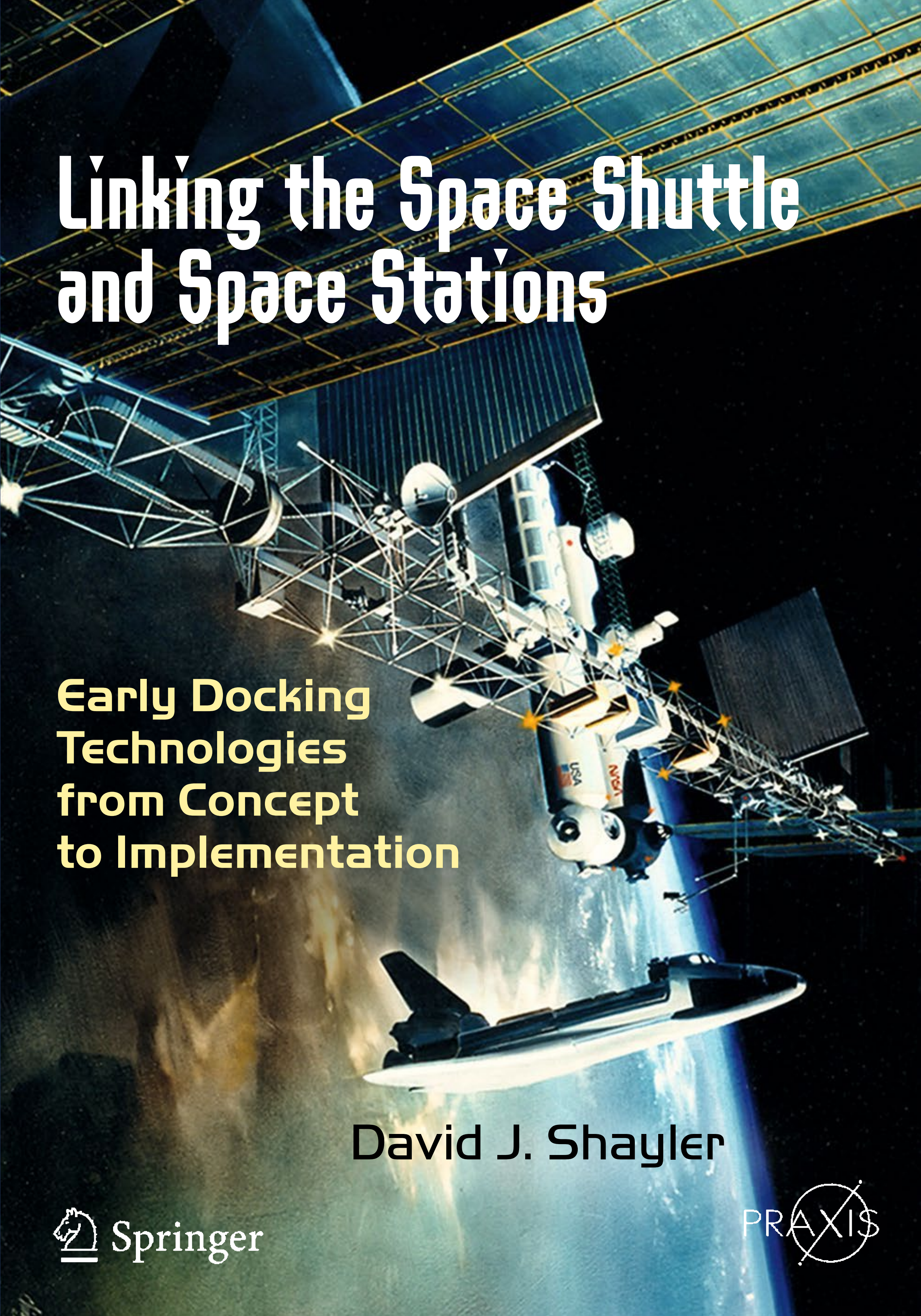
Linking the Space Shuttle and Space Stations

Early Docking Technologies from Concept to Implementation

David J. Shayler



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Front cover: An artist's impression circa 1990 of the Space Shuttle approaching the planned Space Station Freedom, the abandoned forerunner of the International Space Station. Back cover: The front cover of the companion volume *Assembling and Supplying the ISS: The Space Shuttle Fulfills Its Mission* (left) and the official Shuttle-Mir Program Emblem (right).

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Preface

On June 1, 1991, during the 12th Soviet Technical Forum convened at the London headquarters of the British Interplanetary Society, I presented a paper on the mid-1970s proposal for an American Space Shuttle to dock with a Soviet Salyut space station by 1981. This program was a logical follow-on to the highly successful first international docking mission, the 1975 Apollo-Soyuz Test Project. Despite serious discussions between the two sides, the project never developed to flight status, but 20 years later, under the Shuttle-Mir Program, a Shuttle finally docked with the successor to the Salyut series of stations. The Mir docking missions that followed were precursors to a far more ambitious plan to assemble a large international facility in space over a period of several years, mostly by using the resources of the Shuttle fleet.

Research carried out for that presentation, and the published papers that followed, identified common elements of a Shuttle mission that were basically generic to all flights involving space stations. Using this research as a starting point, I was able to piece together how the design of the Space Shuttle, its additional components and procedures, and its basic mission profile became integral to the creation of a large permanent scientific research station in Earth orbit. What has also become evident from investigations over the subsequent two decades is that the story of sending a Shuttle to a space station was a complex one in which the frequent changes of plan caused the people involved tremendous disappointment and frustration.

Originally, this writing project was to have been confined to a single volume, but it soon became apparent that it was, in fact, a story of two halves, and therefore, two separate titles have been produced. Firstly, in *Linking the Space Shuttle and Space Stations*, the development of key components in the Shuttle system are described. These include the massive infrastructure on the ground to prepare the vehicles for launch, the major hurdle of developing a suitable rendezvous and docking system, and the most appropriate flight profile. The story includes a number of ultimately abandoned plans that were intended to gain experience in docking a Shuttle to a smaller space station ahead of the more complex task of assembling a much larger space complex.

In the early 1970s, initial concepts for the Space Shuttle orbiter envisaged the vehicle possessing an integral docking system, but this was not present in the final design. It was during this time frame that the United States, through NASA, was discussing with the

Soviet Union the possibility of developing a common docking apparatus and perhaps undertaking a joint mission to evaluate the design. This plan became the Apollo-Soyuz Test Project. So successful was this mission in July 1975 that it prompted interest on both sides to develop a subsequent, more advanced joint docking mission. *Linking the Space Shuttle and Space Stations* includes an account of the concept for docking a Shuttle orbiter with a second-generation Salyut space station. Unfortunately, a downturn in superpower politics ruled this out. This book also discusses a later plan by NASA for the Shuttle to rendezvous with the vacated Skylab, with a view to reactivating or updating its systems in order to reoccupy it. But this idea had to be abandoned because delays of qualifying the Shuttle system meant that Skylab fell back into the atmosphere before the new spacecraft entered service.

When President Ronald W. Reagan announced in January 1984 that NASA should assemble a space station (later called Freedom) within a period of 10 years, this followed years of debate, delay, and changes of configuration. Similar hurdles were to plague the project in years to come. Although frustrating to the designers, these years of endless indecision gave NASA the opportunity to acquire hands-on experience in using the Shuttle Remote Manipulator System (RMS) to deploy, grapple, and retrieve a variety of payloads and to support the first US spacewalks since Skylab. This was a valuable breathing space not only to qualify the Shuttle RMS and EVA hardware but also to demonstrate the limitations of both systems in the face of an expanding, much more complex, and ultimately hugely over budget Space Station Freedom.

By the early 1990s, a change was essential to ensure that the construction of space station hardware could finally begin. Firstly, the design was dramatically reduced. Secondly, Russia joined the international partnership bringing a vast experience of space station operations from a succession of Salyuts and the current Mir complex. This provided NASA with a stepped approach to creating what would become the International Space Station (ISS). During the 1990s, NASA gained further experience of RMS operations and EVAs from Shuttles that rendezvoused with a variety of free-flying payloads.

As the first elements of the ISS arrived at the launch site for processing, a series of missions to Mir afforded NASA and its astronaut corps much needed experience in rendezvousing with a large space station, performing difficult maneuvers around it, and physically latching on to it.

This book does not focus on the details of the Shuttle-Mir missions nor the seven periods of residency by NASA astronauts on Mir (these are related in a forthcoming title), so it is sufficient to say simply that they provided valuable experience prior to embarking on the assembly of the ISS. Shuttle-Mir offered American astronauts the opportunity to fly the first long-duration missions since Skylab, two decades earlier. It also saw the relocation of many tons of bulky logistics to and from the aging Mir space station and demonstrated the need for a coordinated launch manifest that not only addressed national interests but also international concerns.

Although the Shuttle did little assembly work at Mir, indeed it installed only one component – this was supplied by Russia to simplify the docking of orbiters – the docking missions enhanced confidence not only on orbit but also on the ground that the International Space Station could be assembled using the Space Shuttle system. This would mark the realization of an idea that was first proposed some 30 years previously.

Linking the Space Shuttle and Space Stations explores the lessons that were learned in the early 1970s and then lost and regained. It also reviews various plans to use the Shuttle in conjunction with small modular space stations through to the latter half of the 1990s. And it concludes the successful Shuttle-Mir missions which opened a new era of international cooperation in space. This was also the period in which the infrastructure and flight procedures were established that would eventually support a huge effort to embark on one of the most ambitious construction projects in history, a story that is related in the companion volume *Assembling and Supplying the ISS: The Space Shuttle Fulfills Its Mission.*

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February, 2017

Acknowledgements

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. I often compare writing a book to swimming in a pool of hot water: you must endure a great deal of emotional pain and at times frustration, but remain dedicated and sacrifice countless hours to research, compilation, checking, and adjustments. However, once the book is published, you feel a whole lot better! My problem is that I habitually jump right back into that pool and start the process all over again.

When I select a topic to write about, I immerse myself in the subject, frequently turning up things which were not in the plan for the book. Such discoveries prompt further work (and sometimes additional titles) to continue a story that simply could not be covered by a single volume. This present work evolved from a presentation delivered to the British Interplanetary Society in 1991 and from a number of papers that they published over the next 15 years in which I explained the rich history and development story of sending a Space Shuttle to a space station in Earth orbit. This work later expanded not only into this title and its companion *Assembling and Supplying the ISS: The Space Shuttle Fulfills Its Mission*, it also prompted research that will further discuss the sending of Shuttles to space stations.

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

I appreciate the help of former NASA astronaut and USN Captain Robert "Hoot" Gibson, who commanded the first Shuttle to dock with a space station, not only for his excellent Foreword but also for his guidance in the activities on the flight deck of Atlantis during that initial docking with Mir. Thanks also to his wife and fellow former NASA astronaut, Dr. Rhea Seddon, for her interest in my work. Thanks go to ESA astronaut Jean-François "Billy-Bob" Clervoy for writing the Afterword for this book, for his insight into the Shuttle docking program from a European perspective, for explaining the details of certain operational matters, and for allowing me to use images from his collection. Other former astronauts who have helped with research for this and closely related recent and future books were Tom Akers, Bob "Crip" Crippen, Steve Hawley, Tom Jones, Janet Kavandi, and George "Pinky" Nelson. I thank all of you for taking the time to tell me about your experiences and also for explaining certain techniques and procedures.

Again, a network of international contacts and colleagues over the years deserve mentioning for their continued support and help on several projects, including this one. They include Colin Burgess, Michael Cassutt, Phil Clark, Brian Harvey, Bart Hendrickx, and Bert Vis. Bert also gave me some elusive images for this book from his extensive collection and filled several 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 topic. Their loss is greatly lamented.

Special thanks must be given 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.

The various public affairs and history office staff of NASA and of the University of Houston at Clear Lake and Rice University, also in Houston, who have provided assistance and support in my research over a period of nearly 40 years also deserve thanks. Their help has 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 personal visits to NASA JSC and KSC in the period 1988–2002.

All images are courtesy of NASA via the AIS collection unless otherwise stated. And thanks to the various contractors, partner agencies, and Novosti Press Agency for supplying images over the years used in support of research for this and related projects and presentations. I am also indebted to Joachim Becker of *SpaceFacts.de* and Ed Hengeveld for their encouragement and unselfish permission to use images from their extensive collections.

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 who also refined the final draft. To David M. Harland for his excellent editorial skills and suggestions. He greatly improves 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 guide 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 and her assistants at Springer in New York, first Nora Rawn and latterly Elizabet Cabrera, are also to be thanked for their encouragement and management skills during 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 complete the work. 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 I start my next writing project.

To each and every one who helped, may I offer a very hearty thank-you.

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

Foreword

"*Houston, Atlantis. We have capture!*" I spoke those words on June 29, 1995, as I docked the Space Shuttle Atlantis with the Russian space station Mir, marking the first docking performed by a Space Shuttle. After over 14 years of flying, the Shuttle was finally performing one of the primary tasks envisaged at the time of its conception in the early 1970s, that being to transport astronauts and supplies to and from orbiting space stations. The flight was a milestone in the Shuttle program, but was also a major achievement in ending the Cold War and bringing Russia into the partnership that would ultimately lead to the construction of the International Space Station.

The Shuttle would prove to be pivotal in the construction of the ISS due to its ability to carry large modules for addition to the assembly of the largest and most capable structure ever built in space.

During its prior operations, the Shuttle had developed the capabilities of living and working in space, performing spacewalks, using the manipulator arm to grapple satellites, and performing repairs and construction tasks on orbit. All of these skills would be necessary for the construction of the ISS.

The actual docking itself is the end result of so many individual capabilities such as orbital rendezvous, proximity operations, and the fine control of spacecraft which were first demonstrated in the Gemini program in the 1960s and further refined over the years. Add to that the teamwork and coordination required by Mission Control in Houston and Mission Control in Moscow, and the tasks multiply greatly. My docking with Mir was the end result of efforts that started many years earlier and marked the culmination of years of training on the part of the flight crews, the flight controllers, and so many capable designers and engineers. Thanks to their combined work, it was a spectacular success.

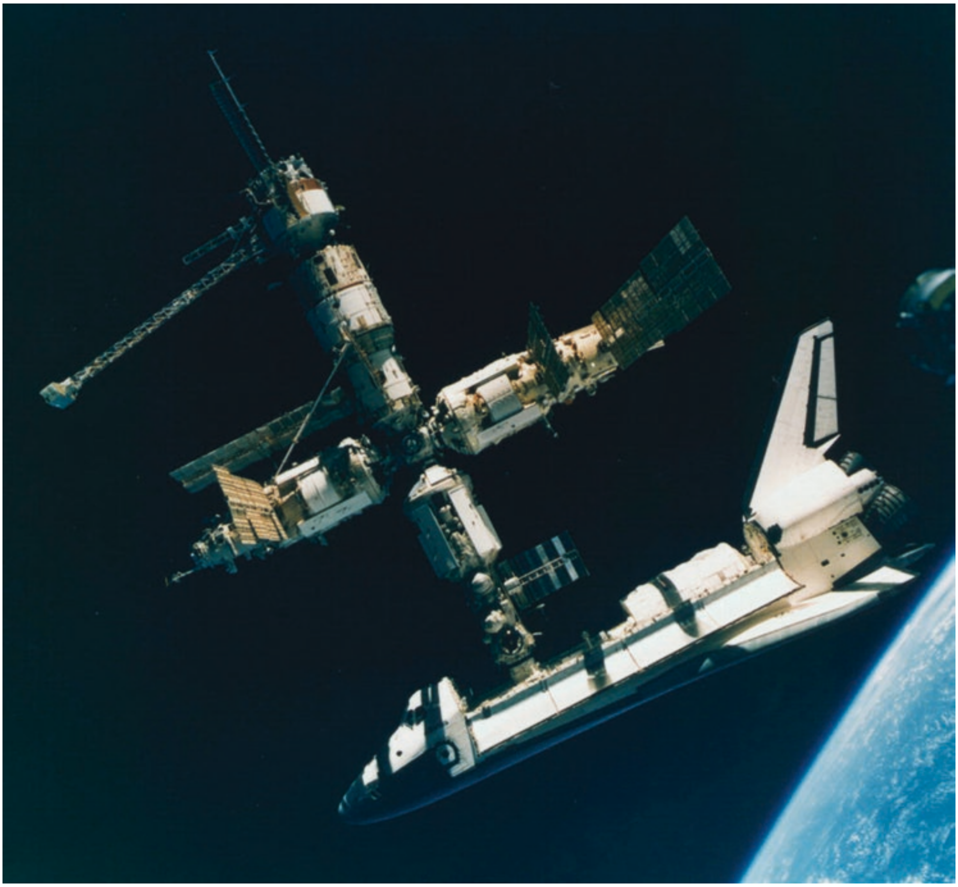
The many and varied requirements of designing, manufacturing, launching, and assembling the ISS are quite possibly the most challenging that humans have ever attempted. Building on the successes and failures of 34 years of human space flight, the ISS represents a marvelous achievement not only in technology and operations but also – and perhaps most significantly – in international cooperation in space.

Captain Robert L. 'Hoot' Gibson, USN (Retired) in front of an F-18 Hornet.

STS-71 Commander 'Hoot' Gibson displays the rendezvous docking target retrieved from the Kristall module of the Mir space station.

In *Linking the Shuttle and Space Stations: Early Docking Technologies from Concept to Implementation*, David Shayler has methodically analyzed the overall picture of how the many skills were assembled; then in *Assembling and Supplying the ISS: The Space Shuttle Fulfills Its Mission*, he relates how these skill were put into practice to enable this amazing structure known as the ISS to become reality!

Captain Robert 'Hoot' Gibson, USN (Retired)
NASA Astronaut 1978–1996
Pilot STS-41B
Commander STS-61C, STS-27, STS-47, and STS-71 'Shuttle-Mir'



The First Docking. STS-71 Atlantis docked with the Russian Mir space station in June 1995.

Dedication

To the thousands of dreamers, planners, managers, controllers, workers, engineers, researchers, scientists, politicians, tax payers, general public, and crewmembers who imagined, designed, debated, budgeted, tested, assembled, simulated, trained, supported, and completed the mission. And to the families who let them create and operate the Space Shuttle, visit the space station Mir, and achieve the dream called the International Space Station – the brightest star in the heavens for all to see.

Prologue

THE FIRST: ***STS-71 Atlantis, Flight Day 3, Thursday, June 29, 1995.*** Today would be a special day for the crew of Atlantis, orbiting the Earth at 17,500 mph (28,165 km/h) at an altitude of 216 nautical miles (395 km). Not only was Pilot Charles Precourt celebrating his 40th birthday, it was also docking day. For the first time since the Apollo-Soyuz Test Project 20 years before, American astronauts and Russian cosmonauts would link their spacecraft, with Atlantis docking to space station Mir. On board the station were Russian Mir-18 crewmembers Commander Vladimir Dezhurov and Flight Engineer Gennady Strekalov, along with American astronaut Norman Thagard. This was their 105th day aboard the station. They were to return to Earth with the STS-71 crew on Atlantis, which was also to deliver their replacements, Commander Anatoly Solovyov and Flight Engineer Nikolai Budarin, who would remain in space as the Mir-19 resident crew.

It would be a long day for both crews. Just 90 min after waking up to begin the day's operations, Commander Robert L. "Hoot" Gibson fired the Shuttle's orbital maneuvering engines for 45 sec in order to slightly raise the orbit. Called the NC-4 (Nominal Corrective) burn, this maneuver brought Atlantis approximately 8 nautical miles (14.81 km) behind Mir. One orbit later, Gibson fired the OMS again for the Terminal Injection burn that put Atlantis onto a path to intercept the orbit of Mir from directly below the station, up the Earth radius vector in what was referred to as the R-Bar mode.

Less than 3 hours later, with Atlantis stable at 250 ft (76.2 m) from the Russian station, Gibson awaited approval to proceed. This would be a joint decision from NASA's Flight Director Bob Castle and his Russian counterpart in Moscow, Viktor Blagov. Then the final approach began. On board the flight deck, with the historic docking event in front of them, the Shuttle crew were busy going about their assigned tasks, as Hoot Gibson recently recalled, "I was at the aft window on the controls using the COAS [Crew Optical Alignment Sight] for alignment, as well as the centerline TV, watching the laptop for range and closure. Charlie [Precourt, Pilot] was at the center console, keeping the laptop updated and monitoring range versus closure rate on the RPOP [Rendezvous and Proximity Operations Program]. Greg [Harbaugh, Mission Specialist] was in the aft station taking photos and hand-held laser [ranging] marks. Ellen [Baker, Mission Specialist] was mostly doing photography in the aft station. Bonnie [Dunbar, Mission Specialist] was in the [forward] Commander or Pilot seat transmitting range and [closure] rate on the air-to-ground, in Russian, for the Mir crew. [Russian cosmonauts] Anatoly [Solovyov] and Nikolai [Budarin] were at the inter-deck access openings so they could be watching as well. It was quite crowded, but in weightlessness you have more room because we didn't all have to inhabit the floor."*

Atlantis approached to within 30 ft (9.14 m) of Mir, ready for its final approach to the docking port at the end of the Kristall module. With the two spacecraft traveling over the Lake Baikal region of Siberia, Russia, Gibson gently guided Atlantis to a flawless docking with Mir, reporting, "We have capture!" This was only the second time that vehicles from two different countries had linked up in space. Successfully connected in a soft dock, Greg Harbaugh engaged the mechanism to achieve a hard dock. Two hours later, after a series of leak checks of the tunnel connecting the two spacecraft, the hatches were opened, and Gibson shook hands with Mir Commander Dezhurov. The media gleefully reported the event as "the end of the space race and the beginning of a new era of cooperation in exploring the stars." Perhaps it was a little premature to allude to such a bold ambition, but the docking was a significant step toward the goal of building the International Space Station.

It is often hard to realize that 22 years have elapsed since that remarkable event. The ISS is now operational and is hosting its fiftieth crew.†

STS-71 was the first of 9 dockings with Mir and a prelude to 37 docking missions to the ISS. It was the start of a challenging but rewarding adventure that put into practice the many skills and experiences not only from Shuttle-Mir and the Shuttle program in general but from years of planning and organizing as well. The effort that culminated with the final Shuttle flight to Mir put NASA and its international partners on the verge of realizing a dream. When STS-135 made the final visit of a Shuttle to the ISS in 2011, this concluded not only the Shuttle program but also an historic period in human space flight. And fittingly, Atlantis was the vehicle which achieved that feat, but that is another story…

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* E-mail from 'Hoot' Gibson to AIS May 9, 2016.

† At the time of writing in 2017, members of the 50th ISS Expedition Shane Kimbrough (NASA, Commander), Andrei Borisenko (Russian Flight Engineer) and Sergei Ryzhikov (Russian Flight Engineer) were nearing the end of their tour.

1

The Space Shuttle and the Space Station

The next major thrust in space will be the development of an economical launch vehicle for shuttling between Earth and installations, such as the orbiting space stations, which will soon be operating in space.

George E. Mueller,
NASA's Associate Administrator for Manned Space Flight,
August 10, 1968

Addressing the audience at Imperial College, London, during a function organized by the British Interplanetary Society to mark his election as an Honorary Fellow of the Society, George E. Mueller emphasized the proposed Space Shuttle's capability to resupply consumables and to exchange or augment crews and equipment on future space stations. At that time, NASA was intending to develop an efficient Earth-to-orbit transportation system capable of lifting between 25,000 lb (11,337.9 kg) and 50,000 lb (22,675.7 kg) of payload in cargo compartments, for delivery to orbiting stations. Mueller observed that, "[The] design of space stations and payloads [are] presently under study at NASA" and "the maturity of these designs would coincide with those for the Space Shuttle."

Thus the idea of using the Space Shuttle to launch elements of a small modular space station for assembly on-orbit can be traced back to the very beginning of the program.

A PLAN FOR THE FUTURE

As the era of Apollo faded and that of the Space Shuttle dawned, a grandiose plan also emerged to establish a huge scientific platform on-orbit. Key to achieving this objective was the ability to master several techniques and procedures, including on-time delivery and preparation of not only the components that went into making up the Shuttle 'stack' but also the on-time preparation of the components and supplies for the space station. Building upon this was the requirement to maintain a regular and sustained flight rate to enable hardware to be launched on time, the training of astronauts to assemble components on-orbit with the support of advanced robotics and extensive spacewalking activities,

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and the creation of an efficient infrastructure on the ground to sustain an assembly process lasting many years. These challenges were further complicated by the introduction of international partnerships, and the need for procedures and contingency plans to address a wide variety of setbacks or possible failures, whilst maintaining a plausible momentum and being mindful of budgetary constraints.

A Platform to Work From

This development included the design of the Space Transportation System (STS), which was the formal name for the Space Shuttle, along with the related hardware, facilities and components. Establishing a reliable and efficient method of bringing together the various components of the space station and launching them into space would be essential to its assembly on-orbit. Other important areas to be developed involved controlling the mission and the preparing of astronauts to achieve (and at times surpass) the mission objectives. It was also important to ensure a prompt and safe recovery of both the vehicle and the crew to enable the ground team to begin a prompt turnaround of the Orbiter for its next mission.

These activities were essential not only to the basic Shuttle program but also to building up confidence that this system could, with modest adjustment, sustain the assembly and regular resupply of a space station, whilst also carrying out missions which were unrelated to space station operations and, most crucially, using a small fleet of Orbiters and very limited resources.

What became frustrating in the planning of a large space station were the delays in securing the necessary funding and the constantly changing design, while all the time dealing with issues involving the Shuttle itself which often required amending the proposed annual manifest, sometimes several times during any given year. After several years of delays and false starts in trying to assign a mission to a small space station, the Shuttle achieved its inaugural launch in the spring of 1981. This proved that the basic concept worked. It flew again in the autumn of that year, confirming the reusability of the Orbiter. NASA's declaration in the summer of 1982 after only four Orbital Flight Test missions that the Shuttle was *operational* was (as time would reveal) premature.

In January 1984, concurrent and parallel to developing flight experience with the Shuttle both on the ground and in space, came the long awaited decision that NASA should develop a space station over a ten year period. The plan called for a complex series of Shuttle missions that would carry the hardware elements into space so that the station could be progressively expanded by means of an exhausting program of EVAs. Along the way, the Shuttle would regularly exchange the crew of the station and resupply its consumables. This reliance on the Shuttle would severely limit its utility for other programs and missions that were then in the planning stage.

Furthermore, a cadre of astronauts would rapidly require to learn the skills and gain experience in rendezvous and docking, in EVA construction and assembly, in the use of advanced robotics aboard the Orbiter, and in the transfer and stowage of tons of logistics, supplies, and unwanted waste materials.

Unfortunately, in the mid-1980s these skills were severely lacking. It was more than a decade since American astronauts had made a manual or automated docking with anything in space, let alone a space station. Most astronauts with rendezvous and docking expertise from the Gemini and Apollo programs had retired long ago. Secondly, the skills of extended spacewalking operations were still relatively new, despite EVA being undertaken on an experimental basis two decades earlier. From the Gemini program in the mid-1960s NASA and its astronauts had discovered the hard way that rendezvous and docking in space, and efficient EVA operations, are difficult to master.

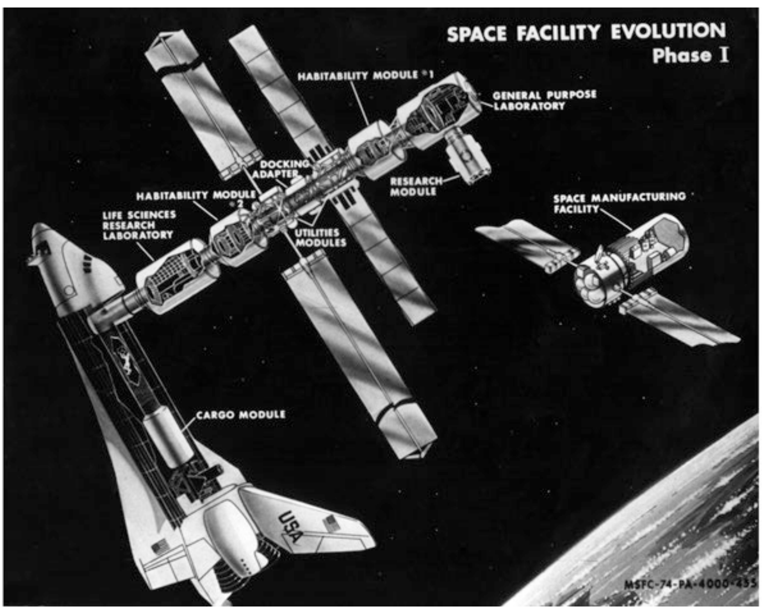
In addition, although a docking system had been proposed in some early designs of the Space Shuttle, none had emerged as an operational system when the vehicle entered service. In fact, in the early 1980s NASA had no definite plans to mate the Orbiter with another object. It was envisaged that astronauts would use the robotic arm to grapple and berth payloads, or release them into orbit. If the Shuttle was to assemble a space station, then a change of direction would have to be made…and rapidly.

Fortunately, all the old plans were able to be dusted off in order to resume a path that had its origins in the golden years of NASA at the height of the Apollo program.

THE AGE (AND AGING) OF APOLLO

In the fall of 1968, NASA was gearing up to launch the first manned Apollo mission into Earth orbit, just eighteen months after the loss of the Apollo 1 crew in a fire that engulfed their spacecraft on the launch pad during what was believed to be a routine test. On the same day that Mueller addressed the BIS, Deke Slayton, the Director of Flight Crew Operations, was at the Manned Spacecraft Center in Houston informing astronaut James A. McDivitt that his Apollo 8 mission was to be sent to the Moon at Christmastime.

The suggestion by Mueller that Apollo was to be followed by the development of a space infrastructure was a clear indication of NASA's future plans, but the priority remained Apollo – everything else would have to wait until the agency had achieved the goal set by President John F. Kennedy in 1961 of a manned lunar landing within the decade.

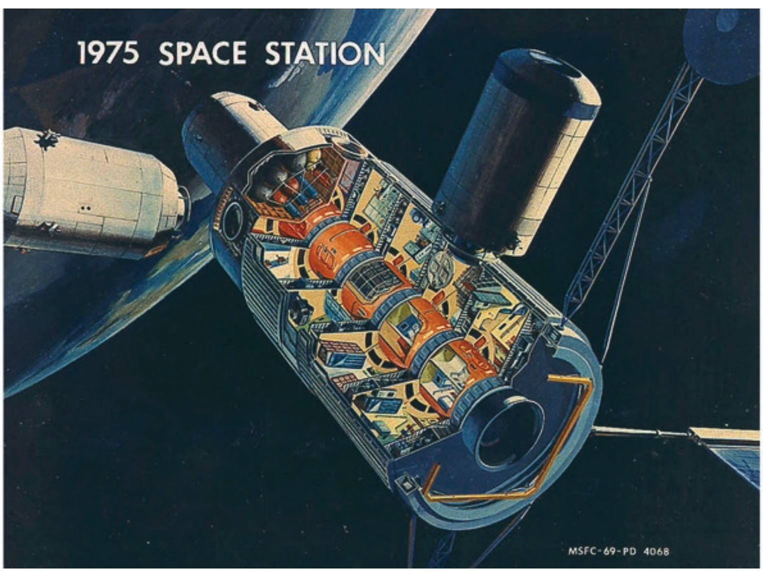


The Space Facility Evolution envisaged by NASA circa 1974, bearing a remarkable similarity to the current core elements of the ISS. (Courtesy British Interplanetary Society)

In order not to risk losing funds for Apollo at such a critical time, all official talk at NASA of subsequent programs was being discouraged. Plans for a space station had existed for years, however, with proposals being submitted in many guises and formats. Ironically, a number of proposals had envisaged using surplus or purpose-built Apollo hardware for extended missions in Earth orbit and in some cases even around the Moon.

On August 19, a week after Mueller's speech in London, NASA announced that Apollo 8 would shoot for the Moon, albeit with a different crew. McDivitt and his colleagues David R. Scott and Russell L. ('Rusty') Schweickart, had opted to stick with the Lunar Module (LM) whose development they had been following for two years in preparation for taking it on an orbital test. They exchanged missions with the Apollo 9 crew of Frank Borman, James A. Lovell and William A. Anders – who flew Apollo 8 between December 21–27, 1968 without a LM. The spectacular success of Apollo 8 and the tests by Apollo 9 in Earth orbit in March and Apollo 10 in lunar orbit in May paved the way for Apollo 11 to make the historic first landing on the Moon in July 1969, with Neil A. Armstrong becoming the first man to stand on that surface. Never an agency to rest on its laurels, NASA repeated the feat with Apollo 12 in November.

By the end of the 1969, NASA was looking forward to a schedule that included eight more lunar landings of increasing sophistication. It was also poised to release details of its new space policy for the 1970s and 1980s. The plans were audacious, considering that the Space Age was only twelve years old. Over the next two decades, NASA was envisaging extensive operations in Earth orbit and beyond, large space stations, a regular Earth-to-orbit ferry service, an Earth-Moon transportation system, lunar orbital stations, and research bases on the surface. There were even proposals to fly humans to Mars with a fly-by of Venus on the way home.



NASA's Space Base, circa 1969. (Courtesy British Interplanetary Society)

The Stark Reality

Although the summer of 1969 was a time of triumph for NASA, dark clouds were looming. The remaining Apollo lunar missions were scheduled across the next few years, partly to fit them into the fiscal budgets but also to allow time to analyze the results of one mission during the planning for the next. With Apollo 12 slipped to November, on October 9, 1969, NASA announced plans for Apollo 13 through 20. The future mission plans, which included timescale variations to allow for different levels of funding, envisaged the 'original' Apollo series terminating with Apollo 20 around 1972. After that, an advanced lunar exploration program would be pursued during the rest of the decade. This would include extended duration missions on the surface that would venture far and wide. There would also be polar orbital missions to map the entire surface. It was expected that by the early 1980s there would be a space station in lunar orbit and a small, permanent research facility on the surface.

But in December 1969 the financial ax fell on Apollo 20. This was announced at the First Lunar Science Conference in January 1970, hosted by the space agency to report the analysis of the Apollo 11 samples. Then in April of that year, Apollo 13 suffered an explosion on the way to the Moon that canceled the planned third lunar landing and began a three day struggle to save the crew; an achievement which has been dubbed "NASA's finest hour." And just five months later, three more flights were scrubbed and the remaining four renumbered and rescheduled. The program would now end with Apollo 17 in 1972. Whilst it was clear that there would be no further manned lunar missions for the foreseeable future, few could have expected that sorry state to persist for more than fifty years.

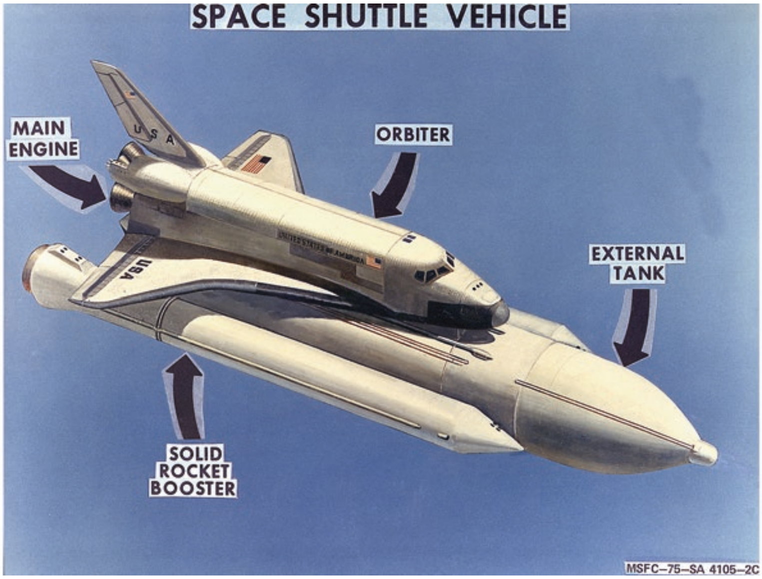
Saved (but only just) from the budget cuts was one of a planned series of Skylab orbital workshops. Fabricated from the S-IVB stage of a Saturn launch vehicle and outfitted on the ground to serve as an orbital workshop, solar telescope, and Earth-observation platform. Launched on May 14, 1973 by a two-stage Saturn V rocket, the unmanned Skylab was occupied between May 1973 and February 1974 by three crews who flew aboard Apollo Command and Service Modules (CSM) launched by Saturn IB rockets. These missions, lasting in turn 28, 59 and 84 days, set endurance records, with the final flight establishing an American record that would remain for twenty years.

Although Skylab was a major success for NASA, it was only ever intended to be an interim design. The proposals for much larger complexes were lost to a series of budget cuts. The follow-on Skylab B, built and paid for using the back-up hardware for the first workshop, was canceled after much debate. By 1975 there remained just one American manned mission on the books – a short, one-week joint docking flight with the Russians.

Much was made at the time of the détente of this international venture, but it was a dead-end mission. No further American space flights were planned until the Space Shuttle, which was expected to make its debut in 1979. In hindsight, however, both Skylab and the Apollo-Soyuz Test Project laid the groundwork for Shuttle-Mir and, eventually, the International Space Station.

A Space Transportation System

The Space Shuttle was the lynchpin of NASA's 'Grand Plan' for space exploration from the late 1970s towards the end of the century, and a significant element of the proposed infrastructure of Earth-orbiting ferry craft, space tugs, logistic vessels and space stations



A 1975 representation of the main elements of the Space Transportation System.

for crews of up to 100 astronauts. However, it was the only element left standing after the budget wrangling of the early 1970s.

The Space Shuttle was promoted as the answer to most, if not all, of the nation's launch requirements for the foreseeable future. It would allow scientific research to be conducted with space laboratories carried in its cavernous payload bay, it would serve as a platform to deploy advanced robotic probes to the farthest reaches of our solar system, and it would facilitate most of the orbital requirements of the national security forces. Artwork of the time depicted the Shuttle deploying and retrieving satellites, as well as serving as an orbital repair shop and as a platform to undertake vast construction projects, including assembling space stations.

Authorized in 1972, the Shuttle was designated the Space Transportation System (STS) because it was ultimately intended to replace all expendable launch vehicles. It featured a manned spacecraft called the Orbiter (OV) which incorporated a three-deck crew module. The upper deck, called the flight deck, would have the controls and displays required to enable astronauts to fly the vehicle. It would also serve as the work station for deploying and retrieving payloads using a robotic manipulator arm that was eventually supplied by Canada. The mid-deck was the living quarters, with sleep compartments, a galley, a toilet, and storage facilities. It also housed the airlock to enable space-suited astronauts to access the payload bay for spacewalks. Additionally, sometimes the mid-deck would provide access to a hatch and tunnel system connected to a pressurized research laboratory in the payload bay. Initially known as the Sortie, or Research Application Module (RAM), this was eventually provided by the European Space Agency as the Spacelab Module. The lowest deck contained avionics bays and other subsystems needed to keep the vehicle flying.

It was not habitable as such, but the astronauts could access it in order to replace the lithium hydroxide canisters that scrubbed the cabin air clean.

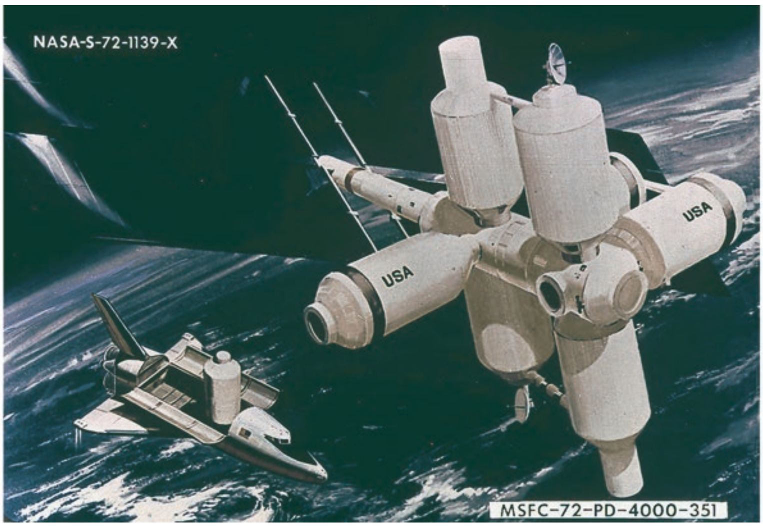
Originally, it was intended to create a totally reusable two-stage launch system, involving a huge manned booster that would carry the Orbiter 'piggy-back' style to the altitude at which it would be released to continue its journey into orbit while the booster was flown back to the launch site. But this configuration was soon rejected for budgetary reasons. It was replaced by a large unmanned External Tank (ET) to provide the propellants for the three main engines in the tail of the Orbiter, and lift-off would be supplemented by a pair of liquid propellant boosters strapped onto the sides of the ET. When the budgetary ax fell once again, the liquid boosters were in turn replaced with segmented solid propellant boosters. The Solid Rocket Boosters (SRB) would be separated after about 2 min and parachute back to the ocean to be retrieved, refurbished, and used again. At one stage, plans also existed to place the spent ETs into orbit and convert them into rudimentary space stations but this idea was also discarded. Instead, a jettisoned ET burned up in the atmosphere high over the ocean just minutes into the flight. Only the Orbiter would achieve insertion into orbit to undertake the assigned mission.

One of the key features of the Orbiter was its large payload bay, some 15 ft in diameter and 60 ft long (4.5 × 18.29 m). This volume was primarily to satisfy the needs of the USAF, to carry its new generation of spy satellites installed atop their upper stages. In an early proposal, the Orbiter was to have had a capacity of 50,000 lb (22,700 kg) and a volume of around 10,000 cu ft (283 cu m), making it suitable for payloads with diameters in the range 15–22 ft. This suited the USAF, who were developing payloads of similar size for their Titan IIIC expendable launch vehicle. But NASA's focus was on assembling a space station from small modules that had diameters of 14 to 15 ft (4.2 to 4.5 m), so the agency preferred a narrower, shorter payload bay. The Air Force was adamant, however. Their proposed participation in the program included the use of Vandenberg AFB in California for missions which would fly at higher inclinations (including polar orbits) than were possible from the Florida launch site. And there was the prospect of the USAF buying Orbiters for its own use. If NASA wanted this program, the payload bay simply had to meet USAF specifications. By way of compromise, NASA initially suggested a bay that was 22 ft (6.7 m) wide and 30 ft (9.1 m) long but this was rejected. With NASA unwilling to let a disagreement over the dimensions of a payload bay scupper the funding for developing the Shuttle, which was the only viable program after Apollo, it accepted a carrying capacity of 65,000 lb (29,250 kg) and a payload bay sized to the USAF's requirements. This was part of the design proposed by NASA Administrator James C. Fletcher and approved by President Richard M. Nixon on January 5, 1972.

Three months later, in April, as Apollo 16 astronauts John W. Young and Charlie M. Duke explored the Descartes region of the Moon, their Capcom relayed the news that authorization for Shuttle development had been given. Less than a decade later, it was Young who sat in the command seat of the first Shuttle and, along with Pilot Robert L. Crippen, put the Orbiter Columbia through the basic mission profile that proved the concept. That concept would form the link between the ASTP program and a new chapter of international cooperation in space for America, initially at the Mir space station and later in assembling and crewing the ISS, but it would require the better part of thirty years for the Shuttle to forge that link.

BUILDING A MODULAR SPACE STATION

Following the 1972 authorization of the Space Shuttle, a number of internal NASA and contractor reports focused on the capabilities of the Shuttle concept to support the assembly of a modular space station, as this concept had grown in popularity and replaced the earlier large (and expensive) 50–100-man Space Bases. A summary of these new studies was presented at the annual meeting of the American Association for the Advancement of Science in Washington DC, December 27–28, 1972, as part of a series of presentations on future Space Shuttle payloads.



NASA's Modular Space Station, circa 1972. (Courtesy British Interplanetary Society)

Twin Manipulators

In this very early proposal, the Orbiter would initiate station assembly by delivering core and power modules, with the next few missions adding resident crew facilities and laboratories. The physical assembly of the station suggested the installation of a pair of remote manipulator systems on the Orbiter, a concept often depicted in early artwork but never adopted in practice. Over 19 missions, this modular station would gradually be expanded with control, cargo, research and application modules, along with a galley and further crew modules. By the seventh mission it would be capable of supporting a resident crew of four. This would increase to six by flight eleven. As the number of modules increased, so too would the size of the resident crew, so that by the 15th mission a nine-person crew could be sustained, and by the 19th mission the goal of a twelve-person crew would be attained. Additional 'specialist facilities' would be added over time, including medical, exercise, and 'recreational' modules.