A Technical Examination of the Space Station Redesign

by
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ABSTRACT

By January of 1992, Space Station Freedom was rapidly approach critical design review. In March of 1993, in light of past NASA debacles and in the interest of decreasing the deficit, the new administration asked NASA to redesign the space station. The redesign produced three less expensive options, which were, however, almost immediately discarded as a result of Russian interest in joining the program. The joint U.S.-Russian space station, called Space Station Alpha, has since then itself undergone a number of incarnations.

This thesis attempts to track the different conceptions of the space station through the redesign process and its aftermath. The technical differences among the three options and Station Alpha are discussed. The selection of the design was based on a combination of political and technical advantages, although the technical changes were, in the final analysis, primarily cosmetic. The addition of Russian elements to the program arose entirely from political interests, and its led to extensive tampering with the existing design, which was not well enough thought through. The space station, in its current design, has many flaws, which can be traced to the lack of understanding of the specifications and requirements of the program.

Dedicated to my parents,
Alan and Ferne Kantsiper,
for their encouragement,
support and love

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Introduction

The period following the election and inauguration of President Clinton was one of confusion for NASA. The administration was conspicuously silent on its intent for the space program, while asserting its intent to attack the budget deficit by attacking government spending. This led many to wonder whether the new Democratic administration would be less willing than its Republican predecessors to support large NASA programs. To all of this was added the general popular opinion, with the Hubble debacle firmly in mind, that all NASA projects have cost and schedule overruns and will break before they can be useful. The future of NASA was, to put it mildly, uncertain.

Into this political and fiscal confusion came the space station. Space Station Freedom (SSF) was the largest, most ambitious, and, consequently, most expensive of the projects that were being undertaken at the time by NASA. It was rapidly approaching its critical design review. Accusations that the space station program was pork-ridden and contained many hidden costs made it the natural place for the budget cuts NASA was given to expect to begin. This event was made only more likely by the general uncertainty as to the purpose of such a space station, with the Space Exploration Initiative, to all appearances, eliminated and the value of any valuable scientific research, according to the space science community, marginal at best. The prospects of SSF were not promising.

In addition, it was increasingly apparent that SSF was an ailing program. There were many fiscal and scheduling problems that were still unresolved. Many space station system designs had cost and development schedule overruns. The Advanced Solid Rocket Motor (ASRM), which was required to launch the Japanese contribution to the station, was also behind in development. These difficulties were rendered more critical by the recognition that the development schedules had inadequate margins allocated. Operational costs, such as the purchase of replacement parts and installation of system upgrades, had not been funded. In addition, there were several technical considerations that had not been addressed, including the lack of an Assured Crew Return Vehicle (ACRV) and the failure of the baseline station to meet the program orbital debris requirements. Finally, it was obvious that the management structure for SSF was confused and unworkable.

In recognition of the political and fiscal pressures that were apparent in the early stages of the Clinton presidency, the administration proposed that the SSF program be reexamined in an attempt to reduce costs. To this end the Station Redesign Team was formed. It consisted of 45 NASA employees along with representatives of the international partners in the program. Begun on March 10, 1993, the redesign effort was to last 90 days. Soon afterwards, the Advisory Committee on the Redesign of the Space Station was formed in order to submit recommendations based on the several options the Redesign Team was to propose.

As a starting point for the redesign effort, the administration stated what it considered to be the benefits of a space station that justified its existence. The primary purpose of the station was to be space science research, primarily in material and life sciences. This is a slight change from the original purpose, where the station was, as much as anything else, to be built as a stepping stone for future manned exploration, although the primary activity on board was to be research. The station was also to exhibit international cooperation in advanced technology, with the intent of helping to solidify the new diplomatic situation in the post-Cold War political arena. The redesign team was instructed specifically to consider proposals that included Russian participation. Finally, the space station program was to contribute to the revival of the struggling U.S. economy. In the short term, it was to accomplish this through direct stimulation of the aerospace industry from government spending. In the long run, the station was to encourage new users to become involved in space research and, hopefully, to discover new and profitable ways of exploiting the space environment and provide valuable fallout to the civil economy[1] .

The redesign effort was to reconfigure the space station in such a way that initial on-orbit research would occur by 1997, with assembly complete by 1998. The specifications for the station were to remain largely unchanged, although the targeted lifetime for the program was decreased drastically (from thirty years to ten). The interfaces with the international partners especially were to be unaltered in the new configuration. The charter required the reduction of the extravehicular activity (EVA) necessary for assembly and the implementation of a simpler and more efficient management structure. And, of course, the primary focus of the redesign effort was the reduction of the cost of the SSF program. The cost levels that the administration proposed were 5, 7, and 9 billion dollars through the five year period in which the station was to be assembled. The redesign team addressed three different options in their attempt to satisfy these requirements; these were Modular Buildup (Option A), Space Station Freedom

[1] Goldin, Daniel. Memo to NASA Headquarters Directors. Subject: Redesign Process.

Derived (Option B), and Single Launch Core Vehicle (Option C). These options will be discussed in later sections.

Design Drivers

There were a number of issues that were important design drivers for all three options. The most obvious and important of these was, of course, the cost. The need to reduce costs, both developmental and operational, was at the root of nearly every design change made by the redesign team. The costing issue was very complicated and will be handled separately in a later section.

Another overarching design issue was the inclination of the orbit of the space station. SSF had been baselined for a 28.8 degree inclination orbit, but there are many benefits to a higher inclination orbit. First, it improves the availability of launches. At a higher inclination orbit (greater than 40 degrees), the space station could be reached by the Russian man-rated launch system, the Proton/Soyuz, in addition to by the Space Shuttle. In this scenario, the Soyuz would be the ACRV for SSF and would, in fact, be launched on a Proton rather than the Shuttle. Also, the Russian Proton and the European Ariane could be used as backups for unmanned launches. This alternate launch capability provides much greater confidence in our ability to maintain a flight schedule in the operational phase.

The increased inclination also provides a greater degree of flexibility in the case of an emergency. Both ACRVs considered by the redesign team, the Soyuz and the Space Shuttle, require a land-based landing. Since the Shuttle has limited aerodynamic control and the Soyuz almost none, the latitude range of possible landing sites are effectively limited by the orbital inclination when the deorbiting boost occurs. It turns out that, while the latitude range available at the 28.8 degree inclination is almost entirely ocean, the higher latitude (51.6 degrees) provides a number of convenient landing sites. This results in much improved likelihood of survival of catastrophic damage.

Another minor side effect of the higher inclination orbit is slightly increased power production. The higher inclination orbit have less eclipse time per orbit. This results in longer periods of power production and, therefore, more power produced per orbit (on the order of 4-6 kW). This effect also increases the lifetime of the batteries slightly.

Finally, the higher inclination orbit, for the same reason it results in more landing sites for the ACRV, allows a greater range of earth observation. With the Mission to Planet Earth missions receiving the most interest from the vice-president, the increased global coverage would allow for some interesting possibilities for earth science research on the station that would be unavailable at lower inclinations. Some common systems from the Earth Observing System (EOS), for example, might be placed on the station, allowing the EOS satellites to be smaller, and, consequently, less expensive. As a number of experiments already planned for SSF require that the station orbit in local vertical, local horizontal (LVLH) mode, it would already be orbiting in an orientation appropriate for earth observation.

The higher inclination is, of course, not without its cost. It decreases the mass that the Shuttle can boost into orbit significantly. This mass limitation increases the number of assembly flights required, as well as necessitating the ASRM program and the production of the aluminum-lithium (Al-Li) tank. The increased inclination also changes the radiation environment of the station as well.

Another design driver was the required power allocation to the users. 30 kW are to be provided for experiments (with the International Partners on board). In many cases, the design alterations that were made to decrease costs had adverse effects on the power production. This became a thorny issue, especially in the case of Option C, and it is unclear that the redesign team ever found the optimum balance. Other technical drivers were mass and volume (limited by the assumption of Shuttle launches), the requirement of decreased EVA, and the necessity of keeping the interfaces with the international units stable. The interaction of these issues and other option specific design drivers will be examined more fully in later sections. The political pressures, from the administration, the Congress, and the international partners, were also major, if not the most important, design drivers, but these considerations are will not be dealt with in any depth in this discussion* .

* These and other design drivers are discussed in greater detail in the "Final Report to the Advisory Committee on the Redesign of the Space Station," 7-15.

Freedom Derived Options

Options A and B are both predominantly derived with few changes from the baseline Freedom design. The specifications of the redesign committee required Option B to maximize the use of existing designs, but Option A was not in this way limited[2]. Option A was specified to be a modular approach to fulfilling the same requirements as the baseline station, but, given that the requirements were the same, it is unsurprising that the two options were, in the end, extremely similar to each other and the original proposal. Since the similarities are so pronounced, both options will be dealt with in this chapter.

Baseline Design

The fundamental mission of the baseline station is the establishment of an orbiting research facility with lifetime of at least 30 years (now shortened to 10) with two crewmembers dedicated to scientific activity. In support of the two crewmembers dedicated to research are two others whose purpose is to take care of the operational requirements. The number of crew members can be increased to a total of 8 through the addition of another habitation module.

The station design calls for a set of laboratory and one habitation module joined by various nodes and all attached to a connected series of truss segments. The complete truss is 355 feet long. 56.25 kW of electrical power, with 30 kW allocated to the users (with the international modules present), are produced by three photovoltaic arrays, with two arrays on the starboard side

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[2] Shea, Joseph F.. Conversations with the author.

of the truss. A fourth array may be added on the port side truss to boost the power output to 75 kW if required. The solar arrays are fitted with both alpha and beta joints to allow for increasing sun tracking capabilities, maximizing power production and improving the stability of the power profile throughout the year.

Space Station Freedom is to be placed at an altitude of 220 nautical miles with an orbital inclination of 28.8 degrees. The guidance, navigation, and control system performs orbital maintenance, as well as maintaining the attitude of the station in local vertical, local horizontal mode at all times. The GNC system consists of four control moment gyros and four magnetic dampers, two star trackers, and three inertial sensors.

The station allocated 44 m to all users in the form of 45.5 International Standard Payload Racks. The active equipment in the modules, the subsystem equipment as well as that designated for research, is to be stored in such International Standard Payload Racks. Among the facilities included in the design are a centrifuge, a furnace, and a refrigerator/freezer. The microgravity levels in these regions are constrained to meet certain frequency dependent requirements[3]. The various modules and nodes are capable of maintaining normal living conditions for four crewmembers over the required lifetime.

Space station freedom utilizes both active and passive thermal controls to manage heat regulation and rejection. The passive thermal control elements consists of thermal coatings to enhance heat absorption or heat loss, insulation, and heaters. Heat rejection from the station is accomplished through five external radiators, three

[3] Space Station Redesign Team. "Presentation to the Advisory Committee on the Redesign of the Space Station," Apr 22, 1993, 17.

designated for the solar arrays plus one for each side of the truss.

The active thermal control system is divided into the internal, external, and photovoltaic control systems. The photovoltaic active thermal control system consists of four single phase loops with ammonia as the thermal medium that could reject an 8.4 kW of heat, averaged over the orbit. The external active thermal control system consists of three two-stage ammonia loops which can reject about 96 kW of heat in the completed configuration. The internal active thermal control system consists of two single phase water loops.

Transportation, for both crew transfer and operational and assembly flights, is dependent on the Space Shuttle. 18 (23)[*] flights are required for the completion of assembly, and the space station will require two operations flights per year. The baseline design does require the Al-Li tanks for assembly, but the ASRM boosters are not necessary, except for the ESA and JEM contributions. Two Shuttle orbiters may be docked at the space station at one time. The baseline station does not provide for ACRVs.

The baseline station, according to the redesign team estimates[4], would cost 14.4 billion dollars through fiscal year (FY) 1998, with another 5.6 billion dollars required for completion. Permanent human capability would be achieved in September, 2000.

Option B

The purpose of Option B was to determine what alterations could be made in the baseline design to decrease

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[*] Throughout this analysis, the number of flights stated to reach a milestone will, unless otherwise stated, will be given for an orbit with 28.8 degrees inclination, with the number required for 51.6 degrees inclination following in parentheses.

[4] Space Station Redesign Team. "Final Report to the Advisory Committee on the Redesign of the Space Station," Jun 7, 1993.

the cost. This design was expected to resemble the baseline strongly. The Option B team realized early on in the design process that, without much more significant changes in the requirements, cost savings would not be achieved through hardware changes alone.[5] The cost benefits in this option derive almost entirely from a restructured management plan, simplified software and infrastructure for data management, and some improvements in early operation and utilization costs.[6] The final design is shown in Figure 1.

Description

The subsystems, as was expected, remained predominantly unchanged from the baseline. The electrical power system (EPS), the guidance, navigation, and control (GNC) system, propulsion, and the robotics for Option B were all exactly the same as in the original Freedom design. The environmental control and life support system (ECLSS) and the communication and tracking system both underwent very minor alterations. Only the data management system (DMS) was changed significantly from the baseline design. Even for DMS, the hardware changes were largely peripheral, with most of the cost and power savings deriving from the proposed simplifications in the software and user support.[7]

This is not to say that more profound deviations from the baseline were not considered. As of the April 12 report, four other configurations were being considered.[8] One of these alternate configurations was designated the "Quick Lab." This option combined two of the truss segments (the M1 and S1 truss elements) and launched the lab before

[5] Space Station Redesign Team. "Report to the Advisory Committee on the Redesign of the Space Station," Apr 22, 1993.
[6] Ibid.
[7] Space Station Redesign Team. "Final Report to the Advisory Committee on the Redesign of the Space Station." 16. Except where otherwise noted, the description of the three options is based on this report.
[8] Priest, Pete, et. al. "Option A Modular Buildup Concept, Option Lead Status Report," Apr 13, 1993.

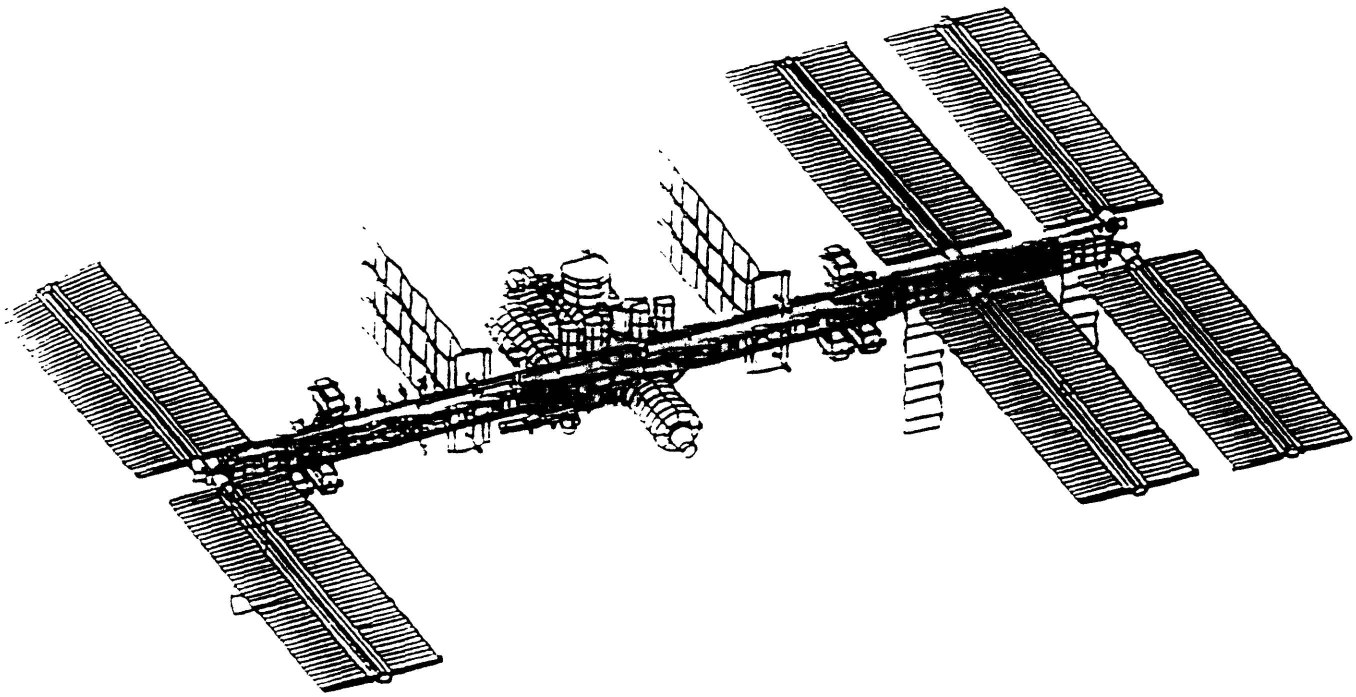

Figure 1. Option B - Permanent Human Capability[9]

the node or habitation module. This would allow human-tended capability (HTC) after only five flights. This design was conceived as a possible stopping point in the assembly of the station at which some research was possible. With additional assembly flights this design would evolve into one of the other options. This option was eventually rejected because the required redesigns would increase the cost.

The other three configurations considered by the Option B team were designated Option 2, Option 2A, and Option 4. All of these options eliminated the habitation module, distributing its functions throughout the lab modules and nodes. All three options differed from the baseline station in that various truss elements were eliminated. Option 2A eliminated the port-side truss elements (P1 and P2), keeping two solar arrays on the starboard truss. This configuration would be much simpler than the baseline, in that it would have only one alpha joint and one truss segment. HTC would

[9] Advisory Committee on the Redesign of the Space Station, Final Report to the President, 23.

be achieved at an inclination of 51.6 degrees in only 9 assembly flights, and permanent human capability (PHC) in 21. This option had a number of problems associated with it, including lack of redundancy in critical areas, array shadowing, poor microgravity resulting from the asymmetric design, and limited thermal rejection capabilities due to the absence of the S1 truss segment.

Options 2 and 4 both have a "symmetric" design, in that there are solar array assemblies on both sides of the truss. Option 2 eliminates the S1 and P2 truss elements, while Option 4 eliminates only the P2 element. In both these cases, the redesign team determined that the additional redundancy and expandability associated with the complete truss validated the extra cost and complexity.

While the alternatives described above did not, in fact, become part of the final form of Option B, their influence can be seen in the modular structure of the final design. It is not surprising that the Option B team, unable to meet the cost target for FY 94-98 of nine billion dollars and recognizing the unstable funding environment large NASA programs find themselves in from year to year, opted for a modular approach to the station assembly, similar to the one which will be discussed under Option A.

The Option B assembly plan has five major stopping points. Initial Research Capability (IRC) is achieved in only 2 (3) assembly flights. The "Power Station," as the resulting system is referred to, consists of the starboard truss elements with one photovoltaic array. The Power Station is equipped with S-band communications, complete attitude control, and an active thermal control system. The Power Station provides 13.5 kW to an attached Shuttle orbiter. The purpose of the Power Station is to provide power and an improved microgravity environment to an attached Extended Duration Orbiter (EDO) equipped with a Spacelab research facility. The similarity between the Power Station and the "Quick Lab" discussed above should be clear.

The next milestone occurs after flight 8 (10) and is designated Human-Tended Capability (HTC or MTC). The US Laboratory Module is already deployed at this point, providing 13 International Standard Payload Racks in a microgravity environment of less than 2 mg.* 11 kW out of a total 18.75 kW are allocated to the users. The MTC configuration allows for research activity without an orbiter attached but does provide accommodation for docking of two orbiters at once. The Canadian mobile service station is also present and provides for robotic maintenance of the space station. The station can at this point be maintained indefinitely with periodic Space Shuttle support flights.

The next stage in the station assembly is International Human Tended Capability (IHTC). This occurs after 17 (21) assembly flights. At this stage, the station is two fault tolerant for station survival. By this point, the International modules, as well as the port-side truss elements, have been added, but these laboratories are not yet outfitted with payload racks or equipment. These require additional flights.

The full power production of 56.25 kW (30 kW for users) is now provided, with all three photovoltaic assemblies. The third solar array assembly is on the port side of the truss. This change from the baseline design was implemented to improve the microgravity environment by moving the center of mass closer to the laboratory modules. All of the laboratory modules are in place, and each is maintained with less than 1 mg of acceleration* . The P2 truss segment has been deleted. The deletion of this truss element is a leftover from the Option 4 design discussed above.

By flight 20 (25), the station is complete** . This stage is designated Permanent Human Capability (PHC). The ACRVs and the US Habitation Module have been added. This assembly sequence assumes Space Shuttle capabilities without the Al-Li tank or the ASRM. The availability of these improvements would, of course, decrease the number of flights and provide for earlier completion of the assembly.

Similar to the baseline station, Option B may be expanded with the addition of another habitation module and port-side solar array to allow for 8 crew members and to provide 75 kW. Because of the larger truss length, Option B provides for the greatest expandability of all the options. Also, due to the advanced stage of the design, Option B has the lowest programmatic risk and provides for the best use of the 8.5 billion dollars already spent on the space station.

Evaluation

The Option B design contains only minor changes from the baseline station. The design is mature, but still extremely complex. It is the most expensive of the options and has the highest risk associated with it, due to the number of launches and the large amount of EVA it requires. It also has the additional disadvantage of being perceived as exactly the same as the baseline design, in which case

* All microgravity levels cited here are taken from the analyses contained in the Redesign Team reports, which are steady-state accelerations. They do not include estimates of periodic variations in the microgravity environment, caused by human and instrumental disturbances or other transitory accelerations.

** The number of assembly flights required for complete assembly differs from that stated for the baseline station only because of the inclusion of two flights to place the two Soyuz modules in orbit to act as ACRVs the entire redesign process appears to be a waste of time and money. This was politically unacceptable. In light of these problems, it is hardly surprising that Option B was rejected in favor of the other two options by the Blue Ribbon Panel.

Option A

Option A was very similar to Option B and to the baseline station, in that it is a modular design based on the baseline, but it was allowed more freedom in altering the hardware. The design that resulted is a slightly simplified version of the baseline, with little decrease in capability. The similarity to Option A is easily seen in Figure 2.

The most significant hardware alteration lies in the conception of a "core module." In the baseline design, as has previously been discussed, a combination of pressurized modules and nodes is used. In this option, core modules, which combine one node and one module into a single unit, are the building block for the station.

The core module has one third less volume than that of a baseline module (e.g. the U.S. laboratory module) available for payload. This decrease results from the inclusion of four berthing ports, to replace the function of the nodes. These are used for ACRVs, airlocks, etc. The redesign team claims that this decrease in effective volume can be accommodated by the combination of "phased requirements definition...,subsystems simplification..., and elimination of equipment duplicated in the Space Station Freedom modules and nodes."[10] This point will be further discussed below.

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[10] Space Station Redesign Team, <u>Final Report to the Advisory Committee on the Redesign of the Space Station</u>, Opt A rpt, 5-6.

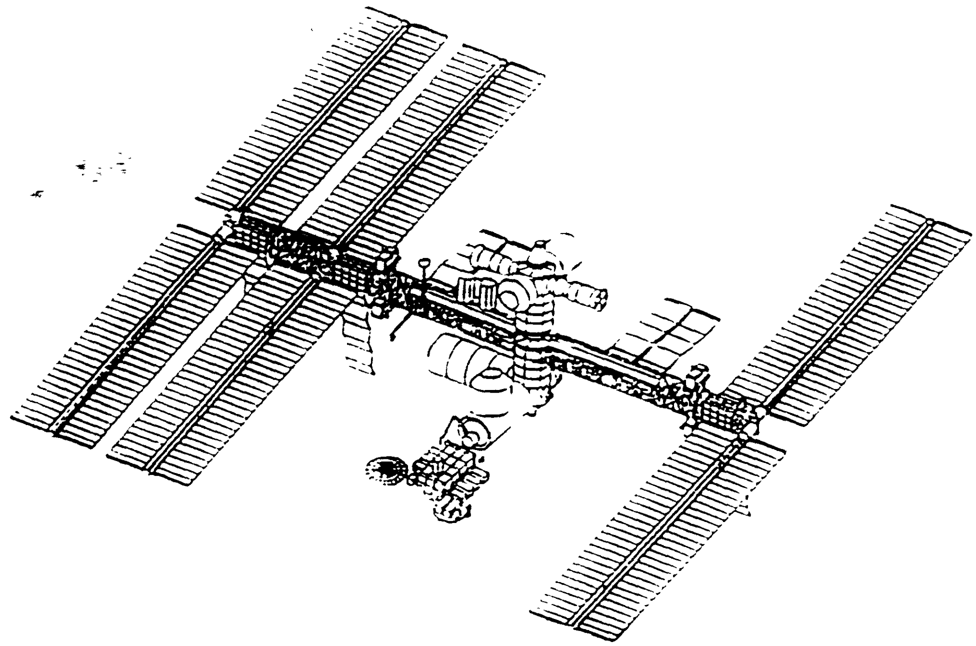

Figure 2. Option A - Permanent Human Capability[11]

Another point that differentiates this option from Option B is the consideration of the use of an existing satellite, the Lockheed Bus-1 spacecraft, to perform propulsion, GNC, and some data management functions. This version of the design is designated Option A-1. The other version, in which baseline Freedom subsystems are used for these functions is called Option A-2.

The Bus-1 Spacecraft

The Lockheed Bus-1 is a semi-classified reconnaissance/ surveillance satellite. The Bus-1 spacecraft contains 11660 lbs of N_2O_4 and MMH propellants. The propellant is stored in six tanks. It had six small thrusters and one large engine for reboost. Currently, no method for on-orbit refueling has been determined to be practical; the only method available is to refuel on the ground. Research into on-orbit refueling of Bus-1 is underway.

[11] Advisory Committee on the Redesign of the Space Station, <u>Final Report to the President</u>, 22.

Bus-1 determines attitude through a combination of nine rate gyros, two magnetometers, and an assortment of sun and star sensors. Attitude is controlled by six single axis control moment gyroscopes, in addition to the twelve reaction control thrusters. There is currently some question regarding the ability of Bus-1 to control the space station sufficiently. This research is also ongoing.

There are some modifications to the Bus-1 that are necessary for its utilization onboard the Space Station. The reaction control thrusters and the satellite's solar array must be relocated. Some systems, such as an electrical converter, power/data grapple fixtures, and communications interfaces, must be added. In addition, a mechanical interface that will allow the spacecraft to determine the center of gravity of the Space Station is also required. Even so, the Bus-1 spacecraft cannot be configured for on-orbit maintenance.

The use of the Bus-1 drives many substantial differences between Options A-1 and A-2. It is obvious that the propulsion, GNC, and data management systems will be different, as these are the functions that the Bus-1 is intended to fill. Other changes, however, result from the use of this satellite. One example is that a transition section, connecting the Bus-1 to the previously designed truss, must be built for Option A-1. Also, the replacement of a substantial amount of hardware by the Bus-1 allows for the elimination of a greater number of truss segments, five for Option A-1 compared to only three for Option A-2. This translates to a further 36 ft decrease in the end-to-end length of the Space Station. In addition, the optimized flight modes for the two options differ by a 90 degree in-orbit rotation.

Description

Both Options A-1 and A-2 attempt to simplify the subsystems that were to be used on the baseline station. In both designs, for example, the alpha joints on the solar arrays are deleted. The beta joints, however, are maintained, allowing for some adjustments to adverse solar angles. In addition to the capability of the beta joint, another adjustment to solar angle is made through varying the flight mode. The station varies its flight mode to decrease cosine losses, half of the time flying with solar arrays in the orbital plane, the other half with them perpendicular to it. This increases the power generated slightly without seriously impinging on earth observation activity.

The central thermal control system is a single-phase ammonia system, with redundant radiators and pumps. This system is similar to the system already baselined for the thermal control of the photovoltaic system. This system is much simpler than the dual-phase ammonia system that was in the baseline design. This alteration also has the advantage of avoiding the necessity of two separate designs for thermal control, simplifying the design process and decreasing the cost. The remaining elements of the thermal control system are identical to those in the baseline.

The life support systems (ECLSS) are also simplified, partly due to the use of the common module. Where separate life support equipment for two different pressurized structures, a module and a node, had been necessary, now only one system is required. This elimination of redundant equipment, as well as the deletion of the U.S. pressurize logistics module, allow for some hardware based cost savings. Further savings are realized through the simplification of the data management system, by removing the fiberoptic elements, simplifying the software and the verification procedure, and replacing terminals with laptop computers.

The assembly manifests for the two options are almost identical, with only minor differences that occur in the first few flights. In both cases, the Power Station is achieved in 3 flights and HTC in 4. IHTC occurs after 9 flights, and assembly is complete after 13. The assembly sequence is exactly the same for a 51.6 degree inclination orbit, although the Soyuz ACRVs are delivered in this case by the Russian Proton launch system rather than the Shuttle. This sequence, however, assumes the availability of the Al-Li external tank for the Space Shuttle and requires some assembly at low altitudes, since the orbiter has an effective 175 nmi ceiling at this inclination. This necessitates additional propellant expenditure for reboost to 230 nmi altitude.

Issues

There are several issues regarding Option A that remain to be resolved. Some of the ones pertinent only to Option A-1 were mentioned above: the controllability of the station and the refueling and maintenance of the Bus-1 on-orbit. Another point that has been mentioned is the necessity of the Al-Li tank for high inclination. This requirement is not particularly damaging to the option's prospects, as it is necessary for high inclination for all the options, but the reboost requirements from low altitude assembly are costly. One final concern relevant only to Option A-1 is the possibility of difficulty in docking the orbiter with the solar arrays parallel to the final orbiter approach. This problem is easily remedied by flying in the same mode as in Option A-2 (rotated 90 degrees in the orbital plane), with only a slight penalty in performance.

Related to the docking issue is the possibility of unacceptable plume loading on the solar arrays. The decreased truss length brings the solar arrays in closer to where the Shuttle plumes are discharged. This could lead to an unacceptable rapid decay in the power output of the photovoltaic cells. This effect is naturally expected to be worse for Option A-1, since the truss is shorter than that for Option A-2.

Another unresolved problem is the prevention of micro-meteoroid penetration. Similarly to both Option B and the baseline station, neither Option A-1 nor A-2 provide protection sufficient to meet the baselined safety requirements. The redesign team estimate a 70 - 80 percent likelihood of no penetration through the ten year lifetime. This probability, they claim, can be improved up to about 90 percent through the results of studies currently in progress for the baseline station. This is still a far cry, however, from the 99.55 percent probability of no penetration that is baselined.

Option A does fail to meet the specifications of the redesign in other areas as well. Most importantly, the number of payload racks available in this option is only nine, four less than what was specified. This is caused by the one third reduction in the volume of the modules that results from the use of core modules. The redesign team claimed to have accommodated the reduced volume by design simplifications, but, in reality, it appears that it was accommodated by reduced performance. A much less significant failure of this option is its inability to launch the Remote Manipulator System before HTC for Option

A-1. This failure is not serious, as it is launched on the very next flight.

Evaluation

Of the three options, Option A provides the best balance between simplification and maximum use of the baseline station hardware. It is significantly cheaper than the baseline and has relatively low programmatic risk associated with it, as nearly all the hardware is identical or nearly so to that of the baseline system. The simplifications that were incorporated into this option primarily eliminate redundancy. These advantages, coupled with its political feasibility, make it the best of the three options that were produced by the Redesign Team for the current situation.

Option C

The last option under consideration was Option C. Option C represents a completely different approach to the development of a space station. Unlike the previous two designs, which were constructed with only minor changes from the Freedom baseline, Option C is derived from the Shuttle orbiter systems and infrastructure. The resultant design, while utilizing many of the same assemblies as the other two options, is markedly different from the baseline station. A sketch of the Option C configuration with the International Modules deployed is shown in Figure 3.

Both Options A and B were based on a modular approach to station assembly. A central truss is assembled, and various modules are attached to that truss and to each other. Option C consists primarily of a single pressurized module that replaces the body of the Shuttle in the launch assembly. This concept was suggested by the previous NASA research for the Shuttle C program, in which a stripped-down Space Shuttle was proposed as a heavy-lift launch vehicle.

In light of the radically different nature of this design and its consequent immaturity, it was clearly a concern to maximize the use of previously developed hardware and software in order to decrease the programmatic risk of the redesign. These systems could come from two sources, either the previous Freedom design or the Shuttle systems themselves. One goal in the development of this option was, therefore, to minimize the development of new hardware, especially in the engine and launch systems, where such alterations are most expensive.

Another important issue was the maintenance of the interfaces with the international modules. In the other two options, because only minor revisions were being made to the

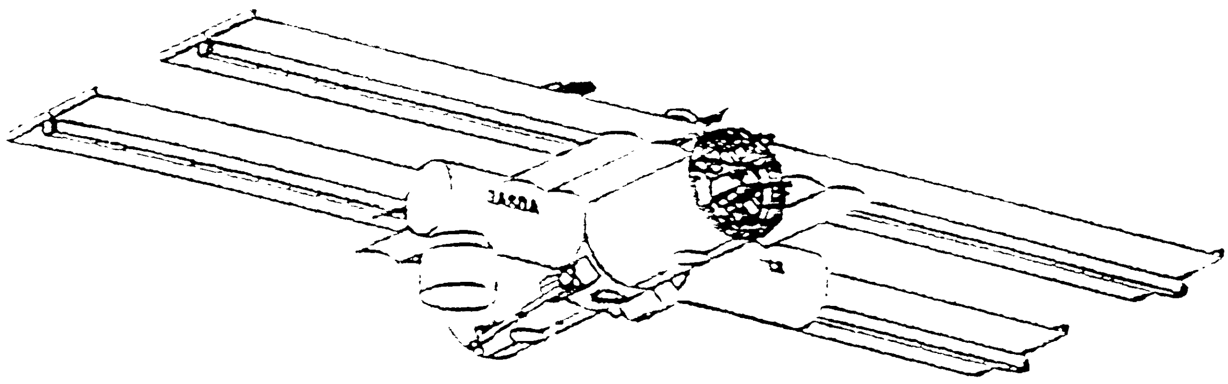

Figure 3. Option C - Permanent Human Capability[12]

baseline design, it was clear that the agreements with the Internationals could be maintained, but this was not obvious for Option C. This requirement was especially constraining. The strength of the Option C concept was the volume it provided; it was, however, more limited in surface area, which is what the International Modules required, than the other two options. Maintaining these modules as external was a major disadvantage, in that they were somewhat cramped in terms of external area and in that the full internal capacity was not being utilized.

This concern was made more pressing in light of the adamant distaste the Internationals exhibited, primarily for political reasons, toward Option C throughout the redesign effort.[13] The redesign did not entirely succeed in this arena; the final design for this option would require extensive reexamination and redesign by the International Partners.

Description

The main body of the station, called the Core Module, consists of a pressurized aluminum cylinder approximately 64 ft long with a 22 ft diameter. This cylinder is formed from

[12] Advisory Committee on the Redesign of the Space Station. Final Report to the President, 24.
[13] See for example the "International Partners' Evaluation," Final Report to the Advisory Committee on the Redesign of the Space Station, 82-119.

seven smaller cylinders joined between by rings. This structure provides sufficient volume for 75 International Standard Payload Racks as well as a space for the crew similar to that of the baseline Habitation Module. In fact, Option C can support a crew of six for short periods of time (about a week), an ability that might prove valuable in the event of a Shuttle failure after docking.

At each end of the cylinder a docking facility is attached, allowing for simultaneous access to two orbiters. In addition to the two primary docking assemblies, several berthing ports lie along the core module. The design includes provision for two ACRVs (Soyuz modules) and five berthing ports for the International Modules and the pressurized logistics module. The entire station, including the docking ports, is 92 ft long.

Power is provided by four "fixed," or non-rotating, solar arrays, identical to the assemblies provided in the Freedom baseline. The deletion of both the alpha and beta joints simplifies the power system design dramatically. Thermal rejection is accomplished through a combination of body-mounted and deployable radiators.

Attitude is controlled by a two-fault tolerant GNC system. Attitude is determined primarily through three Global Positioning System links, from which position, velocity, and attitude can be determined. The attitude is controlled by four control moment gyroscopes (with only three active at any given time). Attitude control maneuvers are performed through reaction control thrusters identical to those currently used on the Space Shuttle. The fourth gyroscope provides one backup, and the primary reboost propulsion system can also be used for attitude alteration.

Reboost is accomplished through six primary thrusters, also identical to those used on Shuttle. The station utilizes a bipropellant system, with monomethylhydrazine (MMH) and nitrogen tetroxide (N_2O_4). The propellant is stored in a total of ten tanks, five for fuel and five for oxidizer. These tanks are identical to those under development for the baseline station. Approximately 6000 lb of fuel will be used each year for reboost and orbital maneuvers. Since it is estimated that only 3500 lb can be transferred to the station in one rendezvous, the station must be resupplied at least twice a year. This limitation can be weakened somewhat if the orbiter (with appropriate modifications) transfers any excess propellant to the Station propulsion system.

Prior to launch, one end of the station is covered by a Shuttle-style nose cone. The other end is attached via a transition section to a modified Shuttle aft fuselage, which contains the main engine and the avionics. The modifications to the aft fuselage are minor, consisting of removal of the tail fins, the Shuttle orbital maneuvering system, and the active body flap. These deletions can be made because the station is not intended for reentry. It is in the transition structure that most of the design work was required.

The Core Module is attached to the External Tank in a fashion similar to that used for the Shuttle. The solar arrays are originally rolled up and covered by a shroud. The launch sequence is similar to that of the Shuttle. After external tank separation, the nose cone and shroud are jettisoned. The engines are fired to circularize the orbit. Finally, the solar arrays are deployed, and the station becomes active. The station is launched unmanned and only partial outfitted. The crew, the International Modules, and some of the payload racks are brought up on subsequent flights.

Issues

The most important outstanding issue for the Option C design is electrical power. As was previously mentioned, the four solar arrays are fixed and are therefore incapable of adjusting to varying sun angles. The decision to eliminate the alpha and beta joints was mandated by the interference with the JEM and the self-shadowing which result from rotating arrays. These issues are avoided in the other designs because the arrays are deployed much farther apart, separated from each other and the modules by the length of the truss. The minimum power provided to the users in Option C when the station is flying in the preferred LVLH mode is only 18 kW, much less than the specified 30 kW.

One remedy for this problem, which was proposed by the Redesign Team, is to vary the flight mode of the station. If the station is flown in solar inertial mode, in which the station is maintained at a constant attitude with respect to the sun, the cosine losses that the arrays were subject to disappear, and power production increases drastically. This flight mode is, however, unsuitable for earth or space viewing activities. A complicated orbital profile is therefore required, in which the station alternated between LVLH and solar inertial mode in order to try to provide enough power and time for all the scientific activities.

Even this does not wholly remedy the situation. There is some concern that the rotation of the local gravity vector caused by these flight mode variations will be sufficient to negate the value of some microgravity experiments. There were some proposals near the end of the redesign process (about mid-May) of launching an additional solar array on a tube that would be attached to the station on a subsequent flight. The addition of this extra array, while possibly simplifying the time-sharing schedule, would not provide power sufficient to fly only in LVLH mode. This issue remains unresolved.

Another concern that faced the Redesign Team was the mass budget for Option C. The modified STS system described above has the capability to launch approximately 190000 lb to a standard orbit at 28.8 degrees. The estimated mass of the station, with a ten percent margin, is a little above that limit.* The report emphasizes that there are many steps which can be taken to transfer mass to subsequent flights, e.g. offload payload racks or other non-critical equipment or optimizing the flight profile, but, with every additional outfitting flight required, the advantage of a "single-launch" space station decreases. In addition, a ten percent mass margin is not very large, particularly for an immature design where major structural components, such as the transition section, are yet to be designed.

Related to the mass problem is the question of orbital inclination. The higher inclination orbit is desirable for all the reasons described in preceding chapters, but it does exacerbate the mass problem. Even with the Al-Li tank, the launch system can deliver only 178000 lb to a 51.6 degree inclination orbit. In addition, the higher inclination orbit drastically decreases the launch window from Kennedy Space Center, from 55 min for a 28.8 degree orbit to only 5 min at 51.6 degrees. Given NASA's succession of delayed launches in recent years, the increased risk for operational, logistic, and personnel transfer flights is obvious.

* This is somewhat surprising considering the liftoff capacity of the launch vehicle. It seems possible that the Option C team was being excessively conservative.

As was alluded to above, this option also requires reexamination of the interfaces with the International Modules. In addition to the failure to meet required power levels, there are also significant viewing obstructions, both from the solar arrays and the core module itself. These problems are only made more complicated when the station is flying in solar inertial mode instead of LVLH. Other regions where redesign is required of the International Partners to interface properly with this design are in the fluid and electrical connections, which are accomplished internally rather than externally, as in the baseline station, and in the DMS, which is based on the Shuttle system rather than that of the baseline.

Evaluation

Option C does have a number of advantages over the other options. First and foremost, it decreases the number of launches required for PHC from over twenty to a mere handful. While the launch costs for the station were not included in the costing analysis associated with redesign, the benefits from the decrease in assembly flights would likely outweigh the estimated one billion dollar cost of modifying Shuttle hardware for Space Station use. This occurs concurrently with a significant increase in volume available to payload.

Perhaps even more important than the decrease in launch costs is the feasibility of complete integrated testing on the ground. This is contrasted with the assembly approach of the other two options, in which extensive on-orbit assembly is required, and ground testing is limited to the modules, rather than the complete system. Again, given NASA's predilection in recent years for expensive blunders, this advantage cannot be emphasized too greatly.

Another important advantage of Option C is that it is the safest of the options. This results partially from the added confidence which complete ground testing can provide, but there are other reasons as well. One reason is the simplicity of the structure. Another important point is that Option C does meet the requirement of .995 probability of no penetration of the hull by micrometeoroids or space debris over the ten year lifetime that was baselined. Option C is the only design that has met this requirement. In addition, the necessary amount of EVA activity is cut dramatically. Finally, it decreases the risk of a launch delaying assembly, although at the expense of increasing the cost of a single failure. On the whole, these features tend to make Option C safer than the other two designs.

Option C has one final advantage. According to the cost estimates of the Redesign Committee, it is the cheapest of the options. It was estimated that Option C would cost about 15 billion dollars through PHC, 2 two billion less than Option A, the next cheapest. While the validity of any estimate for such an immature design is questionable, and the costing process itself has been called biased by some, the launch savings were not included in this analysis. These effects will likely cancel out.

There are, however, a number of drawbacks to this design. Many of the problems were discussed in the preceding section: the insufficient power production, the short launch window at high inclination, and the mass budget overruns. There are also other areas in which the assumptions made by the Redesign Team are questionable. The figures for power production are based on the assumption that improved transmission efficiency over that of the baseline is possible because of shorter distance over which the power must be transferred, but this claim has not been substantiated.

More importantly, the cost savings quoted above arise primarily due to the frequent use of Shuttle and baseline Freedom hardware with only "minor" changes. As the design is immature, it is not impossible that these "minor" changes turn out to be more expensive that originally thought, or even impractical.

Another less technical but equally important drawback is the dislike the International Partners have expressed toward it. This distaste arises, in part, from resentment over having a redesign in the first place and, also, in part, from the recognition that any changes are likely to cost them money in redesigns, but their dislike for Option C goes beyond this. This design provides so much volume that the International Modules are largely extraneous. This causes the Internationals to appear as unnecessary guests on a predominantly U.S. project, and the quite rightly, from their point of view, resent this.

All of these problems are in some way symptomatic of a deeper flaw in Option C. The single launch conception, while capable of providing a station that meets the specifications in an efficient and even elegant fashion, is less suitable as a redesign than the other two options. The Redesign Committee, in an attempt to maximize the use of baseline Freedom designs and hardware, tried to impose the same modular approach on Option C. The use of extra laboratory or logistic modules simply does not make sense in this design, and this unsuitability of course shows up in fundamental flaws in the final design. Option C is an interesting and exciting alternative to the conception entailed in the baseline and is very likely the approach that should have been taken from the beginning, but is not appropriate as a redesign in the current situation.

Summary

The Option C would have been preferable had it been adopted from the onset of the Space Station Program. It is a much simpler and more elegant conception of the space station, decreasing the number of launches, the amount of EVA, the cost required for assembly. The mass limitations are minimal, and the power limitations could almost certainly have been overcome with a properly optimized time-sharing schedule for the experiments. The additional value and improved reliability would have made it vastly superior to the baseline station.

As a redesign, however, it less reasonable. It does not take full advantage of the development that has already been accomplished, and it would antagonize the International Partners unnecessarily. Finally, it does not showcase the exciting and daring technology which NASA so loves to display. Option C is an extremely clever idea that was thought of far too late.

Aftermath

The redesign effort produced three designs that were, if of varying maturity and suitability, all at least viable. The Blue Ribbon Panel then made its recommendations to the administration, and one design was chosen and presented to Congress. The space station design, however, has gone through a number of incarnations since that point, largely due to increasing interest in Russian participation. The alterations to the station design made to accommodate the Russians have been motivated primarily by political considerations, with little or no effort to determine whether they are appropriate or even reasonable technically.

The Blue Ribbon Panel

Many of the points pertaining to the individual options that the Blue Ribbon Panel raised in their report to the President have been considered in previous chapters; this section will therefore be confined to discussing the motivations for the recommendations that were made to the President.

The first point made in the report is that the Power Station should not be considered, for either Option A or B, as a viable space station. The Power Station concept was developed in an attempt to meet the 5-9 billion dollar cost requirement that the administration had set at the onset of the redesign effort. When it became obvious that it would be impossible to meet this requirement and still maintain permanent human capability, the Redesign Committee introduced the Power Station as an option that would enable some scientific research within the cost limitations.

The Blue Ribbon Panel in their report points out that the length of experiments on a Power Station would be limited by the time that the orbiter could remain on orbit. This limits the experiments to under 30 day duration. The Panel rightly argues that, as this limitation eliminates the most useful experiments, the research capacity of a Power Station configuration does not justify the developmental costs. This recommendation indicates a recognition that the cost targets that the Redesign Committee were set were unreasonable.

The Blue Ribbon Panel went on to indicate that it considered Option A to be superior to Option B. Option B carries much higher risk, due to greater EVA requirements, a larger number of assembly flights, and greater complexity. The greater cost and late completion date were also factors in this decision. Of the modular design concepts, Option A was considered preferable.

In the evaluation of Options A and C, it was unclear which one was superior. Option A, the report concludes, is superior to Option C in technical and international capability, largely due to the power limitations on Option C (although, as has been discussed above, these limitations might be eliminated through proper time management). It also achieves a somewhat earlier initial utilization, although at the expense of a later completion, than does Option C.

Option C, on the other hand, has lower development and launch risk, due to decreased EVA time and the possibility of complete on-ground testing before launch. It is also the cheapest of the options presented to the Blue Ribbon Panel by the Redesign Committee. The Panel concluded by avoiding the decision; it recommended both options to the administration for further consideration.

The administration selected Option A, and, after a difficult political struggle, the Congress accepted and funded it (at least, temporarily). It seems likely that political feasibility and popular opinion influenced the administration's decision as much as any technical issues; they were caught between the necessity of producing a "different" space station for popular support and the practical impossibility of convincing Congressmen whose districts stood to benefit from the old design to accept a completely new option. Option A was similar enough to the baseline to keep key Congressmen placated, while different enough (i.e. inexpensive enough) to be presented as a bold redesign. For whatever reason, however, the choice of Option A was appropriate, balancing the need for a change in the Freedom program with the interest in maximizing return from the money that was already invested.

The Blue Ribbon Panel also emphasized in their report that, in order for any cost savings to be realized, some sense of stability, in funding, design, and management, was absolutely mandatory. How well this requirement is met will likely determine the quality and utility of the space station finally produced.

Space Station Alpha

Toward the end of the redesign process, it became clear that the Russian Space Agency was extremely interested in joining the Space Station Freedom effort. Since then it has also become clear that the Clinton administration is just as interested in involving the Russians, in order to, among other things, provide another channel for financial aid to the struggling Russian economy. As no firm commitment was made before the end of the redesign effort and given the interest on both sides, it was only a matter of time before another redesign would be required to provide for Russian involvement.

The Redesign Team did assume a certain amount of Russian participation. The ACRVs were almost from the beginning assumed to be the Soyuz vehicle, and one of the chief advantages of the higher inclination orbits was the possibility that Russian launch vehicles could reach it. The redesign effort did not, however, examine the repercussions of Russian involvement comparable to that of the other international players. As a result, the systems engineering required for sensible use of Russian capabilities went largely undone.

Space Station Alpha represents a massive shift of policy from that which led to the redesign effort in the first place. The portion of this new design provided by the United States is far closer to the Freedom baseline than to the designs presented by the Redesign Committee. Added to this fully operational space station will be elements of the Russian Mir-2 station. The resulting hybrid is being presented as improved, providing greater capability for less cost and risk.

There are two versions of Space Station Alpha that are being discussed. The first is a revised version of Option A-1, with both Bus-1 and the Russian Salyut FGB being considered as candidates for the "space tug" that would provide the propulsion and GNC functions on the revised space station. Salyut is superior to Bus-1 for this purpose, in that it has the capability of controlling the station sufficiently and can be refueled on orbit, but, in the case the Russian Space Agency is unable to fulfill their obligations, the Bus-1 would be a possible backup.

The station would be placed in a 51.6 degree inclination orbit and will therefore require either the Al-Li external tank or the ASRM for assembly. In virtually all respects not related to propulsion or GNC, this version of

Station Alpha is identical to the baseline Freedom design, although NASA is claiming some cost savings from "subsystem simplifications,"[14] most notably in the data management and thermal subsystems.

The other version of Space Station Alpha utilizes elements from the Russian Mir-2, the planned replacement for the current Mir station, in addition to the space tug. In both cases, NASA claims, the basic configuration for Space Station Alpha remains unchanged. This new Space Station will cost 19 billion dollars and will be complete by 2003. In a report to John Gibbons, the Presidential Advisor for Science and Technology, NASA claims that the Space Station Alpha design both simplifies the design and "avoids costly redesign."[15]

Evaluation

The proposed use of a "space tug" is an excellent idea. The inclusion of the Salyut FGB solves most of the problems inherent in Option A-1, as described above: the need for costly redesign of Bus-1 (which would make its extensive on-orbit database irrelevant), the difficulty of refueling, and the questions regarding its control moment capacity. If, however, Salyut becomes unavailable, whether from political or economic turmoil or any other reason, the Bus-1 could be used as a replacement. In an emergency, the original Freedom baseline subsystems would also insure lower programmatic risk. In all, the possibility of acquiring Salyut for the space station makes the Freedom program, and Option A-1, significantly more robust.

This, however, is virtually the only positive aspect of the Space Station Alpha redesign. In many other respects,

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[14] Goldin, et. al. Alpha Station Program Implementation Plan, iii.
[15] ibid.

the claims made for it are woefully inaccurate. First, NASA is claiming lower costs from the Freedom Baseline resulting from Russian participation and the avoidance of redesign. It is unclear, however, how the creation of a complete new set of interfaces, both technical and managerial, can be created without redesign. Integration with Russian elements will be a significant problem, especially as the design will not be finalized until it is already well into development. In summary, it is difficult to believe any projected cost savings claimed by NASA resulting from Space Station Alpha when no one really knows exactly what Station Alpha is.

Another claim made for Space Station Alpha is that it has a lower programmatic risk. This assertion is based on the fact that the basic configuration is independent of what form the Russian participation takes. The Station Alpha conception, however, seems almost designed for schedule slippage; NASA is already estimating that the Space Station will not be complete until the year 2003, two years later than original estimates for the Freedom Baseline. In addition, as the form Russian participation will take will not be finalized until well along into the design, it is not unreasonable to expect an integrations nightmare. This will only be made worse by the fact that, given the fact that many parts of the baseline design are already at critical design review, a great deal of manufacturing may well take place before the design is finalized. All of this factors indicate a much higher programmatic risk than is assumed.

In addition to the technical problems discussed above, the Russian involvement leads to significant management and contracting difficulties. These issues are, of course, more prominent in the "unified" design, in which Mir-2 components will replace some Freedom systems. It seems inevitable that a parallel management structure will result, undoing all of the improvement that resulted from the recommendations of the Redesign Committee and the Blue Ribbon Panel. There also remain significant questions regarding the role of NPO Energia and how it will be worked into the already revised contracting structure.

Summary

In conclusion, it appears more and more that NASA and the administration have little or no idea of what exactly is desired from a space station. What began as an attempt to streamline the Freedom Program has developed into an ill-defined design that will, in all likelihood, cost more and take longer to produce. It is unclear that the inclusion of the Russians in such a haphazard manner will provide any additional functionality or cost reduction, while incurring sizable programmatic risk. In short, Russian involvement must be rethought and a design finalized before the uncertainty and confusion destroys the Space Station program.

Russian Involvement

With the design for the space station essentially returning to the baseline, the only important products of the redesign effort resulted from the addition of Russian involvement. As the only design driver to actually result in sizable changes from the baseline, one would hope that Russian involvement was implemented rationally and intelligently. Unfortunately, while some improvements did arise from this, the full ramifications of Russian involvement were not sufficiently considered.

There were two major Russian elements included in the redesigned Space Station Alpha. The first of these was the inclusion of the Soyuz capsule as an ACRV. The second was the replacement of the baseline GNC and propulsion subsystems with the Salyut FGB. These changes were well thought out and carry little programmatic risk. Indeed, it was widely accepted that Soyuz would be utilized as the ACRV even before the redesign began.

From a political and philosophical perspective, the inclusion of the Russians is a breakthrough. The symbolic value of the U.S. and Russia cooperating in space, formerly an arena for intense conflict, is obvious. In addition, it is also a step toward actually implementing international cooperation in space, a stated goal of the redesign effort.

Before the redesign effort, the U.S. had been adamant in refusing to allow any other country in the critical design path. The U.S. portion of the Space Station would be complete in and of itself. The European partners and Japan would contribute experimental modules, providing extra laboratory volume, and Canada, a remote manipulator. But the U.S. would also provide a laboratory module, and the functions of the Canadian contribution could be met with the

Shuttle arm. In effect, the International "Partners" were largely accessory to the program, not fully integrated into the development process. This policy hardly seems to be designed to promote international cooperation in space in any meaningful way.

In the redesigned Station Alpha, the Russians are now in the critical design path, supplying GNC and propulsion as well as the ACRVs. Certainly the U.S. will consider the use of Bus-1 and additional Shuttles respectively in the case of total collapse of the Russian space program, but finally an international partner is involved in some critical part of the design. In addition, the Russians will be counted upon the provide additional station access capability (in the event of a Shuttle failure), and there is still an argument ongoing over the use of Russian launch vehicles for assembly flights. All in all, the addition of the Russian elements has been a step toward the international cooperation in large space programs that more and more people consider necessary, although at the expense of antagonizing the other International Partners.

The conception of Russian involvement in the Space Station Freedom program is flawed, not technically, but at a programmatic level. The addition of the Russians offered an opportunity for NASA to reduce the cost of the space station significantly. These possibilities went largely unrealized due to the redesign team's focus on purely technical issues and its inability or refusal to attack the specifications that they were given.

The research planned for the space station can be divided into microgravity and life science experiments. The life science experiments are extensions of the work that had been done previously by the Russians on the Mir station. Space Station Freedom's life science capabilities have received some criticism, primarily from Russian cosmonauts, saying that no new experiments will be accomplished.

Regardless of how complete you consider the Russian life science experiments, it is certainly true that Mir was designed primarily with the life sciences in mind. The recent agreement with Russia allowing U.S. astronauts to utilize Mir raises the possibility of using Mir for some of the life science experiments envisioned for Space Station Freedom. While Mir's technical capabilities are inferior to the proposed station, it could certainly be used to supplement Freedom and alleviate scheduling problems in the event of a conflict. In addition, it would possibly provide convenient storage for some spare equipment.

It is anticipated that Mir, although not as well maintained in recent years as before the breakup of the Soviet Union, still has several years of use left in it. The current plan for American utilization of Mir facilities provides for experiments upon Mir up until Space Station Freedom is operational. As it seems increasingly likely that there will be some schedule slippage in the Freedom program, this will provide a database of up to six years, easily large enough for the experiments currently envisioned. The resulting database might even be more valuable, as it would not be interrupted by the microgravity experiments under some time-sharing program. This would allow the Space Station to be designed as primarily a platform for microgravity experiments, with life science information being an added benefit, but of secondary importance.

An important result of such a change would be the focus that it would bring to the design. The Space Station has been haunted throughout all of its incarnations by a lack of quantifiable and justifiable specifications. Such a drastic change in the purpose of the Space Station would allow for well-defined and well understood specifications. This, in turn, would lead to a more intelligent design that would be much cheaper to assemble and operate and would have a much lower programmatic risk.

Conclusion

In conclusion, I would like to return to the four programmatic objectives discussed in my introduction, which, I believe, are largely unfulfilled by the current program. The first of these was to "perform significant long-duration space research in materials and life sciences." The current design, Space Station Alpha, will have significant capacity for such research. The question that has not been addressed by the redesign is whether the space station needs to be able to carry out all of the promised experiments at once. If the timesharing issue is not addressed fairly early in the design process, the resulting Space Station will either be unable to carry on all of the planned experiments or will not be utilized to its fullest capacity.

The second object was to promote international cooperation in space science and technology. The previous chapter discussed the benefits in this area which result from the inclusion of Russia in the Freedom program. This is a sizable step in the right direction. The Redesign Effort has not, however, been without setbacks in the area of international relations. The initial International Partners were united in expressing their discontent over another in a long series of redesigns by the U.S. Every time the Space Station is redesigned, they are forced to spend additional money to adapt to it. Perhaps justly, they consider this redesign as a sign of a lack of respect and consideration on the part of the U.S. toward their space programs.

The third object of the Redesign Effort was to encourage industry to invest in space science experiments. While the Redesign Team did put some effort into understanding the interface with users, it is hard to believe that industries, which have been notoriously conservative in their investments in space science, will be motivated to invest in a program which has been burdened by so many problems and which, even ten months after the redesign began, has little design stability. If the Space Station produces valuable scientific results, this attitude may change, but progress in this area will certainly be gradual.

The final avowed objective of the Freedom program was to determine the feasibility of continuing manned space exploration. The jury is still out on this issue and will remain so until the Station is actually operational. The only point that can be made at this stage is that the more time that is spent in redesign, the longer it will be before any such information will be available.

It seems clear that the Space Station that has emerged from the Redesign Effort does not directly address the issues that it is purported to target. The source of this problem was a lack of understanding of the specifications for the Space Station. Instead of seeking to understand the motivations for the numbers (lifetime, power requirements, etc.), the redesign team blindly accepted them, perhaps because the motivations for these numbers have been lost since the early stages of the Freedom program.

For whatever reason, the Redesign Team was content to design to the numbers that they were given, and, as a result, they made what amount only to purely cosmetic changes in the design, when changes on a much deeper level were necessary to retarget the goals which were claimed for the Space Station.

The development of the Space Station has now been halted for almost a year with little fundamental change in the design to show for it. The design is only now beginning to stabilize. Critical elements have been replaced with Russian equipment. The simplifications that the Redesign Team made in the management and contracting structures will be complicated by dealing with the Russian Space Agency and NPO Energia. Every day spent, along with the time spent in transition between designs, in further redesign will increase the cost of the program. Despite the time and money spent in redesign, NASA persists in claiming for the new Space Station Alpha sizable cost reductions and an earlier date for full operational capability. It seems certain at this point that some sort of space station will be built, one that, in all likelihood will meet the numbers which were specified in the Redesign, but in light of such claims, it is difficult to place any confidence in NASA's cost and schedule estimates for the station, its scientific value, or NASA itself.

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