US Permanent Space Presence

An Analysis of the Technical and Political Decisions that led to the ISS

1) Introduction

In the early 1980s, NASA began work on creating a permanent US space station. Originally called Space Station Freedom, the project was intended to be a mainly US endeavor with support from the Japanese Aerospace Exploration Agency (JAXA), European Space Agency (ESA), and Canadian Space Agency (CSA). However, as time went on, the project evolved into what is today the ISS with the addition of the Russian Roscosmos (ROSCOS) and other international partners. This paper will explore the history of this evolution through an analysis of the organizational decisions of the US government and NASA that resulted from the political and technological developments of the latter half of the 20th century.

2) The End of One Era and the Start of Another

As the Apollo Program began to wind down in the 1970s, the focus began to shift towards the future of NASA and the US civilian space presence. While the creation of NASA was driven almost solely by the space race and the corresponding political motivations to beat the USSR, the scope of NASA itself was relatively broad regarding its space activities and purpose. As such, the scientists and engineers who had sent men to the Moon began to come up with ideas for the future. While countless individual proposals were floated around, three main themes began to emerge amongst them: manned missions to Mars, cheaper launch vehicles (improving space logistics) to enable more science and missions for less money, and a permanent US space presence (in the form of an orbiting space laboratory). These ideas, flushed out into more solidified proposals, were then presented to the President in the early 1970s. President Nixon, not as supportive of space programs as the previous administrations due to the end of the space race but eager to distance himself from Apollo (the work of his political adversaries), was open to the idea of a new mission for NASA, one that he could put his own name on. However, his less enthusiastic support was compounded by his goal to control the budget deficits that were on the rise. Balancing these, he decided to allow NASA to pursue only one of the options presented, giving them the choice of how they wanted to proceed.

After deliberation within NASA, the agency chose to pursue the space logistics vehicle. Seeing the extremely high cost of the Apollo program and determining that these costs were likely to deter future investment in their programs, this was a logical choice for the agency. If they were able to effectively reduce the cost of putting things in space, missions would become cheaper and the government may be more inclined to support them. Indeed, the other options would require a cheaper and more efficient launch vehicle anyways, so this was a clear first step towards their other goals. Thus, the Space Shuttle was born.

While the Space Shuttle program has a long and involved history, a detailed analysis of the program is outside the scope of this paper. However, the important details are that Shuttle quickly evolved into a jobs program for NASA employees and contractors in the eyes of Congress, much as the Space Launch System is today. It was a relatively inefficient system that failed at the goal of significantly reducing costs since, even though part of it was reusable, the costs of repairs and maintenance were astronomically high. Indeed, by the end of the program, the cost of each launch to Earth orbit was comparable to an Apollo Moon mission. Despite these issues, however, the Space Shuttle was eventually completed.

3) The Motivations for a US Permanent Space Presence: The Dawn of Space Station Freedom

A. *NASA's Desire for an Orbiting Laboratory*

After the creation of Shuttle, the focus again began to shift towards the future, and NASA was still eager to pursue an orbiting space laboratory, the next of their original three proposals for the future. This would allow them to research the effects of prolonged space missions on humans and equipment in anticipation of a manned Mars mission. Since any Mars mission would take approximately 2 years (it takes about 7 months to complete each of the Earth-Mars Hohmann Transfers), this research into long-term space missions would be crucial. Additionally, since the astronauts would only be in Earth orbit, the risks would be low compared to a Mars mission – if something goes wrong on a Mars mission, there is no hope of rescue, but if something goes wrong on an orbiting space station, it takes just a few hours to evacuate to Earth. Thus, for the engineers at NASA, this was the next logical choice after the development of the space logistics vehicle on the path to Mars, which was the main driving factor for their desire to build the station.

B. *The Government's Willingness to Fund the Program*

Until this point, Congress had been unwilling to fund such a project due to both their apprehension about increasing NASA's budget and their (justified) fear that such a project would be prohibitively expensive. Now that NASA had Shuttle developed, however, it had no other major manned spaceflight projects. Thus, while they had the launch vehicle, they did not have many projects to launch with it. As a result, Congress realized that if they did not provide for a new project that could use Shuttle, the NASA employees and contractors in their districts would likely begin to lose their jobs, thereby reducing their job approval ratings in their districts. Thus, support for a new manned mission program began to slowly build within Congress.

At about the same time, the USSR launched Mir, their orbiting laboratory. While nowhere near as sophisticated as the current ISS, at the time this program was the largest artificial satellite ever created. Thus, with the memory of the humiliation that was faced by the Eisenhower Administration at the Russians beating them in the space race for so long and fear that the American public could begin to worry again that the US was losing its technical edge to Russia, the Reagan Administration also began to support the creation of a US-led space station.

Both the desire to maintain NASA jobs for reelection purposes and fear of repeating the mistakes of the Eisenhower Administration led to President Reagan announcing plans to build Space Station Freedom in 1984. After this, NASA began to plan for the actual implementation of the program. Initially, they desired a manned station that would serve as a repair station for other satellites, an assembly point for spacecraft, a laboratory for microgravity experiments and long-term human space flight, an observation post for astronomical experiments, and even a microgravity factory for private companies.

4) The End of Space Station Freedom and the Beginning of the ISS

A. The Loss of the Political Factors

As design and development proceeded, the anticipated scope of the project and costs of implementation began to quickly rise. Design time stretched out as debate ensued over the various trade-offs and design iterations. Balance between development cost and long-term viability, gravity gradient stability and size, solar panel costs and operating electricity, and other design challenges took time to iron out, and years of studies were conducted without any material gains to show to Congress and to the American people. With these delays and development costs, Congress began to cut NASA's budget as part of larger budgetary concerns, which in turn caused further delays and required redesigns to be able to construct the station with the reduced financial support, thereby leading to more budget cuts. This positive feedback loop continued throughout the 1980s and early 1990s.

Figure 1: Space Station Freedom Concept Design - This design was optimized for gravitational gradient stability, as seen by its large height compared to its other dimensions.

As the budget continued to get smaller and the timeline continued to fall behind, capacities continued to be reduced and costs continued to rise. Finally, the fate of Space Station Freedom was sealed by the change in administration. Without the need of the President to meet the commitments of his predecessor and with Congress's displeasure at continuing to fund a program that appeared to be going nowhere, the station became politically unviable. The international political pressures of demonstrating American technological superiority were also reduced by the Apollo-Soyuz Test Project in 1975 signaling the end of the space race. As such, there was not enough political motivation remaining to pursue the station project in the face of such high costs. While several proposals were submitted to President Clinton, none of them ever got his approval. Thus, the complete loss of the political factors led to the government's decision to no longer pursue Space Station Freedom.

Figure 2: Apollo-Soyuz Test Program – This project signaled the end of the space race and reduction of tensions between the US and the USSR.

B. A New Political Factor - Keeping Russia in Check

Then, in December of 1991, the Soviet Union fell. With its fall, the (small) hope that a project by the Soviets may re-inspire NASA's funding also died. However, this apparent extinguishing of the last flame of viability for the station is perhaps the only thing that saved the space station project. With the fall of the Soviet Union, the now Russian government found itself low on money and unwilling to support any further space programs. Like NASA, however, ROSCOS also had hopes to continue their space station program in the form of Mir-2. With their financing also drastically cut, that dream also seemed completely dead. However, sensing a new opportunity for political motivation, representatives from NASA and ROSCOS met in October of 1993 and created a plan that would change the world and help lead to the greatest level of trust between the two nations since the beginning of the Cold War by combining their two projects into one - the International Space Station.

Despite the thaw in tensions between the US and Russia that resulted from the fall of the USSR, tensions were still high, especially amongst politicians. While most did not have a problem with limited contributions between the agencies at this point, there was significant fear that working together on such a large project would give the Russians the opportunity to steal US secrets, especially relating to missile technology. Indeed, there was a regulatory regime put in place during the Cold War that expressly prohibited the sharing of information that related to national security: the International Traffic in Arms Regulations (ITAR). There was also fear that Russia would break several treaties after the fall of the USSR, and that working with Russia would encourage these actions. As such, there were several opponents to combining Mir-2 and Space Station Freedom into one project, such as Representative Tim Roemer. With this fervent opposition, the proposals did not pass Congress.

Despite Congressional apprehension, however, President Clinton saw an opportunity. While Congress was afraid of the Russians stealing US technology, he saw this as a way to keep the Russians in check. If they were locked into a major financial project with the United States, they would be less likely to take hostile and/or destabilizing actions. In effect, he desired to buy their demilitarization through the ISS program. Thus, while risking some stealing of US technology, the creation of the ISS would result in new diplomatic channels and the need for logistical cooperation, which would lead to cooperation and trust. This goal of increasing international relations with the Russians and keeping them from taking hostile actions and starting a new Cold War led to his supporting the project, and in 1993 he announced the ISS project. While Congress took some convincing, they too began to see the international benefits of the decision to build the ISS, and the project was approved. Russia was then added to the project under NASA Administrator Daniel Goldin's supervision.

Even though both countries were now contributing financially, the project was still too expensive, and the scope of the station was reduced one last time with the hope that additional modules could be added in the future if the financial support was available.

5. The Enabling Technologies

The ISS, while meant to be a proving and development ground for the work needed to get humans to Mars, still required many technologies to even become feasible itself. Several developments in the 1970s, 80s, and 90s, however, allowed for the station to become a practical and feasible project, at least from a technological standpoint. These developments arose from research conducted for Space Station Freedom and Mir, independent research, and lessons learned from Apollo, Soyuz, and other prior space programs.

A. Computers

The most important enabling technology for any space program, the advancement of computers was the most important enabling technology for the ISS. Not only is it almost impossible to launch a rocket without a computer control system, but the ISS uses 52 computers to control its orbit, conduct science, maintain the life support systems, rotate the solar panels, and conduct many other tasks that are either too complex or too mundane to be done by the astronauts (especially since the cost of the astronauts' time is so high). Additionally, without computers, the astronauts would spend most of their time on all of the mundane tasks required to maintain the station, so there would not be much motivation to build and man the station in the first place since the cost would be so high for little scientific benefit. Thus, the advent of the computer in the 1950s and 1960s enabled not just the ISS, but all of human space activities.

However, the computers of the 50s and 60s were still not enough for the ISS. These computers were too large and heavy, and they barely had enough computational power to do anything beyond simple calculations, never mind run a space station. It is the developments of the Apollo Era in shrinking computers and increasing their performance that began to make the prospect feasible.

B. Air Recycling

Throughout the US space program, breathable air was never a major concern. Oxygen is relatively light, and so it never was a large concern to just carry the amount oxygen that was required for a mission (plus a large safety margin). Indeed, the largest air-related concern until that point was the buildup of toxic CO_2, which needed to be filtered out. This was flushed out in the Apollo Program, and, with the exception of Apollo 13, there were never any major issues with this process. However, for the ISS, the prolonged length of the missions required a different solution since, while it would not cost a lot to bring more oxygen to the ISS from a payload weight standpoint, it would require launches much more frequently than would otherwise be necessary and thus would drastically increase launch vehicle costs. Additionally, the purpose of the ISS is to try and prepare for a Mars mission, and there is no feasible way to bring enough air for a 2 year trip to Mars.

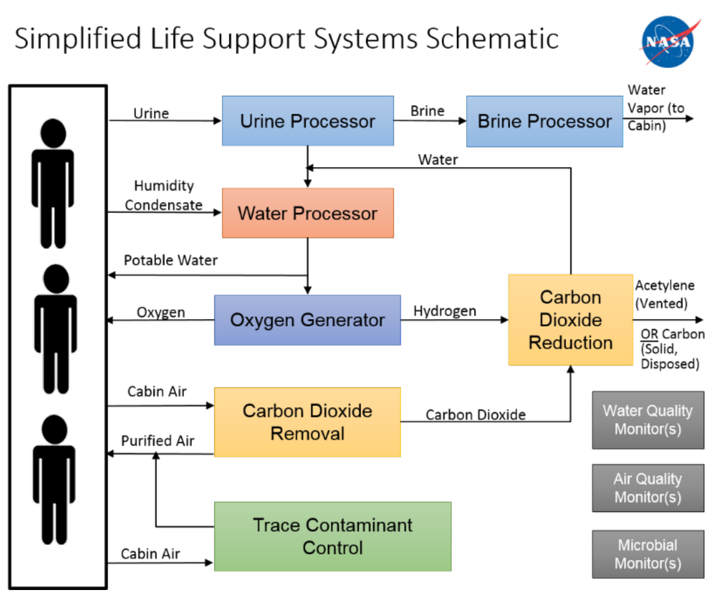

Figure 3: ISS Simplified Life Support System Schematic

Instead, the ISS uses a process discovered in the early 19th century: electrolysis. Electrolysis is the process of using electricity to forcefully separate a material with a charge imbalance into its constituent parts. On the ISS, water electrolysis is used to generate oxygen and hydrogen gas via the reaction $2H_2O$ (l) + energy → $2H_2$ (g) + O_2 (g). This simple process is a very easy way of generating oxygen, and engineers have significant experience in such systems. Most importantly, it only requires energy, unlike other processes which may require catalyzing materials. The resulting oxygen is cycled into the life support systems, and the hydrogen is expelled overboard.

Carbon dioxide, on the other hand, is still dealt with in relatively the same way as it was in Apollo. A filtration medium is used to remove the CO_2 from the air, which is also ejected into space. On the ISS, this material is a sponge-like mineral called a zeolite which captures carbon dioxide and releases it again when exposed to the vacuum of space (King, 2018).

Currently, there is also an algae experiment onboard looking at the feasibility of sustaining a crew with food and air via plants, the scenario most likely to be used on a future Mars mission due to the inability to constantly supply water to Mars. While this does not constitute a major source of oxygen at the moment, the experiment does help to reduce the strain on the water resources slightly.

C. *Water Reclamation*

On the ISS, water is used for countless tasks, including cooling, oxygen generation, and drinking. As such, it is the most valuable resource on the station. Additionally, due to its weight, it is also the most costly resource to transport to the station. Unfortunately, there are no resources on the station that can be used to generate water (other than combining hydrogen and oxygen gas, but that would consume oxygen which is problematic for the reasons above). Thus, an efficient water reclamation system is essential for the station from a functional and cost standpoint. As such, NASA and ROSCOS conducted significant work into water reclamation systems between the beginning of Apollo and the creation of the ISS.

Through significant development and through lessons learned on Mir, NASA developed a system that would recycle water from urine and extract water vapor from the air. Indeed, on the ISS, the Environmental Control Life Support System (ECLSS) "…can recycle about 93 percent of the water it receives…" (Siceloff 2008). The system functions by spinning rapidly to create artificial gravity and then distills the water. However, this system is not perfect, and replenishment water still has to be transported to the station (which is discussed later in this paper).

D. *Electricity*

Both the electrolysis process and the water reclamation system require electricity, as do the other systems onboard. However, unlike in Apollo where batteries and fuel cells were used, those systems do not have the operational longevity to sustain a space station (or a mission to Mars). As such, there were only two possibilities available to NASA: solar panels or radioisotope thermoelectric generators (nuclear reactors). However, the nuclear reactors were still a new and costly technology at the time and had yet to be tested in any large scale. That, combined with the desire to not irradiate the astronauts in the event of a malfunction, led to the decision to use solar panels. Given Earth's proximity to the Sun and the high efficiency of solar panels when not constrained by an atmosphere, it was determined that it was feasible to generate the power with solar panels. Thus, they chose this option. However, the size of the solar panels would be difficult to construct in space, therefore NASA and other partners developed the "blanket" array, which could be stored rolled up and then unfurled once in space. This updated method of a tried technology enabled the generation of enough power to sustain the station without the high cost and danger of a nuclear system, therefore enabling the construction of the station.

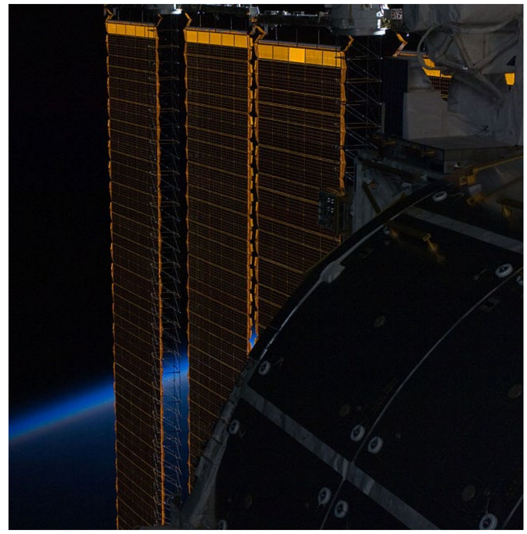
Figure 4: ISS "Blanket" Solar Panel Arrays- The large solar arrays are the main source of power on the ISS.

E. Launch Vehicles

While all of the onboard systems needed to make a large, long-term station were established by the designing of the ISS (other than challenges resulting from scaling the systems), therefore enabling the construction of the station, there is still one important component missing from the previous analysis: the ability to get the materials and people into space in a cost-effective manner (or at least a method which Congress was willing to pay for, since Shuttle was not cheap but Congress was willing to pay for it anyways). For the US, the Shuttle program still had the support of Congress, and its high versatility in being able to launch segments of the ISS with crews to assist in construction enabled the Americans to feasibly put large amounts of hardware into space. On the Russian side, the Proton and R-7 families of rockets were a very well tested and relatively inexpensive rocket systems for the time. This, combined with the extensive work by the Russians on autonomous systems during the Apollo Era for their various spacecraft and launch vehicles, enabled them to lift their hardware into space and assemble it autonomously.

6. The Logistics

While the ISS was very much a technological challenge and a technological achievement, it was, and still is, also a logistical one. Indeed, one can argue that the logistical aspects of the ISS were the most challenging part of its implementation.

A. Food and Water

As mentioned previously, despite the water reclamation, the ISS still needs supplemental water from Earth. Additionally, for obvious reasons food also has to be supplied from the Earth. As such, one of the major concerns of Congress was the high operational cost of the station. Unlike other projects, where the costs had a finite end date, the ISS did not. Therefore, fearing a commitment that they would be unable to get out of in the future, Congress built a reauthorization system into the ISS budget. However, the benefit for Congress was that it was a guarantee of job opportunities within the space districts for many years due to the continuous need for launch vehicles, which helped to get the project passed.

Not only is food important for the survival of the crew, but it is also essential to their mental health. Looking towards mental health research conducted by the Navy on submariners' health, NASA realized that the astronauts would have the same issues and find it taxing to be locked in a confined space for long periods of time. Additionally, unlike a submarine which can put in to port for a period of time, the astronauts would be stuck in the same confined space until the end of their mission, which could be as long as years. As such, NASA felt that it was important to keep the crew as happy as possible. Thus, unlike in Apollo where the food was relatively simple, the food preparation for the ISS is extremely complex and tailored to each astronaut's preferences. This effort to ensure that the mental health of the astronauts remains strong is just as important as the other life support systems on the ISS for a crewed mission.

A. *Ground Support and Interagency Cooperation with ROSCOS*

One of the other main logistical necessities for the creation of the ISS was the ground support network and the corresponding coordination with ROSCOS. While the logistics of the ISS being manned are challenging, it is also important to note that the astronauts would need support teams working around the clock on the ground to ensure that all of the systems were operating correctly and to address any emergency situations. Additionally, due to the proximity to Earth of the ISS, a much more expansive system of communication would be needed on Earth to ensure that communication could be ensured all of the time. Manufacturing centers would be needed to prepare cargo missions, astronaut training would have to be done continuously, and many other facilities would be needed. Indeed, the ground logistics for the ISS are larger in many ways than that of the Apollo missions, and they have been operating continuously for the entire time the station has been manned - far longer than Apollo required. Thus, the ground infrastructure and support systems needed to run such a station involved a significant undertaking. However, armed with the experience of the Apollo missions, NASA was prepared to effectively implement these and ensure that a space station was feasible.

What NASA was not prepared for, however, was the challenge of coordinating all of these systems with the Russian Space Agency and other international partners. Unlike all of NASA's previous major manned projects, this was a joint endeavor and would require significant interagency coordination. Now, manufacturing centers, launch complexes, communication relays, and control centers would need to be located in both the US and in Russia. This meant that the logistical challenges of the mission were amplified by having to confer with Russian counterparts and agree upon any changes or solutions to problems. For example, during Apollo, if NASA wanted to change a system, they would contact the corresponding contractor and tell them to do so. However, if NASA wanted to make a change on the ISS program, they would need to coordinate with Russia such that both agencies agreed upon the change and how to implement it. Additionally, during Apollo, NASA learned that it was essential to have a single person who was responsible for making decisions that were final, the flight director, but now there was no way to have such a person since both agencies need to have equal control due to the joint nature of the mission. Thus, a system of conferring between agencies was built into the control structure of the ISS program to ensure that there was a fair division of power.

While that settled the issue of how to coordinate the mission, there was still the issue of how to build the station itself. While NASA had some experience working with other agencies to construct systems, like the ESA on the Cassini/Huygens mission and ROSCOS on the Apollo-Soyuz Test Project, it had never undertaken such a large task with any international partners, never mind several. This, combined with the concern that the Russians would use the opportunity to steal US technology, created issues for the project.

The solution to both of these problems was for NASA to treat the ISS as any of its other international partnerships: while it would be a joint effort, the different countries would each contribute their own segments of the station, which would act in a semi-autonomous way. Thus, instead of having to coordinate a monumental information exchange, administrative structure, and other related coordination efforts, the only factors that needed to be coordinated for constructing the station would be the logistical support and docking/integration. While this was still a large and new undertaking, it was drastically reduced in scope compared to the fully-integrated cooperation proposal.

B. Other Miscellaneous Logistics and Infrastructure

There are a myriad of smaller logistical issues and technologies that are necessary for the astronauts to be able to conduct their mission effectively. One such example is printing. Printing technology had existed for a while before the ISS, and it is essential to the mission to pass information from the ground to the crew, especially given the scientific experiments. This reduces a lot of the strain on the astronauts compared to Apollo since information no longer had to be relayed via voice, a system that is susceptible to errors. Another example of a minor logistical necessity is the structure of international law. Until Sputnik, it was unclear what the boundary was between a country's airspace and international space, and it was unclear what laws would govern space. By the time of the ISS, however, many of those issues had been cleared up with the Outer Space Treaty, which allowed for NASA to have the clarity regarding the legal implications they needed to invest in such a mission without fear that there would be international diplomatic consequences.

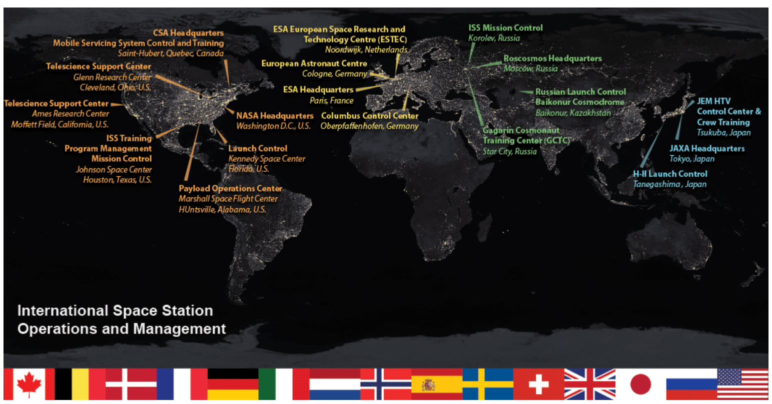

Figure 5: International ISS Cooperation- The bottom shows all of the partner countries who contribute to the ISS, and the image shows all of the logistical centers for operating the ISS.

8. Conclusion

While widely regarded as one of the best demonstrations of human achievement, the technological decisions and factors behind the ISS are only half of the picture that describes the history and decision to build a permanent space station in Earth orbit. NASA wanted a space station to prepare for Mars missions, but it was Congress and the President who enabled its construction. At first, the program was started in a Cold War competition as part of the larger space race aimed at beating the Soviets to demonstrate US technological superiority; however, as the Cold War died and the space race came to an end, the project continued to be politically motivated as a way of keeping Russia in check. Thus, while it would not have been possible to construct the station without the decisions that NASA made regarding the development of the technology and logistical support necessary to actually make it feasible, it was ultimately a political decision to build the ISS. This integration and alignment of the technological capacity, NASA's desires, and the government's political agenda is why there is a manned space station in orbit around Earth. As such, in a way, one of the greatest symbols of international peace and accomplishment is rooted in international conflict and mistrust.

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