AEROSPACE INDUSTRIES ASSOCIATION

Space in our World

November 2012

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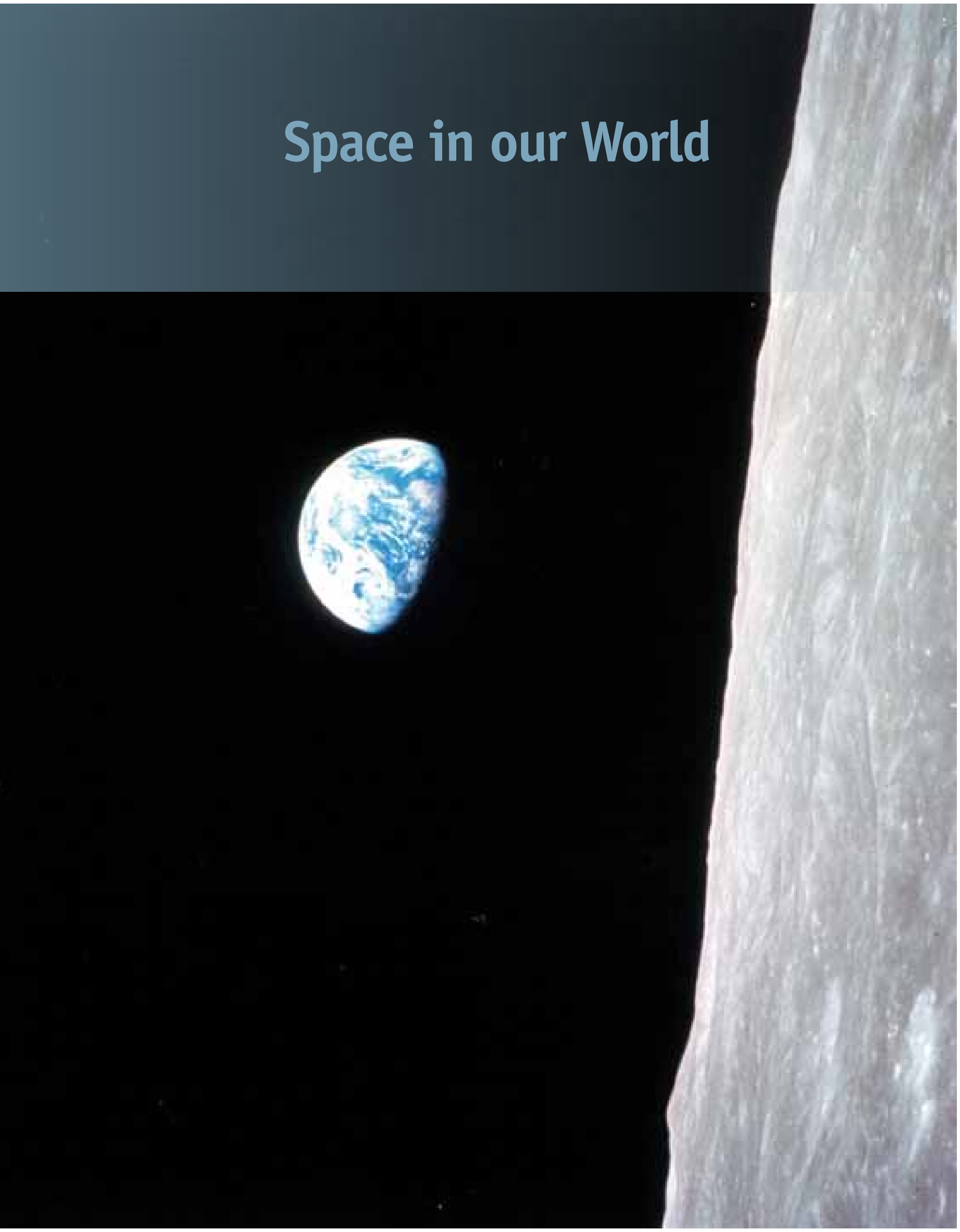

AIA
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Now more than ever, space systems are essential to our society. Space programs keep us safe, grow our economy and advance the progress of civilization as no other field can. As we face our difficult fiscal challenges, it's important to remember that investments in space keep our nation second to none in ways that nothing else can.

Most Americans recognize space as a key expression of our national character. A Pew Research Poll found in 2011 that nearly 60 percent of Americans believe the United States should continue to lead the world in space exploration. They know our space programs are a globally recognized brand of American ingenuity. The recently landed Mars Rover Curiosity was the latest reminder that our space capabilities are the crown jewels of our nation.

Less known is the indispensible value space systems bring to our everyday lives. Space provides irreplaceable capabilities for defense, public health, finance, medicine, energy, agriculture, transportation, development and countless other fields. Investments in space programs are precisely about improving and protecting life on Earth.

Today, it's not just about launches. Astronauts on the International Space Station are researching vaccines in microgravity lab conditions that can't be replicated on Earth. Earth observation satellites and the Global Positioning System prepare and guide first responders during disasters like the 2010 earthquake in Haiti. Weather satellites provide advanced warning to the emergency response officials and the public about hurricanes and other severe storms and help save lives when other natural disasters strike. Missile detection satellites warn soldiers, sailors, marines and civilians of impending danger. Robotic space missions shed light on the laws of nature and help us understand how our planet works.

In this new report, *Space in our World*, AIA outlines how space systems help improve our lives in a myriad of ways. A quick look at the following pages will make it abundantly clear: we cannot afford to live in a world without capable, robust space systems.

However, space capabilities require steady policy support and stable long-term investments. The recommendations in this report urge policymakers to continue their support of U.S. space programs by developing currently planned systems and moving forward with new research and development in space systems. With a sustained U.S. government commitment to space programs, the aerospace industry can continue to deliver crucial capabilities that protect our national security, grow high-skilled jobs, develop new technologies, make fundamental scientific discoveries and inspire the pipeline of technical talent who will advance our frontiers in the future.

Sincerely,

Marion C. Blakey

President and Chief Executive Officer

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Space and American Exceptionalism– The Need for a Bipartisan Space Program

The term "American Exceptionalism" has become something of a litmus test for political candidates in recent years – do you believe in it? How do you define it? How do you demonstrate it?

Our nation's space successes over the past fifty years are a source of national pride and have tangibly contributed to the progress of people throughout the world. The former Soviet Union certainly had its share of early space firsts, as have other nations; however in the centuries ahead, it is names of American heroes such as Armstrong, Glenn and Ride and those of ingenious spacecraft such as Voyager, COBE and Hubble that will be forever remembered just as we still recall Magellan and Columbus. If these accomplishments don't mark our nation as exceptional, what would?

How can it be that a nation with five percent of the world's population achieved so much in so little time? Part of the answer lies with our free market economic system and our willingness as a people to invest in education, science and technology to create a better future. Indeed, our belief in a future that is better than the present has long been a distinctive hallmark of our culture.

Another major contributor to our success has been a bipartisan commitment to strong space programs. Space is an arena where the magnitude of the challenges involved requires consistent focus and effort despite partisan power shifts in our legislative and executive branches of government and steady investment despite the economy's ups and downs.

Overall, our space program has exhibited remarkable stability. The Apollo lunar landing – first proposed by President Kennedy at Rice University in 1962 – was actually witnessed in 1969 by President Nixon, the same politician who was defeated by Kennedy nine years earlier.

Similarly, the Space Shuttle program, first approved by President Nixon in 1972 during an economic boom was funded through the stagflationary economy of the 1970s and finally flown under President Reagan during the deep recession of 1981. During the Carter Administration and the troubled energy crisis period of the 1970s, NASA launched the two Voyager missions on their journeys through the solar system and beyond.

The examples continue throughout our nation's space history – the International Space Station, the largest international scientific and engineering initiative in human history began as a NASA proposal by the Republican President Reagan as a Cold War response by the Western allies to a Soviet space station in orbit at the time. It was largely funded and built during the Democratic administration of President Clinton – even though he was often embroiled in highly partisan battles with the Republican leaders of Congress. On Capitol Hill, bipartisan consensus has been much more the rule than the exception over this five-decade period even as party control has shifted over time.

As we look back at the remarkable benefits discussed in this report and as we marvel at the lengthy record of accomplishment, it is useful to recall the bipartisan spirit of support that our nation has had for space programs, as well as our long held commitment to a better future that propelled us forward. As our nation grapples with the lingering effects of the Great Recession, the federal debt, rising powers overseas and an increasingly partisan political system, it is important to remember that exceptional nations do great things – space programs are unequivocally one of the great things that we do, as President Kennedy said, "not because they are easy, but because they are hard."

Introduction

The time has come to recognize space systems as national infrastructure and space programs as an irreplaceable force for good for our nation and the world. Thousands of lives are saved each year thanks to space system data that predicts life threatening events and directly empowers emergency first responders. Numerous medical advances from space-based research along with countless space technologies are improving the health of millions of people around the world across all demographics. Space systems keep the U.S. homeland safe and enable our military to carry out its mission with unmatched effectiveness. The space sector is also creating economic prosperity by growing highly-skilled jobs, developing new technologies and uncovering new scientific findings. After more than fifty years in space, these programs have become a part of our national identity but they're also a key to modern competitiveness. As we make tough fiscal choices, it's important to remember that space program investments are meeting national needs in the economy, national security, energy and the environment. Now more than ever, space programs keep our nation second to none.

Saving Lives

Space programs save lives by providing:

- Satellite observation data for prediction of extreme weather events, including devastating hurricanes, tornadoes, blizzards, floods and other phenomena. More than 90 percent of all observation data used in three- to seven-day weather forecasts is acquired through satellites.
- Innovative technology for the medical field and new public health techniques like telemedicine for remote communities.
- Space-based research of disease and genetics.
- Verification of treaties.
- Warning of genocide and war crimes through satellite imagery.

Space programs protect national security and the warfighter by providing:

- Global positioning and timing through GPS, which enables coordination of all military forces including navy fleets, ground troops, fighter jets, bomber aircraft, unmanned aerial vehicles, precision guided munitions, tanks and countless other military units.
- Instant, global coordination through protected communication satellites that allow the president to make real time decisions during the most critical operations.
- Warning of incoming missiles.
- Intelligence data collection from satellites.
- High fidelity weather observation and forecast data for troops and operations in the field.

Creating Prosperity for Millions

Space programs create and enhance multi-billion dollar markets by providing:

- Satellite communications to all corners of the globe.
- Television programming accessible anywhere, including areas restricted by repressive regimes.
- Position and timing capabilities for finance, shipping, transportation, agriculture, energy extraction and more.
- Weather observation data for supply chain management.
- Environmental observation of economically important conditions like drought, wildfire, beach erosion, deforestation, etc.
- Development of new products and technologies for use by the commercial markets such as integrated circuits.
- New technical competencies and capabilities that advance other sectors of the economy such as the energy industry.
- Motivation for entrepreneurial investment in new commercial space ventures.
- New laboratory conditions for ground-breaking research such as microgravity that cannot be reproduced on Earth.
- New applied science research in challenging fields for exploration like radiation exposure and automated computer systems.
- New research findings on the cutting edge of science, including insights on how our planet, solar system, galaxy and universe work.

Inspiring our Pipeline of Scientists and Engineers

Space programs provide an irreplaceable intellectual stimulus for U.S. competitiveness.

- Our science, technology, engineering and mathematics (STEM) workforce is crucial to U.S. economic competitiveness.
- Highly visible, exciting space programs provide a unique intellectual stimulus for steady and sustained growth in the STEM workforce. History has shown that several years following the ramp up of major human spaceflight programs, the United States sees an increase in the number of STEM degrees.
- Professionals first inspired by space frequently advance society in numerous other fields such as medicine, biology, computer science, physics and engineering.

Recommendations

Recommendation 1: Stable funding and steady policy support is needed from the U.S. government to ensure NOAA Environmental Satellite, Data and Information Service, NASA's Earth Science program, USGS Landsat program and other U.S. government and commercial earth observation systems can replenish aging Earth observation satellites and maintain essential data coverage that contributes to saving thousands of lives every year.

Recommendation 2: Continued stable investments by the U.S. government in space programs at DOD and the intelligence community are needed to maintain irreplaceable strategic capabilities that protect warfighters, enhance their missions and guard the U.S. homeland.

Recommendation 3: The U.S. government should pursue cost-effective launch service strategies that enable competition and industry participation and help strengthen the U.S. space industrial and technology base to meet future requirements.

Recommendation 4: Continued investment in research and development (R&D) and science and technology for space capabilities is required to ensure the U.S. military and intelligence agencies maintain decisive advantages with cutting-edge space systems.

Recommendation 5: The U.S. government should fully utilize the International Space Station to 2020 and beyond, in order to advance scientific research that can only be done in space.

Recommendation 6: America needs support for a robust, competitive commercial crew program to provide domestic low Earth orbit transportation – particularly to the International Space Station – as soon as possible.

Recommendation 7: Steady development of the Orion Multi-Purpose Crew Vehicle and the Space Launch System is required to advance human exploration beyond Earth orbit for the benefit of our entire nation.

Recommendation 8: The U.S. government should continue development of the James Webb Space Telescope as well as other NASA space science missions in order to keep U.S. science at the cutting edge.

Recommendation 9: Continued support and funding is required for highly visible, world-class space programs to uniquely inspire our nation's students to pursue courses and careers in science, technology, engineering and mathematics.

Introduction

It's easy to recognize the value of space for national prestige. When Neil Armstrong took his first steps on the Moon, he instantly became the most famous living person on Earth. The United States was simultaneously recognized as the most technologically advanced, scientifically savvy nation on the planet. Landing on the Moon was an achievement that anyone on any continent could understand and the potent soft power value of space endures today. We see this in our latest space achievement – the Mars Rover Curiosity. Curiosity, a two ton rover the size of a small car, is a symbol of the United States' continuing global leadership in space and represents a triumph of American technology and ingenuity.

The wonder of space is uniquely captivating. Many space achievements are historic, high-profile events and it is easy to forget that practical solutions from space are meeting essential national needs *every single day*. Living and working in space enables us to live better and work smarter on Earth.

Space programs save thousands of lives each year thanks to satellite observation data that warns of impending weather disasters and equips emergency first responders with detailed information of conditions on the ground. Numerous public health breakthroughs from space-based research are improving millions of lives around the world.

The space sector grows highly skilled jobs, develops innovative new technologies and produces leading-edge scientific results. Not only does space enable new markets, it facilitates existing ones to work faster, safer and more efficiently. All of these elements enable an economy to lead in the 21st century.

Space systems are also the lifeblood of national security and defense. Space offers irreplaceable means of monitoring our world and fundamentally enables our military to be the best, most effective armed service on the planet.

The time has come to recognize space systems as vital infrastructure and space programs as a unique fulcrum of advancement for our nation. In the same sense that police, fire fighters and public schools are valued investments for the common good, space makes direct and lasting contributions to our national well-being by saving lives and growing prosperity across all demographics. Funding space programs is precisely about advancing our society on Earth with new jobs, new technology, new science and new perspectives on ourselves, our planet and our universe. Those societies that learn, explore and push knowledge to new boundaries inherit the future.

Although this report will outline outstanding examples of innovation and discovery from space programs, it will by no means be an exhaustive list of achievements. After all, space sector ingenuity regularly contributes to key national challenges in the economy, national security, energy and the environment. Instead, this report will provide a basic overview of how space programs save millions of lives and billions of dollars in the United States and the world.

Protecting Society

Space programs are known for their innovation, groundbreaking science and ability to solve hard technical problems. Implicitly, these are all fundamental to our economic strength and quality of life. They also serve as hallmarks of innovation and inspiration needed for science, technology, engineering and mathematics (STEM) education. Visionary space programs showcase truly unique national capabilities. At the same time, space programs are frequently overlooked for their practical, daily benefits – saving thousands of lives every single year at a negligible per-capita cost.

As world population grows beyond seven billion, there is an increasing awareness that economies, public safety and security are all globally connected. Global observation, communication and navigation assets from space provide an unmatched vantage point to serve our society. We benefit from space missions performing tasks that are not feasible from the ground – it would simply be too expensive to deploy enough ground-based systems for global coverage.

For instance, take weather and environmental conditions. Natural phenomena frequently span national borders and local communities and weather travels from one city to another. Space-based infrastructure provides the necessary sensors to monitor conditions on the ground, communication satellites provide advance warning to threatening conditions and position and navigation satellites directly aid disaster response efforts around the Earth. Hurricane forecasting, advance notification of tornadoes and search and rescue communications for distressed planes and boats are only a few of the core capabilities provided to our families.

Predicting and Mitigating Disaster

September 21, 1938, began like any other warm fall day in East Hampton, New York. At around 11:30 in the morning, a weather report from New York City led one resident to casually remark, "Guess we're in for a no'theaster. I better get the rest of the tomatoes off the vine and take down the awnings. Time they were down anyway." By 2:30, the barometric pressure had plunged and wind speeds were more than a hundred miles an hour.[1] In just a matter of hours, the pleasant fall day in East Hampton and other Northeastern towns had given way to a devastating category three hurricane now referred to as the "Long Island Express." Residents along the East Coast were caught totally by surprise. By the time each town could see a major catastrophe was at hand, the means to warn other towns in the path had been destroyed by the storm.

The Northeast's total blindness to the storm resulted in major causalities and devastating destruction. It is estimated that more than 500 people died in the storm and 57,000 homes were destroyed.[2] Property losses would have roughly translated to more than $4 billion in 2012 U.S. dollars.[3] It is now unthinkable to wake up to a hurricane completely unprepared – without emergency food and water, without evacuations, without the chance to secure homes ahead of the storm. Yet this was a constant possibility for cities and towns along coasts during hurricane season before the advent of weather satellites and modern forecasting technology.

This photograph of Hurricane Sandy was taken from NOAA's Suomi NPP weather satellite, which provided critical observation data that alerted the East Coast of the United States to the massive storm.
(Image courtesy NOAA)

Contrast this with the recent super storm Hurricane Sandy – a storm whose path and intensity has been compared to the 1938 Long Island Express. This time there were no surprises. Before Sandy left the Bahamas, the entire East Coast of the United States was on alert that the storm was likely to affect up to 60 million people. From Washington, DC, to Boston, flights and trains were cancelled, public transit halted, schools and government offices closed, businesses boarded up and emergency first responders put on alert. Despite the complexity of this historic and unprecedented storm, weather satellite data provided stunning forecast fidelity, accurately predicting the severity and size of the storm well in advance of its arrival.

Before weather satellites, American cities suffered from unexpected hurricanes time and again. In Galveston, Texas, more than 8,000 lives were lost in 1900 due to a surprise hurricane – the worst natural disaster in U.S. history.[4] Miami, Florida, was unexpectedly hit a by hurricane in 1926 that resulted in damage losses equivalent to $100 billion in today's dollars.[5] Hurricane Audrey in 1957 stormed the Gulf Coast without warning and killed more than 500, wiping away entire towns in Louisiana.[6] Prior to the satellite era, some hurricanes regularly formed without any knowledge of their existence by meteorologists. For example, hurricanes form off the coast of Baja California every year and although they rarely reach California or Hawaii, the potential still exists for millions of people to be affected by these storms. Satellites exposed an annual potential threat to life and property that *no one even knew existed*.

Today, more than 90 percent of all observation data used in three- to seven-day forecasts from the National Weather Service comes from satellites.[7] This data informs all forecasts for the civil, commercial and military worlds, including forecasts in smart phone apps, television and radio reports, websites and newspapers. These forecasts all get their information from space-based data and there is no equivalent to U.S. government-funded capabilities from any other sector or company. The need for these forecasting systems could not be clearer after 2011's record number of deadly, extreme weather events. In fact, there were more weather events in 2011 that inflicted at least $1 billion in damage than in all of the 1980s, even with inflation adjustments.[8] In 2012, our country experienced severe drought, which badly damaged our agricultural productivity and spawned destructive wildfires across the nation. Again, weather forecasting assets helped predict the duration and extent of the drought.

Although the number of fatalities from storms like Hurricane Sandy in the age of weather satellites is much lower, even one fatality is one too many. The deadly tornado outbreaks of 2011 are reminders that nature still strikes with devastating power. But agencies like NASA and NOAA are working hard to improve the forecasting techniques of these storms using space-derived data and the results thus far have been impressive. Since the 1990s, NOAA's hurricane storm track forecast error has been reduced by 60 percent.[10] With such a remarkable improvement in storm predictability, not only are those in the storm's path alerted to potential danger, but unnecessary evacuations are reduced dramatically – avoiding major losses in economic productivity.

In fact, NOAA's forecast location accuracy for a hurricane five days into the future is now as accurate as the three-day outlook was 15 years ago, giving communities much more time to prepare for impending natural disasters.[11] Already we have reaped major benefits from these improvements. For example, thanks to increased accuracy of forecast data derived from satellite observations, no unnecessary evacuations were issued in Florida for Hurricane Irene, saving millions of dollars.[12]

Well organized storms like hurricanes aren't the only weather events better understood thanks to space-based satellite observations. Tornadoes have been known for their terrible power and seemingly unpredictable nature, but thanks to satellites, major improvements have been seen in tornado warnings. In April 2011, observations from Polar Operational Environment Satellites (POES) indicated a tornado outbreak could occur across the Southeast United States. Meteorologists from NOAA alerted localities across six states for the potential of tornadic activity up to five days ahead of tornadic conditions. Twelve hours before the storm, additional satellite imagery from the Geostationary Operational Environmental Satellite (GOES) constellation, along with NOAA's NEXRAD network of ground-based radars, provided yet more precise warning to specific communities.

Even more lead time for tornado warnings is possible with future satellites under development. Currently, the average immediate warning time to take cover from a tornado is 13 minutes. The GOES-R series satellites currently being built by Lockheed Martin for NASA and NOAA will increase the immediate warning of time by 7 minutes, allowing as much as 20 minutes or more to take cover from an imminent tornado. An increase of nearly 50 percent warning time in the most dire weather circumstances will save many lives; however, steady investment in such space assets must continue in order to make these capabilities a reality.[14]

The combined effort of the GOES and POES weather constellations in predicting tornadoes highlights an important reality about these space assets. NOAA and NASA collaborate with nations around the world to provide comprehensive, coordinated and sustained global coverage from geostationary and polar orbiting satellites. However, these spacecraft periodically must be updated and replaced. In 2011, NASA launched the Suomi National Polar-orbiting Partnership (NPP) satellite for NOAA's POES Constellation and is now building the Joint Polar Satellite System (JPSS) to provide essential observations and search and rescue communications into the next decade after NPP goes offline. Currently, due to budget cuts and program changes, the first JPSS will be operational at least 17 months after the NPP's planned operational lifespan *(see The Potential Weather Satellite Gap)*.

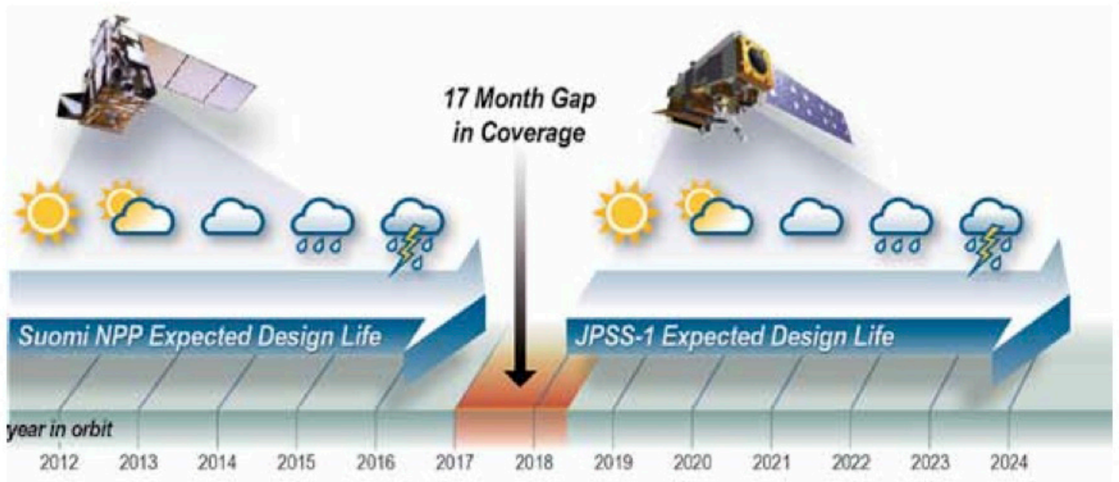
"Through the work of NOAA and other scientists who utilize polar-orbiting satellites to develop weather forecasts, the American Red Cross is able to make accurate and informed response decisions based on those forecasts."[9]

– Neil Denton, American Red Cross (2011)

"You can't predict what you can't observe."[13]

– Dr. Heidi Cullen, Climate Scientist

Potential Weather Satellite Gap



The timeline above highlights the tenuous condition of our nation's weather satellite constellations. The Suomi NPP satellite is one of three polar orbiting satellites that provide essential data for forecasts three days into the future. Should the Suomi NPP stop functioning at the end of its expected design life in 2016, the replacement satellite, JPSS, will not be available to take over until at least 17 months later. As a result, the nation is facing a near certain weather data gap by late 2016 to early 2017. There are no replacements for this coverage and the civil, military and commercial sectors all rely on this data on a daily basis. **(Data for timeline courtesy of the GAO)**[15]

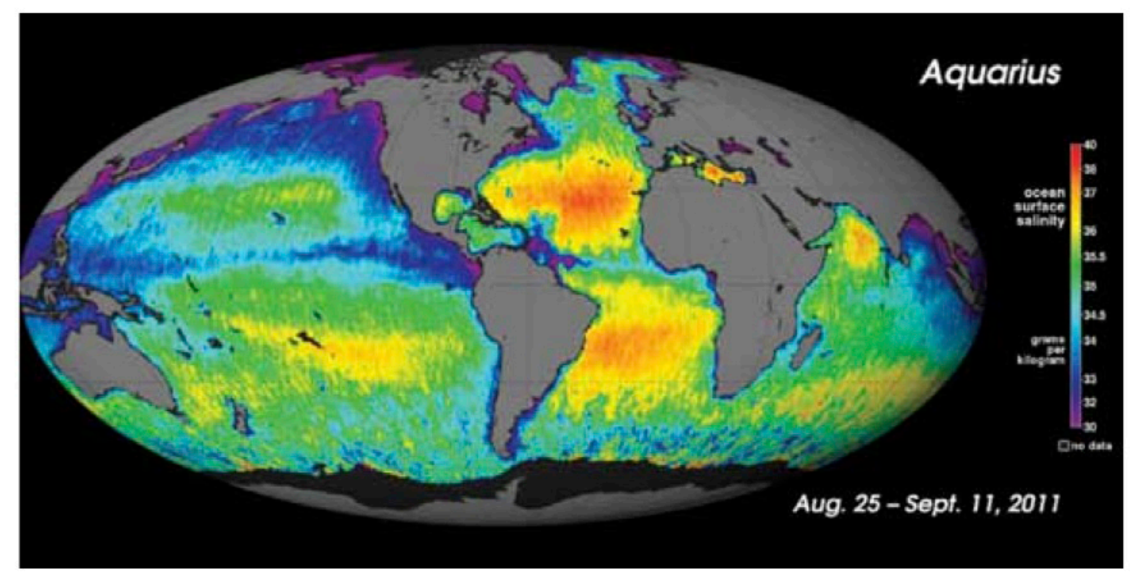
It is important to note that there are no backups to these venerable systems. Each satellite performs a specific role in providing a complete weather prediction. NOAA has shown that if just one of the POES satellites was not functioning in 2010, the 2010 Mid-Atlantic snowstorm would have been under-forecast by at least 10 inches with a predicted storm track off by at least 200 miles.[16] Consequently, while NPP may last longer than its design life, it is important to keep these vital new systems on track.

Satellite measurement is also integral to understanding the Earth's environment – observing deforestation, tracking invasive species, identifying diseased crops, monitoring wildlife parks and determining habitat losses.[17] By taking global scientific measurements of environmental phenomena, satellite observations provide breakthrough insights into the Earth as a complex system. For example, in 2011 the NASA satellite Aquarius provided the first ever global surface salinity map for the entire ocean system. Prior to that only 25 percent of ocean salinity ever had been measured. After just two months of operation, Aquarius acquired more salinity measurements than the entire 125-year history of observations from ships and buoys! Salinity affects significant aspects of the environment, including ocean currents, sea level, sea ice, water cycles and climate.[18] To date, more than 60 NASA Earth observation missions like Aquarius have provided invaluable data for a more complete and global understanding of how Earth works.[19] Each mission contributes to our composite understanding of the whole Earth.

The benefits of a more comprehensive view of the environment are numerous. For example, the World Food Program uses a sophisticated Famine Early Warning System (FEWS) for monitoring at-risk regions

of the world. FEWS analysis relies on satellite observation to gauge rainfall, vegetation indices and water measurements to warn localities of impending famine conditions. One official from the World Food Program remarked that FEWS helped predict the recent Somali famine, sounding the alarm to the world before the crisis peaked. By collecting numerous types of data from space, a more complete picture informs decision makers of potential environmental catastrophes.[20]

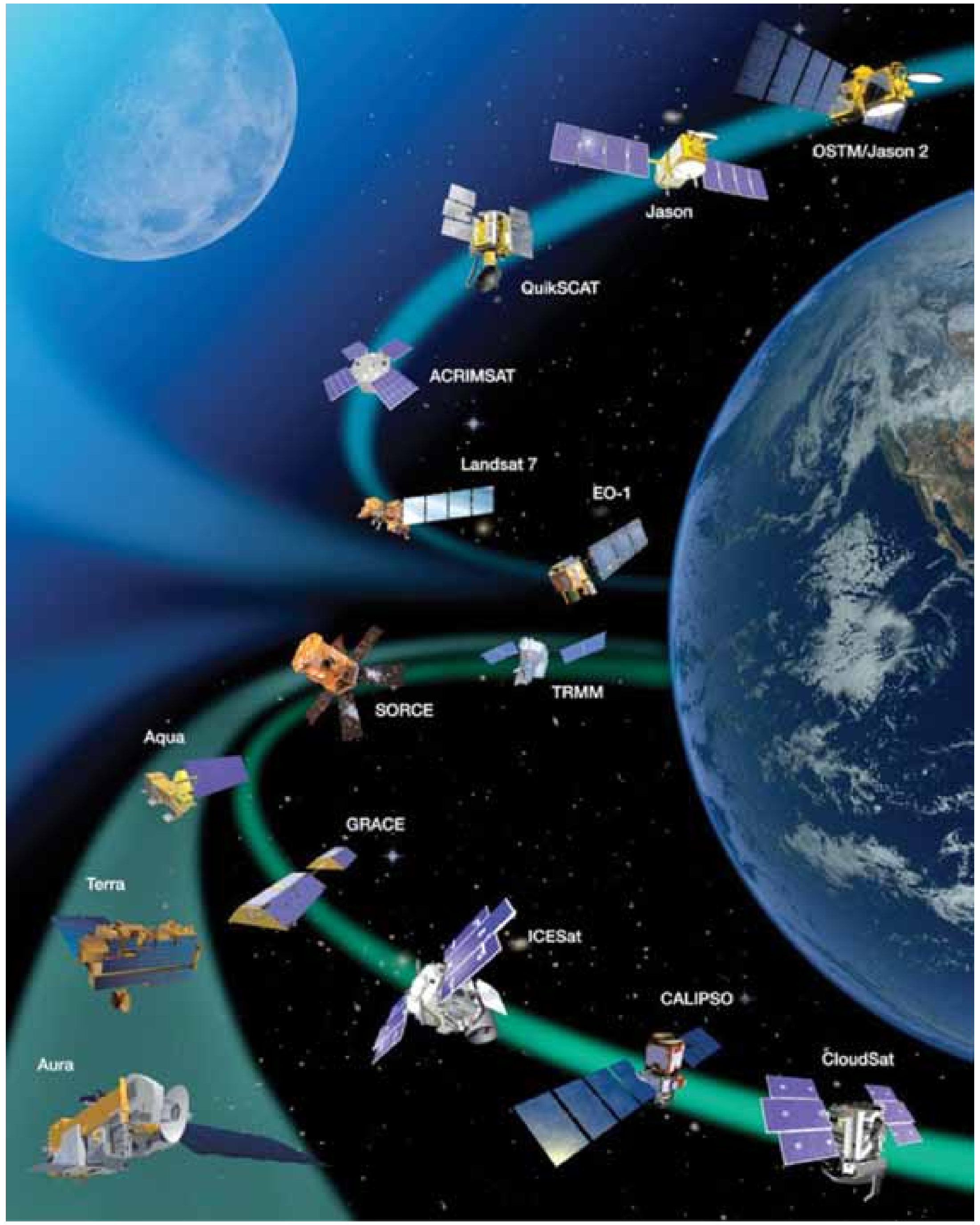
Although Earth observation and weather satellites provide continuous, high-fidelity warnings for one-off events like hurricanes or tornadoes, these assets also protect against less obvious, longer-term catastrophes. History has shown that environmental awareness can be a significant asset to a society struggling with challenging natural conditions. For example, in 695 A.D., the once robust Mayan Civilization began experiencing dramatic collapses of entire cities. Researchers have recently shown that the Mayans faced a rapidly drying climate and subsequently a drought – 60 percent of which was due to unprecedented deforestation for Mayan farming. Having no understanding of how their ecosystem functioned likely made it very difficult to grasp the aggregate environmental conditions that probably contributed to the civilization's decline.[21] Thankfully, Earth observation and weather satellites that are in service today are precisely the tools needed for maintaining environmental awareness for our nation and the world – mitigating not only short term disasters, but also long-term environmental degradation that could threaten our way of life and our safety.



NASA's Aquarius satellite provides the first ever global map of ocean salinity – an immense achievement for environmental insight that would be virtually impossible to do on the ground at the cost of the Aquarius program. **(Map courtesy of NASA)**

NASA's Earth Observing System

Although NASA has several satellite missions studying the Earth's oceans, continents, atmosphere and ice – many of these assets are aging and will need replacing in the very near-term. There are no backup systems if these capabilities are lost and each satellite performs unique measurements. **(Image courtesy of NASA)**

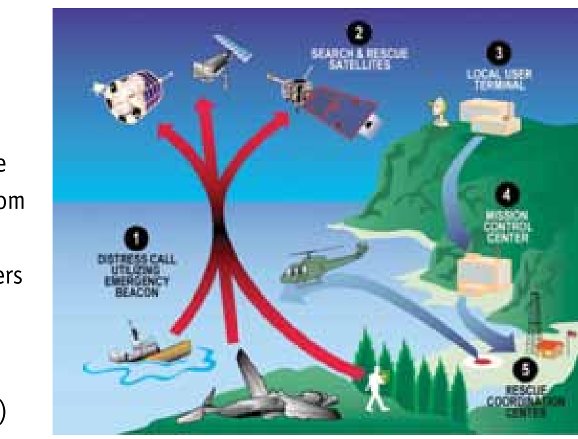


Disaster Response

In addition to being always on guard for impending disasters, satellites are also at the leading edge of rescue response and recovery all around the world. Since 1982, the NOAA Search and Rescue Satellite Aided Tracking (SARSAT) system has been used in more than 30,000 worldwide rescues at sea and on land – saving the lives of downed aviators, mariners and recreationalists all over the globe. The SARSAT program provides a beacon detection and location system for finding and tracking distressed individuals in almost any weather condition.[22]

The NOAA SARSAT is a first responder satellite system that has saved more than 30,000 people since it was activated. **(Image courtesy of NOAA)**

U.S. space assets have also been at the heart of countless disaster mitigation and recovery efforts. For example, emergency responders rely heavily on NOAA's polar satellites to find wildfires, identifying the hot zones and smoke within wilderness to inform firefighters where to concentrate their efforts. By providing up-to-the-minute observations from space, first responders can more intelligently respond to crises – saving lives and bringing comfort and stability to disaster victims.



During the 2011 earthquake and tsunami disaster in Japan, geospatial intelligence was given to the Japanese by satellite imagery provider DigitalGlobe. The view from above helped assess the state of the nuclear emergency at the Fukushima power plant and even provided a street-by-street look at damage to inform first responders where disaster victims may have been trapped in collapsed structures.

Similar geospatial imagery was utilized following the 2010 earthquake in Haiti. Within hours of the earthquake, the National Geospatial Intelligence Agency (NGA) began collecting satellite imagery of Port-Au-Prince. Through commercial remote sensing satellite imagery acquired by NGA from DigitalGlobe and GeoEye, FEMA determined the best locations for medical facilities, pinpointed the best routes for travel and triaged the disaster zones. FEMA's team leader in Haiti at the time remarked that the work of NGA in Haiti possibly saved up to 37,000 lives.[23]

FEMA's team leader in Haiti estimated that the NGA's satellite imagery possibly saved up to 37,000 lives during the earthquake crisis of 2010.[24]

In May 2008, an earthquake struck Honduras and inflicted heavy damage to local infrastructure. A partnership between NASA and U.S. AID, known as SERVIR, immediately provided satellite imagery of the affected region. By the time the Honduran earthquake struck, this partnership had already seen action 24 times in Central America and the Caribbean in some of the most desperate of circumstances.[25] The SERVIR partnership provides Earth observation satellite data to numerous nations in the Americas, East Africa and the Himalayan region, relaying important data on local ecosystems, weather, water and agriculture for the benefit of public health in developing countries.

Partnerships like this one demonstrate the responsive, practical information space assets provide countless societies around the world. In addition to NASA and U.S. AID, the United Nations is also utilizing space assets in concert with organizations like the Red Cross to facilitate disaster relief efforts. The U.N. Operational Satellite Applications Program (UNOSAT) regularly delivers satellite imagery for regions of the world experiencing humanitarian crises, human security issues or general development challenges. In 2012, UNOSAT provided tools and expertise for the mapping of water resources in Chad using satellite imagery.[26] UNOSAT's latest efforts involve setting up a camera aboard the International Space Station for video monitoring of disaster zones, providing a new type of live view over an affected area.[27]

In Brentwood, Tennessee, firefighters responding to emergencies used to locate fire hydrants by searching for a blue reflector in the middle of the road. This wasted precious time in an emergency. Sometimes the reflectors weren't even in place because of repaving, snow removal, or regular wear and tear. This all changed with GPS. Now, the location of every hydrant is pinned to a map using GPS technology. This map can be accessed from the laptops in every fire truck and firefighters locate a hydrant before even arriving on scene. [29]

In addition to satellite imagery, many emergency personnel are now equipped with precise position and navigation capabilities thanks to the Global Positioning System (GPS). Police, fire and rescue services can now coordinate with near perfect location information, whether they're on roads or in the wilderness.[28] Although emergency situations are often confusing and unpredictable, GPS and satellite imagery are clearing away the fog of chaos and enabling emergency responders to save lives.

Medicine

Space programs have tangibly contributed to significant medical technology advancements and pioneered public health techniques that have expanded access to health care. The significance of these advancements is not lost on the medical community. That's why in 2007, a conference of the American Medical Association (AMA) formally endorsed NASA's plans to send astronauts beyond Earth orbit. Recognizing the immense benefits of exploration programs, AMA stated further exploration will "undoubtedly yield both projected and unanticipated biomedical breakthroughs." AMA's support for space programs shows that funds for space exploration are direct investments in improving society.

Microalgal experiments for spaceflight led to the development of new baby formula supplements called DHA that encourage healthy brain and eye development for infants. These supplements are now strengthening the health of more than 33 million babies in more than 75 nations.[30]

The track record for previous advancements is impressive. Pacemakers that monitor and defibrillate the heart were derived in part from technologies developed in the Apollo program.[31] The Space Shuttle's robotic arm technology was adapted for robotic surgery techniques inside of MRIs, enabling surgery on dozens of patients whose operation had been previously classified as impossible.[32] Instruments used in space for infrared astronomy have enabled instant ear thermometers.[33] Microalgal experiments for spaceflight led to the development of new baby formula supplements called DHA that encourage healthy brain and eye development for infants. These supplements are now strengthening the health of more than 33 million babies in more than 75 nations.[34] A physics experiment conducted by astronauts in space led to a device that assesses the effectiveness of non-surgical therapies for early-stage cataract development. The device is also being adapted to diagnose other eye diseases, diabetes and possibly Alzheimer's.[35] Microgravity research on ISS is now investigating infectious diseases like Salmonella that affect millions of people worldwide (see section: Reinventing Research and Development).

Not only have space programs contributed to medical technology advancements, they have also pioneered techniques that expand health care access to more people. In the 1960s, NASA faced a daunting challenge: how to keep astronauts healthy and strong, 200,000 miles away from the nearest doctor's office. The space environment adversely affects muscles, bones and immune systems. Efforts to solve these challenges led to techniques now known as telemedicine and are highly relevant to treating Earth-bound patients that are remotely located – whether in a rural village or a disaster zone cut off from typical infrastructure.

In the case of the 2010 earthquake in Haiti, a former NASA engineer who specialized in telemedicine equipment on the Space Shuttle set up video equipment in Haiti that transmitted live video feeds between earthquake patients and doctors in the United States. NASA telemedicine techniques also provided local Haitian doctors advice from the global medical community – allowing for the transmission of X-rays and pathology reports. NASA continues to share its telemedicine expertise with remote locations in South America, Asia and Africa – by equipping partnerships that treat medical conditions from heart disease to diabetes.[36] The use of ultrasound has also been expanded for a host of new medical diagnoses thanks to telemedicine findings on the International Space Station. Trained personnel are now accurately diagnosing conditions with ultrasound in the developing world, as part of the U.N. Millennium Development Goals program.[37]

Cochlear Implant

In the late 1970s, a Space Shuttle engineer by the name of Adam Kissiah Jr. set out to solve a problem he understood all too well – his own hearing impairment. Adam had tried previous hearing aids but they all had one fundamental problem: they could amplify sounds, but not stimulate impaired nerve endings. For his role on the Shuttle team, Adam possessed a wealth of knowledge in acoustics, telemetry and electronic sensing systems. Equipped with this extensive expertise, Adam developed a new technology that would first electronically sense acoustics and then stimulate auditory nerves to deliver the signal to the brain. In 1977, Adam's technology was patented and developed into an implant (known today as the cochlear implant) for those with hearing impairments like his own. The Food and Drug Administration has estimated that more than 219,000 patients have since received cochlear implants, allowing those with deafness to hear sound – in some cases for the first time ever. For others who experienced deafness due to injury, cochlear implants have restored hearing they may have once thought was gone forever. One patient in his 50s remarked after having received the implant, "The birds singing…I would say that's the most beautiful thing I've heard. I never heard birds before…"[38, 39]

Telemedicine can also provide incredible value to rural communities within the United States. For example, a North Carolina hospital was able to diagnose a rural patient's spinal injury at a distance using video imaging, which avoided a long-distance patient mobilization that could have resulted in the death of the patient.[40] As incredible as these examples are, it's important to remember that telemedicine is just getting started. Telemedicine techniques will have to become yet more sophisticated as space programs extend exploration beyond Earth orbit – no doubt these improvements will be passed on to enhance the standard of care for people here on earth.

Civilian Protection

With continuous coverage of the Earth from orbit, space assets supply a global perspective that holds governments and regimes across the world far more accountable for their actions than ever before. Satellites not only provide imagery for treaty verification, they alert the world to humanitarian crises and war crimes taking place in regions typically restricted to outsiders.

Qabun, Damascus, Syria-July 18, 2012: This is a satellite image of the Qabun neighborhood in Damascus, Syria, provided by DigitalGlobe. Satellite imagery shows military vehicles on 6th Rishreen road in the lower left portion of the image, as well as a smoking building on the feeder road in the center of the image. Vehicle tracks and possible rubble are visible just above the smoking building. Four additional military vehicles are located elsewhere in Qabun, encircling the neighborhood.

(Image courtesy of DigitalGlobe)

In the case of recent atrocities in Syria, satellites yielded detailed, objective images of events as they have unfolded. When tanks moved into the Syrian city of Hom in February 2012, satellites alerted the world community to the regime's violent maneuvers in suppressing the uprising. Satellites continue to provide an unbiased look at the carnage experienced by the Syrian people. In fact, in May 2012 satellite images documented recently dug mass graves in the town of Houla.[41] Images like these convey the seriousness and scale of the violence occurring within the country in ways that a written account never could.

Today it's extremely difficult for oppressive regimes to execute campaigns of violence or genocide against civilians without the world quickly finding out through immediately responsive and unbiased satellite imagery. For example, satellite photography of mass graves and other atrocities occurring within Kosovo enabled Yugoslav president Slobodan Milosevic to be charged with crimes against humanity before the NATO-led Kosovo air war had even finished in 1999.

The power of satellites to alert nations around the world to instances of violence against the innocent is now so widely recognized that non-profits can use these instruments to expose crimes against humanity and take unprecedented action to prevent their perpetuation. Actor and activist George Clooney's Satellite Sentinel Project (SSP) is a joint effort between the Harvard Humanitarian Initiative and earth imagery provider DigitalGlobe to monitor for evidence of bombings, razed villages and possible threats to civilians in Sudan and South Sudan.[43]

Already this imagery has accurately alerted the towns of Kurmuk and Abyei, Sudan, to likely violence – affording civilians the chance to evacuate in real time. SSP imagery has also been used to document acts of violence against the people of Darfur in the International Criminal Court at The Hague and to monitor Sudan's compliance with UN Security Council.[44] Thanks to space, it is impossible to inflict systematic violence on civilian populations in absolute secrecy – now the world is always watching.

"In the hands of well-trained and experienced analysts guided by humanitarian principles, satellite technology provides a potent new way of ensuring that the world witnesses threats to civilians."[42]

– Michael Van Rooyen, Director of the Harvard Humanitarian Initiative

Treaty Verification

Treaties among nations are important instruments for global peace and security, but they only work effectively if nations live up to the terms of the agreement. Thankfully, many treaties now incorporate important verification measures to ensure all are playing by the same rules. Satellite imagery is often the primary source of objective verification that all parties are abiding by the terms of international agreements. In the case of the recently ratified New Strategic Arms Reduction Treaty (New START), satellites are identified within the treaty as a means of verifying nuclear weapon reductions in the United States and Russia. New START is one of several nuclear weapons treaties in recent history that have been empowered and strengthened by provisions that feature objective satellite observations as a means of verification. By corroborating conditions on the ground, satellite imagery verifies that other nations fulfill their legal obligations.

> **Recommendation 1:** Stable funding and steady policy support is needed from the U.S. government to ensure NOAA Environmental Satellite, Data and Information Service, NASA's Earth Science program, USGS Landsat program and other U.S. government and commercial earth observation systems can replenish aging Earth observation satellites and maintain essential data coverage that contributes to saving thousands of lives every year.

Defending our Nation

In February 1991, the U.S. military was on the brink of its first ground war since the Vietnam era. Poised for a massive attack on Iraqi ground forces at the Persian Gulf beaches of Kuwait, more than 15,000 U.S. Marines were staged on 13 different Navy ships in the Gulf. All were waiting for orders to begin the liberation of Kuwait from the repressive regime of Saddam Hussein. U.S. air strikes had eliminated countless Iraqi defense targets in anticipation of the largest U.S. amphibious movement since the Korean War. Sensing a 'D-Day' style invasion was inevitable, the Iraqi military had assembled five soldiers for every Marine in the Gulf. Everything was in place for a dramatic, contested beginning to the ground war.[45]

But the beach invasion never came.

Instead, 100,000 U.S. troops and 20,000 vehicles stormed through the western Iraqi desert, reaching the heart of Iraq in less than 100 hours. The beach invasion had been a total deception and the Iraqi Republican Guard was caught completely unprepared. The maneuver was dubbed the 'Left Hook.' Iraq's military not only doubted that the Americans could invade through the desert, the Iraqis themselves had no operational experience in the desert. In one swift maneuver, the U.S. military eliminated Iraqi home field advantage, along with months of defensive preparation by Saddam's military in Kuwait.[46]

The left hook strategy in Operation Desert Storm completely depended upon GPS. **(Image courtesy of the Department of Defense)**

In any previous war, the Left Hook would have been all but impossible. The desert is a deadly and unforgiving environment with few distinguishing features for navigation and guidance. This all changed with the introduction of a new space-based guidance capability – GPS. The implementation of space capabilities like GPS in the first Gulf War demonstrated that the battlefield had changed forever. Although space systems were not integrated into every U.S. operation in 1991, they did enable the U.S. war strategy – especially the ground war offensive.

Thanks to space, the U.S. military operated as a single coordinated force – even during night operations in the vast roadless deserts of Kuwait and Iraq. **(Image courtesy of the Department of Defense)**

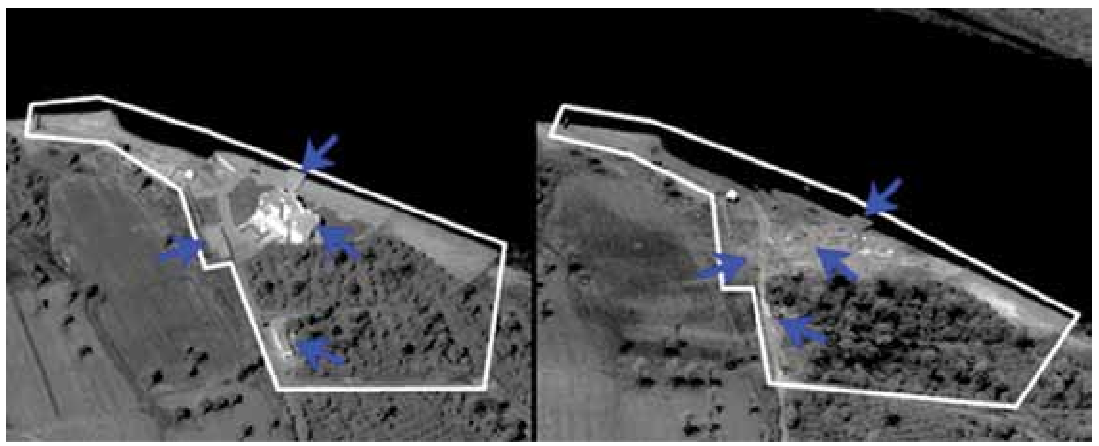
The first Gulf War was an impressive display of how space capabilities could significantly affect the outcome of conflict, with unmatched advantages in speed and efficiency. This lesson was not lost on the Chinese, who stood up and took notice of the U.S. space-based strategy. The People's Liberation Army (PLA) of China noted the U.S military had successfully integrated its services under one combatant command – an operational structure that was enabled by space capabilities providing instantaneous communication and information.

Following the Gulf War, the PLA invested heavily in space. Today, China has a multitude of national security and military space capabilities. The PLA is even in the process of building its own version of GPS called Beidou. Chinese military investment in space is a sobering reminder that space is the true high ground for defense in the 21st century.[47]

Unquestionably, U.S. military and national security strategy hinges on maintaining robust, state of the art systems in space. Space systems play essential roles in the nation's security by providing force enhancement, situational awareness and even continuity of government. These capabilities cannot be easily replaced and there is no terrestrial substitute for the high ground afforded by space assets.

Force Enhancement

Although GPS made its dramatic operational debut in the Left Hook maneuver, the full potential for GPS in national security and military applications is just now being realized. In fact, during the first Gulf War, only seven percent of all munitions were precisely guided by GPS. By the Iraq War of 2003, more than 65 percent of all munitions were guided by GPS receivers. The capability to guide munitions with precision control from space deeply enhances their effectiveness in pinpointing adversaries, while drastically reducing the loss of civilian life and property. For example, during the invasion, Saddam Hussein had positioned his tanks to avoid another dramatic advance like the Left Hook, but due to satellite reconnaissance and precision GPS guided weapons, more than 90 percent of Iraqi tanks were destroyed long before U.S. troops arrived. Before the land assault, F-16s would routinely get target lists generated by space observation and take out the tanks one by one. Not only do precision guided munitions save lives during the immediate military campaign, they ensure that important civilian infrastructure such as electrical grids and water systems are more readily available in the post-war rebuilding effort.[48]



Satellite imagery showing the results of a GPS guided munitions campaign in the Iraq War of 2003. On the left is an Iraqi compound before the campaign. On the right is the aftermath. Dramatic results like these are the norm for GPS guided munitions – decimating targets, but minimizing civilian casualties through precision. **(Image Courtesy of U.S. Central Command)**

GPS has become a basic tool for even the most basic U.S. military operations. The military's Joint Precision Air-Drop System or JPADS has shown success in combat zones in Iraq and Afghanistan, allowing air-dropped supplies to be guided via GPS to troops below. Such capability dramatically reduces risks to air crews by allowing them to drop supplies from higher altitudes, minimizes enemy detection and increases the number of drop zones possible per mission.

Satellite-based coordination among navy fleets, ground troops, unmanned aircraft, precision guided munitions, tanks and countless other military units is not only central to large scale campaigns, it's critical to counter-insurgency operations on the unit scale. In fact, GPS played a crucial role in the Battle of Sadr City, a major turning point in the Iraq War.

"We're surrounded by mountains – the snow sets in. The helicopter passes are impassible by helicopter and the roads could be clogged up … Utilizing airdrops with the GPS-guided parachutes allows us that avenue to use in case we can't get resupplied by helicopters or vehicles by the road, which is a typical case come winter here."[49]

–Army Staff Sgt. Denton Poe
1st Platoon Sergeant,
Combat Outpost Herrera, Afghanistan

In 2007, U.S. forces experienced an elusive and dangerous insurgency in Iraq that regularly launched rockets into the heart of Sadr City. In order to disrupt the insurgency, the U.S. military deployed intelligence, surveillance and reconnaissance (ISR) assets, including an extensive use of unmanned aircraft systems (UAS). UAS rely heavily on GPS for navigation and control and their munitions are precisely guided by GPS as well. The space-enabled ISR campaign reduced attacks dramatically. Insurgent attacks in Sadr City totaled more than 1200 in July 2007. After a hard-fought ISR campaign, these attacks had been reduced to less than 240 in February 2008.

Intelligence, surveillance and reconnaissance assets such as the Global Hawk unmanned aerial vehicle built by Northrop Grumman completely rely on the space-based Global Positioning System (GPS). Almost all ISR assets require direct support from space systems for their operations. **(Image courtesy of Northrop Grumman)**

Military communications satellites also play an integral role in force enhancement, allowing for communications between theater operations and off-site commanders. Modern space systems like the Wideband Global Satellite and the Defense Satellite Communication constellation provide instantaneous, broadband communications between commanders and warfighters across continents. In fact, during the first Gulf War, more than 90 percent of all communications were transmitted via satellite.[50] Prior to the deployment of satellites, the president and senior military leaders could only be informed of events after they unfolded, with considerable time delay.

Today, the president and his national security team can receive real time updates in the most critical national security and military operations thanks to military communications satellites. The raid on Osama Bin Laden's compound demonstrated the irreplaceable capability that space offers the commander-in-chief and other critical officials. As Seal Team Six conducted its operation, the president monitored the mission at the Situation Room in the White House. The Bin Laden raid exemplifies the unique ability of space assets to provide communications in remote and contested environments, but these systems are not just reserved for the president – they are used daily throughout the Armed Forces. Satellite systems like Military Strategic and Tactical Relay (Milstar), Mobile User Objective System (MUOS) and Wideband Global Satcom (WGS) enable the U.S. military to project force anywhere in the world, with up-to-the-minute coordination between military branches and command structures.

Space systems like GPS, communications satellites and intelligence satellites enabled Seal Team Six to conduct the raid on Osama Bin Laden's compound and allowed the president to make real time decisions from the White House Situation Room. **(Image courtesy of the White House)**

Space-based communication systems not only allow highly coordinated operations in all corners of the globe, they provide the backbone of continuity for unimaginable wartime circumstances. The Advanced Extremely High Frequency (AEHF) satellite constellation provides guaranteed communication between the president and the military even in the event of nuclear war. AEHF transmissions are designed to penetrate even the most devastating electromagnetic radiation induced by a nuclear event. With systems like AEHF, space provides a continuity of government that cannot be replaced by any ground system.

Enabling the president and other national security leaders to make faster, better informed decisions throughout military operations is a crucial development from space, but also important is the game-changing capability space offers the warfighter. The Defense Support Program (DSP) satellite constellation continuously monitors the Earth for the heat of a missile plume to alert U.S. forces of incoming threats. In the case of the first Gulf War, DSP was able to detect nearly every Scud missile launched by Saddam Hussein's regime, offering precious minutes of warning to coalition warfighters who might otherwise be endangered. Not only did U.S. Central Command alert troops on the ground to Scud missiles, they also warned local civilians who were also in the missile path.[51] Subsequent to the deployment of DSP, another satellite constellation known as the Space Based Infrared System (SBIRS) has been initially deployed, providing even greater monitoring and warning capabilities.

Missile Defense

Space also offers the opportunity to develop new defensive techniques and capabilities that cannot be easily replicated or replaced by terrestrial military systems. Space systems are an essential element of our missile defense capabilities, detecting missile launches and alerting U.S. interceptor systems to take counter measures. The DSP and SBIRS systems are sophisticated systems that detect missile plumes of all kind, including missiles with nuclear warheads. The initial alert provided by these two systems is complemented by other space systems that track missiles from launch all the way through collision. The Space Tracking and Surveillance System on orbit today is a demonstration system being used to develop and refine techniques for tracking missiles throughout their flight. Space assets like these keep the United States at the cutting edge of missile defense technology and capabilities and hold the key to protecting our nation, our deployed forces and our allies from missile attacks.

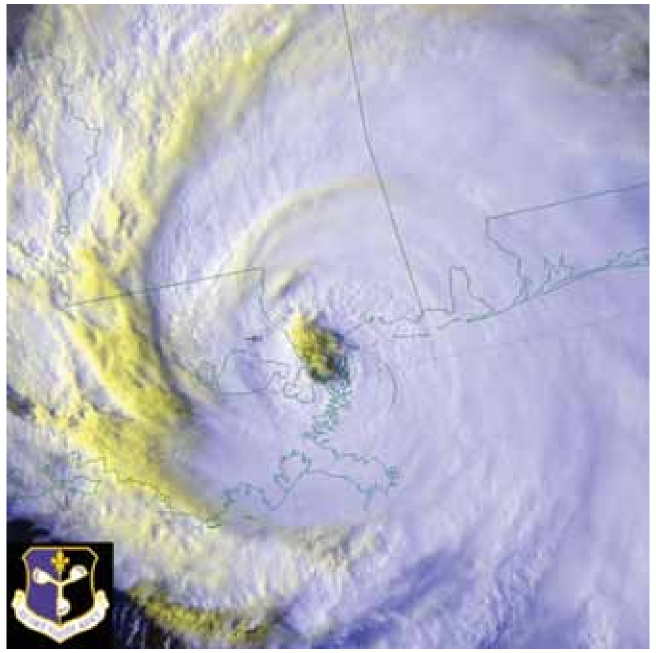
Missile defense systems like the ground-based interceptor pictured here depend on space assets for their operation. **(Image courtesy of The Boeing Company***)*

Intelligence

In a world where both nation states and non-state actors present growing threats to the United States, it is more challenging than ever to acquire relevant and timely intelligence on threats to our interests. Space assets provide a decisive advantage in acquiring highly sophisticated intelligence across the world through a number of media – visible and invisible across the electromagnetic spectrum. These systems not only provide real time assessments of conflict areas and adversaries, they give special insight into global conditions and future threats – helping inform policy makers on defense investments and diplomatic priorities. As silent sentinels in orbit around the Earth, it's easy to forget the immense advantage these systems provide our nation. Nevertheless, space has been an integral capability for national security since the early 1950s.

Through the CORONA spy satellite program, the U.S. government gained a much clearer picture of Soviet military capabilities. CORONA lifted the veil of secrecy from the "Iron Curtain," allowing the United States to accurately gauge the military threat posed by the Soviet Union. CORONA imagery was especially important as it dispelled the mistaken belief of some U.S. policy makers that a missile gap was forming with the Soviet Union. Since the development of CORONA, satellite imagery has improved exponentially. Imagery from Earth orbit provides clear views of areas restricted to the United States and its allies. For example, satellites have supplied detailed observations of the facilities and technologies in Iran's nuclear programs. Satellite imagery allows the world community an opportunity to identify the Iranian regime's true nuclear ambitions and monitor changes over time at their facilities.[52]

In addition to the CORONA satellite imagery program, the GRAB and Poppy satellite programs were also mobilized in the 1960s to collect Soviet radar transmissions in Earth orbit, helping to locate Soviet radar assets, measure their capabilities and pinpoint Soviet air defense systems. Recently the U.S. government declassified even more advanced satellite reconnaissance systems, code-named Gambit and Hexagon, further revealing the vital role space has played in our national security for decades.[53]



Air Force weather satellites capture data on Hurricane Katrina. **(Imagery Courtesy of Air Force Space Command)**

Today, the United States maintains a fleet of space assets that provide a decisive edge against adversaries, but steady investments are needed to keep that lead. Although space systems for intelligence gathering were conceived in the Cold War, they have become essential to a host of current national security activities that protect the warfighter, assure mission success and keep the U.S. homeland safe. In 2011 alone, the National Reconnaissance Office (NRO), the primary agency for developing intelligence collection systems in space, provided crucial intelligence for more than 15 operations that captured or killed high value targets in combat. Incredibly, NRO systems were also used last year in 120 operations to locate improvised explosive devices and prevent deadly attacks against U.S. troops and personnel in combat zones. Intelligence satellites were used in 17 missions for combat search and rescue and more than 33 operations were aided by satellites for safe passage of U.S. Naval ships in the Strait of Hormuz.[54]

Space systems that collect imagery and other sources of information from Earth orbit offer unmatched views on complex geopolitical conditions. Often forgotten however, is the U.S. military's basic need for timely, accurate and precise intelligence on another dangerous and unpredictable global phenomenon: the weather. Just as weather conditions can significantly affect civilian populations, they can disrupt and halt the most sophisticated and well-prepared military operations. When the first Gulf War's Left Hook maneuver was executed in the desert of Iraq, the U.S. military kept a constant monitor of the weather from space to ensure U.S. troops would not be endangered by an unexpected sand storm or other perilous desert conditions.

For more than fifty years, the Defense Meteorological Support Program (DMSP) has been providing the military timely information on weather conditions to ensure warfighters are completely aware of ever-changing meteorological conditions that can put missions and lives in jeopardy. Thanks to satellites, the fog of war is being lifted from the battlefield. The DMSP constellation offers a number of measurements that can make all the difference for combat success, including ice thickness, sea-surface winds, cloud data and contrails. Any number of these conditions can impact success for naval fleets, aircraft, soldiers and special forces.[55]

Weather Support Needed For U.S. Army Tactical Operations[56]

	Weather Elements					
	Cloud Cover	Surface Visibility	Precipitation	Thunder and Lightning	Temperature	Humidity
Military Operations & Equipment Impacted	• Jump Altitudes • Target Acquisition • Selection of Weapon Systems • Aircraft Detection and Identification • Aerial Reconnais-sance • Engagement Range • Flight Hazards	• Infrared Sensors • Navigation & Target Acquisition • Takeoff & Landing Capabilities • Aircraft Detection and Identification • Concealment and Cover • Ground Movement of Munitions and Supplies • Laser Range-finding and Target Designation	• Radar Signal • Infrared Homing • Lift Capabilities • Fuel and Weapons Load • Soil-bearing Strength • Storage of Munitions and Supplies • Ground Transport Over Unpaved Surfaces • Water Supply	• Electronic Systems • In-flight Refueling and Rearming Operations • Radio and Wire Communications • Synchronization for Data Communications • Storage • Handling and Transportation of Munitions and Fuels • Storage and Protection of Missile Systems	• Estimation of Ballistic Atmosphere Pressure and Densities Aloft • Calibration of Artillery Systems • Storage of Supplies • Effectiveness of Electronic Systems • Lift Capabilities	• Refractive Index for Optics • Radar Effectiveness • Effectiveness of Crews In Closed Vehicles • Stamina of Foot Soldiers • Storage of Munitions and Other Supplies

This table was generated from the U.S. Army's own regulation on weather support for tactical operations. By taking continuous weather measurements of these phenomena with the DMSP satellite constellation, the U.S. military obtains crucial situational awareness for carrying out successful military missions and maintaining warfighter safety.

Recommendation 2: Continued stable investments by the U.S. government in space programs at DOD and the intelligence community are needed to maintain irreplaceable strategic capabilities that protect warfighters, enhance their missions and guard the U.S. homeland.

Recommendation 3: The U.S. government should pursue cost-effective launch service strategies that enable competition and industry participation and help strengthen the U.S. space industrial and technology base to meet future requirements.

Recommendation 4: Continued investment in research and development (R&D) and science and technology for space capabilities is required to ensure the U.S. military and intelligence agencies maintain decisive advantages with cutting-edge space systems.

Creating and Enhancing Markets

In 1945, the visionary writer Arthur C. Clarke originated the idea that artificial satellites orbiting the Earth at the right distance (in a so-called "geosynchronous orbit") would appear stationary and could be used to relay communications signals around the globe. At the time, it no doubt seemed fanciful to envision an expensive telephone switchboard floating in the sky. Yet Clarke's proposed use of technologies that had not yet been invented gained enough traction that in 1962, NASA's Telstar I became the first satellite to demonstrate active communication relay capability; the Hughes-Syncom satellite launched in 1964 became the first communications satellite in geosynchronous orbit, realizing Clarke's vision.

Since then, the world has never looked back. In 2011, the satellite industry generated more than $100 billion in revenue from satellite services and of the 986 satellites on orbit today, 37 percent are used for the communications industry.[58]

Today, space capabilities like communications satellites have become an irreplaceable economic infrastructure for modern society – creating new markets and enhancing existing ones. Space systems provide near-instantaneous communication, observation and precision measurement that is fundamental to competing in the global economy. All of these sophisticated tools from orbit have become standard for commerce, enabling rapid business transactions, better informed decision making and more efficient supply chains.

For the consumer, the benefits from space capabilities are not always apparent – yet satellites in orbit are constantly used to ensure our grocery stores are stocked, our bank accounts are accessible from anywhere and our television screens are filled with live images we'll never forget. We enjoy the benefits of these space systems on a daily basis as goods and services are distributed faster and at lower cost.

Pictured in foreground is a Syncom satellite, an early test satellite used to determine the utility of communication satellites. In the background is a modern Boeing communications satellite. Over the course of just a few decades, communication satellites have evolved from a testable concept to a fully operational technology relied upon by billions of people. **(Image courtesy of The Boeing Company)**

"The benefits to our economy, national defense and environment from a half-century commitment to our space programs are clear. Maintaining these investments is essential to our competitiveness in a 21st Century global economy and is one of my top priorities."[57]

–Rep. Donna Edwards (D-Md.) **(Image courtesy of Rep. Edwards)**

The first image to be transmitted via satellite was that of an American flag in 1962 – a fitting reminder that U.S. space programs and the U.S. private sector took the lead in developing this space-based technology that has changed the world. **(Image courtesy of Smithsonian Magazine)**

Communications

Thanks to programs by NASA, DOD and the aerospace and telecommunications industries, new communications satellites were designed and launched in the decades since 1960, gradually perfecting a capability the private sector now relies upon every single day. By working together, industry and government proved that telephone calls, data and pictures could be actively relayed from Earth orbit and transmitted from one side of the planet to another. The developmental investments and technical ingenuity of these programs revolutionized communications and laid the foundation for the current information age.

Telecommunications enabled by commercial satellites have made the world a much smaller place, leaving virtually no part of the globe unconnected. There are now more than 360 commercial communication satellites in orbit that enable telephone calls in remote locations and disaster zones, and on ships at sea and aircraft.[59, 60]

For example, satellite phones are frequently the only means to connect with the outside world in some of the most desperate circumstances. During Hurricane Katrina, an estimated three million landlines were destroyed, along with 1,000 cell phone sites. Satellite phones provided most of the communication systems for rescue efforts on the scene in the first 72 hours after the storm. One satellite provider in the region alone saw a 3000 percent increase in satellite phone traffic. In fact, even three weeks after the storm passed, only 60 percent of all landlines had been restored and more than 2 million cell phone calls still failed. Nearly a month after the hurricane devastated the Gulf coast, satellite phones remained essential to recovery efforts.[61]

During Hurricane Katrina, satellite phones were the most reliable and effective means of communication for emergency rescue and recovery personnel. **(Image courtesy of the U.S. Coast Guard)**

Television

It's easy to forget that just a few decades ago, television was limited to just a few local broadcast channels. We take for granted that when we pick up the remote, we have hundreds of channels to choose from, with options that span wide spectrums of taste and interest. The ability of television to serve countless choices to millions of people, no matter where they live is in large part enabled by satellites.

In 1972, HBO became the first pay television network, but the network struggled in its first year of operation with only 8,000 subscriptions. Before satellites, HBO was limited by the number of subscribers who were close enough to microwave transmission centers. In 1975, RCA launched Satcom, a communications satellite that could relay cable television signals to the entire lower 48 United States. HBO, along with other notable cable networks like TBS, jumped at the opportunity to increase their viewership by an order of magnitude with domestic satellite transmission.

By 1977, HBO was making full use of Satcom and had grown its subscriptions to 1.7 million viewers. Within just a few short years, commercial satellites had taken cable television from a small industry to a robust service that millions of American households rely upon everyday for news and entertainment.[62]

The first live television transmission of the Olympic Games occurred during the 1964 Olympic Games in Tokyo via Relay and Syncom communications satellites. **(Image courtesy of Boeing)**

Satellites continue to be a keystone capability for premium television. Some services offer direct transmission from satellite to home, while others beam their programming to cable television satellite ground stations, which transmit to the home via ground wire. Thus, no matter whether the consumer opts for cable or direct satellite television, space capabilities make content delivery possible.

Satellites enable not only a plethora of content on television, but also the capacity to broadcast live to nearly every part of the world. Global events like the Olympics and the World Cup – which had a staggering 3.2 billion viewers in 2010 – are transmitted across the globe via satellites.[63] Live coverage of war zones in Iraq and Afghanistan via space systems have allowed citizens and policy-makers alike instantaneous media coverage not previously available in war time. The immediate transmission of all presidential debates is available at the finger tips of voters on tablets, laptops, smart phones and televisions thanks to space technology circling the Earth. For the first time in human history, many of the historic world events that shape our perspectives unfold live before our eyes thanks to satellites. No longer are we dependent upon second hand accounts of events to understand our world. News is witnessed as it happens, no matter where it occurs.

Perhaps less appreciated in the Western world is the ability of satellites to transcend national borders, making it difficult for regimes to tightly control the news media. In fact, until the 1980s, several nations with repressive regimes in the Middle East only received outside news media from shortwave radio, which was often jammed. With the advent of communication satellites came an explosion of independent news and entertainment television channels that could not be easily censored by repressive governments. By the mid 2000s – years before the Arab Spring – over 300 satellite television channels were transmitting uncensored news and entertainment directly to the people of repressive Middle Eastern regimes.[64]

Thanks to U.S. government and industry investments developing, demonstrating and deploying communications satellites, the world has become smaller, freer, safer and better informed.

Navigation & Timing

Space programs are often cited for their technological innovations, which are often later applied to other fields like medicine or emergency response. However many important benefits are derived directly from the space capabilities themselves.

In the 1970s, DOD embarked upon development of satellite-based navigation and timing for the U.S. military. After decades of steady, forward-thinking investment, DOD's Global Positioning System (GPS) became fully operational in 1994 with the launch of its 24th satellite. The GPS concept of operations devised by DOD allowed for anyone in the world to access the ultra-precise position and timing satellite signals. This simple choice held enormous consequence for the world: with the signal openly available for use, the public and private sectors could use the GPS system in ways the initial designers likely never imagined.[65]

"Our space industrial base is a critical part of our nation; the problems we solve up there mean solutions to problems down here. These are critically important investments we must continue to make."[66]

–Rep. Randy Hultgren (R-Ill.) **(Image courtesy of Rep. Hultgren)**

Of course, the most conspicuous use of GPS today is found in cars and mobile devices for navigating the streets of an unfamiliar place. GPS guides everyone from taxi cab drivers to families on vacation with precise, turn-by-turn directions. GPS also powers thousands of smartphone apps, adding capabilities that enable proximity-aware weather reports, restaurant reviews, hotel recommendations, mass transit time tables and even location-based reminders. As smartphones continue to become further woven into our lives, it's important to remember that GPS is at the heart of the countless mobile apps that are saving us all time and money.

Numerous other industries also have integrated GPS into their day to day operations for both navigation and timing. GPS' timing capabilities largely go unnoticed, but they are absolutely vital for our economy and our safety. The leading securities exchange operator for the New York Stock Exchange and the Euronext executes more than $70 billion in security exchanges every business day. Most of these transactions are done using computer automation that requires a precise and accurate time stamp for cost pricing at time of purchase. This requires a 5- to 20-millisecond resolution in timing.[67] Most computer electronics on Earth are not sophisticated enough to provide this degree of accuracy for transactions. Thankfully, GPS satellites provide universally available atomic clocks that synchronize financial markets and allow security exchanges to move at the speed of business. Today's economy unequivocally depends upon these timing capabilities from GPS to enable trillions of dollars of transactions each year.

The finance industry isn't the only major user of GPS timing information. GPS also synchronizes the base stations of wireless telephone and data networks, harmonizes the network computers of major investment banks around the world, reconciles FAA weather reports, coordinates power plants and substations and syncs National Weather Service Doppler Radars.[68]

Agriculture has also enjoyed enormous advances due to GPS-enhanced practices. Crop fields are now precisely treated with fertilizer down to the scale of centimeters.[69] Farmers can work in their fields even when there is fog or other weather-related visibility problems.[70] Companies like John Deere, long known for tractors and other farming equipment, now produce GPS receivers and software for enhancing farming that save money and reduce agricultural run-off of fertilizer and pesticides.[71] According to the USDA, by utilizing GPS, a 1,000-acre corn crop farm reduces its use of fuel, natural gas, herbicide and insecticide enough to yield $13,000 in savings annually.[72] With more than 80 million acres of corn planted in the United States, GPS saves corn farmers more than a billion dollars annually.[73]

Aviation traffic management is on the verge of a complete makeover thanks to GPS. A new system called Required Navigation Performance (RNP) is already being used at 70 airports in the United States, with satellite guided precision approaches for runways that reduce time in the air, fuel consumption and emissions for all flights.[74] In 2006 alone, Alaska Airlines used RNP to save 1,300 flights from being delayed or cancelled.[75] The demonstrated improvements from RNP have been impressive, but the best is yet to come.

The FAA's Next Generation Air Transportation System, or NextGen, will move from reliance on an aging, radar-based system of air traffic control, to a GPS-based system. NextGen will allow aircraft to fly closer together on more direct routes – enhancing safety while reducing noise and carbon emissions. In fact, FAA estimates that full implementation of NextGen would reduce aircraft emissions up to 12 percent by 2025—the equivalent of taking 2.2 million cars off the road for one year.[76] Outside of the United States, the Aireon system will use GPS to track and coordinate international flights, with an opportunity to save at least 2 percent on all fuel used in transoceanic flights per year.[77]

The direct economic benefit of GPS has been estimated at more than $67 billion per year in the United States alone, with more than three million jobs that rely upon the service.[78] New uses for GPS are constantly being invented and the U.S. government continues to augment and modernize the satellite constellation. GPS receivers are now being used on buoys for oil spill tracking, guiding commercial maritime shipping around the world and measuring changes in the tectonic plates to predict earthquake activity.[79]

Increasingly, GPS is at the heart of our economy and our safety.

Miami, FL – August 4, 2011: Satellite image of Miami, FL, which is used by Google Earth. **(This image was taken by DigitalGlobe's WorldView-2 satellite.)**

Urban Planning & Development

It's hard to imagine a world in which satellite photography is not always available in the palm of our hands through tablets or smart phones. The ubiquity of today's satellite observation data speaks to the enormous utility this space capability has for our modern society – it is now as readily available as email.

Satellites have a unique capability to obtain a large, unobstructed view of the Earth and can also be used to track changing conditions over time. Comprehensive assessments of highly dynamic events like major storms, beach erosion, drought, melting glaciers and wildfires are significantly enhanced by orbital observation – providing situational awareness for city planners and logistics managers. Maps augmented by satellite imagery are used to conduct urban planning studies and even analyze real estate. Today, small businesses, non-profit organizations and private citizens are all empowered with unobstructed views of the Earth to an unprecedented degree through programs like Google Earth. Satellites make these everyday mapping capabilities available to everyone.

Architects and engineers regularly use commercial satellite measurements to construct three-dimensional models of an environment and determine building obstacles. Satellite observations assess natural resource availability and depletion – including the potential for energy exploration and extraction. Multispectral imagery from space can even be used to determine mineral availability below ground, before mining operations begin.

Satellite imagery is frequently used by the insurance industry to determine risk and speed insurance claim response with comprehensive imagery after devastating weather events. Prompt claims response allows victims of natural disasters to get back on their feet much sooner. Imagery also prevents costly insurance fraud and is used to reach equitable judgments in litigation.

A recent study estimated that in 2008, nearly a half trillion dollars of the U.S. gross domestic product was impacted by weather variability.[80]

Weather Forecasting for Commerce

High-fidelity weather forecasts are needed not only for minimizing casualties in natural disasters, but also for maintaining our livelihoods and our quality of life. In the case of the 2010 Mid-Atlantic "snowmageddon" blizzard, an accurate forecast made possible through the application of POES data allowed businesses and emergency services to plan ahead. Airlines were able to adjust flight schedules. Grocery and retail stores could stock their inventories to accommodate potential shortages. Shipping routes could be adjusted to minimally impact supply chains.[81]

The snowstorm is only one example, however. Weather affects us on a daily basis and accurate satellite observational data is crucial to a strong economy. In fact, a recent study estimated that in 2008, nearly a half trillion dollars of the U.S. gross domestic product was impacted by weather variability.[82] Such variability affects a wide variety of sectors including commercial airlines, shipping, agriculture and food production, insurance, energy production and tourism. These sectors in turn form the foundation of secondary and tertiary economic activities in other areas.

Consider for example, the impact of weather on the electrical grid. Rainfall and snow pack levels determine how much water hydroelectric plants can expect for electricity production. Temperature and heat indices affect the grid's ability to distribute power, right down to individual transformers. For new and emerging sources of power, cloud cover and sunlight affect solar cell productivity and weather patterns influence the operation of wind turbines and offshore wave power. All of these variable conditions impact tactical, daily decisions made by power companies. By making choices based on weather conditions and trends observed from orbit, power companies optimize their production and distribution of electricity, producing cost savings for consumers and businesses every day, while also reducing emissions.[83]

In addition to daily prediction data, weather satellites also provide data for long-term weather trend prediction. Such forecasting is indispensable for decision making in major capital investments like power plants. The decision of where to locate a new power plant can be heavily impacted by predicted regional weather and climate trends. For example, if predictions indicate that a river flow will weaken in the coming decades, a power company will look elsewhere to locate a hydroelectric plant. Satellite data is vital to strategic decision making in both the near and far term.[84]

'Earthrise' image from Apollo 8. **(Image courtesy of NASA)**

'Earthrise'

Astronaut Eugene Cernan once poignantly remarked that during the Apollo Program, "We went to explore the Moon and in fact discovered the Earth."

In 1968, Apollo 8 became the first crew to leave Earth orbit and circle the Moon. As they came from behind the Moon for the first time, the astronauts were suddenly stunned by the beauty of the Earth rising above the Moon's horizon. Astronaut Bill Anders quickly snapped a photo that has since become universally known as 'Earthrise.' In describing the new perspective he acquired on the mission, Apollo 8 astronaut Jim Lovell said, "The vast loneliness up here of the Moon is awe inspiring and it makes you realize just what you have back there on Earth. The Earth from here is a grand [oasis] to the big vastness of space."

It's unlikely the crew of Apollo 8 could have predicted how influential this perspective-changing photo would become. Yet this single, color image of the whole Earth in the vast emptiness of space is now widely credited with helping to inspire the modern environmental movement. Earthrise captured the fragility of the planet, the uniqueness of our home and the interconnected nature of our environment in one dramatic image. With the publication of this image, the entire world could comprehend these notions in a visceral way that transcended data, culture or language. In the years following the dissemination of 'Earthrise', a multitude of actions were taken for stewardship of the environment – including the founding of the Environmental Protection Agency, the passage of the Clean Air Act, the passage of the Clean Water Act and the establishment of Earth Day.[85, 86]

'Earthrise' is a classic example of the nature of space exploration. Taking photos of the Earth from lunar orbit was never in the flight plan of Apollo 8. Yet the Earthrise image forever changed humanity's view of its home planet. This is a value of space that can't be quantified. Living, working and exploring space collectively enriches our lives on Earth with new perspectives and new ways of thinking.

Electronics Innovations

Sometimes the potential benefits of space program innovation are obvious from the start. The development of communications satellites is a good example. The potential for incredible utility to society from transoceanic communication signals was readily apparent to researchers at the onset of communications satellite development and testing. The program succeeded and a new space capability was quickly made available for civil, commercial and military use.

In other cases, the challenges of living and working in space bear serendipitous fruit by creating demand for products and technologies that do not exist in the open market. By creating a large and steady demand for these items, costs are driven down dramatically and made affordable to the commercial sector for mass production. New markets are enabled and the snowball of innovation becomes unstoppable. The integrated circuit is a classic example.

Up until the early 1960s, computers filled entire rooms. The Cold War need for smaller, more practical computers in missile guidance systems drove much of the development for integrated circuits – a technology that miniaturized computers into the palm of a hand. Although the U.S. military was the initial customer for this technology, its demand was not great enough to drive down its cost for commercial use. All of this changed with the Apollo program.[87]

"When I think about NASA and I think about Google, I think of both as being in the business of making things that were amazing commonplace."[88]

–Eric Schmidt
Co-founder of Google

In 1962, the integrated circuit market was approximately $15 million, with an average unit price of $50.[89] Project Apollo's challenge of landing humans on the Moon demanded vast amounts of computing power on spacecraft, but saving weight for launch was an equally important concern. The integrated circuit was exactly the electronics innovation needed to provide the perfect balance between computing power and weight savings. Apollo unilaterally necessitated an anchor demand for the integrated circuit and forever changed electronics as we know them today.

By the height of the Apollo Program in 1968, production of integrated circuits had gone up by a factor of 60 and by the end of the program the unit price of one integrated circuit had plummeted to 63 cents! Thanks to NASA's assured demand of a technology essential to the extraordinary challenges of spaceflight, the commercial market began employing the integrated circuit in countless products.[90]

Today, we depend on this technology in nearly every device and machine. Integrated circuits were precisely the leap in electronics that paved the way for laptops, smart phones, tablets, televisions and even modern automobiles and appliances. Low-cost integrated circuits enabled further computer innovations to take place in the garages of Silicon Valley. Dishwashers, refrigerators and coffee makers all utilize integrated circuits – they permeate almost every aspect of our modern lifestyle. The ubiquity of electronic technology enjoyed today is in large part owed to the U.S. human spaceflight program and its unparalleled demand for state of the art technology. Each time we turn on a tablet computer, take a picture with a digital camera or even do a load of laundry, we enjoy the largely unheralded benefits of the U.S. human spaceflight program.

Energy Advances

In some instances working in the unforgiving environment of space yields economies of scale for new technologies in the commercial market. In other cases, the demands of space forge new workforce expertise that spurs innovation across entire sectors of the economy. The space launch vehicle sector is an excellent example of how space is advancing another industry in unexpected ways.

For more than 50 years, the United States has been a world leader in propulsion development. From Project Mercury to the Space Shuttle, from Titan to Atlas and Delta and the newly developed Falcon, the United States has developed launch vehicles for a variety of space programs with missions to protect our national security and keep our science and exploration at the forefront. Designing and building rocket engines to power space launch vehicles is no easy task – it requires highly specialized, world-class, technical expertise. The reason for this is simple: it truly is "rocket science." As U.S. industry has honed this special launch expertise, it has also applied this knowledge to other technologies that we rely upon every day.

Findings from U.S. space launch propulsion are now fueling new developments in the energy industry. **(Image courtesy of NASA)**

Consider the Space Shuttle's main engine. Within seconds of ignition the Shuttle's main engine heated from -435 F to more than 6,000 F. Although not much bigger than a jet engine on a commercial airliner, the Shuttle's main engine produced the thrust of more than ten 747 jet engines. More than 70,000 horsepower is required just to pump enough liquid hydrogen into the engine nozzle to prevent its steel from literally boiling. Developing the workforce capacity to design, build and operate this incredibly complex machine for 135 Space Shuttle missions was an enormous feat that is paying dividends in the energy industry.

Today, intellectual capital that was cultivated by programs like the Space Shuttle is generating new techniques for cleaner and more efficient energy production. One company is now developing new gasifiers for power plants that are able to reduce plant capital costs by as much as 20 percent, while also reducing CO_2 emissions by 10 percent over existing gasifiers. Many of their technologies for engine manufacturing have been developed for the economy at large – including chemical lasers and polymer selective laser sintering. The company is also sharing thermal expertise from rocket engine design with a company that specializes in commercializing solar power plants.[91]

It's important to remember that all of these advancements were generated by the commitment to lead in the enormously difficult field of space. The complex conditions of space require cutting-edge expertise in combustion, high speed machines, thermal management, structures, materials and manufacturing. Few other fields demand a more multi-disciplinary approach to a more physically challenging environment than space and the workforce that rises to meet these challenges is uniquely equipped to succeed in the fields that define global leadership in the 21st century.

Reinventing Research and Development

The following fields have received patents from microgravity research done in space: Biotechnologies, Materials, Electronics, Chemical Processes, Water and Air Purification, Fuel Cells, Combustion, Propulsion, Energy, Robotics and Software.[92]

It's no secret that a keystone of success in an increasingly globalized economy is a nation's ability to relentlessly innovate – both in terms of new technologies and new ways of doing business. Those nations that live and work in space are known to inspire a pipeline of technical talent that seeds the entire economy with new ways of thinking, new ways of problem-solving and new technical skills. At the same time, the space environment itself offers unique laboratory conditions that are ideal for new, cutting-edge research.

For example, since the dawn of science, the effects of gravity have been present in every Earth-bound experiment. Before the era of spaceflight, scientists could not entirely remove these effects in labs – they simply had to be accepted. Imagine conducting a life sciences experiment without the ability to precisely control air temperature or light exposure within a lab. Thanks to spaceflight, the effects of gravity can now be wholly modified or removed from a scientific investigation. With this revolutionary development, a curtain has been lifted for scientists, revealing startling new insights.

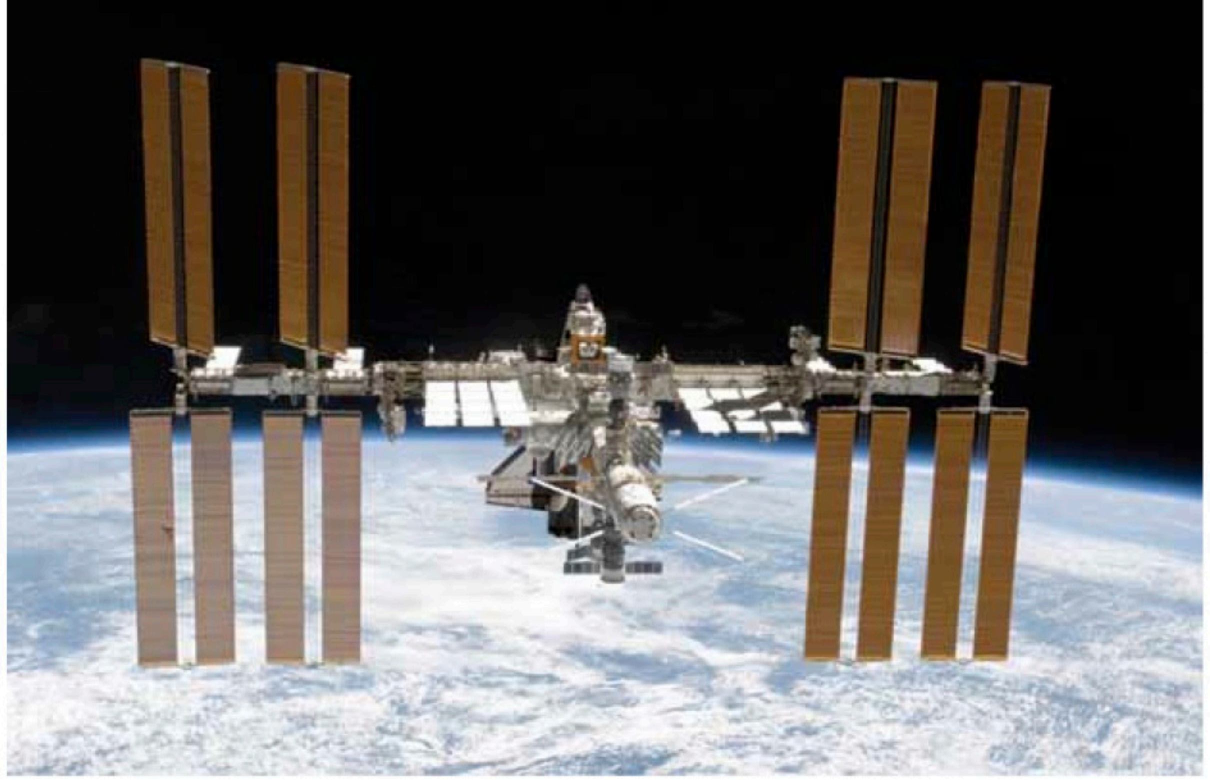
For chemical reactions involving inorganic materials such as metals, alloys, glass and ceramics, the condition of microgravity fundamentally alters behavior at the molecular level. Organic materials are no different – cellular reactions in biochemical and biophysical processes are affected by microgravity. In the case of diseases, microgravity can affect the virulence of a virus, helping to pinpoint exactly what makes it tick. In genetics, microgravity can alter what genes are activated, helping biologists to understand what motivates genetic activity. The ability to conduct in-space research has enormous potential for economic and scientific advances in numerous fields from manufacturing to biotechnology.[93]

Space program research has produced more than 800 patents since 1981, and thanks to the laboratory condition of microgravity in space, the pace is accelerating – 587 applications were filed in the last decade alone.[94] Much of this research was conducted directly by human spaceflight programs and a very large fraction of these activities were conducted with the intention of directly investigating science and engineering for Earth-bound breakthroughs.

Progress in ISS Research

In 2011, NASA completed construction of the largest, most complex structure ever built in space. Although production of the International Space Station (ISS) spanned more than two decades, each successive presidential administration and Congress recognized the importance of the United States leading a highly capable outpost in space that could utilize the unique environment of space for research. The microgravity environment and lack of atmosphere in Earth orbit create conditions for research that make the ISS the most robust platform ever constructed for harnessing the power of space for research and development.

The ISS represents a paradigm change in microgravity research in space. Prior to the space station, scientific and engineering investigations in microgravity could only take place within the span of a Space Shuttle mission lasting no more than two weeks. ISS allows for steady, continuous research on the order of months and years. Long-term experiments are now conducted in space allowing scientists and engineers to make adjustments and account for unexpected results.



Although the International Space Station just completed its construction in 2011, the Station has already produced hundreds of scientific findings from more than 60 participating nations. **(Image courtesy of NASA)**

The ISS research platform puts the United States and its partners at a distinct advantage in a whole host of scientific and technological fields – no other facility possesses capabilities like those of the ISS. Just during the construction phase, astronaut crews conducted 1,441 scientific investigations from more than 60 nations aboard the ISS, leading to 504 scientific papers thus far.[95]

Research being conducted on ISS *right now* is yielding impressive results for life saving research. Microgravity holds special promise for vaccine design and development, as the foodborne pathogen Salmonella has exhibited increased virulence when cultured in microgravity; yet genes known to be important to virulence were not turned on and off as they are when this organism is grown on Earth.[96] This demonstrates that the spaceflight environment imparts a unique signal that can unveil novel molecular mechanisms in Salmonella and identify new targets for vaccine development. Salmonella infection affects millions of people worldwide and is one of the top three causes of infant mortality in the developing world.[97] Microgravity-induced changes seen in the bacteria have opened a world of insight into Salmonella that could eradicate the disease on Earth – a solution that will be particularly critical to saving lives and improving quality of life in some of poorest parts of the world.

The International Space Station's U.S. National Laboratory is conducting unprecedented long-term microgravity science experiments for life on Earth that cannot be reproduced on the ground. **(Image courtesy of NASA)**

The use of the ISS microgravity research platform to unveil novel mechanisms of infectious disease is just getting started. In follow-on studies from the Salmonella spaceflight work, researchers recently experimented to improve an existing pneumonia vaccine currently in human clinical trials. More than 10 million people die annually from this disease and its complications, largely newborns and the elderly. This work will determine if the microgravity environment can accelerate genetic engineering of a recombinant Salmonella vaccine strain that carries a protective antigen against the pneumonia virus, in order to maximize its ability to induce a protective immune response. Because these recombinant Salmonella vaccines can be produced against a wide variety of human and animal pathogens, the outcome of this study could influence the development of vaccines against many other diseases in addition to pneumonia.[98, 99]

ISS research is also leading exciting new efforts against Duchenne's muscular dystrophy through a technique that can only be effectively done in space. One of the complex challenges in pharmaceutical research is modeling three-dimensional protein crystals. Fortunately, these crystals grow into larger, higher quality structures in space. Better crystals mean better insight into how proteins are composed. In the case of Duchenne's muscular dystrophy, protein modeling on board ISS has led to a more potent inhibitor that is being used to develop a new treatment for the disease. Amazingly, these protein crystal growth techniques on ISS also hold great promise for treating and preventing other diseases and conditions such as cancer and stroke.[100]

"I like to be involved in things that change the world. The internet did and space will probably be more responsible for changing the world than anything else."[101]

–Elon Musk
Founder and CEO of SpaceX

Just as pathogens and protein crystals are affected by microgravity, so too are plants. In fact, plant genetics are being examined on ISS to understand biomarker control. Manipulation of biomarkers could lead to crops with improved resistance to drought or greater tolerance to temperature variations. This could offer direct market benefits to a $100 billion agriculture and food production industry.[102] Other biological investigations on ISS hold potential to improve longevity and quality of health in the elderly. Station experiments on lymphocytes have yielded intriguing findings on enzyme levels that correlate with cellular death. By researching the effects of microgravity on health for astronauts aboard ISS, future therapeutics may be developed for making immune systems stronger in the elderly.[103]

In the same way that NASA and DOD pioneered communications satellites at the dawn of the space age, the ISS program is researching spacecraft materials that could lengthen the lifespan of satellites used in the public and private sector. Tests on materials carried on board the Station are being utilized to assess their endurance and reliability in space for future use on satellites – testing that cannot be replicated on Earth. Already, materials testing that has taken place on board ISS is valued at nearly $650 million, with an extensive database being built for engineers on Earth.[104] In fact, Apple has already licensed LiquidMetal™ – an alloy with roots in ISS research – for use in their electronics.[105] Metallurgic research on ISS has also led to the development of a far lighter titanium aluminide alloy in turbine fan blades for jet engines, with the potential to reduce the weight of jet engines by 50 percent. Needless to say, such a massive weight reduction would lead to significant fuel and emissions savings in air travel.[106]

Boeing CST-100 Crew Capsule (top) and the Sierra Nevada Dream Chaser (bottom). **(Images courtesy of Boeing and Sierra Nevada)**

The U.S. segment of ISS was designated as a National Laboratory by the NASA Authorization Act of 2005 and is an unmatched platform of research and development. Scientific and technological research on ISS cannot be replicated in any meaningful form on Earth. As the only continuously crewed space station in existence, the ISS is precisely the type of R&D facility that can bring about economic revitalization.

Currently, Russia's Soyuz program is the only means for human access to ISS, leaving America at the mercy of Russian scheduling with no choice but to purchase rides to ISS at $63 million per seat. In order to continue the impressive track record of success seen thus far on ISS, it's imperative the United States restore domestic access as soon as possible. To meet this need, a number of commercial crew providers are making steady progress toward new space transportation systems. New commercial systems will enable both larger crew complements and more frequent missions to ISS, enabling vanguard research on the unique laboratory. Further, they are reducing the cost of space access for the United States, critical to incubating high-tech domestic jobs and ensuring a robust industrial base.

Recommendation 5: The U.S. government should fully utilize the International Space Station to 2020 and beyond, in order to advance scientific research that can only be done in space.

Recommendation 6: America needs support for a robust, competitive commercial crew program to provide domestic low Earth orbit transportation – particularly to the International Space Station – as soon as possible.

Innovations from Travel Beyond Earth Orbit

Imagine for a moment the extreme conditions astronaut crews will face as they travel to destinations like an asteroid or the moons of Mars. In some cases, the distance between a spacecraft and the Earth will be so great it could take up to thirty minutes for ground control to hear a voice message from a spacecraft. The ability to hold a conversation between astronauts and mission control will become impossible. By traversing deep space, crews will encounter longer exposures to microgravity that reduce muscle and bone density and degrade the eyes. Spacecraft that go beyond Earth's orbit will be bombarded by radiation, exposing astronauts to the risk of debilitating sickness, cancer and death.[107]

The Space Launch System will be NASA's heavy lift launch vehicle for the Orion Multi-Purpose Crew Vehicle, sending astronauts beyond Earth orbit for the first time in more than 40 years. **(Image courtesy of NASA)**

Energy and consumables will come at a premium unseen since the days of pioneering. There will be no means of obtaining new, outside sources of food. Breathable oxygen will be limited by whatever is brought aboard and how well a spacecraft can recycle its own air. Water will be a precious and limited resource. All of these are daunting challenges, but they're also opportunities. Going beyond Earth is an opportunity to reinvigorate research and development in fields that raise the quality of life for all of us.

On board spacecraft computers will have to be more self-reliant and autonomous than ever before. Sophisticated medical procedures and techniques will have to be developed well in advance. Emergencies of all kinds will have to be addressed with resources on board a spacecraft that is months away from Earth. New strategies will be developed for either mitigating radiation exposure with material shielding, or medically treating the effects of radiation after exposure – perhaps even at the DNA level.[108]

Those nations that take on the farthest frontiers of space raise the bar of their own scientific and technical prowess and boost their economies on Earth. Space uniquely stimulates a multitude of scientific and engineering disciplines with unmatched depth. We saw this happen the last time we ventured beyond

When we buy groceries or eat at a restaurant, few of us give any consideration to the safety of our food supply. We happily sit down to meals secure in the knowledge that our food is safe from contaminants in its handling and delivery. Yet this presumption of safety was not always assured. Starting in 1971, a series of well publicized food contamination events occurred throughout the United States. Contamination incidents were so severe at one point that glass had even slipped into baby food.

A consumer movement for food safety subsequently took hold. Food industry surveys found quality control programs sorely lacking, so the industry turned to the space program for a solution. During the Apollo Program, food poisoning was a dangerous prospect for astronauts traveling to the Moon. In response, NASA outlined specifications for quality control points in Apollo food production with Pillsbury, in an approach known as Hazard Analysis and Critical Control Point (HACCP).

By 1977, 10,000 people had attended workshops on HACCP for low-acid canning operations. Today, HACCP processes have been expanded and implemented by the FDA for a wide range of items – from seafood to juice. USDA also uses HACCP in the meat and poultry industries. Even foreign governments are utilizing HACCP – officials in Scotland began using the process after 21 people died from contaminated beef. It's estimated that HACCP now protects food safety for literally billions of people – all thanks to the human spaceflight program pushing the boundaries of exploration.[109]

The Orion Multi-Purpose Crew Vehicle will have its first test flight in 2014.
(Image courtesy of NASA)

Earth orbit during Apollo. As long as the nation continues to invest in new human space exploration missions beyond Earth orbit, the future is bright for a resurgence of new advances in science and technology. We're already seeing this occur as NASA works on new techniques for addressing the most significant barriers to human spaceflight beyond Earth orbit.

Recognizing the dangerous and debilitating impact of radiation exposure in space, NASA is pioneering next generation medical techniques for mitigating those health effects. One of the promising technologies that have emerged from this research is the Biocapsule.

Solar events can be unpredictable and dangerous, emitting intense radiation that can disable an astronaut's immune system. During such an emergency, crew members will likely need immediate warning of dangerous radiation along with automated treatment – every astronaut on board potentially could be simultaneously incapacitated. To address this challenge, NASA developed a very small "Biocapsule" made of nanotubes, filled with therapeutic proteins that diffuse from the capsule to the tissue needing treatment. After detection of harmful radiation during flight, Biocapsules can administer targeted treatments as needed. With a simple and non-invasive outpatient surgery, these capsules could be implanted within an astronaut's body before they ever leave Earth. In a sense, Biocapsules act almost like an automated, molecular "EpiPen."[110]

Although originally developed by NASA for spaceflight to destinations like asteroids and Mars, Biocapsules have could have immense potential to save millions of lives on Earth. Approximately 285 million people have diabetes today and many suffer from blood sugar problems during comas or sleep. It is these unmonitored portions of the day that are especially dangerous, as there is no way for a patient to monitor and treat his or her own blood sugar levels. Biocapsules have the potential to immediately treat dangerous blood sugar levels in diabetes patients.[111]

And this is just the start. Biocapsules could be used in a variety of medical emergencies and general treatments to target and treat a patient faster than most medical procedures used today. Imagine an instantaneous treatment for food allergies or a more localized chemotherapy that reduces the debilitating side effects typically seen today.

The potential for NASA's research involving Biocapsules to save millions of lives and improve the quality of life for millions more cannot be overstated. Tests on Biocapsules will begin on ISS soon and Earth-bound uses could be widespread as soon as the next decade. This is the nature of innovations we can expect from investments in human spaceflight – incredible solutions to unique requirements that would likely have never been imagined.

Space is a dangerous and unforgiving environment, especially as we get farther away from the Earth. By launching astronaut crews to new destinations far beyond where the Space Shuttle flew, the space program and its supporting industry will confront challenges not previously seen in human spaceflight. Our computers will have to be smarter, our medicine more advanced and our engineering more sophisticated. A successful and robust human spaceflight program beyond Earth orbit not only breeds a culture of innovation across the nation – *it requires it.*

> **Recommendation 7:** Steady development of the Orion Multi-Purpose Crew Vehicle and the Space Launch System is required to advance human exploration beyond Earth orbit for the benefit of our entire nation.

Why Explore Space?

"Why explore space when we have so many pressing problems here on Earth?" This is a question that frequently comes up in some form when the space program takes center stage in the news media. It's a legitimate question that deserves an answer. At the height of the Apollo Program in 1970, NASA scientist Dr. Ernst Stuhlinger took time to reply to this question when it was posed by a Catholic nun aiding starving children in Zambia. Dr. Stuhlinger offered the following parable as a simple but powerful explanation of how innovation and discovery from fields like space exploration address our most pressing societal problems.

"About 400 years ago, there lived a count in a small town in Germany. He was one of the benign counts and he gave a large part of his income to the poor in his town. This was much appreciated, because poverty was abundant during medieval times and there were epidemics of the plague which ravaged the country frequently. One day, the count met a strange man. He had a workbench and little laboratory in his house and he labored hard during the daytime so that he could afford a few hours every evening to work in his laboratory. He ground small lenses from pieces of glass; he mounted the lenses in tubes and he used these gadgets to look at very small objects. The count was particularly fascinated by the tiny creatures that could be observed with the strong magnification and which he had never seen before. He invited the man to move with his laboratory to the castle, to become a member of the count's household and to devote henceforth all his time to the development and perfection of his optical gadgets as a special employee of the count.

The townspeople, however, became angry when they realized that the count was wasting his money, as they thought, on a stunt without purpose. "We are suffering from this plague," they said, "while he is paying that man for a useless hobby!" But the count remained firm. "I give you as much as I can afford," he said, "but I will also support this man and his work, because I know that someday something will come out of it!"

Indeed, something very good came out of this work and also out of similar work done by others at other places: the microscope. It is well known that the microscope has contributed more than any other invention to the progress of medicine and that the elimination of the plague and many other contagious diseases from most parts of the world is largely a result of studies which the microscope made possible.

The count, by retaining some of his spending money for research and discovery, contributed far more to the relief of human suffering than he could have contributed by giving all he could possibly spare to his plague-ridden community."[112]

Rewriting Science Textbooks

This composite image from the Hubble Space Telescope shows a mapped ring of dark matter. **(Image courtesy of NASA)**

NASA's space science programs are an incredible success story of innovation and inspiration that have continuously rewritten our textbooks since the dawn of the space age. Over the course of just a few decades, NASA programs have produced scientific findings that have completely altered our understanding of the Earth, the solar system, the galaxy and the universe.

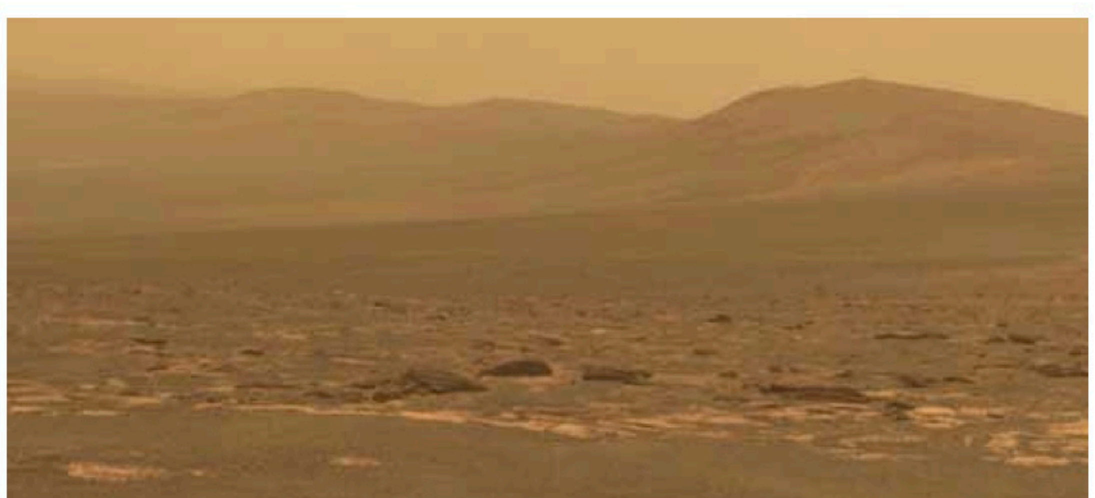
For instance, NASA's first satellite, Explorer I, discovered our planet is surrounded by radiation bands known as the Van Allen belts – providing important insights for protecting satellites from space-borne radiation. The Aquarius Earth observation satellite mapped global salinity of the oceans for the first time.[113] The LANDSAT satellite program provided the first comprehensive photographs of the entire Earth from space.[114] The GRACE mission precisely mapped gravity variations in the Earth, an important knowledge base for understanding plate tectonics, earthquakes and volcanic activity.[115, 116] The ACE mission has provided countless observations of solar magnetic storms on the Sun, warning us of solar flares and other solar activity as they occur.[117] Over the course of just 54 years, NASA has launched more than 100 missions to directly observe the Earth or Sun for the practical benefit of understanding our home planet.[118]

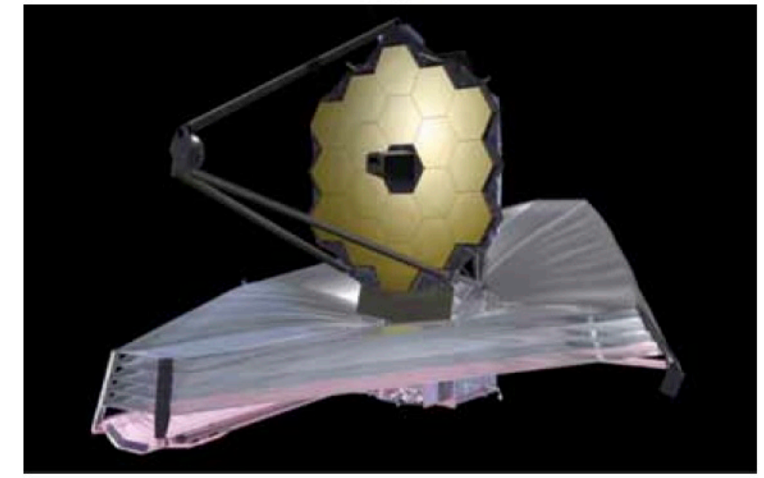
Pursuing science beyond Earth to the vast expanse of the universe, NASA has deployed more than 50 astrophysics missions.[119] The COBE mission, resulting in the 2006 Nobel Physics Prize for NASA astrophysicist John Mather, heralded the age of cosmology as a precise science, with measurements of remnant microwave radiation from the Big Bang.[120] Dr. Stephen Hawking said the findings from COBE were "the greatest discovery of the century, if not all times."[121] Research from Hubble Space Telescope data recently contributed to a Noble Prize for physics by surprisingly demonstrating that the expansion of the universe is speeding up.[122] Black holes were once a theoretical construct, but Hubble confirmed that super massive black holes are embedded in the cores of most galaxies in the universe.[123] The Chandra X-Ray Observatory provided direct proof of dark matter – a material believed to make up about 22 percent of the universe.[124, 125]

The WMAP mission produced the first fine resolution full sky map of radiation from the Big Bang, dating the age of the universe to a precise 13.7 billion years. WMAP even cataloged the percentages of dark matter, dark energy and regular atoms that make up the universe.[126] The Kepler Space Telescope has gathered compelling evidence that infers nearly every star in the sky has at least one orbiting planet.[127] Thanks to NASA space science missions, we have expanded our awareness from eight planets in the solar system to billions of planets in the universe.

NASA continues to pursue some of the most fascinating questions in human history with the development of the James Webb Space Telescope (JWST). JWST will study the first galaxies that formed in the universe, the formation of stars and planetary systems and the origins of life.[128]

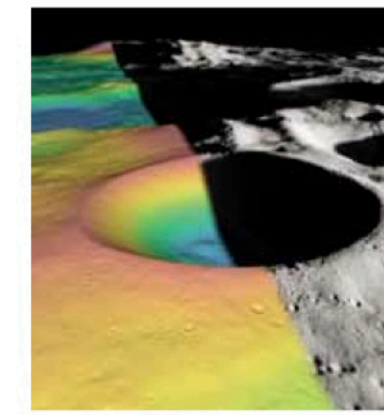
Views of Mars from the Spirit, Opportunity and Curiosity rovers are expanding our understanding of a planet with a fascinating history of free flowing water and important implications for understanding the development of our home planet. **(Image courtesy of NASA)**





The infrared James Webb Space Telescope currently in development will build upon the incredible legacy of the Hubble Space Telescope with new scientific findings of the formation of the universe. **(Image courtesy of Northrop Grumman)**

Within our own solar system, NASA has launched more than 85 planetary missions.[129] The Mars rovers Spirit and Opportunity revealed mineral veins on the Martian surface, uncovering fascinating new evidence about Mars' wet past.[130] Just recently the Mars Reconnaissance Orbiter photographed water flowing on the surface for the first time.[131] Our understanding of Mars has been completely revolutionized, changing notions of what was thought to be an arid, Moon-like place inhospitable to life, to an understanding of a tundra world where water seems to be located in the subsurface. The LCROSS mission found water on the Moon, a place formerly thought to be completely dry and barren.[132] The Pioneer and Voyager missions to the outer solar system discovered not only new rings around Jupiter and Neptune, but new worlds in our own solar system – moons orbiting the outer planets.[133, 134] The Pioneer Venus program conducted the first radar mapping of Venus.



The Lunar Reconnaissance Orbiter discovered water at the Moon's poles. **(Image courtesy of NASA)**

Our world is enjoying rewards from steady investments in space science missions, as NASA continues to make scientific discoveries like those of Copernicus and Newton; yet these discoveries are no longer occurring centuries apart – *they happen regularly now.* These missions not only examine our existence in time and space, they further reveal the fundamental laws of nature. Thanks to NASA space science missions, the United States is at the forefront of advancing basic scientific laws.

This photograph from the Mars Reconnaissance Orbiter shows the first direct observation of water flowing on Mars. **(Image courtesy of NASA)**

NASA Space Science Missions contributed 7.3 percent of all scientific papers in 2010.[135]

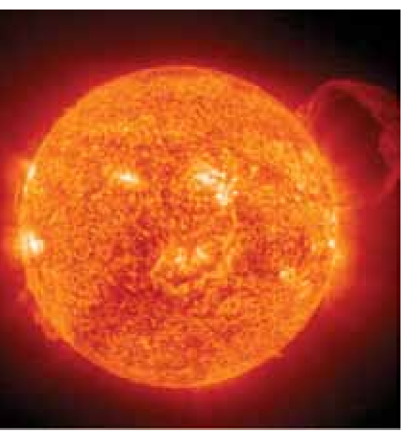
How then do we estimate the value of these developments? After all, how does one calculate the return on investment in discovering gravity? Or assess the worth of Newton's laws of motion?

In the case of seemingly esoteric subjects like dark energy, it can be challenging to see how society at large benefits from a major finding in cosmological phenomena. Nevertheless, tangible economic and societal benefits have resulted from this research. In the early 1900s, it may have been difficult to see the value of studying quantum mechanics in physics. How could our society and our economy possibly benefit from particles we can't even see? We now know that pioneering basic research in quantum mechanics led to the development of a range of components that enable all electronics today including smart phones, laptops, televisions and even kitchen appliances. Economic impacts from quantum mechanics advances for electronics have been estimated in the trillions of dollars.[136]

Research from NASA's Hubble Space Telescope observations have resulted in more than 10,000 peer reviewed scientific publications.[137]

Imagine then the potential for dark energy. It is estimated that 95 percent of the universe is composed of dark energy and dark matter. Dark energy seems to be motivating the acceleration of expansion for all matter in the universe – atoms, planets, stars and galaxies. As a result, scientific examination of dark energy and other space science subjects could yield significant returns for society.

In addition to understanding a formidable and fascinating new type of energy, the value in studying something like dark energy is also found in the derivative technologies developed to sense it in the first place. At present, no instrument exists to directly measure dark energy. Developing technology to observe and measure such cosmological phenomena maintains the United States' high competitive advantage. Nearly a half billion dollars of annual investment on space science programs is directed to develop new technologies each year – a cornerstone of future innovation.[138] Frequently these space derived technologies are later employed by entrepreneurs. Today's space science technology is fertile ground for tomorrow's commercial market innovation; in fact, technology from JWST has already been extended to other beneficial applications for government and industry.



The SOHO mission provides real time monitoring of the sun, alerting key infrastructure managers of potential damage. **(Image courtesy of NASA)**

Space science missions also provide practical value on a daily basis by conducting scientific research and observation that could not be achieved on Earth. Solar magnetic observations of the Sun are a great example. The Earth's atmosphere and magnetosphere provide a sheath of protection from the bombardment of protons, electrons, X-rays and other radiation hurled at the Earth. The solar events that send radiation bursts and charged particles to the Earth create "space weather" and bring potential dangers to our modern quality of life in much the same way that other debilitating weather events affect our society.

Often we'll hear warning of a coming solar emission thanks to space assets like SOHO, a joint mission between the European Space Agency and NASA. SOHO is a space-based mission that observes coronal mass ejections from the Sun and provides valuable warning time to power grid operators and other infrastructure managers.[139] NASA's ACE mission also monitors the Sun on a continuous basis and can provide up to an hour of warning about coronal mass ejections to the civil and private sectors.[140] Monitoring the Sun for incoming solar activity is a unique capability that can only be done in space. Robust investments in space science assets continuously protect our modern quality of life.

For instance, in 1989, a moderate solar emission knocked out Quebec's electric grid almost instantaneously and the subsequent electric surge nearly took down electrical grids from the Northeast United States to the Pacific Northwest. In the case of the Quebec storm, nearly six million people lost power for nine hours. While this event was surely disruptive, the Sun is capable of much worse and its cyclical nature makes it almost certain that even more dangerous solar events are yet to come.[141]

In 1921, a major solar emission struck the Earth, but thankfully had minimal impact due to minimal reliance on electronics at the time. Had the storm struck today, the potential for catastrophic damage to electrical grids, oil pipelines, nuclear power plants and telephone networks would be enormous. In fact, the damage would have been so widespread that a 2008 FEMA report estimated this storm would likely have inflicted $1 trillion worth of damage if it occurred today.[142] Make no mistake, another solar event such as this one will occur – it is only a question of when. A storm at least 50 percent larger struck the Earth in 1859, disabling even rudimentary telegraph networks at the time.[143] Thankfully, space science missions have been at the forefront of investigating and observing solar activity to better understand what causes such storms and how to better predict them for frontline warning.

In addition to contributing situational awareness of space weather, space science missions also provide irreplaceable environmental analogue research that is crucial to current and future policy makers. Environmental changes on the Earth are constant throughout the life cycle of the planet. Understanding change on the Earth can be difficult, yet planetary science can provide useful insight.

Studying other planets in our solar system with space science missions offers an immensely important comparative understanding of our Earth and what makes it so suitable for life. The ability to assess and protect these special qualities is uniquely enabled by planetary science investigations on space missions.[144]

Thus while seemingly abstract and disconnected from daily life, space science missions regularly contribute to our society in the most practical terms possible. Space science offers us situational awareness to very practical phenomena like space weather, but also unique perspectives on how our planet functions. These missions not only provide us with a sense of where we come from and where we're going, they develop new scientific instrumentation and reveal the nature of the universe.

The team at NASA's Jet Propulsion Lab celebrate Curiosity's successful landing on Mars. **(Image courtesy of NASA)**

Yet the ability to make these discoveries is not a birthright. They are made by the dedicated and hardworking scientists, engineers and technicians of America's space program and space industry that build, launch and operate spacecraft and then study their findings. NASA science missions are directed by a deliberative process from the National Academy of Sciences, which assembles top-tier scientists in the fields of Astronomy, Astrophysics, Planetary Science, Heliophysics and Earth Science and Applications to develop decadal roadmaps for space science programs. After the science community has identified valuable space science to be conducted, NASA and industry deliver these missions and the world reaps the reward of advancements.

At the moment, the United States is unmatched in the breadth and depth of its scientific success in space. No other nation has successfully landed spacecraft on Mars, or sent spacecraft to the boundary of the solar system. These missions are crown-jewel capabilities that have come to define American leadership. Maintaining the competency to lead the world in this field is absolutely dependent upon steady investments in NASA space science.

> **Recommendation 8:** The U.S. government should continue development of the James Webb Space Telescope as well as other NASA science missions in order to keep U.S. science at the cutting edge.

The SpaceX Dragon Capsule berths with the International Space Station in May 2012. **(Image courtesy of SpaceX)**

Accelerating Entrepreneurial Investment

Today, the United States is experiencing a virtually unprecedented growth in spacecraft design and manufacturing for systems that will carry humans into space. Numerous launch vehicles, spacecraft and capsules are being designed and developed by a variety of companies for space transportation to and from Earth orbit, including the International Space Station, as well as destinations beyond. The surging growth of America's commercial spaceflight industry is central to keeping the United States second to none in our technological competitiveness.

Virgin Galactic's SpaceShipOne vehicle is berthed with the WhiteKnightTwo in a test flight for commercial suborbital service. **(Image courtesy of Virgin Galactic)**

While several other countries are participating in human spaceflight today, the United States remains unmatched in the number of activities and companies engaged in the development of new human transportation systems for space. Moreover, no other country in the world has as much commercial space industry activity as the United States.

The investments made by the government in U.S. space programs in the half century since Alan Shepard's Mercury flight in 1961 laid the foundation for a strong space industrial base that is intimately familiar with the challenges and opportunities that lie ahead in developing future space systems. Past space successes like Project Apollo motivated a generation of innovative entrepreneurs who are creating space systems that could once again shift paradigms of what is thought possible.

Now these investments are paying new dividends in the U.S. commercial launch sector. Bold designers are diligently developing systems to recapture U.S. commercial launch market share that was once as high as 100 percent in the 1980s. In 2011, there were no commercial orbital launches from a U.S. spaceport, but thankfully a wave of private sector investment has the potential to increase the U.S. commercial launch market share while also opening up exciting new markets.

"Ever since I saw the Moon landing as a young teenager, I was determined I would go into space one day."[145]

–Sir Richard Branson, Founder and CEO of Virgin Galactic **(Image courtesy of Virgin Galactic)**

Sir Richard Branson of the Virgin Group is one such entrepreneur. Branson founded Virgin Galactic, a company developing a "space line" that will regularly launch paying customers into suborbital space. Virgin Galactic's success thus far has been widely publicized, with more than 500 customers placing deposits for upcoming flights. When asked what inspired Branson to invest in developing new private spacecraft and operate a private spaceflight venture, he replies it all comes back to Project Apollo.

Elon Musk, CEO and CTO of SpaceX, was also deeply influenced by the possibility and promise of spaceflight demonstrated by the U.S. space program. SpaceX has already developed two new Falcon launch vehicles and is in development of a third. SpaceX was recently awarded a contract to continue the development of their Falcon 9 rocket and Dragon spacecraft to safely transport astronauts to and from the ISS.

"There have to be things that make you proud to be a member of humanity. The Apollo program is an example of that. Only a handful of people went to the Moon and yet we all went to the Moon. We shared in that adventure. I don't think anyone would say that was a bad idea. That was a good idea."[146]

–Elon Musk, Founder and CEO of SpaceX **(Image courtesy of SpaceX)**

Inspiring our Pipeline of Scientists and Engineers

"If you want to build a ship, don't drum up people to collect wood and don't assign them tasks and work, but rather teach them to long for the endless immensity of the sea."

–Antoine St. Exupery

In October of 1903, a New York Times editorial boldly asserted, "The flying machine which will really fly might be evolved by the combined and continuous efforts of mathematicians and mechanicians in from 1 million to 10 million years." Two months later the Wright Brothers made their first flight at Kitty Hawk, North Carolina.

In the course of world events, there are inflection points in history that forever alter what is considered possible. Just as the first airplane liftoff at the dunes of Kitty Hawk broke the long held belief that humans would never fly, the lunar module touchdown at the Sea of Tranquility opened a world of possibility to future generations – living and working in space was an achievable goal – not just a worthy aspiration, but a demonstrated capability. The ability of programs like Apollo, the Space Shuttle and the Hubble Space Telescope to forever change what is believed possible is not lost on young people. Very young children are the first among us to "get it." Space programs stoke an instinctual curiosity among young people that frequently lasts into adulthood. The passion for space is seeded at an early age and instills an expectation of innovation – not just in space but in society at large.

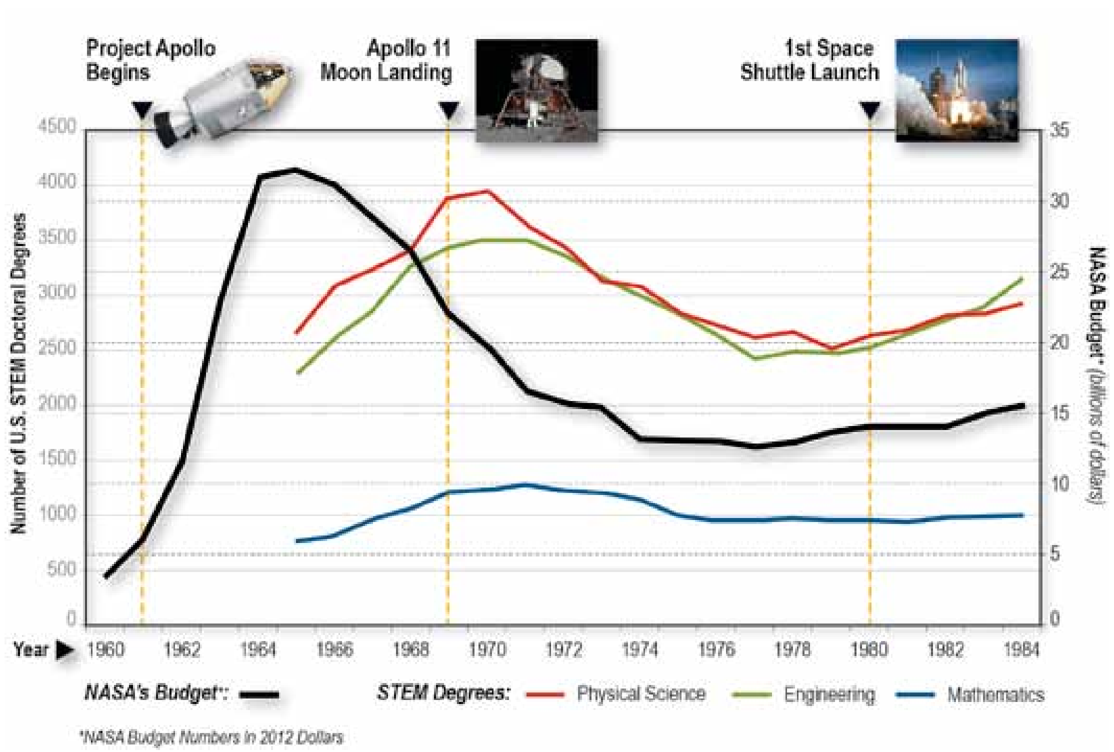
In 2006, only 15 percent of U.S. college graduates received a diploma in engineering or science – Singapore graduated 67 percent, South Korea 38 percent and France 47 percent.[147]

In 2007, the highly regarded National Academies report, "Rising Above the Gathering Storm," provided a sobering call to action on alarming declines in U.S. competitiveness. The need to continually develop a world-class, U.S. technical workforce is becoming increasingly clear as rising powers in the global economy grow vast and competent workforces from major investments in science, technology, engineering and mathematics (STEM).

At the heart of the report's findings was a fundamental imperative to invest in the development of our own STEM workforce. Although the report identified policy and legislative actions the U.S. government could take to address STEM shortages, it's important to remember that most students find the drive and motivation to complete challenging STEM degrees because of formative experiences that instill a lifelong passion for science and technology. When it comes to inspiring a student to enroll in a STEM career there is no substitute for a highly-visible, exciting space program of exploration and scientific discovery.

Following the beginning of the Apollo and Space Shuttle Programs, healthy increases in STEM Doctoral degrees were seen in the United States.[148, 149]

Number of STEM Doctoral Degrees vs. NASA Budgetary Trends, 1960-1984



Remarkably, despite the end of the Space Shuttle program in 2011, NASA's 2012 astronaut candidate recruiting class was its second largest in history – demonstrating that Americans are as excited and motivated as ever by the U.S. human spaceflight program.

U.S. space programs are exactly the kind of intellectual stimulus needed for steady, sustained growth in STEM workforces. Frequently students stimulated by dramatic space activities become our nation's scientists, doctors, mathematicians, engineers and technicians in a wide variety of highly technical fields that are critical to U.S. competitiveness. Countless professionals in the fields of chemistry, biology, computer science, physics, astrophysics, geology, aerospace engineering, electrical engineering and mechanical engineering enrolled in these fields and changed the world because as children they witnessed footage of Armstrong and Aldrin at Tranquility Base, or felt the rumble of a Space Shuttle launch.

"Millions of people were inspired by the Apollo Program. I was five years old when I watched Apollo 11 unfold on television and without any doubt it was a big contributor to my passions for science, engineering and exploration… NASA is one of the few institutions I know that can inspire five-year-olds. It sure inspired me…"[150]

–Jeff Bezos,
Founder of Amazon.com and the human spaceflight startup company Blue Origin. **(Image courtesy of Amazon.com)**

It should be no surprise that as the United States led the world in spaceflight for the latter half of the twentieth century, our nation also revolutionized computing and mapped the human genome. In fact, less than ten years after the peak budgets of the Apollo program, a wave of new U.S. technical doctoral degrees was seen in physical sciences, engineering and mathematical sciences. The National Science Foundation even noted, "The 1960s were characterized by a high rate of growth in annual production of doctorates, fueled by public and government reaction to the launching of the Soviet satellite Sputnik in 1957."[151] To compete in space is to compete in STEM. Virtually no other field has demonstrated the ability to enrich and renew STEM careers for the entire nation.

Sometimes professionals who were first inspired by space go on to make incredible discoveries in astrophysics, pilot a robotic rover on the surface of Mars or design propulsion systems for next generation crew vehicles. Other times, they touch society in ways we could not have imagined – making discoveries in medicine, developing new sources of energy or designing next generation unmanned aircraft.

Not surprisingly, we see NASA's technical workforce solving numerous challenges outside of the field of spaceflight, because their skills and expertise are applicable to a wide range of fields. When Toyota had widespread problems with automobile brakes in 2010, NASA engineers helped diagnose the problem.[152] During the dramatic Chilean miner rescue that same year, NASA personnel provided design advice on the rescue capsule built to reunite the miners with their families.[153] NASA and the U.S. space industry are a globally recognized brand standing for competency, expertise and technical mastery – qualities that continue to attract the best and brightest from our own country, to say nothing of those students around the world who seek to study in the United States.

Succeeding in space lays the groundwork for widespread technological competitiveness, by making STEM a truly compelling calling. Active and highly visible space programs are as much investments in prosperity as they are in exploration. As a vital source for new STEM professionals, an exceptional symbol of American strength and a foundry of cutting-edge innovation, strong space programs are central to our nation's future.

Those that lead in space, lead on Earth.

> **Recommendation 9:** Continued support and funding is required for highly visible, world-class space programs to uniquely inspire our nation's students to pursue courses and careers in science, technology, engineering and mathematics.

"The United States takes deserved pride in the vitality of its economy … That vitality is derived in large part from the productivity of well-trained people and the steady stream of scientific and technical innovations they produce. Without high-quality, knowledge-intensive jobs and the innovative enterprises that lead to discovery and new technology, our economy will suffer and our people will face a lower standard of living."[154]

Each year, thousands of students from around the United States participate in the AIA Team America Rocketry Challenge. More than 70 percent of students who participated in 2010 reported that they intend to study a STEM degree in college.

Students at the Challenge Center perform a science experiment. Each year, over 500,000 Challenger Center students conduct space mission simulations across the country. **(Image courtesy of the Challenge Center)**

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Myth: **Space programs are extraordinarily expensive.**

Fact: The total funds committed for space programs by the U.S. government each year make up a negligible fraction of the entire federal budget. NASA's budget is roughly one half of one percent while NOAA's weather satellite program makes up roughly 0.04 percent. DOD funding for space is only 0.7 percent of the federal budget. Despite the fact that these programs are essentially rounding errors in overall U.S. government spending, their returns to society are vast – DOD space programs keep the warfighter safe, NOAA satellites enable weather forecasting and NASA missions keep the United States a world leader in science and exploration.

U.S. Federal Government Spending, FY2011

Myth: **We should cut spending on space until our nation's fiscal outlook improves.**

Fact: Space program funding is so small that completely eliminating their budgets would not appreciably reduce yearly deficit spending or the national debt in any way. It would however, decimate national security, economic innovation and ground-breaking science. Some may suggest these programs are somehow discretionary and that we can wait for greener pastures to fully fund them in the future. In reality our economy, our security and our global leadership will face steady decline without continued investments in space. Funding for the Space Shuttle Program and the Global Positioning System faced similar fiscal conditions in the stagflation of the '70s, as did the ISS in the early '90s recession. In all of these cases perseverance paid off and our preeminence in space has yielded unprecedented dividends in keeping our nation second to none.

Myth: **We should spend less money on space and more money on solving our problems on Earth.**

Fact: Investments in space programs are precisely about improving life on Earth. On board the International Space Station, astronauts are pioneering scientific discoveries in genetics, disease and vaccines using microgravity conditions that can't be replicated on Earth. Telemedicine technologies developed for human spaceflight are now being used to expand health care access in the developing world. Earth observation satellites and the Global Positioning System are guiding first responders and saving thousands of lives during emergencies like the recent earthquake in Haiti. Baby formula improvements from human spaceflight research have been implemented in more than 75 countries, strengthening brain and eye development in infants. Weather satellites are alerting the public to hurricanes and other natural disasters days in advance. Missile detection satellites stand guard to warn soldiers, sailors, marines and civilians of impending danger. Satellite imagery is alerting the world to violence against the innocent in repressive regimes. Robotic space missions are revealing the fundamental laws of nature and providing new insights on our own planet by studying planets like Mars.

By living and working in space, we raise the standard of living in our country and the world by advancing critical fields like medicine, public health and international development. Space provides a unique intellectual stimulus for Earth-bound challenges and many space systems assist us directly every day in ways that could not be replicated otherwise.

Myth: **NASA is the only U.S. space program.**

Fact: Although NASA has an impressive history of U.S. space achievements, the Department of Defense (DOD) and the National Oceanic and Atmospheric Administration (NOAA) also have world class space programs that meet specific national needs and have a rich history of vital contributions to the nation.

Within DOD, a large number of organizations do important work in space that protects our homeland, defends the warfighter and gives our military a decisive edge against its adversaries. The Army, Navy and the Air Force all have programs that develop and operate space systems essential to their missions. Additionally, a number of intelligence agencies use and operate space systems to provide our government a much needed view of current events, including the National Reconnaissance Office (NRO) and the National Geospatial Intelligence Agency (NGA). Other DOD organizations like the Missile Defense Agency (MDA), DARPA and National Labs like Los Alamos and Sandia regularly develop new defense capabilities for space.

NOAA's weather satellites provide 90 percent of the observation data used by the National Weather Service for forecasting. All weather predictions in the United States utilize NOAA weather satellite data, no matter whether they come from television, radio, smart phones, websites or newspapers.

It's important to remember that there are no redundancies in space programs across the U.S. government. Each of these programs fulfills a specific need that is unique to their overall mission for the nation.

Glossary of Terms and Acronyms

ACE	*Advanced Composition Explorer*
AEHF	*Advanced Extremely High Frequency communications satellite*
Aireon	*Aireon LLC; an air traffic management company*
AMA	*American Medical Association*
Apollo	*An American human spaceflight program that landed on the Moon*
Apple	*Apple, Inc.; an American consumer technology company*
Aquarius	*Satelite de Aplicaciones Cientificas-D; an Argentine Earth science satellite*
Atlas	*A family of American expendable launch systems*
BeiDou	*Satellite navigation system of the People's Republic of China*
Boeing	*The Boeing Company; an American multinational aerospace corporation*
Chandra	*Chandra X-ray Observatory*
CO-2 / CO2	*Carbon dioxide*
COBE	*Cosmic Background Explorer satellite*
CORONA	*An American strategic reconnaissance satellite program*
CSAR	*Combat Search and Rescue*
CST-100	*Boeing Crew Space Transportation reusable crew capsule*
Delta	*A family of American expendable launch systems*
DHA	*Docosahexaenoic acid*
DigitalGlobe	*DigitalGlobe Inc., a commercial satellite-imagery vendor*
DLR	*Deutsches Zentrum für Luft-und Raumfahrt; the German Aerospace Center*
DMSP	*Defense Meteorological Satellite Program*
DNA	*Deoxyribonucleic acid*
DoD / DOD	*United States Department of Defense*
Dragon	*SpaceX Dragon; an American reusable spacecraft*
Dream Chaser	*A crewed lifting-body spaceplane by the Sierra Nevada Corporation*
DSCS	*Defense Satellite Communications System*
DSP	*Defense Support Program missile early-warning system*
EpiPen	*A brand of epinephrine autoinjectors*
Explorer	*First artificial satellite of the United States*
FAA	*Federal Aviation Administration*
FDA	*Food and Drug Administration*
FEMA	*Federal Emergency Management Agency*
FEWS	*Famine Emergency Warning System*
GOES	*Geostationary Operational Environmental Satellite*

GOES-R	*Geostationary Operational Environmental Satellite, R Series*
GPS	*Global Positioning System*
GRAB	*Galactic Radiation and Background electronic intelligence satellite*
GRACE	*Gravity Recovery and Climate Experiment earth science satellite*
HACCP	*Hazard Analysis and Critical Control Point*
HBO	*Home Box Office Inc.; an American television network*
Hubble	*Hubble Space Telescope*
ICC	*International Criminal Court*
IED	*Improvised Explosive Device*
ISR	*Intelligence, surveillance and reconnaissance*
ISS	*International Space Station*
JWST	*James Webb Space Telescope*
Kepler	*Kepler Space Telescope*
LANDSAT	*A series of American terrestrial imaging satellites*
LCROSS	*Lunar Crater Observation and Sensing Satellite*
LiquidMetal™	*A series of amorphous metal alloys*
Mercury	*First human spaceflight program of the United States*
Milstar	*Military Strategic and Tactical Relay communications satellite*
MRI	*Magnetic resonance imaging*
MRO	*Mars Reconnaissance Orbiter*
MRSA	*Methicillin-resistant Staphylococcus aureus; a bacterium*
Multispectral	*An image that captures data from various electromagnetic frequencies*
MUOS	*Mobile User Objective System communications satellite*
NASA	*National Aeronautics and Space Administration*
NATO	*North Atlantic Treaty Organization*
New START	*New Strategic Arms Reduction Treaty; signed April 2010*
NextGen	*Next Generation Air Transportation System*
NGA	*National Geospatial Intelligence Agency*
NOAA	*National Oceanic and Atmospheric Administration*
NRO	*National Reconnaissance Office*
NWS	*NOAA National Weather Service*
Opportunity	*Mars Exploration Rover-B; a robotic rover on Mars*
Orion MPCV	*Orion Multi-Purpose Crew Vehicle*
P&W Rocketdyne	*Pratt and Whitney Rocketdyne Inc.; a rocket engine manufacturer*

Pillsbury	*General Mills Pillsbury Company; an American foodstuffs company*
Pioneer	*An early series of American unmanned space missions*
PLA	*People's Liberation Army of the People's Republic of China*
POES	*Polar Operational Environmental Satellite*
POPPY	*A series of American electronic intelligence satellites in the 1960s*
Project Apollo	*See "Apollo"*
Project Mercury	*See "Mercury"*
RCA	*RCA Corporation; an electronics and technology company*
RNP	*Required Navigation Performance*
R&D	*Research and development*
Rocketdyne	*P&W Rocketdyne Inc.; an American rocket engine manufacturer*
SARSAT	*Search and Rescue Satellite-Aided Tracking*
Satcom	*An early series of American communications satellites produced by RCA*
SATCOM	*Satellite communications (generic)*
SBIRS	*Space-Based Infrared System*
Scud	*A series of tactical ballistic missiles*
SEAL	*U.S. Navy Sea, Air and Land soldier*
SERVIR	*Joint USAID / NASA Regional Visualization and Monitoring System*
Sierra Nevada	*Sierra Nevada Corporation; an American aerospace company*
SLS	*Space Launch System*
SOHO	*Solar and Heliospheric Observatory*
SpaceX	*Space Exploration Technologies Corporation; a space transport company*
Space Shuttle	*An American partially-reusable launch system and orbital spacecraft*
Spaceport America	*A commercial spaceport located in New Mexico*
Spirit	*Mars Exploration Rover-A; a robotic rover on Mars*
Sputnik	*First artificial earth satellite; built and launched by the Soviet Union in 1957*
SSP	*Satellite Sentinel Project*
START	*Strategic Arms Reduction Treaty*
STEM	*Science, Technology, Engineering and Mathematics*
STSS	*Space Tracking and Surveillance System*
Syncom	*Synchronous Communications Satellite*
Telstar	*An early series of American commercial communications satellites*
TBS	*Turner Broadcasting System, Inc.; an American television network*
Titan	*A family of American expendable launch systems*

Tranquility	*Tranquility Base; landing site of the first manned lunar landing*
U-2	*An American high-altitude manned reconnaissance aircraft*
UAS	*Unmanned Aerial Systems*
UNOSAT	*United Nations Operational Satellite Applications Program*
USAID	*United States Agency for International Development*
USDA	*United States Department of Agriculture*
Van Allen belts	*A region of charged particles within the Earth's magnetosphere. Named after scientist James Van Allen, who built the Explorer I instrument that detected it.*
Virgin Galactic	*Virgin Galactic LLC; a sub-orbital spaceflight company*
Voyager	*A series of American unmanned space missions*
WFP	*World Food Programme*
WGS	*Wideband Global Satcom communications satellite*
WMAP	*Wilkinson Microwave Anisotropy Probe*
747	*Boeing 747; a wide-body commercial airliner*

Endnotes

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AIA
AEROSPACE INDUSTRIES ASSOCIATION

1000 Wilson Blvd., Suite 1700
Arlington, VA 22209-3901 USA
703 358-1000
www.aia-aerospace.org