Space Shuttle Challenger

Ten Journeys into the Unknown

Ben Evans

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Preface

Ironically, the loss of Challenger in January 1986 fired my interest in space exploration more than any other single event. I was nine years old. My parents were, at the time, midway through moving house and, luckily, the TV was one of the few domestic items still to be packed. I watched the entire horror unfold live on all of the network stations. Admittedly, my fascination with rockets and astronauts, stars and planets had begun several years earlier, but Challenger's destruction turned it from an occasional hobby to a fascination which has remained with me ever since. In September 1988, aged 11, I came home from school to watch STS-26 return the Shuttle fleet to orbital operations. Five years later, I gave a speech on the STS-51L disaster to my teacher as part of my GCSE English assessment. Another decade passed and, now a teacher myself, I returned to my school one cold Monday morning to explain to my pupils what had happened to Challenger's sister ship, Columbia, a few days earlier.

In some ways, the loss of Columbia affected me more deeply than Challenger. Aside from the fact that I was older, I had also corresponded with and interviewed many of the lost astronauts. Signed photographs of the STS-107 crew had adorned my bedroom walls. Personalised, hand-written notes and letters from my heroes had filled scrapbooks. I did not have the same personal link with Challenger's crew. However, in my mind, my passion for space exploration might not have endured were it not for STS-51L.

I find it depressing – even distressing – that, in the case of both Challenger and Columbia, most observers focus upon their final, fateful missions, avoiding the spectacular triumphs that both venerable orbiters achieved during their all-too-short lives. At the time of her loss, Challenger had flown more times than all three of her sister ships. She had rocketed into the heavens nine times successfully in less than three years, transporting nearly four dozen astronauts aloft – several of them on two occasions, one of them as many as three times – and had spent over two months in space. Twelve satellites had departed her payload bay, dozens of experiments ranging from studies of bees to sophisticated crystal growth facilities had flown aboard her, a snazzy jet-fed backpack had been tested and spacewalking astronauts had captured and deftly repaired NASA's crippled Solar Max observatory. In June 1983, the world got its first photographic glimpse of the 'whole' Shuttle in space, drifting serenely above a cloud-bedecked Earth: and the Shuttle in question was Challenger.

Of course, there were dismal times, including embarrassments and near disasters. Before she even undertook her maiden voyage, problems with her main engines enforced a delay of several months; then, when she finally achieved orbit, a booster malfunctioned and left a $100 million Tracking and Data Relay Satellite in a lower-than-planned orbit. On her fourth mission, two more satellites were lost and an experimental rendezvous balloon burst minutes after deployment. What should have been her seventh trip was cancelled six days before launch and her eighth mission experienced a harrowing on-the-pad main engine shutdown. When it finally set off, a main engine failed as she sped towards orbit at 15,000 km/h and a hairy abort landing in Spain was narrowly averted. On January 28th 1986, Challenger's luck finally ran out.

My intention in writing this book, as with its sister volume about Columbia, was to tell the story of Challenger from technical esoterica, press kits, reports, personal interviews, correspondences, newspaper and magazine articles from the time and original NASA sources. My goal was to present, in as much detail as I could possibly achieve, not a critique, but rather an appraisal of her many accomplishments. It will be up to the reader to gauge how successful I have been in this endeavour, but I hope that this book will prove interesting and informative when, a few years from now, the Shuttle fades into history, taking its place alongside Vostok, Voskhod, Mercury, Gemini and Apollo, and the next stage of space exploration begins.

Acknowledgements

I am indebted to a number of individuals for helping to make this book happen. Among them are several astronauts who actually flew Challenger – Norm Thagard, Vance Brand, Bruce McCandless, George 'Pinky' Nelson and Gordon Fullerton – who kindly took time to speak with me at length over the telephone or answer my many questions via email correspondence. Their insights into the similarities, differences and idiosyncracies of the orbiters, the development of the Manned Manoeuvring Unit, spacewalking procedures and early efforts to understand the causes of space sickness have proven invaluable. Thanks are also due to Roberta Ross and Beth Hagenauer of NASA and Linn LeBlanc of the Astronaut Scholarship Foundation for arranging interviews.

Once more, I am grateful to David Harland and Ed Hengeveld; to the former for reading the first draft of the manuscript, pointing out my errors and sharpening up the text, and to both for giving up their time to identify high-quality illustrations for this book. The enthusiasm of Clive Horwood of Praxis is acknowledged, as is the project's aptly-named copy editor and typesetter, Neil Shuttlewood.

Alongside the loss of Challenger, a unique group of friends from the Midlands Spaceflight Society helped foster my fascination with space exploration. In particular, Andy Salmon's infectious enthusiasm and encyclopaedic knowledge have been immensely helpful, as has the inexhaustible reservoir of astronaut and cosmonaut esoterica from Rob and Jill Wood. My family have constantly supported my interest and I must thank my fiancee, Michelle Chawner, for her endless love and encouragement. Additional grateful thanks go to my parents, Marilyn and Tim Evans, to Sandie Dearn, Ken and Alex Jackson, Malcolm Chawner and Helen Bradford and the ever-present distraction provided by a playful golden retriever named Rosie and a frog-catching kitten called Simba.

To Michelle – with love and thanks for your constant, unfailing support
In memory of Astronaut Chuck Brady (1951–2006)

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Abbreviations and acronyms

ACIP	Aerodynamic Coefficient Identification Package
ACOMEX	Advanced Composite Materials Experiment
AEM	Animal Enclosure Module
AFRSI	Advanced Flexible Reusable Surface Insulation
AFT	Autonomic Feedback Training
APE	Auroral Photography Experiment
APU	Auxiliary Power Unit
ASE	Airborne Support Equipment
ASEAN	Association of South-East Asian Nations
ASTP	Apollo–Soyuz Test Project
ATMOS	Atmospheric Trace Molecule Spectroscopy
ATO	Abort To Orbit
BMFT	German Federal Ministry of Research and Technology
BTS	Biotelemetry System
CFC	chloroflurocarbon
CFES	Continuous Flow Electrophoresis System
CHAMP	Comet Halley Active Monitoring Program
CHASE	Coronal Helium Abundance Spacelab Experiment
CRNE	Cosmic Ray Nuclei Experiment
CRRES	Cosmic Release and Radiation Effects Satellite
CRT	Cathode Ray Tube
CRUX	Cosmic Ray Upset Experiment
DDM	Drop Dynamics Module
DDU	Data Display Unit
DEMS	Dynamic Environment Measuring System
DFI	Development Flight Instrumentation
DFVLR	Federal German Aerospace Research Establishment
DPM	Drop Physics Module

DSO	Detailed Supplementary Objective
DSP	Defense Support Program
DTO	Detailed Test Objective
EIS	Experiment Initiation System
ELDO	European Launcher Development Organisation
EMU	Extravehicular Mobility Unit
EOIM	Evaluation of Oxygen Interaction with Materials
EOS	Electrophoresis Operations in Space
ERBE	Earth Radiation Budget Experiment
ERBS	Earth Radiation Budget Satellite
ESA	European Space Agency
ESRO	European Space Research Organisation
ET	External Tank
EUVE	Extreme Ultraviolet Explorer
EVA	Extravehicular Activity
FEE	French Echocardiograph Experiment
FES	Fluid Experiment System
FILE	Feature Identification and Location Experiment
FRF	Flight Readiness Firing
FSS	Flight Support Structure
GAS	Getaway Special
GFFC	Geophysical Fluid Flow Cell
GLOMR	Global Low Orbiting Message Relay
GPC	General Purpose Computer
GPWS	General Purpose Workstation
GRO	Gamma Ray Observatory
GSFC	Goddard Space Flight Center
GSOC	German Space Operations Centre
HiRAP	High-Resolution Accelerometer Package
HRTS	High-Resolution Telescope and Spectrograph
HUD	Heads-Up Display
HUT	Hopkins Ultraviolet Telescope
HXIS	Hard X-ray Imaging Spectrometer
IML	International Microgravity Laboratory
IPS	Instrument Pointing System
IRAS	Infrared Astronomy Satellite
IRT	Infrared Telescope
IRT	Integrated Rendezvous Target
IUS	Inertial Upper Stage
IWG	Investigators Working Group
JPL	Jet Propulsion Laboratory
JSC	Johnson Space Center
KSC	Kennedy Space Center
LATS	LDEF Assembly and Transportation System
LDEF	Long Duration Exposure Facility

LFC	Large Format Camera
LRSI	Low-Temperature Reusable Surface Insulation
MADS	Modular Auxiliary Data System
MAPS	Measurement of Air Pollution by Satellite
MAUS	Materialwissenschaftliche Autonome Experimente unter Schwerelosigkeit
McIDAS	Man–computer Interactive Data Access System
MDD	Mate–Demate Device
MEA	Materials Experiment Assembly
MEDEA	Materials Science Experiment Double Rack for Experiment Modules and Apparatus
MEM	Meteoroid and Exposure Module
MLP	Mobile Launch Platform
MLR	Monodisperse Latex Reactor
MMS	Multi-Mission Modular Spacecraft
MMU	Manned Manoeuvring Unit
MOMS	Modular Optoelectronic Multi-spectral Scanner
MPESS	Mission Peculiar Equipment Support Structure
MSE	Manned Spaceflight Engineer
MSFC	Marshall Space Flight Center
MSL	Microgravity Science Laboratory
NOAA	National Oceanic and Atmospheric Administration
NOSL	Day/Night Optical Survey of Lightning
NUSAT	North Utah Satellite
OMS	Orbital Manoeuvring System
OOE	"Out of the Ecliptic"
OPF	Orbiter Processing Facility
ORS	Orbital Refuelling System
OSP	Optical Sensor Package
OSTA	Office of Space and Terrestrial Applications
PAM	Payload Assist Module
PAPI	Precision Approach Path Indicators
PDP	Plasma Diagnostics Package
PEAP	Personal Egress Air Pack
PEC	Photoelectric Cell
PFTA	Payload Flight Test Article
PGU	Plant Growth Unit
POCC	Payload Operations Control Center
PSN	Pasifik Satelit Nusantara
RAHF	Research Animal Holding Facility
RCS	Reaction Control System
RME	Radiation Monitoring Experiment
RMS	Remote Manipulator System
RTG	Radioisotope Thermoelectric Generator
RTLS	Return to Launch Site

SAEF	Spacecraft Assembly and Encapsulation Facility
SAFER	Simplified Aid For Extravehicular Activity Rescue
SAGE	Stratospheric Aerosol Gas Experiment
SAL	Scientific Airlock
SFHE	Superfluid Helium Experiment
SIR	Shuttle Imaging Radar
SLF	Shuttle Landing Facility
SLS	Spacelab Life Sciences
SOS	Space Operations Simulator
SOUP	Solar Optical Universal Polarimeter
SPARTAN	Shuttle Pointed Autonomous Research Tool for Astronomy
SPAS	Shuttle Pallet Satellite
SRB	Solid Rocket Booster
SSBUV	Shuttle Solar Backscatter Ultraviolet
SSIP	Shuttle Student Involvement Program
STA	Shuttle Training Aircraft
SURF	Synchrotron Ultraviolet Radiation Facility
SUSIM	Solar Ultraviolet Spectral Irradiance Monitor
SWAA	Scientific Window Adaptor Assembly
TAL	Transoceanic Abort Landing
TCDT	Terminal Countdown Demonstration Test
TDRS	Tracking and Data Relay Satellite
TISP	Teacher In Space Project
TLD	Thermoluminescent Dosimeter
TPAD	Trunnion Pin Attachment Device
UARS	Upper Atmosphere Research Satellite
UIT	Ultraviolet Imaging Telescope
USML	United States Microgravity Laboratory
VAB	Vehicle Assembly Building
VCAP	Vehicle Charging and Potential
VCGS	Vapour Crystal Growth System
VHRR	Very High Resolution Radiometer
VPF	Vertical Processing Facility
WCDT	Wet Countdown Demonstration Test
WETF	Weightless Environment Training Facility
WUPPE	Wisconsin Ultraviolet Photopolarimeter Experiment

1

Flight of the Geritol Bunch

SPACE COWBOYS

Publicly, Paul Weitz' STS-6 crew was nicknamed 'The F-Troop'.

The nickname originated from a television series about an ageing cavalry unit and partly honoured their military backgrounds, as well as reflecting the fact that they were the sixth team of astronauts to fly the Space Shuttle. It was Weitz' idea and they even had 'official' F-Troop photographs and memorabilia produced.

"We had little T-shirts and pants," remembered Mission Specialist Don Peterson, "and bought cowboy hats. I had a sword that had once belonged to some lieutenant in Napoleon's army. We got a Winchester lever-action rifle, a bugle and a cavalry flag. Weitz was the Commander and sat there, very stern-looking, with the sword sticking in the floor. We had that picture made and were passing them out and NASA asked us not to do that. They thought it was not dignified, but I thought it was hilarious!"

Certainly, the aged cowboy image was apt, because when Challenger roared into clear Florida skies on April 4th 1983 to begin her first orbital voyage, Weitz, Peterson, Pilot Karol 'Bo' Bobko and Mission Specialist Story Musgrave may have inspired the movie 'Space Cowboys' as the oldest astronaut crew to date.

In fact, behind their backs and with tongues firmly embedded inside cheeks, fellow astronauts dubbed Weitz' team, somewhat less flatteringly, 'The Geritol Bunch'. Years later, Peterson would not recall that nickname with quite as much fondness. "Maybe that was something everybody said about us when we weren't around," he said, "but when we were in orbit, somebody was talking about 'how old you guys are'. We had a bunch of F-Troop pictures and I couldn't resist, so I said 'We're not going to show these to anybody under 35 when we come back, so you wises-asses won't see them!' "

It was true that the four men of STS-6, with a combined age of 191, were the oldest yet launched. Only Weitz had flown before – on a four-week mission to the Skylab space station in mid-1973 – and later assumed the mantle of deputy chief of NASA's astronaut corps. For his crewmates, it was their first flight, but all had vast expertise on the ground. Particularly notable was Musgrave, who had amassed extensive flying time as a US Marine Corps aviator and secured half a dozen degrees, yet waited an unenviable 16 years for his first trip into space.

Scientist, doctor, engineer, pilot, mechanic, poet and literary critic, Musgrave approached STS-6 with the characteristically philosophical outlook for which he was to become famous. "I got into this business to be on the intellectual and physical frontier," he said. "I wanted a transcendental experience – an existential reaction to the environment. I'm not talking about an illusion or seeing something that wasn't there, but a magical emotional reaction to the environment. That is what I've been after all my life: to experience and feel new sensations."

Many astronauts, without much hesitation, have labelled six-time spacefarer John Young as their hero, icon and one of the most outstanding pilots ever rocketed into the heavens; if that is true, then Musgrave is undoubtedly among the most spiritual. Indeed, Swiss astronaut Claude Nicollier – who flew with him on STS-61 in 1993 – likened Musgrave's intelligence to that of a super-developed alien. Others who worked with him over the years have paid tribute to his remarkable attention to detail and insistence on knowing every part of his mission, down to the tiniest aspect.

Musgrave has freely admitted that, even on his first flight, he exuded an aura of self-confidence "in myself and the mission. I knew what was going to happen – and it happened! I knew every valve, every switch and every number on this flight. It was sheer play for me to be able to so completely interact with my environment."

UNEXPECTED CHANGE

"Story was a fun guy to work with," remembered Peterson. "On the job, he was extremely dedicated and would do anything; he'd work 20 hours a day! He didn't argue about anything, but just did whatever needed to be done. It's really delightful to work with a guy like that." Musgrave would ultimately fly six times into orbit, but was already a rising star at NASA, having closely followed, virtually from conception, the development of the Shuttle's spacesuit. Entirely appropriately, on STS-6, he and Peterson became the first men to perform a 'real' spacewalk and show what it could do.

Their historic excursion came about by accident, rather than design.

A planned outing on STS-5 in November 1982, featuring astronauts Bill Lenoir and Joe Allen, was jinxed from the start when two members of Space Shuttle Columbia's crew suffered severe bouts of motion sickness. More trouble was afoot, however, when they finally donned their suits and ran through the laborious, pre-spacewalk checks. A problem was noted in Allen's ventilation fan; it sounded, said the crew, "like a motorboat". In effect, it was starting up, running unexpectedly slowly, surging, struggling and finally shutting itself down.

Nor was Allen's suit the only one causing headaches. The primary oxygen regulator in Lenoir's snow-white ensemble – which he would have used during a series of 'pre-breathing' exercises and throughout the spacewalk itself – failed to produce enough pressure; regulating to 3.8 psi instead of the required 4.3 psi. Several of the astronauts' helmet-mounted floodlights also failed to work properly. After fruitless attempts to troubleshoot the problems, the spacewalk was cancelled and deferred to Weitz' mission, scheduled for just ten weeks later.

"It didn't give us much time to train," recalled Peterson. "I didn't have much experience in the suit, but the advantage we had was that Story was the astronaut office's point of contact for the suit development, so he knew everything there was to know. He'd spent 400 hours in the water tank, so he didn't really have to be trained."

This water tank was known as the Weightless Environment Training Facility (WETF) in Building 29 of NASA's Johnson Space Center (JSC) in Houston, Texas. In anticipation of the immense spacewalking load required to build the International Space Station, in 1997 the WETF was superseded by the larger Neutral Buoyancy Laboratory. Since the mid-1960s, the use of 'neutral buoyancy' – placing astronauts, fully suited and laden with lead weights, underwater – has been recognised as an effective means of simulating the 'zero gravity' of low-Earth orbit.

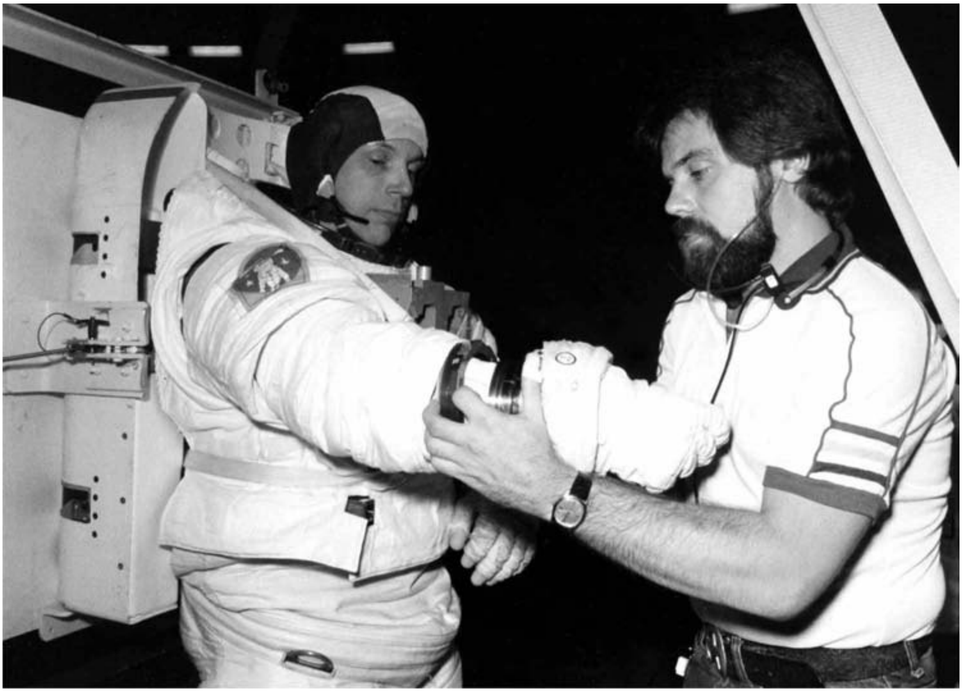
Accompanied by scuba divers to ensure their safety, Musgrave and Peterson were thus able to rehearse both planned and contingency procedures for their spacewalk in the 7.6 m deep tank. Measuring 23.8 m long, 10.1 m wide and holding almost 1.9 million litres of water, together with a full-size model of the Shuttle's crew cabin, airlock and cavernous payload bay, the WETF's value was balanced by a number of lingering concerns.

"Its disadvantages," said astronaut Bruce McCandless, whose involvement in the suit's development closely rivalled Musgrave's own, "included the optical distortion caused by looking out through a concave helmet in the optically denser medium of water. That caused everything to look smaller, coupled with the viscous drag from the water and the risk of 'bends' if you stayed in too long and too deep."

Of course, during their training, neither Musgrave nor Peterson was truly 'weightless', and two key differences between operating in the tank and working in space were that they could still 'feel' the weight of their 125 kg suits and the effect of the water, which tended to make some tasks easier to perform on the ground. "The WETF lied to us," admitted astronaut Kathy Sullivan, explaining that pressure differences 'inside' and 'outside' the suits in orbit were greater than in the tank, meaning that fingers, arms and legs became harder to bend in space.

Nevertheless, even today, the concept remains the closest parallel to the real thing. During typical training runs, the scuba divers guided Musgrave and Peterson into the pool and fitted the weights onto their suits, to enable the pair to 'hang' in the water, neither rising nor sinking.

Inside the bulky ensembles, conditions became both uncomfortable and painful. The men's bodies were supported by the weight of their suits, which meant "the blood ran to your head when upside down," explained McCandless, "and your weight was supported on your collarbone!" This made a precise fit essential: both astronauts' heels had to be firmly planted against the backs of their boots, their shoulders against their harnesses and their heads touching the crowns of their helmets. Horror stories from earlier missions, in which astronauts lost untrimmed nails because of imperfectly fitting suits, also required gloves to be close to fingertips.



Fully suited, Story Musgrave prepares for submersion in the WETF to practice his upcoming spacewalk.

"It used to be a form of medieval torture to hurt people's fingernails," Peterson said, "but the gloves, if they're wrong, can be really bad." On the Apollo 15 expedition to the Moon in mid-1971, astronaut Dave Scott's gloves were so tight that he lost several fingernails and was forced to take aspirin to keep working. Too loose, on the other hand, and spacewalkers could lose the ability to feel and grip objects or make precise movements.

Astronaut George 'Pinky' Nelson, who worked on the development of the spacesuit before making two excursions of his own in April 1984, likened the effects of hand fatigue to "squeezing a balloon", adding that any irritation or pressure points could quickly lead to soreness in the fingers. Consequently, the gloves were manufactured in 15 sizes, permitting sufficient dexterity, according to Nelson, to pick up a coin the size of a penny, "given enough time!"

"My training was pretty rushed," recalled Don Peterson of his STS-6 preparations. "I was in the water 15 or 20 times, and that's not really enough to know everything you need to know. But all we were doing was testing the suit and the airlock, so we weren't doing anything critical to the survival of the vehicle. We were just testing equipment and the deal was that if something went wrong, we'd stop and come back inside. The fact that I wasn't highly skilled in the suit didn't matter that much."

Immediately after Columbia landed from STS-5, a task force was established, led by NASA's Richard Colonna, to investigate the spacesuit anomalies. The fault in Lenoir's suit was traced to two missing 'locking' devices – each the size of a grain of rice – in the primary oxygen regulator. The paperwork provided by its manufacturer, Hamilton Standard of Hartford, Connecticut, indicated that the devices had been fitted in August 1982, but actually they had not been fitted at all and inadequate checking failed to discover this. It was their absence that allowed the pressure in Lenoir's suit to drop back by half a pound.

The problem with Allen's suit was a faulty magnetic sensor in the fan electronics. Colonna's report, published in December 1982, pointed out that "even with no improvements, if the regulator were fabricated properly, the [backpack] would function properly". It also listed ways to test and inspect the regulators and motors, in addition to recommending checks inside the Shuttle's airlock on the day before launch. Additional plans were laid out to provide sensors with better moisture resistant coatings to future motors and to initiate new tests to highlight manufacturing defects, although these measures were not ready in time for STS-6.

BIRTH OF CHALLENGER

Musgrave and Peterson's moment of triumph would make them the first Americans to leave their spacecraft in orbit since February 1974 and give the world a glimpse of the new Shuttle suit in action. Today, it has become increasingly familiar as missions have routinely serviced the Hubble Space Telescope and begun constructing the International Space Station. Yet, originally, in the early developmental days of the Shuttle, an Extravehicular Activity (EVA) capability was considered unnecessary and was not provided.

"The NASA perspective of the Shuttle was an airliner," explained spacesuit engineer Jim McBarron, "and the people inside it wouldn't need suits. It was through prompting and questioning that Aaron Cohen, who was then the Shuttle's project manager, accepted a contingency capability for closing the payload bay doors – which was an issue they were faced with – to put in an EVA capability."

To understand the purpose of this payload bay, one must first comprehend the underlying reasons for the Shuttle's existence and the billions of dollars invested in what was undoubtedly the most advanced spacecraft yet to leave Earth. As well as being advanced, the four-strong fleet of orbiter vehicles were also to be reusable; capable of flying, supposedly, every fortnight to carry commercial satellites, scientific laboratories, space probes, astronomical instruments and – for the first time – ordinary civilians aloft. Plans were underway to send teachers, journalists and foreign nationals into space, with up to seven seats available on each mission.

The delta-winged Shuttle, which made its first orbital flight in April 1981 with a pioneering, two-day voyage by Columbia, was appropriately named: it would whisk people into space frequently, reliably, relatively cheaply and in conditions a world away from the cramped, one-use-only ballistic capsules of the 1960s. History has shown that only a few of these promises were fully realised.

Challenger rolls from the Orbiter Processing Facility to the Vehicle Assembly Building for attachment to her External Tank and Solid Rocket Boosters. Delta-winged and intended to be the spacegoing equivalent of a commercial airliner, the Shuttle never fully realised NASA's promise of 'routine' access to space.

Before such a complex machine could be declared to be operational, it had to be exhaustively tested. Much of this work took place during and after its construction and a series of high-altitude approach and landing runs were conducted in mid-1977 using an aerodynamic test vehicle called Enterprise, hauled aloft from Edwards Air Force Base in California by an adapted Boeing 747 airliner and released to glide back. Astronaut Fred Haise, one of her pilots, later called it "a magic carpet ride". Although she was never capable of flying into space and is now on display in the Smithsonian, Enterprise demonstrated the Shuttle's aerodynamic performance and ability to make precise landings on pre-determined runways.

Overall, Haise was happy with her flying characteristics. "It handled better, in a piloting sense, than we had seen in any simulation," he said later, "either our mission simulators or the Shuttle Training Aircraft. The term I use is that it was tighter. It was crisper in terms of control inputs and selecting a new attitude in any axis and being able to hold that attitude. It was just a better handling vehicle than we'd seen in the simulations."

Initially, it was hoped that, following her approach and landing tests, Enterprise would be extensively upgraded to make her capable of travelling into space. In March 1978, she moved to NASA's Marshall Space Flight Center (MSFC) in Huntsville, Alabama, and spent the following year undergoing further tests. The results prompted a number of design changes, after which she would be modified for her first orbital mission. However, as time has shown us, this never happened.

Lessons learned during her fabrication were subsequently incorporated into the design of Columbia and NASA realised in 1978 that Enterprise weighed too much to transport a full payload into orbit; she would need a new set of plans, quite different from those of her sister, to render her spaceworthy. Moreover, she contained no propulsion system, plumbing, fuel lines or tanks. Her three main engines were all dummies, her payload bay had no mounting hardware for cargo, its doors had no opening mechanisms or radiators and her thermal protection system was little more than black and white polyurethane and fibreglass.

In view of the fact that Enterprise would not be launched in the manner planned for her successors, nor fly in space, the instrument suite in her cabin was sparsely furnished with switches and dials, compared to later orbiters. She had no guidance equipment, such as star trackers or heads-up displays, and no indicators of the systems of an external fuel tank and twin solid-propellant rocket boosters that would support her violent climb into space. Elsewhere, she had no aft flight deck or overhead windows, no airlock, no middeck lockers, no galley and her fuel cells were high-pressure tanks, rather than cryogenic powerplants. Her landing gear was operated by explosive bolts, with no hydraulic mechanisms or manual backup systems.

She did, however, carry a pair of Lockheed-built ejection seats which would have fired her two pilots through a pair of aluminium panels in the ceiling in the event of an emergency. Modifying her for space missions, therefore, was envisaged to be a long, complex and costly process. Additionally, the new design specifications called for much stronger wings and mid fuselage than Enterprise possessed and several aluminium components would have been changed to titanium to save weight.

Transportation and modification funds to accomplish this were simply unavailable and, as 1978 wore on, NASA was already looking to a high-fidelity structural test article known as 'STA-99' as a cheaper option to upgrade for orbital service. Since the original Shuttle contracts were signed in July 1972, the reusable spacecraft's design had evolved under such weight-saving pressures that virtually all airframe components were required to handle significant structural stress. Furthermore, in view of the difficulties involved in accurately predicting mechanical and thermal loads on the vehicle using the limited 1970s-era computers, NASA opted to build STA-99 specifically as an engineering tool.

As a result, after its completion in February 1978, the structural test article underwent a year of intensive evaluation in a steel rig at Lockheed's Plant 42 facility in Palmdale, California. Originally built to test the Lockheed TriStar aircraft, the rig's 256 jacks subjected 836 load application points to pressures equivalent to those of launch, ascent, orbital flight, re-entry and landing. Even the tremendous jolt of main engine ignition was simulated by three hydraulic cylinders, each imparting a force of 450,000 kg. Additionally, cold nitrogen gas and thermal blankets were employed to recreate the frigid conditions of orbital flight and the intense heat of atmospheric re-entry. The decision to modify STA-99 as a 'true' orbiter came about because, unlike Enterprise, it was a bare, incomplete airframe and could be more economically upgraded.

Traditionally, manned spacecraft had been tested to 140 per cent of their design strength, but NASA engineers recognised that this might cause so much damage to STA-99 as to make it inadvisable to do so. Consequently, JSC's Thomas Moser and his team developed an analytical computer model to simulate over 3,000 measurement points on the airframe. Their results confirmed that it could easily withstand 140 per cent loads, with actual stress distributions in critical areas comparing favourably with pre-test model data.

On January 29th 1979, it was made official. Under a $1.9 billion contract between NASA and Rockwell International, STA-99 would follow Columbia into orbit as the second space-capable vehicle and two new orbiters would be built. On February 2nd the structural test article was renamed 'Challenger'.

Like Columbia (and, indeed, the subsequent vehicles), Challenger was named for a seafaring vessel that had made an outstanding contribution to exploration. The historical, nautical Challenger made a prolonged cruise from December 1872 until May 1876, gathering the equivalent of 50 volumes of information about the Atlantic and Pacific Oceans. Later, the name's proud heritage continued when the Apollo 17 crew chose it for their lunar module in December 1972.

However, ground evaluations, practice landings and structural test articles were no substitute for actually operating in space. Before she could be declared ready for flight, Challenger required substantial disassembly and rework – including the 'beefing-up' of her wings and installation of heads-up displays for her pilots – that got underway at Rockwell's Palmdale plant in November 1979. Her payload bay doors, aft body flap and elevons were removed and returned to their vendors for refurbishment, with her tailfin following in January 1980.

She had been built with a simulated crew cabin, which required the two halves of

The airframe of STA-99 during construction at Rockwell's Palmdale plant in 1977.

her forward fuselage to be 'cracked open' to remove it for modifications. In July 1981, after its own series of improvements, the aft fuselage returned to Palmdale. In physical appearance, the rebuilt Challenger looked similar to Columbia and Enterprise, at least at first cursory glance. External appearances, though, proved deceptive.

All three vehicles were similar in shape and approximate dimensions to the DC-9 airliner: roughly 36 m long with wings spanning 24 m from tip to tip. They comprised a two-tiered cockpit, cavernous, 18-m-long payload bay with clamshell doors and an aft compartment housing a cluster of three main engines, bulbous Orbital Manoeuvring System (OMS) pods and a vertical tailfin. Forty-four tiny Reaction Control System (RCS) thrusters in her nose and tail would provide additional manoeuvrability whilst in space.

Opening the graphite epoxy payload bay doors – the largest aerospace structures ever built, at that time, from composite material – was among the astronauts' first tasks in orbit, in order that radiators lining their interior faces could begin to shed excess heat from the electronic systems into space. The five-piece doors were hinged at either side of the mid fuselage, mechanically latched at the forward and aft bulkheads and thermally sealed at the centreline. Ordinarily, they were driven 'open' and 'closed' by electromechanical power drive units and gears, but if Weitz' crew had been unable to open the doors, flight rules dictated they return to Earth at the earliest opportunity. Conversely, if the doors would not close at mission's end, then Peterson and Musgrave were to go EVA and operate the mechanism manually.

WORKCLOTHES

As well as practicing how to manually winch the doors closed, plans for STS-6 called for Musgrave, designated 'EV1', with red stripes on the legs of his spacesuit for identification, and Peterson ('EV2') to rehearse procedures for the tricky recovery and repair of NASA's crippled Solar Max satellite, which was scheduled for the spring of 1984. Although the excursion was intended to last barely four hours, preparing for and conducting it consumed virtually the crew's entire work day on April 6th 1983.

Aided by spacewalk choreographer Bo Bobko, the two men rose early that morning to begin readying their equipment and Challenger's airlock, before spending three and a half hours 'pre-breathing' pure oxygen to wash nitrogen from their bloodstreams and avoid potentially lethal attacks of the 'bends'. Otherwise known as 'caisson disease', the bends are triggered by the formation and expansion of nitrogen gas bubbles in the blood when subjected to a rapid decrease in external pressure. The consequences can be dire: ranging from severe pain in the joints to paralysis and eventually death. Indeed, the name 'bends' comes from the fact that sufferers instinctively bend into a foetal position.

To sidestep this danger, in a procedure similar to that commonly followed by deep-sea divers, Musgrave and Peterson spent time in Challenger's 14.7-psi middeck, pre-breathing pure oxygen from facemasks to prepare themselves for operating inside the spacesuits at 4.3 psi pure oxygen.

Shortly before the onset of pre-breathing, the entire cabin had been reduced from its normal pressure to around 10.2 psi, while the percentage of oxygen in the atmosphere was slightly increased. As Musgrave and Peterson breathed through their masks, they were still able to attend to their other tasks on the middeck. At the end of pre-breathing, with sufficient dissolved nitrogen now cleared from their blood, they were at last ready to begin donning their spacesuits.

Most of this was done inside the airlock – a cylindrical structure about the size of a Volkswagen Beetle, situated at the rear of the middeck. Its inclusion within the cabin preserved the maximum amount of usable volume in the payload bay. It had two hatches: one for the astronauts to enter from the middeck and another through which they would venture into the payload bay. The interior was decidedly cramped and veteran spacewalker Michael 'Rich' Clifford lucidly described hanging in his bulky suit, barely able to even move his arms ...

Depressurisation was controllable either from the flight deck or within the airlock itself. Normally, two spacesuits were stored inside the chamber, although there was room for up to four, if needed. In fact, long after Challenger's tragic demise, many missions have involved four spacewalkers, working in two alternating pairs, and in May 1992 on STS-49 the airlock successfully demonstrated its ability to support three fully suited astronauts at the same time.

Since reaching orbit, Weitz, Bobko, Peterson and Musgrave had checked and rechecked their equipment for the long-awaited spacewalk: testing a third, 'spare' upper torso in accordance with flight rules, verifying that oxygen regulators and fans operated normally, inspecting for leaks and confirming that communications were satisfactory. In fact, the only problem raised was a need to replace some flat floodlight batteries. With everything in place, spacesuit donning began and, in true F-Troop fashion, it ran as crisply as a military campaign.

"You don't just put the suit on and open the hatch," Peterson explained. "You make sure everything's laid out properly and everything that you check is working properly. We were instrumented with little stick-on patches to measure our heart rates. Then we put on what looked like long underwear – a cooling garment – which had water tubes that ran through it and hooked through a connector to the suit."

This long underwear, officially known as the 'liquid cooling and ventilation garment', was a one-piece, zip-up suit, based on one developed for moonwalkers, composed of stretchable spandex fabric and laced with 91.5 m of plastic tubing. During the course of their spacewalk, cooling water would be pumped through this tubing to control Musgrave and Peterson's body heat, exhaled gases and perspiration. Next, anti-fog compound was rubbed onto the insides of their helmets. "I wore glasses," said Peterson, "and we rubbed this on the lenses so they wouldn't fog up, because I was inside a helmet and couldn't get my hands inside the suit."

To provide an additional measure of safety and prevent them from falling off, Peterson's glasses were tied to an elasticated strap around the back of his head.

Before actually clambering into the two-piece spacesuits, electrical harnesses were attached to their 'hard' upper torsos to provide biomedical and communications links through the backpack. A wrist mirror and spiral-bound, 27-page checklist were placed on each suit's left arm, followed by the insertion of a small fruit and nut food bar and water-filled drink bag. The next step was the connection of a black-and-white communications hat – famously nicknamed the 'Snoopy cap' since Apollo days – to the top of the torso.

Physically, the so-called Extravehicular Mobility Unit (EMU) was a $2.5 million miniature spacecraft in its own right, consisting of 'upper' (above-waist) and 'lower' (below-waist) segments, together with helmet, gloves and life-support backpack. Musgrave and Peterson firstly pulled themselves into the lower torso, which featured joints at its hips, knees and ankles and a metal body seal closure for connecting to a ring on the upper torso. It also included a large bearing at its waist, which offered greater mobility and allowed the astronauts to twist whilst their feet were held firmly in restraints.

After donning the trousers of the suit, their next step was to plug the airlock's service and cooling umbilical into a display and control panel on the front of the upper torso. This would provide cooling water, oxygen and electrical power from the Shuttle until shortly before they were scheduled to go outside, thereby conserving the limited consumables available in their backpacks. The two men finally entered the airlock itself, where the upper torsos 'hung' on opposing walls and, through a half-diving, half-squirming motion, manoeuvred themselves into the top halves of their suits.

With arms outstretched, and Bobko nearby to assist, they slipped themselves into the upper torsos and their waist rings were brought together, connecting the cooling water tubing and ventilation ducting of the long underwear and the biomedical sensors to their backpacks. Bobko then helped them to lock the body seal closure rings at their waists.

The hard upper torso was essentially a fibreglass shell under several fabric layers of a thermal and micrometeoroid garment. On its back, it held the life-support system and on its chest the display and control unit by which the spacewalker would manage his or her oxygen, coolant and other consumables; in fact, due to the difficulties in seeing 'down' to read labels on the unit, the mirrors on the suits' left wrists would help immeasurably. For additional ease, the labels were written backwards!

"The displays and controls in the suit are a challenge," said Pinky Nelson, who worked with Musgrave to develop them, "because you have to see them from inside the suit, looking down, so a lot of the old guys in the astronaut office couldn't read the displays as they were close to your face. We worked on [Fresnel] lenses and all kinds of ways to make the displays legible to people with old eyes!"

To aid his 49-year-old eyes, just before donning the helmet, Peterson tied his glasses securely onto his head and pulled on his Snoopy cap, equipped with microphone and headphones to provide two-way communications with his crewmates and Mission Control. Next came the gloves. Snapped into place on the wrist rings of the upper torso, these had silicone rubber fingertips to provide a measure of tactile sensitivity when handling tools in Challenger's payload bay.

Finally, the enormous polycarbonate bubble helmets were lifted over the astronauts' heads and clicked into place on the neck rings of their upper torsos. Over the top of each helmet was an assembly containing manually adjustable visors to shield their eyes from solar glare, together with two EVA lamps to illuminate work areas out of range of the Sun or the Shuttle's own payload bay floodlights. Mobility in the neck rings was unnecessary, because the helmets were easily big enough to allow the astronauts to move their heads around.

Unlike previous Apollo spacesuits, the modularised Shuttle ensemble, with its waist closure ring, eliminated the need for pressure-sealing zips and therefore had a much longer shelf life. Additionally, the use of newer, stronger and more durable fabrics enabled spacesuit engineers to design joints with better mobility, resulting in lower weight and a reduction in overall cost.

TIME TO OPERATE

Story Musgrave and Don Peterson, by now floating motionless in Challenger's tiny airlock, were, in effect, small spacecraft in their own right. However, they were not yet 'self-contained', as their oxygen, electricity and cooling water were still being provided by the Shuttle's systems; not until shortly before the two men ventured outside would they transfer to the life-support utilities of their suits' onboard consumables. Before they could do that, they had to lower the airlock's pressure to 4.3 psi in order to check their integrity, necessitating a final 45 minutes of pre-breathing.

At last, at 9:21 pm on April 6th 1983, Musgrave initiated the final depressurisation of the airlock and pushed open the outer hatch leading into the payload bay. The plan called for three hours of activities, but in order to accommodate delays he and Peterson had up to six hours' worth of consumables. Entering the overwhelmingly floodlit bay for the first time, one of his first comments, somewhat understatedly, was that "it's so bright out here!"

Their time outside was limited, but the experience would remain with both men for the rest of their lives. "You remember little things like sound," Musgrave told a post-flight press conference. "Even though there's a vacuum in space, if you tap your fingers together, you can hear that sound because you've set up a harmonic within the spacesuit and the sound reverberates within it. I can still 'hear' that sound today. But the main impression is visual: seeing the totality of humanity within a single orbit. It's a history lesson and a geography lesson – a sight like you've never seen."

Watching through the aft flight deck windows, Paul Weitz would later quip that "Story seemed like a butterfly coming out of a chrysalis – only he's not as pretty!" For Musgrave, who had spent years virtually designing the spacesuit that he now depended upon for his life, it was an intensely personal accomplishment. "This was to be only three hours of experience on top of 48 years," he said later, "but it's like a surgeon who's been training 16 years to operate. Sooner or later, a surgeon has to operate. Sooner or later, I knew I was meant to walk in space."

The poetic justice of being first to venture into space wearing the fruit of so many of his labours was clearly not lost on the intensely philosophical Musgrave.

Although somewhat different from the ensembles worn on previous Gemini and Apollo missions, they were designed with the same objective in mind: to leave the pressurised confinement of a spacecraft. However, the near-flawless procedures followed by Musgrave, Peterson and Bobko to don the suits masked a complex, tumultuous and near-tragic developmental history. "We had ten major replans,"