Liftoff

New Zealand's space exploration magazine

Issue 265
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Also inside:

- **Shuttle in retrospect**
- **STS-135 launch – an eyewitness account**

Liftoff

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NZSA News and Notices

Auckland meetings

The next Auckland meetings are on **7 November** and **5 December** at 7:45 pm at MOTAT, Great North Road, Western Springs (entry via Stadium Rd).

The Auckland Branch meets at MOTAT on the first Monday of each month (except January).

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Subscriptions 2011-2012

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Note, too, that for each new member you introduce to the NZSA, providing they join for a full year and nominate you on their membership form, you will receive a credit of $5 against your next subscription. There is no limit to the number of credits you can qualify for.

Cover Photo: Artist's impression of the Juno spacecraft in orbit around Jupiter. (NASA)

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Editor's Corner

Now that the Space Shuttle programme is over and the launch pads at the Kennedy Space Center have fallen silent (for a few years anyway), there will doubtless be many books and articles assessing whether or not the whole thing was worth it. It's probably too soon to make any kind of final assessment of the Shuttle's place in history, but beginning on page 11, I offer up my own views, for what they're worth. Yes, I'll miss it, sort of – but I'm much more concerned with what's coming next (or not, as the case may be…)

Staying on the Shuttle theme, the NZSA's publicity officer, Matt Pavletich, and his wife Maree made the pilgrimage to the Cape to see Shuttle Atlantis fly into the history books. An illustrated account of their amazing trip starts on page 17. I'm green with envy! I'd certainly loved to have seen one more launch before it all ended.

But onwards and upwards (excuse the pun!) – there's lots of good stuff happening, and our cover story this month is on NASA's new Jupiter mission, the Juno orbiter, which is now happily on its way to the giant planet, getting there in 2016. The Dawn mission to Vesta is starting to produce some amazing results too, and there's an update on that on page 23.

In next month's issue I'll be taking a critical look at the International Space Station in the post-Shuttle world, and there will also be articles on the GRAIL lunar mission, and the latest revelations from MESSENGER in orbit around Mercury – not to mention a look at NASA's proposed new heavy-lift rocket, the Space Launch System.

-- *David Maclennan*

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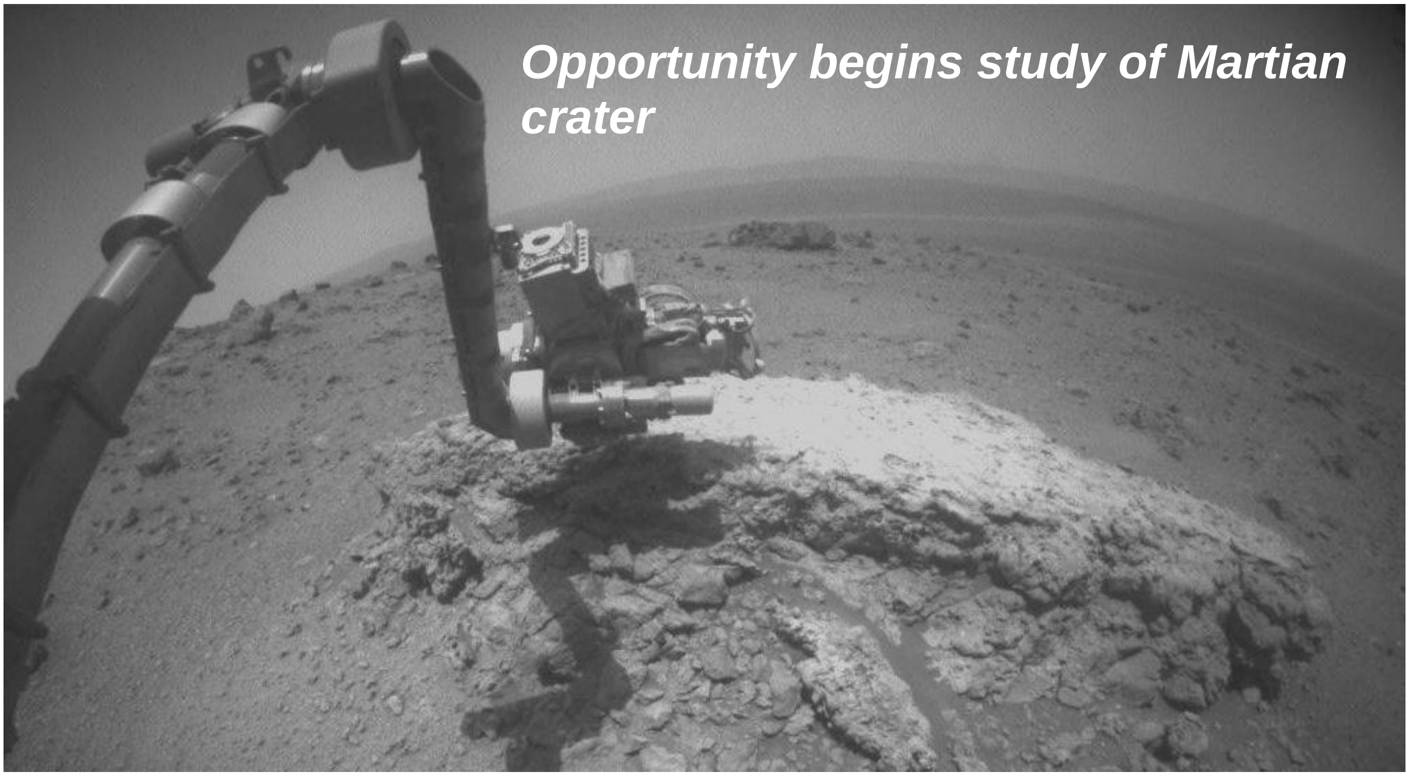


NASA's Mars Exploration Rover Opportunity used its front hazard-avoidance camera to take this picture showing the rover's arm extended toward a light-toned rock, "Tisdale 2," during the 2,695th Martian day, or sol, of the rover's work on Mars (23 August 2011). Tisdale 2 is about 30 cm tall. (NASA/JPL-Caltech)

The initial work of NASA's Mars rover Opportunity at its new location on Mars shows surface compositional differences from anything the robot has studied in its first 7.5 years of exploration. Opportunity arrived in early August at the rim of a 22-kilometre-wide crater named Endeavour. The first rock it examined is flat-topped and about the size of a footstool. It was apparently excavated by an impact that dug a crater the size of a tennis court into the crater's rim. The rock was informally named "Tisdale 2."

"This is different from any rock ever seen on Mars," said Steve Squyres, principal investigator for Opportunity at Cornell University in Ithaca, N.Y. "It has a composition similar to some volcanic rocks, but there's much more zinc and bromine than we've typically seen. We are getting confirmation that reaching Endeavour really has given us the equivalent of a second landing site for Opportunity."

The diversity of fragments in Tisdale 2 could be a prelude to other minerals Opportunity might find at Endeavour. In the past two weeks, researchers have used an instrument on the rover's robotic arm to identify elements at several spots on Tisdale 2. Scientists have also examined the rock using the rover's microscopic imager and multiple filters of its panoramic camera.

Observations by Mars orbiters suggest that rock exposures on Endeavour's rim date from early in Martian history and include clay minerals that form in less-acidic wet conditions, possibly more favorable for life. Discontinuous ridges are all that remains of the ancient crater's rim. The ridge at the section of the rim where Opportunity arrived is named "Cape York." A gap between Cape York and the next rim fragment to the south is called "Botany Bay."

"On the final traverses to Cape York, we saw ragged outcrops at Botany Bay unlike anything Opportunity has seen so far, and a bench around the edge of Cape York looks like sedimentary rock that's been cut and filled with veins of material possibly delivered by water," said Ray Arvidson, the rover's deputy principal investigator at Washington University in St. Louis. "We made an explicit decision to examine ancient rocks of Cape York first."

The science team selected Endeavour as Opportunity's long-term destination after the rover climbed out of Victoria crater three years ago this week. The mission spent two years studying Victoria, which is about one twenty-fifth as wide as Endeavour. Layers of bedrock exposed at Victoria and other locations Opportunity has visited share a sulfate-rich composition linked to an ancient era when acidic water was present. Opportunity drove about 21 kilometres from Victoria to reach Endeavour. It has driven 33.5 kilometres since landing on Mars.

"We have a very senior rover in good health for having already worked 30 times longer than planned," said John Callas, project manager for Opportunity at NASA's Jet Propulsion Laboratory in Pasadena, Calif. "However, at any time, we could lose a critical component on an essential rover system, and the mission would be over. Or, we might still be using this rover's capabilities beneficially for years. There are miles of exciting geology to explore at Endeavour crater."

Opportunity and its rover twin, Spirit, completed three-month prime missions in April 2004 and continued working for years of extended missions. Both have made important discoveries about wet environments on ancient Mars that may have been favorable for supporting microbial life. Spirit ended communications in March 2010.

"This is like having a brand new landing site for our veteran rover," said Dave Lavery, program executive for NASA's Mars Exploration Rovers at NASA Headquarters in Washington. "It is a remarkable bonus that comes from being able to rove on Mars with well-built hardware that lasts."

Spacecraft data suggest water flowing on Mars

Observations from NASA's Mars Reconnaissance Orbiter have revealed possible flowing water during the warmest months on Mars. Dark, finger-like features appear and extend down some Martian slopes during late spring through summer, fade in winter, and return during the next spring. Repeated observations have tracked the seasonal changes in these recurring features on several steep slopes in the middle latitudes of Mars' southern hemisphere.

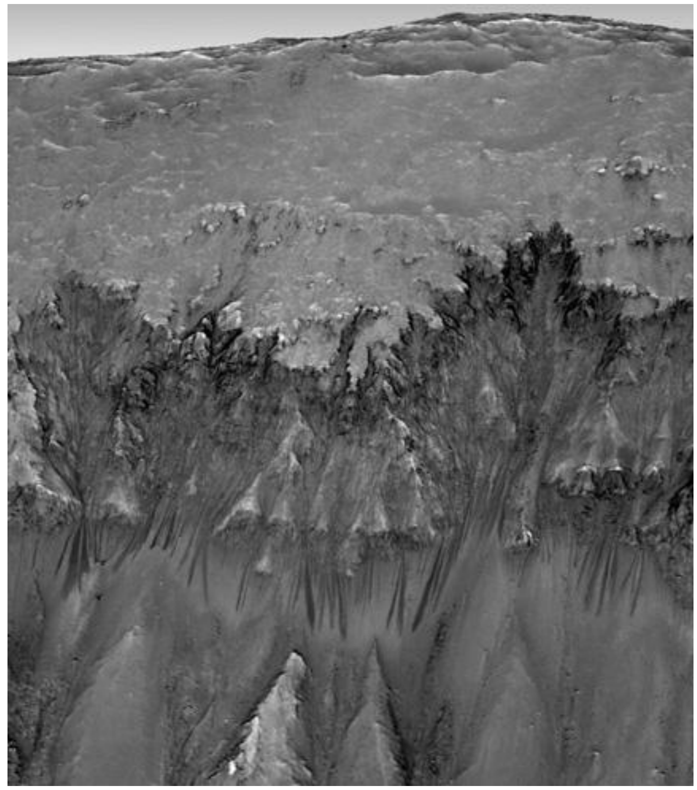
"The best explanation for these observations so far is the flow of briny water," said Alfred McEwen of the University of Arizona, Tucson. McEwen is the principal investigator for the orbiter's High Resolution Imaging Science Experiment (HiRISE) and lead author of a report about the recurring flows published in the journal *Science*.

Some aspects of the observations still puzzle researchers, but flows of liquid brine fit the features' characteristics better than alternate hypotheses. Saltiness lowers the freezing temperature of water. Sites with active flows get warm enough, even in the shallow subsurface, to sustain liquid water that is about as salty as Earth's oceans, while pure water would freeze at the observed temperatures. "These dark lineations are different from other types of features on Martian slopes," said Mars Reconnaissance Orbiter Project Scientist Richard Zurek of NASA's Jet Propulsion Laboratory in Pasadena, Calif. "Repeated observations show they extend ever farther downhill with time during the warm season."

The features imaged are only about 0.5 to 5 metres wide, with lengths up to hundreds of metres. The width is much narrower than previously reported gullies on Martian slopes. However, some of those locations display more than 1,000 individual flows. Also, while gullies are abundant on cold, pole-facing slopes, these dark flows are on warmer, equator-facing slopes. The images show flows lengthen and darken on rocky equator-facing slopes from late spring to early fall. The seasonality, latitude distribution and brightness changes suggest a volatile material is involved, but there is no direct detection of one. The settings are too warm for carbon-dioxide frost and, at some sites, too cold for pure water. This suggests the action of brines, which have lower freezing points. Salt deposits over much of Mars indicate brines were abundant in Mars' past. These recent observations suggest brines still may form near the surface today in limited times and places.

When researchers checked flow-marked slopes with the orbiter's Compact Reconnaissance Imaging Spectrometer for Mars (CRISM), no sign of water appeared. The features may quickly dry on the surface or could be shallow subsurface flows. "The flows are not dark because of being wet," McEwen said. "They are dark for some other reason." A flow initiated by briny water could rearrange grains or change surface roughness in a way that darkens the appearance. How the features brighten again when temperatures drop is harder to explain.

"It's a mystery now, but I think it's a solvable mystery with further observations and laboratory experiments," McEwen said.



An image combining orbital imagery with 3-D modeling shows flows that appear in spring and summer on a slope inside Mars' Newton crater. Sequences of observations recording the seasonal changes at this site and a few others with similar flows might be evidence of salty liquid water active on Mars today. Evidence for that possible interpretation is presented in a report by McEwen et al. in the Aug. 5, 2011, edition of Science. (NASA/JPL-Caltech/Univ. of Arizona)

These results are the closest scientists have come to finding evidence of liquid water on the planet's surface today. Frozen water, however has been detected near the surface in many middle to high-latitude regions. Fresh-looking gullies suggest slope movements in geologically recent times, perhaps aided by water. Purported droplets of brine also appeared on struts of the Phoenix Mars Lander. If further study of the recurring dark flows supports evidence of brines, these could be the first known Martian locations with liquid water.

Nuclear power for settlements on the Moon and Mars

The first nuclear power plant being considered for production of electricity for manned or unmanned bases on the Moon, Mars and other planets may really look like it came from outer space, according to a leader of the project who spoke at the 242nd National Meeting & Exposition of the American Chemical Society (ACS) on 31 August. James E. Werner said that innovative fission technology for surface power applications is far different from the familiar terrestrial nuclear power stations, which sprawl over huge tracts of land and have large structures such as cooling towers.

"People would never recognize the fission power system as a nuclear power reactor," said Werner. "The reactor itself may be about 1 foot wide by 2 feet [0.3 by 0.6 metres] high, about the size of a carry-on suitcase. There are no cooling towers. A fission power system is a compact, reliable, safe system that may be critical to the establishment of outposts or habitats on other planets. Fission power technology can be applied on Earth's Moon, on Mars, or wherever NASA sees the need for continuous power."

The team is scheduled to build a technology demonstration unit in 2012. This is a cooperative project between the National Aeronautics and Space Administration (NASA) and the U.S. Department of Energy (DOE). Werner leads the DOE's Idaho National Laboratory involvement in this effort, which includes participation in the reactor design and modeling teams, fuel development and fabrication and development of a small electrical pump for the liquid metal cooled system.

Sunlight and fuel cells were the mainstays for generating electricity for space missions in the past, but engineers realized that solar energy has limitations. Solar cells do a great job supplying electricity in near-Earth orbits and for satellite-borne equipment, but nuclear power offers some unique capabilities that could support manned outposts on other planets or moons.

"The biggest difference between solar and nuclear reactors is that nuclear reactors can produce power in any environment," Werner explained. "Fission power technology doesn't rely on sunlight, making it able to produce large, steady amounts of power at night or in harsh environments like those found on the Moon or Mars. A fission power system on the Moon could generate 40 kilowatts or more of electric power, approximately the same amount of energy needed to power eight houses on Earth." In addition, he said that a fission power system could operate in a variety of locations such as in craters, canyons or caves.

"The main point is that nuclear power has the ability to provide a power-rich environment to the astronauts or science packages anywhere in our solar system and that this technology is mature, affordable and safe to use," Werner said.

Fission power systems rely on energy generated from nuclear fission. Nuclear fission works by splitting uranium atoms to generate heat that is then converted into electric power. The primary components of a fission power system are similar to those found in the commercial reactors currently in use: a heat source, power conversion, heat rejection and power conditioning and distribution.

Werner added that despite the similarities in components, fission power systems for space applications feature a number of differences compared with commercial reactors. "While the physics are the same, the low power levels, control of the reactor and the material used for neutron reflection back into the core are completely different," Werner said. "Weight is also a significant factor that must be minimized in a space reactor that is not considered in a commercial reactor."

Werner contends that once the technology is developed and validated, it may prove to be one of the most affordable and versatile options for providing long-term base power for the space exploration programs.

Deep space capsule comes alive with first weld

Construction began in early September on the first new NASA spacecraft built to take humans to orbit since space shuttle Endeavour left the factory in 1991. Engineers at NASA's Michoud Assembly Facility in New Orleans started welding together the first space-bound Orion Multi-Purpose Crew Vehicle. "The Orion team has maintained a steady focus on progress, and we now are beginning to build hardware for spaceflight," said Orion Program Manager Mark Geyer, NASA's Johnson Space Center, Houston.

ATK's Liberty launcher looks sort of familiar… (ATK)

The first welds were completed using an innovative new friction stir welding process, developed especially for Orion construction. The process creates a seamless, leak-proof bond that has proven stronger and higher in quality than can be achieved with conventional welding. After welding is completed at Michoud, the Orion spacecraft orbital test article will be shipped to NASA's Kennedy Space Center in Florida, where the heat shield will be installed. At Kennedy, it will undergo final assembly and checkout operations for flight.

NASA begins commercial partnership with ATK

NASA and Alliant Techsystems (ATK) of Salt Lake City have agreed to collaborate on the development of the company's Liberty Launch System as part of the agency's Commercial Crew Development Round 2 activities. The unfunded Space Act Agreement (SAA) through NASA's Commercial Crew Program will allow the agency and ATK to review and discuss Liberty system requirements; safety and certification plans; computational models of rocket stage performance; and avionics architecture designs. The agreement outlines key milestones including an Initial System Design review, during which ATK will present to NASA officials the Liberty systems level requirements, preliminary design, and certification process development.

"This agreement will provide the opportunity to look at the Liberty system to understand its design solution and risks, its capabilities and how it could be used to fly our NASA crew," said Ed Mango, NASA's Commercial Crew Program manager. The program is based at the agency's Kennedy Space Center in Florida. NASA will provide feedback to ATK based on its human spaceflight experience for advancing crew transportation system capabilities and the agency's draft human certification requirements.

"With this SAA we believe NASA will benefit from gaining insight into the various systems we are developing, and we can benefit from the feedback," said Kent Rominger, vice president, strategy and business development for ATK Aerospace. "In the end, we hope to offer a commercial solution to NASA, the Department of Defense, and other commercial human spaceflight programs."

The Liberty launch vehicle combines two of the world's most reliable propulsion systems. ATK is the prime, providing the human-rated five-segment solid rocket motor as the first stage, and Astrium (an EADS Company), is providing the core stage from the Ariane 5 rocket, including the Vulcain 2 engine as Liberty's upper stage. Liberty has the capability to lift 19,954 kilograms to low-Earth-orbit, the highest kilograms to orbit of any other vehicle currently working under commercial agreements.

Both of the Liberty propulsion systems were designed for human rating. The five-segment motor is derived from the Space Shuttle Reusable Solid Rocket Motors and the core stage for the Ariane 5 was originally slated to lift the Hermes spaceplane. The fact that its upper stage was designed to lift a winged vehicle gives Liberty additional capability. The current goal is to have a test launch in 2014, with a crewed flight on the vehicle's third flight in 2015.

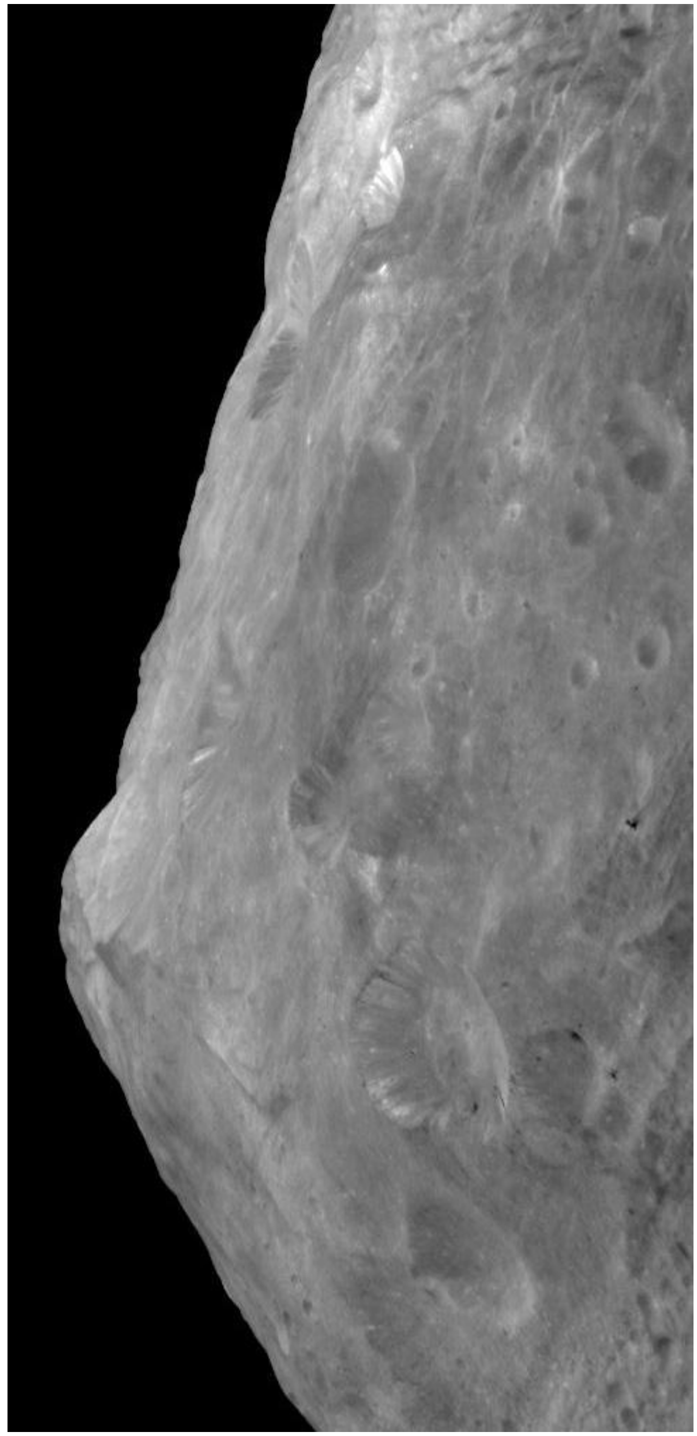
Dawn spacecraft begins new Vesta mapping orbit

The Dawn spacecraft has completed a gentle spiral into its new science orbit for an even closer view of the giant asteroid Vesta. Dawn began sending science data on 29 September from this new orbit, known as the high altitude mapping orbit (HAMO). In this orbit, the average distance from the spacecraft to the Vesta surface is 680 kilometres, which is four times closer than the previous survey orbit. The spacecraft will operate in the same basic manner as it did in the survey orbit. When Dawn is over Vesta's dayside, it will point its science instruments to the giant asteroid and acquire data, and when the spacecraft flies over the nightside, it will beam that data back to Earth.

Perhaps the most notable difference in the new orbit is the frequency with which Dawn circles Vesta. In survey orbit, it took Dawn three days to make its way around the asteroid. Now in HAMO, the spacecraft completes the same task in a little over 12 hours. HAMO is scheduled to last about 30 Earth days, during which Dawn will circle Vesta more than 60 times. For about 10 of those 30 days, Dawn will peer straight down at the exotic landscape below it during the dayside passages. For about 20 days, the spacecraft will view the surface at multiple angles. Scientists will combine the pictures to create topographic maps, revealing the heights of mountains, the depths of craters and the slopes of plains. This will help scientists understand the geological processes that shaped Vesta.

HAMO, the most complex and intensive science campaign at Vesta, has three primary goals: to map Vesta's illuminated surface in color, provide stereo data, and acquire visible and infrared mapping spectrometer data. In addition, it will allow improved measurements of Vesta's gravity.

Following a year at Vesta, the spacecraft will depart in July 2012 for Ceres, where it will arrive in 2015.



In this image of the south pole region of the asteroid Vesta, a mountain is rising approximately 15 kilometres above the floor of a crater (at left). This mountain, which measures about 200 kilometres in diameter at its base, is one of the highest elevations on all known bodies with solid surfaces in the solar system. (NASA/JPL-Caltech/UCLA/MPS/DLR/IDA)

Juno to unveil Jupiter's secrets

NASA's solar-powered Juno spacecraft lifted off on an Atlas 5 booster from Cape Canaveral Air Force Station in Florida at 9:25 a.m. PDT (12:25 p.m. EDT) on Friday 5 August to begin a long journey to Jupiter. Juno's detailed study of the largest planet in our solar system will help reveal Jupiter's origin and evolution. As the archetype of giant gas planets, Jupiter can help scientists understand the origin of our solar system and learn more about planetary systems around other stars.

Juno will take five years and 2,800 million kilometres to complete the journey to Jupiter. The spacecraft will orbit the planet's poles 33 times and use its collection of eight science instruments to probe beneath the gas giant's obscuring cloud cover to learn more about its origins, structure, atmosphere and magnetosphere, and look for a potential solid planetary core.

With four large moons and many smaller moons, Jupiter forms its own miniature solar system. Its composition resembles that of a star, and if it had been about 80 times more massive, the planet could have become a star instead. "Jupiter is the Rosetta Stone of our solar system," said Scott Bolton, Juno's principal investigator from the Southwest Research Institute in San Antonio. "It is by far the oldest planet, contains more material than all the other planets, asteroids and comets combined, and carries deep inside it the story of not only the solar system but of us. Juno is going there as our emissary -- to interpret what Jupiter has to say."

Juno's name comes from Greek and Roman mythology. The god Jupiter drew a veil of clouds around himself to hide his mischief, and his wife, the goddess Juno, was able to peer through the clouds and reveal Jupiter's true nature.

Why Juno?

Jupiter is by far the largest planet in the solar system. Humans have been studying it for hundreds of years, yet still many basic questions about the gas world remain. In 1995, NASA's Galileo mission made the voyage to Jupiter. One of its jobs was to drop a probe into Jupiter's atmosphere. The data returned from that probe showed us that Jupiter's composition was different than scientists thought, indicating that our theories of planetary formation were wrong.

Today, there remain major unanswered questions about this giant planet and the origins of our solar system hidden beneath the clouds and massive storms of Jupiter's upper atmosphere.

- How did Jupiter form?
- How much water or oxygen is in Jupiter?
- What is the structure inside Jupiter?
- Does Jupiter rotate as a solid body, or is the rotating interior made up of concentric cylinders?
- Is there a solid core, and if so, how large is it?
- How is its vast magnetic field generated?
- How are atmospheric features related to the movement of the deep interior?

- What are the physical processes that power the auroras?
- What do the poles look like?

Juno's primary goal is to reveal the story of the formation and evolution of the planet Jupiter. Using long-proven technologies on a spinning spacecraft placed in an elliptical polar orbit, Juno will observe Jupiter's gravity and magnetic fields, atmospheric dynamics and composition, and the coupling between the interior, atmosphere and magnetosphere that determines the planet's properties and drives its evolution. An understanding of the origin and evolution of Jupiter, as the archetype of giant planets, can provide the knowledge needed to help us understand the origin of our solar system and planetary systems around other stars.

Mission overview

Following launch, the Juno spacecraft is scheduled to use its main rocket motor twice (on 30 August 2011 and 3 September 2012) to modify its trajectory towards Jupiter. During cruise, there are also 13 planned trajectory correction maneuvers to refine its orbital path. An Earth flyby 26 months after launch will provide a boost of spacecraft velocity, placing it on a trajectory for Jupiter. The transit time to Jupiter following the Earth flyby is about three years, including the period of the initial capture orbit. The 30-minute orbit insertion burn will place Juno in orbit around Jupiter in early July 2016.

To accomplish its science objectives, Juno will orbit over Jupiter's poles and pass very close to the planet. Juno needs to get extremely close to Jupiter to make the very precise measurements the mission is after. This orbital path carries the spacecraft repeatedly through hazardous radiation belts, but avoids the most powerful radiation belts. Jupiter's radiation belts are analogous to Earth's Van Allen belts, but far more deadly.

The spacecraft will orbit Jupiter 33 times, skimming to within 5,000 kilometers above the planet's cloud tops every 11 days, for approximately one year.

The spacecraft

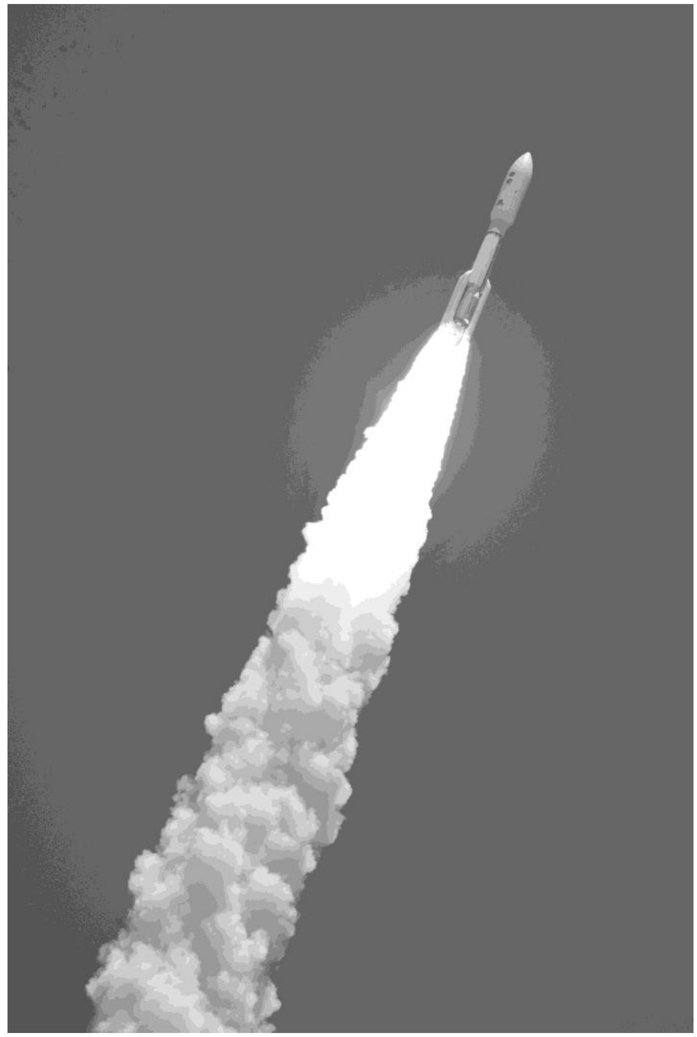
Juno uses a spinning, solar-powered spacecraft in a highly elliptical polar orbit that avoids most of Jupiter's high-radiation regions. The designs of the individual instruments are straightforward and the mission did not require the development of any new technologies.

For Juno, like NASA's earlier Pioneer spacecraft, spinning makes the spacecraft's pointing extremely stable and easy to control. Just after launch, and before its solar arrays are deployed, Juno will be spun-up by rocket motors on its still-attached second-stage rocket booster. Juno's planned spin rate varies during the mission: 1 RPM for cruise, 2 RPM for science operations and 5 RPM for main engine manoeuvres.

To simplify and decrease weight, all instruments are fixed. While in orbit at Jupiter, the spinning spacecraft will sweep the fields of view of its instruments through space once for each rotation. At two rotations per minute, the instruments' fields of view sweep across Jupiter about 400 times in the two hours it takes Juno to fly from pole to pole.

The spacecraft's main body measures 3.5 metres tall and 3.5 metres in diameter. The spacecraft's hexagonal two-deck structure uses composite panel and clip construction for decks, central cylinder and gusset panels. Polar mounted off-center spherical tanks provide spinning spacecraft designs with high stability.

For weight savings and redundancy, Juno uses a dual-mode propulsion subsystem, with a bi-propellant main engine and mono-propellant reaction control system thrusters. The Leros-1b main engine is a 645-Newton bi-propellant thruster using hydrazine–nitrogen tetroxide. Its engine bell is enclosed in a micrometeoroid shield that opens for engine burns. The engine is fixed to the spacecraft body firing aft and is used for major maneuvers and flushing burns.



Launch of Juno atop an Atlas 5 booster from Cape Canaveral Air Force Station in Florida at 9:25 a.m. PDT (12:25 p.m. EDT) on Friday 5 August 2011 (NASA)

To protect sensitive spacecraft electronics, Juno will carry the first-of-its-kind radiation shielded electronics vault, a critical feature for enabling sustained exploration in such a heavy radiation environment. Each of the titanium cube's eight sides measures nearly a square metre in area, about 1 centimetre in thickness, and 18 kilograms in mass. This titanium box — about the size of an SUV's trunk — encloses Juno's command and data handling box (the spacecraft's brain), power and data distribution unit (its heart) and about 20 other electronic assemblies. The whole vault weighs about 200 kilograms.

Solar Power

Jupiter's orbit is five times farther from the sun than Earth's, so the giant planet receives 25 times less sunlight than Earth. Juno will be the first solar-powered spacecraft designed to operate at such a great distance from the sun, thus the surface area of solar panels required to generate adequate power is quite large. Power generation is provided by three solar arrays consisting of 11 solar panels and one magnetometer boom. Two 55 amp-hour lithium-ion batteries provide power when Juno is off-sun or in eclipse, and are tolerant of the Jupiter radiation environment. The power modes during science orbits are sized for either data collection during an orbit emphasizing microwave radiometry or gravity science.

Juno benefits from advances in solar cell design with modern cells that are 50 percent more efficient and radiation-tolerant than silicon cells available for space missions 20 years ago. The mission's power needs are modest. Juno has energy-efficient science instruments. Solar power is possible on Juno due to the energy-efficient instruments and spacecraft, a mission design that can avoid Jupiter's shadow and a polar orbit that minimizes the total radiation.

The spacecraft's three solar panels extend outward from Juno's hexagonal body, giving the overall spacecraft a span of more than 20 metres. The solar panels will remain in sunlight continuously from launch through end of mission, except for a few minutes during the Earth flyby.

Juno science

The Juno spacecraft carries a payload of 29 sensors, which feed data to nine onboard instruments. Eight of these instruments (MAG, MWR, Gravity Science, Waves, JEDI, JADE, UVS, JIRAM) are considered the science payload. One instrument, JunoCam, is aboard to generate images for education and public outreach.

Primary science observations are obtained within three hours of closest approach to Jupiter, although calibrations, occasional remote sensing and magnetospheric science observations are planned throughout the science orbits around Jupiter.

Juno is spin-stabilized. Because of the spacecraft mission design and the fact that its science instruments were all developed together, and there is no need for a scan platform to point instruments in different directions. Gravity science and microwave sounding of the atmosphere observations are obtained through orientation of the spacecraft's spin plane. All other experiments utilize ride-along pointing and work in either one or both orientations. This design allows for very simple operations.

The science instruments

Gravity Science – The Gravity Science experiment will enable Juno to measure Jupiter's gravitational field and reveal the planet's internal structure.

Magnetometer (MAG) – Juno's Magnetometer will create a detailed three-dimensional map of Jupiter's magnetic field.

Microwave Radiometer (MWR) – Juno's Microwave Radiometer instrument will probe beneath Jupiter's cloud tops to provide data on the structure, movement and chemical composition to a depth as great as 1,000 atmospheres, about 550 kilometers below the visible cloud tops.

Jupiter Energetic Particle Detector Instrument (JEDI) – The Jupiter Energetic Particle Detector Instrument will measure the energetic particles that stream through space and study how they interact with Jupiter's magnetic field.

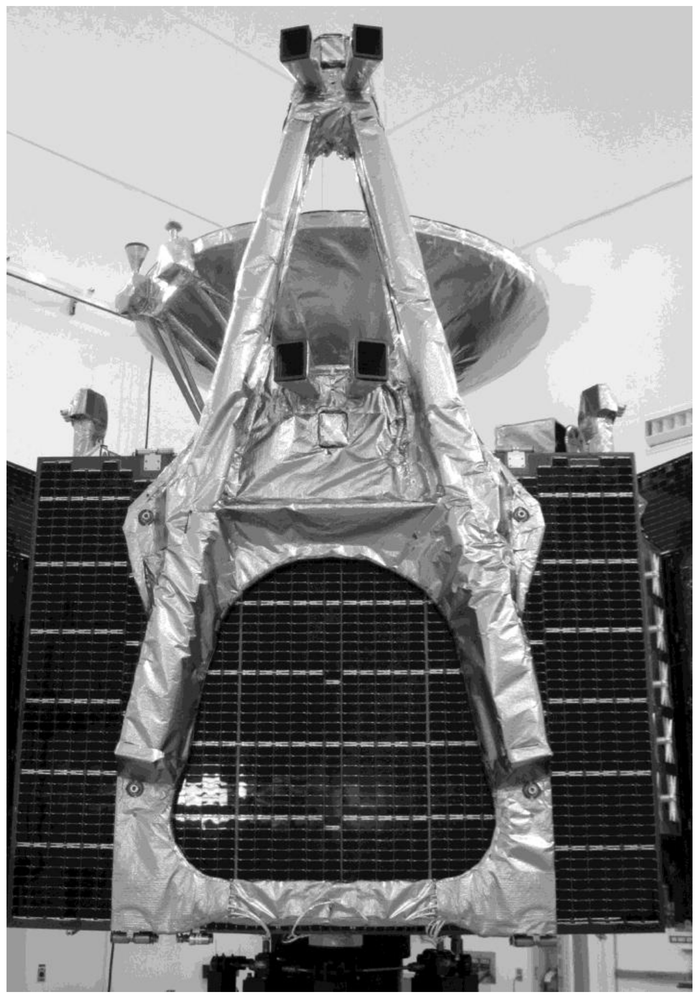
Jovian Auroral Distributions Experiment (JADE) – The Jovian Auroral Distributions Experiment will work with some of Juno's other instruments to identify the particles and processes that produce Jupiter's stunning auroras.

Waves – The Waves instrument will measure radio and plasma waves in Jupiter's magnetosphere, helping us understand the interactions between the magnetic field, the atmosphere and the magnetosphere.

Ultraviolet Imaging Spectrograph (UVS) – The Ultraviolet Imaging Spectrograph will take pictures of Jupiter's auroras in ultraviolet light. Working with Juno's JADE and JEDI instruments, which measure the particles that create the auroras, UVS will help us understand the relationship between the auroras, the streaming particles that create them and the magnetosphere as a whole.

Jovian Infrared Auroral Mapper (JIRAM) – The Jovian Infrared Auroral Mapper will study Jupiter's atmosphere in and around the auroras, helping us learn more about the interactions between the auroras, the magnetic field and the magnetosphere. JIRAM will be able to probe the atmosphere down to 50 to 70 kilometers below the cloud tops, where the pressure is five to seven times greater than on Earth at sea level.

JunoCam – JunoCam will capture color pictures of Jupiter's cloud tops in visible light. JunoCam is designed as an outreach full-color camera to engage the public. The public will be involved in developing the images from raw pixels.



The Juno spacecraft, folded up and awaiting encapsulation in the rocket fairing. The 3.9-metre-long magnetometer boom, wrapped in bright thermal blankets, is in the foreground atop a stack of folded solar arrays. One of the twin magnetometers is mounted in the middle of the boom, and the other is mounted at the outermost end. Next to each magnetometer sensor is a pair of rectangular hoods, or light baffles, peeking out from under the thermal blankets; these define the fields of view for the two star cameras, which determine the orientation of each magnetometer sensor with great accuracy. (NASA/JPL/LMSS)

The Space Shuttle in retrospect

By David Maclennan

Space Shuttle Endeavour approaching the International Space Station (NASA)

When Space Shuttle Atlantis rolled to its final stop at the end of the STS-135 mission, it marked the last gasp of the impetus that had driven the US human space flight programme since its inception at the end of the 1950s. The Shuttle programme, like the Mercury, Gemini and Apollo programmes that preceded it, was a product of the Cold War and the competition between the US and the then-Soviet Union to be pre-eminent in space, and on Earth.

An overly pessimistic editorial in 2 July 2011 issue of The Economist claimed that the end of the Shuttle programme represents the end of the Space Age. This is a gross exaggeration, of course. However, it is certainly the end of the era that began in May 1961, with Alan Shepard's brief suborbital hop aboard the first Mercury craft and which peaked in July 1969 with the triumph of Apollo 11's Moon landing.

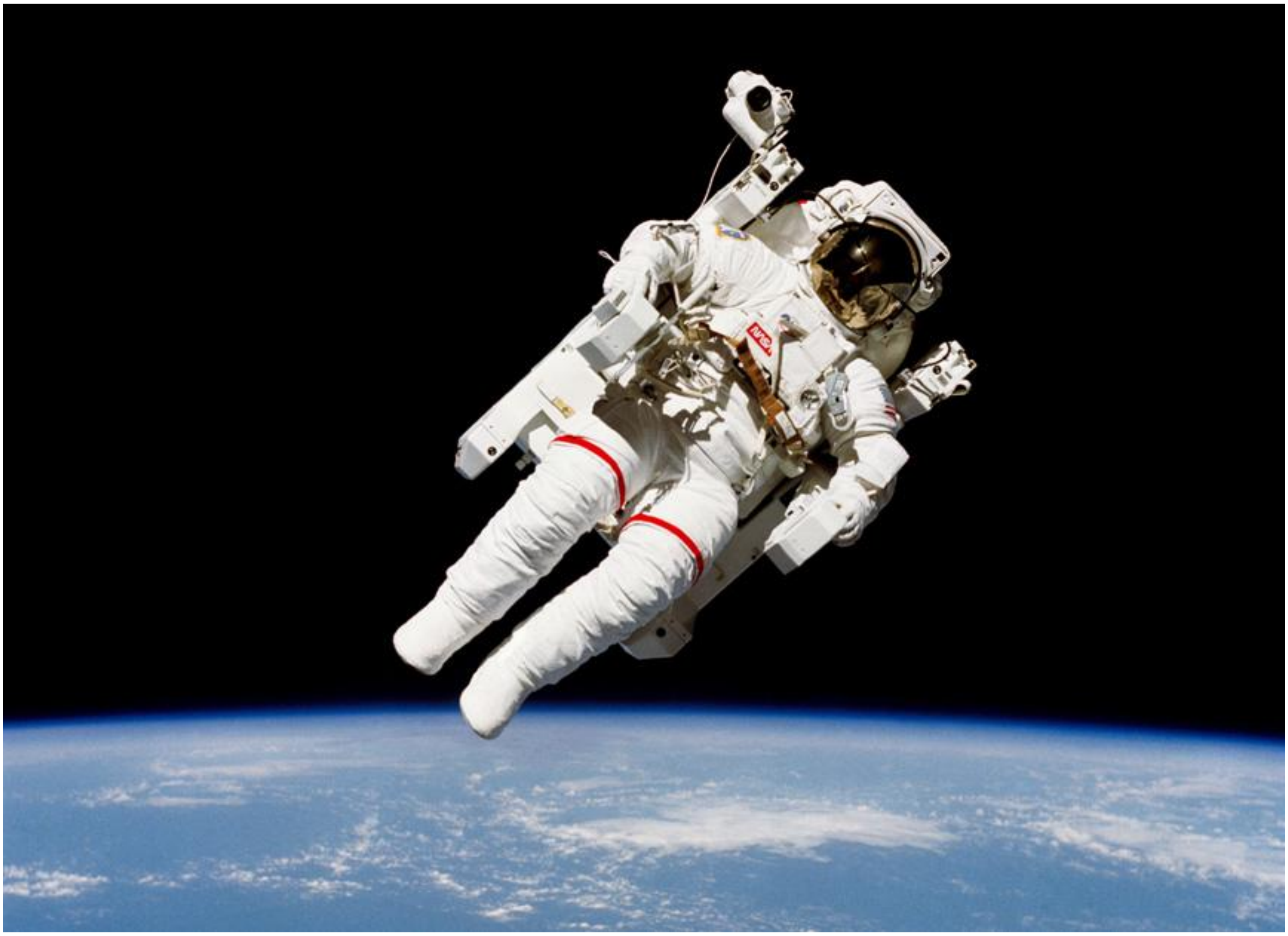
Following the end of the Shuttle era, the future of US human space flight is in a state of flux. It will likely be at least five years before the US once again has the means to launch its own people into orbit. Several private-sector companies are developing vehicles to carry astronauts, including old hands such as Boeing with their Apollo-like CST-100, and several "NewSpace" entrepreneurial companies such as SpaceX and Sierra Nevada. NASA, too, is continuing with development of the Orion spacecraft (which they now refer to as the Multi-purpose Crew Vehicle, or MPCV), with the aim of using it as a deep-space exploration vehicle to once again go beyond low Earth orbit. However, the Obama administration has set no firm goal for NASA's exploration efforts beyond vague talk of a mission to an asteroid and – eventually – a mission to Mars. Lacking such a firm goal, development and utilization of Orion, and the heavy-lift rocket that will also be essential to future exploration efforts, could well be stretched out indefinitely, given the US's current financial woes.

It is probably too soon to fully assess the Shuttle's place in the history of humanity's journey into space. Doubtless there will be many books and articles on this subject in the years ahead. The article you are about to read is this writer's own preliminary take on the impact of the Shuttle which, for better or worse, has defined human space activity (at least in the US) for the past four decades. – DM

In the beginning…

Plans for a reusable spacecraft began to gel around the time of NASA's greatest triumph, the first lunar landing in 1969. The idea was not new: the famous early-1950s series of articles in Colliers magazine by Wernher von Braun and Willy Ley featured winged, reusable spacecraft in the spectacular illustrations by Chesley Bonestell.

In September 1969 the Space Task Group (STG), a blue-ribbon panel set up to present options for a post-Apollo space programme, laid out a series of options, the most grandiose of which envisaged a human mission to Mars in the 1980s, along with a space station and a reusable space shuttlecraft. The STG's timing wasn't good: with the Vietnam war in full swing, there was little public appetite for another grandiose space programme straight after Apollo, and in any case the Nixon administration had no money to spend on such an effort. So out went Mars and a space station, leaving just a shuttle with nothing to shuttle to.



One of the iconic images of the Shuttle era: STS 41-B astronaut Bruce McCandless floats untethered in space in February 1984 during the first test of the Manned Maneuvering Unit (NASA)

But what sort of shuttle was it going to be? NASA originally envisaged a two-stage vehicle, with a straight-winged orbiter launched atop a huge crewed fly-back booster. NASA's plans received support from the US Air Force, which had abandoned its own plans for military human space missions. However, its support was contingent on NASA modifying its design to meet Air Force requirements, which basically meant being able to launch a heavy load into a polar orbit, and a cargo bay just over 18 metres long in order to accommodate its large spy satellites. It also required a vehicle that could launch from California and return to the launch site in a single orbit, meaning a cross-track capability of just over 2,000 kilometres. Together, these requirements drove the size and double-delta wing planform of the final design.

NASA's initial grand two-stage design had an estimated cost of around US$13 billion. However, the Office of Management and Budget (OMB) decreed they had to do it for US$5.5 billion. Out went the big reusable booster, and, after numerous iterations, in came the "stage and a half" configuration of twin reusable boosters and a large throwaway fuel tank, to which the orbiter would be attached. NASA was still looking at liquid-fuel boosters, but with a price tag of up to US$1.4 billion versus an expected US$350 million for solid-fuel boosters, the choice was a foregone conclusion if they wanted to stay within the budget cap.

The choice of solid-fuel boosters for a crewed spacecraft was highly controversial because unlike liquid-fuel boosters, solid-fuel rockets cannot be shut down once ignited. This wasn't the only engineering compromise that would come back to bite NASA hard in the years ahead.

In January 1972, the decision to proceed with the Space Shuttle we know today was announced by the White House, and funding was approved by Congress in April as the man who would fly the first Shuttle into orbit, John Young, was working on the Moon as commander of Apollo 16.

And just as the final Shuttle design was shaped by budgetary limitations, four decades later its eventual successor is facing similar issues.

Developing the Shuttle

NASA exhibited considerable hubris as it launched into developing the Shuttle. After all, the agency had put men on the Moon from a standing start in just eight years, so developing a vehicle that looked something like an aeroplane shouldn't be that difficult.

But difficult it was, and despite the brilliance of its engineers NASA underestimated just how difficult – and the finished product never quite lived up to its expectations.

For a start, NASA's flight-rate estimates proved wildly optimistic. President Nixon had been sold the Shuttle on the promise of a flight a week, equating to 580 flights during the 1979-1990 timeframe (compare that to the 135 flights it eventually flew in 30 years of operations). Later, NASA upped the estimate to 6o flights a year. In actuality, the most flights ever flown in a 12-month period was nine (1985-86) – and then

The Russian Mir space station flies above New Zealand in this view from Shuttle Atlantis during the STS-79 mission in 1996, which was docked with the station (NASA)

the system broke, killing seven astronauts in the *Challenger* disaster.

Another promise made was that the Shuttle would replace all existing expendable launchers such as the Atlas, Delta and Titan vehicles. By January 1986 the production lines for these vehicles had all but ceased (when I visited General Dynamics' Atlas plant in October 1985, only two vehicles were left on the production line). But the *Challenger* disaster proved the folly of putting all your eggs (or satellites) in one basket, and the production lines for the expendable rockets restarted, and new versions developed, largely at the Air Force's behest.

One of the real challenges in developing the Shuttle lay with the main engines. Unlike earlier engines, such as those that powered the Saturn rockets, the Space Shuttle Main Engines (SSMEs) were to be reused for many flights. The SSMEs quickly became the pacing item in Shuttle development. The SSME was a remarkable machine: a precision piece of engineering that in its day was for its size was the most powerful rocket engine yet developed. Weighing just under 5,000 kilograms, the SSME developed over 170,000 kilograms of thrust at sea level. To get the fuel into this hungry beast, turbopumps whirred at 23,700 rpm.

But getting there took time. Engines or turbopumps exploded in the early days, and there were 726 hot-fire tests totaling 110,253 seconds before the first Shuttle flew. The first Shuttle was to have flown in 1979, but it was not until December of that year that the first full-duration firing of three engines together in a test stand was successfully achieved. It was generally accepted that if there was ever a catastrophic launch failure of a Shuttle, an SSME would be the culprit because of its complexity and the high pressures it operated under. It is a testament to the NASA and Rocketdyne engineers that, apart from the premature shutdown of one engine late in the 1985 launch of STS 51-F, an SSME never failed to do its job.

STS-49, May 1992: the first three-astronaut EVA saw the crew of Shuttle Endeavour's maiden voyage repairing a faulty Intelsat satellite (NASA)

Another big challenge was thermal protection. Earlier one-shot spacecraft such as Apollo employed ablative heat shields that melted away during re-entry, taking the heat with it. But the

Shuttle needed a reusable thermal protection system, and this led to the development of the familiar silica tiles that covered most of the Shuttle orbiters. Each orbiter required over 24,000 of these, each one unique, and all installed by hand. When the first Shuttle orbiter, *Columbia*, was delivered from California to Florida atop the converted Boeing 747 carrier plane, many tiles fell off during the cross-country flight, sending NASA back to the drawing board to revise the tile bonding procedures, further delaying the first launch.

An "operational" vehicle?

In another display of post-Apollo hubris, NASA decided that the shuttle would carry a crew on its very first launch, something unprecedented in human space flight. All previous crewed spacecraft, US and Russian, had undergone a number of unpiloted flight tests before carrying a crew. But the Shuttle, it was felt, was far too complicated a vehicle to fly uncrewed. There had been a series of approach and landing tests during 977 using the first orbiter, *Enterprise*, which was launched from the back of the 747 carrier aircraft, but these were crewed, and only tested the final phase of the mission, the steep glide to a landing.

In 1988 the Soviet Union successfully conducted the first flight of its copycat shuttle, Buran, unscrewed, but depite its superior technology, NASA evidently felt that such a feat was beyond them.

As it turned out, the first Shuttle flight, STS-1 in April 1981, (which, thanks to a two-day launch delay, coincided with the 20th anniversary of Yuri Gagarin's epic flight), was a resounding success, and performance generally matched expectations, though engineers were disturbed to see that a number of the thermal protection tiles had come off near *Columbia*'s tail and a number of others were damaged. Post-flight, expectations were high that the Shuttle would live up to its promise of becoming an all-purpose "space truck", capable of carrying military and civilian payloads, servicing broken-down satellites, or even returning them to Earth.

Three additional flights of *Columbia* during 1981-82 comprised the Orbital Flight Test programme, after which, in a much ballyhooed ceremony at NASA's Dryden centre in California, President Reagan declared the Shuttle system "operational".

In fact, the Shuttle was far from operational, and in fact never was an "operational" space vehicle, even after 135 flights. There has never been anything routine about Shuttle operations, and throughout its life it proved to be a highly complex vehicle that required a small standing army of engineers and technicians to keep flying. Very few Shuttle missions met their original launch dates thanks to technical or weather issues cropping up, sometimes in the last seconds before launch.

One of the Shuttle's major design deficiencies was the lack of an escape system for the crew, unlike all previous US spacecraft. The first four test flights had ejection seats for the two crewmembers, but these would not have been much use above about 30,500 metres. The ejection seats were removed after the early flights to make room for more crewmembers, who would be accommodated on two decks. NASA had once considered an ejectable crew cabin, but the limited budget did not allow for this. Whether such a cabin would have saved the *Challenger* and *Columbia* crews, however, is debatable.

Extending the envelope

Once it was declared "operational", and once additional orbiters (*Challenger, Discovery* and *Atlantis*) joined the fleet, the capabilities of the Shuttle were gradually extended. The two years leading up to the *Challenger* disaster were exciting times for Shuttle watchers, as NASA deployed and repaired satellites, carried out research missions, and began flying the European Space Agency's modular Spacelab laboratories in the cargo bay, which helped pave the way for today's International Space Station (then envisaged a US-only effort named *Freedom*).

One piece of Shuttle hardware quickly proved its worth: the Canadian-supplied Remote Manipulator System (RMS), or Canadarm. First flown on STS-2 in November 1981, the robot arm has been invaluable in deploying and retrieving satellites and in moving astronauts to work stations on such craft as the Hubble Space Telescope and the International Space Station (which also has its own similar robot arm that can be moved to different points outside the station). The 15.3-metre shuttle RMS weights less than 453 kilograms, yet can handle loads of up to 265,751 kilograms (upgraded from only 29,477 kilograms when first flown). The RMS has been essential in the construction and ongoing maintenance of the ISS.

Another piece of kit used to spectacular effect in 1984 was the Manned Maneuvering Unit (MMU). Under development since the early 1970s (an early prototype was tested inside Skylab), the MMU made its debut in February 1984 under the controls of astronaut Bruce McCandless, who was closely involved in its development. The image of McCandless floating free in space, with no umbilical connecting him to the spacecraft as on all previous orbital spacewalks, is one of the iconic images of the whole Shuttle programme. The MMU was used again in April 1984 during the retrieval and repair of the Solar Max satellite, but in the end the RMS proved more useful in snaring the craft. In November of that year the MMU was used for the last time to retrieve two communications satellites that had ended up in the wrong orbit after launch from the Shuttle the previous February. (The failure was no fault of the Shuttle, it should be added, but of the upper-stage PAM-D solid-fuel motors.) The satellites were returned to Earth for refurbishment and subsequent re-launch – on expendable rockets.

The bulky MMU was never used again, but a smaller jetpack named SAFER has been used on Shuttle and ISS spacewalks for some years as insurance lest an astronaut come adrift while outside.

Another satellite repair mission occurred in 1985, but NASA would not return to the satellite rescue business again until May 1992 when a large Intelsat communications satellite was captured, repaired and redeployed from the Shuttle *Endeavour* on its maiden flight – a feat that required an unprecedented three-person spacewalk to achieve.

The pre-*Challenger* disaster "golden age" of 1983-85 also saw tests of space station construction techniques (STS 61-B, November 1985) and the first flights of ESA's Spacelab laboratory, which first flew on the ninth Shuttle flight at the end of November 1983, a flight that also carried ESA's first astronaut, Ulf Merbold, into orbit. Spacelab consisted of two main elements: a pressurized laboratory module, and U-shaped pallets for mounting external payloads. Spacelab missions could comprise the lab module only, pallets only, or a combination of these elements. Spacelab missions would continue into the 1990s and were a valuable precursor to today's ISS operations. As well as ESA-sponsored Spacelab flights there were others sponsored by Germany, Japan and the US.

Another thing that characterized some Shuttle flights in this period was the carrying of non-astronaut passengers. These included a couple of US politicians, an Arabian prince, and representatives of countries or companies that NASA was launching payloads for. With a couple of notable exceptions, these junkets came to an end after the *Challenger* disaster.

The military dimension

The US Defense Department was NASA's biggest customer for Shuttle flights, having block-booked nine missions for a bargain price in 1982. Military Shuttle missions contrasted sharply with civilian missions. The launch time was not announced until minutes before liftoff, and there was no public air-to-ground voice or TV transmissions. The nature of the payloads were also secret, and no post-flight mission photos were released. (Some years later a limited number were released, but only those that showed crewmembers engaged in non-payload-related activities.)

The first military Shuttle flight, STS 51-C, launched in January 1985 carrying a classified payload named Magnum. A second flight later in the year (the maiden flight for the orbiter *Atlantis*) deployed two military communications satellites.

The US Air Force built a Shuttle launch pad at Vandenberg Air Force Base in California, the launch site for most Defense Department missions because of the ability to launch into polar orbit from there. Known as Space Launch Complex 6 ("Slick Six"), the pad only hosted one Shuttle when the orbiter Enterprise was mated to a set of dummy boosters and external tank to test facilities and procedures. SLC-6 was due to launch its first Shuttle in July 1986, but this was cancelled in the wake of the *Challenger* disaster.

In truth, the Defense Department was never entirely comfortable with using the Shuttle. Part of this was due to the inevitable glare of publicity surrounding crewed missions, but there were other factors. When the fast launch rate NASA promised failed to materialize, payloads began to stack up at the Kennedy Space Center. Also, some Defense officials were uneasy about the policy (decreed by the Carter administration in 1978) of having the Shuttle as the sole US launch system. The US Air Force decided in 1983 to keep building expendable rockets as a backup, a move that NASA strongly opposed, but which would ultimately prove prescient in the wake of *Challenger*. There were several post-*Challenger* military Shuttle missions, but where possible payloads were moved to expendables such as the big Titan boosters.

Challenger* and *Columbia

To a casual observer, the string of spectacular Shuttle missions up to the end of 1985 did seem to herald a new "golden age" for human spaceflight. But any thoughts of Shuttle operations becoming "routine" came crashing down to Earth with the rain of debris and bodies (including Teacher-In-Space Christa McAuliffe) from the destroyed orbiter *Challenger* on 28 January 1986.

As the post-accident investigation unfolded over the course of the next few months it became very clear that the disaster could have been avoided. It wasn't just a "major malfunction" of the Shuttle vehicle but of the whole NASA engineering and management culture. O-ring anomalies, including the blow-by of exhaust gases, had been noted on a number of earlier flights, but the problem was not corrected, leading to a "normalization of deviance", in the words of sociologist Diane Vaughn in her landmark book *The Challenger Launch Decision*.

The booster joints were redesigned and other safety features incorporated into the Shuttle before flights resumed in September 1988. There were some new ground rules around Shuttle operations, however: Congress mandated that the Shuttle only be used for missions that required a human presence or the unique capabilities of the vehicle (such as assembling a space station). The Defense Department went back to using expendable rockets (apart from a couple of payloads that were specifically designed to be flown on the Shuttle), and the almost-complete SLC-6 at Vandenberg was

A highlight of the Shuttle programme was the first Hubble Space Telescope repair mission in December 1993, which saw five days of back-to-back EVAs to restore the telescope to full working order (NASA)

mothballed. Commercial payloads were also out, as were joyrides for non-astronauts. Shuttle missions through the 1990s leaned more towards scientific research (e.g. Spacelab missions) and launching iconic payloads such as Galileo and the Hubble Space Telescope.

But on 1 February 2003 disaster struck again when the oldest orbiter, *Columbia*, disintegrated during re-entry following a one-off 16-day scientific mission (STS-107). A large piece of foam came loose from the external tank just after launch, striking the leading edge of the left wing. The impact was sufficient to either crack or punch a hole in the reinforced carbon-carbon panels that bore the brunt of re-entry heating, allowing hot gases to enter the wing and melt the structure behind it.

Had the Shuttle Mission Management Team approved a request to have a spy satellite image the wing the problem may have been spotted and an Apollo 13-scale rescue effort undertaken. The accident investigation revealed that there had been numerous incidents of foam shedding on Shuttle launches, but that nothing had been done about it: once again, the "normalization of deviance" had cost the lives of seven astronauts. The lessons of *Challenger* had not been fully learned.

International cooperation

By the time of the *Columbia* disaster, the Shuttle's principal job was to assemble the International Space Station. (*Columbia* couldn't be used for this as it could not carry the same payload weight as the later, lighter orbiters, hence its use for the ill-fated STS-107.) The ISS grew out of the cancelled space station *Freedom* project, and brought former rivals Russia into the picture, joining a consortium that already included the US, Europe, Japan and Canada.

The European Space Agency was already deeply involved in the Shuttle programme through the Spacelab effort. The Spacelab hardware was built in Europe and essentially gifted to the US in return for access to space by its own astronaut researchers. Twenty-five Spacelab missions were flown prior to ISS construction commencing, but it is highly debatable whether or not Europe actually got its money's worth out of the deal: total cost to Europe eventually amounted to US$559.1 million. But as a precursor to European involvement in ISS, Spacelab was essential.

Shuttle *Atlantis* paved the way for ISS when it docked with the Russian space station Mir during the STS-71 mission in 1995, the first of ten Shuttle flights to Mir that gave US astronauts their first experience of long-duration spaceflight since Skylab in 1973-74, seven astronauts accumulating a total of 907 days aboard Mir.

Construction of the ISS proper began in late 1998 with the launch (by Russia) or the Zarya module, followed shortly after by the first US element. Construction of ISS was finally competed this year (though Russia has two more small modules it plans to launch to the station in the coming years), and the finished station is very much an international effort, with laboratory modules from the US, Europe, Japan and Russia comprising the core of the huge vehicle, with crewmembers drawn from the participating nations. ISS operations were recently extended to at least 2020.

Working outside

Most of the heavy-lifting and construction work for the ISS has been carried out by Shuttle crews, and this activity has considerably expanded the envelope for extravehicular activity, or spacewalking. Over 150 spacewalks totaling nearly 1,000 hours were required, all of them very demanding – some more demanding than others, such as Scott Parazynski's repair of an ISS solar panel that had torn during redeployment. On that November 2007 spacewalk, Parazynski was riding on an extra-long robot arm comprising the station's own arm coupled with the 15-metre boom used to inspect the underside of the Shuttle while in orbit. Parazynski managed to repair the damaged array, allowing it to be fully extended.

The first Shuttle-based EVA was on *Challenger*'s maiden flight, STS-6, in April 1983, but it was the first Hubble Space Telescope repair mission in December 1993 (STS-61) that proved to be something of a turning point in Shuttle-based EVA activity. Five days of back-to-back spacewalks restored Hubble to full operation, and gave NASA the confidence to carry out the type of assembly work required to build the ISS.

The Shuttle's legacy

Thirty years – 40 if you include the decade it took to develop and build it – 135 flights (including two disastrous failures), and some US$209 billion dollars… In the final analysis, was the Shuttle worth it?

If you measure against the goals and targets originally set for the Shuttle system (which in hindsight were wildly over-optimistic), it has to be judged a failure. It simply did not live up to its original expectations. Had the US continued down the exploration road, that US$209 billion could have bought a permanent base on the Moon and humans might have been on Mars by now, or be very close to going there.

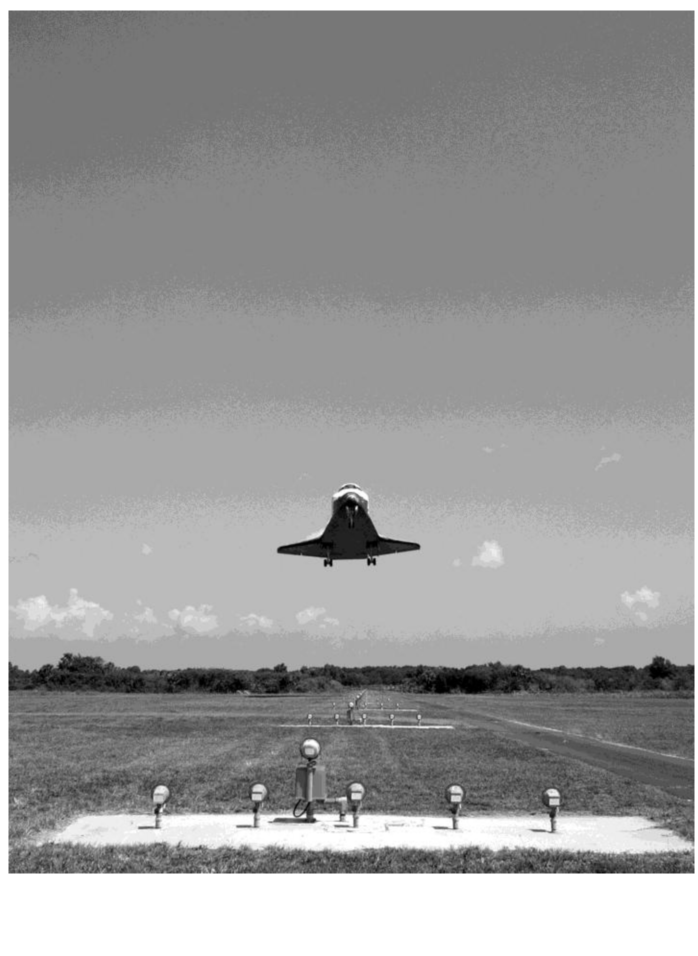
Instead, for the past three decades we've been boring a hole in Earth orbit and not really going anywhere, all at a cost of about US$1.6 billion a flight. And we're no closer to sending humans to Mars than we were at the end of Apollo.

Some of the fault for the Shuttle not living up to the original hype lies in the compromises that were made in the system's design to accommodate the conflicting needs of its potential users. The Shuttle was billed as being all things to all potential users, be they civilian, military or commercial, but the design was not optimised for any of those groups.

On the other hand, the Shuttle programme has also achieved a lot. It has significantly advanced space technology development, and if it didn't quite make space travel routine (which is something it will never be really), it has greatly enhanced human capabilities in space. Where once we visited space for a week or two at a time, we now have a permanent human presence in Earth orbit, thanks in no small part to the Shuttle's capabilities. The International Space Station could not have been built without the Shuttle, and the Hubble Space Telescope would have expired years ago as its systems gave out, denying us many significant astronomical discoveries.

In judging the Shuttle's worth, history's final verdict will probably lie somewhere between these two extremes.

And the Shuttle's legacy will live on, as NASA's next big rocket, the Space Launch System (can we please just go back to calling it Ares?) will utilise much Shuttle hardware, including the main engines and solid rocket boosters, and the first stage structure will be built using the same jigs used for the Shuttle external tank.



The last Shuttle launch

- An eyewitness account

By Matthew and Maree Pavletich

Matt in front of the launch pad – the banner says it all!

As these things go, it was a fairly last-minute decision by my wife Maree and I to go to Kennedy Space Center, Florida to see the final launch of the Space Shuttle. Back in January of this year I hatched the plan to book accommodation at a Titusville hotel to ensure we at least had somewhere to stay. This was relatively straightforward but it was a gamble: STS-135 had not as yet become an 'official' Space Shuttle mission. STS-134, commanded by Mark Kelly with Shuttle '*Endeavour*' was still the official last mission.

I made the booking at the Days Inn, Titusville, hoping that the crew of the Shuttle launch-on-need mission would get to fly. Eventually, the mission was confirmed. However, launch date changed not once, but twice! In fact, if I hadn't been up very late one night with a stomach bug, I would never had gone online at 3:30am to have a sleepy browse and see what was to become *Atlantis*'s final launch date: 8 July 2011. I swiftly got onto the hotel's website and changed our booking. I was later told that if I had not been awake so early that morning and changed the booking, I would have missed out on a room, the demand was *that* high!

Secure in the knowledge that I had our room sorted out, I then made arrangements to update my passport and obtain non-immigrant visas for both Maree and I. We did this on good advice from Mark MacKay, as he had needed to do the same for his attendance of STS-134. Also, anyone pursuing press accreditation from NASA needed the visas. I also contacted the producer for Mike Hosking's breakfast show on Newstalk ZB, asking for a letter of reference and permission to identify ourselves as Newstalk ZB affiliates. I had done many interviews over the last few years with them. The reason I contacted them was purely a hunch, an instinct. It was to prove very valuable as I shall later explain.

We obtained our visas, booked our flights and other accomodation, filled out our press accreditation applications online then settled down for the relatively long weeks to wait. In the meantime, I struck upon the idea to get in the KSC launch ticket lottery, to have as a backup should we be refused access to KSC for any reason. The ticket lottery would – all going well - give you the chance to purchase tickets to view the launch from one of the several relatively close places near KSC. And while I waited to hear back about the ticket lottery, I started gnawing my fingernails. It was hard waiting for a yea-or-nay from the KSC media office to see if we had been granted press accreditation for the NZSA. And then, less than a week from our departure, we received the news that we had been declined the opportunity to purchase KSC-vicinity viewing tickets.

With still no word from the KSC media office, I contacted our good old mate, Dr Jack Bacon, to see if he had any suggestions. He put me in contact with his friend, Ron Caswell. Ron was a former ISS Module and Equipment Launch Integration Manager, who had worked for NASA up until the ISS Assembly had ended. He and his wife Judy lived in nice apartment block overlooking the Banana River, with a clear view of the VAB and most of the launch pads! Ron and Judy said they would be glad to include us in their 'launch party' should KSC refuse us access.

Maree and I flew out on 2 July, still having heard nothing from the KSC media office. I wasn't overly concerned, as I figured they were likely very busy with this, the final Shuttle mission. This would turn out to be an understatement. Our flight

Chillin' in the Press Center…

was about 90 minutes late leaving Auckland because Qantas baggage handlers had started loading another plane's luggage onto ours! This little screw-up meant that we missed our direct connecting flight from Los Angeles to Orlando, Florida. American Airlines helpfully put us onto the next plane they could, but it meant having to wait for several hours both in LA and then Dallas Fort Worth. We finally arrived at our Hotel in Orlando on the evening of 3 July, tired and somewhat grumpy by this point. We had been awake for a day and a half. But after a good night's sleep, we took in the sights of Universal Studios Florida. This was because our Titusville Hotel couldn't take us any earlier than the morning of 5 July which is when we dutifully turned up, driving our rental car down to there.

The next morning we made our way to the KSC Media Affairs Badging Station, only to find that our Media Accreditation for the New Zealand Spaceflight Association had been declined! My mind in a whirl of disappointment, I politely asked NASA Media Officer Laurel Lichtenberger why. Her reply was a bit vague but went something along the lines that after 9/11 and STS-114's Return To Flight, only recognized, professional media organisations from around the world were to be granted access to KSC for launches and to JSC for mission coverage: no special interest groups and foreign 'educational publications'. I explained that the NZSA and myself had been to KSC a couple times before, but this cut no ice – it was too far in the past and times had changed. But Laurel then helpfully told me to re-apply online again for a 'Late Badging Request' – the only way you can these days – and to perhaps use a different organisation for reference and accreditation. Maree and I rushed back to our hotel room and turned on the laptop.

Then, armed with a letter of reference from Newstalk ZB and permission to use it, I reapplied two days out from launch. Since the online process did not allow documents to be attached, I had to send the reference letter as an attachment in a regular e-mail to Laurel. We then waited to see what would happen, also checking in with Ron Caswell to see if his kind offer was still good. Of course, it graciously was.

But by 7:00am the very next morning, our new applications came back approved! Maree and I were practically fizzing with excitement now and we wasted no time getting down to the badging office to pick up our precious STS-135 Media Accreditation badges and lanyards. Along the way, we met a lovely bloke named Brett Houston who had been writing space and science articles for a small town newspaper for years. He told us that his trip was very last minute and therefore he had not had time to arrange rental transport. He became our guide that afternoon and we came to value his experience on and off in the days to come.

The three of us proudly proceeded to enter KSC itself. The causeway/drawbridge, checkpoints and long roads into the Kennedy Space Center were just as I remembered them from 15 years before. The enormous Vehicle Assembly Building (VAB) loomed impressively on the horizon, the tallest structure for many kilometres around. We parked the car and looked about. The tall, new Mobile Launch tower intended for the cancelled Ares 1 launcher stood next to the VAB. It looked a bit forlorn to me, sadly now bereft of purpose. The weather was very hot and fine with humid sea-breezes scarcely easing the discomfort of our NZ winter-acclimated bodies.

The NASA-TV televised preflight briefing with NASA Shuttle management had just started so we quietly entered the briefing room and stood along the walls. I got to ask a question of KSC Director Bob Cabana near the end of the briefing about commemorations to be held at Pad 39A, once the final launch had gone ahead. We then went into the main Press Center and saw that many work stations had already been claimed by professional American press, which was to be expected. We ended up sharing half of a big table with another organisation and a high-school student journalist. Maree improvised a fairly good sign that read 'Radio Network NZ and NZ Spaceflight Association' and taped it to the table. In the coming days it was to become our faithful work station and would include our laptop, cameras and notepads.

And also as expected, the Press Center became very, very busy; bustling with activity over the coming days. Maree and I signed up for every activity and press event we could, including the visits to launch pad 39-A, the various industry presentations for the Lockheed-Martin Orion spacecraft, the Boeing CST-100 capsule, the satellite refueling technology demonstration etc. The visit to Pad 39-A the evening before launch was truly a high point for me. After the final rollback, *Atlantis* stood tall, proud and ready to go. She looked capable of many more missions, not just one. And as I narrated to my video camera, paying tribute to the wonderful NZSA members back home, my voice cracked with emotion. This was truly history I was witnessing, larger than life and somewhat bittersweet. The big throng of press warily eyed the steadily-worsening weather, for there had been heavy rain and lightning in the hours before. But all to soon, we were being called away to go. We all looked back to *Atlantis* through the fogged-up windows as the buses pulled away, fresh rain starting to fall. We all hoped that the launch would not be delayed the next morning, but most of us had contingency time up our sleeves should this happen.

After getting back to the Press Center, Maree and I drove back to our hotel to have dinner, shower and snatch a couple hours sleep before heading back into KSC in the pre-dawn hours. This was so we wouldn't miss the buses to the astronaut walkout from the crew quarters that morning. The Press Center was truly crowded and very much alive by now. The excitement

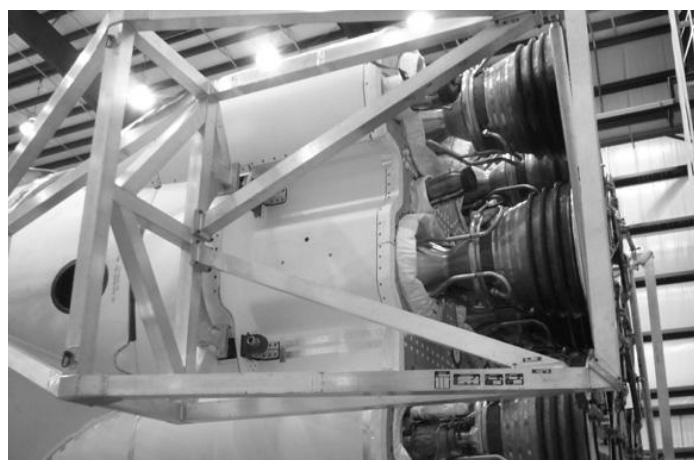
SpaceX's next Falcon 9 rocket drew a lot of interest. (Below right) The business end – the Falcon's Merlin engines

was really a tangible thing. We all waited in hopeful anticipation for the weather to improve. But as the dawn came, it appeared to be only a 50/50 proposition.

A parade of famous astronauts past and present came through the Press Center as did notable NASA managers from various eras. We got to briefly meet and greet legendary Launch Director Bob Sieck, who eventually remembered me from 15 years before! I also got to meet former NASA Administrator Michael Griffin, which gave me mixed feelings – for here was a man of great intellect, someone who'd had a grand Vision for Space Exploration beyond Earth Orbit. Dr Griffin had a literally once-in-a-lifetime opportunity to make NASA an agency for spectacular Exploration once more. But sadly, many believe he fumbled that opportunity and lost it for at least another generation.

In the coming hours I met so many famous 'space faces' it was almost a blur to me: legendary CNN reporter John Zarella, the space video bloggers from NASA-Edge, the husband and wife team from Space Vidcast; Ben and Carrie-Ann Higginbotham, veteran space reporter Jay Barbree, Keith Cowing, Todd Halvorsen from Florida Today, and astronauts including Kay Hire, Koichi Wakata, Shannon Walker, Cady Coleman, Bob Thirsk and Chris Hadfield.

The time to board the buses for astronaut walkout arrived and we crowded aboard with our new friends and colleagues, excited and happy that NASA appeared to be seriously considering launching *Atlantis*. A bit after 8:00 a.m. we disembarked and all rushed to pick out a spot behind the barriers that were opposite the crew quarters doors. Helicopters were circling overhead the crew quarters and we saw how calm all the security and support staff appeared to be. The famous, silver astronaut van was already in place, awaiting its final



Shuttle crew. We didn't have to wait long: Chris Ferguson, Sandy Magnus, Doug Hurley and Rex Walheim emerged from the main door, dressed in their pumpkin-orange launch and entry suits and paused for quite awhile, posing in front of the van. They smiled broadly and waved at the cheering onlookers, press and KSC workers. Flashbulbs were going off in a continuous, flickering barrage. And then it was time to embark into the van for their journey to Pad 39-B.

There was quite a scramble to get back on the buses and head back to the press site, but everyone did so without too much trouble. We checked that our table and laptop were okay, then settled in with everyone else to wait out the countdown process. We watched the crew climbing aboard *Atlantis* on TV and in between milestones, many of us raced over to the KSC cafeteria to get a bite to eat. We all kept an eye on the weather,

Maree with Japanese astronaut Koichi Wakata, and (below) Matt with Canadian astronaut Bob Thirsk

too. There were just so many US and international press there, that old hands informed us that nothing like this had been seen since John Glenn's Shuttle flight in 1998 and the return-to-flight after 'Columbia'. I was to later describe it as a 'friendly, high-tech zoo'.

About 90 minutes before launch, the weather finally began to look promising. We heard and sometimes saw the T-38s and the Gulfstream jet flying about the area, keeping tabs on the sky. Everyone's adrenalin was steadily rising, especially Maree who was going to see her one and only Shuttle launch. This was to be my second, though I was fully aware that there were quite a few people there at KSC who had witnessed nearly all the 135 Space Shuttle departures. Soon it was time for the very final one. Hundreds of thousands were lining the streets of Titusville and Cocoa Beach and the causeways leading out to Merritt Island. It will be many years before the crowds for a space launch will be this big again.

The journalist and VIP onlooker crowd outside the Press Center, on the field before the countdown clock and in the carparks beyond was big and excited, to say the least. The late morning weather was very hot and humid. A large scattering in the cloud cover above the launch pad had formed only in the last hour, as if wished that way by everyone. Then finally – there's always a final finally – the last few minutes came. The cliché about excitement being so thick, you could cut it with a knife was literally true. Or perhaps it was the 38-degree Celsius, 90-percent humidity of the air?

Down by the countdown clock, there was no working public address system – turned off apparently, so as not to drown out the outdoor TV presenters. So when the countdown abruptly stopped at T-minus 31 seconds, we all gasped: What the heck was going on? Everyone was muttering and grumbling until various folk with iPads and Smart phones were shouting out the answer: "*The vent hood may not be properly retracted!*" I was skeptical, believing it to be an instrumentation glitch or faulty indicator. It turned out I was correct – an alternate television camera view proved this to be so. The countdown was picked up with plenty of launch window time left to spare. At the ten second mark cameras began to click and thousands began to chant the classic final countdown. I was just trying to keep my camcorder steady!

"Main Engine start; Six, all three engines up and burning, three, two, and Liftoff! The final liftoff of Atlantis. On the shoulders of the Space Shuttle, America will continue the dream!"

The yells and cheers rose up from throats of thousands. Desperately trying to both keep *Atlantis* in my camcorder viewfinder *and* store a quick memory with my own eyes, I cried out; "Oh yeah!! Gorgeous! Gorgeous!" *Atlantis* was climbing swiftly, her bright-golden SRB flame appearing to twist as she made a startlingly quick roll maneuver. Higher, higher she climbed and then the crackle and roar of her mighty engines swept over KSC before *Atlantis* punched through the cloud deck. The thick shadow of her exhaust fell across the cloud ceiling, looking almost like *Atlantis* had made a sudden left-turn. I briefly thought the towering SRB smoke pillar looked eerily like a mushroom cloud. But this was no detonation; instead, kilotons of chemical energy were driving the mighty spaceship towards space. And two minutes after launch, that SRB smoke shadow abruptly stopped as *Atlantis* shed the empty boosters, continuing on to space with her huge external tank and its load of LOX and LH2.

And just like that, the final launch of a Space Shuttle was done. In space, *Atlantis'* mighty engines shut down and the ET was smoothly jettisoned. She would roar no more.

Clapping, cheering and smiles all round gave KSC a festive atmosphere. But as the cameras were packed away and the adrenalin wore off, the smiles were replaced by sober reflection. Many witnesses to the launch, myself included, were interviewed by TV crews. We all seemed to be saying similar things: that this was a bittersweet day. We were glad that *Atlantis* and her crew were safely in orbit, yes. But it was hard to accept that no American crews would launch into space from an American launch pad for unknown years to come. Many of us hoped that commercial space would be successful and that NASA would get to build its new-generation heavy lift launcher and Orion exploration spacecraft as well. But in the uncertain economic times ahead, NASA would struggle for funding in a

Things to know at The Cape

By Maree Pavletich

Getting to go to a launch does require a leap of faith. There are many things that can go wrong but here are a few things you can do to help matters. (Note: this is just from my own experience and there are undoubtedly things that others, who have been there before, will be able to tell you as well.)

- *We applied for a non-immigrant visa as we wanted to be press-accredited. New Zealand is part of the visa waiver scheme which ordinarily means you don't need a written visa to get to the US. However if you apply for press accreditation you need a non-immigrant visa and this has to be in writing, costs a fee, which they will direct you to pay at the Post Office when you go for your short interview at the US Consulate. So set aside some time - it is worth it. Press accreditation is only given to people recommended by recognised press like radio networks, newpapers etc. Since 9/11, special interest groups like the NZSA or groups like Rotary, for example, are no longer on the list.*
- *Do your online application properly before you go and if you have to reapply, for any reason, we found that having brought our own laptop was great, saved us having to find an internet café and we were able to blog in our own time. Most places you stay have WiFi now.*
- *The passes for NASA are in two parts. When you get your first of two passes you will be told how to get to the press badge building which is through the checkpoint, turn right and down about 3-4 kilometres. Its sign is very small so know that if you see the Space Shirts store on your left you have gone too far. By the way the Space Shirts store is brilliant for t-shirts! They can make to order!*
- *The launch may be waved off (repeatedly) so always build a few days into your schedule to accommodate at least three deferments. After that the launch window generally slips a month, in which case unless you have taken a lot of time off work, you will miss it anyway.*
- *Places to stay: you may have a favourite brand of your own but we stayed at the Day's Inn at Titusville, it was comfortable rather than flash but it had a lot to recommend it: It was not far from the NASA complex or Titusville. You can also get stuff posted there, just tell the person addressing the parcel to make it out to the person whose name the room is under, e.g. "Matthew Pavletich (Guest)". It has a pool (remember it is 39 degrees most of the time!) It is a short car ride to a Walmart. Adjoining the hotel was an IHOP (used to be called International House of Pancakes) this is like a Denny's and it is very useful to have a 24 hour restaurant attached to the hotel, as you will be up all hours getting to the launch and or press site tours. Note: the press site badge will give you access to the NASA canteen but they also have a mobile food truck in the lower carpark to save you the walk in the wee small hours.*
- *If you have press accreditation and want to sign up for the press tours, the sign-up sheets come out twenty-four hours prior to the tour. This means that for the astronaut walkout at 6:30 a.m., we had to be ready to sign-up for it at 6:30 a.m. the day before. If it's a popular tour don't take chances, be there to sign up or you could miss out.*
- *Hire a car through one of the many car rental companies around - the US is made for drivers, so getting around, especially getting around The Cape is impossible without a car. (OK, you could do it by taxi but that could run to serious money, or the driver may not be allowed onto the NASA sites.) The roads are wide and flat in Florida - we had no trouble driving there. The intersections are massive, inducing a case of "Are we there yet, are we there yet?" as you drive through.*
- *Get some rolls of quarters - you are going to need them for the vending machines, coin-operated laundry, coin-operated everything.*
- *When you get to the Kennedy Space Centre Visitors Centre immediately upgrade your ticket to an annual pass. Your normal ticket will give you two days of access to Kennedy Space Centre Visitors Centre and the Astronaut Hall of Fame and the tours you can do to the launch sites. This two-day access can be used anytime within a week. But you would be in a terrible rush to do all of this in two days. Upgrade to an annual pass for a few dollars more and you can relax and take your time. It will pay for itself as you can then get 10% off souvenirs and 20% off food in the complexes. Do the historic NASA sites tour, it is brilliant!*
- *If you have been issued a badge, wear it. Don't go wandering around exploring. The press site badge, as I said, will let you go to the NASA canteen and gift shop unescorted but nowhere else, except the press centre which includes the countdown clock area and carpark.*
- *When you go on one of the press tours to a government site, you must be wearing long trousers and closed-toed shoes. No tank tops, t-shirts are fine. Yes, it was 39 degrees and 100% humidity but you just have to cope. Matthew wore cargo pants and sneakers, I had some silk slacks and sneakers. We kept these in a backpack ready to slip on at a moment's notice. Despite the fact that we heard some people being told that Capri pants for women*

were OK, one women had to hastily borrow her partner's spare trousers to go on a trip! All luggage carried by the press corps is laid out and sniffer dogs go over it before every bus ride to a site or an event, like the astronaut walkout before the launch.

- *After the launch any one you meet in Titusville will just have two questions: "Where were you?" No need to ask what for, it's obvious they just want to know where you saw the launch from. You try not to smirk immodestly as you nonchalantly say "Countdown clock". And then inevitably "Where did you get your t-shirt?" There are lots of shirts available in lots of styles. Be sure to set aside some budget for this.*
- *Talk to everyone- Titusville is a small place and astronaut and NASA engineer spotting is easy. Also lots of people we met turned out to be retired NASA employees, so you never know.*
- *Take extra batteries at all times and extra memory cards. Also water and muesli or, as the Americans call them granola, bars for hydration and a snack, that heat really takes it out of you.*

way it had not had to even in the 1970s. Times were tough then, they were probably even tougher now.

The evening after launch day, Maree and I were having dinner at a Titusville restaurant with old friend, Dr Jack Bacon and his companions. We were surprised to discover that we were seated next to NASA Administrator Charles Bolden and his family! Jack asked Mr Bolden if I might speak to him and he graciously granted me a couple minutes of his time before his dinner was served. We mostly talked about the Christchurch earthquakes but I did manage to wish him luck for the future.

"I sure hope you get the funding and support you need for the Heavy Lift Vehicle and Orion, sir!" I said. Bolden clasped his hands together in a prayer-like gesture and whispered; "I hope so, too!"

In the days following the launch, Maree and I were to meet some amazing people and see amazing things. One of the highlights was an unscheduled visit to the VAB that we got to go on simply by being in the right place at the right time. Walking into that immense, cathedral-like building after all these years was emotional. But this time, there were no ET and SRB stacks waiting for a processed Orbiter to mate with then rollout to a launch pad. And this time, there was no giant External Tank sitting on a trailer, waiting its turn to make up yet another mission Stack. Not anymore. And we got another surprise and shock – in a bay just a short walk from one of the huge side doors sat '*Discovery'*. A clear plastic sheet was taped over the gap where the forward OMS pod used to be. The rear OMS pods and main engines had been removed as well.

Discovery looked sad. She looked like she'd been gutted. Then, thanks to a one-of-a-kind offer; I got to travel up more than 50 floors to be near the VAB ceiling 500 feet above the vast bays and concrete floors. Two crane operators had invited me into their control cab. I marveled at the unique view, one that few non-NASA personnel had ever seen. They were setting up for a practice run with a steel and concrete container that contained more than 70 tonnes of water. I had to leave their control cab before the test started. The VAB is a special place and as I said; like a high-tech cathedral.

In the following days we did a lot of driving around the Cocoa Beach and Titusville area, also missing by only minutes the towed SRBs as they arrived back into port. We visited the KSC Visitors Center and Astronaut Hall of Fame several times, and the Saturn V Center and museum. We also went on the historic launch pads tour which took in Pad 34 as well. I had tried 15 years before to get to this pad, the one where the Apollo 1 crew had died decades before. But back then, access was denied because a top-secret payload was on a Delta rocket at an adjoining launch pad. To finally reach Pad 34 was a sobering thing for me, bittersweet just as the final Shuttle mission was. After our return to New Zealand the bitter sweetness reached its peak. Almost two weeks after launch I watched the final re-entry and landing of a Space Shuttle on TV and over the Net. As *Atlantis* rolled safely to wheels stop and her chuffing, panting auxiliary power units fell silent forever, someone was playing the sad, 'Taps'-like theme music from the movie 'Apollo 13'. And so with Maree standing beside me, in a moment thirty years in the making, I wept…

What will the Future bring? I no longer care which nation walks on the Moon again, or who walks first on Mars. But I do care that it will take too long a time to accomplish. I was seven years old when manned Lunar exploration had finished after barely even starting. I'm forty-six years old now. I will be old when humans walk on Mars; as old as the surviving Apollo Astronauts are now. But as long as some other seven year old gets to actually *see* those footprints on Mars on their high-definition 3-D television, I will be reasonably content. It will not happen overnight. But it *must* happen.

After punching through the clouds, the exhaust plume from Atlantis casts a shadow.

All photos by Matt and Maree Pavletich

Latest Results from Dawn at Vesta

NASA's Dawn mission, which has been orbiting Vesta since mid-July, has revealed that the asteroid's southern hemisphere boasts one of the largest mountains in the solar system. Other results show that Vesta's surface, viewed at different wavelengths, has striking diversity in its composition particularly around craters. The surface appears to be much rougher than most asteroids in the main asteroid belt. Preliminary results from crater age dates indicate that areas in the southern hemisphere are as young as 1-2 billion years old, much younger than areas in the north.

"We are learning many amazing things about Vesta, which we call the smallest terrestrial planet," said Chris Russell, the Dawn Principal Investigator. "Like Earth, Mars, Venus and Mercury, Vesta has ancient basaltic lava flows on the surface and a large iron core. It has tectonic features, troughs, ridges, cliffs, hills and a giant mountain. The south polar mountain is larger than the big island of Hawaii, the largest mountain on Earth, as measured from the ocean floor. It is almost as high as the highest mountain in the solar system, the shield volcano Olympus Mons on Mars."

In mid-July Dawn entered orbit around Vesta and began imaging what is possibly the oldest planetary surface in the solar system. The surface of Vesta shows the ravages of time. Many more craters are seen in the northern hemisphere than the southern because an enormous impact altered the earlier cratering record in the south. Since July the Dawn spacecraft has been moving ever closer to Vesta, moving into a polar orbit to look down on every square kilometer of the planetary surface. In mid August it entered Survey orbit at 2,700 kilometre altitude and mapped the entire sunlit surface with its framing camera and Visible and IR mapping spectrometer.

"We completed that phase at the beginning of September and since then have been moving the spacecraft to its next mapping orbit, the High Altitude Mapping Orbit at 680 kilometre altitude, which it reached on the weekend. Over the coming month it will return complete coverage of the sunlit surface with a resolution of 60 metres," said Carol Raymond, Dawn's Deputy Principal Investigator.

A new coordinate system has been defined for Vesta because the old coordinate system, based on low-resolution telescopic data, was wrong by almost 10 degrees. Even with data from the Hubble Space Telescope it had been difficult to determine Vesta's rotation axis. After defining the coordinate system, the team has begun naming the prominent features.

"The head of the mapping spectrometer group, Angioletta Coradini, suggested that the large southern crater on Vesta be called Rheasilvia after the mother of Romulus and Remus and the mother of the Vestal virgins. The IAU has accepted this suggestion, as well as the names of thirteen Vestal virgins for craters that define quadrangles. The team is now measuring the craters, identifying ridges, hills and lineations to have the sunlit surface totally mapped by the end of the year," said Russell.

The Dawn framing camera, built and operated by the Max-Planck Institute for Solar System Research (MPS), in cooperation with DLR, Berlin and the Technical University of Braunschweig, provides more information than the black and white images suggest. The framing camera is equipped with seven colour filters in order to collect spectral information. This makes it possible to highlight certain spectral features in false colour maps that would not be visible to the naked eye. The surface of Vesta shows striking diversity when viewed in false colours that are ratios of light intensity at different wavelengths. These false colour variations are diagnostic of different surface materials. The spectral variations are particularly strong around craters. Where the clear filter images show bright and dark features, the colour data show these are also comprised of different materials, likely excavated by the impacts. "One of the most prominent colour features on Vesta's surface is associated with a 40 kilometre diameter crater near Vesta's equator. It shows a spectacular red ejecta blanket to the south. We believe that this eject blanket, which covers only a half-circle, has been created by an impactor hitting the surface on a trajectory of oblique incidence," said Andreas Nathues of MPS.

Dawn also carries a Visible and Infrared Mapping Spectrometer (VIR), provided by the Italian Space Agency, and managed by Italy's National Institute for Astrophysics (INAF-IASF), in collaboration with Selex Galileo, where it was built. Data from VIR reveal the composition and nature of the materials on the surface of Vesta. "Data from different wavelengths can be combined to investigate different types of materials. The colour variations seen by VIR suggest variability in the surface mineralogy. Brightness variations seen in visible light can be compared with the thermal emission at five microns to determine the source of the variations. Measured surface temperature variations range from 240 to 270K," said Maria Cristina de Sanctis, of INAF-IASF.

The difference in the number of craters between the two hemispheres is also striking. By counting the number of craters per unit area in different terrains, the relative ages of these different terrains can be obtained. Preliminary results of these crater age dates indicate much younger ages for areas in the south versus the north, as young as 1-2 billion years old. So far, the oldest ages, in the northern hemisphere, are younger than 4 billion years old, which is an unexpected result given that meteorites from Vesta have ages of 4 billion years. However, the crater counts will be refined with the more detailed data to be collected, and the assumptions about how the impact flux decays with time will be evaluated, so the absolute ages are preliminary.

"Vesta's surface has a surprisingly complex set of structural features, including the massive south polar mountain, steep slopes, deep troughs, and sets of curved lineations that appear in some cases to be associated with slumps, or landslides. The variation in Vesta's brightness as the sun angle changes indicates that the surface of Vesta is very rough, causing the light to scatter. This roughness could be at the scales of surface features or at the scale of individual minerals in the rocks, or both. Vesta's roughness is larger than most asteroids in the main asteroid belt," said Raymond.

"Tragically, the leader of the VIR spectrometer team, Angioletta Coradini, passed away last month but not before she got to see this amazing alien world and to see her suggestion to name the craters of Vesta after the Vestal virgins fulfilled. We are going to miss very much this amazing woman, brilliant scientist and esteemed leader of the VIR investigation," said Russell.

Sourced from Europlanet
www.europlanet-eu.org

The launch of STS-1 (Columbia), the first flight of the Space Shuttle, on 12 April 1981. Mission Commander John Young was making his fifth space flight, while Pilot Robert Crippen was making his first.