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978-1-108-42284-0 — Dynamics and Control of Autonomous Space Vehicles and Robotics
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Excerpt
More Information

1 Introduction to Autonomous Space Vehicles and Robotics

1.1 Space Exploration: The Unmanned Spacecraft That Ventured into Space

The dream of exploring the space surrounding the Earth has been around for many hundreds of years. Space exploration needed rockets to go to space, and engineers such as the Russian Konstantin Tsiolkovsky, the German Herman Oberth, and the American Robert H. Goddard were among many who successfully attempted to build rockets for space travel. The dream of space travel was fueled by such science fiction writers as Cyrano de Bergerac (1619–1655), Jules Verne, who published his novel *From the Earth to the Moon* in 1865, and H. G. Wells, whose novel *First Men on the Moon* was published in 1901, and these works inspired scientists such as Robert H. Goddard and Werner von Braun, who led the US effort to send an astronaut to the Moon. On the October 4, 1957 the Soviet Union launched the first autonomous artificial satellite, *Sputnik 1*, illustrated in Figure 1.1, which orbited the Earth in 96.2 minutes in an elliptic orbit at an inclination of 65 degrees.

The satellite was 58 cm in diameter and orbited the Earth at the rate of 8,100 m/s for three weeks before its batteries ran out of power. It was launched on board a Soviet R7 rocket that was just over 29 m long and developed a thrust of 3.9 mega Newtons. It crashed back to Earth six months after its launch. Soon afterward, the Soviet Union launched *Sputnik 2* with a dog on board. Unfortunately, the dog did not survive the flight, although it spent a week in Earth orbit. In 1958 the *Explorer 1* satellite that was responsible for detecting the radiation belts around the Earth was launched by the United States. The first US communications satellite, *Telstar 1*, was launched in July 1962. Over 3,000 satellites have been launched since then for communication and navigation applications, weather observation, space and deep space research, and military applications. The first successful space probe was *Luna 2*, which crashed on the Moon in 1959. After this, several other *Luna* spacecraft visited the Moon, the *Mariner* series of spacecraft visited the planets Venus, Mars, and Mercury, while the *Pioneer 10* and *11* spacecraft visited the planets Jupiter and Saturn, respectively. Early *Pioneer* spacecraft were used to launch probes that landed on the surface of Venus. Figure 1.2 illustrates *Mariner 5*, built as a back-up for *Mariner 4*, the first spacecraft to go to Mars, which eventually went on to probe the planet Venus.

The outer planets Uranus and Neptune were visited by *Voyager 2* in 1986 and 1989, respectively. The asteroid Gaspra was examined by the US spacecraft *Galileo*, while the

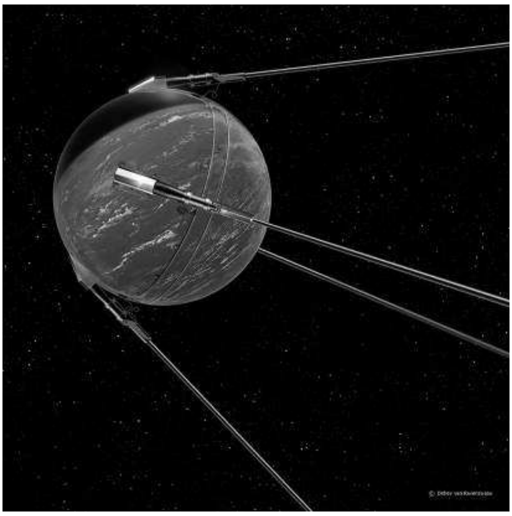

Figure 1.1 *Sputnik 1*. (credit: Detlev van Ravenswaay / Picture Press / Getty Images)

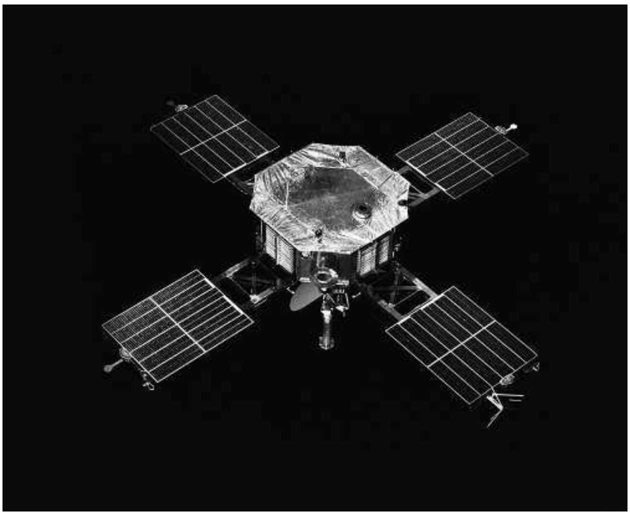

Figure 1.2 The *Mariner 5* spacecraft *en route* to the planet Venus. (credit: Stocktrek Images / Getty Images)

European spacecraft *Giotto* surveyed Halley's comet. Figure 1.3 illustrates NASA's *STARDUST* spacecraft, which was launched in 1999, *en route* to the comet Tempel 1, following a NASA spacecraft's successful fly-by of the comet Hartley 2. NASA's *Mars Atmosphere and Volatile Evolution* (*MAVEN*) satellite, which began orbiting Mars in September 2014, was designed to fly-by the comet C/2013 A1 Siding Spring and is shown in Figure 1.4. The *Near Earth Asteroid Rendezvous* (*NEAR*) satellite mission profile and its journey to the Asteroid 433 EROS, which involved several Deep Space

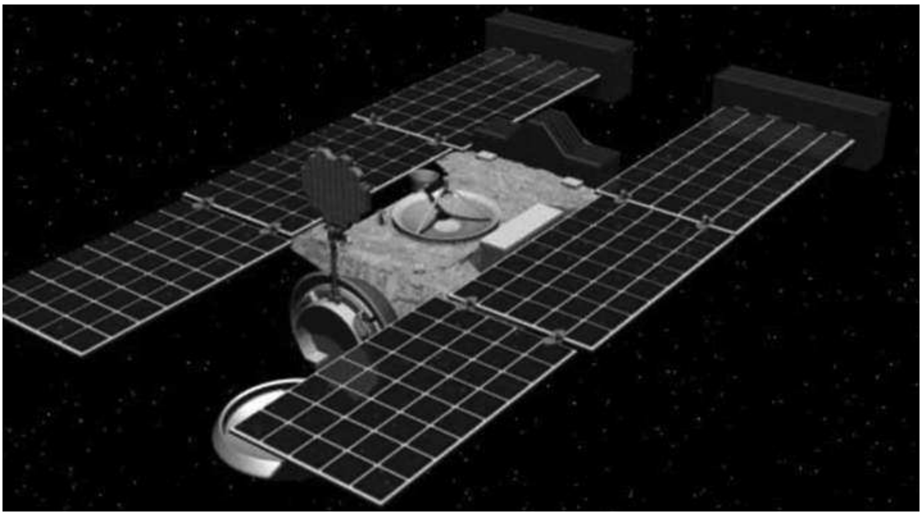

Figure 1.3 NASA's *STARDUST* spacecraft *en route* to the comet Tempel 1. (courtesy: NASA)

Figure 1.4 NASA's *Mars Atmosphere and Volatile Evolution* (*MAVEN*) satellite orbiting Mars after a Comet fly-by. (courtesy: NASA)

Maneuvers (DSM) that were executed shortly after the asteroid 253 Mathilde fly-by, on July 3, 1997, is shown in Figure 1.5.

Using a novel slingshot maneuver around the planet Jupiter, the *Ulysses* spacecraft was redirected to the Sun and it passed by the Sun's North Pole in 1995. The first planetary rovers, known as Lunokhods and illustrated in Figure 1.6, were landed on the Moon by the Soviet Union between 1970 and 1973.

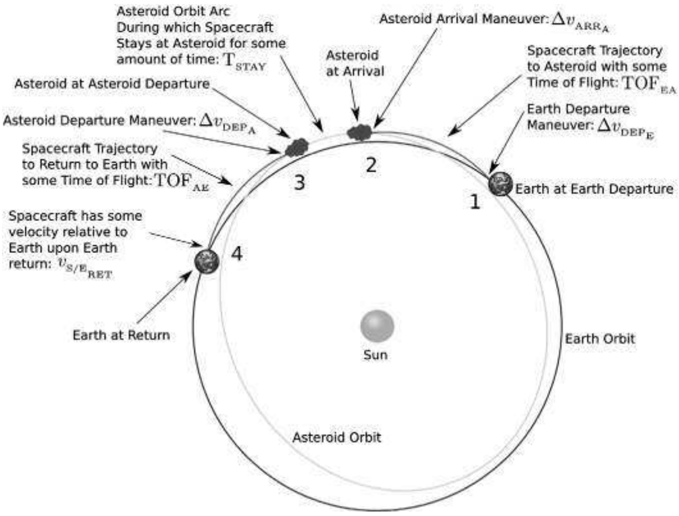

Figure 1.5 The diagram illustrates the parts of a conceptual mission to the asteroid. The outer oval represents Earth's orbit, the inner oval is the asteroid's orbit, and the red arcs are the spacecraft's trajectory to and from the asteroid. (courtesy: NASA, image credit: Brent Barbee)

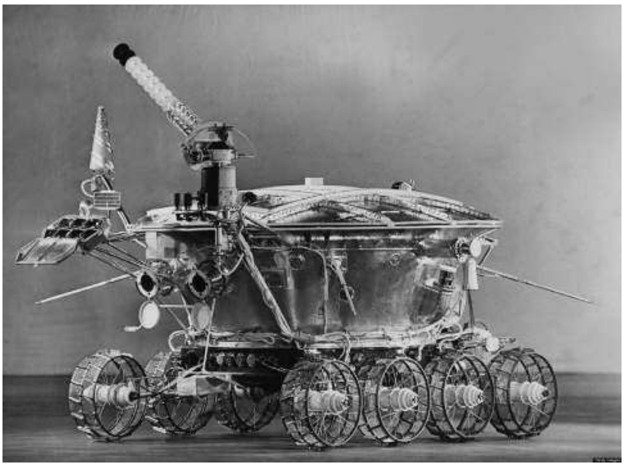

Figure 1.6 The Lunokhod Moon rover. (courtesy: NASA)

Figure 1.7 shows the space shuttle *Endeavour* docked with the *International Space Station (ISS)* [1].

Although space exploration is extremely expensive, countries like China and India have also designed and launched low-cost missions to the Moon and Mars. Almost all of these spacecraft were autonomous. The *ISS*, led by the United States, involved the use of robotic manipulators in space to assemble several modules over several years to

Figure 1.7 Space shuttle *Endeavour* docked with the *International Space Station*. (courtesy: NASA)

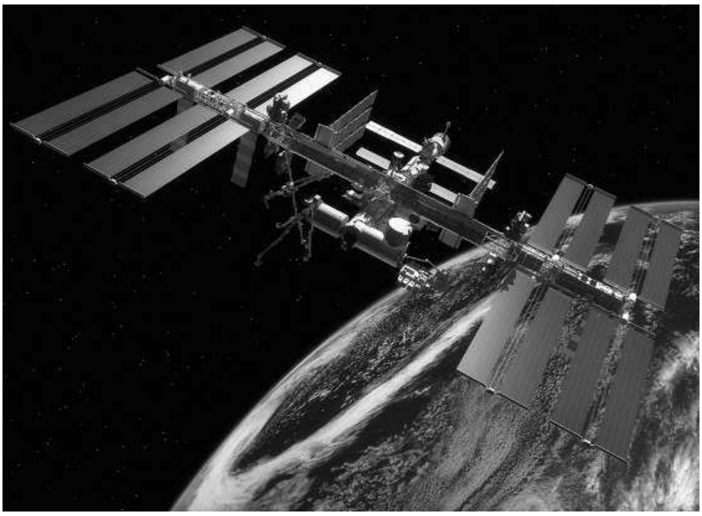

Figure 1.8 The *International Space Station*. (credit: Matthias Kulka / Corbis / Getty Images)

make the design and deployment of a permanent artificial orbiting outpost in space, about 400 km above the Earth and moving at the rate of 7.7 km/s, a reality. A space shuttle fitted with a robotic arm was used to shuttle modules from the Earth for assembly and deployment on the *ISS*. The *ISS*, illustrated in Figure 1.8, was assembled using several robotic manipulators and was truly an international effort. The *ISS* and the space shuttle successfully demonstrated the use of tele-operated and autonomous robots in space.

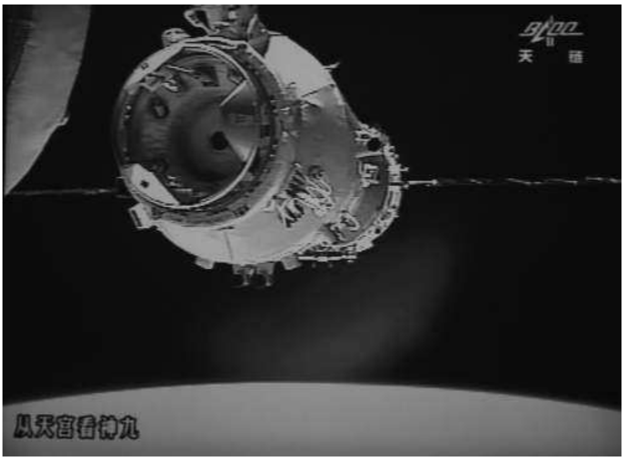

Figure 1.9 A Chinese satellite preparing to dock with a Chinese space station. (credit: AFP / Stringer / Getty Images)

Apart from the US National Aeronautics and Space Administration (NASA), the Russian Federal Space Agency (ROSCOSMOS), and the European Space Agency (ESA), the Japan Aerospace Exploration Agency (JAXA), the China National Space Administration, and the Indian Space Research Organization (ISRO) have also been active in launching satellites. Figure 1.9 illustrates a Chinese satellite preparing to dock with a Chinese space station.

In another development, Arthur C. Clarke predicted in 1945 that satellites could be used for terrestrial communications in an article first published in *Wireless World* magazine in 1945. The first commercial communications satellite, *Intelsat 1*, was launched 20 years later in April 1965. Following the launch of the first communication satellite in 1962, proposals were made to develop radio navigation systems similar in principle to LORAN and DECCA but with satellite transmissions of precise radio navigation signals. This led to the development of the TRANSIT system, involving seven orbiting satellites, where the position of the user was determined from the Doppler shift in the received radio frequency signal. TRANSIT was made available in 1967 and soon after led to the development of the GPS system. After 10 years of development, proposals for establishing the GPS system were approved in the 1970s and the system was made available on a selective basis in the 1980s. Since the 1990s the GPS navigation system has been made available internationally for navigation applications worldwide.

Besides the United States' GPS (with 24 satellites in a constellation, orbiting the Earth at an altitude of 20,200 km), Russia's GLONASS, and the European Union's *Galileo*, the Indian Space Research Organization launched the Indian Regional Navigation Satellite System (IRNSS) satellites, a set of 7 dedicated satellites, in 2016, which form the NavIC (Navigation with Indian Constellation) system for navigation applications. Operating on dual frequency bands using the S and L bands, the NavIC system covers a limited region over the Indian subcontinent. Four of the satellites are

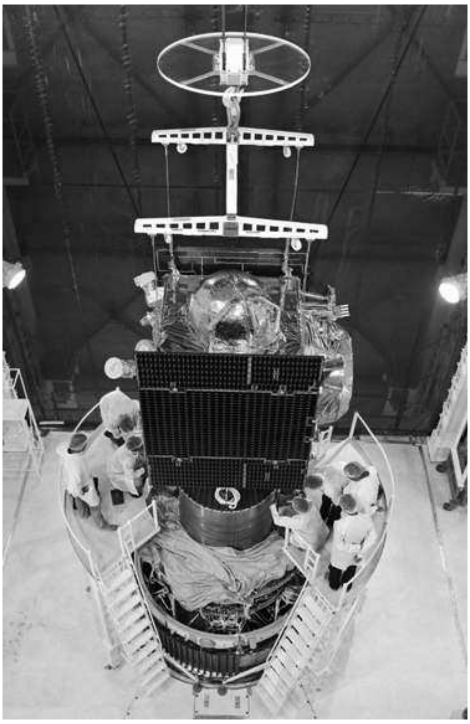

Figure 1.10 A typical IRNSS satellite is shown being assembled in a factory in Bangalore, India. (credit: Pallava Bagla / Corbis News / Getty Images)

geosynchronous, orbiting in pairs so the ground track looks like a figure of eight, north and south of the equator, while the remaining three are geostationary, all orbiting the Earth in a circular orbit at an altitude of 35,787 km above the equator. The Indian space research establishment crossed a major threshold when for the first time a factory owned by the private sector became involved in making a full multi-million dollar navigation satellite. In Figure 1.10, a typical IRNSS satellite is shown being assembled in a factory in Bangalore, India.

The use of the dual frequency band permits corrections to be easily made for transmission times due to atmospheric and tropospheric delays. The deployment of the system demonstrated the feasibility of developing and installing a system that can provide limited navigation coverage over any planet. The China National Space Administration is also in the process of building its own satellite navigation system known as the Beidou Navigation Satellite System.

1.2 Exploring Mars

Mars is one of the most enigmatic planets and a neighbor of our own planet. The manned *Apollo 11* mission to the Moon landed on the lunar surface on July 20, 1969 almost 10 years after the first unmanned lunar landing by a Luna spacecraft. After the successful landing on the Moon, the attention of almost all space researchers turned back to Mars, which had evoked considerable interest from scientists in the early 1900s. It was believed, at that time, that Mars was inhabited and that there were large canals on the surface that were filled with water. This was later considered to be an illusion and probably caused by the reflection of the blood vessels in the human eye in a telescope's eyepiece as astronomers viewed the surface of Mars. However, the more recent discovery of "ghost dunes" by the Mars Reconnaissance Orbiter seems to indicate the presence of extreme environmental conditions (winds and dust storms coupled with extreme temperatures), which seem to be responsible for creating special features on the surface of Mars.

Mars has an equatorial diameter of 6,759 km in comparison to the corresponding equatorial diameter of Earth of 12,756 km, which makes the Earth's diameter almost 1.88 times the diameter of Mars. Mars' orbital period is 687 days, making it also about 1.88 times the orbital period of the Earth (365.25 days). Mars' mean orbital distance from the Sun is 227.94 million km, while the corresponding distance of the Earth is 149.59797 million km, making the distance of Mars about 1.52 times that of Earth or about 1.88 raised to the power of 2/3. The eccentricity of the Martian orbit is a lot greater (0.093) than that of the Earth (0.0167), which makes it 5.57 times that of the Earth. The inclination of Mars' orbit is just less than 2 degrees that of the Earth, while the inclination of the Martian equator is slightly greater than the inclination of Earth's equator to its orbit. Yet the mean density of Mars is only 71.3% of that of Earth, while acceleration due to gravity on the surface of the planet is 3.71 m/s^2, which in comparison to the corresponding value on the surface of the Earth (9.81 m/s^2) is less than 38%. Moreover, Mars has two moons, Phobos and Deimos, orbiting it at distances of 9,370 and 23,460 km, respectively, from its center. Another interesting feature of Mars as seen from Earth, due to its much larger orbital period, is that it appears to briefly move backward as it journeys from one end of the sky to the other.

Following the *Mariner 9* spacecraft's visit to Mars in 1971, two *Viking* spacecraft, *Viking 1* and *Viking 2*, had landed on its surface in 1976 and transmitted pictures of the Martian surface. In 1996, NASA launched *Mars Pathfinder* and *Mars Global Surveyor* followed by *Mars Odyssey* in 2001. It was named in honor of Arthur C. Clarke's novel entitled *2001: A Space Odyssey* and reached Mars in just over six months. The spacecraft returned pictures of the surface of Mars in stunning detail and set the scene for the launch of spacecraft carrying the twin planetary exploration rovers and the planetary science laboratory in the years that followed.

Mars Express Orbiter, a cube-shaped satellite with two sets of solar panels on either side, was launched by the European Space Agency in June 2003 and arrived in the Martian environment in December 2003, after a six-month journey covering the 400 million km distance. *Mars Express Orbiter* is the second longest surviving, continually active spacecraft in orbit around a planet other than Earth. Although it was accompanied by *Beagle 2*, a Mars lander that failed to deploy properly after a successful landing, *Mars Express Orbiter* has now continuously surveyed the structure of the Martian surface for over a decade and in July 2018 it was reported that it had discovered a 12-mile-wide lake containing liquid water beneath the Martian surface, thus indicating the possibility of some life forms existing on the planet.

The *Mars Reconnaissance Orbiter* was launched in 2005, following the launch of the Mars exploration rovers, Spirit and Opportunity, and was fully focused on its mission almost 13 months later. The *Mars Science Laboratory* was launched in 2011, culminating in the landing of the Curiosity rover on the surface of Mars in 2012.

1.3 Robotic Spacecraft for Planetary Landing and Exploration

While NASA's *Mariner 2* was the first spacecraft to reach the planet Venus, it was the Soviet Union's *Venera 3* that made the first landing on the surface of that planet. The first manned spacecraft to land on the surface of the Moon was the Lunar module, which left its mother ship, *Apollo 11*, while it was in a lunar orbit and landed on the lunar surface. NASA plans a return to the lunar surface in the years to come. To realize this project, NASA is launching a satellite, *Orion*, which will fly approximately 100 km above the surface of the Moon, and then use the Moon's gravitational force to move itself into a new deep space orbit. The Orion mission is the first of a series of launches that are designed to explore deep space. Figure 1.11 is an illustration of the *Orion* spacecraft in lunar orbit.

More than 30 missions worldwide have been launched by several countries to explore the Martian environment. Several of these missions have been responsible for taking Martian planetary landers and rovers, such as Pathfinder, Spirit, Opportunity, and Curiosity, and landing them safely on the Martian surface. The latest mission planned as part of the ExoMars program are an *Orbiter* plus an Entry, Descent, and Landing Demonstrator Module, which was launched in 2016. Figure 1.12 is an artist's

Figure 1.11 The *Orion* spacecraft. (courtesy: NASA)

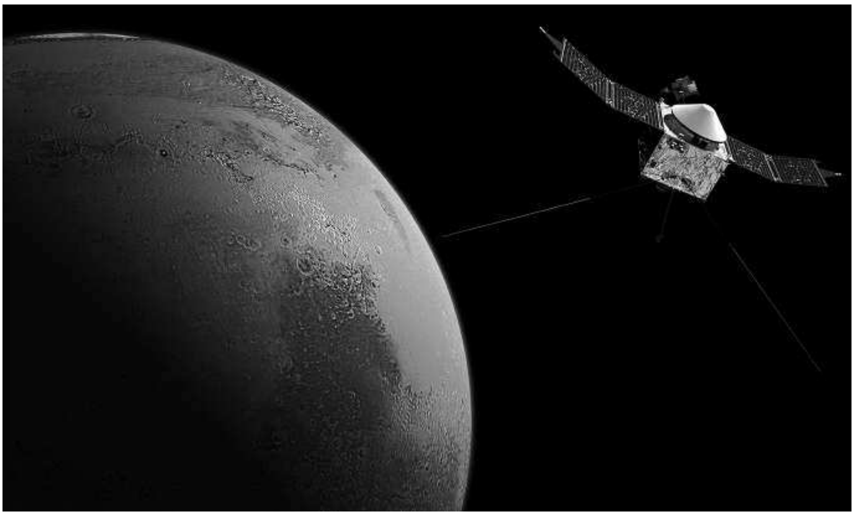

Figure 1.12 A satellite approaching the planet Mars. (credit: Stocktrek Images / Getty Images)

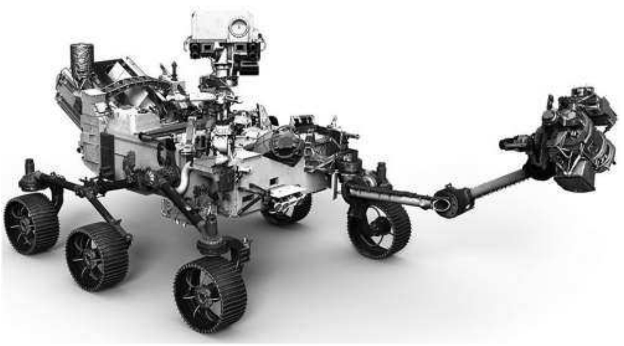

Figure 1.13 The proposed new Mars rover. (courtesy: NASA)

impression of a satellite approaching the planet Mars. Another launch, featuring a new rover, with a launch date in 2020, is also planned. Figure 1.13 is an illustration of the proposed new rover that is to be sent to bring back a rock from the surface of Mars.

1.4 Exploring a Comet

NASA JPL's *Deep Space 1* mission in 1998, on its way to an asteroid and then to a comet, was the first satellite to be powered by an electric propulsion system, using an electrostatic ion thruster that generates thrust by accelerating charged particles or ions by creating electrostatic fields. The European Space Agency tested an electric