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The success of the US mission planned as a grand tour of the planets is surpassing all expectations

The endless flight of our fantastic Voyagers

In August this year, after spectacularly successful encounters with the other planets, Voyager 2 will leave our solar system for eternal flight between the stars, writes ALEX CAMERON

THEY were nor superstitious, those scientists and engineers who named the Voyager spacecraft.

Apt though the name is for the most successful and ambitious unmanned space mission ever planned and executed, it was also the name of an earlier Mars lander mission which suffered endless management problems and eventually failed due to bad planning and political ineptitude within the United States' National Aeronautical and Space Agency (NASA).

The two Voyager craft travelling through space now have achieved more than their designers could have thought possible.

Voyager 2, having made close encounters with Jupiter, Saturn, and Uranus, is scheduled to skim over the cloud tops of Neptune at 4am GMT on August 25, 1989.

At its closest approach Voyager 2 will be a mere 29000km from the centre of Neptune. An astonishing 30 times further times further from the Sun than Earth, or 4496 million kilometres away, Voyager 2 will be controlled by a feeble 20 watt radio link whose signals will take more than four hours to reach Earth while travelling at the speed of light.

Five hours after encountering Neptune, Voyager 2 will fly within 40000km of the centre of Triton, Neptune's largest moon. It will then leave our solar system to begin an endless flight between the stars.

The success of the Voyager program has allowed spectacular photographs of the giant planets Jupiter, Saturn and Neptune to be obtained as well as a wealth of scientific data relating to the makeup of our part of the cosmos.

Voyager was an ambitious plan, conceived during the early '60s to perform a "grand tour", so to speak, of the outer planets.

The timing was right: the planets had aligned into a configuration which occurred only once every 177 years: the political climate was right and the technology was ready.

This was an exceptional opportunity. If NASA missed this opportunity it would have to wait for another 177 years, or until the year 2150, before such an alignment would again be in place.

Technology was also a key issue.

Could the scientists and engineers design and develop an intelligent, computer-controlled robot, capable of sending reliable data back to

Earth from such immense interplanetary distances?

There had been earlier, less ambitious probes, namely Mariner and Pioneer, which had been pathfinders and had proved we could at least travel to the planets.

The importance of planetary alignment was directly tied to the realisation that the gravitational pull of a planet could be used by spacecraft in place of large amounts of hydrazine fuel.

Thus the feasibility of the Voyager mission depended entirely on the spacecraft being launched into trajectories which could trade hydrazine fuel for gravity assist.

The discovery of the trajectories which led to the grand tour concept was made at the Pasadena based Jet Propulsion Laboratory (JPL) during 1965 by Gary Flandro and Michael Minovich.

The concept is both elegant and simple and relies on a conversation of energy between the planet and an inbound spacecraft, insofar that if a spacecraft catches up with a planet from behind it sweeps along in its orbit, it gains energy and is flung outward at an increased speed relative to the Sun, instead of being returned to the inner solar system.

As conservation of energy basically states that nothing is given up for free, then using gravity assist dictates that the planet providing the gravity assist be slowed down in its orbit.

This is not a calamitous event; for a planet the size of Jupiter the amount of slowdown has been calculated to represent an orbit degradation of a mere 30cm in one million million years.

THE initial budget for the Voyagers allowed for a truly grand tour – Jupiter, Saturn, Uranus, Neptune and Pluto. However, a changing political and financial climate forced a cutback and thus the trajectories planned for the Voyagers were a compromise.

Voyager 2, launched first on August 20, 1977, would take the slow route which Voyager 1, launched on September 5 in the same year, would be sent on a trajectory which would allow a close encounter with Jupiter and Saturn as well as Saturn's largest moon, Titan.

The requirement for a close encounter with Titan prevented Voyager 1 being targeted for either Uranus or Neptune and as a consequence the craft's mission ended at Saturn, as the effect of Saturn's gravity flung it out of the plane of the ecliptic at an angle of 35.5 degrees north.

Voyager 2's trajectory was planned so that it would hopefully be able to go on to the other planets.

Two hundred and twenty days after Voyager 2 left Earth orbit en route to the grand tour it made its closest approach to Jupiter. The craft began its encounter with Saturn on August 22, 1981, when it began imaging Saturn's moon, Iapetus, from a distance of 900,000km.

After this encounter Voyager 2 began breaking new ground as it headed off on its four-and-a-half year journey towards distant Uranus.

The image data returned from the Jupiter and Saturn encounters were breathtaking and generated a great deal of excitement.

So much was the public response that JPL scientists were quick to indicate just how inexpensive such exploratory spacecraft were and how rich were the benefits.

The type of "interesting facts" published were that Voyager cost each American 20 cents a year for seven years, less than one chocolate bar; or the cost of the total program was equivalent to the amount spent by the US on defence expenditure in two days.

Voyager 2 has been travelling for 12 years and through the ingenuity of the engineering staff, it is getting better and better.

While Voyager 2 appears to be indestructible it has had its share of problems. Each problem encountered has extended the intellectual limits of the ground-based scientists and engineers.

A failed primary receiver and a partially crippled secondary or back-up receiver have meant that all communications between the spacecraft and the controllers on Earth has been extremely restricted.

Although the secondary receiver is faulty, it can work in a restricted mode, which allows only a small range of frequencies to be received.

Because Voyager hurtles through space at speeds of more than 24000 km per hour, the frequency of the received signals is varied due to Doppler effects (variation of radio frequency with velocity.)

As well as this the on-board receiver is sensitive to temperature changes. These variations in frequency are normally contained by a circuit element called a frequency tracking filter.

A single capacitor in this filter had failed, effectively making the receiver deaf to all but a very narrow band of frequencies.

All the encounters since Saturn have been programmed through this receiver, which at times is so affected that it cannot receive any signals at all. **Continued page 55**

Voyagers' grand tour of the cosmos

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Other problems involving stuck bits in program memory and jammed scan platforms all had to be solved before the Uranian encounter.

The resolution of these problems was often assisted by the healthy Voyager 1, Voyager 2's sister spacecraft.

Although Voyager 1's mission was complete, it was still alive and well and was often used to try out new fixes and ideas before downloading programs and sequences to the more vulnerable and valuable Voyager 2.

Considering that a computer load can take up to 12 hours and that each load must be repeated at least three times to ensure the correct data has been loaded, the process is long and critical.

The adaptation of Voyager 2 to the Uranian encounter did not stop there. Many of the design trade-offs of Voyagers 1 and 2 were made on the assumption that the Voyagers would not be going on past Saturn. Thus the spacecraft's transmission capability was not designed for communication across the vast distances between the planets, although some clever data reduction techniques had been allowed for in the spacecraft's software. It is interesting to note that the earlier NASA spacecraft Mariner 4 in 1965 took a week to transmit 21 pictures at 81.3 bits per second!

Voyager on the other hand, through improved technology and communication techniques, was initially able to transmit at rates of 115.2k bits/second during its Jupiter encounter, but this rate fell to 44.8k bits/second during the Saturn encounter and finally 21.6k bits/second during the Uranus encounter during January 1986.

The fall in data rates has nothing to do with the ability of the spacecraft but is due to the inverse square law imposed by distance on any spreading signal.

Simply put, this states that both light and electromagnetic signals reduce in intensity in inverse proportion to the square of the distance.

Thus the signals from a spacecraft at twice the distance from Earth as from some original reference point will have four times less signal strength, and so on.

In order that the signal information does not com-pete with the noise caused by the electronic systems as well as the noise of deep space, the data rates must be reduced.

As the data rates fell, a technique had to be used to reduce the amount of data being returned without reducing the information rate.

This entailed sending the same amount of images back to Earth but with fewer bits of data than would normally be required. No, it's not magic but relies on a technique of sending only the difference in picture element (pixels) intensity, rather than the absolute levels.

As the absolute intensity level of a pixel is generally a larger number, more bits of information would be required to represent this data than is the case in sending a value which represents the difference between two adjacent pixels.

Each image from Voyager contains 800 x 800 pixels of information. This provides acceptable resolution but as colour imaging requires that each image be a compilation of three primary colour images, then each final image requires Voyager to send more than 15 million bits of information back to Earth.

When Voyager reaches Neptune the light levels will be 900 times less than the light that falls on Earth, comparable to late dusk on Earth.

Taking a photograph under these conditions means holding the shutter open for several seconds. With the object moving at such large speeds, blurring is inevitable.

The ground-based programmers came up with an ingenious solution of panning the camera or spacecraft platform in the opposite direction, using the spacecraft's hydrazine jets at a rate designed to compensate for the relative motion of the spacecraft and its target.

As it sped away, it turned its cameras back towards Earth

The sharp, astounding images of a tortured looking Mirandian surface are testimony to the success of this encounter.

VOYAGER is now close enough to Neptune to allow images of the bluish planet to exceed those resolutions available from earth-based telescopes.

The pre-encounter phase has passed and the encounter team is now in training and linking the Deep Space Network (DSN), which includes Tidbinbilla (near Canberra), to the 64m-diameter Parkes radio telescope to form an antenna dish comparable to the distance separating the Canberra and Parkes antennas.

As with the Uranian encounter, Tidbinbilla will play an important role as much of the encounter will take place while Neptune is in the Southern sky.

The final trajectory of Voyager 2 was for some time the source of much concern. Some scientists would have liked a close equatorial approach while others would have liked a polar encounter.

Each trajectory has merit and danger associated with it. How close in should the spacecraft aim for more gravity assist?

Ideally we would like to obtain close images of both Neptune and its moon, Triton. Unfortunately, obtaining close images of Triton would call for a higher degree of gravity assist to be derived from Neptune. The closer the spacecraft flies to a planet the higher the influence on its trajectory. Thus, achieving a close fly-by of Triton would involve a great deal of risk from either unknown ring systems or other local debris.

The trajectory eventually chosen for the fly-by was for Voyager 2 to skim over the planet's north pole at a height of 5000km above the cloud tops.

About 12 hours before its closest approach to Neptune, the spacecraft will pass within 4.6 million kilometres of the tiny moon, Nereid. Voyager will fly within 40,000km of the centre of Triton five hours after encountering Neptune.

Such a close encounter is a unique challenge to the JPL navigators to test their aim on a target more than three billion kilometres away; a feat comparable to a golfer dropping a thousand-kilometre putt.

Once Voyager's trajectory is bent down and out of the elliptic, it will leave our solar system and hopefully remain operational until 2013, expanding our knowledge of the cosmos as it travels out of our solar system into interstellar space, away from the influence of our Sun.

It is anticipated that the fuel store is sufficient to power the spacecraft until then. There is, however, doubt that the navigational star detectors will enough sensitivity to provide the information necessary to keep the spacecraft antennae locked and pointing to earth.

Once Voyager leaves our solar system it will, in its own way, be like earth – a microcosm adrift in the cosmos, hopefully carrying with it the images of a still alive planet. Nothing could more clearly have demonstrated the fragility of planet Earth and how much we need to protect our home, than the first image Voyager took of our own planet.

As it sped away after the encounter with Uranus, it turned its cameras back to Earth as if to bid farewell. The image taken was the first ever photograph to show the Earth and the Moon together in deep space. We looked alone and unique.

JPL navigators have run a careful plot of Voyager 2's path into interstellar space. In 8554 years it will pass within four light years of Barnard's star; it will be a further 12,149 years before it will encounter Proxima Centauri at a distance of more than three light years.