SPACE CHRONICLE
THE BRITISH INTERPLANETARY SOCIETY JOURNAL OF SPACE HISTORY
VOLUME 73 APRIL 2020

Hubble at 30

THREE DECADES IN SPACE AND STILL GOING STRONG

SOVIET AND RUSSIAN NUCLEAR SPACECRAFT

THE US NAVY'S SPACE SHIP

CHINA AND JAPAN EYE UP THE MOON

SPACE CHRONICLE

THE BRITISH INTERPLANETARY SOCIETY JOURNAL OF SPACE HISTORY

Letter from the Editor

Welcome to the new-look SPACE CHRONICLE, with its fresh design and focus on international aspects of space history across the decades. Published quarterly, in January, April, July and October each year, forthcoming issues will include in-depth features on rockets and spacecraft, early politics and space infrastructures, and human and robotic operations. As the magazine develops, each full-colour 40-page issue will also cover the space sciences and engineering, and investigate obscure developments and failed projects as well as the successes. There will be reviews of new and second-hand space history books, a section for your letters, a look back at key events from over a century of space history and much more.

SPACE CHRONICLE is first and foremost a magazine for all those with a passionate interest in how the global space programmes of today came to be. And, as we know, present-day activities and visions of the future very quickly become tomorrow's history, providing yet more fertile ground for future issues of the magazine to explore and share with other readers.

Readers are warmly invited to contact the Editor about writing features for SPACE CHRONICLE and we're especially keen to provide an outlet for new and emerging talents to publish their research – much as the present editor Editor was able to do back in the 1970s. Mike Bryce, who wrote this issue's feature article on the 30th anniversary of Hubble is one such author who has taken up that opportunity in this issue. So, please read on and I look forward to your feedback and participation with the BIS in this new and exciting voyage through annals of international space history.

David J. Shayler FBIS
editorchronicle@bis-space.com

About your editor
Space flight historian David J. Shayler was born in England in 1955. After leaving school, he trained as an engineering draughtsman prior to serving in HM Forces Royal Marines. After returning to civilian life, he worked in a variety of roles in the retail industry for over 20 years before becoming a full-time writer.

David's life-long interest in space began with drawings of rockets at the age of five but it was with the launch of Apollo 8 in December 1968 that it became a passion. He fondly recalls staying up all night with his grandfather to watch the Apollo 11 Moonwalk.

David joined the British Interplanetary Society (BIS) in January 1976, becoming an Associate Fellow in 1983 and a Fellow in 1984. Over the past 20 years he has sat, at various times, on the Society's Education, History, Library (including a term as its Chairperson), Membership and Publications Committees. From 2013 to 2019 he also served as a Member of the Council of the BIS and since 2012 he has coordinated the annual Sino-Russian Technical Forum.

The BIS published the first of David's articles in *SpaceFlight* during the late 1970s and in 1982 he created Astro Info Service (**www.astroinfoservice.co.uk**) to focus his research efforts. His first book was published in 1987 and has been followed by almost 30 other titles, including works on the U.S. and Russian space programmes, spacewalking, women in space, and the human exploration of Mars. His authorized biography of Skylab 4 astronaut Jerry Carr was published in 2008.

OUR MISSION STATEMENT

The British Interplanetary Society promotes the exploration and use of space for the benefit of humanity, connecting people to create, educate and inspire, and advance knowledge in all aspects of astronautics.

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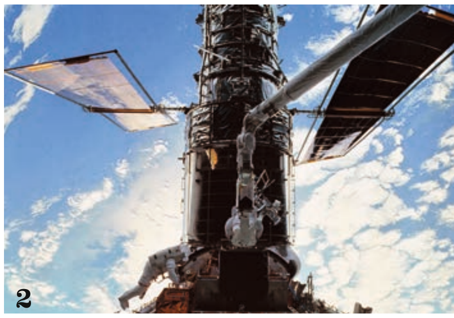
On the cover: 30 years ago, on April 25, 1990, the Remote Manipulator System (RMS) of *Discovery* releases the Hubble Space Telescope, captured here in an IMAX® frame still, with a cloudy blue Earth reflected in the closed Aperture Door.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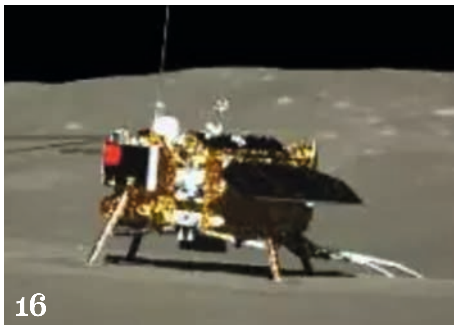
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Contributors to this issue

Mike Bryce first became interested in astronomy while at school and since 1993 has edited the Midland Spaceflight Society magazine *Capcom*. Professionally, he started as a draftsman before joining British Rail's Civil Engineering department in 1990. After 28 years in the rail industry he took early retirement to follow his primary interests of astronomy, space exploration and photography.

Philip Mills served in the Royal Air Force, working on V-Bombers and surface-to-air missiles. Nowadays he combines an interest in space exploration with a fascination for modelling, which led him to build scratch-built models of the early Soviet orbital space stations and even took him to the Pentagon, where he gave a talk to high-ranking members of the National Security and Space Office.

Dwayne A. Day is a senior program officer with the Aeronautics and Space Engineering Board of the National Academies of Sciences, Engineering, and Medicine in Washington, DC. He writes frequently on the history of intelligence collection on the Soviet space programme, U.S. satellite reconnaissance, and American civilian space programmes – both human and robotic.

Vadim Zakirov is a technical expert for Commercial Space Technolgies (CST) who has published more than 30 papers. He has a BSc in Aerospace Engineering from the Moscow Aviation Institute, an MSc in Aerospace Engineering from the University of Florida at Gainesville, and a PhD from the University of Surrey. Vadim worked as an Associate Professor for 10 years at Tsinghua University in Beijing.

Brian Harvey is a writer and broadcaster on spaceflight who lives in Dublin. He has a degree in history and political science from Dublin University (Trinity College) and an MA from University College Dublin. His first book was *Race into Space – the Soviet space programme* (Ellis Horwood, 1988), followed by over a dozen books for Springer/Praxis on the Russian, Chinese, European, Indian and Japanese space programmes.

NASA

NASA

HAPPY BIRTHDAY HUBBLE

30 YEARS EXPANDING OUR KNOWLEDGE OF THE UNIVERSE

On 24 April 1990, NASA launched the Space Shuttle *Discovery* on a mission to expand our knowledge of the heavens. The Hubble Space Telescope (HST), billed as the largest telescope to be placed in Earth orbit at the time, would come to revolutionise our current understanding of the Universe. But it was not without its problems.

by Michael Bryce

For centuries, mankind looked to the stars and wondered; and for centuries, those views of the heavens were marred by the Earth's atmosphere. Many astronomers thought that it would be possible one day to place a telescope in orbit, above the atmosphere, and have the sharpest and clearest possible view of the heavens.

In 1923, Hermann Oberth – considered a father of modern rocketry, along with Robert H. Goddard and Konstantin Tsiolkovsky – published *Die Rakete zu den Planetenräumen* ("The Rocket into Planetary Space"), which mentioned how a telescope could be launched into Earth orbit by a rocket.

Then, in 1946, the astronomer Lyman Spitzer wrote a paper "Astronomical advantages of an extra-terrestrial observatory". Spitzer discussed the two main advantages that a space-based observatory would have over ground-based telescopes. First, the angular resolution (the smallest separation at which objects can be clearly distinguished) would be limited only by diffraction rather than by the turbulence in the atmosphere, which causes stars to twinkle and is known to astronomers as seeing. At that time, ground-based telescopes were limited to resolutions of 0.5–1.0 arc seconds, compared to a theoretical diffraction-limited resolution of about 0.05 arc seconds for a telescope with a mirror 2.5 m in diameter. Second, a space-based telescope could observe infrared and ultraviolet light, which are strongly absorbed by the atmosphere.

ABOVE
Hubble in Earth orbit pictured from the Space Shuttle.

LEFT
The space telescope is successfully deployed from the payload bay of the Shuttle *Discovery*, 25 April 1990.

»

« During his devoted career, Spitzer pushed for the development of a space telescope. In 1962, a report by the U.S. National Academy of Sciences recommended development of a space telescope as part of the space program, and in 1965 Spitzer was appointed as head of a committee given the task of defining scientific objectives for a large space telescope.

Astronomy from space was in its infancy after the Second World War. Scientists made use of developments in rocket technology and in November 1946 the first ultraviolet spectrum of the Sun was obtained with an instrument on board a Sounding Rocket (an instrument-carrying rocket designed to take measurements and perform scientific experiments during its sub-orbital flight).

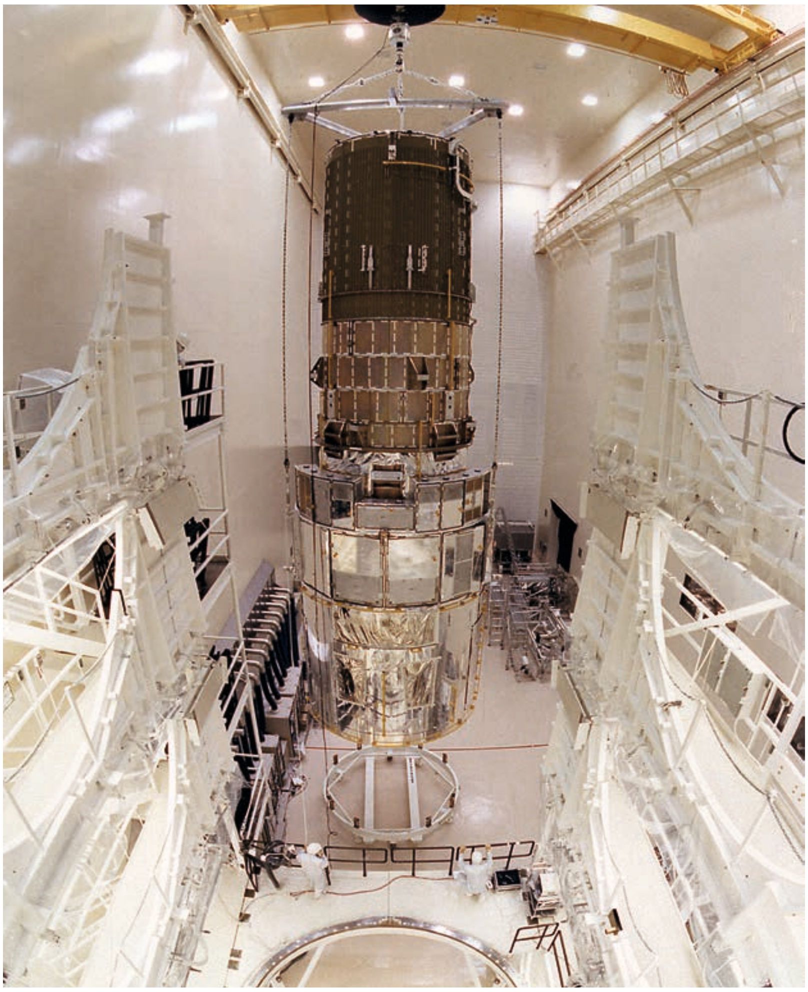
The first dedicated space-based solar observatory was launched in 1962 by NASA. The Orbiting Solar Observatory (OSO) was designed to obtain UV, X-ray, and gamma-ray spectra. Also in 1962, the United Kingdom launched an orbiting solar telescope as part of its Ariel space program. NASA launched the first Orbiting Astronomical Observatory (OAO) in 1966.

Although the first OAO suffered battery failure after just three days which terminated the mission, OAO-2 was a success, carrying out ultraviolet observations of stars and galaxies from its launch in 1968 until 1972,

ALL IMAGES: NASA

ABOVE
Namesake: the astronomer Edwin Hubble (1883-1953), who is credited with the discovery that what were once thought to be clouds of dust were, in fact, galaxies of stars far beyond our own.

BELOW
Hubble at Cape Canaveral being prepared for launch – delayed for four years by the *Challenger* disaster.



well beyond its original planned lifetime of one year. Although these spacecraft observatories were limited to the technologies of the time, including the size of their light-gathering mirror, the OSO and OAO missions demonstrated the important role space-based observations could play in the advancement of our astronomical knowledge.

In 1968, NASA began development of a space-based reflecting telescope with a mirror 3 m in diameter. Known provisionally as the Large Orbiting Telescope or Large Space Telescope (LST), with a launch slated for 1979, these plans emphasised the need for crewed maintenance missions to the telescope, to ensure such a costly program had a lengthy working life and that instruments and system parts could be replaced as technology advanced or when required.

In the 1970s, after the successful crewed missions of Apollo and Skylab, NASA focused attention on a reusable space Shuttle system that could deliver large payloads into Low Earth Orbit (LEO). As this Space Transportation System (STS) was being developed, the idea of developing a large space-based telescope which could be serviced by astronauts seemed a logical goal alongside the Shuttle system. In 1977, the American Congress approved the funding for the Large Space Telescope.

American astronomers outlined five principal objectives for the LST: "Explore the Solar System, measure the age and size of the universe, search for our cosmic roots, chart the evolution of the universe, and unlock the mysteries of galaxies, stars, planets, and life itself." Accomplishing such diverse objectives required a telescope that was capable of making minute geological observations of small asteroids and comets little more than a few hundred feet across on the one hand, while on the other hand studying and photographing super galaxy clusters billions of times larger than asteroids and comets in hopes of revealing the origins and destiny of the Universe.

The LST was constructed by NASA contractors Lockheed in Sunnyvale, California, while optics company Perkin

Elmer Corporation was chosen to build the 2.3 metre primary mirror, at its plant in Danbury, Connecticut. Under the European Space Agency (ESA) umbrella, British Aerospace designed and built the large solar panels at its Bristol site.

The telescope was built as an astronomical observatory for the use of the scientific astronomical community worldwide and as such, rules and procedures were put in place to allocate observation time for astronomers and researchers, along the lines of existing ground-based observatories. In 1981, a special science institute was set up on the Johns Hopkins University campus in Baltimore to operate the science instruments and allocate time to researching astronomers. The agreement between NASA and ESA enabled the European astronomical community to gain 15% of the telescope's observing time.

In 1983, NASA renamed the Large Space Telescope as the Hubble Space Telescope, after the renowned astronomer Edwin Powell Hubble who proved the existence of other galaxies and discovered the first evidence for an expanding Universe. By 1985, construction of the Hubble Space Telescope was completed and it was ready to be shipped to the Cape and launched into orbit. Hubble was designed with a 15-year lifespan, with four planned servicing missions.

Hubble was to be launched in August 1986 by *Atlantis* on mission STS-61J, in what could have been a bumper year for Shuttle flights. With no less than 15 Shuttle flights in NASA's manifest, including four missions with astronomical agendas and one flight from the West Coast, NASA and its Shuttle fleet had a mammoth year ahead.

However, as 1985 drew to a close, it became clear that the Hubble deployment mission on Atlantis would be delayed from its original August date until at least October 1986. This was due to swelling program costs and processing issues, which had pushed the astronomical observatory 30% over-budget and three months behind schedule.

Then, on 28 January 1986, disaster struck. The unforgettable *Challenger* accident forced NASA to ground the Space Shuttle fleet for more than two years. However, this extra time was well spent by the HST Project. Solar panels were improved with new solar cell technology, the aft shroud was modified to make instrument replacement during servicing easier and computers and communication systems were upgraded. The HST was subjected to further stress tests in the harsh environments of lift off and space.

Following more than two years of investigation, reorganisation and implementation within both NASA and its contractors, the Space Shuttle was given Return to Flight status. In September 1988, the 26th flight of the Space Shuttle was performed by *Discovery*. Launched from Kennedy Space Center on 29 September 1988, some 975 days after the *Challenger* incident, *Discovery* carried a long awaited Tracking and Data Relay Satellite (TDRS), which was successfully deployed.

"HUBBLE WAS TO BE LAUNCHED IN AUGUST 1986 BY ATLANTIS ON MISSION STS-61J, IN WHAT COULD HAVE BEEN A BUMPER YEAR FOR SHUTTLE FLIGHTS."

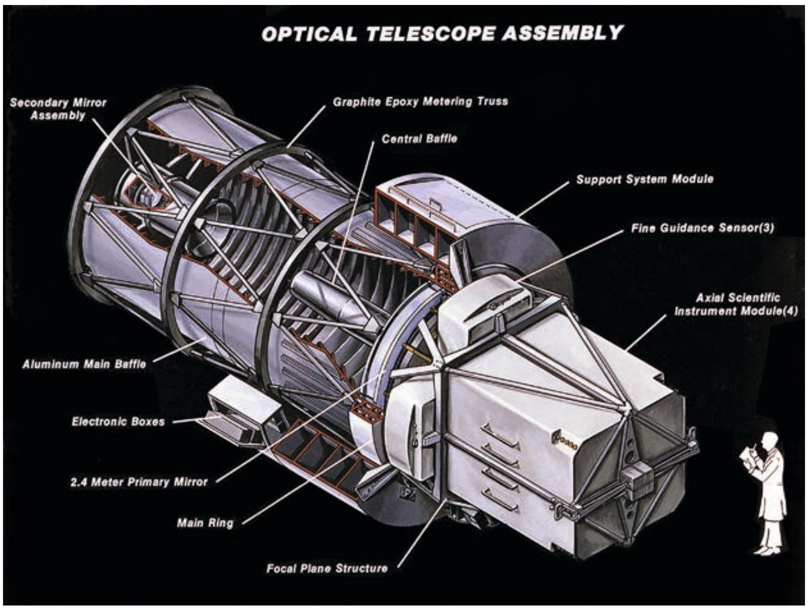
After eight more successful missions, it was finally time to launch the Hubble Space Telescope. HST was assigned to STS-31, the 35th mission of the Space Shuttle program, and used the Space Shuttle *Discovery* (the tenth flight for this Orbiter). Five crew members were assigned to STS-31 on a mission to last just over five days: Commander Loren J. Shriver on his second space flight; Pilot Charles F. Bolden Jr. on his second space flight; Mission Specialist 1 Bruce McCandless II on his second and last space flight; Mission Specialist 2 Steven J. Hawley on his third space flight; and Mission Specialist 3 Kathryn D. Sullivan on her second space flight.

In the words of Commander Shriver: "If there were ever two missions that were completely opposite in terms of the public attention that was given to them, it would be my first and second missions." It was no understatement. His first Shuttle flight had been totally cloaked in military secrecy, whereas his second launched NASA's scientific showpiece: the $1.5 billion Hubble Space Telescope.

LAUNCHING HUBBLE

Now targeted for the March-April 1990 timeframe, this launch posed its own challenges. Astronaut Kathryn Thornton said: "The year 1990 was close to a solar maximum year, so the envelope of the atmosphere is physically larger." This had implications for the precise altitude of Hubble's orbit and as a result, the Hubble deployment altitude was raised to a little over 610 km. This high altitude meant that a long-duration Orbital Manoeuvring System (OMS) firing of more than five minutes was needed for orbital »

BELOW
A contemporary NASA cutaway shows the basic internal layout of Hubble, plus a human silhouette for scale.



« insertion, and the effect upon the Shuttle's performance was that no less than 50% of the available OMS propellant for the whole five-day mission would be consumed by the time Discovery achieved orbit.

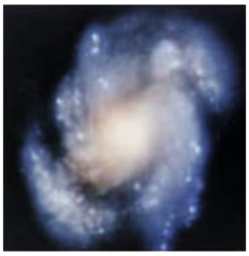
In the weeks before launch, it became evident that STS-31 would have much lower reserves of propellant at the start of its mission than had been typical on other flights. As a result, a significant amount of training time was devoted to how the crew responded to propellant leak alarms. On a regular mission, the first prudent step would have been to verify whether the alert was a false one, but on STS-31 the assumption had to be taken that it was a leak and preparations either to substantially lower their altitude or de-orbit had to be made quickly. All those steps had to be performed in parallel.

Discovery finally lifted off from Launch Complex 39B at Kennedy Space Center, Florida, on 24 April 1990. A previous launch attempt on 10 April was scrubbed at T-4 minutes for a faulty valve in auxiliary power unit (APU) number one. The APU was eventually replaced and the Hubble Space Telescope's batteries were recharged. On launch day, the countdown was briefly halted at T-31 seconds when *Discovery's* computers failed to shut down a fuel valve line on ground support equipment. Engineers ordered the valve closed and the countdown continued.

The primary payload was the Hubble Space Telescope, to be deployed in a 611.5 km orbit, the highest altitude reached by a Shuttle at that time. Secondary payloads were: IMAX Cargo Bay Camera (ICBC) to document operations outside the crew cabin, and hand-held IMAX camera for use inside the crew cabin; Ascent Particle Monitor (APM) to detect particulate matter in the payload bay; Protein Crystal Growth (PCG) to provide data on growing protein crystals in microgravity; Radiation Monitoring Equipment III (RME III) to measure gamma ray levels in the crew cabin; Investigations into Polymer Membrane Processing (IPMP) to determine porosity control in the microgravity environment; Shuttle Student Involvement Program (SSIP) experiment to study effects of near-weightlessness on electrical arcs; and Air Force Maui Optical Site (AMOS) experiment.

Astronaut Steve Hawley was assigned to operate the controls to lift Hubble away from the cargo bay. This was fitting as Hawley was an astronomer. In his NASA Oral History, Hawley quipped that he was chosen for the role because he was such a good RMS (Remote Manipulator System, the robot arm) operator, but he was convinced that the need for an astronomer on this most astronomical of missions was crucial, "for the simple reason that we want to make sure … that the needs and requirements of the customer are understood and dealt with appropriately." Of course, Hawley would not actually be using Hubble, nor would there be any real astronomy for him to perform, but he believed that it helped the scientists by having someone aboard who knew what they wanted to accomplish, knew the constraints, and, in a nutshell, cared about it.

With Hubble deployed successfully, and the event recorded on the IMAX camera in the cargo bay, the crew went on to other experiments before preparing *Discovery* for the return home to Edwards Air Force Base.



ABOVE
Hubble trouble: the telescope's initial myopia is amply demonstrated in these 'before and after' pictures of the M100 spiral galaxy.

> "IRONICALLY, A BACKUP MIRROR WAS CONSTRUCTED BY THE PHOTOGRAPHY GIANT KODAK AND THIS MIRROR DID NOT SUFFER THE SAME PROBLEM AS THE PERKIN ELMER VERSION"

BELOW
The official Service Mission 1 emblem. Assigned to STS-61 this was the first mission to return to the telescope in order to maintain it.

FIRST LIGHT

With any new telescope, the act of using the instrument on the sky for the first time is known as "First Light". This is usually quite a grand affair with the scientists and astronomers involved in the project.

A few weeks after deployment, in May 1990, Hubble's "First Light" images were downloaded to the computers at the Space Telescope Science Institute in Baltimore to the amazement of the astronomers, for the wrong reasons. What they saw was not good, not what they wanted to see. The images were not as sharp or as detailed as expected. In what was to be a pinnacle moment in NASA history, problems had struck again.

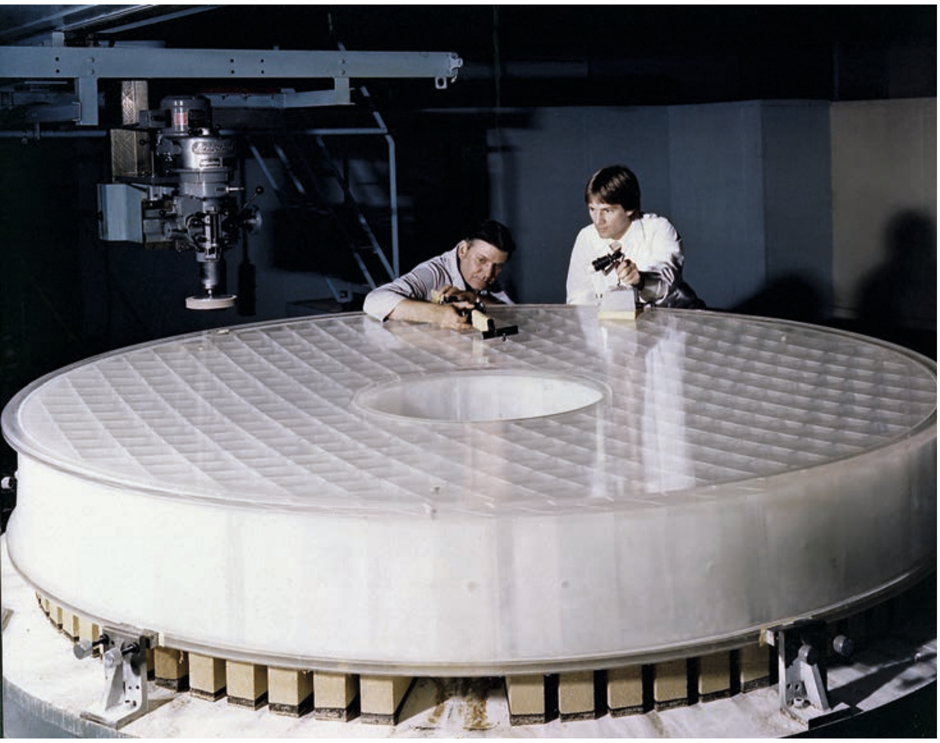
NASA was once again in investigation mode. Ultimately, the problem was traced to miss-calibrated equipment during the mirror's manufacture. The result was an aberration of one-50th the thickness of a human hair in the grinding of the mirror. Fortunately, Hubble was the first space telescope designed to be visited by astronauts to perform repairs, replace parts and update its technology with new instruments. NASA addressed Hubble's problem with the astronomical community and their contractors with the aim of providing a "solution" to Hubble's flawed vision.

Ironically, a backup mirror was constructed by the photography giant Kodak and this mirror did not suffer the same problem as the Perkin Elmer version. But it was too late. Hubble had been launched and the mirror was not designed to be changed whilst on orbit. The Kodak mirror is on public display at the Smithsonian National Air and Space Museum in Washington DC.

FIRST HUBBLE SERVICING MISSION: (STS-61) 2 DECEMBER 1993

When launched, the HST carried five scientific instruments: The Wide Field and Planetary Camera (WF/PC), Goddard High Resolution Spectrograph (GHRS), High Speed Photometer (HSP), Faint Object Camera (FOC) and the Faint Object Spectrograph (FOS). WF/PC was a high-resolution imaging device primarily intended for optical observations.

All the instruments were of a modular design, enabling them to be changed or upgraded on a service mission by astronauts during a spacewalk. This design was instrumental in providing a solution to



ALL IMAGES: NASA

ABOVE
Engineers check the curvature on Hubble's primary mirror. Their error cost the builders a $25 million dollar penalty.

the mirror problem in that it enabled later instruments to be designed with "corrective" optical systems that would greatly reduce the effects of the mirror aberration.

As the next generation instruments were planned for much later in Hubble's operational life, a dedicated set of optics was designed and built to "correct" the problems with the main mirror. Much like our eyes need correction with spectacles, NASA designed an optical correction package to bring Hubble back as near as possible to its original design potential Called COSTAR, for Corrective Optics Space Telescope Axial Replacement, the instrument was designed to replace one of the telescope's existing instruments so that the remaining instruments could benefit. The instrument chosen to be replaced was the High Speed Photometer (HSP).

STS-61 was designated as the First Hubble Servicing Mission and NASA selected space Shuttle *Endeavour* as the Orbiter for this flight. A crack team of seven experienced astronauts would fly this high profile mission: Commander Richard O. Covey (fourth and last space flight); Pilot Kenneth D. Bowersox (second space flight); Mission Specialist 1 Kathryn C. Thornton (third space flight); Mission Specialist 2 Claude Nicollier from the European Space Agency (second space flight); Mission Specialist 3 Jeffrey A. Hoffman (fourth space flight); Mission Specialist 4 F. Story Musgrave (fifth space flight) and Mission Specialist 5 Thomas D. Akers (third space flight).

With its very heavy workload, the STS-61 mission was one of the most complex in the Shuttle's history. Its planned flight was for ten days with five spacewalks (EVAs), an all-time record. The eyes of the world were on NASA to deliver. Teams of media reporters from all over the world would gather at Kennedy Space Center for the launch. NASA was open to the world.

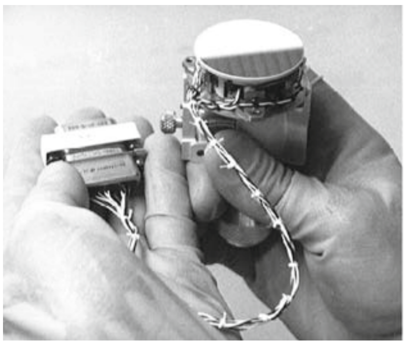
The launch date was slated for 1 December 1993. It was the fifth flight of Endeavour and it would be one of the few night launches of the Shuttle. The first launch attempt on 1 December 1993 was scrubbed due to weather constraint violations at the Shuttle Landing Facility. Just before the scrub, the range was also in a no-go situation due to a 243.8-m-long ship in the restricted sea zone. A 24 hour scrub turnaround was put into effect, with a launch window extending from 4:26 am to 5:38 am on 2 December 1993. Launch mass was 113,540 kg. Payload mass was 8,012 kg. After launch, the astronauts carried out a series of checks on the vehicle and went to sleep seven and a half hours after lift-off.

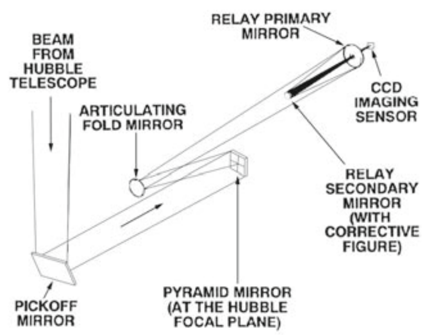
On Flight Day 2, Endeavour performed a series of burns that allowed the Shuttle to close in on the Hubble Space Telescope at a rate of 110 km per 95-minute orbit. The crew made a detailed inspection of the payload and checked out both the robot arm and the spacesuits. All of Endeavour's systems functioned well as the crew got a full day's sleep in preparation for the evening's rendezvous. At the end of Flight Day 2, Endeavour was 350 km behind HST and closing.

On Flight Day 3, astronaut Jeffrey Hoffman spied the Hubble using binoculars. Trained as an astrophysicist, Hoffman was the second astronomer/astronaut to work with Hubble following astronaut Steve Hawley, who had deployed the telescope out of the Payload Bay on STS-31. Upon spotting the telescope, Hoffman noted that the right-hand solar array was bent at a 90-degree angle. These 12-metre solar arrays, provided by the European Space Agency, were scheduled to be replaced during the second spacewalk because they wobbled 16 times a day (as the telescope heated up and cooled off while passing from the night-time side of the Earth to the daytime side and vice versa), thus disturbing Hubble's ability to maintain precise pointing.

Earlier in the day, controllers at the Goddard Space Flight Center's Space Telescope Operations Control Center uplinked commands to stow HST's two high-gain antennas. Controllers received indications »

BELOW
An individual example of the COSTAR corrective optics package designed to rectify the telescope's faulty eyesight.





that both antennas had nested properly against the body of the telescope, but micro switches on two latches of one antenna and one latch on the other did not send the "ready to latch" signal to the ground. Controllers decided not to attempt to close the latches, as the antennas were in a stable configuration. The situation was not expected to affect plans for rendezvous, grapple and servicing of the telescope.

With the telescope berthed in the Shuttle's payload bay, the astronauts looked forward to five spacewalks over five very busy days to service the iconic telescope, beginning with EVA 1 on Flight Day 4 by Story Musgrave and Jeffrey A. Hoffman and culminating with the same pair on EVA 5 on Flight Day 8. Astronauts Thomas D. Akers and Kathryn C. Thornton replaced HST's solar arrays during the second EVA. Musgrave and Hoffman then performed the third EVA, which involved the replacement of the Wide Field Planetary Camera (WF/PC) with the new and upgraded WF/PC2 that sported its own set of correction lenses. The fourth EVA began on Flight Day 7 and was performed by Thornton and Akers. The primary task of the EVA was to replace HST's High Speed Photometer (HSP) with the Corrective Optics Space Telescope Axial Replacement (COSTAR) system which would correct HST's spherical aberration of the main mirror for all instruments except the WF/PC2 camera.

On Flight Day 8 it was the turn of Musgrave and Hoffman again, whose main task was to replace the Solar Array Drive Electronics (SADE). The EVA team also fitted an electrical connection to the Goddard High Resolution Spectrograph. The crew then installed some covers on the magnetometers, fabricated on board by Claude Nicollier and Kenneth D. Bowersox.

On Flight Day 9 it was time to release Hubble, but concerns about one of HST's four on board Data Interface Units (DIUs) delayed its release. Each of the 16 kg. DIUs transfer data between the HST's main computer, solar arrays and other critical systems. A failure on Side A of DIU #2 led to erratic current fluctuations and some data dropouts, but controllers at the Space Telescope Operations Control Center (STOCC) located at NASA's Robert H. Goddard Space Flight Center in Greenbelt, Maryland and mission control at JSC came up with a troubleshooting procedure to determine the extent of the problem.
HST was transferred to internal power and disconnected from its power umbilical at 11:43 pm EST. Controllers then switched channels on the DIU from the A side to the B side and then back to the A side. They determined that HST should be deployed. The drum brakes on the new solar array were applied to prevent them from vibrating during future observations.

European Space Agency Astronaut Claude Nicollier then took hold of the satellite with the robot arm. The satellite was lifted and moved away from *Endeavour*. The telescope's aperture door was then reopened (a 33-minute procedure) and then the telescope was released from the RMS at 5:26 am EST. Commander Dick Covey and pilot Kenneth D. Bowersox fired Endeavour's small manoeuvring jets and moved the Shuttle slowly away from HST.

With all the planned tasks now completed, the crew prepared to return home. The Shuttle landing occurred at Kennedy Space Center on Runway 33 at 12:26 am on 13 December 1993.

OPPOSITE
Astronaut Jeff Hoffman replaces Hubble's Wide Field Planetary Camera during the STS-82 five-day repair mission.

> "WITH THE TELESCOPE BERTHED IN THE SHUTTLE'S PAYLOAD BAY, THE ASTRONAUTS LOOKED FORWARD TO FIVE SPACEWALKS OVER FIVE VERY BUSY DAYS"

BELOW
Official Service Mission 2 emblem for STS-82 and (bottom) Shuttle crewmember Joe Tanner carefully monitoring one of the repair mission EVAs.

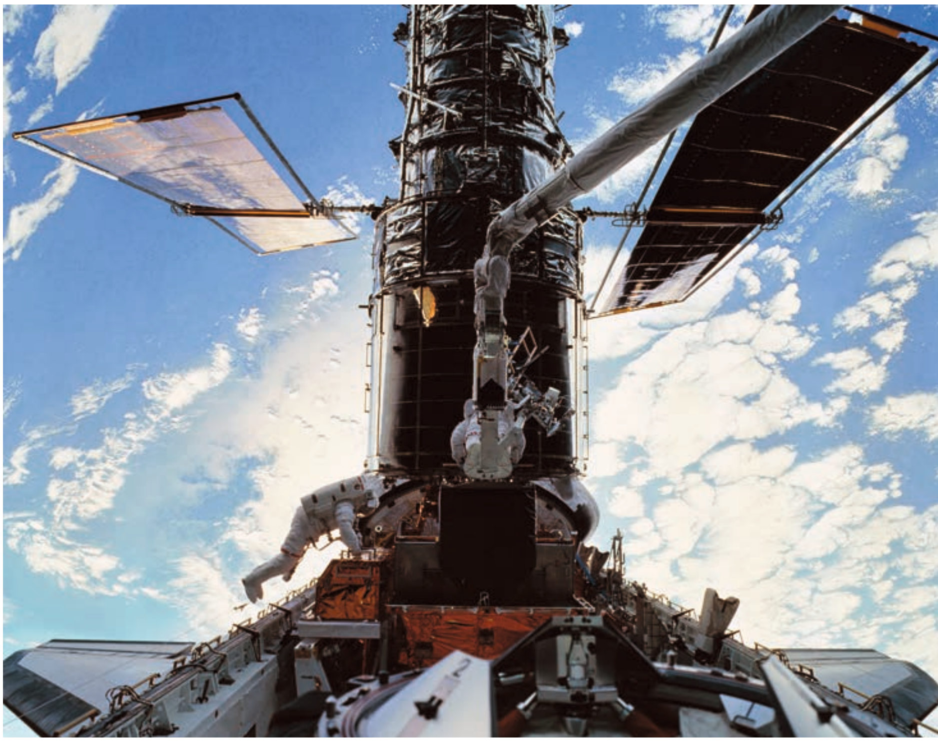
SECOND HUBBLE SERVICING MISSION (STS-82) 11 FEBRUARY 1997

STS-82 was the 22nd flight of *Discovery* and the 82nd mission of the Space Shuttle program. *Discovery's* crew repaired and upgraded the telescope's scientific instruments, increasing its research capabilities, while the mission achieved the highest known, non-classified altitude ever attained by a STS Orbiter (620 km). Discovery launched from Kennedy Space Center, Florida, on 11 February 1997, landing back there again on 21 February 1997.[1]

The seven crew were all veteran space farers: Commander Kenneth D. Bowersox on his fourth space flight and his second visit to Hubble; Pilot Scott J. Horowitz on his second space flight; Mission Specialist 1 Joseph R. Tanner making his second space flight; Mission Specialist 2 Steven A. Hawley making his fourth space flight and his second mission involving Hubble, having deployed the satellite on its inaugural flight on STS-31; Mission Specialist 3 Gregory J. Harbaugh was on his fourth and final space flight; as was Mission Specialist 4 Mark C. Lee; Mission Specialist 5 was filled by Steven L. Smith on his second space flight.

In addition to installing the new instruments, the astronauts replaced other existing hardware with upgrades and spares. Hubble received a refurbished Fine Guidance Sensor, an optical device used to provide pointing information for the telescope and as a scientific instrument for astrometric science.

ALL IMAGES: NASA



« The Solid State Recorder (SSR) replaced one of HST's reel-to-reel tape recorders. The SSR provides much more flexibility than a reel-to-reel recorder and can store ten times more data. One of Hubble's four Reaction Wheel Assemblies (RWA) – part of the telescope's Pointing Control Subsystem – was replaced with a refurbished spare. The RWAs use angular momentum to move and maintain the telescope in a desired position. The wheel axes are oriented so that the telescope can provide science with only three wheels operating, if required.

Study of returned mechanisms provides a rare opportunity to examine equipment that has undergone long-term service (seven years) in space, particularly for the effects of vacuum on lubricants which in this case were found to be in "excellent condition".

The STS-82 mission again demonstrated the capability of the Space Shuttle to service orbiting spacecraft. *Discovery's* crew completed servicing and upgrading of the Hubble Space Telescope during four planned EVAs, later performing a fifth unscheduled spacewalk to repair insulation on the telescope.

THIRD HUBBLE SERVICING MISSION (STS-103) 19 DECEMBER 1999

While planning the third Hubble Servicing Mission, then slated for June 2000, NASA realised that after three of the six on board gyroscopes had failed, the number of tasks the astronauts were required to carry out was growing and would be far greater than a single mission could achieve. So, NASA decided to split Servicing Mission 3 into two and bring the first part of the mission forward six months. The fourth gyroscope then failed a few weeks before the mission, rendering the telescope incapable of performing scientific observations. This mission was becoming an ever-more crucial flight for NASA. Splitting the mission into two meant that the required tasks would become more manageable by the astronauts and NASA.

ABOVE
The Servicing Mission patch for STS-103 and (top) British NASA astronaut Mike Foale and ESA mission specialist Claude Nicollier during their repair EVA.

BELOW
The crew of STS-103 in festive mood.

ALL IMAGES: NASA

Four new gyros were installed during the first servicing mission (STS-61) in December 1993 and all six gyros were working during the second servicing mission (STS-82) in February 1997. After that, a gyro failed in 1997, another in 1998 and a third in 1999. Having fewer than three working gyroscopes would preclude science observations, although the telescope would remain safely in orbit until a servicing crew arrived.

The Third Servicing Mission then became 3A and was flown by *Discovery*, the Orbiter that had deployed the telescope back in 1990. The mission launched on the night of 19 December 1999 and was the 23rd night launch of the Space Shuttle System.

The seven-person crew were as follows: Curtis L. Brown, Mission Commander; Scott J. Kelly, Pilot; Steven L. Smith, Mission Specialist 1; Jean-François Clervoy, ESA Mission Specialist 2; John M. Grunsfeld, Mission Specialist 3; C. Michael Foale, Mission Specialist 4; and Claude Nicollier, ESA Mission Specialist 5. This was the first time that two European Space Agency astronauts had flown on a Shuttle mission together.

The mission replaced all six gyroscopes, a Fine Guidance Sensor and the computer, as well as installing a Voltage/temperature Improvement Kit (VIK) to prevent battery overcharging and replacing thermal insulation blankets.

FOURTH HUBBLE SERVICING MISSION (STS-109) 1 MARCH 2002

STS-109, also known as Servicing Mission 3B (SM3B) launched from the Kennedy Space Center on 1 March 2002. It was the 108th

mission of the Space Shuttle program and the 27th flight of the Orbiter *Columbia.* This was the last successful mission of that Orbiter before the ill-fated STS-107 mission, which culminated in the 2003 *Columbia* disaster.

Four astronauts trained for five scheduled spacewalks to upgrade and service Hubble during the STS-109 mission. Three veteran astronauts, John M. Grunsfeld, Mission Specialist 1, Richard M. Linnehan, Mission Specialist 3, and James H. Newman, Mission Specialist 4, were joined by Michael J. Massimino, as Mission Specialist 5, who would be making his first space flight.

Grunsfeld had flown three times: STS-67 in 1995, STS-81 in 1997, and STS-103 in 1999 when he performed two spacewalks to service the Hubble Space Telescope. Newman was a veteran of three space flights: STS-51 in 1993, STS-69 in 1995, and STS-88 in 1998, and had conducted four previous spacewalks. Linnehan had flown on STS-78 in 1996 and STS-90 in 1998. Massimino was a member of the 1996 astronaut class.

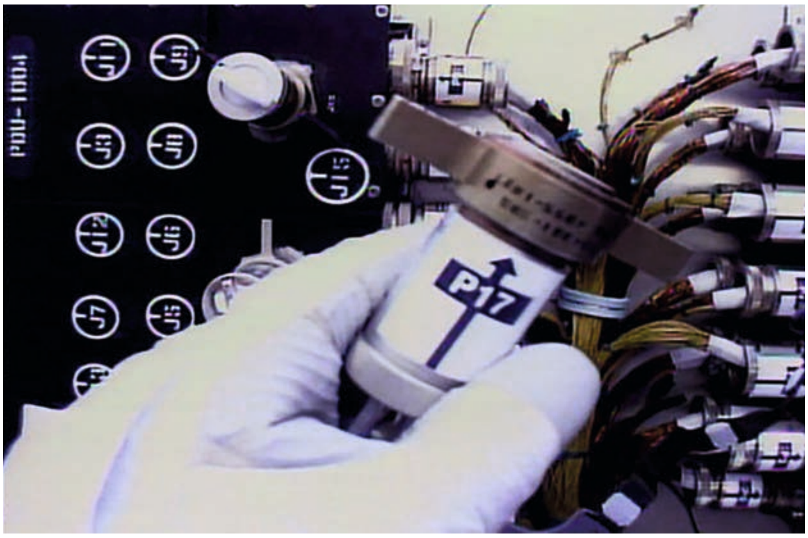
Scott Altman, (Cmdr., USN), a two-time Shuttle veteran, commanded the STS-109 mission. He was joined on the flight deck by pilot Duane "Digger' Carey, (Lt. Col., USAF), making his first space flight, Mission Specialist 2 and flight engineer Nancy Currie (Lt. Col, USA, Ph.D.) who had three previous space flights to her credit.

A new science instrument – the Advanced Camera for Surveys (ACS) – was installed during SM3B. The crew also replaced the Solar Arrays, this time installing rigid arrays which do not roll up and therefore are more robust. Although one-third smaller than the first two pairs, the power increase was between 20 and 30%. Several other activities were accomplished as well over a 12-day mission with five spacewalks.

The astronauts also retrofitted an existing but dormant instrument, called the Near Infrared Camera and Multi-Object Spectrometer (NICMOS), with a new, experimental cooling system to return it to active duty. NICMOS was placed on Hubble in 1997 but became inactive two years later, after depleting the ice it needed to cool its infrared detectors. By fitting NICMOS with the experimental cryogenic system, NASA re-cooled the detectors to revive its infrared vision and extend its life by several years.

FIFTH HUBBLE SERVICING MISSION (STS-125) 11 MAY 2009

Following the *Columbia* disaster of 1 February 2003 and within the recommendations of the Columbia Accident Investigation Board, it was determined that Shuttle flights should be restricted to ISS missions, whereupon the ISS would be utilised as a "safe haven" for Shuttle crews if the Orbiter was damaged in such a way that it could not return the crew home safely.



ABOVE
The Servicing Mission Emblem for STS-109 and (top) a helmet camera closeup of one of the 36 connectors on the telescope's solar array Power Control Unit (PCU).

> **"THE DECISION WAS WIDELY CRITICIZED BY THE MEDIA, THE SCIENCE COMMUNITY, AND NASA EMPLOYEES"**

According to the Investigation White Paper: "It has been projected that a typical Space Shuttle flight crew of seven astronauts could stay aboard the ISS for up to ninety days, if warranted, due to an emergency situation on the Space Shuttle. This safe haven capability allows the flight crew and ground teams to consider all options, determine the best course of action, take the time required to understand the cause of the failure and affect repairs, or send the appropriate rescue vehicle with the right equipment to bring the crew home. Clearly, rushing this process would introduce considerable new risk and in the worst-case result in the loss of another vehicle."

In the case of a Hubble Servicing Mission, the amount of stay time on orbit was significantly shorter due to the limited stores of cryogenic oxygen on the Orbiter. Therefore, other measures would have been required. Specifically, a second Space Shuttle on an adjacent launch pad would need to have been specially prepared, uniquely configured to launch expeditiously if required to perform a rescue mission.

With this in mind and with Hubble's successor, the James Webb Space Telescope to be on stream "just around the corner", NASA Administrator Sean O'Keefe announced the cancellation of Servicing Mission SM4, as the risk to the crew (citing safety constraints imposed by the Columbia Accident Investigation Board) would outweigh the loss of future science with the Hubble. During the announcement, O'Keefe stated that it was his decision alone, and not a recommendation from any other departments. The decision was widely criticized by the media, the science community, and NASA employees. Maryland Senator Barbara Mikulski, a member of the Senate subcommittee that oversaw NASA's budget, publicly accused O'Keefe of making a decision outside the transparency process against the wishes of the science community, and stated she would work to reverse the decision. »

« It is interesting to note that the said white paper stated: "The James Webb Space Telescope (JWST) program has been strengthened to assure a 2011 launch date…"

However, with the ever-increasing delays to the JWST and the concerns that the loss of Hubble would leave a big hole in space-born astronomical research, the world wide astronomical and scientific community rallied, NASA scientists and astronauts rallied. The House of Representatives rallied.

O'Keefe's replacement, Michael D. Griffin, took just two months after his appointment to announce that he disagreed with O'Keefe's decision, and would consider sending a Shuttle to repair Hubble. As an engineer, Griffin had previously worked on Hubble's construction and respected the discoveries the telescope brought to the science community. He agreed with the National Academy of Sciences that a robotic mission was not feasible and said that in light of the "Return to Flight" changes made following the *Columbia* accident, a Shuttle mission to repair Hubble should be reassessed. After the successes of the Return to Flight STS-114 and STS-121 missions, and the lessons learned and improvements made following those missions, managers and engineers worked to formulate a plan that would allow the Shuttle to service Hubble, while still adhering to the post-*Columbia* safety requirements.

On 31 October 2006, Griffin announced that the Hubble Servicing Mission was reinstated, scheduled for 2008, and announced the crew that would fly the mission, which included Grunsfeld. Senator Mikulski expressed her delight at the news, stating "The Hubble Telescope has been the greatest telescope since Galileo invented the first one. It has gone to look at places in the universe that we didn't know existed before."

To accommodate the Accident Investigation Board findings, two Shuttles were prepared at the same time. Space Shuttle *Atlantis* was readied on Launch Pad 39A,

ALL IMAGES: NASA

ABOVE
Official mission emblems for the Shuttle Hubble missions. From top left to right: STS-31; STS-61; STS-82; STS-103; STS-109 and STS-125.

BELOW
Atlantis comes into land, marking the end of Shuttle repair missions to Hubble.

accompanied by Space Shuttle *Endeavour* on Launch Pad 39B. This was the last time two Shuttles were on launch pads simultaneously. The *Atlantis* mission, STS-125, was the final Servicing Mission to upgrade NASA's Hubble Space Telescope. *Endeavour* was prepped for contingency support (Launch On Need), standing by at pad 39B in the event Atlantis was damaged during flight and unable to return safely to Earth, necessitating an emergency rescue mission (STS-400).

The crew of seven astronauts who flew STS-125 were: Scott D. Altman, Commander; Gregory C. Johnson, Pilot; Michael T. Good, Mission Specialist 1; K. Megan McArthur, Mission Specialist 2; John M. Grunsfeld, Mission Specialist 3; Michael J. Massimino, Mission Specialist 4 and Andrew J. Feustel, Mission Specialist 5. The Orbiter chosen for this flight was *Atlantis*, the only time this Orbiter visited Hubble.

The astronauts repaired and upgraded Hubble over five spacewalks during their mission to extend the life of the orbiting observatory. They successfully installed two new instruments: the Cosmic Origins Spectrograph and the Wide Field Camera 3, and repaired two others, bringing them back to life. They also replaced gyroscopes and batteries, and added new thermal insulation panels to protect the orbiting observatory. On completion of the mission on 24 May 2009, Hubble had six working, complementary science instruments with capabilities beyond what was available at the time of Hubble's deployment, as well as an extended operational lifespan of at least another five years.

With its new Wide Field Camera 3, Hubble can observe in ultraviolet and infrared spectrums as well as visible light. It can peer deep into the cosmic frontier in search of the earliest star systems and study planets in the solar system. The telescope's new Cosmic Origins Spectrograph allows it to study the grand-scale structure of the universe, including the star-driven chemical evolution that produces carbon and the other elements necessary for life.

The mission was hailed a success as *Atlantis* touched down at Edwards Air Force Base in California, after two earlier opportunities in Florida were waived off due to dynamic weather conditions. This was the final Shuttle landing at Edwards. *Atlantis* completed a flight of 14 days, after making 197 orbits and covering a distance of approximately 8.3 million kilometres.

HUBBLE POST-SHUTTLE

As a footnote, Hubble is continuing to work well after 30 years on orbit, achieving twice its nominal design life. It continues to make discoveries as it expands our knowledge of the deep universe as well as the planetary neighbours in our back yard. The James Webb Space Telescope is further delayed and is now not expected to be launched until March 2021.

With the Shuttle fleet retired servicing Hubble is currently not possible. In June 2006 the primary electronics on the Advanced Camera for Surveys (ACS) main camera failed, and in January 2007 the power supply for the backup electronics also failed, although the Solar Blind Channel (SBC) remains operable using the side-1 electronics. More recently, in January 2019, the telescope entered a partial safe mode following suspected hardware problems with Wide Field Camera 3. This was found to be a software error and following a few days troubleshooting and resetting the circuits the instrument was restored to its normal operation and began gathering data again.

For now Hubble continues its work in orbit and could remain in operation for another decade, though this depends upon low solar activity, no serious equipment failures and adequate funding. The original plans envisaged a Shuttle mission to return the telescope to Earth for eventual museum display, but this was deemed too expensive and at a high risk for the crew. While future servicing missions by crewed commercial vehicles remains a possibility, the natural atmospheric re-entry of Hubble is currently estimated to be 2028-2040 and ending a remarkable era in astronomy and spaceflight history. SC

ABOVE
Still gazing after all these years: Hubble could be in orbit for another decade providing there are no serious equipment failures and sufficient funding remains available.

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Steve Hawley, STS-31


Jean-François Clervoy, STS-103

Michael Foale with Caude Nicollier


Chuck Shaw

HANDS ON WITH HUBBLE – NASA AND ESA ASTRONAUTS REMEMBER

"As we separated from the Hubble Space Telescope (HST) after the successful deployment in 1990, I remember thinking about how our understanding of the universe would change with HST now in orbit. Today, thirty years later, I confess that I was too conservative in my initial assessment. When I saw HST again in 1997 on Service Mission 2 (SM2) I was surprised how 7 years in the harsh environment of space had affected its appearance. However, HST's performance has improved over time, just as planned. As I tell my students, great things don't just happen. The fact that HST is still a world-class observatory is tribute to everyone who played a role."
STEVE HAWLEY, NASA Mission Specialist STS-31, Hubble deployment and STS-82, Service Mission 2

"Releasing the HST on Christmas day 1999 was a very special space gift, after 3 of the longest duration spacewalks aimed at taking it out of lethargy. On that same day the control center called up stating that the telescope was back 100% healthy and even 'Santa Claus' appeared in the cockpit of *Discovery*! The Hubble Space Telescope holds many astronomical and astronautical records including being the most beautiful and loved one."
JEAN-FRANÇOIS CLERVOY, ESA Mission Specialist STS-103, Service Mission 3A

"For me, getting to see the Hubble Telescope up close, and during a spacewalk was the culmination of the "dream" space shuttle mission. The telescope is of course iconic, and as an astrophysics PhD starting out from the Cavendish laboratory in Cambridge to become an astronaut I knew that to be a part of a Hubble mission was to be a part of science history in the making. The view of Hubble in space is amazing. It is huge, the size of a school bus. The altitude above the Earth was around 592.6 km, 50% higher than I had ever been on previous missions, so that we could see the whole of the Atlantic from side to side, or so it seemed. Even though I have been one of the lucky few to see the Hubble from the outside, the best views from Hubble are the images it takes from the inside, and those fantastic images and scientific discoveries are available to all humans to wonder at and enjoy."
MICHAEL FOALE, NASA Mission Specialist STS-103, Service Mission 3A

Up close and personal with Hubble

As well as the recollection above, Mike Foale also expanded on the background to his single EVA, on 23 December 1999, during STS-103 the third Hubble Servicing Mission. This spacewalk was the second of the mission and recorded 8 hours 10 minutes in duration, becoming the third longest in history at that time. It currently stands as the sixth longest EVA in history:

"I first had an inkling that my NASA bosses were thinking of assigning me to STS-103, repair mission 3A, when I was still on the Mir space station in 1997. Mark Lee, the chief of the Astronaut Office EVA Branch happened to be on a Radio Ham call with me, and let it slip they were thinking of making me part of a Hubble servicing mission, assuming all went well with me from that point on Mir (This was after the collision by a Progress vehicle with the Mir station).

"As it turned out, the mission goals shifted from instrument enhancements to a full up repair of the telescope at the end of 1999. My EVA partner was ESA astronaut Claude Nicollier, an astronomer and military pilot from Switzerland, who I had always respected massively, because he had flown Hawker Hunter jets. Together we spent hundreds of hours together preparing for our tasks. These were for me to change out the Hubble main computer, replacing a 386 processor box with a 486 processor, with co-processor. Claude was to change out a baby piano sized box called a Fine Guidance Sensor.

"It was when Claude and I were actually outside the shuttle, being hoisted up by our second ESA astronaut Jean-François [Clervoy] on the remote manipulator that I really started to feel scared. What if I bent one of the hundreds of gold pins within the connectors that I must reattach to the computer? I dreaded the idea of trying to use a pin straightener with pressurized EVA gloves. I decided if I actually did break the telescope irreparably during the computer change out, I could always open that little valve in the side of the helmet. Of course, providence smiled on us, and we all completed our tasks and got the telescope back to a working and upgraded condition."

"Space Shuttle missions were always very carefully orchestrated activities. However, few other missions were in the league of how each of the Hubble Space Telescope servicing missions successfully pushed the envelope of planning, training and intense real time execution. The telescope was designed to be serviced in a very sophisticated "plug & play" type approach. The final servicing mission also required actually repairing instruments (in addition to swapping out others). This required the development of special tools and new techniques. The approaches used to do this are an important part of the Legacy of the HST."
CHUCK SHAW, Mission Director, STS-125 Fourth and final Shuttle HST Servicing mission

A SHOT IN THE DARK

THE POLITICAL SIGNIFICANCE OF CHANG'E 4 LANDING IN VON KÁRMÁN CRATER

China's Chang'e 4 touched down on 3 January 2019 in von Kármán crater on the Moon's far side, becoming the first space vehicle to do so. But why was that exact site chosen in preference to the South Pole where future landings have been suggested?

by Philip Mills

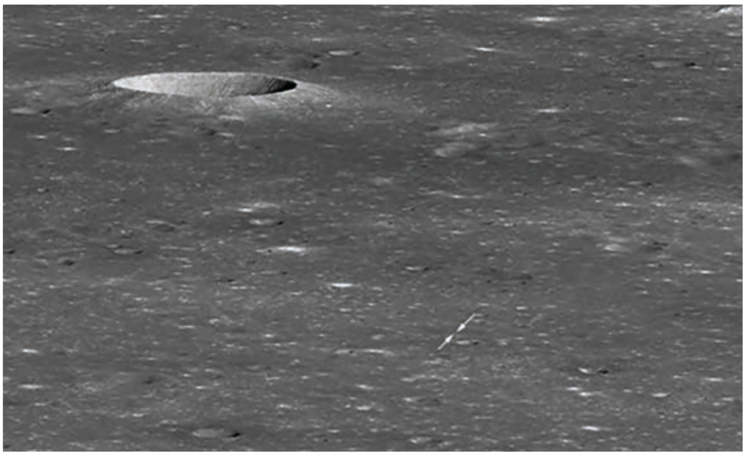
Von Kármán is a 180 km diameter crater located within the Aitken Basin which is an impact crater 2,500 km in diameter. The Aiken Basin is 13 km deep and is one of the largest known impact craters in the solar system. Because the Aitken Basin extends over such a vast region and borders on the lunar south pole, including regions believed to contain ice, the Aitken basin has been described as the most valuable real estate in the solar system. However, the von Kármán crater itself is not at the south pole but it does have other politically symbolic reasons for why the Chinese chose to land there.

This paper was first presented at the BIS Sino-Russian Technical Forum in London on 1 June 2019.

ABOVE The Chang'e 4 lander with its landing ramp deployed, pictured from the Yutu-2 rover – the first ground vehicle to explore the lunar far side.

HISTORICAL BACKGROUND

The founder of the Chinese space programme, Tsien Hsue Shen, won a scholarship in 1935 to study aeronautical engineering in the USA. He eventually ended up at Caltech's Guggenheim Aeronautical Laboratory in Pasadena, where he gained his PhD in 1939 under the guidance of the Austro-Hungarian mathematician, aerospace engineer and physicist, Theodore von Kármán. Von Kármán is regarded as one of the outstanding aeronautical theoreticians of the 20th century. A crater was eventually named in his honor on the lunar far side. In 1939, Tsien led a team at Caltech that developed a method of rocket-propelled take-off for bombers known as jet-assisted take-off, popularly referred to as JATO. Later, in 1944, the team helped to set up the Jet Propulsion Laboratory at Pasadena. At the end of the Second



ABOVE: CNSA VIA IAU / RIGHT: NASA

World War, Tsien was in a team that went to Germany to interrogate any German aeronautical and rocket engineers. Tsien interviewed Wernher von Braun and advised that he be chosen to be taken to the USA. Tsien had high security clearance and was working within the US defence department. However in the 1950s, with the rise of Senator Joseph McCarthy and his anti-communist witch hunts, Tsien lost his security clearance even though there was no evidence that he was a communist. Von Kármán was one of many who protested at this. Tsien spent five years under house arrest and was deported to the People's Republic of China in 1955.

He was welcomed in China and led the development of rocket and missile technology in the Peoples Republic. He later became Chinese Space Administrator.

THE CHOICE

In choosing a landing site for Chang'e 4, which the Chinese had previously mentioned was to land on the lunar far side, there can be many locations to choose from. Communications would be achieved via a previously launched relay satellite Queqiao which was located in a halo orbit at the lagrangian point L2. This probably permitted a landing site at any location on the lunar far side, but not at an actual pole location because of the communication angles from such locations to the relay satellite.

The Aitken basin is an obvious scientific target, as it is located on the lunar far side and is near enough to the South Pole to warrant a landing there. But where within the basin? There are many craters within the Aiken basin which meet the criteria, such as Poincare crater and Planck which are both further south. Mare Ingernii is a similar crater to von Kármán and is larger so would be an easier target. But von Kármán was chosen. That choice, to me, was an obvious, soft, power political as well as scientific target. They could not have chosen a better landing site to rub the American noses in the lunar dust. It was like saying China was number one in lunar exploration. It would be the same as Neil Armstrong and Buzz Aldrin landing in Mare Moscoviense or Tsiolkovsky or Korolyov craters.

ABOVE Chang'e 4 (between white arrows) pictured in the von Kármán crater in January 2019 by NASA's Lunar Reconnaissance Orbiter.

" IT WAS PROBABLY A SCIENTIFIC PLAN TO GET THE USA BACK INTO A RACE "

CONCLUSION

When Chang'e 4 landed, this author realised the politically symbolic reasons and mentioned this on the BIS Facebook page. It was apparently missed and never gained any comments. However, the point was obviously not missed in the US Department of State. Someone there did not want or like to have their noses rubbed in the lunar dust by China. Previously, NASA had a plan to return to the Moon by 2028 utilizing the controversial lunar gateway. The Trump administration in Washington, obviously looking for political capital and some form of historically significant scientific undertaking with which to be remembered, looked at the Chang'e 4 landing as a challenge from China. Someone must have seen the symbolic reasons for landing in von Kármán crater and realized what it meant. On 26 March 2019, Vice President Mike Pence delivered a speech at a meeting of the National Space Council outlining his administration's new plan, direct from the President, to land on the Moon by 2024. The Chang'e 4 landing was mentioned as was the challenge that China posed in pre-eminence in space. The target of the landing was announced to be the lunar south pole. International partners and commercial companies were also invited to partake in what was recently named Project Artemis, the sister of Apollo. Even though the five-year plan to return to the Moon was described by commentators as not feasible, on 9 May the world's wealthiest man Jeff Bezos, CEO of commercial space company "Blue Origin", announced and revealed his company's design for a lunar lander. Bezos said that the timeline was doable because his company had been working on the lander for three years.

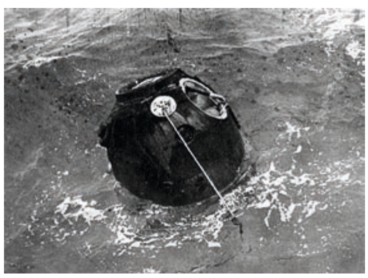
It is not known if the Chang'e 4 landing in von Kármán crater and its symbolic significance had the official backing of the Chinese government. Awakening the sleeping giant probably was not an intention. Landing in von Kármán crater was more than likely an engineering and science decision, but at the same time noted the symbolic significance to please the party elite. It was probably a scientific plan to do just what it has done and get the USA back into a race. An increase in Chinese Space spending to challenge the USA is the likely outcome. As Elon Musk recently mentioned, races are a good thing. SC

US NAVY

LITTLE BIG SHIP

THE US NAVY'S SPACECRAFT HUNTER

Built to hunt Soviet submarines during the Cold War, the USS *McNorris* ended up in search of far more exotic quarry – in the shape of Soviet spacecraft.



S.P.KOROLEV RSC ENERGIA VIA NASA

by **Dwayne A. Day**

ABOVE
Spacecraft hunter: the USS *McNorris* in her heyday.

LEFT
The quarry: the Soviet Zond 5 spacecraft, which splashed down in the Indian Ocean on 14 September 1968 following its circumlunar flight.

In the US Navy they are called "tin cans"—because they're so small they bounce around in the ocean. The USS *McMorris*, a Destroyer Escort (DE) commissioned in 1960, was one such ship, and like other DEs, her primary job was hunting submarines. But she was not very good at it, and so in the latter 1960s she was given another mission, hunting Soviet spacecraft.

In September 1968 the *McMorris* was assigned to shadow two Soviet space tracking ships, the *Morzhovets* and the *Nevel*, in the Indian Ocean. For six weeks *McMorris* followed the Soviet vessels around. According to Frederick Gary Hareland, in an article in *Sea Classics* magazine, "every time they got underway and headed out to sea, *McMorris* tagged along like an eager puppy." Although her crew affectionately – and probably ironically – called her "the Mighty Mac," the *McMorris* was a tiny ship lacking any appreciable armament, or any particular grace. Her more aesthetic contemporaries, like the *Dealey* and *Bronstein* class escorts, did a better job of pleasing the eye, but the *McMorris* looked somewhat awkward, like a chunky adolescent, or worse, a tugboat. She had forward and stern 0.762 mm fifty-calibre guns, six torpedo tubes, and two anti-submarine mortars, at a time when modern warships were nuclear-powered, missile-armed, and launched atomic depth bombs. The Navy had designed the ships of *McMorris'* class to be cheap and capable of mass production in event of war, but even before the first of her four-ship class was commissioned, the Navy had second thoughts and cancelled plans for more of them. *McMorris* also had another weakness: a single propeller shaft hooked up to four diesel engines, a rather complex arrangement for an engineering plant.

When ships get to sea, things break. If an engine goes down, sailors refer to it as a "casualty;" sometimes it means that the ship floats in the ocean until a tug shows up to tow her into port. A single screw meant that *McMorris* or her sisters were vulnerable to engineering "casualties." But, defying fate, in actual service, the ships' machinery tended to be reliable. If war broke out, their crews might have been more effective sailing up to Soviet submarines and throwing rocks at them, but the ships could travel far on a single tank of fuel and they didn't break down, which made them excellent choices for operating solo. So by the late 1960s the Navy converted *McMorris* and her sisters for gathering electronic intelligence and fitted them with special antennas.

The Soviet *Morzhovets* and *Nevel* were sister ships, both covered with tracking antennas. They were former timber freighters and surprisingly, before they were fitted with the antennas, they were graceful, practically elegant. But they were workers in the space race and they had a job to do. According to Russian space historian Asif Siddiqi, the two ships had entered service as space trackers only a year before the *McMorris* began dogging them. As Hareland tells it, the *Morzhovets* and *Nevel* spent a lot of time out at sea, simply drifting, waiting for a spacecraft to fly overhead. *McMorris* did the same, floating a few miles away on relatively calm seas, waiting for whatever the two Soviet tracking ships were waiting for. They called it operating DIW, or drift-in-water.

By mid-September 1968, all three ships had floated for several days in the Indian Ocean when a Soviet Proton rocket with the Zond 5 spacecraft roared off its launch pad in Kazakhstan. The capsule headed off towards the Moon, swung around, and sped back towards Earth. Jodrell Bank picked up a tape-recorded voice transmitted from the spacecraft, a clear indication that Zond 5 was a prototype for a human spacecraft.

Hareland wrote that on the night of 21 September, Zond 5 came screaming back to Earth, splashing down only 100 kilometres away. *McMorris'* antennas sucked up all the radio waves that they could from the little capsule that had just gone around the Moon. The three ships fired up their engines and headed off toward the splashdown point as fast as they could. But none of them were greyhounds and they did not break any speed records on their way to the capsule.

According to Hareland, on the morning of 22 September, 1968, the Russians hauled the little Zond spacecraft aboard one of the ships as sailors on the *McMorris* photographed it. He wrote that some of *McMorris'* crewmen were able to take chemical and debris samples from the water.

This intelligence catch for the US Navy was an accident. According to Russian space expert Anatoly Zak, the Zond 5 capsule was actually supposed to come down in Kazakhstan, not in the ocean. But there were problems with its guidance and control systems and instead of a single, long rocket blast, controllers hurriedly commanded it to make a series of short quick pulses and were able to direct it to a splashdown in the Indian Ocean, where the McMorris was waiting for it. Another Soviet ship, the *Borovichi*, was actually the first to reach Zond-5, but was not equipped to recover the spacecraft. It was picked up by a ship called *Vasiliy Golovnin*.

Zond 6 was launched on 10 November. A day later, as the spacecraft was heading to the Moon, NASA administrator Tom Paine announced that Apollo 8 would fly astronauts to the Moon for the first time. Paine's announcement was merely the first public acknowledgement of the decision – NASA officials had been discussing such a mission since the summer.

The intelligence information collected by the *McMorris*, such as the radio signals gathered by her antennas and the photographs of the Zond capsule being lifted from the water, has not been released, but it would only be a small part of the overall intelligence collection about the Soviet lunar programme that was underway by the US intelligence community such as the CIA and National Security Agency. The Soviets themselves released photos of Zond 5 being pulled from the water. *McMorris* is now barely a footnote in history. But she and other ships and aircraft were busy throughout the sixties keeping an eye on the Soviet Union, trying to figure out Apollo's competition in the race to the Moon.

P-D ART

BRIEF ENCOUNTER

SECRETS OF THE SOVIET UNION'S NUCLEAR SPACE PROGRAMME

At once time Soviet space engineers had high hopes for nuclear power – but in the end, the risks outweighed the benefits.

by Vadim Zakirov, Alan Perera-Webb, Gerald M. Webb and Constantine Milyaev, Commercial Space Technologies Ltd

ABOVE
A 10 kopek Soviet stamp issued to commemorate the achievements of Sergei Korolev, who briefly flirted with the idea of nuclear rocket propulsion in the late 1950s before embarking on the development of the conventionally fuelled N1.

The Soviet nuclear reactor spaceflight history involved 34 missions over 18 years. The nuclear reactors were used for spacecraft electric power supply. The nuclear reactors with two types of energy converters (thermoelectric and thermionic) were operated in orbit with average altitudes ranging from 250 to 990km. While spacecraft power plants with thermoelectric conversion had the longest in-orbit lifetime record of 135 days, the thermionic ones worked for up to almost a year. The progress made by the reactors with thermionic converters led to development of the next generation Topaz-2 space power plant with advanced specifications. Unfortunately, the further development of space nuclear power plants was halted by lack of finances during the break-up of the Soviet Union in the 1990s. The experience obtained during the programme led to the conclusion that the technological challenges limit electric power generation capacity for thermoelectric and thermionic conversions to kW level, so that MW-level space nuclear power systems must use turbo-machine conversion.

This paper was first presented at the BIS Sino-Russian Technical Forum in London on 1 June 2019.

INTRODUCTION

The present Russian MW power-class nuclear vehicle project for future space exploration missions [1-4] is a continuation of the earlier developments started by the former Soviet Union. [5-21] During the 1970s and 1980s, nuclear reactors could be found aboard a number of the Soviet reconnaissance satellites

ABBREVIATIONS

CPSU	Communist Party of the Soviet Union
IPPE	Institute for Physics and Power Engineering
JSC	Joint Stock Company
kW	kilo-watt
MW	mega-watt
NPS	Nuclear Power System
SAR	synthetic aperture radar
RORSAT	Radar Ocean Reconnaissance Satellite
TEG	thermoelectric generator
UN	United Nations
USSR	Union of Soviet Socialist Republics

as electric power supplies. [6-9,13-16] The reconnaissance aimed at getting detailed all-weather imaging, primarily targeting military ships and their formations, as well as aircraft carrier groups. [14] Such imaging was delivered by synthetic aperture radars (SAR), which required kW-level electric power for their operation. For higher image resolution, the spacecraft's operational orbit was intended to be as low as possible, i.e. about 250 km. At such an altitude, the use of large solar arrays is impossible because the significant atmospheric drag would cause the spacecraft to de-orbit rapidly and re-enter the atmosphere. In addition, the specifications of solar cells and chemical batteries at that time were rather poor, making the whole system too large and heavy for the application. The consideration of alternative power systems for spacecraft demonstrated the superiority of nuclear reactor-based power supplies for the task, because they could be made more compact and lighter.

At the end of its mission, the reconnaissance spacecraft was injected into a disposal orbit. The disposal orbit is a circular orbit of 800-900 km altitude in which the reactor will remain long enough for decaying fission material radiation to reduce to an acceptable safe level – at least 10 half-lives of the most survivable radioactive isotopes – to ensure radiation safety.

SPACE NUCLEAR POWER SYSTEMS

The simplified schematic of a power system with a nuclear reactor on board a reconnaissance satellite carrying SAR is shown

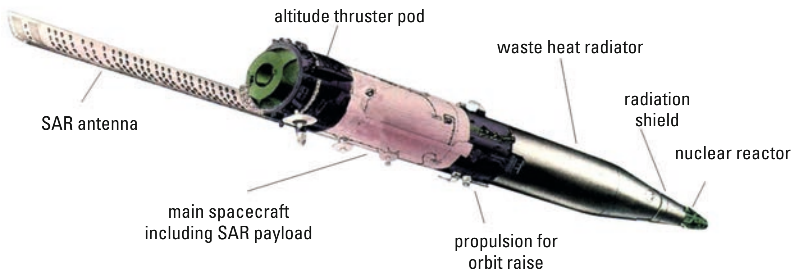


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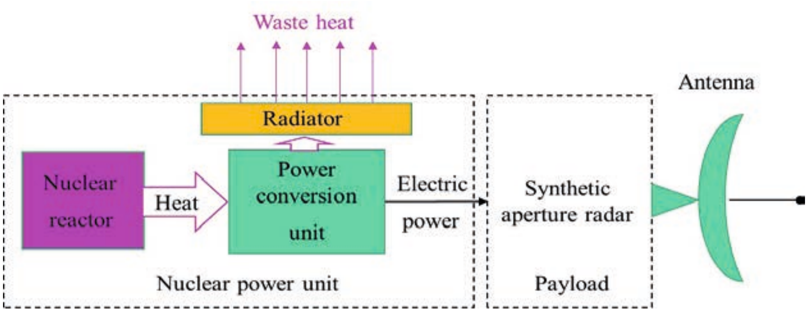
FIG 2 (above) Principal features of the RORSAT US-A reconnaissance spacecraft. See Ref. [10].

"AT THE END OF ITS MISSION, THE RECONNAISSANCE SPACECRAFT WAS INJECTED INTO A DISPOSAL ORBIT"

FIG 1 (below) Principle schematics of a nuclear power system aboard a radar satellite.



in Fig 1. The schematic illustrates the basic operating principle of how the nuclear power system was applied aboard a reconnaissance satellite. Heat generated by the nuclear reactor was transferred to a power conversion unit that transformed it to electricity. Electricity was used to power the main spacecraft payload, consisting of the SAR and the other subsystems. Unconverted heat was radiated into the space environment by a waste heat radiator.

For such an arrangement, power conversion is a key technology, because the converters determine the whole system's key specifications such as system weight, output electric power, lifetime, etc. Two types of converters were applied: thermoelectric and thermionic ones. Thermoelectric conversion relies on the application of a temperature gradient to p-n (positive-negative) type semiconductor pair, while in thermionics the gradient induces electron emission through the inter-electrode gap to generate electric power. Thermoelectric converters are typically placed outside the nuclear reactor core to protect them from radiation that degrades their performance. Thermionic converters are typically placed inside the reactor core because their performance is not affected by radiation. Within the reactor core, thermionic converters are exposed to a higher temperature gradient so that their conversion efficiency is higher than that of thermoelectric ones, although it is a challenge to keep a micro-meter scale inter-electrode gap inside a hot reactor core for a long time.

SPACECRAFT

The spacecraft, shown in Figs 2, 3 and 4, carried onboard nuclear reactor power units. The spacecraft were the well-known RORSATs (Radar Ocean Reconnaissance Satellites). They were manufactured by the "Arsenal" design bureau and looked similar.

The RORSAT US-A spacecraft (Cosmos 954 type) shown in Fig 2 carried a Bouk nuclear power unit generating 2.5kW of electric power and had a rocket-like shape that would fit well under the launcher payload fairing. The nuclear reactor was placed at the cone tip. A shadow-type shield protected the rest of the spacecraft from radiation. A waste heat radiator radiated unconverted heat into the space environment. It also covered the reactor control actuators and power conversion system located inside. Propulsion for raising

« the spacecraft to the disposal orbit separated the rest of the spacecraft from the nuclear power unit. The main spacecraft hosted SAR payload equipment. The spacecraft is depicted with deployed SAR antenna. An attitude thruster pod was situated close to the launcher payload adapter.

In an emergency situation or at the end of a mission, the propulsion for raising the spacecraft to the disposal orbit was activated automatically or by ground station tele-command. Receiving this signal, the pyros separated the nuclear reactor power unit from the rest of the spacecraft and then solid-fuel motors located in the middle section of the spacecraft injected it into the disposal orbit. This system was considered the primary one for radiation safety.

During the serial production of RORSAT US-A type satellites, their lifetime was increased from 45 to 120 days.

In the second half of the 1980s an upgraded spacecraft, shown in Fig 3 and designated as US-AM, was developed. The lifetime of the US-AM spacecraft was about 300 days and it used a double antenna radar, significantly expanding the image resolution capabilities of the equipment for targeting.

The Plasma-A spacecraft (Cosmos 1818 type) shown in Fig 4 carried a Topaz-1 nuclear power unit. Its layout and subsystems were similar to the RORSAT US-A.

DEVELOPMENT

The development of space nuclear power systems started in the former Soviet Union in 1956. [5] Table 1 summarizes the specifications attained by nuclear power systems during their development, which ended in the early 1990s. The development of the Soviet space nuclear power systems went through four main conceptual designs. Fast neutron spectrum reactors were abandoned in favour of thermal and epithermal spectra ones. This change meant that the amount of fission material loaded into the reactor was reduced from 50 to 12 kg. Highly enriched uranium carbide nuclear fuel and uranium molybdenum mixture was replaced by more robust uranium oxides. The nuclear fuel enrichment by the U235 isotope rose from 90 to 96% by weight. Passive cooling in a Romashka reactor-converter was abandoned for a more efficient active one, using sodium/potassium liquid metal eutectic alloy coolant circulating in a closed loop cycle. Thermoelectric converters applied in the earlier systems were abandoned for thermionic ones, which were more resistant to radiation damage and slightly more efficient. The nuclear power systems' thermal powers rose from 28 to 150 kW. Thermal to electric conversion efficiencies increased from 1.6% in the earlier Romashka reactor-converter to 4% in later Bouk and Topaz plants, bringing the peak electric power generated by Topaz up to 7kW. Record lifetimes of 1.5-2 years were attained by space nuclear power systems at maximum core temperatures ranging from 1,500 to 1,900°C.

Although the Romashka reactor-converter modification was intended for space applications under the leadership of Sergei Korolev, the project was cancelled after his death in 1966.

Despite the outstanding performance of the Topaz-2 nuclear power unit for its time, that project was also abandoned due to financial reasons. For these reasons only two out of the four main conceptual designs, Bouk and Topaz-1, finally made it to orbit.

FIG 3 (above) The RORSAT US-AM reconnaissance spacecraft. See Ref. [14].

“ ALTHOUGH THE ROMASHKA REACTOR-CONVERTER MODIFICATION WAS INTENDED FOR SPACE APPLICATIONS UNDER THE LEADERSHIP OF SERGEI KOROLEV, THE PROJECT WAS CANCELLED AFTER HIS DEATH IN 1966 ”

FLIGHT QUALIFIED SYSTEMS

For the reasons explained above, two types of nuclear power system were under development and placed in orbit. The power systems using thermoelectric converters were tried first because they were considered to be less technologically challenging.

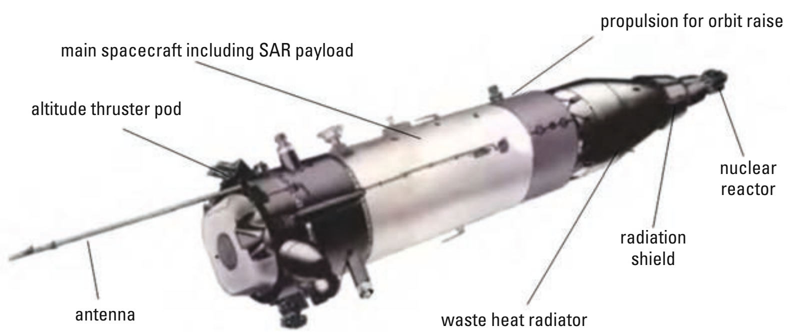
BOUK

The Russian space nuclear reactor power system with thermoelectric converters is typically referred to as Bouk.

The development of Bouk was initiated by the resolutions of the Central Committee of the Communist Party of the Soviet Union (CPSU) and the Council of Ministers of the USSR on 16 March 1961, 3 July 1962 and 24 August 1965. A great collaboration of developers participated in the project, including Joint Stock Company (JSC) “Krasnaya Zvezda”, the JSC “State Scientific Centre “IPPE”, the Science and Technology Centre “Istok” and the Russian Research Centre “Kurchatov Institute”, as well as many other enterprises.

Bouk was intended to power the equipment of Russian radar reconnaissance satellites at the launch site and during the entire active life of the spacecraft, in a circular orbit at an

FIG 4 (below) The Plasma-A spacecraft. See Refs [11, 12].



ALL IMAGES COURTESY VADIM ZAKIROV COLLECTION

TABLE 1 – RUSSIAN SPACE NUCLEAR POWER SYSTEMS

The pictures on the right are not to scale. The picture of the Romashka reactor-converter below was taken inside a test bench facility.

	ROMASHKA	BOUK	TOPAZ-1	TOPAZ-2
Alternative name			Topol	Yenisey
Program duration, years	1964-1966	1966-1988	1970-1988	1975-1988
Neutron spectrum	fast	fast	thermal	thermal/epithermal
Reactor weight, kg	455	<390	320	1061
Core Temperature (maximum), °C	1900	~800	1600	1500-1650
Nuclear fuel	UC2	U-Mo	UO2	UO2
Enrichment by U235, % by weight	90	90	90	96
Fuel loading, kg	49	25-30	11.5	27
Coolant	none	Na/K	Na/K	Na/K
Converter type	thermoelectric	thermoelectric	thermionic	thermionic
Thermal power, kW	28.2	100	150	135
Electric power, kW	0.45	2.5	5-7	5
Conversion efficiency, %	1.6	2.5	~4	3.7
Control material	Be	Be	Be	Be
Lifetime, months	24	3-6	4-12	18
Number of tests	1	36	9	6
Ground	1	4	7	6
Orbit	none	32	2	none

altitude of about 260 km. Bouk was supposed to generate an output electric power of 2,800W for 1,080 hours.

By 1970, almost all the key issues of Bouk development were practically solved by the computational, design, and experimental work done. In particular, during 1963–1969, the liquid metal cooling loop was tested and the reactor-free Bouk was tested with a simulator of a thermoelectric generator (TEG) and then with a real TEG. In 1968–1970, tests of the Bouk nuclear power unit were carried out with the operating reactor in "Krasnaya Zvezda". The tests of the nuclear power plant were successful and all the set goals were achieved. The output electrical power of the main section of the TEG during 1,200-hour tests decreased by 10% and, at the end of the tests, was 905W and 1,040W at temperatures of 690° C and 715° C, respectively. The neutron-physical specifications of the reactor, taken at steady-state operation, were stable over time and satisfactorily correlated with the calculated values and the values experimentally determined on physical assemblies at the Physics and Energy Institute.

" BY 1970, ALMOST ALL THE KEY ISSUES OF BOUK DEVELOPMENT WERE PRACTICALLY SOLVED "

One of the three tested systems had to be stopped due to "boiling" of the primary loop coolant in the reactor zone, due to insufficient pressure in the compensation tanks. The testing was continued after the calibration of the autonomous neutron source, according to a newly developed method using new high-precision test equipment. A full cycle of tests was carried out on the Bouk power unit according to the flight qualification program at the test bench in "Krasnaya Zvezda". The positive test results cleared the Bouk nuclear power unit for launch on-board US-A-type radar reconnaissance spacecraft, shown in Fig 2, in 1970.

Simultaneously with the ground tests of the nuclear reactor, the development and testing of the spacecraft proceeded. A full-scale dummy of the reactor was installed on the Cosmos-102 and Cosmos-125 satellites launched on 27 December 1965 and 20 July 1966, respectively. The main purpose of these launches was proof testing technical solutions, mainly the layout. Those solutions were later implemented in

« real nuclear power units. No radioactive materials were placed in the reactor core, while one of the modifications of the R-7, rather than a standard launcher, was used for their injection into orbit.

The flight qualification took place a few years later, when the development of the launch vehicle, the spacecraft and the nuclear power unit entered their final stage. The "Tsyklon-2A" inserted the Cosmos-198 satellite into orbit on 27 December 1967. For a long time, western experts believed that this spacecraft was the first Soviet spacecraft with a real nuclear power unit on board. In fact, it carried a Bouk full-scale mock-up and the satellite itself was a full-scale dummy. Chemical batteries were used as onboard power sources, which made it possible to test the operation of some of the onboard systems of a future reconnaissance satellite. The Cosmos-209 satellite, launched on 22 March 1968, also carried a Bouk full-scale dummy.

A third test flight was planned but did not take place due to an accident at the launch site. This happened on 25 January 1969, and became a pretext for another legend that existed for many years regarding the radioactive contamination of the area as a result of the destruction of the reactor. In fact, this was not possible, because there were no radioactive materials on-board the satellite during that launch.

By 1970, almost all the development problems of the reconnaissance spacecraft equipped with an onboard nuclear reactor power unit were solved.

The first operational Bouk nuclear power unit was installed on the Cosmos-367 satellite launched on 3 October 1970. It worked for only 110 minutes, after which the reactor was promptly taken to the disposal orbit due to "overheating" in the primary coolant loop caused by the melting of the reactor core. Reliable operation of the propulsion system of the spacecraft itself saved the mission from serious consequences. Ironically, the cause for the "emergency situation" was a flaw by a technician, who had jammed the control thermocouple. While this was revealed, other shortcomings of Bouk, which required additional work, were identified.

After almost five years of modifications carried out at "Krasnaya Zvezda", the flight qualification of the system continued. Between 1971 and 1972, three satellites with the Bouk nuclear power unit were launched into orbit: Cosmos-402, Cosmos-469 and Cosmos-516. Their missions passed without significant flaws. That allowed the radar reconnaissance system to enter into limited operation in the shortest possible time. Unfortunately, on 25 April 1973, the spacecraft failed to reach orbit due to the failure of the launcher's upper stage engine and the nuclear power unit, with a subcritical reactor, fell into the Pacific Ocean.

Flight qualification continued with the launch of the Cosmos-626 satellite on 27 December 1973. During this mission, the pressure of the gas in the shutdown module of the reactor was reduced to zero. Although this failure did not have any dangerous consequences, the designers had to perform more thorough pre-launch check-ups of the shutdown module on the ground and develop a methodology that would prevent the recurrence of similar incidents in the future. Unfortunately, this was not fully achieved and a similar failure occurred on the Cosmos-724 satellite, also launched during flight qualification.

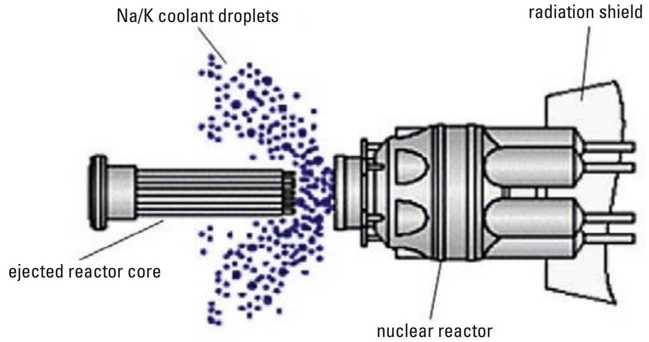
Before the radar reconnaissance system entered service in the second half of 1975, ten launches took place. Two of them were failures: one due to the failure of the launcher, the other due to the reactor malfunction.

During the flight qualification, the need to upgrade Bouk was acknowledged. This was stated in the CPSU Central Committee and Council of Ministers resolution on 26 May 1975. The new requirements were: higher radiation safety of the unit; higher electrical power output, reaching 3kW at the end of its lifetime; and an extension of that lifetime to 6–12 months. Further work on enhancing the design of Bouk was delayed by several years, when the reconnaissance spacecraft were actively exploited. Unfortunately by that time, there were a number of incidents that necessitated focusing primarily on the nuclear safety problem and only after that on enhancing the technical specifications.

On 18 September 1977, the Cosmos-954 satellite with Bouk on board was launched into Earth orbit. This mission proceeded as scheduled until the end of October, when the spacecraft lost its orientation and could not be controlled by the ground station. The command sent to the satellite to take it to the disposal orbit failed and its uncontrolled deorbit began. The situation worsened in early January 1978 when spacecraft depressurization occurred. This accelerated the spacecraft's descent and led to its disintegration on 24 January. Unburned debris fell on north-western Canada in the Great Slave Lake area, causing radioactive contamination of an area of about 100,000 square kilometres. There was an international scandal that made the

“IT WORKED FOR ONLY 110 MINUTES, AFTER WHICH THE REACTOR WAS PROMPTLY TAKEN TO THE DISPOSAL ORBIT DUE TO “OVERHEATING” IN THE PRIMARY COOLANT LOOP CAUSED BY THE MELTING OF THE REACTOR CORE”

FIG 5 (below)
Illustration of the backup safety system ejecting nuclear fuel elements out of the reactor core.
See Ref. [13]



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Soviet Union temporarily abandon launching spacecraft carrying nuclear reactors. For the first time, the Soviet government officially acknowledged launching spacecraft with "small nuclear reactors on board".

After the accident with the Cosmos-954 satellite, work on the onboard radiation safety systems intensified: on the primary one which ensured the insertion of the nuclear reactor into the disposal orbit of 890 km altitude; and on the backup one for ejecting the nuclear fuel elements out of the reactor core using a piston-type mechanism activated by pyros and their subsequent aerodynamic destruction.

The operation of the backup system is illustrated in Fig. 5.

The efficiency of the onboard back-up safety system was confirmed in ground testing and during flight qualification of the nuclear power unit aboard the Cosmos-1176 satellite launched on 29 April 1980. All subsequent Bouks were equipped with such systems.

The missions of the reconnaissance spacecraft resumed in 1980 and continued more or less safely for two years until another accident occurred. On the Cosmos-1402 satellite, launched on 30 August 1982, the situation was similar to that of Cosmos-954. The reactor unit also entered Earth's atmosphere and burned over the southern part of the Atlantic Ocean, but, unlike the "Canadian incident", the modifications prevented radioactive fallout. The backup safety system of the nuclear power plant scattered the reactor core in the atmosphere.

Another break in the launches lasted about 1.5 years before the reconnaissance spacecraft missions were resumed in 1984. This was the last operational period for the Bouk spacecraft. During these years several accidents happened. The missions of the Cosmos-1670 and Cosmos-1677 spacecraft were terminated in 1985 due to failures in the nuclear unit autonomous control system.

In April 1988, communication was lost with the Cosmos-1900 satellite, launched on 12 December 1987. Until mid-September of the following year, it slowly deorbited, threatening to bring new troubles to some part of the globe. The U.S. space monitoring service was involved in tracking the orbit of the spacecraft. Fortunately, on 30 September 1988, a few days before re-entering the atmosphere, the safety system automatically started on the satellite and took it to a safe disposal orbit.

The last launch of the spacecraft with the onboard nuclear power plant took place on 14 March 1988. A modified nuclear unit, with a six-month lifetime and an electrical power of 2,400W at the end of mission, was installed on the Cosmos-1932 satellite. Although the mission went as planned, it was decided to abandon the exploitation of spacecraft with nuclear power plants.

The main reason for this was pressure from the United States and international organizations, demanding that the Soviet Union "stop the pollution of space". But an important factor was the relatively low technical specifications of the nuclear power plants.

The total number of space missions with the Bouk nuclear power unit was 32. One of them never flew and two have re-entered, while the rest till now remain in Earth orbits of between 700–800 km altitude. More information about all the launches of satellites with Bouk nuclear power units is given in Table 2.

The last Bouk nuclear power unit, which never flew into space, was returned from the Baikonur cosmodrome to the "Krasnaya Zvezda" enterprise in 1993, to be disposed of.

NUCLEAR SAFETY

Accidents, in particular that of Cosmos-954, demonstrated that substantial amendments to safety rules for the application of nuclear systems in space had to be made. The revised safety requirements for future space nuclear power systems [7, 9] stated that:

- The design and construction of the nuclear reactor shall ensure that it remains subcritical before reaching the operating orbit during all possible events, including rocket explosion, re-entry, impact on ground or water, submersion in water, or water intruding into the core.
- Nuclear reactors shall not be made critical before they have reached their operating orbit or interplanetary trajectory.
- Nuclear reactors must be shut down in the case of accidents and at the end of a mission.
- Nuclear reactors must be isolated from individuals and populations during the time required for a sufficient decay of the fission products to levels non-harmful for humans.
- In the event that this isolation of nuclear reactors from individuals and populations is not possible, the reactors must be dispersed to levels that ensure the safety of humans in the region of radioactive fallout. These rules were later modified into the guidelines for the UN resolution regarding the use of nuclear power sources in outer space. [24]

> "THE REACTOR UNIT ALSO ENTERED EARTH'S ATMOSPHERE AND BURNED OVER THE SOUTHERN PART OF THE ATLANTIC OCEAN, BUT, UNLIKE THE "CANADIAN INCIDENT", THE MODIFICATIONS PREVENTED RADIOACTIVE FALLOUT"

TOPAZ

Alongside the development of the Bouk nuclear power plant, a whole range of nuclear power plants were developed for electrical power supply from 10 to >500kW. The power supplies were intended for a wide range of space applications, including a lunar base, an expedition to Mars and a manned space station. Out of these, only the Topaz-1 nuclear power unit and Topaz-2 were made into hardware, with only the first one launched to orbit.

The nuclear power plant Topaz-1, also known as "Topol", was developed in accordance with the resolution of the Central Committee of the CPSU and the USSR Council of Ministers dated 3 July 1962 for the radar reconnaissance satellite, while the Topaz-2 nuclear power plant, also known as "Yenisey" was developed in accordance with the resolution of the CPSU Central Committee and the Council of Ministers of the USSR dated 21 July 1967 for a direct television broadcasting satellite system.

The first full-scale ground tests of the Topaz-1 prototype were carried out at the

TABLE 2 – SOVIET NUCLEAR SPACECRAFT LAUNCH HISTORY

	Launch date	Spacecraft	Reactor type	Mission Duration	Disposal orbit (ave. altitude, km)	Comments
1	3/10/70	Cosmos-367	Bouk	110 min.	970	Flight qualification. Reactor core melted. Spacecraft inserted into burial orbit.
2	1/04/71	Cosmos-402	Bouk	< 3 hours	990	Flight qualification. Mission completed.
3	25/12/71	Cosmos-469	Bouk	9 days	980	Flight qualification. Mission completed.
4	21/08/72	Cosmos-516	Bouk	32 days	975	Flight qualification. Mission completed.
5	25/04/73	N/A	Bouk	N/A	N/A	Flight qualification. Reentered: Launcher failure. Sub-critical reactor ended in Pacific ocean.
6	27/12/73	Cosmos-626	Bouk	45 days	945	Flight qualification. Pressure drop in reactor shutdown module.
7	15/05/74	Cosmos-651	Bouk	71 days	920	Flight qualification. Reactor pressure sensor failure.
8	17/05/74	Cosmos-654	Bouk	74 days	965	Flight qualification. Mission completed.
9	2/04/75	Cosmos-723	Bouk	43 days	930	Flight qualification. Mission completed.
10	7/04/75	Cosmos-724	Bouk	65 days	900	Flight qualification. Pressure drop in reactor shutdown module.
11	12/12/75	Cosmos-785	Bouk	< 3 hours	955	Mission completed.
12	17/10/76	Cosmos-860	Bouk	24 days	960	Reactor pressure sensor failure.
13	21/10/76	Cosmos-861	Bouk	60 days	960	Mission completed.
14	16/09/77	Cosmos-952	Bouk	21 days	950	Mission completed.
15	18/09/77	Cosmos-954	Bouk	~43 days	N/A	Reentered: Accidental spacecraft reentry spreading of radioactive debris over a remote region of Canada.
16	29/04/80	Cosmos-1176	Bouk	134 days	920	Mission completed. Back-up safety system flight qualification.
17	5/03/81	Cosmos-1249	Bouk	105 days	940	Mission completed.
18	21/04/81	Cosmos-1266	Bouk	8 days	930	Mission completed.
19	24/08/81	Cosmos-1299	Bouk	12 days	945	Mission completed.
20	14/05/82	Cosmos-1365	Bouk	135 days	930	Mission completed.
21	1/06/82	Cosmos-1372	Bouk	70 days	945	Mission completed.
22	30/08/82	Cosmos-1402	Bouk	120 days	N/A	Reentered: Accidental spacecraft reentry over Atlantic ocean.
23	2/10/82	Cosmos-1412	Bouk	39 days	945	Mission completed.
24	29/06/84	Cosmos-1579	Bouk	90 days	945	Mission completed.
25	31/10/84	Cosmos-1607	Bouk	93 days	950	Mission completed.
26	1/08/85	Cosmos-1670	Bouk	83 days	950	Reactor automatic control system failure.
27	23/08/85	Cosmos-1677	Bouk	60 days	940	Reactor automatic control system failure.
28	21/03/86	Cosmos-1736	Bouk	92 days	950	Mission completed.
29	20/08/86	Cosmos-1771	Bouk	56 days	950	Mission completed.
30	1/02/87	Cosmos-1818	Topaz-1	142 days	800	Flight qualification. Mission completed.
31	18/06/87	Cosmos-1860	Bouk	40 days	950	Mission completed.
32	10/07/87	Cosmos-1867	Topaz-1	342 days	800	Flight qualification. Mission completed.
33	12/12/87	Cosmos-1900	Bouk	124 days	720	Spacecraft communication system failure. Automatic insertion into burial orbit.
34	14/03/88	Cosmos-1932	Bouk	66 days	965	Mission completed.

« SSC "IPPE" test bench in 1970. The unit generated an electrical power of 10kW. The tests were run for 150 hours before termination due to coolant leakage. Four prototypes of the Topaz-1 nuclear power unit were tested in total. On 8 December 1976, the Commission of the Presidium of the Council of Ministers of the USSR on military-industrial issues set prospective dates in 1979–1980 for flight qualification testing of the Topaz-1 nuclear power unit aboard the Plasma satellite.

The lack of a backup radiation safety system for the nuclear power unit led to modification of the Plasma satellite into the Plasma-A satellite, shown in Fig 4. This, in turn, delayed the flight qualification tests, pushing them to 1983–1984. The decision regarding this issue was made by the Central Committee of the CPSU and the Council of Ministers of the USSR on 23 May 1981.

This was not yet the document that cleared the "Topaz-1" for space missions. The final decision was made on 12 February 1986. Two nuclear power units were prepared for the flight qualification. They differed in the cathode coating of their thermionic power converters. Molybdenum cathodes were used in the first unit, while the molybdenum cathodes in the second were coated with tungsten.

The first unit was launched into orbit on 1 February, 1987 and operated aboard the Cosmos-1818 satellite for 142 days. The flight qualification confirmed the consistency of the nuclear power unit specifications within the specified lifetime. The next unit, installed aboard the Cosmos-1867 spacecraft, was launched into orbit on 10 July 1987 and operated for 343 days.

The operation of both nuclear power plants was terminated due to the supply of the working fluid (Caesium) coming to an end.

Apart from these two missions, no other tests of the Topaz-1 nuclear power unit have been accomplished, although talks about its possible application, including in the framework of international projects, had been going on for a long time.

Development of the Topaz-1 and Topaz-2 nuclear power plants proceeded simultaneously. More than 18 full-scale units of the power plant were manufactured and tested, seven of which passed nuclear power tests. Endurance tests of the first experimental samples revealed that the selected thermionic converter design did not guarantee the lifetime requirements. Gaseous fission products caused nuclear fuel swelling and the fuel expansion resulted in pressure build-up on the cathodes' internal wall, causing an increase in the cathodes' diameter and closing the gap with the corresponding anodes. That led to short circuits, so that total electric power dropped. It was also revealed that due to surface changes in the properties of the electrode pair of the cathode-anode and the increase in the blackness coefficient, the degradation of the electric power of the thermionic converters was 3% per 1,000 hours.

After improvements in the thermionic converter design, a lifetime of more than 22,500 hours was achieved during thermal tests with electric heating.

In addition, in order to increase the nuclear power plant lifetime up to 1.5 years, a new upgraded reactor design was applied. The design featured an increased number of thermionic converter channel assemblies in the reactor core (from 31 to 37). Ten samples of the head units of such a nuclear power unit were manufactured for cold and dynamic tests, with subsequent electric power tests on the "Baikal-1" test bench: three units for endurance tests for 1.5 years; three units for flight qualification; and backup samples. During testing of one of the samples, 12,500 hours lifetime was achieved for a full-scale prototype of a space nuclear power unit.

“ RUSSIAN MILITARY SPACE FORCES ADMITTED THE INCIDENT BUT ASSURED THAT THIS DID NOT POSE A THREAT OF RADIOACTIVE CONTAMINATION TO THE EARTH. THE SPACECRAFT IS PREDICTED TO RE-ENTER THE ATMOSPHERE AROUND 2045. BY THAT TIME IT WILL BE SAFE. ”

Unfortunately, all of these records proved fruitless because work on the spacecraft intended to carry the Topaz-2 nuclear power plant had been halted. The development of the nuclear power plant ended at the ground testing stage because the Russian government stopped financing the programme.

According to the report published by Orbital Debris Quarterly News in January 2009, the 21-year-old Cosmos-1818 satellite containing a dormant nuclear reactor was the cause of an unexpected debris cloud in early July 2008. [22-23] The fragmentation event, which occurred on or about 4 July 2008, released dozens of small particles during the unexplained debris generation, according to the U.S. Space Surveillance Network. The bulk of this debris, including 30 clearly identified 30 small objects, were ejected in a posigrade direction with velocities below 15 meters per second, suggesting a low energy event. A larger number of very small pieces of debris had also been released, but routine tracking was difficult by radar. [22-23]

Strict scrutiny of a few of the debris pieces suggested them to be metallic spheres. It was guessed, therefore, that the debris was sodium/potassium (Na/K) droplets. Like the older RORSATs, Cosmos-1818 employed Na/K as a reactor coolant. Although the post-Cosmos-954 RORSATs were known for releasing significant amounts of Na/K droplets in their disposal orbits, Cosmos-1818 and Cosmos-1867 had not followed this precedent till the debris generation event. [22-23]

The bulk of the Na/K coolant within Cosmos-1818 was probably in a solid state at the time of the debris generation event, while some Na/K present in the radiator coolant tubes might have reached a temporary liquid state, particularly when the spacecraft was exposed to direct sunlight. Two possible causes of the event have been suggested. A rupture in a coolant tube at such a time (for example, due to long-term thermal stress) could have resulted in the release of Na/K droplets. Alternatively, a hyper-velocity impact of a small object might have generated sufficient heat to melt some of the Na/K, which then would have formed spheres with metallic properties. To date, no similar debris generation by Cosmos-1867 has been observed. Russian military space forces admitted the incident but assured that this did not pose a threat of radioactive contamination to the Earth. The spacecraft is predicted to re-enter the atmosphere around 2045. By that time it will be safe. [23]

Cosmos-1818's generated debris remains under constant monitoring by the U.S. Space Surveillance Network as well as its Russian counterpart.

CONCLUSION

The experience obtained during the Soviet programme for the application of nuclear

« reactors for the power supply of spacecraft is valuable in many ways. In particular, the decision about the application of turbo-machine conversion for the recent Russian MW-class nuclear power plant module was based on a firm understanding of the thermoelectric and thermionic conversion systems scaling limitations resulting from that programme. Nuclear reactor units with thermionic converters are still under consideration as power supplies for future space missions in which the application of solar arrays is non-feasible or inefficient, for example, deep space missions.

The developed safety guidelines for the use of nuclear power sources in outer space will serve future space missions. The importance of radiation safety precaution measures, not only during the exploitation and lifetime, but also the decay (including disposal period) of radioactive isotopes inside nuclear reactor units, cannot be underestimated or neglected. SC

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JAXA

ABOVE
Earthrise as pictured in a low horizon shot from Japan's Kaguya lunar spacecraft.

ONCE IN A BLUE MOON?

A review of the state of the Japanese lunar programme in 2019 to coincide with the 50th anniversary of the first Apollo Moon landing in July 1969. Japan was the third country to reach the Moon but its lunar programme subsequently fell back as the nation's space agency focused on other solar system objectives.

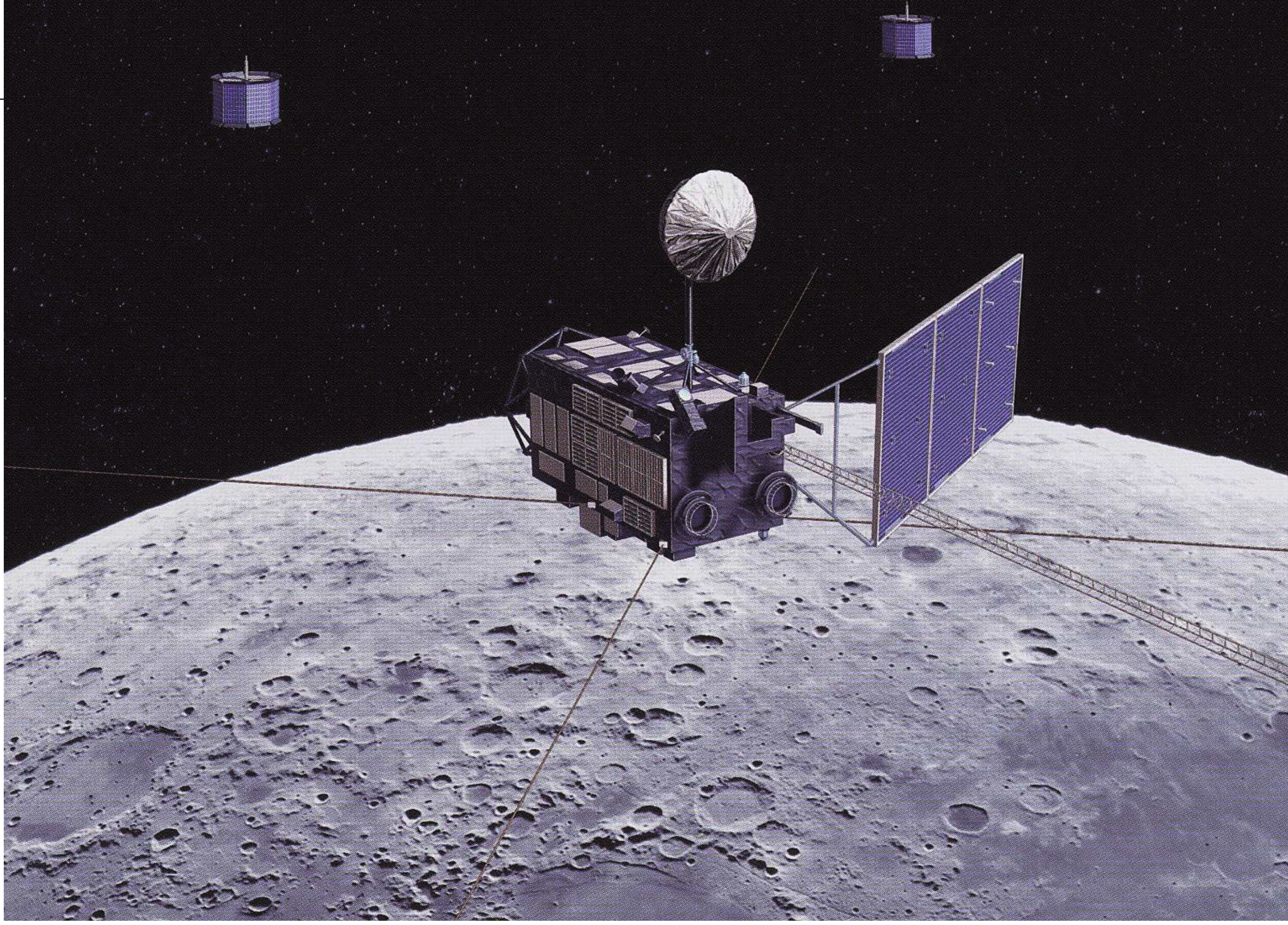
by **Brian Harvey**

Under the guidance of chief designer Hideo Itokawa, Japan developed small solid-fuel rockets in the 1960s, enabling the country in February 1970 to become the fourth nation to orbit a small satellite, following the Soviet Union, United States and France, but ahead of China and India. In the mid-1980s, Japan was able to send two small spacecraft, Sakigake and Suisei, into the tail of Halley's Comet, so a lunar demonstration mission was the next logical step.[1]

Japan became the third country to reach the Moon, in 1990, following the Soviet Union and United States, the first lunar mission since Luna 24 brought samples back from the Sea of Crises in 1976. Launched on 24 January, this was a complex double mission that used a 54-day looping trajectory to reach the Moon, where a small 11kg lunar satellite, Hagoromo, was released into a 7,400 km by 20,000 km orbit on 18 March. Unfortunately its radio failed, but it demonstrated Japan's ability to reach the Moon. The 193 kg mother craft, Hiten, followed a trajectory back toward Earth and used aero braking to return to the Moon, where it entered an unstable 422–49,200 km lunar orbit on 15 February 1992, which led to impact at 38°S, 5°E, on 10 April 1993.

Japan moved on to its next Moon project, the purpose of which was to obtain a substantial

This paper was first presented at the BIS Sino-Russian Technical Forum in London on 1 June 2019.


JAXA

« scientific return. Called Lunar A, this was an orbiter that would drop penetrometers with seismometers to detect seismic activity and heat flow probes to measure the thermal environment below the lunar surface. It was a sophisticated project with an extensive testing phase and went through multiple evolutions, but was eventually abandoned as too complex and expensive.

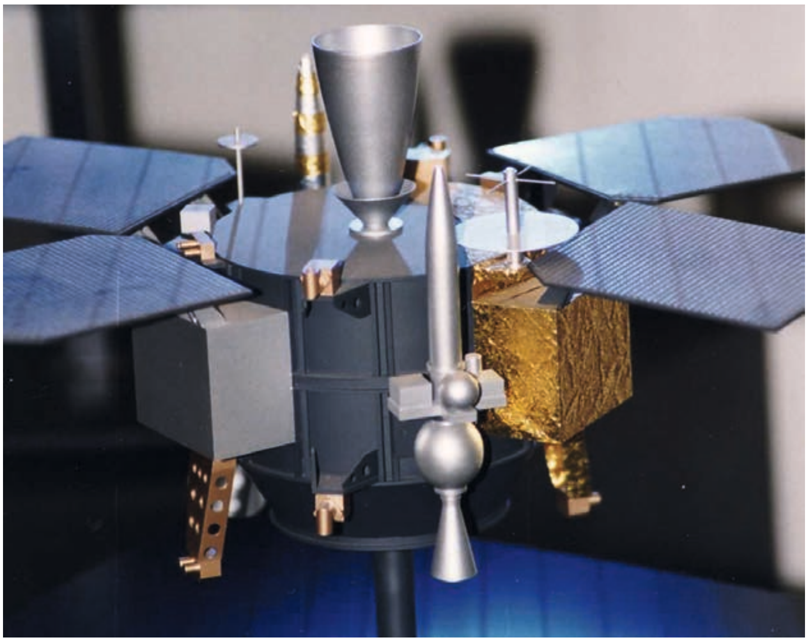
The next Moon probe, SELenological and ENgineering Explorer, or SELENE, was already in development and was a happier story. It was finally launched on the powerful H-IIA rocket on 14 September 2007, the first country out of the gates in the 'great Asian Moon race' that year, to be followed by China's Chang' e 1 and India's Chandrayaan 1. Following standard Japanese practice, SELENE was renamed, being called Kaguya. It took a slow trajectory to reach the Moon on 4th October 2007, entering an initial orbit of 101–11,741 km, later adjusted to an operational orbit of 80–123 km. On arrival in lunar orbit, Kaguya dropped off two sub-satellites, Okina and Ouna.

Kaguya, with 14 instruments, was a

ABOVE
An artist's impression of the Kaguya spacecraft in orbit around the Moon.

BELOW
The long-delayed Smart Lander for Investigating Moon (SLIM), now due to launch in 2021.


JAXA



BRIAN HARVEY

substantial scientific mission. Kaguya carried out high-definition mapping and the Japanese talent for high-quality photography quickly became apparent. The most famous of its 30,000 photographs were of the dimly-lit polar regions bathed in Earthshine, but those of most scientific value were the skylight holes found in the roofs of lava tubes in the Marius Hills. Its radar sounder reached to 5 km below the surface, suggesting the earlier presence of magma oceans. Kaguya led to an initial 150 scientific papers, which made it possible to reconstruct lunar history, indicating the end of most vulcanism 2.4 billion years ago, but with a final surge 1.2 billion years ago to fill the maria.

ABOVE
A model of the early JAXA orbiter Lunar A.

> "JAPAN HAS BEGUN DEVELOPMENT OF A JOINT MISSION WITH FRANCE, TO THE MARTIAN MOONS"

PRESENT AND FUTURE

It had always been planned that there would be a SELENE II and with the success of Kaguya, this project was intensified. SELENE II was an ambitious mission, comprising a rover, lander and orbiter, with a total of 16 instruments, with small cones to be left on the lunar surface. Eleven landing sites were under consideration in 2014 when the project was delayed indefinitely for cost reasons.[2]

It was replaced by a much less costly alternative, Smart Lander for Investigating Moon (SLIM), weighing a modest 130 kg. To contain costs, it would use the new, small, solid fuel launcher, the Epsilon. Its main objective was highlighted as being to achieve a precision landing – to within 100 m accuracy – in the Marius Hills. The rationale for the project was not entirely clear and there has been no stated instrumentation for the project. SLIM was originally scheduled for launch in the mid-2010s, slipping to 2019, then 2020 and presently 2021. Japan's lunar ambitions appear to have suffered from the relatively flat long-term spending pattern of the programme as a whole.

Japan seems to have lost the lead position in the Asian Moon race it established in 2007. China has now sent five spacecraft to the Moon (Chang'e 1, 2, 3, 4, 5T1), including a spectacular far side landing, whereas India concluded the successful Chandrayaan 1 mission and subsequently launched Chandrayaan 2. Israel joined the lunar club with the Beresheet mission in 2019, although it failed shortly before landing. Japan, though, has enjoyed spectacular success with its two asteroid missions, Hayabusa 1 to asteroid Itokawa and Hayabusa 2 to asteroid Ryugu, while Akatsuki was put in orbit around Venus. Japan has begun development of a joint mission with France, called MMX, to the Martian moons in the 2020s.

Despite its relatively small current investment in lunar exploration, Japan has declared its intention of participating in the United States Lunar Gateway project. Japan has sketched ways in which adaptations of the Kibo module on the International Space Station could be purposed as a cargo vehicle, called SELENE X, to bring supplies to a lunar base. Artistic designs of a Japanese lunar base have even been published. Marking the anniversary of the lunar landing, the Japanese space agency, JAXA, signed an agreement with Toyota for the development of a large pressurized lunar rover, presumably part of the American project to return to the Moon in the 2020s. With the austere SLIM mission progressing only slowly, testing crewed lunar rovers seems a bit previous, but it shows that there is continued Japanese interest in lunar exploration. SC

BELOW
Artist's impression of a lunar exploration vehicle developed for JAXA by Toyota but so far still on the drawing board.

JAXA

[1]For a history of the Japanese space programme, see Harvey, Brian; Smid, Henk; & Pirard, Théo: *Emerging space powers – the new space programmes of Asia, the middle east and South America*. Praxis/Springer, 2010.

[2]For the evolution of the Japanese space programme after Kaguya, see this author: *Japan in space, the first 50 years, 1970-2020: past, present and future*. Praxis/Springer, forthcoming.

TalkSPACE...

"I wish I was a spaceman, the fastest guy alive..."

Sir,

Dateline: January 23, 2065.

In actual fact, it's 1965, and thus began a brand new weekly British children's comic *TV Century 21* (or **TV21**, as it came to be more commonly known), published by City Magazines during the latter half of the 1960s. It promoted the many science-fiction television series created by the Century 21 Productions company of Gerry and Sylvia Anderson. The comic was published in the style of a newspaper of the future, with the front page usually dedicated to fictional news stories set in the worlds of *Fireball XL5* (the first line from the catchy theme tune is reproduced above), *Stingray*, *Thunderbirds*, *Captain Scarlet and the Mysterons* and other stories. It ran from January 23 1965 to September 25 1971.

Within the first 51 issues (that I know of), there was a series of articles entitled "The Truth About Space" written between 1965 and 1966 by "Roger Dunn, member of the British Interplanetary Society".

Unfortunately no records or details are available about this person, but his articles covered a wide range of 'real' space topics for the time – docking techniques, spacesuit design, astronaut training, quasars, moon bases, space junk, space stations, comets & asteroids, planets of the Solar System, with many illustrations by renowned space artist and long-time BIS Fellow David A. Hardy FIAAA. There were also individual profiles of the (few) astronauts and cosmonauts of the time.

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ABOVE RIGHT
The first issue of *TV Century 21*.

WWW.LISTAL.COM

BELOW
The ski ramp-launched Fireball XL5 departs Space City on another mission on behalf of the World Space Patrol – located on an unnamed island "somewhere in the South Pacific".

Dunn even makes a direct reference to the BIS in issue no.8, entitled "Space Eyes" (March, 1965), where a special BIS award was given to physicist Dr William H. Pickering of JPL for his contribution to the exploration of space, specifically, the Mariner and Ranger spacecraft programmes. Regrettably, *TV Century 21* issue no.10 is missing from this archive.

You can see my collection of these articles on my Pinterest pages: **https://www.pinterest.co.uk/salmon0655/tv21-truth-about-space-articles/**

Steve Salmon FBIS
(steve.salmon@bis-space.com)

Editor's Note: *As an enthusiastic nine year old when TV21 first appeared I have fond memories reading the adventures set a century in the future each week, inspired by the imagination of Gerry Anderson, and watching the 30-50 minute early evening programmes mentioned above on our small black and white TV. For me Fireball XL5, which first aired in 1962/1963, more than anything else 'launched' my young imagination into the possibilities of space travel. To have, in TV21, a blend of factual articles and escapism stories only enlightened this interest which by the end of the decade led to an avid following of the 'real' space programme, a passion which has never ceased, over 50 years later. Even now the early Anderson programmes remain nostalgic viewing*

The Truth About Space by Roger Dunn, Member of the British Interplanetary Society

TV21 Issue#	Dateline 2065 [1965]	Episode
1	23 Jan	The Truth About Space
2	30 Jan	Project Gemini
3	6 Feb	10-9-8-7-6-5-4-3-2-1 Countdown
4	13 Feb	Man on the Moon
5	20 Feb	Spaceport 1
6	27 Feb	Tailored for Space
7	6 Mar	School for Astronauts
8	13 Mar	Space Eyes
9	20 Mar	How to Become an Astronaut
10	27 Mar	[missing from the archive]
11	3 Apr	Operation GT-3
12	10 Apr	Gemini Adventurers
13	17 Apr	Dinner in Space
14	24 Apr	X-15 Half Plane Half Rocket
15	1 May	Destination Moon!
16	8 May	Trans-World Link-Up!
17	15 May	Moonwalkers!
18	22 May	SNAP Nuclear Space Reactor System
19	29 May	Moon Bug
20	5 Jun	Messages from Space
21	12 Jun	A Dot in the Universe
22	19 Jun	Mercury Nearest to the Sun
23	26 Jun	Venus Earth's Twin
24	3 Jul	Earth Planet for Life
25	10 Jul	Mars Planet of Mystery

TV21 Issue#	Dateline 2065 [1965]	Episode
26	17 Jul	Jupiter The Solar Giant
27	24 Jul	Saturn The Ringed Planet
28	31 Jul	Uranus Odd Man Out
29	7 Aug	Neptune The Poisonous Planet
30	14 Aug	Pluto The Frozen Planet
31	21 Aug	The Asteroid Belt
32	28 Aug	The Dead Planet Mariner Reports on Mars
33	4 Sep	The Milky Way
34	11 Sep	Comets and Meteors
35	18 Sep	The Exploding Universe
36	25 Sep	Space Stations
37	2 Oct	Floating Telescopes
38	9 Oct	8 Years The Record
39	16 Oct	Birth and Death of a Star
40	23 Oct	Space Junk
41	30 Oct	Moon Town
42	6 Nov	Quasars
43	13 Nov	World Space Patrol Manned Orbital Laboratory
44	20 Nov	Astronaut -Aquanaut
45	27 Nov	Operation Space Rescue
46	4 Dec	Sun Hot
47	11 Dec	Emergency Exit
48	18 Dec	Eyes in the Sky
49	25 Dec	Bird Men
	2066 [1966]	
50	1 Jan	Lunar Touchdown
51	8 Jan	Space Fireworks

ABOVE & LEFT
A definitive listing and sample pages from Roger Dunn's *The Truth About Space*, courtesy of TV21 fan Steve Salmon.

ShelfSPACE...

Chronicle, according to the dictionary, relates to "a factual written account of important or historical events in the order of their occurrence." In terms of space exploration this has, for most of us, meant collecting our own library of books documenting aspects of space exploration which fascinate us. Archived within a wealth of news releases, magazine articles, reports, images and memorabilia, their origin in the collection is fondly recalled in our memories. Expanded over many years, our own personal, space library is much treasured with each title fondly thumbed and our favorites taking pride of place on our bookshelves. In an era of digital downloads and social media platforms, the wonder and enjoyment of turning each page in a real book remains, and while the internet can offer instant access to a wealth of reading material, the fun of owning and reading hard copy books still attracts.

As we embark on this new format of Space Chronicle in this regular feature we take the opportunity to look back and reflect on those books which have been milestones in our personal journey into space, if only through the words and images they spread before us. In this first feature the Editor reveals a personal connection between one of the first books in his collection, a long association with the Society and his own writing career. In future issues we will explore new and archival titles, endeavour to learn more about readers' own collections, and review the broad range of books that have become synonymous with key events throughout space history.

David Shayler

Oldie but goldie

It was during the closing months of 1968, that our class teacher tasked us to produce a '3rd year-project' to be delivered by the end of spring term 1969. As a 13-year old facinated by spaceflight, the choice of topic for me was easy – The Apollo Lunar Program.

I had become intrigued with the prospect of landing men on the moon after watching TV reports about the Apollo 7 mission. Routinely pasting newspaper clippings in a scrap book, I was looking forward to the next mission – Apollo 8 which would take the first astronauts around the Moon and, I thought conveniently, right over the Christmas holidays from school.

Eager to conduct some research in the school library beforehand I found a new copy of *Manned Spacecraft* by Kenneth Gatland and was enthralled by its 80-page coloured section , and an additional 150 pages describing the first decade of human spaceflight. Published in 1967 this book, I read, was part of the "Pocket Encyclopaedia In Colour" series by Blandford Press that would subsequently include the titles Frontiers of Space and Robot Explorers by the same author. So enthralled by the modern presentation I put the book at the top of my Christmas list for that year, and as a result it became the first 'space book' in my collection. From that book, my own space library, over the next five decades, has significantly increased in number, but that first book by Ken Gatland, remains pride of place in my collection.

For this teenager, the exciting mission by mission accounts in *Manned Spacecraft* opened up the stories of both the American and also the then Soviet manned space programmes, igniting a desire to find out more and a passion for human space exploration that has never waned. Thanks in part to the superb artwork by John W. Wood

Pocket Encyclopaedia In Colour: Manned Spacecraft
Kenneth Gatland
Blandford Press, 1967, 256 pages, illustrated

and Tony Mitchell, who like Ken Gatland had previously worked at Hawker Aircraft, also attracted me as at the time I was intending to become an apprentice engineering draughtsman once I left school. The book was so popular it would be revised at least twice with an updated 2nd edition published in 1976.

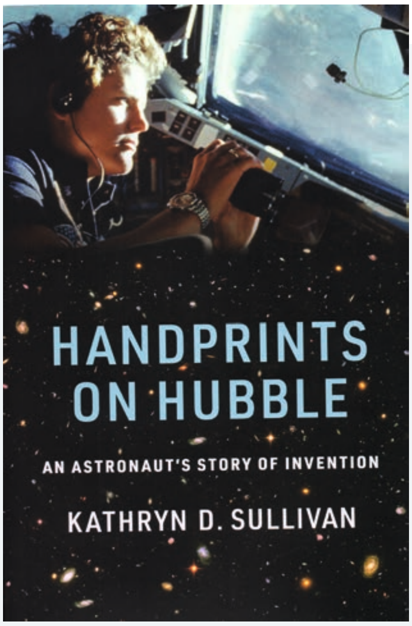
I was so taken with the book that, from the dust jacket I read that Kenneth Gatland was the Vice-President of the rather futuristically named British Interplanetary Society, was a "foremost authority on space exploration" authoring of several books on the topic and the current "editor of the magazine *Spaceflight*". So in this one book

I had found a great source of factual information and technical artwork, the existence of a space society right here in the United Kingdom and a man who not only wrote space books but also edited a magazine on spaceflight. This I had to explore further.

It was some time later that I finally wrote to Ken at the BIS, then located in Bessborough Gardens in London. Ken duly replied and kindly sent a sample copy of *Spaceflight*. Unfortunately I was too young to join the Society at that time and with school exams and a new working life taking precedence, I filed the BIS information away.

I finally joined the BIS as a member in January 1976 and wrote to Ken asking if he was interested in small news items written by me for the Space Report feature in *Spaceflight*, which he eagerly agreed, and soon suggested I tried my hand with full articles. My first article, "Callsigns of Soviet Manned Spacecraft", appeared in the January 1977 issue of *Spaceflight* followed by many more articles over the next few years. Soon I was assisting other authors with the supply of information and images for their books, including in 1989, Ken Gatland's second edition of the *Illustrated Encyclopedia of Space Technology* (Salamander Books) 20 years after I had found Ken's book on that shelf in my school library. Today, over 50 years later, when I take down my copy of *Manned Spacecraft* from the bookshelf I recall how, in 1968 I began my writing career and association with the BIS with that school project and my scrapbook on Project Apollo. SC *David Shayler*

Hands on Hubble



Handprints on Hubble:
An astronaut's story of invention
Kathryn D. Sullivan
Massachusetts Institute of Technology (MIT) Press, 2019, 300 pages, illustrated
ISBN: 978-0-262-04318-2

The story of the Hubble Space Telescope is a fascinating, multi-faceted one. The problems with its long gestation, troubled construction and delayed launch were exacerbated by a fault in its optical system that was not discovered until after it had been released into orbit and the deployment crew had returned home. Then there is the background saga of resolving the optical problem and how a series of Shuttle missions enabled the telescope to do what it was designed to do. This was to provide astronomers and scientists with ground-breaking data from deep within the universe, while allowing many of us to admire the stunning images Hubble has generated for a remarkable three decades. The Hubble Space Telescope has truly changed the way we see our universe and our place within it.

For a researcher fascinated with how the telescope was designed to be serviced, upgraded and maintained by astronauts, and how the teams on the ground and in space actually achieved this, I found talking to those directly involved in the servicing missions to be priceless. Reading first-hand accounts can be equally as informative and exciting, filling in gaps in understanding the topic. When I learned that former astronaut Kathy Sullivan, one of the STS-31 crewmembers who placed Hubble in orbit, was writing a book about the years of developing the tools to service the telescope, I was eager to read her account. I was not disappointed. In Handprints on Hubble, Sullivan explores not only her personal journey on that historic mission but also discusses becoming one of America's first female astronauts and the first U.S. female to perform a spacewalk. As if this was not enough, she skilfully takes the reader through the journey to make Hubble 'maintainable' and, importantly, features the key people in the extensive "Hubble Team" that made the maintenance possible.

This is not just an insider account of developing the procedures, tools and opportunities to keep the telescope flying, it is also a valuable historical record of people passionately devoted to their craft and how they devised ingenious problem-solving solutions for a piece of hardware operating about 540 km above the Earth. The Hubble story is one of a perfect blend between human and robotic space flight, but it is also one of international team-work, and of balancing the desires of the scientists and astronomers against the limitations of the engineers and flight controllers, utilising the capabilities of the crew trainers and astronauts. This is an approach in which Kathy Sullivan admirably succeeds.

Together with the titles Hubble Wars (1998) by Eric J. Chaisson and The Universe in a Mirror (2010) by Robert Zimmerman, Kathy Sullivan's Handprints on Hubble is a must-read and an essential addition to other Hubble titles in your space library. SC *David Shayler*

BackSPACE...

HISTORY LESSONS

SPACE CHRONICLE'S EVOLUTION OVER THE YEARS

This is the third era of the BIS *Space Chronicle* magazine, which was initially published as part of the JBIS family between August 1980 and July 1986 under the editorship of Andrew Wilson. Its widely read articles were aimed at a more general level than the more formal content found in the pages of JBIS. Then, from August 1981, the short-lived and irregular *Astronautics History* added to the BIS portfolio as a second outlet for features from space history. Supplementing the *Space Chronicle* from February 1982 was the increasingly popular *JBIS Soviet Astronautics* series, edited by the late Rex Hall. For over 20 years, this published papers from the popular annual Soviet Technical Forum, which is now known as the Sino-Russian Technical Forum and this year celebrates its 40th anniversary.

After a gap of 15 years, a re-launched *Space Chronicle* was introduced, edited by John Becklake. Between 2002 and 2019, the new version retained the character of the original format, but introduced features that recorded important historical aspects of worldwide space activities, topics of more general interest and papers presented at the Sino-Russian Forum.

History has always been an integral element of the BIS, but over the years has required new outlets to do the topic justice. As explained in the first issue of *SpaceFlight* in October 1956, the venerable *JBIS Journal* had been published since 1934 and the papers contained within had "been of considerable value to research workers." The membership at that time became divided between *JBIS* being too technical or not technical enough. The solution, on the eve of the space-age, was to create a new, more popular magazine called *SpaceFlight.* Here, a clear picture of current research could be presented, as well as "discussing historical matters," and for over 60 years the magazine has achieved that admirably under the guidance of a series of Editors, from Patrick Moore in 1956 to current incumbent David Baker. But once again the time is right for expansion in the publishing portfolio of the Society. This new, re-designed *Space Chronicle* will become the premier space history publication within the BIS, while *JBIS* continues its 75-year plus pedigree of technical features and *SpaceFlight* focuses upon current operations and future developments. *David Shayler*

TIMELINES

SELECTED MILESTONES FROM THE CHRONICLE OF SPACE HISTORY [April – June 2020]

Years ago	Year	Date	Event
100	1920	6 April	Birth of Anatoli I. Savin (1920-2016); became a specialist in (military satellite) information and automatic control systems; and later the Chief Designer of KB-1 and TsNII Kometa.
95	1925	1 May	Birth of Scott Carpenter; NASA Original 7 Astronaut (1959); pilot Mercury-Atlas 7 (1962) & USN Sealab aquanaut (1965).
90	1930	17 May	Max Valier, 35, Austrian rocketry pioneer, is killed when an alcohol-fuelled rocket exploded on his test bench.
85	1935	31 May	A Robert Goddard 'A' series rocket reached 2.28 km.
80	1940	9 April	Birth of Vasily D. Shcheglov; Soviet pilot cosmonaut (1965-1972) who was medically retired before he could fly in space. Shcheglov died of cancer on 16 July 1973.
75	1945	13 June	Birth of Ronald ('Ron') Grabe, NASA Pilot astronaut (1980-1994) who flew on four shuttle missions, twice as a Pilot and twice as Commander.
70	1950	5 May	X-1 flight 133; Pilot Jack Ridley, investigated buffeting, wing and tail loads on the aircraft.
65	1955	6 April	X-2 Flight 6. Pilot Pete Everest. A glide flight; the X-2 (#46-674) became unstable on landing resulting in damage. It was subsequently returned to Bell Aircraft for landing gear modifications.
60	1960	1 April	Tiros 1 (Television Infrared Observation Satellite) was launched; the first successful low-Earth orbital weather satellite.
55	1965	3 June	Edward H. White II, Pilot Gemini 4, becomes the first American to walk in space (20 min).
50	1970	14 April	The oxygen tank #2 failure in Apollo 13's Service Module aborts the third moon landing mission two days into the flight, resulting in an intense three-day journey back to Earth.
		24 April	Dongfanghong 1('The East is Red 1') China's first satellite is launched by a Chang Zheng 1 (Long March 1) launch vehicle.
		19 June	Soyuz 9 (Andrian Nikolayev and Vitaly Sevastyanov) descent module lands after a flight of 17 days, 16 hours, 58 minutes, 55 seconds, setting a new human spaceflight endurance record. Five decades later Soyuz 9 remains the longest crewed flight by a solo spacecraft.
45	1975	5 April	Soyuz 18-1 (Vasily Lazarev and Oleg Makarov) became the first launch abort with a crew on board, after the launch vehicle's third stage failed to separate from second stage of the carrier rocket resulting in a 20+G entry and an emergency landing 22 minutes after launch.
40	1980	9 June	Soyuz T-2 (Yuri Malyshev and Vladimir Aksyonov) lands following a successful four-day and first crewed test flight of the improved Soyuz ferry craft to the Salyut 6 space station.
35	1985	24 June	STS-51G (Discovery) lands at Edwards AFB, California after a successful 8-day satellite deployment mission.
30	1990	7 April	Hubble Space Telescope is deployed by RMS from Discovery (STS-31).
25	1995	1 June	Spektr (Spectrum) module is automatically docked to the Mir space station. The module was equipped for remote sensing of Earth's environment.
20	2000	22 May	STS-101 (Atlantis, ISS flight 2A.2a) crewmembers Jeff Williams and James Voss conduct a 6 hour 44 minute EVA to install the final parts of the Russian built crane, replaced a faulty antenna and installed some handrails and a camera cable outside the embryonic ISS.
15	2005	16 April	Cassini completes its fifth planned close-fly by (1,025 km) of Saturn's moon Titan to gather data on the constituents in the upper atmosphere.
10	2010	2 April	Launch of Soyuz TMA-18 (22S), carrying the ISS E023/24 crew (Alexander Svortsov, Mikhail Kornienko and Tracy Caldwell Dyson) to the ISS. (4 April) TMA-18 docked at the Poisk docking port on the space station.
5	2015	28 April	Launch of Progress M-27M (59P) to ISS. A planned docking 6 hours into the mission was aborted due to a failure of the upper stage of the Soyuz-2.1a launch vehicle prior to separation of Progress, leaving it spinning and not fully controllable. Deemed a total loss, Progress M-27M performed a destructive re-entry on 8 May 2015.

SPACE EXPLORATION AUCTION

May 22, 2020 | Dallas | Live & Online

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See all results from our November auction at HA.com/6219

Apollo 11: Flown MS67 NGC Sterling Silver Robbins Medallion, Serial Number 332

Sold for $41,250

Apollo 11: Lunar Module Flown Section of the Wright Flyer's Wing Fabric, Position #109

Sold for $96,875

Apollo 11: Framed Presentation including a Flown MS67 NGC Robbins Medal, a Crew-Signed Insurance Cover, a Neil Armstrong Photo, and a Crew Patch

Sold for $60,000

Apollo 11: Crew-Signed "Type Three" Insurance Coverr

Sold for $12,500

Neil Armstrong: Uninscribed Signed White Spacesuit Color Photo

Sold for $7,500

INQUIRIES: 877-HERITAGE (437-4824)

Michael Riley | *Director, Space Exploration*

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