

THE COMPLETE COSMOS

Chapter 14: Robots

Our scouts in the Solar System. Probes that trail-blaze on Mars, plunge into Jupiter, and land on Saturn's moon Titan.

Outline

Montage of the robot probes whose mission is to explore the Solar System. One such is Mars Surveyor Orbiter - programmed to use aero-braking to alter orbit around the Red Planet. Mission objectives.

Past missions - the heroic journeys and discoveries of Voyagers 1 and 2. They looked at Jupiter, Saturn, Uranus and Neptune. The odyssey of the Ulysses probe, gravity assisted by Jupiter, over the poles of the Sun. How Earth helped slingshot the Galileo craft to Jupiter. Galileo's tour of Jupiter and its moons. A descent into the Jovian atmosphere. The triumph of the Mars Pathfinder mission - the landing on an ancient Martian flood plain. Pathfinder movies of its Sojourner rover. How Pathfinder imaged Mars in 3-D. Missions that go wrong. The explosion, shortly after lift-off, of the Ariane 5 rocket - a maiden flight that destroyed the four robot probes aboard. Russia's Mars '96 spacecraft that never got beyond Earth-orbit. The craft was supposed to fire penetrators into the Martian soil and analyze the sub-surface.

The giant radio dishes of NASA's Deep Space Network which pick up the transmissions of robot explorers and send commands to guide them through space.

Sub-chapters

Lift-Off for Mars

- An array of robot probes, which have visited, or are due to visit the other planets of the Solar System.
- Launch, on a Delta rocket, of Mars Surveyor Orbiter - shedding its nose cone and propulsion units, unfurling its solar array.
- Slipping into an elliptical orbit, the spacecraft has to achieve a close, circular orbit to conduct its survey of the Red Planet. To do so, it must use its solar array as an "aerobrake" in the upper atmosphere.

Mars Surveyors

- Mission objectives of Mars Surveyor, part of a ten-year program.

The Voyagers

- Voyagers 1 and 2, both launched in 1977. They pass Jupiter in 1979 - with Voyager 1 arriving at Saturn in 1980 and Voyager 2 in 1981.
- Saturn and its rings imaged by the Voyagers - including spectacular time-lapse of a Saturn approach. Saturn is the climax for Voyager 1 and it exits the Solar System.
- Voyager 2 continues on to Uranus, collecting data on both the planet and its craggy little moon, Miranda. Images are converted into an animated flight over Miranda's surface.
- 1989: Voyager 2 finally arrives at Neptune. Time-lapse of the south pole, an arc over the north pole. Then Voyager 2 heads for interstellar space.

To the Sun and Jupiter

- 1990: An ingenious route to the Sun by the spaceprobe Ulysses. By traveling first to

Jupiter and using it as a gravity-assist to catapult downwards and backwards, Ulysses achieves the trajectory required to view and image both poles of the Sun.

- 1989: Again using gravity assist, the Galileo spacecraft swings by Venus once and Earth twice, to gather sufficient energy for the journey to Jupiter.
- Galileo parachutes a probe through Jupiter's clouds. Before it is crushed by pressure, the probe gathers fascinating information on atmospheric composition and conditions.
- Galileo loops round Jupiter and its moons.

Mars Pathfinder

- July 4, 1997: Mars Pathfinder touches down on Mars.
- A Martian sunrise and Pathfinder is activated. It transmits to Earth 16,500 images and two-and-a-half-billion bits of information.
- Pathfinder's stereo imaging camera equipment. Light enters the lens and passes through three filters to produce a color image. This occurs again with a second lens.
- Two images of the same scene are produced. When merged, Mars is seen in 3-D for the first time.
- Pathfinder time-lapse of the Sojourner rover negotiating the Martian terrain and colliding with the large rock dubbed Yogi.

Space Mishaps

- Ariane 5 explodes shortly after lift-off. Aboard, four robot probes are destroyed - the Cluster mission that should have investigated the solar wind.
- Russia's Mars '96 spacecraft carries penetrators designed to fire into the Martian soil to examine the sub-surface. Rocket failure means the craft never leaves Earth orbit.
- On Earth, giant radio dishes listen to the transmissions of journeying robots. In return, commands are beamed through space to tell the robots what to do.
- Robots allow us to see worlds we will never experience at first hand.

Background

Gaining Speed by Gravity Assist

In 1961, Michael Minovitch, a 25-year-old graduate in mathematics, was hired as a summer employee at NASA's Jet Propulsion Laboratory (JPL). Minovitch wondered if a planet's gravity could be used to provide a "kick" to a passing spacecraft. In doing so, he created a revolution in the design of interplanetary space missions.

Minovitch's notion was that a carefully aimed spacecraft could pick up momentum from the "gravity-assist" of one planet in order to travel on to a second planet. Indeed, a further boost could be obtained from the second planet to take the craft to a third – and so on.

The only energy required would be to launch the craft from Earth to the first planet. All subsequent planets were, so to speak, a free ride. As an added bonus, due to the gains in speed, the travel times to each of the planets beyond the first would be significantly reduced.

To achieve gravity-assist, is a precise business. As it closes in, a spacecraft will pass either the "trailing" or "leading" hemisphere of a planet. Such a close encounter causes two effects. Firstly, the spacecraft's path is bent. Secondly, the spacecraft either gains or loses energy - i.e. speed.

Bending occurs regardless of whether the spacecraft passes the leading or the trailing hemisphere. The direction of bending is determined by scientists choosing the appropriate hemisphere. The amount of bending is controlled by how closely the craft approaches the planet.

The bending of the flight path occurs both with respect to the planet and with respect to the Sun. There is no net change in speed, however, with respect to the planet. The spacecraft is in continual free-fall with respect to the planet. Its final speed – far after approach - is exactly the same as its initial speed - far before approach – with respect to the planet.

But, with respect to the Sun, it's a different story. The spacecraft's velocity relative to the Sun is always equal to the spacecraft's velocity relative to the assisting planet, together with the planet's velocity relative to the Sun.

From the point of view of the Sun, imagine an outward-bound spacecraft passing the trailing edge of a planet. As it approaches the planet, the craft's velocity is less than when it leaves. In other words, there is a net increase in the speed of the outward-bound spacecraft - and a net slowing down of the planet. Energy has been transferred from the planet to the spacecraft.

On the other hand, if an outward-bound spacecraft swings by the leading edge of a planet - from the point of view of the Sun - the roles are reversed. The spacecraft slows down and the planet speeds up. Energy has been transferred from the spacecraft to the planet.

These principles also apply to gravity-assist from the big moons of the Solar System – a trick brilliantly exploited by the Galileo spacecraft in its orbital tour of Jupiter's satellite system.

When they flew by Jupiter, Saturn and Uranus, the Voyager 1 and Voyager 2 spacecraft picked up speed from the trailing hemispheres of the planets. The Voyages gained speed at the expense of the planets. In precise terms, when Voyager 1 passed Jupiter, the craft gained 16 kilometers per second relative to the Sun - and the planet lost one centimeter per 30 billion years relative to the Sun, causing Jupiter's orbital period to shrink by nearly one nanosecond.

Early Uses of Gravity-Assist

The first application of gravity-assist was in Mariner 10's mission to Mercury via Venus. Mariner 10 launched from Earth in 1973 and traveled directly to Venus. In February 1974, Venus bent and boosted Mariner's trajectory to Mercury. Then, in March/April 1974, as it swung by Mercury, Mariner received a another gravity-assist. This enabled the craft to encounter Mercury a second time - in September 1974. And guess what? Mercury delivered another gravity-assist that allowed a third and final Mercury encounter in March 1975.

The Pioneer 11 mission was the second application of gravity-assist. Pioneer was originally intended to encounter only Jupiter - in 1974 - as a trailblazer for the subsequent Voyager 1 and Voyager 2 missions. As it turned out, there was an opportunity for Pioneer to get a gravity-assist from Jupiter for an onward trip to Saturn. Pioneer's "bend" was almost 180 degrees - causing the spacecraft to travel all the way back across the inner Solar System to pass closely by Saturn five years later, in 1979!

The Grand Tour of the Outer Planets

Michael Minovitch (see above) realized that the powerful gravity of Jupiter was the key to outer planet exploration. As the largest planet, Jupiter had the strongest gravity field. It was suddenly possible, Minovitch believed, to explore Saturn, Uranus, Neptune and Pluto by using the gravity-assist of Jupiter to slingshot spacecraft speedily to the outer planets. Minovitch identified windows of opportunity between 1962 and 1966 and between 1976 until at least 1980. He suggested a 1976 launch for a "Grand Tour" of the outer planets.

In 1965, Gary Flandro - then at NASA's Jet Propulsion Laboratory (JPL) - designed a set of Grand Tour trajectories using the gravity-assist concept. He included an example of an Earth-Jupiter-Saturn-Uranus-Neptune mission. Flandro pointed out that these planets align themselves for such a mission only once every 176 years or so. The next set of Earth-launch opportunities would occur in 1976, 1977 and 1978. Thus came the impetus for what ultimately became the Voyager Project, including Voyager 2's Grand Tour of the outer planets

Between 1974 and 1976, scientists at JPL evaluated the merits of over ten thousand Voyager spacecraft trajectories. The objective was to maximize the knowledge that could be gleaned from the Jovian and Saturnian systems. Of primary interest were Jupiter's moon Io and Saturn's moon Titan. The Voyager 1 and 2 trajectories must, therefore, have at least one close approach to each of the moons. Additionally, the best trajectories had to have the largest number of close fly-bys of the remaining Jovian and Saturnian moons.

When the Voyagers launched, their actual trajectories included two gravity swing-bys at Jupiter, two at Saturn, one at Uranus and one at Neptune.

Communicating with Spacecraft

The antennae of NASA's Deep Space Network (DSN) are the link between unmanned spacecraft - robot explorers - and space scientists on Earth. DSN tracks the craft, DSN transmits or uplinks commands and information to the craft, and DSN receives or downlinks data from the craft. From NASA's Jet Propulsion Laboratory in California, commands to robots are routed via the Ground Communication Facility (GCF) to the appropriate DSN Deep Space Communications Complex (DSCC) for transmission to the spacecraft.

GCF uses a combination of communication satellites and conventional surface and undersea circuits to link JPL and the DSCCs. Three DSCCs - at Goldstone in California, Canberra in Australia and Madrid in Spain - are located at widely separated longitudes to provide continuous tracking of interplanetary craft as the Earth rotates. Each site is similarly equipped.

The Goldstone DSCC is in the heart of the Mojave Desert. It has three main antennae – a 34-metre diameter antenna which can both transmit and receive, a 70-metre antenna that can both transmit and receive, and a 34-metre diameter antenna which can only receive. More than one antenna can be used simultaneously to increase the strength of the signal coming from a spacecraft.

The Canberra DSCC is at Tidbinbilla, New South Wales. It has three main antennae – a 34-metre transmit/receive station, a 70-metre transmit/receive station, and a 34-metre receive-only station. The Madrid DSCC is at Robledo. It also has three main antennae - a 34-metre transmit/receive antenna, a 34-metre receive-only station, and a 70-metre transmit/receive antenna. Voice communication - in fact, a continuous phone call – is maintained between all three DSCCs and the Network Operations Control center at JPL. Despite its DSCC capability, NASA sometimes requires enhanced power. At the time of its Neptune encounter, the signals from Voyager 2 were so feeble that NASA needed giant ears to catch the spacecraft's news. When they reached Earth, Voyager's signals were a mere 0.000000000000001 watts. A digital wrist watch operates at a power 20 billion times greater !

So in the US, NASA had to hook up with the Very Large Array in New Mexico - 27 dishes each measuring 27 meters, part of the National Radio Astronomy Observatory. And because Voyager's closest approaches to Neptune and Triton occurred when Australia was best positioned to hear the craft, the 64-metre Parkes Radio Observatory was roped in to help. Yet more tracking was

provided by Japan's 64-metre radio observatory antenna at Usuda, Japan.

As Voyager 2 passed Neptune, signals from Earth - traveling at the speed of light – took over four hours to reach the craft. It took another four hours for Voyager's acknowledgement of their receipt to bounce back to Earth. Such a time lag greatly complicates spacecraft operations. Imagine steering a ship where navigational data and the views from the bridge are more than four hours old.

Links for Further Information

Mars Surveyor Orbiter page - mission overview, objectives, launch phases, aero-braking and images.

<http://mars.jpl.nasa.gov/msp98/orbiter/mission.html>

Mars Surveyor Lander page - mission overview, objectives, launch phases, landing scenario and images.

<http://mars.jpl.nasa.gov/msp98/lander/mission.html>

Voyager home page - extensive images, daily and weekly reports, missions summaries for each planet.

<http://vraptor.jpl.nasa.gov/voyager/voyager.html>

Ulysses mission page. Extensive information - the spacecraft, its trajectory, the Jupiter fly-by, mission overview, comet-watch program, scientific results and images.

<http://stardust.jpl.nasa.gov/comets/ulysses.html>

Galileo home page. Full information on mission objectives, scientific firsts, results, press releases and images.

<http://nssdc.gsfc.nasa.gov/planetary/galileo.html>

Mars Pathfinder page. Comprehensive image gallery with accompanying text - plus links to other images, animations and the Mars sunset movie.

<http://www.brandx.net/dbajot/mpf/>

Questions and Activities for the Curious

1. What are the benefits of using robots, as opposed to humans, for space exploration?
2. Describe the highlights of the Voyager 1 and 2 missions to the outer planets.
3. Explain the principles of "gravity-assist" with an example of its use.
4. Outline the circuitous six-year flight of the Galileo spacecraft from Earth to Jupiter, identifying the various bodies it passed en route.
5. What characteristics are important in designing a robot vehicle to move about on the rock-strewn surface of Mars?
6. How might robots, developed for tasks in outer space, be used for our benefit here on Earth?
7. What are the problems of communicating with deep space probes?
8. Pluto, the most distant planet, is the only one yet to be explored by spacecraft. What problems might be encountered on such a mission?