INTRODUCTION TO ROCKET PROPULSION

Lo: Space Exploration and Society

Why should we care about rocket propulsion?
In this lecture, we will consider three ways to answer this question. First, we will investigate what rocket propulsion technology has provided for humankind and what it could potentially provide for us in the future. Second, we will consider the contributions rocket propulsion has made to scientific advancement. Finally, we will explore the meaning rocket propulsion and, more broadly, space exploration has for us as individuals and for humankind as a whole.

Figure 1: Space Shuttle Atlantis. The fleet of Space Shuttles carried humans to Earth orbit for over thirty years! The Shuttle Program ended in 2011.

Learning Goals

1. List some of the technologies that were developed as a result of space exploration missions.
2. Describe some of the scientific advancements made possible through space exploration.
3. Understand how space exploration has created a paradigm shift in human perspective.

IMPACT ON HUMAN LIFE

Rocket propulsion technology has been developed to serve the broader goal of space exploration. Therefore, the benefits of space exploration are also the benefits of rocket propulsion.

Past Contributions

Space exploration necessitates the development of new technologies to solve engineering problems related to the goals of the space mission. Oftentimes, space missions require us to do and create things that have never been done or been created before. More than sixty years of space exploration has produced a multitude of technologies, many of which benefit human life. The following is a list of just some of technologies that were developed as a result of space exploration:

Figure 2: A weather monitoring satellite. Weather satellites allow us to track larger weather systems and gather data in order to predict their evolution.

Satellite-based:

- Satellite communications (enables live TV!)
- Satellite weather forecasting
- Global Positioning System (GPS)
- Earth-monitoring satellites (climate monitoring, disaster response, oceanography, surface maps, etc.)

SUSTAINABILITY:

- Solar panels
- Water purification systems
- Fuel cells

DIGITAL:

- Robotics
- Light Emitting Diodes (LEDs)
- Digital imaging technology, miniature cameras
- Portable computers (also known as laptops!)
- Wireless headsets
- Software: 3D modeling, 3D mapping, structural analysis

FOOD AND MATERIALS:

- Freeze-dried food, infant formula
- Home insulation, memory foam, aerogel
- Athletic shoes, Velcro
- WD-40

HEALTH AND SAFETY:

- Artificial limbs, ear thermometers, respirators
- Health monitoring, chemical detection, and warning systems
- Fire-fighting equipment, fire-resistant materials
- Grooved pavement, improved tire design and materials
- The "Jaws of Life"

This list is just the tip of the iceberg. There are *so many* inventions and advancements made as a result of space exploration. Sometimes these are called "spinoff" technologies. As an example, in the 1990s, JPL scientists needed a tiny camera for one of their missions, but tiny cameras didn't exist - so they invented them! Later down the road, these tiny cameras have provided the technology for one third of cameras used in smart phones today.

Figure 3: Global Positioning System (GPS) Technology. What would we do without GPS?!

Figure 4: Solar panels.

Figure 5: Digital camera that has been partially disassembled.

Figure 6: Prosthetic hand.

The Downside of Rocket Propulsion: Rockets As Weapons

In the twentieth century, rocket propulsion technology was, for the first time, seriously studied from a scientific and engineering perspective. This was done for the purpose of creating war technology. These efforts resulted in significant advancements in rocket design, construction, and testing capabilities. As a result, rocket science was better understood, and engineers could design rockets to serve specific purposes. It was no longer a "trial and error" process to develop a working rocket like it had been for centuries.


Figure 7: A weaponized rocket, also called a missile.

Much of the development of modern rocket science was made possible by military efforts. Unfortunately, rocket technology has been used to cause horrific violence and destruction. The loss of life and livelihood resulting from the military use of rocket technology is devastating. Fortunately, humans have found more constructive and unifying ways to use this technology such as building the International Space Station, which is a multi-national, space-based laboratory.

Future Impacts

What advancements might come as a result of future space exploration missions? We can't know for sure how future space missions will impact life on Earth, but there are several technological areas that are likely to benefit:

- **Environmental science:** space-based systems will help reveal and monitor the impacts of human activity on Earth's climate and ecology.
- **Sustainability technology:** crewed space missions will enable future life-supporting and sustainability technologies.
- **Earth protection:** asteroid detection and deflection technologies will continue to be developed.
- **Global communications:** satellite-based internet could bring internet access to the entire globe, making humankind more connected than ever before.
- **Autonomous systems:** development of uncrewed space vehicles will advance technologies related to robotics, control algorithms, and sensors.
- **Scientific advancement:** future scientific discoveries might include finding life in the Solar System and/or on extrasolar planets, better understanding dark matter and dark energy, and uncovering new, fundamental physics!

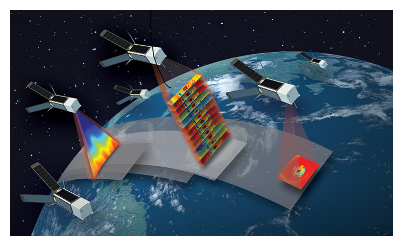
Figure 8: NASA is developing a fleet of microsatellites to monitor Earth's climate.


Figure 9: Future space technologies could help protect the Earth from asteroid impacts.

IMPACT ON SCIENCE

Space Science

Space-based experiments have had enormous impact on space science fields such as astronomy, astrophysics, cosmology, and planetary science.

One of the major challenges Earth-based astronomers face is an atmospheric effect called "seeing." The density of Earth's atmosphere varies both spatially and temporally, which can cause the light rays coming from space to refract. The atmosphere is also a moving fluid with unsteady currents that cause further distortion of light rays. The result is a blurring effect that limits the resolution of Earth-based telescopes. This means that if we want to see the finest details of nearby space objects or even detect celestial bodies millions of light-years away, we need space-based telescopes like the Hubble Space Telescope.

Another challenge with Earth-based astronomy is the water vapor in Earth's atmosphere. Water molecules strongly absorb light in the infrared range, which makes it impossible to measure the infrared light from space objects. Space-based telescopes such as Spitzer and James Webb (coming soon in 2021!) are able to measure the infrared light emitted by stars, nebulae, extrasolar planets, and much more. They can do this because they orbit (or will soon orbit) the Earth far above the atmosphere. Water and other gaseous molecules, such as diatomic oxygen, absorb radiation in the microwave bands. This has necessitated the use of space-based experiments such as PLANCK and WMAP to map out the cosmic microwave background radiation.

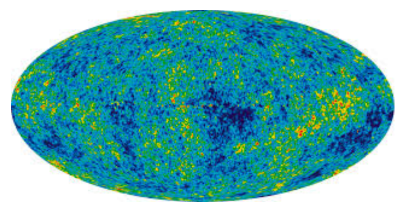

Figure 10: The Cosmic Microwave Background Radiation (CMBR) measured by the WMAP spacecraft. This is the first light of the universe after the Big Bang.

Significant contributions to the fields of Solar System science and planetary science have been made by sending space probes to Solar System bodies. As of 2020, humans have sent at least one spacecraft to every planet in the Solar System! We now have a large collection of data and images that are used to characterize Solar System planets and asteroids. These spacecraft have provided essential information for understanding how the Solar System formed, where we might find life in the Solar System, and how planetary systems evolve. One of the most exciting accomplishments in recent years is the ROSETTA mission, which sent a spacecraft to a comet and landed on it!

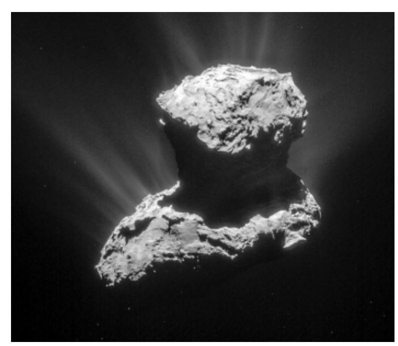

Figure 11: The comet that the ROSETTA spacecraft tracked down and landed on.

After sixty years of space exploration, there have been many space-based experiments that have advanced our scientific understanding of the universe. The following is a brief and incomplete list of some of the major achievements:

- Mapping of the Cosmic Microwave Background Radiation
- Estimation of the age of the universe
- High resolution imaging of distant, early galaxies
- Discovery of dark matter and dark energy
- Discovery and study of thousands of extrasolar planets
- Exploration of the surface of Mars
- Characterization of Solar System planets and moons
- Mass spectrometric analysis of a comet's tail and surface
- Orbiting and landing on an asteroid, gravitational mapping of small Solar System bodies
- Solar observatory, detailed characterization of solar dynamics

Figure 12: A spiral galaxy, imaged by the Hubble Space Telescope.

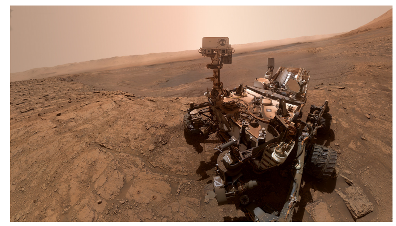

Figure 13: The Curiosity rover, taking a selfie on Mars.

Earth Science

Earth orbit provides an incredible vantage point from which to study the Earth. An orbiting satellite or constellation of satellites can map out much of Earth's surface, just by looking down! We have equipped satellites with a variety of sensors and cameras to study Earth's surface, atmosphere, and oceans. In the short term, we are better able to predict weather patterns, study the evolution of hurricanes and typhoons, and track ecological disasters such as wildfires and oil spills. There are also satellites that monitor Earth's atmosphere for radioactive compounds, which can help locate sites where unsanctioned nuclear testing is being carried out. Satellite imagery can also be used to study human activity and provide support in disaster scenarios.

In the long term, we can monitor climate change and the effects of human life on Earth's ecology. Satellites have and continue to play a vital role in monitoring the health of our planet. With a global vantage point, satellites can track changes in the temperature and composition of Earth's surface, atmosphere, and oceans. With this data, we can monitor greenhouse gas emissions, pollution, deforestation, desertification, ocean acidification, changes to the polar ice sheets, and much more. Satellite data can also help us find solutions to climate change and environmental degradation and allow us to track our progress as we work to restore Earth's vitality.

There are also missions that have contributed to our understanding of how the Earth formed and evolved. For example, a spacecraft called GRACE mapped the gravitational field of the Earth. This has helped us to better characterize Earth's composition and understand how the Earth formed. One of the most famous in-space experiments was sending humans to the Moon! The astronauts collected rocks and dust from the lunar surface and returned them to Earth. Detailed mass spectrometric analysis of Moon rocks has significantly contributed to our understanding of how the Earth-Moon system formed. The Moon rocks are remarkably similar in composition to those of the Earth. The current theory is that a protoplanet, similar in size to Mars, shallowly impacted the Earth billions of years ago. The collision vaporized part of the Earth and sent the particulates into orbit. The vaporized Earth material eventually coalesced into what we now know as the Moon. The protoplanet itself did not become the Moon, as previous theories had suggested, and instead is thought to have flown off into space, never to be seen again.

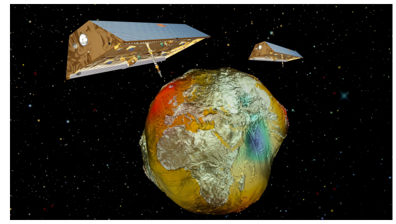

Figure 14: The GRACE spacecraft, which mapped Earth's gravitational field in exquisite detail.

Biological Science

Space exploration has also had a significant impact on the biological sciences. Most notable is the study of human beings in space environments. Before the first astronauts went to space, we didn't know if humans would be able to survive. Significant engineering and technological advances were made to ensure that humans could not only survive visiting space but thrive while living and working there. Astronauts regularly spend months living in space on board the International Space Station. The longest stay on the ISS was 365 days, which was completed by astronaut Scott Kelley. Scott, and his twin brother Mark, who was also an astronaut (and is now a US Senator), is currently being studied to determine the long-term physiological effects of living in space. The results of this research will undoubtedly inform how human missions to Mars will be carried out.

Figure 15: Astronaut Scott Kelly on board the International Space Station (ISS). Scott was one of the first astronauts to spend a full year on the ISS. He worked alongside Russian cosmonaut Mikhail Kornienko, the only other person to spend a year on the ISS. Russian cosmonaut Valeri Polyakov holds the record for longest consecutive time spent in space, which is 438 days.

Humans are not the only biological organisms that have been studied in space. Research on the ISS has focused on the growth and development of bacteria and plants in space environments. Yes, plants have been grown in space! When humans visit Mars and build a long-term habitat there, the Martian astronauts will need to grow their own food in greenhouses. It sounds like science fiction, but there is plenty of research being conducted today that will help astronauts of the future grow their own food!

Figure 16: Plants growing in space on board the ISS!

IMPACT ON HUMAN PERSPECTIVE

A Paradigm Shift

Before Orville and Wilbur Wright flew the first powered aircraft in 1903, society was generally skeptical of human flight. Many people thought that the concept of powered aircraft was impossible. The old adage, "The sky is the limit." reflects the paradigm of this time period. If the idea of humans flying in aircraft was far-fetched, then the idea of humans escaping Earth's atmosphere to visit the Moon was *beyond* preposterous. Even still, there were some individuals who believed in the possibilities. In 1903, Russian schoolteacher Konstantin Ziolkovsky performed some of the first calculations to determine if it was even possible to escape Earth's gravity. In the early 1900s, the technology needed for crewed spaceflight was far off in the distance, but even still there were curious minds dreaming about astronauts.

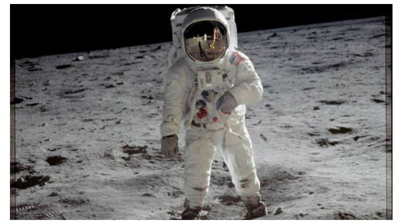

Figure 17: Astronaut Neil Armstrong on the surface of the Moon.

Figure 18: International crew of astronauts living on board the ISS. These days, there is always someone living and working in space!

All of us grew up knowing what happened next – *humans made it to space!* We orbited the Earth in the International Space Station and even walked upon the surface of the Moon. Since the 1960s, we have sent thousands of satellites and spacecraft into to Earth orbit and beyond. We have robots driving around the surface of Mars, digging up soil samples, and searching for signs of life. We even sent a probe to intercept a comet! We have telescopes that can see deeply into the past, imaging the earliest galaxies. We discovered planets orbiting distant stars. It is easy to take all this for granted, living in the era of space exploration, but we can try to imagine what it was like 100 years ago or more. Consider how profoundly things have changed as a result of rocket technology and space exploration missions. The sky is no longer the limit!

Pale Blue Dot and Earthrise

In 1977, the Voyager I spacecraft went where no spacecraft had gone before – to the outer Solar System to image the giant planets. Amazingly, someone had the idea to turn the camera back towards Earth, revealing a pale blue dot floating in the expanse of space. This image can evoke feelings of awe, because we can start to grasp how small the Earth is and how much smaller we are. While this may make us feel insignificant, we can look at things from a different perspective. In the vastness of this universe, there exists a beautiful blue planet teeming with life. It is profound that we are here. Even if other life exists in the universe, our existence is no less meaningful.

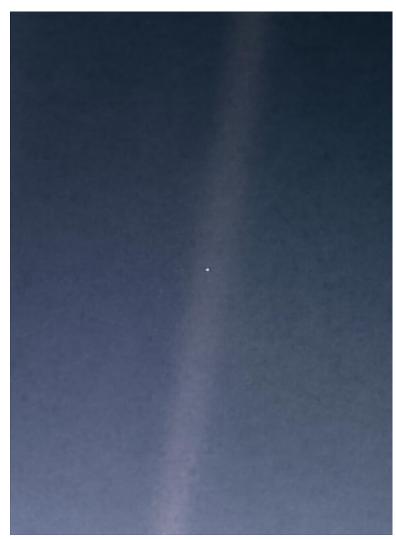

Figure 19: Pale blue dot.

When US astronaut William Anders orbited the Moon, he witnessed something that no one had seen before – an "Earthrise." The Earth rose up above the horizon of the Moon, just like we observe the sun rise above the horizon on Earth. He took a photo to capture this profound moment. He and his crew were the only human beings not in the picture. This photo reminds us that we are all living on this blue dot together and shows us how precious our Earth home is. We only have one planet to live on, although Elon Musk might argue otherwise, and it is our responsibility as a species to care for this special place for the sake of all living things.

Figure 20: Earthrise, captured on the Apollo 8 mission.

Is There Anybody Out There?

While crewed spaceflight was made possible by military investments and Cold War era competition, the inspiration for space exploration has always been rooted in humankind's most profound questions. What is out there, beyond Earth? Is there anybody out there? Is there life elsewhere in the universe? How is it that we came to be here? Why are we here?

Space exploration may not be able to answer all of these questions, but we have learned *a lot* about what exists beyond Earth. The universe is massive, complex, and evolving. Stars, galaxies, black holes, dark matter, dark energy, extrasolar planets. Every day we are learning more about what is "out there". We are even getting closer to finding life elsewhere in the universe. The science and technology required to detect life are advancing rapidly, and it's possible that life beyond Earth could be discovered within our lifetimes.

Science can't answer why we are here on planet Earth, but it can help us uncover part of the "how". Cosmology is the study of the evolution of the universe. From what we can tell, the space-time fabric of our universe expanded rapidly from a tiny point, producing the diversity of space-objects that we observe today. What happened before that moment, we may never know.

Space exploration has provided humankind with many answers, but perhaps even more questions. It is a valuable pursuit because it provides us with a means to explore the depths of these essential questions, even if we may never find the answers through scientific investigation alone.