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Paper Session III-B - Utilization of Common Pressurized Modules of Space Station Freedom

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Utilization of Common Pressurized Modules on Space Station Freedom

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Abstract

Typical of past space projects following preliminary design review, most of the major Space Station critical subsystems will be required to reduce costs, weight, and power consumption prior to flight article hardware production. One such subsystem consists of the pressurized modules which provide the environment in which the crew members live and work. The current baseline station has two types of U.S. pressurized vessels: four resource nodes, and two modules 44 feet in length which must be transported to orbit nearly empty due to structural weight alone. Thus, user and system racks must be outfitted on–orbit rather than integrated on the ground.

In this feasibility study, a shorter common pressurized module concept is assessed. The size, transportation, location, and accommodation of system racks and user experiments are considered and compared to baseline. It is shown that the total number of flights required for station assembly can be reduced, assuming both nominal Space Shuttle capacity, as well as Advanced Solid Rocket Motor capability. Baseline module requirements regarding crew size and rack accommodation are preserved. Considering the criteria listed above and current weight estimates, a six module option appears optimal. The resulting common module is 28 feet in length, and, in addition to two end cones, contains three radial ports near one end, which allows for a "racetrack" configuration pattern. This pattern exhibits several desirable attributes, including dual egress capability from any U.S. module, logical functional allocation distribution, no adverse impact to international partner accommodation, and favorable air lock, cupola, Assured Crew Return Vehicle, and logistics module accommodation.

Introduction

The currently baselined Space Station Freedom (SSF) pressurized volume primarily consists of two uncommon 44 foot U.S. modules as well as two different length international modules connected using four resource nodes. The pressurized volume provides the environment in which the Space Station crew works and lives and comprises a major portion of the Space Station program. In July of 1990, a feasibility study was initiated to assess alternate module and module pattern approaches based on the current Space Station assembly element weights and the current Space Shuttle upmass limits. The overriding emphasis of the study was to evaluate technical simplification concepts that would maximize ground verification and minimize on–orbit integration and check–out of station elements. This study focused on a shorter common pressurized module concept because it was determined that this approach was well suited to satisfying the goals of the study and reducing the cost of the pressurized volume.

Module Sizing

The first objective of this study was to establish the proper sizing of the pressurized module in terms of length. Historically, the 44 foot module length was driven by the size of the Space Shuttle cargo bay. The intent was to maximize the volume of the pressurized vessels and therefore the modules were designed to fill the cargo bay. The 14.5 foot module diameter, also cargo bay size driven, was preserved in this analysis. Modules with smaller diameters and the current internal layout concept would not provide a viable work and living environment for the Station astronauts. Maximizing the volume of individual modules was a reasonable initial approach. The idea was to bring up the module core structure and as many of the internal system and user racks as possible and then outfit, on orbit, the remaining user racks at a later date. However, this strategy utilizes a pressurized logistics module resulting in a considerable weight penalty when outfitting additional racks, because the logistics module acts simply as a carrier and is then returned to earth by the Shuttle. Unfortunately, continual increases in the module component weight estimates combined with decreases in the Space Shuttle's upmass capability have resulted in an empty module core structure weight close to the Shuttle lift capability. Thus, the 44 foot modules cannot be launched with even the minimal system racks to keep the module habitable. The outfitting and subsequent on–orbit verification of systems racks, along with the fact that astronauts may have to wear pressurized suits initially in the modules, significantly detract from the 44 foot module concept in light of the increased weights and reduced Shuttle capability.

The primary driver for module sizing was to minimize the number of flights required to assemble the module pattern. A secondary objective was to assess the sensitivity of the selected module size to potential increases in the module element weights. Finally, the selected module size was compared to the baseline configuration to determine and demonstrate the advantages of a shorter common module.

In performing the analysis for this study three major ground rules were incorporated. The first was that each module would be composed of common elements in terms of weight, length, and number. Each module would possess the same number of radial ports and identical port positions for each module. However, the interior arrangements of each module could be different to accommodate the various functions that each module is designed to perform. The second ground rule assumed that the module core and all vital systems racks must be launchable utilizing the baseline Space Transportation System (STS) lift capacity of 32,000 lb. All parametric analysis involving the use of the Advanced Solid Rocket Motor (ASRM) assumed an additional 10,000 lb. of capability compared to the baseline STS. The final ground rule maintained the current number of system and user racks in the baseline configuration (104 racks), and accommodated the eight crew members.

A range of feasible common module lengths was determined based on the 104 rack ground rule. A racetrack of common modules shorter than the baseline modules could realistically be accomplished with three different combinations. The first was four modules each 37 feet in length. Although possible, this option was not studied in depth due to the fact that it provided extremely little margin for system rack and core weight increases. Even slight increases in these weights would force a violation of the ground rule requiring that each module must be launched with all vital system racks integrated on the ground. The other two combinations consisted of five 33.25 foot long modules and six 28 foot modules. Both of these options were considered viable. Other common module combinations involving more than six modules, although within the STS launch capability, presented too many problems to be considered feasible. For example, a large number of modules forced an undesirable allocation and duplication of system racks, an excessive number of module–to–module connections, and a total launch weight greater than that of the baseline racetrack.

Weight sensitivity analysis was performed on both the five and six common module options. The 33.25 foot module consisted of four radial ports (two at each end located 90 degrees apart). Each module could accommodate 22 standard Space Station double racks (42 inches wide). The 28 foot module was made up of three radial ports located at one end, spaced 90 degrees apart, and could accommodate 18 double racks per module. Figures 1 and 2 illustrate the two module lengths examined in this study. Two weight cases were examined during this study. The first set of weights was based on the weights as described in the SSF Level II PDRD weight targets database (December 1989), subsequently referred to as the "baseline" weights. The second set of weights was derived from the baseline weights in order to determine a reasonable upper limit on the weights. This "maximum" weight case incorporated a 15% contingency on portions of the module core structure, increases in both system and user rack average weights (22% and 52% increases respectively), and increased flight support hardware weight. A summary of these weights is shown in Table 1.

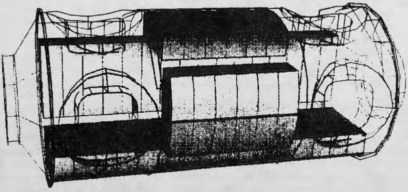

Figure 1 Five Common Module Layout

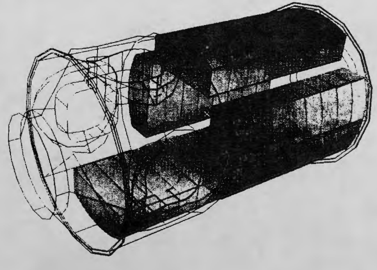

Figure 2 Six Common Module Layout

Table 1 Module Weight Assumptions

		Baseline Weights	Maximum Weights
Module Core Component Weights:	2 End Cones (lbs.)	4,700	5,405
	4 Radial Port Ring (lbs.)	7,210	8,292
	Cylindrical Section (lbs./ft.)	573	573
Standard Rack Weights:	Average System Rack (lbs.)	905	1,100
	Average User Rack (lbs.)	592	900
Flight Hardware Weights:	EVA Reserve (lbs.)	2,873	2,873
	Docking Module (lbs.)	1,550	1,850
	FTS/MSC Control Station (lbs.)	80	750
	Attach Fittings (lbs.)	1,100	1,100
	Flight Support Equipment (lbs.)	250	250
	Fluids & Gases (lbs.)	300	300

Figure 3 compares the weight breakdown of a single module for the five and six module options and shows how the total compares to the Space Shuttle lift capability to Space Station altitudes. Each column represents the total weight on–orbit for a *single* module using both the baseline and the maximum weight assumptions. This total weight is comprised of the module core structure, system and user racks (based on an average rack weight), a 5% managers reserve, and all required flight support equipment. The first two columns, derived from the baseline weights, show that the six module option can be completely integrated on ground and meet the baseline STS mass limits (with about 4,000 lbs. of margin), while the five module option requires the off–loading of some user racks (approximately 2,500 lbs.). Assuming baseline weights, either option could be launched fully outfitted using STS with ASRM capability and possess considerable mass margin.

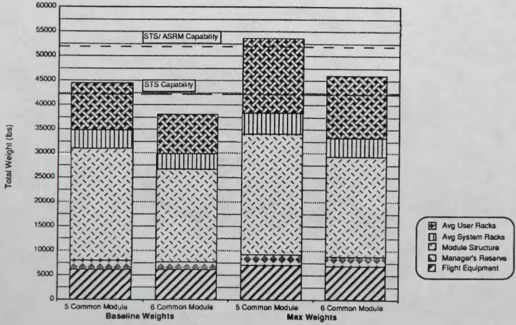

Figure 3 Common Module Comparison: Weight Sensitivity (104 Racks)

The second set of columns, based on the maximum weights, shows that neither option can be fully outfitted using the STS capability. Even with ASRM capability, the five common module option cannot be fully outfitted on ground while the six module option can be fully integrated and still maintain approximately 5,300 lb. of margin.

A comparison of the number of flights and the number of delivered racks was performed for each option and compared to the baseline configuration. (It should be noted at this point that only the basic U.S. pressurized volume was assessed in this section of the study. The International modules, cupolas, airlocks, etc. were excluded due to the fact that they are common to any option as well as the baseline.) Based on an STS upmass capacity of 32,000 lb. and the baseline element weights, Figure 4 demonstrates the efficiency of each option to deliver the most usable volume, in terms of number of racks, in the least number of flights. Additionally, a comparison of the resulting mass launched in support of the baseline racetrack and both common module options is shown in Table 2. Additional considerations for assembly operations, such as Shuttle center of gravity constraints, were also accounted for in determining the number of flights for each configuration. Based on the reference weights, both common module options and the baseline configuration

Table 2 Total Upmass Comparison – STS Capability and Baseline Weights

	Baseline	5 Module	6 Module
Racetrack Weight (lbs.)	187,500	184,200	185,900
Flight Equipment Weight (lbs.)	52,500	40,900	35,100
Logistics Module Weight (lbs.)	41,500	20,700	0
Total Upmass (lbs.)	281,500	245,900	221,000
Number of Flights	9	7	6

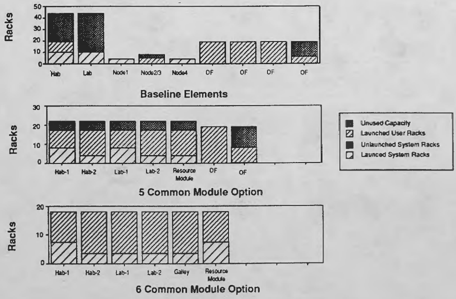

Figure 4 Flight Efficiency Comparison – STS Capability and Baseline Weights

are capable of launching all system racks fully ground verified. However, due to the weight of the core structure, the baseline modules are launched relatively empty of user racks and require four outfitting flights. The five common module requires two less outfitting flights, while the six common module option has *all* system and user racks ground integrated. Overall, nine flights are required for the baseline elements, seven flights for the five common module option, and six flights for the six common module option. There is some margin on the outfitting flights of the baseline and five module option, which could be utilized to transport other Space Station elements and/or supplies during assembly. The upmass comparison illustrates the increased mass penalty of the four outfitting flights required for the baseline configuration, and the reduction of required upmass for the common module approaches. The racetrack weights for all configurations are approximately equal, but the total upmass of the baseline station (281,500 lb.) is approximately 15% greater than the five module option (245,900 lb.) and 27% greater than the six module option (221,000 lb.). This decrease in upmass associated with both common module options allows a substantial reduction in the total number of flights required when compared to the baseline Station.

Figure 5 is similar to the previous example, however the maximum weight estimates are used. The effect of these increased weights is that the baseline modules cannot be launched with all system racks ground verified. This would require on–orbit integration of critical life support functions in the Station before Man–Tended

Table 3 Total Upmass Comparison – STS Capability and Maximum Weights

	Baseline	5 Module	6 Module
Racetrack Weight (lbs.)	221,000	222,900	224,600
Flight Equipment Weight (lbs.)	68,000	61,200	54,500
Logistics Module Weight (lbs.)	51,800	41,500	20,700
Total Upmass (lbs.)	340,800	325,600	299,800
Number of Flights	10	9	8

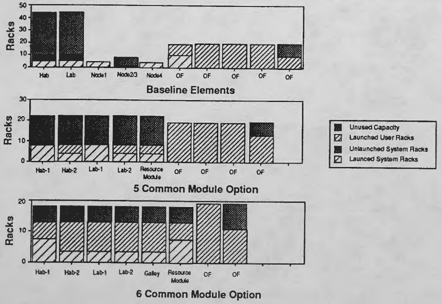

Figure 5 Flight Efficiency Comparison – STS Capability and Maximum Weights

Capability (MTC) would be possible. The only effect on either common module approach would be to off–load several user racks. This case clearly shows the robust nature of the common module options compared to the baseline configuration. The total upmass comparison (Table 3) shows that the racetrack weights of all of the options are again approximately equal. However, for this set of weights, the total upmass for the baseline station (340,800 lb.) is still 5% greater than the five common module option (325,600 lb.) and 14% greater than the six module option (299,800 lb.). The result is that the six module option can be launched in eight flights while the baseline Station requires a total of ten flights.

Finally, Figure 6 details the flight efficiency based on ASRM capability and the maximum weights. While the increased lift capacity benefits all three options, the common module options are able to realize a more substantial decrease in the total number of flights. Slightly more than eight flights are required for baseline, while only six Space Shuttle flights are required for either of the common module options. Again, for the baseline Station, there is a substantial penalty for the extra outfitting flights required to complete the racetrack. The total upmass, shown in Table 4, of the baseline station (323,800 lb.) is 18% greater than the five module (274,200 lb.) and 22% greater than the six module (265,500 lb.) options.

Table 4 Total Upmass Comparison – STS with ASRM Capability and Maximum Weights

	Baseline	5 Module	6 Module
Racetrack Weight (lbs.)	221,000	222,900	224,600
Flight Equipment Weight (lbs.)	61,300	40,900	40,900
Logistics Module Weight (lbs.)	41,500	10,400	0
Total Upmass (lbs.)	323,800	274,200	265,500
Number of Flights	9	6	6

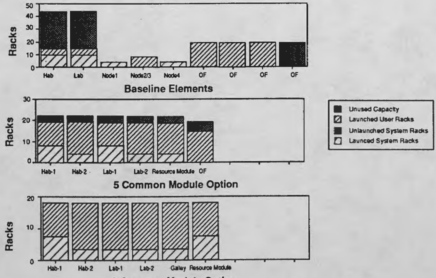

Figure 6 Flight Efficiency Comparison – STS with ASRM Capability and Maximum Weights

While there exist substantial differences in the total mass that is launched in order to complete the pressurized portion of the Space Station, there is actually a slight increase in the amount of rack space and the number of ports available for the common module options versus the baseline module pattern.

Module Pattern

Many factors influence how the modules are arranged on Space Station. A high priority consideration is safety. Criteria such as providing dual egress or sufficient safe havens throughout the pattern drive the design of the module configuration. As mentioned previously, the assumption of commonality among the modules affected how the modules could be arranged due to the number and location of radial ports. Another primary consideration was the desire to not impact international module accommodation, location, or dimensions. The module pattern also must not present any operational problems relating to assembly operations. Similarly, the pattern must be able to accommodate two docking module mechanisms, preferably without the need for internal pressurized bulkheads, and ideally allow for two Orbiters simultaneously. The configuration should facilitate all aspects of logistics module accommodation. The optimal module pattern configuration should be able to accommodate an evolutionary growth path which preserves microgravity, pointing, controllability, etc., suitable for a wide variety of research or transportation node missions. The module arrangement must provide for dual cupolas, positioned optimally to observe docking and EVA operations, as well as one or more air locks with appropriate clearances and proximity to any attached support structure. The module pattern should be arranged such that the accommodation of one or two Assured Crew Return Vehicles (ACRV) is not precluded. Ideally, the ACRVs should not be attached to the same module, and the locations should facilitate ease of approach and departure. Finally, the pattern should avoid the introduction of any new module pattern elements such as nodes on tunnels.

The two candidate module patterns developed for the module options are shown in Figure 7. Four U.S. modules form the basic racetrack and a fifth U.S. module is attached below the racetrack for the five module configuration, while all six U.S. modules are required to form the complete racetrack for the six module pattern.

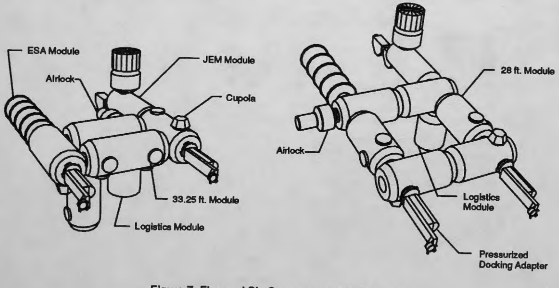

Figure 7 Five and Six Common Module Patterns

For both patterns, two pressurized docking adapters and two cupolas are positioned in the same manner as on the baseline station, and the two international modules are not adversely impacted – both configurations actually provide greater separation between the international modules over baseline. The airlock and pressurized logistics carrier are adequately accommodated in both configurations. Many other patterns are also possible, and various trade–offs, including flight control characteristics, should be performed to determine the best configuration.

Functional Allocation

The final area of concentration in this study was the functional layout of the system and user racks for each module option/pattern studied. Four major ground rules were observed in determining functional allocation for both the five and six common module approaches. The first was to maintain the current functionality or potentially improve the functional distribution of system and user racks on the baseline station. The second ground rule was to maintain the current level of outfitting specified for the baseline Assembly Complete Station (104 total racks). The third requirement was to satisfy all contingency requirements currently imposed on the baseline station. And the final goal was to create a rack distribution such that the total weight of each module was approximately equal to eliminate any relationship between internal distribution and launch capability.

Crew safety and pressurized element survival systems for Space Station Freedom must meet two failure tolerant criteria and adequate allowances must be made for crew survivability during orbiter down times. In this study, redundancy was accomplished through the use of module–to–module backup. Dependence on two primary elements to provide all life support functions, such as in the baseline 44 foot Hab and Lab, was eliminated. The crew can rely on environmental control from several locations throughout the Station with either common module approach. This lessens the overall crew impact if a pressurized element is lost, and provides more robust safe haven contingencies. In addition, the balancing of resource requirements across the elements reduces mechanical strain on any single critical system as exists in the current nodes.

Figures 8 and 9 pictorially illustrate potential functional allocations of system racks for both the five and six common module options. Both functional layouts attempt to minimize the potential impact of the loss of a single module to normal Space Station operations by distributing critical systems throughout the racetrack.

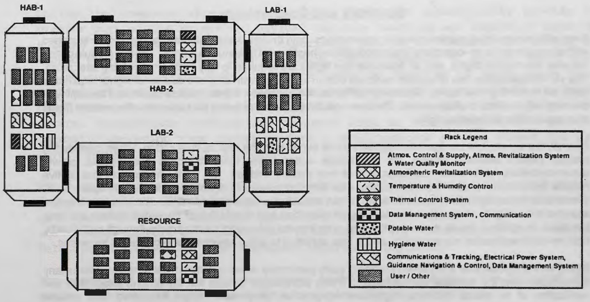

Figure 8 Functional Allocation of System Racks for Five Common Module Option

In addition, the modules are each allocated distinct functions, such as life science lab, microgravity lab, galley, habitation area, etc., in order to minimize adverse crew interference. The layouts simply demonstrate which system racks would reside in each module and do not depict actual placement of the racks. However, feasible detailed functional layouts were determined for both the five and six common module configurations studied.

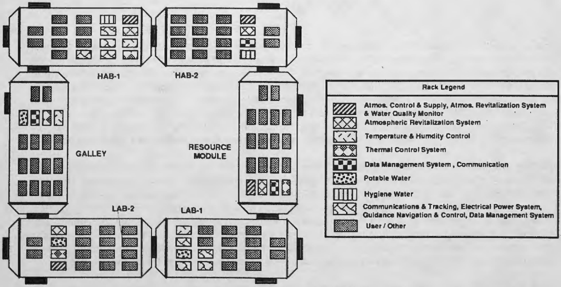

Figure 9 Functional Allocation of System Racks for Six Common Module Option

Summary and Conclusions

Even with conservative maximum weight assumptions, both the five and six module options can be launched with all system racks on–board and integrated utilizing baseline STS launch capability. The five module option requires five module flights, and an additional four flights are required to fully outfit all remaining user racks. The six module option has all system racks on orbit in six flights, with only two additional flights required to outfit the remaining user racks. Assuming ASRM launch capability, the six module option can be deployed on–orbit fully outfitted in six launches. The five module option also requires six launches – five module flights plus one additional logistics flight.

Overall, the six module configuration appears to be superior to the five module option. When considering module pattern selection criteria, the six module option yields more favorable dual egress, growth accommodation, ACRV accommodation, and air lock accommodation. It is worthwhile to note that the five module option has a closed racetrack pattern after only four assembly flights. The six module option is not closed until the completion of the sixth flight. When considering functional allocation, the six module option appears to be slightly more conducive to a logical allocation and distribution of on–board system and user functions. In addition, the six module option has more internal volume for rotating racks through radial ports, less on–orbit verification requirements, and is less sensitive to either structural or rack weight increases.

Based on the module size and pattern feasibility study performed, either common module option offers many advantages over the baseline configuration. These advantages include the on–ground integration and verification of all critical systems, significant margins for component weight increases, and module redundancy that translates into a robust division of system functionality. Although the cost impact of either common module approach was not conducted in this study, it appears reasonable that a savings could be realized due to the commonality of the elements.

Reference

Space Station Engineering Integration Contractor (SSEIC), "Space Station Stage Summary Databook", December 15, 1989.