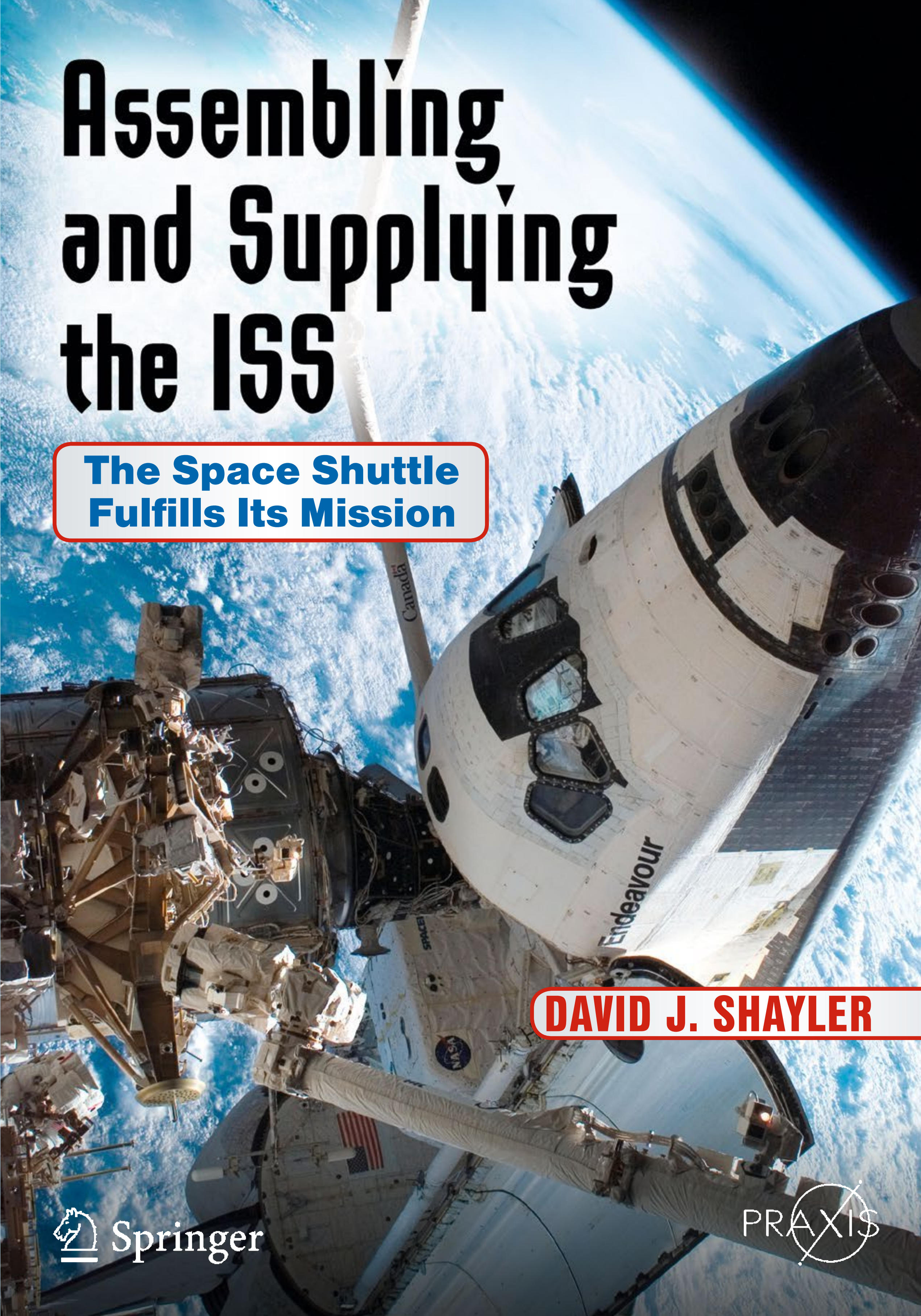
Assembling and Supplying the ISS

The Space Shuttle Fulfills Its Mission

DAVID J. SHAYLER



Springer
PRAXIS

Assembling and Supplying the ISS

The Space Shuttle Fulfills Its Mission

David J. Shayler

Assembling and Supplying the ISS

The Space Shuttle Fulfills Its Mission

Springer

Published in association with
Praxis Publishing
Chichester, UK

PRAXIS

David J. Shayler, F.B.I.S.
Astronautical Historian
Astro Info Service Ltd
Halesowen
West Midlands
United Kingdom

SPRINGER PRAXIS BOOKS IN SPACE EXPLORATION

Springer Praxis Books
ISBN 978-3-319-40441-7 ISBN 978-3-319-40443-1 (eBook)
DOI 10.1007/978-3-319-40443-1

Library of Congress Control Number: 2017945669

Front cover: The Space Shuttle Endeavour docked to ISS in August 2007. This image captures the major elements of Shuttle missions to space stations. The robotic arms of both the Shuttle and ISS can be seen, along with the Spacehab logistics module in the payload bay as one of the crewmembers conducts an EVA at bottom left of frame. Back cover right: Endeavour is seen docked to the ISS in November 2002. The station's robotic arm appears in between the Shuttle and Mission Specialist John Harrington making an EVA. (NASA images) Back cover left: The front cover of the companion volume *Linking the Space Shuttle and Space Stations: Early Docking Technologies from Concept to Implementation*.

Cover design: Jim Wilkie
Project Editor: David M. Harland

Printed on acid-free paper

This Springer imprint is published by Springer Nature
The registered company is Springer International Publishing AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Contents

Preface

For any researcher the history of the American Space Shuttle program is both complex and extensive. It is therefore difficult to condense almost fifty years of development and operations into a single book, or even to a series of volumes. A more suitable aim for a single volume is to provide an in-depth account on a specific topic, a single flight, or a series of related missions. Even then, it is a challenge to condense the voluminous data into a single volume and still present a worthy account. This was the challenge I faced when commencing the research into how the Space Shuttle program was organized and operated to support the delivery, assembly, and resupply of the large structure in Earth orbit that we now know as the International Space Station.

Central to this story were the missions themselves, but the planning which went into each flight, the support provided by numerous ground facilities and teams of engineers, controllers and managers, plus the selection and training of the astronauts that flew the missions were also stories worth investigation. Trying to understand how each Shuttle stack arrived at the launch pad highlighted the extensive and interwoven preparations undertaken at the Kennedy Space Center in Florida, and this prompted further research into the process of integrating the hardware, experiments, and payloads, in addition to the facilities that supported the processing prior to launch. Next I came to the research for the various phases of a mission: the launch, the period of rendezvous and docking, the activities of the Shuttle crews at the station, the transfer of the payloads externally using the Canadian-built Remote Manipulator System, or internally by crewmembers manhandling the supplies into the station and the trash back out. Then there were the spacewalks conducted to support the external assembly and relocation of hardware at the station. Finally, there were the undocking and fly-around phases prior to returning to Earth.

For BIS publications, I had already briefly reviewed the series of Shuttle-Mir flights and the first four years of Shuttle-ISS operations spanning STS-88 to STS-113. For this project, I decided I would bring the story up to date, through to the completion of ISS assembly and the termination of the Space Shuttle program. I included the 1994 flight of the first Russian cosmonaut aboard an American mission (STS-60) that initiated the Shuttle-Mir program. These activities involved forty-eight flights of the Shuttle spread across seventeen years, encompassing one rendezvous and nine dockings with Mir and an impressive thirty-seven missions to the International Space Station. Having briefly covered each of these missions in the two editions of the *Manned Space Flight Log* by Springer-Praxis in 2007 and 2013, I did not wish merely to repeat the flight activities recorded in therein. Equally, the constraints of the original single volume would not allow me to delve as deeply into each mission as I would have liked. I also couldn't merely update the articles in the BIS publications. Hence this project started out as a different approach to recording the extensive program.

From the start, it became apparent that a distinct profile was flown by each Shuttle mission to a space station. Of course a 'typical mission' never really existed, as each flight was unique in its own right. Nevertheless, I have reviewed a number of generic processes and sequences that can be considered to be common ground for each of the missions flown. What was also evident, was the clear division between the story prior to commencing the assembly of the ISS and the period after construction commenced. In researching for this project, I found that the desire to send a Shuttle to a station was almost as old as the program itself, and was one of the original reasons for developing what became the Space Transportation System (STS) concept in the first place.

In fact, the background to blending the Shuttle system with a space station program, and the other way around, was over twenty years in the making. From early conceptual studies for the Space Shuttle through to the dockings of the Orbiter at the Russian Mir space station in the 1990s was a long journey of design, development, cancelation, and eventual success. And this was before a single element of the ISS was launched. After discussing the scope of my research with Springer, they decided that rather than cover the entire story in a single huge volume, I should write two separate books.

In *Linking the Space Shuttle and Space Stations: Early Docking Technologies from Concept to Implementation*, I wound the clock back to the start of the Space Shuttle era and the ambitions to use that system to create and supply a scientific research station in Earth orbit, the background story to the proposed 1981 Shuttle-Salyut docking mission, as well as a simultaneous study by NASA into using the Shuttle to return to the Skylab orbital workshop and restore it to use. The narrative continues with the plans to use the Shuttle to assemble Space Station Freedom, before this morphed into the International Space Station with the inclusion of the Russians enabling NASA to gain much-needed experience of operating the Shuttle in concert with a large space facility by performing the series of Shuttle-Mir docking missions prior to initiating ISS operations. This first volume explains the background to key milestones required to 'link' the Shuttle to the space station, the development of a successful rendezvous and docking system, and an effective method of carrying and transferring tons of hardware to and fro between the two vehicles. The nine dockings by Shuttles at Mir between 1995 and 1998 provided a 'proof of concept' for more extensive operations planned at the ISS.

This second book takes up the story from the end of Shuttle-Mir, at the point where there was some concern that the start of the ISS assembly might be delayed once again due to the unavailability of Russian hardware to initiate assembly. The second chapter briefly reviews the three dozen Shuttle flights between starting to assemble the ISS in December 1998 and the retirement of the Shuttle in July 2011. The third chapter steps away from flight operations to review the fascinating and often complicated world of how crews are assigned. The how and why of a particular astronaut's assignment to a given flight remain a largely mysterious process, a closely guarded secret confined to higher NASA management. Even those in the Astronaut Office who actually flew the missions sometimes have no idea why they were chosen over their colleagues.

Chapter four recalls the myriad procedures, facilities and activities that were needed to get a Shuttle mission off the launch pad, and specifically those to the ISS. Details of the principal facilities at the Kennedy Space Center in Florida which supported Shuttle pre-launch and launch operations were covered in depth in the first volume, and so are only briefly recalled here. Instead, specific to the International Space Station program, is the description of the specialized building that was created in order to handle the vast amount of hardware and cargo that was assigned to the Shuttle missions to the ISS over a period of thirteen years. A 'flight' into space can be viewed as the sequence of events from a spectacular launch through to a safe landing, but a 'mission' often starts months or indeed years before anything reaches the pad, let alone leaves it, and it can continue for some time after landing. Each mission is inseparably linked to the activities on the ground needed to prepare, launch, and return an Orbiter and its payload (including the crew) to Earth…prior to starting the process all over again. It is a fascinating story of management, planning, dedication and sometimes compromise, while also keeping an eye on the weather, not just at the launch site but also at the various potential landing sites around the globe. In fact, Shuttle processing throughout the program, not merely for the missions to Mir and the ISS, deserves a dedicated book!

Chapter five returns to flight operations and the journey from the launch pad to the ISS and, after the loss of Columbia in 2003, the introduction in 2005 of an impressive 'back-flip' maneuver known as the Rendezvous Pitch Maneuver that was executed by each Orbiter to allow ISS crewmembers to conduct a detailed examination, especially of the thermal tiles on its underside. The chapter also recalls the docked phase, during which a visiting Shuttle crew would integrate with the long-duration station crew.

The following two chapters review how the tons of hardware and cargo destined for the space station was delivered and then either transferred inside or bolted on. Chapter six covers the transfer of large elements of hardware internally by the crew, physically moving equipment from the pressurized compartments of the Shuttle. This transfer was often through numerous hatches, tunnels, and crowded compartments into the modules of the space station. By a reverse route unwanted materials, samples from experiments, and trash were loaded aboard the Shuttle for the trip home. This chapter also reviews the various methods and items of crew apparatus that were available to carry logistics between vehicles, and the skills required by the 'loadmaster' to ensure that every item was positioned just where it ought to be. A series of procedures developed during the Shuttle-Mir missions were found to be very effective during the Shuttle-ISS assembly and resupply flights.

The seventh chapter explores, in some depth, the development of using the Shuttle Remote Manipulator System (RMS or Canadarm) in an extensive program of robotics at the expanding station. Operating the RMS was never a large part of Shuttle-Mir but with a wide range of experience from using the arm on several other projects, such as the Hubble servicing missions, NASA was confident it would function satisfactorily during the early stages of ISS assembly. As the station expanded, in 2002 the reach of the RMS on the Orbiter became a limiting factor in continued assembly, requiring the installation of a robotic arm on the station (SSRMS, named Candarm2). Despite these restrictions, the RMS continued to be used on missions to the end of the program for examining the Orbiter, working jointly with the SSRMS, and in supporting teams of astronauts during EVAs. The history of the RMS also warrants a separate story to be written.

The series of EVAs at the ISS are explored over two chapters, and how after many years of study the myriad of tasks were approached, resulting in the highly successful series of spacewalks that supported the assembly and expansion of the facility. Here a more in-depth approach is presented in the build-up to space station EVA activities *by Shuttle flight crew members*, with those conducted by resident crews left to be covered elsewhere. The story begins with plans to use extensive EVA operations to support the assembly of Space Station Freedom and the enormous growth in the projected number of spacewalks that would be required not only to assemble that facility but to maintain it throughout its operational lifetime. It would have been difficult for the astronauts of visiting Shuttles to support station resident teams in a seemingly endless series of back to back EVAs during each year of operations.

The penultimate chapter continues the EVA story at the ISS and the preparations to scale what was known as the 'Wall of EVA' for assembling the ISS, and how, step by step the use of a larger neutral buoyancy training facility and a series of spacewalks to evaluate tools and techniques helped to create the baseline to support an extensive and highly successful series of EVAs at the ISS over the thirteen-year period of assembly. As with other aspects of the Shuttle and ISS programs, it is hoped a far more detailed history of EVA at space stations will appear in due course.

The closing chapter reviews the undocking from the station, fly-around inspection, and return of an Orbiter to Earth. It is remarkable how smoothly missions to Mir and the ISS were executed. Nevertheless there were always plans and procedures available to overcome a variety of potential problems. One of these 'what if' scenarios addressed the difficult situation of an Orbiter that had docked at the ISS and was unable to return safely to Earth. This chapter concludes by looking at how an unmanned Orbiter would be undocked and disposed of. This situation never occurred of course, but it is worth recording here in order to complete the story of the Shuttle activities at space stations.

In researching for my project about the Hubble service missions – which were also instrumental in developing techniques for Shuttle rendezvous and EVA operations at the ISS – I found so much more to study and record. The same is true for this current work, which has prompted more in-depth research into each Shuttle assembly mission and the people who prepared and flew them. There was simply not enough room even within two volumes to tell those stories in great detail, but this work continues…

David J. Shayler, FBIS
Council Member, British Interplanetary Society,
Director, Astro Info Service Ltd.,
www.astroinfoservice.co.uk
Halesowen, West Midlands, UK
March 2017

Acknowledgements

As recorded in the companion title *Linking the Space Shuttle and Space Stations: Early Docking Technologies from Concept to Implementation,* "Each book project undertaken requires not only a significant amount of personal research and input but also a network of contacts, assistance from a number of key individuals, and a great support team to convert the initial ideas and scribbles into the finished product." This volume has been no different.

In researching both books, the network of contacts around the world from these and other activities I have conducted at (and with) the British Interplanetary Society, have been of great help in my ongoing work. I should like to thank the long-term assistance and support of the former and current members the BIS Council and former Executive Secretary Suzann Parry and her successor Gill Norman. And thanks also to Ben Jones and Mary Todd, who were always most helpful and supportive.

I would like to extend my deep appreciation to former NASA astronaut Jerry Ross, veteran of seven Shuttle missions, including the second Shuttle docking flight to Mir and the first and thirteenth Shuttle-ISS assembly missions, for his excellent Foreword and Afterword. Other former astronauts who have assisted with research for this and closely related recent and future books were Tom Akers, Leroy Chiao, Jean-François Clervoy (ESA), Bob 'Crip' Crippen, Robert 'Hoot' Gibson, Steve Hawley, Tom Jones, Janet Kavandi, George 'Pinky' Nelson, Ellen Ochoa, Jerry Ross, Steve Smith, and Joe Tanner. Thank-you one and all for taking the time to tell me of your experiences and also for explaining certain techniques and procedures.

Again, a network of international contacts and colleagues over the years deserve a mention for their continued support and assistance on several projects, including this one: Colin Burgess, Michael Cassutt, Phil Clark, Brian Harvey, Bart Hendrickx, and Bert Vis. Bert also provided several elusive images for this book from his extensive collection and plugged gaps in my records of American astronaut activities in Russia. And mention must also be made of the late Rex Hall and Andy Salmon, both of whom cooperated and supported my early research and publications in this field; their loss is greatly lamented.

The various public affairs and history office staff of NASA and at the University of Houston at Clear Lake and Rice University, also in Houston, who provided assistance and support in my research over a period lasting nearly forty years also deserve thanks. Their help ranged from simply replying to recent E-mail queries (or in the 'old days' to written letters) to assisting and directing my research focus during my visits to NASA JSC and KSC in the period 1988–2002.

My special thanks go to Lynne Vanin, Manager, Public Affairs, MDA Corporation, Ontario, Canada, for detailing the flight assignments and activities of the Shuttle and Station Remote Manipulator Systems on space station missions.

All images are courtesy of NASA via the AIS collection unless otherwise specified. Thanks also to the various contractors and partner agencies for supplying images over the years used in support of research for this and related projects and presentations. I also thank Joachim Becker of *SpaceFacts.de* and Ed Hengeveld for their assistance in providing me some really elusive pictures. The *Space Shuttle Almanac*, painstakingly compiled by Joel W. Powell and Lee Robert Brandon-Cremer between 1992 and 2011 was also a very useful and highly recommended reference source.

On the production side, I am once again indebted to my brother Mike Shayler, who continues to guide me through the quagmire of developing my wordsmithing skills and refined the draft. To David M. Harland for his excellent editorial skills and suggestions that greatly improve the presentation of each book he works on. To Jim Wilkie for his mastery in converting my original notions for a cover to the final product. Thanks also to Clive Horwood at Praxis in England for supporting the proposal, and to his wife, Jo, for letting Clive continue to steer book projects through the refereeing process when by rights he ought to be relaxing and driving their VW camper van around the countryside in a leisurely manner. Maury Solomon, Nora Rawn and Elizabet Cabrera at Springer in New York are also to be thanked for their encouragement and management throughout the production process.

Last, but certainly not least, love and appreciation go to my mother Jean Shayler who once again read the initial draft and offered useful observations and suggestions, and to my wife Bel who used her interview transcribing skills and also assisted with scanning images, collating tables, and checking the final manuscript. Of course it is thanks to Bel that I was given 'parole' from domestic chores to undertake this project. I also welcome our young and rather large German Shepherd 'puppy' Shado, as both the latest addition to the Shayler clan and the new mascot for Astro Info Service. He can finally enjoy the longer walks that he asks for and deserves…at least until the next writing project makes its way to the launch pad.

To each and every one who helped, a very large thank-you.

Also to the memory of our beloved German Shepherd, Jenna (2004–2016), who was the original company mascot and is much missed and will always be remembered.

Foreword

In 1984, four years after I had been selected by NASA to become an astronaut, the agency made the decision to build a large space station in Earth orbit. This was to be assembled and supplied using the capabilities of the Space Shuttle. I was to fly on the Shuttle as a Mission Specialist, trained to operate the robotic arm, deploy and retrieve satellites, perform scientific experiments, and conduct spacewalks. It was exciting to anticipate actually being involved in the assembly of a space station someday.

By the time of my first mission in November-December 1985, NASA was evaluating many options for the configuration of the station and how best to build it. Indeed, on my first mission, STS-61B, Sherwood 'Woody' Spring and I completed two spacewalks to evaluate two different techniques for assembling structures in space. Six years later, on my third mission, STS-37, I again performed a spacewalk associated with space station development. This time Jay Apt and I evaluated a [CETA] rail cart that was intended to facilitate the movement of astronauts and equipment along the main body of the station. The Shuttle was an indispensable tool for developing new techniques and procedures in preparation for assembling a station. But the maturing design of the station, at that time named Freedom, was encountering difficulties concerning its complexity and cost, and was projected to require hundreds of hours of spacewalking activities for its assembly.

After years of debate and redesign, a revised configuration called the International Space Station (ISS) emerged, with Russia as a new partner. The station was still to be assembled and supplied by the Shuttle, but some elements were to be launched by the Russian Space Agency. In addition, a series of Shuttle missions were planned to fly to the Russian Mir space station in order for NASA to gain experience in rendezvous and docking with a large object in space. Meanwhile, during my fourth spaceflight, STS-55 in 1993, I was the Payload Commander for Spacelab-D2, a 10 day US-German science mission with eighty-eight experiments from around the world. The research performed on this mission was a forerunner of the work that was to be conducted on the ISS.

In 1995, I was a member of the second Shuttle crew to dock to Mir. During mission STS-74 we focused on adding a Russian-built docking module to Mir and delivering a significant amount of supplies and equipment to the station. On all subsequent Shuttle missions to the Russian space station, this docking module was used by the Shuttle to mate to Mir.

NASA astronaut Jerry Ross.

Following my only visit to Mir, I served as the Chief of the Astronaut Office's EVA and Robotics Branch and helped to lead the development of the spacewalking hardware, tools, and procedures to be used to build and maintain the International Space Station. Development was proceeding at a hectic pace. It was a challenging effort to make sure that every aspect of every spacewalking task was reviewed, tested, corrected, retested, and verified ready for flight. We also conducted a series of developmental spacewalks that significantly increased the number of astronauts with experience of spacewalking. This was an exciting time, and it was personally very rewarding to be involved in all aspects of the station assembly process. Much to my delight, I was assigned to be the lead space-walker for STS-88, the first ISS assembly mission.

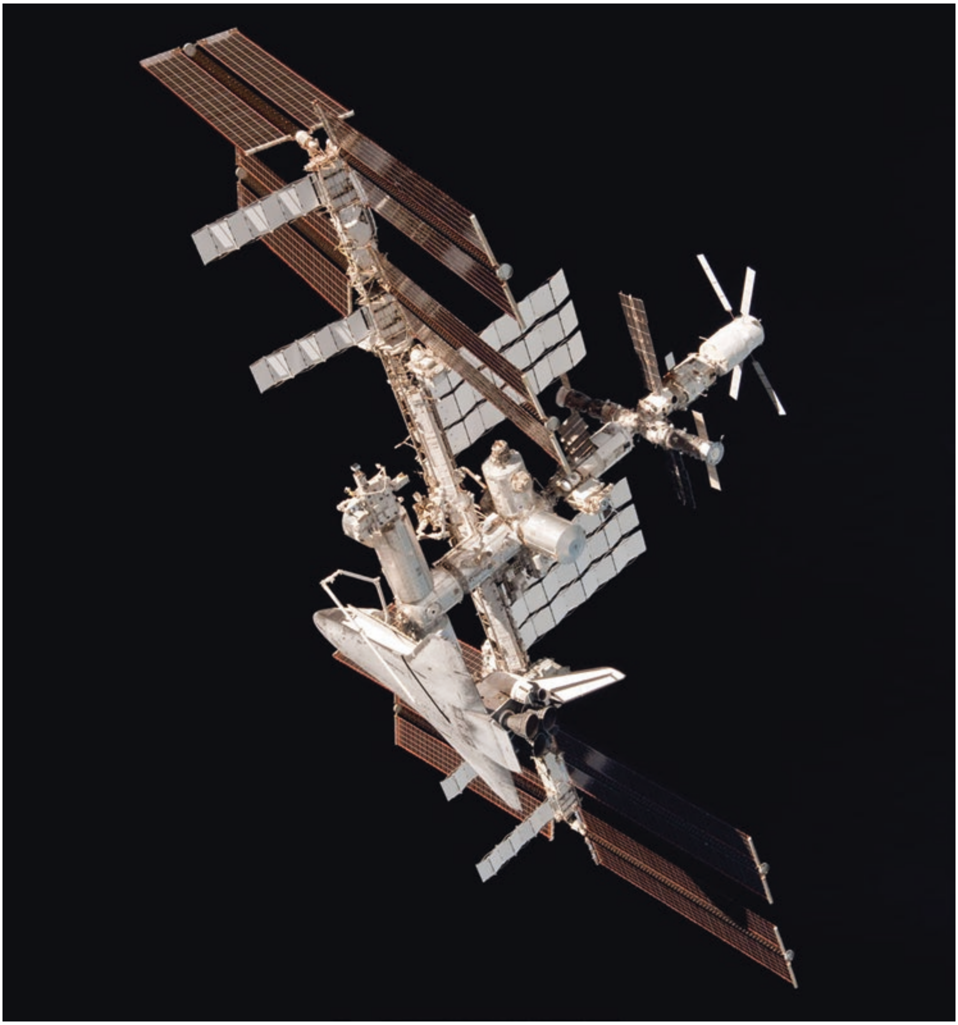
From my previous Shuttle flights and spacewalks, it was clear that the Shuttle was going to be an ideal vehicle to support the assembly of the station. For nearly twenty years, the ability of the Shuttle to carry tons of cargo in its cavernous payload bay, its versatile robotic arm, and its ability to support extensive spacewalking activities had been demonstrated in over ninety missions, including nine docking missions with the Mir station. Though a daunting challenge lay ahead, including a substantial number of spacewalks that we called the 'Wall of EVA,' we were ready and eager to get on with the task in front of us.

As author David J. Shayler explains in this book, assembling the ISS was not just a matter of sending the next Shuttle to space. There had to be an infrastructure in place to build and prepare the ISS hardware, to train the crews, and to conduct over thirty highly successful missions. The story of how the Shuttle program supported the assembly of the International Space Station by applying the rendezvous and docking experience at Mir and by using a blend of robotics and spacewalking, while delivering tons of station elements and supplies, reveals what a complex and involved program it became. It is a real testament to those who designed and built the Shuttle that they had the foresight to provide the vehicle with the awesome capabilities it could draw upon in order to reach 'assembly complete' of the ISS in just thirteen years.

I am honored and proud to have played a part in the creation of the ISS, and pleased that the story of how we used the Space Shuttle to achieve that goal has been expertly presented in this book.

Colonel Jerry L. Ross USAF (retired)
NASA Astronaut (1980–2012)
Mission Specialist, STS-61B, -27, -37, -55, -74, -88 & -110

Author of *Spacewalker: My Journey in Space and Faith as NASA's Record-Setting Frequent Flyer* (2013) and *Becoming a Spacewalker: My Journey to the Stars* (2014).



The almost completed ISS, with the docked Space Shuttle Endeavour, as viewed by the Expedition 27 crew on Soyuz TMA-20 shortly after its undocking in May 2011.

Dedication

In memory to my aunt Gwen Waldron (1924–2015) who found it hard to believe that a ‘house’ could be built in space, even after meeting several astronauts and cosmonauts who had visited one.

Prologue

THE FINAL SHUTTLE MISSION: ***STS-135 Atlantis, Flight Day 12, Tuesday, July 19, 2011.*** Sixteen years and 31 days since Atlantis' historic first docking with Mir, that same Orbiter was now preparing to leave the completed International Space Station for the final time, flying the very last Shuttle mission. As the complex passed 211 nautical miles (391 km) above and off to the east of Christchurch, New Zealand, Pilot Douglas Hurley flipped the switches to release the docking latches and allow the Orbiter to slip its moorings. In synchrony Commander Chris Ferguson radioed, "Physical Separation. Atlantis departing the International Space Station for the last time." In accordance with tradition on the station, ISS-28 Flight Engineer Ron Garan rang the ship's bell and bid his farewell to his departing colleagues, "Thank-you [Atlantis] for your twelve docked missions to the [station] and for capping off thirty-seven Shuttle missions to construct this incredible orbiting research facility."

Following the undocking, Hurley moved Atlantis into position for the formal fly-around maneuver to take pictures to document the exterior of the station. To provide optimum illumination, the ISS was yawed 90°. During the 27 min photo opportunity, the never--before-seen perspective of the longitudinal axis of the ISS from a departing Shuttle was recorded. Chris Ferguson informed the residents, "We just wanted to give you a final good-bye."

In Mission Control, Houston, Capcom Dan Tani, a veteran of a Shuttle assembly and a residency mission to the station, spoke for all in the flight control room when he told those on board Atlantis and the ISS, "We are proud to be the last in a countless line of Mission Control teams that have had the honor to watch over the ISS while Discovery, and Endeavour and Atlantis have visited during the last thirteen years. From this room, we have watched and supported as the Shuttle has enabled the station to grow from a humble single module that was grappled by the Shuttle's arm to a stunning facility that has grown so large that some astronauts have momentarily got lost in it…you can take it from me. The ISS wouldn't be here without the Space Shuttle, so while we have the communications link up for the last time, we want to say thank-you and farewell to the magnificent machines that delivered, assembled, and staffed our world-class laboratory in space."

With the STS-63 and -71 missions to Mir in 1995, these missions formed the 'book-ends' of a remarkable series of flights that had its origins in the late 1960s and the very beginning of the Shuttle program. If events had turned out differently, the first docking of a Shuttle with a space station could have occurred in the early 1980s but that wasn't to be. Instead of assembling Space Station Freedom, the three Orbiters had visited the Russian Mir space station as a prelude to assembling the ISS.

But there is so much more to the story than the three dozen docking missions which the history books record. The assembly of the station and the flights of the Shuttle may now be over, but the story of that achievement has only just begun to be told.

1

An Alternative Plan

I am directing NASA to develop
a permanently manned space station
and do it within a decade.

President Ronald W. Reagan,
State of the Union Address,
January 25, 1984

The 40th President of the United States of America spoke those words at a time when the idea of creating a large research facility in space seemed to be the next natural goal after demonstrating the Space Shuttle could fly, and fly again. The idea of a significant national space station had turned into plans for a largely 'international' station to help with the operating costs and development of associated hardware and logistics supply.

Echoing the May 25, 1961 call by John F. Kennedy to land Americans on the Moon "before the decade is out," some insiders may have foreseen the complexity and costs of such an undertaking, but no one could have guessed that it would take over twenty-seven years and the support and infrastructure of a former Cold War opponent to make that dream a reality.

To the casual observer, it might appear that it was somewhat simpler to develop the capability within eight years to travel a quarter of a million miles out to the Moon than the three decades it took to create a large space station at an altitude of several hundred miles but that surmise would neglect the huge and complicated background story of the years of planning, negotiations, the amendments to those plans, and further negotiating, before junking almost everything in order to pursue a simpler design. Nevertheless, the Shuttle was required to launch the majority of the hardware, support the assembly, and deliver the bulk of the logistics, supplies, and resident crews. It turned out that the new space station program also needed the talents and resources of the former Soviet Union to ensure that the first element of the facility literally got off the ground.

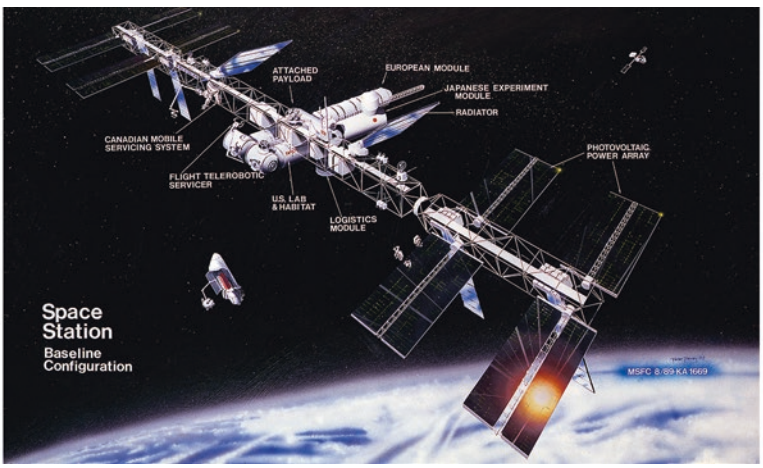
As documented in my *Linking the Space Shuttle and Space Stations: Early Docking Technologies from Concept to Implementation*, the journey from the early suggestions that

D.J. Shayler, *Assembling and Supplying the ISS*, Springer Praxis Books,
DOI 10.1007/978-3-319-40443-1_1

the Shuttle could support the creation of a large research facility in Earth orbit to actually visiting one was a matter of repeated delay, re-design, disappointment, huge expense, and compromise. Despite these struggles, the addition of the Russians in the station program was both fortuitous and timely. The interim Shuttle-Mir program was mostly highly successful for both the Americans and the Russians, with seven NASA astronauts spending many months aboard Mir, and despite challenges that included a fire and a collision, the prospects for continued cooperation with the assembly of the International Space Station looked promising.

There were, naturally, some doubters, mainly in the United States, who questioned what would happen if Russia proved unable to deliver the promised commitment. The question then arose of how should NASA and its other international partners fulfill the commitment to launch, assemble, and operate the space station.

To address this dilemma there had to be a back-up plan, a second 'tier' of assembly designed to ensure that at least *something* made it into orbit, because further delay and expense would be unacceptable not only to the other international partners but also the US Congress.



This image shows the baseline configuration of the proposed Space Station Freedom circa 1989. The design featured the phased approach to building the station, which ensured an initial capability at a reduced cost to the original design, followed by an enhanced capability at a later date.

SHUFFLING THE SHUTTLE TO ASSEMBLE THE STATION

Planning any mission into space can take several years. The drawing up of a workable Shuttle manifest became a daunting task to mission planners. In addition to selecting a crew, the payload had to be received and checked and the vehicle assembled, checked, and loaded. A complication for the scheduling of missions to the space station was the uncertainty in the timing of not only the hardware to be launched but also the funds to support the protracted program. This fluidity also affected the preparation of hardware and the sequence in which elements would be launched. The assistance of the Russians would help the program, but there was no short-term guarantee that they would launch on time. That uncertainty threatened to undermine the planning of Shuttle missions for station assembly.

Furthermore, the Shuttle manifest during the 1990s was now to include at least ten missions to the Russian Mir space station as a sort of stepping stone to the ISS. On top of this were Spacelab missions, servicing flights to the Hubble Space Telescope, a plan to launch and routinely service a commercially operated Industrial Space Facility with the prospect of at least fifteen missions, and a number of satellite deployments and a range of 'observation' missions for the Mission to Planet Earth program.

By 1994 NASA had plans for seventy-eight Shuttle flights running through 2003, including the ten to Mir, no fewer than thirty related to the new space station, and at least two servicing missions to the Hubble Space Telescope. The schedule was by no means an official manifest but a regular internal KSC document aimed at scheduling long range plans, and therefore the resources needed to achieve those missions. Later flights had not yet been assigned specific payloads but the schedule (see Appendix 3) gives an indication of the intensity of Shuttle operations planned for a ten-year period. This was a pace that the space agency came nowhere close to matching. There was a shuffling of the Shuttle vehicles in order to match the changing forecasts almost right up to the end.

To accommodate the Shuttle-Mir program, other intended missions were delayed, canceled, and deleted from the manifest. This process continued as the effort switched to the assembly of the ISS. The missions that lost out included at least three additional ATLAS surveys, the series of Industrial Space Facility deployments, over half a dozen intended Shuttle Radar Laboratory missions, and a number of science flights using the Spacelab module. In scrapping other projects in order to commit the Shuttle to the ISS NASA had to ensure that if Russia was unable to launch its promised elements then at least certain of the hardware envisaged for Space Station Freedom could be pursued to get the ISS assembly started on time.

NASA'S TIER-2: AN ALTERNATIVE ASSEMBLY PLAN

In 1995, in the light of American concerns about Russia being in the 'critical path' of ISS assembly, NASA devised an alternative scenario in case the Russian hardware for the nominal scheme did not materialize for whatever reason.

When the agreement on full cooperation with the redesigned Space Station Freedom was signed between the USA and Russia on September 2, 1993, the name of the station was changed to 'Alpha' because that was a more diplomatic label. The new station had become essentially a slimmed down Freedom configuration that was to be assembled in four phases. The final hybrid configuration included elements from both Option A and Option B, and also incorporated some elements of what had been intended for the now canceled Russian Mir-2 proposal. The renewed partnership with the Russians for Alpha naturally generated a lot of media interest and for a time the new station was referred to as 'RAlph.' But the name Alpha never really caught on, and the project became known simply as the International Space Station.

By 1994 the configuration of Space Station Freedom had been abandoned and instead a mutually agreed stripped down configuration had been accepted. Here the image shows the core configuration using Russian elements and the first Shuttle-delivered components up to the attachment of the Joint Airlock (Phase II).

American doubts of sustained Russian participation in the ISS included the amount of finance NASA was injecting into the ailing Russian space industry. The agreement was for Russia to launch the first two elements of the new station. NASA would add a docking node and a science laboratory to form the core of the station. This plan meant that the major elements that were to be supplied by Canada, Europe, and Japan would be seriously delayed because the truss that carried the solar arrays would require to be in place to support their operation.

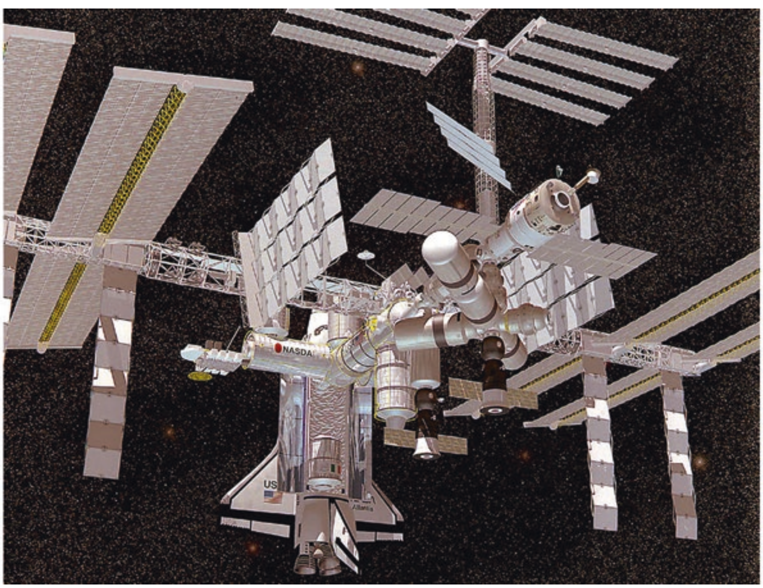
As plans for the ISS were defined, the challenge of securing sufficient, sustained funding also remained, even to the point of having to assure the Russians that the US had no intention of pulling out of the project. With budget reductions in Europe and Canada and with continuing fears of the Russians failing to produce their hardware, a back-up scheme was a prudent (and costly) move. This came at a time when issues in the struggling Russian space infrastructure imposed further budgetary pressure which led to requests for even more finance just to survive, let alone prepare for and support ISS operations – even in the short term.

In addition there were concerns regarding Shuttle safety, with news that the strict launch safety regulations would be compromised if the Orbiter had to meet the very narrow 5 min windows for ISS missions heading for the 51.6° orbit, in contrast to the 28.8° inclination that had been planned for Freedom. A direct consequence of this was the development of a lighter aluminum-lithium construction External Tank for Shuttle-ISS assembly flights, as this would allow a greater fuel margin. Another concern with the Shuttle was that the three-Orbiter fleet would not be sufficient for the twenty-three assembly and utilization missions planned at that point. The venerable Columbia was too heavy to lift the large elements to the station's orbital inclination and altitude, so it could not participate in the assembly work. Another worrying factor was the very fluid politics of the former Soviet Union, with the newly independent nations of Kazakhstan and Ukraine in open dispute with Russia. Consequently, there was a lot at stake as the time approached to start the actual assembly of the station.

The Interim Control Module

If the Russians failed to launch the Salyut FGB that was to serve as the Control Module that NASA intended to buy rather than lease, then a Lockheed-built military propulsion module known as Bus-1 would be sent up as a substitute. If the crucial Service Module also failed to appear, was lost at launch, or was unable to dock with the FGB or Bus-1 (as appropriate) then NASA would launch an Interim Control Module, which was also based upon the Bus-1 design, as a stand-in. If all else failed, a much bigger American propulsion unit was a possibility. Although all this alternative hardware would require budgetary approval Congress was eager for NASA to take precautions against Russian failures.

Both Russian modules were successfully delivered, albeit much later than intended. The first, the FGB named Zarya ('Dawn') was launched in November 1998. A month later STS-88 added the first American element. Russia launched the Service Module Zvezda ('Star') in July 2000. With these modules docked on-orbit, the nascent station was able to support its first crew. The expansion of the station progressed remarkably smoothly with only the loss of Columbia in February 2003 imposing a pause between December 2002 (STS-113) and September 2006 (STS-115).



In this 1995 graphic the completed International Space Station is portrayed with the planned Russian segment prominent in the foreground.

But if the worst case scenario had happened, and Russia had failed to deliver, then NASA's plan to assemble the ISS without the Russians was ready to be implemented. The account in the next section is based on the document 'Tier-2 Bus-1 Option of the ISS.'[1]

Tier-2 Assembly

The premise of the Tier-2 study was the assumption: "Russian participation had been eliminated and that the functions that were once supplied by the Russians (propulsion, resupply, initial attitude control, communications, etc.) are now supplied by the United States." The Lockheed-built Bus-1 was to replace the Russian hardware, and the data was adjusted in the report to reflect this. The role of the Data Book was to define some of the issues that this situation would impose and to recommend means by which they could be solved.

Firstly, several of the early assembly flights would deploy station hardware at the designated assembly attitude, but it was found that in doing this the hardware would have an orbital lifetime of less than 90 days without a re-boost capability. The study also identified a significant shortfall in the time available to undertake both assembly and maintenance EVAs on Shuttle missions. During the first half of the construction sequence, the mass properties of the assembly stages would create large flight angles and poor microgravity environments, hence new CMG hardware must be developed to resolve the problem. In addition, there was insufficient re-boost propellant manifested to compensate for expected increases in the density of the upper atmosphere during the part of Solar Cycle 23 (June 1996 through January 2008) when this construction was to take place. With the solar maximum occurring in March 2000, significant delays could be expected in achieving the program's milestones.

One of the most significant issues in the Tier-2 plan was to retain the station at an orbital inclination of 51.6°. According to the report this was to enable the Russians to rejoin the program if they were able to do so at some point in the future. The assembly altitude was restricted to 150 nautical miles (277.8 km) to achieve the minimum of 90 days of orbital life. To reduce the Shuttle flight rate the manifest called for at most six assembly missions per annum, with the option of a seventh flight to supply additional fuel and to replenish the gases used during EVA airlock activities. This plan therefore manifested a Shuttle flight every other month starting in February 1998. This assumed that delivery of the pressurized nodes wouldn't be accelerated, and it took into account any delays caused by the non-participation of the Russians.

Though the Tier-2 assembly sequence included margins, reserves, and overheads similar to the baseline plan and was not meant to deviate far from that sequence, the order of several flights was changed and some of the proposed cargo elements were rearranged to accommodate the alternative planning. The Tier-2 assembly manifest in Table 1.1 details thirty-six Shuttle launches between February 1998 and December 2003 that would have lifted some 760,036 lb (344,752.3 kg) into orbit and involved at least sixty-five EVAs spread across 286 mission days. This daunting program was expected to be accomplished in less than six years.

Ground Rules And Assumptions

It became clear to the authors of the report that a significant amount of EVA would be required by the Tier-2 program. To assess the EVA resources that would be needed to complete assembly in this new scenario, the following assumptions were made:

Table 1.1 Tier-2 Assembly Sequence Manifest Circa 1995

Flt	Launch Date	Flight Name	Delivered Elements	Altitude (Nm)	Mass to Orbit (lb)	Mission Duration (Days)	STS Crew	Scheduled EVA's
1	2/1998	1A	Bus-1, Spacer	210	31,221	7	5	0
2	4/1998	2A	Node 1 (2 storage racks), PMA3, PMA2	205	27,631	7	5	2
3	6/1998	3A	Z1 truss, CMG's, Ku-band, HP Gases, EVAs (Spacelab Pallet)	200	14,004	9	5	3
4	9/1998	4A	P6, PV Array (4 battery sets) / EATCS radiators, S-band	190	32,956	8	5	2
5	11/1998	5A	Lab (4 Lab Sys racks)	205	29,765	9	5	3
6	12/1998	6A	1 Storage, 7 Lab Sys racks (on MPLM), UHF, SSRMS (on Spacelab Pallet)	215	12,852	12	5	3
7	2/1999	UF-1	ISPRs (on MPLM)	215	15,000	12	7	0
8	4/1999	7A	Airlock, HP gas (on Spacelab Pallet)	215	21,609	9	5	2
9	6/1999	8A	SO, MT, GPS, Umbilical's, A/L Spur	215	30,205	7	5	2
10	8/1999	Bus	Bus-1, spacer	215	28,256	9	5	3
11	10/1999	UF-2	ISPRs, 2 Storage Racks (on MPLM), MBS	215	5,615	12	7	1
12	12/1999	9A	S1 (3 rads), TCS, CETA (1), S-band	215	31,026	7	5	2
13	2/2000	10A	Node 2 (4 DDCU racks), Cupola	215	27,359	12	5	4
14	4/2000	11A	P1 (3 rads), TCS, CETA (1), UHF	215	30,720	9	5	3
15	6/2000	UF-3	ISPRs, 1 Storage Rack (on MPLM)	215	12,890	12	7	0
16	8/2000	1 J/A	JEM ELM PS (5 JEM Sys, 2 ISPR, 1 Storage Rack), 2 O2 tanks (on ULC), SPDM	220	22,810	10	7	6

(continued)

Table 1.1 (continued)

Flt	Launch Date	Flight Name	Delivered Elements	Altitude (Nm)	Mass to Orbit (lb)	Mission Duration (Days)	STS Crew	Scheduled EVA's
17	10/2000	12A	P3/4, PV Array (4 battery sets), 2 ULCAS	220	32,781	8	5	2
18	12/2000	12A+	P5, P4/P5 MT/ CETA Rails, P4 PV Battery Sets (2) 16-day EDO Pallet	230	6,083	15	7	7
19	2/2001	UF-4	ISPRs (on MPLM)	230	13,000	12	7	0
20	4/2001	BF-1	Bus-1	230	25,000	7	5	0
21	6/2001	13A	S3/4, PV Array (4 battery sets), 4 PAS	230	31,994	8	5	2
22	8/2001	13A+	S4 PV battery sets (2), S4 & P6 MT/ CETA rails (on ULC), 16-day EDO Pallet	230	2,556	15	7	6
23	10/2001	UF-5	ISPRs on (MPLM), Attached Payloads (on ULC)	230	9,000	12	7	0
24	12/2001	1J	JEM PM (3 JEM Sys racks), JEM RMS	230	30,864	9	5	2
25	2/2002	2E	1 APM Storage, 3 U.S. Storage, 7 JEM racks (on MPLM), S5	230	13,229	9	5	1
26	4/2002	UF-6	ISPRs (on MPLM)	230	13,000	12	7	0
27	6/2002	2J/A	JEM EF, ELM-ES, P6 PV battery sets (2) (on ULC)	230	14,540	7	5	1
28	8/2002	15A	S6, PV Array (4 battery sets)	230	26,886	9	5	3
29	10/2002	BF-2	Bus-1	230	25,000	7	5	0
30	12/2002	UF-7	ISPRs, 1 Storage Rack (on MPLM)	230	14,390	12	7	0
31	2/2003	14A	Centrifuge	230	24,255	9	7	1
32	4/2003	1E	APM (5 Sys, 1 Storage, 5 ISPR racks)	230	26,467	9	5	1
33	6/2003	16A	Hab (6 Hab racks)	230	27,502	8	5	2

(continued)

Table 1.1 (continued)

Flt	Launch Date	Flight Name	Delivered Elements	Altitude (Nm)	Mass to Orbit (lb)	Mission Duration (Days)	STS Crew	Scheduled EVA's
34	8/2003	17A	1 Lab Sys, 8 Hab Sys racks (on MPLM), S6 PV battery sets (2) (on ULC)	230	10,913	8	5	0
35	10/2003	18A	CTV#1	230	24,255	8	5	0
36	12/2003	19A	3 Hab Sys, 11 U.S. Storage racks (on MPLM)	230	14,402	7	7	0

- Checkout of the SSRMS would be undertaken by the flight that delivered it to orbit, ensuring its operational readiness for the next flight. [In 2001 the actual checkout of Canadarm2 continued after STS-100 had delivered it to the ISS.]
- Every EVA during the assembly phase would be undertaken from the Shuttle airlock rather than the station airlock. [This was not the case during the actual assembly of the ISS. Quest was the primary airlock from 2002. The Orbiter airlock was used by only one subsequent assembly flight (STS-114 in 2005) through to 2011.]
- A baseline of two spacewalks per flight would be established (plus a nominal contingency EVA). Additional spacewalks would be feasible by placing extra tanks of gas in the payload bay. [Consumables were an issue on each mission and reserves had to be husbanded in case a late contingency EVA was called for, such as manually closing the payload bay doors after departing the station. On average, three EVAs were accomplished per ISS assembly mission during the actual program.]

For the purpose of this study the ground rules for the EVA baseline included:

- Maintenance EVAs were not addressed during the reference version of the study. [Presumably time was the critical issue here. It was easier and more important to plan the assembly of the station before setting out to review its maintenance requirements, because until the station was actually built these could only be notional at best. Detailed timelines of known procedures had been studied over the years and there had been extremely detailed time and motion exercises (see Chapter 8).]
- There would be no planned EVAs during utilization flights. [Again the focus was on the assembly missions; the role of the utilization flights during Tier-2 was to stock the station with internal supplies and apparatus. In reality EVAs were scheduled for every assembly and utilization flight. There were several reasons for

this, chiefly that they reduced the pressure on the assembly flights to achieve their primary tasks and they also addressed maintenance issues and any delayed or get-ahead tasks.]

For the Tier-2 studies, electronic models were used to determine the mass and aerodynamic properties for the various flights, while several models of the Earth's atmosphere were used to assess flight characteristics. In addition, CMG and RCS attitude control simulations were performed, using a peak solar cycle worst-case scenario. This predicted a denser atmosphere and a probable slip in the schedule. Attitude control models were studied, both with and without a docked Shuttle. The CMG control of the station was simulated with the units of the Bus serving prior to activating the Z1 truss containing the station's own CMGs. Re-boost analysis used a Freedom RCS control algorithm which once again used the Bus to initiate the burns. Under the Tier-2 planning, propellant resupply for ISSA (International Space Station Alpha) would be by "an as yet undetermined delivery mechanism aboard the Shuttle." This was not an entirely new proposal because the STS-41G mission in October 1984 had demonstrated automated transfer of hydrazine for an experiment. Nothing further had been attempted since, but several NASA field centers had made studies of orbital refueling during space servicing missions, most notably by the Goddard Space Flight Center for Nimbus and Landsat satellites and some of the Great Observatories which NASA was developing.

The minimum operating altitude of the station during its assembly was required to offer "90 days of gradual orbital decay to a low point of 278 km [150 n. miles]." The minimum operational attitude thereafter was given at 180 days of orbital decay down to an altitude of 278 km. During both phases the station would hold a reserve propellant that included a 'skip cycle' (which essentially meant missing a refueling mission slot) in order to re-boost to an altitude that could provide at least 360 days of orbital decay to 278 km under nominal operations, thereby gaining sufficient time to launch a refueling mission.

Systems And Logistical Impacts

In the Tier-2 report, the authors highlighted the changes to the various ISSA system capabilities. They compared the baseline capability from Russian-provided services versus the Tier-2 capabilities without the Russians. This included studies of thermal control; command and data handling; communications and tracking; environmental control and life support; electrical power systems; guidance, navigation and control; propulsion; and EVA and robotics.

Most of these areas were worked around in the Tier-2 model but some couldn't be satisfactorily addressed. The use of the Lockheed Bus-1 prior to activating the US Lab, for example, would have prevented the launching of a resident crew in the early stages. The Tier-2 scenario also ruled out station-based crews being available for maintenance and assembly EVA support activities. It was also noted that when a Shuttle was docked with Node 1, the safe entry of astronauts into that module would require the Orbiter to provide ventilation and atmospheric control. Extra high pressure oxygen and nitrogen would need to be manifested early in the sequence to allow for gas seepage out of the pressurized modules. And during the second phase of the assembly, the Orbiter would have to provide waste management. But atmospheric control and supply, fire detection and suppression, atmosphere revitalization, temperature, humidity, and water recovery and management would all be managed through the laboratory in which the crew were to live. To address the requirement for consumables, any additional gases would have been delivered using modified Gas Conditional Assembly (GCA) tanks on EDO-type pallets in the payload bay.

A Useful But Redundant Study

Whilst useful and thought provoking, the Tier-2 document was happily discarded after the launch of the Russian Zarya and Zvezda modules. Despite being a dead-end study, it did raise a few issues and instigated a useful second look at the assembly plan in the event of Russian involvement being either delayed or withdrawn. Similar studies were performed when the assembly sequence was revised after the loss of Columbia led to a reduction of NASA's overall budget and the decision to retire the Shuttle as soon as the assembly of the ISS was completed.

Studies of this type address something that is often under-reported, namely the huge effort involved in taking into account potential 'what if' situations, and the planning of alternative missions. Alternative, back-up, and contingency plans are part and parcel of space flight, no matter how large or small the project or mission. It is always hoped that such plans won't be enacted, but when they are required (such as switching to the two-person caretaker crews for the ISS between 2003 and 2006) they do provide reassuring breathing space when flight operations go off-nominal and time is needed to work out the next step.

In this image of the completed ISS the American segment, with the European and Japanese laboratories, is shown the foreground, this time with the planned Russian segment in the background.