HARVARD | BUSINESS | SCHOOL

9-721-054

MAY 30, 2021

MATTHEW WEINZIERL

MEHAK SARANG

The International Space Station, Principal-Agent Problems, and NASA's Quest to keep Humans in Space

In January 2014, Charlie Bolden[1], in his fifth year as NASA Administrator, issued a statement along with John Holdren[2], the Director of the White House Office of Science and Technology Policy (OSTP), extending the life of the International Space Station (ISS) from 2020 to at least 2024.[3] In so doing, Bolden and Holdren were breathing new life into a flagship NASA project with roots a half-century old—NASA had been committed to a space station as its "next logical step" since its Apollo missions to the moon in the 1960s—and a proud record of sustaining continuous human presence in space since 2000.[4] But they were also keeping alive a program that at its peak absorbed 70% of NASA's budget for space activities[5] and – once built – half of NASA's annual human spaceflight budget while delivering, at least in the eyes of critics, limited benefit.[6] NASA's own Inspector General had issued a report in 2013 saying: "The final configuration of the ISS cost more, took longer to complete, and is less capable than NASA and its partners envisioned."[7]

In 2011, with Bolden and Holdren serving in the same positions, President Obama had dramatically cancelled NASA's Constellation program after years of missed budgets, delayed schedules, and mixed results. Constellation, which Michael Griffin (NASA Administrator under Obama's predecessor George W. Bush) had described as "Apollo on Steroids,"[8] launched in 2005 and prioritized the construction of large rockets to facilitate missions to the Moon and Mars. But it had come under criticism for slow progress and escalating costs. OSTP Chief of Staff Jim Kohlenberger justified Obama's decision, "the fact that we poured $9 billion into an in-executable program really isn't an excuse to pour another $50 billion into it and still not have an executable program."[9]

President Bush had made a similar decision nearly a decade earlier, cancelling the Space Shuttle program after the tragic loss of the Space Shuttle *Columbia* and its crew. Despite having no alternative means of transporting Americans to space after 2010, including to the ISS, Bush and his advisors decided to end the Space Shuttle program and build a new system for access to space. Over its 30-year career, the Space Shuttle program had cost NASA $209 billion and underperformed its promised flight cadence and cost.[10]

Why had the ISS escaped the fate of the Constellation and Space Shuttle programs? Was extending the ISS to at least 2024 justified, or was it throwing good money after bad?

Professor Matthew Weinzierl and Research Associate Mehak Sarang prepared this case. Funding for the development of this case was provided by Harvard Business School. HBS cases are developed solely as the basis for class discussion. Cases are not intended to serve as endorsements, sources of primary data, or illustrations of effective or ineffective management.

A Space Shuttle and a Station: NASA's Second Act

In July of 1969, NASA seemed unstoppable, as its behemoth Saturn V rocket, designed and built in less than a decade, launched the Apollo 11 mission from the Kennedy Space Center and put the first men on the Moon while a stunned world watched from below.

The revolutionary Saturn V was the brainchild of Wernher von Braun—often deemed "the father of modern rocketry"—who saw the Apollo missions as the first step in achieving a grand vision of a new space age.[11] At the heart of von Braun's vision was a free-flying, permanently inhabited, rotating and orbiting space station (rendered in **Exhibit 1**) to and from which astronauts would travel onboard a fleet of reusable spacecraft. According to von Braun, "the Earth [would] have a new companion in the skies…the artificial moon carried into space, piece by piece, by rocket ships. From this platform, a trip to the moon itself [would] be just a step."[12]

Von Braun was far from alone in his ambitious plans: in 1969, the newly elected U.S. President Richard M. Nixon appointed a Space Task Group to propose a vision for NASA's future. The group issued a report recommending that the agency pursue—over only the next two decades—an earth-orbital space station, a lunar-orbital space station, a lunar surface base, and a manned mission to Mars, all enabled by a fleet of reusable space shuttles. The plan for the space station was particularly ambitious. Prominent space historian Howard McCurdy wrote: "Starting with a six-to-twelve-person module, the nation could construct a space station in orbit around the earth large enough to eventually house fifty to one hundred men and women."[13]

Two components common to von Braun and the Space Task Group's vision—the shuttle and the earth-orbiting station —would come to define NASA's human spaceflight directive in the four decades after Apollo. NASA would spend $270 billion from 1972 through 2010 to build the Space Transportation System (STS), or "Space Shuttle" (as it was better known) and what eventually became known as the International Space Station (ISS).[14] Together, the STS and ISS would be NASA's second act.

The 1960s and 1970s: Skylab and the Space Transportation System

Paradoxically, as the 1960s wound down and NASA was achieving its most improbable successes, enthusiasm for the grand visions proposed by the agency and the Space Task Force evaporated. As historian McCurdy notes: "Nixon knew that little public support remained for an ambitious space program…By mid-1970, after two successful landings on the moon, 50 percent of the public in poll after poll stated that the United States should "do less" in space. Only 20 percent thought that the United States should "do more."[15]

Foreseeing and then responding to this collapse in political support, NASA officials repeatedly had to prioritize among their vision's components. The twin goals of a space station and a shuttle would remain the agency's priorities throughout, but political and budgetary constraints would mean that they would have to be pursued sequentially, rather than simultaneously (as NASA had hoped).[16]

The first station: Skylab

Von Braun and George E. Mueller, NASA Director of the Office of Manned Spaceflight, anticipated the drop in support that would follow the end of the Apollo program, and they feared that the 400,000 individuals they had trained would be out of work once the program wound down. In 1966, they established the Apollo Applications Program (AAP), and tasked it with determining how best to apply

the technologies (and talent) developed for the Apollo missions to create a new era of human spaceflight.[17]

Von Braun's first proposal for the AAP was the development of a scaled-back version of the orbiting space station he had long championed. Rather than designing and building new architecture for the space station, as in his grander vision, von Braun proposed converting the third stage of a Saturn V vehicle (usually discarded in orbit after launch) into a makeshift living quarters and "wet workshop" to conduct a series of experiments in LEO.[18] Mueller expanded upon von Braun's idea and proposed "Skylab": a 169,950-pound orbiting space station containing a wet workshop, solar observatory, and multiple docking adapters and systems to allow crews to spend up to 84 days in space (see **Exhibit 2** for a Skylab schematic).[19]

Skylab was a tactical project: with a range of experiments and crewed missions to the station, it would serve as an important testing ground for understanding the effects of microgravity on biological systems while furthering space sciences research. It was designed to be only "one of the initial steps in the actual landing of a man on the moon in 10-15 years."[20] Skylab was also designed to be an easy sell. With Apollo progressing rapidly, the original fleet of Saturn rockets would not be fully utilized, freeing them up for deploying and supplying Skylab. Under these pretenses, Skylab was approved as AAP's first mission by NASA Associate Administrator Robert C. Seamans in March 1966, and formally proposed to NASA Administrator James E. Webb in November of the same year.[21]

However, the Skylab proposal meant little without Congressional approval to fund it, and that approval was getting harder to obtain as Apollo neared its end. Webb wrote, "As to long-range planning…NASA was constantly warned by those political, educational, press, and congressional sources who were most supportive that any evidence of commitment to a large, long-term, expensive program beyond Apollo would lose us the margin of strength needed to finish Apollo."[22]

1968 proved to be a crucial turning point in Congressional attitudes towards NASA. The ongoing war in Vietnam and assassination of Martin Luther King, Jr. increased public pressure for more domestic spending as well as a reduction in non-essential federal programs. Despite the initial elation of the Apollo landings, Congress soon came under pressure to justify space spending. Congressman Emilio Q. Daddario, the acting chairman of the Manned Space Flight Subcommittee of the House Committee on Science and Astronautics, captured the skepticism towards the space program, asking, "[While] we feel that we have seen great accomplishments…how do we, with the great expenditures made, prove that the technology that is developed from it is worth the cost?"[23]

James Webb later described the hearings for the FY 1969 NASA budget request as "a mass walkout of Congressional support."[24] After reaching $5 billion in the mid-1960s, NASA's annual budget was reduced to $4 billion in 1969, with $253 million allocated to the AAP, only three-fifths of the amount requested.[25] Facing a heavily reduced budget, NASA cut costs in the Skylab program: no longer calling for continuous occupation of the module, reducing the number of experiments, and simplifying the onboard equipment.

Albeit in a much-reduced form, the AAP managed to get Skylab off the ground in 1973, becoming the first (and only) space station operated exclusively by the United States. The program boasted important achievements: three crews spent a collective 168 days in orbit, and astronauts onboard conducted medical tests as well as studies regarding fluid mechanics and material properties in microgravity in addition to space science experiments. Within minutes of its initial lift-off, however, Skylab had suffered damage from a premature deployment of the meteoroid protective shield. The first crew arrived on the space station for a repair mission, and two crewed missions followed. But due to budget cuts and delays in the STS program (discussed below), NASA was unable to boost Skylab to a

higher orbit, and the station was on track for an early decommissioning.[26] It fell out of orbit on July 11, 1979, crashing down in the Indian Ocean and shedding debris over parts of Western Australia.[27]

The Space Transportation System

As the Skylab program tailed off, NASA was forced to choose between continuing its pursuit of a space station or tackling its other main priority: a space shuttle. The choice was a painful one for the agency, but James Fletcher, the agency's new Administrator in 1971, believed that the political support for NASA's grander visions was so diminished that the pursuit of both the shuttle and an earth-orbiting station more advanced than Skylab was asking too much. "There is no way we can do that," McCurdy quotes Fletcher as saying in 1971.[28]

Fletcher chose the shuttle, and he spent much of his first year as NASA Administrator negotiating with President Nixon's budget staff to develop a cost-effective design for the Space Transportation System (STS), which Nixon authorized in January 1972. [29] The STS was christened the Space Shuttle in evocation of its promise to make space access routine, and both its unmistakable silhouette and its tangled path to realization would become emblematic of the new post-Apollo era for NASA.

The STS was designed as a partially reusable space plane, utilizing solid rocket boosters to launch a winged spacecraft into orbit which could then reenter Earth's atmosphere as a glider and land horizontally on a runway. The main components of the shuttle were the Orbiter, the main engine, Solid Rocket Boosters, and the External Tank; all components, except for the External Tank, were designed for reuse (see **Exhibit 3** for the Space Shuttle launch configuration). The Orbiter vehicle component had a servicing period of 5 months, and was designed to last 100 space missions, while the Solid Rocket Boosters (SRBs) were parachuted and recovered once jettisoned after launch for refurbishment. In terms of capability, the STS required 35 million newtons (7.8 million pounds-force) thrust to launch up to 65,000 lbs (29,000kg) of crew or cargo to orbit.[30]

The shuttle design approved in 1972 was meant to serve many interests, not just NASA's. As McCurdy wrote: "Within NASA, the Space Shuttle was viewed as a sophisticated technology for transporting people and equipment to an earth-orbiting space station, which in turn would support their exploration goals. Neither the space station nor the exploration goals had been approved by the U.S. Congress, however, so NASA officials adopted a more utilitarian rationale. They turned to earth-bound arguments, in particular the cost-effectiveness of the system for delivering payloads into orbit."[31] Those payloads would serve scientific, commercial, and even military goals—all of which were higher priorities in Congress—but they meant a sharp turn away from the goal that had made NASA's reputation: putting humans in space. As Handberg wrote, "The agency's only purpose despite much rhetoric to [the] contrary is the conduct of human spaceflight, everything else supports that goal."[32]

Consistent with the mismatch between NASA's objectives and Congressional priorities, obtaining sufficient funding from Congress for the STS was not easy. The initial design negotiations had slashed NASA's multi-year shuttle-program budget from more than $10 billion—the agency's original estimate—to $5.15 billion. Cost containment remained a crucial goal, as cuts to NASA's overall budget continued past the pivotal year of 1969: in 1970, the budget stood at $3.7 billion, and by 1974 it had fallen to just over $3 billion.[33] As the Space Shuttle program's costs nevertheless rose and schedule slipped, Congress reluctantly added funding. In exchange, as historian Roger Handberg writes, "…NASA made several commitments regarding the Space Shuttle that the agency in the end could not meet. Those coerced commitments represented a desperate agency's response to an extremely skeptical administration and Congress."[34] The shuttle flew successfully for the first time in 1981, after a total

development cost of $10 billion (FY 1983 dollars).[35] The cost of production for four orbiters was about $3.8 billion, and each launch cost the agency an average of $1 billion over the lifetime of the program.[36]

A "businesslike" space agency

As the stories of Skylab and the STS demonstrate, the early 1970s marked an important transition for NASA's space program. In the words of James Fletcher, NASA Administrator at the time, "from the Apollo era to the Space Shuttle…[Skylab] moved the space program from the realm of the spectacular, into a new phase that [could] be characterized possibly as almost businesslike."[37] Scott Pace, director of the Space Policy Institute at George Washington University, said "I would make an argument that, actually, Nixon has had a longer-term legacy [than Kennedy] on human spaceflight…People remember Kennedy and going to the moon, but it's Nixon and his choices and nonchoices about shuttle in 1972 that have arguably been with us for 40 years."[38]

The 1980s and the "next logical step": Space Station Freedom

To NASA, the most important purpose of a space shuttle had always been to build and supply the space station. As McCurdy writes of the agency in 1970: "…the Space Station was viewed within NASA as more important than the Space Shuttle. The Space Shuttle would 'support the station,' providing 'airline-type operations' between the station and the surface of the earth."[39] Historian Roger Handberg concurs, writing: "…NASA set out to employ the shuttle as the teaser or come-on regarding humans' future in space. This was an opportunity to demonstrate in a preliminary way outer space's research and commercial potential while making clear that its full potential could only be reached through a space station."[40] It was not a surprise, then, that the first shuttle flight in 1981 coincided with NASA officials turning their attention once again to building a space station.

As had his predecessors, James A. Beggs, the NASA Administrator under President Ronald Reagan (1981-1985), saw the pursuit of a space station in LEO as a top priority.[41] Not coincidentally, Russia—with which the United States was locked in a Cold War—planned to launch its own station, *Mir*, into orbit in 1986. In 1982, Beggs said the following in support of an American space station, "The compulsion to know the unknown built our nation. It spurred the creativity of our scientists and engineers so that today we lead and are indeed envied by the rest of the world in science and technology. I believe our *next logical step* is to establish a permanent manned presence in low-Earth orbit. This can be done by developing a manned space station."[42]

On Beggs' advice, Ronald Reagan appointed a Space Station Task Force in May 1982, which proposed the development of a space station in an international partnership. Despite significant opposition from his closest advisors,[43] Reagan approved the construction of "Space Station *Freedom*" in 1984 and, in his State of the Union speech, touted it as a means through which to "follow our dreams to distant stars, living and working in space for peaceful economic and scientific gain."[44] An initial plan proposed an ambitious eight functionalities spanning these three broad objectives:[45]

Exploration

1. A transportation node where payloads and vehicles are stationed, processed and propelled to their destinations
2. A servicing facility, where these payloads and vehicles are maintained, and if necessary, repaired
3. A storage depot where payloads and parts are kept on orbit for subsequent deployments
4. A staging base for more ambitious future missions

Commercial

5. An assembly facility where, due to ample time on orbit and the presence of appropriate equipment, large structures are put together and checked out
6. A manufacturing facility where human intelligence and the servicing capability of the station combine to enhance commercial opportunities in space

Scientific

7. A permanent observatory, to look down upon the Earth and out at the universe
8. A laboratory in space, for the conduct of science and the development of new technologies

Despite Presidential support and the spate of partnership agreements, *Freedom*'s road to development was full of obstacles. In the first budget negotiations after Reagan's announcement, Congress approved only two-thirds of the funding request for the station. That pattern continued: as former NASA official Donald Beattie writes, "The bitter wrangling between supporters and opponents that began with the FY 1985 budget would continue as each new fiscal year budget request was forwarded to the Congress. As a result, the program was never able to achieve the classic 'bell curve' funding profile that is the hallmark of successful R&D programs…Program compromises, rather than good program management, were the only way the program would survive."[46] Between 1984 to 1993, NASA spent $10 billion on the design—and seven major re-designs—of the station, and its cost estimates reported to Congress varied from an additional $8 billion to $78 billion.[47] The low-end estimates were viewed as NASA's "foot in the door" by opponents, according to Beattie, and an increasingly skeptical Congress subjected the program to persistent budgetary constraints.

Skepticism of the station was not limited to Congress, with critics asserting the station was not being designed to fulfill any important purpose. A *New York Times* editorial in 1984 charged that "…the reason for pushing the space station is primarily bureaucratic. It's a big-ticket, make-work program to keep the agency busy after the shuttle."[48] Scientists were similarly unimpressed. Freeman Dyson, a theoretical physicist and prominent futurist, recalled an Office of Technology Assessment committee meeting which he and famed astronomer Carl Sagan had joined: "We listened while experts from NASA and the aerospace industry described forty-eight scientific experiments that they proposed to do on the space station…we decided that forty-six of the experiments could be done better without the space station… We concluded that the scientific justification for the space station was illusory."[49] Moreover, an internal NASA panel convened in 1985 to evaluate the station's commercial potential raised concerns regarding the lack of "strong, dedicated customer offices" for the program; the implied recommendation was never fully implemented.[50]

As the 1990s approached and then arrived, the station came under serious political pressure. In the late 1980s, Reagan's tight (non-defense) fiscal policy took hold. As Donald Beattie writes, "There could be no further pretense. The Space Station program was being driven by just one consideration—cost….NASA would manipulate the numbers, schedules and content trying to keep the program alive while continuing to provide some semblance of a useful facility…Meanwhile, Congress was becoming more agitated as leaks of the new costs were circulated. The Congressional Budget Office (CBO) suggested canceling the program in order to take a bite out of the growing deficits."[51]

The 1992 election of President Bill Clinton seemed to exacerbate the crisis. As Handberg summarized the situation, "…by 1992, instead of in-orbit station being well underway, the space station program was effectively in free fall toward unmitigated disaster and probable cancellation. When combined with high Space Shuttle operation costs, the two programs were effectively absorbing NASA's entire budget…During the Clinton presidential transition, NASA was strongly and, in some

cases, bitterly attacked both in the media and within the government…The space station was put forth as one prime sacrifice to finding fiscal sanity in an era of escalating budget deficits."[52]

In response, NASA trimmed its ambitions for the station. A redesign (named Space Station Alpha) reduced its scale, capabilities, and projected cost. The name and vision of Space Station *Freedom* was retired in favor of the *International Space Station* as the cooperation of Russia was sought to reduce the cost to the United States (Japan, Europe, and Canada had signed on earlier as partners).[53] In the end, after intense negotiations and reworking, the U.S. House of Representatives authorized NASA to build the ISS by a one-vote margin on June 23, 1993, saving the space station program.

Significantly, the decade of redesign and negotiation had brought a new, geopolitical objective for the ISS to the fore. As the Cold War ended, it was hoped that the ISS—with Japanese, Russian, Chinese, and European partners—could help solidify a new peace. In a statement in support of the station, President Clinton stated, "I will seek to enhance and expand the opportunities for international participation in the space station project so that the space station can serve as a model of nations coming together in peaceful cooperation… offering a Vision of the new world in which confrontation has been replaced with cooperation."[54]

The International Space Station

After NASA received the authorization to build the ISS, it would take another five years and billions of dollars for the first structures to reach orbit, and throughout its first twenty years the project would experience significant cost growth, schedule delays, and functional changes.

The long road to deployment

Initial cost and schedule estimates for the ISS proved too optimistic. The design approved by President Clinton in 1993 had included $12.8 Billion for development and launch plus $16.5 billion in operational costs, with proposed completion by 2002. Crucially, spending per year was capped at $2.1 billion during the development phase.[55] In reality, construction was not completed until 2011, and by 2013 NASA had already spent approximately $74.4 billion for the ISS development, operations, research, and associated Space Shuttle flights. NASA's Office of the Inspector General found that there had been an average increase of 8% annually over the lifetime of the program.[56] As the cost of the ISS increased, NASA's overall budget failed to keep pace, such that the ISS consumed an increasing share of the agency's resources (see **Exhibit 5** to see NASA's expenditure on the ISS, as well as **Exhibit 6** to see the changing estimates of the cost of development compared to actual expenditure).

NASA's reliance on the Space Shuttle to build and access the ISS had proven to be a major obstacle. Originally designed to launch 48 flights per year at $50 million per launch[57], once built and operational, NASA estimated it could reasonably launch about 12 flights per year at $450 million. Ultimately, the shuttle would never fly more than 9 flights in a year, at a cost per launch estimated to be $1 billion. These higher costs and slower flight cadence delayed ISS development and deployment. Furthermore, in 2003, with the *Columbia* disaster, the shuttle was grounded for 29 months, forcing a reduction in the U.S. crew onboard the station.[58]

According to some observers, an even more important obstacle to the ISS's development was Congress's interventions in the ISS design process and its reluctance to commit sufficient resources to the program. Andrew Stofan, former NASA Associate Administrator, said "Congress issued directives that were as detailed as those typically made by a chief engineer or project manager, which weakened the ability of NASA managers and their industry counterparts to perform reasonable management

functions."[59] (See **Exhibit 4** for an example of the types of directives issued by Congress). The incremental nature of the budget process also gave Congress outsized influence over the project lifecycle. Space historians John Madison and Howard McCurdy wrote in 1999 that "rather than a single-sum appropriation, which would have encouraged station managers to spend funds in the most efficient manner…the whole system of budgeting encouraged a spending pattern in which the maintenance of $2 Billion per year spending was more important than building the station at a reasonable over-all cost."[60] In 2010, an Air Force Institute of Technology report argued that this spending cap was the source of much of the ISS project cost growth, as it created misalignment between the funding profile allotted by Congress and the project profile planned by NASA.[61]

The constant redesign and struggle to sustain Congressional support led to a vicious cycle: as timelines grew and the project swelled, managing the extended development cycle created more issues. Faced with turnover in the engineering staff, government transitions, and problems associated with technology maturation and obsolescence, the development process only grew longer and more sacrifices were required. For example, the length of the ISS decreased from the originally proposed 493 feet to 357 feet, while crew capacity dropped from eight to seven.

Historian Roger Handberg diagnosed the persistent frictions between policymakers and NASA as symptoms of a so-called "principal-agent problem," with Congress as the principal working through its agent, NASA, whose goals differed from its own. In a 2003 book, he wrote, "NASA's behavior as an organization in pursuing its quest for human space activity has been consistent (while remaining tactically flexible) across a now forty-year plus time span.…Outside intrusions and pressures are channeled as much as possible in those directions considered supportive for achieving the agency's agenda…At a formal level, the information levels of the principal-agent relationship are asymmetric in favor of the agent, NASA in this case, being the dominant party"[62]

The ISS in action: critiques

The compromises made during the ISS's development left it ill-equipped, at least in its early years, to pursue its creators' lofty commercial, scientific, and exploration objectives. In 2000, Freeman Dyson issued a stinging critique: "The International Space Station falls ludicrously short of Carl [Sagan]'s expectations for a pioneering space venture. It is merely revolving in low orbit around the Earth. It is a welfare program for the American and Russian aerospace industries, driven by mundane politics rather than by visions of cosmic connections."[63]

Attracting commercial activity to the ISS proved difficult, with critics arguing that it was poorly designed for the needs of companies. In an early policy briefing from 2002, Lance Bush, manager of the International Space Station Commercial Development noted that "to date, ISS commercial use is limited…commercial interest is also limited but this is because, for many, the perceived value is not great enough to justify investment.[64] Brent Sherwood, notable space architect and Vice President of Advanced Projects at Blue Origin, would later reflect that transforming the ISS, a "single-purpose…government-funded, fundamental research laboratory", into a "commercially-viable operations facility" was especially difficult due to the limited functionality resulting from compromises made during early design and construction of the station to manage costs. Extensibility of the ISS beyond the research laboratory-focus NASA had adopted would be made difficult, and sustainment costs would only balloon as the facility began to age.[65]

Some blamed this difficulty on a fundamental lack of interest in commercialization within NASA. While NASA "committed to set aside at least 30% of the ISS payload capacity for commercial development"[66] after 1998, NASA's budget allowance towards commercialization efforts would

consistently fall below 1% of the total budget,[67] and between 1998 and 2010 commercial entities funded only 9% of experiments conducted onboard the U.S. segment of the ISS.[68] As historian Handberg put it, "The point is that the agency has not truly grasped commercialization to its bosom. In fact,…commercialization is accepted only as much as is necessary to assure the station's completion and successfully operation for at least ten years."[69]

The ISS also got off to a slow start in pursuing its scientific goals. In 2005, space policy expert Marcia Smith concluded in testimony to Congress that, "the extent to which space station research [would] 'rewrite textbooks' … remain[ed] to be seen." Even a decade further on, an article published in *Nature* in 2014 claimed "many [had] questioned the value of the science done in orbit [aboard the ISS]." Early countermeasure experiments – studying how to counter the effects of microgravity and space environment on human health systems – had proved largely ineffective, and research in the physical and biological sciences hadn't led to significant breakthroughs as anticipated.[70]

A major limiting factor for scientific research was access to crew time, a concern raised in an early advisory meeting, where advisors from the scientific research community suggested a minimum crew of 8 astronauts onboard, with 6 dedicated to research. As crew size continued to be decreased due to budget cuts as well as the cancellation of the Space Shuttle Program, Representative Tim Roener remarked, "we were at the extreme edge of maintaining a credible science endeavor, we might as well completely discontinue".[71] Even after the ISS was fully staffed in 2011, a US National Research Council panel argued that NASA was, "poorly positioned to take full advantage of the scientific opportunities offered by the now fully equipped and staffed ISS laboratory."[72]

In part due to such critiques, Congress made efforts to drive commercial and scientific activity on the ISS. In 2005, it designated the U.S. portion of the ISS research facilities as a National Laboratory,[73] and in 2010 it granted the non-profit Center for the Advancement of Science in Space (CASIS) a 10-year, $136 million cooperative agreement to manage it. [74][75] CASIS was specifically tasked with three major functions: promoting scientific research in the lab; stimulating research activity by funding proposals, matching outside investors with researchers, and encouraging self-funded research; and stimulating private demand for the National Lab. According to a NASA liaison officer, CASIS became the main driver in the commercialization strategy of the ISS, stating, "it is encouraging to see the strong emphasis on stimulating demand for a sustained commercial economy in low-Earth orbit. This is of critical importance to the fulfillment of one of NASA's strategic goals, and CASIS is playing the leading role."[76]

NASA was responsible for funding and managing CASIS, but in a series of reports the Office of the Inspector General (OIG) concluded that a lack of oversight from NASA had led to CASIS failing to make significant progress. The OIG claimed that, "from FYs 2012 through 2014, NASA failed to conduct any meaningful performance assessments of CASIS and therefore CASIS essentially operated independently. Specifically, CASIS's performance plans contained goals but lacked metrics or quantifiable targets to describe how NASA would measure its performance…consequently, without significant change, CASIS will likely fall short of advancing NASA's goal for a commercial economy in low-Earth orbit."[77]

Even the pursuit of the ISS's exploration objectives had been limited relative to the initial vision of it as a transportation, servicing, and staging platform. Instead, the focus narrowed to gauging and reducing the human health risks of future exploration. In 2004, President Bush's Vision for Space Exploration called for the ISS to target the reduction of risks associated with exploration missions to the Moon, Mars, and beyond. It would serve as "the only space-based platform that provides extended access to the spaceflight environment, and as such, provides the only means to assess the long-term

effects of this environment on terrestrial organisms, on physical systems, and on how physics and engineering principles can be utilized to mitigate the long-term effects of spaceflight on biological organisms, structures, and physical processes."[78]

Finally, even the geopolitical objectives foisted upon the ISS in the early 1990s would turn out to be challenging to achieve. The ISS did manage to maintain cooperative relations between the space programs of its participant countries, an especially notable achievement as overall relations between the United States and Russia in general deteriorated in the 2000s. At the same time, the exclusion of China from the ISS would become a new source of tension, as China's space aspirations grew along with its economic clout and it formulated plans for its own space station in the 2020s.[79]

The ISS in action: commendations

Supporters of the ISS saw naivete behind these critiques. Despite all the challenges that arose during its development, the ISS was a massive achievement of engineering that could claim substantial successes in its exploration, scientific, commercial, and geopolitical objectives.

A hugely complex engineering project and the largest structure humans had constructed in space (involving contributions from fifteen countries), the ISS had enabled a continuous human presence in low Earth orbit from the year 2000.[80] In that way, it had achieved a vital step toward a—and perhaps the—central goal of NASA. As Roger Handberg wrote, NASA is "driven by a future vision not previously experienced in human history. …The ultimate goal involved moving humankind into outer space on a permanent basis, …creating an entirely new facet of human civilization."[81]

The ISS was also a unique laboratory for research in space habitation and exploration systems, and it boasted an expansive research portfolio across fields such as bioengineering, pharmaceutical development, and in-space manufacturing.[82] A 2016 review of international research boasted 1,200 journal publications, 59 patents, and over 400 conference proceedings linked to ISS utilization.[83]

As the only orbiting space station, the ISS proved to be an important geopolitical asset and tool for diplomacy. In addition to the partners actively engaged in the program from its inception, the hundreds of experiments onboard the ISS supported research from across the globe. Charlie Bolden would later emphasize this point, arguing that if NASA ever relinquished its role as a tool of soft power for the nation, "you might as well pack NASA up and send them away because they don't really have a purpose if not to provide the entry point for people of other nations – particularly as President Obama put it, nontraditional partners – to get into the family of spacefaring nations… [without them] this future that we all dream about withers and dies."[84] The ISS served as this critical entry point for such nations interested in developing spacefaring capabilities.

On the commercial side, supporters argued that the ISS was just realizing its potential in the mid-2010s, so that failing to extend its life would be foolish. The ISS had a long list of commercial and scientific partners interesting in providing and using new, modular technologies for research. Commercial companies like NanoRacks and SpaceTango installed standardized payload lockers onboard the ISS to lease out to customers for microgravity research.[85] Made In Space (MIS) had 3-D printed a wrench for the use of the ISS crew in 2014, on its way to developing the first commercial manufacturing platform to operate onboard the ISS.[86] And there was promise of future activity from habitat companies such as Bigelow Aerospace, which hoped to use the ISS as a platform off of which to build commercial, eventually free-flying stations.

Finally, and perhaps most important, the ISS provided the destination for a new class of commercially focused launch companies—most notably SpaceX—who would supply cargo (in 2012)

and eventually crew (in 2020) to it through innovative NASA contracts under the Commercial Orbital Transportation Services, or COTS program. As the Space Shuttle program wound down in the early 2000s, President Bush directed NASA to "acquire cargo transportation as soon as practical and affordable to support missions to and from the International Space Station."[87] While the bulk of the efforts to meet that directive went toward Constellation elements, the COTS program was launched in 2005 as an experimental, commercial backup. In the end, COTS was credited by many with revolutionizing the space sector, as launch costs were pushed down by private-sector competition and innovation. In the end, the cost of resupplying the ISS through SpaceX came in at less than half what NASA estimated would have been its own costs. These lower costs of launch and delivery setting the stage for a renaissance in human space activity, and the ISS had been its (accidental) linchpin.

Charlie Bolden and the future of the ISS and NASA

Charlie Bolden brought a lifetime of experience to his role as Administrator and to the pressing decision on the ISS's extension.

For a young Charlie Bolden, growing up in the segregated South, becoming an astronaut didn't seem plausible. In his own words, "…not in my wildest imagination could somebody like me become an astronaut, because they were all white, Anglo-Saxon, Protestant, all test pilots, all about five-feet-ten. They all looked alike. And I was none of those."[88] As a high school student, Bolden instead aimed to secure admission to the Naval Academy, but in this pursuit, he would also face obstacles. Initially denied a nomination to the academy from his home state of South Carolina's state representatives, a Bolden took the initiative to write an appeal to Vice President Lyndon B. Johnson. Johnson personally secured a nomination for Bolden from a Chicago congressman. In 1968, Charlie Bolden graduated from the Naval Academy, only one of four African-American students in a class of 1,400. [89]

Upon graduating with a degree in electrical science, Bolden entered the Marine Corps, spending 34 years as a Marine Aviator and flying in more than 100 combat missions while deployed in Southeast Asia. He later credited that experience with helping him develop a "firm foundation in … the core values of the Navy and Marine Corps [of] honor, courage, commitment, and integrity", values he would later bring to his position as NASA Administrator.[90]

Bolden entered the astronaut program in 1980, shortly after the shuttle was fully operational, upon encouragement from astronaut Ronald McNair. According to Bolden, "I never dreamed of being [an astronaut] until I met [Ron McNair] while I was a test pilot and he challenged me to apply for the shuttle program."[91] After being accepted, Bolden flew on four Space Shuttle missions, serving for 14 years – a period that included the devastating *Challenger* disaster. Following *Challenger*, he would serve a critical role in overseeing efforts to safely return the shuttle to flight.[92]

In 2009, Charlie Bolden was nominated to the NASA Administrator position by President Barack Obama. Formerly considered for the Deputy Administrator position by President George W. Bush, the nomination was lauded by most. As Florida Senator Bill Nelson summed up, Bolden's suitability for the position was no question, especially considering his numerous qualifications, "He's a rocket scientist. He's an astronaut. He is a test pilot for aeronautics. He is a leader, and he inspires people to follow him."[93] However, Bolden was taking over the agency at a point when NASA was slated to transition away from the shuttle. For some, such as Bob Park, a physicist at the University of Maryland and NASA critic, the fact that Bolden was a former astronaut was his "only one serious flaw."[94]

Ultimately, his experience as an astronaut would prove useful as he oversaw the final shuttle flights and the development of the Commercial Cargo and Crew programs. Especially with regards to

Commercial Crew, he pushed NASA to "[educate] the private sector on the critical demands of keeping crew members alive and well-functioning during spaceflight."[95]

Taking over the agency in a period of such transition, however, was a challenge. Bolden found it particularly difficult navigating the highly politically charged environment of Washington D.C., later reflecting that, if he were able to go back, he would "learn a little bit about politics and how Washington D.C. functions. I got rolled by the establishment because I had no clue how any of that stuff worked."[96]

Regardless, Bolden's tenure marked a major progression for the agency in terms of building capabilities in commercial spaceflight. Ensuring the transition from the Space Shuttle to Commercial Cargo and Crew proved critical in launching the final elements of the International Space Station and servicing the station once it was fully operational. As administrator, he advocated for the commercial space industry, and believed it would be "an engine of 21st century American economic growth [which] will help us carry out even more ambitious deep space exploration missions…America's best days in space exploration are ahead of us thanks to the grit and determination of those in government, and the private sector, who dare to dream big dreams and have the skills to turn them into reality."[97]

The ISS extension decision

On the one hand, Bolden knew that the continued operation of the ISS was a drain on NASA's resources, and with every extension it continued to eat into the exploration budget and threaten the development of new programs. Specifically, NASA had devoted $2.9 billion, or 17.2 percent of its $16.9 billion FY 2013 budget, to the ISS.[98] According to Bolden, "what became obvious to all of us – and the international partners especially – was that we [would] have to find a way to find money to run [the ISS] from outside of our agency... we [couldn't] join together to do deep space exploration if the US alone [was] putting 2 billion dollars into it."[99] He added that, while the international partners agreed upon phasing out of owning and operating the space station, "they weren't as warm as we were to recognizing…the limited lifetime of Station."[100]

At the same time, Bolden knew that terminating the ISS would be controversial. Historian Roger Handberg noted, after the crisis-inspired redesign in 1993, that "The space station program domestically became the poster child for spreading the wealth or contracts around. At one point, NASA had space station related contracts in all states plus most congressional districts."[101] Moreover, the ISS had not had any failures as explicit as the shuttle disasters. As Handberg wrote, "Deciding when a program has 'failed' is often difficult for the principal because failure often comes wrapped in a web of contradictory policies and events subject to multiple interpretations. The International Space Station (ISS) represents one classic example of the difficulty in saying exactly when 'failure has occurred'…"[102]

The argument for extending the ISS's lifetime went far beyond politics, however. After all, the ISS had been one of the few constants in the space program over the last several decades, and the establishment of a space station had been the single most important objective of NASA since Apollo. From an engineering standpoint, the ISS was slated to be operational through 2028, perhaps even 2030.[103] Extending its lifetime would give the ISS more time to generate a return on NASA's large initial investment, for example by allowing the crew to pursue additional scientific research and commercial applications. This argument had supported a similar extension of its lifetime from 2011 (when construction was finished) to 2020 several years earlier.[104]

In the end, Bolden argued for extending the termination date to the natural lifetime of the ISS. The White House limited its support through only 2024, but for now, at least, the ISS survived.

Looking to Act III

As NASA looked ahead, its commitment to not abandoning low-Earth orbit meant that the ISS termination deadline increased pressure to find a replacement for the station or alternative ways to finance it. The original impetus for NASA's interest in building a space station - the need for an orbiting station to serve as a staging platform and testbed for deep space missions – had not diminished. In many ways, the demand for a station in LEO had only increased. Following the disruptive innovation of launch vehicle companies such as SpaceX and Blue Origin, a number of small launch vehicle companies were starting to crop up in the 2010s.

For Bolden, the priority was to establish a sustainable low-Earth infrastructure, enabled by commercial destinations in LEO. Bolden went as far as to say that "if [NASA could not] facilitate the success of the commercial space sector to have a viable replacement for station flying with astronauts by 2024…the program deserves to end, and NASA should get out of spaceflight." [105] In his view, a sustainable LEO infrastructure would consist of a variety of destinations in diverse orbits, with NASA serving as one of many customers for orbital services.

At the heart of the decision over the ISS was a deeper question: what was NASA's objective, and what would be its role in pursuing it? During the Apollo program, NASA Administrator James Webb had a clear strategy for maintaining the agency's political support: "by committing itself to extremely precise, measurable, all-or-nothing goals, NASA had powerful incentives not to fail." Webb believed that "enabling legislation, formal delegations of authority, and descriptions of powers and functions are important because they determine that the agency shall be this rather than that." With a clear directive from the President, Webb galvanized support from Congress and secured a "blank check" to manage the lunar landing.[106]

The subsequent fifty years had brought a substantial shift to strategy, with evolving objectives and a focus on multipurpose assets—the STS and ISS, in particular—whose goals were far from precise. As summarized by General Sega, the Vice Chair of the National Resource Council's committee on NASA's strategic direction in 2017,

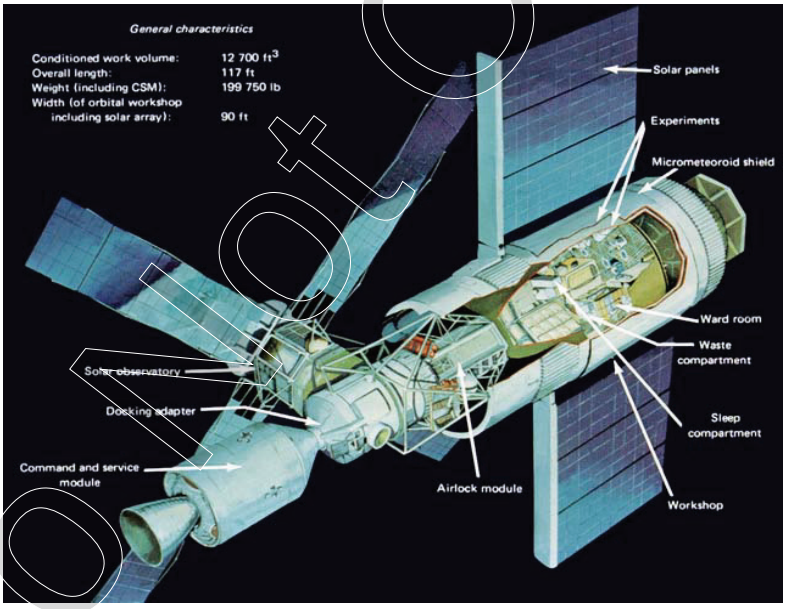
> "There is a lack of consensus on the agency's future direction among the United States political leadership. Without such a consensus, the agency cannot be expected to develop or work effectively toward long-term priorities. In addition, there is a mismatch between the portfolio of programs assigned to the agency and the budget allocated by Congress … although NASA develops a strategic plan on a regular basis, the agency itself does not establish its strategic goals. Those are developed by the national leadership, and key stakeholders within the national leadership do not always agree on the goals the agency should pursue."[107]

Looking back on the era of the ISS and STS, space historian Howard McCurdy wrote, in *The Space Station Decision: Incremental Politics and Technological Choice*, "given the absence of a presidentially imposed purpose…NASA officials and their allies shifted their strategy. Rather than seek a comprehensive, Apollo-type commitment, they decided to pursue the steps in their plan one by one. Agency leaders would not abandon their vision, but would reach for it incrementally rather than comprehensively."[108] As NASA looked to its second fifty years, it would have to distill lessons from both the successes and failures of this second act and establish, as Charlie Bolden would later emphasize, "consistency of purpose."

Exhibit 1 Wernher von Braun's Space Station Concept

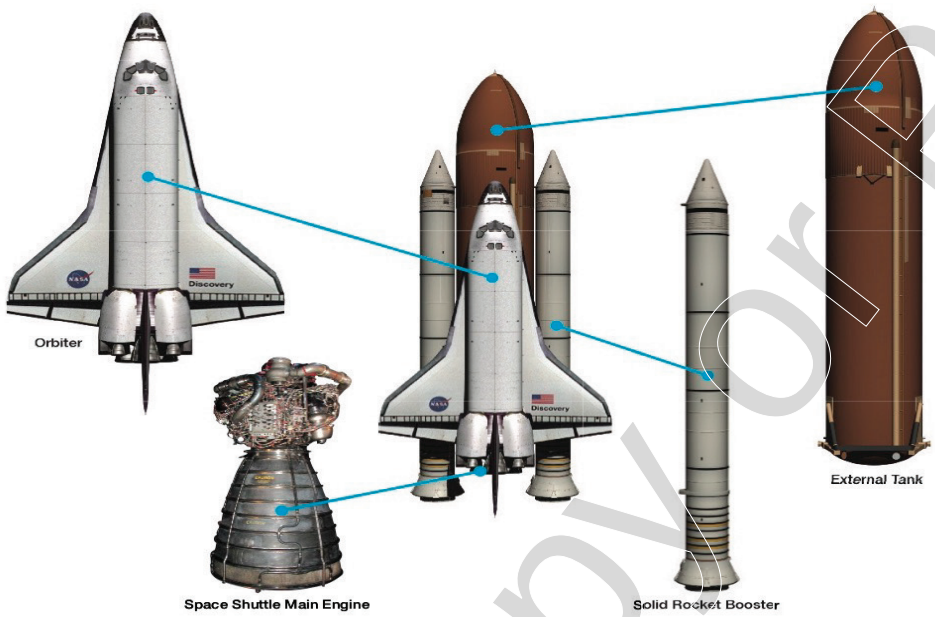
Source: Harbaugh, Jennifer. "Space Stations." NASA, February 19, 2016. https://www.nasa.gov/centers/marshall/history/stations.html.

Exhibit 2 Skylab Diagram



Source: "Skylab Diagrams." Accessed 10-2-20. https://history.nasa.gov/SP-4225/diagrams/skylab/skylab-diagram-1.htm.

Exhibit 3 Space Shuttle Launch Configuration



Source: Galvez, Roberto. "The Space Shuttle and Its Operations." NASA Johnson Space Center. Accessed October 2, 2020. https://www.nasa.gov/centers/johnson/pdf/584722main_Wings-ch3a-pgs53-73.pdf

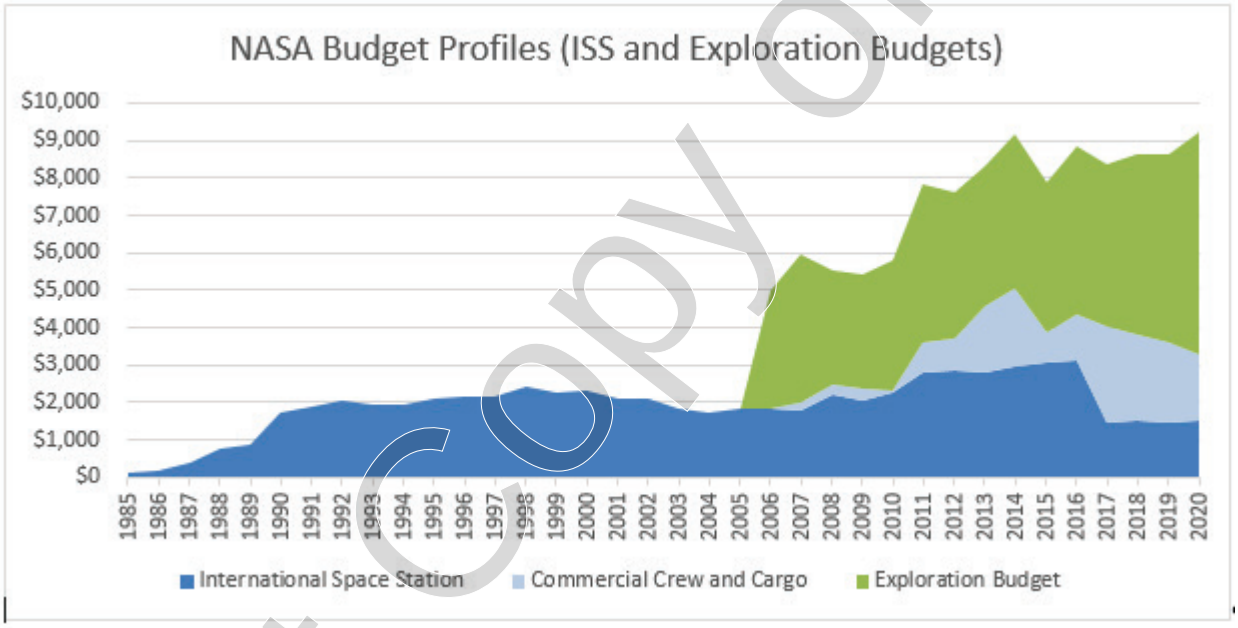
Exhibit 4 Congressional Directives in Managing the Development of the Space Station Program

- Redirected NASA to emphasize "man tended" rather than "permanently manned" capability.
- Restructured major parts of the space station launch and on-orbit assembly sequence.
- Specified75 kW of electric power before any international modules were attached.
- Directed NASA to assign the major life sciences research responsibility to the European Space Agency module.
- Forbid animal holding facilities in the microgravity laboratory.
- Required three shuttle flights per year for utilization of the microgravity laboratory.
- Required that Congress approve all NASA rescoping reports.
- Withheld $225 of a $425 million appropriation until NASA filed a plan with the Congress rescoping the program
- Prohibited the expenditure of systems definition and integration funds until NASA officials completed a study of space station automation.
- Withheld $90 million until NASA officials produced a plan to lease a free-flying competitor to the space station.

- Required NASA officials to spend unwanted funds for development of a Flight Telerobotic Servicer.
- Specified funding cuts resulting in the termination of space station engineering and integration activities.

Source: Madison, John, J., and Howard E. McCurdy. "Spending without Results: Lessons from the Space Station Program." Space Policy 15, no. 4 (1999): 213-21. https://doi.org/10.1016/S0265-9646(99)00036-3

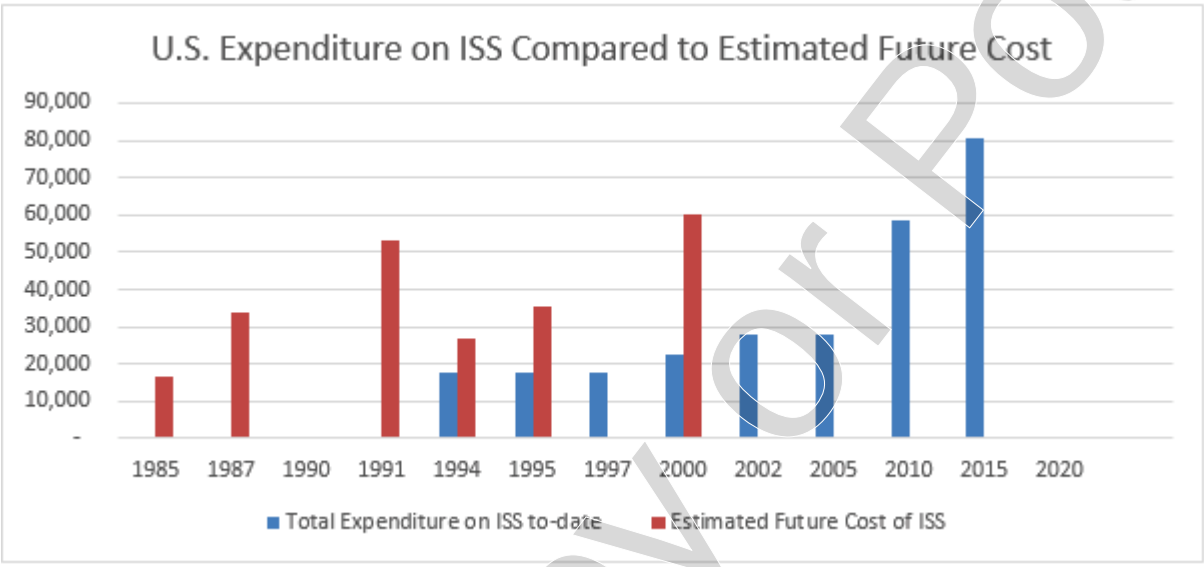
Exhibit 5 NASA Budget Profiles



Source: Compiled by casewriter

Notes: The Exploration budget from 2005-2011 consisted of the *Constellation* Program. After the cancellation of *Constellation*, the Exploration budget was described as funding the development of Human Exploration Capabilities, Commercial Spaceflight, as well as Research and Development. After the announcement of the Artemis program in 2019, the Exploration budget was expanded to include funding for Artemis elements such as the Lunar Gateway and Human Landing System contracts.

Exhibit 6 NASA Estimates for the Cost to Build the ISS compared to the Actual Cost



Source: Compiled by casewriter.

Exhibit 7 NASA Human Spaceflight Projected Available Budget

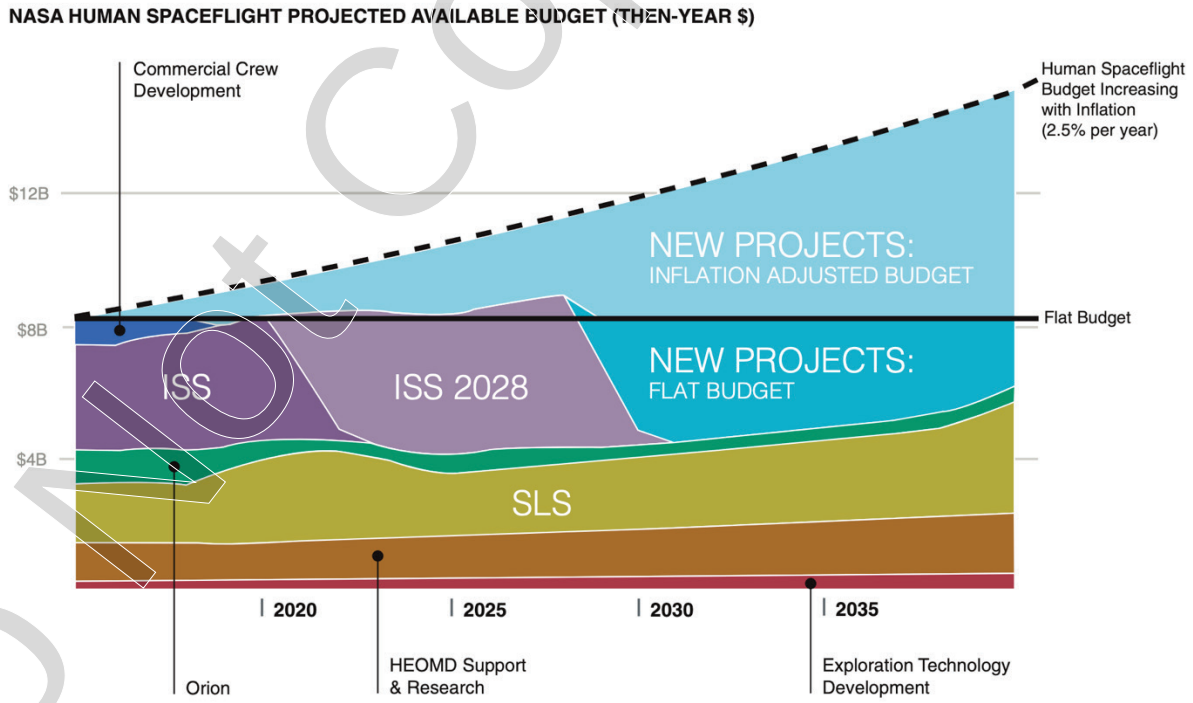


FIGURE 4.29 Projected available budget and costs of the currently planned human spaceflight program.

Source: "Download: Pathways to Exploration: Rationales and Approaches for a U.S. Program of Human Space Exploration | The National Academies Press." Accessed April 21, 2021. https://www.nap.edu/download/18801#.

Endnotes

[1] The career of NASA Administrator Charlie Bolden was an inspiration to many. Raised in South Carolina, he overcame segregationist resistance to attend the U.S. Naval Academy, from which he graduated in 1968 as president of his class. After extensive flight time in the Marine Corps, Bolden was selected as an astronaut in 1980 and served as part of the Astronaut corps until 1994, after which he returned to pursue a distinguished career with the Marines. While an astronaut, Bolden piloted the Shuttle mission which launched the Hubble space telescope and commanded the first joint American-Russian mission. President Barack Obama nominated Bolden to serve as NASA Administrator in 2009, making him the first African-American to serve in that role on a permanent basis. (Sources: https://www.nasa.gov/about/highlights/bolden_bio.html and https://en.wikipedia.org/wiki/Charles_Bolden)

[2] John Holdren began his illustrious academic career with degrees in aerospace engineering and theoretical plasma physics from MIT and Stanford, after which he served as a professor at Harvard and UC Berkeley for decades before joining the Clinton and then Obama Administrations. An awardee of a MacArthur Fellowship for his work on energy and peace, he had written extensively on the threat of nuclear weapons and climate change, among other topics. (Sources: https://obamawhitehouse.archives.gov/administration/eop/ostp/about/leadershipstaff/director and https://en.wikipedia.org/wiki/John_Holdren)

[3] whitehouse.gov. "Obama Administration Extends International Space Station until at Least 2024" January 8, 2014. https://obamawhitehouse.archives.gov/blog/2014/01/08/obama-administration-extends-international-space-station-until-least-2024.

[4] Hansen, James R. "Skipping 'The Next Logical Step.'" NASA History, November 1994. https://history.nasa.gov/SP-4308/ch9.htm.

[5] Security, International, Commerce Program, R A Williamson, and R DalBello. "Access to Space: The Future of U.S. Space Transportation Systems." n.d. https://www.princeton.edu/~ota/disk2/1990/9002/9002.PDF.

[6] "NASA's Management and Utilization of the International Space Station." NASA Office of Inspector General, July 30, 2018. https://oig.nasa.gov/docs/IG-18-021.pdf.

[7] "Extending the Operational Life of the International Space Station Until 2024." NASA Office of Inspector General, September 18, 2014. https://198.116.65.49/docs/IG-14-031.pdf.

[8] Davis, Jason. "'Apollo on Steroids': The Rise and Fall of NASA's Constellation Moon Program." The Planetary Society, August 1, 2016. https://www.planetary.org/blogs/jason-davis/2016/20160801-horizon-goal-part-2.html.

[9] Foust, Jeff. "The Space Review: An Agency in Transition." The Space Review, February 8, 2010. https://www.thespacereview.com/article/1560/1.

[10] SpaceNews. "NASA's Shuttle Program Cost $209 Billion - Was It Worth It?," November 30, 1AD. https://spacenews.com/nasas-shuttle-program-cost-209-billion-was-it-worth-it/.

[11] NASA. "100 Years of Possibility: Celebrating the Centennial Birthday of Dr. Wernher von Braun." Brian Dunbar, March 20, 2012. https://www.nasa.gov/topics/history/features/vonbraun.html.

[12] Logsdon, John, ed. Exploring the Unknown: Selected Documents in the History of the U.S. Civial Space Program, Volume I: Organizing for Exploration. The NASA History Series. NASA, 1995, p. 179.

[13] McCurdy, H.E. *The Space Station Decision: Incremental Politics and Technological Choice*. The Space Station Decision. Johns Hopkins University Press, 2007, p. 23.

[14] Wall, Mike. "NASA's Shuttle Program Cost $209 Billion — Was It Worth It?" Space.com, July 5, 2011. https://www.space.com/12166-space-shuttle-program-cost-promises-209-billion.html.

[15] McCurdy, H.E. *The Space Station Decision: Incremental Politics and Technological Choice*. The Space Station Decision. Johns Hopkins University Press, 2007, p. 25.

[16] Ibid, p. 4.

[17] Compton, W. David, and Charles D. Benson. *Living and Working in Space. A History of Skylab*. The NASA History Series, 1983. https://history.nasa.gov/SP-4208/ch5.htm.

[18] Belew, Leland F., and Ernst Stuhlinger. *Skylab: A Guidebook*. NASA History Series, n.d.

[19] Mack, Pamela E., ed. *From Engineering Science to Big Science*. The NASA History Series. NASA History Office, 1998.

[20] NASA History. "The Human Touch: The History of the Skylab Program." Accessed May 15, 2020. https://history.nasa.gov/SP-4219/Chapter9.html.

[21] Ibid.

[22] Levine, Arnold. *Managing NASA in the Apollo Era*. The NASA History Series, 1982. https://history.nasa.gov/SP-4102.pdf.

[23] Panel on Science and Technology Ninth Meeting, § Committee on Science and Astronautics (1968). https://books.google.com/books?id=Jd5dlCCOprgC.

[24] Compton, W. David, and Charles D. Benson. *Living and Working in Space. A History of Skylab*. The NASA History Series, 1983. https://history.nasa.gov/SP-4208/ch5.htm.

[25] Ibid.

[26] KSC, Anna Heiney: "NASA - Skylab Operations Summary." Other. Brian Dunbar. Accessed October 2, 2020. https://www.nasa.gov/mission_pages/skylab/missions/skylab_summary.html.

[27] "The Day Skylab Crashed to Earth: Facts About the First U.S. Space Station's Re-Entry - HISTORY." Accessed October 2, 2020. https://www.history.com/news/the-day-skylab-crashed-to-earth-facts-about-the-first-u-s-space-stations-re-entry.

[28] McCurdy, H.E. *The Space Station Decision: Incremental Politics and Technological Choice*. The Space Station Decision. Johns Hopkins University Press, 2007, p. 27.

[29] Ibid.

[30] Galvez, Roberto. "The Space Shuttle and Its Operations." NASA Johnson Space Center. Accessed October 2, 2020. https://www.nasa.gov/centers/johnson/pdf/584722main_Wings-ch3a-pgs53-73.pdf.

[31] McCurdy, H.E. *The Space Station Decision: Incremental Politics and Technological Choice*. The Space Station Decision. Johns Hopkins University Press, 2007, p. 27.

[32] Handberg, Roger. Reinventing NASA: Human Space Flight, Bureaucracy, and Politics. Greenwood Publishing Group, 2003.

[33] Aerospace Security. "History of the NASA Budget". May, 2, 2020. https://aerospace.csis.org/data/history-nasa-budget/

[34] Handberg, Roger. Reinventing NASA: Human Space Flight, Bureaucracy, and Politics. Greenwood Publishing Group, 2003.

[35] "Issues Concerning the Future Operation of the Space Transportation System." US Government Accountability Office, December 28, 1982. https://www.gao.gov/assets/80/79498.pdf.

[36] Pielke, Roger, and Radford Byerly. "Shuttle Programme Lifetime Cost." *Nature* 472, no. 7341 (April 2011): 38–38. https://doi.org/10.1038/472038d.

[37] Granath, Bob. "Skylab Paved Way for International Space Station." Text. NASA, March 2, 2015. http://www.nasa.gov/content/40-years-ago-skylab-paved-way-for-international-space-station.

[38] Wall, Mike. "President Obama's Space Legacy: Mars, Private Spaceflight and More." Space.com, January 20, 2017. https://www.space.com/35394-president-obama-spaceflight-exploration-legacy.html.

[39] McCurdy, H.E. *The Space Station Decision: Incremental Politics and Technological Choice*. The Space Station Decision. Johns Hopkins University Press, 2007, p. 24.

[40] Handberg, Roger. Reinventing NASA: Human Space Flight, Bureaucracy, and Politics. Greenwood Publishing Group, 2003.

[41] Beggs, James M. "Why the United States Needs a Space Station" June 23, 1982. In *NASA Activities*, NASA, 1982.

[42] Ibid.

[43] Handberg, Roger. Reinventing NASA: Human Space Flight, Bureaucracy, and Politics. Greenwood Publishing Group, 2003.

[44] NASA History. "Excerpts of President Reagan's State of the Union Address, 25 January 1984." Accessed October 2, 2020. https://history.nasa.gov/reagan84.htm.

[45] U.S. Congress, House, Committee on Appropriations, Subcommittee on HUD-Independent Agencies. Department of Housing and Urban Development — Independent Agencies Appropriations for 1985, Part 6, National Aeronautics and Space Administration, March 27, 1984 (Washington, DC: U.S. Government Printing Office, 1985), p. 8

[46] Beattie, Donald. ISScapades: The Crippling of America's Space Program. Apogge Books, 2006, p. 26.

[47] Madison, John J., and Howard E. McCurdy. "Spending without Results: Lessons from the Space Station Program." *Space Policy* 15, no. 4 (November 1999): 213–21. https://doi.org/10.1016/S0265-9646(99)00036-3.

[48] Beattie, Donald. ISScapades: The Crippling of America's Space Program. Apogge Books, 2006, p. 31.

[49] Sagan, Carl. Carl Sagan's Cosmic Connection: An Extraterrestrial Perspective. Cambridge: Cambridge Univ. Press, 2000.

[50] Beattie, Donald. ISScapades: The Crippling of America's Space Program. Apogge Books, 2006, pg. 37.

[51] Beattie, Donald. ISScapades: The Crippling of America's Space Program. Apogge Books, 2006, p. 61-2.

[52] Handberg, Roger. Reinventing NASA: Human Space Flight, Bureaucracy, and Politics. Greenwood Publishing Group, 2003, p. 110.

[53] "A History of U.S. Space Stations." *NASA Facts*, June 1997. https://er.jsc.nasa.gov/seh/history.pdf.

[54] William J. Clinton. Public Papers of the President. June 17, 1993. Available from the 10 Government Printing Office at: [http://www.gpoaccess.gov/pubpapers/index.html].

[55] Stockman, Bill, Joe Boyle, and John Bacon. "International Space Station Systems Engineering. Case Study:" Fort Belvoir, VA: Defense Technical Information Center, January 1, 2010. https://doi.org/10.21236/ADA538763.

[56] "Extending the Operational Life of the International Space Station Until 2024." National Aeronautics and Space Administration - Office of the Inspector General, September 18, 2014. https://oig.nasa.gov/docs/IG-14-031.pdf.

[57] Pielke, Roger A. "NASA Needs a New Vision," October 7, 2007, 2.

[58] Shayler, D.J. *Assembling and Supplying the ISS: The Space Shuttle Fulfills Its Mission*. Springer Praxis Books. Springer International Publishing, 2017. https://books.google.com/books?id=TtYtDwAAQBAJ. The *Columbia* disaster effectively brought an end to the Shuttle program. The Shuttle had achieved a great deal over thirty years: in addition to being used to build and maintain the ISS, the shuttle supported extravehicular activities (EVA), proving to be an important training ground for astronauts, launched the Hubble space telescope, and housed a highly utilized microgravity testing facility to deploy, test, and retrieve scientific experiments (see Galvez, Roberto. "The Space Shuttle and Its Operations." NASA Johnson Space Center. Accessed October 2, 2020. https://www.nasa.gov/centers/johnson/pdf/584722main_Wings-ch3a-pgs53-73.pdf.). At the same time, it was beset by criticism for costing much more to build and operate than forecast and flying much less reliably or frequently than promised (see Security, International, Commerce Program, R A Williamson, and R DalBello. "Access to Space: The Future of U.S. Space Transportation Systems." n.d. https://www.princeton.edu/~ota/disk2/1990/9002/9002.PDF).

[59] Madison, John J., and Howard E. McCurdy. "Spending without Results: Lessons from the Space Station Program." *Space Policy* 15, no. 4 (November 1999): 213–21. https://doi.org/10.1016/S0265-9646(99)00036-3.

[60] Ibid.

[61] Stockman, Bill, Joe Boyle, and John Bacon. "International Space Station Systems Engineering. Case Study:" Fort Belvoir, VA: Defense Technical Information Center, January 1, 2010. https://doi.org/10.21236/ADA538763.

[62] Handberg, Roger. Reinventing NASA: Human Space Flight, Bureaucracy, and Politics. Greenwood Publishing Group, 2003, p. 13.

[63] Sagan, Carl. Carl Sagan's Cosmic Connection: An Extraterrestrial Perspective. Cambridge: Cambridge Univ. Press, 2000.

[64] Bush, L. "International Space Station Commercialization Policy." *Technology in Society* 24, no. 1 (2002): 69–75. https://doi.org/10.1016/S0160-791X(01)00044-6.

[65] Sherwood, Brent. "Space Architecture for MoonVillage." *Acta Astronautica* 139 (October 2017): 396–406. https://doi.org/10.1016/j.actaastro.2017.07.019.

[66] Aeronautics, United States Congress House Committee on Science Subcommittee on Space and. Fiscal Year 2001 NASA Authorization: NASA Posture, Parts I-VI : Hearing Before the Subcommittee on Space and Aeronautics of the Committee on Science, House of Representatives, One Hundred Sixth Congress, Second Session, February 16, March 16, March 22, April 11,

May 10, and September 13, 2000. U.S. Government Printing Office, 2001.

[67] Blesma, John. "Commercializing the International Space Station." *Space Policy* 13, no. 3 (August 1, 1997): 245–55. https://doi.org/10.1016/S0265-9646(97)00022-2.

[68] "NASA's Management of the Center for the Advancement of Science in Space." Audit. NASA Office of the Inspector General, January 11, 2018. https://oig.nasa.gov/docs/IG-18-010.pdf.

[69] Handberg, Roger. Reinventing NASA: Human Space Flight, Bureaucracy, and Politics. Greenwood Publishing Group, 2003, p. 121.

[70] Witze, Alexandra. "Space-Station Science Ramps Up." *Nature News* 510, no. 7504 (June 12, 2014): 196. https://doi.org/10.1038/510196a.

[71] Ibid, pg. 181

[72] Witze, Alexandra. "Space-Station Science Ramps Up." *Nature News* 510, no. 7504 (June 12, 2014): 196. https://doi.org/10.1038/510196a.

[73] Hutchison, Kay Bailey. National Aeronautics and Space Administration Authorization Act of 2005 (2005). https://www.congress.gov/bill/109th-congress/senate-bill/1281.

[74] Rockefeller, John, D. National Aeronautics and Space Administration Authorization Act of 2010 (2010). https://www.nasa.gov/pdf/649377main_PL_111-267.pdf.

[75] "NASA's Management of the Center for the Advancement of Science in Space." Audit. NASA Office of the Inspector General, January 11, 2018. https://oig.nasa.gov/docs/IG-18-010.pdf.

[76] Scimeni, Sam. "Letter From NASA to CASIS 31 March 2016," March 31, 2016. http://spaceref.com/news/viewsr.html?pid=49012.

[77] Ibid.

[78] The ISS After 2024: Options and Impacts, § Science, Space, and Technology (n.d.). https://www.govinfo.gov/content/pkg/CHRG-115hhrg25097/pdf/CHRG-115hhrg25097.pdf.

[79] SpaceNews. "China Outlines Intense Space Station Launch Schedule, New Astronaut Selection," May 28, 2020. https://spacenews.com/china-outlines-intense-space-station-launch-schedule-new-astronaut-selection/.

[80] "Engineering Achievements: ISS." Accessed October 2, 2020. https://www.nesgt.com/blog/2017/03/top-engineering-achievements-international-space-station.

[81] Handberg, Roger. Reinventing NASA: Human Space Flight, Bureaucracy, and Politics. Greenwood Publishing Group, 2003., p. 3.

[82] "NASA's Management and Utilization of the International Space Station." NASA Office of Inspector General, July 30, 2018. https://oig.nasa.gov/docs/IG-18-021.pdf.

[83] Ruttley, Tara M., Julie A. Robinson, and William H. Gerstenmaier. "The International Space Station: Collaboration, Utilization, and Commercialization*." *Social Science Quarterly* 98, no. 4 (2017): 1160–74. https://doi.org/10.1111/ssqu.12469.

[84] Charlie Bolden, interview with authors, January 13, 2021.

[85] eoPortal Directory "ISS Utilization: NanoRacks Logistics Services for Small Satellites and ISS Deployment Systems" https://directory.eoportal.org/web/eoportal/satellite-missions/i/iss-nanoracks-services

[86] Made In Space. "Additive Manufacturing Facility (AMF)" https://madeinspace.us/capabilities-and-technology/additive-manufacturing-facility/

[87] SpaceRef. "NASA Executive Council Approved Level 0 Exploration Requirements and Level 1 Objectives," June 12, 2004. http://www.spaceref.com/news/viewsr.html?pid=13100.

[88] Bolden, Charlie. Charles F. Bolden Oral History, January 6, 2004. https://historycollection.jsc.nasa.gov/JSCHistoryPortal/history/oral_histories/BoldenCF/BoldenCF_1-6-04.htm.

[89] Hook, Brittany. "Q&A with Charles Bolden, Former NASA Administrator and Astronaut." UC San Diego News Center, October 12, 2017. https://ucsdnews.ucsd.edu/pressrelease/qa-with-charles-bolden-former-nasa-administrator-and-astronaut.

[90] Charlie Bolden, interview with authors, March 9, 2021.

[91] Siceloff, Steve. "NASA - In Their Own Words: Charles Bolden." Podcast. Brian Dunbar, October 20, 2011. https://www.nasa.gov/multimedia/podcasting/itow_charlesbolden.html.

[92] Garcia, Mark. "Charles F. Bolden, Jr. NASA Astronaut." Text. NASA, January 17, 2017. http://www.nasa.gov/node/396058.

[93] https://www.waff.com. "President Obama Nominates New NASA Administrator," May 24, 2009. https://www.waff.com/story/10416206/president-obama-nominates-new-nasa-administrator.

[94] Potter, Ned. "Obama Picks Charles Bolden As NASA Chief." ABC News, May 26, 2009. https://abcnews.go.com/Technology/Space/story?id=7679385&page=1.

[95] Bolden, Charlie. "Reflections on Commercial Crew and Cargo Missions | National Academies," November 16, 2020. https://www.nationalacademies.org/news/2020/11/reflections-on-commercial-crew-and-cargo-missions.

[96] Charlie Bolden, interview with authors, March 9, 2021.

[97] "NASA Hails Success of Commercial Space Program Private Space Station Resupply Underway, Plans Readied for Astronauts," NASA press release, November 13, 2013.

[98] OIG Report.

[99] Charlie Bolden, interview with authors, March 9, 2021.

[100] Ibid.

[101] Handberg, Roger. Reinventing NASA: Human Space Flight, Bureaucracy, and Politics. Greenwood Publishing Group, 2003.

[102] Ibid.

[103] "After 20 Years of Service, the Space Station Flies into an Uncertain Future | Ars Technica." Accessed April 2, 2021. https://arstechnica.com/science/2020/11/after-20-years-of-service-the-space-station-flies-into-an-uncertain-future/.

[104] Morgan, Daniel. "The Future of NASA: Space Policy Issues Facing Congress," n.d., 44.

[105] Charlie Bolden, interview with authors, January 13, 2021.

[106] Levine, Arnold. *Managing NASA in the Apollo Era*. The NASA History Series, 1982. https://history.nasa.gov/SP-4102.pdf.

[107] The Future of NASA: Perspectives on Strategic Vision for America's Space Program, Committee on Science, Space, and Technology (2012). https://www.govinfo.gov/content/pkg/CHRG-112hhrg77034/html/CHRG-112hhrg77034.htm.

[108] McCurdy, H.E. *The Space Station Decision: Incremental Politics and Technological Choice*. The Space Station Decision. Johns Hopkins University Press, 2007.