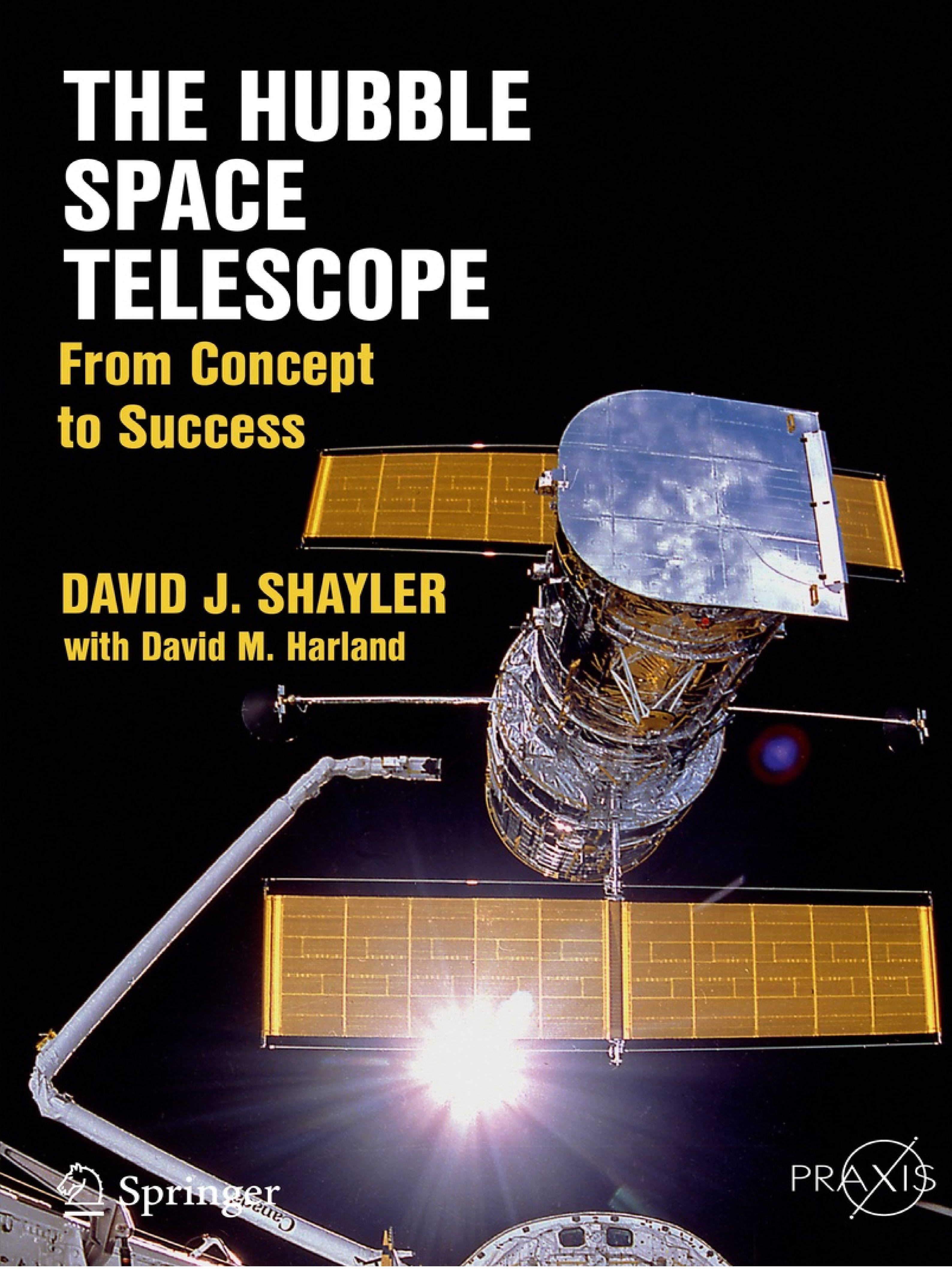
THE HUBBLE SPACE TELESCOPE

From Concept to Success

DAVID J. SHAYLER

with David M. Harland



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David J. Shayler and David M. Harland

The Hubble Space Telescope

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David J. Shayler (Astronautical Historian)
Astro Info Service Ltd., Halesowen, West Midlands, UK

David M. Harland (Space Historian)
Glasgow, UK

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Front cover: An IMAX film still from STS-31, showing the Hubble Space Telescope released from th Remote Manipulator System. A cloudy blue Earth is reflected in the closed Aperture Door.

Rear cover: Left: STS-31 deployment mission emblem; Center, STS-61 Service Mission 1 emblem; Right, the cover of the companion book *Enhancing Hubble's Vision: Service Missions That Expanded Our View Of The Universe.*

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This~~ project is dedicated to Hubble Huggers everywhere. In particular recalling the work, skills,~~ and dedication of all who worked, from the ground up, on the Hubble servicing program, and to their families for allowing them to devote time to work when they really should have been at home.

Also to the memory of Andrew Salmon

(1961–2013)

Fellow author and amateur astronomer who would have loved this project, and who would have offered countless suggestions and guidance.

Foreword

The Hubble Space Telescope is arguably the single most important scientific instrument ever developed. Astronomers knew that a large telescope in orbit would fundamentally change our understanding of the universe. However, in conjunction with the advances over the last two decades i the technology of ground-based telescopes, HST has initiated a revolution in our understanding of th universe unprecedented since the time of Galileo. Astronomers now know the age of the universe to a few percent, have confirmed the existence of black holes, have imaged planets around other stars, an in the Hubble Deep Field and Ultra Deep Field have found a rich population of galaxies of different types and different ages, some of which apparently formed less than a billion years after the Big Ban HST has helped confirm the existence of “dark matter” and “dark energy” which together make up roughly 96 percent of the universe and about which we know almost nothing. As a wise person once pointed out, we are still confused, just confused at a more sophisticated level.

Crucial to the success of HST was the ability, envisioned right from the beginning, for the telescope to be repaired and upgraded while on-orbit. That capability was provided by the space shuttle and astronauts using sophisticated techniques in robotics and EVA. The first service mission i 1993 was the most complex shuttle mission attempted up to that time, and probably the most important NASA mission since Apollo 11. At stake was not only the very future of HST, but NASA’s reputation. Service Mission 1 was to replace the original solar arrays that were impairing HST’s pointing stability and to install hardware that would compensate for the spherical aberration in the main mirror that was preventing the telescope from simultaneously attaining both its design sensitivity and spatial resolution. This success was followed by four more challenging but successful service missions that replaced failed components and upgraded the science instruments.

In addition to HST’s impact on science, developing the methods necessary to successfully execut the deployment and service missions provided valuable experience and confidence in the numerous operational techniques needed to assemble the International Space Station—perhaps the single greatest engineering accomplishment in history. Lessons learned by my crew on the HST deploymen mission in 1990 led to improvements in our ability to handle large, massive payloads using the robot arm of the shuttle, increased the EVA time available for maintenance or assembly tasks, motivated important improvements in crewmember situational awareness during rendezvous and robot arm operations, and instigated better training for integrated robotics and EVA activities.

Dr. Steve Hawley, NASA astronaut 1978–2008. (Courtesy Steve Hawley)

Perhaps not well-known is that HST data are archived and ultimately made available for the general researcher community. This allows for even greater use of the data for projects other than those for which it was originally obtained. New computer processing has been used to reveal previously unknown information in existing observations. One example is the direct detection of a planet orbiting another star, made possible by enhanced data processing capabilities and the remarkable stability of HST imagery. More scientific publications are now being written using HST archived observations than are published using newly obtained data. The science legacy of HST will increase for decades after the telescope is no longer in orbit.

During my astronaut career, I met many people who thought that the shuttle launched from ~~Houston and flew to the Moon. However, the vast majority had heard of the Hubble Space Teles~~cope and were amazed at the images. HST imagery is commonplace in class rooms. It inspires new generations of scientists, engineers and explorers. I was privileged to be one of the few people to get to work on HST in space twice. I may also be the only person to have been blessed to have had the opportunity to work on HST in space and then the chance to use it for research. My career as an astronaut and as an astronomer has been closely tied to the Hubble Space Telescope. Now that the shuttle and I are both done flying in space, the most significant accomplishment for which we will ultimately be remembered may be our long and successful association with the Hubble Space Telescope.

The Hubble Space Telescope in orbit.

Dr. Steve Hawley (Professor, Physics and Astronomy Director, Engineering Physics Adjun Professor Aerospace Engineerin

Preface

It always fascinates me how my various book projects evolve from ideas, sometime going back years even decades. During the late 1960s, I, like many of my generation, became fascinated with space exploration and the race to the Moon. As a young teenager I soaked up all I could on “the space age,” which was at the start of its second decade. As the early Apollo missions reached for the Moon, I became more interested in what the astronauts would do on the surface, using the equipment provided and the procedures developed, to enable them to venture across that alien world. I suppose it was the sense of wonder and magic at that time, the grainy images on a black and white television, and the artistic impressions of research bases on the Moon and projections towards a far distant future—the 1980s—and exciting expeditions to Mars.

This period is fondly remembered as the start of my interest in extravehicular activity, EVA, commonly known as spacewalking. In addition to following the progress towards the lunar landings, the early months of 1969 included my first introduction to Soviet space flight with the EVA transfer from Soyuz 5 to Soyuz 4, followed soon thereafter by the first Apollo EVA. There were media forecasts of extensive spacewalking activities in plans for the rest of the century, of a new spacecraft called the space shuttle, of large space stations, and the repair and servicing of satellites in space. Wow, what an adventure the future held.

Well, one thing I learnt quickly in following the space program was patience and optimism: patience in waiting for things to happen, and optimism that they would become a reality—eventually While investigating EVA in more depth, I became aware of grand plans for Apollo, spacewalking techniques from space stations, and how the shuttle would support EVAs to service and maintain various payloads and satellites, including an astronomical observatory called the Large Space Telescope. Over the next two decades, I gained further insight into EVA involving the shuttle and what was expected to be achieved by astronauts visiting the telescope. The years between 1971 and 1981 saw many changes from the heady days of my youth to the reality of understanding the complexity of the space program. The shuttle suffered from many delays and setbacks, as did the payloads it was planned to carry, including the Large Space Telescope—which for a while was known simply as the Space Telescope prior to its being named in honor of acclaimed astronomer Edwin P. Hubble in 1983.

By the mid-1980s there was more detail available about the shuttle program and the Space Telescope, including reports on how astronauts would maintain and service the instruments, not on Earth as first reported, but in space. Now that caught my attention! Just how are they going to manag that, I asked myself. No one had yet performed an EVA from the shuttle—in fact no American had walked in space for a decade since Skylab, but now teams of astronauts were going to do “space age home improvements” a few hundred miles above the Earth flying at 5 miles per second, this clearly required more study. And so the research began on what became known as the Hubble Space Telescope Service Missions and the genesis of this book.

Across the next three decades my research followed many tracks connected with this project, and soon became aware of the huge infrastructure that was required to support humans in space, the shuttle, and the telescope in particular. There was the challenge of how all three elements were put together. Thrown into this mix was the complication of carrying out useful work while wearing a bulky pressure suit and thick cumbersome gloves in order to improve or repair the delicate parts of th telescope, without disturbing its science work, or breaking it.

Of course the telescope had first to be launched, and that presented its own problems and setback In researching the service missions that were to follow, it became very clear that an immense amoun of work had to be conducted to put each spacewalk together. But it was not just the EVAs, there had t be t~~he replacement items prepared and tested, the tools for the astronauts to complete the task, a~~nd th crews trained to achieve the objectives. Researching all of this also took me into other areas, such as creating the facility to allow for servicing the telescope, ensuring the safety of hardware, crews and equipment at all times, organizing the ground teams, and understanding the environment in which th telescope was operating and the astronauts would work. It also took me into the realms of materials science, human factors engineering, flight control dynamics, orbital operations, and systems engineering. I quickly decided that, not being an astronomer, I would leave the pure science of Hubbl to others. Also, much had been written over the years on the politics and management of getting the idea of Hubble from the drawing board to orbit. Though I knew I would have to touch on this subject, decided I would not delve too deeply into it. What was *not* really covered was the network of small things which together made up the service missions—the hundreds of hours spent on the ground preparing for each mission, and more than anything the devotion, dedication, belief, and tenacity of everyone involved from the worker who put together the smallest components, to the teams who prepared and tested the hardware, the launch team, the flight controllers, the managers, scientists, engineers, technicians, and, last but not least, the astronauts “at the sharp end.” There were, over the period of Hubble operations literally thousands involved in keeping the telescope flying. Many of these people were not directly involved in Hubble’s scientific activities, but every one of them nevertheless contributed to enabling the telescope to obtain the stunning results that the instruments have returned and rightly proud they should be.

This was the story I set out to tell. It is not simply a detailed account of six space shuttle flights, nor is it a historical narrative of the people involved, but a blend of both, together with background information of the hardware and preparations, a jigsaw puzzle of small items which when put togethe presents the finished result. And that result has been flying around our planet for over 25 years, altering the way that we look at the universe, our understanding of that infinite depth, and how we se ourselves as part of that infinity.

This story has been spread across two titles. Firstly, in *The Hubble Space Telescope: From Concept To Success* , I return to April 1990 to recall the deployment of the telescope in space by STS 31, and the challenges addressed to achieve that feat. Then the background to the Hubble story unfolds, from its origin and the birth of satellite servicing, to developing the techniques and tools to achieve that capability at the telescope, and of the huge infrastructure on Earth to support such mammoth undertakings. This work closes with the huge success of the first servicing mission and restoration of its vision.

The second title, *Enhancing Hubble’s Vision: Service Missions That Expanded Our View Of The Universe* , takes up the story with the development of the series of servicing missions required to kee the telescope flying and at the forefront of science, despite inflight failures and a second tragic blow to the shuttle program. The story closes with the often overlooked work on post-flight analysis of returned items of Hubble hardware, and to the fate of the telescope as the 25th anniversary of its launch was celebrated in 2015.

I have enjoyed the complexity of putting this book together and continue to be fascinated in the deeper story of each mission. This work has generated follow-on projects and new ideas that will appear in other titles, so enjoy the journey as I continue to do so.

David J. Shayler (Director, Astro Info Service Lt

Halesowen, West Midlands, U

May 20

Prologue

The year 2009 marked the 400th anniversary of the first use of a telescope to look skywards. Italian physicist and astronomer Galileo, used a crude instrument to make ink renderings of the Moon, recording mountains and craters, as well as a ribbon of defused light stretching across the night sky, a region that we know as the Milky Way. To celebrate this event the International Astronomical Union (IAU) and United Nations Educational, Scientific and Cultural Organization (UNESCO) created, in 2003, the International Year of Astronomy as a global effort to engage “citizens of the world” and encourage them to rediscover their place in the universe by observing the day and night sky and communicate their finding across the world. The program was endorsed by the United Nations and th International Council for Science (ICSU).

When the final report on the project was released, it was revealed that at least 815 million people in 148 countries across the world participated in one of the world’s largest scientific projects. Astronomy was at the forefront of news, and one of the major driving forces of this popularity was a telescope, not on Earth but orbiting it at an altitude of 380 miles (600 km). This telescope, called Hubble, has changed the face of astronomy and our understanding of the universe far beyond anythin that could have been envisaged by Galileo. Over the last four centuries, improvements to telescopes and our knowledge of the sciences has enabled us to make observations that penetrated progressively deeper into space and time. However, it was soon recognized that the distorting effects of our own atmosphere impose a limit on the clarity of the image provided by a telescope on Earth. The next ste was to place a telescope in orbit to observe from above the atmosphere. The full story of Hubble has yet to be written, detailing its successes and difficulties in delivering stunning images and fascinatin insights into the nature of the universe. Some people have said that Hubble does not deliver ground-breaking science, but merely confirms what we already suspected. Others maintain that this is nonsense. Arguing the case for or against Hubble science is not the purpose of this current volume.

In fact, this is not a typical book on the Hubble Space Telescope (HST) because it is not devoted the science and images generated by the facility. Instead, this book examines the vast infrastructure and effort that was created to keep the Hubble flying and how the various techniques were brought together to build, launch, repair, service, and maintain it, thereby learning how to fly such an intricat instrument in space, and keep it operating for years in order to obtain, at the very least, some of the most breathtaking images ever seen of the universe around us.

Originally intended as a one-book project, in-depth research and generous cooperation by many individuals personally involved in the project resulted in the inspired decision by Springer to divide the project across two titles. This first part of the story focuses upon the development of the Hubble Space Telescope concept and the ability to service it to facilitate prolonged research over many years The story of how an idea for a large optical telescope in orbit evolved over four decades into what became the Hubble Space Telescope is matched by the long period of development which resulted in the ability to service the telescope on-orbit using specially designed tools and procedures.

The story opens with the deployment of Hubble by the STS-31 mission in April 1990. The milestone of placing the telescope into space drew to a conclusion decades of proposals that such a facility would be of immense benefit to astronomy and space sciences, followed by debates about ho that feat should be achieved. Astronomers were jubilant. But just a few weeks later came the shockin discovery that the optical system of the telescope was not as precise as expected, and was unable to focus correctly.

With the telescope on-orbit, the challenge was to deliver not only what had be proposed for almo as long as the instrument had been suggested, that of maintenance and servicing, but also to repair what had gone wrong. Five additional shuttle missions over the next two decades met and kept that pro~~mise, allowing Hubble to deliver its science and imagery for a decade longer than its planned~~ 15 year lifetime, and, with a little of the Hubble luck, it will surpass its 30th anniversary in space, still delivering first class science and great images. The rest of the opening chapter looks in more detail a STS-31, and the efforts involved in taking the telescope into orbit.

The second chapter travels back in time and describes how the original idea for placing an optica telescope in orbit evolved and was slotted into the wider astronomical program of the early Americar space program. This chapter recalls early plans for satellite servicing, reviews the proposal for man-tended astronomical platforms, and the role envisaged for astronauts in astronomical research from space.

The third chapter summarizes the turbulent years of the 1970s and early 1980s, and picks out several key developments in technology and procedures that would prove crucial to the later service missions. These include the decision to launch on the shuttle with its capability for on-orbit servicin the sizing of the shuttle’s payload bay to suit the requirements of the US Air Force, which was responsible for launching the nation’s classified satellites, the need for and development of a remote manipulator system, and various rendezvous techniques. This chapter also summarizes the management of the project, which, along with the never-ending battle for funding, featured a number of key decisions that affected the manner in which the telescope would be maintained. It concludes with a review of the participation of a European partner in the program, and the environment in whic the service missions would have to operate.

The next two chapters review the plans for the predecessor of Hubble, called the Large Space Telescope, and how this emerged as the Space Telescope prior to its being named the HST. These chapters also give a brief summary of the HST hardware at the time of launch in 1990. They are a guide to the approaches to servicing and a useful reference for later chapters on the individual servic missions. While the science instruments are mentioned and briefly explained, the science program o the telescope is only mentioned in passing as the main focus remains the on-orbit servicing of such a spacecraft rather than its utilization between shuttle service missions. The development of underwate EVA simulations years before Hubble flew was the key to mastering the service missions. These wat tank exercises, begun in the late 1970s, ended only a few weeks before the final service mission in 2009. The fifth chapter also describes how the EVA servicing of the telescope evolved and the techniques of maintaining and repairing the telescope were developed mainly underwater, although there were exercises involving models, mockups and other 1-g simulators.

The sixth chapter reflects on the equipment developed to support the servicing objectives on the missions. As would any professional craftsman here on Earth, the astronaut servicing crewmember o orbit required certain “tools of the trade,” and these are detailed along with first-hand accounts by people who were at the cutting edge of developing such tools and the procedures for their use.

The public face of the shuttle service missions were the astronauts plying their trade in space, bu on the ground there were several important and vital teams of engineers, flight controllers, and scientists who were the often unseen backup team on every mission. The seventh chapter explains th support team infrastructure and the roles they fulfilled on each mission. The astronauts who would fl a mission, the Mission Control team in Houston, the Hubble team at Goddard, and the launch team a Kennedy, all worked together as one huge team.

With the HST safely in space with defective vision, and with an impressive operational infrastructure in place, the eighth chapter recalls the heady days of the first service mission. During December 1993, STS-61 saved Hubble and NASA from disaster. The series of five EVAs installed th corrective optics to restore Hubble’s vision and completed other repairs and upgrades to the telescop in what was arguably the most important mission by the space agency since the historic lunar landin by Apollo 11, restoring its reputation to a level last seen on Skylab or perhaps Apollo 13 over two decades before.

This first part of the story spans the years from the birth of a concept through many years of uncertainty, delays, frustration and hope, to a final launch, then more disappointment with a flawed mirror, to the plans to overcome what appeared to be a major setback, and to the first servicing mission that restored the telescope to a fully operational observatory.

But this was not the end of the Hubble story. Now that the telescope was up and running, the challenge became to keep it so: to provide new instruments and hardware to improve and extend its capabilities and potential far beyond that initially envisaged, to enhance its vision. The planning, preparation and creation of an infrastructure to support a protracted scientific program was in place. was now time to execute that plan. This part of the Hubble story is told in the companion volume *Enhancing Hubble's Vision: Service Missions That Expanded Our View Of The Universe*. It details th next four servicing missions. This period of almost 15 years also includes the recovery by NASA fro the second tragedy to hit the shuttle program—the loss of Columbia. As the 25th anniversary of the Hubble Space Telescope is celebrated, the story is brought up to date with details of activities after th servicing missions were completed—a time where the Hubble Space Telescope enjoys the status of a national treasure.

Acknowledgements

This was a far reaching project involving the support and cooperation of a number of individuals whose names are etched in the history books of the Hubble Space Telescope program. Firstly I must extend my personal thanks and appreciation to all who have offered their help and assistance in compiling both books, from those who supplied information or offered their recollections and experiences to those who pointed me in the right directions. There are also a number of people who worked tirelessly on the production side, which is never an easy task.

My thanks go to a number of former astronauts who went out of their way to provide at times some very personal recollections of their time working on the Hubble service missions, as well as their insights into the “real” workings of what it means to be an astronaut and all that this entails. Specific to the Hubble missions, my thanks go to Steve Hawley who, in addition to providing valuabl explanations of what it was like to “be the arm man,” also crafted the Foreword to the book. With Bruce McCandless, Steve also offered personal recollections of the mission to deploy the telescope. From the crew of STS-61 my thanks go to Dick Covey, Tom Akers, Jeff Hoffman and Story Musgrave; from STS-82, Steve Smith, Joe Tanner and once again Steve Hawley supplied useful information in response to my queries; Mike Foale and European astronaut Jean-François “Billy-Bob Clervoy provided generous support; and from STS-109 Jim Newman and “Digger” Carey gave fascinating insights into their roles and experiences on the third and fourth service missions. Story Musgrave is to be thanked for providing the Afterword to the book.

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To one and all, a huge thank-you.

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1. Deployment

David J. Shayler[1] and David M. Harland[2]

(1) Astro Info Service Ltd., Halesowen, West Midlands, UK
(2) Kelvinbridge, Glasgow, UK

I really did not want to mess this u

Steve Hawley , RMS operator, STS -3

On April 25, 1990 professional astronomer, NASA astronaut and STS -31 Mission Specialist Steven A. Hawley , was looking intently out of the aft flight deck windows of the space shuttle Discovery orbiting 380 miles (600 km) above the Earth, at the large payload on the end of the robotic arm that h was controlling. To his left was Mission Commander Loren J. Shriver , flying the orbiter. With them on this the 35th mission of the shuttle series were Mission Specialists Bruce McCandless II and Kathryn D. Sullivan , both of whom were on the middeck, preparing for a possible spacewalk if thing went wrong with the payload. Floating between decks was Pilot Charles F. Bolden Jr., who was helping both pairs of colleagues. It was a tense time.

For Hawley , it seemed all attention was on his actions over the next few minutes. He was also monitoring the small TV screens which displayed views of the payload that he was about to deploy: the Hubble Space Telescope . It seemed appropriate that the responsibility to place the long-awaited 'Great Observatory ' into orbit should fall to a professional astronomer. For many who had worked o the project, Hubble had dominated their entire professional career, and it carried the hopes and expectations of the astronomical community, together with scores of designers, engineers, contractor scientists, controllers, managers, politicians and even the general public at large.

Deploying a Telescope

The responsibility of his next actions was not lost on Hawley . "I remember, throughout the mission, but in particular on deploy day, thinking about all of the people and all the years of effort that had le up to this moment. To some extent, what I was doing was just representing the community of scientists and engineers who had taken [Lyman] Spitzer 's idea for an optical telescope on-orbit and made it a reality. So I really did not want to mess this up. I did feel, particularly as a professional astronomer, the weight of the astronomical community. They had done all their jobs, and it's up to m to finish it off. I remember thinking about that quite a lot."

Looking out the overhead aft flight deck windows [left to right] Bruce McCandless, Steve Hawley and Loren Shriver.

Unwanted motions and collision avoidance

Hawley , an astronaut for 12 years, was on his third flight into space, fully proficient and experienced in operating the Remote Manipulator System (RMS) . Although he had operated the arm in simulator and had gained insights from colleagues who had already operated it in space, he had yet to 'fly' the arm in space. But the task was daunting. Hubble was by far the largest mass that the arm had been required to hoist out of the payload bay to date, and the tolerances were tight, so the trick was to recognize the momentum of movement and be able to react quickly enough to do something about it.

Hawley explained this as "the worse failure you can have, when you are trying to unberth Hubble and it is very near the orbiter structure [where] tolerances are very small. With a run-away motor you can have your first hypothetical failure. As there was no collision avoidance software available, the collision avoidance is the RMS operator and you can make [all kinds] of estimates as to how long it would take the operator to recognize a run-away and take [the appropriate corrective] action. Obviously, when the telescope is that low in the bay, and that happens, you have a concern that it is going to take longer to recognize and stop it than the [time and distance] you have. In order to protect for that failure, what they did was, through the software, to limit the amount of current that you can send to the motors and that way, if a motor failed 'on' for some reason it would drive slowly enough that the operator, in principle at least, would be able to recognize that and take action before there was an impact." [1]

That is what was planned for STS -31 . Hawley could control the rate of motion, or drive, through the software. As he unberthed Hubble , the software load would be changed so that when he had lifted the payload high enough, greater current was sent to the motors slowing the rate down. But what happened on-orbit was that these loads became lost in the general 'noise' of the system, to the extent that the signal 'noise' that Hawley was sending from the controller to the arm was not that much bigger than the 'noise' in the system. This combined noise then acted like a command, as far as the motors were concerned, confusing the system. Normally the ground simulators did not model this effect, and the crew didn't notice it until they were actually deploying Hubble. As Hawley explained, “The consensus was, when I would command pure ‘up’ motion, it wouldn’t move purely up, it would wal~~low around. I remember that it was really confusing when it was doing that, because it wasn~~’t the way it behaved in the sims and made the deployment task [about] 50 percent longer, because we kept having it stop and take out the commands that we weren’t requesting and the different axis [that the arm was heading in].”

“Once we came back after STS -31 ,” Hawley continued, “we went over to the Shuttle Engineerin Simulator and we modeled the ‘noise’, and my recollection is that we very accurately reproduced wh we saw in deployment. Ultimately, what we did was develop a control mode for the arm called POHS [pronounced POSH] for Position Orientation Hold Submode [in which] you could select that mode, then command in the minus Z orbiter axis, purely straight up out of the bay, with the software only allowing motion in that one axis. It would cancel out the noise in the system that we had on STS-31 that was trying to rotate the telescope in pitch and yaw, and send opposite commands. That made it quite a bit easier.” [2]

Hubble on the arm

The training for the mission had rehearsed a number of contingency and backup modes, including tw worse-case scenarios that involved deploying the telescope in the backup mode and the total loss of the RMS. A failure of the orbiter’s Main Bus A or Manipulator Controller Interface Unit (MCIU) could disable all the modes reliant on software. It had also been found that in the event of a failure of the systems management general purpose computer this could be replaced by a guidance navigation and control computer in order to support the operation of the arm. Should it be required, the crew had trained to remove and replace a MCIU with a spare. The individual joint motors could be driven in th backup mode, but without computer support or information displays. Reflecting on these contingency procedures, Hawley wrote in 2014 that had such a failure occurred, it would have been preferable to have delayed the deployment of Hubble until the MCIU backup unit had been installed. [3]

Although the Earth return mode for servicing needs had been abandoned in 1985 owing to the cos and the risk to the integrity of the telescope, the option for a contingency return was discussed in the event that Discovery was unable to attain the minimum deployment altitude. The overriding concerns which fuelled the decision to pursue orbital servicing remained, and as a result the team developed a means of deploying the telescope even if the RMS was not functional. This concept, which became known as “backaway deploy”, would have involved turning the orbiter to the tail-to-Sun attitude to allow the telescope’s Sun sensors to lock onto the Sun after its release. The disconnection of the umbilical would then have been followed by the opening of the four payload retention latch assemblies. With Hubble essentially free of the orbiter, Discovery would then have flown out from under the telescope. During flight techniques meetings in 1989, the question of providing the procedures in the STS -31 flight plan were discussed several times. There were many issues to be resolved with this proposal, and of course if anything had gone wrong in the post-deployment period, such as the failure of solar array or high gain antenna deployment, there would have been very little the crew could have done without an operational RMS. In 2014 Hawley recalled that some standalone training was done in the shuttle mission simulator for this mode, but they did not progress to the integrated simulation level. The backaway deployment procedures were available on the checklists fo the mission, but fortunately neither this nor any other contingency plans were needed in deploying th telescope.

As he maneuvered Hubble , Hawley realized that the window view was not helpful once he had th telescope very high above the bay, because the aperture door was blocking the rear windows and was highly reflective, forcing a reliance on the TV cameras. He suspected that he over-drove the cameras