Chapter 23

Space Stations: Base Camps to the Stars[*]

Roger D. Launius[†]

Introduction

This paper reviews the history of space stations in American culture, from an 1869 work of fiction in the *Atlantic Monthly* to the present realization of the *International Space Station* (*ISS*). It also discusses the history of space stations "real and imagined" as cultural icons. From winged rocket ships, to the giant rotating wheels of Wernher von Braun and *2001: A Space Odyssey*, to the epic, controversy-wracked saga of the *ISS*, the paper also discusses *Mir*, *Skylab*, and the Salyuts. It will close with a projection into the future as *ISS* is realized—or perhaps deferred—and perhaps future generations begin work on space stations elsewhere in the Solar System.

The Attraction of a Space Station

From virtually the beginning of the 20th century, those interested in the human exploration of space have viewed as central to that endeavor the building of a massive Earth-orbital space station that would serve as the jumping-off point to the Moon and the planets. Always, space exploration enthusiasts believed, a

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[†] Division of Space History, National Air and Space Museum, Smithsonian Institution, Washington, D.C., U.S.A.

permanently occupied space station was a necessary outpost in the new frontier of space. The more technically minded recognized that once humans had achieved Earth orbit about 200 miles up, the presumed location of any space station, the vast majority of the atmosphere and the gravity well had been conquered and that people were now about halfway to anywhere they might want to go.

As early as 1869 Edward Everett Hale, a New England writer and social critic, published a short story in the *Atlantic Monthly* titled "The Brick Moon." The first known proposal for an orbital satellite around Earth, Hale described how a satellite in polar orbit could be used as a navigational aid to ocean-going vessels. When the heroes of the story substitute a brick moon for this ring—brick because it could withstand fire—it is hurled into orbit 5,000 miles above Earth. However, an accident sends the brick moon off prematurely with 37 workers and other people aboard. In contrast to what is now known about the vacuum of space, these people lived on the outer part of the brick moon, raised food, and enjoyed an almost utopian existence.[1]

Russian schoolteacher Konstantin E. Tsiolkovsky also studied the possibility of establishing a space station in Earth orbit before the beginning of the 20th century. Tsiolkovsky even discussed the feasibility of building a dramatic wheeled space station that rotated slowly to approximate gravity with centrifugal force.[2] During the 1920s Romanian–German spaceflight theorist Hermann Oberth and Austrian engineer Hermann Noordung both elaborated on the concept of the orbital space station as a base for voyages into space. In Noordung's case, the technical attributes of a space station to support planetary exploration took up the bulk of his 1929 book, *Das Problem der Befahrung des Weltraums* (*The Problem of Space Travel*).[3]

Wernher von Braun/*Collier's* 1952 Concept

In the United States during the 1950s, German émigré Wernher von Braun, the leader of the rocket team that had developed the V-2 ballistic missile for Germany in World War II, argued for an integrated space plan centered on human exploration of the solar system and involving these basic ingredients accomplished in this order:

1. Robotic Earth orbital satellites
2. Human Earth orbital flights
3. Winged reusable spacecraft
4. Permanently inhabited space station
5. Human lunar exploration
6. Human expeditions to Mars.

Von Braun espoused these ideas in a series of important *Collier's* articles over a two-year period in the early 1950s, each with striking images by some of the best artists of the era.[4]

In part because of this persistent vision of human destiny to explore the solar system and the central role of a space station in facilitating this goal, studies of space station configurations had been an important part of NASA planning in the 1960s. NASA scientists and engineers pressed for these studies because a space station met the agency needs for an orbital laboratory, observatory, industrial plant, launching platform, and dry dock. The station, however, was forced first to the bottom of the priority heap in 1961 with the President John F. Kennedy decision to land an American on the Moon by the end of the decade. With that mandate, there was no time to develop a space station despite the fact that virtually everyone in NASA recognized its use for exploration beyond Earth orbit.

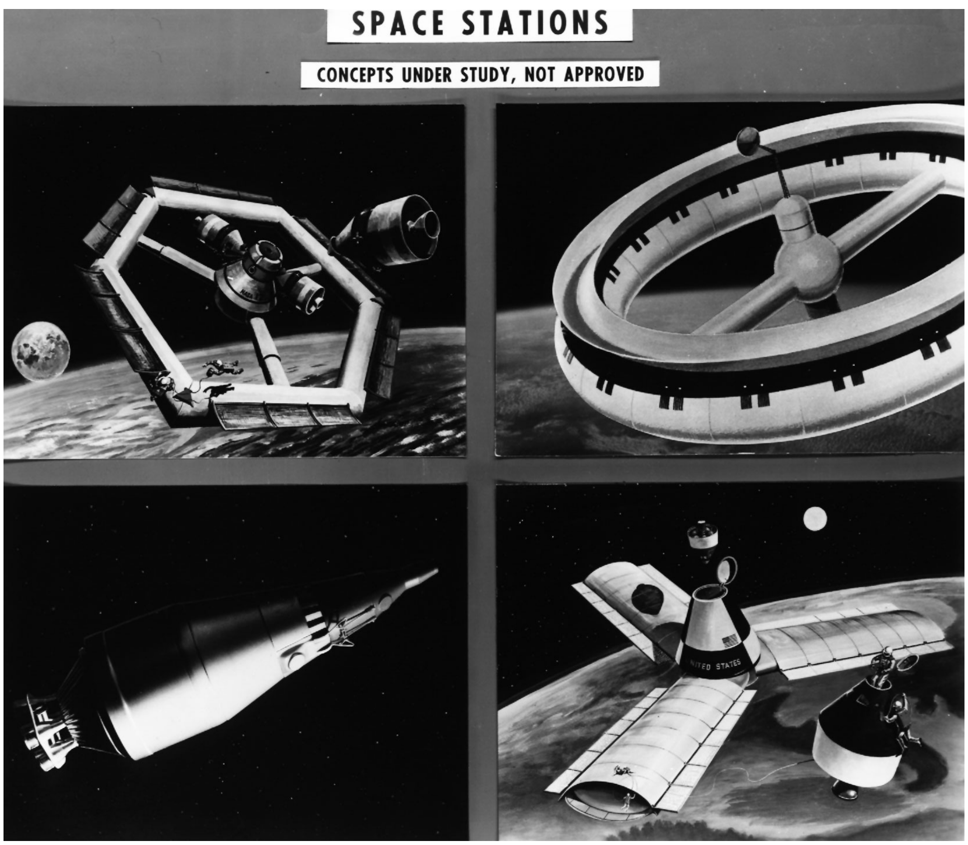

Figure 23–1: This collage is a collection of space station concepts as envisioned by artists at the Manned Spacecraft Center in Houston, Texas, in 1963. NASA Photo S-63-1270.

Even so, some studies continued (Figure 23–1). The most unusual, intriguing, and perhaps uniquely viable concept for a space station was one that inflated after reaching Earth orbit. The design for a 24-foot two-person space station came from the Goodyear Aircraft Corporation in 1961 and ground tests proceeded for several years thereafter without anything flight worthy being built. In the 1990s inflatables returned to the space engineering vocabulary and several concepts are presently on the drawing board. In a similar vein, Langley Research Center's Rene Berglund came up with a concept to put together a series of six rigid modules that were connected by inflatable passageways coming off a central non-rotating hub, thus making another sort of hub-and-spoke design. The structure would self deploy after being launched into orbit atop a Saturn V rocket.[5]

A space station surfaced as the foremost NASA program even while Apollo became a reality in the latter 1960s, but took several unusual turns before emerging as the principal project of the agency at the end of the 20th century.[6]

2001: A Space Odyssey—The High Point of von Braun's Space Station

The film *2001: A Space Odyssey*, released by Director Stanley Kubrick in 1968, set a high mark for depicting a wheel-like space station on the von Braun model. Kubrick depicted a human race moving outward into the solar system, and the station served fundamentally as base camp to the stars. A great space station orbited Earth, serviced by a reusable, winged spacecraft traveling from the globe's surface. Activities in low Earth orbit had become routine in this film, with commercial enterprises carrying out many of the functions seen in the film's first segments. The shuttle to the space station was flown by Pan American, a Hilton hotel was located on the station, and AT&T provided the station's communications.[7]

Kubrick's film was, from start to finish a special-effects masterpiece, especially for the pre-computer graphics era of filmmaking. Perhaps its most scintillating segment involved the docking of a winged space shuttle with the gigantic rotating wheeled space station. Kubrick's depiction of this space station expressed the dream of a base camp to the stars. With its twin hubs still under construction, Kubrick's station measured an astounding 900 feet across as it spun in its orbit 200 miles above Earth. It held an international crew of scientists, bureaucrats, and passengers on the way to and from the Moon.[8]

The impact of von Braun's station, especially as Kubrick presented it, has been nothing short of astounding. John Hodge, the leader of NASA's Space Station Task Force that worked to design a space station in the 1980s, told Congress in 1983 that “I think if you ask the public at large, and quite possibly most of the people within NASA what a space station was, they would think in terms of the movie that came out 15 or 20 years ago.” He added that they expected a space station to consist of “a very large rotating wheel with 100 people on it and artificial gravity.”[9]

Writing for the popular *Science 83* magazine, Mitchell Waldrop felt it necessary to explain why any real space station would not look like the von Braun version. He observed that the actual station “will look more like something a child would build with an Erector set.” It would not resemble a wheel, it would not rotate, and it would not soar very high. “*2001* it’s not,” Waldrop explained.[10]

Skylab: A Preliminary Space Station

Without clear presidential leadership in the late 1960s, NASA began to forge ahead on its own with whatever plans it could get approved for a continuation of U.S. spaceflight in the 1970s. One of these, and a very important one, used Apollo technology to realize, at least partially, the longstanding dream of a space station. What NASA built was a relatively small orbital space platform, called *Skylab*, which could be tended by astronauts. It would be, NASA officials hoped, the precursor of a real space station.[11]

The 100-ton *Skylab 1* orbital workshop was launched into orbit on 15 May 1973, the last use of the giant Saturn V launch vehicle. Almost immediately, technical problems developed due to vibrations during lift-off. Sixty-three seconds after launch, the meteoroid shield—designed also to shade *Skylab*’s workshop from the Sun’s rays—ripped off, taking with it one of the spacecraft’s two solar panels, and another piece wrapped around the other panel to keep it from properly deploying. Because of this, *Skylab 2*, the first mission with astronauts Charles Conrad, Jr., Paul J. Weitz, and Joseph P. Kerwin was launched on 25 May 1973 to undertake substantial repairs requiring extravehicular activity (EVA).

In orbit the crew conducted solar astronomy and Earth resources experiments, medical studies, and five student experiments. This first crew made 404 orbits and carried out experiments for 392 hours, in the process making three EVAs totaling 6 hours and 20 minutes. The first group of astronauts returned to Earth on 22 June 1973, and two other *Skylab* missions followed. *Skylab 3*, was launched using Apollo hardware on 23 July 1973, and its mission lasted 59 days. *Skylab 4*, the last mission on the workshop was launched on 16 November 1973, and remained in orbit for 84 days.

During the three missions, a total of three Apollo crews had occupied the *Skylab* workshop for a total of 171 days and 13 hours. In *Skylab*, both the total hours in space and the total hours spent in performance of EVA under microgravity conditions exceeded the combined totals of all of the world's previous spaceflights up to that time. NASA was also delighted with the scientific knowledge gained about long-duration spaceflight during the *Skylab* program despite the workshop's early and reoccurring mechanical difficulties. It was the site of nearly 300 scientific and technical experiments.

Following the final occupied phase of the *Skylab* mission, ground controllers performed some engineering tests of certain *Skylab* systems, positioned *Skylab* into a stable attitude, and shut down its systems. It was expected that *Skylab* would remain in orbit eight to ten years, by which time NASA might be able to reactivate it. In the fall of 1977, however, agency officials determined that *Skylab* had entered a rapidly decaying orbit—resulting from greater than predicted solar activity—and that it would reenter Earth's atmosphere within two years. They steered the orbital workshop as best they could so that debris from reentry would fall over oceans and unpopulated areas of the planet.

On 11 July 1979, *Skylab* finally impacted Earth's surface. The debris dispersion area stretched from the southeastern Indian Ocean across a sparsely populated section of Western Australia. NASA took criticism for this development, ranging from the sale of hardhats as "Skylab Survival Kits" to serious questions about the propriety of spaceflight altogether if people were likely to be killed by falling objects. In reality, while NASA took sufficient precautions so that no one was injured, its leaders had learned that the agency could never again allow a situation in which large chunks of orbital debris had a chance of reaching Earth's surface. It was an inauspicious ending to the first American space station, not one that its originators had envisioned, but it had opened some doors of understanding and whetted the appetite of NASA leaders for a full-fledged space station.

The Quest for a Full-Fledged Space Station

With *Skylab* gone from the scene after 1979, and the coming on line of the Space Shuttle as a system in 1981, NASA returned to its quest for a real space station as a site of orbital research and a jumping off point to the planets during the early 1980s. There had been studies of space stations made throughout the 1970s. One adventurous 1977 approach using Space Shuttle hardware proposed a space spider concept for unwinding a solar array from the spent main fuel tank of the Space Shuttle. The "Space Spider" would be capable of forming and assembling a structure in one integrated operation. With such an unwinding of a solar array, the main engine tank could then become a control center for space operations, a crew habitat for Space Shuttle astronauts, and a focal point for space operations, including missions to the Moon and Mars. At the same time, in a measure of political acumen rarely seen before, NASA Administrator James M. Beggs persuaded President Ronald Reagan, against the wishes of many presidential advisors, to endorse the building of a permanently occupied space station.[12]

In a "Kennedyesque" moment in 1984, Reagan declared that:

> America has always been greatest when we dared to be great. We can reach for greatness again. We can follow our dreams to distant stars, living and working in space for peaceful, economic, and scientific gain. Tonight I am directing NASA to develop a permanently manned space station and to do it within a decade.[13]

In 1985 the space agency came forward with designs for an $8 billion dual-keel space station configuration, to which were attached a large solar power plant and several modules for microgravity experimentation, life science, technical activities, and habitation. This station also had the capacity for significant expansion through the addition of other modules.[14]

From the outset, both the Reagan administration and NASA intended Space Station *Freedom*, as it was called, to be an international program. Although a range of international cooperative activities had been carried out in the past—Spacelab, the Apollo–Soyuz Test Project, and scientific data exchange—the station offered an opportunity for a truly integrated effort. The inclusion of international partners, many now with their own rapidly developing spaceflight capabilities, could enhance the effort. In addition, every partnership brought greater legitimacy to the overall program and helped to insulate it from drastic budgetary and political changes. Inciting an international incident because of a change to the station was something neither U.S. diplomats nor politicians relished, nor that fact, it was thought, could help to stabilize funding, schedule, or other factors that might otherwise be changed in response to short-term political needs.[15]

NASA leaders understood these positive factors, but recognized that international partners would also dilute their authority to execute the program as they saw fit. Throughout its history the space agency had never been very willing to deal with partners, either domestic or international, as coequals. It has tended to see them more as a hindrance than help, especially when they might get in the way of the "critical path" toward any technological goal. Assigning an essentially equal partner responsibility for the development of a critical subsystem meant giving up the power to make changes, to dictate solutions, and to control schedules and other factors. Partnership was not a synonym for contractor management, something agency leaders understood very well, and NASA was not very accepting of full partners unless they were essentially silent or at least deferential. Such an attitude militated against significant international cooperation.

In addition to this concern, some technologists expressed fear that bringing Europeans into the project really meant giving foreign nations technical knowledge that only the United States held. No other nation could build a space station on a par with *Freedom*, and only a handful had a genuine launch capability (Figure 23–2). So many government officials questioned the advisability of reducing America's technological lead. The control of technology transfer in the international arena was an especially important issue to be considered.[16]

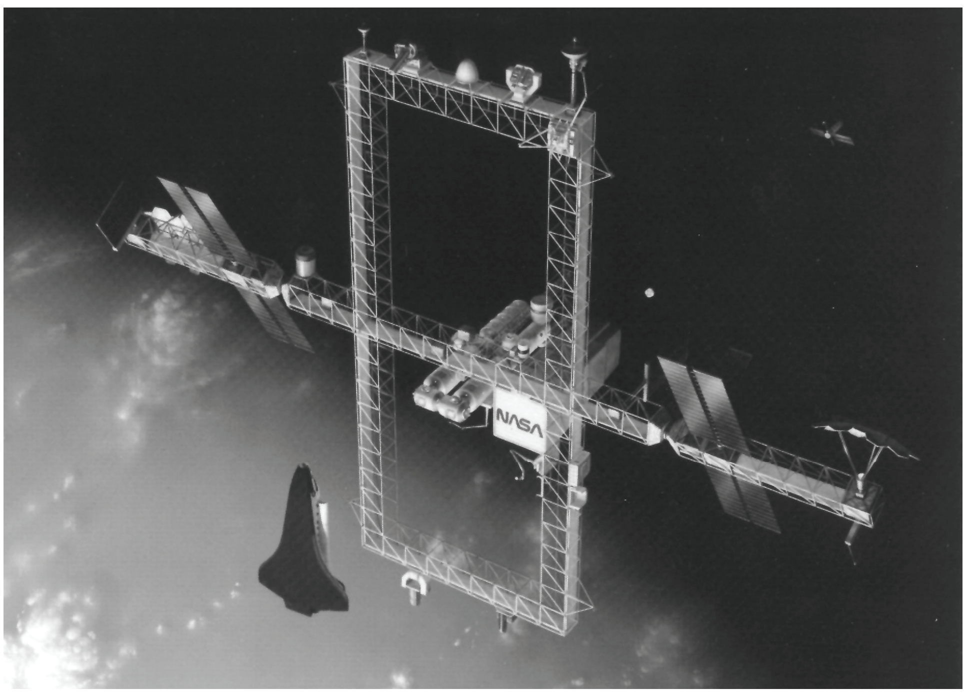

Figure 23–2: "Space Station." The Space Station was viewed as a commitment to leadership in space with the United States involving other nations in the effort. Space Station *Freedom* concepts early hit on two major designs. The first of these was the "dual keel" design, shown here. The second major design for Space Station *Freedom* was the "power tower" concept depicted here. Ultimately selected as the reference configuration by NASA in 1985, the power tower mounted solar arrays at the top of the trusses and modules and most experiments at the bottom. NASA Photo HqL-195, n.d., but ca. 1990.

Despite these concerns, NASA leaders pressed forward with international agreements among 13 nations to take part in the Space Station *Freedom* program. Japan, Canada, and the nations pooling their resources in the European Space

Agency (ESA) agreed in the spring of 1985 to participate. Canada, for instance, decided to build a remote servicing system. Building on its Spacelab experience, ESA agreed to build an attached pressurized science module and an astronaut-tended free-flyer. Japan's contribution was the development and commercial use of an experiment module for materials processing, life sciences, and technological development. These separate components, with their "plug-in" capacity, eased somewhat the overall management (and congressional) concerns about unwanted technology transfer.[17]

Almost from the outset, the Space Station *Freedom* program was controversial. Most of the debate centered on its costs versus its benefits. One NASA official remembered that "I reached the scream level at about $9 billion," referring to how much U.S. politicians appeared willing to spend on the station.[18] As a result, NASA designed the project to fit an $8 billion research and development funding profile. For many reasons, some of them associated with tough Washington politics, within five years the projected costs had more than tripled and the station had become too expensive to fund fully in light of a national debt explosion in the 1980s.[19]

NASA pared away at the station budget, in the process eliminating functions that some of its constituencies wanted. This led to a rebellion among some former supporters. For instance, the space science community began complaining that the space station configuration under development did not provide sufficient experimental opportunity. Thomas M. Donahue, an atmospheric scientist from the University of Michigan and chair of the National Academy of Sciences' Space Science Board, commented in the mid-1980s that his group "sees no scientific need for this space station during the next twenty years." He also suggested that "if the decision to build a space station is political and social, we have no problem with that" alluding to the thousands of jobs associated with it. "But don't call it a scientific program."[20]

International Space Station (*ISS*) Origins

Redesigns of Space Station *Freedom* followed in 1990, 1991, 1992, and 1993 (Figure 23–3). Each time the project got smaller, less capable of accomplishing the broad projects originally envisioned for it, less costly, and more controversial. As costs were reduced, capabilities also had to diminish and political leaders who had once supported the program questioned its viability. It was a seemingly endless circle and political wits wondered when the dog would wise up and stop chasing its tail. Some leaders suggested that the nation, NASA, and the overall space exploration effort would be better off if the space station program were terminated. Then, after a few years had passed and additional study and planning had been completed, NASA could come forward with a more viable effort.[21]

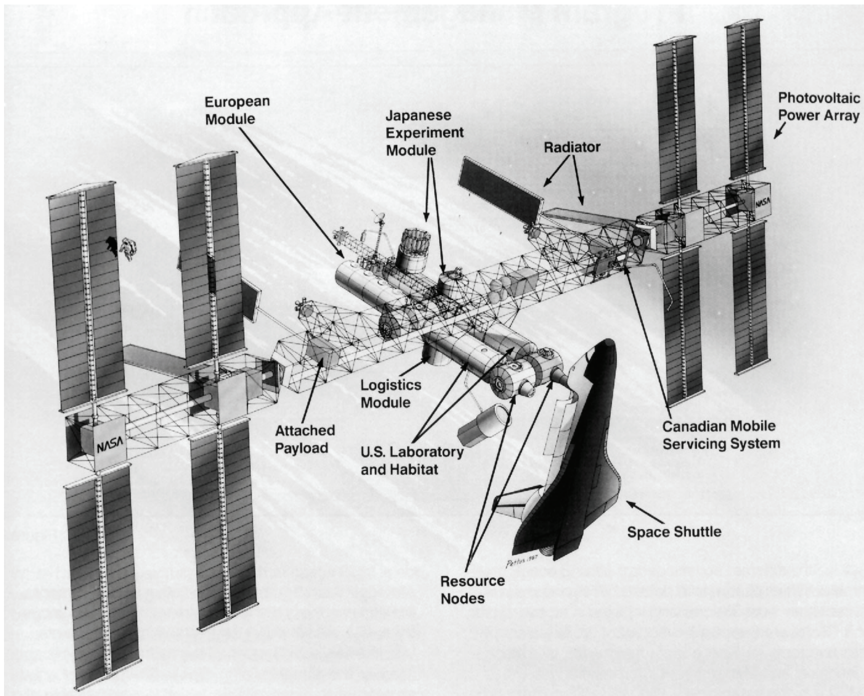

Figure 23–3: This is the baseline configuration of Space Station *Freedom*, as conceived in 1991. It was published in the booklet, *Space Station: A Research Laboratory in Space* (NASA PAM-512, n.d.).

That Congress did not terminate the program was in part because of the desperate economic situation in the aerospace industry—a result of an overall recession and of military demobilization after the collapse of the Soviet Union and the end of the Cold War—and the fact that by 1992 the project had spawned an estimated 75,000 jobs in 39 states, most of which were key states, such as California, Alabama, Texas, and Maryland. Politicians were hesitant to kill the station outright because of these jobs, but neither were they willing to fund it at the level required to make it a truly viable program. Barbara Mikulski (D-MD), chair of the Senate Appropriations Subcommittee that handled NASA's budget, summarized this position, "I truly believe that in space station *Freedom* we are going to generate jobs today and jobs tomorrow—jobs today in terms of the actual manufacturing of space station *Freedom*, but jobs tomorrow because of what we will learn."[22]

In the latter 1980s and early 1990s a parade of space station managers and NASA administrators, each of them honest in their attempts to rescue the program, wrestled with *Freedom* and lost. They faced on one side politicians who demanded that the jobs aspect of the project—itself a major cause of the overall cost growth—be maintained, and with station users on the other demanding that *Freedom*'s capabilities be maintained, and with people on all sides demanding that costs be reduced. The incompatibility of these various demands ensured that station program management was a task not without difficulties. The NASA administrator beginning 1 April 1992, Daniel S. Goldin, was faced with a uniquely frustrating situation when these competing claims were made official by the new president, William J. Clinton, who told him in the spring of 1993 to restructure the space station program by reducing its budget, maximizing its scientific use, and ensuring that aerospace industry jobs were not lost.

After months of work, NASA came forward with three redesign options for the space station and on 17 June 1993, President Clinton decided to proceed with a moderately priced, moderately capable station design. Near the same time, a dramatically changed international situation allowed NASA to negotiate a landmark decision to include Russia in the building of an international space station. On 7 November 1993, the United States and Russia announced that they would work together with the other international partners to build a space station for the benefit of all. Even so the 14-nation international space station program remained a difficult issue thereafter and public policymakers wrestled with competing political agendas without consensus.[23]

The Shuttle/*Mir* Program

After a few more months of discussion, NASA and the Russian Space Agency decided to increase the extent of their interactions, particularly with respect to flights of the U.S. Space Shuttle to dock with the Russian space station *Mir*. They determined that the program be organized into three phases. Phase One (1994–1997) was fundamentally an expansion of cooperative venture of seven to ten Shuttle flights to *Mir*, in addition to five medium- to long-duration flights on *Mir* by U.S. astronauts. Phase Two (1997–1998) involved U.S., Russian, and Canadian elements and achieved the ability to support three people in 1998 with the delivery of the Soyuz-TM crew-rescue vehicle to support the *ISS* then under construction. Phase Three (1998–2002) completed assembly of the *ISS*, including European and Japanese components (Figure 23–4).

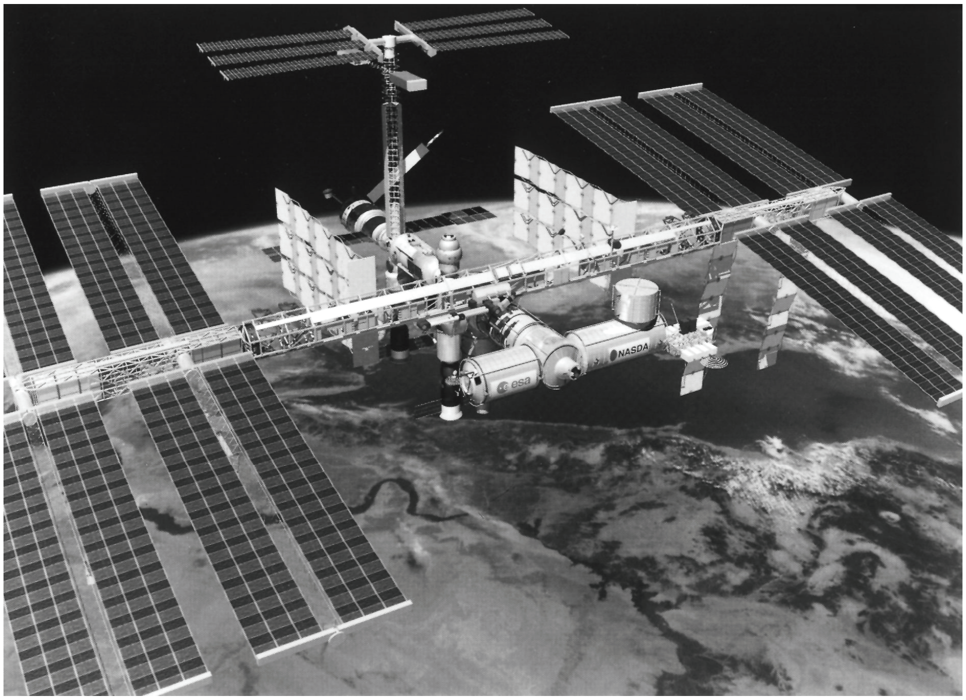

Figure 23–4: This is an artist's conception of the "International Space Station: Assembly Complete." The early space program and experiments conducted on the Space Shuttle have made remarkable contributions to medical research and the study of life on Earth. The Space Station is the next step: a permanent laboratory for long-term research that takes advantage of the unique environment in space. This environment cannot be replicated on Earth for any great duration. The Space Station will be a test bed for the technologies of the future, a laboratory for research on new, high-technology industrial materials, communications, transportation, and medical research, among others. The International Space Station draws upon the resources and scientific expertise of 13 nations in a cooperative effort. The new design of the Space Station will provide more laboratory space, more electrical power, a larger crew, and greater international participation. Participating nations include: the United States, Canada, Italy, Belgium, Netherlands, Denmark, Norway, France, Spain, Germany, the United Kingdom, Japan, and now, Russia. NASA Photo HqL-407, 8/94.

This cooperative effort led directly to the February 1994 flight of cosmonaut Sergei Krikalev on STS-60, alongside American astronauts in Space Shuttle *Discovery*, and continued in February 1995, when *Discovery* rendezvoused with *Mir* during the STS-63 mission with cosmonaut Vladimir Titov aboard. On 16 March 1995, U.S. astronaut Norman E. Thagard, M.D., lifted off in the Russian Soyuz-TM 21 spacecraft with two Russian cosmonauts for a three-month stay on *Mir*. One of the most significant missions to take place in recent years, Thagard spent more than three months on the Russian space station *Mir*. Thagard's flight set a record for length of time in space by a U.S. astronaut. He broke the *Skylab 4* crew record of 84 days set in 1973. He and the two Russian members of the *Mir*-

18 crew, Vladimir Dezhurov and Gennadiy Strekalov, were also the first *Mir* crew to return to Earth via the Space Shuttle.

After undertaking a set of biomedical experiments on *Mir* during his stay, Thagard returned home on the Space Shuttle *Atlantis*, STS-71, when it docked with *Mir* in July 1995. "This flight heralds a new era of friendship and cooperation between our two countries," said NASA Administrator Goldin at the time. "It will lay the foundation for construction of an international Space Station later this decade."[24]

This mission by *Atlantis* was the first of nine Shuttle/*Mir* link-ups between 1995 and 1997, including rendezvous, docking, and crew transfers. Robert L. "Hoot" Gibson commanded the STS-71 crew, and his pilot was Charlie Precourt. Gibson was no novice to spaceflight, having made four previous flights, including command of the STS-41-B, STS 61-C, and STS-47 missions. The three STS-71 mission specialists aboard *Atlantis*—Ellen S. Baker, Bonnie Dunbar, and Gregory J. Harbaugh—were also veterans of spaceflight, having undertaken 10 missions among them. Also aboard *Atlantis* were cosmonauts Anatoly Y. Solovyev, making his fourth spaceflight, and Nikolai M. Budarin, making his first flight. Solovyev and Budarin were designated as the *Mir-19* crew and would remain aboard *Mir* when *Atlantis* undocked from the nine-year old space station and returned to Earth with the *Mir-18* crew.[25]

In all NASA undertook nine Shuttle docking missions to *Mir* between 1995 and 1998. While there is much yet to do, these docking missions conducted were aimed toward increasing international spaceflight capabilities and seemed to signal a major alteration in the history of space exploration.[26] With the launch of the first two *International Space Station* components in late 1998, it may well be that international competition had been replaced with cooperation as the primary reason behind huge expenditures for space operations. As the dean of space policy analysts, John M. Logsdon, concluded: "There is little doubt, then, that there will be an international Space Station, barring major catastrophes like another Shuttle accident or the rise to power of a Russian government opposed to cooperation with the West."

Not everything on *Mir* was idyllic. A series of failures on *Mir* in 1997, including a major fire and the ramming of the Spetkr module by a Progress resupply vessel, proved exceptionally taxing. Originally designed to last five years, the station had been in space for eleven years and was quite literally falling apart. Warning alarms went off regularly. Hoses split, releasing antifreeze that the astronauts had to breathe. Devices broke down. There were numerous power failures. Garbage and broken equipment built up because there wasn't enough room in the spacecraft to get rid of it. And according to several astronauts, Russian mission controllers lied to the crew about the dangers they were facing, berated them for failures that were not their fault, and treated them like idiot stepchildren.[27]

In outward appearance, *Mir* has also been compared to a dragonfly with wings outstretched, an appropriate physical characterization. NASA astronaut Jerry Linenger, who flew on *Mir* in the mid-1990s, compared the space station to six school buses all hooked together:

> It was as if four of the buses were driven into a four-way intersection at the same time. They collided and became attached. All at right angles to each other, these four buses made up the four *Mir* science modules . . . Priroda and Spektr were relatively new additions . . . and looked it—each sporting shiny gold foil, bleached-white solar blankets, and unmarred thruster pods. Kvant-2 and Kristall . . . showed their age. Solar blankets were yellowed . . . and looked as drab as a Moscow winter and were pockmarked with raggedy holes, the result of losing battles with micrometeorite and debris strikes over the years.[28]

Inside, *Mir* looked a cluttered mess with obsolete equipment, floating bags of trash, the residue of dust, and a crust that grew more extensive with the passing years. Astronaut Michael Foale said it reminded him of "a frat house, but more organized and better looked after."[29]

Logsdon noted that it is remarkable that the space station program has survived to this point, because of its weak support over the years, both internationally and domestically. "One hopes that all of this is behind us now," he added, "and that for the next seven years the 14-state station partnership can focus all of its energies on finally putting together the orbital facility, without the diversion of continuing political arguments over its basic existence and overall character." He also commented:

> Even with all its difficulties and compromises, the space station partnership still stands as the most likely model for future human activities in space. The complex multilateral mechanisms for managing station operations and utilization will become a *de facto* world space agency for human spaceflight operations, and planning for future missions beyond Earth orbit are most likely to occur within the political framework of the station partnership.[30]

So what does this mean? The significance seems to rest on the international context of the *Atlantis*/*Mir* docking mission and what it signals for the future of spaceflight. Humans of several hundred years hence may well look back on this flight as the tangible evidence of the beginning of a cooperative effort that was successful in creating a permanent presence for Earthlings beyond the planet. It could, however, prove to be only a minor respite in the competition among nations for economic and political supremacy. Perhaps the most important thing to remember is that the future is not yet written and that humans in the "here and now" have the unique opportunity to support and contribute to the success of an international space station, an outpost that will serve as a base camp to the stars and enable the move from this planet to a wide universe beyond.[31]

Building *ISS*

Beginning in 1993 NASA transformed the Space Station *Freedom* program to the *International Space Station* (*ISS*). NASA leaders were thereafter remarkably successful in maintaining the political coalition supporting the effort, and in late 1998 the station's first elements were launched into orbit. Assembly of the station continued through 2002, and NASA expected to complete it by 2006. The first crew went aboard in the fall of 2000, and a total of nine crews have served aboard this station through October 2003. While there have been enormous difficulties to be overcome in the project—cost overruns, questions about the quality of science to be undertaken, the role of civilians who want to fly, the need for the facility—one may appropriately conclude that the *ISS* effort has thus far been successful, if only moderately so. This is true for three major reasons.

First, the fact that this station is being built at all by a large international consortium is extraordinary, given the technical, financial, and political obstacles involved. The U.S. House of Representatives came within a single vote of canceling the entire effort in 1993. Space organizations from a multitude of nations have struggled to overcome cultural differences on this enormously complex high-technology undertaking. Second, the *ISS* provides the most sophisticated model ever offered for tax-financed human activities in space. One hundred years hence, humans may well look back on the building of the station as the first truly international endeavor among peaceful nations. No question, it is the most sophisticated international effort ever attempted on the space frontier. Third, the station could quite possibly revitalize the spacefaring dream. Once functioning in space, the station may energize the development of private orbital laboratories. Such laboratories could travel in paths near the *ISS*. The high-tech tenants of this orbital "research park" could well take advantage of the unique features of microgravity and achieve truly remarkable results. The *ISS* would permit research not possible on Earth in such areas as materials science, fluid physics, combustion science, and biotechnology.[32]

Beginning in 1994 the *ISS* project took off in the new direction mandated in the redesign that had taken place the year before. At that time NASA operated under an annual fiscal year constraint of $2.1 billion per year for *ISS* funding and with a total projected cost of $17.4 billion. As an independent blue ribbon assessment on *ISS* cost assessment and validation under Jay Chabrow concluded in 1998, "NASA's schedule and cost commitments were definitely success-oriented, especially considering the new realigned contracting approach with a single Prime contractor and that the specifics of Russia's involvement were just being definitized."[33] In other words, NASA over promised on what it could deliver for the money expended and the schedule agreed on.

In addition, transitioning from Space Station *Freedom* contracts to the *ISS* in 1994 presented some challenges. As it brought Russia into the program, NASA undertook in March 1994 a full systems design review, thereby effectively completing the redesign by establishing a new baseline for the system. NASA and the partners also devised an *ISS* assembly sequence on 28 November 1994, reflecting an initial occupancy in November 1997, with *ISS* assembly complete by June 2002. But these rosy forecasts could not mitigate the reality of the station's complexity.

In April 1994, Canada shifted away from human spaceflight and space robotics toward space communications and Earth observation. As a consequence, NASA was forced to assume more responsibility (and about $200 million more in costs) for the extravehicular robotics function previously the purview of the Canadian Space Agency (CSA). The program also experienced some shifting in requirements. For example, in June 1994 the Centrifuge Accommodation Module (CAM), which had been a part of the Space Station *Freedom* design but was not identified specifically as integral to the *ISS*, reentered the program but without additional funding. The CAM was a much-valued laboratory that would house an 8.2 foot diameter centrifuge, the essential component of a larger complement of research equipment dedicated to gravitational biology. It would make possible the use of centrifugal force to simulate gravity ranging from almost zero to twice that of Earth. It could also imitate Earth's gravity for comparison purposes while eliminating variables in experiments and might even be used to simulate the gravity on the Moon or Mars for experiments that would provide information useful for future space travels. While the scientific community applauded the addition, paying for the module proved a challenge. As a result, NASA later negotiated with Japan for the CAM in return for paying the launch costs of Japanese modules and astronauts.[34]

Even so, at the end of the century NASA's international partners—Canada, Japan, the European Space Agency, and Russia—were expected to contribute the following key elements to *International Space Station*, according to a NASA fact sheet:

- Canada is providing a 55-foot-long robotic arm to be used for assembly and maintenance tasks on the Space Station.

- The European Space Agency is building a pressurized laboratory to be launched on the Space Shuttle and logistics transport vehicles to be launched on the Ariane 5 launch vehicle.
- Japan is building a laboratory with an attached exposed exterior platform for experiments as well as logistics transport vehicles.
- Russia is providing two research modules; an early living quarters called the Service Module with its own life support and habitation systems; a science power platform of solar arrays that can supply about 20 kilowatts of electrical power; logistics transport vehicles; and Soyuz spacecraft for crew return and transfer.
- In addition, Brazil and Italy will be contributing some equipment to the station through agreements with the United States.[35]

The first two station components, the Zarya and Unity modules, were launched and joined together in orbit in late 1998. Several other components were nearing completion at factories and laboratories in the United States and elsewhere. Orbital assembly of the *International Space Station* has begun a new era of hands-on work in space, involving more spacewalks than ever before and a new generation of space robotics. The Space Shuttle and two types of Russian launch vehicles will launch a total of 46 missions to assemble the station, 3 of which—2 Shuttle missions and 1 Russian launch—have been completed as of March 2002. Of the total flights, 37 will be Space Shuttle flights, and 9 will be Russian rockets.

Up to the date of the *Columbia* accident in February 2003, numerous Russian and U.S. flights to the *ISS* have been made, including 16 Space Shuttle missions, 5 Soyuz missions, several Progress cargo supply missions and 2 Russian missions launched with Proton Rockets. The first of these was what some have called the space tugboat, the FGB or Zarya control module. Launched on 20 November 1998, by a Russian Proton Rocket from the Baikonur Cosmodrome, Kazakstan, Zarya was essentially an unpiloted space "tugboat" that provided early propulsion, steering, and communications for the station's first months in orbit. Later during assembly, Zarya became a station passageway, docking port, and fuel tank. Zarya was built by Russia under contract to the United States and is owned by the United States. This unit was followed quickly by the Unity connecting module taken aloft on Space Shuttle mission STS-88. This was the first of the 37 planned Space Shuttle flights to assemble the station. *Endeavour's* crew rendezvoused with the already orbiting Zarya module and attached it to Unity on 6 December 1998. When the Space Shuttle left, Unity and Zarya were in an orbit 250 miles above Earth monitored continuously by flight controllers in Houston and Moscow.[36]

The third mission to *ISS* began on 27 May 1999, when the shuttle *Discovery* performed the first docking with the *International Space Station* on 29 May 1999 as part of STS-96. *Discovery's* crew unloaded almost two tons of supplies and equipment for the station, including clothing, laptop computers, water, spare parts, and other essentials. The crew also performed one EVA to install a U.S. developed spacewalkers' "crane," the base of a Russian-developed "crane," and other spacewalking tools on the station's exterior to await use by future station assembly crews. *Discovery* also fired its thrusters to reboost the station's orbit and then undocked on 3 June 1999. *Discovery* landed on Earth on 6 June 1999.[37]

While the launches of Zarya and Unity had been good news, and some work had taken place after their assembly in December 1998, a 19-month hiatus followed before the Russians completed building the Zvezda module. This module provided living quarters, life support, navigation, propulsion, communications, and other functions for the early station. Without it, crews could not remain on the *ISS* without the Space Shuttle being present. The Zvezda module was the first fully Russian station contribution and the core of the Russian station segment. Launched without a crew aboard on 25 July 2000, Zvezda docked with the orbiting Zarya and Unity modules by remote control and the gates were opened for *ISS* assembly. Its guidance and propulsion systems took over those functions from the Zarya module, which then became a passageway between the Unity and Zvezda modules.[38]

According to the original assembly sequence for the redesigned space station in 1993, the Service Module was supposed to have been in orbit in April 1998. However, a series of delays, caused mostly by Russia's continued inability to generate the funds required to pay for the Service Module, pushed the launch date back by some two years. The Service Module's launch was delayed even further when the Proton rocket fleet suffered two launch failures. The failures were eventually traced to manufacturing problems within upper stage rocket engines and the system had to be redesigned. The continued delays forced NASA to come up with several contingency plans that were themselves also plagued by delays and cost overruns. The launch of Zvezda finally paved the way for the launch of the U.S. laboratory module, Destiny, and occupation by a permanent crew.[39]

In anticipation of the first crew boarding the *ISS*, the Space Shuttle *Atlantis*, STS-101, made a second cargo flight beginning on 8 September 2000. *Atlantis* docked with the *ISS* carrying supplies to be transferred to the interior. *Atlantis'*s crew performed a spacewalk to attach a telescoping boom to the Russian spacewalker's crane left on the station's exterior during mission STS-96, and also to conduct other assembly tasks. The station remained unoccupied after *Atlantis* undocked.[40] Before the Expedition One crew's arrival at the *ISS*, STS-92 delivered the Z-1 Truss, Pressurized Mating Adapter 3, and four Control Moment Gyros in October 2000. Astronauts performed four days of spacewalks to finish these connections.[41]

Then on 31 October 2000, a momentous occasion arrived when the first crew to occupy the *International Space Station* inaugurated a new era in space history. When American astronaut Bill Shepherd and Russian cosmonauts Yuri Gidzenko and Sergei Krikalev lifted off in a Russian Soyuz spacecraft from the Baikonur Cosmodrome in Kazakhstan en route to their new home aboard the *ISS*, it represented the last day in which there were no human beings in space. Shepherd, of Babylon, New York, was commander of the three-person Expedition One crew, the first of several crews to live aboard the *ISS* for periods of about four months. With cosmonauts Gidzenko and Krikalev, Shepherd worked on assembly tasks as new elements, including the U.S. laboratory, were added to the orbiting outpost. They also conducted early science experiments.[42]

Entering 2003, the *ISS* assembly effort continued to be hampered by some of the same problems that it faced in preceding years. While reasonable progress continued on the U.S. elements, there were many challenges ahead that will result in increased cost and schedule erosion. U.S. development problems continue to be overshadowed by Russian funding shortfalls and delays in its commitments; however, U.S. production delays and the incorporation of much needed multi-element integrated testing have slowed down the construction process. There also continues to be recurring problems such as late part and component deliveries on flight elements, similar to those that plagued earlier flight units. All of this was exacerbated by the 1 February 2003 loss of *Columbia*, which grounded the Shuttle fleet until at least March 2005.[43]

Much of this revolves around cost. When the *Freedom* program became the *International Space Station*, NASA believed it could build the station on a budget of $17.4 billion over a 10-year period. It could not have been more wrong had it set out to offer disinformation. After three years of insisting that it could build *ISS* for $17.4 billion, in September 1997, NASA finally conceded it could not. Cost overruns on Boeing's contract and the need for an additional $430 million for NASA in fiscal year (FY) 1998 were announced. NASA began transferring funds from other NASA programs into *ISS* construction. By the time of a major review in the fall in 2001, the estimated U.S. portion of the *ISS* development stood at about $23 billion.[44]

Most troubling, NASA managers kept silent until after the 2000 presidential election the fact that they were tracking about $4 billion in cost growth for *ISS* for fiscal years 2002 to 2006. This not only blew the legislated cap for the total cost, it also demolished the annual funding constraints. Since 1998 the estimated total cost to build the *ISS* has grown every year by an average of $3.2 billion. The complete *ISS* was estimated in 2001 to cost more than $30 billion and would not be completed until 2006 (Figure 23–5). Much of the U.S. hardware had already been built, and more was in the process of completion. And some had already been assembled on orbit and made operational. Many at NASA assumed by this time that, barring a catastrophe, the program was past its major cost hurdles. Instead, NASA leaders found themselves with a set of additional costs that would be required to complete the project. Most of these costs had been pushed forward in time throughout the years and were now coming due. The CRV, habitat module, propulsion module, and the bulk of the science program intended for *ISS*, all fell under the budget ax. An air of crisis permeated the *International Space Station* program all through the summer and fall of 2001.[45]

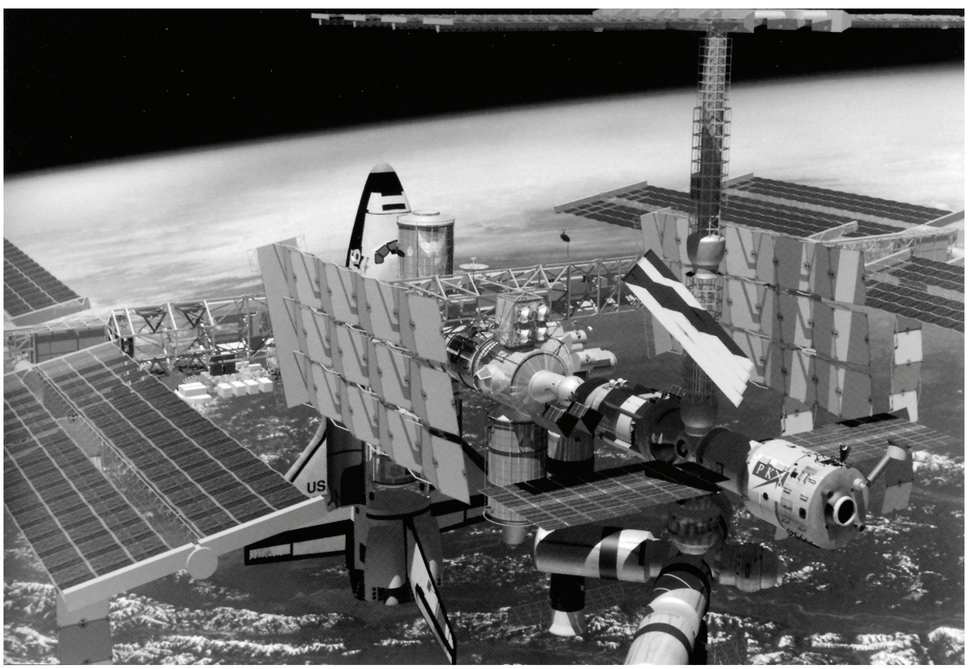

Figure 23–5: "*International Space Station*: Assembly Complete with Shuttle." This illustration depicts the international Space Station when assembly is completed with elements from the United States, Europe, Russia, Japan, and Canada. The Space Shuttle, shown docked with the space station, transports science investigators to relieve crew members who have spent several months on orbit. NASA photo HqL-427 1/96.

By the first part of the 21st century, *ISS* had devolved to a debate about serious questions of mismanagement and cost overruns. As the *ISS* program continues the budget will dictate what direction the final program takes. Without a doubt, more debate and decision making will be necessary before the *ISS* is completed.[46]

Conclusion

The dream of a permanent presence in space, made sustainable by a vehicle providing routine access at an affordable price has driven space exploration advocates since at least the beginning of the 20th century. All of the spacefaring nations of the world have accepted that paradigm as the raison d'etre of its programs in the latter 20th century. It drove the United States to develop the Space Shuttle as a means of achieving routine access and prompted an international consortium of 14 nations to build a space station to achieve a permanent presence in space. Only through the achievement of these goals, space advocates insist, will a vision of space exploration that includes people venturing into the unknown be ultimately realized. This scenario makes eminent sense if one is interested in developing an expansive space exploration effort, one that would lead to the permanent colonization of humans on other worlds.

At the same time, this vision has not often been consistent with many of the elements of political reality in the United States. Numerous questions abound at the end of the century concerning the need for aggressive exploration of the solar system and the desirability of colonization on other worlds. A vision of aggressive space exploration, wrote political scientist Dwayne A. Day,

> implies that a long-range human space plan is necessary for the nation without justifying that belief. Political decision makers have rarely agreed with the view that a long-range plan for the human exploration of space is as necessary as—say—a long-range plan for attacking poverty or developing a strategic deterrent. Space is not viewed by many politicians as a "problem" but as at best an opportunity and at worst a luxury.[47]

Most important, the high cost of conducting space exploration comes quickly into any discussion of the endeavor.

Of course, there are other visions of spaceflight less ambitious that are more easily justified within the democratic process of the United States. Aimed at incremental advances, these include robotic planetary exploration and severely limited human space activities. Most of what is presently underway under the umbrella of NASA in the United States and the other space agencies of the world fall into this category. Yet, these only moderately ambitious space efforts also raise important questions about public policy priorities and other fiscal responsibilities. At present the NASA budget, however, stands at only about one-seventh of one percent of the federal budget and is declining both in real terms and as a percentage of the federal budget every year as the new century progresses. Is that too much to pay to achieve the goal of discovery and exploration of the universe around us and ultimately to achieve the long sought dream of journeying elsewhere to new lands and to contact new cultures?[48]

Space has always had the ability to excite and inspire humanity, just as exploration of the world beyond Europe in the 15th and 16th centuries inspired and excited those nations. Like those earlier explorations it holds the allure of discovery of a vast unknown awaiting human assimilation, an allure particularly appealing to a society such as the United States that has been heavily influenced by territorial expansion. In many respects, space exploration represents what the 1960s popular culture television phenomenon of *Star Trek* dubbed it, the "final frontier." The goal of a permanent presence in space could be and is routinely considered by advocates of exploration as major steps in opening that "final frontier" but is a more apt characterization at this point "space: the failed frontier?"

Notes

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