Shuttle's Final Mission

Thirty years and 134 missions after its debut, NASA got down to the business of flying a Space Shuttle for the final time this summer. Clive Simpson witnessed the historic launch from Kennedy Space Center, Florida

Optimism surrounded the early days of the Space Shuttle programme and when NASA flew its test vehicle Enterprise around Europe on the back of a 747 jumbo jet as a PR stunt shortly after the first launch, NASA's deputy administrator at the time, Dr Hans Mark, predicted there would be almost one Shuttle mission per week by the mid-1990s and that several thousand people would have flown in space before the end of the century. Ultimately those numbers proved way off the mark and things didn't turn out as he and many others had predicted.

But despite its compromised design – the original idea was to both take off and land on a runway – and the fact that it was only partly reusable and therefore never made the cost of taking men or cargo to low Earth orbit much cheaper, the Space Shuttle is likely to be remembered for many years to come as the most iconic spacecraft of the past three decades, if not all time.

Dream Spaceship

In many ways it looked like a dream spaceship and had the capabilities no other spacecraft can claim or is likely to match in

MAIN ENGINE

Each Space Shuttle main engine operates at greater temperature extremes than any mechanical system in common use today. The fuel, liquefied hydrogen at minus 423° Fahrenheit, is the second coldest liquid on Earth and when it combusts with the liquid oxygen the temperature in the main combustion chamber is 6,000° Fahrenheit, hotter than the boiling point of iron. The engines use a staged combustion cycle so that all propellants entering the engines are used to produce thrust more efficiently than any previous rocket engine. In a staged combustion cycle, propellants are first partially burned at high pressure and relatively low temperature, and then completely at high temperature and pressure in the main combustion chamber. The rapid mixing of the propellants under these conditions is so complete that 99% of the fuel is used. At normal operating level, each engine generates 490,847lb (2,183kN) of thrust; full power is 512,900lb (2,281kN) and can be throttled by varying the output of the pre-burners, thus varying the speed of the high-pressure turbo pumps and, therefore, the flow of the propellant. To reduce overall stress on the vehicle, the main engines are throttled down to 316,000lb (1,405kN) of thrust some 26 seconds into ascent to keep the dynamic pressure on the vehicle below about 580lb per square foot (27.7kN per square metre), known as max q. Then they are throttled back up to normal operating level at about 60 seconds.

this generation. With an orbital velocity of ten times the speed of a high-powered rifle bullet, it was the fastest manned winged vehicle ever to fly and to date is the only crewed winged vehicle to reach orbit.

It was dubbed the most complex machine ever built and countless engineering and technological advances were required in its development. Its main engines stretched design and metallurgical capabilities, and its thermal protection system – which shields the orbiters from temperatures as high as 3,000° Fahrenheit during re-entry – was designed for repeated reuse.

The prospect of reusable spacecraft capable of carrying large cargos and humans into space had been talked about for decades in science fiction and by scientists since shortly after World War Two. But like any project of this magnitude, the Space Shuttle ended as a series of compromises ranging from political and funding concerns to competing design ideas and conflicting systems requirements – when one system changed, others were impacted upon.

All in all, more than 50 different Shuttle versions were developed during the design process. Eventually, however, they evolved into the Space Shuttle that has flown since Columbia's first launch in April 1981. Three years later than originally targeted, it was the first of 135 launches in total, a string that ended on a heady and emotional day this summer.

The Space Shuttle was to be a multi-purpose ship that would carry all of America's space cargo. Its biggest selling point was reusability – more like an aircraft than a traditional rocket that is discarded after doing its job. Such a concept should have brought down the cost of reaching orbit, but a fully reusable spacecraft was in reality still well beyond the technology of the late 1970s.

If the Shuttle had flown up to once a week as originally conceived then its development costs could have been amortised over many launches, but that was never to be and even NASA puts the costs of a single launch at around $450 million. In the end, the originally planned $2,000 per kilogram of payload turned out to be ten times more expensive.

Then there was safety. In 1986 after the failure of a gasket on one if its booster rockets on a freezing January morning, the Space Shuttle Challenger disintegrated shortly after lift-off, killing its crew of seven. And in 2003, as it was re-entering Earth's atmosphere, Columbia broke apart high over Texas because unknowingly the craft's heat shield had been compromised after being hit by a piece of stray foam which broke away from the external fuel tank during launch. Again, all seven astronauts were killed.

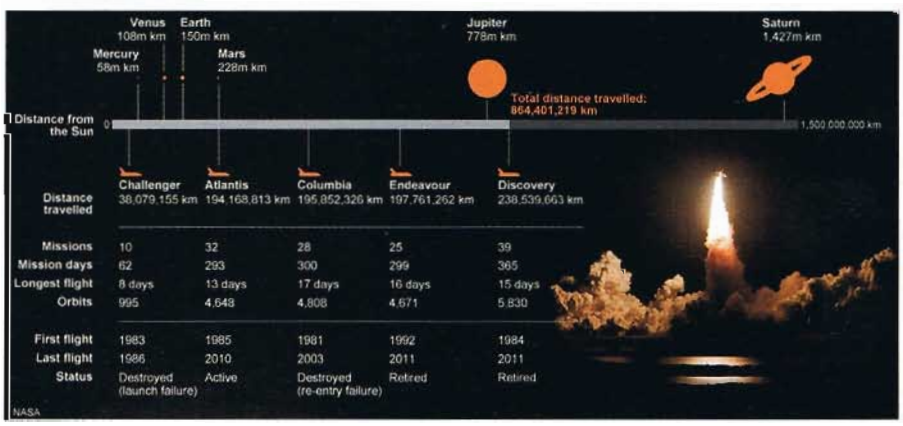
For an experimental space plane, two disasters in 135 flights is not such a bad record. But they were high-profile losses and the first was blamed on poor management of known technical issues and a culture of complacency within NASA. According to subsequent inquiries, both had been accidents waiting to happen.

The Space Shuttle is about the size of a DC-9 airliner and is designed to survive the rigours of launch and landing, including vibration, high acoustic levels from the rocket engines, high levels of acceleration and various heat loads on different parts of the structure. The layout is dominated by two key requirements – to carry a payload of up to 65,000lb (29,500kg) into orbit and to fly back down through the atmosphere like an aircraft, landing as an unpowered glider.

Final Go

It was a typically hot and humid summer's day on Florida's Space Coast as nearly a million spectators gathered along the beaches, rivers and causeways to watch history in the making. The weather forecast for the launch of *Atlantis* on July 8, 2011, was a daunting 70% 'no-go', yet the countdown proceeded smoothly.

Atlantis was the last of the original five Shuttles built for spaceflight to launch, with *Discovery* and *Endeavour* (the youngest craft) having completed their final missions earlier in the year. Despite the dire weather forecast it had been a good call by NASA managers to proceed with the overnight tanking and final preparations of *Atlantis*. The atmosphere at the press site was electrified as the minutes



1 Six Americans, three Russians and a Japanese astronaut eat together on Atlantis' middeck on 14 July 2011. It was the last opportunity for sharing such a meal during a Shuttle mission. *All images NASA* 2 The STS-135 crew of (from left) Sandra Magnus, Rex Walheim, Chris Ferguson and Doug Hurley ride in the Astrovan to launch pad 39A to board Atlantis. 3 NASA's Mike Leinbach who supervised the launch countdown of the final 17 Shuttle missions. 4 Chris Ferguson, Commander of the last Shuttle flight. 5 T minus three seconds.

towards countdown rolled back and it looked likely the clouds would thin in time.

Just as expectations peaked and launch looked imminent, a last-minute glitch held the clock at T -31 seconds. The issue – whether the gaseous oxygen vent arm had fully retracted – was quickly resolved by the team inside the control centre at KSC and, with about a minute left in the day's launch window, the clock began counting down the final seconds.

Smoke billowed from the pad and at first the Shuttle rose in silence. Burning thousands of litres of rocket fuel every second and blasting superheated gas into the water-filled trench beneath the pad, the three main engines and twin solid rocket boosters kicked up vast clouds of steam and smoke that have characterised all Shuttle launches. A rippling roar, emanating from its three main engines and boosters, thundered across the three miles between the pad and the author's viewpoint near NASA's famous countdown clock, transforming into a ground-shaking noise that rocks through your whole body.

Atlantis powered into the sky, climbing on a blinding column of fire from the same pad that launched *Columbia* in 1981 as spectators and Shuttle workers everywhere marvelled for the last time. The flame was bright and almost too piercing to look at in real life – a jewel of brightness climbing into the heavens.

As it accelerated out across the Atlantic its flight flattened from vertical to almost horizontal and just two minutes after launch the twin solid rocket boosters fell away to be recovered after parachuting into the ocean below.

Atlantis was now being powered by its three main engines – mounted on the aft fuselage in a triangular pattern and far enough apart so they are moveable in order to steer the Shuttle during its rapid climb. Each engine is about 14ft (4.27m) long, weighs bout 7,000lb (3,175kg) and is 7½ft (2.29m) in diameter. They operate for about 8½ minutes during liftoff and ascent, burning more than 500,000 gallons (1.89 million litres) of super-cold liquid hydrogen and liquid oxygen stored in the orange coloured external tank. The engines shut down and the tank is jettisoned just before the Shuttle, now travelling at around 17,500mph (28,150km/h), reaches orbit.

Witnessing a Space Shuttle launch is always an emotional event – but especially so when it is the last one ever in the 30-year history of the programme. Mike Moses, NASA's long-serving Shuttle Integration Manager, was visibly moved, admitting that he was normally 'choked up' after a launch. But this time, he said, it was even before blast-off. "It looked like *Atlantis* was lifting off in slow motion," he added. "It was very moving, very beautiful."

For the tightly knit launch team that runs every launch, the tension and fun was over too. As mission control in Houston took over the job of managing the flight, the KSC controllers lingered in the firing room, exchanging pats on the back and taking photos together.

"We will never see that again – it was a special moment," Mike Leinbach, Shuttle Launch Director, remarked. "We didn't want to leave. It was like the end of a party and you just don't want to go."

By now the crew of four veteran astronauts aboard *Atlantis* – Commander Chris Ferguson, pilot Doug Hurley, and mission specialists Sandy Magnus and Rex Walheim – were enjoying their first moments of weightlessness in orbit as they opened the Shuttle's payload doors to dissipate the heat of launch. Their mission was to deliver a stockpile of supplies and parts to the Space Station.

Space Station Rendezvous

Atlantis caught up with the Station two days after launch and from a distance of about 600ft (183m) Ferguson executed a back flip manoeuvre to enable Station crew members to photograph the Shuttle's heat shield, looking for potential tile damage.

During the intricate rendezvous and docking, which occurred as the two craft hurtled around Earth at 17,500mph, crew members operated laptop computers to process navigational data, laser ranging systems and finally the docking mechanism.

Waiting to greet a Shuttle crew for the final time with a ceremonial ringing of the Station's bell were Expedition 28 Commander Andrey Borisenko and Flight Engineers Alexander Samokutyaev, Ron Garan, Sergei Volkov, Mike Fossum and Satoshi Furukawa, all on long-term flights.

Getting down to the main objective of their mission, Magnus and Hurley took the controls of the Space Station's robotic arm and removed the Raffaello multi-purpose logistics module – a giant pressurised storage canister – from the Shuttle's cargo bay and temporarily installed it on the Earth-facing port of the Station's Harmony node.

While the bulk of the work on many Shuttle missions has revolved around spacewalks, this mission's main focus was inside. Over the course of the more than eight days, both crews spent much of their time unloading more than 9,400lb (4,260kg) of supplies and equipment from Raffaello, plus the additional 2,200lb (1,000kg) stowed on the Shuttle's mid-deck. For the return trip to Earth, Raffaello was filled with 5,900lb (2,675kg) of equipment and discards no longer needed in orbit.

Recovery

Coming home on July 21 to a future clouded by tight budgets and uncertain political support, Ferguson guided Atlantis through a sweeping left overhead turn and lined up on runway 15 at KSC, quickly descending into the glare of powerful xenon spotlights.

The one-off shot at landing a Shuttle is a critical point of the mission and calls on all the flying skills and countless hours of training for the Shuttle commander and his pilot.

NASA's Shuttle Training Aircraft (STA) – a modified Gulfstream II business jet that plunges 28,000ft (8,534m) in a little more than a minute – is used by astronauts to mirror a Space Shuttle approach. Astronaut veteran Ken Cockrell, an instructor pilot, says: "It's a fairly clean airplane and it likes to glide and it's got good thrust. So we have to ruin all that to make it fly like a Shuttle."

During repeated training runs, the STA's engines are put into reverse at 28,000ft, the main gear lowered and flaps on the wings opened. An onboard computer changes the normal flying rules to make the sleek jet fly like a 110-ton Shuttle and the aircraft dives at 18 to 21°, seven times steeper than an airliner's approach, falling toward Earth at more than 330mph (530km/h).

The Shuttle's aerodynamic properties once it re-enters the atmosphere are often described as "like a brick falling out of the sky" by Shuttle pilots and commanders. There is only one chance to get the landing right so everyone of the 1,400 practice dives logged by Ferguson is invaluable.

It was a textbook descent from orbit and a ghostly, picture-perfect landing. Flying upside down and backward over the Indian Ocean, Ferguson and Hurley had fired the Shuttle's twin braking rockets for three minutes and 16 seconds, slowing the ship enough to drop it out of orbit.

Around 30 minutes later the Shuttle plunged

SOLID ROCKET BOOSTERS

The two reusable solid rocket boosters (SRBs), required for the first two minutes of powered flight, boast the largest solid-propellant motors ever flown. They are the first large rockets designed for re-use and are the only solid rocket motors rated for human flight. The SRBs provide 71.4% of the thrust required to lift the Space Shuttle off the launch pad during first-stage ascent to an altitude of about 150,000ft (45,270m) or 28 miles. At launch, each booster has a sea-level thrust of approximately 3.3 million pounds (14,680kN) and is ignited after the ignition and verification of the three main engines. Each booster is subsequently recovered from the ocean and towed back to port for refurbishment.

Above right: Liberty Star, one of NASA's solid rocket booster retrieval ships, tows the right spent booster from space shuttle Atlantis' final launch, as it is taken to Port Canaveral in Florida. The boosters impact the Atlantic about seven minutes after lift-off and the retrieval ships are stationed about 10 miles from the impact area at the time of splashdown.
Top left: One of two solid rocket boosters is transported to Hangar AF at Cape Canaveral Air Force Station in Florida.
Top right: A segment of a solid rocket booster, the aft skirt, can be seen as the booster is lifted above a mooring at Port Canaveral.

1 Atlantis attached to the Space Station during the final Shuttle mission. 2 Vapour trails follow space shuttle Atlantis as it approaches Runway 15 on the Shuttle Landing Facility at NASA's Kennedy Space Center in Florida for the final time. Atlantis marked the 26th night time landing of NASA's Space Shuttle Program and the 78th landing at Kennedy. It also was the final mission for the shuttle program. STS-135 was the 33rd and final flight for Atlantis, which has spent 307 days in space, orbited Earth 4,848 times and travelled 125,935,769 miles

into the top of the atmosphere at an altitude of about 75 miles (120km) above the southern Pacific Ocean, enduring the hellish heat of re-entry as it descended along a north-easterly trajectory back toward KSC. The flight path carried Atlantis high above Central America, across the Gulf of Mexico just west of Cuba and on to Florida, approaching KSC from the southwest.

Heralded by the Shuttle's signature dual sonic booms as Atlantis dropped below the speed of sound, Ferguson took over manual control at an altitude of about 50,000ft (15,240m), guiding it through a sweeping 240° left turn to line up with the three mile long runway for the Shuttle programme's last landing. In the dark, pre-dawn dark skies of July 21, Ferguson pulled the Shuttle's nose up in a graceful flare as pilot Doug Hurley lowered the ship's landing gear and *Atlantis* settled to a tyre-smoking touchdown. A few seconds later, as the spacecraft barrelled down the runway at more than 200mph (320km/h), Hurley deployed a red-and-white braking parachute and the Shuttle's nose gear settled to the runway.

Moments later *Atlantis* coasted to a halt on the runway centreline at 5:57:54AM EDT bringing three decades of Shuttle operations to a close. "Mission complete, Houston," Ferguson radioed. "After serving the world for over 30 years, the Space Shuttle has earned its place in history. It's come to a final stop."

Reflection

Now, with Atlantis and its crew safely home, the emotional process of remembrance and celebration began in earnest as engineers and technicians marvelled at the technological grandeur of the winged space plane and struggled to cope with the reality that it will never fly again.

"Out on the runway I found myself taking in the beauty of the vehicle, taking pictures of the workers, them asking for a picture with me – it was just a family event out there today," Mike Leinbach said. "There were good emotions that we brought the crew home safely and the mission's complete but certainly sadness that it's over and people will be moving on."

Americans are immensely proud of NASA but with the Shuttle now consigned to history and museum displays the agency is struggling to find a vision for the future. American citizens will still live and work aboard the orbiting International Space Station, but for many years to come the US will be reliant on the Russians for the ride there and back.

Launching people into space is a potent symbol of technological and engineering prowess – but for the Space Shuttle programme it was the pre-dawn landing of *Atlantis* that truly signalled the end. "When the wheels stopped on the runway, the displays went blank and the orbiter was unpowered for the final time there was a rush of emotion," said 'Fergie' after stepping from his craft. "That was the moment when we all finally realised that it's all over, the crowning jewel of our space programme. The Space Shuttle changed the way we view the world and it changed the way we view the universe."

Future Craft

NASA has been working hard to counter the notion that the end of the Shuttle means the end of US human spaceflight. And there are commercial companies waiting in the wings. Before the launch of *Atlantis*, Lockheed Martin displayed a test model of its Orion Multi-Purpose Crew Vehicle that may one day take Americans to destinations beyond the Space Station – like the asteroids and Mars.

Alongside, Boeing showcased its CST-100 capsule concept, one of the 'crew taxis' NASA hopes to hire to get its astronauts to and from orbit by mid-decade. And Elon Musk's SpaceX company threw open its doors on the nearby Cape Canaveral Air Force Station where it has a rocket integration hanger and launch pad. From here it will fly its Falcon rocket – the next test flight is planned for this autumn – and 'Dragon Rider' capsule, another commercial answer to America's astronaut taxi dilemma.

But they are all pursuing the more traditional route into orbit while others, such as the US Air Force and the Colorado-based Sierra Nevada Corporation (SNC), are convinced the future is still in winged reusable spacecraft. SNC's mini-shuttle called Dream Chaser could be launched for the first time in 2015.

Many argue that these new spacecraft represent a more affordable, commercial and even more exciting approach to future human spaceflight. Not surprisingly, NASA administrator Charlie Bolden, himself a former Shuttle astronaut, is convinced that human spaceflight has a bright future. "You'll hear me say that over and over and over again. The future is incredible and you're witnessing the first steps NASA is taking to create that future right now," he said.

Even as museum pieces, Space Shuttles will remain an inspiration to many. These remarkable flying machines have travelled 542,398,878 miles in space, orbited Earth 21,152 times, deployed 180 payloads and carried 355 humans and 3.5 million pounds of cargo into orbit. History may yet judge this winged spaceship as one of America's – and perhaps humankind's – greatest technological achievements.