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Utilization of Common Pressurized Modules on Space Station Freedom

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Introduction

During the preliminary design review of the Space Station Freedom elements and subsystems, it was shown that reductions of cost, weight, and on-orbit integration and verification would be necessary in order to meet program constraints, particularly nominal Orbiter payload launch capability. At that time, the Baseline station design consisted of four resource nodes and two 44 ft modules. In this study, the viability of a common module which maintains crew and payload accommodation of system racks and user experiments are considered and compared to Baseline. Based on available weight estimates, a module pattern consisting of six 28 ft common elements with three radial and two end ports is shown to be nearly optimal. Advantageous characteristics include a reduction in assembly flights, dual egress from all elements, logical functional allocation, no adverse impacts to international partners, favorable airlock, cupola, Assured Crew Return Vehicle (ACRV), and logistics module accommodation, and desirable flight attitude and control characteristics.

LEVEL 1 SYSTEMS ENGINEERING AND ANALYSIS

Utilization of Common Pressurized Modules on Space Station Freedom

January 31, 1991

Module Sizing

There are two primary considerations that influence the design of the manned pressurized elements: the *size* of the modules, and the arrangement or configuration *pattern*. The following section discusses the module sizing criteria, and the rationale for the final size recommended.

Module Sizing

Module Sizing Objectives

Because of cost considerations, the decision was made early in the study to assume a *common* module approach, until and if the analysis revealed any "show stoppers." The primary objective driving module sizing, also consistent with the desire to contain costs, was to minimize the number of flights required to assemble the module pattern.

A secondary objective was to assess the module size sensitivity to potential changes in the module element weights (e.g., structural weight, rack weight, flight related support hardware, etc.). Module sizes with little or no residual margin to accommodate weight increases were noted.

The final objective of the module sizing study was to compare the results obtained with the current baseline configuration, in order to serve as a "sanity check" and as a reference with which to compare.

Space Station Technical Simplification Feasibility Study

Module Sizing Objectives

- Minimize number of flights to assemble pressurized modules
- Assess sensitivities to weight changes
  - System and User Racks
  - Structure weight
  - Flight hardware (docking module, FTS/MSC, ...)
- Compare with Baseline

Module Sizing Ground Rules and Assumptions

In this study a common module approach was assumed, whereby all elements were identical in terms of weight, length, number and location of radial and end ports, etc.

A second driver on module sizing was that all *system* racks required per module to assure a viable pressurized volume must be launchable assuming the baseline STS lift capacity (32,000 lb). Implicit in this ground rule is the assumption that *user* racks may be off-loaded when utilizing baseline STS launches (Advanced Solid Rocket Motor launches which were assumed to supply an additional 10,000 lb of lift capacity were examined to determine accommodation of outfitted user racks during launch)

The third and final ground rule adhered to in the analysis was to provide or exceed the total number of system and user racks present in the baseline configuration (104), and to accommodate the 8 crew members.

Space Station Technical Simplification Feasibility Study

Module Sizing Ground Rules and Assumptions

- **Assume common module approach**
- **Modules will be sized to accommodate all system racks assuming baseline STS lift capacity**
  - User racks may be off-loaded assuming baseline STS capability
  - User racks may be accommodated assuming ASRM capability (additional 10,000 lb lift)
- **Preserve :**
  - Crew Size : 8
  - Number US racks : 104 (2x44 + 4x4)

Module Weight Assumptions

This chart provides a breakdown of all weight assumptions made in this feasibility study. Two weight cases were examined during the study. The first set of weights was based on the Level II baseline weights as described in the Level II PDRD weight targets database (April, 1990). The second set of weights was based on maximum weight estimates directed by Level II for the purposes of this study. There are three major differences between the "Baseline Weight Case" and the "Level II Max. Weight Case". The first is a 15% weight contingency on portions of the module core structure, specifically the end cones and the radial ports. The second variation is an increase in the weights of both system and user racks for the maximum weight case over the baseline case. System rack weights increased from an average of 905 lb. to an average of 1100 lb. (22% increase) and user racks increased from 592 lb. to 900 lb. on average (52% increase). The third difference reflects a 970 lb. increase in flight support hardware over the baseline weights.

Space Station Technical Simplification Feasibility Study

Module Weight Assumptions

Baseline Weight Case:

1. Baseline Module Core Weights-
   No Structural Contingency
   - 4,700 lb. 2 End Cones
   - 7,210 lb. Radial Port Ring
   - 573 lb/ft Cylindrical Section
2. Baseline Rack Weights-
   - 905 lb. Average System Racks
   - 592 lb. Average User Racks
3. 5% Manager's Reserve
4. Baseline Flight Hardware
   - 2,873 lb. EVA Reserve
   - 1,550 lb. STS Docking Module
   - 80 lb. FTS/MSC Control Station
   - 1100 Attach Fittings
   - 250 lb FSE
   - 300 lb fluids & gases

Level II Max. Weight Case:

1. Baseline Module Core Weights-
   15% Structural Contingency
   - 5405 lb. 2 End Cones
   - 8,292 lb. Radial Port Ring
   - 573 lb/ft Cylindrical Section
2. Level II Maximum Rack Weights-
   - 1,100 lb. Average System Racks
   - 900 lb. Average User Racks
3. 5% Manager's Reserve
4. Level II Maximum Flight Hardware
   - 2,873 lb. EVA Reserve
   - 1,850 lb. STS Docking Module
   - 750 lb. FTS/MSC Control Station
   - 1100 Attach Fittings
   - 250 lb FSE
   - 300 lb fluids & gases

Common Module Number Sizing Progression

This chart explains the rationale for deciding the size and number of the common modules analyzed in this study. The number of modules and their length were driven by the ground rule of maintaining the number of racks in the current baseline program. The configuration consisting of three modules 54 feet long was found to be a limiting case because the modules became too heavy to launch using the baseline STS and could not fit into the shuttle cargo bay. A four module configuration could be launched but provided extremely little margin for system rack weight increases. Slight increases in the system rack weights would force a violation of the second ground rule which required launching the module outfitted with all required system racks. The five and six module options were considered feasible and presented in detail in this study. Module configurations of seven or more, although well within the STS launch capability, were determined to present too many problems to be feasible. A large number of modules would force an undesirable allocation and duplication of vital system racks. In addition, the total launch weight would be greater than the baseline racetrack. Finally, there would be a considerable break-up of logical rack groupings which would make the functional allocation of racks potentially undesirable.

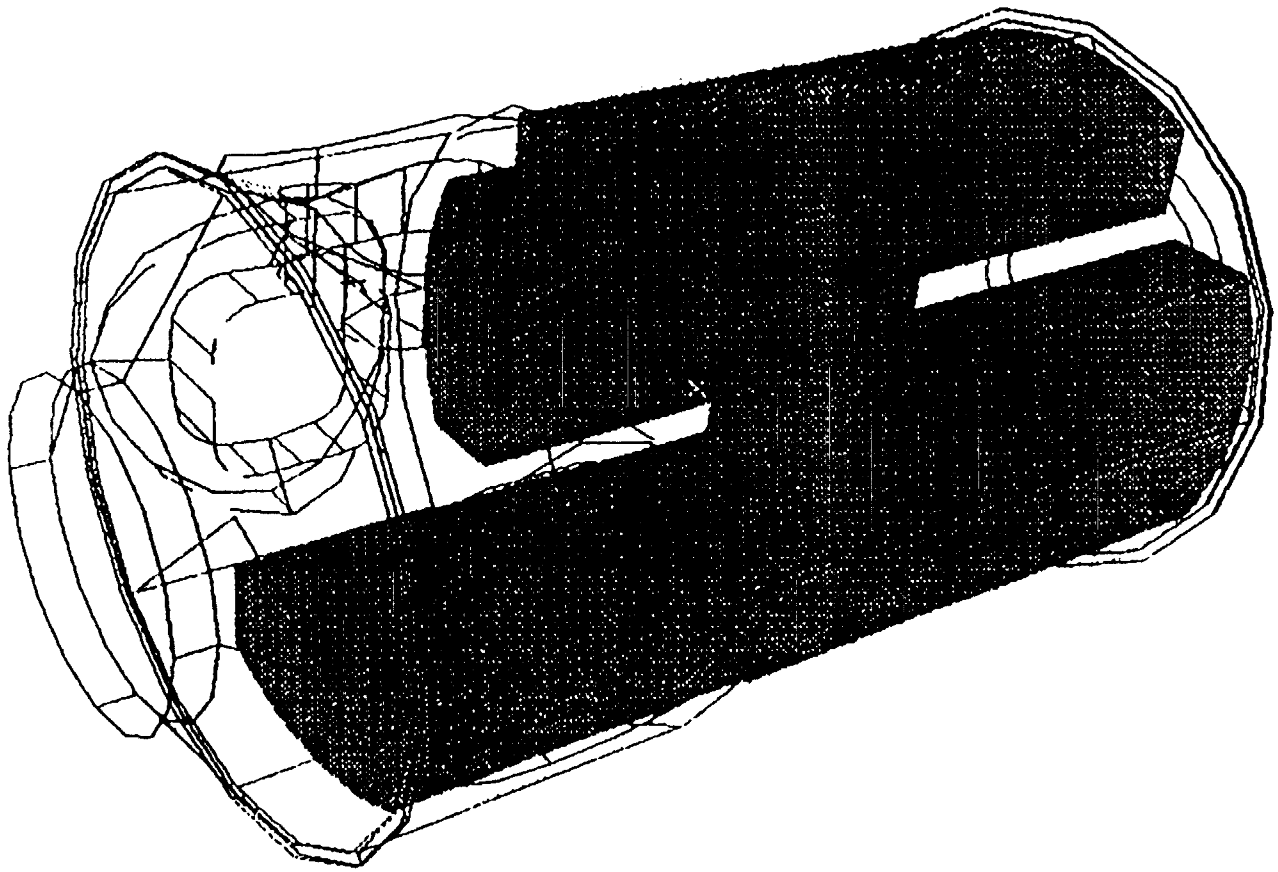
Common Module Number Sizing Progression

Number of Modules	Minimum Length	Total Racks	Pro/Con
3	54	108	• Too heavy to launch – module does not fit in cargo bay
4	37	104	• No margin for system rack weight increases
5	33.25	110	• Feasible
6	28	108	• Feasible
≥ 7	≤ 26.75	≥ 115	• Non-feasible allocation of system racks • Total launch weight greater than baseline • Considerable break-up of rack groupings

6 Common Module Option – Interior Layout

Shown in this illustration is the general internal layout for the six common module option. Each module has three radial ports and two end cones, and is approximately 28 feet long. Each module can accommodate a total of 18 double racks allowing for a total of 108 racks contained within the racetrack. Three sides of the module contain four double racks and the fourth side contains six double racks. There is additional room for a single rack along the fourth wall, but the additional single rack was not included in this study.

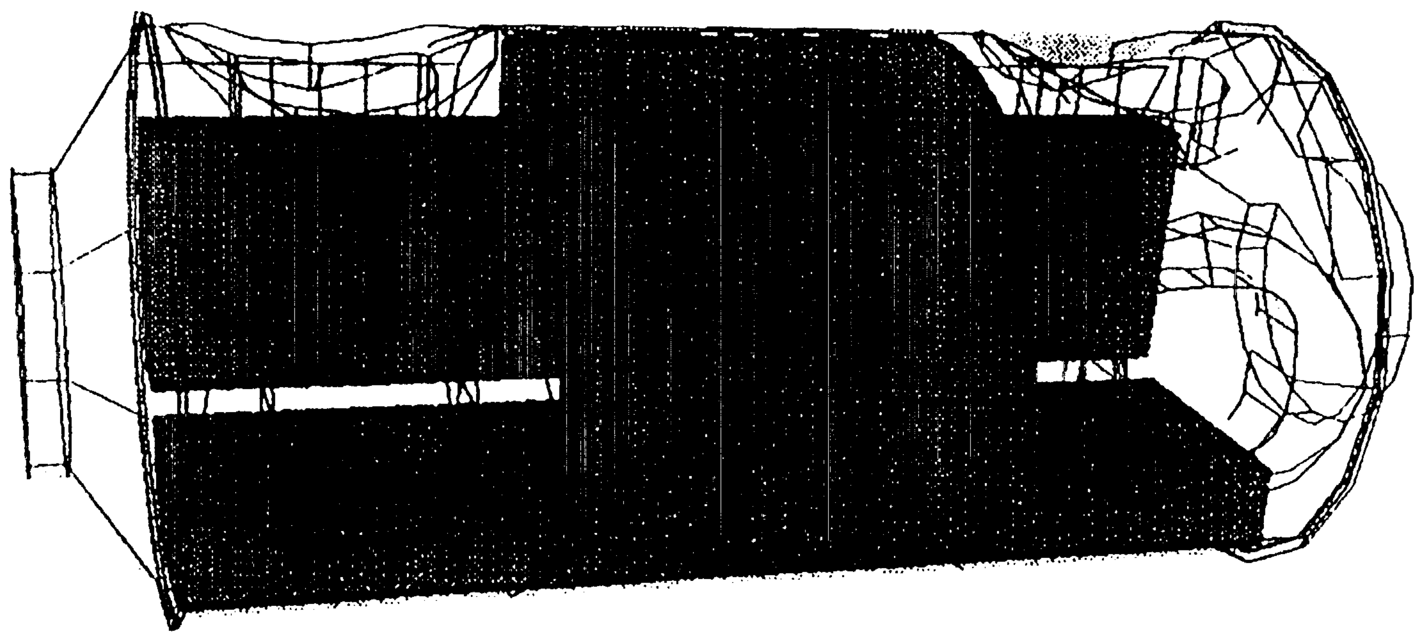
6 Common Module Option – Interior Layout



5 Common Module Option – Interior Layout

Shown in this illustration is the general internal layout for the five common module option. Each module has four radial ports and two end cones, and is approximately 33.25 feet long. Each module can accommodate a total of 22 double racks allowing for a total of 110 racks contained within the racetrack. Two sides of the module contain three double racks and the other two sides contains eight double racks.

5 Common Module Option – Interior Layout



Common Module Comparison
Weight Sensitivity

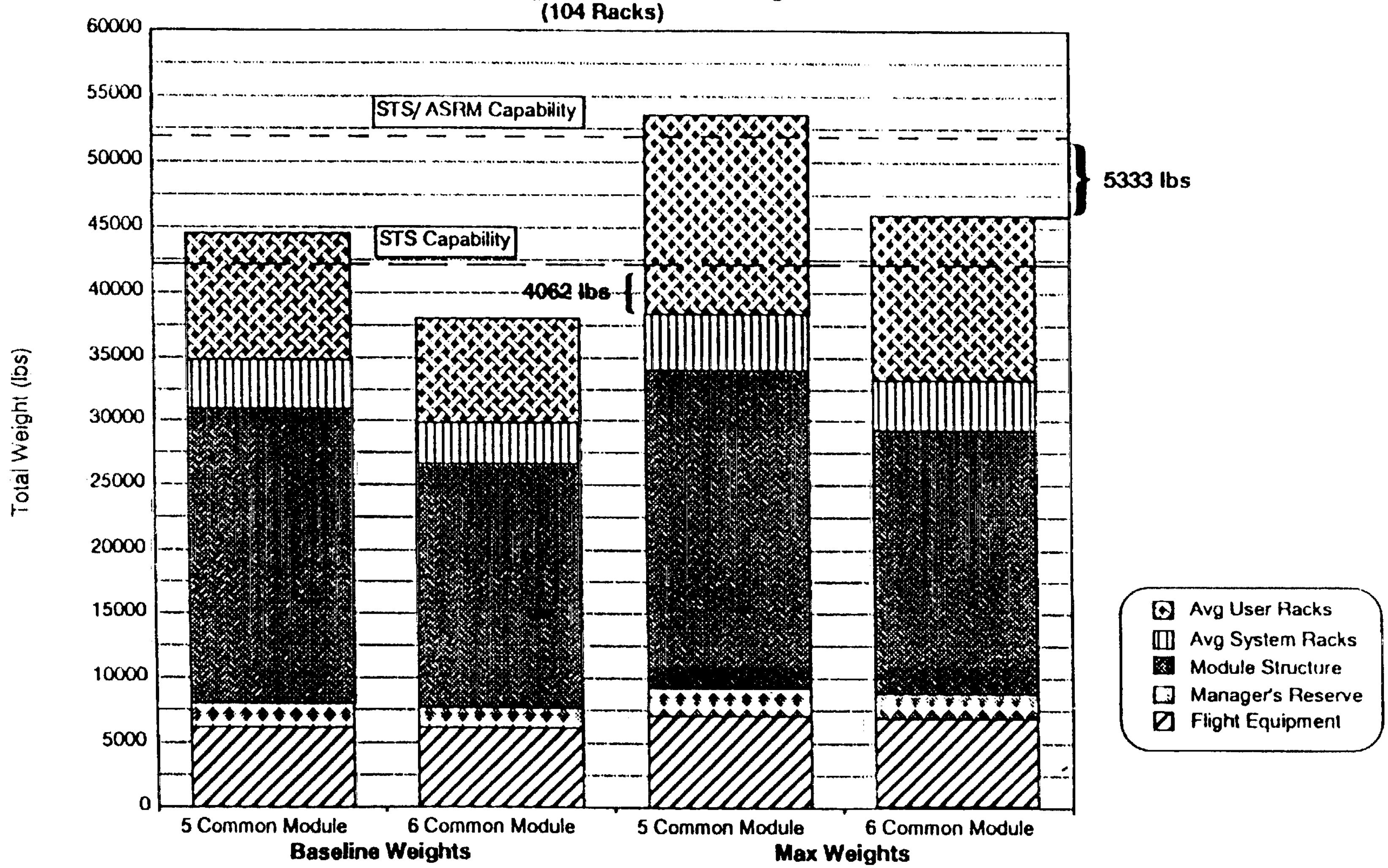
This graph compares the weight breakdown of a single module for the five and six module options and shows how the total weight compares to Space Shuttle lift capability. Two sets of comparisons are made, based on the Level II baseline weights as well as the Level II maximum weight estimates. Each bar represents the total weight to orbit for a single module. This total weight is comprised of the module structure, system and users racks (based on average rack weight), a five percent managers reserve, and all required flight support equipment.

The first two bars, based on 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 lb. of margin) while the five module requires the off–loading of some of the user racks (about 2,500 lb.). Assuming baseline weights, either option could be launched fully outfitted using a STS with ASRM capability and possess considerable mass margin. The second set of bars, based on Level II maximum weights, show that neither option can be fully outfitted using STS baseline capability. The five common module option allows all system racks to be integrated on ground but only allows approximately 4,000 lb. of user racks to be integrated assuming baseline STS capability. Even with ASRM capability, the five module option cannot be fully outfitted to 104 racks on the ground. Assuming STS/ASRM capability, the six module option can be fully integrated on ground and still maintain approximately 5,300 lb. of margin.

Common Module Comparison

Weight Sensitivity

(104 Racks)



5 Common Modules/ Max Wts/ STS → All System Racks with 4062 lbs Margin
6 Common Modules/ Max Wts/ ASRM → All Racks with 5333 lbs Margin

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STS Flight Efficiency
Common Module vs. Baseline
(Baseline Weights)

This graph compares the overall flight efficiency of the 5 and 6 common module approach to that of the SSF baseline pattern based Level II PDRD target weights and current STS lift capability (~ 32000 lbs). Additional considerations of assembly operations were also taken into account.

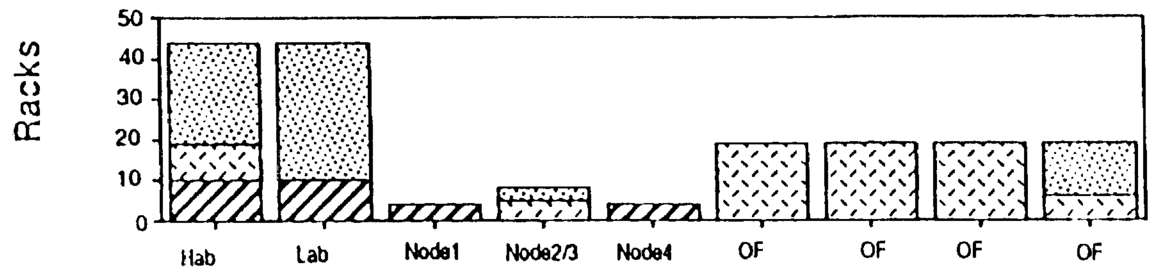
All three configurations are capable of launching all system racks fully ground verified, however, due to the weight of the primary structure, baseline modules are launched relatively empty and would require a little more than 3 pressurized logistic module (PLM) outfitting flights. The 5 common module approach is able to launch with more user racks than baseline, but again nearly 1.5 PLM flights are necessary to fully outfit. The 6 common module option can launch with all system and user racks fully ground verified and would not require any additional outfitting flights, and thus eliminates the penalty of launching the PLM (~ 10,000 lbs) to orbit.

Using these assumptions then, a total of 8.5 STS flights would be required to assembly and fully outfit the baseline elements, while only 6.5 and 6.0 flights are needed for the 5 and 6 common moudle approach respectively.

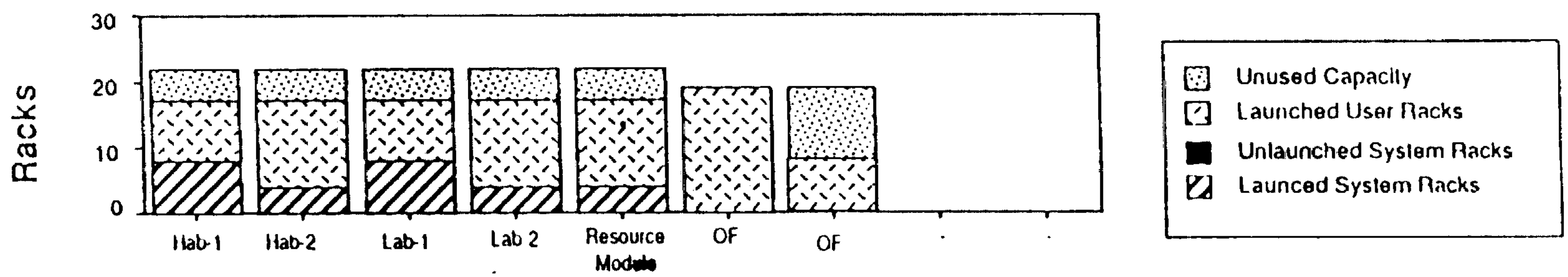
STS Flight Efficiency Comparison

Common Module Vs. Baseline

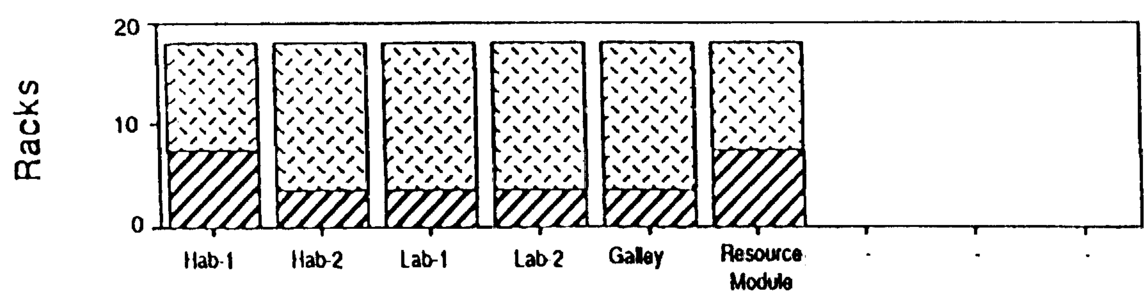
(Baseline Weights)



Baseline Elements



5 Common Module Option



6 Common Module Option

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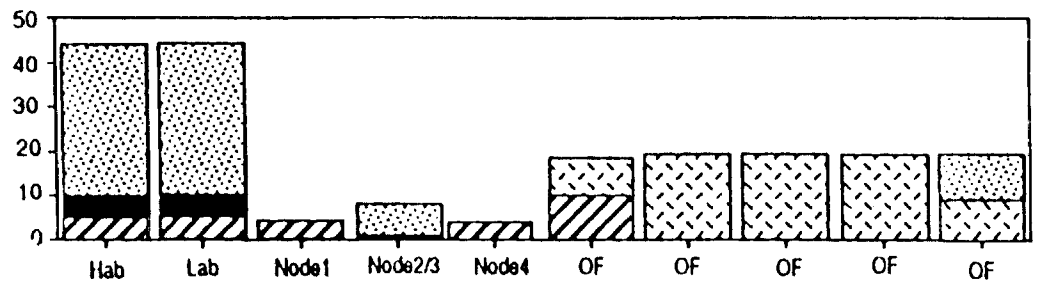
STS Flight Efficiency Comparison
Common Module vs. Baseline
(Level II Max. Weights)

This chart is similar to the previous example, however the Level II directed maximum weights were utilized in this comparison. The effect of these assumptions is that the baseline elements can no longer 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 Capability (MTC) would be possible. The only effect on the either common module option would be to off-load several user racks. This is another example of the weight sensitivity of the current Baseline approach versus either the five or six module option.

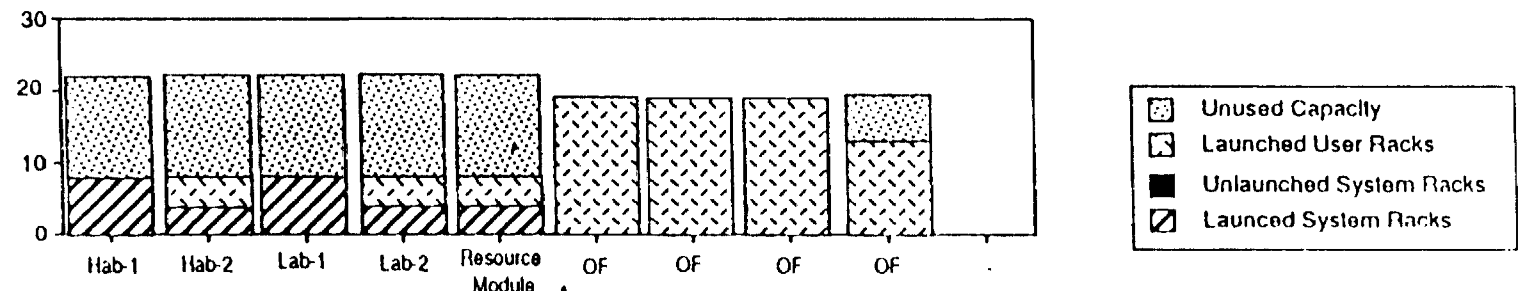
STS Flight Efficiency Comparison

Common Module Vs. Baseline

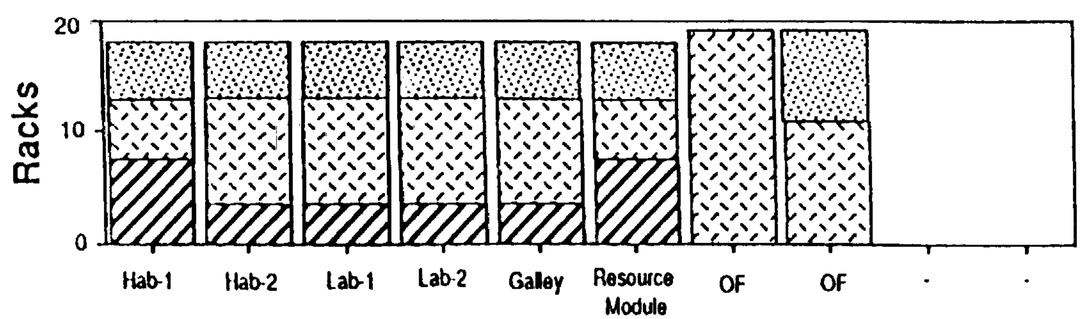
(Max Weights)



Baseline Elements



5 Common Module Option



6 Common Module Option

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STS/ASRM Flight Efficiency Comparison
Common Module vs. Baseline
(Level II Max. Weights)

This chart details the effect on all configurations if the STS with ASRM were available to the program. While the increased lift capability (estimated at 10,000 lbs) benefits all three options, the largest gain occurs for either common module because the total number of launches is decreased – approximately six launches for the common module option compared to approximately eight launches for the baseline elements.

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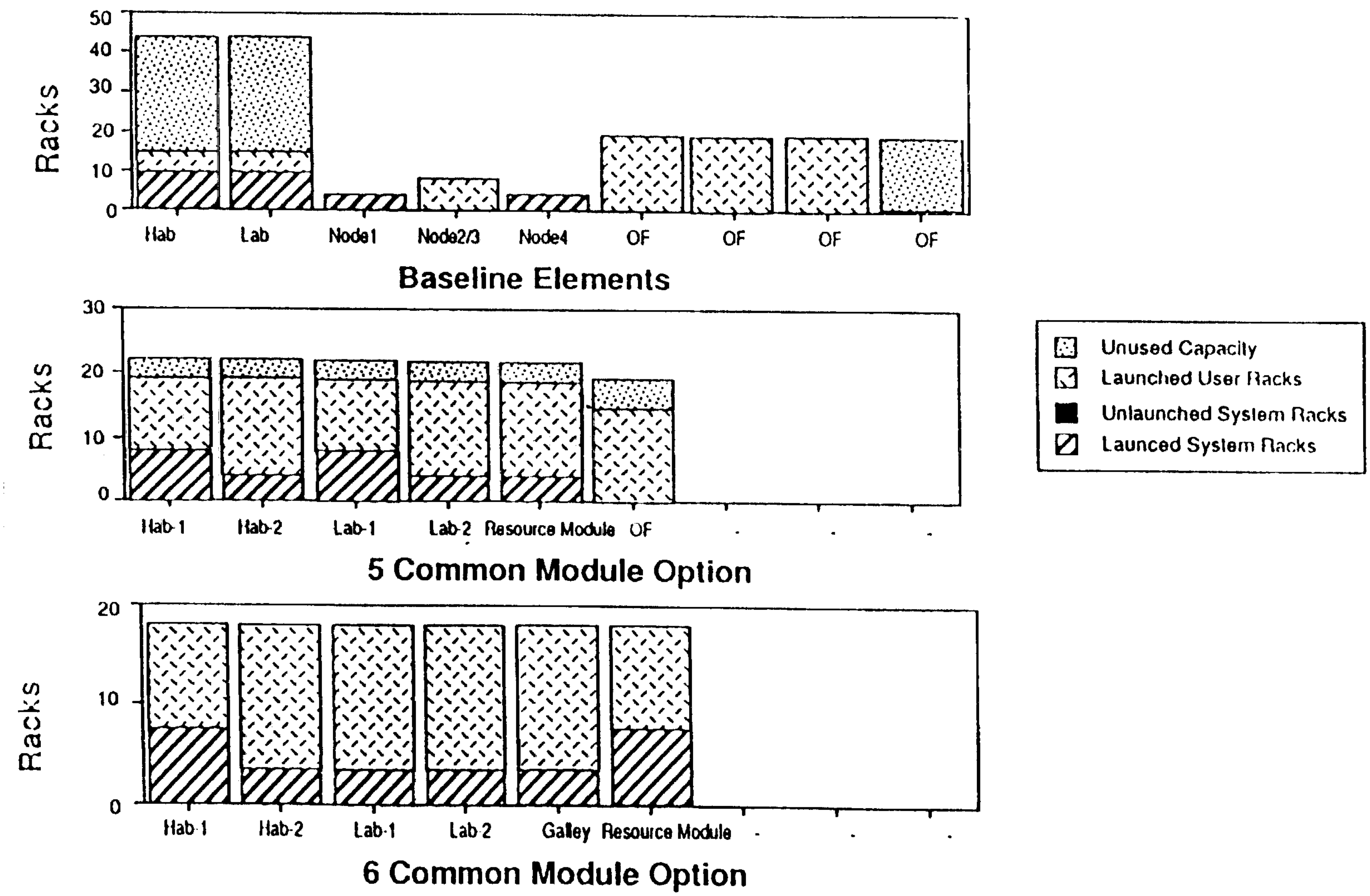
STS/ASRM Flight Efficiency Comparison

Common Module Vs. Baseline

(Max Weights)



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Total Upmass Comparison
Common Module vs. Baseline
(Baseline Weights and STS Capability)

This chart shows a weight comparison of the two common module options studied versus the baseline station racetrack weight. The mass totals are based on Level II baseline weights and the total number of flights are based on baseline STS capability. Structures such the cupolas, airlock, pressurized docking masts, etc. were not included in these mass estimates since they are assumed equal for all configurations. The chart illustrates the increased mass penalty of four outfitting flights required for baseline and the reduction of outfitting flights for both common module options. The racetrack weight of all configurations are approximately equal, but the total upmass of the baseline station (281,511 lb.) is approximately 15% greater than the five module option (245,802 lb.) and 25% greater than the six module option (221,003 lb.). This decrease in mass allows the six module option to be launched in six flights while the baseline racetrack requires a total of nine flights.

Total Upmass Comparison
Common Module Vs. Baseline
(Based on STS Capability and ***Baseline*** Weights)

	Baseline *	5 Module	6 Module
Racetrack Weight:	187518	184173	185885
Flight Equipment :	52529	40897	35118
Logistics Module Wt:	41464	20732	0
Total Upmass:	281511	245802	221003
Number of Flights	9	7	6

* Note: Remanifested to accommodate only module pattern weights within operational considerations.

Total Upmass Comparison
Common Module vs. Baseline
(Level II Max. Weights and STS Capability)

This chart shows a weight comparison of the two common module options studied versus the baseline station racetrack weight. The mass totals are based on Level II directed maximum weight estimates and the total number of flights are based on baseline STS capability. Structures such the cupolas, airlock, pressurized docking masts, etc. were not included in these mass estimates since they are assumed equal for all configurations. The chart illustrates the increased mass penalty of five outfitting flights required for baseline and the reduction of outfitting flights for both common module options. The racetrack weight of all configurations are approximately equal, but the total upmass of the baseline station (340,906 lb.) is approximately 5% greater than the five module option (325,600 lb.) and 14% greater than the six module option (299,882 lb.). This decrease in mass allows the six module option to be launched in eight flights while the baseline racetrack requires a total of ten flights.

Total Upmass Comparison
Common Module Approach
(Based on STS Capability and Level II *MAX* Weights)

	Baseline	5 Module	6 Module
Racetrack Weight:	221031	222877	224640
Flight Equipment :	68045	61259	54510
Logistics Module Wt:	.51830	41464	20732
Total Upmass:	340906	325600	299882
Number of Flights	10	9	8

Total Upmass Comparison
Common Module vs. Baseline
(Level II Max. Weights and STS/ASRM Capability)

This chart shows a weight comparison of the two common module options studied versus the baseline station racetrack weight. The mass totals are based on Level II directed maximum weight estimates and the total number of flights are based on STS capability with an additional 10,000 lb. of lift capability provided by the ASRM. Structures such the cupolas, airlock, pressurized docking masts, etc. were not included in these mass estimates since they are assumed equal for all configurations. The chart shows that the six module option can be fully integrated on ground and the racetrack can be completed in six flights. The charts illustrates the increased mass penalty of four outfitting flights required for baseline and the reduction of outfitting flights for both common module options. The racetrack weight of all configurations are approximately equal, but the total upmass of the baseline station (323,754 lb.) is approximately 18% greater than the five module option (274,144 lb.) and 22% greater than the six module option (265,578 lb.). This decrease in mass allows the six module option to be launched in eight flights while the baseline racetrack requires a total of nine flights.

Total Upmass Comparison

Common Module Approach

(Based on STS/ASRM Capability and Level II *MAX* Weights)

	Baseline	5 Module	6 Module
Racetrack Weight:	221031	222877	224640
Flight Equipment :	61259	40901	40938
Logistics Module Wt:	41464	10366	0
Total Upmass:	323754	274144	265578
Number of Flights	9	6	6

TOTAL USEFUL VOLUME
Baseline vs Common Module Approach

Consistent with the objective to compare results with the baseline configuration, and in order to demonstrate compliance with the ground rule to match or exceed the total number of racks to orbit provided by the baseline, a table of useful volume was generated. Note that the five module configuration option contains 110 racks (22 racks per module), six more than baseline. Similarly, the six common module option contains 108 racks (18 racks per module). The total number of radial ports and end cones are also tabulated in order to demonstrate that no loss of interconnect capability was sacrificed, i.e., that the total *useful* volume was preserved. In fact, the total volume was approximately 5% larger for both common module approaches when compared to baseline.

Space Station Technical Simplification Feasibility Study

TOTAL USEFUL VOLUME
Baseline vs Common Module Approach

	Baseline	5 Module	6 Module
Number racks	104	110	108
Number radial ports	16	20	18
Number end cones	12	10	12

The common module approach has about 5% more volume than baseline

Module Pattern

Concurrent with the selection criteria for choosing an optimal module container *size*, the second component considered in designing a pressurized element option was the configuration *pattern* or arrangement of modules.

Module Pattern

Module Pattern Design Drivers

Several factors influence how the modules are arranged on space station. A high priority is the *safety* factor : are safe havens available throughout the pattern? Do crew members have dual egress capability from anywhere within the pressurized volume? The module pattern also influences the station mass properties, and hence, the Torque Equilibrium Attitude (*TEA*) flown. Large TEAs rotate the pressurized volume out of the favorable microgravity regions, and thus should be avoided. Certain mass properties are overly sensitive to variations in altitude or atmospheric density profiles, also an undesirable characteristic. 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 prime 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 to accommodate two Orbiters simultaneously. The configuration should facilitate *logistics module* accommodation, especially with respect to STS reach and swap operations. The optimal module pattern configuration should be able to accommodate an *evolutionary growth path* which preserves micro-g, pointing, controllability, etc., suitable for a wide variety of research or transportation node missions (ideally avoiding the introduction of new module pattern elements such as nodes or tunnels). The module arrangement must accommodate dual *cupolas*, positioned optimally to observe docking and EVA operations, and not co-located on the same module. The arrangement and location of the module pattern should accommodate one or more *air locks* with appropriate clearances and proximity to the attached truss. 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.

Space Station Technical Simplification Feasibility Study

Module Pattern Design Drivers

- **Safety** – dual egress, safe haven
- **TEA/μG** – local vertical attitude, maximum pressurized volume in desirable microgravity environment (Assembly Complete and Intermediate configurations), sensitivity to altitude/atmosphere variations
- **Commonality** – minimal variations among modules
- **Impact to International Partners**
- **Ease of Assembly Operations**
- **Docking Module Accommodation** – pres'd bulkhead sep, dual Orbiter accomm.
- **Logistics module accommodation** – ease of Orbiter reach and swap,clearances
- **Evolutionary growth path accommodation** – retain μG, viewing, avoid tunnels
- **Cupola accommodation** – viewing, non-co-located
- **Air Lock accommodation** – proximity to truss, clearances
- **ACRV accommodation** – non-co-located, ease of approach, departure, clearances

5 Common Module Option – 33.25 ft. Modules

These views depict a possible configuration for the five common module option and the location of the module pattern along the integrated isogrid truss transverse boom. In this configuration each module has two radial ports on each end located 90 degrees apart. Four U.S. modules form the basic racetrack and a fifth U.S. module is attached below the racetrack. Two pressurized docking adapters and two cupolas are positioned in the same manner as on the baseline station. The two international modules are not adversely impacted, and this configuration results in greater separation between the international modules over baseline. The airlock is partially under the transverse boom and is oriented perpendicular to the truss. The pressurized logistics module is located on the port side of the fifth (vertical) U.S. module and is oriented parallel to the module.

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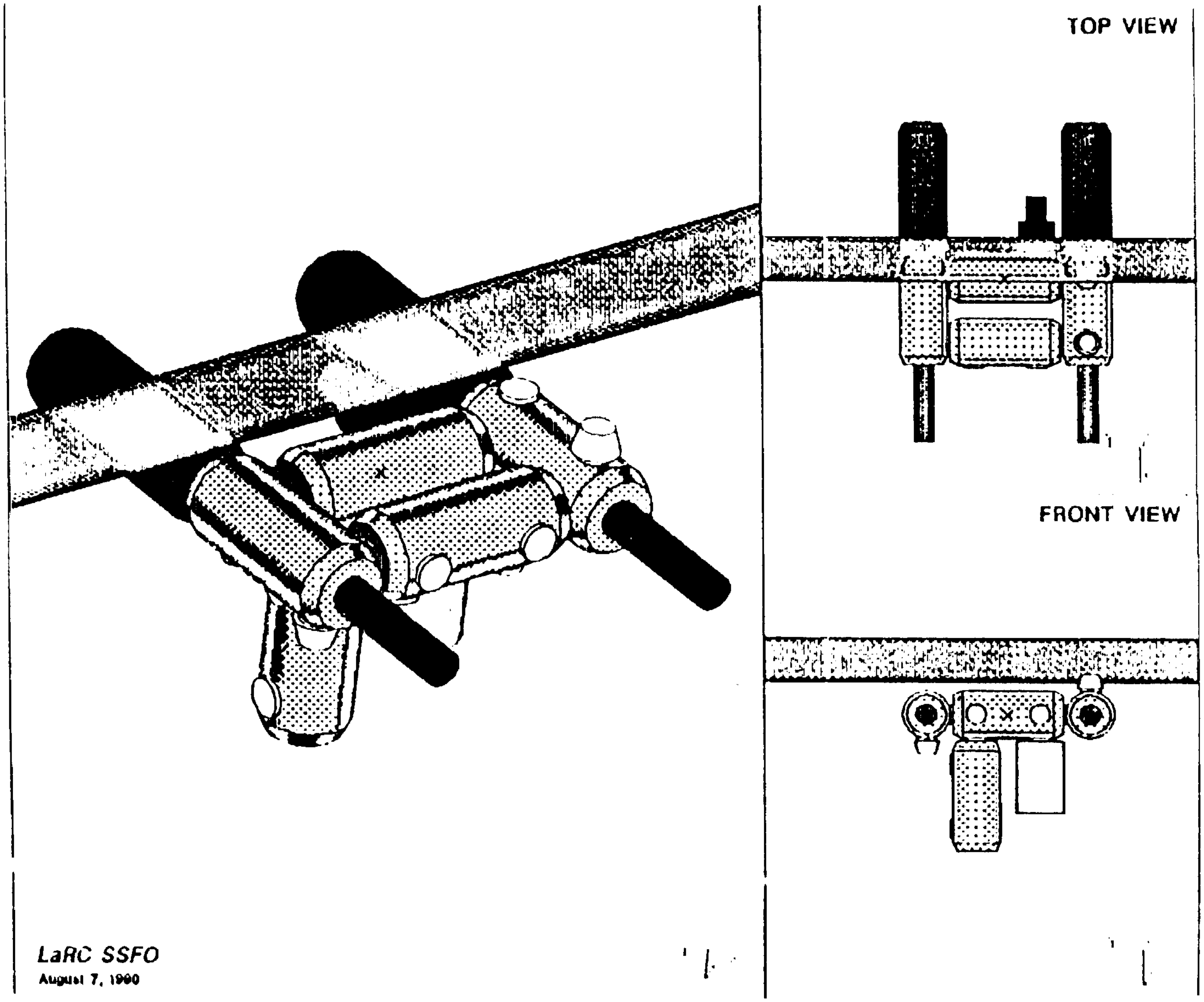
5 Common Module Option

33.25 ft. Modules



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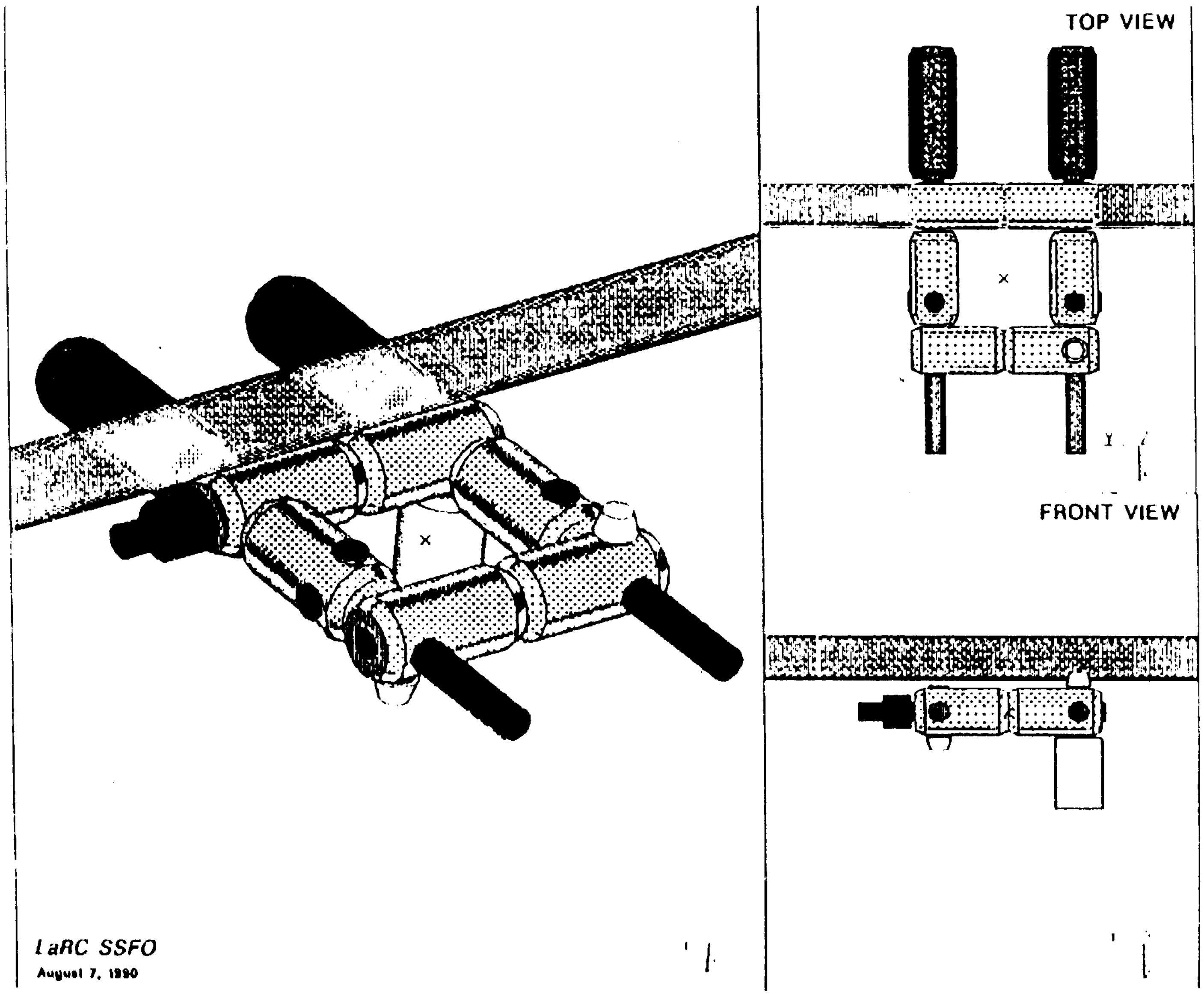
6 Common Module Option – 28 ft. Modules

These views show a possible configuration for the six common module option and the location of the module pattern along the integrated isogrid truss transverse boom. In this configuration each module has three radial ports all located at one end and separated by 90 degrees. All six U.S. modules are required to form the complete racetrack. Two pressurized docking adapters and two cupolas are positioned in the same manner as on the baseline station. The two international modules are not adversely impacted, and this configuration results in greater separation between the international modules over baseline. The airlock located under the transverse boom and is oriented parallel to the truss. The pressurized logistics module is located under one of the aft port U.S. module similar to the baseline station.

6 Common Module Option

28 ft. Modules



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Functional Allocation

Consistent with the ground rules to preserve the total number of user and system racks, the following section details the functional allocation and distribution of the racks throughout the module pattern. Allocations presented are meant only as one possible solution and are not to be taken as fixed. Further, detailed study would be required to optimize any reallocation of Station functionality.

Functional Allocation

Functional Allocation Rationale
Common Module Approach

Four major ground rules were maintained during this study 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 of 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.

Functional Allocation Rationale
Common Module Approach

- Maintain functional capabilities of baseline station configuration
  - Identify resource allocation and interface requirements and drivers
- Maintain outfitting level to at least baseline Assembly Complete
- Satisfy contingency requirements
- Allocate rack distribution such that all common modules weigh approximately the same.

Redundancy
Common Module vs. Baseline

This chart reviews the redundancy and contingency requirements for the current baseline Station and gives a comparison of the redundancy features between baseline and the common module approaches studied. Crew safety and pressurized element survival systems 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 rather than the dual-redundancy per module philosophy utilized on baseline. A comparison of the baseline racetrack to either common module approach shows that the common module can result in a better distribution of system racks and thus the loss of a single module would have a smaller impact on station operations than the baseline. For example, two habitation and two laboratory modules would allow station astronauts to continue somewhat normal work and sleep schedules if one module became nonoperational.

Redundancy
Common Module vs. Baseline

Requirement:

- Functional redundancy for crew safety and pressurized element survival shall be a minimum of 2 failure tolerant.
- Contingency requirements shall be satisfied through the allocation of critical prepositioned ORU's, skip cycle supplies, and safe haven consumables

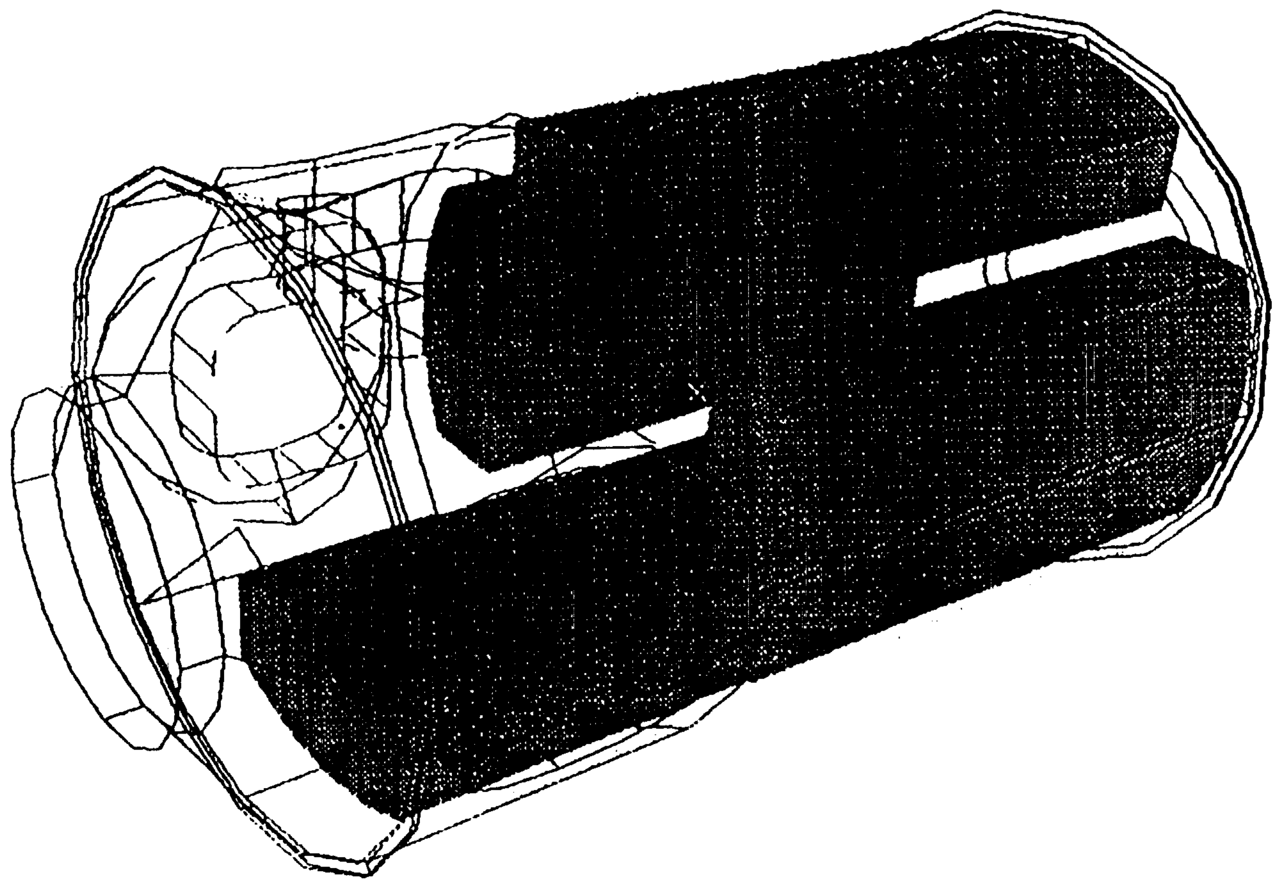
Baseline:	Common Modules:
• 2 modules & 4 nodes	• 5 or 6 common module
• Full dual (4-man) redundancy per module	• Partial (4-man) single redundancy per module with safe haven capability in 2+ modules
• 19 baseline system racks	• 20 - 21 baseline system racks
• Loss of module severely impairs station operations	• Loss of module has less effect on station operations

* In addition redesign and distribution of system racks taking advantage of common module - to - module redundancy may have significant weight savings

6 Common Module Option – Interior Layout

Shown in this illustration is the general internal layout for the six common module option. Each module has three radial ports and two end cones, and is approximately 28 feet long. Each module can accommodate a total of 18 double racks allowing for a total of 108 racks contained within the racetrack. Three sides of the module contain four double racks and the fourth side contains six double racks. There is additional room for a single rack along the fourth wall, but the additional single rack was not included in this study.

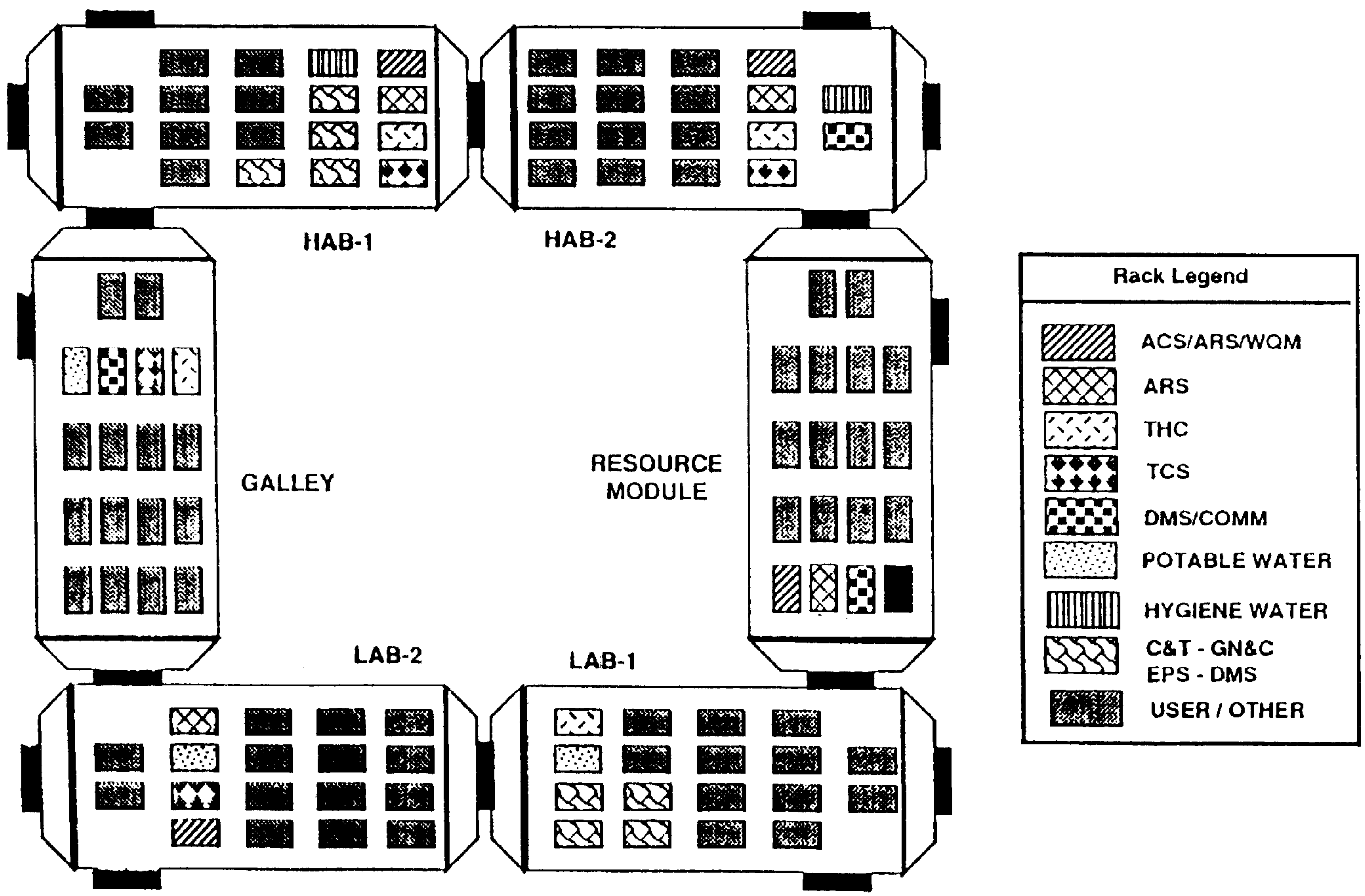
6 Common Module Option – Interior Layout



Functional Distribution
6 Common Modules

This graphical representation of the six common module option shows a potential function allocation of system racks within the module racetrack. This functional layout attempts to minimize the potential impact of the loss of a single module to normal Space Station operations by distributing critical systems throughout the racetrack. In addition, the modules are each allocated a distinct function such as life science lab, microgravity lab, galley, habitation area, etc. This differs greatly with the baseline where such distinctions tend to overlap. Note that this layout is intended only to demonstrate what system racks would reside in each module and does not indicate actual placement of the racks inside the modules.

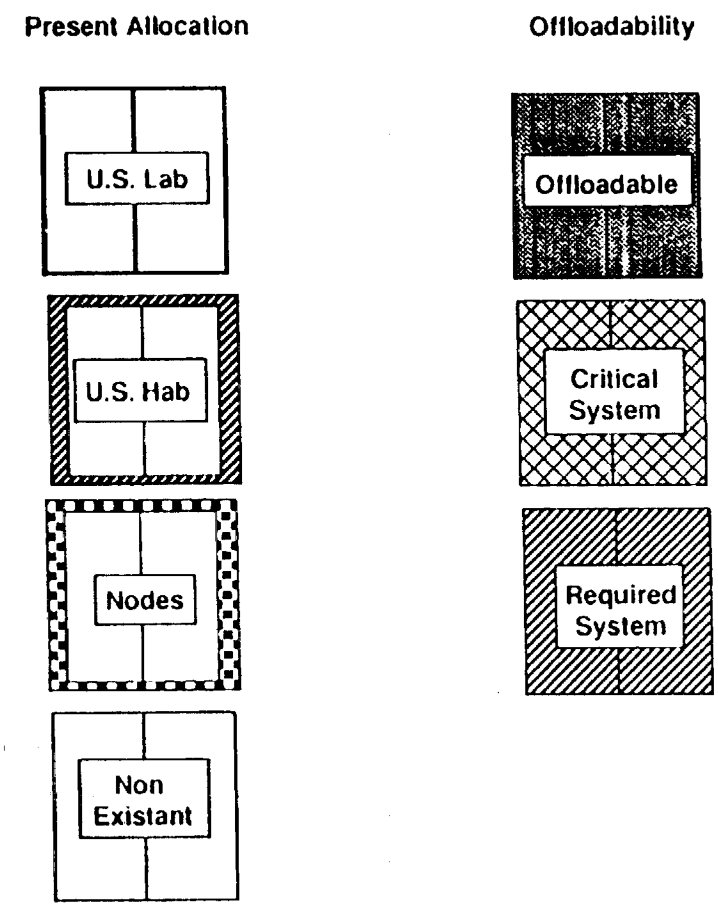
Functional Distribution
6 Common Modules



Guide to Functional Reallocation

This chart provides a guide to the reallocation of baseline system and user racks for the five and six common module approaches studied. Racks are identified by their present allocation in the baseline layout (i.e. U.S Laboratory, U.S. Habitation, Nodes, or currently non-existent) and their degree of off-loadability (i.e. off-loadable, highly important, or required).

Guide to Functional Reallocation



6 Common Module Option – Habitation 1 Topology

Like all of pressurized elements in the six common module approach, the first habitation element in the six common module option includes 18 rack locations. Noteworthy system and user racks include crew quarters, crew core equipment, a single four man life support system, safe haven supplies, and node element critical systems (primary command control, electrical power system, etc..).

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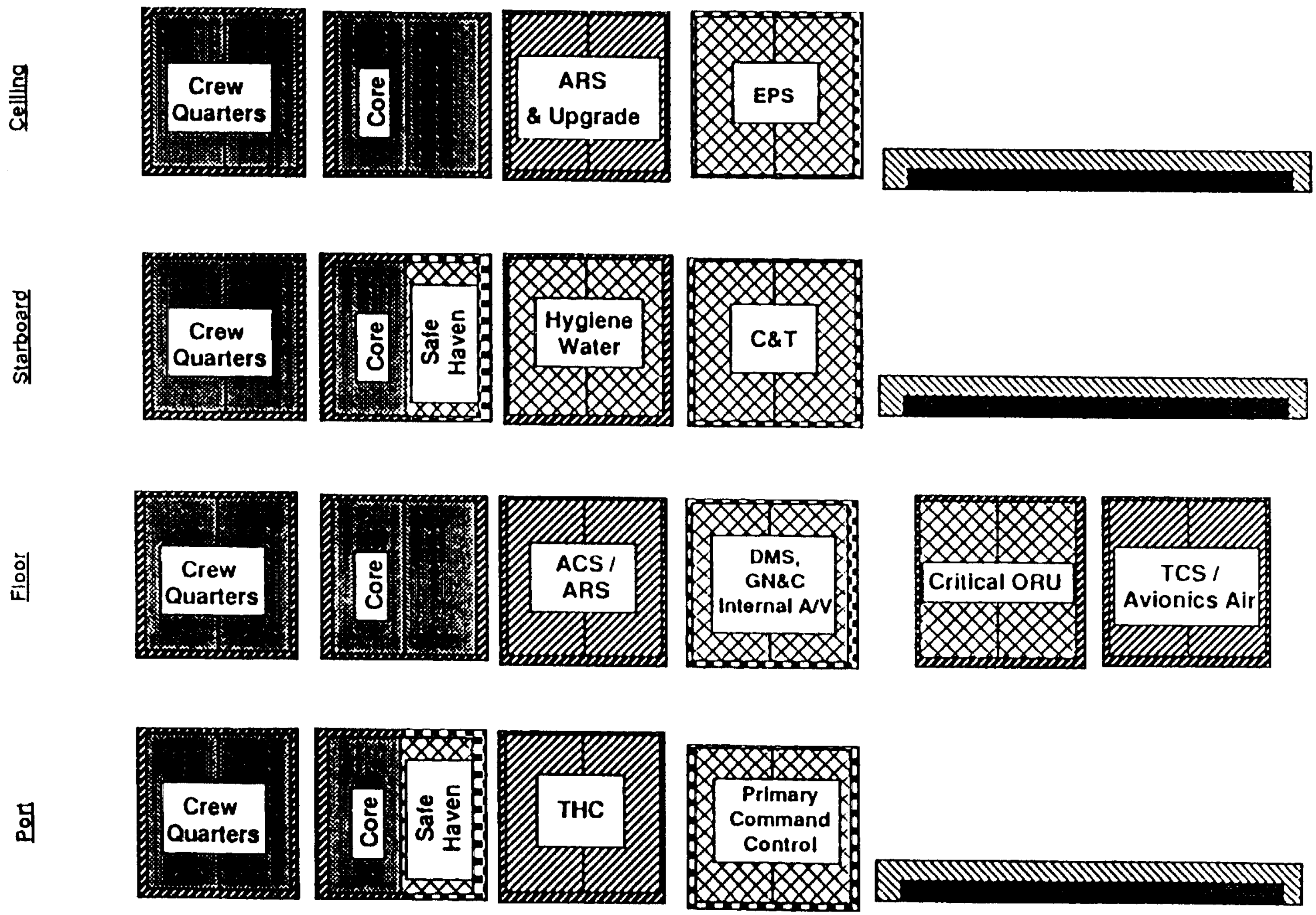
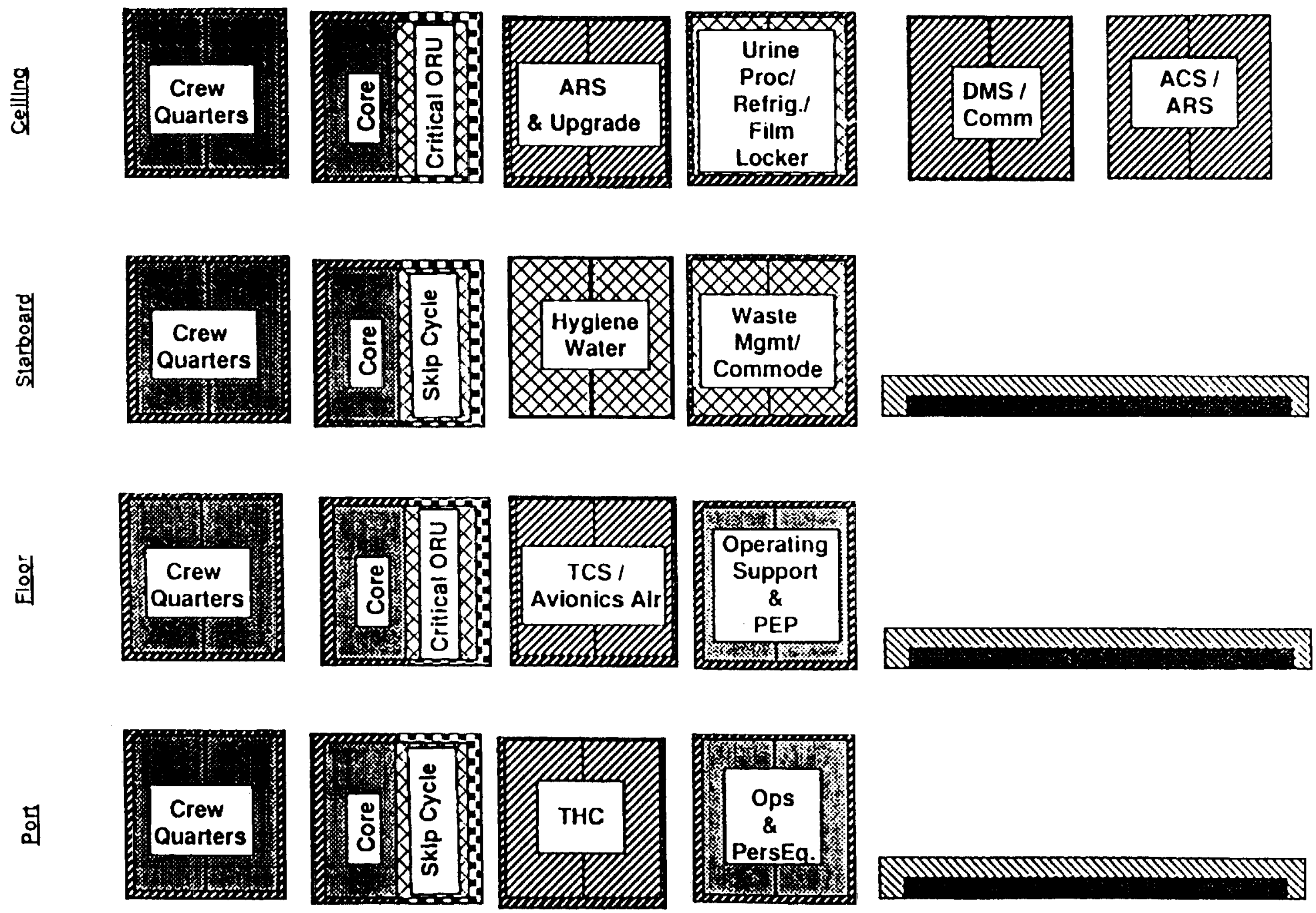
Hab -1 Module Topology



6 Common Module Option – Habitation 2 Topology

The second habitation module is similar to the first habitation module for the six common module option. The second habitation module contains crew quarters, crew core equipment, a single four man life support system, operational support equipment, skip cycle consumables, and a waste management system.

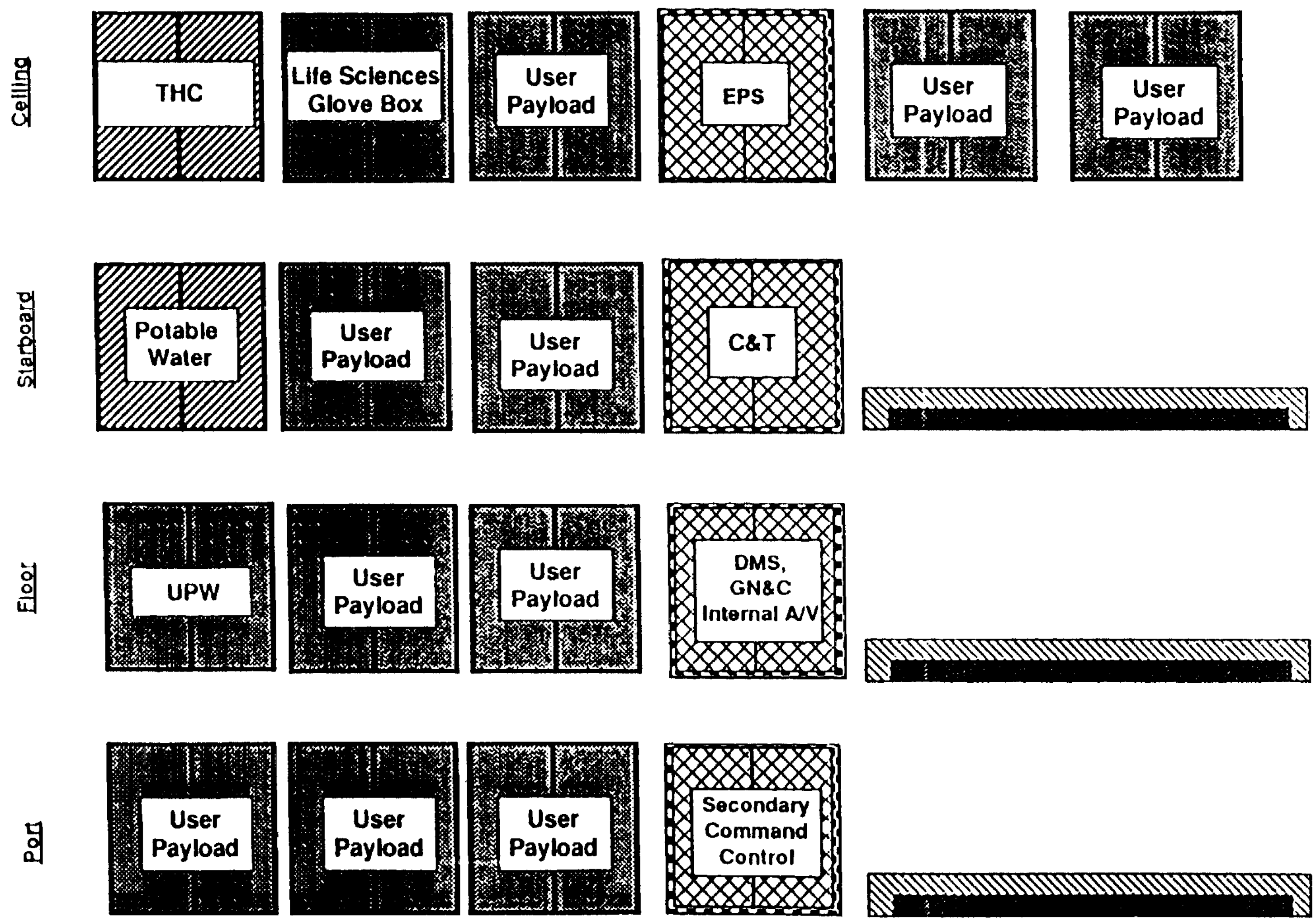
Hab -2 Module Topology



6 Common Module Option – Laboratory 1 Topology

The first laboratory will be primarily a life sciences work station. Among its racks are 10 user payloads, life sciences specific hardware, two primary system racks, and the second set of control station racks. The latter allocation is due to the fact that this module will be first on-orbit and must include critical systems necessary when a temporary docking mast is attached. Operational considerations may dictate that at some point these racks be reallocated.

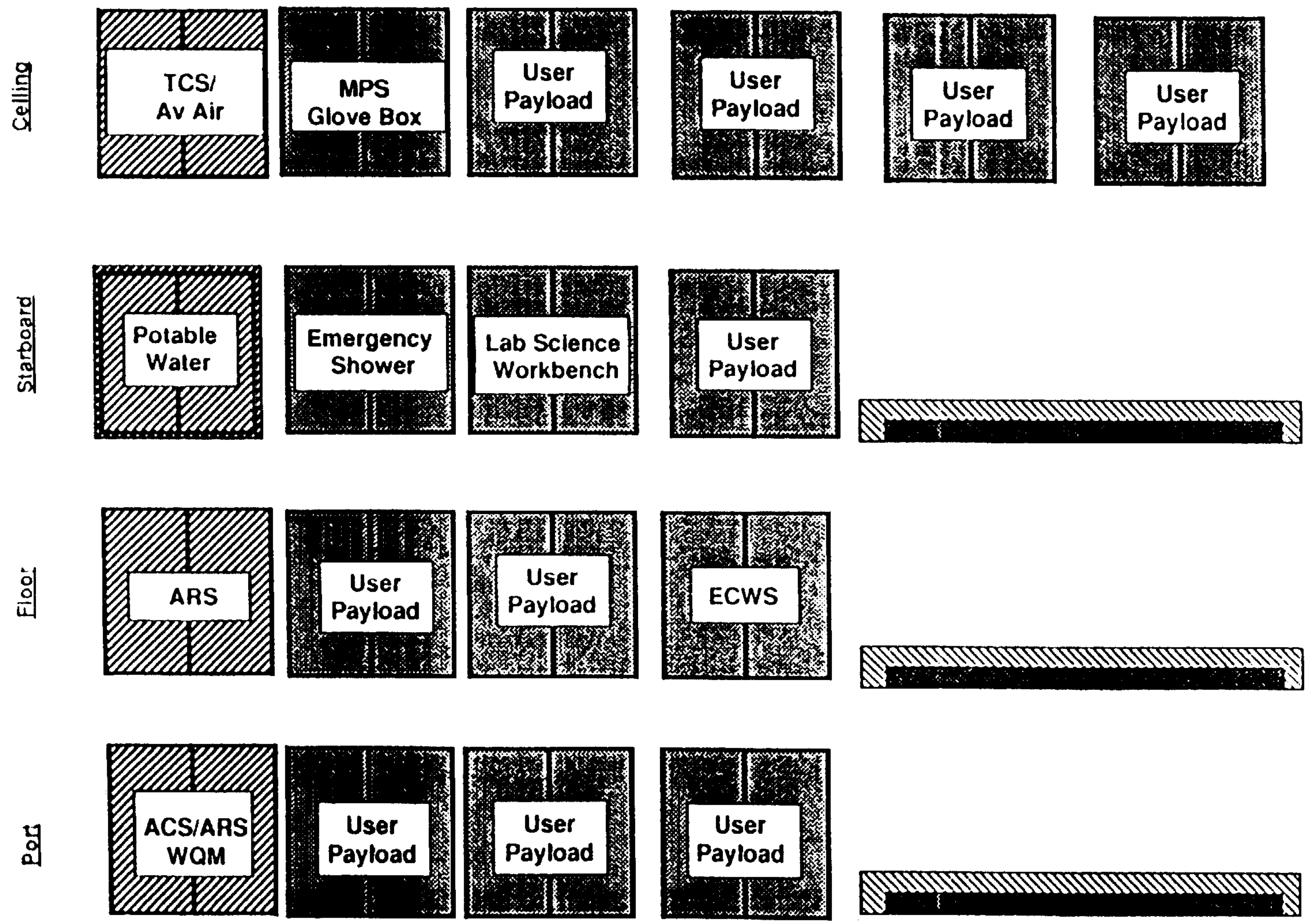
Lab -1 Module Topology



6 Common Module Option – Laboratory 2 Topology

The primary utilization of this module will be as a materials processing laboratory. Included in its allocation are eight user payloads, work equipment, a single four man life support system, and the emergency shower.

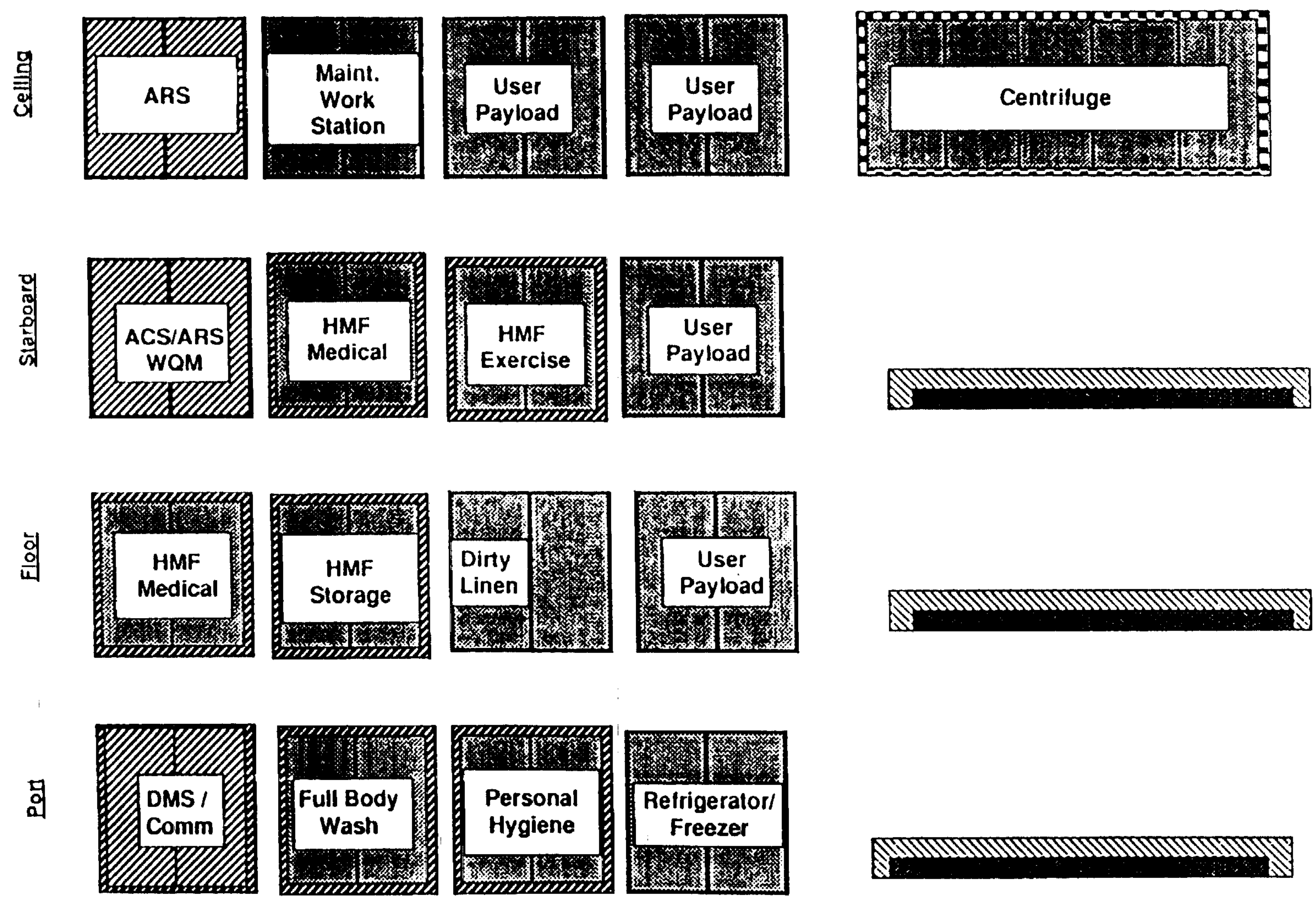
Lab -2 Module Topology



6 Common Module Options – Resource Module Topology

The rack allocation in the fifth (Resource) module of the 6 common module option includes the Health Maintenance Facility, a four man life support unit, four user payloads and space allocation for the life sciences centrifuge.

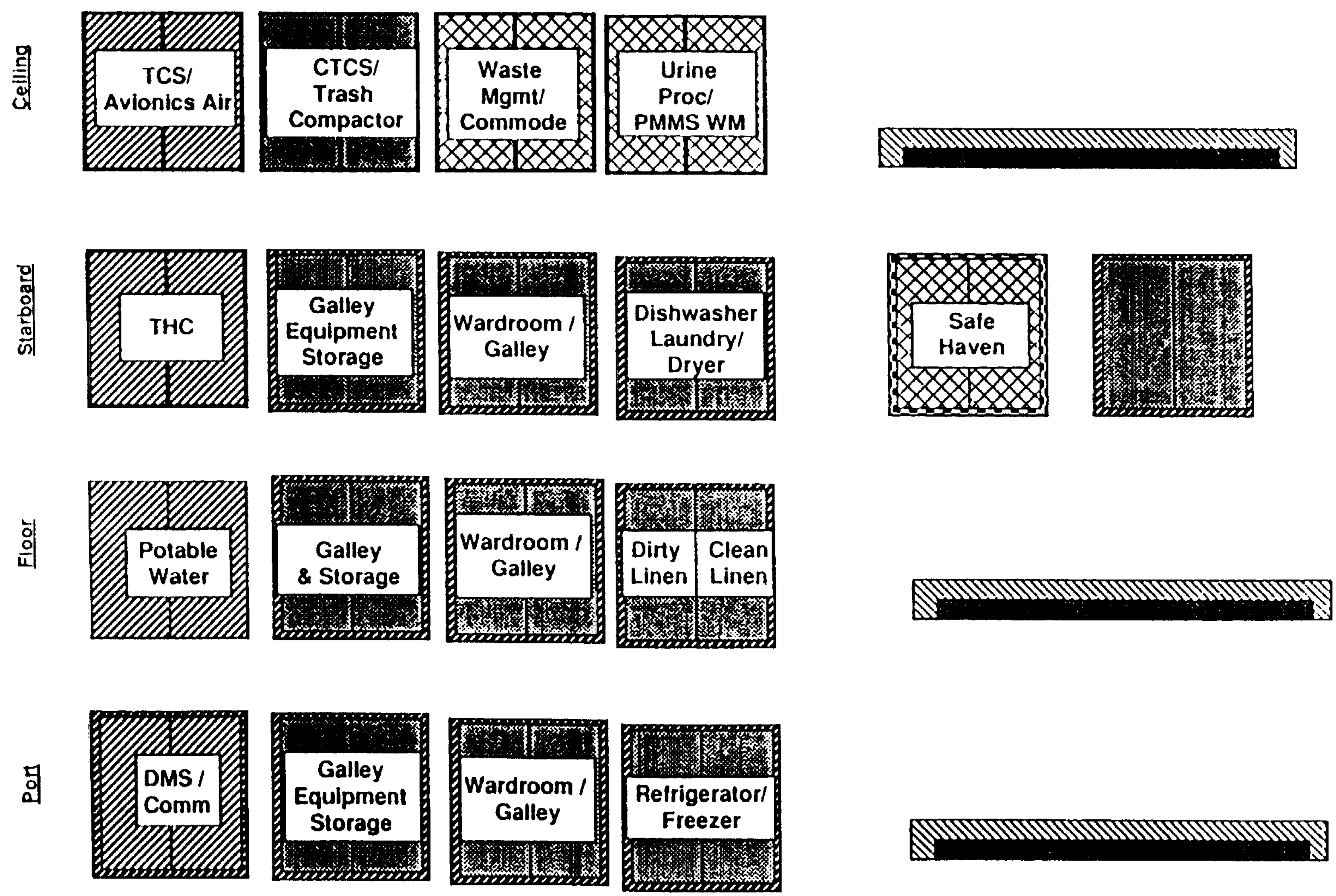
Resource Module Topology



6 Common Module – Galley Topology

The final module of the six common module option is a dedicated galley and wardroom facility. Included are a four man life support unit, and all galley and wardroom storage and equipment racks.

Galley Topology



5 Common Module Option – Interior Layout

Shown in this illustration is the general internal layout for the five common module option. Each module has four radial ports and two end cones, and is approximately 33.25 feet long. Each module can accommodate a total of 22 double racks allowing for a total of 110 racks contained within the racetrack. Two sides of the module contain three double racks and the other two sides contains eight double racks.

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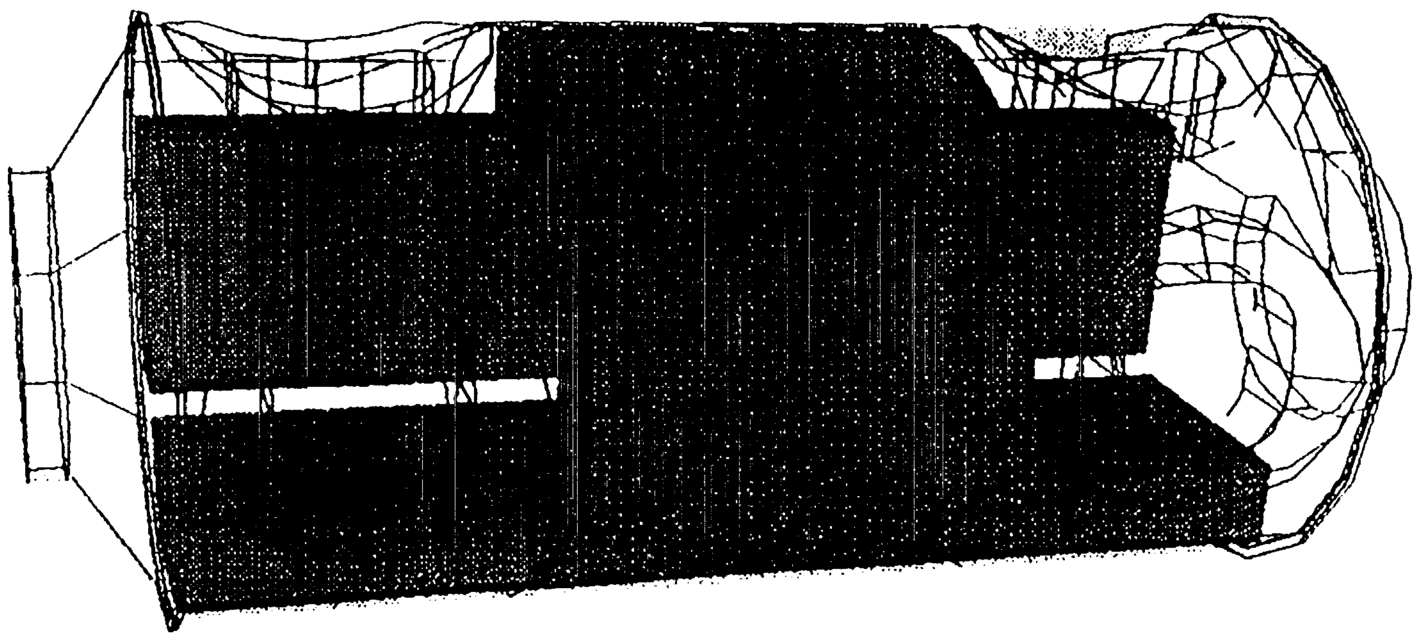
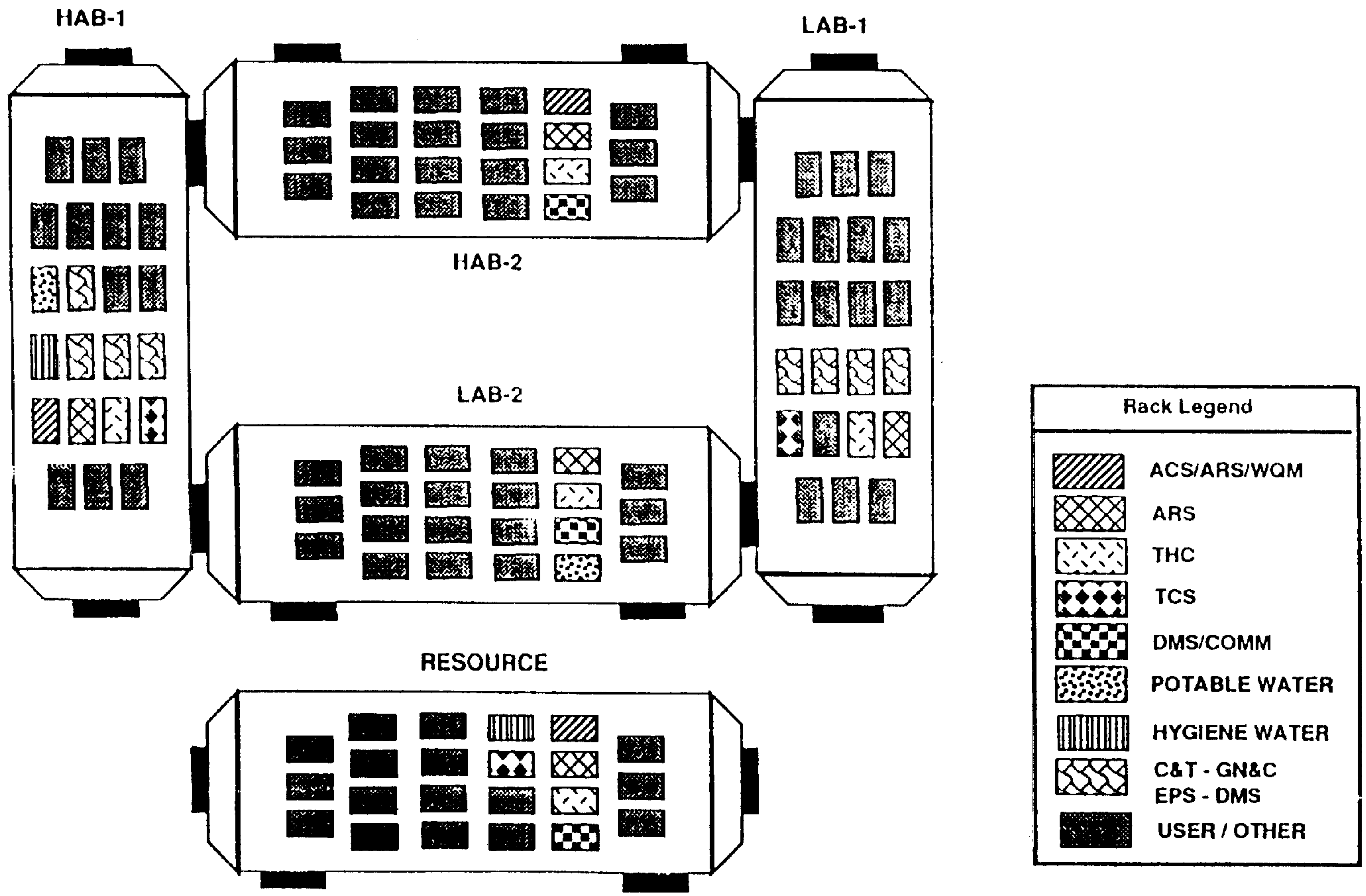
5 Common Module Option – Interior Layout



Functional Distribution
5 Common Modules

This graphical layout of the five common module option shows a potential function allocation of system racks within the module racetrack. This functional distribution attempts to minimize the potential impact of the loss of a single module to normal Space Station operations. Note that this layout is intended only to demonstrate what system racks would reside in each module and does not indicate actual placement of the racks inside the modules.

Functional Distribution
5 Common Modules



5 Common Module Option – Habitation 1 Topology

All of the pressurized elements in the five common module approach include 22 rack locations. This layout depicts the allocation of system and user racks in the first habitation module. Noteworthy system and user racks include crew quarters, crew core equipment, a single four man life support system, skip cycle and critical ORU supplies, and node element critical systems (primary command control, EPS, etc.)

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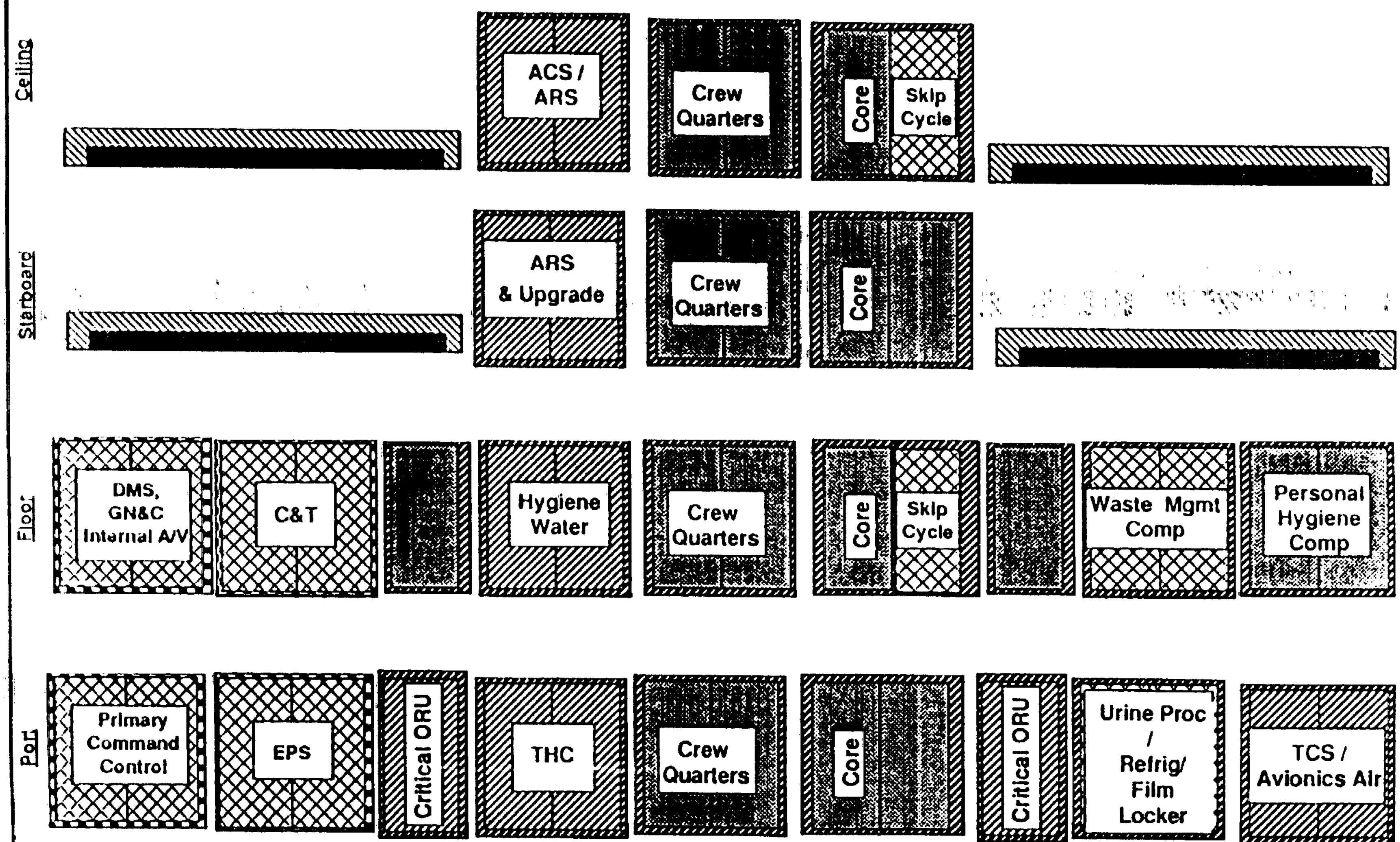
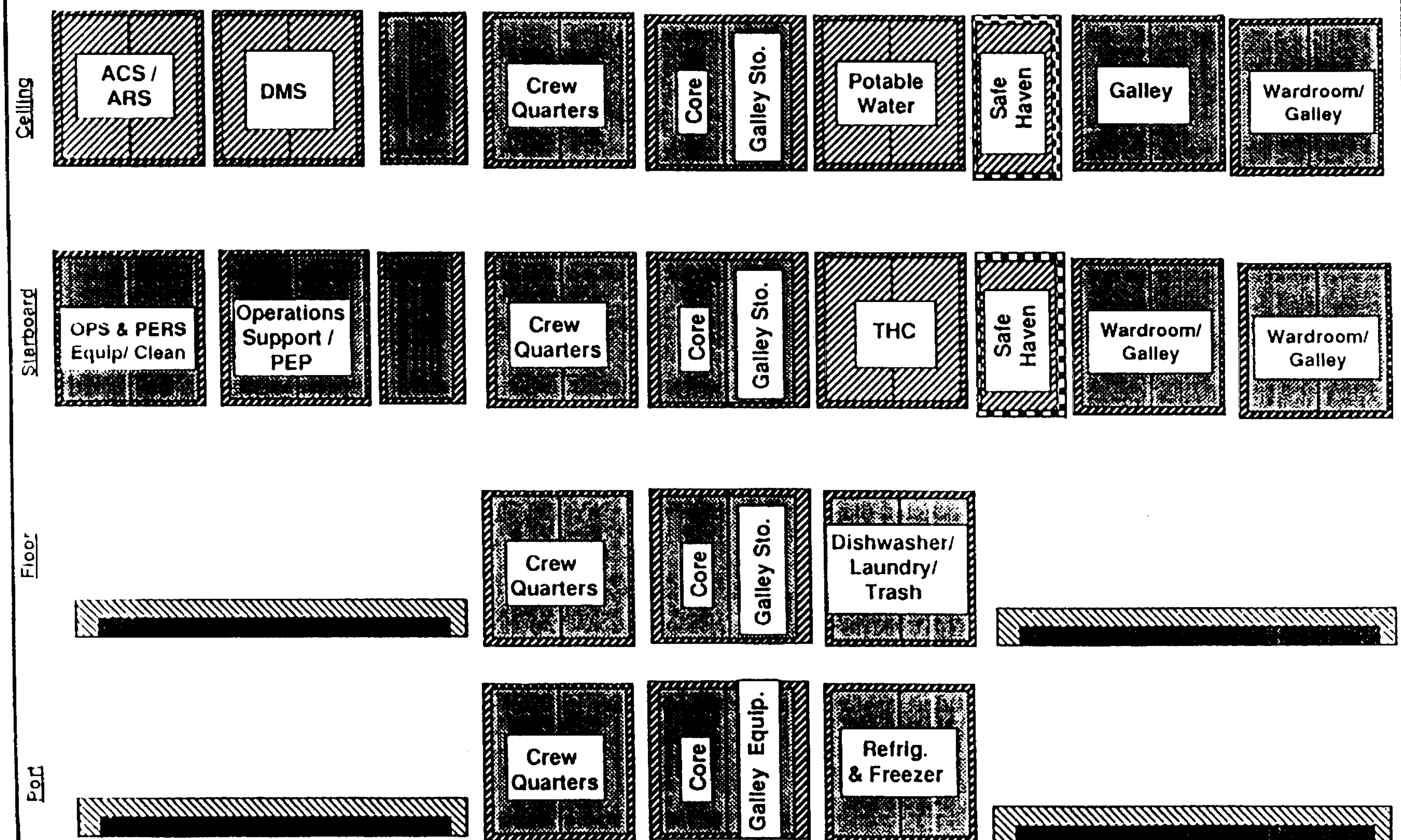
Habitation -1 Topology



5 Common Module Option – Habitation 2 Topology

The second habitation module is similar to the first five module habitation module. The second habitation module contains crew quarters, crew core equipment, a single four man life support system, operational support equipment, safe haven consumables, galley and wardroom equipment and storage.

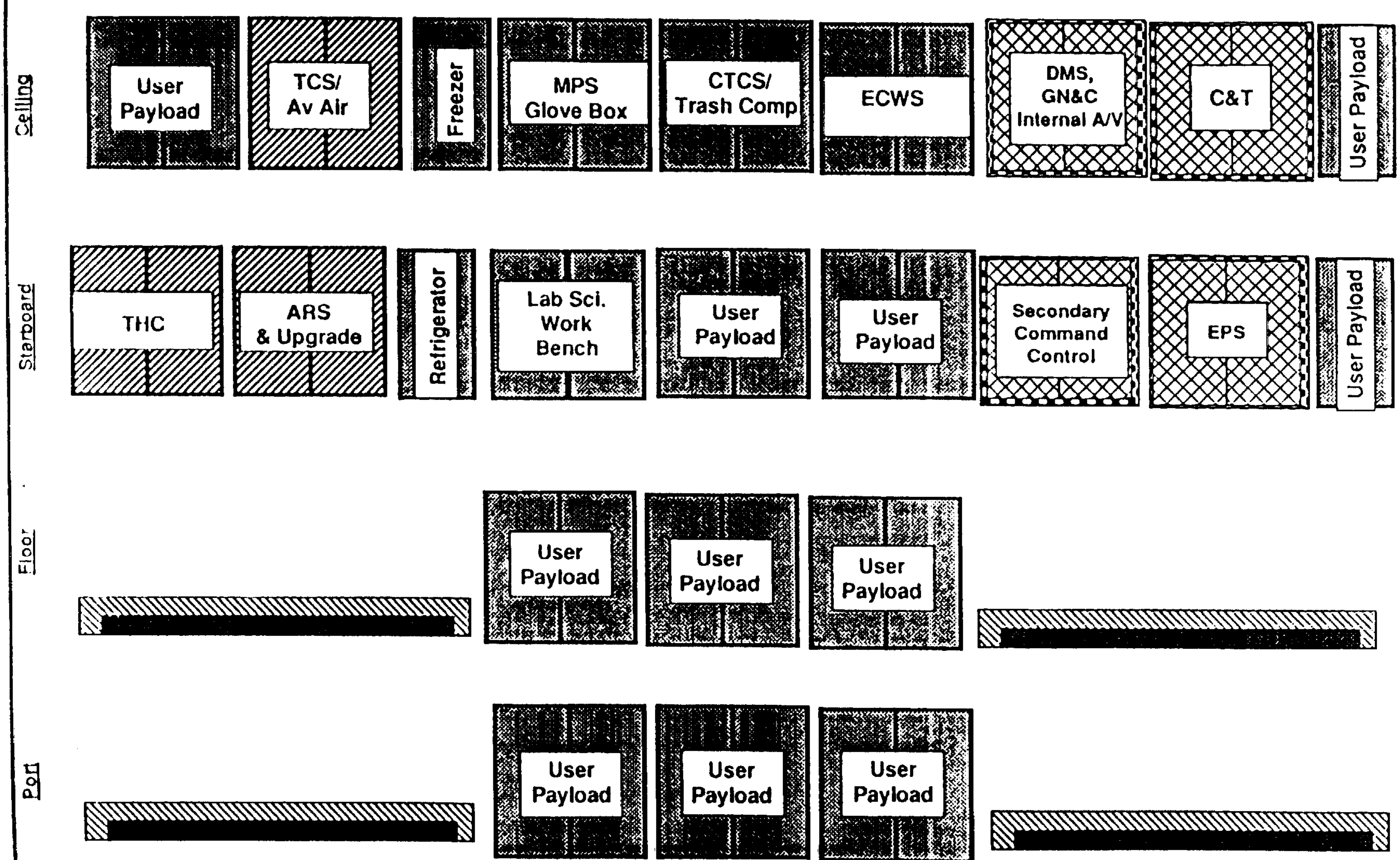
Habitation -2 Topology



5 Common Module Option – Laboratory 1 Topology

The first laboratory module will be primarily a materials processing lab. Among its racks are ten user payloads, material sciences specific hardware, three primary system racks, and the second set of control station racks. The latter allocation is due to the fact that this module will be first on–orbit and must include critical systems necessary when a temporary docking mast is attached.

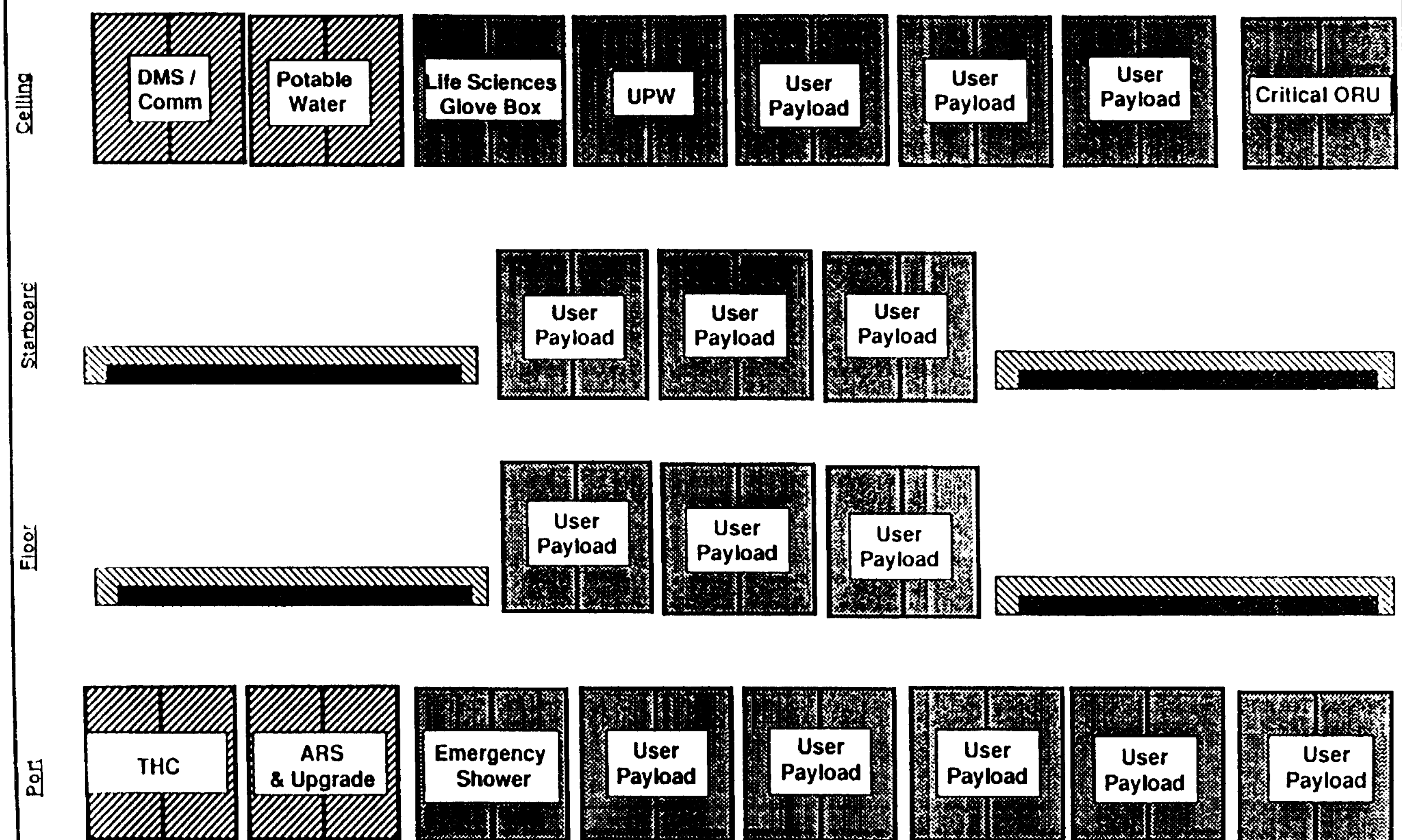
Laboratory -1 Topology



5 Common Module Option – Laboratory 2 Topology

The primary utilization of this module will be as a life sciences laboratory. Included in its allocation are 14 user payloads, work equipment, a single four man life support system, the emergency shower, and critical ORU storage.

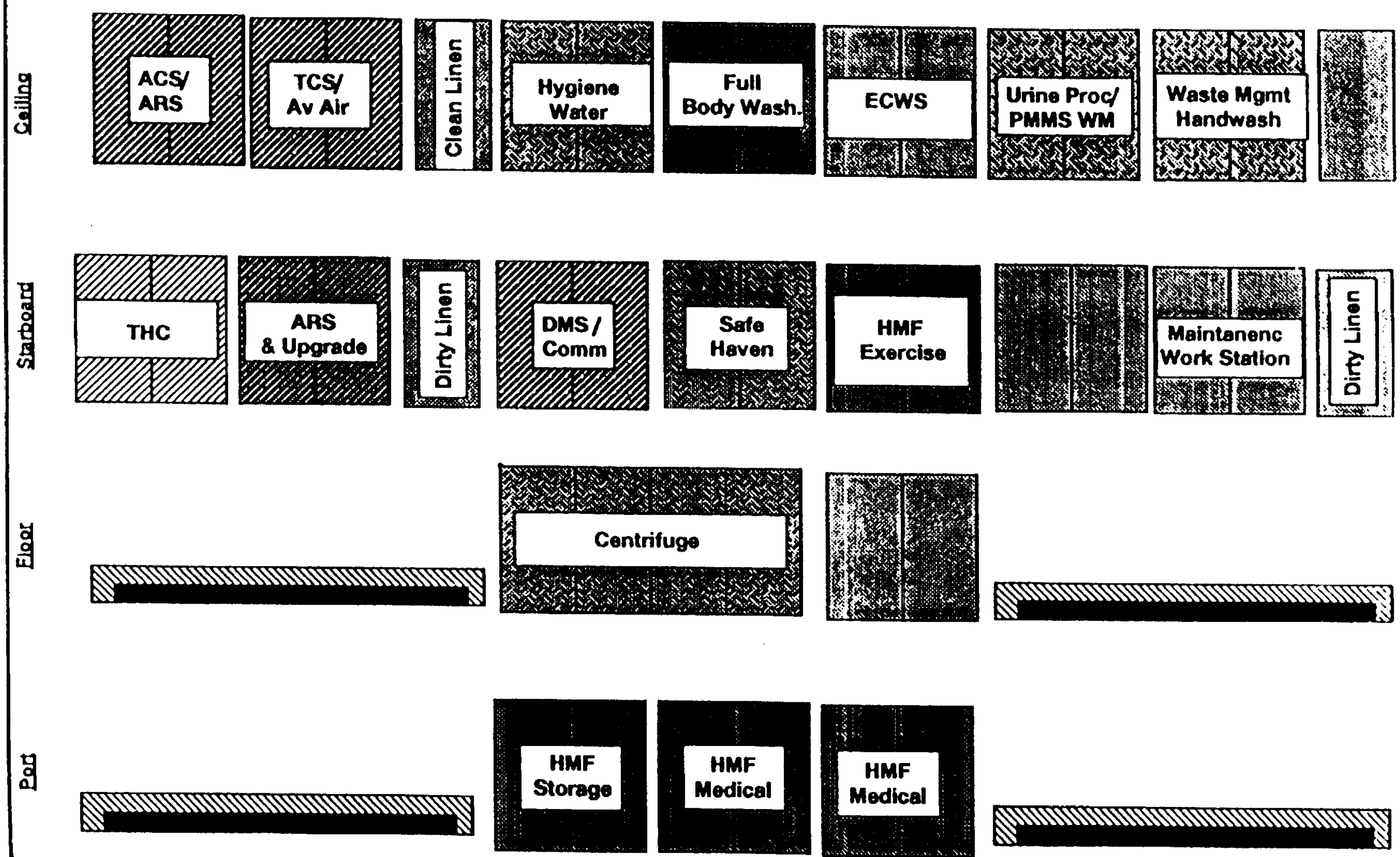
Laboratory -2 Topology



5 Common Module – Resource Module Topology

The last module in the five Common Module Option will contain the Health Maintenance Facility racks, a single four man life support system, the Maintenance Work Station, Waste Management Systems, safe haven supplies, and two double racks for the life sciences centrifuge.

Resource Module Topology



Resource Allocation
Common Module Approach

Several characteristic benefits of the allocation approach used in the common module study are evident. Due to the number and commonality (in size) of the pressurized elements, distinct functional divisions are possible (i.e. Hab, Lab, Galley, ... etc.). This would greatly add to the internal operational characteristics of the Station. Crew performance of a particular function would be partitioned from other crew members performing other various duties, thus minimizing adverse crew interference. In addition, the balancing of resource requirements across the elements would eliminate any mechanical strain on a particular critical system as exists in the current nodes. Another major benefit is the robustness of safe haven contingency. Dependence on two primary elements (such as in Baseline Hab and Lab) to provide all life support functions is eliminated. The crew can rely on environmental control from several locations throughout the Station when the common module approach is utilized. This lessens the overall impact to the crew of the loss of Station pressurized elements.

Resource Allocation
Common Module Vs. Baseline Approach

- The functional divisions of the common module approach are more distinct when compared to Baseline, and thus greatly enhance operational characteristics of the Space Station.
- Safe Haven contingency is more robust.
  - The loss of each successive module has less of an overall effect on Station when compared to loss of either a Baseline module or node. In addition, the number of locations for safe haven is increased.
  - Survivability of common modules are only severely in question if 4-5 modules are lost.
- Reallocation increases module performance
  - Decrease of overall weight and volume penalty/module for system racks.
  - Increasing the number of user racks launchable with ground verification.
  - Increase in the total percentage of user racks per module.

Summary
Common Module Approach

Assuming the Level II maximum weights, both the five and six module options can be launched with all system racks onboard and integrated assuming baseline STS launch capability as was specified in the objectives. The five module option requires five flights – 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 an additional two flights required to outfit the remaining user racks.

Assuming ASRM launch capability, the six module option can be deployed onorbit *fully outfitted* in six launches. The five module option also requires six launches – five module flights plus one additional logistics flight.

When considering module pattern selection criteria, the six module option is slightly superior to the five module option in terms of 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.

The six module option is more conducive to a logical allocation and distribution of onboard system functions.

Space Station Technical Simplification Feasibility Study

Summary
Common Module Approach

- Assuming Level II Maximum Weights and STS capability
  - The 5 module option can get all system racks up in 5 flights (Outfitted in 9 flights)
  - The 6 module option can get all system racks up in 6 flights (Outfitted in 8 flgihts)
- Assuming Level II Maximum Weights and STS/ASRM capability
  - The 6 module option can get all modules up *fully outfitted* in 6 flights
  - The 5 module option can get all systems up with outfitting in 6 flights
- The 6 module option is slightly superior in terms of dual egress, growth, ACRV and airlock accomodation
- The 5 module option racetrack is closed after 4 flights, the 6 in 6 flights
- The 6 module option provides better functional allocation compared to 5 module option

Summary
Common Module Approach (Continued)

During the course of this study support analysis of the assembly complete configuration assuming an integrated truss concept, indicated the six module pattern was much less sensitive to variations in altitude and atmospheric density, an important advantage.

In terms of microgravity environment, the five module option had slightly more total volume within the one μG region than the six module pattern, although the fifth (vertical) module was completely outside of the two μG region. Nevertheless, the six module configuration is completely within the two μG region. All microgravity studies assumed a 190 nmi altitude and an *average* 2–σ atmosphere (flux = 120, geomagnetic index = 13.5). The results of this analysis are shown in the Configuration Characterization section of this study.

The six module option had the following advantages over the 5 module option :

1) more internal volume for rotating racks through radial ports
2) less on-orbit verification requirements
3) less sensitive to either structural or rack weight increases.

Finally, it was noted that the five module option has two of the parallel modules separated by only 4.75 feet.

The conclusion based on the preliminary module size and pattern study was that *either* option (five or six common module) offered many advantages over the baseline configuration which would warrant additional study. Overall, the six module configuration appears to be superior to the six module option.

Space Station Technical Simplification Feasibility Study

Summary
Common Module Approach
(Continued)

- The 6 module option TEA is much less sensitive to variations in altitude and atmospheric density
- The 5 module option has more total volume within the 1-micro -G environment, although the 5th (vertical module) is entirely outside the 2 micro - G environment
- The 6 module option is completely inside the 2 micro -G environment
- The 5 module option has a 4.75 ft clearance between 2 parallel modules
- The 6 module option has more internal volume available for rotating racks through radial ports.
- The 6 module option demands less on-orbit verification
- The 6 module option is less sensitive to increases in either structural or rack weight increases

Bottom Line: Initial Studies indicate either 5 or 6 module option offer many advantages over Baseline and warrent further study

Advantages
Common Module Approach

The advantages of a common module approach include:

1) All critical systems are integrated and verified on the ground prior to on–orbit deployment
2) Significant margins exist to accommodate potential future weight increases
3) Module redundancy translates into a robust division of system functionality
4) The six module option exhibited desirable flight characteristics and microgravity accommodation
5) Radial port allocation afforded optimal placement of cupolas, docking mechanisms, ACRVs, air locks, and evolutionary growth paths
6) Current Space Station structural design concepts (end cones, radial ports, etc.) have not been modified.

Advantages
Common Module Approach

- Full Ground Verification of Critical Systems
- Significant Margin for Growth
- Robust Functional Divisions (Module Redundancy)
- Good Flight Characteristics (TEA, Micro-Gravity)
- Ports Available for Placement of Cupolas,A/L,PLM, ACRV, Growth...
- Current SSF design concepts utilized

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15. Supplementary Notes

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16. Abstract

During the preliminary design review of Space Station Freedom elements and subsystems, it was shown that reductions of cost, weight, and on-orbit integration and verification would be necessary in order to meet program constraints, particularly nominal Orbiter payload launch capability. At that time, the Baseline station consisted of four resource nodes and two 44 ft modules. In this study, the viability of a common module which maintains crew and payload accommodation is assessed. The size, transportation, and orientation of modules and the accommodation of system racks and user experiments are considered and compared to baseline. Based on available weight estimates, a module pattern consisting of six 28 ft common elements with three radial and two end ports is shown to be nearly optimal. Advantageous characteristics include a reduction in assembly flights, dual egress from all elements, logical functional allocation, no adverse impacts to international partners, favorable airlock, cupola, ACRV, and logistics module accommodation, and desirable flight attitude and control characteristics.

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