States and abroad for breaking through barriers that had prevented their participation in the 1960s and 1970s. Millions celebrated the launches of Sally Ride, Guion Bluford, John Herrington, and Mae Jemison: first American woman, African American, Native American, and African American woman, respectively, in space.

When the crews of STS-51L (1986) and STS-107 (2003) perished, Americans grieved. Lost in two separate-but-tragic accidents, the astronauts immediately became America's heroes. In honor of their sacrifice, two separate memorials were erected at Arlington National Cemetery to the crews of the Challenger

and Columbia accidents, and numerous other tributes (coins and songs, for instance) were made to the fallen astronauts. Naturally, national interest in the Return to Flight missions of STS-26 (1988) and STS-114 (2005) was high, with a great deal of attention showered on America's newest idols. Richard Covey, pilot of the STS-26 flight, recalled, "it was unprecedented, the attention that we got." The crews of the Return to Flight missions after the accidents also symbolized the changes within the Astronaut Corps. For Return to Flight after the Challenger accident, the crew members were all male. By 2005, the Return to Flight mission following the Columbia accident had a female commander.

Johnson Space Center, Texas, Changes

As the definition of the term "astronaut" became more fluid over time, America's idea of what constituted a flight director or flight controller also evolved. In NASA's heyday, all flight directors and nearly all flight controllers were men, with the exception of Frances Northcutt. She blazed the trail during the Apollo Program, becoming the first woman to work in the Mission Control Center. The number of women expanded over the years as the agency prepared for the orbital test flights. Opportunities to work in the cathedral of spaceflight (Mission Control) also expanded for other underrepresented groups, like African Americans. Angie Johnson, the first African American female flight controller in the control center in 1982, served as payloads officer for STS-2.

Over the years, the number of women working in mission operations increased dramatically. But, in general, NASA was slow to promote women into the coveted position of flight director, with the first selected



in 1985—7 years after women were first named as astronaut candidates. Change came slowly, however. Eventually, flight teams became so open to women that they were nearly equally composed of men and women.

Kennedy Space Center, Florida, Changes

In the mid 1970s, women and minorities did not have a strong presence at Kennedy Space Center (KSC). In fact, many operational facilities at KSC did not even provide separate restroom facilities for women. Women had to work extra hard to gain acceptance within the KSC community. Nevertheless, a handful of talented and dedicated women and minorities broke through the cultural barriers that were in place. JoAnne Morgan became the first and, at the time, only female system engineer. By the mid 1980s, many men from the Apollo-era workforce began retiring from NASA, providing management opportunities for women and minorities. Ann Montgomery became the first female flow director for the shuttle and Ruth Harrison was one of the first system engineers within the External Tank Ground Support group. The first female senior executive—JoAnne Morgan—was soon joined by others. Ruth Harrison rose to the level of associate director of shuttle processing. By the 1990s, Arnold Postell, an African American engineer, and Hugo Delgado, a Hispanic American engineer, became branch chiefs for the shuttle Launch Processing System on their way to senior management. As of October 2010, all flow directors at KSC were women along with the lead test director and the directors for shuttle processing. The workforce culture at KSC clearly evolved into one of inclusion and equal opportunity.

Marshall Space Flight Center, Alabama, Changes

Alabama women broke the glass ceiling and accepted Space Shuttle management positions during the 1990s and the following years. From 1992 to 1996, Dewanna Edwards served as deputy manager of the Space Shuttle Main Engine Project Office. In 2002, Jody Singer was appointed manager of the Reusable Solid Rocket Booster Project, making her the first woman to lead a propulsion element office at NASA. She remained in that position until 2007, when she became deputy manager of the Shuttle Propulsion Office, which was responsible for the main engines, boosters, and External Tank. Management appointed Sandy Coleman project manager for the tank project in 2003—a position she held until 2006. From 2000 to 2004, Ann McNair managed the Ground Systems Department of Flight Projects. She was responsible for the Huntsville Operations Support Center and its key facilities, including the Payload Operations Integration Center that supported payload and science research for the International Space Station. During the same period, she led the development of the Chandra X-ray Observatory Operations Control Center. In 2004, McNair was appointed manager of the Mission Operations Laboratory in the Engineering Directorate. In 2007, she was named the center's director of operations.

Summary

Despite these advancements at NASA's shuttle field centers, women and minorities did not break into some key positions. As of 2010, not one minority or woman served as shuttle launch director or managed the Space Shuttle. NASA could, however, point to significant workforce diversification by the end of the program.

NASA Impacts US Culture

Since its inception, NASA has captivated the dreamers and adventurers, and its Apollo Program captured the public's interest and imagination. Similarly, the Space Shuttle broadly impacted art, popular music, film, television, and photos, as well as consumer culture. Over the years, the shuttle became a cultural icon—a symbol of America's technological prowess that inspired many people inside and outside of the agency.

Paintings and murals of the shuttle, payloads, and flight crews abound. Numerous pieces of art in a variety of mediums—fabric, watercolors, acrylic, oil, etching, triptych, and pencil—depict the launch and landing of the shuttle, simulations, spacewalks, and the launch facilities. Artist Henry Casselli used watercolors to depict Astronaut John Young as he suited up for the first shuttle flight (1981). Space artist Bob McCall painted several of the murals that adorn the walls of many of NASA's centers, including Johnson Space Center. “Opening the Space Frontier: The Next Giant Step”—the large mural in the now decommissioned visitor center—includes the shuttle and one of NASA's female astronauts. Coincidentally, at Young's urging, McCall designed the STS-1 patch.

Music

The shuttle, the crews, and the missions inspired many musicians, who composed songs about the shuttle and its flights. Canadian rockers Rush, who were present at the first launch, wrote their 1982 song “Countdown” about that event and dedicated that song



to “Astronauts Young, [Robert] Crippen, and all the people of NASA for their inspiration and cooperation.” When First Lady Hillary Rodham Clinton announced that a woman would command a mission for the first time in NASA’s 40-year history, the NASA Arts Program asked Judy Collins to write a song to commemorate the occasion. She agreed and composed “Beyond the Sky” for that historic flight. The song describes the dream of a young girl to fly beyond the sky and heavens. The girl eventually achieves her goal and instills hope in those with similar aspirations. This is foreshadowed in the fifth verse.

*She had led the way
beyond darkness*

*For other dreamers who
would dare the sky*

*She has led us to believe
in dreaming*

*Given us the hope that
we can try*

Authored for NASA as part of the NASA Arts Program.

Inspiration

The shuttle inspired so many people in such different ways. Much as the flag came to symbolize American pride, so too did the launch and landing of the shuttle. As an example, William Parsons, Kennedy Space Center’s former director, witnessed his first launch at age 28 and recalled, “When I saw that shuttle take off at dusk, it was the most unbelievable experience. I got tears in my eyes; my heart pounded. I was proud to be an American, to see that we could do something that awesome.”

Film and Television

IMAX® films built on the thrill of spaceflight by capturing the excitement and exhilaration of NASA’s on-orbit operations. Shuttle astronauts were trained to use the camera and recorded some of the program’s most notable events as the events unfolded in orbit, like the spacewalk of Kathryn Sullivan, America’s first woman spacewalker. Marketed as “the next best thing to being there,” the film *The Dream is Alive* documented living and working in space on board shuttle. *Destiny in Space* featured shots from the dramatic first Hubble Space Telescope servicing mission in 1993, which boasted a record-breaking five spacewalks. Other feature films like *Mission to Mir* took audiences to the Russian space station, where American astronauts and cosmonauts performed scientific research.

The excitement inspired by the Space Shuttle and the technological abilities—both real and imagined—did not escape screenwriters and Hollywood directors. In fact, the shuttle appeared as a “character” in numerous films, and several major motion pictures featured a few of NASA’s properties. These films attracted audiences across the world and sold millions of dollars in tickets based on two basic themes: NASA’s can-do spirit in the face of insurmountable challenges, and the flexibility of the shuttle. They include *Moonraker*, *Space Camp*, *Armageddon*, and *Space Cowboys*.

Television programs also could not escape the pull of the Space Shuttle. In 1994, the crew of Space Transportation System (STS)-61 (1993), the first Hubble servicing mission, appeared on ABC’s *Home Improvement*. Six of the seven crew members flew to California for the taping, where they starred as guests of *Tool Time*—the fictional

home improvement program—and showed off some of the tools they used to work on the telescope in space. Following this episode, astronauts from the US Microgravity Laboratory-2, STS-73 (1995), appeared on *Home Improvement*. Astronaut Kenneth Bowersox, who was pilot for one flight and commander of two flights, made three appearances on the show. Bowersox once brought Astronaut Steven Hawley, who also flew on STS-82 (1997).

The Space Shuttle and its space fliers were also the subject of the television drama *The Cape*. Based on the astronaut experience, the short-lived series captured the drama and excitement associated with training and flying shuttle missions. Set and filmed at Kennedy Space Center, the series ran for one season in the mid 1990s.

Consumer Culture

The enduring popularity of the Space Shuttle extended beyond film and television into consumer culture. During the shuttle era, millions of people purchased goods that bore images of shuttle mission insignias and the NASA logo—pins, patches, T-shirts, polos, mugs, pens, stuffed animals, toys, and other mementos. The shuttle, a cultural icon of the space program associated with America’s progress in space, was also prominently featured on wares. Flight and launch and re-entry suits, worn by the astronauts, were particularly popular with younger children who had hopes of one day flying in space. People still bid on thousands of photos and posters signed by shuttle astronauts on Internet selling and trading sites.

Photos of the shuttle, its crews, astronaut portraits, and images of notable events in space are ubiquitous.



Chiaki Mukai, MD, PhD

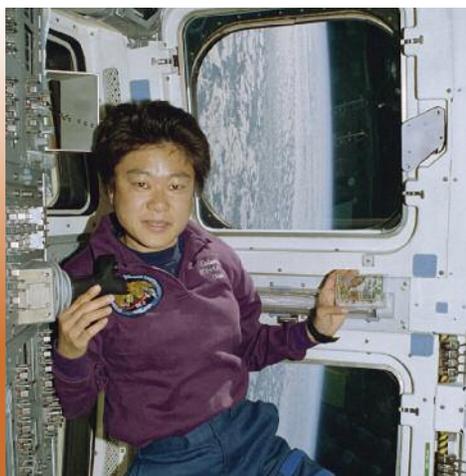
Japanese astronaut.

Payload specialist on STS-65 (1994) and STS-95 (1998).

Deputy mission scientist for STS-107 (2003).

My Space Shuttle Memory

“From the mid 1980s to 2003, I worked for the space program as a Japanese astronaut. This was the golden time of Space Shuttle utilization for science. Spacelab missions, which supported diverse fields of research, were consecutively scheduled and conducted. The science communities were so busy and excited. I flew two times (STS-65/IML [International Microgravity Laboratory]-2 and STS-95) and worked as an alternate crew member for two other science missions (STS-47 and STS-90). On my last assignment, I was a deputy mission scientist for the STS-107 science mission on board the Space Shuttle Columbia. I really enjoyed working with many motivated people for those missions. I treasure these memories. Among the many photographs taken during my time as an astronaut, I have one favorite sentimental picture. The picture was taken from the ground showing STS-65, Columbia, making its final approach to Kennedy Space Center. The classic line of the shuttle is clearly illuminated by the full moon softly glowing in the dawn’s early light. When I see this photo, I cannot believe that I was actually on board the Columbia at that moment. It makes me feel like everything that happened to me was in a dream.



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The Space Shuttle Program enabled me to leave the Earth and to expand my professional activities into space. My dream of ‘Living and working in space’ has been truly realized. Thanks to the enormous capacity of human and cargo transportation made by the Space Shuttles between Earth and space, people can now feel that ‘Space is reachable and that it is ours.’ I want to thank the dedicated people responsible for making this successful program happen. The spirit of the Space Shuttle will surely live on, inspiring future generations to continue using the International Space Station and to go beyond.”

They can be found in books, magazines, calendars, catalogs, on television news broadcasts, and on numerous non-NASA Web sites. They adorn the walls of offices and homes across the world. One of the most famous images captures the historic spacewalk of Astronaut Bruce McCandless in the Manned Maneuvering Unit set against the blackness of space. Another

well-known photo, taken by the crew of STS-107 (2003), features the moon in a haze of blue.

Tourism

The Space Shuttle attracted vacationing travelers from the beginning of the program. Tourists from across the country and globe flocked to Florida to

witness the launch and landing of the shuttle, and also drove to California, where the shuttle sometimes landed. Kennedy Space Center’s Visitor Complex in Florida and the US Space and Rocket Center in Alabama welcome millions of sightseers each year—people who hope to learn more about the nation’s human spaceflight program. Visitors at Kennedy Space Center have



the unique opportunity to experience the thrill of a simulated launch on the Shuttle Launch Experience, with veteran shuttle Astronaut Bolden walking riders through the launch sequence. Others visit Space Center Houston in Texas and the Smithsonian’s Udvar-Hazy Center in Virginia, the latter of which includes the Enterprise, the first Space Shuttle Orbiter rolled out in 1976.

One need only visit the areas surrounding the space centers to see the ties that bind NASA’s longest-running program with their local and state communities. In the Clear Lake area (Texas), McDonald’s restaurant attracted visitors by placing a larger-than-life astronaut model donned in a shuttle-era spacesuit on top of the roof. A mock Space Shuttle sits on the lawn of Cape Canaveral’s city hall. Proud of its ties to the space program, Florida featured the shuttle on the state quarter released by the US Mint in 2004; Texas, by contrast, included the Space Shuttle on its state license plates.

Summary

For nearly 30 years, longer than the flights of Mercury, Gemini, Apollo, and Skylab combined, the Space Shuttle—the world’s most complex spacecraft at the time—had a tremendous influence on all aspects of American culture. Television programs and motion pictures featured real-life and imaginary Space Shuttle astronauts; children, entertained by these programs and films, dreamed of a future at NASA. Twenty-five years after Sally Ride’s first flight, thousands of girls—who were not even born at the time of her launch—joined Sally Ride’s Science Club, inspired by her career as the first American woman in space.



Brewster Shaw
Colonel, US Air Force (retired).
Pilot on STS-9 (1983).
Commander on STS-61B (1985)
and STS-28 (1989).

Space Is For Everyone

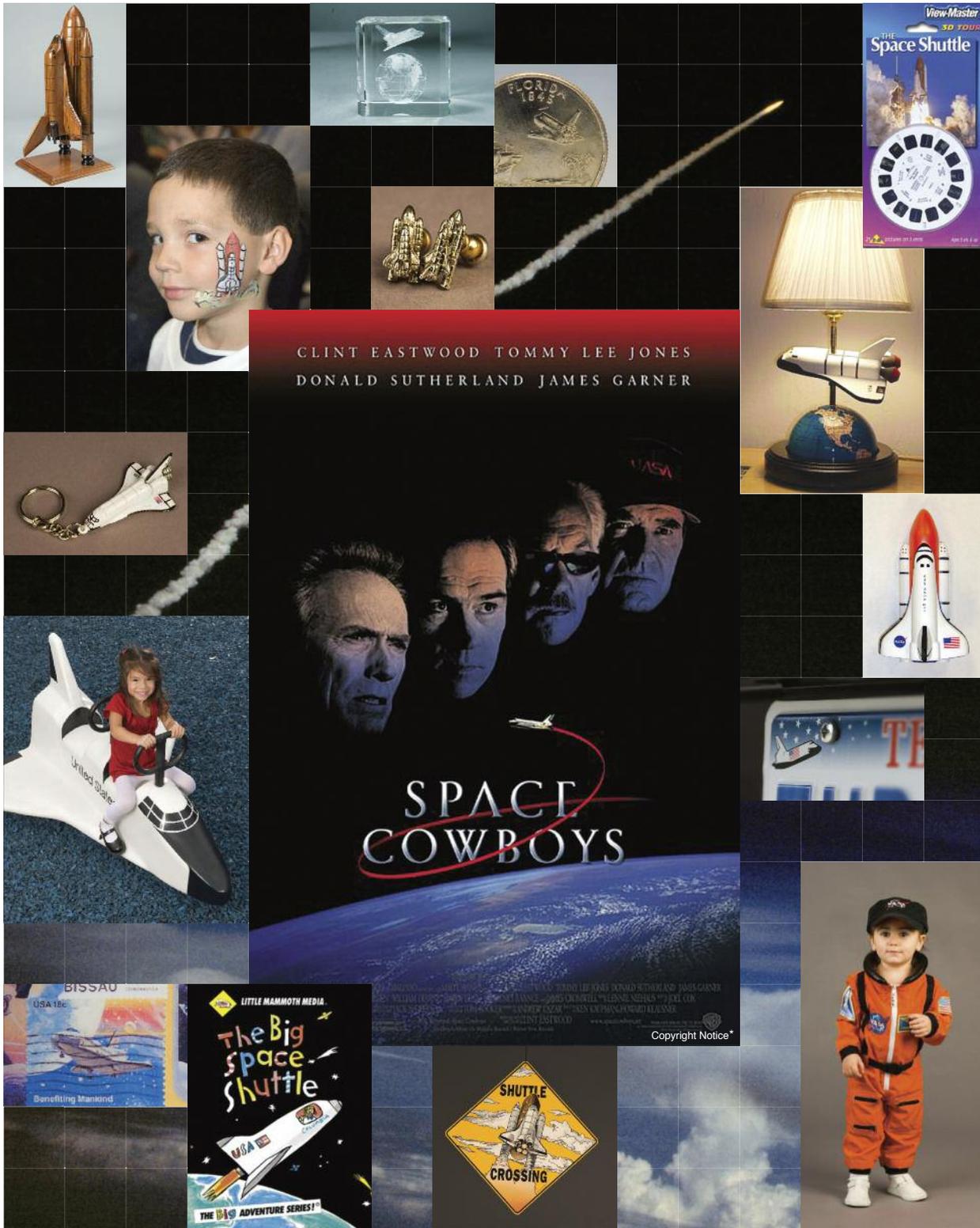
“I was on STS-9 and we had waved off several revs before landing in California. My wife joined me after the postflight conference. I asked her what she thought. She replied that I said ‘Space is for everyone.’ I have reflected on that. I remember looking out the back window of the shuttle and looking at Earth as it passed by very quickly. I marveled at the fact the human brain has developed the capability to lift 250,000 pounds of mass into orbit and is flying around at the orbital velocity of 17,500 miles per hour—what an accomplishment of mankind! Looking at Earth from that vantage point made me realize that there are a lot of people on Earth who would give their arm and a leg to be where I am! Here I was a 30-something macho test pilot and I was humbled!

“Suddenly it occurred to me how privileged I was to be here in space! It was a revelation. I had no more right than any other human being to be here—I was just luckier than they were. There I realized that space is for everyone! I decided to dedicate my career to helping as many humans as possible experience what I was experiencing.”

An Expansive Legacy

The Space Shuttle became an “icon” not only for the capabilities and technological beauty of the vehicles, but also for the positive changes NASA ultimately embraced and further championed. Through the efforts of those who recognized the need for diversity in the workplace, the Space Shuttle Program was ultimately weaved into the fabric of our nation—on both a social and a cultural level. The expansion of

opportunities for women, minorities, industry, and international partners in the exploration of the universe not only benefitted those individuals who had the most to gain; the expansion also made the program an even greater success because of each individual’s unique and highly qualified contributions. No longer regarded as a “manned” spaceflight in the most literal sense of the term, the shuttle ushered in a new era of “human” spaceflight that is here to stay.



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Education: Inspiring Students as Only NASA Can

Introduction

Helen Lane
Kamlesh Lulla

The Challenger Center

June Scobee Rodgers

The Michael P. Anderson Engineering Outreach Project

Marilyn Lewis

Long-distance Calls from Space

Cynthia McArthur

Project Starshine

Gilbert Moore

Earth Knowledge Acquired by Middle School Students

Sally Ride
Kamlesh Lulla

Toys in Space

Carolyn Sumners
Helen Lane
Kamlesh Lulla

Flight Experiments

Dan Caron
John Vellinger

Spaceflight Science and the Classroom

Jeffery Cross

Teachers Learn About Human Spaceflight

Susan White

College Education

Undergraduate Engineering Education

Aaron Cohen

Graduate Student Science Education

Iwan Alexander

NASA's commitment to education is played out with the Space Shuttle, but why?

“And to this end nothing inspires young would-be scientists and engineers like space and dinosaurs—and we are noticeably short of the latter.”

— Norman Augustine, former president and CEO of Lockheed Martin Corporation

Every Space Shuttle mission was an education mission as astronauts always took the time, while in orbit, to engage students in some kind of education activity. In fact, the shuttle served as a classroom in orbit on many missions.

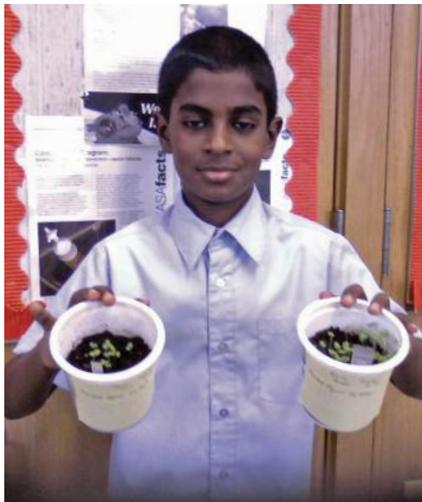
Of the more than 130 flights, 59 included planned student activities. Students, usually as part of a classroom, participated in downlinks through ham radio (early in the program) to video links, and interacted with flight crews. Students asked lots of questions about living and working in space, and also about sleep and food, astronomy, Earth observations, planetary science, and beyond. Some insightful questions included: Do stars sparkle in space? Why do you exercise in space?

Through student involvement programs such as Get Away Specials, housed in the shuttle payload bay, individual students and classes proposed research. If selected, their research flew on the shuttle as a payload. Students also used the astronaut handheld and digital-camera photos for various research projects such as geology, weather, and environmental sciences in a program called KidSat (later renamed Earth Knowledge Acquired by Middle School Students [EarthKAM]). Teacher materials supported classroom EarthKAM projects. Concepts of physics were brought to life during Toys in Space payload flights. Playing with various common toys demonstrated basic physics concepts, and teacher materials for classroom activities were provided along with the video from spaceflight. Not all education projects were this specific, however. Starshine—a satellite partially built by middle school students and launched from the shuttle payload—provided data for scientific analysis completed by students from all over the world. In fact, most of the scientific missions contained student components. Students usually learned about research from the principal investigators, and some of the classrooms had parallel ground-based experiments. Teacher workshops provided instruction on how to use the space program for classrooms.



The Space Shuttle became a true focus for education when President Ronald Reagan announced the Teacher in Space Program in 1984. Of course, the pinnacle of NASA's educational involvement was the selection of Astronaut Christa McAuliffe, first teacher in space. Although her flight was cut short (Challenger accident in 1986), she inspired the nation's educators. Created as a legacy of the Challenger crew by June Scobee, Challenger Centers focus on scientific and engineering hands-on education to continue NASA's dedication to education. Barbara Morgan, the backup to Christa, flew 11 years later as the educator astronaut on Space Transportation System (STS)-118 (2007), and this program continues. From the Columbia accident (2003), the education legacy continued with the establishment of the Michael P. Anderson Engineering Outreach Project in Huntsville, Alabama, to promote education of minority students through hands-on science and engineering.

Educational activities were, indeed, an integral part of the Space Shuttle Program.



Sivaker Strithar, fifth-grade student at the Harry Eichler School, New York City Public School 56Q, compares the growth of seeds flown on the Space Shuttle with earthbound control seeds. NASA flew 10 million basil seeds on STS-118 (2007) to mark the flight of the first educator and mission specialist, Barbara Morgan. The seeds were distributed to students and educators throughout the country.



Donald Thomas, PhD
Astronaut on STS-65 (1994), STS-70 (1995), STS-83 (1997), and STS-94 (1997).

"The Space Shuttle has without a doubt demonstrated remarkable engineering and scientific

achievement, but I believe an even more impressive accomplishment and enduring legacy will be its achievements in the field of education. The Space Shuttle was not just another space program that students were able to watch 'from the sidelines.' It was a program in which they could participate first-hand, speaking directly with the astronauts and performing their own original research in space with experiments like SEEDS, SAREX**, and many more. For the first time we made access to space available to the classroom, and many teachers and students from across the country and around the world were able to participate. Since its first flight in 1981, the Space Shuttle, its crews, and the NASA team have inspired a whole generation of students. By exciting them and motivating them to work hard in the STEM (Science, Technology, Engineering, and Mathematics) disciplines, the Space Shuttle Program has helped prepare this next generation of scientists and engineers to take over the torch of exploration as we move from the Space Shuttle to Orion*** and resume our exploration of the moon, Mars, and beyond."*

**SEEDS—Space Exposed Experiment Developed for Students*

***SAREX—Space Shuttle Amateur Radio Experiment*

****Crew Exploration Vehicle named Orion*

Kindergarten Through 12th Grade Education Programs

The Challenger Center

The Challenger Center for Space Science Education, created by the families of the Space Shuttle Challenger astronauts, is an outstanding example of how a tragic event can be transformed into a positive force for educational achievement across the nation.



Christa McAuliffe, payload specialist and first Teacher in Space, trains on shuttle treadmill for Challenger flight STS-51L. The Challenger accident occurred on January 28, 1986.

Education became the primary focus of the Challenger STS-51L (1986) mission as teacher Christa McAuliffe was to use the shuttle as a “classroom in space” to deliver lessons to children around the world. It was to be the ultimate field trip of discovery and exploration; however, the Space Shuttle Challenger and her crew perished shortly after liftoff, and the vision for education and exploration was not realized.

The goal of the Challenger Center and its international network of Challenger

Learning Centers is to carry on the mission of Space Shuttle Challenger and continue “Inspiring, Exploring, Learning” for the next generation of space pioneers and teachers.

Since its inception in 1986, the Challenger Center has reached more than 8 million students and teachers through its 53 centers scattered across the globe. Using simulation in a Mission Control Center and space station environment, expert teachers foster learning in science, mathematics, engineering, and technology. In fact, each year, more than 500,000 students and 25,000 educators experience hands-on learning in those disciplines. The Challenger Center simulators provide cooperative learning, problem solving, decision making, and teamwork—all key ingredients of any successful mission. This experiential learning is structured to support the National Science Education Standards as well as national standards in mathematics, geography, technology, and language arts. Using “Mission to Planet Earth” as one of the themes, the center also inculcates, in young minds an awareness of global environmental issues.

The centers offer a wholesome, integrated, and engaging learning environment. It is truly an authentic science- and mathematics-based learning approach that grabs students’ attention, engages them to develop problem-solving skills, and provides satisfaction of accomplishing a tough mission during a team effort that takes them to the moon, Mars, or even Jupiter.

Educators wholeheartedly support this learning environment. For example, the State Board of Education in Virginia considered the Challenger Center model to be highly effective, and the US Department of Education cited the center as significantly impacting science literacy in the country.



Students at a Challenger Center learning about shuttle science by working in a glove box.

A former governor of Kentucky requested three Challenger Learning Centers for his state to improve the science literacy of Kentucky’s youth population. Police officials in Canada created a Challenger Center as a gift to the youth for nontraditional outreach uses. Other youth groups, such as the Girl Scout and Boy Scout organizations, also participated.

Tomorrow’s aerospace and scientific workforce and the destiny of our nation’s space exploration leadership are being shaped in Challenger Learning Centers across our nation. This is a powerful educational bridge that the Space Shuttle helped build for “teaching and touching the future.”

The Michael P. Anderson Engineering Outreach Project

The Michael P. Anderson Engineering Outreach Project is part of the educational legacy of the Space Shuttle. Named for Columbia Astronaut Michael Anderson (who lost his life in the accident), the project seeks to engage underserved high school students in engineering design challenges in aerospace, civil, mechanical, and electrical engineering so these students become aware of engineering career options. Participating students learn about the life and accomplishments of Anderson, and they see him as a role model.



Astronaut Michael Anderson (Lieutenant Colonel, US Air Force) flew on STS-89 (1998) and then on the ill-fated Columbia (STS-107 [2003]).

The objectives are to inspire students to prepare for college by taking more advanced mathematics courses along with improved problem-solving skills, and by learning more about the field of engineering. Parents are involved in helping plan their child's academic career in science, mathematics, or engineering.

Students participate in a 3-week training program each summer. Alabama A&M School of Engineering faculty and NASA employees serve as students' leaders and mentors. At the end, the students present their engineering and mathematics projects. The curriculum and management design are disseminated from these activities to other minority-serving institutions.



Michael P. Anderson Project students Alecea Kendall, a tenth-grade New Century Technology student, and Hilton Crenshaw, a tenth-grade Lee High student, work as a team to assemble their LEGO NXT Mindstorm robot.

Long-distance Calls from Space

Students and teachers have friends in high places, and they often chat with them during shuttle missions. In November 1983, Astronaut Owen Garriott carried a handheld ham radio aboard Space Shuttle Columbia. The ham radio contacts evolved into the Space Shuttle Amateur Radio Experiment, which provided students with the opportunity to talk with shuttle astronauts while the astronauts orbited the Earth. Ham radio contacts moved from shuttle to the International Space Station, and this activity has

transitioned to amateur radio on board the International Space Station. In addition to ham radio contacts, students and teachers participated in live in-flight education downlinks that included live video of the astronauts on orbit. The 20-minute downlinks provided a unique learning opportunity for students to exchange ideas with astronauts and watch demonstrations in a microgravity environment. Ham radio contacts and in-flight education downlinks allowed more than 6 million students to experience a personal connection with space exploration.

Astronauts Speak to Students Through Direct Downlink



The STS-118 (2007) crew answering a student's question.



Elementary school student asking the crew a question.



Student watching the downlink for STS-118.

Students participated in in-flight education downlinks that included live video of the astronauts on orbit. Students asked questions and exchanged ideas with astronauts.

Project Starshine

Project Starshine engaged approximately 120,000 students in more than 4,000 schools in 43 countries.

NASA deployed reflective spherical student satellites from two separate shuttle missions—STS-96 (1999) and STS-108 (2001). NASA had flown a third satellite on an expendable launch vehicle mission, and a fourth satellite was manifested on a shuttle mission but later cancelled following the Columbia accident (STS-107 [2003]). A coalition of volunteer organizations and individuals in the United States and Canada built the satellites. Each satellite was covered by approximately 1,000 small front-surface aluminum mirrors that were machined by technology students in Utah and polished by tens of thousands of students in schools and other participating organizations around the world. During the orbital lifetime of the satellites, faint sunlight flashes from their student-polished mirrors were visible to the naked eye during certain morning and evening twilight periods. The student observers



Students in the Young Astronauts/Astronomy Club at Weber Middle School in Port Washington, New York, proudly display a set of mirrors destined for Starshine.

measured the satellites' right ascension and declination by reference to known stars, and they recorded the precise timing of their observations through the use of stopwatches synchronized with Internet time signals. They used global positioning satellite receivers or US Geological Survey 7.5-minute quadrangle maps, or their equivalents in other countries, to measure the latitude, longitude, and altitude of their observing sites. They posted their observations and station locations on the Starshine Web site.



Launching Starshine satellite from Endeavour's payload bay during STS-108 (2001).

As an example of Project Starshine, children in the Young Astronauts/Astronomy Club at Weber Middle School in Port Washington, New York, contributed to the project.

“The club members arrived at school at 7:30 a.m. every day to make sure the project would be completed on time. They worked diligently and followed instructions to the letter,” said their science teacher, Cheryl Dodes.

Earth Knowledge Acquired by Middle School Students

How does one inspire school students to pursue science and engineering? Imagine creating an opportunity for students to participate in space operations during real Space Shuttle flights.

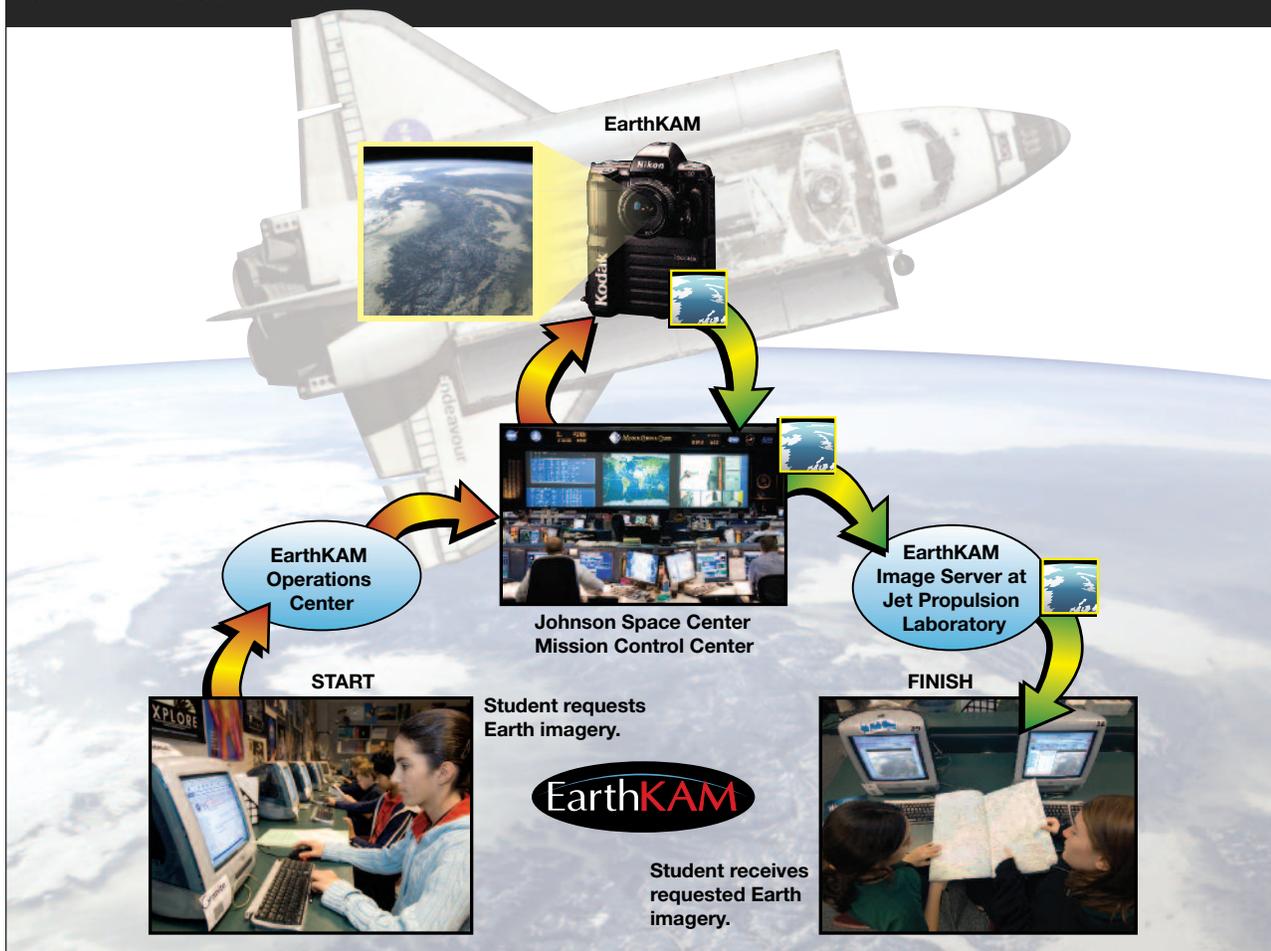
The brainchild of Dr. Sally Ride—first American woman in space—the **Earth Knowledge Acquired by Middle School Students (EarthKAM)** education program, sponsored by NASA, gives students “hands-on” experience in space operations. During the Space Shuttle Program, NASA’s EarthKAM was the next best thing to being on board for junior scientists.

The idea is as simple as it is elegant: by installing a NASA camera on board a spacecraft, middle school students across the United States and abroad had front-row seats on a space mission. They used images to study Earth science and other science disciplines by examining river deltas, deforestation, and agriculture. The hardware consisted of an electronic still camera and a laptop that was set up by an astronaut and then operated remotely from the ground with imaging requests coming directly from the students.

While this hands-on, science-immersive learning was cool for kids, the high-tech appeal was based on proper science



Students as Virtual Astronauts



Students on Earth obtained photos from orbit by using computers to request images of specific locations from the Earth Knowledge Acquired by Middle School Students (EarthKAM) on the Space Shuttle.

methods. Students prepared a solid research proposal outlining the topic they wanted to study. The program was similar to a time-share facility. Schools were to take a certain number of photographs. During the Space Shuttle Program, students set up a 24-hour classroom Mission Control operation to track the shuttle's orbit. By calculating latitude and longitude, they followed the shuttle's route and monitored weather conditions. After choosing photo targets, students relayed

those instructions over the Internet to University of California at San Diego operations unit. Undergraduate volunteers wrote the code that instructed the camera when to acquire imagery. The students received their photo images back through the Web site and began analyzing their data.

Since its first launch in 1996, EarthKAM flew on six shuttle missions and now continues operations on the International Space Station. To date, more than 73,000 students from 1,200 schools in

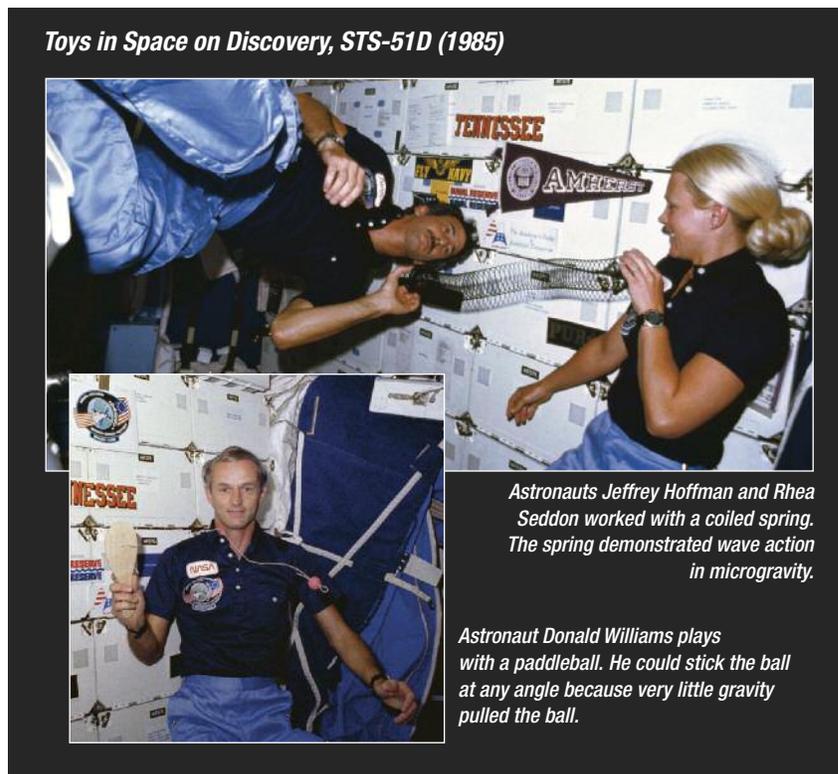
17 countries have participated in the program. This exciting adventure of Earth exploration from space is a great hit at schools all over the globe. While youngsters can learn latitude, longitude, and geography from a textbook, when their lesson comes first-hand from the Space Shuttle, they really pay attention. "In 20 years of teaching," says Sierra Vista Middle School (California) teacher Mark Sontag, "EarthKAM is by far the most valuable experience I've ever done with kids."

Toys in Space: Innovative Ways to Teach the Mechanics of Motion in Microgravity

Toys are the technology of childhood. They are tools designed to be engaging and fun, yet their behaviors on Earth and on orbit can illustrate science, engineering, and technology concepts for children of all ages. The STS-51D (1985) crew carried the first 11 toys into orbit. The STS-54 mission (1993) returned with some of those toys and added 29 more. The STS-77 (1996) mission crew returned with 10 of the STS-54 toys that had not been tested in space. For all these missions, crews also carried along the questions of curious children, teachers, and parents who had suggested toy experiments and predicted possible results. A few dozen toys and a few hours of the crew members' free time brought the experience of free fall and an understanding of gravity's pull to students of all ages.

Toys included acrobats (showing the positive and negative roles of gravity in earthbound gymnastics)—toy planes, helicopters, cars, and submarines (action-reaction in action), spinning tops, yo-yos, and boomerangs (all conserving angular momentum), magnetic marbles and coiled-spring jumpers (conserving energy), and the complex interplay of friction and Newton's Laws in sports, from basketball and soccer to horseshoes, darts, jacks, Lacrosse, and jump rope.

Toys are familiar, friendly, and fun—three adjectives rarely associated with physics lessons. Toys are also subject to gravity's downward pull, which often stops their most interesting behaviors. Crew members volunteered to perform toy experiments on orbit where gravity's tug would no longer affect toy activities. Toy behaviors on Earth and in space



Astronauts Jeffrey Hoffman and Rhea Seddon worked with a coiled spring. The spring demonstrated wave action in microgravity.

Astronaut Donald Williams plays with a paddleball. He could stick the ball at any angle because very little gravity pulled the ball.

could then be compared to show how gravity shapes the motions of toys and of all other moving objects held to the Earth's surface.

The toys were housed at the Houston Museum of Natural Science after flights. A paper airplane toy used during the flight of US Senator Jake Garn (shuttle payload specialist) was displayed at the Smithsonian Air and Space Museum in Washington DC. McGraw-Hill published two books for teachers on using the Toys in Space Program in the classroom. NASA created a DVD on the International Toys in Space Program with the other Toys in Space videos included. The DVD also provided curriculum guides for all of the toys that traveled into space.

The Toys in Space Program integrated science, engineering, and technology.

The National Science Education Standards recognized that scientists and engineers often work in teams on a project. With this program, students were technicians and engineers as they constructed and evaluated toys. They became scientists as they experimented with toys and predicted toy behaviors in space. Finally, they returned to an engineering perspective as they thought about modifying toys to work better in space or about designing new toys for space. Designing for space taught students that technical designs have constraints (such as the shuttle's packing requirements) and that perfect solutions are often not realistic. Space toys, like space tools, had to work in a new and unfamiliar environment. Ultimately, however, Toys in Space was about discovering how things work on Spaceship Earth.



Flight Experiments: Students Fly Research Projects in Payload Bay

The Space Shuttle provided the perfect vehicle for students and teachers to fly experiments in microgravity. Students, from elementary to college, participated in the Self-Contained Payload Program—popularly named Get Away Specials—and the Space Experiment Modules Program. These students experienced the wonders of space.

Get Away Specials

Get Away Specials were well suited to colleges and universities that wished for their students to work through the engineering process to design and build the hardware necessary to meet criteria and safety standards required to fly aboard the shuttle. Students, along with their schools, proposed research projects that met NASA-imposed standards, such as requiring that the experiment fit in the standard container, which could be no heavier than 91 kg (200 pounds), have scientific intent, and be safe. For biological experiments, only insects that could survive 60 to 90 days were allowed. The payload had to be self-contained, require no more than six crew operations, and be self-powered (not relying on the Orbiter’s electricity). The payload bay was in the vacuum and thermal conditions of spaceflight, so meeting these goals was difficult.

DuVal High School (Lanham, Maryland) students look inside a Get Away Special canister to see whether any of the roaches survived spaceflight.



DuVal High School in Lanham, Maryland, however, did experience success with their experiment—Get Away Special 238, which flew on STS-95 (1998). The National Capital Section of the American Institute of Aeronautics and Astronautics, a professional society, and the school district (through fund-raisers) financed this project.

From day one, the students wished to fly a biological experiment and debated whether to select termites or cockroaches since both could survive in a dark, damp environment. Once a decision was made, DuVal’s project became known as the Roach MOTEL—an acronym for Microgravity Opportunity To Enhance Learning. The insects included three adults, three nymphs, and three egg cases sealed in separate compartments of a habitat inside a Get Away Special can that had sufficient life support systems for a journey into space and back—a journey lasting no longer than 6 months. The students expected the roaches to carry out all life functions (including reproduction) and return alive. The project stretched on for more than 7 years while students and teachers entered and left the program. The two factors that finally brought the project to completion were a team of administrators and teachers that was

determined to see it through and NASA’s relaxation of the dry nitrogen/dry air purge of the canister. The ability to seal the Get Away Special can with ambient air was the key to success for this experiment. Over the course of 7 years, 75 adults from 16 companies and organizations assisted with the project. Seventy-seven students were directly involved with engineering solutions to the many problems, while hundreds of other students were exposed to the project. Two roaches survived, and the egg cases never hatched.

Nelson Columbano, one of the students, described the experience as follows:

“I was involved with the Get Away Specials Program at DuVal High School in Lanham, Maryland, in 1996/97. Our project involved designing a habitat for insects (roaches) to survive in orbit for several days. I can’t say the actual experiment is something I’m particularly proud of, but the indirect experiences and side projects associated with planning, designing, and building such a complex habitat were easily the most enriching part of my high school experience. The Get Away Specials Program introduced me to many aerospace industry consultants who volunteered to work with the class. It also presented me with real-world challenges like calling vendors for quotes, interviewing experts in person and over the phone, evaluating mechanical and electrical devices for the project and other activities that gave me a glimpse of what it’s like to interface with industry professionals. At the end of the school year, some of the consultants came back to interview students for summer internships. I was lucky to receive an offer with Computer



Sciences Corporation, 11 years later becoming the proud IT Project Manager. I often think about how different my career path may have been without the Get Away Specials Program and all of the doors it opened for me.”

The Get Away Specials Program was successful for both high school and university students. Over the years, it changed to the Space Experiment Module Program, which simplified the process for students and teachers.

Space Experiment Modules

To reduce costs to get more students involved, NASA developed the Space Experiment Module Program since much of the engineering to power and control experiments was done for the students. Space Experiment Module experiments, packaged 10 modules to a payload canister, varied from active (requiring power) to passive (no power). Since no cost was involved, students in kindergarten as well as college students proposed projects. During the mid 1990s, 50 teachers from the northeastern United States, participating in the NASA Educational Workshops at Goddard Space Flight Center and Wallops Flight Facility, designed Space Experiment Modules with activities for their students. During this 2-week workshop, teachers learned about the engineering design process and designed module hardware, completed the activities with their students, and submitted their experiment for consideration. One of the Get Away Special cans on STS-88 (1998) contained a number of Space Experiment Module experiments from NASA Educational Workshops participants. Students and teachers

attended integration and de-integration activities as well as the launch.

Martin Crapnell, a retired technology education teacher who attended one of the NASA Educational Workshop sessions, explained.

“Experiencing the tours, briefings, and launch were once-in-a-lifetime experiences. I tried to convey that excitement to my students. The Space Experiment Modules and NASA Educational Workshops experience allowed me to share many things with my students, such as the physics of the thrust at launch and the ‘twang’ of the shuttle, long-term space travel and the need for food (Space Experiment Modules/Mars Lunchbox), spin-offs that became life-saving diagnostics and treatments (especially mine), job opportunities, and manufacturing and equipment that was similar to our Technology Lab.

“Even though delays in receiving all of the Space Experiment Modules materials affected the successful completion we desired, I believe I was able to share the experience and create more excitement and understanding among the students as a result of the attempt. The Space Experiment Modules and NASA Educational Workshops experiences allowed relevant transfer to lab and life experiences.”

A Nutty Experiment of Interest

One of the many experiments conducted by students during the Space Shuttle Program was to determine the effects of microgravity and temperature extremes on various brands of peanut butter. Students microscopically examined the peanut butters, measured their viscosity,

and conducted qualitative visual, spreadability, and aroma tests on the samples before and after flight. The students from Tuttle Middle School, South Burlington, Vermont, and The Gilbert School, Winsted, Connecticut, called this research “a nutty idea.”

Students Go On to Careers in Engineering

John Vellinger, executive vice president and chief operating officer of Techshot, Inc. (Greenville, Indiana), is an example of how one participating student secured a career in engineering.

As an eighth-grade student in Lafayette, Indiana, Vellinger had an idea for a science project—to send chicken eggs into space to study the effects of microgravity on embryo development. Vellinger entered his project in a science competition called the Shuttle Student Involvement Program, sponsored by NASA and the National Science Teachers Association.

In 1985, after Vellinger’s freshman year at Purdue University, NASA paired him with Techshot, Inc. co-founder Mark Deuser who was working as an engineer at Kentucky Fried Chicken (KFC). Through a grant from KFC, Deuser and Vellinger set out to develop a flight-ready egg incubator.

By early 1986, their completed “Chix in Space” hardware was launched aboard Space Shuttle Challenger on its ill-fated STS-51L (1986) mission. Regrouping after the tragic loss of the shuttle, its crew, and the Chix in Space incubator, Deuser and Vellinger continued to develop the payload for a subsequent flight. Together, the pair designed, fabricated,



and integrated the flight hardware, coordinated the project with NASA, and assisted the scientific team.

More than 3 years after the Challenger accident, Chix in Space successfully reached orbit aboard Space Shuttle Discovery on mission STS-29 (1989). The results of the experiment were so significant that the project received worldwide interest from gravitational and space biologists, and it established a strong reputation for Techshot, Inc. as an innovative developer of new technologies.

Spaceflight Science and the Classroom

Can students learn from Space Shuttle science? You bet they can. To prove this point, life sciences researchers took their space research to the classroom.

Bone Experiment

STS-58 (1993), a mission dedicated to life science research, had an experiment to evaluate the role of microgravity on calcium-essential element for health. With the assistance of Lead Scientist Dr. Emily Holton, three sixth-grade classes from the San Francisco Bay Area in California conducted parallel experiments to Holton's spaceflight experiment. Research staff members traveled to the schools 10 days prior to the launch date. They discussed the process of developing the experiment and assembling the flight hardware and reviewed what was needed to include the experiment on the shuttle flight. The students conducted experiments on cucumber, lettuce, and soybean plants



Japanese Astronaut Mamoru Mohri talks to Japanese students from the aft flight deck of the Space Shuttle Endeavour during the STS-47 (1992) Spacelab-J mission.

using hydroponics—the growing of plants in nutrient solutions with or without an inert medium to provide mechanical support. Half the plants were fed a nutritionally complete food solution while the other half was fed a solution deficient in calcium. During the 2 weeks of the mission, students measured each plant's height and growth pattern and then recorded the data. Several of the students traveled to Edwards Air Force Base, California, to witness the landing of STS-58. The students analyzed their data and recorded their conclusions. The classes then visited NASA Ames Research Center, where they toured the life science labs and participated in a debriefing of their experiment with researchers and Astronaut Rhea Seddon.

Fruit Flies—How Does Their Immune System Change in Space?

Fruit flies have long been used for research by scientists worldwide because their genome has been completely mapped, their short life cycle enables multiple generations to be studied in a short amount of time, and they have many analogous processes to humans. The fruit fly experiment flew on STS-121 (2006). Its goal was to characterize the effects of space travel (including weightlessness and radiation exposure) on fruit flies' immune systems.

Middle school students (grades 5-8) were directed to a Web site to follow this experiment. The Web site provided information about current NASA space biology research, the scientific method, fruit flies, and the immune system.

Using documentation on the special site, teachers and their students conducted hands-on activities relating to this experiment. Students communicated with expert fly researchers, made predictions about the results, and asked questions of the scientists.

Frogs in Space—How Does the Tadpole Change?

In the United States and Japan’s quest to learn how life responds to the rigors of the space environment, NASA launched STS-47 (1992)—a Japanese-sponsored life science mission. The question to be answered by this mission was: How would space affect the African clawed frog’s life cycle? The life cycle of this particular frog fit nicely into this time period. Fertilized eggs were packaged in small grids, each housed in specially designed plastic cases. Some of these samples were allowed to experience microgravity during the mission, while others were placed in small centrifuges and kept at various simulated gravities between microgravity and Earth environment. The education portion of the experiment allowed student groups and teachers to learn about the frog embryology experiment by studying the adaptive development of frogs to the microgravity environment. NASA produced an education package and educational CD-ROM from this experiment.

Teachers Learn About Human Spaceflight

“Reach for your dreams, the sky is no limit,” exclaimed Educator Astronaut Barbara Morgan while encouraging teachers to facilitate their students’ discovery, learning, and sharing about human spaceflight.

The excitement of spectacular shuttle launches and on-orbit science enriched students’ learning. For 30 years, the Space Shuttle Program provided teachers around the nation an unparalleled opportunity to participate in professional development workshops—promoting students to get hooked on science, technology, engineering, and mathematics careers. Historically, NASA has focused on teachers because of their profound impact on students. The main objective of NASA teacher programs was professional development while providing numerous classroom and curriculum resources.

Exciting educator workshops with themes such as “Blastoff into Learning”

or “Ready, Set, and Launch” focused on the Space Shuttle as a classroom in space. Teachers responded enthusiastically to these initiatives.

Damien Simmons, an advanced placement physics teacher at an Illinois high school, said it best after attending a Network of Educator Astronaut Teachers workshop at the NASA Glenn Research Center in Cleveland, Ohio. “I’m taking home lessons and examples that you can’t find in textbooks. When my students see the real-world applications of physics, I hope it will lead them to pursue careers in engineering.”

Melanie Brink, another teacher honored by the Challenger Center, said, “Embracing the fundamentals of science has always been at the core of my curriculum. Preparing students to be successful young adults in the age of technology, math, and science is an exciting challenge.”

NASA continues to provide teachers opportunities to use spaceflight in their classrooms to promote education.



City of Bellflower, California, luncheon “Reaching for the Stars/Growing Together” honored teacher Pam Leestma’s second- and third-grade students for their spaceflight learning activities. Back row (left to right): Kaylin Townsend, Jerron Raye, Brendan Mire, Payton Kooi, and Rylee Winters. Front row: Julianne Bassett and teacher Pam Leestma.



Barbara Morgan

*Educator astronaut on STS-118 (2007).
Idaho teacher.*

“Inspiring and educating future scientists and engineers are major accomplishments of the Space Shuttle Program. Much of this began with the Teacher in Space Program, despite the tragic 1986 loss of Space Shuttle Challenger and her crew.

“Before Challenger, American teachers were stinging from a report, titled ‘A Nation at Risk,’ that condemned the American education system and appeared to tar all teachers with the same broad brush. Even the noble call to teaching was dismissed, by many, with the saying, ‘Those that can, do. Those who can’t, teach.’

“But NASA was the first federal agency to start to turn that around, by making a school teacher the first ‘citizen’ spaceflight participant. NASA selected a stellar representative in New Hampshire social studies teacher Christa McAuliffe, who showed what great teachers all over the country do. I was fortunate to train as Christa’s backup. Barely a day went by without NASA employees coming up to us to tell us about those teachers who had made a difference for them. We felt that Teacher in Space was more than just a national recognition of good teaching; it was also a display of gratitude by hundreds of NASA employees.

“Thousands of teachers gathered their students to watch Christa launch on board Challenger. The tragic accident shook all of us to the core. But for me, the pain was partly salved by what I saw in the reactions of many to the tragedy. Instead of defeatism and gloom, I heard many people say that they’d fly on the next Space Shuttle ‘in a heartbeat.’ Others told me how Challenger had inspired them to take bold risks in their own lives—to go back to college or to go into teaching. Also, 112 Teacher in Space finalists made lasting contributions to aerospace education in this country. And the families of the Challenger crew created the superlative Challenger Center for Space Science Education.

“After Challenger, NASA’s education program grew in many ways, including establishing the Teaching From Space office within the Astronaut Office, and producing many astronaut-



taught lessons from orbit to school children around the world. I returned to teaching in Idaho, and continued working with NASA, half-time, until I became an astronaut candidate in 1998. I am proud that NASA later selected three more teachers to be educator astronauts. It marked the first time since the scientist astronauts were selected for Apollo that NASA had made a major change in its astronaut selection criteria.

“So, certainly, the Space Shuttle Program has made a major impact on American education and on the way teachers are seen by the public. And this brings me back to that old comment of ‘Those who can’t, teach.’ It reminds me of how, to pay tribute to those who went before, engineers and scientists are fond of quoting Sir Isaac Newton. He said, ‘I stand on the shoulders of giants.’ We teachers have a similar sense of tradition. We think of teachers who teach future teachers, who then teach their students, who go on to change the world. For example, Socrates taught Plato, who taught Aristotle, who taught Alexander the Great. So I’d like to end this little letter with a quote that far predates ‘Those who can’t, teach.’ Two millennia ago, in about 350 BC, Aristotle wrote, ‘Those who know, do. Those who understand, teach.’ Aristotle understood.

“I want to thank the Space Shuttle Program for helping teachers teach. Explore, discover, learn, and share. It is what NASA and teachers do.”



College Education

Undergraduate Engineering Education

A legacy of building the shuttle is strengthening the teaching of systems engineering to undergraduate students, especially in design courses. The shuttle could not have been designed without using specific principles. Understanding the principles of how systems engineering was used on the shuttle and then applying those principles to many other design projects greatly advanced engineering education.

Engineering science in all fields of engineering was advanced in designing the shuttle. In the fields of avionics, flight control, aerodynamics, structural analysis, materials, thermal control, and environmental control, many advances had to be made by engineers working on the Space Shuttle—advances that, in turn, were used in teaching engineering sciences and systems engineering in universities.

The basic philosophy underlying the teaching approach is that the design must be a system approach, and the entire project must be considered as a whole rather than the collection of components and subsystems. Furthermore, the life-cycle orientation addresses all phases of the system, encouraging innovative thinking from the beginning.

The use of large, complicated design projects rather than smaller, more easily completed ones forces students to think of the entire system and use advanced engineering science techniques. This was based on the fact that the shuttle itself had to use

advanced techniques during the 1970s. The emphasis on hierarchical levels provides an appreciation for the relationship among the various

functions of a system, numerous interface and integrating problems, and how the design options are essentially countless when one

Katie Gilbert

Inspired by NASA to become an aerospace engineer.



“In the school year of 2000, NASA released an educational project for elementary-aged students. Of course, this project reached the ears of my fun-seeking fourth-grade science teacher, Mrs. Maloney. For extra credit, we were to group ourselves up and answer the critical question: What product could be sent up to space on the shuttle to make our astronauts’ lives easier?”

“For weeks, our fourth-grade selves spent hours of time creating an experiment that would answer this question. My group tested cough drops; would they still have the same effectiveness after being in zero gravity for extended periods of time? We sent it in, and months later we received a letter. Four of our school’s projects were to be sent up on the Space Shuttle Endeavour. Our projects were going to space!”

“When the time finally came, we all flew down to Florida to watch Endeavour blast off with our experiments on board. This all gave me the opportunity to visit the Kennedy Space Center, see a real Space Shuttle, and talk to actual astronauts. The entire experience was one of the most memorable of my life. With all of the excitement and fascination of the world outside of ours, I knew right then that I wanted to be an astronaut and I made it my life goal to follow my cough drops into space.

“As it turns out, cough drops are not at all affected by zero gravity or extreme temperatures. The experiment itself didn’t bring back alien life forms or magically transform our everyday home supplies into toxic space objects, but it wasn’t a complete waste. The simple experiment opened my eyes to the outside world and the possibilities that exist within it. It captivated my interest and held it for over 8 years, and the life goals I made way back then were the leading factor in choosing Purdue University to study Aerospace Engineering.”



considers all the alternatives for satisfying various functions and combinations of functions.

Also, learning to design a very complex system provides the skills to transfer this understanding to the design of any system, whereas designing a small project does not easily transfer to large systems. In addition, this approach provides traceability of the final system design as well as the individual components and subsystems back to the top-level need, and lowers the probability of overlooking an important element or elements of the design.

For designing systems engineering educational courses, general topics are addressed: the general systematic top-down design process; analysis for design; and systems engineering project management. Specific topics are: establishment and analysis of the top-level need with attention to customer desires; functional decomposition; development of a hierarchical arranged function structure; determination of functional and performance requirements; identification of interfaces and design parameters; development of conceptual designs using brainstorming and parameter analysis; selection of criteria for the evaluation of designs; trade studies and down-selection of best concept; parametric analysis; and preliminary and detailed designs. Application of engineering analysis includes the depth and detail required at various phases during the design process. Systems engineering management procedures—such as failure modes and effects analysis, interface control documents, work breakdown structures, safety and

risk analysis, cost analysis, and total quality management—are discussed and illustrated with reference to student projects.

In summary, due to NASA's efforts in systems engineering, these principles were transferred to undergraduate engineering courses.

Graduate Student Science Education

The Space Shuttle's impact on science and engineering is well documented. For scientists, the shuttle enabled the microgravity environment to be used as a tool to study fundamental processes and phenomena ranging from combustion science to biotechnology. The impact of the microgravity life and physical science research programs on graduate education should not be overlooked.

Many graduate students were involved in the thousands of experiments conducted in space and on the ground. A comparable number of undergraduates were exposed to the program. Perusal of task books for microgravity and life science programs reveals that, between 1995 and 2003, flight and microgravity research in the life and physical sciences involved an average of 744 graduate students per year. Thus, the shuttle provided thousands of young scientists with the opportunity to contribute to the design and implementation of experiments in the unique laboratory environment provided by a spacecraft in low-Earth orbit. Such experiments required not only an appreciation of a specific scientific discipline, but also an appreciation of the nature of the

microgravity and how weightlessness influences phenomena or processes under investigation.

In addition to mainstream investigations, shuttle flight opportunities such as the self-contained payloads program—Get Away Specials—benefited students and proved to be an excellent mechanism for engineering colleges and private corporations to join together in programs oriented toward the development of spaceflight hardware.

All shuttle science programs significantly enhanced graduate education in the physical and life sciences and trained students to work in interdisciplinary teams, thus contributing to US leadership in space science, space engineering, and space health-related disciplines.





Industries and Spin-offs



Industries and Spin-offs

Industries

Aerospace Industry

Jennifer Ross-Nazzari

Helen Lane

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Charles Walker

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Spin-offs

NASA Helps Strengthen

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Jennifer Fogarty

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Joel Stoltzfus

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Brad Cragun

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Pedro Medelius

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An Environmentally Friendly

Option for Shuttle Transport

Carole-Sue Feagan

Perry Becker

Daniel Drake

In the late 1960s, many of America’s aerospace companies were on the brink of economic disaster. The problems stemmed from cutbacks in the space agency’s budget and significant declines in military and commercial orders for aircraft. President Richard Nixon’s approval of the Space Shuttle Program came along just in time for an industry whose future depended on securing lucrative NASA contracts.

The competition for a piece of the new program was fierce. For the Space Shuttle Main Engines, the agency selected North American Rockwell’s Rocketdyne Division. The biggest financial contract of the program, estimated at \$2.6 billion, also went to North American Rockwell Corporation to build the Orbiter. The announcement was one bright spot in a depressed economy, and California-based Rockwell allocated work to rivals in other parts of the country. Grumman of Long Island, New York, which had built the Lunar Module, constructed the Orbiter’s wings. Fairchild Industries in Germantown, Maryland, manufactured the vertical tail fin. NASA chose Martin Marietta of Denver, Colorado, to build the External Tank, which would be manufactured at the Michoud Assembly Facility in Louisiana. Thiokol Chemical Corporation, based in Utah, won the Solid Rocket Motor contract. In addition to these giants, smaller aerospace companies played a role. Over the next 2 decades, NASA placed an increased emphasis on awarding contracts to small and minority-owned businesses, such as Cimarron Software Services Inc. (Houston, Texas), a woman-owned business.

Shuttle engineering and science sparked numerous innovations that have become commercial products called spin-offs. This section offers seven examples of such technological innovations that have been commercialized and that benefit many people. Shuttle-derived technologies, ranging from medical to industrial applications, are used by a variety of companies and institutions.



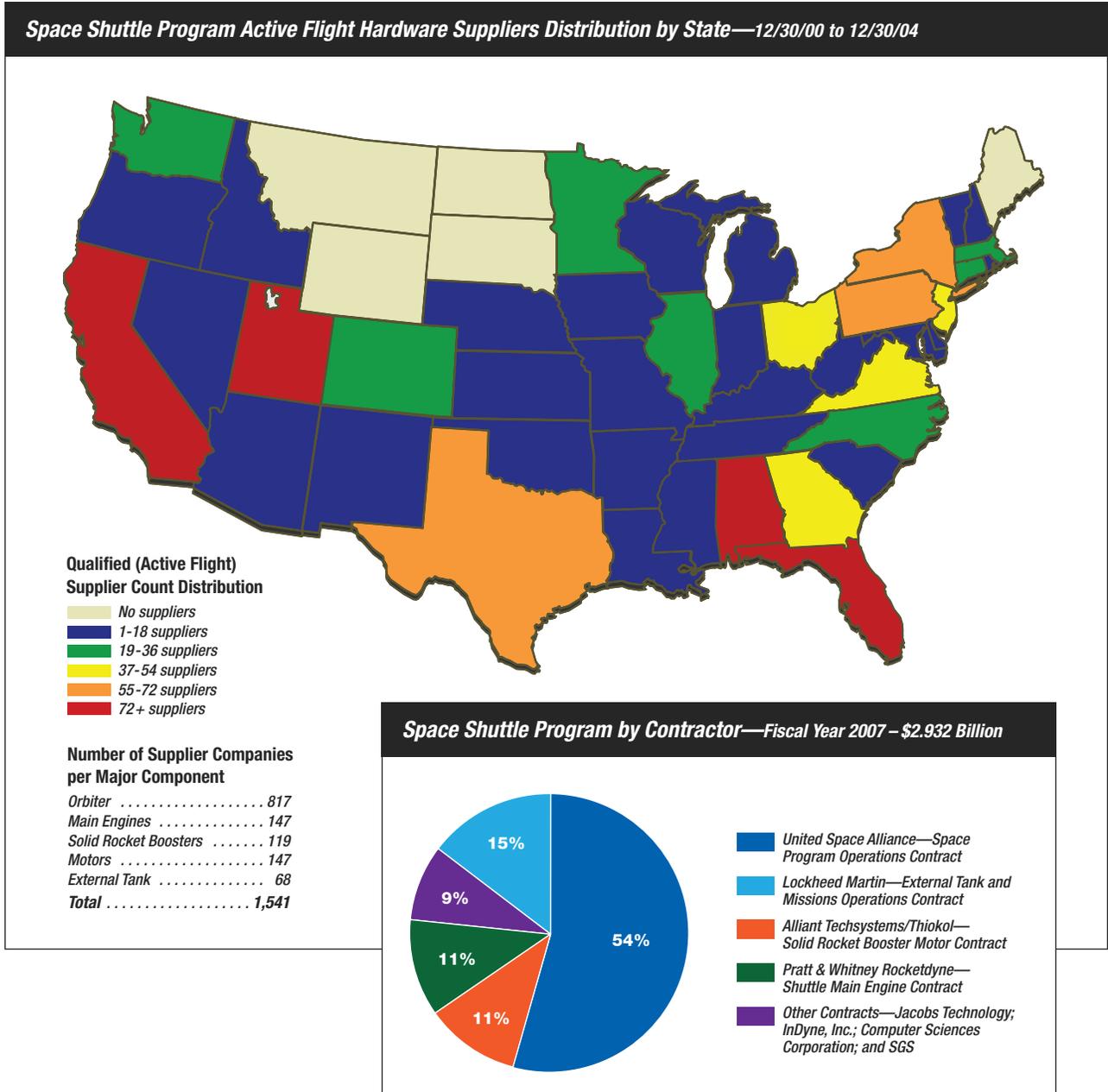
Industries

Aerospace Industry

Concurrent with the emphasis placed on reduced costs, policy makers began studying the issue of privatizing the shuttle and turning over routine

operations to the private sector. Complete and total privatization of the shuttle failed to come to fruition, but economic studies suggested that contract consolidation would simplify oversight and save funds. In 1980, NASA decided to consolidate Kennedy Space Center (KSC) contracts, and 3

years later, KSC awarded the Shuttle Processing Contract. Johnson Space Center followed KSC's lead in 1985 by awarding the Space Transportation System Operations Contract, which consolidated mission operations work. Industry giants Lockheed and Rockwell won these plums.





Wyle Laboratories, Inc. works with scientists for the payloads on Neurolab (STS-90 [1998]). The experiment shown is the kinematic, eye tracking, vertical ground reaction force study in March 2002. In the foreground are test operators Chris Miller (left) and Ann Marshburn. The test subject in the harness is Jason Richards and the spotter is Jeremy House.

NASA introduced a host of new privatization contracts in the 1990s to further increase efficiency in operations and decrease costs.

Over the years, companies provided the day-to-day engineering for the shuttle and its science payloads. For instance, Hamilton Sundstrand and ILC Dover were instrumental companies for spacesuit design and maintenance. Lockheed Martin and Jacobs Engineering provided much of the engineering needed to routinely fly the shuttle. Both Lockheed Martin and Wyle Laboratories, Inc. are examples of companies that assured the science payloads operations were successful.

Commercial Users

US industry, aerospace, and others found ways to participate in the Space Shuttle project. Hundreds of large and small companies provided NASA with hardware, software, services, and supplies. Industry also provided technical, management, and financial assistance to academia pursuing government-granted science and technology research in Earth orbit. Yet, a basic drive of industry is to develop new, profitable business.

Beginning in the late 1970s, NASA encouraged American businesses to develop profitable uses of space. This meant conceiving of privately funded, perhaps unique, products for both government and commercial customers—termed “dual use”—as well as for purely commercial consumers. While several aerospace

companies were inspired by earlier work in American space projects, a few had ideas for the use of space entirely founded in the unique characteristics of orbital spaceflight. These included launching commercial-use satellites, such as two communications satellites—Anik C-2 and Palapa BI—launched from Space Transportation System (STS)-7 (1983). The shuttle phased out launching commercial satellites after the Challenger accident in 1986.

Non-aerospace firms, such as pharmaceutical manufacturers, also became interested in developing profitable uses for space. Compared to those of previous spacecraft, the capabilities of the shuttle provided new opportunities for innovation and entrepreneurship. Private capital was invested because of these prospects: regular transport to orbit; lengthy periods of flight; and, if needed, frequent human-tended research and development. Even before the first flight of the shuttle, US private sector businesses were inquiring about the vehicle’s availability for industrial research, manufacturing, and more, in space.

During the 30-year Space Shuttle Program, companies interested in microgravity sciences provided commercial payloads, such as a latex reactor experiment performed on STS-3 (1982). These industry-funded payloads continued into the International Space Station Program.

Although the shuttle did not prove to be the best vehicle to enhance commercial research efforts, it was the stepping-stone for commercial use of spacecraft.



Small Businesses Provided Critical Services for the Space Shuttle

As of 2010, government statistics indicated that almost 85% of Americans were employed by businesses with 250 employees or fewer. Such “small businesses” are the backbone of the United States. They also play an important role in America’s space program, and were instrumental during the shuttle era. For example, the manufacture and refurbishment of Solid Rocket Motors required the dedication and commitment of many commercial suppliers. Small business provided nearly a fourth of the total dollar value of those contracts. Two examples include: Kyzen Corporation, Nashville, Tennessee; and PT Technologies, Tucker, Georgia.

Kyzen Corporation enabled NASA’s goal to eliminate ozone-depleting

chemicals by providing a cleaning solvent. This solvent, designed for precision cleaning for the electronics industry, was ideal for dissolving solid rocket propellant from the manufacturing cleaning tooling. The company instituted the rigid controls necessary to ensure product integrity and eliminate contamination.

PT Technologies manufactured precision-cleaning solvent with non-ozone-depleting chemicals. This solvent was designed for use in the telephone and electrical supply industry to clean cables. It also proved to perform well in the production of Solid Rocket Motors.

Small business enterprises are adaptive, creative, and supportive, and their partnerships with NASA have helped our nation achieve its success in space.

Spin-offs

NASA Helps Strengthen the “Bridge for Heart Transplants”

Innovation can occur for many reasons. It can arise from the most unlikely places at the most unlikely times, such as at the margins of disciplines, and it can occur because the right person was at the right place at the right time. The story of David Saucier illustrates all of these points.

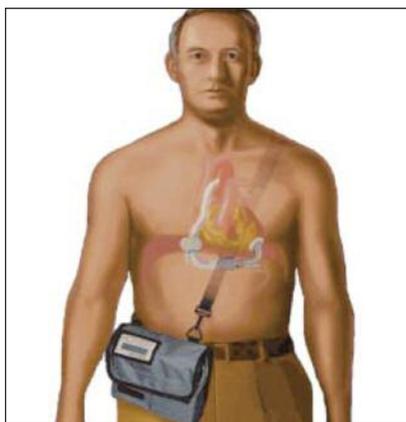
Dave Saucier sought medical care for his failing heart and received a heart transplant in 1984 from Drs. DeBakey and Noon at the DeBakey Heart Center at Baylor College of Medicine, Houston, Texas. After his transplant, Dave felt compelled to use his engineering expertise and the expertise of other engineers at Johnson Space Center (JSC) to contribute to the development of a ventricular assist device (VAD)—a project of Dr. DeBakey, Dr. Noon, and colleagues. A VAD is a device that is implanted in the body and helps propel blood from the heart throughout the body. The device was intended to be a bridge to transplant. This successful collaboration also brought in computational expertise from NASA Advanced Supercomputing Division at Ames Research Center (Moffett Field, California).

This far-reaching collaboration of some unlikely partners resulted in an efficient, lightweight VAD. VAD had successful clinical testing and is implemented in Europe for children and adults. In the United States, VAD is used in children and is being tested for adults.

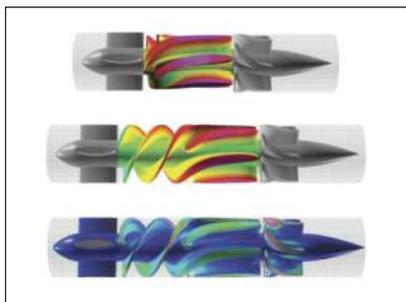


A mixing tank used to produce the cleaning solvent for dissolving solid rocket propellant at Kyzen Corporation. This solvent was free of ozone-depleting chemicals.

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The DeBakey VAD® functions as a “bridge to heart transplant” by pumping blood throughout the body to keep critically ill patients alive until a donor heart is available.



These illustrations show a visual comparison of the original ventricular assist device (top) and the unit after modifications by NASA researchers (center and bottom). Adding the NASA improvements to the MicroMed DeBakey VAD® eliminated the dangerous backflow of blood by increasing pressure and making flow more continuous. The highest pressure around the blade tips are shown in magenta. The blue/green colors illustrate lower pressures.

So, what was it that Dave Saucier and the other engineers at JSC thought they knew that could help make a VAD work better, be smaller, and help thousands of people seriously ill with heart failure and waiting for a transplant? Well, these folks had worked on and optimized the turbopumps for the shuttle main engines that happen to have requirements in common with VAD. The turbopumps needed to manage high flow rates, minimize turbulence, and eliminate air bubbles.

These are also requirements demanded of a VAD by the blood and body.

In the beginning, VADs had problems such as damaging red blood cells and having stagnant areas leading to the increased likelihood of blood clot development. Red blood cells are essential for carrying oxygen to the tissues of the body. Clots can prevent blood from getting to a tissue, resulting in lack of oxygenation and buildup of toxic waste products that lead to tissue death. Once engineers resolved the VAD-induced damage to red blood cells and clot formation, the device could enter a new realm of clinical application. In 1996 and 1999, engineers from JSC and NASA Ames Research Center and medical colleagues from the Baylor College of Medicine were awarded US patents for a method to reduce pumping damage to red blood cells and for the design of a continuous flow heart pump, respectively. Both of these were exclusively licensed to MicroMed Cardiovascular, Inc. (Houston, Texas) for the further development of the small, implantable DeBakey VAD®.

MicroMed successfully implanted the first DeBakey VAD® in 1998 in Europe and, to date, has implanted 440 VADs. MicroMed’s HeartAssist5® (the 2009 version of the DeBakey VAD®) weighs less than 100 grams (3.5 oz), is implanted in the chest cavity in the pericardial space, which reduces surgical complications such as infections, and can operate for as many as 9 hours on battery power, thereby resulting in greater patient freedom. This device not only acts as a bridge to transplant, allowing patients to live longer and better lives while waiting for a donor heart, it is now a destination therapy. People are living out their lives with the implanted device and some are even experiencing recovery, which means they can have the device explanted and not require a transplant.

Making Oxygen Systems Safe

Hospitals, ambulances, industrial complexes, and NASA all use 100% oxygen and all have experienced tragic fires in oxygen-enriched atmospheres. Such fires demonstrated the need for knowledge related to the use of materials in oxygen-enriched atmospheres. In fact, on April 18, 1980, an extravehicular mobility unit planned for use in the Space Shuttle Program was destroyed in a dramatic fire during acceptance testing. In response to these fire events, NASA developed a test method and procedures that significantly reduced the danger. The method and procedures are now national and international industrial standards. NASA White Sands Test Facility (WSTF) also offered courses on oxygen safety to industry and government agencies.

During the shuttle era, NASA made significant advances in testing and selecting materials for use in high-pressure, oxygen-enriched atmospheres. Early in the shuttle era, engineers became concerned that small metal particles could lead to ignition if the particles were entrained in the 277°C (530°F) oxygen that flowed through the shuttle’s Main Propulsion System gaseous oxygen flow control valve. After developing a particle impact test, NASA determined that the stainless-steel valve was vulnerable to particle impact ignition. Later testing revealed that a second gaseous oxygen flow control valve, fabricated from an alloy with nickel chromium, Inconel® 718, was also vulnerable to particle impact ignition. Finally, engineers showed that an alloy with nickel-copper, Monel®, was invulnerable to ignition by particle impact and consequently was flown in the Main Propulsion System from the mid 1980s onward.



The original shuttle extravehicular mobility unit with an aluminum secondary oxygen pack isolation valve and first-stage regulator ignited and burned during acceptance ground testing on an unoccupied unit in 1980 (left). The redesigned unit with a nickel-copper alloy secondary oxygen pack isolation valve and first-stage regulator is being used with much success (right).



NASA's activities led to a combustion test patent (US Patent Number 4990312) that demonstrated the superior burn resistance of a nickel-copper alloy used in the redesigned, high-pressure oxygen supply system. Member companies of the American Society for Testing and Materials (ASTM) Committee G-4 pooled their resources and requested that NASA use the promoted combustion test method to determine the relative flammability of

alloys being used in industry oxygen systems. Ultimately, this test method was standardized as ASTM G124.

NASA developed an oxygen compatibility assessment protocol to assist engineers in applying test data to the oxygen component and system designs. This protocol was codified in ASTM's Manual 36 and in the National Fire Protection Association *Fire Protection Handbook*, and has gained international acceptance.

Another significant technology transfer from the Space Shuttle Program to other industries is related to fires in medical oxygen systems. From 1995 through 2000, more than 70 fires occurred in pressure-regulating valves on oxygen cylinders used by firefighters, emergency medical responders, nurses, and therapeutic-oxygen patients. The Food and Drug Administration approached NASA and requested that a test be developed to ensure that only the most ignition- and burn-resistant, pressure-regulating valves be allowed for use in these medical systems. With the help of a forensic engineering firm in Las Cruces, New Mexico, the WSTF team developed ASTM G175, entitled *Standard Test Method for Evaluating the Ignition Sensitivity and Fault Tolerance of Oxygen Regulators Used for Medical and Emergency Applications*. Since the development and application of this test method, the occurrence of these fires has diminished dramatically.

This spin-off was a significant development of the technology and processes to control fire hazards in pressurized oxygen systems. Oxygen System Consultants, Inc., in Tulsa, Oklahoma, OXYCHECK™ Pty Ltd in Australia, and the Oxygen Safety Engineering division at Wendell Hull & Associates, Inc., in Las Cruces, New Mexico, are examples of companies that performed materials and component tests related to pressurized oxygen systems. These businesses are prime examples of successful technology transfer from the shuttle activities. Those involved in the oxygen production, distribution, and user community worldwide recognized that particle impact ignition of metal alloys in pressurized oxygen systems was a significant ignition threat.



Pretest.

This gaseous oxygen valve was found to be vulnerable to ignition when small metal particles were ingested into the valve. The test method developed for this is being used today by the aerospace and industrial oxygen communities.



Ignition by particle impact.



Preventing Land Mine Explosions—Saving Lives with Rocket Power

Every month, approximately 500 people—including civilians and children—are killed or maimed by accidental contact with land mines. Estimates indicate as many as 60 to 120 million active land mines are scattered across more than 70 countries, including areas where hostilities have ceased. Worldwide, many of the more than 473,000 surviving victims require lifelong care.

In 1990, the US Army solicited existing or short-term solutions to in-field mine neutralization with the ideal solution identified as a device that was effective, versatile, inexpensive, easy to carry, and easy to use, but not easily converted to a military weapon.

Rocket Science— An Intelligent Solution

The idea of using leftover shuttle propellant to address this humanitarian crisis can be traced back to late 1998 when shuttle contractor Thiokol (Utah) suggested that a flare, loaded with propellant, could do the job. To validate the concept, engineers tested their idea on small motors. These miniature rocket motors, no larger than a D-size battery, were used in research and development efforts for ballistics characterization. With some refinements, by late 1999, the flare evolved into a de-mining device that measures 133 mm (5 in.) in length by 26 mm (1 in.) in diameter, weighs only 90 grams (3.2 oz), and burns for approximately 60 seconds. NASA and Thiokol defined an agreement to use the excess propellant.



The Thiokol de-mining flare used excess shuttle propellant resulting from Solid Rocket Motor casting operations to burn through land mine casings and safely ignite the explosives contained within. The flares were activated with an electric match or a pyrotechnic fuse.

Ignition Without Detonation— How It Works

The de-mining flare device is ignited by an electric match or a pyrotechnic fuse; it neutralizes mines by quickly burning through the casing and igniting the explosive fill without detonation. The benefit of this process includes minimizing the destructive effect of demolition, thereby preventing shrapnel from forming out of metallic and thick-cased targets. The flares are simple and safe to use, and require minimal training. The flare tube can be mounted on a three-legged stand for better positioning against the target case.

These de-mining flares were tested against a variety of mines at various installations. These trials went well and generated much interest. Thiokol funded further development to improve production methods and ease deployment.

All branches of the US armed services have purchased the flare. It has been successfully used in Kosovo, Lebanon, Jordan, Ethiopia, Eritrea, Djibouti, Nicaragua, Iraq, and Afghanistan, and has been shown to be highly effective.

LifeShear Cutters to the Rescue—Powerful Jaws Move Life-threatening Concrete

Hi-Shear Technology Corporation of Torrance, California, used NASA-derived technology to develop a pyrotechnic-driven cutting tool that neutralized a potentially life-threatening situation in the bombed Alfred P. Murrah Federal Building in Oklahoma City, Oklahoma, in April 1995. Using Jaws of Life™ heavy-duty rescue cutters, a firefighter from the Federal Emergency Management Agency Task Force team sliced through steel reinforcing cables that suspended an 1,814.4-kg (2-ton) slab of concrete, dropping the slab six stories. It took only 30 seconds to set up and use the cutters.

The shuttle used pyrotechnic charges to release the vehicle from its hold-down posts on the launch pad, the Solid Rocket Boosters from the External Tank after their solid fuel was spent, and the tank from the shuttle just prior to orbit. This type of pyrotechnical separation technology was applied in the early 1990s to the development of a new generation of lightweight portable emergency rescue cutters for freeing accident victims from wreckage. Known as LifeShear cutters, they were developed under a cooperative agreement that teamed NASA and Hi-Shear Technology Corporation. Hi-Shear incorporated this pyrotechnic feature into their Jaws of Life™ heavy-duty rescue cutters. The development project was undertaken to meet the need of some 40,000 US fire departments for modern, low-cost emergency cutting equipment.

Hi-Shear Technology Corporation developed, manufactured, and supplied pyrotechnically actuated thrusters,



explosive bolts, pin pullers, and cutters, and supplied such equipment for a number of NASA deep-space missions plus the Apollo/Saturn, Skylab, and shuttle.

The key technology for the LifeShear cutter is a tailored power cartridge—a miniature version of the cartridges that actuated pyrotechnic separation devices aboard the shuttle. Standard cutting equipment employs expensive gasoline-powered hydraulic pumps, hoses, and cutters for use in accident extraction. The Jaws of Life™ rescue tool requires no pumps or hoses, and takes only about 30 seconds to ready for use. It can sever automotive clutch and brake pedals or cut quickly through roof posts and pillars to remove the roof of an automobile. Firefighters can clear an egress route through a building by cutting through reinforcement cable and bars in a collapsed structure situation.



NASA-developed tool, licensed under the name "LifeShear," used at the bombed Alfred P. Murrah Federal Building (1995), Oklahoma City, Oklahoma.



Kennedy Space Center engineers conduct wire fault testing using portable Standing Wave Reflectometer. From left to right: Ken Hosterman; John Jones; and Pedro Medelius (inventor).

The Ultimate Test Cable Testing Device

It's hard to imagine, when looking at a massive launch vehicle or aircraft, that a problem with one tiny wire could paralyze performance. Faults in wiring are a serious concern for the aerospace and aeronautic (commercial, military, and civil) industries. The shuttle had circuits go down because of faulty insulation on wiring. STS-93 (1999) experienced a loss of power when one engine experienced a primary power circuit failure and a second engine had a backup power circuit fault. A number of accidents occurred as a result of faulty wiring creating shorts or opens, causing the loss of control of the aircraft or arcing and leading to fires and explosions. Some of those accidents resulted in loss of lives, such as in the highly publicized TWA Flight 800 accident in 1996.

With the portable Standing Wave Reflectometer cable tester, it was possible to accurately pinpoint malfunctions within cables and wires to reliably verify conditions of electrical power and signal distribution. This included locating problems inside shuttle. One of its first applications at Kennedy Space Center (KSC) was to

detect intermittent wire failures in a cable used in the Solid Rocket Boosters.

The Standing Wave Reflectometer cable tester checked a cable with minimal disruption to the system under test. Personnel frequently had to de-mate both ends of cables when troubleshooting a potential instrument problem to verify that the cable was not the source of the problem. Once a cable was de-mated, all systems that had a wire passing through the connector had to be retested when the cable was reconnected. This resulted in many labor-hours of revalidation testing on systems that were unrelated to the original problem. The cost was exorbitant for retesting procedures. The same is true for aeronautical systems, where airplanes have to be checked frequently for faulty cables and sensors. The most useful method and advantage of the Standing Wave Reflectometer technology over other existent types of technologies is the ability to measure from one end of a cable, and to do comparative-type testing with components and avionics still installed.

Eclipse International Corporation, Corona, California, licensed and marketed two commercial versions of the Standing Wave Reflectometers



based on the prototype designed and patented by KSC. One called ESP provided technicians with a simple, plain-English response as to where the electrical fault was located from the point at which the technicians were testing. A second product, ESP+, provided added memory and software for looking at reflections from the aircraft, which was useful in determining some level of “soft fault”—faults that are not open or shorted wires.

The technology was evaluated by the US Navy, US Marines, and US Air Force to test for its ruggedness for deployment in Afghanistan. The country was known for a fine grade of sand and dusty conditions—a taxing combination rarely found in the United States. The model underwent operational evaluation by the US Navy, US Marines, and US Air Force, and the US Army put these instruments into the battle damage and repair kits that went to Afghanistan, Iraq, and other parts of the world where helicopter support is required. This innovation has proved to be versatile in saving time and lives.

The Ultimate Test

In Bagram, Afghanistan, October 2004, one particular Northrop Grumman EA-6B Prowler aircraft was exhibiting intermittent problems on a critical cockpit display panel. To make matters worse, these problems were seldom seen during troubleshooting but occurred multiple times on nearly every flight. It was a major safety problem, especially when flying at night in a war zone in mountainous terrain. Squadron maintainers had been troubleshooting for weeks, changing all associated removable components and performing wire checks with no discernable success.

After approximately 60 hours of troubleshooting, which included phone consultation with engineering and the manufacturer of the electronic system that was providing intermittent symptoms, the Naval Air Technical Data & Engineering Service Command decided to try the Standing Wave Reflectometer and immediately observed a measured change of conductor length as compared with similar paths on the same aircraft. Technicians were able to isolate the problem and replace the faulty wire.

Keeping Stored Water Safe to Drink—Microbial Check Valve

The Space Shuttle system for purifying water has helped the world’s need for safe water, especially for disaster situations, backpackers, and remote water systems where power and active monitoring were limited. This well-tested system, called the Microbial Check Valve, is also used on the International Space Station. This valve is ideal for such applications since it can be stored for a long period of time and is easily activated.

The licensee and co-inventor, with NASA, of the Microbial Check Valve was Umpqua Research Company (Myrtle Creek, Oregon). The system was used on all shuttle flights to prevent growth of pathogens in the crew drinking water supply. The valve is a flow-through cartridge containing an iodinated polymer, which provides a rapid contact microbial kill and also imparts a small quantity of dissolved iodine into the effluent stream. This prevents further microbial growth and maintains water safety.



The Microbial Check Valve—measuring 5.1 cm (2 in.) in diameter, 12.7 cm (5 in.) in length—is a stainless-steel cylinder with connections on its ends that facilitated its installation in the shuttle water system line. The cylinder is packed with iodinated ion exchange resin (the base resin is Dowex SBR®). A perforated plate backed by a spring presses against the resin and keeps it compacted to prevent short-circuiting of the water as it flows through the resin.

Treatment of uncontrolled microbial growth in stored water was essential in the shuttle because water was produced through the fuel cells of oxygen and hydrogen, and the resultant water was stored in large tanks. The shuttle was reused and, therefore, some residual water always remained in the tanks between launches. Iodine, like chlorine, prevents microbial growth, is easy to administer, and has long-life effectiveness as it is much less volatile than chlorine.

The innovation was a long-shelf-life iodinated resin. When water passed through the resin, iodine was released to produce acceptable drinking water. This system inactivated seven bacteria, yeasts and molds and three different viruses, including polio. The costs were also very reasonable.



The volume of the resin in the valve was selected to treat five 30-day shuttle equivalent missions (3,000 L [793 gal]: based on 2.8 L [0.7 gal]/day/person use rate for a seven-person crew) for the maximum shuttle fuel cell water production rate of 120 L (31.7 gal)/hr. All in-flight-produced water flowed through the microbial check valve to impart a small iodine residual to prevent microbial growth during storage and back contaminations, further contributing to the safety and purification of drinking water during shuttle missions.

“Green” Lubricant— An Environmentally Friendly Option for Shuttle Transport

In the mid 1990s, NASA uncovered an environmental problem with the material used to lubricate the system used to transport the shuttle. The agency initiated an effort to

identify an environmentally friendly lubricant as a replacement.

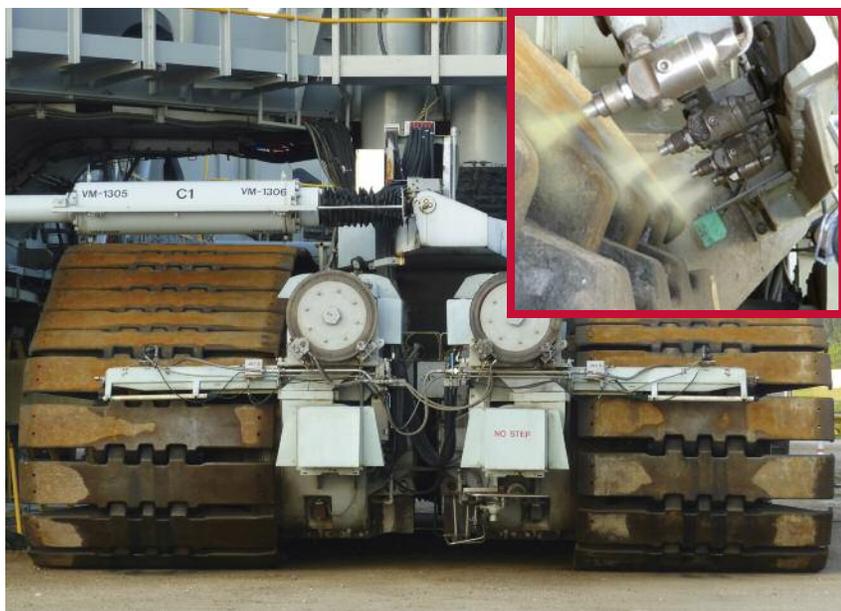
The Mobile Launcher Platform at KSC provided a transportable launch base for the shuttle. NASA used a vehicle called a “crawler” with a massive track system to transport the platform and a shuttle. During transport, lubricants had to withstand pressures as high as 5,443 metric tons (6,000 tons). Lubrication reduced wear and noise, lengthened component life, and provided protection from corrosive sand and heat.

NASA personnel injected low-viscosity lubricant on the pins that structurally linked 57 individual track “shoes” together to form an individual tread belt. Periodic application during transport minimized crankshafting of individual pins inside the shoe lug holes, thus reducing the risk of structural damage and/or failure of the tread belt system. The performance

parameters of the original lubricant resulted in a need for operators to spray the pins approximately every mile the transporter traveled.

Lockheed Martin Space Operations, NASA’s contractor for launch operations at KSC, turned to Sun Coast Chemicals of Daytona, Inc. (Daytona Beach, Florida) for assistance with co-developing a biodegradable, nontoxic lubricant that would meet all Environmental Protection Agency and NASA requirements while providing superior lubricating qualities. Sun Coast Chemicals of Daytona, Inc. assembled a team of researchers, production personnel, and consultants who met with NASA personnel and contractors. This team produced a novel formulation that was tested and certified for trial, then tested directly on the crawler.

The new lubricant—Crawler Track Lube—had a longer service life than previous lubricants, and was injected at longer intervals as the transporter was being operated. Additionally, the product was not an attractive food source to wildlife. Success with its initial product and the Crawler Track Lube led to an industrial product line of 19 separate specialty lubricants.



The Mobile Launch Platform transported the shuttle to the launch pad. Inset photo shows the dispenser that injects the lubricant on the pins, which are necessary for the treadbelt.





The Shuttle Continuum, Role of Human Spaceflight



The Shuttle Continuum, Role of Human Spaceflight

President George H.W. Bush

Pam Leestma and Neme Alperstein
Elementary school teachers

Norman Augustine
*Former president and CEO of
Lockheed Martin Corporation*

John Logsdon
*Former director of Space Policy Institute
The George Washington University*

Canadian Space Agency

General John Dailey
*Director of Smithsonian National
Air and Space Museum*

Leah Jamieson
*Dean of the College of Engineering
Purdue University*

Michael Griffin
Former NASA administrator

The theme of this book is the scientific and engineering accomplishments of the Space Shuttle Program. The end of this longest-running human spaceflight program marks the end of an era for our nation. At this juncture, it is natural to ask: Why human spaceflight? What is the future of human spaceflight? What space exploration initiatives should we engage in, in the future?

The editor in chief of this publication invited some noted leaders from the government and industry, educators, students, and others to share their views and thoughts on these questions. Each contributor provided his or her own unique perspective. The editors are pleased and grateful for their contribution.



GEORGE BUSH

First and foremost, I am pleased to contribute a few words to this worthwhile project on the legacy of the Space Shuttle program because of my respect for the remarkable men and women who have shaped the program, and led it, and made it one of the most vital forces for scientific discovery and progress in our world.

To me, there are few public endeavors that best exemplify the American spirit of innovation and daring than does our Space Shuttle program. Like the manned space flight programs that preceded it — indeed, as was the case with each and every explorer throughout the ages — the Americans leading the Shuttle program yesterday, today, and tomorrow are drawn to challenge. They seek to push back the horizon of discovery. And, yes, maybe as creator Gene Roddenberry of *Star Trek* fame suggested, they also seek to “go boldly where no man has gone before.”

Was it not the same spirit that inspired the pioneers of old to take to the ancient spice trails of Asia, or to alight from the ports of medieval Europe for the highly uncertain journey ahead?

Just as important to me is the way NASA and our government has opened our Shuttle and Space Station program to our partners and allies across the world, to ensure that the exploration of space benefits not just America — but mankind as a whole.

This, then, is the essence of American leadership, your leadership, that today is expanding our scientific awareness even as it brings our world closer together.

President Kennedy was right: we do these things not because they are easy, but because they are hard. But because they are hard, and because you continue to persevere and succeed, and because, furthermore, you succeed based on the values that have always made America a force for goodness and progress in our world, you also help to continue inspiring our world and capturing our imagination.

So to the heirs of our manned space program, keep up the wonderful work. Keep pushing back that horizon, and boldly seeking new places to go. And in the process, help us to keep setting higher standards for the kinds of scientific research and courageous exploration that make this a better world than we found it. Succeeding generations of Americans have blessed us in such a manner; now it is your time to answer the call.

May God bless you all, and our United States.

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Inspiring Students Through Human Spaceflight

Pam Leestma and Neme Alperstein

Pam Leestma taught elementary school for 30 years at Valley Christian Elementary School, Bellflower, California. She won the 2008 National American Star Teaching Award.

Neme Alperstein taught for 22 years at the Harry Eichler School, a New York City public school. She was the New York City Teacher of the Year in 2000.

Neil Armstrong's "one small step for man, one giant leap for mankind" changed the course of history in our quest to explore space. "Failure is not an option" was the Apollo Program's vision to inspire the nation and is the space agency's legacy for the next generation.

Today we are a global community with international space partners exploring a new frontier filled with imagination and innovation. Scientific discoveries, human spaceflight, space tourism, moon colonies, and the exploration of Mars and beyond will be the vehicles that will continue to find common ground for transcending borders through understanding, respect, friendship, and peace.

NASA's education programs have provided the powerful resources to engage young minds. Their essential 21st century tools have brought our youth closer to those on the frontier of exploration through numerous multimedia interactive technologies. Some ways that we, as educators, have been able to get our students "up close and personal" with NASA include speaking with an astronaut aboard the International Space Station in real time (a downlink), using the facilities of a local California city hall and a New York City community center for a NASA first coast-to-coast downlink, videoconferencing with NASA's Digital Learning Network experts and astronauts living and training under water off the Florida coast (NASA's Extreme Environment Missions Operations), growing basil seeds flown in space with astronaut and educator Barbara Morgan, participating in NASA's live webcasts, watching NASA TV during coverage of Space Shuttle launches and landings, and organizing stargazing family nights for the school community. The impact of these extraordinary experiences has been life changing.

The unimaginable has become the world of infinite possibilities in science, technology, engineering, and mathematics. Human spaceflight missions reflect the diversity of our global community and the best that such collaboration offers mankind. This diversity reaches out to all students who see increased opportunities for participation. They see the potential to create the next generation of "spinoffs" that will improve daily life

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as a result of NASA research and development. They include medical breakthroughs, the development of robotics in exploration and in everyday life, materials science in the creation of materials with new properties (i.e., spacesuits), researching the effect of extreme environments, and the quest for cures and developing new medicines in microgravity.

NASA continues to support teachers through its professional development, conferences, workshops, content across the curriculum, and its willingness to provide access to its scientific community and experts. We never cease to be amazed by NASA's generosity of spirit ever present at the Space Exploration Educators Conference we always attend. Teachers return to their classrooms inspired. It's a ripple effect.

NASA's vision has provided the spark that ignites the excitement and wonder of exploration and discovery. Our students see themselves as the next explorers of this new frontier. It is an imperative that we continue human spaceflight if for no other reason than to improve life here on Earth and foster cooperation within the global community. Space exploration offers our children hope for the future.



What's Next for Human Spaceflight?

Norman Augustine

Former president and CEO of Lockheed Martin Corporation and recipient of many honors for his national defense, homeland security, and science policy accomplishments.

Parachuting an instrument package onto the summit of Mt. Everest would, without question, have been a significant and exciting scientific contribution. But would it have had the broad impact of Sir Edmund Hillary and Tenzing Norgay standing atop the 29,035 ft peak?

There are many important missions that can and should be accomplished with robotic spacecraft, but when it comes to inspiring a nation, motivating young would-be scientists and engineers and adaptively exploring new frontiers, there is nothing like a human presence. But humans best serve a nation's space goals when employed not as truck drivers but rather when they have the opportunity to exploit that marvelous human trait: flexibility. A prime example is the on-orbit repair of the Hubble Space Telescope using the shuttle. Without that capability for in situ human intervention, Hubble, itself a monumental accomplishment, would have been judged a failure. Indeed, there are important missions for both humans and robots in space—but each is at its best when it does not try to invade the other's territory.

So what is next for human spaceflight? There is a whole spectrum of interesting possibilities that range from exploring Mars, Demos, or Phobos, to establishing a station on the moon or at a neutral gravity point. It would seem that the 1990 recommendations of the White House/NASA commission on the Future of the U.S. Space Program still make a lot of sense. These include designating Mars as the primary long-term objective of the human space program, most likely with the moon as a scientific base and stepping-off point, and getting on with developing a new heavy-lift launch capability (probably based on the shuttle's External Tank).

The cost of space transportation was, and is today, the most intransigent impediment to human space travel. The mission traffic models are sparse; the development costs large; the hazard of infant mortality of new vehicles daunting; and the arithmetic of discounted cost accounting and amortization intimidating. Thus, at least in my opinion, the true breakthrough in human spaceflight will occur only when space tourism becomes a reality. Yes, space tourism. There is a close parallel to the circumstance when World War II solved the chicken and egg problem of commercial air travel.

By space tourism I do not refer to a few wealthy individuals experiencing a few moments of exposure to high altitudes and zero g's. Rather, I mean a day or two on orbit for large numbers of people, peering through telescopes, taking photographs, eating, and exercising. There are, of course, those who would dismiss any such notion as fantasy—but what might the Wright Brothers have said if told that within the century the entire population of Houston would each day climb aboard an airplane somewhere in the US and complain that they had already seen the movie? Or Scott and Amundsen if informed that 14,000 people would visit

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Antarctica each summer and 50 would live at the South Pole? Or James Wesley Powell if advised that 15,000 people would raft the Grand Canyon each year? Or Sir Edmund Hillary if told that 40 people would stand on top of Mount Everest one morning? In short, to be human is to be curious, and to be curious is to explore. And if there is any one thing we have learned about space pursuits, it is that they are a lot like heart surgery...if you are going to do any of it, it is wise to do a lot of it.

We have of course learned many other important things from the Space Shuttle Program. Those include how to integrate extraordinarily complex systems so as to operate in very unforgiving environments; that high traffic rates can and must be satisfied with reusability; that subsystems intended to be redundant are redundant only when they are independent; that long-term exposure to space can be tolerable for humans, at least in near-Earth orbit; and that the problems you expect (read tiles) can be overcome, while the problems you don't expect can overcome you (read seals and high-velocity, low-density fragment impacts). These and other lessons from the Space Shuttle human space programs have had a major effect on engineering discipline throughout the aerospace industry and much of the electronics industry as well.

There is a noteworthy parallel between the situation in which America found itself just after the Sputnik wake-up call and the circumstance that exists today just after the toxic mortgage wake-up call. In the former instance, much attention was turned to our nation's shortcomings in education, in producing future scientists and engineers, and in underinvestment in basic research. After Sputnik, the human space program became the centerpiece in an effort to reverse the above situation and helped underpin several decades of unparalleled prosperity. Today, the nation once again suffers these same ailments and once again is in need of "centerpieces" to focus our attention and efforts. And to this end nothing inspires young would-be scientists and engineers like space and dinosaurs—and we are noticeably short of the latter.

As for me, nothing other than the birth of my children and grandchildren has seemed more exciting than standing at the Cape and watching friends climb aboard those early shuttles, atop several hundred thousand gallons of liquid hydrogen and liquid oxygen, and then fly off into space.

My mother lived to be 105 and had friends who crossed the prairies in covered wagons. She also met friends of mine who had walked on the moon. Given those genes I may still have a shot at buying a round-trip ticket to take my grandchildren to Earth orbit instead of going to Disney World. And the Space Shuttle Program provided important parts of the groundwork for that adventure. All I need is enough "runway" remaining.

Global Community Through Space Exploration

John Logsdon, PhD

Former director of Space Policy Institute and professor, The George Washington University, and member of major space boards and advisory committees including the NASA Columbia Accident Investigation Board.

The Space Shuttle has been a remarkable machine. It has demonstrated the many benefits of operations in low-Earth orbit, most notably the ability to carry large pieces of equipment into space and assemble them into the International Space Station (ISS). Past research aboard the shuttle and especially future research on the ISS could have significant benefits for people on Earth. But research in low-Earth orbit is not exploration. In my view, it is past time for humans once again to leave low-Earth orbit and restart exploration of the moon, Mars, and beyond. President George W. Bush's January 2004 call for a return to the moon and then a journey to Mars and other deep space destinations is the policy that should guide US government human spaceflight activities in the years to come.

The 2004 exploration policy announced by President Bush also called for international participation in the US exploration initiative. The experience of the ISS shows the value of international partnerships in large-scale space undertakings. While the specifics of the ISS partnership are probably not appropriate for an open-ended exploration partnership, the spirit and experience of 16 countries working together for many years and through difficult challenges certainly is a positive harbinger of how future space exploration activities can be organized.

Since 2006, 14 national space agencies have been working together to chart that future. While the United States is so far the only country formally committed to human exploration, other space agencies are working hard to convince their governments to follow the US lead and join with the United States in a multinational exploration effort. One product of the cooperation to date is a "Global Exploration Strategy" document that was approved by all 14 agency heads and issued in May 2007. That document reflects on the current situation with words that I resonate with: "Opportunities like this come rarely. The human migration into space is still in its infancy. For the most part, we have remained just a few kilometers above the Earth's surface—not much more than camping out in the backyard."

It is indeed time to go beyond the "camping out" phase of human space activity, which has kept us in low-Earth orbit for 35 years. Certainly the United States should capitalize on its large investment in the ISS and carry out a broadly based program of research on this orbiting laboratory. But I agree with the conclusions of a recent White Paper prepared by

the Space, Policy, and Society Research Group at MIT: “A primary objective of human spaceflight has been, and should be, exploration.” The Group argues that “Exploration is an expansion of human experience, bringing people into new places, situations, and environments, expanding and redefining what it means to be human.” It is exploration, so defined, that provides the compelling rationale for continuing a government-funded program of human spaceflight.

I believe that the new exploration phase of human spaceflight should begin with a return to the moon. I think the reasons to go back to the moon are both that it is the closest place to go and it is an interesting place in its own right. We are not technologically ready for human missions to Mars, and the moon is a more understandable destination than just flying to a libration point in space or to a near-Earth object. The moon is like an offshore island of the planet Earth, and it only takes 3 days to get there. During the Apollo Program, the United States went to the surface of the moon six times between 1969 and 1972; the lunar crews explored only the equatorial region of the moon on the side that always faces the Earth. So we have never visited 85 to 90 percent of the moon’s surface, and there are lots of areas yet to explore. The far side of the moon may be the best place in the solar system for radio astronomy. Most people who are looking at the issue now think that one of the poles of the moon, probably the South Pole, is a very interesting place scientifically, and that there may be resources there that can be developed for use in further space exploration. So the moon is an interesting object to study, and to do science from, and perhaps as a place to carry out economically productive activity.

The Space Shuttle has left us a legacy of exciting and valuable exploits in low-Earth orbit. But it is now time to go explore.



The Legacy of the “Space Shuttle”

Views of the Canadian Space Agency

The Space Transportation System; a.k.a. the “Space Shuttle”; is the vehicle that arguably brought Canada to maturity as a global space power. Canada was an early advocate in recognizing the importance that space could play in building the country. Initially, this was achieved through the development of small indigenous scientific satellites to study the Earth’s upper atmosphere, beginning with Alouette, launched by NASA in 1962, which positioned Canada as the third nation, after the Soviet Union and the United States of America, to have its own satellite successfully operate in the harsh and largely unknown environment of space. The follow-on Alouette-II and ISIS series of satellites (1965 to 1971) built national competence and expertise and set the foundation for Canada’s major contributions to the rapidly developing field of satellite communications (Anik series and Hermes), to using Earth Observation data to meet national needs, as well as to the development of signature technologies that were the basis of Canada’s space industry (e.g., STEM* deployable systems, antennas). By the mid-1970s, however, Canada’s emerging space program was at a crossroads: space communications were becoming commercialized, Canada was not yet ready to commit to the development of an Earth Observation Satellite, and no new scientific satellites or payloads were approved. This situation changed dramatically in 1974 when the Government of Canada approved the development of a robotic arm as a contribution to the Space Shuttle Program initiated by NASA two years earlier. This Shuttle Remote Manipulator System was designed to deploy and retrieve satellites from and to the Shuttle orbiter’s payload bay, as well as support and move extra-vehicular astronauts and payloads within the payload bay. The first “Canadarm” was paid for by Canada and first flew on the second Shuttle flight in November 1981. Originally planned by NASA to be flown only occasionally, Canadarm has become a semi-permanent fixture due to its versatility and reliability, especially in support of extra-vehicular activities; i.e., spacewalks; and, more recently, as an essential element in the construction and servicing of the International Space Station and the detailed remote inspection of the Shuttle after each launch that is now a mandatory feature of each mission. Canadarm has become an important and very visible global symbol of Canadian technical competence, a fact celebrated in a recent 2008 poll of Canadians that identified the Canadarm as the top defining accomplishment of the country over the last century.

Returning to scientific endeavours, the Shuttle’s legacy with respect to the space sciences in Canada was more circuitous. Towards the end of the 1970s, following the successful Alouette/ISIS series, Canada turned its attention to defining its next indigenous scientific satellite mission. As the merits of a candidate satellite called Polaire were debated, Canadian

**STEM—storage tubular extendible member*

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scientists were encouraged to propose experiments in response to an Announcement of Opportunity released by NASA in 1978 to fly future missions on the Shuttle. This was during the heady days when a Shuttle mission was proposed to fly every couple of weeks with rapid change-out of payloads—the “space truck” concept—and with the possibility to utilize the formidable advantage of the Shuttle to launch and return scientific payloads leading to multiple mission scenarios for the same experiment or facility. Three Canadian proposals to fly sophisticated, complex experiments in the Shuttle payload bay were accepted by NASA—an Energetic Ion Mass Spectrometer to measure the charged particle environment; an ambitious topside-sounder experiment called Waves In Space Plasmas, a follow-on to the Alouette/ISIS program, to measure the propagation of radio waves through and within the Earth’s atmosphere; and an optical measurement of atmospheric winds from space called Wide Angle Michelson Doppler Imaging Interferometer. Ironically, none of these three experiments flew on the Shuttle, all falling to the reality of a technically challenging program where missions every few months became the norm rather than every couple of weeks. However, the impetus to the Canadian scientific community of this stimulus through the infusion of new funds and opportunities enabled the community to flourish that, in turn, led to the international success of the space science program that is recognized today. Since 1978, Canada has successfully flown well over 100 scientific experiments in space with practically a 100% success rate based on the metric of useful data returned to investigators. The other contribution to science that Canada’s partnership in the Shuttle Program provided was the possibility to develop new fields related to the investigation of how living systems and materials and fluids behave in space, especially the understanding of the effects of gravity and exposure to increased radiation. The possibility to fly such experiments on the Shuttle was reinforced in 1983 when, during the welcoming ceremony for the Shuttle Enterprise in Ottawa, the Administrator of NASA formally and publically invited Canada to fly two Canadians as payload specialists on future missions and the Minister of Science and Technology accepted on behalf of the Government of Canada. Canada responded by launching a nation-wide search for six individuals to join a newly formed Canadian Astronaut Program. In October 1984, now 25 years ago, Marc Garneau successfully flew a suite of six Canadian investigations called CANEX* that was put together in approximately 9 months—a development schedule that, today, would be practically impossible. Since that time, Canadian scientists have flown approximately 35 more experiments on the Shuttle, all producing excellent results for the scientific teams and significantly advancing our understanding of the way that living and physical systems behave in space.

**CANEX—Canadian experiments in space science, space technology, and life sciences*

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The Canadian astronaut program has been a remarkable success for Canada, not only in relation to the excellent support that the outstanding individuals who make up the corps have provided to the overall program but also by virtue of the visibility the individuals and missions have generated, especially within Canada. Canadian astronauts remain inspirational figures for Canadians, with every mission being widely covered in the media and appearances continuing to draw significant interest. It is a notable fact that after the Soviet Union/Russia and the USA, more Canadians have flown Shuttle missions than any other single country, fourteen such missions as of 2009.

In conclusion, it is fair to say that Canada's contribution to the Space Shuttle Program has dramatically changed the way that Canada participates in space activities. Over the past 35 years, since Canada initially decided to "throw its hat into the ring" in support of this new and revolutionary concept of a "space plane," Canada has become a leading player in global space endeavours. It can be argued credibly that Canada would not today be at the forefront of space science activities, space technology leadership, human spaceflight excellence and as a key partner in the International Space Station program if it had not been for the possibilities opened up by the Space Shuttle Program. A great debt of gratitude goes to those who saw and delivered on the promise of this program and to NASA for its generosity in believing in Canada's potential to contribute as a valuable and valued partner. Both gained enormously from this mutual trust and support and Canada continues to reap the benefits from this confidence in our program today. As we finish building and emphasize the scientific and technological use of the International Space Station, we look forward collectively to taking our first tentative steps as a species beyond our home planet. As we do so, the Space Shuttle will be looked upon as the vehicle that made all of this possible. Ad astra!

What is the Legacy of the Space Shuttle Program?

General John Dailey (USMC, Ret.)

Director

Smithsonian National Air and Space Museum

John Young, commander of the first space shuttle mission, pegged the shuttle perfectly as “a remarkable flying machine.” Arising from the American traditions of ingenuity and innovation, the Space Shuttle expanded the range of human activity in near-Earth space. Serving as a cargo carrier, satellite deployment and servicing station, research laboratory, construction platform, and intermittent space station, the versatile shuttle gave scores of people an opportunity to live and do meaningful work in space. One of the most complex technology systems ever developed and the only reusable spacecraft ever operated, the shuttle was America’s first attempt to make human spaceflight routine. For more than 30 years and more than 125 missions, the Space Shuttle kept the United States at the forefront of spaceflight and engaged people here and around the world with its achievements and its tragedies. The experience gained from the Space Shuttle Program will no doubt infuse future spacecraft design and spaceflight operations for years to come.

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Inspiring Generations

Leah Jamieson, PhD

*Dean of the College of Engineering
Purdue University*

The space race, set in motion by the 1957 launch of Sputnik and reaching its pinnacle with the Apollo 11 landing on the moon, is credited with inspiring a generation of engineers. In the United States, Congress in 1958 provided funding for college students and improvements in science, mathematics, and foreign-language instruction at elementary and secondary schools. Math and science curricula flourished. University enrollment in science and engineering programs grew dramatically. For over a decade, not only engineers themselves, but policy makers and the public genuinely believed that the future depended on engineers and scientists and that education would have to inspire young people to pursue those careers.

Almost as if they were icing on the cake, innovation and technology directly or indirectly inspired by the space program began to shape the way we live and work: satellite communications, satellite navigation, photovoltaics, robotics, fault-tolerant computing, countless specialty materials, biomedical sensors, and consumer products all advanced through the space program.

Over the 30-year era of the Space Shuttle, it sometimes seems that we've come to take space flight for granted. Interest in technology has declined: bachelor's degrees awarded in engineering in the US peaked in 1985. Reports such as the *Rising Above the Gathering Storm* (National Academies Press, 2007) urge a massive improvement in K-12 math, science, and technology education in order to fuel innovation and ensure future prosperity. Engineering educators are looking to the National Academy of Engineering's "grand challenges" (NAE, 2008) not only to transform the world, but to inspire the next generation of students.

Has space exploration lost the ability to inspire? I don't think so. Over the past five years, I have talked about engineering careers with more than 6,000 first-year engineering students at Purdue University, asking them what engineers do and why they are studying engineering. Not a session has gone by without at least one student saying "I'm studying engineering because I want to be an astronaut." Purdue students come by this ambition honestly: 22 Purdue graduates have become astronauts, including Neil Armstrong, the first man to walk on the moon, and Eugene Cernan, the last—or as he prefers to say, "the most recent." A remarkable 18 of the 22 (all except Armstrong, Cernan, Grissom, and Chaffee) have flown Space Shuttle missions, for a total of 56 missions. Inspiration lives.

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I've also talked with hundreds of IEEE* student leaders in Europe, Africa, Latin America, and Asia, asking them, as well as the Purdue undergrads, what their generation's technological legacy might be. In every session on every continent, without exception, students have talked about space exploration. Their aspirations range from settlements on the moon to human missions to Mars. These students, however, add a layer of intent that goes beyond the simple "we'll go because it's there." They talk about extraterrestrial settlements as part of the solution to Earth's grand challenges of population growth, dwindling resources, and growing poverty. More nuanced, perhaps, and more idealistic—but again, evidence of the power to inspire.

These students are telling us that space exploration is about dreaming, but it's also about doing. This isn't a new message, but it's one that is worth remembering. It's unlikely that the inspiration for the next generation of engineers will come from one galvanizing goal, as it did in the Sputnik and Apollo era. Yet, space exploration has the exquisite ability to stretch both our physical and spiritual horizons, combined with the proven ability to foster life-changing advances in our daily lives. This combination ensures that human exploration of space will continue to be a grand challenge that inspires. As the Space Shuttle era draws to a close, it's a fitting time to celebrate the Space Shuttle Program's achievements, at the same time that we ask today's students—tomorrow's engineers—"what's next?" I believe that we'll be inspired by their answers.

**The Institute of Electrical and Electronics Engineers*

The Legacy of the Space Shuttle

Michael Griffin, PhD*

NASA administrator, 2005-2009

When I was asked by Wayne Hale to provide an essay on the topic of this paper, I was as nearly speechless as I ever become. Wayne is a former Space Shuttle Program Manager and Shuttle Flight Director. In the latter capacity, he holds the record—which cannot now be broken—for directing shuttle ascents and re-entries, generally the most dynamic portion of any shuttle mission. His knowledge of the Space Shuttle system and its history, capabilities, and limitations is encyclopedic.

In contrast, I didn't work on the shuttle until, on April 14, 2005, I became responsible for it. Forrest Gump's mother's observation that "life is like a box of chocolates; you never know what you're going to get," certainly comes to mind in this connection. But more to the point, what could I possibly say that would be of any value to Wayne? But, of course, I am determined to try.

The first thing I might note is that, whether I worked on it or not, the shuttle has dominated my professional life. Some connections are obvious. In my earlier and more productive years, I worked on systems that flew into space aboard shuttle. As I matured—meaning that I offered less and less value at higher and higher organizational levels—I acquired higher level responsibility for programs and missions flying on shuttle. I first met Mike Coats, director of the Johnson Space Center, through just such a connection. Mike commanded STS-39, a Strategic Defense Initiative mission for which I was responsible. Later, as NASA Chief Engineer in the early '90s, I led one of the Space Station Freedom redesign teams; the biggest factor influencing station design and operations was the constraint to fly on shuttle.

My professional connections with the Space Shuttle are hopelessly intertwined with more personal ones. Many of the engineers closest to me, friends and colleagues I value most highly, have worked with shuttle for decades. And, over the years, the roster of shuttle astronauts has included some of the closest friends I have. A hundred others have been classmates and professional colleagues, supervisors and subordinates, people I see every day, or people I see once a year. Speaking a bit tongue-in-cheek, I once told long-time friend Joe Engle that I loved hearing his stories about flying the X-15 because, I said, they were different; my other friends had all flown on shuttle.

From time to time, I make it a point to remember that two of them died on it.

Most of us have similar connections to the Space Shuttle, no matter what part of the space business in which we have worked. But the influence of the shuttle on the American

* Written in 2009 while serving as NASA administrator.

space program goes far beyond individual events, or even their sum, because the legacy of the Space Shuttle is a case where the whole truly is more than the sum of the parts.

Because of its duration at the center of human spaceflight plans and activities, because of the gap between promise and performance, because of the money that has been spent on it, because of what it can do and what it cannot do, because of its stunning successes and its tragic failures, the Space Shuttle has dominated the professional lives of most of us who are still young enough to be working in the space business. I'm 59 years old as I write this, and closer to retirement than I would like to be. Anyone my age or younger who worked on Apollo had to have done so in a very junior role. After Apollo, there were the all-too-brief years of Skylab, the single Apollo-Soyuz mission, and then—Space Shuttle. So, if you're still working today and spent any time in manned spaceflight over the course of your career, you worked with shuttle. And even if you never worked in human spaceflight, the shuttle has profoundly influenced your career.

So, as the shuttle approaches retirement, as we design for the future, what can we learn from having built and flown it, loved and feared it, exploited and been frustrated by it?

If the shuttle is retired by the end of 2010, as presently planned, we will have been designing, building, and flying it for more than 4 decades, four-fifths of NASA's existence. This is typical; aerospace systems normally have very long life cycles. It was Apollo that was an aberration. We must remember this as we design the new systems that will, one day, be commanded by the grandchildren of the astronauts who first fly them. We must resist making compromises now, just because budgets are tight. When a system is intended to be used for decades, it is more sensible to slip initial deployment schedules to accommodate budget cuts than to compromise technical performance or operational utility. "Late" is ugly until you launch; "wrong" is ugly forever.

The shuttle is far and away the most amazingly capable space vehicle the world has yet seen, more so than any of us around today will likely ever see again. Starting with a "clean sheet of paper" less than a decade after the first suborbital Mercury flight, its designers set—and achieved—technological goals as far beyond Apollo as Apollo was beyond Mercury. What it can do seems even now to be the stuff of science fiction.

But it is also operationally fragile and logistically undependable. Its demonstrated reliability is orders of magnitude worse than predicted, and certainly no better than the expendable vehicles it was designed to replace. It does not degrade gracefully. It can be flown safely and well, but

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only with the greatest possible attention to every single detail, to the consequences both intended and unintended of every single decision made along the path to every single flight. The people who launch it and fly it are the best engineers, technicians, and pilots in the world, and most of the time they make it look easy. It isn't. They work knowing that they are always one misstep away from tragedy.

It was not intended to be this way; the shuttle was intended to be a robust, reliable vehicle, ready to fly dozens of times per year at a lower cost and a higher level of dependability than any expendable vehicle could ever hope to achieve. It simply didn't happen. What shuttle does is stunning, but it is stunningly less than what was predicted.

If it is true that "satisfaction equals results minus expectations," and if ultimately we have been unsatisfied, maybe where we went wrong was not with the performance achieved, but with the goals that were set. What if we had not tried for such an enormous technological leap all in one step? What if the goal had been to build an experimental prototype or two, fly them, and learn what would work and what was not likely to? Then, with that knowledge in hand, we could have proceeded to design and build a more operationally satisfactory system. What if we had kept the systems we had until we were certain we had something better, not letting go of one handhold until possessed of another?

That we did not, of course, was not NASA's fault alone. There was absolutely no money to follow the more prudent course outlined above. After the cancellation of Apollo by President Nixon, the NASA managers of the time were confronted with a cruel choice: try to achieve the goals that had been set for the shuttle, with far less money than was believed necessary, or cease US manned spaceflight. They chose the former, and we have been dealing with the consequences ever since. That they were forced to such a choice was a failure of national leadership, hardly the only one stemming from the Nixon era. But the lesson for the future is clear: in the face of hard choices, technical truth must hold sway, because it does so in the end, whether one accepts that or not.

I will end by commenting on the angst that seems to accompany our efforts to move in an orderly and disciplined manner to retire the shuttle. In my view we are missing the point, and maybe more than one point.

First, the shuttle has been an enormously productive step along the path to becoming a spacefaring civilization. But it does not lie at the end of that path, and never could have.

It was an enormous leap in human progress. The shuttle wasn't perfect, and we will make more such leaps, but none of them will be perfect, either.

Second, even if the shuttle had accomplished perfectly that which it was designed to do, we must move on because of what it cannot do and was never designed to do. The shuttle was designed to go to low orbit, and no more. NASA's funding is not such that we can afford to own and operate two human spaceflight systems at the same time. It never has been. There were gaps between Mercury and Gemini, Gemini and Apollo, Apollo and Space Shuttle. There will be a gap between Space Shuttle and Constellation*. So, if we can have only one space transportation system at a time—and I wish wholeheartedly that it were otherwise—then in my opinion it must be designed primarily to reach beyond low-Earth orbit.

If we are indeed to become a spacefaring civilization our future lies, figuratively, beyond the coastal shoals. It lies outward, beyond sight of land, where the water is deep and blue. The shuttle can't take us there. Our Constellation systems can.

So, yes, we are approaching the end of an era, an era comprising over 80% of NASA's history. We should recognize and celebrate what has been accomplished in that era. But we should not be sad, because by bringing this era to an end, we are creating the option for our children and grandchildren to live in a new and richer one. We are creating the future that we wanted to see.

**Constellation refers to the NASA program designed to build the capability to leave low-Earth orbit.*

